Analysing Smart Metering Systems from a Consumer Perspective

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Declaration

This dissertation is the result of my own work and includes nothing, which is the outcome of work done in collaboration except where specifically indicated in the text. It has not been previously submitted, in part or whole, to any university of institution for any degree, diploma, or other qualification.

Rani Yesudas
11 July 2016

DEDICATED
to

My father (Yesudas)
who gave wings to my dreams

My mother (Mary Josephine)
who strengthened my roots to be well-grounded

and last but not the least...

My loving son (Rohan)
who taught me to take life as it comes!

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Abstract

Many countries are deploying smart meters and Advanced Metering Infrastructure systems as part of demand management and grid modernisation efforts. Several of these projects are facing consumer resistance. The advertised benefits to the consumer appear mainly monetary but detailed analysis shows that financial benefits are hard to realise since the fixed services charges are high. Additionally, the data collected from smart meters have security and privacy implications for the consumer. These projects failed to consider end-users as an important stakeholder group during planning stages resulting in the design and roll-out of expensive systems, which do not demonstrate clear consumer benefits.

The overall goal of the research reported in this thesis was to improve the smart metering system to deliver consumer benefits that increase confidence and acceptance of these projects. The smart metering system was examined from an end-user perspective for realistic insights into consumer concerns. Processes from Design Science Research methodology were utilised to conduct this research due to the utilitarian nature of the objective.

Consumer segmentation was central to the proposed measures. Initially, a consumer-friendly risk analysis framework was devised, and appropriate requirement elicitation techniques were identified. Control options for smart meter data transfer and storage were explored. Various scenarios were analysed to determine consumer-friendly features in the smart metering system, including control options for smart meter data transfer and storage. Proposed functionalities (billing choices, feedback information and specific configurations to match the needs of different user segments) were studied using the Australian smart metering system.

Smart meters vary in capabilities depending on the manufacturer, mode and place of deployment. The research showed that features proposed in this thesis are implementable in smart meters, by examining their applicability to those used in Victoria (Australia). This study demonstrated that intelligent systems for demand and distribution-side management can be built without the use of detailed consumption data from the consumer. Many issues related to smart meter data could be avoided by distributing intelligent metering devices across the network. A check-list was generated to guide project proponents to achieve a consumer-friendly outcome.

This research establishes that by applying well-established theories during the planning process, in particular requirement elicitation and risk analysis, consumer support can be gained leading to the deployment of user-friendly and sustainable systems. The

check-list generated will help industry to appropriately plan and develop systems that can avoid opposition and even stimulate adoption. Options proposed provide choices for different consumer segments without affecting major operations such as billing. On evaluation, it has been identified that the proposed measures do not affect the quality attributes of the system.

Since the proposals presented in this thesis were based on smart meters used in Victoria (Australia), smart meters used in other areas may require upgrades or revisions to support these functions. The scope of this research is limited to identifying improvements in the system that will benefit the residential consumer and does not extend to analysis of the effects of these improvements on the profitability of the investors.

List of Publications

Accepted conference papers

1. Yesudas R. and Clarke R., 'A Framework for Risk Analysis in Smart Grid' - In Critical Information Infrastructures Security (CRITIS), 2013, Netherlands.
   Content from this paper is included in Chapter 3, Chapter 6 and Appendix.

2. Yesudas R. and Clarke R., 'Identifying Consumer Requirements as an Antidote to Resistance to Smart Meters' - In Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2014, Turkey.
   Content from this paper is included in Chapter 3, Chapter 6 and 8.

3. Yesudas R. and Clarke R., 'Architecture and Data Flow Model for Consumer-Oriented Smart Meter Design' - In Information Systems Development: Transforming Organisations and Society through Information Systems (ISD), 2014, Croatia.
   Content from this paper is included in Chapter 7.

4. Yesudas R. and Clarke R., 'Consumer Concerns about Smart Meters' - In International Conference on Human-Computer Interaction (HCII), 2015, US.
   Content from this paper is included in Chapter 5 and 6.

5. Yesudas R. and Clarke R., 'Measures to Improve Public Acceptance of Smart Metering System' - In Requirements Engineering for Sustainable Systems (RE4SuSy15 part of RE), 2015, Canada.
   Content from this paper is included in Chapter 7 and Chapter 8.

6. Yesudas R., 'Measures to Improve Adoption of Smart Metering Systems - In Americas Conference on Information Systems (AMCIS), 2015, US.
   Content from this paper is included in Chapter 7.

7. Yesudas R., 'A Framework for Analysing Smart Grid Initiatives' - In International technical conference of IEEE Region 10 (TENCON), 2015, China.
   Content from this paper is included in Chapter 8.

Chapters in this thesis contains verbatim information from the above published papers.

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List of Abbreviations

3DES Triple Data Encryption Standard 67
A/D Analog to Digital 21
ABCD Attitudes, Behaviour, Choice, and Demand 37
ACT Australian Capital Territory 73, 131, 164
AEMC Australian Energy Market Commission 71
AEMO Australian National Energy Market Operator 11, 71, 72
AER Australian Energy Regulator 158
AES Advanced Encryption Standard 67
AFLC Audio Frequency Load Control 60, 72
AGC Automatic Generation Control 112, 173
AMI Advanced Metering Infrastructure ix, 18, 21–24, 26, 30, 46, 72, 93, 114, 157
AMR Automated Meter Reading 20, 21, 72
ANSI American National Standards Institute 23
AR Action Research 49–51
ASN Access Service Network 188
ATAM Architecture Trade-off Analysis Method 40
AVR Automatic Voltage Regulator 112, 173, 174
Capex Capital Expenditure 187, 188
CATS Consumer Administration and Transfer Solution 71
CD Contextual Design 45, 46
CDMA Code Division Multiple Access 22
CEMS Consumer Energy management System xvi, xxi, 131–137, 139–142, 149, 150, 160–163, 165
CEN European Committee for Standardisation 19
CENELEC European Committee for Electrotechnical Standardisation 19
CER Commission for Energy Regulation 35
CERT Computer Emergency Response Teams 194
CG Centralised Generation 10, 15, 17, 147, 177

CHP	Combined heat and power 15, 177
CMU	Carnegie Mellon University 18, 194
COAG	Council of Australian Government 71, 72, 126
COSEM	Companion Specification for Energy Metering 23, 24, 190
CPE	Customer-Premises Equipment 188
CPP	Critical Peak Pricing 154
CRG	Consumer Reference Group 26
CSE	Centre for Sustainable Energy 64
CsEng	Computer Science and Engineering 52
CSN	Connectivity Service Network 188
CUAC	Consumer Utilities Advocacy Centre 144
DECC	Department of Energy and Climate Change 26, 27
DER	Distributed Energy Resource 19, 112, 182
DEWHA	Department of the Environment, Water, Heritage and the Arts 71, 73
DG	Distributed Generation xiii, 15–17, 147, 177
DIIS	Department of Industry, Innovation and Science 72
DLC	Direct Load Control 12, 59
DLMS	Device Language Message Specification 23, 24, 190
DNSP	Distribution Network service provider 11, 71, 173
DoS	Denial of Service 41
DPC	Peak Clipping 12, 175
DPIA	Data Protection Impact Assessment 43
DR	Demand Response xiii, xiv, 7, 13, 21, 40, 44, 55, 57, 59, 61, 62, 64, 74, 95, 96, 100–102, 127, 158
DS	Design Science 50–52
DSM	Demand Side Management xiii, xvii, 2, 3, 13, 111, 174–177
DSO	Distribution Service Operator 10, 11, 172, 173, 181
DSP	Distribution Service Provider 11, 22, 28
DSR	Design Science Research ix, xiv, xvii, xix, 7, 49, 51, 52, 56, 57, 145, 166, 202, 203

DSRM Design Science Research Methodology 52–56
DU Dense Urban 186–188
ECHR European Convention of Human Rights 72
EEGI European Electricity Grid Initiative 18, 180
EHS electromagnetic hypersensitivity 4, 64, 66
EIA U.S. Energy Information Administration 9
EMF Electromagnetic Fields 64
EMS Energy Management System 53, 105, 106, 109, 130, 131, 133–136, 140–142, 149, 160–162, 164
EPRI Electric Power Research Institute 13
EPSEM Extended Protocol Specification for Electronic Metering 190
ERT Encoder Receiver Transmitter 20
ETSI European Telecommunications Standards Institute 19, 191
EU European Union 18, 31
EV Electric Vehicle 12, 14, 34, 156, 165, 191
FACTS Flexible AC Transmission System 174
FERC Federal Energy Regulatory Commission 172
FLS Flexible Load Shape 12, 175
FMET Federal Ministry of Economics and Technology 34
GIUC Global Intelligent Utility Coalition 18
GPRS General Packet Radio Services 20, 22–24, 187, 190
GSM Global System for Mobile communication 23, 24, 187
GT Grounded Theory 49–51
GWAC GridWise Architecture Council xix, 19, 183, 184
HAN Home Area Network 21–23, 94, 95, 141, 186, 188, 189, 191
HVDC High-voltage Direct Current 112, 173, 174
IBT Inclining Block Tariff 20
ICT Information and Communications Technology 5, 158
IDS Intrusion Detection System 41
IEC International Electrotechnical Commission 193

IEI Idiopathic Environmental Intolerance 64, 66
IHD In-House-Display xvi, 1, 21, 23, 26, 37, 38, 53, 62, 68, 73, 74, 81, 94, 95, 97, 105, 106, 109, 114, 127, 130–132, 134, 140, 141, 153, 161, 162, 184
IoD Institute of Directors 27, 158
IP Internet Protocol 22, 23, 187, 188, 191
IS Information System xvi, 49, 52, 147, 148, 160, 163
ISMS Information Security Management Systems 193, 194
ISO Independent System Operator 11, 172, 193
IST Information Society Technologies 194
IT Information Technology 50
kVA kilo-Volt-Ampere 9, 169
kW Kilowatt 9, 169
kWh Kilowatt Hour 9, 19, 169
LAN Local Area Network 127
LCR Load Control Relay xvi, 62, 95, 97, 105, 126–129, 132, 133, 140, 141, 160, 162
LD Logical Devices 190
LN Logical Nodes 190, 191
LOS Line of Sight 141, 187–189
LP Load Profile 32, 95, 96, 98, 100, 104, 111, 127, 129, 130, 132–134, 136, 143, 158, 160–162, 164
LS Load Shifting 12, 175
LSE Load-serving entities 11, 173
LV Low Voltage xvi, 15, 136, 140, 142, 143, 155, 156, 158, 161, 164, 166
MAC Media Access Control 187
MDM Metering Data Management 71
MDPP Metering Data Provision Procedures 71, 72
MMS Multimedia Messaging Service 24, 191
MSATS Market Settlement and Transfer Solutions 71, 72
NAN Neighbourhood Area Network 21, 95, 96, 186–188
NARUC National Association of Regulatory Utility Commissioners 13

NEM National Electricity Markets 71, 172
NER National Electricity Rules 71
NERM National Energy Retail Markets 71
NERR National Energy Retail Rules 71
NIPP National Infrastructure Protection Plan 40
NIST National Institute of Standards and Technology xix, 18, 19, 44, 181
NLOS Non-Line of Sight 141, 187–189
NSW New South Wales 60, 72, 73
OCTAVE Operationally Critical Threat, Asset, and Vulnerability Evaluation 44, 194
OpEx Operating Expenditure 188
OSGP Open Smart Grid Protocol 191
PAN Personal Area Network 23, 186, 189
PDCA Plan-Do-Check-Act 194
PKI Public Key Infrastructure 40
PLC Power Line Communication 20, 22–25, 161, 188, 190
PoC Power of Choice 71
PSEM Protocol Specification for Electronic Metering 190
PSERC Power Systems Engineering Research Center 111
PV Photo-Voltaic 15, 129, 147
QoS Quality of Supply 94, 96, 104, 105, 110, 128, 129, 134
RE Requirements Engineering xxi, 45, 46, 88
RES Renewable Energy Source 15, 112, 128, 129
RF Radio Frequency 20, 22, 31, 69, 104, 126, 187
RTO Regional Transmission Organisation 11, 172
SBR Service Breaker Relay 62, 97, 126–129
SC Strategic Conservation 12, 175
SCED Security-Constrained Economic dispatch 112, 174
SEI Software Engineering Institute 18, 182, 194
SG Smart Grid xiii, 3, 4, 7, 17, 18, 180
SGAM Smart Grid Architecture Model 19, 182, 183
SGCM Smart Grid Conceptual Model 18, 19, 181
SGFM Smart Grid Functional Model 18, 180
SGIMM Smart Grid Interoperability Maturity Model 19, 183

SGMM	Smart Grid Maturity Model 18, 182
SLG	Strategic Load Growth 12, 175
SM	smart meter ix, x, 1–7, 14, 17–19, 21–28, 32–35, 49, 51, 53–57, 59, 62–74, 77, 78, 81, 83, 86–88, 91, 93–96, 99, 100, 102, 103, 105, 106, 110, 111, 113–118, 120–123, 125–135, 137, 139–145, 148–152, 157–166, 181, 184–186, 190, 193, 196
SML	Smart Message Language 190
SMS	Short Message Service 94, 140
SOAP	Simple Object Access Protocol 24, 191
SP	Scarcely Populated 186–188
SQUARE	Security Quality Requirements Engineering 42
SU	Semi-Urban 186–188
TAM	Technology Acceptance Model 35, 38
TC-PLT	Technical Committee for Powerline Telecommunications 191
TCP	Transmission Control Protocol 191
TNSP	Transmission Network service provider 11, 172
TOU	Time-of-Use xix, 4, 5, 26, 39, 60, 61, 71, 78–80, 90, 94, 102, 126, 128, 133, 154, 158, 176
TSO	Transmission Service Operator 10, 172
UK	United Kingdom xiv, 26, 27, 30, 36, 53, 64, 141, 157, 158
ULS	Ultra Large Scale 29
UMTS	Universal Mobile Telecommunications System 22
US	United State xi, 4, 38, 53, 64, 111, 126, 173
VAGO	Victorian Auditor-General's Office 26
VAR	Volt-Ampere Reactive 112, 173, 174
VF	Valley Filling 12, 175
VPN	Virtual Private Network 67
VPP	Virtual Power Plant 16
WAN	Wide Area Network 96, 186–188
WDMA	Wideband Code Division Multiple Access 22
WMN	Wireless Mesh Network 187, 188
WT	Wind Turbine 15

Chapter 1

Introduction

Electricity is not merely a commodity; it is a social necessity as well as an ecological resource. Disruption of electricity negatively affects consumers with the impact of disruption varying from low to critical based on the nature of the activity. Additionally, electricity should not be rationed entirely on the propensity to pay. However, electricity usage leads to depletion of non-renewable resources and various other ecological side-effects and hence the introduction of conservative measures has become a necessity [Lugaric et al., 2010; Sheldrick and Macgill, 1988]. In the recent years increased interest have been shown in developing better feedback and control mechanisms for the power grid.

A power supply chain consists of generation, transmission, and distribution, retail, and consumers. Traditionally, electricity grid requirements were estimated based on historical consumption data; demand was expected to increase every year. To avoid blackouts and brownouts, electricity providers invested in additional infrastructure only to meet the requirements of the peak period. This method was an expensive and inefficient operating model [Strbac, 2008; Albadi and El-Saadany, 2007]. Additionally, in the traditional grid, there was little or no information flow between network elements and the only information that consumer has available to them was the total consumption over a period, typically three months. Significant changes are currently being implemented in the power grid to improve the efficiency of network operations and for data exchange between elements in the grid. One such effort is the introduction of smart metering systems [Farhangi, 2010; Gungor et al., 2011].

Smart meters are digital meters that record consumption in short time-intervals and communicate to and from the electric utility provider. The smart meter sends billing and monitoring information and receives control information to and from the provider, respectively. These meters have and are being introduced for remote retrieval of consumption data for billing purpose and also as a measure to control demand [Depuru et al., 2011; Benzi et al., 2011].

The smart meters can provide the consumers with real-time information from the power grid. Devices such as In-House-Display (IHD) can be attached to the smart meters, enabling display of instantaneous information on power usage to the consumer. It can display price signals and other control signals sent to the smart meter from the provider. The suppliers have represented that the smart metering system offers enormous benefits to the consumer [Choi et al., 2009; Hargreaves et al., 2013].

Many countries are undergoing trials and deployments of smart meters. The energy industry is promoting the smart metering system as an essential element that can manage demand and consequently contribute to the green and sustainable economy. However, most of the recent smart metering projects are facing substantial adverse reactions from residential consumers. Most consumers view smart meters with distrust. They perceive smart meters to be a means whereby electricity utilities maximise benefits at the expense of consumers' costs, choice, privacy, and even health.

Intelligent information systems are required to improve the operational efficiency of the power grid. These systems should have a balanced outcome on all the stakeholders involved. Investors have a tendency to narrow the system requirements only to match their business goals. It is necessary to understand if the current challenges with smart meter projects are due to neglect by industry to identify end-user needs, or if consumer reaction to a smart meter is a problem of perception due to exaggerated reports in the media.

1.1 Context

Some factors have led to the traditional power grid as being perceived to be outdated and ineffective at meeting the needs of the modern society. The design of the grid is not regarded as being capable of addressing the needs of the time due to limitations in forecasting load, reducing peak demand, and minimising wastage [Farhangi, 2010; Fang et al., 2012]. Additionally, energy needs of consumers are no longer limited to the continuous power supply. Consumers are becoming 'prosumers' i.e. apart from consuming electricity from the grid they are generating excess electricity using solar panels and renewable sources. Consumers want these excesses from individual generation to be either stored or sold back to the grid [Grijalva and Tariq, 2011; Lampropoulos et al., 2010]. A modernised network is therefore required to support the changing energy needs of consumers. In addition to upgrading the physical grid to support a two-way flow of energy, better information systems are required to support the two-way flow of information between all the elements in the grid [Farhangi, 2010; Amin, 2012; Gungor et al., 2011].

The total demand from the power grid has dropped in many developed countries, but the problematic peak demand continues to grow [Saddler, 2013]. Though peak demand occurs only for short periods, networks must be designed to cope with these variations. Networks also have limitations to change rapidly according to the demand; hence, most countries have peaking plants to cope with peak demands [Ramchurn et al., 2012; Kohlenberg et al., 1976]. Those plants are run only during periods of high demand. The current perception is that these peaking plants are expensive and not efficient. Alternatively, the electric utility may employ various demand management techniques to avoid unnecessary cost and wasteful practices. It is cheaper to use techniques to modify load rather than investing in new power plants and storage devices [Palensky and Dietrich, 2011].

Demand Side Management (DSM) activities are designed to leverage consumers to modify their energy behaviours in such a way that the desired load curve is achieved by the utility. It also includes appliance efficiency and energy saving programs. Gellings has classified load-shaping objectives into the following categories: peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape. [Gellings, 1985; Gellings and Chamberlin, 1987]. Service Providers choose a category that resolves the situation and is aligned with their business model.

There is an intense search for measures to improve the business processes and identify grid elements that affect operational efficiency. Some of the network modernisation efforts are geared to improve billing services and identify power thefts and leakages that cause revenue loss. There is a concerted focus towards identifying easier methods to implement DSM programs. Distributors and retailers identified a key unmet need as the absence of an intelligent electricity meter that has the potential to combine all these requirements cited.

Interval meters and remote meter reading concepts have been available as early as the 1990s though not widely used. The interval meters with remote communication capabilities can be loaded with additional functionalities to provide the electric utility with a broad range of opportunities to achieve business goals. Smart meters can record consumption data at short intervals and transfer the data to the electric utility's head-end removing the need for manual reading [Frew and Fuller, 1989; Williams et al., 1998]. Service providers consequently developed the concept of smart meters to minimise cost, avoid human errors, and have functionalities that can apply preferable DSM techniques. From the perspectives of investors and industries, smart meters are highly favourable as they can improve operational efficiency and reduce costs. Smart meters also provide opportunities to control load easily through remote operations.

The electric utility industry believes that smart meters play a significant role in power modernisation projects [CEN-CENELEC-ETSI, 2012]. The modernised power grid, which is also known as Smart Grid (SG), is expected to provide utility companies with full control and visibility over their operations and services [Farhangi, 2010]. To promote efficient uptake of the modern power grid, electric utilities need to convert passive consumers to become active players; smart meters are considered a crucial role in this transformation. Consequently, smart meters are referred to as the building blocks in many SG models and roadmaps [Locke and Gallagher, 2010; SEI and CMU, 2009].

Smart meter advocates expect that with the use of smart meters, consumers can become more energy-conscious and reduce usage resulting in reduced electricity bills that would directly benefit consumers. Government bodies also hope that DSM programs through smart meters will reduce demand and in turn reduce carbon reduction and support green policy goals. Therefore, smart metering systems are promoted as being equally beneficial to consumers and investors. Many countries started smart meter roll-out, some of them even mandatory, without detailed consumer impact analysis [Frantisek et al., 2012]. Contrary to the SG supporters' vision, smart meters are currently facing negative reactions from consumers [Zachary, 2011].

1.2 Problem Statement

The electric utility needs a resilient grid that can evolve and expand to meet the needs of the modern consumer. The energy transactions between each element of the grid should be efficient. Peak demand is an all-time problem faced by the energy industry and it requires efficient and cost-effective measure rather than adding more generators. These improvements need intelligent information systems to support the activities in the power grid efficiently. These new intelligent systems are expected to communicate bi-directionally with other systems in the grid to make an accurate decision.

The current trend reveals that the starting point to grid modernisation is through the deployment of smart meters at consumer sites. Smart meters can provide real-time information on consumption and quality of power supply to the distributors and the customers. For the electric utility, this information can help improve its operational efficiency. For the consumer, this information may provide guidance in making better energy choices. In practice, these initiatives have been challenged and disliked in many countries by the users, particularly residential consumers. There are several international examples of major consumer resistance towards smart metering programs. Australia (Victoria), United State (US)(California), Canada (Montreal) and Europe (Netherlands) have reported consumer resentment towards smart metering projects [UKERC, 2011].

Many of the negative reactions to smart meter remain unresolved. Smart meters are perceived as spying devices and a threat to consumer privacy. Radiation emitted from smart meters are blamed for causing health issues related to electromagnetic hypersensitivity (EHS). In regions where Time-of-Use (TOU) tariffs are being newly introduced, residential consumers are resistant for fear of increased bills. Consumers are also wary that the cost of maintaining the infrastructure and network for the smart metering system will be forced upon them. Overall, it appears that most consumers are unsure if they can benefit from the system without making significant changes to their daily routines and habits.

The intelligent meter, its communication network, data storage units, and other infrastructure are in the order of several million dollars and have wide a economy impact. It is therefore critical for project sponsors to achieve consumer confidence before deployment to avoid prolonged battles with consumers on potential benefits when smart meters are facing activism over issues like security, privacy, and health effects. Unless smart meter technology is equipped to readily support the end-user, it will not be accepted even if it could potentially contribute to resolving major issues such as lowering carbon footprints and climate change.

1.3 Motivation

Smart meters are considered to be the starting point for change in many SG models. Unresolved issues looming around smart meters will not only affect SG projects but will also affect advancements in other areas of SG. Spending funds on expensive projects are not justifiable if the results cannot be guaranteed to all parties involved. Unlike other commodities, the electric utility cannot limit their supply to preferred consumer segments. Smart metering systems have complex Information and Communications Technology (ICT) systems and a significant portion of their operational and maintenance costs are transferred to the end-users. While consumers need to be educated on efficient energy usage, there is no rationale to justify that end-users have to pay excessive charges. A newly introduced system should demonstrate sufficient benefits to gain consumer acceptance. It is important that the industry identifies the right balance to ensure all stakeholders, including consumers, receive benefits.

Currently, many countries have invested significant funds into the smart metering system and are therefore not is a position to abandon the system. However, ineffectively running the system will eventually be more expensive. For example, in Victoria, Australia, smart meters were introduced to apply TOU rates and also remotely control the load [VAGO, 2015b]. When specific customer segments in Victoria actively protested with the help of consumer advocacy groups, the service provider had to retain the previous single rate tariff. Retrofits and system modifications will be required to utilise existing systems more efficiently and simultaneously boost consumer confidence.

The motivation for the research described in this dissertation was to identify solutions to the challenges faced by smart metering systems from residential consumer resistance. This study identifies measures to boost consumer confidence in the smart metering system. An in-depth analysis of the schemes and the perspective of residential customers was undertaken to propose improvements to the current smart metering system.

1.4 Aim

The aim of this research was to identify, design, and process corrections to smart metering systems to overcome the resistance from residential consumers. In this analysis, the residential consumer was not considered as a single entity with a common requirement but was segmented based on various factors. Specific needs that satisfy different consumer segments were identified. Much of the negative reactions towards smart meters are due to the data it generates. These data, when stored and transmitted, can violate the security and privacy of consumers. The aim of this research was also to identify the types and amounts of user data required for the smooth operation of power grid functionalities. This will help to reduce unnecessary storage and transfer of consumers' consumption data and thereby reduce resultant privacy and security concerns.

This study also aimed at identifying user-friendly functionalities that would align user requirements with business goals. For current projects, these identified measures can be used to retro-fit new features to existing device designs. For new projects, electric utilities can consider these proposals during the early planning phase to avoid delays and costly modifications.

1.5 Objectives

Of particular interest in this dissertation was the identification of design and process measures that could save smart metering projects from the verge of failure. The objectives of this thesis were as follow:

- A deeper understanding of consumer concerns and issues with smart metering projects.
- A set of measures that addressed the concerns and challenges, such that enthusiasm replaced consumer wariness and opposition.
- Specific proposals as to how these measures could be implemented and adequately evaluated within the context of contemporary meters, grids, and projects.

1.6 Research Questions

Following the research objectives presented above, the following questions were investigated in this thesis:

1. What are the distinguishing characteristics of various smart metering projects?
   (a) What is the status of the smart metering projects around the world?
   (b) What are the characteristics of the smart metering projects that succeeded when compared to the those that faced consumer resistance?
2. Do the reported concerns highlight significant drawbacks?
   (a) What are the reported concerns? Are there concerns real or perceived?
   (b) What initiatives have been taken towards the reported concerns?
   (c) What steps can be taken to overcome the weaknesses?
3. Can consumer-friendly corrections be made to the smart metering system?
   (a) What features are required for a consumer-friendly smart metering system?
   (b) Can the identified measures be implemented in existing projects?
   (c) Can the solutions be generalised?

These questions will be revisited and discussed in the final chapter of this thesis.

1.7 Thesis Outline

This dissertation comprises 9 chapters (including the introduction) and an appendix. A brief outline of the remaining chapters are as follows:

Chapter 2: This chapter provides a description of various elements of the power grid, demand side management technique used by the electricity industry, and the role of smart metering system in power modernisation projects.

Chapter 3: This chapter provides a literature review of smart metering systems, their challenges and measures identified. This chapter also analyses various energy behaviour studies on residential consumers. Various risk analysis and requirement elicitation strategies have been analysed to identify suitable ones for a consumer-focused smart metering system. Some of the analysis in this chapter have been published in conference proceedings.

Chapter 4: This chapter details the research methodology adopted for this research. DSR methodology was used to conduct this study. This method focuses on social and behavioural domains, which makes it is suitable for identifying consumer-friendly measures in the smart metering system. The remaining chapters are categorised based on the DSR process steps.

Chapter 5: This chapter identifies and details the problem scenario. Scenario analysis method was used to determine the challenges that Demand Response (DR) programs and smart meter caused the consumer. The result of this analysis was compared with the customer concerns reported. The primary objective was to have an in-depth understanding of consumer concerns to propose measures that will facilitate consumer-friendly features in current projects and future designs. The consumer concerns were classified and the real risks identified. Subsequently, the risk to consumers' assets was determined. The Victorian smart metering context was further analysed as it was used for demonstrating the effectiveness of the proposed measures. This analysis helped to determine the factors the project sponsors overlooked which led to the consumer concerns. There are contributions in this chapter that have been published as conference proceedings.

Chapter 6: This chapter details the first steps taken towards developing a consumer-friendly model. This chapter focuses on the three most important areas the current smart metering project lacked: consumer segmentation, risk analysis process with customer focus and end-user friendly requirements elicitation strategies. As part of consumer segmentation, the residential consumers were further classified into various categories to propose realistic measures. Scenarios were then used to demonstrate consumer-friendly analysis of risk and elicitation of requirements. There are contributions in this chapter that have been published as conference proceedings.

Chapter 7: This chapter contains the major contributions of this thesis. Consumer perceptive was used to develop the abstract architectural model, data flow diagram, and frameworks for the smart metering system. One of the primary concerns about the smart metering system was data content. Measures were identified to reduce the necessity for detailed interval data from the consumer. Then consumer-friendly features are proposed. These functions include specific functionalities, different billing, and feedback choices to satisfy several consumer segments. The findings in this chapter are published in conference proceedings.

Chapter 8: This chapter also contains major contributions of this thesis. This section demonstrates the realisation of consumer-friendly features in the current smart metering system. The smart metering system in Victoria, Australia was used for this discussion. This chapter further evaluates the effectiveness of the proposed measures. The evaluation further helped in improving the architectural model for the smart metering system. Though the conceptual models are general, a generalised implementation plan was not possible from the analysis. This limitation is due to the variation in the smart meter types and communication technologies used in each location. However, it was possible to create a generalised framework for consumer-friendly SGs projects. This can be utilised as a checklist by electricity service providers planning grid automation projects. The findings in this chapter are also published in conference proceedings.

Chapter 9: This chapter summarises all the findings from this study and then compares the results with other research findings in relevant sectors.

Chapter 10: This final chapter revisits the research questions and then lists the contributions, further directions as well as limitations of the project.

Appendix: This thesis draws from various bodies of knowledge and domains. This section acts as a quick reference to the definition and descriptions of various concepts and terminologies used in this thesis. It has been compiled from various established sources.

Chapter 2

Background

Understanding the power grid is the first step towards identifying and proposing correction measures for consumer-friendly smart metering system. To analyse energy consumers, it is necessary to understand demand, its effect on the power grid, demand management techniques and grid modernisation efforts to ensure the reliability of service.

This chapter on background presents the electricity industry, demand for electricity, demand management techniques and technologies involved in demand management. Furthermore, a general review of smart grid and its main elements are also provided. Then the smart meter and its related elements are discussed. Finally, this chapter concludes with reference to electricity consumers.

2.1 Electricity Industry

Electricity plays an essential role in modern society. The commonly used terms about electricity are 'energy' and 'power'. Electric energy(kWh)is the ability of an electric current to produce work, heat, light, or other forms of energy whereas electric power (kW) is the rate at which electric energy is transferred and it is measured by capacity (U.S. Energy Information Administration [EIA, 2017]). Other important terminologies are 'demand' and 'load'. Demand(kVA/kW) is the rate at which energy is delivered to scheduling points whereas load(kWh) refers to the electricity consumed by the end-user [National Grid, 2015]. A simple scenario is presented here to explain demand. One 100-watt light bulb burning for 10 hours consumes 1kWh. The entire time it is on, it demands 0.1kW from the service provider. Similarly, ten 100-watt light bulbs burning for only 1 hour also consumes 1kWh. In both cases, the consumption (load) is 1 kWh but the demand is different. The service provider should be prepared to provide ten times as much 'capacity' in response to the 'demand' of the 10 light bulbs operating all at once [TEM, 2015]. For this reason, it is important for the electricity service providers to track and manage demand.

2.1.1 Market Players

From the generation site, electricity reaches the consumer through numerous players. The main electricity markets players are electricity generators, transmission operators, distribution operators, power exchanges, retailers, and regulators.

Centralised Generation (CG) units like the thermal power plants or renewable sources like wind farms could be used for power generation. Based on the source of generation, electricity is either injected into the (high-voltage) transmission system or directly into (medium or low-voltage) distribution systems before being delivered to the end user. The end users can be a residential customer to major industrial players. Industrial users are often directly connected to the high-voltage grid. The transmission operators maintain the high-voltage transmission lines. They also ensure the long-term ability of the system. In most cases, the distribution operators maintain the medium to low-voltage distribution systems that moves the low voltage electricity to the consumer premises. They also install the meters that are used to measure the amount of electricity used. Electricity retailers manage the sales and billing of electricity. The consumer's bill comprises of generation, transmission distribution and retail charges. Apart from these major players, there are also Power Exchanges. Power exchanges become a platform for the market players to negotiate sales and purchases of electricity anonymously. This platform provides an open market and transparency on market prices. There are regulators to scrutinise the operations of the market players. The regulator has to ensure that operations line with the public interest and overall energy policy [EU, 2009].

2.1.2 Supply Chain Structure

For most countries till the early 1990s, the electricity industry was mostly run by government-owned entities, and this composition is changing. The restructuring aims to move from the vertically integrated monopoly utilities to unbundled electricity businesses which support full competition. For the supply chain structure to support full competition, intelligent information systems and improved networks are required. The stages of changes to the power supply chain may vary among countries. However, they can be classified as follows: vertically integrated monopoly, unbundled monopoly, unbundled limited competition and unbundled full competition. In an unbundled supply chain structure that supports full competition, different generators will be able to compete to provide electricity. The transmission and distributions lines will be accessible to all competing generators. Apart from retailers, there may be energy brokers for supplying power to the consumers [EFA, 2004].

2.1.3 Service Providers

There are various terminologies used for the service provider. Terminologies used to refer to transmission, distribution and retails service providers in the US, Europe, and Australia are discussed in this section. In Europe Transmission Service Operators (TSOs) are responsible for the transmission services. They schedule and dispatch resources with the help of other regional balancing authorities. In Europe, Distribution Service Operators (DSOs) acts as distribution system operators and neutral market facilitators. They provide generators with non-discriminatory access to their networks and also maintain the system to ensure the secure flow of electricity. In some countries, public authorities are the long term owners of the network, and they provide a license to the DSOs to operate the network. In some countries, there are different levels of retailers [EURELECTRIC, 2011].

In the US, Independent System Operators (ISOs) and Regional Transmission Organisations (RTOs) provide reliability planning for the region's bulk electricity system. RTO additionally is responsible for maintaining the transmission network. Their planning approach helps to optimise resources and reduce the need for new power plants. The US also has Load-serving entities (LSE). LSEs looks after energy requirements of end-use customers [EPSA, 2015; NERC, 2015].

In Australia, Australian National Energy Market Operator (AEMO) operates the markets and energy systems. The generating units are classified as market and non-market. Non-market generators sell all supply to one customer or retailer, whereas market generators sell all supply to the market and receives payment from AEMO at spot prices [AEMO, 2014]. Transmission Network service providers (TNSPs) manage the high voltage lines that transmit electricity to cities, towns and across state borders. Large users of electricity connect directly to the transmission network, and they pay more significant transmission network charges. The residential consumers and other small businesses are not directly linked to the transmission network, and network charges form about 10% of the consumption bill [AER, 2013]. In Australia, Distribution Network service providers (DNSPs) are responsible for managing the distribution systems that deliver electricity to the end user [AER, 2014b]. There different tiers of customers based on the retailer that supplies them. Local retailers must be registered as market customers to purchase electricity through spot market and supply to the end-users. First-tier loads are settled through a local retailer whereas second-tier loads are established through a market customer who is not the local retailer. Both these customers must not participate in the spot market [AEMO, 2014].

In this thesis, reference will be made to the distribution service provider as they install the electricity meters in most cases and to the retailers as they are the first contact point for the customers for their power connection. Though various terminologies exist for these service providers, they will be referred to as Distribution Service Providers (DSPs) and retailers in this thesis.

2.2 Demand management

The need for reliable and high-quality electric services has increased over time. A reliable power system will be able to deliver electricity in the quantity and quality demanded by its customers. The reliability of power supply is often measured by the frequency, duration and extent of power system disturbances and outages. Peak demand causes some of the disturbances in the electrical system. Peak demand has always been an issue for the electricity service providers [Osborn and Kawann, 2002]. Weather, demographics, economy, equipment and technology choice, are some of the main factors that influence peak demand. Weather is one of the most important factors for peak demand. Air conditioning loads in hot summer days and electric heating during cold winter days have a significant effect on peak demand [Koomey and Brown, 2002].

Economic growth in an area leads to denser pollution due to migration. This trend can cause local, and system peak demands as there will be rapid growth and energy intense practices in those localities. Settlement and equipment usage patterns are affected by demographic trends. Equipment ownership and daily usage patterns are found to be affected by household size, lifestyle, and age of the occupants. Types of the dwelling/ building also influence the appliances and technologies used. Though energy efficient products are more in use, the number of those products and how often they are used can affect peak demand. Policies from government and electric utilities can also influence peak load in short to medium term. This includes equipment efficiency standards, building codes, government procurement, and rebate programs [Koomey and Brown, 2002].

All the factors mentioned above influence the end user's energy behaviour. Both electricity service provider and government bodies are interested in identifying mechanisms that will promote modification in energy response which will, in turn, modify demand in a way favourable to the economy and environment.

2.2.1 Load Shaping

Load shaping refers to techniques applied to modify or smooth out the load curve. Six main load shaping objectives are peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape [Gellings and Chamberlin, 1987; Goswami and Kreith, 2007; Khedkar and Dhole, 2010].

Peak Clipping (DPC), Valley Filling (VF), Load Shifting (LS), and Flexible Load Shape (FLS) are four options by which electricity consumption can be altered. Each of these four goals can be applied in operational time-frames through utility load management. Strategic Conservation (SC) and Strategic Load Growth (SLG), represent objectives to decrease or increase load at levels remaining useful in the long-run [Chuang and Gellings, 2008; Gellings and Chamberlin, 1987]. Direct Load Control (DLC) is used to achieve peak clipping. With DLC, the utility can strictly control consumer's power consumption. VF can be achieved by building off-peak loads. This strategy is preferred when the long-run incremental cost is less than the average price of electricity. Adding thermal storages is one way of accomplishing VF. LS involves shifting load from on-peak to off-peak periods. Current applications include customer load shifts. Energy efficiency programs are commonly referred to as SC. This includes weather-proof residence and appliance efficiency improvement. SLG involves increasing load level through electrification. This includes an increase in market share of loads assisted by competing fuels. This will include the emerging electric technologies for Electric Vehicles (EVs) and industrial process heating. FLS is a concept related to reliability, and it is being replaced by the idea of dynamic energy management which involves demand-side management, demand response, and distributed energy resource programs merged in an integrated framework [Chuang and Gellings, 2008; Gellings and Chamberlin, 1987; Parmenter et al., 2008].

2.2.2 Demand Side Management (DSM)

The activities conducted by the electric utility to produce desired change to the shape of the load is referred as DSM program, and this term was coined by Clark W. Gellings of the Electric Power Research Institute (EPRI) in the early 1980s. DSM includes planning, implementation, and monitoring activities designed by electric utilities. Load management, energy efficiency, and conservation are the three most important elements in DSM [York and Kushler, 2005].

Load management mainly intends to lower peak demand by introducing a measure to reduce usage during that limited period of time. Efficient load management programs that tackle short term needs in the grid are also referred to as DR. Energy efficiency mainly intends to provide better services using less energy. Energy efficiency measures save energy across all times and are mostly long lasting. Conservation involves reducing usage, and it includes mainly consumer‘s effort in changing energy behaviour [Bellarmine, 2000].

2.2.2.1 Demand Response (DR)

The National Association of Regulatory Utility Commissioners (NARUC) defines DR as follows: “Demand response resources include all intentional modifications to the electric consumption patterns of end-use customers that are intended to modify the quantity of customer demand on the power system in total or at specific time periods” [Cowart and Harrington, 2001]. The modification is intended for both instantaneous demand (kW or MW) and total consumption (kWh or MWh) but the focus is mainly on short-term adjustment in demand. In most cases on receiving signals (particularly price signals) from the utility, the consumer intentionally modifies usage [York and Kushler, 2005].

2.2.2.2 DSM Techniques

The objective of any DSM technique is to produce a load-shape change. The success of the implementation relies in the ability to balance the service provider’s target and the customer needs [Gellings, 1985]. An important part of DSM process involves the consistent evaluation of demand-side to supply side alternatives and vice versa. This approach is referred to as integrated resource planning [Goswami and Kreith, 2015].

DSM technique can be mainly categorised as follows: Alternative Pricing, Direct Incentives, Outreach and Cooperation, and Regional Codes and Standards [Chuang and Gellings, 2008; Palensky and Dietrich, 2011]. For alternative pricing, rate structures are used to influence the consumer’s electricity consumption behaviours. Direct incentives program provides financial assistance to encourage the consumer to adopt a DSM technique. In outreach and cooperation settings, consumers are educated and provided with information to modify their energy behaviour. Under the regional codes and standards scheme, compliance with standards and codes will be mandated to achieve the target [Chuang and Gellings, 2008; Palensky and Dietrich, 2011].

2.3 Changing Power Grid

Many changes are happening in the power grid with new loads like EVs; distributed generation like the wind and solar farms, micro generation like rooftop solar panels, and automated systems like smart meters. Active load management will be needed to avoid network congestion and provide smoother system operation. Distributors also require efficient automated control systems to become more active. Generation, Transmission, Substation, Feeder and Service Point are the major elements of a power grid. The voltage levels at each component vary from country to country. Table 1 shows the characteristics of the major segments in a power grid.

Table 1: Major elements of power grid

System Level	**Equipment**	**Remarks**	**Voltage levels**
Generation	Turbine generators	In most power plants the turbine is driven by steam. In some case, hydro is also used	11-25 kV
Transmission	Step-up transformers	The voltage is stepped up before transmission	230- 756 kV Generally (500, 400, 345, 275, 230) kV
	High voltage transmission network	The transmission lines run over a long distance. The power is usually delivered into a common pool called the grid.	
	Switching station	The power from the transmission line is stepped down before delivering to the substation.	69 - 230 kV Generally (161, 132, 115, 69) kV (sometimes 33kV)
	Sub transmission line - lower voltage	Takes power from the transmission switching station and delivers to the substation	
Distribution	Substation / Load centres	The transmission lines terminate into the load centres or the substation	33kV (sometimes 66kV)
	Step-down transformers at Substation	The voltage is stepped down before delivering to the Feeder.	

Feeder	Load Points LV feeders	From the substation power is then distributed to the load points	$\sim$ 11kV
	Step-down transformers at LV feeder	The voltage is further stepped down at the feeder.	
Consumer Service Point	Metering Device	From the feeder, the power flows to the end-user	120/ 240V- single phase supply
			415V- three phase supply

A traditional grid mainly includes Centralised Generation (CG), one-directional power flow, and weak integration. The centralised power plant generates power in bulk and mainly relies on fossil fuels to create steam in large boilers to drive turbine generators. Now the focus has shifted to Distributed Generation (DG) and Renewable Energy Sources (RESs) [Bari et al., 2014; Simoes et al., 2012; Wang and Lu, 2013]. Consumers are showing interest towards micro-generation technologies like roof solar panel, micro wind. Combined heat and power (CHP) is an established technology at industrial scale, and now it is gaining popularity among residential consumers. In some places, micro-CHP systems are used for space heating and hot water systems. These systems are capable of producing useful heat and power [Sauter and Watson, 2007]. Figure 1 is a diagrammatic representation of the changing power grid.

Many distributed generators can be coupled to form a micro-grid. It can be either integrated into the main grid or can run as a standalone system. Energy storage systems can be added at different levels in the grid to avoid wastage and for quick access in case of emergencies. All the modifications in the grid necessitate improvements to the information systems that are controlling and managing the network. The distributed control system should become more active, and it may require data from generation sites, transmission and distribution systems and even the consumer.

2.3.1 Distributed Generation

In DG more preference is given to Wind Turbines (WTs) and Photo-Voltaic (PV) systems than fossil fuels. Though the power generation capabilities of distributed generators are not as efficient as centralised generators, they have significantly lower transmission & distribution cost and related reliability issues [Bari et al., 2014; Simoes et al., 2012; Wang and Lu, 2013]. Higher penetration of DG is facing issues due to the limitations of the traditional grid which is only used to power flow in one direction.

Existing centralised and autonomous control systems will have to work in coordination to ensure quick and safe operations. The infrastructure is also not capable of efficiently handling the generated power from DG. In the traditional grid, the transformers at distribution level only have to convert a higher voltage to lower voltage. But the power flowing back to the grid from DG sources will require the transform-

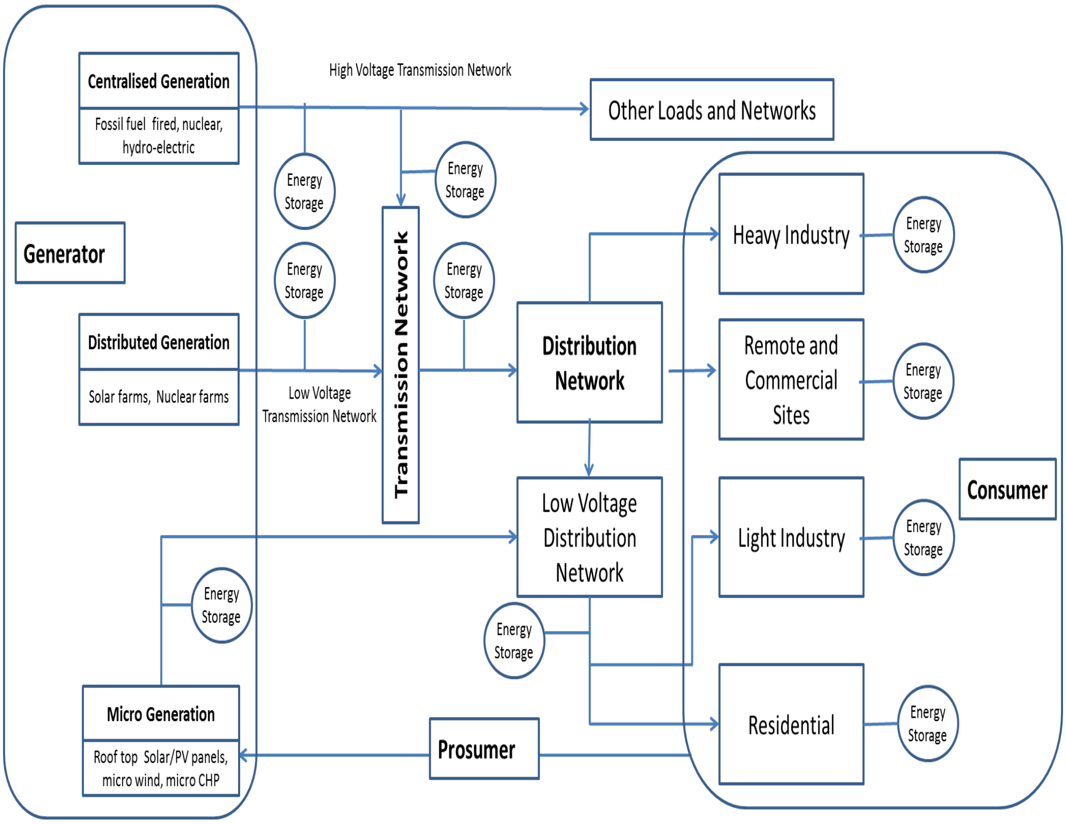

Figure 1: Changing Power Grid

ers to handle the reverse flow. If various DG sources try to inject the oversupply simultaneously into the grid, it can overload the cables, lines and transformers. The distribution loss also goes up when the power supply from DG goes high [Albadi and El-Saadany, 2007; Wang and Lu, 2013]. DG also tends to increase the voltage level in the distribution network. With the excessive addition of distributed generators, there is a possibility that voltage level will increase above the set threshold levels for the low voltage network and destabilise it. Also, the switching on and off of the DG source causes the power line frequency to fluctuate for a short period, and this could again destabilise the system. Another risk is if DG supplies the grid when the network is switched off for particular purposes like maintenance. These situations create a significant risk to the maintenance operators working on the power lines unaware of supply from DG sources [Albadi and El-Saadany, 2007; Wang and Lu, 2013; Xu and Lai, 2011].

2.3.2 Micro Grids and Active Networks

Many DGs can be coupled to form a micro-grid. It can be either integrated into the main grid or can run as standalone. A coordination of several DG units to act as an integrated plant is also known as a Virtual Power Plant (VPP). Unlike the traditional grid, VPP requires the integration at low voltage and hence existing power management systems will require improvements and developments [Bari et al., 2014; Sechilariu et al., 2013].

In CG, adjustments to the supply are made mostly at the transmission level. The integration of DGs on a large scale will require the distribution network to be active. It should be able to sense and manage the power flow from both CG and DG. This setup will require improvements and developments to the information systems that are controlling and managing the grid. For the electricity grid elements to operate jointly, a decentralised control system will be necessary. It should be able to identify and forecast the levels of output from both CG and DG and analyse voltage variations, power quality and stability [Lo and Ansari, 2013]. In future, these control networks will be able to expand to self-healing systems. Similar to communication systems, power routers will be needed at critical points in the network to facilitate the reliable flow of power. These power routers will need power-related information from various entities in the grid to identify measures to avoid congestion and improve reliability. It will require data from generation sites, transmission and distribution networks and even from the consumer. New information systems are needed to provide functionalities that do not exist in the current infrastructure [Efthymiou and Kalogridis, 2010; Fang et al., 2012].

2.3.3 Smart Grid

In an era of an energy revolution, advanced power management systems are needed to overcome the current shortfalls to balance electricity consumption and production efficiently and to integrate new components. This transformation will lead to a smarter power grid. The power-delivery system will need additional power electronic components, data communication network, automation tools and automated management solutions to pave the way to an intelligent grid [Abayateye et al., 2013; Beidou et al., 2010; Fang et al., 2012; Locke and Gallagher, 2010; NIST, 2010].

In a SG, generation capacity can be easily identified using advanced mechanisms. The improved system will be capable of determining the production capacity of generation sources (central, distributed and micro-level) using power electronic (actuators) and control tools. It will be capable of optimising energy output and automatically maintain voltage, frequency and power factor standards using data from various sources in the grid. The transmission and distribution will use superconducting cables for long distance transmission to reduce losses. Monitoring tools will be capable of detecting cable failures. It will also be able to transform into the self-healing and self-balancing network using the real-time and past data from various sources in the grid. Substations will be using power electronics and control tools to improve its operation. The system will be able to automate the protection of equipment and dynamic process in the substation. Critical and non-critical operational data such as power factor performance and status of the breaker will be used to make decisions [Hoang, 2006; SG3, 2010].

In a SG, customers are also expected to become important players. Consumers and load had been passive in a traditional network. By making the users' connection points more flexible and interactive, the service provider can implement demand response programs. Smart meters and smart appliance are two options available to the end-user.

Smart meters are capable of remote load control, dynamic tariffs, and power quality monitoring. Smart devices are capable of deciding when to consume power based on pre-set customer preferences. Using a smart meter and smart appliances consumer can also actively participate in demand management [Hoang, 2006; SG3, 2010].

SG requires various technologies for its operation. These technologies can support activities in the generation, transmission, distribution and electricity consumer domains. Some of the implemented technologies include the smart meters. A fully operational SG will apply suitable techniques in all areas. Now many countries are deploying smart metering systems/Advanced Metering Infrastructure (AMI) as part of their grid modernisation initiatives. The European Union (EU) is planning to roll-out smart meters to 80% of citizens by 2020, subject to a positive national cost-benefit analysis. This program corresponds to 200 million smart meters in total. Distribution service providers will be responsible for the roll-out of smart meters in most countries [EU, 2009].

2.3.4 Smart Grid Reference Models

As the power infrastructure is huge, a reference model is used by the service provider to achieve the power grid modernisation goals. These reference model describe and discuss the characteristics, behaviour, interfaces, requirements, and standards for the system [Locke and Gallagher, 2010]. This section will discuss five well-known smart grid reference models.

European Electricity Grid Initiative (EEGI) has provided Smart Grid Functional Model (SGFM). It is a 5-level model that aims to help project sponsors achieve their goal. According to their model, the energy consumer has a major role to play. They want the consumers to interact with other stakeholders like distribution utility and free market players like retailers and aggregators. They also want the consumers to get involved in smart integrations and energy management activities. [EEGI, 2010].

Smart Grid Conceptual Model (SGCM) is developed by NIST. It provides a visualised diagram of seven different domains and their interaction. In SGCM model too, the consumers are expected to play a major role. The consumers are also considered as prosumers as they can generate electricity in their premises and sell it back to the grid. Through smart meters, smart appliances, and other information systems, they are expected to get involved with other domain elements [SG3, 2010].

Smart Grid Maturity Model (SGMM) was developed by IBM and Global Intelligent Utility Coalition (GIUC) a group of leading utilities and then later transferred to Software Engineering Institute (SEI)/Carnegie Mellon University (CMU). This model consists of five maturity matrix which rates the different values set by eight domains namely: Strategy, Management, and Regulatory; Organisation and Structure; Grid Operations; Work and Asset Management); Technology; Customer; Value Chain Integration; Societal and Environmental. Based on this model the Customer domain includes retail, customer care, pricing options and control, advanced services and visibility into utilisation quality and performance. They portray that customer can become empowered using the smart grid technologies like smart meter to make choices regarding their usage and cost of energy [SEI and CMU, 2009].

Smart Grid Architecture Model (SGAM) is developed by members from European Committee for Standardisation (CEN), European Committee for Electrotechnical Standardisation (CENELEC), and European Telecommunications Standards Institute (ETSI) and it builds over established domain models like SGCM from NIST. It was proposed in the context of the European standardisation mandate M/490. It expresses domain-specific viewpoints on architecture models. It contains Domains, Zones and Interoperability Layers. The domains are: generation, transmission, distribution, Distributed Energy Resources (DERs) and customer premises and the Zones are: process, field, station, operation, enterprise and market [CEN-CENELEC-ETSI, 2012].

Smart Grid Interoperability Maturity Model (SGIMM) was developed by the GWAC. Its main objective is to monitor the automation of all areas in the electrical grid, particularly transmission, distribution and demand side resources. It also focuses on a gap analysis of technologies involved and safety measures in utility control schemes [GridWise, 2008].

All reference models expect consumers to become active players in the modern grid. All these models want interconnection between different domains in the power grid and have data shared for creating applications to improve the operational efficiency of the grid. All these reference models also consider smart meters as the key element and starting point for grid modernisation.

2.4 Electricity Meters

Electricity meters are installed at customer's premises for billing purpose. It measures the energy consumed by the customer. The billing unit is kWh and the value is read once a billing period. These meters were initially of accumulation type. In many places, these accumulation meters are being replaced by interval meters.

2.4.1 Meters Types

Meters can be mainly classified as accumulation and interval type meters. Accumulation meters only have the option to record the accumulated usage. Electromechanical meters and earlier digital meters are of this type. The total consumption for the billing period is calculated by taking the difference between the current and previous meter reading. For the electromechanical meters, the displays were mostly a dial or a cyclometer. The electronic meters had a digital display that showed the accumulated kWh. These meters were also referred to as 'Flat Rate' meters as only a single rate could be applied to the consumed electricity to calculate the bills [Ausgrid, 2014; DSDBI, 2015].

Interval meters can record consumption over a time interval that is programmed into the meter. Each interval data will be associated with a time stamp, and this enables the use of variable tariff rates on the power consumed. Advanced interval meters are also capable of recording other data related to power quality [Ausgrid, 2014; DSDBI, 2015].

2.4.2 Meter data Retrieval Methods

There are various ways in which the meter data could be retrieved. In the traditional set-up, a meter reader would go the customer's premises and read the data on the meter's display. With later generation meters, other data retrieval mechanisms were introduced. The meter data retrieval methods can be mainly classified as on-site meter reading and remote reading [Knight and Banks, 1998]. There are prepayment meters which operate by inserting cards. These cards have the amount of energy encoded on them. When the amount on the card is exhausted, the energy flow through the meter will be blocked. This method does not require consumption data to be retrieved as this type of consumers do not need to be billed [Colton, 2001].

For on-site reading, a technician or a meter reader from the utility company will have to go to the premises where the meter is located to note the readings. For older version meters, the technician either writes down the value or enters the data into a hand-held device. Advanced meters have an optical port and the hand-held meter reading devices are connected to the meter using an optical probe. For interval meters, the readings include billing data and load profile data. Remotely read meters will have a communication module. These meters are also referred to as Automated Meter Reading (AMR) meters [Chandler, 2005]. The distribution service provider can read consumption data and other meter data remotely using various communication technologies. Power Line Communication (PLC), Radio Frequency (RF) mesh technology, General Packet Radio Services (GPRS), and Wi-Fi are some of the commonly used communication methods [Usman and Shami, 2013]. Some of the initial models of AMR were also referred to as Encoder Receiver Transmitter (ERT) devices, 'wake-up' meters, etc. The meter reading vehicle would transmit wake-up signal as it drove past an area. The ERT's receiver will detect the signal and transmit the needed data. Another type of AMR meters are referred to as 'bubble-up' meters. These meters did not require a wake-up signal and transmitted frequently or at certain intervals as programmed [Rouf et al., 2012].

For prepayment meter, consumers can add credit into the meter using cards that have a specific amount of energy encoded into it. After the credit runs out, energy is completely blocked or reduced to the bare minimum. This method is used where the consumers are considered a credit risk and is often referred to as a useful budgetary tool. [Colton, 2001]. Apart from the flat rates, these meters also support Inclining Block Tariff (IBT). IBT was introduced in many countries to protect the poor. In IBT, the electricity price has several blocks. The first block of electricity purchased in a month has the lowest price and this price increases in the subsequent purchases done during the same month [IPRT, 2003]. At the end of each month, the history gets reset, and the consumer starts again from the lowest price. Prepayment meter provides direct feedback to the consumers on their consumption. It can help them manage their bills and save by limiting their purchase to what is sufficient for a month [IPRT, 2003].

2.5 Smart Meters

The AMR meters evolved to become Advanced Metering Infrastructure (AMI) meters or 'Smart Meters'. AMR meters only utilised one-way communications to collect meter data for the utility whereas AMI meter has two-way communication. Apart from receiving data from the meter, the distributor and retailer can also send information to the meter. Smart meters capture data on power consumption and quality of supply. This data is transferred and stored into the distributor's back-end. The data is processed to generate energy management decisions. Information useful to the consumer is then transferred through the system to the user to help them in making intelligent choices [Molina-Markham et al., 2010; NETL, 2008].

A smart meter mainly consists of metering unit, communication unit, and control (connect/disconnect) unit. A high-end smart meter has a micro-controller with an Analog to Digital (A/D) and the meter firmware performs various data processing and calculations. There are sensors that measure the current and voltage of the power supply. The A/D converter converts this data, and the micro controller calculates power usage. There is an EEPROM section in which this data along with other measurements are stored. The control unit in the smart meter can connect/disconnect the power supply. There is also a display section that shows the power usage and other related information [Bourns, 2015]. Then the meter has an optical/Infra-red port through which the data is locally read [Patterson et al., 2006; Yan et al., 2012]. An IHD module can be connected to the smart meter to provide feedback to the consumer and it is optional in most of the recent projects [Fan et al., 2013]. The meter also has communication modules to connect to Neighbourhood Area Network (NAN) and Home Area Network (HAN). The smart meter communicates to IHD via the HAN network. It helps the consumer to monitor their energy usage in real-time. The smart meter communicates to the collector/ concentrator through the NAN network.

With smart meters, the distributor can monitor and manage load and take necessary measures to protect the distribution network. The utility can send time-based tariff rates to the consumer as part of DR program. The user can access instantaneous consumption data through IHD or similar feedback mechanism. smart meter can help in revenue protection for the utility as they can remotely disconnect or limit a load of consumers who have not paid bills. Tamper and power outage alerts created by the meter are helpful in preventing thefts and faster restoration of power respectively. The utility can also remotely monitor power quality of the supply. This process improves services and operations of the utility [EEI, 2011; NETL, 2008].

The energy industries are keen to make smart meter a core component of the grid modernisation efforts as it has potential in controlling and managing the load. Utility companies want their smart metering system and technologies to be forward compatible with future smart grid features [Farhangi, 2010]. These meters use various communication technologies to enable two-way communication with the service provider.

2.5.1 Communication Technologies

The smart metering system requires robust communications technologies. The utility industry uses both wired and wireless communication technologies. Choosing the right communication technology is still a challenge. Ideally, the communication solution should have minimal investment and should be easy to install, operate and maintain. The energy consumed should also be low. Though a smart meter consumes little power, it adds up when many meters are connected point-to-point. smart meters roughly have a lifespan of 15 years, and the communication network chosen should be able to operate reliably for the same span of time. It must be able to survive extreme environmental conditions (temperature, humidity, corrosion, etc.). The system should assure interoperability even if the components are changed. It should also have good capacity and low latency. The system should also be secure. Confidentiality, integrity and authenticity of the data should be assured, and availability of data should be guaranteed [Gungor et al., 2011; Haidine et al., 2013]. RF Mesh, a cellular network, and PLC are the most commonly used communication technologies. All technologies have authentication and confidentiality over the air links, but application layer security mechanisms have to be applied for end-to-end security [Gungor et al., 2011; Joseph and Jesse, 2012]. The most commonly used technologies are discussed below.

RF mesh consists of a group of nodes and has self-healing characteristics. If any node becomes inactive, the communication signal can find another route via other active nodes. In this setup, the smart meter becomes a signal repeater, and the data hops through neighbouring meters to reach the collector/concentrator. From the collector, the data is transferred to the DSP's back-end. With the multi-hop routing capability, it can provide good coverage in urban and semi-urban areas. The coverage and capacity of the network are enhanced as meters can act as signal repeaters. It also faces challenges from interference and fading. Coverage challenges also exist due to meter density in urban areas. There are loop problems when data travels through many neighbours, and this causes reduction of bandwidth due to communication overhead [Gungor et al., 2011; Kim et al., 2012; Lewis et al., 2009].

Cellular networks are also used for smart metering systems. Existing networks are used to reduce operational costs as there is no need for investing in a dedicated network. It is even suitable for communication between far nodes. 2G, 2.5G, 3G, and WiMAX are the cellular communication technologies applied by to utilities for smart metering deployments. 2.5G describes the state of wireless technology and capability usually associated with GPRS. It allows the user to transmit Internet Protocol (IP) packets to external networks. Code Division Multiple Access (CDMA), Wideband Code Division Multiple Access (WDMA) and Universal Mobile Telecommunications System (UMTS) wireless technologies are also used in AMI related projects. Cellular communication is widespread and cost-effective and provides sufficient bandwidth for a huge amount of data, and it is beneficial for collecting a large amount of data generated by smart meters. Cellular networks also have security controls. User data protection, anonymity, and authentication are some of the strengths. It is also suitable for smart meter deployment in rural or semi-urban areas. It is also be used for HAN applications.

The downside of cellular networks is congestion as they are shared with other users and hence they are not ideal for time-critical applications. Harsh weather conditions like storms may affect the service. Using a private network may be much better. However, that will make the infrastructure more expensive [Gungor et al., 2011; Haidine et al., 2013; Lewis et al., 2009; Lopez et al., 2014; Yan et al., 2013].

PLC is also used for smart metering systems. It uses the existing power lines to transmit data, and it is a popular choice for many electric utilities as it avoids the need for constructing new infrastructure. It is usually used in conjunction with other cellular technologies. Power lines are used for communication between the meters and the data collector and the data from the collectors is then transferred to the back-end using a cellular network. In some of the AMI setups in Europe, PLC technology is chosen for data communication between the meters and the data concentrator, whereas GPRS or Global System for Mobile communication (GSM) technology is used for transferring the data to service provider's database. Ubiquitous nature and availability make PLC more feasible as the network already covers the area. However, these networks have low bandwidth and are noisy, and this affects the quality of the signal. These characteristics make PLC not suitable for frequent transmission of a large quantity of data [Chen et al., 2012; Gungor et al., 2011; Yan et al., 2013].

Zigbee is a wireless communications technology commonly used for home automation. Zigbee has low power requirements and is cost effective. Many vendors have Zigbee integrated into their smart meters so that the meter can easily communicate with other Zigbee devices. IHD is one such device controlled by Zigbee protocol. With most utilities, the IHD is an optional feature and as the meters are Zigbee enabled the customer can easily opt for a GPRS later without any hassle. The main disadvantage of Zigbee includes short range, low complexity, and low data speed. These characteristics make them only suitable for HAN or Personal Area Network (PAN) and not for other parts of the AMI as they require large coverage. Even for home automation, they are not suitable if the meters are more than 80 m away. In big buildings where smart meters are located in basements, it can be difficult to penetrate concrete walls and communicate with many apartments in the building [Bilgin and Gungor, 2012; Gungor et al., 2011].

2.5.2 Metering Protocols

Some of the commonly used metering protocols are American National Standards Institute (ANSI) C12, Device Language Message Specification (DLMS)/Companion Specification for Energy Metering (COSEM) and IEC 61850. The ANSI has provided a standard metering protocol for many years and is widely used in US, Canada, and Australia. The C12 series of standards ensures interoperability between meter vendors by describing common data structures for typical meter exchanges (for example the collection of interval energy data). The protocol has been extended to provide remote meter reading over a range of communications links and most recently over IP connections. It has been successfully implemented on very modest microprocessors with less potential to impact hardware costs than other protocols [Gill and Koller, 2011].

The DLMS and COSEM standard suite (IEC 62056 / EN 13757-1) are more commonly used in Europe. DLMS/COSEM together forms the application layer communication protocol and an interface model for metering applications [Feuerhahn et al., 2011].

IEC 61850 uses Simple Object Access Protocol (SOAP) or Multimedia Messaging Service (MMS) mapping and is a group of standards originally designed for the use in substation automation. IEC 61850 is used for applications that have no billing requirements though it is technically capable of doing so [Feuerhahn et al., 2011].

2.5.3 Smart Metering Projects

There have been various initiatives around the world. Some projects have completed successfully on a schedule whereas some are facing various issues after roll out has started. There are other projects that are delayed to avoid facing the similar fate of the struggling projects. Five projects that received media attention have been chosen and they are the ones in Sweden, Italy, Netherlands, Australia and the UK.

2.5.3.1 Sweden

- Sources referred for the smart metering project in Sweden [Andrésen, 2009; Mannikoff and Nilsson, 2009; Widegren, 2013].
- Sweden successfully completed 100% smart meter roll-out within the scheduled time-frame.
- Sweden didn't face notable resistance from their residential consumers towards smart meter roll-out. Compared to other countries, there was little resistance or concerns about the accuracy of data and customer privacy in conjunction with the smart meters.
- PLC was chosen as the communication technology; it is used either alone or in combination with radio or with GSM/GPRS. PLC was considered to be a cost effective solution since all infrastructure was already present.
- Regarding AMI functionality, Sweden's infrastructure does not yet have all of the components for customer demand response activities.
- Meter replacements were needed in places where the PLC communication did not work, and around 10,000 meters had to be switched from PLC to radio communication enabled meter.
- In 2012, a bill was passed to provide customers at no extra cost hourly-based electricity reading if they were interested. Early experience showed that only a few consumers showed interest.

2.5.3.2 Italy

- Sources referred for the smart metering project in Italy [Andrésen, 2009; Balmert et al., 2012; ICER, 2012].
- Reduction in non-technical losses was the primary motivation for smart metering deployment. Fraud and energy theft were a problem, and it was carried out by

a single company called Enel. The roll-out was mandatory and was included in the Energy law.
- PLC was chosen as the communication technology
- There were interoperability issues later in the project.
- The system lacks set-up for customer feedback as it was designed mainly to reduce fraud.

2.5.3.3 Netherlands

- Sources referred for the smart metering project in Netherlands [Balmert et al., 2012; Cuijpers and Koops, 2013; Gutwirth et al., 2012; Rambi, 2013; Hoenkamp et al., 2011].
- The smart meter roll-out was initially (in 2009) mandatory. Not accepting a smart meter was punishable as an economic offence, with a heavy fine or imprisonment. The mandate had to be removed with campaigns from consumer advocacy groups. The bill was later amended to allow voluntary participation in the smart meter scheme.
- Later privacy and customer impact assessment were done, and there was too little evidence to support the necessity to enable controlling (switching-off) supply remotely. It was worried that it provided new opportunities for abuse by malevolent hackers.
- Many people considered their privacy and security a higher priority than their electricity bill.
- Functional overload in the smart meter was also considered as an issue. It was considered that the functionality was expanded beyond the original purpose.
- The impact studies conducted also mention that inducing consumers to become more energy-saving could be much better than using a smart meter.
- Later in 2012, a two-stage voluntary smart meter roll-out was again initiated. Latest media reports announce that Netherlands are planning to go ahead with the large-scale roll-out which will install 15 million smart gas and electricity meters by 2020. It also states that the trial shows that there are customer satisfaction and energy savings, and the national introduction of the smart meter will not be impeded in the second attempt.
- It is also reported that key finding of the trial was that consumers need a user interface to interact with the smart meter and it should match customers' practical preference and engage them to achieve energy efficiency.

2.5.3.4 Australia

- Sources referred for the smart metering project in Australia [AER, 2014a; Deloitte, 2011; Consulting, 2011; SCER, 2012].
- In Australia, Victoria was the first state in Australia that decided to have a statewide roll-out of smart meters, preceding the nationwide attempt to roll-out smart meters.

- The smart metering program faced problems in the initial phase of roll-out and the Victorian Auditor-General's Office (VAGO) examined the advice and recommendations provided to the Victorian Government on the AMI roll-out and concluded that the extent of technology risks and their implications on the economic case for AMI were significantly underestimated.
- Due to VAGO's criticism, further analysis was conducted, it was concluded that the roll-out should continue as it was expensive to continue managing two different metering systems.
- The concerns over security were dismissed by the analysis conducted by Deloitte. It was mentioned that the technology chosen for the smart metering system had sufficient security features like firewall and encryption.
- There was significant resistance from the residential customers towards the introduction of TOU pricing, and the providers had to let the consumers stick to the flat rates even after the deployment of smart meters.
- More reforms were made to reduce the customer opposition. The changes included that use of smart meters should ensure that consumers receive value for the services regardless of the form of deployment.
- A "Better Regulation" program and The Consumer Reference Group (CRG) was later introduced. CRG members include small business, welfare, consumer and residential advocacy bodies and large user associations. But these groups also failed to engage residential customers. They expected customers to choose billing options based on the consumption data provided.
- Finally, by mid-2014, Victoria declared its smart meter roll-out as complete. The latest report in 2015 states that Victoria's electricity consumers have paid around $2.239 billion for metering services, including the roll-out and connection of smart meters.
- With the smart meter roll-out complete and infrastructure in place, VAGO wants the government to take the role in enabling and ensuring that consumers also benefit from the scheme.

2.5.3.5 United Kingdom

- Sources referred for the smart metering project in the United Kingdom (UK) [DECC, 2013; UK Parliament, 2013; Gosden, 2014, 2015; Raw and Ross, 2015; IoD, 2016]
- In 2008, the government announced the mandate of smart metering for the residential sector. Issues faced by other installation around the world provided the UK with an opportunity to do a better analysis.
- After the initial analysis, the following requirements were identified: the ability to switch to prepayment scheme; IHD to provide customers with real-time information and a central communication model for smart metering system throughout the country.
- An impact assessment report done by Department of Energy and Climate Change (DECC) noted that that smart meter program would become cost-effective only

if it enabled the smart grid. The report also stated that if energy saving were not achieved then this expensive project simply ends up as an initiative to avoid estimated bills.

- The analysis by DECC also identified that if important technical and infrastructure requirements were not in place before roll-out, costs could increase significantly and some consumers could have a poor experience, which might have an impact on the reputation of the roll-out program.
- In 2014, it was reported that the government is further delaying its £11 billion plan to install smart meters as there are still issues with the communication technologies involved.
- In 2016, the much delayed smart meter roll-out started. Institute of Directors (IoD) in the UK has criticised the roll-out and have even asked for it to be halted. IoD states that this initiative can only provide the residential consumers with an insignificant energy saving of two percent a year.

2.6 Electricity Users

Users purchase electricity that is supplied to their connection point from the local retailers. These end-users are mainly classified into large and small users based on consumption. Large users consist of medium and large businesses, and they usually consume more than 100 MWatts electricity. Small users include commercial users, industrial users and residential consumers [DEWS, 2015].

Residential consumers will be the primary focus of this thesis. The residential sector consists of private households. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a variety of other appliances. Commercial sector consists of service-providing facilities and equipment of businesses; federal, state, and local governments; and other private and public organisations. The commercial sector also includes institutional living quarters and treatment (water, sewage, etc.) facilities. They also use energy for the same purposes as the residential consumer; additionally, they need electricity to run a wide variety of business operations and equipment [EIA, 2017].

2.6.1 Consumer Reaction to Smart Metering System

There are both positive and negative reactions reported towards smart meter.
Reported positive responses from consumer include,

1. Accurate bills and better customer service
2. Identification of energy leaks in the customers' premises.
3. Automatic reporting of power outages and meter malfunction to the service provider.

The negative responses reported outnumber the positive responses. The negative responses that received media attention include health issues caused by the radiation from the meter and breach of privacy from the detailed data collected through smart meter as it could reveal the living pattern of the consumer. There are various other complaints, and these will be critically analysed further in the thesis.

2.7 Summary

This chapter presents information about the electricity industry and its essential elements. This chapter also discusses the roles of different service providers in the power sector. Among the service providers, the DSP and retailer are the two entities that interact with the end-user/customer and several references to these service providers will be made in this thesis. The demand management activities and demand response operations provided by these service providers are also discussed in this chapter. Then changes occurring in the power grid are detailed. The role of smart meters in grid modernisation projects are also presented in this chapter. The communication technologies, metering protocol and features of the smart meter are also explained. This chapter concludes with the discussion of electricity consumers who are the end-users in the supply chain. The positive responses of residential customers to the smart metering projects are also listed. This thesis will focus on adverse reactions of residential consumers towards smart metering projects. The next chapter will provide a literature review of all key concepts related to the research in this thesis.

Chapter 3

Literature Review

The previous chapter has presented the background of the power grid, its elements, the main players in the electricity supply chain and measures by which the distribution service providers are trying to control demand. The information systems in the traditional grid were simple and were mostly stand-alone systems. The smart metering system goes beyond this norm as it has the capability to transfer information across different sectors of the power grid. A smart meter is presented as an accessible solution that will help the distributors and retailer in improving their operations. It is perceived as a tool that could facilitate smooth implementation of demand side management programs. It is also considered to have the potential to track outages, identify power thefts and help consumer control their usage. However, current smart metering programs are facing various issues and resistance from the users. Consequently, some projects could not finish the roll-out as planned. Other countries delayed their project. The service providers have overlooked risks, sensitivity and trade-off points in the new solutions mainly due to lack of examples and guidance.

This chapter conducts a literature review on the current smart metering system, its challenges and measures identified. This chapter also analyses various energy behaviour studies on residential consumers. A detailed analysis is also conducted on risk analysis, and requirement elicitation strategies to identify suitable methods for a consumer-focused analysis of the smart metering system.

Each country adopts different reference models for guidance in their grid modernisation projects. The first step is to identify if those reference models demonstrate consumer focus

3.1 Analysis of Smart Grid Reference Models

The smart metering system is part of the power grid which is an Ultra Large Scale (ULS) system and it has multiple stakeholders and control elements, and all these entities will get affected by wrong decisions and investments. Kazman et al. identified that in the current context, concrete architecture does not exist for power grid modernisation projects. However, they found that the problems faced by different distribution companies were the same though they didn't follow the same architecture [Kazman et al., 2011]. In this section, the effectiveness of smart grid reference model is discussed. Five smart grid reference models were discussed in the background chapter, namely:

1. Smart Grid Functional Model by EEGI
2. Smart Grid Conceptual Model by NIST
3. Smart Grid Maturity Model by SEI
4. Smart Grid Architecture Model by CEN, CENELEC, and ETSI
5. Smart Grid Interoperability Maturity Model by GWAC

All the above reference models [CEN-CENELEC-ETSI, 2012; EEGI, 2010; GridWise, 2008; SEI, 2010; SG3, 2010] want the consumers to become active players in the modern grid. All these reference models also aim for better and efficient control systems for improving operational efficiency and interoperability. For that, smart meters at consumer sites are considered the chief element as it can collect the end-users' consumption data and transfer it to other entities in the power grid. Customers are also expected to use this data and get empowered to make ideal energy choices. But these agendas are from the investor's point of view. It shows how the investors or the electricity providers can improve their functioning. It is not clear how the data generated by smart meters can bring guaranteed benefits to the consumer. They have to pay for the implementation and maintenance of the new information systems, yet it is not clear how they can obtain the benefit. In effect, the consumers become active 'payers' rather than active players. Technology and infrastructure should support the user rather than the user having to modify their circumstances to match the system.

Next, the smart metering programs around the world are analysed to identify the similarities and differences in issues faced by different smart metering projects.

3.2 Analysis of Smart Metering Programs

Five smart metering/ AMI projects were discussed in the background chapter. After analysing these projects, they can be classified into three categories as follows:

- Projects that completed as planned
- Projects that faced significant issues
- Projects that delayed roll-out

The smart meter projects in Sweden and Italy completed on time. The AMI projects in Netherlands and Australia faced significant issues during their roll-out. The UK considerably delayed their smart meter roll-out. All the benefits of smart grids will require one or more decades to be fully realised, but as an initiative, many countries have decided to roll-out smart meter expecting that it will be the stepping stone to the progress. Some projects have managed to complete the roll-out without major issues, others have faced significant setbacks, and complexities and few others are delaying their roll-out to conduct further analysis to avoid problems faced by others.

Though few countries completed their smart meter roll-out as per schedule, it does not indicate that they can be chosen as role models by other programs. For instance, in Sweden, before the smart meter roll-out, the consumers had only estimated bills that were later corrected on a yearly basis. If there were a major difference in the estimated bills and the real amount, it always created negative reactions on the customer especially if they had to pay a huge difference. For the customer, the smart meter's functionality of monthly bills based on accurate consumption provides a great solution. Swedish consumers showed less concern about privacy and health matter, and this supports the fact that when technology can achieve the necessity of the user, perceived concerns become less prominent. The Swedish smart meter roll-out also used existing PLC lines for communication that reduced the cost of the infrastructure. But PLC has communication issues, and it may not be able to support functionalities that require frequent transmission. It should also be noted that several thousand of meters had to be replaced in places where PLC wasn't suitable. As the population density of Sweden is low, the number of replacements was not significantly high to impact the roll-out. But in future, this infrastructure may not support advanced smart grid features. Even other communication technologies have limitations, so their choice to reduce overhead cost on infrastructure has been apt for their situation.

In Italy, the most compelling factor for the smart meter roll-out was to reduce energy theft. Remote disconnect and load limiting were the initial features that were introduced. As preventing theft was a significant requirement, it even became part of the Energy Law. In this scenario, consumers can't resist remote disconnect feature in the smart meter as law supported measures to prevent energy theft. Italy also used PLC system for communication and hence they also had fewer infrastructure costs. Later the requirements for smart meter were modified to coincide with the general EU specification, but the infrastructure may not be suitable for those features. Since Italy's main focus was on preventing theft; there was less focus on consumer-friendly functionalities.

Now considering the smart meter roll-out in Netherlands and Australia (Victoria), it can be noted that major delays were caused by consumer resistance. In both cases, consumers were expected to make changes to their consumption behaviour and use the smart meter as a tool to assist it. Functionalities like remote disconnect were considered as a threat in a democratic outlay as the majority of these societies abide the law. Before demonstrating to the consumers how the smart meter could be beneficial, the service providers showed hurried interests in introducing them. In Australia, energy price is deregulated. The concerned entities expected that with few market choices and a smart meter, the consumer would be well equipped to manage their consumptions efficiently. This added to the suspicion of the majority of the consumers. Most of them feared that they would not be able to avoid the peak periods and their bills would increase. They suspected the smart meter roll out to be motives of utility provider to make a profit at the cost of the consumer. When the system lacked visible benefits but showed possibilities for harm, other perceived risks like health and privacy became more prominent.

Outage tracking was one main feature highlighted for the Victorian Smart Metering Program. But that feature did not materialise as advertised. The limitations of the communication technology used were overlooked. When there is an outage, the smart meters are capable of sending an alert message in its last gasp. In a RF mesh setup, the meters act as a repeater. If the meters closer to the concentrators are down, the communication will not be completed and the alert message will not reach the utility. In the ideal scenario, the node should try to re-establish communication using another path when one path fails. But in the field, the set-up failed to demonstrate this capability.

Rolling out smart meters requires smart legislation. Many countries are delaying their roll-out as they can witness similar projects facing communication issues and consumer resistance. The lessons learnt from such projects are motivating other countries to do cost-benefit analysis, technology analysis, customer impact analysis, and privacy impact analysis before designing and implementing the system. For communication issues, it is necessary to have realistic goals within the limitation of the technology chosen. Alternately the smart meter can be designed to be extensible and interoperable so that later it can be modified if technology changes. For consumer issues, the solution is not straight forwards. It is essential to understand the socio-economic factors that affect their choices and reasons for concern. Geographical and climatic conditions and even government policies and regulations play a role in the energy consumption behaviour.

The next section analyses various studies undertaken on risks faced by the smart metering system.

3.3 Meter Interval Data and Privacy

One of the major claims against smart meter is that it could act as a spy at home. To understand these issues, it is necessary to analyse how the smart meter data can reveal end-user's energy profile. All smart meters are capable of generating interval data. An interval period can be set in these meters, and everyday energy consumption will regularly be recorded at these intervals. Interval data is also referred to as Load Profile (LP) data.

Energy disaggregation is a process that can be applied to the consumption data by which consumer's appliance level information can be extracted. It involves a set of statistical methods, and it requires fine-grained data regarding electricity consumption. There are both hardware and software solutions using which appliance-specific data can be obtained. Smart meter can be used for energy disaggregation [Armel et al., 2013; Beckel et al., 2014; Zoha et al., 2012].

According to Armel et al., smart meter is the cheapest option for disaggregation as it requires no additional hardware support and installation efforts. They compared various disaggregation analyses on different data frequencies and its capability to identify appliances. Their studies reveal that for an interval data of 15mins – 1 hr it will only be able to differentiate between 3 main load categories namely, continuous, space heating/cooling and time-dependent. To identify top ten appliance types the interval should be between 1min – 1 sec. For identifying more appliances current and voltage data at a higher frequency is required. Based on the information they have gathered data, a frequency greater than 1 MHz is required for identifying appliances more precisely. Current meters are constrained to 10W power levels and for better resolutions a 0.1 W power level is required. The A/D converters in current smart meters also does not support data frequency > 10kHz. Hence the meters will require an upgrade, preferably at hardware level or as a minimum at firmware level to support appliance level identification. Even the network that supports the smart metering system will need to be upgraded to handle high frequency of data [Armel et al., 2013].

Current smart meters mostly record data at 15min – 30 mins intervals. However, there are meters capable of recording data at 1min interval and even 10secs-1sec interval; but those smart meters require additional capabilities to support high frequency data collection. With the current smart meter setup of 15–30 mins intervals, it will not be possible to identity all electrical gadgets in a house. With interval read between 1hr-15mins, the most energy intensive operations could be identified. This information can be used to identify when the house is unoccupied (based on low consumption values, energy usage values without variations, etc.). Such inferences can also be derived from other methods like a car parked in a spot for a long time, no lights in most rooms for a longer time, mails piling in the mailbox etc. With a 15min-1 hr read it will be possible to identify the electricity usage patterns, e.g., when most of the energy intense operation takes place in a house.

The media has exaggerated the privacy issues regarding smart meter data. Even if the meter was read at one minute intervals, detailed knowledge of the appliances presents in the home and the habits of the consumer would be required to deduce the actual living patterns [Roberts and Redgrove, 2011]. If erroneous information sources find ready access to the mass media without effective remedies, then large social impacts, even for minor events, becomes possible [Kasperson et al., 1988]. To avoid or reduce public resistance towards the smart metering system especially from poorly drawn evidence, the risk from the system should not only be analysed and managed but also effectively communicated. The proponents of the system should be able to demonstrate how they have dealt with the real privacy and security issues.

3.3.1 Inferences

Privacy becomes an issue for the consumer when the utility provider or a third-party (which includes an attacker) gets to view the LP data generated by the smart meter. This data can be accessed inside the smart meter, at the utility provider's database and can also be intercepted during transmission.

A consumer-friendly solution will:

1. Mainly limit LP data to the consumer and provide the consumer with the choice to decide on the interval in which it is recorded. It will also provide the consumer with the authority to decide on sharing this information with a third party.
2. Ensure that there are features in the system to protect the identity of the consumer if the LP data is intercepted during transmission.
3. Securing smart meter data from attacks and corruptions.

3.4 Consumers' Energy Behaviour

The consumer's resistance to smart metering projects warns that the consumer energy behaviour has not been taken into consideration when the automation projects were designed. Hence, in this section various researches that have been conducted on power consumption data and consumer characteristics are analysed.

Verbong et al. state that there is a knowledge gap with regards to consumer's actual attitude to incorporating technological options in their daily life. They state that it is necessary to pay attention to the social practices (heating and cooling devices, EVs, increase in electronic gadgets, etc.) that may lead to increase in electrification in households. Hence, there is a possibility of an increase in demand and rise in electricity bills even if efficient feedback mechanisms and home energy management systems are used [Verbong et al., 2013]. Wigan states that most the studies have focused on identifying how smart meters can enable peak load reduction by introducing time-varying rates or by disconnecting devices at the individual level. He adds that these studies lacked any consideration for the consumer perspective [Wigan, 2012].

Hargreaves et al. analysed the role of feedback on energy consumption. They interviewed 15 UK householders who trialled smart energy monitors of differing levels of sophistication. They examined if increased awareness among consumers will lead to the decision of reducing consumption to reduce cost and emissions [Burgess and Nye, 2008]. They state that studies which report feedback to have raised awareness leading to a reduction in consumption are laid on the foundation of 'information-deficit' model [Wilhite and Ling, 1995]. However, they point out that more sociologically and anthropologically grounded research suggests that such assumption neglects the importance of dynamics of household practices (e.g.[Aune, 2007; Gram-Hanssen, 2004; Lutzenhiser, 1993; Shove et al., 1998]). Practices are important for residential consumers, and these practices decide whether and how feedback might be used. Hargreaves et al. asks interesting questions like, "If the wind fails to blow, would households be willing to go to bed in the dark? Forego cooked breakfast and coffee?". Hargreaves et al. conclude from their studies that domestic energy consumption is a social and collective process and not an individualised process. They also note that future research should focus on the household as the fundamental unit of analysis and identify strategies which focus on encouraging collective and energy-saving household dynamics and not on educating individuals about their energy consumption [Hargreaves et al., 2013].

Figueiredo et.al did a case study using the information from 165 low voltage consumers in Portugal. The data used were measured during a period of three months in summer and another three months in winter for working days and weekends in each customer of the sample population. Their study found that based on the energy usage data at night time along with load factor they could classify consumers into various groups [Figueiredo et al., 2005].

Kranz et.al conducted a study to investigate smart meters' acceptance by the consumer. They conducted an online survey that was posted on the official e-energy project website of the Federal Ministry of Economics and Technology (FMET), Germany. Of 351 participants, 60% completed the survey and it had both male and female participant in the age range 18 to 78. The results of their study indicate that perceived usefulness followed by subjective control were the main factors that affected a person's attitude to use a smart meter. The results also indicated that perceived ease of use affected perceived usefulness which was consistent with Technology Acceptance Model (TAM) [Kranz et al., 2010].

Albert et.al did a consumer segmentation study using smart meter data from about 1100 households of U.S-based Google employees and socio-economic data from an online survey in which approximately 950 participants took part. They had taken into consideration the age, employment status and condition, the electrical and electronic appliances and the property type. They found that there is randomness in consumption during work days for people who stayed at home, and that included stay-at-home parents with little kids, pensioner, unemployed and those who worked from home whereas those who went to work had a more regular schedule of consumption. According to them, irregular users may benefit from enrolment in peak-pricing and predictable users, who may be less flexible could be targeted for rebates for efficient appliances to reduce their consumption [Albert and Rajagopal, 2013].

Dunstan et.al conducted a Demand Management Barriers Survey to gather perception on the barrier to uptake of demand management in Australia. They claim that the survey was done systematically to explore attitudes by gathering input from a range of stakeholder groups across the country and around 808 groups participated. In their list of survey question barriers listed related to the consumer were: "B22 – electricity consumer lack interest in saving energy" and "B23 - customers want to use power when and how they choose". The survey results showed that the participants did not think those statements to be true and that the consumers are interested in saving energy. These results convey that their reluctance to accept smart meter (the Victorian scenario) is a lack of useful functionality. [Dunstan et al., 2011].

McLoughlin conducted an analysis of domestic electricity consumption based on dwelling and occupant characteristics by using the smart meter data from 4200 Irish residential properties. Their study found that three largest contributors to demand were tumble dryers, dishwashers, electric cookers and electric heaters as they all had significant heating components. Homes with electric heating and cooking had higher maximum demand compared to those that use other methods to heat water and to cook. Comparing the dwelling types, larger houses such as detached and semi-detached homes had higher consumption. The number of bedrooms was found to influence total electricity consumption strongly. And they found that for each additional bedroom, load factor on average increased by 1%. The age group 36–55 were considered to be the largest consumers of electricity, and that could be due to the possibility of children living at home with them. Income also had significance on demand. Professionals with higher income were found to be consuming more electricity than middle or lower classes. The study also notes high energy consumer had a potential for reducing consumption as there was a possibility that they were wasting energy [McLoughlin et al., 2012].

Wijaya et al. performed a consumer segmentation using Irish Commission for Energy Regulation (CER) smart meter dataset which contained energy consumption measurements of around 5000 users over 1.5 years. Along with the dataset, they also did a survey to obtain information on demographics (like occupation, family type), house information (ownership, age, floor area, etc.), and appliance usages (dishwasher, TV, water pump, etc.). They identified top 3 characteristics of consumer segments, formed by total consumption and consumption variability. They found that medium/high use was from non-single family groups and the least consumption from singles. Using tumble dryers for the long duration contributed to high consumption in many cases. With residence size, smaller floor area consumers were typically associated with lower usage [Wijaya et al., 2013].

Firth et al. performed an analysis of the electricity consumption of UK domestic buildings to identify the influence of appliances usage and energy user groups on demand. They monitored 72 dwellings at five sites over a period of 2 years. Four of the sites were social housing, and all had central gas heating. They found that dwellings on the same site and with similarly built form had distinctly different annual electricity consumption. They found that electricity consumption increased by 4.5% from the first to the second year. They identified that factors such as the number of occupants, number and type of appliances, and occupancy patterns were more relevant than the form of residence. They categorised device into three groups: standby, cold and active. Devices in standby mode are televisions, and consumer electronics which when not in use is still consuming power. Cold appliances are fridges, freezers, etc. which is in continuous use but do not draw a constant amount of power. Active devices are lighting, kettles, etc. which are actively switched on or off by the user. They found that there was a 10.2% increase in the consumption of 'standby' appliances and a 4.7% increase in the use of 'active' devices. They also analysed consumers by classifying then into low, medium and high users based on their consumption pattern. They found that low and high-energy users were responsible for the overall increase in electricity consumptions. They identified that standby and active devices also led to the rise in total consumption. [Firth et al., 2008].

Stragier et al. conducted two studies on consumer perception. In their initial study, they analysed consumers' perception of smart meter and smart appliances to gain insight into the willingness to adopt smart meters. He performed a large-scale face-to-face user survey in Flanders, Belgium. It was found that both Perceived Ease of Use and Perceived Usefulness had a significant influence on the attitude which directly affected intention of use. They also found that perceived Ease of Use had a strong influence on Perceived Usefulness. The survey results showed that the price of smart meters was an important issue. Many participants responded that the utility should provide smart meters to everybody for free as they benefited the most. Most people were not willing to provide the service provider with the control over their appliances. They didn't want their freedom of choice to be violated. They were also concerned that utilities might switch on devices at high rate times which would be difficult to detect. None of the participants considered replacing their household appliances with smart ones as they were too expensive and would only consider it if the present devices stopped working. They found that the key drivers that could lead to adopting or rejecting smart home technologies were price, convenience, ecology, transparency and technical equipment. Even though most participants understood the benefits of load-shifting they still generally preferred less dynamic tariffs [Stragier et al., 2010]. Stragier et al. in their second study developed and tested a user-centric home energy management system. Their focus was in identifying the needs of the consumer regarding insights in their energy use. The participants were provided with four options for energy management: i) Basic applications like detailed billing from a smart meter. ii) Creating awareness of energy consumption using visualisation tools in PC and smart-phones iii) Detailed feedback through an IHD iv) Home automation for managing energy consumption. The survey results showed that the participants were most interested in the feedback from the IHD. Most of them also considered home automation (fourth option) as something of a distant future. They found that in the first week of installation of the system, every participant used the system and over weeks their reporting of usage decreased. They found that a small, but consistent part of the participants actively adapted the use of certain appliances based on the feedback. The appliances that are often shifted were those with a large flexibility such as dishwashers, washing machines and tumble dryers. The participants also stated that it is not always easy to change their behaviour according to dynamic prices [Stragier et al., 2013].

Strengers has conducted a series of studies on consumer behaviours in Australia. She has a different view to electricity consumption. She states that if the comfort of the user is given importance, they will continue to use electricity without any constraint. According to her, variable pricing programs will inspire them to change their usage during peak periods. She argues that instead of considering comfort expectations as a non-negotiable 'human right' it should be seen as a factor that should be modified to the situation, except for few consumer segments. When she interviewed the electricity distributors and retailers responded that they only want the peak demand to be controlled and not to lower the overall consumption as it will negatively affect their profit [Strengers, 2008]. In 2011, she analysed the role of IHD in providing effective feedback. She analysed 28 Australian households from three separate IHD feedback trials (Victoria, New South Wales and Queensland). Feedback in the form of traffic-light was provided in all IHD (i.e. green for low, yellow for medium and red for a high amount of electricity). She reports that this feedback technique shifts the responsibility of consumption to the consumer. However, she adds that the feedback does not bring about the skills in identifying changes needed in household activities to get optimum energy saving. Further, she states that if the consumer considers practices are non-negotiable then the feedback from the IHD may be viewed as irrelevant [Strengers, 2011]. In 2012, she analysed peak electricity demand using two different perspectives - Attitudes, Behaviour, Choice, and Demand (ABCD) theory and social practices theory. In ABCD model, the focus is on educating, informing and providing incentives to consumers to overcome barriers. In social practices, the focus is on identifying innovation to reorient practice elements. She states that for the peak demand problem, the current trend is to use ABCD theory and she suggests that it is better to use social practices theory. Applying the social practices approach, she identified three areas to focus on: building co-management relationship with consumer, working with a broad range of human and non-human actors in the system and promoting new needs and expectation [Strengers, 2012].

Davis et al. conducted a study on setting a standard for electricity pilot studies and found that results obtained from opt-in participant studies substantially diminished when studied in the general population. They state that the design of user studies for electricity research mostly face methodological problems and this leads to results that are artificially inflated than if it were conducted on the general population. They identified six biases that can have serious effects in electricity research: volunteer selection bias, intervention selection bias, sequence generation bias, allocation concealment bias, blinding bias and attrition bias.

- In volunteer selection bias, the participants are more likely to respond to the intervention than the general populations positively.
- Intervention selection bias occurs when there are several methods of participation and the participants only follow their preferred method of participation.
- Allocation concealment bias occurs when the participants were chosen are not random.
- Blinding bias happened when the researcher's knowledge affects the way they interpret the participants' behaviour.
- Attrition bias happens when participants withdraw from a study that doesn't benefit them.

Davis et al. created a correction for the bias and applied it to their study on the impact of IHD, dynamic pricing, and automated devices on the residential consumer. They did a meta-analysis of 32 studies in United State (US)/Canada. They found that for overall electricity use, all the three methods showed statistically significant reductions after the correction was applied. They identified that IHD was the most effective intervention method for reducing overall electricity use. It provided 3% (corrected value) energy reduction. Applying the correction for peak electricity use roughly halved the observed result. To reduce peak demand, they found dynamic pricing to be a better solution. It provided 6% (corrected value) reduction in peak demand. They noticed that if dynamic pricing was used along with home automation, it provided around 14% (corrected value) reduction in peak [Davis et al., 2013]. Findings of Davis et al. with regards to participation bias causing errors in energy studies have significant importance. It explains why many electricity project trials provide positive results but later gets abandoned and face resistance when the real roll-out happens.

3.4.1 Summary

Analysing various studies that have been conducted on energy consumer provides an understanding of various aspects of their behaviour, attitude and factors that affect their energy choices and needs. With regards to acceptance of new technologies like a smart meter, perceived usefulness followed by perceived sense of control were the main factors that affected the consumers' reactions. Perceived ease of use strongly influenced perceived usefulness which is similar to the factors in TAM. The results obtained from the survey conducted on Australian stakeholders also agree to this finding. It was found that the consumers are willing to reduce their energy consumption to make saving and also reduce their impact on the environment, but the system should also prove to be useful for them.

Systematically reviewing many energy-user studies helped in identifying the energy profile of the consumers and used house-hold equipment. Middle-aged people, with families having young kids living with them, had high consumption profile. Residence size also was seen as a factor affecting consumption. Larger properties, particularly detached and semi-detached properties consumed more energy. It was also found that people with the same number of household, in the same dwelling settings had a considerable increase in their energy usage over time. It was mainly attributed to the usage of more standby and active appliances. This increase was noted be same among the low and high energy usage groups. Among the appliances, electric cooker, electric heater, air-conditioner, washers and dryers consumed most of the electricity.

Among various options for energy efficiency programs (which includes home energy automation systems), consumer's preferred to mainly have an informative feedback mechanism rather than a automated controlling system. It was not economical for most consumers to replace their devices and appliances to operate with the automated system. Most consumers were not interested in giving their control of the operation to service providers. Reasons for their disinterest included lack of trust. Few consumers even worried that utility might operate their appliances during peak period to increase their bills. As there were limitations to changing their energy habits, many consumers were worried of TOU tariffs as they had fewer options to change their routines.

At the same time studies conducted by social scientists like Strengers look at energy consumption and consumer comfort from a different angle. According to them, comfort and energy habits are elements that are built over time and if pressed can change. So instead of identifying measures to increase the comfort level, measure have to be identified to promote new needs and expectation based on the system limitations.

3.4.2 Inferences

On analysing the effect of socio-technical aspects on energy behaviours of the consumer; the following inference can be made.

1. Energy reduction is readily applicable in circumstances where there is wastage. People may not be aware of the power loss e.g. power loss in standby mode. Consumers can be educated and be made aware to switch-off appliances after use rather than leaving them in standby mode. Certain activities like washing clothes and dishes can be shifted to the off-peak period. The time of operation can be programmed in many new machines. People often use this feature as they don't want to stick around the devices and remember time schedules. Though these features are handy, they require the appliance to be switched on all the time or be in stand-by mode.
2. When only reasonable amount of energy is used, it will be difficult to find ways to reduce usage or even change habits and routines. Also, few high consumption appliances like washers can be made to operate at off-peak periods, but that is not applicable to all appliances that have high energy consumptions. The effect may also be based on inhabitants and dwelling size.

3.5 Studies on Risk and Challenges to Smart Metering System

Though over the years, experts have stressed the need to have risk analysis embedded into the design, it seldom happens. The issues that smart metering systems are facing reflects on the lack of efficient risk management for these systems. This section analyses the research work done related to risk and challenges faced by the smart metering system and smart grid.

Kazman et al. applied Architecture Trade-off Analysis Method (ATAM) to identify the challenges faced by the residential DR systems in the United States Power Grid. In 2000, Kazman et al introduced the ATAM to understand the consequences of architectural decisions on the business goals of an information system. The information identified using this method is useful for avoiding problems that may be difficult to change after the system has been implemented. Quality attribute characterisation and scenario identification are the key concepts upon which ATAM is built. The scenarios help in identifying the architectural decisions at risk [Kazman et al., 2000]. They hypothesised a collection of architectures based on the information available and they used concrete scenarios to identify the risks. In the different DR programs, they analysed, the electricity meter's role was mainly limited to billing. Then using different scenarios of how a consumer could respond to a demand response program, they identified the challenges to the system [Kazman et al., 2011]. Their work didn't focus on the issues faced by the consumer. Instead, they analysed how consumer choices can affect the system's quality attributes.

Ray et al. discuss how to conduct security risk management for the information systems in the smart grid. A unified framework for risk management in smart grid is provided. It had combined the Critical Infrastructure framework described by National Infrastructure Protection Plan (NIPP) with enterprise business risk management framework for the physical, cyber, human and organisational aspects. They have mentioned that security goals can be identified by considering the common security threats like spoofing, tampering, repudiation information disclosure (privacy breach or data leak), denial of service and elevation of authority [Ray et al., 2010].

Shein conducted a security analysis mainly focusing on communication technologies and hardware involved. The paper also analyses the public and private domains in smart grid [Shein, 2010].

Metke et al. presents a security solution for the smart grid using Public Key Infrastructure (PKI) and trusted computing. They suggest using PKI, as it supports device attestation and trusted computing elements. They also suggest that defense-in-depth approach should be followed and controls must be in place to assure that the smart meter network traffic is only admitted from authorised sources [Metke and Ekl, 2010]. Podmore discusses disaster recovery and restoration in the smart grid. They mention that in load restoration the priority is for the technical needs of the power system rather than on customer load. The primary focus during restoration will be in providing a load to on-line generators and dampening voltage transients. Higher priority customer loads will be energised only after the system conditions are stable and haste should not be shown to restore the customer load as it could again lead to a shut-down [Podmore, 2010].

Efthymiou et al. discuss the high-frequency and low-frequency metering data security issues and requirements. The authors describe that the transmission of data from smart meters to the utility on a continuous basis presents security and privacy challenge. They address this issue by anonymising the identity of high-frequency metering data through an escrow service. They also state that the escrow service should be trustworthy to ensure the security is maintained and that this measure does not eliminate all the privacy issue [Efthymiou and Kalogridis, 2010].

Berthier et al. discuss different threats targeting smart metering system and based on their finding they have proposed an Intrusion Detection System (IDS). They have identified detection mechanisms for attacks from six types of attackers listed by Le May et al. Le May et al classified attackers as curious eavesdroppers, motivated eavesdroppers, unethical customers, overly intrusive meter data management agencies, active attackers and publicity seekers. According to them, curious eavesdroppers are interested in listening to the surrounding communicating devices to learn their activity, whereas motivated eavesdroppers gather the same information for organised theft. Tampering with meter and meter data to steal electricity is the motivation of unethical customers. Meter data management agencies that are overly intrusive gain detailed interval data to monitor consumer for their business benefits. Active attackers may sabotage the system for financial or terrorist objectives. Attacks may be in the form of Denial of Service (DoS) or corrupting the system with malware. Publicity seekers are interested in fame and may use less harmful way to demonstrate their capability to hack the system [LeMay et al., 2007]. Berthier et al. selected specification-based detection mechanism for their IDS to identify attacks. Specification-based detection uses logical specifications to identify deviations from a correct behaviour. The architecture they proposed to consist of access points, sensors and the smart meter at the consumer premises. They also identified the location of sensors and the protocol layers that need to be monitored for each type of attack. [Berthier et al., 2010].

Wei et al. analysed the configurations and communication specifications of power automation systems to identify the vulnerabilities and cyber-attack sources. Based on this information they propose a framework for security of automation systems in the smart grid. Power, automation and control, and security are the three layers in their framework. With that framework, they decoupled control and security functionalities. Security management data only flows in the security layer. Their security framework has three conceptual components, namely: security agents, managed security switch, and security Manager. They also mention that the security components does not affect communication and that it does not cause a delay of data exchange. In prototype testing, they managed to detect few intrusions and mitigated some vulnerabilities [Wei et al., 2010].

McLaughlin et al. discuss how energy theft can be carried out with a smart meter. One reason for the service provider to introduce a smart meter is to avoid theft, but these authors demonstrate through detailed threat and security analysis that risk of energy theft increases with a smart meter. Using an attack tree, they present various options for energy theft using a smart meter. They detail how consumption data can be tampered when it is recorded, and transferred to the back-end. Physical tampering, eavesdropping, password extraction and meter spoofing are few techniques discussed by the authors. They argue that with the introduction of a smart meter, the attack surface has extended as the communication network provides more options to access consumption data. In has also been noticed that consumer's pay staff who have access to meter programming device to have a pre-made smart meter program overwrite firmware which would record values lower than actual consumption. Similarly, if the password to the data concentrator or the service provider's storage is obtained, data can be modified for multiple smart meters in an area [McLaughlin et al., 2010].

Suleiman et al. and Zafar et al. used Security Quality Requirements Engineering (SQUARE) method for analysing the security requirements of AMI and Smart Grid. Nancy Mead et al. at Software Engineering Institute (SEI) developed SQUARE. It consists of nine steps. It starts with definitions of risk elements followed by identification of security goals. Then the artefacts are developed to support the process, and a risk assessment is performed. Then a suitable requirements elicitation technique is chosen, and the security requirements are elicited. These requirements are then categorised, prioritised and then inspected [Mead and Stehney, 2005]. Suleiman et al. followed these steps to identify the threats and vulnerabilities in the smart metering system. They mainly focused on information security and tried to identify measures to monitor networks and devices in the AMI system so that data is accessed only by designated users and devices and the privacy of consumer related data is maintained. Similarly, Zafar et al applied SQUARE on the smart grid customer domain and analysed from the system-of-systems perspective. They also elicited vulnerabilities and security requirements and used them to specify inter-system interactions [Suleiman and Svetinovic, 2013; Zafar et al., 2014].

3.5.1 Summary

Most of the studies focused on system and data security rather than end-user. The issues faced by consumers are not critically analysed. These analyses lack the perspective of the consumer. In the electrical power system, availability of electricity is the most critical element, as disruptions can cause blackouts to a vast region and affect the consumer. The focus of current research is on securing the systems' data, and this does not the carefully address the consumer's concerns. The consumer's resistance to the smart metering system is not limited to data security and privacy. They are also worried about how the system will affect their choice and control over electricity usage and data. To conduct a risk analysis from consumer perspective, a generalised framework is required that identifies all risks and not just security issues. For that a literature review of risk analysis methodologies, methods and tools are conducted to identify the suitable method.

3.6 Risk Analysis

Analysis of studies on smart metering challenges acknowledges that there is a lack of consumer focus in the risk analysis strategies (if any) that were employed by the project sponsors. Developing a consumer focused risk analysis framework for the smart metering system will be helpful in identifying the risks faced by the consumers.

Over the years, different entities have developed many standards and methods for risk analysis, and the terms and definitions used for risk elements and processes vary. Most commonly used risk process terms are 'Risk Analysis', 'Risk Assessment' and 'Risk Management'. Some of the descriptions given by few standards and organisations are as follows:

- In ISO 27005, 'Risk Assessment' consists of 'Risk Analysis' and 'Risk Evaluation'. 'Risk Analysis' is then further divided into 'Risk Identification' and 'Risk Estimation' [ISO/IEC 27005, 2008].
- In SP 800-30 by NIST, 'Risk Management' is said to encompass three processes, namely 'Risk Assessment', 'Risk Mitigation', and 'Risk Evaluation' [Stoneburner et al., 2002].
- According to a Working Group (WG) established by European Network and Information Security Agency (ENISA), 'Risk Management' consists of 'Definition of Scope', 'Risk Assessment', 'Risk Treatment', 'Monitoring' and 'Communication'[ENISA, 2005-2013].
- Society of Risk Analysis (SRA) defines 'Risk Analysis' to broadly include 'Risk Assessment', 'Risk Characterisation', 'Risk Management', 'Risk Communication', and policies [SRA, 2013].

In one definition, 'Risk Assessment' encompasses 'Risk Analysis' and in another one, it is the reverse. Similarly, 'Risk Management' in one interpretation includes all activities from scope definition to monitoring whereas in another it refers only to the planning and implementation phases. It is also important not to confuse one risk element with others. The Expert Group of the European Commission's Smart Grid Task Force prepared a Data Protection Impact Assessment (DPIA) Template for Smart Grid and Smart Metering Systems in 2012. The main flaw that was highlighted by the Working Party against the DPIA template was that it often confused risk and threats [WP 29, 2013].

Kaplan drew attention to the problems inherent in defining the key term 'risk' [Kaplan, 1997]. A similar approach is adopted in this thesis; rather than attempting a universal definition, each term needed is defined and used consistently (refer Appendix A.10.1). The terms used for each risk element by different entities have been tabulated in Table 2. These elements variously adopt and adapt definitions found in the most relevant sources found during the conduct of the research.

Table 2: Terminologies used for Risk Elements

Risk Elements	**Different Terminologies Used**
Stakeholder	User, Party
Asset	Resource, Property
Threat	Hazard
Vulnerability	Weakness, Susceptibility
Harm	Impact, Consequence, Damage, Effects of Unwanted Incident
Control	Safeguard, Treatment, Countermeasure
Risk	Probability, Chance

There are various risk analysis models for both general and context-specific purposes. They can be categorised into standards, guidelines, methods and tools. A standard is a set of rules commonly used to control how people develop and manage processes and systems. Guidelines are instructions given to guide an action. A method is defined as an orderly arrangement of steps to accomplish a task. A tool is defined as something used to perform an operation. Standards like ISO/IEC 2700x, NIST SP 800-30, BSI 100-x and methods like CORAS and OCTAVE (refer Appendix A.10 for definitions) have been exhaustively analysed to develop a risk analysis framework suitable for the specific needs of smart meter projects [AS/NZS, 2009; BSI, 2008a,b; Stoneburner et al., 2002; Lund et al., 2011; Marek and Paulina, 2006].

The previous section has established that the current focus of risk analysis is on system security and challenges it causes to the service provider. This could be the reason why the project proponents failed to identify the factors that could lead to consumer resistance to DR programs and smart metering systems. This establishes the need for risk assessment to be conducted from the consumer perspective. It is common to perform a risk assessment late in a project, and all too often it is performed only once the deployment is already underway. However, in most cases, retro-fit costs are far greater than designed-in costs, and hence it is highly beneficial if the necessary features are incorporated into the design at the earliest possible stage, rather than deferred until after deployment.

To ensure early discovery of features that are needed for consumer acceptance, a suitable framework needs to be selected for the specification of requirements and the subsequent design and deployment activities. The project's objectives and scope need to reflect consumer needs, rather than only those of the sponsor and the other organisations that exercise institutional and market power within the domain. For this to be achieved, it is crucial that the schemes selected, place great stress on consumer focus at the very early phase of requirements elicitation.

In the next section, a literature review of the requirement elicitation methods and practices is presented to identify suitable methods for eliciting energy consumers.

3.7 Requirement Elicitation Methods and Practices

Consumers need to be identified as stakeholders. Means need to be devised to not merely gain their feedback on requirements specifications, prototypes and design documents, but also to meet with them, or suitable proxies for them, at the very outset of the project, and develop an understanding of their perspectives. Great care must be taken not to rely unduly on intermediaries because many of them are too far removed from consumers themselves to provide designers with appropriate understanding [Wiegers, 2003].

It has been conventional to identify consumers or customers as a large number of homogeneous entities. Even if residential purpose alone is considered, a free-standing house requirement will vary from those of residential apartments and those of holiday apartments. Selection of RE techniques for a project is a challenge. Some of the factors that need to be considered include problem domain, diversity of stakeholders, criticality, time and cost involved [Hull et al., 2010].

Introspection is the method usually applied by the analyst to understand the system properties. Introspection involves experts and stakeholder proxies. It relies on thinking, reasoning, and examining of the expert's thoughts [Goguen and Linde, 1993]. Though this method is helpful, there is a high chance that the experts will not be providing designers with appropriate requirements because many of them are too far removed from consumers themselves.

For the success of a project, satisfactory levels of payback need to exist for all the stakeholders involved. Hence techniques should be chosen to elicit requirements from all stakeholders. To ensure user involvement and appropriate understanding of their needs, user-centric approaches need to be applied during the requirements elicitation phase [DeBellis and Haapala, 1995].

There are various forms of user-centric approach. Most of the methods are closely linked, and they all include an explanation as to why to involve users and how to involve them [DeBellis and Haapala, 1995]. Four groups of methods are usefully distinguished: user-centred design, participatory design, ethnography and Contextual Design (CD) [Kujala, 2003]. The user-centred design gives emphasis to usability whereas participatory design gives emphasis to democratic participation. Social aspects of work are important in ethnography, whereas in CD the emphasis is in the context of work [Kujala, 2003].

In user-centred design, the design team will have direct contact with potential users rather than intermediaries. Intended users need to be invited to utilise simulations and prototypes to gain insights into their objectives and patterns of work. Their performance and reactions are observed and recorded for analysis. In participatory design, users are invited to participate in the analysis of requirements. Then they are asked to plan appropriate socio-technical structures to support both individual and organisational needs. The ethnographic design is concerned with human activities and culture with a focus on the social aspects of human cooperation. It takes place in natural settings and is focused on the point-of-view of the user [DeBellis and Haapala, 1995; Kujala, 2003].

For project success, all stakeholder categories must be included during the requirement elicitation phase. Currently, there is no single technique that provides a solution for all RE needs, and hence suitable techniques have to be carefully selected and combined for complex projects. Jiang et al. identified 8 attributes that need to be considered for deciding on the RE techniques to be applied. Those attributes are: project size, project complexity, requirements volatility, the degree of safety/security criticality, time constraints, cost constraints, acquaintance with domain and reusability. They also suggest the kind of RE technique suitable for each project type. If the project is of large size or has high complexity, systematic RE techniques should be used. Similarly, projects with high-security requirements need rigorous techniques which also identify security goals. On the other hand if the projects have high time constraints, lightweight techniques should be used. Modeling techniques with visual representation are found to be more useful if team carrying out elicitation is not familiar with the domain. Techniques that support requirements reuse is better for projects that are part of the product family and those requirements can be reused [Jiang et al., 2005]. These attributes will be later used in this thesis to define the smart metering system projects.

Some of the commonly used elicitation techniques and approaches have been analysed (refer Appendix A.11 and sources used were [Chen et al., 2012; Lloyd et al., 2002; Maiden and Rugg, 1996; Nuseibeh and Easterbrook, 2000]) and techniques favourable for the smart metering system have been chosen. Maximising the satisfaction of end-user is important for the success of utility related project like AMI. Focus groups are helpful in identifying the general requirements and segment specific requirements. It will help to get a general attitude of the end-user towards smart meter and their willingness to use its functionalities. However, to understand how the consumer would react to different demand response program a specific in-depth analysis is required, and CD is a good choice. CD places emphasis on the context of work and also places more importance on the end-user in comparison with other stakeholders. CD defines the end-user as those stakeholders who may depend on the output of the system, prepare input for a system, and decide on the need for a system or acceptance of the system in practice [Beyer and Holtzblatt, 1997a,b].

For energy consumer as CD is found to be appropriate, it is further discussed in this section. CD was developed by Hugh Beyer and Karen Holtzblatt [Beyer and Holtzblatt, 1997a,b]. It is a synthetic method that systematically combines conversation, observation and analysis. It is focused on the context in which users work, and studies work processes to produce descriptions of them. Analysts watch users and discuss their work with them, while embedded in their environment. The method thereby achieves direct interaction with the various categories of users [Beyer and Holtzblatt, 1997a,b]. CD consists of the following steps: Contextual Inquiry, Interpretation, Data Consolidation, Visioning, Storyboarding, User Environment Design, and Prototyping [Beyer and Holtzblatt, 1997a]. Contextual Inquiry captures the activities of the people using the system rather than just the self-reported practice and official policies [Wixon et al., 1990]. During interpretation sessions, detailed debriefing allows the team to build a common understanding of the various users, and capture all the data relevant for system design [Beyer and Holtzblatt, 1997a,b]. Based on this information affinity diagrams are created. Issues are then detailed to reflect users' concerns and needs. This vision represents the big picture of what the system could do. Then paper prototyping is prepared to ensure the basic system function and structure work for different user segments [Beyer and Holtzblatt, 1997a,b].

3.7.1 Summary

Eliciting the requirements of a system is not an easy task particularly when there are multiple stakeholders involved with different interests. In many cases, the requirements are elicited from the investors and the needs of the end-users are assumed. Unlike other projects and products, electricity providers cannot be selective with its consumers. Electricity is essential to daily activities and consumers not willing to accept a modernisation effort from a service provider cannot be prohibited from the supply. So, the project investors should be more careful in identifying the needs and limitations of their customers and have sufficient choices to cover all types of consumers.

3.8 Conclusion

Like any other critical infrastructure and socio-technical systems, it is not easy to come up with one set of solutions that fit all end users. There should be a variety of choices and functionalities that provide the consumer with an assurance that even if they don't benefit from the systems they are not penalised for factors that are not under their control.

A review of the system identified that the system lacked consumer-friendly processes to identify risk and requirements. A literature review has been performed on the current reference models used in grid modernisation project. Current smart metering projects have also been analysed to identify factors that affected their success and failure. A detailed analysis of the energy behaviour of residential consumers has been performed to identify the needs and limitations of the consumer. Finally, various techniques in risk analysis and requirement elicitation have been analysed to identify suitable techniques for the energy consumer. The next chapter presents the research method that is used for the research described in this thesis.

Chapter 4

Research Method

In the previous chapter, the literature review hints that there is validity for consumer to be concerned over smart metering system. The analysis of various articles identified that the risk and requirement analysis conducted were limited and it mostly ignored the needs and limitations of the consumer. Neither was the energy behaviour of the consumer nor their orientation towards technology taken into consideration when the functionalities for the smart metering system were designed.

The purpose of this research is to identify measures that the power grid project sponsors can follow to reduce consumer concerns. The negative reactions from consumers are not just from technical issues but also due to factors that are influenced by consumer's behaviour and choice. Including the social and behavioural domain helps to explain how people react to circumstances. The requirements gathered in this manner will help to devise artefacts that attain end-user goals and consumer satisfaction [Simon, 1996].

This chapter presents the research method applied in this thesis. This chapter presents the comparison of 3 commonly used research methodologies in ISs. Of the threes methodologies, Design Science Research has been chosen and further detailed. Then this chapter presents how DSR has guided in performing the research presented in this thesis.

4.1 Analysis of Research Methodologies

Action Research (AR), Grounded Theory (GT) and DSR, are three commonly used approaches in ISs research. AR follows an interventionist and collaborative approach [Baskerville and Wood-Harper, 1996; Papas et al., 2012]. In AR the steps are plan, act, observe and reflect and it is followed cyclically [Kemmis et al., 2004]. It helps to frame specific research questions when the situation is unclear [De Villiers, 2005]. According to Susman, in AR a problem is identified and data is collected for analysis. Then several solutions are hypothesised from which an appropriate solution is chosen and implemented. Then the results are analysed and findings are interpreted. Then the problem is re-assessed and this cycle continues until the problem is resolved [Susman, 1983].

GT was developed by Glaser and Strauss. In GT, contextual data is analysed to generate theory and models. This approach originated in sociology [Glaser and Strauss, 2009]. The theory developed should be relevant to the situation and data collected. The conceptual model should be modifiable with the integration of new data [Glaser and Strauss, 2009; Strauss and Corbin, 1994]. Saturation occurs when multiple behaviours indicate similar traits and revisions will be required when disconfirming evidences are found. This inductive method is focused on constant comparison of empirical data but it does not verify existing theories [Lingard et al., 2008].

Design Science (DS) was first introduced by Buckminster Fuller to develop user-friendly artefacts for systems [Brown et al., 1978]. Later Herbert Simon popularised this term for the scientific study of the artificial [Simon, 1996]. The primary focus of design science is to develop knowledge that can be used by professionals to design solutions to problems in their particular field. In DS emphasis is given towards understanding the nature and causes of problems as it will be helpful in developing solutions. It also focuses on developing awareness on the advantages and disadvantages of alternative solutions [Van Aken, 2005].

There are various studies that analyse the differences between the three strategies. According to Baskerville, AR is focused on discovery through action whereas DS is focused on discovery through design. AR is rooted in constructivist ideas while DS is rooted in pragmatism [Papas et al., 2012]. GT, on the other hand, is focused on developing theories that are grounded in the data. Some studies have also found the similarities between the three strategies. All the three methods are executed as cyclical/iterative processes with states that may have similar content or yield equivalent results [Järvinen, 2007; Dick, 2003]. These three strategies have also been described to be complementary for various research problems.

Papas et al. in their article has discussed three approaches of combining research methods. While a dominant research method is used to conduct the research, other research methods may be included 'to examine and explain research questions' and this is referred to as the pluralist approach. Next is the multi-methodology approach. It will have multiple approaches built into the study and the different methods can be used sequentially or in parallel [Mingers, 2001; Chiasson et al., 2009]. The third approach is referred to as the meta-approach [Papas et al., 2012]. There are several illustrations to combining research methods. There are works that show that GT method can be applied in the search phase of a DS research project where the Information Technology (IT) artefacts can be developed in successive steps. The problem area identified using DS method can be systematically analysed using GT method and this can help in the identification of requirements for the development of the artefacts [Gregory, 2011]. Similarly, AR can be used as a meta-methodology within which GT can be reviewed. It has also been demonstrated that by substituting processes in GT with those of AR, the efficiency of data interpretation and theory building of GT research was improved [Dick, 2003].

All the three research methods (AR, GT and DS) have relevance to the research problem discussed in this thesis. The limitation for conducting the research is taken into consideration to identify the most suitable method. This study is restricted to desk/secondary research. For AR, there is an emphasis on producing social action, and there is an expectation for the participation of relevant practitioners and stake holders. For this method, moderate to extensive field work becomes a requirement. Similarly, to conduct the research using GT, interviews and focus group discussions are considered as the primary source of the information on which theories are developed. Though attempts were made for industrial collaboration, it did not materialise. Hence fieldwork was not feasible for this research. Similarly, there were limitations of time and funding to conduct focus-group discussion and interviews to receive sufficient sample of data. The interviews and survey conducted were limited to few industry practitioners and residential consumers. The purpose was not formal evaluation, but rather to check the relevance and comprehensibility of the theory and the conceptual design arising from the research. The information collated was not adequate for application of GT method. These factors made AR and GT less suitable for the research undertaken. DS, on the other hand, is flexible with the approach chosen for artefact generation and evaluation. It also accommodates the generation of theory, though the critical element is the creation of design artefacts. Relevance and rigour are fundamental for DS artefacts. To achieve relevance the artefacts should address a real need. Then rigour can also be achieved by applying the existing body of knowledge. These artefacts can be conceptual models, constructs and frameworks. It also allows for the selection of an evaluation method based on data availability, context and artefact type. Weaker forms of assessment methods like illustrative scenarios and logical arguments are also accepted for the DS method. Hence, the DS approach is observed to be more suitable for conducting the analysis of smart metering systems from a consumer perspective.

The end-users are concerned over the smart metering system for various reasons. Identifying one problem and finding its solutions will not improve their reactions. Currently with concerns over smart meter data, the immediate attention of the engineers and designers are to find privacy preserving techniques to protect data privacy. Some of the research activities in this area were also discussed in the literature review chapter. However, it does not still reduce the consumer concern. There are segments of consumers who don't wish to have their consumption data transferred even if the system is robust. Identifying solutions to this problem needs a better understanding of the energy user with a focus on the bigger picture.

4.2 Design Science Research (DSR) Methodology

There are various approaches for conducting design science research. The development process of DSR artefacts commonly covers problem identification, requirements specification, design, evaluation and communication [Baskerville et al., 2009; Hevner, 2007; March and Smith, 1995; Peffers et al., 2007]. March and Smith provided a four by four research framework with sixteen cells for describing research efforts. The research activities included building, evaluating, theorising and justifying artefacts whereas research outputs comprised constructs, models, methods and instantiations. They stated that the research project can cover multiple cells and that it was not necessary to have all the cells completed for a project [March and Smith, 1995]. Later in 2004, Hevener designed a guideline for DS research. It specified the importance of relevance for the artefacts generated and observing rigour in the creation and evaluation of the artefacts.

He said that the DS research process can be viewed as three cycle of activities which involves a rigour cycle and relevance cycle with the design cycle as the core [Hevner et al., 2004; Hevner, 2007].

In 2007, Peffers et al. reviewed several pieces of literature on DS processes. They found that in engineering, different processes existed with a focus on production of artefacts. According to them many of processes from the engineering field were design focused rather than research focused [Cooper, 1990]. They noted that in computer science the focus was on human-centered design cycle to improve requirements engineering methods. In IS studies, the focus was on functional view. [Hickey and Davis, 2004; Iivari et al., 1998]. Some researchers created abstract models that can be used in specific research projects and others focused on the steps to integrate DS research method with other well-known research methods [Nunamaker Jr et al., 1990; Rossi and Sein, 2003]. Peffers et al used the key findings of various DS literature to create a generalised process model for DS research in IS. They focused on the similarities of the views of various DS researchers to create the process model known asDesign Science Research Methodology (DSRM) [Peffers et al., 2007].

After carefully analysing the different approaches, DSRM model is selected because of the DSRM model is selected because of its general applicability, including to projects of the kind undertaken in this research, and due to the clarity in expectations for steps to be followed. The methodology presented by Peffers incorporates principles and procedures to design and evaluate artefacts. Peffers' methodology has the following six steps [Peffers et al., 2007] (refer Appendix A.12.1):

- Problem identification and motivation
- Definition of the objectives for a solution
- Design and development
- Demonstration
- Evaluation
- Communication

Establishing the utility of a designed artefact is the most important purpose in evaluation in DSR. It also helps to verify existing knowledge by evaluating the theories used to create the artefacts. It helps to identify consequences and side-effects of the designed artefacts. It helps to compare the different artefacts designed to achieve similar purposes. It helps to identify weaknesses and areas of improvement in related artefacts that are in development stage [Venable et al., 2012].

There are various evaluation methods discussed for DSR [Cleven et al., 2009; Fettke and Loos, 2003; Peffers et al., 2012; Pries-Heje et al., 2008; Venable et al., 2012]. Analytical and empirical approaches can be used to evaluate the artefact. Peffers et al. has created taxonomies of artefact types and evaluation methods after reviewing 148 DSR articles (refer Appendix A.12.2). Based on Peffers et al., the most commonly used evaluation methods for IS and Computer Science and Engineering (CsEng) research projects are technical experiments followed by illustrative scenarios. Case studies and logical arguments are also used in IS research, whereas in CsEng research, logical arguments and subject-based experiments are used. They also mention that selection of an evaluation method is based on data availability, context and artefact type [Peffers et al., 2012].

Illustrative scenarios and logical argument evaluation methods will be used for this research. For conceptual models, logical arguments are appropriate form of evaluation technique. They can be presented as plain texts and the process is subjective in nature. Characteristics, strengths and weaknesses are discussed using plain text. The logical arguments can also be feature based whereby a specific set of features is defined to describe the reference model [Fettke and Loos, 2003; Frank, 2007].

4.3 Applied Research Framework

Based on the DSRM process model, there are four research entry points: problem centered initiation, objective centered solution, design & development centered initiation and client content initiation [Peffers et al., 2007]. With consumer concerns as the starting point of this research, the 'Problem Centered Initiation' is the entry point for this research. For evaluating the artefacts, illustrative scenarios and logical arguments are used. The evaluation of smart metering system will have engineering and epistemological elements. This strategy helps in evaluating the effectiveness of the proposed corrections.

4.3.1 Data

The data collected for this research consists of published research papers, government reports, industrial specifications, and media reports. Valuable comments from industry experts (from Australia), high-profile researchers (from across the world) and consumer advocacy group members (from Australia) also added value to the evaluation process carried out in this research.

In relation to smart meter features and architectures, a range of sources were used. These included a particular model of smart meter, the Landis+Gyr U1200. It was appropriate because it is reasonably typical of contemporary smart meters, its feature-set is comprehensive, and it was applied in the Victorian scheme. The features and dataflows of its EcoMeter (an example of an In-House-Display) and its CommandCenter (and example of an Energy Management System) were also used.

A wide variety of textual sources were used in the research, including Government Reports on Smart metering roll-out and related themes from Australia, Netherlands, UK, US etc., media reports on relevant projects around the world, and research articles on Smart grid, Smart meters, demand-side management, demand response programme, energy consumer behaviours and attitude etc. In some cases, raw data used by the authors of research articles have been re-analysed.

4.3.2 Application of DSR methodology

Figure 2 illustrates how each step in the DSR methodology has been covered by this thesis. Consumers concern about smart meters is a significant problem for power grid

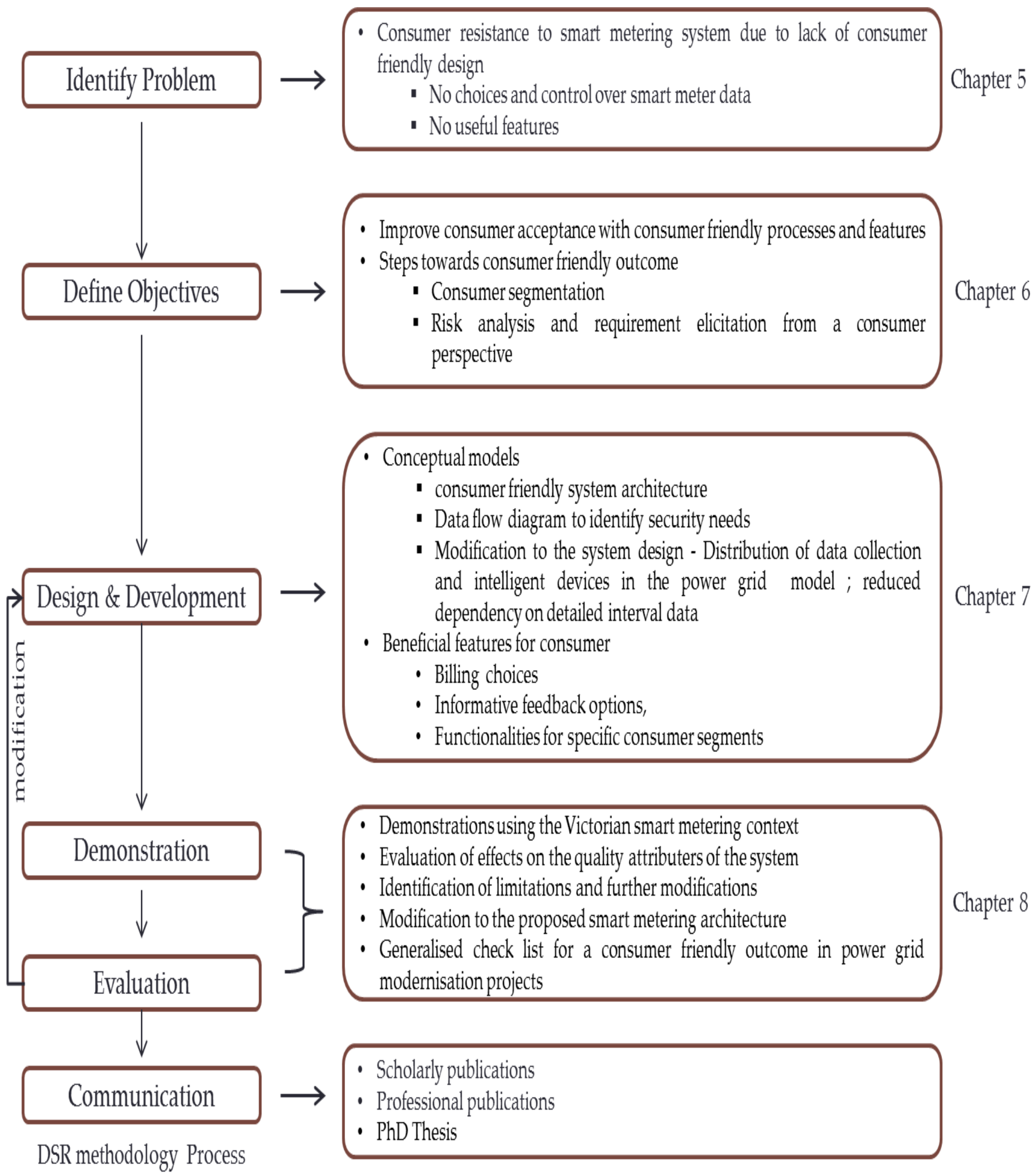

Figure 2: Thesis Research Framework using Peffers DSRM Model

modernisation project. Analysing this problem is core to this thesis and it is a real-world problem. Analysing a real-world problem that needs imperative attention is central to DSRM.

The smart metering system roll-out has not been welcomed in many places across the globe by residential consumers. Smart meters have been introduced by the service providers with the intention to improve their quality of services and in turn benefit their business. However, many of these projects are facing resistance from the end-users. Chapter 2 and Chapter 3 have discussed several smart metering projects and the reported consumer concerns. The aim of the study was to analyse the reported concerns and differentiate real from perceived risk and then identify measures to reduce the real risk. The first direction was to conduct a detailed analysis of the reported consumer concerns. The reported concerns have been critically analysed to classify them into various categories. Then the DR program features and the smart meter specific feature were analysed. This analysis helped in identifying the challenges created by the programmes introduced by service providers. Mapping the challenges generated by the demand management programs and the functionalities that are bundled into the smart meter to the reported concerns helped in the confirming the real risk. Employing scenario analysis technique helped in grounding the validity of the research problem. Of the list of risk to the end-user, the focus of this research was narrowed to smart meter data control and user-friendly features. Hence the objective was to make smart meter benefit the end-user through controls and choices over meter data and user-friendly features. This first step is discussed in Chapter 5.

The next step in DSRM is to define the objectives that will lead to a better design. In this research, the focus is on residential consumer and their concerns. The energy consumers are further analysed and segmented in Chapter 6. This chapter discusses the first steps towards obtaining the objectives. In most projects, it appears that no differentiation was made among residential customers. In order to identify end-user-friendly features, it was found to be necessary to segment residential consumers based on various factors.

During the background analysis, it was also noted that there was a lapse in conducting requirement and risk analysis from a consumer perspective. So, the next step was to identify end-user needs. To elicit requirements, various user-centric approaches exist and few appropriate techniques have been discussed in Chapter 2. Of the various techniques analysed, the contextual enquiry was a suitable option to identify the consumer response and energy-behaviour with the introduction of a smart meter. Using this elicitation technique, a template has been generated to elicit requirements from a segment of residential consumers (people with medical needs). However, this technique and template generated are not further used in this thesis due to the lack of availability of setup and participants. Nevertheless, the artefacts produced in this process are of significant use to the industry practitioners and researchers who plan to conduct detailed human behavioural studies through live laboratory and large-scale end-user analysis.

As this research was limited to desk research, the next best option was to use documentation analysis techniques to identify the requirements. In this research, conducting the risk analysis on the reported consumer categories first helped in synthesising the requirements. Hence risk analysis was performed before requirements identification. To perform the risk analysis from a user perspective, a framework was created using the existing body of knowledge. Using this framework, several scenarios were analysed and the results of this analysis helped in the identification of the consumer requirements. This is presented in Section 7.8.

Then the next step is to design and develop artefacts. Designing a consumer friendly solution is the main purpose of this thesis. These artefacts are discussed in Chapter 7. Based on the information gathered and deductions made (Chapters 2 - 6), artefacts are generated including constructs, framework, models and methods. In this chapter, the architecture of the consumer friendly smart metering system is detailed. Using this architecture and consumer segmentation, various control choices over smart data transfer and storage are proposed. These proposals ensure that there are options for all segments of consumers. Then a data flow model is proposed which identifies the security requirements at each point of flow. Project proponents can use this information to conduct a detailed security analysis for their smart metering system. To reduce privacy issues, suggestions are made to anonymise interval data before it leaves the smart meter and then aggregate it at the collector / data concentrator level before it gets sent to the service provider's head-end.

Then a further evaluation of the proposed model and other elements of the grid and its stakeholder reveal that there is no need for interval data to be transferred to other levels in the power grid. The analysis also reveals that the only stakeholder that benefit from detailed interval data is the consumer. Based on this inference, a model is proposed that distributes intelligent devices and data collection across each level of the power grid. This minimises the residential acrlongsm with features that are not relevant to the consumer. Further evaluation indicates that, the proposed model reduces most of the data related issues caused by the current design. Then functionalities have been proposed in the smart metering system that are beneficial for the consumer. These functionalities include billing choices, informative feedback options and specific configurations to match the needs of different user segments.

Demonstrating the applicability of the designed artefacts is the next step in DSR methodology. Demonstration is presented in Chapter 8. A current smart metering system that is facing consumer resistance is chosen for the demonstration. The Victorian (Australia) context is used for this demonstration. All of the proposed measures are finally evaluated against the quality attributes of the system. This is also presented in Chapter 8. This helped in identifying both modifications required in the system and the limitations of the proposed measures. The initial consumer-friendly architecture is further modified to accommodate the new findings. With the variations in smart meter design and technologies involved a generalised design for the smart meter is not presented. But the inferences from the research conducted in this thesis enabled a check-list to be provided that can be followed for all smart grid initiatives in order to achieve a consumer-friendly outcome.

Communicating the research outcome is another part of DSR. All the analysis and proposed measures have been published in relevant conferences (refer List of Publications). These ideas have been discussed also with personnel from the utility industry, consumer advocacy groups and energy research institutes.

4.4 Summary

This chapter has presented the research framework used in this thesis. DSR methodology has been applied for this research. Peffers' DSRM model is used. The evaluation methods applied are also based on suggestions made by Peffers for DSR.

To summarise, the objective of this research is to identify measures that can be applied to existing and future smart metering projects so that consumers will accept the system. The reported problems have been analysed to identify measures that are suitable for residential consumers. Illustrative scenarios are used throughout this thesis for analysis and evaluation.

The next chapter details the problem statement of this research. It first identifies problem scenarios from various DR programs and then it identifies problem scenarios from smart meter. The smart metering context in Australia is also discussed in the next chapter as it will be used for demonstration of the proposed measures.

Chapter 5

Problem Identification and Definition

This chapter presents a detailed analysis of the problem that is examined in this thesis. This chapter forms the first step of the applied research method. First, the demand response programs that were in place before the addition of smart meters are analysed. Then the smart meters are examined to see the additional issues it has created. Scenario analysis has been used to identify problem situations. Then the problem scenarios are compared with the reported consumer concerns.

5.1 Problem Analysis

As smart metering systems are used to implement DR programs, the issues created by DR programs to the residential consumer will be the starting point of this analysis. For this analysis, the three architectures for DR systems put forward by Kazman et al. are used [Kazman et al., 2011]. They are:

1. Direct load control (DLC) signals sent by the distribution utility.
2. TOU price signals sent to the consumer who has interval meters
3. TOU price signals directly to the advanced meter to act upon the signals

These are the commonly used DR Programs and in all these set-ups the electricity meter's role is mainly limited to billing.

5.2 Analysis of DR programs

This section analyses the effect of three DR programs on the residential consumers.

1. Controller device which receives direct load control (DLC) signals from the distribution utility.
   - There will be a controller device at the consumer premises. In some cases, this controller will be attached to the meter. The meters are usually dual tariff meters which allows for switching from high to off peak rates. The consumer can enrol to a DLC program provided by the distribution utility. The distribution utility will then send the DLC signals to the controller and

based on these signals the load of the consumer will be adjusted. E.g. ripple control system.

- Audio Frequency Load Control (AFLC) / Ripple Control systems are used in Australia (Queensland and some part of New South Wales (NSW), New Zealand and also few countries around the world. Ripple signals are injected by equipment located in local distribution network [Energex, 2014]. The load will be modified (turned off or cycled at a set interval) when these signals are received by the controllers in the customer's premises. This is done to mainly to control peak demand and it is either done based on a schedule charted by the distribution utility or upon the request from the transmission utility. In most places, there will be several ripple channels so that the distribution utility can control different parts of the network differently by choosing between channels. Devices controlled using ripple control includes off-peak hot water heaters, space heating and cooling equipment and lighting (in common areas, parking lots etc.). The high frequency signals (492Hz, 750Hz or 1050Hz) injected by the ripple controller may affect the electrical appliances. It may cause buzzing noise and flickering in certain equipment [APQRC, 2014].

2. Price signals and interval meters

   - There will be interval meters installed in the consumer premises and the consumer can enrol for TOU program. In most cases, a peak, shoulder and off-peak period will be set by the distribution utility. Then the retailers can set a different rate for each period. Based on the TOU program chosen by the consumer, different rates get applied based on the time period of usage. The retailer will use the interval data from the meter and bills will the calculated based on the rates defined for each time period. In most cases the TOU periods never change, but the tariffs may change and these are provided to the consumer in advance. The consumer has to remember the time-slots and adjust their energy behaviours to match their needs and saving goals.

3. Price signals to the controller

   - In this setup, the price signals will be sent to the controller. This controller may be but not necessarily attached to the meter. Controller will be configured to react to the pricing signals. The retailer may provide various programs to the consumer for enrolment. Based on the program chosen by the consumer, the controller will be configured. Then the pricing signals will be sent to the controller and the control device will operate based on the configuration. If the consumer has chosen to avoid peak period, the controller may disconnect or reduce load during the peak period. The meter will be of interval type if TOU pricing is also provided to the consumer.

5.2.1 Challenge Scenarios for DR Program

Kazman et al. in their work have discussed various scenarios that could be a challenge to system supporting DR programs. Some of those challenges also imply negative effects on the consumer [Kazman et al., 2011]. In this analysis, the focus will be in identifying scenarios that are challenging to the residential consumer. Scenarios that affect the residential consumers are listed below:

1. Consumer bill goes up after enrolling to a DR program Though DR programs are meant to ensure system stability and promote sustainable usage of electricity, the consumer's focus will on savings in electricity bills. The bills may go up if the consumer performed most of their energy intensive activities mainly during the peak period. This happens because:
   (a) The consumer did not understand the concept of TOU pricing and unknowingly/carelessly performed energy intense activities during peak period.
   (b) The consumer could not avoid the peak period due to various limitations.
2. Consumer enrols into a DR program expecting to utilise the incentives offered by the programs and later develops a situation that causes hardship.
   Kazman et al. in their article identify a situation in which a consumer enrols to have his air-conditioning controlled by DR and later develops asthma, making the air conditioner safety critical [Kazman et al., 2011]. Some DR programs have a longer lock-in period and this makes it difficult for the consumer to opt out of the program when they have a change in their situation. This happens due to the projects sponsor's inability to understand the fact that consumer's energy needs cannot be static. It changes over time and in some cases, it could be a sudden change.
3. Changes to a DR program due to less uptake from consumers
   In most places, the DR programs are not mandatory and situations may arise where only few people enrol to the program. With only few enrolments, the distribution utility may not be able to achieve the expected results and this could lead to winding up the program or replacing it with a new one. If the program is scraped, all the investment that went towards the program is wasted. If the program is upgraded/ modified then existing program members will be affected negatively if their current devices or investments have to be replaced. Lack of understanding the consumer and their needs is one reason for this. Identifying the consumer's needs and expectation is always necessary before any program is designed and implemented.
4. System failure and glitches causing adverse effects on the consumer premises.
   As the DR controller has the ability to modify load, wrong signals sent or system failing to send the correct signals could affect the consumers negatively. In some cases this could lead to significant damages to the consumer's assets and the effect will be the worst, if damages are caused to critical systems like life support machines.

5.3 Analysis of Smart Metering System

In the previous section, the negative effects of DR programs on consumers have been analysed. No literature has been found that discusses remedies to these issues. This indicates that the smart metering system that is trying to implement the DR programs will also pose similar risk to the consumers. In addition, other risk may also be present as smart meters support additional features.

Smart meters are of various configurations and types. Some of the advanced configurations have two relays – Service Breaker Relay (SBR) and LCR and a controller for the DR program. The distribution utility can send control signals to both the SBR and LCR. The signals send to the SBR are to disconnect/reconnect the whole power supply. The signals sent to the LCR are to control demand during the peak period. The meters also have the option to let the consumer locally initiate an LCR operation, but the control command from the service provider can override the consumer initiated operation.

Apart from the DR program the smart meter also allows distribution utility to remotely access interval data stored in the meter. This can be done in two ways:

1. The meter can automatically send the data at periodic intervals based on the configuration in the meter profile.
2. The distribution utility can send request signals to the meter to fetch the data whenever required.

5.3.1 Challenge Scenarios for the Smart Meter

Apart from the DR program challenges, new challenges also arise due to the additional features supported by the smart meter.

1. Service provider's capability to override consumer initiated LCR operation.
   It will cause inconvenience to the consumer as the planned activity gets interrupted. E.g. Consumer activates the LCR to start the hot water system for a warm shower in winter and the system getting disconnected due the control signal from the utility.
2. Consumer having to pay for smart meter but not being able to benefit from its features.
   In many countries, IHD is not provided along with the smart meter installation. Consumers have to pay additional fee to get the feedback device and many consumers do not opt for it. Even for those consumers with at IHD display, the information provided is limited to current consumption data and the tariff rate that will be applied in that time slot. This information is not sufficient to make ideal choices. It is difficult for the consumer to benefit from such a system, yet they to have pay additional service charges to maintain the newly installed smart meters and its network.
3. Consumer's data accessed without permission
   The interval data generated by the smart meter can lead to privacy issues. Monitoring this data over a period of time can reveal if the premises were occu-

pied/vacant. This could negatively affect the consumer if,

(a) The distribution company discloses this information without consumer consent.
(b) Someone intrudes into the system and access the information without the knowledge of the consumer and service provider.

4. Intrusion into the system causing unexpected operation

The to and fro data flow in the smart metering system gives rise to new security threats as it didn't exist in the system before. Intentional or accidental introduction of wrong information in the system could cause the power grid to crash and cause catastrophes. The end users in particular can be affected if the power supply is cut-off. All the 8 scenarios (4 mentioned under 5.2.1 from and 4 mentioned here) identified for the smart metering system can affect the consumer negatively and these will be analysed in this thesis. All these scenarios pose threat to one or many consumer assets. The projects sponsors must have either overlooked these scenarios. All these scenarios will be taken into consideration in this thesis. The next section will analyse the consumer concerns in detail.

5.4 Detailed analysis of Consumer Concerns

After smart meter roll-outs started in various countries across the globe, consumer concerns arose. Residential consumers are resisting the installation of smart meters in their premises. In many places, roll-outs have been delayed and even stopped, including in some where the scheme had initially been mandated [UKERC, 2011]. 'Stop Smart Meters' groups have been formed by the resistant consumers in almost every country. Even if the resisting consumers only represent a small segment of the entire populations, they can impact major decisions. For example, it has been reported that there is a high chance that Germany could reject smart meters due to a small but vocal minority of energy users who are opposed to any storage of information on households and uncomfortable that utilities could have access to data on how and when they use electricity [Bayar, 2013].

In Victoria (Australia), mid-way through the smart metering project, the state government conducted a review to analyse the need to suspend the installation of smart meters due to consumer complaints and worries that consumer benefits had been overstated [ABC News, 2011]. The review identified that was more expensive to support two different systems and hence to continue with the roll-out. A follow up review was conducted in September 2015 and the report states that consumers will have to spend more than previous forecast to complete the smart meter roll-out and connection. The report also mentions that though 93% of the installations were completed in 2013, only 20% of the benefits were realised. The large part of that financial benefit was from the ability to avoid costs for manual meter reading. The report also adds that benefits did not represent any additional value from the program and that the overall costs of the smart metering program significantly outweighed the savings [VAGO, 2015b].

There are also similar consumer review reports from Europe [ECMA, 2009; Roberts and Redgrove, 2011]. The review report that was prepared by the Centre for Sustainable Energy (CSE) for the UK smart metering project also mentions that the most concerning aspects for consumers are the roll-out costs and the unfair share of the benefits that are acquired by suppliers and others in the system. The proposed remedy was to identify measures to understand consumer concerns followed by the development of interventions to address them [Roberts and Redgrove, 2011]. Although the report purported to be oriented toward consumers, the remedies suggested were from the perspective of the solution providers rather than consumers.

Using varied price signals are considered as preferable DR program and this requires no significant investments in hardware. However, forgoing a high degree of flexibility and scheduling everyday life around different electricity prices as in the case of variable tariffs was regarded as difficult. So, the main barrier to adopting a new technology seems to be the cognitive effort required for changing patterns of behaviour [Paetz et al., 2012].

There have been reports of increased electricity bills associated with the use of smart meters. The complaints include an uninhabited home being billed more than double previous amounts following the installation of a smart meter. Utilities respond that the bills are accurate and that increases may be due to the precision of measurements which was not available with traditional meters, or leakage or theft of power [Betz, 2010].

There have also been complaints that smart meters are causing health problems. The alleged health issues against smart meter included headaches, palpitation and cancer. In various counties (Marin, Fairfax, Santa Cruz etc.) in US moratorium on smart meter installation was approved after public protested and blocked the roads [Baker, 2011; Parkhurst, 2010]. The terms Idiopathic Environmental Intolerance (IEI) and EHS attributed to Electromagnetic Fields (EMF) have been coined to refer to a range of complaints that arise from, or are at least perceived to arise from, among other devices, smart meters and/or associated data transmission devices [Baliatsas et al., 2012; Betz, 2010].

The concerns over security and privacy arise from collection and transmission of fine-granularity consumer data from smart meter modules. Reports suggest that smart meters are capable of revealing a considerable amount of sensitive data about people and their lifestyle and that it would let the observer know about the occupancy and contents of premises [Quinn, 2009]. There are also reports that show that smart data is susceptible to interception during transmission, which creates the possibilities of modification and destruction of information [Angermeier et al., 2012; Baumeister, 2010]. There are also fears that malicious hackers may be able to intrude into the grid and cause harm to individuals' equipment, or blackout an area, or perhaps even undermine critical infrastructure.

There are also safety concerns. It has been reported that power surges have caused some smart meters to overheat and start a fire. Poor quality components and improper assembly of meters has been noted as the reason for overheating [EMF Safety Network, 2012; ESV, 2012]. Utilities respond that smart meters are subject to rigorous safety standards and that the fires are caused by faulty switchboards and unsafe wiring that had hitherto remained undetected. In some cases, investigations conducted by a safety regulator have determined that criminal damage was the cause of the fire [ESV, 2012].

There are also concerns about some consumers being unable to avoid peak demand, resulting in huge electricity bills. Consumers such as pensioners and others who stay at home most of the time can't survive without heating/cooling systems and without operating other essential appliances during the peak period. People belonging to low income groups cannot afford to have expensive solar panels installed as an alternative. People requiring disability or medical assistance, e.g. for life support systems, also cannot adjust their demand in response to price changes. Inadequate financial incentives, health concerns, security issues and violation of privacy are among the most significant obstacles reported [Amin, 2012; Khurana et al., 2010; Yan et al., 2012]. Mah et al in their article have also identified negative consumer responses that have occurred in many instances. However, they have not conducted a deeper analysis of consumer concerns [Mah et al., 2012].

5.4.1 Mapping Consumer Concerns to Meter Functionality

The basic functionalities of smart meter are discussed in section 2.5. Based on the consumer concerns mentioned above, the consumer assets that are affected have been identified and it is mapped to the smart meter functionality. A summary of this analysis is shown in Table 3. All the five functionalities have one or many consumer concerns detailed against it. The consumer concerns need appropriate classification to help in identifying measures. Hence the concerns are classified and presented in the next section.

Table 3: Consumer Concerns over Smart Meter Functionalities

Smart Meter Functionality		**Consumer Concerns**	**Consumer Assets Affected**
1	Storage of fine grained consumption data.	Will provide insights into a households' living patterns to the extent that it could reveal the appliances used and activities conducted by the household.	Confidentiality, Security, Safety, Privacy
2	Two way communication and automated meter reading using various technologies.	Data susceptible to interception during transmission leading to modification or destruction of information.	Integrity, Availability of data and power, Privacy, Security

		Exposures to radio frequency waves causing electro hypersensitive (EHS).	Health, Safety
3	TOU tariff to reduce peak demand.	Unable to avoid the peak period due to various reasons.	Comfort, Convenience, Financial
4	Remote switching (disable and enable) of supply.	Possibility of getting disconnected by error or deliberate attempts by anti-social elements.	Safety, Security, Control
5	Enable energy export and calculation of net usage.	Currently smart meter does not check before injecting the energy into the system and that could destabilise the system.	Availability of power, Safety

5.4.2 Classifying Consumer Concerns

The concerns identified are classified as follows:

1. Health concerns
2. Safety concern
3. Information security and privacy concerns
4. Cost Concerns
5. Usability and functionality concerns
6. Control and Choice concerns

5.4.2.1 Health Concerns

The existence of EHS is contested, and some of the literature refers instead to IEI (cause-unknown) [Baliatsas et al., 2012]. Smart meters have a communication module for transferring data to the remote server, which may transmit and receive using electromagnetic radiation. The meter manufacturers respond that they have complied with industry standards, and that radiation from smart meters is much lower than that from mobile phones [Betz, 2010; Krishnamurti et al., 2012].

5.4.2.2 Safety Concerns

It has been reported that power surges have caused some smart meters to overheat and start a fire. Poor quality components, improper assembly of meters and in a majority of the cases faults in existing wiring have been noted as the reasons for overheating [Betz, 2010; EMF Safety Network, 2012]. Fire risk is a straightforward issue of product safety. The meter manufactures have to ensure product quality and meter installers have to make sure that existing wiring is suitable for the new meter installation.

5.4.2.3 Information security and privacy concerns

There were various media reports that stated that detailed data from smart meters can become a security and privacy issue. An article showed that detailed interval data from the smart meter is capable of revealing people's lifestyle, occupancy and contents in a dwelling [Quinn, 2009]. It was reported that smart meter data is also susceptible to modification and destruction during transfer. There are also fears that blackouts and other disasters could be caused by malicious hackers [Baumeister, 2011].

Armel et al. compared various disaggregation analyses on different data frequencies and its capability to identify appliances. Based on the information they have gathered data, a frequency greater than 1 MHz is required for identifying appliances more precisely [Armel et al., 2013]. Hence it not easy to extract consumers' profile as reported in media. Over a period of time, the data may reveal some energy habit and to identify if a location is inhabited or vacant.

To ensure data security and privacy, data anonymisation and encryption techniques have been proposed by various researchers [Efthymiou and Kalogridis, 2010; Fouda et al., 2011; Garcia and Jacobs, 2011; Li et al., 2010; Marmol et al., 2012]. Based on the system and communication capabilities of the system any of these measures could be added to improve the security of data during transfer.

Yan et al. in their study identified that high performance and strong security are offered by solutions like Advanced Encryption Standard (AES) and Triple Data Encryption Standard (3DES). As power grid components are expected to have long lifetimes, AES would be a better solution. 3DES could be used where the risk of compromise is acceptable and legacy functionality is needed. Wired links can be made secure with firewalls, Virtual Private Networks (VPNs) and IPSec technologies. Wireless protocols also have security mechanisms [Yan et al., 2012]. Electric utilities also have responded that the meters have a firewall and basic encryption and there have been no cases of reported attacks.

5.4.2.4 Cost Concerns

The new infrastructure incurs cost in the order of several millions of dollars. It is also not clear if a smart metering system can reduce bills as claimed by utilities. Consumers have reported increased electricity bills associated with the use of smart meters. Consumers pay a service fee to the retailer for using their service. In many places, this charge has gone up with the introduction smart metering system. Carbon and Energy Markets has reported that in Victoria, Australia the charges had risen 212% since 2008. The report compared the wholesale electricity price with charges later added by retailers. It is also reported that fixed charge proportion of the bill got higher by 30% each year and that there is no incentive to be energy efficient. This is affecting the low-income households and the report states that number of electricity disconnections in Victoria had increased fivefold since 2008. The deregulated retail electricity market is identified as a cause of this problem [ABC news, 2015]. Consumers feel disadvantaged that they are forced to bear the cost of maintaining the power grid. There should be stronger regulation to control the fixed charges levied by the service provider.

5.4.2.5 Usability and Functionality Concerns

A smart meter by itself provides only limited feedback to the consumer. The meter's display can show few readings to the consumer. This information is not sufficient to make informed choices. If an IHD is added, the consumer can also view the real-time signals received from the service provider along with the consumption data. But again, not all consumers have the capability to make decision based on the data provided by IHD. Similarly, the consumers also need to identify which scheme/plan suits their situation when there are different retailers with multiple choices. When the industry expects consumers to become active players, the intelligent systems introduced into the grid should be able to help the consumers make correct decisions. In the current system, except for data being extracted and displayed, it is not efficient to help the consumer. The feedback provided needs better and useful information.

5.4.2.6 Control and Choice concerns

There are also concerns about some consumers being unable to avoid peak demand, resulting in huge electricity bills. Utilities expect consumers to utilise smart meter facilities, and adjust their consumption behaviour accordingly. On the other hand, consumers who stay at home most of the time can't avoid peak as they will have to operate at least some and perhaps most of their appliances. People with low financial capacity may not be able to invest in solar panels and other alternatives [Joskow and Wolfram, 2012]. It is also difficult for most consumers to understand the demand signals, decide on a course of action, and make the necessary changes. Consumers are also hesitant to give control over their appliances to the utility. Consumers want to choose how they operate their appliances. Not all concerns are real. The next section discusses which all risk belongs to the real and perceived category.

5.4.3 Perceived vs Actual Risk

When a system embodies risk to the vital assets of the stakeholder, there will be resistance to it. That is clearly evident in the case of smart metering system. From the perspective of a consumer, there are significant risks to assets that they value, and there is little evidence of significant gains. To a consumer, it will appear that the utility is forcibly introducing a system that is beneficial to the utility's business but not to the consumer. The following insights into perceived risk by Bruce Schneider and Daniel Gilbert [Schneier, 2006] are useful in analysing the consumer concerns about smart meters.

1. "People overreact to intentional actions and under-react to accidents, abstract events, and natural phenomena" [Schneier, 2006].
    - The majority of computer and Internet users are not cautious when using public terminals or do not change the password regularly, thereby exposing personal data. But the same users are worried that personal data will be exposed by smart meters. Most smart metering systems have basic encryption and firewall protection.

- There are numerous ways in which antisocial elements can cause harm to the public. Even without smart meters, houses are being robbed and occasionally terrorists are planning attacks. What would be the motivation to use the smart meter for future attacks? Are they easier than existing methods?

2. "People underestimate risks they willingly take and overestimate risks in situations they can't control" [Schneier, 2006].
   - Electronic devices emit radiation. RF emissions are produced by many wireless devices already found in the home, not just by smart meters. Research suggests that smart meter emissions are lower than those of wireless routers used for internet connectivity, and even less than wireless baby monitors. But unlike those devices, smart meters transmit in short bursts during only a fraction of the day.
3. "People under-react to changes that occur slowly and over time" [Schneier, 2006].
   - Residential electricity prices have increased in many countries over the past five years and consumers have been paying high flat-rate bills. With TOU tariff the consumer is showing resistance to paying high prices during peak periods. If flat rates continue, it is likely that consumers as a whole will pay more under flat-rate arrangements than they would if a TOU tariff were introduced and production costs were able to be reduced.
4. The way in which risks are communicated can affect user perceptions [Fischhoff, 1995; Pidgeon et al., 2003].
   - Closely associated with consumer protests about health hazards breaches have been media reports to the effect that smart meters cause such problems.
   - Similarly, the smart meter has been described as a spying device in the home [Roberts and Redgrove, 2011]. This was based on a report that found that detailed smart meter data at one-minute intervals could provide insights into a household's living patterns to the extent that it could reveal the appliances used and activities conducted by the household [Quinn, 2009]. This reflects the intentions of the visionaries and even of some design engineers. But it does not describe contemporary capabilities. Armel et al., compared various disaggregation analyses on different data frequencies and its capability to identify appliances. Based on the information they have gathered data, a frequency greater than 1 MHz is required for identifying appliances more precisely [Armel et al., 2013]. So, it not easy to extract consumer's profile as reported in media. Most smart meters generate data at intervals of 15mins or above, and inferences are accordingly much harder to draw. Even if and when smart meter data becomes very fine-grained, detailed knowledge of the appliances present in the home and the habits of the consumer might also be required in order to infer living patterns [Roberts and Redgrove, 2011].

The above examples showcase some exaggerations that are communicated through social media. If erroneous information sources find ready access to the mass media without effective remedies, then large social impacts, even for minor events, becomes possible [Kasperson et al., 1988]. A number of consumer concerns do, however, reflect actual risks that need to be addressed.

1. **Fires and explosions** arising from the introduction of smart meters is an actual risk. It is unacceptable to reduce cost of production by using poor quality components, inadequate assembly or short-changed quality control. In addition, a utility cannot blame existing conditions for causing a fire. When a traditional meter is replaced as part of a utility-sponsored scheme, it is the sponsor's responsibility to ensure that the existing wiring and conditions are safe for smart meter operations.
2. **Software quality** must be assured. The meter firmware that calculates the power usage needs to be demonstrated to be accurate and free from bugs. Erroneous billing due to firmware and system defects is unacceptable.
3. **Discrimination** against some categories of consumer is an issue that needs to be addressed, not ignored. This applies to individuals who depend on electrical devices for life-support, safety or maintenance of critical quality-of-life services; and to low-income and low-educational-level households.
4. **Data Disclosure** appears to be a design fault in many schemes. Data with potential sensitivity is passed from smart meters up through other organisations, without controls in place to minimise its distribution and to maximise its aggregation.
5. **Data Interception** is a genuine risk in many scheme designs.
6. **Remote switching of devices**, although not at this stage delivered functionality, is more than a gleam in the eyes of utilities and ambitious designers.
7. **Instability of Supply** is a genuine risk where distributed generation is closely coupled to medium- and low-voltage transmission lines.

An important insight arising from the analysis conducted in this section, is that not only is it essential that real risks be addressed, but it is also necessary that potential misconceptions be recognised in advance, fears allayed, and the ground prepared to counter misinformation when it appears within communities, in social media and in mass media venues.

5.4.4 Comparison

In this section the output of scenario analysis is compared with the concerns reported. The 8 challenges identified by scenario analysis cover all the concerns except the health and safety concerns. This indicates that scenario analysis method is useful in identifying important problem in power grid modernisation projects. Doubts exist about the basis of health concerns, and fire and safety risk is a straightforward issue of product safety. Safety of the product should not be compromised for profit or any other reason. Proposing corrective measures for these two concerns are beyond the scope of this thesis and hence health and product safety will not be further discussed.

5.5 Analysis of context chosen for Demonstration – Victoria (Australia)

In the literature review, the smart metering systems in Australia and Netherlands were among the projects that were discussed for facing significant consumer resistance. Netherlands stopped its mandatory roll-out after active campaigning by consumer advocacy groups and let consumers have the choice. Whereas in Victoria, the roll-out continued and even after the initial review in 2011 which presented negative directions. By mid-2014 the roll-out was declared complete. Now these systems are facing severe criticisms from the Victorian Auditor General for exceeding the budget and lacking in benefits to consumers [VAGO, 2015b].

5.5.1 Australia's Initiatives

Australia has issues managing peak demand and theCouncil of Australian Government (COAG) wanted better solutions than spending money on building infrastructure to cope up with peak demand. In 2007, COAG recommended the roll-out of smart meters and the introduction of TOU tariff as part of demand control strategies [COAG, 2012]. Similarly, the Department of the Environment, Water, Heritage and the Arts (DEWHA) prepared the initiatives for the smart grid system in Australia. DEWHA primarily focused on distribution and retail value chain elements [DEWHA, 2009]. COAG's and DEWHA's recommendation led to the proposal for energy information hub for the customers. This information hub is to provide consumers with better and easier access to the information on energy usage that is held by the Australian Energy Market Commission (AEMC) and retailers [Orme et al., 2012]. The AEMC composed the Power of Choice (PoC) and it highlighted on the need to provide consumers with access to their usage data and made recommendation for modifications in National Electricity Rules (NER) and National Energy Retail Rules (NERR) to accommodate these changes [AEMC, 2012]. In Australia, the NER governs the operation of the National Electricity Markets (NEM) and the NERR governs the operation of the National Energy Retail Markets (NERM) [AEMC, 2014; AEMO, 2015].

In Victoria, most service providers that have deployed smart meters have a web energy portal where their customers can log-in to view their consumption data [DEDJTR, 2015b]. These systems follow the NEM12 data format, data exchange procedures under Metering Data Management (MDM), Consumer Administration and Transfer Solution (CATS) and other parts of Market Settlement and Transfer Solutions (MSATS) [AEMO, 2013]. AEMC wanted AEMO to develop supporting guidelines that outline the details of a standardised format in which information can be provided to the customers. Hence, AEMO formulated the Metering Data Provision Procedures (MDPP) which established the minimum requirements for the manner and form in which retailers and DNSPs must provide metering data to a retail customer, or their authorised representative. The MDPP procedures can be considered as a consolidation of all existing procedures with more clarity on how the data should be provided to the consumer. Retailers and DNSPs must create new consumer information hub or modify existing information hubs based on the MDPP [AEMO, 2015].

The AEMO's MSATS database contains the metering data that is collected from the end-points(consumers' meter). Though the Electricity Rules prescribes the categories of stakeholders entitled to access certain data in the MSATS database, there have been allegations that market participants who had access to this data provided unauthorised access to third parties [Wigan, 2012].

With the introduction of smart meters and the energy information hub, the interval data collected from the smart meter will get stored in the MSATS database. Though personal information of the user is not stored in the MSATS database, it stores the meter identifier number and location of the meter [AEMC, 2012, 2014; AEMO, 2015]. This information can be used to identify the users occupying the location and it could be a violation of their privacy. Hence, rules that restrict the access to the stored meter are not sufficient. It is necessary to have rules that give end-users better control over the meter data that is transferred and stored to any location outside their residential premises. In Europe, Article 8 of the European Convention of Human Rights (ECHR) states that end users' consent is required before meter reading is transmitted to the service provider and any third party there after [Cuijpers and Koops, 2013]. Similar rules should exist world-wide to force the service providers to have control options for consumer over meter data storage and transmission.

5.5.2 Australian Smart Meter Programs and Trials

Most states welcomed the idea recommended by COAG in regards to the smart meter roll-out. However, Queensland having invested in other measures like AFLC was not interested in a sudden change of system [Energex, 2014]. Before the finalisation on recommendations, Victoria rushed into the smart meter roll out. Simultaneously there were smart meter trials in parts of NSW. The Skywalker program tired with the introduction of AMR meter and Smart City project tried with the introduction of the AMI-enabled meter [AEFI, 2014]. Department of Industry, Innovation and Science (DIIS) reports that the Australian Government provided a $100 million grant for this project. It further received $400 million from the project consortium [DIIS, 2015]. Though both trials produced reports that showed positive direction, the uptake of smart meters after that were not positive among residential customers and both the programs were dropped after the trial [Colley, 2014]. The Victoria's mandated smart meter roll-out continued with many issues and criticism. The troubled roll-out was not stopped as it was found that it would be expensive to manage two different systems. With more than 98% of the roll out completed in 2014, the Victoria's smart meter project was announced to be complete. It was noted that the operational costs reduced for the retailers and distributors and there were no significant benefits for the consumer. The review of the program done by the Victorian General criticised the program for having no evidence of consumers receiving benefits from the program and has asked the related entities to identify measures to help consumers [VAGO, 2015b,a]. The other states hesitated with their smart meter roll-out plans as Victoria's smart metering program harboured consumer negativity. However, they are making initiatives to make the user accept the smart meter. Currently, newer schemes have come up in NSW where they are promoting the introduction of a smart meter with smart apps that can be viewed from any smart mobile device [Cormack, 2016].

Significant public funds have been spent towards smart metering programs trials and research as these energy saving initiatives are considered to benefit the public. It is estimated that by 2015, Victoria's electricity consumers have paid over $2 Billion towards the smart metering program, which includes the smart metering rollout and its related metering services. It is also reported that the many of related costs have been transferred into the customers' electricity bills without specifically itemising it as smart meter charges. The VAGO report show that an average residential consumer has paid around $760 since 2009 for the smart metering services [VAGO, 2015b, pg 29].

5.5.3 Approach towards Consumer Needs

When DEWHA made recommendations for smart meters and related initiatives, they also insisted that trials should thoroughly test the benefits of the consumer applications. For the trial, they also suggested that customer segments with different patterns of electricity use be identified and included, because each segment appeared likely to respond differently to the customer applications components being tested [DEWHA, 2009].

The smart metering program that is currently (2016) campaigned in NSW involves the use of smart applications that can access smart meter data. It has also added that as these applications can be accessed anywhere, it will be more beneficial to the consumers. They have also linked that the failure of Victoria's smart metering program to the lack of flexibility of the feedback device. IHD can be used only from homes whereas with the smart apps, the data will be available from anywhere [Cormack, 2016].

5.5.4 Analysis of another DR Program in Australia

ActewAGL is the energy distributor in Australian Capital Territory (ACT), Australia. One of their energy savings initiatives was to replace all the halogen downlight globes with LED globes for free and help customers save on their bills [ActewAGL, 2016]. On analysing the program, it was found that not all consumers have taken up the program though it was free and guaranteeing saving in the bills. Some of the customers who tried the program also have reported being unhappy about it. The reasons are as follows.

(a) The free LED globes were 6 Watts, and it produced around 800 lumens. Some customers were not satisfied with the brightness and light quality as their replaced globes produced higher lumens.
(b) The service provider took all the halogen globes that were replaced. The customers who didn't like the replaced LED globes had to invest in a new set of halogen globes.
(c) Some of holders/ case for the globes were not compatible with the LED globes provided, and this made them damage faster.

(d) The globes provided were also not compatible with the dimmers.
(e) Indicative savings that are advertised were misleading for some consumers. The website advertises a savings of around $234 per year [ActewAGL, 2016]. However, in the footnote, it is mentioned that this could be achieved by replacing 20 halogen downlight globes of 50 Watts with LED globes of 6 Watts. The information for replacing one bulb should have been provided, even if the saving figures may not look impressive.

5.5.5 Inference Made from the Australian Context

Current smart metering and DR programs and trials show a lack of involvement and understanding of the consumer need and limitations. The recommendations to provide consumers with access to detailed data also lack the insight of consumer realities. A small DR program stated in section 5.5.4 also had segments of unhappy customers. However, that scheme didn't have a significant negative effect on the consumer, and they had the choice for not taking part in the program. Electricity is an essential utility that is used to perform and ease various day-to-day activities. So, when programs are designed, the need for consuming electricity has to be taken into consideration and not just the quantum that is used. When designing improvements for DR programs, consumer-friendly approaches have to be applied to understand the user and elements that affect their choices. In some new smart metering projects proposals are made to replace IHD with smart applications. Providing detailed consumption data in flexible devices will not alone help consumers make the informed choices. Similar to the earlier failed attempt, these projects also lack in considering the human factors that affect energy usage. Any remedial measures made on the side-effect may again face consumer negativity.

Smart metering and demand response projects receive significant public funding for their research and development initiatives. The regulatory bodies need to scrutinise these programs carefully before releasing funds. With the funding, the loss of the businesses is partially or entirely covered. However, for the public, the funds that could have been used for other beneficial programs gets drained, and they also have to bear the adverse effects of the failed projects. There should be stricter regulations to scrutinise these projects to ensure that they can clearly demonstrate benefits to the consumer.

5.6 Summary

This chapter has analysed the problem situation the smart meter is facing from a consumer perceptive. Scenarios analysis has been used to reveal challenges posed by the system to the consumer. The challenges identified using scenario analyses were able to cover most of the concerns reported. This research has shown that scenarios analysis can be used to determine the risk a relatively new system can cause to its stakeholders, particularly the end users. As the power grid is ultra large, practices such as scenarios analysis should be followed by the electricity service providers to identify the consequences of the newly introduced/ planned systems on the various stakeholders involved.

Different actors participating in the same system may have a different perception of risk and they react according to those perceptions. This confirms that the system lacks risk analysis from a consumer perspective. There is a tendency to ignore consumers when various analyses that are conducted. Ultimately it will be the consumer who will have to bear the cost of running the system and if the safety, security and benefits are not guaranteed, consumer preparedness to accept the scheme will inevitably be harmed.

The next chapter identified and details the initial steps toward achieving the objectives of the research.

Chapter 6

First-Steps Towards Consumer-Oriented Solutions

Based on the research method established, the next step is to identify the steps to achieve the objectives. This chapter focuses on the preliminary steps required to obtain the objectives of this research. The previous chapter has detailed on the problem scenario. The major problem the smart metering systems are facing is its lack of consumer focus. The key objectives of this research are to:

- Obtain a deeper understanding of consumer concerns and issues arising in smart metering projects.
- Identify a set of measures that address the concerns and issues, and result in consumer wariness and opposition being replaced by enthusiasm.
- Specify how those measures can be implemented within the context of contemporary meters, grids and projects

This chapter starts with a detailed analysis of consumer concerns.

6.1 Initial Steps to Address Concern

The characteristics of the residential energy consumers must be identified to propose consumer-friendly measures. It has been conventional to define customers as homogeneous entities. Despite the many sources of difference among end-users, there is a tendency by designers to lump all customers together into a single entity. All users are considered to want the same things. In a multi-stakeholder system, eliciting the requirements from all parties involved is not an easy task. In many cases, the investors' requirements get the priority and the end-users' needs are often ignored or assumed. Performing risk analysis is also a challenge. The consumer concerns discussed in section 5.4 indicates that smart metering projects lacked considerations in the three above mentioned areas. Hence as the first step towards consumer-friendly solutions, this research identifies:

1. Consumer segmentation necessary for smart metering projects
2. Risk analysis process suitable for identifying risk to end-user assets.
3. Requirement elicitation techniques that are appropriate to identify end-user and other stakeholder needs.

6.2 Consumer Segmentation

In order to avoid public reactions against smart meter schemes, sponsors must take stakeholder analysis beyond this limited conception of an army of undifferentiated consumers. Stakeholder segmentation offers details that the traditional "one lump" views cannot. The possibility exists that the agendas of different stakeholder segments may give rise to incompatible and inconsistent requirements. In such circumstances, stakeholder segments need to be ranked, in order to resolve requirements conflicts and make appropriate decisions.

Valocchi et al. divides customers into four categories – high energy users; the passive customers; the innovative consumer; and the frugal customers. This segmentation can be considered as based on orientation towards energy efficiency and saving. This categorisation is more beneficial to the utility in determining how to implement TOU tariffs and other curtailing measure [Valocchi et al., 2009]. However, the earlier analysis has shown that high energy usage could also be due to a necessity that cannot be avoided (e.g. running a life support system 24 x 7) and that passive user necessarily does not mean that the user is not interested in making efforts to save electricity (e.g. a family with kids will need to have cooked meals on time, hot shower and heating/ cooling based on weather).

In this section the residential consumer are categorised on various attributes that will be needed for building the system requirements. Consumer categorisation is proposed on the key elements that were identified during socio-economic analysis and those elements are:

1. Energy requirements
2. Ability to modify usage
3. Willingness to accept new technologies
4. Ability to comprehend information

6.2.1 Classification based on Energy requirements

Based on analysis conducted in literature (Section 3.4) review the factors that affect demand choices are as follows:

1. **Occupants in the dwelling:** including sole- and multi-person occupancy, distinguishing families from non-related individuals sharing accommodation.
2. **Characteristics of the dwelling:** particularly size, number of rooms, type (detached, semi-detached, apartment), conditions (insulation, weather-proof).
3. **Occupants' Propensity to Pay:** particularly income and attitude towards convenience (balanced anything for comfort, go-green, careless, enduring hardship due to no other alternative).
4. **Appliance Working Mode:** including stand-by, active, cold (appliance in continuous use but do not draw a constant amount of power).
5. **Other factors:** including climatic and weather conditions, heath-related factors (e.g. continuous life support systems), security-related (e.g. security and theft control systems), and occupation-related (work at home office and production

units)

Using this information the consumer can be classified as follows.

1. People requiring medical and disability assistance.
2. Pensioners and concession card holders.
3. Households with low incomes, a single income, or a single parent.
4. Wealthy people with additional security requirements for person and property.
5. Households living in particular types of premises, including free standing houses, and units, flats and apartments.
6. Households that include the owner of the property - variously as head-of-family and as landlord - tenants / renters / lessees, and boarders / sub-lessees.

6.2.2 Classification based on Ability to Modify Usage

A scenario analysis is done to identify the consumer's ability to modify energy usage. This section analyses how different consumer segments will respond to the TOU signal on a winter day and the issues they will face. In Victoria, Australia for TOU tariff, the higher rates (shoulder + peak) are from 7am to 10 pm with peak-rates at 3pm – 9pm [DEDJTR, 2015a]. In Ontario, Canada for TOU Tariff, the higher rates are from 7 am to 7 pm, with summer peak-rates at (11am to 5pm) and winter peak rates at (7 am to 11 am and 5 pm to 7 pm) [OEB, 2016]. The analysis assumes that electricity is used for all purposes, which are primarily heating, cooking and cleaning. The common case and specific cases are detailed as follows.

1. **Common case**
   Most residential consumers are active between 7 am and 10 pm. So they have some unavoidable energy needs during that period of the day. In general, spatial heating or cooling will be required from 5pm – 7 am depending on the weather.
2. **Specific Cases**

   - A single working professional is out of their dwelling during work hours. They can also avoid cooking by eating out. They can also choose to be away from home during the peak demand periods. Their usage can then be limited to night/resting time.
   - Families with children fall into two segments:

     (a) Working parents with school-going children can avoid consumption during work-hours, but after and before work-hours they have unavoidable energy requirements for cooking, cleaning, etc. It is not easy to avoid those activities or the peak period.

     (b) Stay-at-home parents with young children can organize some high energy consumption activities during off-peak time, e.g. cooking and washing, but they cannot avoid heating the dwelling, and if it is not energy efficient their heating requirements will be higher. They can possibly go out during the day to reduce energy usage, but it is not easy to make it a daily activity.

Table 4: Users Types based on Flexibility with power Usage

Flexible Consumers		
This category of users can follow the demand signals issued by the utility. This includes mostly single, working, less stay at home consumers.		
Non-flexible Consumers		
Low usage but can't avoid peak period - This category of consumer has low energy consumption but they cannot avoid the peak period. This includes working families with dependent kids.	**Low and Medium usage with constant usage throughout the day** - This category of user includes stay-home parents with young children, and pensioners. They may be able to shift some or most of their high energy needs to off-peak or shoulder periods.	**High usage** – They have high energy requirements due to various reasons. The high usage consumers are discussed in the next row.
High usage – Non Flexible consumers		
Due to unavoidable medical conditions e.g. having life support machines, some consumers need to run various devices and hence have less control over demand. They will need it to be functioning 24x7.	**Due to work from home/ home based business** - These consumers need energy supply for running their business without any hindrance during the business hours and hence cannot follow the demand signals. Some users may only have medium energy requirement for their business.	**Due to high profile lifestyle supported by very high income** - These consumers have very high energy needs to match their standard of living. They may have an expensive security system operating continuously, lighting systems and many other devices.

- Pensioners and people with medical needs face a situation very similar to Stay-at-home parents, but as they may have mobility issues and medical conditions that prevent them from leaving out, they will have energy needs throughout the day. Moreover they may also have life-supporting machines that will draw even more electricity.
- Work-from-home professionals work and live in the same premises, and hence have energy needs throughout the day. Their energy needs will be high throughout their work-hours.

From the above analysis it is evident that very few consumer-segments can adapt their energy needs to reflect the TOU pricing periods. Hence Consumer segmentation based on users' capability to modify usage is as shown in Table 4.

6.2.3 Classification based on Technological Acceptance

Consumers' reactions to smart meters vary from extreme resistance to high acceptance. There are consumers who see a smart meter as a device that causes serious health effects and are also technology enthusiasts who would like to use every possible feature provided by it to manage their power consumption. Some people don't mind detailed meter reading but don't want the smart meter to manipulate or control their appliances. Classifications based on these characteristics are as shown in Table 5.

Table 5: Users Types based on technological acceptance

User Characteristics		User Reaction
Type 1	They have strong resistance to communicating devices in their premises. In most cases, they will also strongly object to the escape of personal data from their premises.	High resistance
Type 2	They don't mind having a communicating device installed but don't trust the meter functionality and they don't want any support and prefer to manage energy personally.	Low resistance
Type 3	They don't mind having a smart meter, but they want a very basic setting programmed into it, and do not want to make changes, preferably ever.	Neutral
Type 4	They would like to receive alerts and information through a smart meter but would personally make the changes.	Low acceptance
Type 5	Technology enthusiast and energy conscious user. They want to take maximum advantage of the functionalities provided, including programming the meter to switch particular appliances off during peak periods.	High acceptance

6.2.4 Classification based on ability to Comprehend Information

Consumers' ability to comprehend information is useful in identifying the kind of feedback that will be helpful for them to make intelligent choices in their day to day activity. Current feedbacks like IHD provide real-time consumption value and price signals. This information is not sufficient for all types of consumers to identify what actions should be taken. There are also consumers who don't wish to spend time tweaking their devices as a price signal is received. In this section the consumers are classified based on their ability to comprehend information. The best case is the highly knowledgeable user and the worst case is the disinterested user. Classification these characteristics are as shown in Table 6.

Table 6: Users Types based on ability to comprehend information

User Characteristics	
Highly Responsive	They require only limited information to make decisions. Price signals will be sufficient for this group. They will also have knowledge of measures by which they can supplement their energy uses in times of peak period.
Moderately Responsive	They have an understanding of the electrical and electronic devices and its power rating. But they are not sure about the consolidated effect of activities being carried out or the best way to supplement their energy activities. So they will benefit from reminders and triggers for - excess usage during peak period, how to make best use of their supplementary energy sources.
Novice	These consumers have no idea how and what to decide. They don't know the power rating and category of devices and equipment at home. For these consumers, they require hints on the devices to be turned off when a price signal is received. They also require settings to alert them if there is a change in their desired pattern of usage.
Stimulated by economic benefits	These users are more interested in the economic part (they want their usage to remain within a particular bill amount for the billing cycle). Such consumers need information on the bill amount that is getting accumulated on a day to day basis. They also need information on the quantum of energy that can be used per day so that their target bill is achieved.
Disinterested	These consumers don't wish to spend time tweaking their devices and will not welcome or respond to any kind of feedback.

6.3 Conduct Consumer-Focused Risk Analysis

The field of risk assessment suffers from an excess of frameworks and a great deal of terminological ambiguity. The risk evaluation framework proposed in this section reflects the substantial accumulated literature on risk assessment, and is sculpted to the needs of smart grid projects. In this thesis it will be applied to the existing smart metering systems to identify the risk, the system pose to the consumer. It can also be applied to other categories of project within the smart grid arena.

The framework mainly adopts the theme of ISO 31000 – Risk Management to which certain elements from NIST SP 800-30 and BSI 100-3 are applied [AS/NZS, 2009; BSI, 2008a,b; Stoneburner et al., 2002]. The proposed framework has a set of optimal steps that can be used to identify, evaluate and control risk to mitigate potential negative effects in Smart Grid. Figure 3 provides a visual presentation of the framework (refer Appendix A.10.1 for definition of the terms and steps in the framework). Risk Characterisation is a vital step in this framework for risk analysis. The results from this step will vary based on the perspective of analysis. Many times risk factors that have been assessed as minor by technical experts had elicited strong public concerns. For example, an unauthorised party gaining access to the meter data may occur as a minor risk to a utility provider if the access is read-only but from the perspective of the consumer it is still a major risk as it is an invasion to their privacy. So in this step, the perspective of analysis is vital. The severity levels changes based on the perspective of analysis. CORAS can be used along with this framework to visually represent the risk in a scenario. This model-based approach, improves communication and interaction between parties involved in the analysis. It will help in easily identifying the missing links and errors [Lund et al., 2011].

Risk from a consumer's perceptive is demonstrated in this section. The first step is to identify the target of evaluation and stakeholders involved. In this analysis, a residential premise is the target of evaluation and the residential consumer is the stakeholder and the focus is on the smart meter. Then the next step is to identify assets. These identified assets are further classified as direct and indirect assets. For the consumer, the direct assets involved with a smart meter are the hardware, firmware, and the information stored. Some of the indirect assets are the availability of electricity; integrity of billing and other functionalities; confidentiality of personal information and safety of human and non-human elements involved. The assets are then further classified as physical, functional and informational. The physical assets comprise of the meter hardware and communication module. The functional assets entail measuring, conversion, communication and supply-switching functions.

The informational assets consist of measurement, configuration, monitoring and consumer's personal information data. Identifying threats, vulnerabilities and harms form the next step. If the meter hardware is considered, there have been few reports that power surges have caused the smart meters to overheat and start a fire (EMF Safety Network 2012). The power surge is a non-human threat. The vulnerabilities are poor quality components and improper assembly of the meter. Overheating of the meter is the unwanted incident and fire is the harm caused by the threat. Then the multiple perceptive of analysis can be applied to the scenario. For a service provider, as there were only a few incidents reported, the risk value will be low. But from a consumer perspective, it is very high as there is always a chance of fire that could damage their property and even cause death.

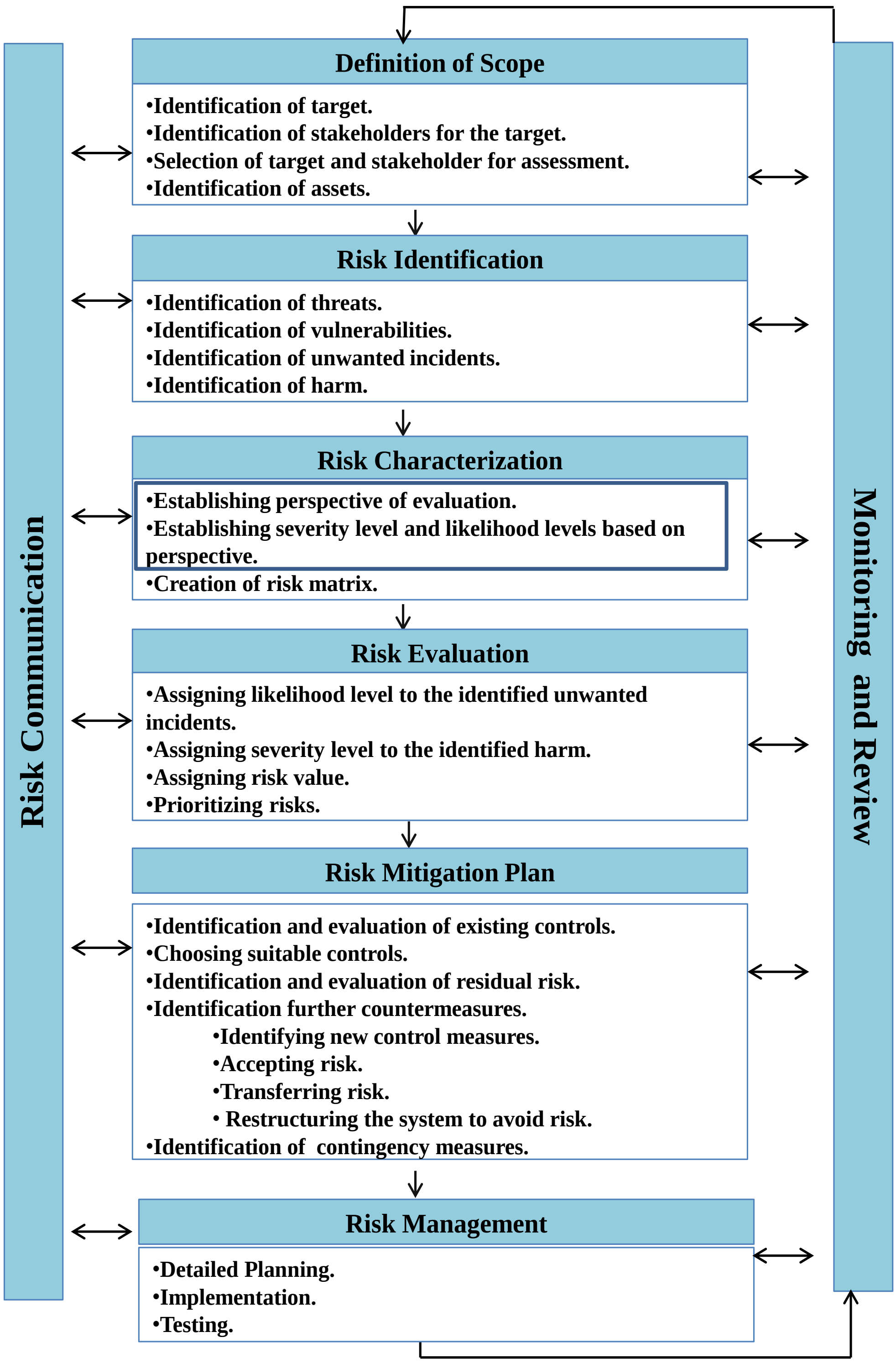

Figure 3: Risk Analysis framework and its steps

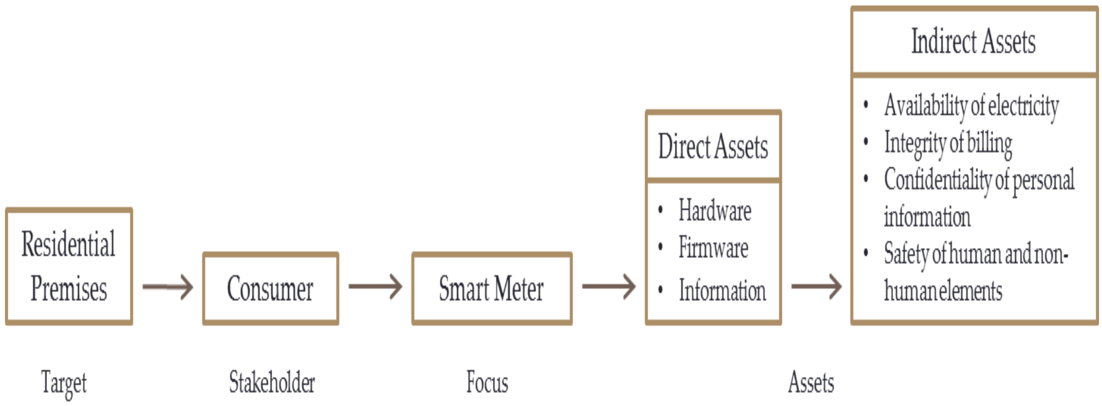

Figure 4: Choosing Focus of Analysis

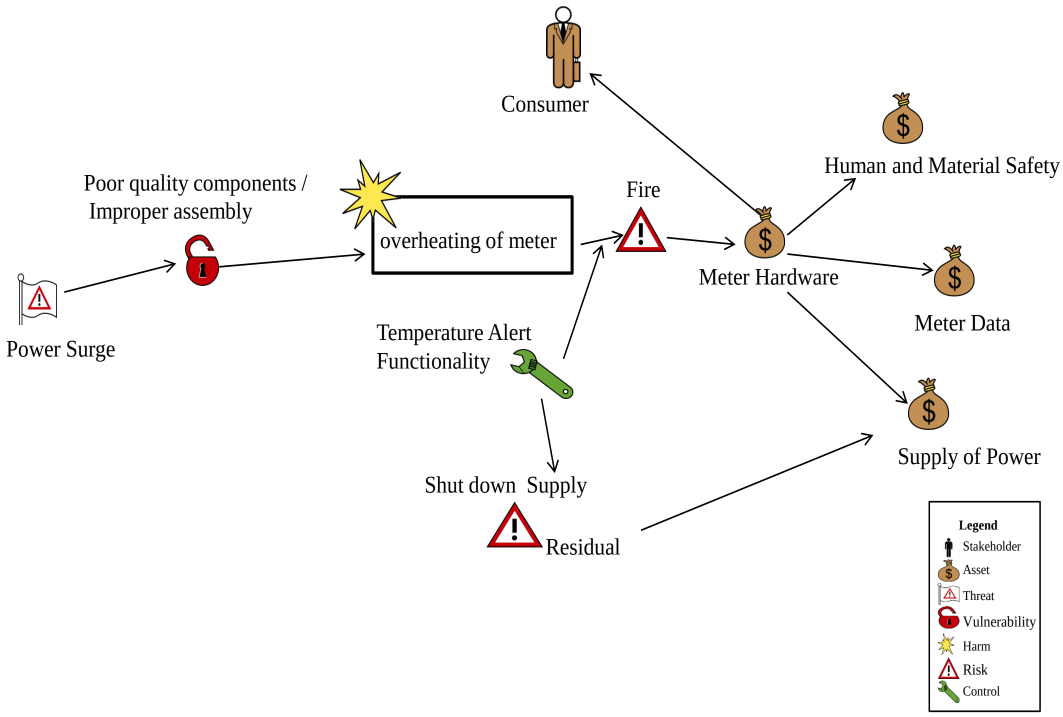

Figure 5: Scenario analysis of fire risk

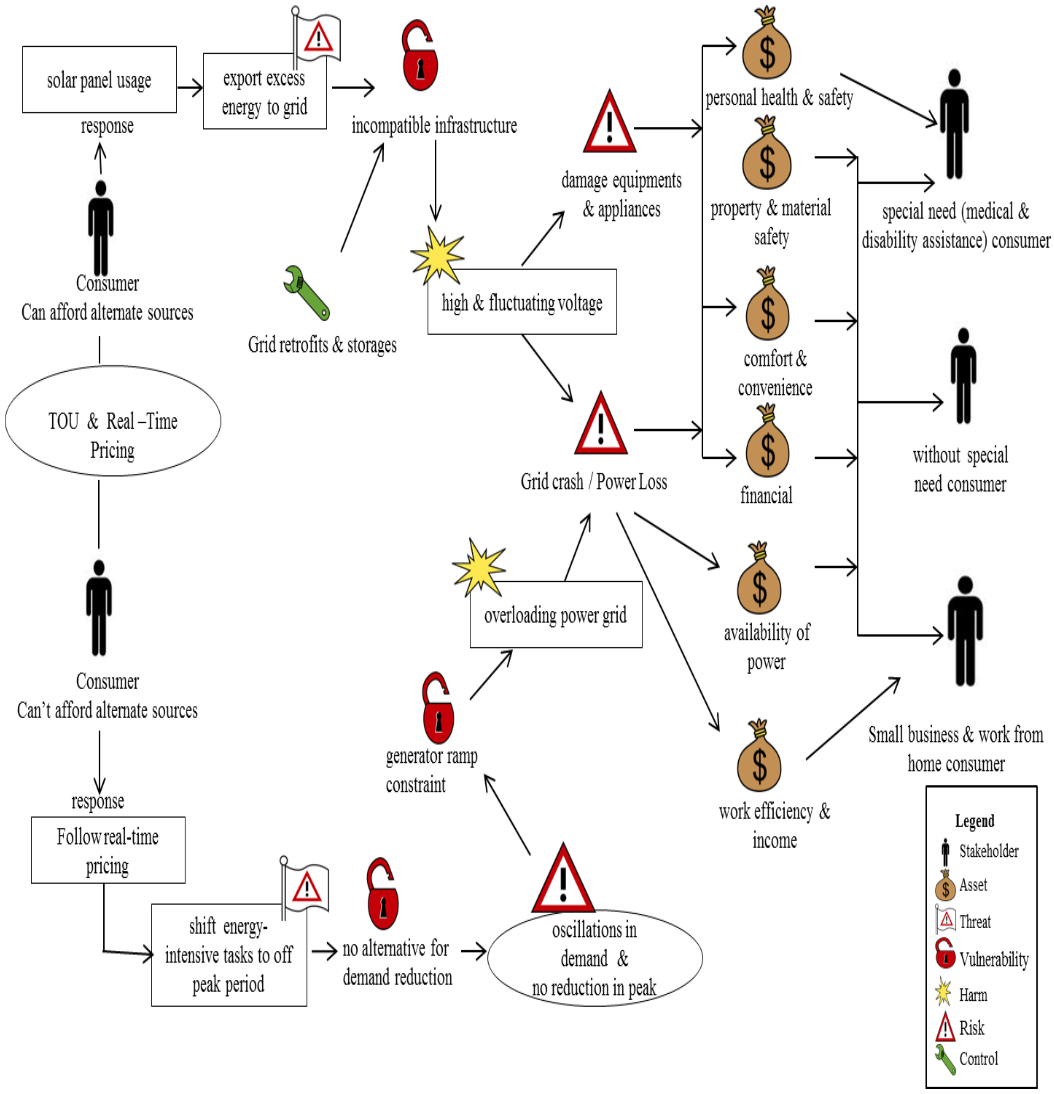

Figure 6: Effects on different consumer groups

As a control measure to overheating, some smart meters have temperature alert functionality. When the temperature rises above a set threshold, it shuts down the supply and alerts the utility management to take further actions. For a service provider, this control is sufficient as it prevents a fire and there is no harm to their reputation. But from the perspective of a consumer, there is still a residual risk. It provides safety by preventing the fire, but the power supply is disrupted. If it is a consumer on a life-support machine, it could even cause death. This scenario clearly shows how the perspective of analysis changes the requirements in control measures for each stakeholder. Diagrammatic representations of some of the elements of the scenario are shown in the following figures (Figure 4 and Figure 5)An adaptation of CORAS is used for the visual representation of the scenario.

The perception of risk is dependent on consumer expectations, preferences, and ability to tolerate the risk. Different consumers have different expectations for the same situation. For instance, if an event creates a loss, there is a possibility that one consumer is able to tolerate it whereas another is not. A further relevant factor is the opportunities that the consumer has available to them when they are contemplating taking a risk [Asnar and Zannone, 2008; Baumeister, 2010]. Figure 6 demonstrates another scenario and the effects on different consumer groups. Parallel developments are also factored into this analysis as smart meter are advertised as key enablers of these features. Of particular significance is distributed power generation through domestic solar panel installations, and the sale of surplus power into the grid.

In many places, smart meters are required for exporting energy into the grid because it is capable of recording both import and export values. Legacy architectures are designed for electrical flows from central power stations to appliances. In areas with a high concentration of solar cells, voltage levels may become unstable. This can have negative consequences for consumers' equipment. It can also trigger shut-downs. Some of the measures suggested are battery storage and retrofits to present infrastructure, but these require further investment from the consumer. Smart meters are also promoted as demand management tools. Another concern is that real-time pricing could overload the power grid. If enough consumer power usage does become highly responsive to real-time price changes, it is quite feasible that rapid swings in demand could represent a serious threat to the reliability of supply. These two scenarios have represented how smart meters can, directly and indirectly, affect the consumer.

6.4 Conduct Consumer-Focused Requirement Elicitation

This section details how a consumer focused requirement elicitation can be accomplished. In literature review, the eight attributes of a project that needs to be considered when planning were discussed. Using this information, the attributes of smart metering system projects are defined and presented in Table 7.

Table 7: System attributes for Smart Metering Project

Project attributes	**Smart Metering System project Attributes**
Project Size	These projects are very large and involve multiple stakeholders.
Project Complexity	The complexity of the project is very high as it involves various elements and communication networks. It also interfaces different entities n the power grid.
Requirements Volatility	The requirements of the system are not very volatile, although the functionality requirements for each stake holder may vary.
Degree of Safety/ Security Criticality	The security and safety requirements are high for the system as attacks could lead to catastrophic blackouts and power thefts.

Time Constraints	The time constraint is medium as most of these projects have1 to years planning phase followed by 3 to 5 year roll-out phase.
Cost Constraints	The cost constraint is high as the infrastructure is expensive and multiple elements and entities are involved.
Acquaintance with Domain	The modernisation projects are fairly new in the power grid, so even the experts in the industry may not all the necessary knowledge.
Reusability	There will be medium reusability as the requirements for the smart metering system may vary based on geographical conditions, demographics and other factors.

Based on project attributes of smart metering systems and an analysis of various requirement engineering techniques (refer Appendix A.10) the following techniques (presented in Table 8)were found suitable for smart metering projects.

Table 8: Proposed RE Techniques for Smart Metering Project

Categories	**Recommended Techniques**	**Justification**
Elicitation - Business Goals	Interview, Brain storming, Documentation studies, Content analysis	high stakeholder heterogeneity, to identify business goals from investing stakeholders
Elicitation - Stakeholder (primary)	Focus Group, Contextual Inquiry, Documentation studies, Content analysis	high stakeholder heterogeneity, clearly identify how different user segments react to each listed business requirement
Elicitation - Stakeholder (secondary)	Passive Storyboards, Repertory Grid, Requirement reuse	high stakeholder heterogeneity, domain knowledge
Analysis and Negotiation	Scenario-Based Analysis, CORAS for risk identification	These techniques are detailed and useful to analyse the faults
Specification and Documentation	UML, State Machine Notation	Visual representations make is easy to analyse
Verification and Validation	Formal Inspection	System with large data, effective than testing.

Contextual inquiry is a suitable elicitation method for identifying how residential energy consumers may respond to features in a smart meter. The next section details how contextual inquiry can be used to identify residential consumer energy behaviours.

6.4.1 Contextual Inquiry on Residential Consumer

Applying contextual inquiry is helpful in identifying how consumers will behave in a scenario. But it requires a balance between interviewing and ethnographic observation. Sessions should be very flexible rather than predictable. The user should perform the tasks naturally without being prompted. The user should be interviewed in a semi-structured way. The participants can be briefed about the focus of interest and they should be observed as they perform a task and they can be questioned while they work in their own environments [Beyer and Holtzblatt, 1997b].

To perform a contextual inquiry, an easy to follow template is required. This section provides one such template that can be used on one of consumer segments identified earlier. Table 9 provides one such template that can be used on one of consumer segments identified earlier. Following this pattern a template (Table 10) is created to carry out contextual inquiry on consumers with medical needs. Information gathered from such sessions will provide insight into how a household with medical needs will carry out its energy consuming activities in the presence of a smart meter. This enables the analyst to visualise the extent to which alternative design choices would enable them to make smart energy choices.

The selection of appropriate participants in the contextual inquiry may be challenging. The key to a contextual inquiry is that participants need to educate the analyst about their tasks. Participants may wait to be prompted to perform a task and may even not provide all information for their choice of actions. Focus groups can be used to support the contextual inquiry method. Initially, focus groups discussions can be conducted to explore people's knowledge and views through open-ended questions [Gotel and Finkelstein, 1994]. This will also provide more information on the collective needs of a particular user segment. User representatives can also participate to give more information. From the responses and willingness of the participants to perform detailed tasks, ideal candidates can be chosen for the contextual inquiry sessions.

Though the use of Contextual Inquiry is recommended for eliciting the residential consumer it cannot be demonstrated in this research due to the unavailability of experimental setup and participants. As this research is limited to desktop research the next suitable methods are documentation studies and content analysis.

Table 9: List of Questions to extract working context, assumptions, and fears

Is a smart meter installed or planned to be installed in the place of dwelling?
Are there changes / expected changes to normal activities / electricity usage after installation? a) If TOU is introduced, how will the activities change during peak, off-peak and shoulder period?
Are there changes happening/ expected to happen to normal activities / electricity usage after installation?
Do they have any energy efficiency goals? a) What alternative sources of energy supply have been considered /invested on? b) How do they expect smart meter to help them with efficiency?
Are they aware of the media speculation on smart meters? a) How has it affected their approach to smart meter?
If a smart meter is already installed, a) Are there notable changes to electricity bills? b) Are there any health issues that have newly emerged? c) Have there been any issues with privacy and security?

Table 10: Sample of contextual inquiry interview template for disabled consumer

Participant Chosen
Households with medical assistance – on life support system and no solar panels
Information gathered before the inquiry
1. What are the energy requirements for the life support system? 2. Are there generators or batteries to operate the system in case of power outage? 3. How many hours can the alternative source last?
Descriptions provided to the participant prior to the task
The household will be provided with information on the smart meter and what conditions they will be tested on. e.g. **Information on smart meter:** They are informed that their energy usage is recorded at an interval selected by the utility and that this information will be used for TOU billing. They are provided with an in-house display to get information on the start of each rate period. **Conditions of testing:** There will be peak period and off-peak period announced. There will be a short power outage and long power outage. The participant will have to perform the work without any assistance or additional information provided by the interviewer. The interviewer can ask the participant reasons for the choice of their actions.

Record information on the task and responses - Work based Interview, Post-Observation Inquiry & Artifact walkthrough
1. Did the participant: a) Take notice of the peak period announced? b) Did they reduce any energy usage during the peak period? c) If the household had an inverter, did they try to run the life-support on the battery and later recharge during off-peak period? d) How did the household react to the power outages – both short outages and long outages? e) On power down did their inverter automatically start supporting the life support system or should it be manually started. After usage does the inverter automatically start the recharge or should it be manually recharged? f) Are there other social–economic factors affecting the choices. E.g. Are the participants having educational background to understand the need in participating in energy efficiency? Are they on systems where the government or other organisations partly or completely pay their electricity bills?
With participants who are unfamiliar about these tasks, it would be better to perform the tasks few times to check if familiarity improved the response.
2. During the performance of these tasks, information should be provided on renewable energy sources that could supplement their energy needs. Record their response on a) Willingness to accept alternative sources to reduce electricity bills. b) Factors that hinder the acceptance.

The template generated in this section is not further used in this thesis due to the lack of availability of setup and participants. However, this template will be useful for industry practitioners and researchers who plan to conduct end-user studies. In this thesis the residential consumer requirements have been synthesised using techniques like documentation studies and content analysis and it is further discussed in section 7.8.

6.5 Summary

This chapter is the first step towards identifying a consumer-friendly solution for the smart metering systems. For that the consumer concerns have been classified and then categorised into real and perceived risks. To address these concerns four steps have been presented. First the consumers have been segmented into various sections based on energy requirements, ability to modify usage, willingness to accept new technologies and ability to comprehend information. Then procedures to follow a consumer focused risk analysis and requirement elicitation has been detailed. A risk analysis framework that has been developed as part of this research has been applied to discuss scenarios that affect consumer. Similarly using contextual inquiry, a suitable requirement elicitation technique, templates have been created to extract consumer requirements.

This information is applied in the next chapter to propose consumer friendly design for smart metering system.

In this chapter it may be noted that first the consumers have been segmented, followed by risk analysis and then suitable requirement elicitation techniques have been discussed. This order has been followed as the analysis is starting from a problem situation. In real scenarios, for new project, the stakeholder and users need to be identified and then suitable requirement elicitation methods should be identified and applied. Based on the requirements elicited, the users should be further classified and segmented. Then risk analysis should be conducted for the identified user groups.

Chapter 7

Consumer-Friendly Design

This chapter details the solution to the identified problem scenario. In DSR methodology, this step is characterised as designing artifacts. This chapter present conceptual models for a consumer-friendly smart metering system. Based on those models consumer-friendly features and functions are also identified and discussed.

This chapter starts with the inspection of a smart meter and its elements. Then data that is generated, transmitted and stored are analysed. Using this information an abstract architecture for a consumer-friendly smart metering system is presented. Through an abstract data flow model, the security and privacy requirements for the smart meter data are detailed. Then measures for minimising consumer concerns on smart meter data have been proposed. Next, consumer-friendly features that can be enabled in smart metering system have been identified and detailed.

7.1 System Models and Definitions

On analysing various articles on smart meters and AMI, generic models on smart meters and its related elements were not found. Reference models of the smart metering system and data classification are required for further analysis. Hence, in this chapter generalised conceptual models are developed and discussed based on analysing few smart meters and AMI that are currently deployed. These models will be useful in identifying the control measures and features required.

7.2 Smart Meter Model

Initially, a block diagram of a smart meter is created (Figure 7) and this will be used for further discussions. In the remote data collection process, data from the smart meter is first collected by a collector/data concentrator. Data of all meters allocated to a concentrator are collectively sent to the service provider's data storage. At the consumer site, data can also be extracted from the meter into the meter-reading technician's hand-held device using an optical probe connected to the meter's infrared port. If a meter reading device is not present, the utility technician can also read the usage data from the meter display as done with traditional meters. If the consumer needs to make use of the real-time interval data, a feed-back mechanism is necessary.

Though IHD has been promoted as part of the smart metering system, it has not yet been made compulsory. If the IHD is present, it can be configured to display usage data, load profile data and pricing signals. IHD can be connected through the HAN interface. If the IHD is not present, the utility can still communicate the pricing signals using Short Message Service (SMS), email or other communication channels. This limits the information provided to the consumer to the TOU or real-time pricing signals that are declared by the utility. Pricing information alone will not help consumers make better demand choices and hence a proper feedback mechanism is required. Hence in a consumer-friendly smart metering system, a good feedback mechanism should become an integral part.

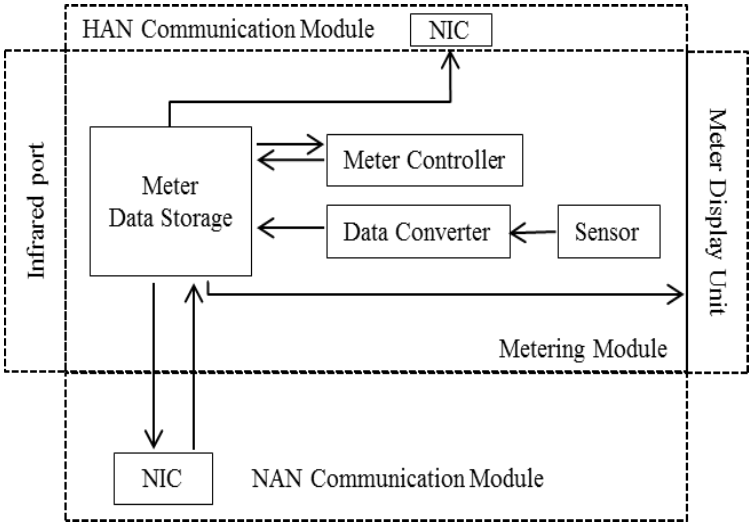

Figure 7: Block Diagram of a Smart Meter

Some service providers also have an online energy management system. It mainly displays the usage data that is stored in the provider's back-end. It will also have historical data that has been erased or rolled-over in the meter. The consumers can log on the system to view their energy data stored with the utility. For a consumer-friendly setup, these online energy management systems should advance to the stage where a consumer can modify their energy profile and meter settings.

7.3 Smart Meter Data

The meter can be programmed to record various power usage related data. The smart meter has a configuration/profile based on which it functions. This configuration is stored as meter profile data. Data stored also includes consumption data at aggregated and interval level and Quality of Supply (QoS) data. This data can be made available to the consumer and utility through various communication options. The display unit will cyclically display the items configured into the meter program. For local meter reads, smart meters are connected using the optical probe to a hand-held meter-reading device. With that device, the meter technician will be able to read the data from the meter. They will also be able to change the configuration in the meter using the same device. The meter data can be remotely read using the attached communication modules.

The utility communicates to the meter using the NAN communication module. The meter can be programmed to continuously transmit the data or to transmit when a command is received. This data then gets stored at the service provider's back-end. The meter data is also communicated to the consumer using tools like IHD and it uses the HAN communication module. These display units only show the data in real-time. Some models of IHDs have storage capabilities.

The smart meter data can be differentiated as stored and transmitted data. The meter should have security features to prevent unauthorised access and modification of data stored in the meter. The smart meter data leaves the meter mainly through three communication channels: Infrared /optical port, HAN and NAN. This classification will help in identification of security goals separately for data with-in the meter and for data in transmission.

7.3.1 Smart Meter Data stored within the Meter

Based on information obtained from analysing smart meters (mainly Landis+Gyr meters) and the data they store, a classification has been defined. The data stored in the meter can be classified into six categories based on their functionalities. It is as shown in Table 11.

Table 11: Categories of data stored in the Smart Meter

Meter Data Type	**Data Functionality**
Meter Profile Data	This data contains settings that determine how the meter operates. Many smart meters have a LCR and they can be made to operate differently from the main load by settings in the meter profile. Settings can also be provided to override operations and commands from the service provider.
Display Data	It includes data that be programmed to be displayed on the meter's display unit and in other devices like IHD.
Command Data	This data includes command and control operations received from the electric utility. This data along with meter profile settings control meter operations.
Accumulated Data	It includes accumulated consumption data which is not required frequently and in most cases, needs to be only sent when requested by the electric utility. E.g. billing operations.
Interval Data	It includes LP data that is recorded at frequent intervals. This information is used for DR and related operations.

7.3.2 Smart Meter Data in Transmission

The smart meter data gets transmitted to the electric utility's back-end via the collector using the NAN and Wide Area Network (WAN). A categorisation has also been identified for the smart meter data during transmission. This data has been classified into three based on their functionality as shown in Table 12. This classification will be used in the later section for identifying security and privacy goals.

Table 12: Categories of data transmitted from Smart Meter

Meter Data Type	Data Functionality
Billing operations data	This data is transferred to utility for billing calculations.
Grid intelligence data	This data involves alerts on power outages, power thefts leakages and variations in QoS.
DR operation data	For the DR operations the LP data is used. In a consumer-friendly system it should be transmitted to the electric utility only with consents from the consumer.

7.4 Security Requirements for the Smart Meter Data

In section 5.3.1, the challenges arising due to the introduction of smart meters were discussed. It was identified that the to and fro data flow in the smart metering system gives rise to new security threats. Hence, intentional or accidental introduction of wrong information in the system could be disastrous. Based on the context, the security requirements of the smart meter data vary. This section separately looks at the security needs for the meter data when it is stored within the meter and during transmission.

7.4.1 Security Needs for Stored Data

The security needs for profile data, display data, command data, accumulated data and interval data will be discussed separately.

(I) **Meter Profile Data**

The meter profile data decides the values to be recorded, displayed and transmitted. Smart meter requires features to ensure the integrity, authenticity and confidentiality of the profile data is assured.

(1) The meter profile data should be programmed into meter only by the electric utility provider personnel (with authorised access).
(2) Reading the program out of the meter should have access control measures. Authorisation procedures should be followed.
(3) Each time the meter-profile is read an event should be created which will be recorded in the meter log with a time stamp.
(4) Meter programming should require higher levels of access as it involves modification of data in the meter.

(5) Verification measures should be included in the meter to validate and accept a change of meter program.
(6) Every time the meter is reprogrammed an alert-event should be created and if the meter has remote communication with the utility, this event should be communicated to the authority in real-time.
(7) As a meter profile can be programmed locally and remotely there should be separate measures to differentiate both the process.
(8) Provisions should be made for consumers to obtain the meter profile from the electric utility. The utility can provide a copy of the files from local reads or it can be provided through other energy management tools. Verification measures should be included to ensure the profile data is provided only to the authorised entity.

(II) **Display Data**
Display data includes the data that will be seen on the meter display and the data that will be displyed via IHD. The data to be displayed on the meter display unit and IHD can be separately configured using the meter profile. For free-standing property or where the access is easy to the meter, this display can provide usage information to the consumer. For consumers who have no IHD, this display data is helpful to get real-time usage details. This information may also be used by meter technicians to record usage locally. The data from the meter's display unit can affect billing and demand choices of the consumer and hence it is very important to maintain the integrity and authenticity of this data.

(1) The meter should have measures to prevent modification of display data from an external source.
(2) To erase the display data there should be access control measures. This access control is provided only in case the meter has to be completely reprogrammed and made to start as a fresh meter.
(3) Verification measures should be introduced to ensure that the actual consumption tallies with display data.
(4) Verification measures should be introduced to identify display unit tampering. This shall ensure that the data displayed is as stored in the meter database and not from an external source.
(5) Verification measures should be introduced to ensure that the display list match with the list in the meter program.
(6) Access control measures should be introduced to create different meter program with a new display list and use it to reprogram the meter.

(III) **Command Data**
The data holds critical information that will decide the meter behaviour. The control commands can connect/disconnect the SBR and LCR which will in turn will affect the supply of electricity. The control data can be sent to the meter locally or remotely. Authenticity of this information is important as this data can modify meter operations.

(1) Verification measures should be introduced in the meter to check the authenticity of the commands received before storing this data in the meter.
(2) The meter should verify the settings on meter program to identify if the command has to be accepted or rejected.
(3) Order of operation should be introduced and this information should be present in the meter profile, so if a meter receives more than one command, the order will decide on which command has to be executed first.

(IV) **Accumulated Data**
This data is mainly used for billing and related purposes. The main purpose of a metering device is to measure the usage and generate bills. It involves many conversion and calculations. Cases have been reported where consumers were over-billing due to the error in meter data, and users had modified their consumption data with the help of utility employees. In one case the use suffers monetary loss and in the other, the service provider loses its revenue. The accuracy and integrity of this data is necessary for both stakeholders.

(1) The meter should have measures to prevent modification of conversions factors and other in-built data used for energy calculations. Modification of this value will result in either low or high value for usage data.
(2) The meter should have measures to prevent modification of accumulation data from an external source.
(3) To erase the accumulation data there should be access control measures. This access control is provided only in case the meter has to be completely reprogrammed and made to start as a fresh meter.
(4) Reading the accumulation data from the meter should have access control measures and should follow authorisation procedures.

(V) **Detailed Interval Data**
The detailed interval data is also known as Load Profile (LP) or interval data. It can be used to provide consumer feedback on their energy usage. This data can affect the privacy of the consumer and hence this security measure this data should be given careful considerations. The accuracy and integrity of this data is necessary as it can affect the demand choices of the user.

(1) The consumer should be provided with the choice to decide on the frequency in which interval data is recorded in the meter. They can choose from lower intervals like 10 min/15 mins or higher intervals like 1/2hrs. They shall also be provided with an option to have no interval data. In that case, the meter will only generate billing data, alerts and events.
(2) The meter should have measures to prevent modification of conversions factors and other in-built data used for generating interval data.
(3) There should be options to erase interval data recorded. The consumer should be provided with the choice to decide on it.
(4) The interval data will wrap over after all the allocated register locations are used up. The meter should have verification measures to ensure wrap-around

happens without any data corruption.

(5) As the interval data can profile the consumer, measures should be added to let the consumer decide on sharing this data. This data can be viewed by other entities only on the permission of the consumer with an exception that law enforcing authorities can access it if situations arise.

In this section, the security goals of data stored in the meter has been identified. In the next section the security and privacy goals of data transmitted will be identified.

7.4.2 Security Needs for Data during Transmission

The data transmitted from the smart meter was classified based on their functionality (billing operation, grid intelligence and demand response operations). Each type is discussed in the following sub-sections.

(I) **Billing Operations Data**
As electricity is a service that needs to be paid for, the utility provider needs details of consumption to charge the consumer.

(1) As billing is a functionality that cannot be avoided, this data needs to be collected by the service provider. The electric utility can access this data either through local or remote reads. If a communicating device is not working in the premises of the consumer or if consumer chooses not to have a communicating device in their meter, the meter has to be read locally. In such cases, a meter technician will read the meter manually, and this may incur additional service charges. This option ensures the availability of the information to the service provider without significantly disadvantaging the consumer.

(2) The smart metering system should have security features to prevent interception and modification during transmission. (case of remote read)

(3) The smart metering system shall have security features to identify the integrity of the data reaching the electric utility's back-end. (case of remote read)

(4) The hand held device that is usually used for local reads should have security features to ensure that the data extracted to the device is same as the data stored.

(II) **Grid Intelligence Data**
Such data is limited in its sensitivity, and disclosures occur with direct benefits to the consumer. Alerts are also required for revenue protection operations; hence the utility should also be given control on setting and transmitting alerts like theft, tamper and outage detection.

(1) For meters without transmitting device, the alerts and events should be logged in the meter and this can be read out when the meter technician does a the billing read. (only possible in the case of high-end digital meter (interval meters) and not analog meters)

(2) For meters that have transmitting devices, meter program should ensure all the necessary alerts and event are set for transmission in real-time.
(3) The meter should have options to prevent change of alert setting in the meter.
(4) The smart metering system should have features to only let genuine sources send alert signals through its communication channel.

(III) **DR Operation Data**
DR operation data involves LP data and it is mainly consumers who could benefit from LP data. DR operations can rely on aggregated data for majority of their operations and in cases where fine-grained data is required, it is sufficient to have it anonymised.

(1) The smart metering system should have security features to prevent interception and modification during transmission.
(2) The current smart metering system does not anonymise the LP data before sending it to the service provider. The LP data that leaves the consumer premises should undergo anonymisation.
(3) Aggregation of data at a higher level will further strengthen privacy measures. Each collector/concentrator will have a set number of meters connected to it. The system should have measures by which the concentrator will be able to identify the anonymised data from all connected meters and aggregate them at the concentrator level. This aggregated data should then be securely transferred to the service provider's head-end.

This section identified security and privacy needs of the smart metering data by analysing all possible scenarios in which smart meter data can be stored and transmitted. The next section will discuss the consumer-friendly options.

7.5 Proposed Consumer-Friendly Models

In analysing the problem situation in Sections (5.3 and 5.4), it was noticed that a major concern about smart metering system arises from its data. In the consumer-friendly models proposed in this section, efforts have been made to reduce this concern by minimising system dependency on consumer's LP data. Control and choice options have also been introduced to improve consumer acceptance.

1. Transmission Options for Operations Data

Among the data that is transmitted from meter, grid intelligence data is limited in its sensitivity, and disclosures occur with direct benefits to the consumer. Hence proposals are made for the other two data categories. Table 13 provides a discussion of the nature and purpose of billing and DR operations data and design features that address consumer concerns.

Table 13: Options to reduce data transmission frequency

	Billing Operation	**Demand Response operation**
Purpose	Electricity is a service that needs to be paid for and hence the utility provider needs details of consumption to charge the consumer.	This data is required for identifying the rise and fall in demand in a locality and for applying certain DR programs.
Data Frequency	i) Less frequent and cyclic ii) Intervals: Monthly/Quarterly/etc.	i) More frequent intervals ii) Intervals: 15 mins/30 mins/1 hr/etc.
Effects on Consumer	Because of the low level of granularity, this data represents a very limited privacy threat, and has long been accepted as being a necessary element of the service.	This data is required frequently with or without a request. The transmission frequency can be programmed in the meter and back-end. This data could breach the security and privacy of the consumer.
Data Requirement	As this data has no other purpose apart from billing, it is only required on request from electric utility. Service provider can send a request to fetch the billing data as per the billing cycle chosen.	Demand response data can be sent at intervals that are programmed at the meter or when triggered by requests sent from utility.
Options to reduce consumer concern		
Permission Control	i) Consumers exhibit limited concern about permission controls for this data. Billing data is the only method by which the consumption can be calculated and hence needs to be performed without any hindrance. ii) Consumers can be given the choice of billing intervals with a limit of one setting per cycle.	i) Consumer should be provided with choices on frequency of data storage, transmission and permissions on control signals to modify the energy usage. ii) There should also be options to disable transmission permanently or temporarily.

Storage settings	The data stored should be read-only. The data should be protected from unauthorised deletion and modification. This data should be available for billing verification in case of disputes	The data should be stored as per the meter profile configurations. The data should be protected from unauthorised deletion and modification. This data should be available to other organisations only under strict controls. In particular, access for law enforcement purposes requires reasonable grounds for suspicion of relevance to the investigation of a criminal offence and demonstrated legal authority.
Transmission settings	Billing should be calculated in the meter based on the TOU tariff declared. This eliminates the need to send detailed data for billing purpose. The data that is required can be reduced to: a) Final/Present Meter Reading. b) Details of consumption accumulated under each period e.g. peak, off-peak and shoulder. This can be used to verify the bill calculation. c) Bill amount.	End user details are not required for DR operations, hence this data transmitted should be anonymous (when data leaves the smart meter) and aggregated at the data concentrator (this should be a point in the system close to the consumer and remote from the utility) to protect the privacy of the consumer.

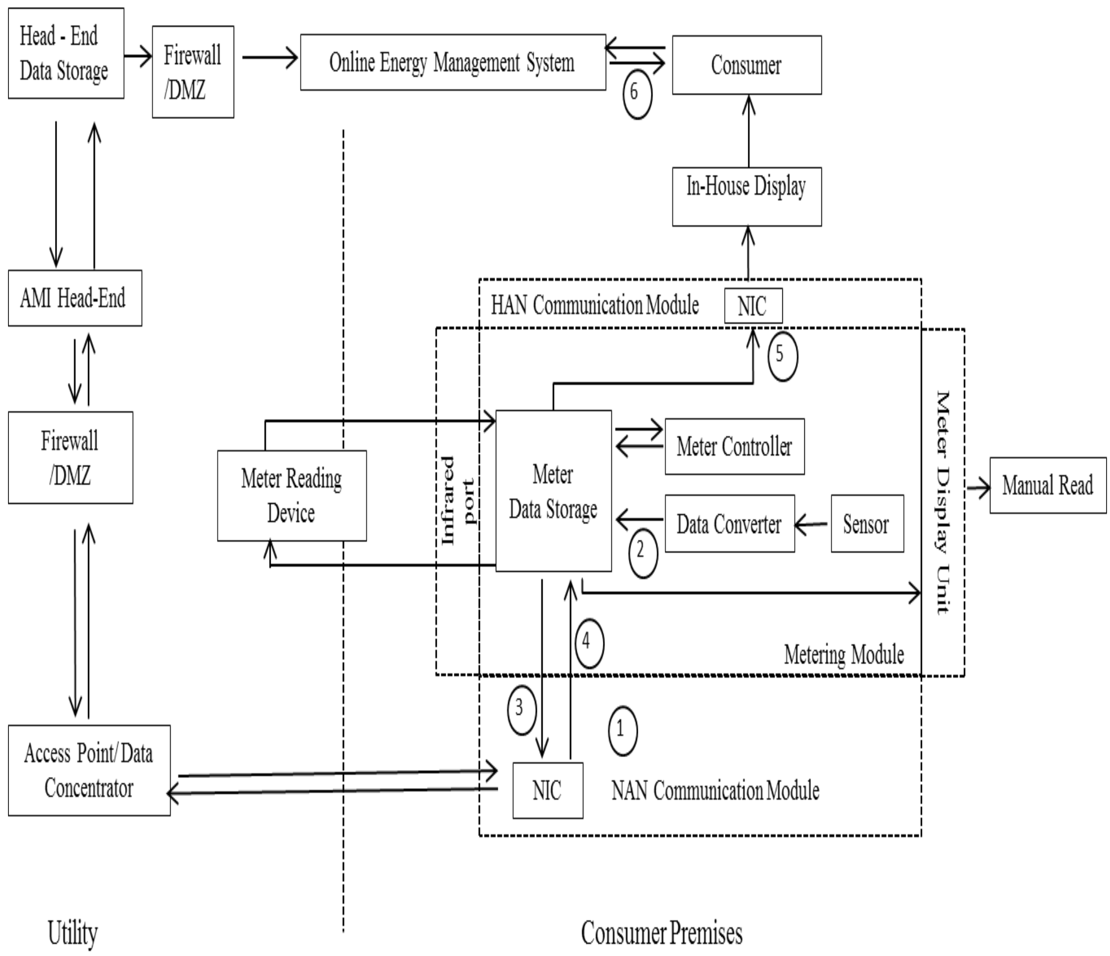

Figure 8: Consumer-Friendly Smart Metering System Architecture

2. Data Control Options based on User Type

In section (6.2.3) consumers have been segmented based on technological acceptance. A consumer-friendly system should have choices and control options for all the 5 types of consumer segments listed. To identify the controls and choices, a schematic representation of a consumer-friendly Smart Metering System Architecture has been developed as shown in Figure 8.

Controls and choices over smart meter data that can be provided to different users through this architecture are presented in Table 14. The critical differences are that consumer has the choice to remove the communication module and consumer also has control over both the data recording intervals and the intensity and frequency of data transmission. These specific features provide consumer with control and choice reducing the intensity of data available to the utility thereby achieving consumer acceptance.

Table 14: Controls/Choices for different consumer types

Option	User Type	Remarks
1. Plug–in Communication-module	Type 1	1. If the communication module is of plug-in type, it can be removed for consumers that don't want a radiating device in their premises. Such meters have to be manually read and the utility may have to charge those consumers extra for labour cost. In future if they wish to use the data transmission functionality the communication module can be easily plugged in. 2. As there is no data transmitted to the head-end, details like outage and issues in QoS have to be communicated manually by the consumer. 3. Limitations - Consumers who worry about RF emission health issues may still be affected by radiations from neighbouring consumer's meter or collectors in the locality.
2. Choice in the interval of LP data storage	Type 1	As Type 1 user may resist having a remote communication module, they may also resist frequent load profile data being stored in the smart meter. Hence for such consumers there should be options to disable load profile channels and record no data or even disable the communication module as a whole. There could also be options for recording larger interval if required (e.g. 15 days / 1 month)
	Type 2	As Type 2 user will personally manage their energy consumption, they won't require frequent interval data. There should be option to program such users to larger intervals with just enough to supply information for grid operations.
	Type 3 Type 4 Type 5	These users favour frequent data collection and hence there should be 2 or 3 options in the choices of shorter intervals (10 min/15 mins/30mins)

3. Frequency and interval of, data transmission	Type 2 Type 3 Type 4	There should be options to: 1. Choose the interval of data transmission. It can be different from the interval in which data is stored. 2. Disable data transmission permanently or temporarily. Though the data can be anonymised and later aggregated during transmission there should be choice provided to disable data transmission. This will ease the worries of the consumer who think their energy consumption data could be used to profile them and distinguish if their premises are occupied or not. 3. Modifications to the data transmission should be notified to the head-end so that they can use prior knowledge or other intelligence to calculate demand response. 4. Alerts like power outage and variations to QoS from the set thresholds don't affect consumer choices, and hence that information should be transmitted to the back end without any interference.
4. Meter-actions/ alerts/ Energy usage variations	Type 2	These users prefer not to use any help for their energy management, they only require options to receive alerts. Those alerts can be made available through IHD or online Energy Management System (EMS).
	Type 3	These users prefer not to constantly change their settings. Such consumers can be given the option to have the smart meter modify their energy usage during peak period declaration. If they have equipment with high energy requirement that are not urgent they could be connected to the LCR and made to switch off or cycle as per need.
	Type 4	These users prefer to be provided with alerts but want the freedom to make choice of their energy usage.

5. Displaying usage with IHD	Type 1 Type 2 Type 3 Type 4 Type 5	All users, including the Type 1 user can utilise an IHD display to monitor consumption and other metering data at real-time, but Type 1 users won't be able to display alerts from the utility as they don't have a communication module. The smart meter should have a display list that can be customised for data to appear in IHD and there should be options to program the meter display based on consumer preference.
6. Online EMS and providing control to service provider	Type 4	As these users would like to be controlled by the service provider, they can use the information in the online system to make informed energy choices or let the service provider control their energy usage.
	Type 5	Technology enthusiast and energy conscious users would like to make use of all data available. They would like to make used of all options available. They would also like to have additional controller devices that can be configured with the system to modify their usage to changes in the supply network

7.6 Data flow points and their security requirements

To reduce security concerns related to smart meter data, efforts must be made by the service provider to analyse maximum threat points in the system. This will help them in analysing what control measures are currently in place and what further needs to done to secure the system. Identifying the data flow points in the system will aid in this process. A detailed data flow diagram will help to systematically identify all possible points of the flow. Based on the smart metering system architecture and smart meter data classification made in this section, an abstract data flow diagram for the smart metering system is generated as shown in Figure 9. 38 data points have been identified and each point has a security and/or privacy requirement that need to be met. Data anonymisation (D.1) and Data aggregation (D.4) are two points that are added which are not currently present in most smart metering systems. Those steps are required for a consumer-friendly and privacy-focused system. The needs at each data point is listed in Table 15 provides more information on the data points.

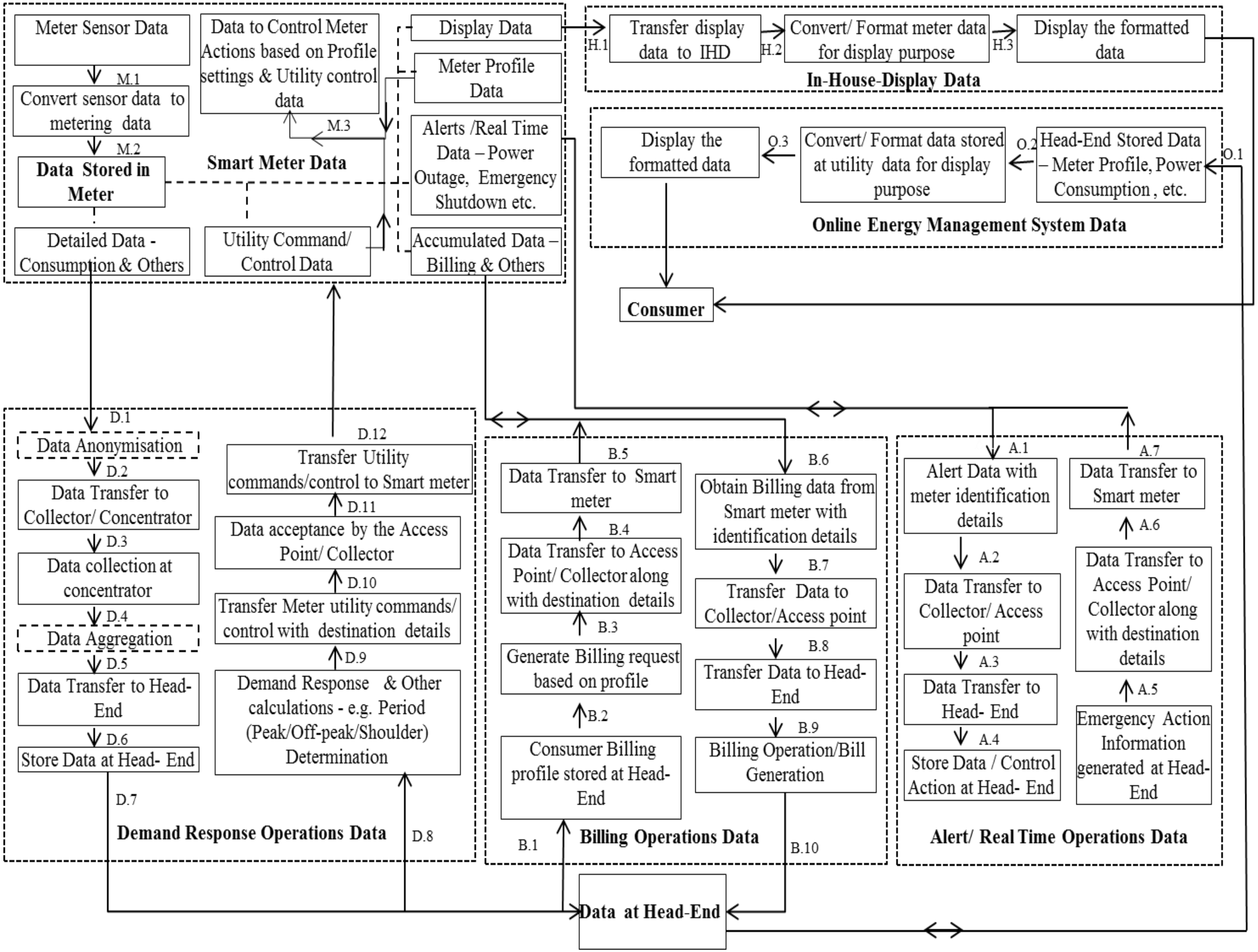

Figure 9: Abstract Data Flow Model for Smart Metering System

Table 15: Data points listed in the abstract data flow model

Point	
Smart Meter Data	
M.1	Readings from the meter sensors are converted to metering data.
M.2	The converted sensor data is stored in meter.
M.3	Data to control meter operations (e.g. cycling the load, service disconnect etc.) are derived from meter profile setting and commands obtained from the head-end. There should be measures to ensure that the control information is accurately derived based on the priorities set in meter profile. This data is very critical as it has the capability to modify meter operations and even cause disruption of service.
Demand Response Operations Data	
D.1	For demand response, the identification details of the consumer operations are not essential. To ensure privacy the data should be anonymised. This will reduce consumer concerns of being profiled from frequently communicated data from the meter.
D.2	The retrieved data is transferred from meter to collector. The data may undergo formatting before transfer.
D.3	The linked collector should receive the data after verification.
D.4	Data aggregation should be done to the demand response data received from multiple end-points linked to a collector. This will further secure the system from privacy threats as the data that is transferred further up the system will be linked to the collector and not a particular individual.
D.5	The aggregated data should then be transferred to the head-end.
D.6	The received data should be accepted and verified before storage.
D.7	The data may require conversion to the format suitable for storage.
D.8	Based on the demand calculations should be made and control operations (TOU determination, breaker and LC relay operations, planned outages) need to be determined.
D.9	Operation information from utility needs to be transferred along with destination details. As one provider may have many linked collectors, it is essential that control data is matched with the exact collector.
D.10	The control commands could be broadcasted or sent specifically to the collector. In either case the collector should verify the destination details and accept the data.
D.11	The received control commands are sent to all meters linked to the collector.
D.12	As data sent to head-end is anonymised and aggregated, the demand response operations will be for all meters linked to the collector. The command operations received from the collector gets stored as utility operations data and after verifying with meter profile data, the meter control actions will be generated.

In-House-Display Data	
H.1	The meter will have a list of items that can be chosen to be displayed. The usual display items includes, instantaneous and cumulative consumption, import energy, export energy, alert data etc. These can be programmed to the meter profile's display settings. The data for items chosen should be extracted from the stored meter data.
H.2	Display data is transferred from meter to IHD.
H.3	As IHD is meant to enhance consumer understanding of energy usage and choices, the raw data from meter needs to be processed to be informative. There should be options in IHD to set thresholds for relevant display items, so that it could alert the consumer if the thresholds are breached.
Energy Management System (EMS) Data	
O.1	Through online energy management systems, end-user related data that is stored at head-end can be made available to the respective consumer. This system provides user the opportunity to verify meter data in their premises and that stored at the back-end. The information available through this system can easily profile or identify a consumer; hence like any other online management system, this system should be highly secure. The data that needs to be displayed to the customer need to be extracted from the Head-End database. The data extraction features provided should be accurate and tamper proof.
O.2	As the user login to the system, data related to their consumptions should be fetched by the online management system. The system should have authentication measures to ensure that the extracted data belongs to the customer. The query to retrieve the data should be tamper proof.
O.3	The data will require further conversion to the format suitable for display to the customer
Billing Operations Data	
B.1	The consumer billing profile data should trigger a billing request based on settings.
B.2	Billing request generated at utility needs to be transferred along with meter identification details. The meter identification details must be able to locate the linked collector.
B.3	As there are meter identification details, the billing requests need to be only transferred from collector to the specific meter.
B.4	On reception of billing request, the meter should trigger functionality to retrieve billing data.
B.5	The fetch process should extract the necessary information from the stored accumulated data.
B.6	The retrieved data may be formatted and then transferred from meter to collector.

B.7	Data received from the collector is transferred the head-end.
B.8	The billing data needs to be stored at the head-end. The data may require further conversion to the format suitable for storage. Using the received data, billing statement needs to be issued to the consumer.
Alert/ Real-Time Operations Data	
A.1	The meter has standard set of events that trigger alerts and other events can also be programmed to create an alert. Standard events include power outage and programmable events include variation in QoS where the thresholds are set by the consumer or provider. When such events are triggered, the meter should trigger functionality to immediately generate alert.
A.2	The retrieved data may be formatted and then transferred from meter to collector.
A.3	Data received from collector is transferred head-end.
A.4	The alert data should either trigger correction measures automatically or notify the utility provider to take necessary actions. This data should also be stored at the head-end and may require formatting before storage.
A.5	If there are critical situations at the head-end, such information should also be informed to the consumer in the form of alerts, so that consumer can be prepared for the situation. For e.g. if there is planned outage, it should be communicated to the consumer in real-time. Such events should immediately generate alerts and this information from utility needs to be transferred along with destination details.
A.6	The information from head-end could be broadcasted or sent specifically to the collector. In either case, the collector should verify the destination details and accept the alert data.
A.7	The data from the collector could be sent to a specific meter or to all linked meters. In either case, the meter should verify the destination details and should only accept the alert data if the credentials match.

7.7 Reducing dependency on Consumer data

The previous section clearly details data flow created by each operation. High traffic is created by the transmission of load profile (LP) data. Privacy becomes an issue for the consumer when the utility provider or a third-party (which includes an attacker) gets to view the LP data generated by the smart meter. This data can be accessed inside the smart meter, at the utility provider's database and can also be intercepted during transmission. Adding security and privacy measures for interval data also becomes a tedious process.

A consumer-friendly solution will be to minimise the usage of LP data for the smart metering system functionality and to mainly limit LP data to consumer. The consumer should be provided with a choice to decide on sharing this information with a third party. Currently most smart metering systems are designed to generate and transmit LP data even though it is not clear how the system will benefit individual consumer's detailed consumption data. Even TOU billing can be easily applied on accumulated data for each period (peak, off-peak, shoulder), detailed LP data is used in many placed for billing operation. In this section an analysis is done to identify if LP data is required for the operation of other control systems in the grid. Analysis is also done to identify which stakeholder will benefit from the detailed data other than the consumer themselves.

7.7.1 Influence on Control Systems

Power Systems Engineering Research Center (PSERC) identified the control elements for a modernised power grid [Govindarasu et al., 2012; Sridhar et al., 2012]. PSERC is a National Science Foundation Industry-University Cooperative Research Center in US. Under PSERC, multiple universities work collaboratively to address the challenges facing the electric power industry. The control elements discussed in their article will be used in this analysis (refer A.5 for details on the control elements). First the distribution controls will be analysed followed by the transmission and generation controls. Table 16 examines if detailed consumer data is essential for the control element's operation.

Table 16: Analysing Control System's need for consumer's energy data

Control Element	Identify need for detailed interval data
Load Shedding	The load is shed at the feeder level. The smart meter data could help in determining the load. But there is no requirement for individual consumer data. An aggregation of data from all users under the feeder is only required. This data needs to be communicated to the back-end in real-time.
Demand Side Management (DSM)	The data from the end-user could assist DSM system in identifying if more power will be needed from bulk generation units. It could also help in identifying if there is excessive feed-in from the consumer. There may be multiple feeders under a substation and for most of its functionalities data at feeder level would be sufficient. Though this control element may benefit from consumer's LP data, it is not necessary to have the identity of the consumer associated with this data. Anonymous LP data is more than sufficient.

High-voltage Direct Current (HVDC) transmission control	In HVDC system to obtain the desired level of power transfer, firing angle control is used to continuously regulate the DC voltages at both ends of the system. With the introduction of DER and RES, firing angle calculations can be improved if the power quality in the grid is available. These operations also do not benefit from individual user's data. The data is desirable at a substations level.
Volt-Ampere Reactive (VAR) compensation	This control mainly relies on local measurements and consumer's data will be of least use for its operation.
State estimation	This control mainly relies on local measurements and consumer's data will be of least use for its operation.
Security-Constrained Economic dispatch (SCED)	Demand is one of the main inputs for this control and the aggregated demand data at substation level could assist in its operation. These operations also do not benefit from individual user's data.
Automatic Generation Control (AGC)	The consumption pattern can be predicted from historical power usage data. This could help in regulating generation at optimal levels. Even for this operation, the system does not benefit from the end-user's data. It is sufficient to get the historical data at substation or feeder level.
Governor Control	This control mainly relies on local measurements and consumer's energy usage data will be of least use for its operation.
Automatic Voltage Regulator (AVR)	This control mainly relies on local measurements and consumer's data will be of least use for its operation.

Various control operation in the grid will benefit from real-time knowledge of load or demand in the system. Even historical data can be used to predict system behaviours and needs. But that does not suggest that power related data should be detailed consumption data from the end-user. For transmission and generation related control applications, the data at substation level will be sufficient. For demand management at a substation for most operations it is sufficient to have information at a feeder level. Consumer data may be beneficial for making predictions and calculations within a feeder. For this purpose it is not necessary to have the identity of the consumer with the LP data. Anonymous LP data is more than sufficient. This data can be aggregated at collector level to identify the consumption in the region covered by that collector. This will require efficient computational processes and communication technologies and the power system cannot rely on this data for time-critical operations. It is not realistic to make the generation and transmission systems wait for data from the consumer point to be processed and transmitted. Even for the distribution management system, to prevent damage of cables and hardware and to make decision on load control there is no need for consumer level data. At the same time, historical data on consumer load can be aggregated to make intelligent predictions and calculations. So it can be concluded that for demand side operations anonymous aggregated data will be more than sufficient for most operations. Finally the need of detailed consumption data narrows down to the end-user. Few of the studies analysed in the literature review had shown that some consumer segments have been able to reduce their demand if they are provided with a feedback. This detailed data of individual consumer could be useful for making predictions on consumer behaviour patterns. Using various feedback mechanisms, the real-time data can be provided to the consumer to help them make informed choices. For the power market operations mostly historical data will be sufficient and the consumers can be given the choice to decide if they need to share this data.

7.7.2 Influence on key Stakeholders

There are various stakeholders involved in the smart metering system and few important stakeholders listed by Edison Electric Institute (EEI) are: Customer Service & Field Operations; Revenue Cycle Services; Billing & Accounting, Revenue Protection; Load Distribution Operations; Utility Customers and Marketing & Load Forecasting [EEI, 2011](EEI 2011). Smart metering data may be useful for many of these stakeholder operations and in this section an analysis is done to identify which other stakeholder will benefit from end-user's LP data apart from the consumer. Table 17 examines if detailed consumer data is essential for the key stakeholders.

Table 17: Analysing Stakeholder's need for consumer's energy data

Stakeholder	**Identify need for detailed interval data**
Customer Service & Field Operations	AMI reduces their need to do the on-site metering reading. Their job becomes easier as the consumer data will be sent to the utility provider. But there is no requirement for detailed consumption data, as it does not make any change to their operation. They will benefit from real-time alerts from the smart meter if a deviational behaviour is shown at the consumer site or on the distribution lines.

Billing & Accounting	Billing and tamper detection become efficient with the remote reading of consumption data. The current smart metering system sends detailed consumption data to utility, and they apply TOU rates to this data and it is an inefficient practice. The smart meters are capable of accumulating the usage under relevant categories for each billing period. E.g. If there are 3 different TOU rate: peak, off-peak and shoulder rates, the smart meter is capable of accumulating the power usage for each period in separate registers. It is sufficient to send this information at the time needed or end of the billing cycle to calculate the bills. This process reduces the need for transmitting detailed data from consumer and also reduces traffic in the communication lines.
Revenue Protection	For revenue protection, real-time tamper alters are beneficial. Sending this data in real-time is beneficial for this stakeholder.
Load Distribution Operations	The power quality and load details are required for these operations. The load details are mainly required at feeder level, and hence this stakeholder does not need to rely on the consumer load data, and if end-user level data is used, it has to be aggregated. The power quality details are also not required frequently. The threshold can be set in the consumer's smart meter to set alerts if it deviates from the settings. So for power quality and outage tracking, it is sufficient for the meter to send alerts if there are issues.
Utility Customers	The consumers can benefit from detailed real-time data from the smart meter. With the help of feedback mechanism like IHD, the user can view their usage in real-time.
Marketing & Load Forecasting	They benefit from detailed consumer consumption data. AMI will reduce the costs for collecting this data for research purpose. As this could invade the privacy of the consumer, this data should be made available to these stakeholders only on consent from the consumer.

The smart metering system can help the utility to avoid errors from billing estimation and to achieve early identification of theft. But for most of these operations, the real-time energy usage data from the consumer is not necessary. As billing is done at a monthly or higher cycle, aggregated usage information is sufficient before the next billing date. Even for time-of use calculation, it is only necessary to have aggregated data for each tariff (peak, off-peak and shoulder) for that billing period. The theft of electricity can be determined by using other parameters like setting alerts for meter tampering. For all the operations discussed above, there a pressing need for transmission of detailed LP data, in real-time or otherwise could not be identified.

The only context that could justify disclosure of detailed data is when there is disagreement between the service provider and consumer over billing or related matter. In such situations the consumer should/can provide service provider access to the LP data to resolve the issue.

With this it can be concluded that consumers are the main stakeholder who could benefit from viewing LP data in real-time. It may provide the consumer with an opportunity to make environmental-friendly choices. But it does not ensure that the consumer will be able to follow exactly to the price signals and the detailed interval data that is currently provided. Moreover, consumer's energy needs are not just driven by energy costs and there will be limitations to the changes they can make to their energy consumptions behaviours.

7.7.3 Distributing intelligence across the grid

Analysis of control systems and stakeholder needs in a modernised power grid leads to the conclusion that, real-time LP data is not required for major operation in the grid. The main entities that may benefit from LP are the consumers themselves. So instead of collecting LP data from individual households, consideration should be given to add intelligent devices and sensors at each level of the grid. These smart devices should be designed to deliver specific functionalities at that level of the grid, i.e. there should be smart devices at power generation, sub-station, feeder levels and end-user level. The detailed LP data that is generated at the end-user should only leave the end-user's smart meter under very specific and carefully controlled circumstances. Figure 10 shows a diagrammatic representation of the system.

Feeder meters and sub-station meters are not new concepts. In 1991, distribution automation study was conducted by Pacific Gas & Electric Company (PGCE) in their service areas. The benefits and costs associated with automating substation, feeder and end-user were analysed and quantified. They had determined that automation at substation level and in most cases even feeder level is cost effective. But the customer level automation was found to be not justifiable due to the associated cost and technology involved [Brown et al., 1991]. In 1996, Baran et al. conducted a study to determine the number, place, and type of meters that are needed for state estimation at feeder level. They found few meters were sufficient in a distribution feeder to provide data needed for real-time monitoring. They even proposed a meter ranking methods that could be used to identify the location and type for meter that will be needed for in a distribution feeder [Baran et al., 1996]. There are various research articles from then till now on meter ranking and meter placement methods [Abur and Magnago, 1999; Antonio et al., 2001; Zamani and Baran, 2014]. This indicates that feeder meters can play an important role in grid modernisation projects. But in the current smart grid

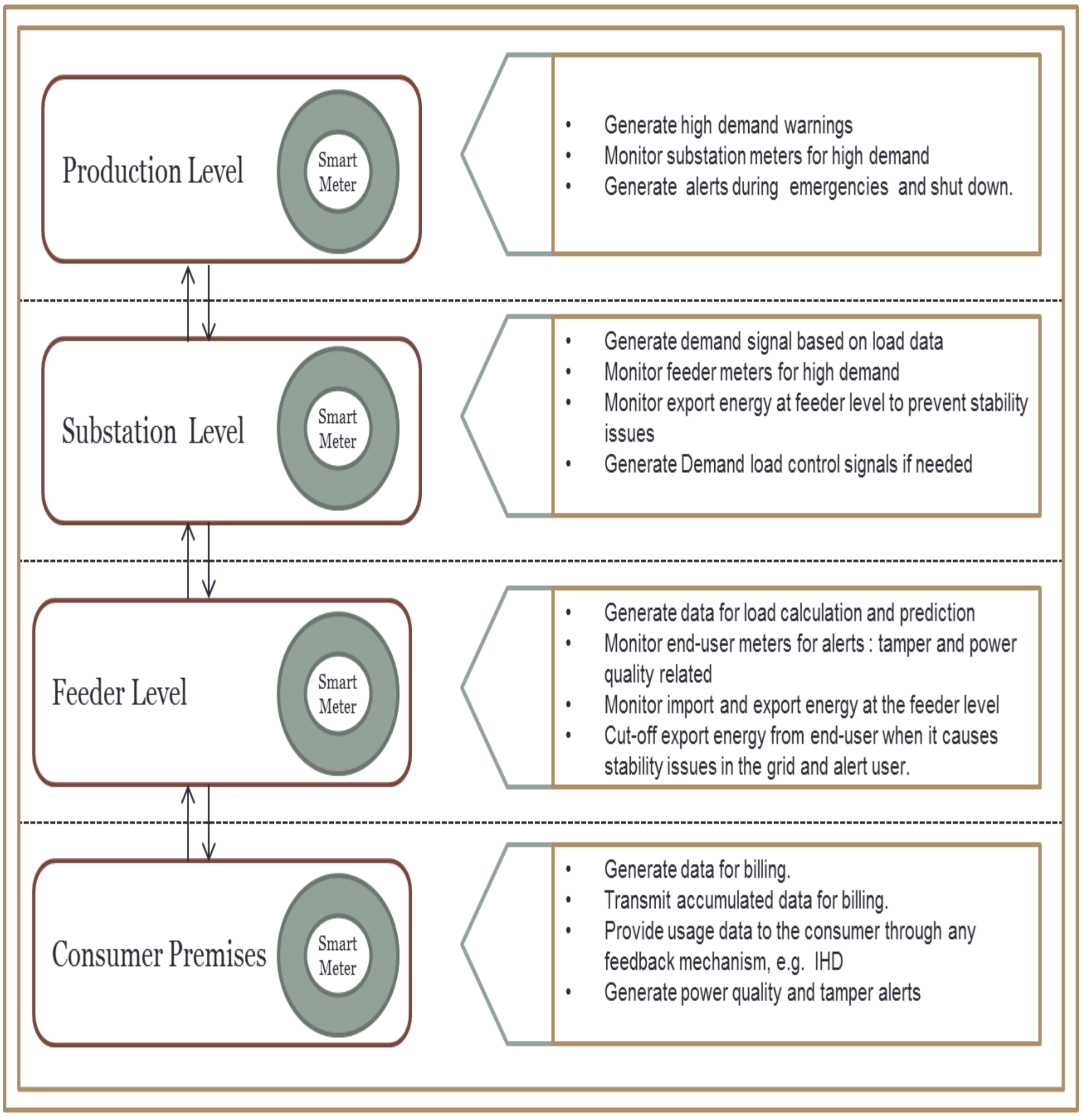

Figure 10: Schematic representation of intelligence required in power grid

schemes they are not represented in any reference models as points for data collection; all focus is only on smart meters at end- user level.

Feeder meters can play a significant role in intelligent operations. Traditional feeder meters have been used in the past to identify theft. An intelligent feeder can quickly provide the load requirement in the area without having to wait for consumers' data to be collected and aggregated. Privacy issues arising from the feeder data are less than an individual consumer meter. Then with a smart meter at substation level, sufficient information can be generated to predict demand signals. Even without a smart meter at the customer site, this information can be communicated to the user using other available technologies. The meter at the bulk generation site will provide the real-time demand information for production purposes. Even for making forecasts, substations and feeder-levels can be a sufficient to provide historical data. This eliminates the need for end-user data for grid intelligence. This removes unnecessary traffic from the system that is currently created by transmission of detailed consumer data. This minimises the need for various computations and greatly reduces privacy issues, because detailed data about the end user does not have to leave the consumer's premises without their consent.

In this section measures to reduce concerns over smart meter data has been presented. Apart from this, consumers should also be provided with useful and easy to use features to improve their readiness to accept the system. Next section presents user-friendly features than can be introduced in the system

7.8 User-Friendly Features

For the consumer to get benefit from the smart metering system, they need to have functionalities that assist their energy needs. In section 6.2 (Consumer Segmentation) energy needs and other choices and limitations have been identified. In section 6.4, the suitable requirement elicitation techniques were tabulated. From the list, documentation studies and content analysis are chosen in this section to identify the user-friendly features. Though the use of Contextual Inquiry was also suggested in 6.4.1, it cannot be demonstrated in this research due to the unavailability of experimental setup and participants. Using the documented consumer concerns that were discussed in section 5.4 the user-friendly features are identified.

The flexibility to vary usage based on price signals differs between user segments. Based on consumers' ability to comprehend information, the type of feedback required also varies. The consumer-friendly features proposed for improving the usefulness to residential consumers include:

1. Informative feedback for different consumer segments
2. Billing choices based on consumer input
3. Specific configurations to improve the energy activities of consumer segments.

7.8.1 Informative feedback

An informative feedback is required that satisfies the different consumer segments identified in section 6.2.4 (based on ability to comprehend information). Consumers need a system that will provide them with informative feedback on their usage patterns and provide them with hints to make intelligent choices and avoid energy wastage. Table 18 provides a list of useful feedback information for all kinds of users.

Table 18: Informative feedback for intelligent choices

1. Consumers' current usage
2. Energy consumption choices • Saving mode – This mode should show consumers the most cheapest energy choices • Essential Usage mode – This mode should show them the average required energy needs for the number of occupants mentioned. • Maximum Usage mode – This mode should show them maximum consumption limits under recommend standards for the total number of occupants so that the consumer understands that beyond this level there is wastage occurring.
3. Energy saving tips - The system should include hints of items that could be operated/ avoided at different time of the day. It should be based on the demand signals from the utility. This will exclude the guess work out of the user
4. Warnings for high usage - Warning should be provided during i) peak period and ii) Over usage during a billing cycle.
5. Provision to set consumption limits – There should be option for the consumer to provide a desired bill amount for the billing period and get information on consumption limits within that billing cycle. The information should show the user how much energy they can use per day to match the billing amount.

7.8.2 Billing Choices

Based on the consumer segmentation identified in section 6.2.2 (based on ability to modify usage), customised billing options are required for consumers. This will provide them with opportunities to make changes/reduction in their usage pattern within their limitation. Table 19 provides varied billing choices for all segments of users identified.

7.8.3 Specific Features

Based on the consumer segments identified in section 6.2.1 (based on energy requirements) specific feature are required for help them in their daily activities. In this section the specific needs of consumers with medical needs and consumers based on tenancy status are detailed.

7.8.3.1 Consumers with medical needs

In section 6.4.1, using contextual inquiry a template was presented to identify user reactions. Based on the information on concerns and needs gathered for users with medical needs, the problem is extracted to identify specific features useful for them in smart metering systems. It involves comparing the business goals with the end-user goals to identify user assumptions and fears and from that the problem needs are extracted. This information for the user with medical needs is presented in tables Table 20, Table 21 and Table 22.

Table 19: Billing options to suit consumer category

<table>
<tr><th colspan="3">Billing based on TOU</th></tr>
<tr><td colspan="3">This category aligns with utility providers' current plan to charge the user based on TOU rates.</td></tr>
<tr><th colspan="3">Billing based on Usage</th></tr>
<tr><td colspan="3">This is calculated based on number of occupants and other parameters</td></tr>
<tr><td>Usage within a recommended level – People using within recommended limits and with minimal wastage of energy shouldn't be penalised for not being able to avoid the peak period. They should have an option to pay lower rates even for the peak period. This will encourage them to continue using less energy.</td><td colspan="2">Usage above a recommended level - these users can be further classified into three: high profile and careless users; people with medical conditions and home based business. The users with usage above recommended level is further discussed below.</td></tr>
<tr><th colspan="3">Usage above a recommended level</th></tr>
<tr><td>Inattentive and High-profile users - They don't require any concessions on their bills as their high usage is their choice. They have to pay as per the utility provider's settings. But as feedback, they should be given sufficient reminders to alter their energy choices.</td><td>People who can't avoid due to various limitations - They require concessions in billing and they should be offered other alternatives like solar panel to supplement their energy needs.</td><td>People doing business/work at home – They should have different tariff rates for the office hours and after hours of operation. Rates for commercial purposes should be higher than the consumer off-peak rate. However, it shouldn't be as high as consumer peak-rates so that the consumer will be not penalised for setting up a home-based business. They should also be offered other alternatives like solar panels to supplement their energy needs.</td></tr>
</table>

Table 20: Business and User Goals for Smart Meter for Consumer with Medical Needs

Business Goals
1. Reducing production cost by reducing peak demand. 2. Prevent damage/overloads on the electrical system. 3. Reducing finance loss – ability to remotely disconnect the customer upon non-payment of bills.
User Goals - (user with medical needs)
1. Uninterrupted supply of power to support the medical needs. 2. Take advantage of the system facilities to have cheaper bills.

Table 21: User Issues - assumptions and fears

System Functionality	**User Needs**	**User Issues**
Remote breaker connect/ disconnect	Uninterrupted supply of power to life support system	Life threatening situations like life support system shut down from forced and accidental outages.
Smooth demand curve using TOU tariffs.	Cheap energy	High bills not being able to avoid peak tariffs.

Table 22: Problem Extraction - consumer with medical needs

Problem Description
The smart meter can operate the breaker remotely. This functionality is mainly intended to disconnect consumer that have not paid bills and to enable load-shedding / brown outs to avoid system damage. This feature could affect people on life support systems.
Specific Likely/Actual Difficulties
There is a risk that the life support system will shut down if the consumer is not reconnected before the temporary supply runs out.
Specific Context
The breaker has been remotely disconnected– forced or accidental
Assumed Causes
a. The user may not have paid his bills. b. The utility forced an outage to avoid system damage. c. Utility accidently triggered the breaker disconnect command. d. Malicious hackers intruded into the grid to issue remote disconnect command.

Based on the problem scenario extracted, specific features that are required in smart metering systems are presented in Table 23.

Table 23: Specific features to benefit users with medical needs

Scenarios and Possibilities for consumer with medical requirement
1. **A user has not paid the bill on time** - People with disabilities usually get help from government and other organisations with bill payment. Hence it is unethical to disconnect such consumer and put their life in danger. A smart meter should be able to stop selectively disconnecting a consumer that has medical requirement likes life support system. Instead, it should send alerts to the consumer and related entities to make a necessary action for the debts.
2. **Load-shedding / brown outs to avoid system damage** - The smart meter should have an option to override or ignore the breaker disconnect command to support consumer that has medical requirement. Providing electricity for few consumers (with medical needs) in an area where the load is shed will not harm the system.
3. **TOU Tariff and peak period** - The smart meter should be able to help the consumer avoid and reduce usage during the peak period. Informing the start time of peak period is not helpful to the user. The smart meter should have provisions to choose alternatives. Few options are: a) **A user without solar panel** - During the peak period let the life support system or related equipment to be switched to the temporary energy supply source like inverter or batteries. The smart meter should also be able to switch back to the regular supply when: i) Peak period is over. ii) The temporary source is about to run out. The smart meter should also recharge the temporary source during the off-peak period. b) **A user with solar panel** – Let the solar panel supplement the energy needs of the consumer, preferably to cover the peak period. If the peak period cannot be covered; follow the same procedure as mentioned above (3.a) and later recharge the temporary energy supply source with either solar panel or off- peak supply.
4. Extra. For consumers generating surplus energy using solar panels, the smart meter should be able to identify surplus generations and export the surplus into the grid.

7.8.3.2 Consumers needs based on tenancy

In a dwelling that is occupied by a tenant, concerns have arisen over the ownership of smart meter data. Tenants are concerned that the data held in the meter will become available to the landlord or next tenant and that this data could reveal the consumption patterns of the concerned party. Smart meters can be used to balance the needs of the tenant and the landlord. Table 24 shows the specific needs of the owner and tenant of a property.

Table 24: Specific features based on tenancy

Landlord
1. Track bill payment • For short term tenancy, provides bills accurately on usage. • For long term tenancy contracts, get confirmation there are no uncleared bills at the end of the contract before vacating the property. 2. Track illegal activities or breach of tenancy conditions. • Illegal subletting of the property • Running illegal activities on the premises.
Tenant
1. To prevent the house owner or any other party to view detailed interval data without permission. • On the end of a lease, the detailed usage to be cleared from the meter, so that this information is not available to the landlord of the next tenant.

7.9 Summary

This chapter presents the major contribution in this thesis. A consumer-friendly design for smart metering system is presented in this chapter. It contains abstract architecture and data flow models for smart metering systems. Using the models the security and privacy requirements for the system are discussed.

An important finding is that by spreading the intelligence across elements in the grid, the concerns arising from smart meter data can be reduced. Electric utility providers considering new smart meter roll-outs should start with meters at the production side and then work their way down the hierarchy. Even if the smart meters are not deployed at the end-user level, the remaining three levels can provide the necessary information to manage load. The feeder level meters have various potentials. The consumer sites need to be deployed with an interval meter that has an option to plug-in communication module. That then provides the user with a choice and control over transmission of their consumption data. For billing purposes accumulated data for each rate type will be sufficient and with the price signals the calculations can be done in the meter and there is only need to send the final calculated values to the service provider. This minimises the issues arising from smart meter data. The detailed interval data in the meter should be mainly limited to the consumer. If the consumer chooses not to have a communication module, their billing data will not be read by the utility provider remotely. Such consumers will require their meters to be read manually and the utility may charge additional service fee for the same. Also, the utility will not be able to remotely monitor alerts generated in the meters of those consumers. Those consumers will have to contact the provider if there is a power outage or issue with power quality.

The next important findings are the user-friendly features based on different consumer segments. This chapter also discusses how these features can benefit different user segments. The next step is to identify how these features can be implemented in the smart metering system.

All the user-friendly features discussed in section 7.8, needs to become capabilities within the smart metering system. As developing a new smart meter is outside the scope of this research, an existing smart meter is chosen and options are identified to bring about these capabilities. The smart meters (U1200 series) deployed in Victoria (Australia) are used for this demonstration and it is presented in the next chapter.

Chapter 8

Demonstration and Evaluation

This chapter demonstrates and evaluates the measures proposed in the previous chapter. Due to the limitation of funds, time and facilities a new smart metering system has not been developed. Instead, an existing smart meter has been scrutinised to identify possible modifications. The demonstration is executed using smart metering system in Victoria (Australia). Australia is a suitable setting for analysis due to the similarities it shares with many other countries with energy usage and interest towards smarter energy solutions. Additionally, the Victorian smart metering program is one that faced significant resistance from consumers. The roll-out of smart meters continued in Victoria even after the initial reviews presented negative directions. Now these systems are facing severe criticisms for exceeding the budget and after completion of the roll-out, the program has not been able to realise significant benefits to the consumer.

A known issue with the application of Design Science is the challenge in creating generalisations. This research also faces the same challenge as the demonstrated solutions are particular to a problem context. Although the conceptual models are of general applicability, the demonstration and evaluation are unique to the Australian context. The smart metering solutions that apply to the Victorian smart metering system may not apply to the smart metering systems used elsewhere. In order to address this weakness, the final section of the chapter draws on the knowledge gained from this research in order to present a generalised consumer-friendly framework that can serve as a check-list for power grid modernisation projects.

8.1 Victoria's Smart Metering Program

The smart metering project in Victoria is chosen for demonstration as it faces all the consumer concerns that have been discussed in this thesis. Victorians were provided consumer education since 2009, yet a survey conducted in 2014 reports that two-thirds of Victorians did not understand the benefits provided by smart meters. The Auditor General also blamed the related entities for letting the cost of the program go above budget [VAGO, 2015a,b].

8.1.1 Synopsis of the Australian Context

The smart metering system in Victoria and the grid modernisation efforts in Australia have been discussed in sections 2.5.3.4 and 5.5. This section commences with a description at a level of detail that enables assessment of the ability to implement the measures specified earlier in this thesis.

In 2007, COAG recommended the roll-out of smart meters and the introduction of the TOU tariff to manage peak demand throughout Australia. The smart meter roll-out in Victoria commenced in 2009. The system mostly used RF mesh technology for its communication. Energy price deregulation was also introduced for all consumers to complement the smart meter roll-out. However, the customers showed significant resistance to the TOU tariff schemes. The consumer advocacy groups intervened, and the service providers had to permit users to remain on the old flat-rate tariff, even after the deployment of smart meters [Benvenuti, 2013].

The current state of smart metering system in Victoria establishes the need for consumer-friendly features. The measures proposed in this thesis reflect the needs of different consumer segments. Features that benefit each group are identified. However, the effect of these measures on the profit to the business has not been analysed as part of this thesis. However, suitable business models can be applied to the services that are provided to the consumer. e.g. a fee for the service business model can be used for providing flexibility to change meter profiles according to user needs.

8.1.2 Smart meter used in Victoria (Australia)

As Victoria is chosen for analysing the existing smart metering context, the E350 - U1200 smart meter used in Victoria is chosen for the demonstration. The U1200 smart meter is detailed in this section.

U1200 smart meters are manufactured by Landis+Gyr, the major meter manufacturer in the world. Landis+Gyr also provide smart meters in US, Europe and other countries around the world. The majority of smart meters installed in Victoria, Australia are the Landis+Gyr E 350 series. The U1200 – E350 meter is a Single Phase meter with two elements (refer Appendix A.9). Both active and reactive energy is recorded and the energy register resolution for active energy is 1 Wh and for reactive energy is 1 varh. The meter features a 100A Service Breaker Relay (SBR) and a 40A Load Control Relay (LCR) to control demand. The hot water systems are usually connected to the LCR. The LCR is generally programmed to operate only during the off-peak period. This setting for the LCR in the meter program can be overridden using the boost operation. The meter has two buttons and button '2' is used to start the boost operation. When the boost operation is initiated, it runs for the time specified in the meter program. It is normally set for 30 minutes. This setting can also be changed in the meter program. Locally the meter can be read either through the meter display or by extracting data from the meter through the optical port [Landis+Gyr, 2012; CitiPower and Powercor, 2012].

The display data can only provide limited data, by default it only presents six items whereas a meter read through the optical port can extract the program file, accumulated data (useful for billing), Load Profile (LP) data and events data. Most utilities provide their meter reading technicians with a hand-held device to read all files out of the meter. Through the optical port, the meter can also be programmed. The data in the meter can also be erased via the optical port. The 'LAN' symbol on the meter display denotes that the meter is communicating, i.e. it is either transmitting or receiving data.

The U1200 – E350 meter uses the ANSI C12 protocol suite (refer Appendix A.9.2) [Snyder and Stuber, 2007]. The U1200 meter supports up to four sets of load profile data. Each set can accommodate up to 4 channels. The individual interval length options currently provided are: 10min, 15min, 30min or 60min [CitiPower and Powercor, 2012; Landis+Gyr, 2012].

In U1200, the controller is part of the meter and it has a remote communication module for two way communication with the distribution utility. The two relays, SBR and LCR, are designed to respond to different control signals. The distribution utility can send SBR disconnect/ reconnected command to the meter and the whole supply will be disconnected/ reconnected. The LCR is designed mainly for the DR operations. This relay can be used to supply power to equipment that needs its operation modified by the DR program. The hot water system and space heating/cooling equipment's are usually connected to this relay. The control actions to the LCR relay does not affect the main SBR or the equipment connected to the SBR. The meter can be configured to control the LCR in few different ways.

1. LCR can be switched OFF as a peak demand signal is received.
2. LCR can be made to cycle (ON-OFF) to a set time interval during the peak period.
3. LCR can be operated by boost-button operation. The UN1200 meters have a boost button which when pressed connects the LCR for the time duration that is configured in the meter. The boost operation can override the settings in the meter profile.
4. A consumer initiated LCR connection (e.g. boost operation ON) can be overridden (switched OFF) by the distribution utility's control command.

The U1200 meters can also be configured into different signal groups (primary, secondary and tertiary). When the service provider broadcasts a control signal, the meter will accept or ignore a signal based on its configuration and the priority. The U1200 meters also have two more communication ports. An IHD is connected to one of the port. An additional control device can be attached to the remaining port. This controller device can be used by the consumer to control the devices connected to the control system. The control system can be made to respond to the signals received from the smart meter. However, this requires the household devices to have communicating capabilities and also compatibility with the control device to receive and react to the controller's signals. This scenario is not widely in practice, and even if few consumers have this setup on their residential premises, they are not in significant numbers and hence will not be considered in this thesis.

8.2 Demonstration of user friendly features

This section details how the user-friendly features identified in section 7.8 can be applied in U1200 meters. This section discusses the features that can be configured into the meter U1200 without making modifications to the meter firmware. First, the specific features to benefit users with medical needs (refer section 7.8.3.1) are discussed.

8.2.1 Demonstration features for consumers with medical needs

Table 25 shows the implementation of consumer-friendly features for consumers with medical need using the U1200 meter (refer 7.8.3.1 for the requirements extracted).

Table 25: Smart meter Functionalities for Consumer with Medical Needs

Specific needs
1. Uninterrupted power supply to medical devices like life support system.
a) Ignore/override disconnect command. U1200 meters have an option to selectively program the meter to override the disconnect command. This will ensure that consumers with medical needs are not harmed if a remote disconnect command is issued (intentional, accidental or attack). b) Ability to operate local breaker commands. The local breaker commands can work independently of the of the remote breaker settings. This option can be used in case the power has to be shut down to prevent a fire or for maintenance work at the premises.
2. Cheaper energy to run the medical devices and other important activities.
Of the three relays in U1200 (the SBR to control complete power; primary and secondary LCR to control the partial load), the LCR can be programmed to work for different relay state machines. Program chosen should match with the main requirements of the user. a) The medical devices and other important devices can be connected to the LCR. The smart meter can be made to monitor the TOU signals. Currently, the TOU periods (peak, off-peak and shoulder) are fixed. The meter can be programmed to switch from direct load to alternative supply if one exists (RES or other storage devices). b) When the load is on alternative supply, the smart meter can be programmed to check for: i) The beginning of off-peak period. If it is a real-time signal from the service provider, the control information should be monitored. Instead, if the TOU periods are already programmed into the meter, that information should be used. ii) The availability of alternative source. If the alternative source is about to run out or if QoS is low or when the supply is back to the off-peak period, switch the LCR back to direct supply.

c) During off-peak period, monitor the charge levels of the alternative supply source. If there is a storage device, charge it if necessary. If RES like PV panels is present along with the storage devices, use it for charging before using the main supply.
General needs
1. Maximise the use of alternative energy source (if present).
The smart meter can monitor the alternative energy source. Monitoring options are currently available. However, additional feature are also required to make it more efficient. a) Based on the generation capacity the smart meter should choose to use the alternative source for the SBR or only the LCR. b) If there is an excess generation using the RES, the smart meter should help the user to export energy into the grid. It should provide the pricing information to the user so that the consumer can make advantage of the best rates.
Limitations
1. U1200 supports both the import and export of energy. It can measure and record the energy data and QoS data for both sources. However, in the current set-up, the smart meter is not using any of these values to determine the choice of the supply. Extra functions are required to make this calculation, though the input data is available. 2. In the current set-up, signals regarding the grid capacity are not received from the service provider. Hence it is not possible to make decisions on the best time to feed-in electricity into the grid. It is not a limitation of the smart meter. The meter can process this information if the control signals are received from the service provider.

8.2.2 Demonstration features for consumers needs based on tenancy

The second demonstration focuses on balancing the data access and privacy requirements (refer section 7.8.3.2) of the tenant and the landlord. Table 26 shows the permission controls that can be provided with the smart meter.

Table 26: Smart meter functionalities for balancing control over detailed data

For the landlord
1. U1200 meters stores accumulation data and interval data (LP data) separately. The owner may be provided with access only to the accumulated data which can be used for generating bills for the short-term tenants. This option also helps them to confirm that the long-term tenants have no unsettled dues before they vacate the premises. 2. The landlord can be prevented from having access to the detailed data until the consent of the tenant is obtained. This option maintains the privacy of the resident.

3. The meter also can be programmed to have threshold limits set. This option will let the landlord know if their premises are used for illegal activities that draw high electricity.
For the tenant
1. The tenant can be provided with access to accumulation data and LP data. To prevent anyone from accessing their detailed consumption information, they can request for their interval data to be cleared as per need or when they complete the tenancy and vacate the property. The U1200 meters can be partially programmed to erase data between a given date range. Using this option, the detailed consumption data of the tenant can be removed (if they wish to do so). Partially programming the meter to remove the LP data will not affect billing or other service provider requirements as all the other data including the accumulation data are intact.

The above synopses illustrate that the current smart meters have the capabilities to bring added advantage to the consumers. The settings are currently configured to help the service providers mainly. They also need to consider the users' needs to provide user-friendly features. This demonstration verifies that the problem is not with the smart meter or its core features but in the way it is utilised.

8.2.3 Demonstration of billing and feedback features

In sections 6.2 various consumer segments and their needs and limitations were identified. For the billing and feedback features as mentioned in sections 7.8.1 and 7.8.2, it is necessary to determine the category to which the user belongs. Based on the user-type the meter profile has to to be customised and programmed into the meter. Full and partial programming options are available in U1200 meters. The profile program that needs to be written into the meter can also be remotely send to the meter. As the meter receives the full profile and the program write (partial or full), the meter profile can be re-programmed. The profile can be changed without affecting any other data (accumulation data, LP data or alerts). The meter is also capable of accumulating consumption data into various segments based on the settings. It is also possible to set threshold values to trigger alerts. The meter can provide feedback and alerts to the user based on the profile configuration. Currently, the smart metering system use IHD and online EMS to provide feedback. The IHD displays the consumption data recorded in the consumer's smart meter, and the online system shows the energy data that is collected from the customer and stored on the service provider's side. Both the systems also display the demand signal like peak period and tariffs rates. The need exists for an intelligent feedback mechanism, not just the display of usage data and tariffs. The current system does not make the consumers well informed about the choices they have. Hence the smart metering system needs to incorporate a system that uses both user input and signals from the utility. Moreover the EMS needs to use the consumer provided information to segment the consumers. This feature is not available in the current EMS. The online EMS used may vary for each service provider. Some service providers use the online EMS from Landis+Gyr called the CommandCenter [Landis+Gyr, 2014].

8.2.4 Demonstration of distributing intelligence across the grid

To distribute intelligence across the grid as mentioned in section 7.7.3 there should be sensors and smart devices and various segments in the grid. On visiting the distribution grid in ACT, it was noted that there are sensors and measuring devices at certain nodes of the network. However, all the features mentioned in Figure 10 cannot be achieved in the current setup. There are two types of low-voltage feeders:, pad-mount feeder and pole-mount feeders. Some of the pad-mount feeder have metering devices but they are not smart meters. Several elements in the grid needs to be upgraded and in the current context, these features cannot be demonstrated.

8.3 System Modification

The previous section discussed the demonstration of the proposed features. However, in sections 8.2.3 and 8.2.4 all features could not be demonstrated in the current context (due to system limitations). This section discusses the modifications that need to be brought about in the system to incorporate the proposed features.

On the basis of the analysis conducted in this research, it is now feasible to propose modifications to existing smart metering system and architecture. The current smart metering system used in Victoria uses IHD and an online EMS for feedback. The IHD displays the consumption data recorded in the consumer's smart meter and the online system displays the energy data that is recorded at the service provider's database. Both the systems also display the demand signal such as peak period and tariffs rates. It does not factor in user needs, behaviours and limitations. The current data does not make the consumers well-informed to make suitable energy choices. The need exists for an intelligent feedback mechanism rather than just display of usage data and tariffs. Hence the smart metering system needs to incorporate a system that uses both consumer input and signals from the service provider.

Modifications are recommended for the online EMS. The EMS needs to provide the user with options to input information on energy behaviour. Additional information like weather data should also be drawn into the system to factor for the environmental conditions affecting the consumer. This will help in fine tuning the calculations. This modified EMS is referred to as CEMS.

8.3.1 Features of Consumer Energy management System (CEMS)

The features of CEMS are as follows:

1. Display accurate information.
2. Identify consumer categories (for billing and feedback purpose).
3. Provide consumer-friendly feedback (for energy consumption and billing activities).

4. Provide LCR control options.

8.3.1.1 Display Accurate Information

This feature is currently present in all smart and interval meters. The usage is displayed on the meter display and IHD. This usage data may also be displayable in the proposed CEMS by synchronising it with head-end data. Information like previously recorded accumulation data (which is used for billing), system alerts can be displayed. However, the detailed LP will not be available in the CEMS though the system is capable to displaying that information (if collected from the consumer). The recommendation from this research is to avoid transmission of detailed data from the consumer. It is sufficient to display the LP using IHD and by choosing that option the detailed consumption data is only made available to the end-user. For that IHD should become an integral part of the smart metering system and not optional as in the current setting.

8.3.1.2 Identify Consumer Categories

Unlike the current systems that focus on gathering detailed data and displaying it to the user as feedback, the focus in CEMS is a consumer focused solution and hence it will be in generating information based on consumer situations. The consumer provided data will be used to identify the consumer segment. CEMS will allow the user to input data related to dwelling characteristics, occupant characteristics and appliance characteristics. This will give sufficient information to calculate the energy requirement for the household. It can be fine-tuned with the weather data from external entities and the supply information the network. The accuracy of the calculation will be dependent on the information provided by the user. The consumer segment and energy quantum limit that is determined for each household using CEMS can then be programmed into the meter profile.

8.3.1.3 Provide Consumer-friendly feedback

Using the information provided by the customer, CEMS will generate energy profiles and this will decide on the billing rates that need to be applied to the particular customer. The rates will vary according to the user type. The head-end will have to store a user profile based on the user category and it will have data regarding allotted energy for the household, the category the household belongs to, and the rates that apply for the category. This profile after verification should be programmed (remotely or locally) into the meter and this should modify the meter configuration. For each billing cycle, this information will be applied to generate a customised bill for the user.

Based on the profiles generated by CEMS, the feedback information will also vary. CEMS will also have an alternative option to calculate consumptions limits based on bill amount. As some consumer wish to control their usage based on money paid for bills, CEMS will have option for the user to input a desired amount (money) and the system can calculate the consumption threshold to match the desired bill amount. For this calculation, the demand signal from the utility should also be used. This information is only used for feedback purpose to help the consumer control the usage. It will not affect the quantum of electricity consumption that is allocated to the user. This provides the user with the option to choose between consumption requirements or bill amount for feedback.

8.3.1.4 Provide LCR control options

The LCR can be operated in various mode. U1200 meter has the following options:

- Operate LCR normally without any control
- Disconnect LCR during peak period.
- Disconnect LCR when a set quantum of energy is exceeded.
- Cycle the LCR (Switch ON/OFF the relay for the full day or peak period - the ON and OFF time periods can be set in the meter).
- Operate by boost button operation (the time period of the boost and the number of times the boost operation can work in a day can be set in the meter).

CEMS can be used to provide the user with the option to choose the LCR mode of operation. The consumers' choice can vary from time to time. With CEMS this requirement can be quickly logged in, and the service provider can send the control signal to change the mode of operation. This option provides the consumer with full control over the ways in which the equipment connected the LCR relay operate.

8.3.1.5 Summary

An EMS based on the concept mentioned in this section has not yet been discussed in the smart metering scenario. Current systems (analysed as part of this research) are focused on extracting LP data from the consumers' smart meter and use that data to make decisions that are not modifiable in most cases. Project proponents of such systems tend to forget the fact that: consumers' energy needs can vary frequently; consumers' day-to-day activities decide on the quantum of energy used (and not the other way). Moreover, such systems don't provide the user with the choice to change the control and feedback options. As CEMS provides the consumer with the option to input their needs, it allows them to communicate their changing needs to the service provider.

Based on the consumer segmentation presented earlier (section 6.2.2) a user may belong to the 'flexible' category and may have opted for the TOU billing options. Later that consumer may meet with an unfortunate incident that may put them on the 'not flexible' category with medical needs. CEMS provides the consumer with the option to input their changed energy needs. This will in identifying the appropriate billing category, meter configuration and feedback that will be required to be modified for the consumer. Similar is the case with the LCR relay operations. A consumer may opt to cycle the operation of equipment (e.g. air-conditioner) connected to LCR and later they may have a change of mind and want to operate it without any modifications. With CEMS, the request can be quickly logged.

Allocating a consumer to a billing category will require further validation of the consumer situation. Currently in Australia, concessions on utility bills are provided after verifying and validating the government provided concession cards. Similar verification and validation will be required even for CEMS to identify the claim made by the customer.

8.3.2 Modifications in the Current System

The current online EMS will need new functionalities. It will require user-friendly interfaces to let the consumer input the data. It will also require algorithms to calculate energy quantum limits for each household and to identify user segments based on the user provided data. Based on these calculations, meter profile that can be written into the smart meter has to be generated. The service providers should then used the meter profiles that are generated using the CEMS to reprogram the smart meter profile.

In the current system, meter profiles can be programmed /reprogrammed into the U1200 meters locally or remotely. U1200 meters can receive new profile programs and have it partially programmed into the meter. Partial programming does not affect important existing data in the meter. The U1200 smart meters are capable of storing accumulated usage data based on the customised settings. Apart from the usual TOU periods (peak, off-peak and shoulder) or the single flat rate, other setting can be programmed into the meter. New settings need to be created for each user type. E.g. For a home-based business, power-usage depends on business-hours and hence such meters can be programmed to accumulate data based on work-time (working hours, outside working hours) rather than demand period. The meter can have various thresholds set for QoS and consumption data. Based on the meter profile, the alerts and events settings can be made to vary in the meter. The current version of U1200 meter can be configured to attain various alerts and events.

There are various kinds of IHDs. Few service providers use ecoMeter provided by Landis+Gyr. EcoMeter uses ZigBee Smart Energy Profile to communicate to the meter and it uses colour coding for energy alerts. Few settings can be made within IHDs to customise the display. EcoMeters also have the capability to store some data [Landis+Gyr, 2007]. This IHD still requires an upgrade to support all the information the U1200 meter can provide. Currently the billing reports, LP reports, events reports and meter program report that can be optically read out by software packages like EMPWin (tool from Landis+Gyr) contains a great deal of more information and ecoMeter is not capable of displaying them.

8.3.3 Architectural Modifications

With the introduction of CEMS to support consumer-friendly features, the smart metering system architecture that was discussed in Section 7.5 has to be modified. In the previous model, the need to extract consumer requirements was recognised. However, it was not explicit as to which part of the system should be equipped with that capability. It became evident after analysing the concrete scenario (Victoria's smart metering system). In the modified model, there will be bidirectional communication between the EMS and head-end. Earlier the communication between the consumer and the EMS were limited to the settings for using EMS. With the introduction of CEMS, the system will also enable the user to provide information that will be used in creating user specific meter profiles. An overview of the modified architecture is provided in Figure 11.

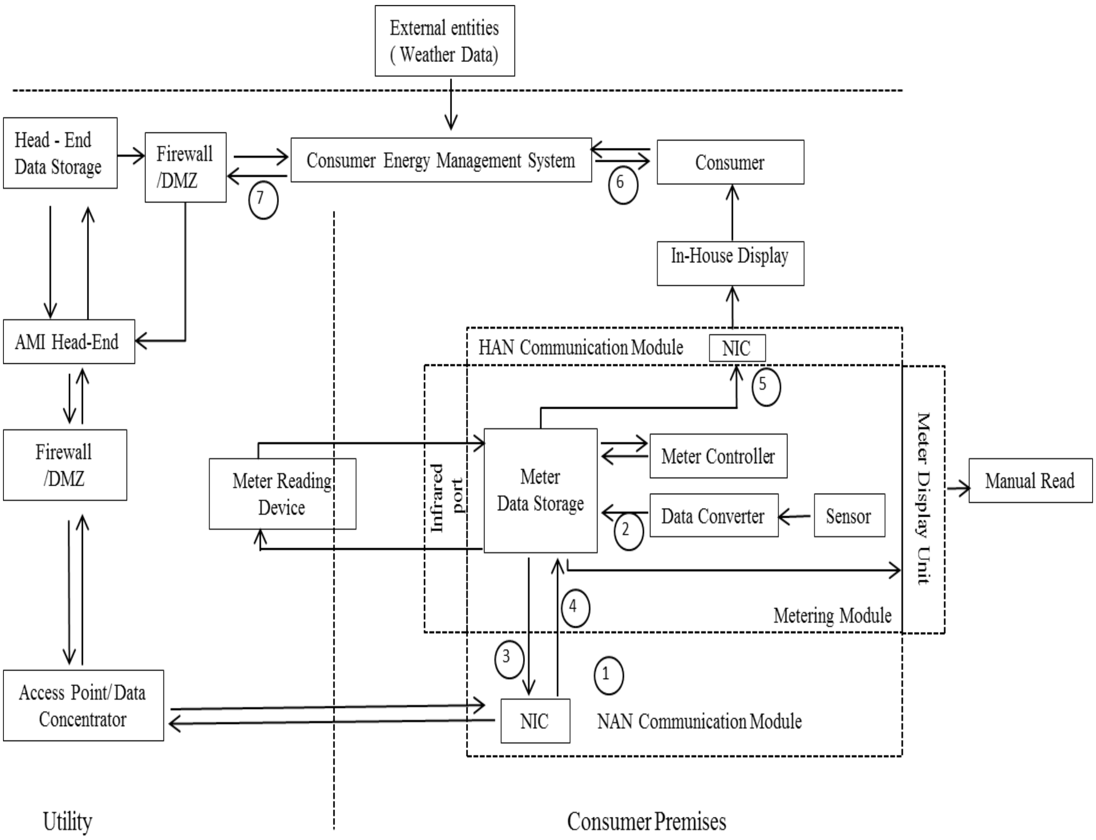

Figure 11: Proposed Modifications to the Smart Metering System Architecture

8.3.3.1 Options based on User Type

In section 7.5 the various control options for different user types were detailed in Table 14. In this section the options for CEMS operation mode will be discussed for the 5 user types based on technological acceptance (refer section 6.2.3). CEMS does not directly send any commands to the smart meter in the consumer premises. It records the consumer input information and transmits it to the service provider's head-end. The service provider upon receipt of the request from CEMS, should verify the content and process the request. Due this process, the consumer request for meter profile change will not be immediately achieved.

CEMS should be able to operate in 3 different modes. The user can opt to use the CEMS as standalone or online. Users who don't wish to share their information with the utility can use the standalone mode. They still can identify the consumer categories and choices without sending the data they have entered to the service provider. They can also view the demand signals issued by the service provider. However, the data entered in the standalone mode cannot become a meter profile as the service provider is not able to receive and verify the user entered details. In the online mode, CEMS can be made to synchronise partially or fully with the service provider's head-end. Partial synchronous mode, is useful for users who wish to get their meter profile customised but would not like any further interaction with the service provider. In this option, the created profile can be remotely or locally programmed into the meter. This mode of operation can also work on interval meters without remote communication modules. In full synchronous mode, the user's meter will have bidirectional communication with the service provider's head-end. The meter profile generated will be used to reprogram the meter. The service provider will send command and signals as per the settings provided. Table 27 provides further details on the operating pattern of CEMS.

Current systems focus on collecting the detailed interval data from consumers. Investments have been centered on data collection and storage and in many cases without even having knowledge on what needs to be done with the data. The operation of CEMS does not require detailed meter data to provide consumer with choices. It uses user entered preferences, demand signals, network conditions, other external factors like weather factors to provide the intelligent information. This mitigates the risk associated with detailed data collection and disclosure to third party. It also reduces network stress.

8.3.4 Modifications to the data flow diagram

Distributing intelligence across the grid as mentioned in Section 7.7.3 can help in removing the need for LP data collection from the consumer endpoints. The detailed data (if required) can be collected from the LV feeder meters. Hence the abstract data flow diagram Figure 9 which was presented in Section 7.6 is modified. Figure 12 shows the new abstract data flow diagram. The the data points D.1 to D.7 remains the same, however the data is collected from the LV feeder meter instead of the end-user's meter. If the numbers of end-user points connected to a LV feeder meter are few, the interval data from the LV feeder meter could still profile the end-users. Hence it is better to apply the data anonymisation and data aggregation process to the interval data from LV feeder meter.

Replacing the existing online EMS with CEMS modifies the existing points O.1 to O.3 (refer Table 15) and also introduces new data points O.4 to O.10. The new data points O.1 to O.10 are discussed in Table 28.

Table 27: Proposed mode of operation for CEMS

Mode	**Operating pattern**	**User Type**
Standalone	In this mode, the application will work without transmitting user-entered data to the service provider. The present demand signals can be fetched from the service provider's website or entered manually. Consumers who are particularly concerned about privacy and data-sharing with the service provider can use the application in this mode. There should also be an option for these users to synchronise their details with the service provider if they wish to. To run the application in this mode, the user does not even need a smart meter in their premises.	Type1 Type2
Online - partially synchronise with service provider	In this mode, the application will work with minimal sharing options. This option is useful for a user who would like to get favourable billing option from the utility. The user can share their self-entered user-profile with the utility. Even for this mode, the user does not need a smart meter in their premises. The meter profile generated using can be locally programmed into the interval meter	Type1 Type3
Online - fully synchronise with service provider	In this mode, the user can receive all alerts and demand signals from the utility. The user can opt to have the meter remotely reprogrammed with the new meter profile and request for receiving (in real-time) all possible hints and tips for energy usage. To operate in this mode, the user requires a smart meter (with remote communication module), and they should consent the utility to have remote access to their meter to make modifications to the meter profile.	Type3 Type4 Type5

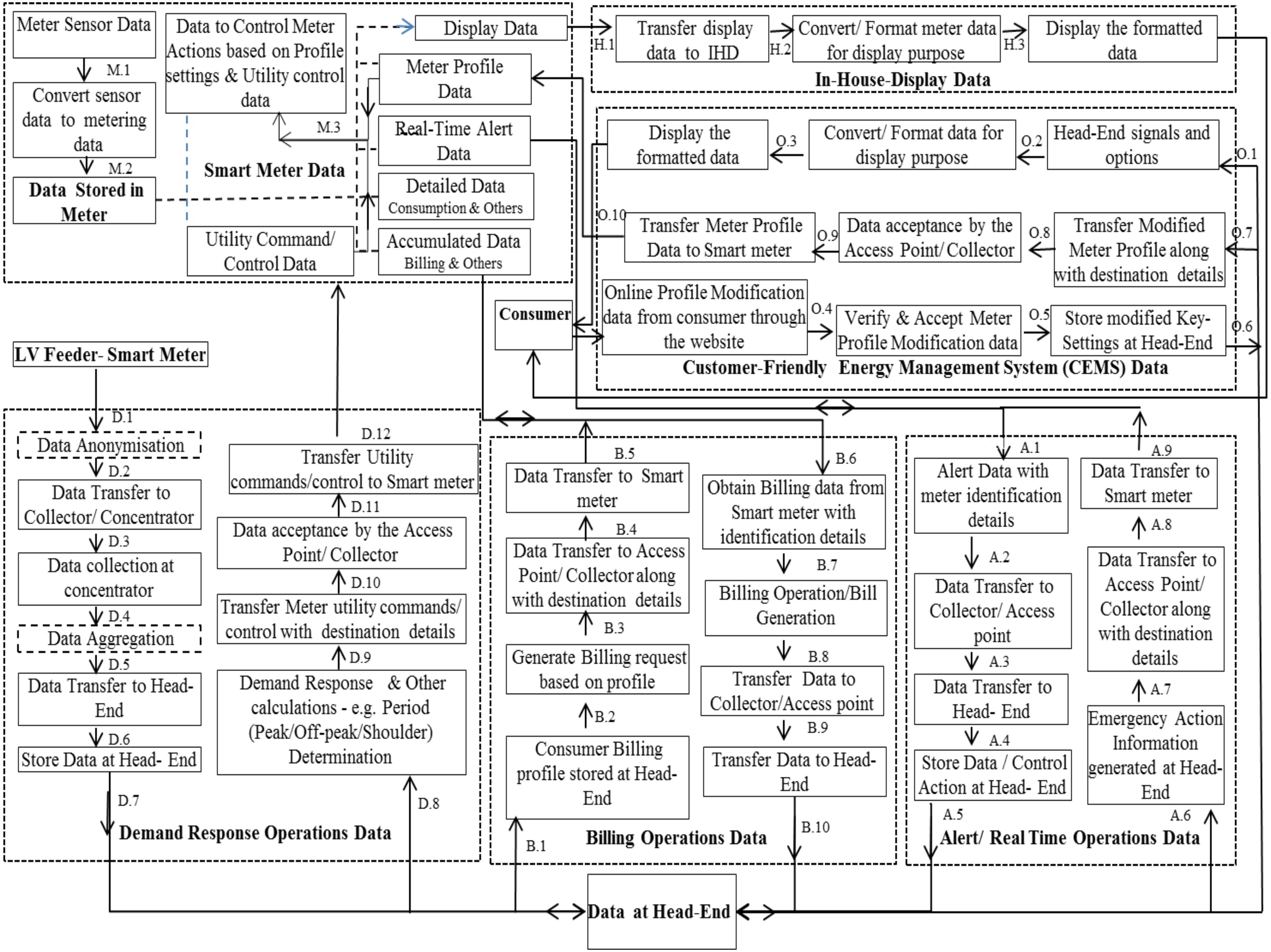

Figure 12: Additional Data Points in the Abstract Data Flow Diagram of Smart Metering System

Table 28: Modified data points listed in the abstract data flow model

Point	Consumer Energy management System (CEMS) Data
O.1	CEMS will be online tool that helps users input preferences to identify energy options and choices. The service provider should have a secure head-end database that stores these options and choices.
O.2	Any information that is retrieved from the head-end database should undergo appropriate conversions and formatting before displaying to the consumer.
O.3	The data and interface available at the front-end should be secure, accurate and user-friendly.
O.4	The user entered data should be accurately captured by CEMS. The algorithms used to perform calculations on the captured data should be accurate and the output generated should be accurately displayed to the user. The data flow finishes at this point for users that opt to use CEMS in standalone mode
O.5	For users who wish to use CEMS partially or fully synchronised with service provider, the input data and the information obtained after calculation will be send to the head-end. At this data point, the system needs to verify and attach the the user profile with the derived data what will be used for meter profile. The verified consolidated data should be send to the head-end.
O.6	The service provider's head-end on receipt of the data should verify, validate and store the information the database.
O.7	Based on the meter profile modification received, the service provider should generate control signals. The control signals should have the accurate information of the new meter profile, the receiving smart meter details and the collector details to which the smart meter belongs.
O.8	The collector on receipt of the signal should check its validity before transmitting to the end-user.
O.9	The smart meter on receiving signal from the collector should verify the meter identification details before accept the control command and the new meter profile. The data may require appropriate formatting before it is stored into the meter
O.10	The meter should verify the compatibility of the new profile data and the priority of meter operations before reprogramming the meter with the new profile data. On the start and finish of meter reprogramming, event and alerts should be generated by the meter. These alerts will help the user and service provider identify that the meter has been reprogrammed.

This step completes the discussion of demonstration, feasibility analysis and recommended system modifications. The next step evaluates the effect on the quality attributes of the current system.

8.4 Evaluation

The proposed measures necessitate the following:

1. Creation of customisable meter profiles that can be programmed into the meter.
2. IHD to become an integral part of the smart metering system with more features than currently supported.
3. Creation of CEMS (alternatively modifying the existing EMS to become customer-friendly.
4. Introduction of smart meters at LV feeders.

This section evaluates the effect of the above modifications on the functioning of the current system.

8.4.1 Customisable meter profiles

The U1200 smart meters are capable of modifying meter profiles without affecting the main functionalities (accumulation data and billing related information). The meter can be programmed locally or remotely. The meter programming function can be executed in a short time (less than 3 minutes). In the case of remote meter programming, the profiling program has to be first sent to the meter. The time consumed for this operation varies on the network traffic and size of the program. The consumer's request will not affect the metering system's communication network as it is done online. However, the control commands and signals from the service provider can influence the network traffic. The service provider can regulate the traffic by executing the requests based on priority and network conditions. The service providers also need to follow verification process before the control signals are transmitted. This process may create a delay in the modification of meter profile at the user end. The meter profiles are mainly to effect the billing cycle, LCR control and feedback. In the case of billing cycle (most cases), a delay of ten working days is acceptable and in the case of LCR control and feedback a delay of two working days is acceptable. However, it may disappoint some consumers who need immediate actions. Although the verification process may cause delays and customer dissatisfaction, it cannot be compromised as a meter profile modifications particularly for billing and LCR mode of operation needs careful execution. The verification process can be automated to reduce delays and human errors. E.g. If a consumer request for a change in the mode of operation of LCR, the service provider can initiate an alert to the customer (through the medium the customer has registered with the service provider e.g. email/SMS/phone call). The control signal can be sent after the consumer validates the message.

8.4.2 Making IHD integral part of the system

In this research, recommendations are made to make IHD an integral part of the smart metering system as feedback is an essential consumer-friendly feature. Using IHD the consumer can view the detailed data (real-time) in the meter, alerts and events generated by the meter and feedback signals provided by the service provider.

Earlier the interval data (not real-time) could also be viewed from the EMS. This research suggests removing interval data collection by the service provider, hence IHD becomes the only viable source for the consumer to view the detailed smart meter data. Interval data can be read locally (optical read using software like EMPwin). However, this option is mainly limited to the service provider as they only have the device and software to read it locally.

Current IHDs provide useful information, but still they require additional features to become more efficient. Moreover, the communication technology used for IHD also has limitations. As mentioned in the earlier section Ecometer uses Zigbee. Zigbee devices have low-cost and power consumption, but its range is an issue. Zigbee has a range of 30-80m for Non-Line of Sight (NLOS) and 1-1.5km for Line of Sight (LOS). This low range may affect the connectivity in multi-dwelling systems. The connectivity limitation of IHD is a known issue. The research conducted by EDF Energy, Scottish Power and Siemens reports on the HAN connectivity issue in UK after surveying over 3000 multi-dwelling units. However, the report does not provide technical solutions [Worrall, 2014].

The communication technology used for IHD should have good range and the cost should also be low. A study of various communication technologies used for the smart metering system (refer Appendix A.9.1), shows that there are other cost effective technologies without range issues, e.g. WiMAX. However, this technology has other limitations. Hence a suitable communication technology cannot be recommended without further analysis and experimentation.

8.4.3 Introduction of CEMS

CEMS can be built on top of the existing online EMS. Instead of displaying the meter reading, it will focus on user's input to understand their needs. Current EMS displays the consumer's usage, alerts from the utility and demand signals. From this information, users have to make assumptions or approach an energy advisor to provide them further help. In that case, consumers have to pay further. With the CEMS the information is processed so that the customer can easily use it. Users who have even opted out of smart meter installation in their premises can use this system because it can work as a standalone tool. Even if the user does not have access to detailed interval data, they can receive tips on how to reduce energy wastage based on the data they input into CEMS.

The design adaptations (billing, feedback and LCR control) proposed are dependent on user information. The user profile needs to be accurate as it will be used to calculate bills. Hence the utility will have to use other verification methods to make sure that such information provided by the user is accurate. They will need to verify tenancy contracts, income certificates and government approved documents on special needs and family member listings. This cannot be considered as a tedious effort as many of these verifications are done for providing concessions (e.g. Centrelink in Australia). For the feedback, the data accuracy is not as vital as it is for the billing operation. For the LCR control, the data accuracy is vital as it changes the operating cycle of the equipment connected to that relay.

The user will need to be educated or provided with easy to follow steps to input their information into the system. The users should be informed that the calculations will be based on the information provided, and hence discrepancies will be observed if they don't provide correct information. Providing user needs and limitations to get a useful response is still better than having to analyse interval data at 15/30 min to make decisions.

Like many other online systems (e.g. banking), the CEMS should possess quality attributes like reliability, integrity, safety, availability and maintainability. Most of these qualities already exist in the current EMS. Additionally, attention should be given to the usability of the system. Current EMS mainly only requires the customer to login and view the details whereas CEMS requires the used to provide information necessary to create a profile and hence the interfaces should be easy to use. The data about user needs and preference could have privacy risk and hence there should be strict measures to patch any system vulnerabilities that will disclose this information. Needless to say, the system needs to be secure, to ensure there is no theft of user profiles and user data. The service providers should not misuse this data for any other purposes and also should not provide these data to a third party without customer consent. Additionally, with CEMS the consumers have the choice to work with the application as standalone and that way they can choose not to share their information with the utility.

8.4.4 Introduction of Smart Meters at LV Feeders

As mentioned earlier in section 7.7.3 feeder meters are not new in the industry. In 2013, Landis+Gyr launched the S650 Smart Grid Terminal in Europe. These meters are currently installed at the substation transformer in Netherlands (through Stedin - a Dutch energy company). Though sufficient information regarding the project is not available, the S650 product brochure states that it is capable of monitoring network and transformer, identifying outage and losses and balancing voltage and power flow [Landis+Gyr, 2013]. Such meters will be beneficial even for the LV feeders. There are also published research articles regarding feeder meters with smart capabilities. Trindade et al. discuss tracking power outage based on voltage deviations with the help of smart feeder meter [Trindade et al., 2014]. However, the use of LV feeders meters to extract interval data is not yet discussed. The smart LV feeders meters can use the existing communication network of the smart metering system. By shifting the collection of detailed data from end-user to the LV feeder, the network traffic and the data storage requirements also reduces. It also reduces the privacy concerns of the user as the detailed data at LV feeder level makes it difficult to relate it directly to the end-user. However, if the number of endpoints connected to a LV is few, some amount of profiling is still possible. Due to this possibility the anonymisation and aggregation of LV data is suggested (refer Figure 12). For consumer level smart meters aggregation was proposed at data collector point. In the case of LV feeder meters, only one or two feeder meter may be connected to a collector. Aggregating at this level will not provide sufficient privacy. There should be another access point further closer to the substation transformer where more feeder meter data can be collected for aggregation. The introduction of feeder meter is beneficial to the service provider and the consumer. Meters with similar capabilities are currently available. e.g. Landis + Gyr S650. However, it is not sure if it cost effective to introduce such meters at every LV feeder. The cost is likely to be lower when compared to the expense of deploying smart meter at consumer premises. In the Victorian context, as smart meters have already been rolled-out to the user, the communication network exists and the additional expense will be the cost of the LV meter. The environment of the LV feeder may also affect the installation. In Australia, there are pad-mount and pole-mount LV transformers. The pad-mount LV transformers are in secured cages, and meters can be safely installed in them. Some pad-mount LV transformers already have regular accumulation meters. For pole-mount transformers, secured cages need to be added to the lower end of the pole as it is done for other overhead network control and monitoring systems.

8.4.5 Effects on existing features

The proposed measures do not affect other features currently supported by the smart meter. The measures proposed are only trying to use existing configurable options within the meter to provide consumer-friendly features. Though the system recommends to avoid collecting the detailed data from consumer that capability is not removed from the meter. Hence it can be used by the service provider if required. The U1200 meter is able to do LP reads for a required time period. So even if the system does not automatically fetch the interval data, it can be later collected if it exists in the meter. The proposed measures also do not affect billing operations. However suggestions are made to have the bill calculation done in the meter and the bill amount only transmitted back to the system. For the bill calculation, the tariff rates can be sent to the meter.

All the proposed measures depend on the smart meters' capability to store meter profiles, perform advanced calculations and respond to control signals. In case of meter firmware corruption, all these activities will get affected. The smart meter has error handlers to check for deviation from calibrated values and other variables. If a deviation is found the meter can be made to ignore all operation commands and merely perform as a supply device. In such scenarios all necessary data in the meter during may get corrupted. However, the availability of supply is not disrupted and in the case of electricity availability of supply is more important than the availability and integrity of energy data. Though meter data corruption has not yet resulted in service shutdown or serious malfunction, it should not be assumed as not possible. Hence it is necessary to have the data flow points (refer Table 15 and Table 28) secured to avoid attacks and accidents.

8.5 Alternative Measures

Apart from accurate billing, the utilities' main business goal in introducing smart metering system is to facilitate demand curtailment. If demand curtailment alone is motive, alternative measures could be considered which may incur lower implementation cost and risks. Three such alternatives are discussed below:

(a) **Load shedding at feeder level**
Electricity substations have control mechanisms by which load can be selectively shed at feeder level [Sridhar et al., 2012]. If the demand is much more than generation capacity, this mechanism can be used to shed load in that area for short intervals. This demand curtailment method is easier, as it does not have too many extra parameters to consider. The provider only needs to choose the feeder and time-period for which the load has to be shed. This mechanism is already in use and usually the time and details of when the load will be shed will be declared in advance so that the end-users can take necessary measures to overcome the power loss. It can, however, have serious consequences for some consumer segments, such as people with medical needs and home-working professionals.

(b) **Higher tariffs for excessive usage beyond units allotted**
Another mechanism that is used for demand management is higher tariffs for excess usage. There is an allotted quantum of energy for each household in a given period. Usage above the allotted amount incurs a higher tariff. This way demand is not curtailed, but the higher production costs can be transferred to the user.

(c) **Prepayment meters with restriction in the units allotted for a family**
Prepayment meters are in use in few countries. Payment has to be made in advance, and the consumer can only use for what has been paid for. In countries where a consumer cannot be disconnected by law, the end-user continues to get minimum amount of energy until the next payment is made. This method could be used for limiting excessive usage. Every household could be allotted a set amount of energy, beyond which they cannot purchase, thereby restricting demand.

8.6 Discussion and Feedback

As part of the research, few interviews were conducted with consumer advocacy groups (Public Interest Advocacy Centre Ltd and Consumer Utilities Advocacy Centre (CUAC) in Victoria) and industrial expert (from Landis+Gyr and Select Solutions) in Australia. Discussions were also made with Energy research groups in prestigious universities (Cambridge and University College London). A survey was done to understand the general opinion of energy consumers.

The consumer advocacy group member from CUAC (in 2013) suggested that currently no actions are being taken towards identifying consumer-friendly features nor are any efforts made in identifying consumer segments and their needs. There are few different contract options provided by the retailers and the consumers can choose an energy plan. He suggested that it will be beneficial if consumers can be provided with additional features as proposed. The industrial expert from Select Solutions (in 2015) indicated that current focus is in creating consumer advisors within the industry who can be approached by the consumers with their energy data to get advice on suitable energy plans. He also indicated that consumer-friendly features would be beneficial.

Ross Anderson (Professor of Security Engineering at the Computer Laboratory in Cambridge University) during the discussion in 2014 stated that smart meters are tools that the service providers can use to make profit. He also added that in a law–abiding society it is sufficient to have a feeder meter to check if there is wastage or theft and to let consumers' phone-in the retailers or service providers to report on the quantum of energy consumed.

The survey which was taken by 50 people from different countries in the world indicated that consumers are willing to accept a smart meter if it can give them better feedback and help in reduction of bills. It also revealed that they will not be willing to use the system if it results in increase of bills and impact their privacy. Due to the small number of participants the results of the survey cannot be considered as conclusive.

The above discussions and feedbacks are positive indicators for the research undertaken. However, small-scale evaluations are not accurate in projects and systems that involve the greater populations. Moreover, it is not easy to setup testbeds to conduct a concrete analysis. Hence the evaluation conducted in this thesis is limited to logical arguments and illustrative scenarios which are acceptable assessment methods for DSR (refer Appendix A.12.2). Moreover, careful considerations have been given to identifying all possible user types and ways in which their needs vary. Based on this information proposals have been made to identify solutions that can satisfy the user groups identified. It is this consideration that is often lacking in smart metering projects.

8.7 Generalisation

The proposed measures have been demonstrated and evaluated in the Victoria's smart metering context. However, the above demonstration may not exactly work in other contexts. It will depend on the capabilities of the smart meter and other elements that are used in the system. To enable other smart metering systems to be compatible with the proposed features, they may require system modification which may include firmware/hardware change and systems upgrades. The expense of those updates and the impact on the stakeholders need to be analysed before any initiatives are made. Hence, a generalised implementation strategy cannot be provided for a smart metering system. Instead, based on the analysis and findings in this thesis, a generalised consumer-friendly framework has been made that can be used as a check-list by those engaging in grid modernisation projects. The current smart grid proposals are mainly narrowing the considerations on the infrastructure and how to add more information systems. If such newly build systems create risk for the stakeholders involved, it will be expensive to retrofit the system. Additionally, it will be inefficient to run those systems merely because they are deployed. This framework will contribute to user-centric and secure architecture which will ensure that the infrastructure supports the requirement of the mass. This framework will also help in identifying the areas of the grid that need modernisation and will help in making appropriate decisions in the Smart Grid design. Figure 13 shows a diagrammatic representation of the proposed framework and its steps are summarised in the following section.

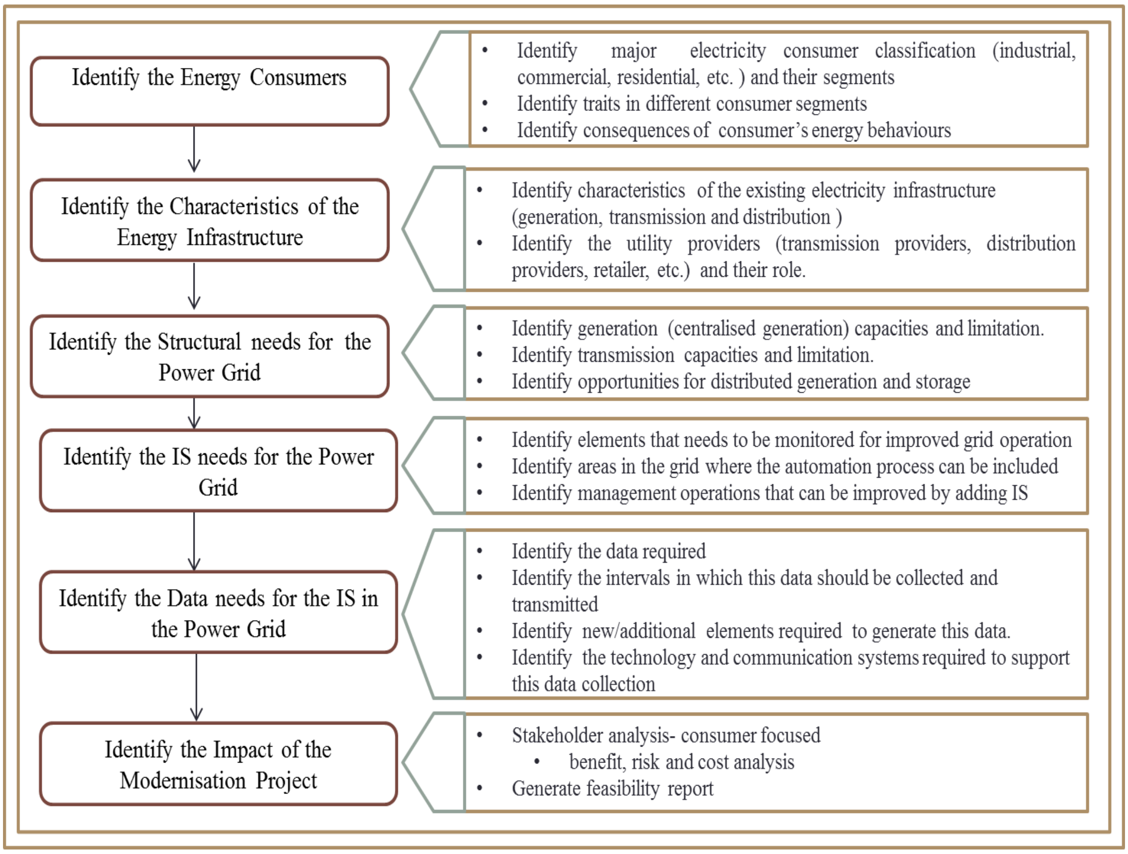

Figure 13: Framework for Consumer Focused Smart Grid Initiatives

8.7.1 Identify the Energy Consumer

The first step is to analyse the consumers in the area where the project is planned.

- Identify the major classifications of electricity users in the area where grid modernisation is considered. Apart from residential consumers it is necessary to identify other users that exist (e.g. commercial and industrial users).
- Identify residential consumers' segment and how they will be affected by changes in the power grid.
- Identify the different supply sources and tariffs existing for different consumer segments.
- Identify the consumer behaviour and attitude leading to unnecessary demand and wastage of electricity.

- Identify control measures are already in place for demand and carbon footprint reduction.

8.7.2 Identify the Characteristics of the Energy Infrastructure

The next step would be to analyse the characteristics of the power supply.

- Identify the existing infrastructure that supports the power supply in the region. This step should identify the power supply sources, quality of transmission and distribution system involved.
- Identify the parties involved in the market supply chain (transmission system providers, distribution providers, retailers and other third parties).

8.7.3 Identify the Structural Needs for the Power Grid

After analysing the consumers and the infrastructure, the operation and performance of the grid needs to be analysed.

- Identify the characteristics of Centralised Generation (CG).
  (a) The resources used for CG have to be identified along with its cost effectiveness.
  (b) The distances between the CG source and the destination have to be identified. This will help in determining its cost effective.
- Identify the characteristics of transmission network.
  (a) Identify problems in the transmission network. Identify the feasibility of replacing elements the transmission network if problems exist.
- Identify possibilities of Distributed Generation (DG) and storage in the area. Micro-generation and DG will be a better choice if replacing elements in the transmission network are expensive or the CG is inefficient.
  (a) Identify suitable DG source and locations for the same.
  (b) Identify feasibility of micro generations using PV panels or other sources.
  (c) Identify feasibility of mass storage units and locations for the same.

8.7.4 Identify the IS Needs for the Power Grid

With the information on the consumer, the infrastructure and characteristics of the it will be feasible to identify the IS required for energy management in the modernisation project.

- Identify consumers' information requirement.
  (a) Feedback on best energy choices.
  (b) Suitable storage options.
  (c) For micro generation, the best time-frame to feed-in power to obtain the best rates.
- Identify service provider's information requirement. The service provider will need information to monitor the reliability of the grid.

(a) If the grid can receive power from different sources, it will be beneficial to identify which sources are more beneficial and economical.

(b) For operational efficiency, information is required to

   (i) Identify if there is excessive power loss in the system by theft and/or power leakage.

   (ii) Identify factors causing power outages: e.g. aging elements in the transmission and distribution network; elements causing network overload there by causing the generator and transformers to trip, and earth fault.

- Identify information requirement of all other stakeholder involved.

8.7.5 Identify the Data Needs for the IS in the Power Grid

After identifying the areas in the power grid that requires automation processes and the information systems needed, the next step will be to determine the data required for the automation process. Identify and analyse the data that will be required for the operation of the IS identified in the previous step. In this research, it has been noted that one of the primary concern with the smart meter is the frequent transmission of detailed consumption data which can affect consumers' privacy and security. If the system can operate without that data, the storage needs, security needs and network traffic reduces.

- Identify data required for improving grid operations.
- Identify the intervals in which this data should be collected and transmitted to efficiently automate the operations.
- Identify the need for new/additional elements to generate the required data.
- Identify the technology and communication system required to support the collection and transmission of the required data.

8.7.6 Identify the Impact of Modernisation Project

By completing the above steps, the information systems and its data requirements can be identified for any power grid modernisation project. This information is not sufficient to make decisions on modifying critical infrastructure like the power grid. It is also necessary to analyse the benefits and risk for most of the stakeholders particularly the end-users. There is a need to conduct the following analysis:

- Benefit Analysis

(a) It is necessary to ensure that the identified requirements are matching the stakeholder expectation. The first step in this framework identifies the consumer needs and limitation. This information will also be helpful in determining the possible benefits. This information can further be confirmed by involving the users or their advocacy groups. As multiple stakeholders are involved, requirement elicitation methods chosen for each segment will also vary.

  (b) Align the system features with the user requirements. Identify benefits as: Guaranteed, and Possible (and the affecting conditions).
  (c) Identify gaps

- Risk Analysis
  A risk analysis framework should be created to follow a structured analysis to identify risk and control measure. A suitable framework for smart grid projects was presented in this thesis (refer Figure 3). During the risk analysis, the external factors, socio-economic and geographic factors also need to be taken into account.
- Cost Analysis
  Finally, the cost effectiveness of the system should be analysed. It is critical to identify if the cost of operating the system, based on the identified features and control measures, will be economical and profitable to the stakeholders involved.
- Generate reports
  Based on the analysis, reports can be generated on the effectiveness of the system and it will have detailed information on the benefits, risk, cost and external factors for the project. This information will be useful in deciding if the system will be accepted by the end-user and other stakeholders involved. It will also help in identifying regulatory measures and alternative measure that could be introduced.
- Recommend Modifications
  Based on this analysis, recommendations to modify the system can be identified. This information can be used to make corrections to the planned system. Consumer resistance to various smart metering projects could have been avoided if the project proponents had considered user needs and realities before or during the system design. By following this framework, the project's sponsors can identify which infrastructure to invest on rather than starting with a smart metering system.

This framework enables a consumer friendly analysis and it helps to understand the energy consumers. It provides sufficient information to identify whether consumer behaviour and attitude are causing the stress to the power system. If it is identified that consumers are energy conscious, and the current tariffs are economical, then introducing a system to collect detailed consumption data and providing it in real-time to the end-user is not going to provide any added benefit to them.

8.8 Summary

This chapter presented a demonstration and evaluation of the proposed artefacts to validate its feasibility in the current context. Most of the proposed measures are configurable features in the meter. Modifications were suggested to the current EMS. The modified system which is referred to as CEMS will have provision for the user to input their needs and limitations. This system will help in identifying consumer segments and the billing and feedback options for each segment. It can work as a standalone system and in two out of three suggested modes of operation; an interval meter will be sufficient (does not require communication capabilities). The proposed measures also don't affect the quality of the existing features. One limitation of CEMS is that the accuracy of its findings depends on the consumer-provided input. However, a consumer can be easily educated to use the system, and it is much easier than having to analyse detailed consumption data. The demonstration indicated that the proposed measured could be implemented in the Victoria smart metering context. However, it cannot be generalised as the smart meters used in each context vary in its capabilities and configurations. To apply the proposed measures in other settings may require the system to have firmware/hardware upgrades. This chapter finally presents a generalised framework for power grid modernisation projects. This consumer-friendly framework can be applied to any smart grid projects to identify the benefits and risks to all the stakeholders involved.

Analysing the problem situation created by the introduction of smart meters in the residential consumer premises has generated several findings that have been reported in Chapter 3- 8. The next chapter is a discussion of all the outcomes derived from this research.

Chapter 9

Discussion

The outcomes from the research is briefly summarised in this chapter. Then this chapter proceeds to compare the finding from this study with other research findings on relevant themes.

9.1 Thesis Findings

This section provides a summary of the thesis as a whole.

The consumer concerns over smart meters and the factors leading to those concerns have been identified and classified. This analysis identified the lack of consumer segmentation and application of customer friendly requirement elicitation and risk analysis practices. Consequently, as the first step towards a consumer friendly solution, customer segmentation based on various socio-economic conditions was derived. Then a risk analysis framework suitable for consumer friendly analysis was developed, and requirement elicitation techniques suitable for residential consumers were determined. This order was followed as the analysis began from a problem situation. These activities need to be incorporated during the planning phase of the project, and it should start by the identification of all stakeholder followed by suitable techniques to elicit the stakeholders. Based on the user requirements, the users need to be further segmented, and then a risk analysis strategy should be identified to analyse how the users will be affected by the system.

Any system that considers end-users a single entity and assumes that they all have the same goal is at the risk of rejection by at least those end-users who do not have the goal assumed by the designer. Hence customer segmentation was given primary focus to identify the different requirements of each user types. This research demonstrates that consumer segmentation and scenarios analysis can be used to determine the dynamics and behaviour of the system. This study further focuses on identifying measures to reduce the concerns over smart meter data and in identifying useful features for residential consumers.

Different control options for smart meter data (transfer and storage) are identified in this research. These options provide choices for different consumer segments, and yet major operations like billing are not affected. The possibility of adding extra security and privacy features to the system does not justify the transfer of consumer's detailed consumption data to the service providers. This study has demonstrated that grid management objectives can be achieved through the use of aggregated consumption data, without acquiring individuals' consumption data. Distributing intelligent metering devices across the grid has been proposed as a better option to achieving network intelligence, and this reduces a significant issue related to smart meter data.

The consumer specific functionalities include billing options to suit circumstances, feedback information that takes the guesswork out of the user and specific features for different consumer segments. The specific features have been demonstrated using two scenarios (consumers with medical need and different tenancy status of users).

The findings in this thesis can be summarised as follows:

1. The research reinforces that residential consumers cannot be considered as a single entity, and they need to be segmented to identify their choices and limitations.
2. This study has demonstrated that consumer's consumption data is not the key element for the demand side management and that intelligent systems can be built without this data.
3. Pricing signals cannot surely control consumer energy behaviours. Various factors affect the energy options, and daily routine is one major factor that mainly limits customers' flexibility in energy decisions. However, rational feedback can be helpful for users, and this research has identified that detailed consumer data is not required for providing intelligent feedback to customers.
4. Consumer-specific features like billing choices and customised user profiles can be implemented without the use of detailed consumption data from consumers.
5. Distribution of monitoring across all elements of the power grid will be more useful for all stakeholder and components in the network and less stressful for the consumer.

A limitation of this study is that quantitative validation on consumer acceptance of the proposed measures has not been conducted. However, many validation studies conducted by the project proponents on a fraction of the users which yielded positive results were later abandoned or faced consumer resistance. This outcome strongly implies that even a minority percentage of unsatisfied customers can cause a project to fail. Wherever empirical investigations need to be conducted for essential services like electricity, the whole population or all categories of consumers need to be covered. It is not within the scope of this research to conduct such an analysis. However, careful considerations were made during consumer classification to include the best and worst case. For each factor examined, the proposed measures provided choices for each customer segment identified.

9.2 Comparison Study

The first discussion is about consumer segmentation. Systematically reviewing the published work on energy-consumer behaviour and their concern to smart metering projects helped in identifying characteristics that define an energy consumer. Those characteristics (Refer Section 6.2) are:

- Energy requirements
- Ability to modify usage

- Willingness to accept new technologies
- Ability to comprehend information

After analysing various smart metering and grid modernisation projects, it was noted that there always existed a small segment of the population that resisted or rejected the modification proposals. Most of the troubled projects had no alternate option for the segments of the consumer that were resistant. This research focused on identifying options and choices that satisfy most consumer segments (even the negative segments). First steps taken in this research were to identify consumer segments for each of the category listed above; and these are discussed in Section 6.2.

Kelly and Knottenbelt (2016) reported on a systematic review to identify the effectiveness of disaggregated electricity feedback in residential consumers. They examined 12 studies from 2002 to 2015 and found that disaggregated electricity feedback may not be necessary to achieve savings and that it would be sufficient to provide users with aggregated feedback. They found that across the 12 studies there was an average of 4.5% reduction in electricity usage. They also mention that the energy enthusiasts are the group of people who used the disaggregated electricity feedback for making necessary changes and reduced their electricity consumption [Kelly and Knottenbelt, 2016].

The findings of Kelly and Knottenbelt are in agreement with the results obtained from this research. The segmentation of consumers based on 'willingness to accept new technologies' created five user types (refer Section 6.2.3). The 5^{th} user-type is referred to as the 'Technology enthusiast and energy conscious user'. They have been classified as the category that will make maximum use of technology to manage their energy usage. Additionally, it was identified (refer Section 3.4.2) that energy reduction is readily applicable in circumstances where there is wastage. This could be the reason why the average energy reduction across all the studies analysed were less than 5%.

In the above study, the authors also noted that the 4.5% energy reduction could be a positively-biased estimate. They idenitified that in eight studies analysed, there was no control for the 'Hawthorne effect' and due to which there were chances that the participants reduced their energy consumption as they knew were being observed as part of the energy study [Kelly and Knottenbelt, 2016]. Davis et al.(2013) has earlier shown the effect of participation bias errors in energy studies (refer Section 3.4).

The research that was undertaken in this thesis carefully avoided similar biased user studies that are often done for the purpose of generating empirical results. Additionally, this research did not focus on identifying the percentage of monetary saving or energy reductions possible with the smart metering system. This was mainly because the analysis conducted showed that only wastage can be easily reduced and any further reduction required significant modification in the individual's or household's lifestyle. This research instead focussed on identifying different possible options and choices for different segments of consumers. The choices also included billing choices based on energy requirements and ability to modify usage. However, conceptual models for the smart metering system generated as part of this research showed the need for IHD to be an inherent part of its design as it will be required for feedback (refer Section 8.4). The IHD should have better features than currently supported (refer Section 7.8.1 for the informative feedback choices based on users' ability to comprehend information).

Opris et al. published a research article in 2015 which analyses the impact of the transition from existing meters to smart meters on different types of consumers. They identified that for smart metering systems to become beneficial, residential consumers should be actively involved from the early stages of the planning process. Similarly, they classified users based on consumption (high to low) and behaviour (good to bad). They noticed that people who benefited the most from the smart meters were those with good behaviour and high consumption and the category that had the least benefit from the smart meter were those with low consumption and bad behaviour [Opriş et al., 2015].

Consumer segmentation discussed by Opris et al. also can be mapped to segments identified in this research (Refer Section 6.2.4 for the consumer segments based on 'ability to comprehend information'). Of the 5 types identified, the 'disinterested' user type may not wish to spend time tweaking their devices and may not welcome or respond to any feedback. This user type is similar to the 'bad behaviour' user segment discussed by Opris et al. Similarly, in this thesis, consumers are categorised into six types based on their ability to modify usage and the 'low usage (non-flexible)' consumer is one user-type. If the capacity to adjust usage is plotted against the capacity to comprehend information, it can be noted that the 'low usage (non-flexible)' consumers who are 'disinterested' will have fewer benefits from a smart meter or similar feedback. If the users are willing to have inverters or batteries, then smart meter (SM)s can help these users reduce peak period consumption. The smart meter can check the signals from the service provider and switch from the grid supply to the inverters or batteries system during the critical peak period. They can also charge the inverters or batteries during the off-peak period (this smart meter feature is discussed in Table 23).

In this thesis, another consumer segmentation is based on 'willingness to accept technology'. If this classification is considered along with the other two classifications discussed above, it can be noted that the 'disinterested', 'low usage (non-flexible)' consumers who are also 'highly resistant to accepting new technologies' will be the category of users who will benefit the least from smart meters. However, in this thesis, different billing options are proposed based on user's ability to modify usage. The proposal contains an option for 'low usage (non-flexible)' consumers (refer Section 7.8.2). This option does not help the user to reduce usage during the peak period, but it will assist them in reducing the bills (in comparison to the application of Critical Peak Pricing (CPP) and TOU tariffs).

The next discussion is on data privacy arising from smart meter data. The detailed interval data from the smart meter is capable of revealing consumer characteristics. It is argued that electricity consumptions information is less sensitive than financial transaction information of the consumer [Horne et al., 2015]. Studies have also revealed that data frequency greater than 1 MHz is required for identifying appliances more precisely [Armel et al., 2013]. Though some concerns over data privacy may be an exaggeration, it is still an issue that needs to be addressed by the service provider. In Australia, Wigan had pointed out that there were allegations that the market participant who had access to meter data provided unauthorised access to third parties (though the Electricity Rules prohibits it) [Wigan, 2012]. This shows that rules alone will not solve privacy issues. The system should have controls measures to ensure privacy of consumers' meter data is maintained. Many of the smart meter projects analysed in this thesis lack any control choices for end-users over their meter data. This thesis has shown in Section 7.5 how various control options can be implemented on a smart metering system to benefit different types of consumers.

The recent literature provides various suggestions for preserving privacy. Efthymiou & Kalogridis (2010) state that the electrical distribution network only requires the energy information at a distribution sub-station level and hence sub-stations should be the point at which all interval data from the end-user meters should be aggregated. However, this option still requires the interval data from the end-user meter to leave the consumer premises. The solution provided in this thesis removes that requirement by the introduction of smart LV feeder meters. Section 7.7 contains an analysis of electricity control systems and their stakeholders. It revealed that detailed interval data from end-users is not required for any control automation or decision making. If the detailed interval data from the consumer is used, it needs to undergo aggregation and conversions before it could be beneficial. Additionally, collection of detailed data from all end-points creates unnecessary traffic in the network. All these issues can be overcome with the use of smart meters at LV feeder level. This removes the need to collect any interval data from the end-user meter. The data from the feeder meter cannot be used to profile the consumer (provided there are sufficient numbers of consumers under a LV feeder). Additionally, suggestions are made to anonymise the data before it leaves the feeder meter and have it further aggregated at the sub-station level. As detailed data from the end-user is not needed, the consumer privacy concerns arising from the transmission of detailed interval data is significantly reduced. This modification will not affect the billing use-case (refer Section 7.5).

Apart from ensuring privacy, the smart metering systems should also be secure. Smart meters have been introduced with the intention of reducing thefts and errors caused by analog meters. However, there have been reports that the service providers have manipulated the meter data to make the meter record readings higher than the actual consumption. Similarly, it has also been reported that some consumers with the help of people working for the service provider (insider attack) have managed to modify consumption reading to lower values. The smart metering system adds new data points. The vulnerabilities in these data points may be exploited by attackers. Skopik et al. identified several vulnerabilities within the smart metering system. They further add that smart metering systems should be made physically robust; should have authentication and authorisation to access the system and should apply encryption to the data involved [Skopik et al., 2012]. However, they did not identify all data points that that could possibly be exploited. This thesis has identified all possible data points and associated security requirements (refer sections 7.3,7.4 and 7.6). During the planning phase of the project, efforts must be made by the service providers to analyse threat points in the system. The findings in this thesis will help in the process. However, control measures over those threats are not identified in this research as it would require detailed information of the infrastructure that will be employed. Cleveland has pointed out that the communication network chosen for smart metering system plays a significant role is deciding what control measures can be applied. Although various security policies and techniques exist, their application is limited. For example, it may not be feasible for smart meters to participate in some cryptographic processes. Similarly, if public cellular networks are used, there will be limitations in the types of security techniques that can be applied [Cleveland, 2008].

Enthusiasts such as Faruqui et al. state that every effort should be made to facilitate smart meter roll-outs to optimise the associated gain [Faruqui et al., 2010]. However, many smart metering projects face resistance from consumers. This thesis found that requirementanalysis and risk analysis from a consumer perceptive had been significantly lacking in most smart metering projects. Hence a risk analysis framework suitable for consumer-friendly smart metering projects was devised and requirement engineering techniques suitable for multiple energy stakeholders (including consumers) were identified. Additionally, sample templates were generated to elicit requirements from energy consumers. These templates are useful for project proponents in the planning phase. Finally, this thesis provides a consumer-friendly framework that can be used as a check-list by those engaging in grid modernisation projects (Refer 8.8). This framework will contribute to user-centric and secure architecture, thereby ensuring that the infrastructure supports consumers' requirements. This framework will also help in identifying the areas of the grid that need modernisation and will help in making appropriate decisions in smart grid transition projects. In the current scenario, a smart meter at LV feeder level and interval meters at consumer level will be more than sufficient. As the technology and communication infrastructure becomes robust and consumer confidence on the interval meters increase, the end-user meters can be upgraded to smart meters.

This thesis did not consider EVs for the estimation of the quantum of electricity for residential consumers. Verbong et al. states that EVs will become a new challenge for the electricity grid. They also state that demand from EV is expected to double the current average electric demand [Verbong et al., 2013]. Currently, in some places, consumers charge EVs from their residence, and this can make huge differences in the energy requirement for those consumers. On the other hand, EV charging stations are common in many countries.

9.3 Summary

This chapter is a summary of all the findings made in this thesis. It further compares the findings with other research work in the smart metering system and residential consumer domain. The next chapter concludes this thesis. The research questions are revisited. It also discusses limitations of this research and future research directions.

Chapter 10

Conclusion

The research questions identified in Chapter 1 are revisited and discussed in this chapter. The research contributions are then listed. Then this chapter proceeds to the limitations and future directions for the research arising from this thesis. The objectives that have been achieved from this research are as follows:

- A deeper understanding of consumer concerns and issues with smart metering projects.
- Set of measures that address the concerns and challenges that caused consumer wariness and oppositions.
- Demonstration and evaluation on the suitability of the proposed measures within the context of contemporary meters, grids, and projects.

10.1 Review of Research Questions

This section briefly reviews each of the research questions that was defined in Chapter 1.

1. What are the distinguishing characteristics of various smart metering projects?

(a) **What is the status of the smart metering projects around the world?**

The smart metering projects can be classified based on their success of roll-out. Some projects completed on time whereas others faced significant difficulties during roll-out and some delayed the roll-out to avoid issues. Some of the factors that affected the projects negatively were the function overload, infrastructure cost and users concern on the lack of friendly features. The smart meter projects in Sweden and Italy completed on time. The AMI projects in Netherlands and Victoria (Australia) faced significant issues during their roll-out. The UK considerably delayed their smart meter roll-out.

(b) **What are the characteristics of the smart metering projects that succeeded when compared to the those that faced consumer resistance?**

In Sweden, the smart meters were accepted by most of the public as they provided the users with an option to receive monthly bills and pay for actual consumption.

Earlier they paid their bills based on previous year's consumption data, and reconciliation bill was generated with the next year's reading. In the case of the smart metering project in Sweden, it is certainly evident that consumers benefited from this initiative. Their smart meter also had limited features. In Italy, smart meters were introduced mainly with the concern over power theft. As societies need to prevent unscrupulous practices, the smart meter installation with service-disconnect function was justified. Smart meter functions were also kept minimal.

In the case of countries like Australia and Netherlands, it was noted that consumer-friendly features were seriously inadequate and there was excessive data collection. Both these countries had frequent billing cycles and meter read(manual) even before the introduction of smart metering system. Based on their program, detailed meter data was collected to be transmitted to the service provider for enabling DR programs. Comparing these program with the succeeded projects it can be noted that these programs failed to demonstrate added benefits to the consumer.

In Chapter 7(sections 7.5 to 7.7), it has been identified that for applying TOU rates or other DR programs there is no actual need for collection and transmission of LP data. Moreover, in a society where most of the public abide by the law, there is no need to consider remote disconnection functionality. An Australian news article [Collier, 2014] reports that Australian Energy Regulator (AER) has approved an annual fee of $100 - $230 for the most common type of smart meter and consumer advocates mentioned that it is high time the system showed benefits for the amount consumers have already paid. This scenario indicates that features proposed by electricity industry mainly benefited the investors rather than the consumers.

Countries like the UK delayed their smart meter roll-out as they wanted to have a common ICT infrastructure to support current and future smart grid activities. They wanted to have a communication network future compatible to avoid changing meters or other devices as technology changes. Though the initiatives have a long-term benefit, these projects can also run into expensive failures if the deployment costs are high. In 2016, the much delayed smart meter roll-out started in UK and Institute of Directors (IoD) has criticised the roll-out and have even asked for it to be halted. In a discussion with Ross Anderson (Professor of Security Engineering at the Computer Laboratory in Cambridge University) in 2013, he stated that a combination of feeder meter and the option for consumers to report their energy usage would be more than sufficient in the UK context. The model that is proposed in this research is to distribute intelligence across the grid. This proposal is consistent with Ross Anderson's idea. In most cases a LV feeder level smart meter would be sufficient. It also reduces the privacy concerns arising from consumers' LP data.

2. Do the reported concerns highlight significant drawbacks?

(a) **What are the reported concerns? Are there concerns real or perceived?**

Consumers have both positive and negative reaction to the smart metering system. Unfortunately, the negative concerns have overpowered the positive features. Project sponsors have presented documents that highlight consumers' possibility to save on energy bills with the new system. However, with a high service fee, there are fewer chances that customers can make such savings as promoted. There is no sufficient documentation or evidence to show consumers have been considered during the requirement elicitation or risk analysis phase. However, not all concerns are real; the media have over exaggerated some. The consumer concerns reported over smart metering project includes privacy, security and control over supply, increased bill and even health issues. There are both real and perceived risks in the list. The health effects related to smart meters can be considered as a perceived risk as there are various radiating devices around the users both inside and outside the house, and consequently, the smart meter alone cannot be blamed for health issues. Control over electricity supply and meter data is a real risk. Lack of consumer-friendly features in the system is also a real concern.

(b) **What initiatives have been taken towards the reported concerns?**

Most of the efforts have been invested in educating the public to accept the system. Some projects have conducted an impact analysis but even then only after the projects were deployed. In most cases, it has been done from the perspective of the businesses. Some efforts are being made to add security and privacy measures to smart metering data. However, those efforts won't be complete until all data points are identified and analysed. In this research, all possible data points have been identified. To ensure that the system is secure there should be some control measure for each point.

(c) **What steps can be taken to overcome the weaknesses?**

The consumer concerns reveal the lack of end-user perspective in the planning of smart metering projects. Moreover, the failed projects also exhibit the lack of application of well-established practices like requirements elicitation and risk analysis. Additionally, all customers have been lumped together into a single entity, and their needs are assumed to be the same. These drawbacks need to be rectified in future projects to avoid consumer resistance to smart metering projects. For a consumer friendly outcome future projects should :

(i) Identify requirements from the end user. To obtain the requirements suitable requirement elicitation techniques should be applied.
(ii) Based on requirements elicited, identify user types and segments. Further analyse their assets and limitations.
(iii) Conduct risk analysis to identify the effect of the proposed system on the

consumer assets.

This thesis has delivered a considerable amount of information about how to address the weaknesses. The responses to third research question provide greater details.

3. Can consumer-friendly corrections be made to the smart metering system?

(a) **What features are required for a consumer-friendly smart metering system?**

The primary interest of the consumer would be financial benefits without a significant downside. With the detailed consumption data, in many cases, consumers are still not able to make efficient choices, and they may further require the help of energy advisors to make decisions. The financial benefits theoretically available to the consumer may only be $50 -$200 a year and obtaining those benefits require unreasonable efforts from the consumer. Additionally, some of the features advertised by the project proponent are not possible unless the electrical appliances are replaced with newer intelligent devices. Hence the project sponsors should focus on consumer-friendly features as well as from economic benefits.

The consumer-friendly features for the smart metering system include:

(i) Providing consumer with control choices over the smart meter data.
(ii) Identifying suitable consumer segment based on consumer input (needs and limitation).
(iii) Generating customisable meter profile to set the appropriate billing category, feedback requirements, mode of operation of LCR, and specific operations based on the identified consumer segment.
(iv) Identifying measure to limit the disclosure of LP to any other stakeholders in the power grid apart from the end-user.

This research has used variously reported consumer concerns to identify different customer segments. Then the conceptual architecture of the smart metering system (based on the current system) was analysed to identify suitable options for all consumer segments identified (best to the worst case). It was identified that all consumer segments could be provided with a choice of control over smart meter data without affecting important operations like billing. This research also showed that billing categories and feedback options can be created based on the factors that influence consumers' energy behaviour. On analysing current smart metering system, it was identified that these options can be programmed into the meter profile to provide the consumer with customised features. However, consumer-friendly IS is required to capture the user requirements. This research has identified that the current EMS can be modified to provide this capability. CEMS (the modified EMS) will use the consumer input to identify the suitable consumer segment and this information will be sent to the service provider to create customised meter profiles. The generated meter profiles after verification will be programmed into the meter (remotely/locally based on customer settings). This method also eliminates the need for LP data to leaves consumer premises. Though smart meters have communication capabilities to interact directly with an EMS, suggestions have been made to avoid connecting CEMS directly to the smart meter. Recommendations have been made to connect CEMS only through service provider to avoid additional data and access points in the smart metering system. It also provides opportunity to verify the request generated through CEMS before they are executed. For the consumer can use an IHD instead of an EMS for the real-time display of consumption data. Additionally, IHDs are customisable and also have the capability to be customised to receive the profile details and alerts from the service provider. Further, when the system and communication network becomes robust and widely accepted, CEMS can be made to connect directly to the smart meter. This option will provide additional benefits to the end-user.

A detailed analysis conducted in this research also revealed that detailed data (LP) from the end-user is not directly useful for other grid operations and stakeholder involved. If that data is used, it will have to undergo various calculations to provide meaningful information. Hence, distributing smart metering devices and sensors in power grid would be a better option. This option may require new infrastructure. The minimum cost includes the cost of the device, and the communication network (if the existing PLC network or the smart metering system network is not compatible). However, the operational costs and consumer related concerns will be less as they remove the need for collection and storage of customers' LP data at the service provider's head-end.

This approach reduces:

(i) The consumers' privacy concerns arising from the need to share LP data.
(ii) The network traffic arising from the frequent transmission of end-users' LP data.
(iii) The need for extensive investments for storage and computational systems (to store the LP data of all end-users and perform calculations on this data).

This research has shown that detailed interval data can be restricted to the consumer, and it will be sufficient to use the data from each level in the grid for appropriate purposes. E.g. LV feeder meter data will be sufficient to identify demand variation in a particular locality.

(b) **Can the identified measures be implemented in existing projects?**
The demonstration conducted in this research identified that the proposed measures could be implemented in the smart metering system in Victoria. Most of the features can be enabled by modifying settings in the meter profile. However, some additional infrastructure and modification to the existing system will be required.

In this thesis, consumer-friendly measures have been proposed to support consumer with useful features and controls. The prevailing smart metering systems were taken into consideration for making these proposals. The current smart metering system used in Victoria, Australia was chosen for the demonstration of the proposed measured. The U1200 smart meters used in Victoria are capable of having customised meter configurations and profiles. These meters are also capable of generating control signals that can be executed locally/remotely. The meter profile programmed into the meter will decide on accepting or rejecting a control signal received. These meters can be partially reprogrammed (locally/remotely) with a new meter profile. This reprogramming will not affect the relevant existing data (accumulated data used for billing and events list). These meters also have different options in which the LCR can be operated. Hence the proposed measures mainly require rely on settings in the meter profile that can be reprogrammed as per requirement.

For the proposed Consumer Energy management System (CEMS) system, additional features have to be developed. It needs interfaces for the user to provide their requirements. It also requires the algorithm to identify consumer segment based on the user input data. However, these calculations are more feasible than identifying user characteristics from LP data. The existing online EMS can be extended to provide the interface for CEMS. However, in CEMS there will be no display of LP data as the proposed system recommends not to transfer LP data to the service provider. It will be sufficient for the consumer to use IHD to view LP, and tariff and control signal from the consumer. Hence, IHD should become an integral part of smart metering system.

(c) **Can the solutions be generalised?**
The conceptual models and consumer-friendly features determined from this research are general to all smart metering system. However, an implementation strategy cannot be generalised as the smart meters and the communication technologies used in each context vary in its capabilities and configurations. To apply the proposed measures in other settings firmware/hardware upgrades or modifications may be required. The geographical and environmental conditions, population density and demographics have an effect on the system. All these elements need to be considered before choosing the communication network for the smart metering system. Each communication technology has strengths and limitations, and it needs to be thoroughly analysed before the project proponents make a choice. Commonly used techniques for the smart metering system have been examined as part of the thesis to identify the possibilities and limitations of the current smart metering networks. However, it has not been possible to suggest a standard network for all smart metering systems. The choice of communication network relies upon on various factors and some of the major factors are: availability of funds, the environment in which the system will be operating, and features that need to be acquired from the system.

Drawing on the knowledge gained from this research, a consumer-friendly framework general to all smart grid initiatives have been developed, though it was not possible to generalise an implementation strategy. This framework can serve as a check-list for all power grid modernisation projects. The analysis of energy consumers is the first and crucial step in this framework. Unlike other smart grid models which focus on system interoperability, this framework gives importance to analysing the end-users in the project location. It examines their energy behaviours and their impacts on the power grid and demand. This information is used to identify the infrastructure and IS required for improving the system. Based on this information the data needed for improved operations can be determined. The next and final step in the framework is also critical. It is the analysis of impact and benefits on the stakeholder involved, particularly the end-users. This framework can help the project sponsor identify the guaranteed benefits to its users.

Existing smart metering systems are a very large investment. These systems may take years to realise monetary benefit, and the life of smart meter is limited to 10–15 years. Hence it is necessary to plan these systems carefully. The project sponsors should be able to demonstrate the benefits to the end-users. The consumer classification and measures provided in this thesis can be used by practitioners to simulate the working of the proposed system. This knowledge can be applied during the planning phase to identify the system dynamics and predict the realisation of benefits. This process will help in avoiding the wastage of funds in costly field trials and roll-outs.

10.2 Research Contributions

The contributions from this research work is summarised in this section.

Major Contributions

The major contributions of this research are:

1. Consumer segmentation those are useful for classifying the residential-energy consumers (Refer Section 6.2). The segmentation is based on

    - Energy requirements
    - Ability to modify usage
    - Willingness to accept new technologies
    - Ability to comprehend information

2. Generalised Conceptual models of user-friendly Smart metering System (Refer Sections 7.1 - 7.6). It includes smart metering system architecture and data flow diagram. This also includes the concept of an energy management system based on consumer input (CEMS).

3. Identification of user-friendly features in smart metering system (Refer Section 7.8)

- Informative feedback for different consumer segments
- Billing choices based on consumer input.
- Specific configurations to improve the energy activities of consumer segments.

4. Generalised Framework for Consumer Focused Smart Metering Initiatives (Refer Section 8.8). The framework can help service providers analyse the power grid and the energy stake-holders and thereby identify areas that require modernisation.

Minor Contributions
The major contributions of this research are:

1. A risk analysis framework for consumer-friendly smart grid initiatives (Refer Section 6.3).
2. Identification of Requirement engineering techniques suitable for consumer-focused smart metering projects (Refer Section 6.4).
3. Identification of the role LV feeder meters in reducing privacy concerns arising from residential consumer LP data (Refer Section 7.7).
4. Identification of User-Friendly features that can be customised into an existing Smart meter (U1200 meter used in Victoria, Australia) (Refer Section 8.8).

10.3 Limitations of the Current Work

Most of the information used in this thesis is based on documents, reports and research articles that are available publicly. There was limited access to detailed information from industry. Four years of working experience on smart meters (in the R&D lab of Landis +Gyr in Sydney) considerably assisted in a comprehensive analysis of the smart meters, particularly the U1200 meters. This knowledge was beneficial for analysis and demonstration of the proposed features for the smart metering system in Victoria, Australia. Additionally, visiting the Energy Management System used by ActewAGL (electricity distributors in ACT, Australia) as part of a student work program during research provided insight into the EMSs used by distribution providers in Australia. Field testing would have helped to enhance the validity of the proposed measures, but it was not feasible without industrial support. Though the problem analysed is relevant to the industry, there was no success in finding the right industrial partner to collaborate on this project. This issue signifies the need to bridge the gap between industry and academia for effective problem solving.

Another limitation of this research was the lack of end-user participation. A survey was conducted to identify the attitude of electricity consumers. Hardly 50 participants took the survey and hence the data was not used to make any judgments. The results from surveys can be reliable only if the most of the users are involved and mass surveys are beyond the scope of this thesis. However, it has been noted that similar surveys that have been done on consumer and energy behaviours and consumer response to smart metering systems and demand response programs had varied results. Further, surveys measure only the subjective characteristics of the artefacts and that becomes questionable as these new features are not well known to the user. It has always been noted that there is at least a small segment of users who resist new schemes. Using CD, a template was created which could have helped in eliciting the requirements from the user. However, a user study using the developed template to identify response to various signals from the service provider was also not possible due to the lack of the setup and suitable participant.

Another limitation of this research is that EV were not considered as part of the discussion. EVs draw more power than other residential requirements. Currently in some places, consumers charge EV from their residence, and this can make huge differences in the energy requirement for the concerned consumers. Estimation of the quantum of electricity such households has not been covered by the classification that was described in this thesis. However, there are other options available for EV charging. In countries like Netherlands, there are separate charging stations for EVs. EV charging stations are currently under trial in Australia. If EV charging stations can become a standard case, the power requirements for EV can be kept separate from other residential energy needs. This would be a better option until EVs are widely accepted.

10.4 Future Directions

Each contribution area in this research can become further areas of research. Using the risk analysis framework developed, a detailed risk analysis can be conducted for all the data points that have been identified in this thesis. This will help to create a detailed inventory of threats, vulnerability, available control and other risk elements. Project sponsors can use this list to analyse existing or proposed projects to identify measures needed to make their system robust. Similarly, the templates that were created to elicit the energy consumers can be used to conduct detailed energy-behavioural studies through live laboratory and setups to study end-users.

The features proposed in the smart metering system were mainly customisable functions in the smart meter and consumer-friendly energy management system. For specific functionalities, two scenarios were discussed in this thesis - requirements for people with medical needs and balancing data access between tenant and landlord). The same method can be used to identify specific needs of other user segments. Similarly, the requirement specification for the CEMS has been described in this thesis. This area has promising research directions. CEMS can help in identifying the energy requirements for the end-user. The consumer segment type, the number of inhabitants, the residence characteristics and the weather conditions will be data that will be used for the calculations. Further research can focus on developing and testing the CEMS and in identifying elements that are required to fine-tune the solution. This research has also not identified the impact of consumer-friendly solutions to the profitability of the investors. Identifying the revenue models that can be successfully incorporated into the services provided will motivate the electricity industry to focus towards more consumer-friendly solutions.

The relevance of feeder meters with intelligent features were identified in this thesis. These LV feeder-meters can provide sufficient information to the service provider and limit the end-user meters to features that are beneficial to the consumers. There is lot of scope for future work in this area. Additionally, in the changing grid, the relevance of energy storage systems and micro grid were discussed in background chapter. Power generation at the consumer end and storage devices like batteries were considered in the thesis. However, in the changing power grid, the relevance of energy storage systems at different levels in the grid and micro-grids are increasing. These elements are not discussed in the representation made in this thesis mainly because they have not become general components in the network. There should be intelligent sensing and measurement devices for these components to be integrated appropriately into the power grid and to identify the capabilities of those intelligent information systems also provides future research directions.

10.5 Conclusion

Smart metering systems are important and high-value infrastructure projects in the smart grid arena. However, these schemes are at risk of consumer rejection, and investment failures. The research reported in this thesis has highlighted ways in which the needs of customers can be included without significant effect on core functionalities. It is necessary to ensure that systems designed to improve the profitability of the businesses also consider the requirements of the end-user. Electricity is an essential commodity and not even a small segment of the user can be excluded for not accepting modernisation efforts from the service providers. The consumer should have the choice to become active players or remain passive users. In the current scenario, the smart metering system has not provided sufficient benefits to the end-user. The current trend shows that the lessons learnt from failed smart metering projects are not assertive enough to make the industry change the direction of their focus. Instead, they are considering educating the users to accept the system.

In this thesis, the smart metering system has been scrutinised from a consumer point of view. DSR methodology has been followed to carry out this research. As DSR focuses on deriving artefacts for real world problems, it was found suitable for this situation. Following the DSR framework, the consumer concerns over smart meters were systematically analysed to design the artefacts that could solve this problem. These artefacts included models, frameworks and methods. An illustrative scenario (the smart metering context in Victoria) was used to demonstrate the effectiveness of the artefacts. Finally, the effect of those artefacts on the quality of the system was evaluated. As generalisation is not part of DSR process, a generalised implementation strategy could not be derived. However, based on the information gathered from this research a framework has been generalised that can be efficiently followed for future smart metering projects to obtain a consumer-friendly outcome.

This research applied consumer-friendly techniques to identify features that are beneficial for a broad range of consumers. Most of the features are easily configurable in a high-end smart meter. The businesses should ethically choose secure, user-friendly solutions over more profitable solutions that have no end-user focus. Additionally, there should be strict regulations to control industrial practices to ensure that their choices do not disadvantage the end-users.

Appendix A

Appendix

This section contains definitions, detail information and diagrams that have been drawn/extracted from various established sources. This section has been added for easy reference.

A.1 Electricity Terminologies

- (**Load** – Load refers to the electricity consumed by the customer and it is measured over a time period. Load/consumption is measured in Kilowatt Hour (kWh).
- **Demand** - Demand is the rate at which energy is delivered to scheduling points. It is measured in both Kilowatt (kW) and kilo-Volt-Ampere (kVA).
- **Energy** - Electric energy (kWh) is the ability of an electric current to produce work, heat, light, or other forms of energy.
- **Power** – Electric power (kW) is the rate at which electric energy is transferred and it is measured by capacity.)[EIA, 2017; National Grid, 2015]
- **Peak Load** – A peak load refers to the maximum simultaneous electricity demand for some portion of the electrical system over a particular time frame [EIA, 2017]. It is unusually distinguished as an annual, daily, or seasonal peak. Peak load is categorised as end-use peak and system peak. The end-use peak is measured at each consumer site whereas system peak is measured at the generating plant.[Koomey and Brown, 2002]

A.2 Electricity Supply Chain

- (**Electricity generators**: They usually generate electricity the traditional way using centralised generation units. It could be thermal power plants, gas turbines or nuclear power stations. Alternately renewable sources like wind, solar farms and hydroelectric power stations are also used. Depending on the source, the power generated is then injected into the (high-voltage) transmission system or directly into (medium or low-voltage) distribution systems before being delivered to the end user.

- **Transmission Operators**: They are responsible for running the transmission systems and for ensuring the long-term ability of the system to meet reasonable demands. They are also responsible for operation and maintenance of the high-voltage transmission lines. In some places, they are, responsible for developing the transmission system and its interconnections with other systems.

- **Distribution Operators**: Distribution operators have to efficiently run medium to low-voltage distribution systems. The distribution network is used to move the low voltage electricity to the consumer premises and meters are used to measure the amount of electricity used.

- **Power exchanges**: They are platforms used by market players to anonymously negotiate same-day or next day purchases and sales of electricity. This arrangement, set up when the electricity market was liberalised, provides an open market, organises the competition and establishes a transparent reference price for market participants.

- **Electricity retailers:** They manage the sales and billing of electricity. The consumer's bill comprises of generation, transmission distribution and retail charges. The end users can be anyone from individuals to major industrial players. Industrial users are often directly connected to the high-voltage grid. Regulators effectively police the energy market in an environment where a number of players have a legal monopoly. They check if the market operates in line with the public interest and overall energy policy.) [Elia, 2015; EU, 2009].

A.3 Electricity Industry Structure

- (**Vertically integrated monopoly**: In this setup, a single electricity utility controls and undertakes all or each business functions. There is no competition at any level and the utility is regulated by the government to prevent monopoly abuse. Consumers have no choice as there will be only one utility to provide electricity.

- **Unbundled Monopoly**: In this setup, generation is separated from all other functions. There will be several generation companies and distribution companies. A monopoly status is maintained by the generators and distributors. One generation company will have the exclusive right to supply distributors in an area, and similarly, one distribution company will have a monopoly to serve customers in an area. In this setup, the transmission is either provided by generators or distributors or in some cases a different entity. There may be competition at the generation level, but there is no competition at the retail level. All customers in an area must purchase electricity from the retailer in that area.

- **Unbundled with limited competition**: In this setup, there is competitive wholesale market. It serves distribution companies and major industries. There is competition at the wholesale level between the generating companies and there may be some competition through the use of self-generation by large customers. But there is no competition at the retail level.

- **Unbundled with full competition**: In this setup, all the functions in the electricity industry are separated. There is complete competition among generators and also at wholesale and retail level. At the retail level, there are independent retailers and energy brokers to supply electricity to the end- user. The independent retailers, purchase electricity in bulk from the wholesale market and sell it to the consumer. They use the distribution network set up by the distributor in that area. Brokers also provide a similar service without ever owning the electricity. In this set-up, the transmission and distribution systems usually have a monopoly in an area and they are regulated by the government.)[EFA, 2004].

Diagrammatic representation of the restructuring of the electricity industry is shown in Figure 14.

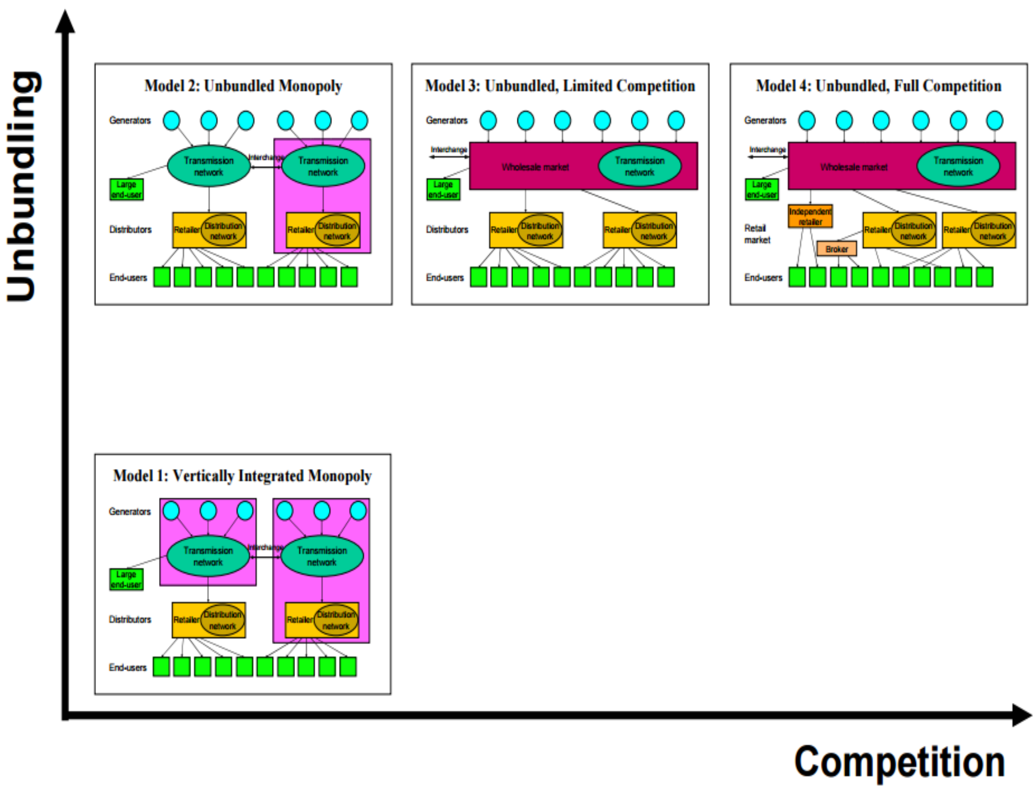

Figure 14: Restructuring of Electricity industry [copied from [EFA, 2004]]

A.4 Electricity Service Providers

- (**Market Generator**: A market generator must sell all sent-out electricity through the market, and accept payments from market operator for sent-out electricity at the spot prices applicable to its connection point. A market generator with relevant capabilities can also classify its units as ancillary service generating units.

- **Non-market Generator**: A generator whose entire electricity output is purchased by a local retailer or customer at its connection point is classified as non-market. A non-market generator is not entitled to receive payment from market operators for any electricity sent out at its connection point, except for any electricity sent out in accordance with a direction issued by market operator to a scheduled generator.) [AEMO, 2014]

- **Transmission Service Operator (TSO)**: In Europe, TSOs are responsible for the transmission systems. They are also responsible for the provision of ancillary services. Their fundamental role is to provide reliable open-access transmission service. This involves maintaining supply-demand balance and transmission reliability by scheduling and dispatching resources and interchange transactions with other regional balancing authorities [EURELECTRIC, 2011].

- **Independent System Operator (ISO) and Regional Transmission Organisation (RTO)**: In US, the transmission operators are referred to as ISOs /RTOs. They provide transmission access to facilitate competition for the benefit of consumers and are regulated by the Federal Energy Regulatory Commission (FERC). They also provide reliability planning for the region's bulk electricity system. ISO and RTO have the same role; however RTO additionally has the responsibility for the transmission network. They provide transaction support as part of their market duties and engage in regional planning to ensure that the right infrastructure gets built. A regional planning approach allows for the pooling of resources and therefore the need for fewer plants than on a state-by-state basis. By cutting the need for more power plants, ISOs/RTOs help consumers save money and reduce emissions [EPSA, 2015].

- **Transmission Network service provider (TNSP)**: In Australia, the network service providers related to transmission are referred to as TNSPs. TNSPs manage the high voltage lines that transmit electricity to cities, towns and across state borders within the interconnected jurisdictions of the NEM. Large users of electricity typically connect directly to the transmission network and they pay larger transmission network charges. For the residential consumers and other small businesses, transmission network charges forms about 10% of the consumption bill [AER, 2013].

- **Distribution Service Operator (DSO)**: In Europe, DSO acts as system operators and neutral market facilitators. They constantly develop and maintain their networks to ensure that the networks operate efficiently and with high levels of system security, reliability, and quality. They also provide non-discriminatory access to their networks for power generators and other system users. In many countries, DSOs also own and manage metering infrastructure, organise supplier switching, or act as an information hub for storing and providing metering data. In some countries, like France or Germany, DSOs are granted concession contracts to operate the network for a certain amount of time while the public authorities remain the owner in the long term. In these cases, DSOs are in charge of operation and maintenance as well as capital investment. [EURELECTRIC, 2011]

- **Distribution Network service provider (DNSP)**: In Australia, DNSPs process all applications to connect to the distribution network. They are responsible for managing the distribution networks that deliver electricity to homes and businesses in their allocated area [AER, 2014b]. **Load-serving entities (LSE)**: In the US, LSEs secures energy and transmission service and related interconnected operations services to serve the electrical demand and energy requirements of its end-use customers. DNSP is similar to the electricity retailer [NERC, 2015].

A.5 Power System Control Elements

- (**Power System Control**: Generation, transmission and distribution, the three most important functional areas in the power system have different control loops. Each control loop will have sensors, devices, computation, control actions, communication signals and protocols associated with it. The control schemes for generation includes Automatic Generation Control, Automatic Voltage Regulator, Governor Control, and Security-Constrained Economic Dispatch. The control systems for transmission include High-voltage Direct Current transmission control, Volt-Ampere Reactive compensation and State Estimation. The control schemes for distribution include demand side management and load shedding.

- **Automatic Generation Control (AGC)**: AGC is a secondary frequency control loop. It fine-tunes the system frequency to its nominal value and assures the power exchange between two control areas is limited to the scheduled value. It makes corrections to frequency deviation and ensures that each balancing authority area compensates for its own load change.

- **Automatic Voltage Regulator (AVR)**: AVR is a generation control system and it controls the amount of reactive power absorbed or injected into the system. These control systems have digital exciter control modules connected to the generation plant control centre. It programs the controller with the with set-point values for voltage. To maintain voltage at the desired level, the current through the exciter is modified ased on the difference between the observed measurement and the set point.

- **Governor Control**: This is the principal frequency control mechanism in the generation functional area. There are sensors to detect disturbances via changes in speed, and consequently, it alters the settings on the steam valve which adjusts the power output from the generator. Similar to the AVR, operating set-point are defined for the frequency control over the governor.

- **Security-Constrained Economic dispatch (SCED)**: SCED is an optimisation process that controls the operation of generation facilities to deliver a reliable supply of secure electricity at the lowest cost possible. It takes into consideration the operational limits of the production and transmission facilities, the variation in demand and the cost of the different types of generation units to select the generating units to dispatch.

- **High-voltage Direct Current (HVDC) transmission control**: HVDC transmission control can stabilise the network against disturbances arising from rapid changes in power by increasing or decreasing the firing angle. It uses the reference voltage and measured voltage to calculate the firing angle. This process allows for the exchange of power between incompatible networks.

- **Volt-Ampere Reactive (VAR) Compensation**: This process improves the performance of the transmission system by controlling the reactive power injection or absorption in a power system. The devices in this control loop minimise voltage fluctuation at a given end of a transmission line and provides voltage support. Flexible AC Transmission System (FACTS) devices are used to exchange operational information.

- **State Estimation**: This technique estimates voltage magnitude and phase angle based on presumed faulty measurements from field devices. It can also make estimations when the control centre fails to receive measurements due to equipment failure or communication channel breakdown. It helps in operational decisions by providing the operator with details on power flows and voltage magnitudes along various parts of the transmission network. These procedures provide dependable assessments of state variables despite faults introduced by device and channel defects.

- **Load Shedding**: This scheme is mainly used to maintain the system's operating variables within safe operating limits and protect the equipment connected to the grid. This option can be used under emergency operating conditions to prevent system collapse. Load shedding can be automated to control the load when the system generation is insufficient.)[Govindarasu et al., 2012; Sridhar et al., 2012]

A.6 Demand Side Management

- **Demand Side Management (DSM)**: DSM is the planning and implementation of those electric utility activities designed to influence customer uses of electricity in ways that will produce desired changes in the utility's load shape

[Gellings, 1985]. DSM has load shaping objectives and Gellings classifies them into six categories as shown in Figure 15[Gellings and Chamberlin, 1987; Gellings and Samotyj, 2013].

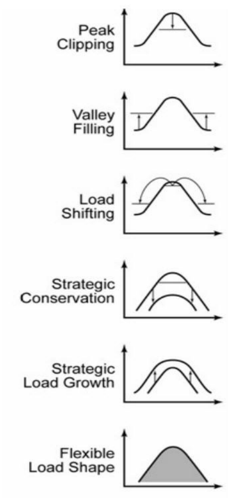

Figure 15: Load shaping objectives [copied from [Gellings and Chamberlin, 1987]]

- (**Peak Clipping (DPC)** - In DPC, peak load is reduced by applying direct load control [Gellings, 1985].
- **Valley Filling (VF)** - The objective of VF is to build off-peak load. The average cost the customer can be reduced by adding appropriate price for off-peak load and in that case the long-run incremental cost will be less than the average price of electricity [Gellings, 1985].
- **Load Shifting (LS)** - By shifting load from on-peak to off-peak periods, LS can be achieved and energy storage devices are used for this purpose. e.g. storage water heating.
- **Strategic Conservation (SC)** - SC techniques are utility introduced programs to modify end-use consumption. It aims for reductions of usage as well as change in usage pattern.
- **Strategic Load Growth (SLG)** - In SLG, utility stimulates load increase to boost sales. It usually involves increased market share of loads that are served by competing fuels) [Gellings and Chamberlin, 1987].
- **Flexible Load Shape (FLS)** - In FLS the customers are presented with various incentives for making variations in the service. The programs involved variations of interruptible load or individual customer load control devices offering service

constraints. Among the many criteria Gellings uses is reliability. Load shape can be flexible-if customers are presented with options as to the variations in quality of service that they are willing to allow in exchange for various incentives. The programs involved can be variations of interruptible or curtailable load; integrated energy management systems; or individual customer load control devices offering service constraints [Gellings and Chamberlin, 1987; Gellings and Samotyj, 2013].

A.6.1 DSM Techniques

- **DSM Techniques**: DSM techniques can be mainly categorised as follows: Alternative Pricing, Direct Incentives, Outreach and Cooperation, and Regional Codes and Standards. Table 29 is a compilation of various DSM categories. The sources referred to are [Chuang and Gellings, 2008; Palensky and Dietrich, 2011].

- **Alternate Pricing**: This program involves using pricing and rate structures to influence the consumer's electricity consumption behaviours. The price that customers have to pay for electric services is used to induce a change in their consumption pattern [Chuang and Gellings, 2008; Palensky and Dietrich, 2011].

  - **Time-of-Use (TOU)**: TOU tariff is a type of alternative pricing and most commonly applied DSM technique. In most places, there are three periods for TOU tariff. Figure 16 shows TOU tariff applied in Ontario, Canada.

    * **Off-peak period**: During this period demand for electricity is lowest.
    * **Mid-peak/ Shoulder period**: During this period demand for electricity is moderate.
    * **Peak period**: During this period the demand for electricity is highest.

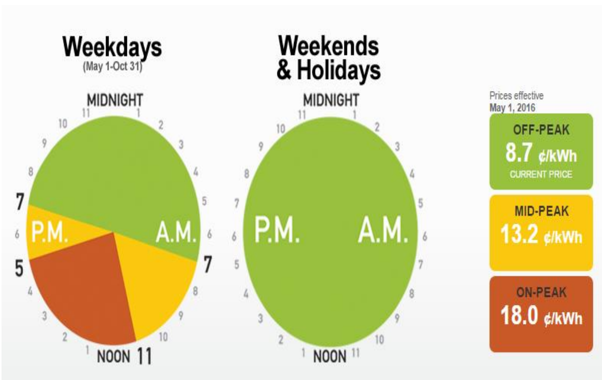

Figure 16: TOU tariffs issued by Ontario Energy Board in Canada [copied from [OEB, 2016]]

- **Direct Incentives**: This program involves encouraging consumer participation by providing financial incentives. The customers are paid for either adopting a

DSM technique or better performance of the accepted DSM technique [Chuang and Gellings, 2008; Palensky and Dietrich, 2011].

- **Outreach and Cooperation**: This program involves consumer education and information exchange to impact consumer's energy behaviour. It involves no direct financial incentives and customers are only expected to voluntarily participate [Chuang and Gellings, 2008; Palensky and Dietrich, 2011].

- **Regional Codes and Standards**: This program involves setting up standards and regional codes to achieve a minimum level of energy efficiency and operating procedures. To achieve the load shaping objectives this method will require mandatory compliance with standards and codes [Chuang and Gellings, 2008; Palensky and Dietrich, 2011].

A.7 Power Generation

- **Centralised Generation (CG)**: In a CG, electricity is generated in large scale, and these facilities are usually located away from the end-users. These sources are connected to high-voltage transmission lines. Through the distribution network, electricity finally reaches the consumers. Fossil-fuel-fired power plants, nuclear power stations, hydroelectric dams are the most common centralised generation sources [EPA, 2015a].

- **Distributed Generation (DG)**: In DG the generation source will be closer to the end point. Renewable energy sources like wind farms and solar farms are gaining popularity as distributed power sources. These generations are usually connected to the low voltage transmission network. Micro-generations like individual roof top PV feed-in are also part of distributed generation. However, the micro-generations are connected to low voltage distribution network [EPA, 2015b].

- **Micro-generation**: Micro-generation technologies are defined as energy generation technologies that are installed in individual households such as solar PV, micro wind and micro Combined heat and power (CHP). Solar panels and micro wind turbines are in general located visibly on the rooftop whereas micro DG is installed in the house replacing the conventional heating boiler [Sauter and Watson, 2007].

Table 29: Categorisation of DSM (compiled from the sources [Chuang and Gellings, 2008; Palensky and Dietrich, 2011]).

DSM Category	**DSM sub-classification**	**DSM Implementation Types**	**Action Time Frame**	**Planning Category**
Alternative Pricing	Pricing and Rate Structures	Demand charge ; Time-based rate ; Off-peak rate; Inverted rate; Seasonal rate; Variable levels of service; Promotional rate; Net metering	Years	Resource Planning
		Time of use	Months	Operational Planning
	Dynamic Pricing	Critical peak pricing ; Real-time pricing	Days/ day- ahead	
	Discounted Rate	Curtailable load; Interruptible load; Dispatchable standby generation; Direct load control; Conservation rate	Minutes to hours (on the day)	
Direct Incentives	Paid for Adoption	Cash grant; Rebate; Buyback program; Low/no interest loan; Subsidised installation or modification; Employee rewards for successful program marketing; Billing credit; Resource Adequacy	Years	Resource Planning
	Paid for Performance	Seasonal Conservation Credit; Installed Capacity	Months	Operational Planning
		Regional operator economic demand response ; Demand bidding of forward energy	Days/ day- ahead	
		Demand bidding of ancillary services; Curtailable load; Interruptible load; Dispatchable standby generation; Direct load control	Minutes to hours (on the day)	
Outreach and Cooperation	Trade Ally Cooperation	Training; Certification; Cooperative ads and marketing; Selected product sales/service	Years	Resource Planning
	Direct Customer Contact	Energy audit; Direct installation; Exhibits/displays/clinics		Operational Planning
	Ads and Promotion	Mass media; Point of purchase advertising; Customer education		

	Public Appeal	Public conservation appeal (e.g. radio, TV, Internet, newspaper appeal)	Months	
		Voluntary day-ahead DR	Days/ day- ahead	
	Emergency operations	Voluntary emergency DR ; Voluntary emergency standby generation; Voluntary emergency load reduction (e.g. pre-planned interruptible load)	Minutes to hours (on the day)	
Regional Codes and Standards	Energy Efficiency Standards	Building codes; Appliance efficiency standards; Industry efficiency requirements	Years	Resource Planning
	Renewable Energy Standards	Renewable portfolio standards		
	Variable Service Subscription	Demand subscription service	Months	Operational Planning
		Demand limiting ; Premium power	Days/ day- ahead	
		mandatory curtailment ; Priority service	Minutes to hours (on the day)	
	Emergency Operating Procedures	Rolling blackout	Minutes to hours (on the day)	

A.8 Smart Grid

- **Smart Grid (SG)**: The SG is a vision for the future power grid that involves the integration of all the network elements from generation to the consumption. SG will support a two-way flow of data and electricity using a secure network, communication technologies and intelligent information systems. The power generation, transmission, substations, distribution and consumer service points will be integrated to achieve clean, safe, secure, reliable, resilient, efficient, and sustainable power supply [Gharavi and Ghafurian, 2011].

A.8.1 Smart Grid Reference model

- **Smart Grid Reference models**: A reference model is used by the service provider to achieve the power grid modernisation goals. These reference model describe and discuss the characteristics, behaviour, interfaces, requirements, and standards for the system [Locke and Gallagher, 2010].

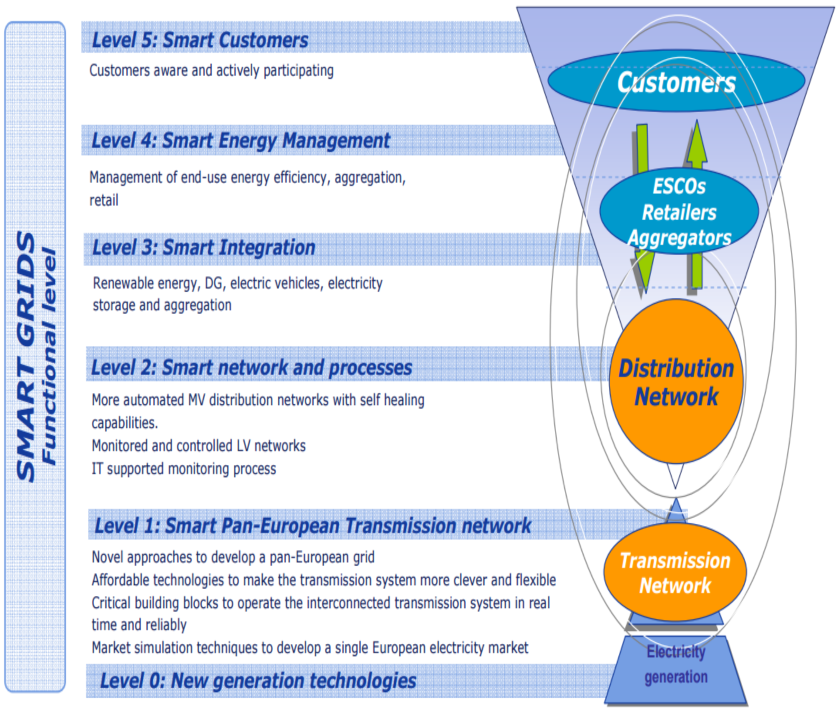

Figure 17: Different functional levels of the smart grid by EEGI [copied from [EEGI, 2010]]

- **Smart Grid Functional Model (SGFM)**: This model was developed by European Electricity Grid Initiative (EEGI) to guide in the process of defining the functionalities that were needed for each smart grid project and to avoid overlaps. Figure 17 summarises the model. Level 0 covers generation technologies. In

Europe, the majority are connected to the European Transmission Grid. Level 1 is the responsibility of European Transmission Operators, and they need to take care of the transmission issues. Level 2 is the responsibility of the DSO, and it covers the matters related to the distribution network. Level 3 to 5 cover issues that require the involvement of DSOs, grid users (distributed generators and customers) and free market players (retailers and aggregators).

- **Smart Grid Conceptual Model (SGCM)**: National Institute of Standards and Technology (NIST) developed the SGCM to support the planning of grid modernisation initiatives. SGCM consists of seven domains (Distribution, Transmission, Bulk Generation, Service Providers, Market and Customer). Each domain includes smart grid actors and applications. The actors include devices and systems that make decisions and exchange information e.g. smart meters, PV generators, etc. Applications are tasks performed by one or more actors within a domain. Figure 18 represents the interaction between actors in different domains [Locke and Gallagher, 2010].

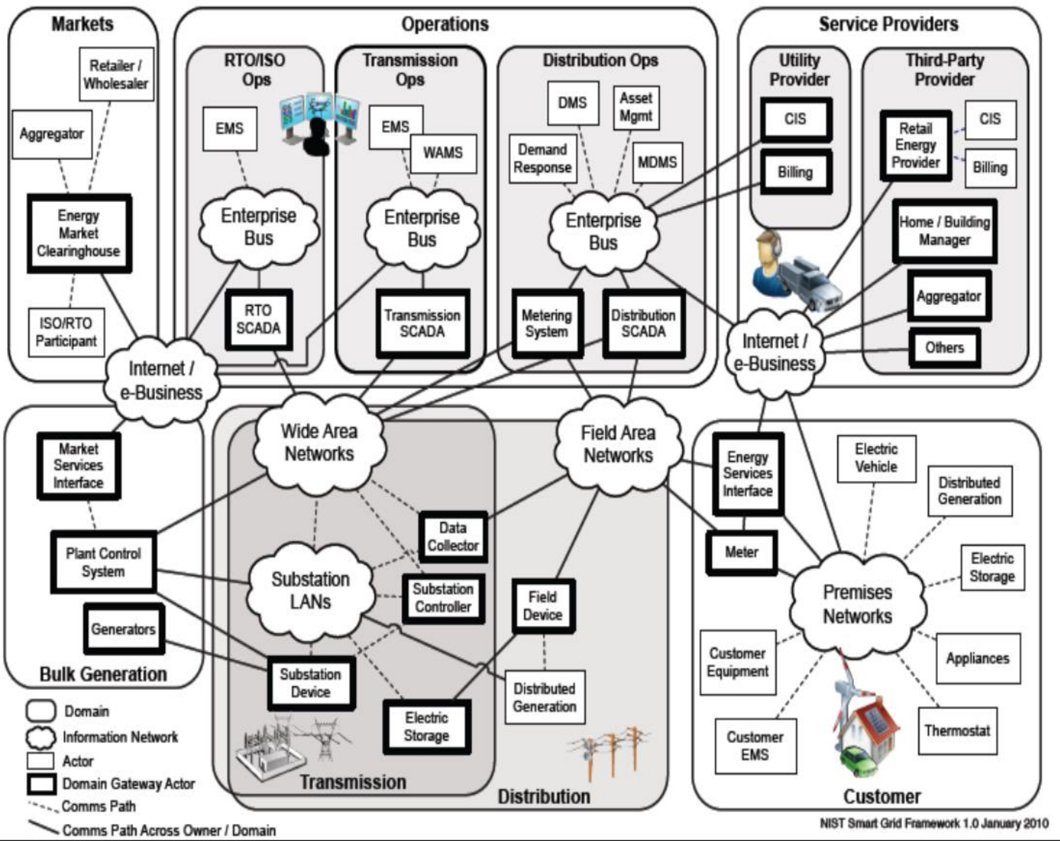

Figure 18: Domains and actors of the smart grid by NIST [copied from [Locke and Gallagher, 2010]]

- **Smart Grid Maturity Model (SGMM)**: The SGMM was founded by the Global Intelligent Utility Network Coalition (a smart grid collaboration of 11 utilities) when they identified the need in the industry for a management tool. It was then transferred to Software Engineering Institute (SEI) - Carnegie Mellon University. SGMM was developed to help utilities in identifying options their smart grid projects and it can also assist them to measure their project progress. The model describes eight domains, which contain logical groupings of incremental smart grid characteristics and capabilities. It also sets five maturity matrix levels that can be used by utilities to monitor their smart grid projects. Figure 19 provides details of the SGMM maturity matrix levels [SEI, 2010].

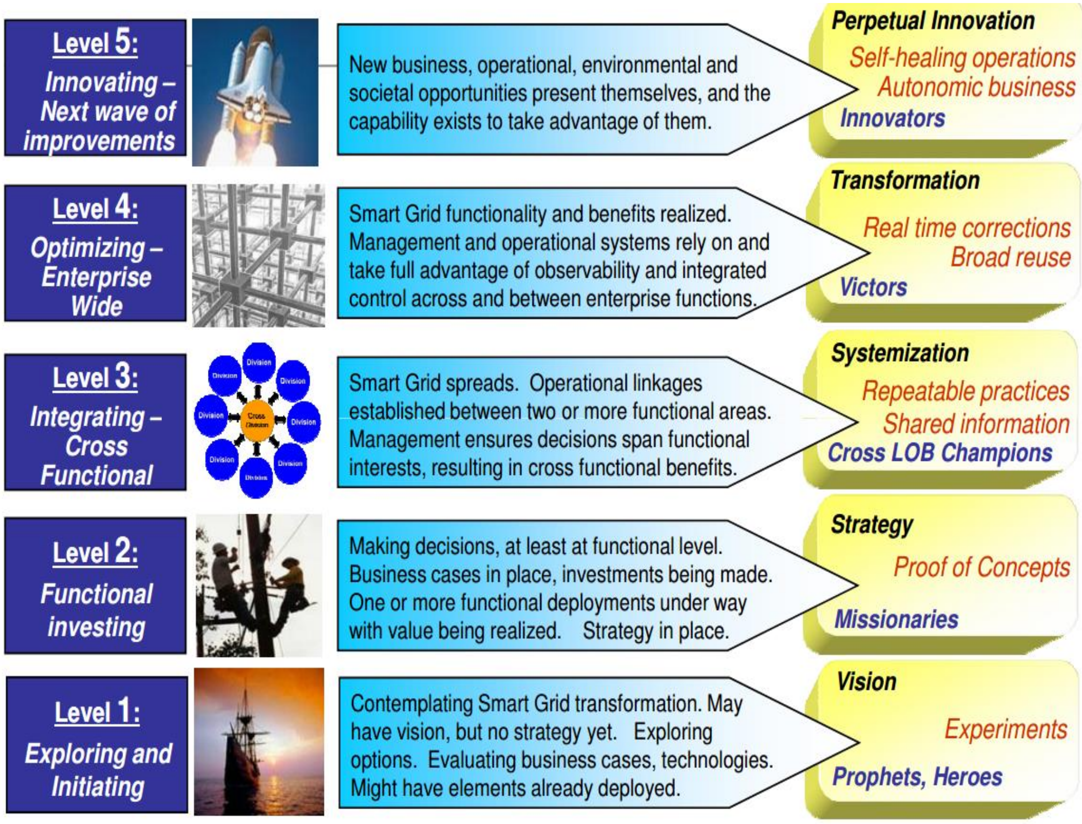

Figure 19: The five maturity matrix levels set for Smart grid project by glssei [copied from [SEI, 2010]]

- **Smart Grid Architecture Model (SGAM)**: SGAM reference model represents the Smart Grid as a plane which spans electrical energy conversion chain in one dimension and the hierarchical levels of power system management in the other. The five domains of energy supply chain represented by SGAM are Generation, Transmission, Distribution, Distributed Energy Resource (DER) and Customer Premises. The six management zones are Process, Field, Station, Operation, Enterprise and Market. Interoperability is then addressed by superimposing it with the five layers: Component, Communication, Information, Function and

Business. The three-dimensional representation of SGAM is shown in Figure 20. This model allows for business as well as technical illustrations. On the business layer, SGAM can be used to map economic structures and policies. The lower four layers allow for technical representations. The function layer describes the services and the component layer describes physical implementations. The information layer defines the information that is being used and exchanged in the system [CEN-CENELEC-ETSI, 2012]

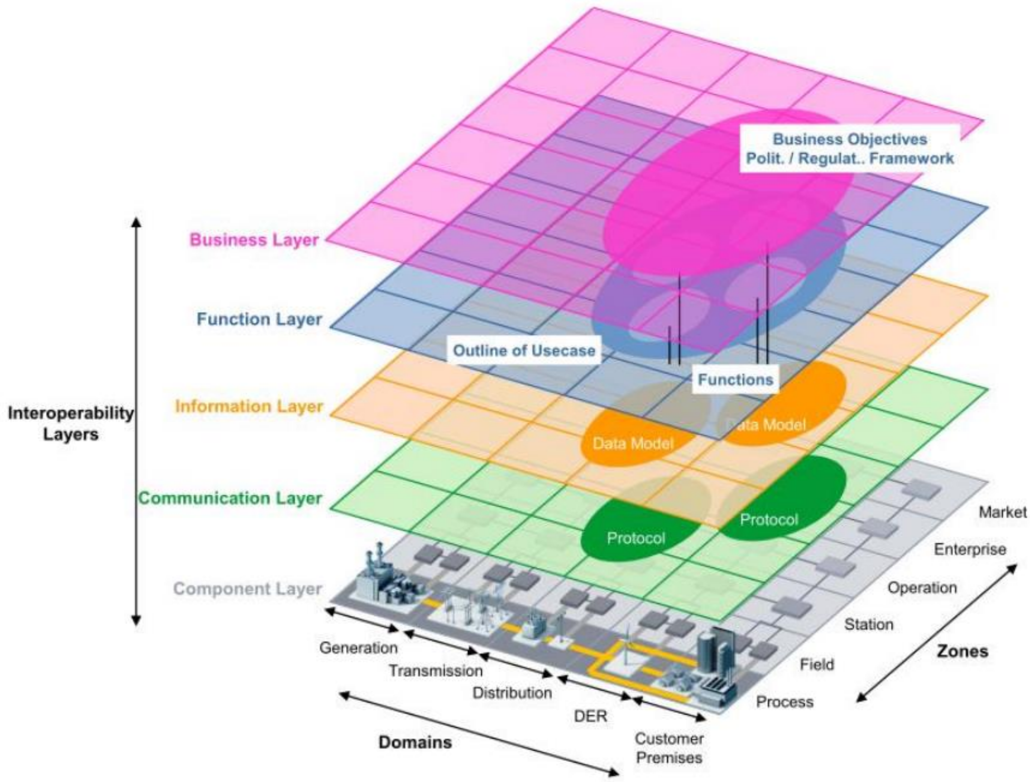

Figure 20: The Domains, Zones and interoperability layers for smart grid by ETSI [copied from [CEN-CENELEC-ETSI, 2012]]

- **Smart Grid Interoperability Maturity Model (SGIMM)**: The GridWise Architecture Council (GWAC) developed the SGIMM to determine the interoperability aspects of the interfaces between various entities in the electric power system. They have defined eight interoperability categories which are further categorised as organisational, informational and technical. According to GWAC, the SGIMM can help in identifying issues on configuration, performance and security of integrated elements in the power grid. Figure 21 provides a schematic representation of SGIMM [GridWise, 2008]

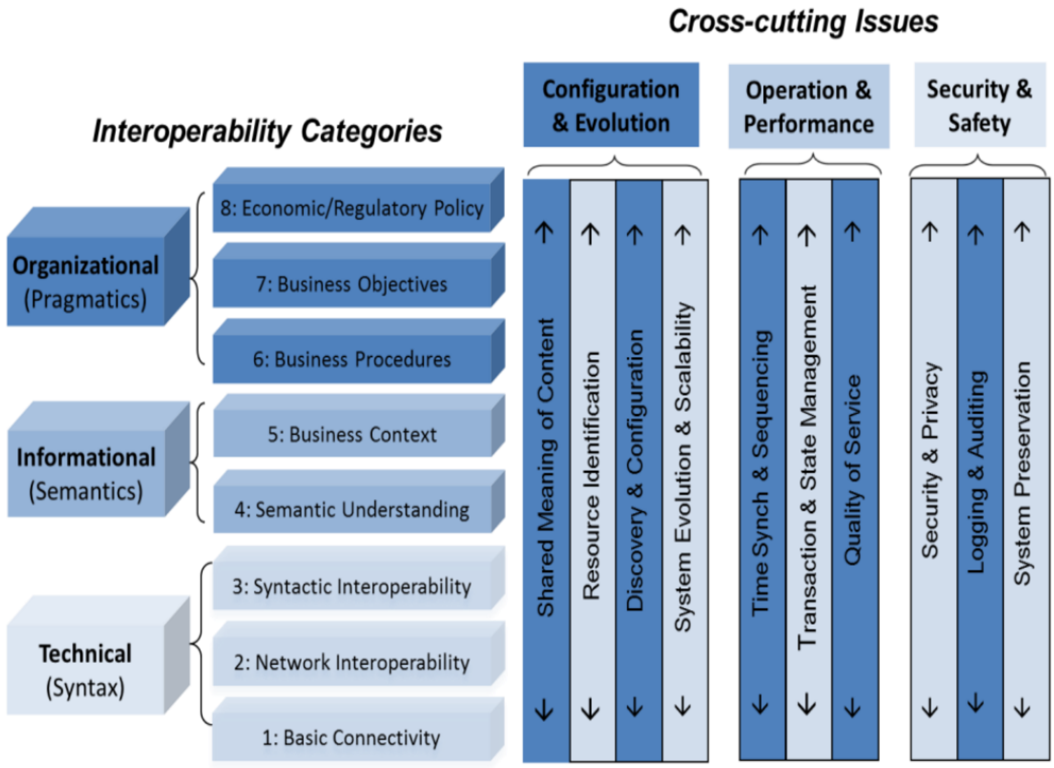

Figure 21: Interoperability Framework Categories by GWAC [copied from [GWAC, 2011]]

A.9 Smart Meter

- **Smart meter (SM)**: They are remotely read interval meters. They are capable of recording of energy imported or exported from a metering point by time trading interval. These meters can be remotely disconnected and reconnected (re-energisation and de-energisation). The loss of supply can be remotely detected [Depuru et al., 2011; Benzi et al., 2011].
  - **E350 - U1200**: Figure 22 shows the smart meter E350 - U1200 from Landis+Gyr that is used in Victoria, Australia. In that figure, section 1) shows the smart meter as a whole, 2) highlights the optical port used to readout data from the meter, 3) shows how the accumulated energy values is displayed in the display unit, 4) shows how to identify the boost operation has been initiated and LC relay is connected and 5) shows the direction in which energy is flowing and -w indicates energy is exported into the grid and +w indicates energy is imported from the grid [Landis+Gyr, 2012].
- **In-House-Display (IHD)**: IHD is an energy monitor that electronically reads information from the smart meter and displays it the consumer. It provides consumer a feedback on electricity usage and price signals from service provider.

- **Energy Data Disaggregation**: "Disaggregation refers to a set of statistical approaches for extracting end-use and/ or appliance level data from an aggregate energy signal without any plug level sensors" [Armel et al., 2013]. It is one of the data analytics that is expected to be applied on smart meter data. Providing this disaggregated information as feedback to the consumer is supposed to help them with their energy choices. Table 30 shows the list of appliances that can be identified at different data frequencies.

- **Smart Meter Data Aggregation**: The smart meter provides granular data on consumption from each household. This data creates privacy concerns for the user. The service providers do not benefit from real-time data from each household. Hence, privacy can be preserved to some extent by obscuring the individual contributions of customers to the aggregated value at a collector level (Klenze 2014).

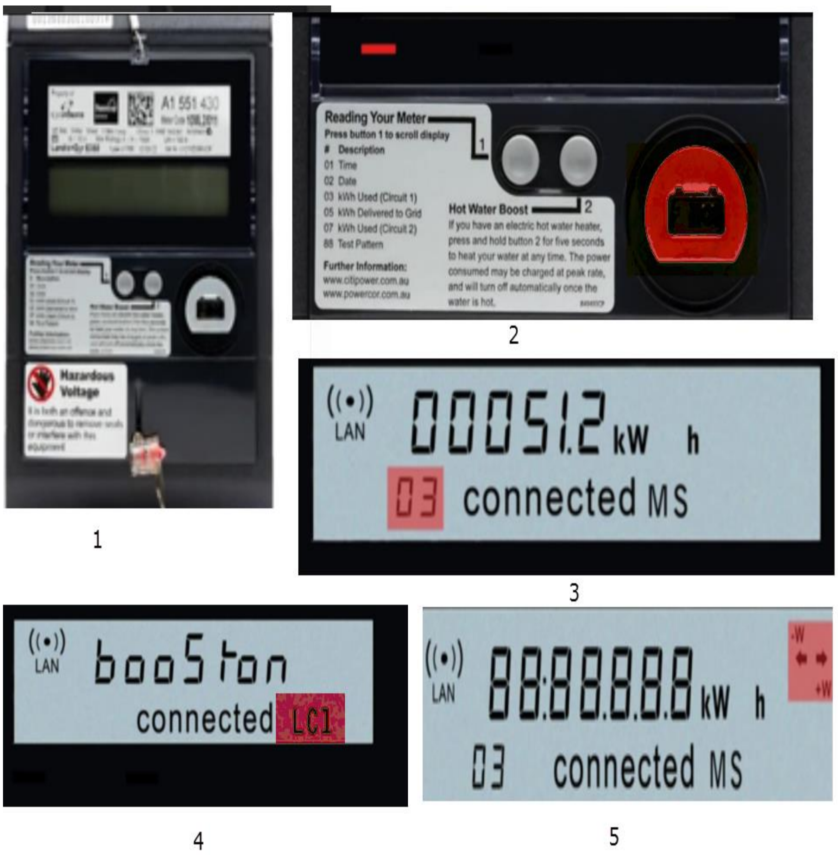

Figure 22: Landis+Gyr E350 - U1200 smart meter and its display elements [snapshots taken from the video - 'How to read smart meter – Landis + Gyr E350' [CitiPower and Powercor, 2012]]

Table 30: Different data frequencies and appliances identifiable [copied from [Armel et al., 2013]

Data frequency	**1 h–15 min**	**1 min–1 s (1 Hz)**	**1–60 Hz**	**60 Hz–2 kHz**	**10–40 kHz**	**>1 MHz**
Data features used by algorithms	Visually observable patterns; duration and time of appliance use	Steady state steps/transitions of power	Steady state steps/transitions of power	Current and voltage, providing low order harmonics	Current and voltage, providing medium order harmonics to identify type of electrical circuitry in appliance	Current and voltage, providing very high order harmonics to identify both transients & the background noise of appliances
Appliances identified	Differentiates around 3 general categories: loads that correlate with outdoor temperature, loads that are continuous, and loads that are time dependent	Top <10 appliance types: refrigerator, ACs, heaters, pool pump, washers, dryers etc.	10–20 appliance types	Not provided	20–40 appliance types: toasters, computers, etc. along with larger loads identified at lower frequencies	40–100 specific appliances: e.g., differentiates between 2 lights; requires separate power consumption data stream

A.9.1 Smart Meter Communication technologies

- **Smart Meter Communication technologies**: The characteristics of different communication technologies used for smart metering system/ AMI have been taken from the various sources are summarised and listed in the table 31. The suitability of each communication technology for different population density (Dense Urban (DU); Semi-Urban (SU)/country side; Scarcely Populated (SP)/deserted) is discussed in the table. Network types (Wide Area Network (WAN);Neighbourhood Area Network (NAN); Home Area Network (HAN); Personal Area Network (PAN)) are also discussed in table 31.

Table 31: Communication Technologies used for Smart Metering System (compiled from various sources [Aviat, 2011; Gungor et al., 2011; Haidine et al., 2013; Jürg et al., 2012])

Tech	Description	Characteristics	Advantage	Disadvantage	Cost	Suitability
RF Mesh 802.11	Outdoor Wireless Mesh Network (WMN) is a communications network made up of radio nodes organised in a mesh topology	Frequency: 900 MHz, 2.4 GHz, 5.8GHz (unlicensed) Data Rate: dependent on link distance; <54 Mbps; as high as 300 Mbps for outdoor. Range: LOS(0-24 km) or NLOS (0-8 km) between links	Mature technology, NLOS integrated antenna to handle wide range of deployment issues; Easily scalable; Mesh design allows improved coverage around obstacles, node failures and path degradation; Rapid deployment using unlicensed; Security and data encryption available	Increased delay/latency introduced by multiple hops; Increased complexity of protocols (Media Access Control (MAC), routing, management, security); Mesh architecture increases the cost and complexity of the network with each additional node	Low to moderate cost, Capital Expenditure (Capex), depends on number of nodes and gateways deployed.	Network: Mainly for NAN Population: DU - best, SU - good, SP - OK
GPRS	GPRS offers a packet-based data service according to the IP. It was introduced as a faster data transfer service for GSM Mobile Stations.	Frequency: 900-1800 Mhz, Data Rate: <170 kbps, Range: 1-10 km	Mature technology; cellular networks can provide sufficient bandwidth for huge amount of data	Shared cellular networks may cause network congestion or decrease in network performance in emergency situations so will need private communications network.	Moderate to high - public network is used; Capex will be moderate; private communications network will increase the cost	Network: NAN and WAN Population: DU - good, SU - best, SP - worst

PLC	Systems for carrying data on a conductor that is also used for electric power transmission.	Frequency:1- 30 Mhz Data Rate: 2 -3 Mbps Range: 1-3 km	Piggyback onto existing network of power transmission cables as long as cables can easily reach the customer point. Viable business model for municipalities because of close proximity to customers	Harsh, noisy channel environment	Moderate - The large existing network base bring the Capex down; cost is mainly for PLC enabled meters and data concentrator	Network: HAN, NAN and WAN Population: DU - best, SU - good, SP - OK
WiMAX	Wireless WMN ecosystem including access, Access Service Network (ASN)and Connectivity Service Network (CSN) for end-to-end	Frequency: 2.5Ghz, 3.5 Ghz, 5.8 Ghz Data Rate: <75Mbps Range:10-50 km (LOS), 1-5km(NLOS)	Efficient backhaul of data - aggregating 100s access points; QoS supports Service Assurance; Battery backup improves reliability and security; Simple scalable network roll-out and Customer-Premises Equipment (CPE) attachment; Faster speeds than 3G cellular; Large variety of CPE and gateway/base station designs.	Limited access to spectrum licenses; Practical bit rate is up to 2 mbps and Trade off higher bit-rates over longer distances; Asymmetrical up and down link speeds; Bandwidth is shared among users; Competing against future 4G cellular standards for high-capacity; all-IP networks	Moderate - Capex is moderately high; Operating Expenditure (OpEx) is low; various CPE designs available at commodity pricing; Chip prices continue to drop in price.	Network: NAN and WAN Population: DU - good, SU - OK, SP - bad

Zigbee	Low-cost; low power; wireless mesh standard for wireless HAN or PAN.	Frequency: 2.4Ghz, Data Rate: 250 Kbps, Range: NLOS- 30-80m, LOS- 1-1.5km	Low cost - for inexpensive consumer devices; Low power consumption - up to 2 year battery life; Self-organizing mesh network - secure, reliable networking; Low data rates - network can support large number of users.	Low data rate; short range; Smart energy specifications are still under development; developer must join ZigBee Alliance	Low - Intended as a low cost; low power product for low bandwidth applications.	Network: Mainly for HAN Mainly between meter and premises

A.9.2 Metering Protocols

- **ANSI C12**: ANSI C12 is the protocol widely used for smart meters in Australia. C12.18 is the protocol used for optical communication with meter. It uses Protocol Specification for Electronic Metering (PSEM) standard for metering and it is session based. C12.19 defines the data structure (tables) standard for metering. C12.21 is the protocol for the modem and it also uses PSEM standards. The latest addition is the C12.22 and it is the protocol for the network. With the development of C12.18, C12.19, and C12.21 it became possible to implement standard methods of communicating with meters over optical probes or telephone lines. Introduction of C12.22 enabled remote access and by creating a standard protocol for network communications it made it possible for utilities to implement solutions that are not locked to a single vendor or technology. The C12.22 defines a transport independent application level protocol for exchanging data between nodes and a physical and data link protocol for linking meters and communication technology. C12.22 extends PSEM with Extended Protocol Specification for Electronic Metering (EPSEM). It gives the ability to chain commands, as well as several new commands for managing communications over a shared media with multiple nodes [Snyder and Stuber, 2007].

- **Smart Message Language (SML)**: The SML was used mainly in Germany. It was part of the Synchronous Modular Meter project with the aim of standardisation of smart metering. It defines messages instead of defining an interface object model and services to access it. A message is either a request or a response message. But a response message can be sent without a request. Thus SML does not enforce a strict client-server principle and meter data can be actively pushed by the meter. The message format supports the transmission of load profiles and their associated digital signatures. The communication of new firmware and clock synchronization is possible with SML [Feuerhahn et al., 2011].

- **Device Language Message Specification (DLMS)/ Companion Specification for Energy Metering (COSEM)**: DLMS/ COSEM can be used over TCP/IP and UDP/IP. DLMS/ COSEM is based on client-server structure. The server is meant to be within the meter while the client accessing the meter could be a gateway or the central office. Before the actual metering information can be exchanged an association has to be build up, which is initiated by the client. The DLMS client can then access the interface object model inside the server. Once an association exists the DLMS server is also able to send notifications to the client without an explicit request. DLMS/ COSEM is used in smart metering projects using GPRS and PLC networks to transport data [Feuerhahn et al., 2011].

- **IEC 61850**: IEC 61850 works according to client-server principle and the server includes an interface object model which can be accessed through standardised services. The interface object model of IEC 61850 consists of Logical Devices (LD) and the LDs consist of two or more Logical Nodess (LNs). Combined with the logging and/or reporting services this LN can be used to transmit load profiles.

Digital signatures are not part of the LN and are thus not supported. MMS mapping enables the server to send data without an explicit request through the IEC 61850. An open Transmission Control Protocol (TCP) socket connection has to be initiated by the client beforehand. Neither the MMS nor the SOAP mapping has any built in security [Feuerhahn et al., 2011].

- **Smart Energy Profile version 2.0**: Smart Energy Profile version 2.0 is a newly developed protocol and is in cooperation with a number of other standards development groups. It is used in parts of US and Canada. It will offer IP-based control for advanced metering infrastructure and home area networks. It supports several important features including dynamic pricing enhancements, tunnelling of other protocols, prepayment features, over-the-air updates and guaranteed backwards compatibility with previous versions. This standard supports the diverse needs of a global ecosystem of utilities, product manufacturers and government groups as they plan to meet future energy and water needs. It supports features like control of plug-in EVs charging, installation, configuration and firmware download for HAN devices, prepay services, user information and messaging, load control, demand response and common information and application profile interfaces for wired and wireless HANs [ZigBee Alliance, 2013].

- **Open Smart Grid Protocol (OSGP)**: The ETSI published two OSGP specifications for Smart Grid that will help drive the development and deployment of open, interoperable smart grid technologies internationally. They are the GS OSG 001 and TS 103 908 [ETSI, 2012].

  - (**GS OSG 001**(group specification) is an application layer protocol that can be used with multiple communication media. It has been produced by ETSI Industry Specification Group.
  - **TS 103 90** (technical specification) defines a high-performance narrow band power line channel for control networking in the smart grid that can be used with multiple smart grid devices. It has been produced by the ETSI Technical Committee for Powerline Telecommunications (TC-PLT).) [ETSI, 2012]

A.10 Risk Analysis

A.10.1 Terminologies

- (**Stakeholder**: Any entity that has interests in the target of evaluation, and whose interests are taken into account during the process.
- **Asset**: Anything to which a stakeholder assigns value and which therefore requires protection. An asset can be physical or intangible. Assets include people, property, information, and reputation.
- **Threat**: Any circumstance that can potentially cause an event (sometimes referred to as an ‘unwanted incident’) that can result in harm or damage to an

asset. A threat can be intentional (in which case it is referred to as an attack) or unintentional (an accident).

- **Vulnerability**: A feature of a system that represents a susceptibility to a threat. Vulnerability may be a weakness, flaw or deficiency, or it may be an intentional aspect of the system.
- **Harm**: The impact or damage to an asset arising from a threatening event.
- **Controls**: A Countermeasure or safeguard against a threat or vulnerability. Four types of control are commonly distinguished:
  - Preventative controls to protect vulnerabilities.
  - Corrective controls to reduce the effect of harm.
  - Deterrent controls to reduce the likelihood of unwanted incident.
  - Detective controls to discover threats and trigger preventative or corrective controls.
- **Risk**: A risk is the probability of the occurrence of a harmful event. It can be considered as a function of threats exploiting vulnerabilities to create unwanted incidents to harm assets.
- **Risk Identification**: In this step for each asset identified, all possible threats will be listed. Using the threats identified, all possible vulnerabilities and unwanted incidents can be identified. Using the unwanted incidents list, the harms on the assets can be extracted. Activities should be conducted to ensure stakeholder participation in this phase of risk analysis.
- **Risk Analysis Steps**: To conduct the risk analysis, a set of steps are usually followed. The choice of steps and its order varies based on the context of analysis. For ultra large systems with various stakeholders, the following steps in its order will be useful: Definition of Scope, Risk Identification, Risk Characterisation, Risk Evaluation, Risk Mitigation Plan and Risk Management. Risk Communication, Monitoring and Review should be carried out throughout the process.
- **Definition of Scope**: The risk analysis process starts with the definition of scope. To define the scope, the target of evaluations should be identified. Each target will have involvement with one or many stakeholders. For ultra large system, there will be a number of targets and stakeholders involved. The first step is to choose the target for assessment. Then each target may have more than one stakeholder, hence, a stakeholder must also be chosen from analysis. Narrowing down the target and stakeholder enables to easily identify the assets involved. At the end of this step assets of stakeholder involved with the chosen target can be identified.
- **Risk Characterisation**: The severity levels and likelihood levels need to be identified and tabulated. A risk matrix can be generated using this information.
- **Risk Evaluation**: In this step the unwanted incidents and the harmful impacts that were identified are evaluated using the established levels for severity and likelihood. A likelihood level is assigned to the unwanted incident listed and a severity level assigned to the harms listed. Based on the values of likelihood and

severity given, a risk value can be assigned to each case. This risk value can be used to prioritise the risks identified.

- **Risk Mitigation Plan**: This section specifies the treatment that needs to be provided to the identified risks. It begins with the identification of existing controls. The suitability of the control for the target of evaluation is then evaluated. Common factors affecting suitability are cost and resource limitations. For example, there are strong and complex encryption techniques available to protect data, but it may not be feasible to apply them on a smart meter with a limited processor. Based on the evaluation, a list of applicable controls can be specified, and the residual risk determined. Apart from countermeasure, contingency response also needs to be identified so that those actions can be taken should the risk event actually occur.
- **Risk Management**: With all the risks and countermeasures identified, the next step is to plan and implement the safeguards. The implementation needs be tested to ensure that the risk have been mitigated as expected during the analysis.
- **Risk Communication**: A planned communication process is very important to improve the awareness of risk to all its stakeholders. In addition, education of the media is needed, in order to avoid negative impacts caused by erroneous information sources.
- **Monitoring and Review**: All identified unwanted incidents, harm and their controls need to be documented and then to be reviewed regularly in order to adapt to new threats and vulnerabilities and to improve control measures and find better ways of implementing and maintaining them.)[Yesudas and Clarke, 2013]

A.10.2 Standards

- **BSI**: The BSI standards 100-1, 100-2 and 100-3 contain information about the structure of Information Security Management Systems (ISMS), methodology and the establishment of risk analysis for high and very high protection requirements. BSI Standard 100-1 describes the general methods for the initiation and management of information security in an organisation. BSI Standard 100-2 provides assistance in setting up and maintaining the information security process in an organisation by revealing paths and methods for the general course of action, but also for solutions to special problems. BSI Standard 100-2 is focused in providing a risk assessment frame to the methodologies specified in BSI Standard 100-2 [BSI, 2008a,b].

- **BS 7799**: BS 7799 was a standard originally published by BSI Group which was eventually adopted by ISO as ISO/IEC 17799. The information security management structure and controls identified in BS 7799-2 was adopted later by ISO as ISO/IEC 27001. **ISO/IEC 27000-series**: It encompasses standards for information security published by the ISO and the International Electrotechnical Commission (IEC) jointly. It provides best practice recommendations on information security management, risks and controls within the context of overall ISMS. ISO/IEC 27005:2008 Provides a general approach to risk management. ISO 27001 mainly follows the Plan-Do-Check-Act (PDCA) model.

- **ISO 31000:2009**: AS/NZS 4360:2004 Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee OB-007. It provides a generic framework for establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risk [AS/NZS, 2004]. It later became ISO 31000:2009. Under the ISO 31000:2009 the definition of "risk" is not just "chance or probability of loss", but "the effect of uncertainty on objectives” thus initiating the word "risk" to refer to a deviation from the expected both positive as well as negative [AS/NZS, 2009].

- **NIST SP 800-30**: The NIST SP 800-30 (Special Publications Risk management Guide for Information Technology Systems) provides guidance for preparing, conducting and maintaining a risk assessment. It also provides guidance for monitor risk on an ongoing basis. In NIST800-30, the steps for risk analysis are: system characterisation, threat identification, vulnerability identification, control analysis, likelihood determination, impact analysis, risk determination, control recommendations, and results documentation. [Stoneburner et al., 2002]

A.10.3 Tools

- **CORAS**: CORAS is a tool for conducting security risk analysis and diagrammatically represents threat and risk. It does not clearly specify the identification of existing safeguards or controls [Bornman and Labuschagne, 2004]. CORAS was developed under the Information Society Technologies (IST) program. CORAS uses a concerns viewpoint perspective. The concerns are further decomposed into models. A model provides the content of a concern with respect to a particular viewpoint. For each model there are guidelines for its development, including recommendations of which modelling languages to use. CORAS furthermore takes into account international standards for risk management, such as AS/NZS 4360:2004, the ISO/IEC 27001, the ISO/IEC 13335, and system documentation in the form of the Reference Model for Open Distributed Processing [Dimitrakos et al., 2002].CORAS can also be used for risk analysis of changing and evolving systems. They present three main classes of change: maintenance, before-after, and continuous evolution. [Lund et al., 2011]

A.10.4 Method

- **Operationally Critical Threat, Asset, and Vulnerability Evaluation (OCTAVE)**: Operationally Critical Threat, Asset, and Vulnerability Evaluation (OCTAVE) method was developed at the CERT Coordination Center by CMU-SEI. It is a technique for performing risk analysis. It considers both technological and organisational issues. OCTAVE also has three phases. In the first phase asset-based threat profile is created. Then the infrastructure vulnerabilities are identified. In the final phase security strategy and plans are developed, in which risks are analysed from the information generated in the first two phases [Marek and Paulina, 2006].

A.11 Requirement Elicitation techniques

15 requirement elicitation techniques that were analysed as part of the thesis to identify the suitable requirement elicitation techniques for the smart meter residential consumer are listed in table 32.

Table 32: List of Requirement Elicitation Techniques (compiled from various sources [Chen and Sauter, 2012; Lloyd et al., 2002; Maiden and Rugg, 1996; Nuseibeh and Easterbrook, 2000; Zhang, 2007])

Method & Type	Description	Advantages	Disadvantages
Interviews (Conversational)	Analyst discusses the desired product with different groups of people and builds up an understanding of their requirements. If the interview is conducted with pre-defined agenda and questions, it is called structured interview; otherwise, it is an open-ended interview.	Collecting the rich and detailed data; Collecting information to design a survey or other usability activity ; Getting a holistic view of the whole system	Not ideal when data needs to be collected from large samples or people or data need to be collected very rapidly
Workshop, Focus groups - (Conversational)	Stakeholder representatives gather together for a short but intensely focused period to create or review high -level features of the desired products.	This technique is very much effective to resolve the conflicts among customers in order to bring them at one table; each and every aspect of requirements is discussed and proper suggestions are given using group work; the stakeholders provide the direct remarks about the software requirements.	This technique needs a lot of effort as compared the other requirements engineering techniques; sometimes all the stakeholders can't join at the same time; group work is less effective in a highly political tense situation.

Brainstorming (Conversational)	Stakeholder representatives gather together and rapidly develop a large and broad list of ideas. It encourages "out -of-the-box" thinking without normal constraints, and involves both idea generation and idea reduction.	Brainstorming is mostly used for the innovative sort of projects where each participant provides his or her own ideas after their personal research about the project to be started; this technique is often used make the key decisions about the requirements of the project; It promotes free thinking and expression of ideas; Brainstorming provides the innovative ideas about the project to be developed.	Brain storming is seriously affected by exploring the critique ideas; brainstorming is not used to resolve the major issues.
Ethnography (Observational)	Ethnography being the study of people in their natural setting involves the analyst actively or passively participating in the normal activities of the users over an extended period of time whilst collecting information on the operations being performed.	This technique is useful when addressing contextual factors such as usability, and when investigating collaborative work settings where the understanding of interactions between different users with the system is paramount. In practice, ethnography is particularly effective when the need for a new system is a result of existing problems with processes and procedures, and in identifying social patterns and complex relationships between human stakeholders.	Requires considerable time to undertake; liable to attribution errors; may fail to detect infrequent events; possible ethical problems in reporting information given confidentially.

Questionnaires (Observational)	Questionnaires are mainly used during the early stages of requirements elicitation and may consist of open and/or closed questions. For them to be effective, the terms, concepts, and boundaries of the domain must be well established and understood by the participants and questionnaire designer.	Generally questionnaires are considered more useful as informal checklists to ensure fundamental elements are addressed early on, and to establish the foundation for subsequent elicitation activities. They provide an efficient way to collect information from multiple stakeholders quickly, but are limited in the depth of knowledge they are able to elicit.	Questions must be focused to avoid gathering large amounts of redundant and irrelevant information; questionnaires lack the opportunity to expand on new ideas; they provide no mechanism for the participants to request clarification or correct misunderstandings.
Protocol analysis (Observational)	A subject is engaged in some task, and is concurrently made to speak out loud and explains their thought. It is helpful in identifying work context, work flow and interaction problems in existing systems.	Good choice for uncovering basic aspects of routine order.	Need a lot of time and these techniques are not good choice when schedule is tight; it is hard to master.

Prototyping (Synthetic)	Prototype is a version of a product launched into market to provide the so for services to the customers. Prototyping is used to provide a version of the software and which is not final so that the customer can gain the experience and also may be able to provide other requirements that need to be implemented in the next prototyping. The response of the user is in the form of a feedback which is recorded as like requirements of the system.	Prototyping provides the detail information by investing each and every prototype by the customer; prototypes are mostly used in conjunction with other elicitation techniques such as interviews; prototypes useful when developing human computer GUI interfaces; prototypes provide a good chance to the stakeholders an effective rule and to be involved in the requirements engineering; the technique is extremely helpful developing new systems for entirely new applications.	In many cases prototypes are expensive to produce in terms of time and cost; a great problem for prototyping is that the user often resists making changes if once they get experience.
Scenarios, passive Storyboards (Synthetic)	It is an interaction session to describe a sequence of actions and events for a specific case of some generic task which the system is intended to accomplish. Clarified system requirements related to procedures and data flows of a task. In a highly uncertain situation, an effective and relatively inexpensive way to develop an initial set of requirements.	Because storyboards exist independently of the software system they describe, they have many advantages over regular prototypes. They cannot crash, are very easy to share with large groups, and do not give the false impression that the system is already developed. Additionally, feedback is easier to accommodate.	One of the biggest problems with storyboards is that they can become outdated very quickly; user interfaces originally defined often change over time, and that creates a maintenance burden.

JAD/RAD sessions (Synthetic)	JAD stands for Joint Application Development and RAD stands for Rapid Application Development. It emphasizes user involvement through group sessions with unbiased facilitator.	Improves quality and speed of the system design. Integrated with current structured methods and CASE tool.	Stakeholders have to be committed to the workshop for several days; only effective for smaller systems.
Contextual Inquiry (Synthetic)	It is a combination of open-ended interview, Ethnography, and prototyping. This method is primarily used for interactive systems design where user interface design in critical.	Reveals tacit knowledge; Information produced is highly reliable; Contextual inquiries focus on the work users need to accomplish, so it is always relevant to the user; The information produced is highly detailed.	The results may be inadequate for conducting statistical inference; it is resource-intensive; it requires travel to the customer site and spending few hours with each user, and then a few more hours to interpret the results of the interview.
Requirement reuse (Analytic – Documentation)	Reuse of the glossaries and specification of legacy systems or systems within the same product family to identify requirements of the desired system.	Domain requirements, User interface characteristics, Organisational policies, standards, legislation, etc. Experts Knowledge and Opinion plays an important role in requirement maturity. Reuse of already available information saves time and cost.	Requires some empirical data, documentation or expert's opinions without these it is difficult to elicit proper requirements; deals with some earlier knowledge so possibility of error replication is a serious and constant threat

Documentation studies Content Analysis (Analytic – Documentation)	A common method consisting of reading and studying available documentation for content that is relevant to and useful on the requirements elicitation tasks.	Organisational policies, standards, legislation; market information; specification of legacy systems	Requires some empirical data, documentation or expert's opinions without these it is difficult to elicit proper requirements. Deals with some earlier knowledge so possibility of error replication is a serious and constant threat
Laddering (Analytic - Expert 's Knowledge)	It involves the creating reviewing and modification of hierarchical content of expert's knowledge, often in the form of ladders (i.e. tree diagrams).	Knowledge is represented in standardised format; can elicit structural knowledge; suitable for automation.	Assumes hierarchically arranged knowledge
Card sorting (Analytic – Expert 's Knowledge)	The expert is asked to sort into groups a set of cards each of which has the name of some domain entity written or depicted on it.	Provides a good foundation for the structure of a site or product, and as a method for investigating label quality; provide insight into users' mental models	Labels are not presented in context; the card sort may vary widely; the result analysis can be complicated and time-consuming, particularly if the results are inconsistent.
Repertory grid (Analytic – Expert's knowledge)	Stakeholder is asked for attributes applicable to a set of entities and values for cells in entity-attribute matrix	Prompt the experts to think more concretely about the problem; providing insight into actual consumer perception.	Difficult to manage when large grids are accompanied by complex details; there are problems in representing some types of attributes (nominal values, ranges of values etc.)

A.12 Design Science Research Methodology

- **Design Science**: R. Buckminster Fuller introduced design science to develop user-friendly artefacts for systems that facilitates mindful design. It takes into account the whole system and the society it caters for rather than just identifying solutions to the immediate problem. Each time a solution is designed to a single problem without consideration of the relationships between that problem and the larger context; new problems are created [Brown et al., 1978].

A.12.1 DSR Methodology Process

- **Process model of DSR methodology**: The six activities in the process model of DSR methodology by Peffers are as shown in Figure 23.

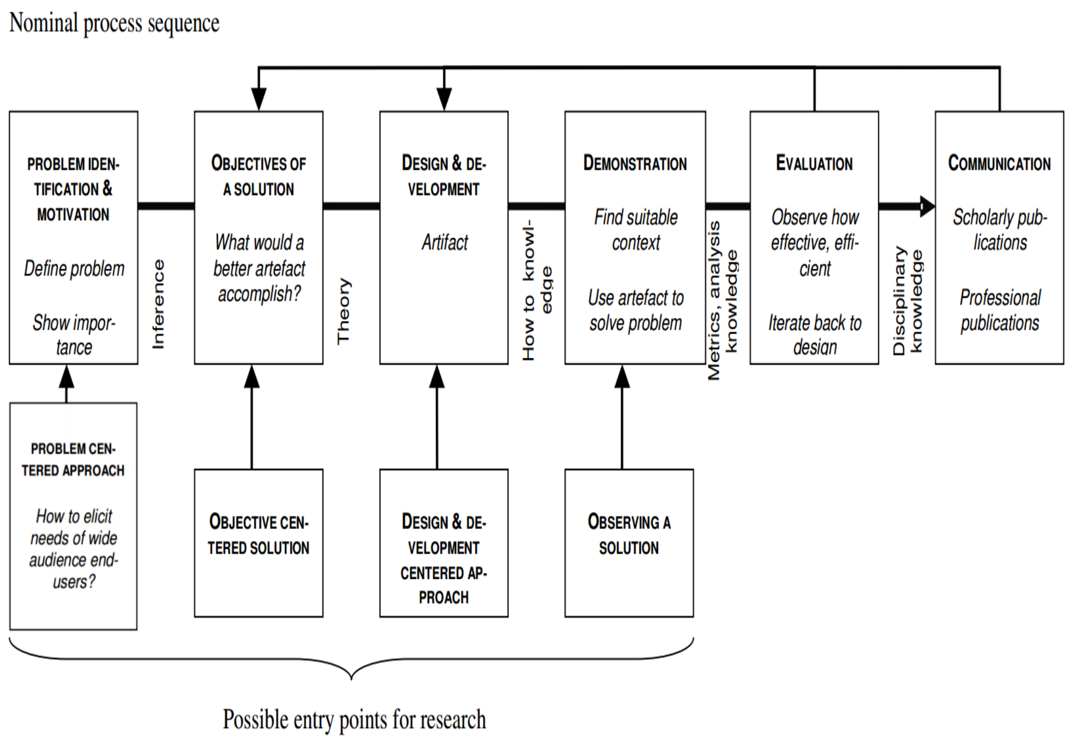

Figure 23: Process model of DSR methodology (copied from [Peffers et al., 2006]

- (**Problem identification and motivation:** In this step, the research problem is defined. It helps to understand the researcher's perception of the problem and the motivation behind accepting the proposed solutions.
- **Objectives of a solution:** Problem specification should be used to derive the objectives. Information of the state of problems, current solutions and their efficacy are required for this step.

- **Design and development:** This step involves creating the artefacts. The artefacts can be constructs, models, methods, or instantiations. This step also includes knowledge of the theory that can be produced to operate as a solution.
- **Demonstration**: This step involves the use of an appropriate activity to demonstrate the efficiency of the artefacts. The developed artefact should be used effectively to solve the problem.
- **Evaluation**: This step involves comparing the objectives to outcomes from use of the artefact in the demonstration. In this step, decisions can be made regarding further iteration of the artefacts to improve the effectiveness.
- **Communication:** This step involves communicating about the research to relevant audiences. It includes scholarly publications.)[Peffers et al., 2007, 2006]

A.12.2 DSR Methodology Evaluation

- **DSR Evaluation Methods**: Peffers et al. presented eight evaluations methods for DSR. They are logical argument, expert evaluation, technical experiment, subject-based experiment, action research, prototype, case study and illustrative scenario [Peffers et al., 2012].

  - (**Logical Argument**: Logical validity of the argument is used for evaluation.
  - **Expert Evaluation**: The artefacts are assessed by field experts.
  - **Technical Experiment**: Technical performance is evaluated by implementation.
  - **Subject-based Experiment**: Subjects are used to test the validity of the artefacts.
  - **Action Research**: Real world scenarios are used as a research intervention to evaluate the effectiveness of the artefacts.
  - **Prototype**: The artefacts are implemented to demonstrate its suitability.
  - **Case Study**: artefacts are applied to a real world scenario to evaluate the effectiveness in a real situation.
  - **Illustrative Scenario**: Synthetic or real-world scenarios are used to illustrate the suitability of the artefacts.)[Peffers et al., 2012]

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