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A Real time electricity usage monitoring system using smart meters for wastage detection in Kenya

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A REAL TIME ELECTRICITY USAGE MONITORING SYSTEM USING SMART METERS FOR WASTAGE DETECTION IN KENYA

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Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by Strathmore University or any other University. To the best of my knowledge, the thesis contains no material previously published or written by another expert except where due reference is made in the thesis itself.

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Abstract

Electricity utilities face dual challenges of generation and distribution. While many utilities are now migrating their operations into modern digitized platforms, most of these utilities have had to rely on old systems to carry out and monitor their commercial activities such as connectivity activity, itinerary scheduling, meter and device management, cycle billing, collections management and management reporting. This is causing utilities to reimagine customer engagements with a focus on feedback, put in place loss detection systems in their grids, use predictive models to schedule maintenance and other asset-management activities, equipping field workers with mobile devices that let them access technical instructions while in the field and deploy customised systems to help manage the extending networks. The main focus of this study was to design a real time electricity usage detection system using smart meters in Kenya, a system that would aid utility companies in providing real time feedback for service provision and anomaly detection. This research was done using smart meters to remotely record usage and record those messages manually into a web based portal. While it was not possible to replace existing old meters with the smart meters, the study made use of a test kit to simulate power consumption and usage recording. This study has put in place a model system that can be remotely connected to a smart meter and feedback generated in real time.

Keywords: Cycle Billing, Demand-Response, Electricity Usage, Feedback, Usage Detection, Smart Meters

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Abbreviations/Acronyms

API	-	Application Programming Interface
BPL	-	Broadband over Power Line
CI1	-	Commercial 1 – 415V
CI2	-	Commercial 2 – 11kV
CI3	-	Commercial 3 – 33kV
CI4	-	Commercial 4 – 66kV
CI5	-	Commercial 5 – 132kV
CME	-	Carbon and Energy Markets
CPP	-	Critical Peak Pricing
DC	-	Domestic
DNSPs	-	Distribution Network Service Providers
EdF	-	Électricité de France
EEA	-	European Environment Agency
EEI	-	Edison Electric Institute
EMAIL	-	Electronic Mail
EPRI	-	Electric Power Research Institute
ERC	-	Energy Regulatory Commission, Kenya
EU	-	European Union
EUCL	-	Energy Utility Corporation Limited
FCC	-	Fuel Cost Charge
FERFA	-	Foreign Exchange Rate Fluctuation Adjustment
GPOBA	-	Global Partnership on Output Based Aid
GPRS	-	General Packet Radio Service
GHG	-	Green House Gas
IA	-	Inflation Adjustment
ICT	-	Information and Communications Technologies
IEC 1107	-	International Electro-technical Commission Standard Number 1107
IEEE	-	Institute of Electrical and Electronics Engineers

IP54	-	International Protection Number 54
KES	-	Kenya Shilling
KVARH	-	Kilo Volt Amperes Reactive Hours
kW	-	Kilo Watt (1,000 Watts)
kWh	-	Kilowatt Hour
KVA	-	Kilo Volt Amperes
kV	-	Kilo Volts
LCL	-	Lower Control Limit
LLC	-	Limited Liability Company
MCB	-	Miniature Circuit Breaker
MCCB	-	Molded Case Circuit Breaker
MDMS	-	Meter Data Management System
MHz	-	Mega Hertz
MIT	-	Massachusetts Institute of Technology
MRI	-	Meter Reading Infrastructure
NSW	-	New South Wales
NTL	-	Non-Technical Losses
PHP	-	Personal Hypertext Preprocessor
PLC	-	Power Line Communications
PMBOK	-	Project Management Body of Knowledge
PSTN	-	Public Switched Telephone Network
QLD	-	Queensland
QoS	-	Quality of Service
RAM	-	Random Access Memory
REP	-	Rural Electrification Programme
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification
Rwf	-	Rwanda Franc
SA	-	South Australia
SAPN	-	South Australia Power Networks

SC	-	Small Commercial
SMS	-	Short Message Service
SSE	-	Scottish and Southern Energy
SWEBOK	-	Software Engineering Body of Knowledge
Tas	-	Tasmania
TEPCO	-	Tokyo Electric Power Company
TOU	-	Time of Use
UCL	-	Upper Control Limit
URL	-	Uniform Resource Locator
USSD	-	Unstructured Supplementary Service Data
VAT	-	Value Added Tax
Vic	-	Victoria
WARMA	-	Water Resources Management Authority

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Many thanks to friends and family for their support. God bless you all.

Chapter 1: Introduction

1.1. Background of the Study

Consumer electricity usage feedback to reduce energy consumption was initially studied as back as 1973 during the oil embargo. The researchers were interested in human behavior as a key factor of usage reduction. Since then, many researchers have done studies that incorporate feedback in the form of physical notes to consumers, usage reading, and usage monitoring. The main concern of the early studies have been to understand the consumer with a view to lessen their consumption and not overload the utility power grid (Farhar, 1989). According to ERC (2015), electricity demand in Kenya will continue to rise in the medium to long term. Several factors have contributed to this usage growth with key among them being: organic growth and network expansion and increased connections and Kenya's drive to implement key projects in line with Vision 2030.

Past research have tried to show the impact of consumer usage feedback since they have thought these approaches have a huge impact to influence household energy consuming behaviours (Martiskainen, 2007). He also noted that several intervention measures may be deployed as a better mechanism of behaviour control as opposed to a single methodology. Such options could include but limited to the use of descriptive bills, financial rewards, employing community-based campaigns and the use of micro-generation technologies.

It was also the opinion of early usage feedback studies that consumers were likely to alter their use of electricity once they were able to receive detailed, regular and effective feedback on their energy usage. Sigurjónsdóttir (2013), observed that in most homes, the electricity usage meters were installed out of sight and the indicator of the consumers' usage is a bill at the end of a given period. In a two month public survey opened to the public and conducted in 2011, the NOBEL project found that over 90% of the consumers who responded did want an improved overview of their electricity consumption, as well as a better understanding of the impact individual devices could have on their energy bill and behavior. By providing a means for the end-user to visually monitor individual appliances as well as the potential for savings by changed behavior, the potential for reduction in electricity consumption for the end-user was noted.

Residential energy is a largely untapped source of energy reductions as consumers, who wish to reduce energy consumption for monetary, environmental, and other reasons, face barriers. One such barrier is a lack of knowledge or understanding of how energy is consumed in a home and how to reduce this consumption effectively through behavioral and technological changes. By predicting how households are likely to consume energy, homeowners, policy makers, and other stakeholders have access to valuable data that enables reductions in energy consumption in the residential sector (Carlson, 2013).

Usage response in a timely manner has the potential to create flexibility by issuing cost and volume signal changes and even financial rewards to enable consumer's consumption accordingly. These actions can be run in concert with the generation and storage schemes within the same utility network whether in a regulated and a de-regulated network. The message is that, the best way to manage to achieve a sustainable result in usage reduction would be to adopt such policies that can be cascaded from generation, transmission, distribution and retail sectors of the energy sector.

Parker, Hoak, Meier and Brown (2006) found that many residential consumers have no way of judging if their consumption at a point in time is low or high except by means of a monthly usage bill. As is the case, this remoteness in usage awareness has contributed heavily to the lack of timely information that would trigger behaviour change in the consumer. As the supply and demand of electrical energy is challenged within the context of environmental awareness, green energy concerns, scarcity concerns and security, the need to evaluate and advance each side is growing rapidly.

Nader (2011) observed that when it comes to human consumption behavior, information is power. It is the intention of this study to provide an easy to understand interface that can be useful to electricity consumers in a bid to empower them with easy to understand information. Consequently, this study has made use of smart meters to demonstrate automated consumer usage acquisition over secure communication protocols. Even though communication established for this study was one way and usage recorded manually, these meters are intended to have a bi-directional communication capacity upon which this demonstration would ride. It was envisaged that a multi-channel approach would be useful as users would be provided with information access and retrieval with the options of SMS, Email and a web portal.

At the same time, a Kenyan analysis of electricity prices for residential consumers shows the numbers on the grid increased while also saw an increase, with a price of 17.14/kWh in January 2013 compared with 22.58/kWh in Jan 2018.

Table 1.1: Electricity Prices for a Domestic Consumer Tariff as at January 2013.

January 2013

January 2013	KSh / kWh
Consumption	8.10
FCC	4.93
VAT	1.79
FERFA	1.59
IA	0.30
WARMA	0.00
ERC	0.03
REP	0.40
Total	17.14

Table 1.2: Electricity Prices for a Domestic Consumer Tariff as at January 2018.

January 2018

January 2018	KSh / kWh
Consumption	12.75
FCC	4.30
VAT	3.02
FERFA	1.40
IA	0.42
WARMA	0.02
ERC	0.03
REP	0.64
Total	22.58

This increase in price is gradual but comes at a great cost to the consumers. Even where we consider the value of other adjustments charged by Kenya Power, the consumption cost is still the greatest cost inhibitor. It is the intention of this study to provide a system interface that can be helpful to residential consumers in a bid to empower them to identify high costs at times when their consumption is above average and cut down on usage. Such a demand-response initiative while it comes handy by providing price and volume signals to the consumers, should also instill behaviour change pattern towards greenhouse gas reductions and energy saving that is much needed for an economy that suffers power outages during peak demand hours like Kenya's.

1.2. Problem Statement

Understanding how energy is spent and knowing how to monitor and control it are key prerequisites for residential energy conservation. Energy efficiency improvements in place today are readily available and can have negative costs, a reduction in energy consumption and consequent drop in greenhouse gas emissions. Unfortunately, without a clear understanding of energy consumption these improvements may not be fully realized. The use of real-time feedback presented an opportunity to decrease energy consumption by 10%-20%. The problem with existing usage collection and billing is that their effectiveness was limited due to mixed information, which ranged from partial and limited to overwhelming and impractical. (Parker et al. 2006).

Management of domestic electricity consumption has mostly been based on manual meter readings, irregular read intervals and therefore, estimated monthly bills. The electricity consumption is amalgamated into one bill which does not allow for differentiation of electricity use within any specific or regular interval. (Gilchrist, 2011).

A multi-channel system interface that monitors electricity usage over time, could empower users to help them reduce their consumption and hence costs, reduce greenhouse gas emissions and help conserve energy. Specifically, a user centric system design that sends feedback to the user via SMS, Email and a provided web portal were the intended design outputs of this study.

1.3. Research Objectives

i) To review the techniques from relevant literature that are in use to detect and monitor usage.

ii) To identify the challenges that hinder accurate usage detection and monitoring.

iii) To design a real time energy usage and monitor application that uses smart meters.

iv) To test the energy usage application.

1.4. Research Questions

i) Which techniques and systems are in use for usage detection and monitoring?

ii) What challenges and limitations compromise accurate usage detection?

iii) How can a usage and detection application that uses smart meters be developed and be used to issue service information and anomaly alerts?

v) How can tests be carried out on usage data to detect exceptions and offer actionable insights?

1.5. Justification

One of the key energy wastage mitigation options is the use of energy efficiency measures in countering the negative impact of global warming. In Kenya and as is the case with many sub-Saharan countries, the race to reverse negative impact to climate change is just one of the challenges that needs attention in the energy space. Other key challenges that are encountered in this space include: inadequate energy supply, intermittent supply and the need to strategize and bring on board alternative energy sources.

According to Kenya utility distributor's medium-term strategy, key issues of operational concern that are planned for action are improving power supply quality and reliability, increasing grid access through a continued connectivity process, and sustained technical and non-technical energy losses. The continued new connections exercise ensured that the company's customer base rose to a near 6 million in 2017 from 2.3 million in the year 2013; showing a notable customer increase of 165% in 5 years.

Against obvious consumers' growth and a rise in usage cost, this research was intended to put the case that to some extent, the consumers' themselves have to take the decision to shelve themselves against high energy usage costs. Surely then, the research suggested that if the consumer were to make any behavioural decision that would reduce usage, then the research would provide such a mechanism that would empower the consumer with feedback information that is relevant and as close as possible to the usage action of concern.

1.6. Scope and Limitations

While this study acknowledged that there existed both supply and demand constraints to efficient energy supply and usage, its aim was to look at demand constraints only. In the interest of time, this study focused on actual usage data taken for a baseline period of between 30 - 60 days only for not more than 5 consumers, and specifically done with smart meters. The study made use of smart energy meters to capture periodic electricity usage every 1 Hour. While Kenya Power had over 6 million digital and analog meters in its consumer premises, only close to 5,000 smart meters had been deployed to few High Voltage energy users.

The established baseline in this study was shorter than those used by others for similar studies such as Mulville, Jones, Huebner, and Powell-Greig (2016), who used a baseline of 100 days to monitor usage for 2 office blocks. The study only focused on the residential sector. While better insight could have been derived using multiple consumers on as many tariffs classes as possible, choosing to use few consumers not exceeding 5, limited the depth to which this study could explore comparative feedback.

Chapter 2: Literature Review

2.1 Introduction

An exposition of the current usage detection and management approaches was discussed together with the impact of the various feedback approaches that are in use in the energy industry. Further, a discussion of the empirical trends of usage management with a highlight of the various usage rating models in use has been done. Challenges faced within the context of the various usage management approaches have been highlighted and a statistical data sampling proposed to confirm the need for an efficient system that can help the electricity customers sampled. A system design to help electricity customers manage their usage was then presented.

2.2 A Review of Existing Usage Detection and Feedback Mechanisms

Kempton and Montgomery (1982) illustrated how dysfunctional our existing electricity usage system is by considering the paradox of consumption without clear information in the following way: That: "Imagine a grocery store without prices on individual items, which presented only one total bill at the cash register. In such a store, the shopper would have to estimate item price by weight or packaging, by experimenting with different purchasing patterns, or by using consumer bulletins based on average purchases".

Ehrhardt-Martinez (2011), noted that lack of a clear usage reference impeded the extent to which individual residential consumers and their peers in other categories could compare and adjust their usage patterns. This, he concluded, was one gap that most energy saving mechanisms ought to address. Ford (2009) observed that a utility invoice which in its presentation is more of a 'black box', presented a challenge from the very go because the recipient consumer was likely to liken such an invoice with a shopping receipt that lacked the itemized values but only displayed a total value.

Such a bulk presentation of usage billing therefore created an ambiguity from the onset and in all necessity and intent, mechanisms must be put in place to get rid of this approach and replace it with an open billing format presentable in both detail and summary; and in both print and soft copy in web based system format.

Houwelingen and Raaij (1989) argued that energy billing invoices are many at times not specific, they arrived when they were almost overdue and thus not able to make people aware of energy saving types of behaviour, and, thus, had a limited function to enable feedback. They put the case that to be effective, for maximum effect, feedback would be provided under specific conditions with goals and intentions of the utility well thought out. Financial rewards would further increase the effect of feedback, which had specific functions namely: learning function, which means consumers learnt the energy consequences of specific behaviours; habit formation function, which were routinely performed acts that would remain after feedback withdrawal; and internalization of behaviour function, that is, energy conscious behaviours were developed overtime as the consumer was alerted to their own habit.

Costanzo, Archer, Aronson, & Pettigrew (1986) asserted that the electricity usage invoice that reflected the 'black box' energy consumed in the household unit presented an undifferentiated information communication that made better understanding of accurate energy very difficult. Zvingilaite and Togeby (2015) mentioned that time-wise, such an invoice when billed to the consumer was remote to the actual consumption event, and also lacked the detail which would allow a clear understanding of usage consumption and relating it to everyday practices.

In order to accurately record, monitor and verify the effect of feedback reporting mechanisms, a number of collaborative projects have been implemented by utility companies. In the United States, Pacific Gas and Electric Company, implemented home energy reports dispatch programme to residential consumers to assess the impact of behavioral demand response on peak electricity usage during summer. (PGE, 2017). In Japan, Jyukankyo Research Institute conducted a home energy report pilot study on close to forty thousand homes connected to Hokuriku Electric Power Company's grid (Hirayama, 2016). In either case, the resultant advice in residential usage reports in the US and Japan was made on the basis of monthly usage consumption and invoicing.

The EDRP in the United Kingdom was an implementation done to test consumers' responses to different forms of information concerning their periodic usage and invoicing. Close to sixty thousand consumers of four utilities participated in the program namely: EDF, E.ON, Scottish Power, and SSE. While examining the effectiveness of economic rewards to promoting electricity usage conservation behavior among households in Japan, Mizobuchi and Takeuchi (2012) mentioned that energy prices play an important role in the long term electricity conservation. The benefit of reducing household electricity consumption was composed of savings in the electricity bill and economic incentives provided by policy intervention directives.

Ida, Murakami, and Tanaka (2015) observed that considering demand-side management, the Japanese government had set targets to improve efficiency in residential energy management. Most Japanese residential consumers were charged flat-rate tariffs for electricity using conventional analog electric meters, but the government planned to install digital smart meters in all households in Japan by the year 2024. Along with smart metering approaches and possibly home energy management systems (HEMS), dynamic pricing schemes, such as critical peak pricing (CPP) and real time pricing (RTP), were expected to induce residential consumers to use electricity more efficiently.

The European Union came up with a raft of energy efficiency directives and guidelines in the year 2012, a directive that provided new mechanisms to accelerate energy efficiency improvements, make clear integrated approaches in implementation and set out timelines with a deadline pegged to the year 2020. The directive also emphasized the criticality of cost-effectiveness, given the urgent need to restore sustainability to public finances. (EEA, 2013). The EEA (2013) stressed a requirement that member states would ensure that national utility regulators encourage demand response programmes, and that network tariffs take into account the costs and benefits of energy efficiency measures.

2.2.1 The Impact of Feedback on Demand Response

The impact of feedback mechanisms as a counter measure one paradigm whose effectiveness is not in doubt. As earlier studies have noted, the most effective forms of demand response feedback were likely to include both products and that enable consumer’s access to timely and detailed information that was presented in multiple ways. These presentations would be tailored to the consumer in a context that provided meaning, clarity and motivation (Ehrhardt-Martinez et al., 2010). Consequently, both individual and group level feedback mechanisms have been shown to positively influence environmentally friendly or ‘green’ behaviour. Ultimately, the effectiveness of feedback lied in it being presented within a time space that was close to the consumer consumption. When done in such a manner, the consumer's behaviour change would become easy to trigger since they would interpret their usage in line with the feedback presented. Specific to residential consumers, effectiveness of feedback had been shown to diminish once feedback was removed suggesting that a long term dispatch methodology was key to ensure a sustained change effort. (Mulville et al. 2016).

Ehrhardt-Martinez et al. (2010) argued that while the importance of feedback insights could not be stated enough, it was good to notice the cost differentiation factor that existed across the several feedback mechanisms to recognize the substantially lower investment costings associated with enhanced invoicing programs. Evidently so, the focus of any feedback approach taken on the residential households hugely influenced the outcome and its sustained impact.

The easiest form of feedback to plan and implement was noted to be direct feedback with real time considerations and an easy access consumption-feedback. For example, an in-house consumer display unit could be mounted within the consumer premises for such feedback. It is particularly useful for illustrating the real-time impact of end user devices. On the other hand, indirect feedback could also be useful when other considerations came in play like the cost of feedback dispatch. Usually such feedback could have been processed in some way before dispatch to the consumer. Nevertheless, in this approach, consumers had no direct access to actual consumption data and could only respond to previous consumption behaviour. This essentially meant that there was a time lag between energy consumption time and the moment feedback reached consumers. The delay could have been in hours, a day or even weeks. In some case, more time was needed to verify the data. (Zvingilaite & Togeby, 2015).

Notable for its equal success had been comparative feedback. In this approach, a consumer's usage and its related feedback was compared to another consumer in the same consumption group and locality to check if there were correlations and follow ups on change. By design, this feedback option translated into good results by evoking a feeling of social competition which eventually led to consumption behaviour change in order to either correspond more closely to the norm or perform better than the consumer group (Abrahamse, Steg, Charles & Rothengatter, 2005). Mahone and Haley (2011) noted that household focus provided information about a specific home's energy use, often with custom efficiency advice & disaggregated data. Community focus by extension sought to engage with consumers through their group affiliation, often by creating a sense of team effort towards a common goal. The figure summarizes these strategies.

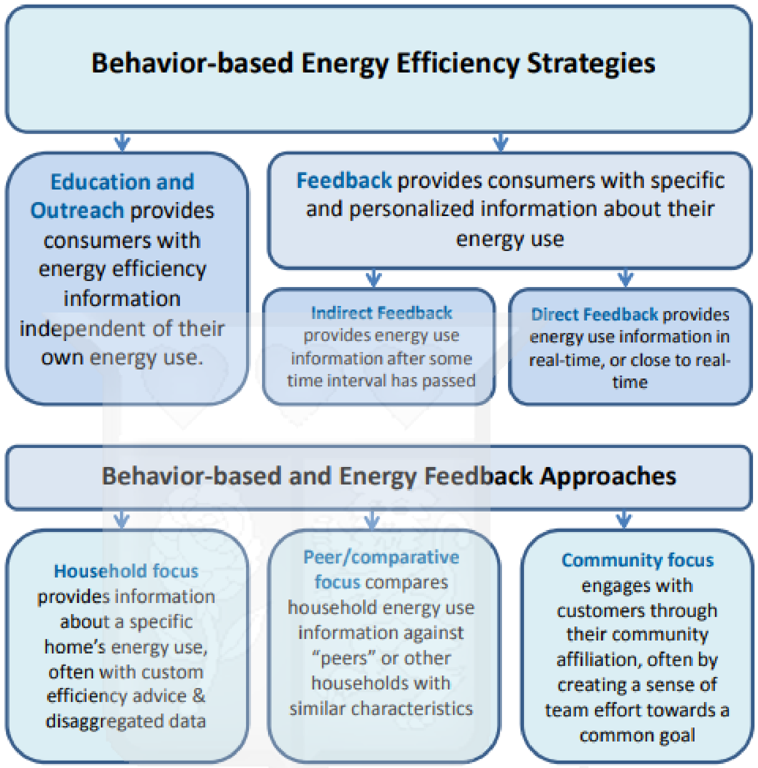


Figure 2.1: Behavior-based Energy Efficiency Strategies & Approaches (Mahone & Haley, 2011)

Ford (2009) mentioned that for homeowners to take green energy drives and related behaviour on board and run with their implementations, they ought to change the way in which they perceive and use energy. This change in usage consumption would require that both motivation and knowledge be inherent in the processes in order that the changes are persistent, effective and sustained. If done appropriately, the individual would possess as much motivation as possible for the task at hand. The end result was that when this was then extended to the larger associated group, useful, timely and interactive feedback could be accomplished at scale.

2.2.2 Comparative review of feedback approaches

Even though it was easily agreeable that there does not exist a single fitting approach as the ultimate solution for feedback, there was not enough information complete and conclusive enough on consumer preferences with respect to the design of the possible systemic interfaces through which the feedback was provided. Further to this ambiguity, it was equally not clear how resultant feedback could be appropriated and integrated into usage consumer's lives.

As a matter of preference, it was important to provide the usage consumption and related monitoring capability to the consumers in kilowatt hour units as opposed to providing other information just because the consumers need them. Thus, providing consumption based feedback in its preferred and effective form is not equivalent to providing efficient feedback (Kendel, Lazaric & Maréchal, 2017). Closely related to this line of thought, Malama, Makashini, Abanda, Ng'ombe, and Mudenda (2015) observed many researchers and authorities have generally thought that dispensing more usage information to the consumers will translate to better change patterns. This they noted was always not the case.

Zhou (2012) recommended that as part of demand-side management approaches, utilities could integrate behavioural change programs as part of their customer service offerings. He noted that as a simple rule of guidance, residential electricity invoices would have to a bare minimum, the following notable attributes: First, they would present usage based calculations that could be easily interpreted by customers with both summary and detailed item lines showing bill rating and miscellaneous calculations. Second, they would be transparent and provide cost breakdowns for every concept to tariff rate calculations and other charges for every consumer group. Third, they would provide information related to invoice payment options and alternatives, contact details for after hour customer services and regulatory authorities. Finally, the invoice would be used as a tool to provide custom feedback information related to energy efficient use and practices, climate change implications related to electricity use, energy mix and use of alternative green energy supplies.

Lesic, De Bruin, Davis, Krishnamurti and Azevedo (2018), summarized that it was not clear whether providing more information at the appliance level after general feedback information provision was done, would translate to more informed energy use decisions. Understanding the consumer usage perceptions and misconceptions of energy use and savings would equally help to influence the design of energy efficiency policies. However, caution ought to be put in place to present feedback in a way that consumers could easily use and understand.

Bertoldi, Serrenho, and Zangheri (2016) suggested that considering both frequent feedback and infrequent feedback, it was noted that the former is more effective than the latter as it helped link the immediate consumer usage actions with the consequences. The strategies using bills were certainly more replicable and could be extended to higher samples, but their effectiveness seemed to be minimal. In the foreseeable future, and as devices and software continue to converge enabled by cheaper communication options, maximum savings are achievable with continuous direct feedback. Indirect feedback alternatives could still be used where other parametric or cost concerns are considered.

2.2.3 Real time feedback approaches

Necessitated by reliable telecommunication connectivity, internet enabled interactive feedback will have a higher traction to engage users for longer or more frequent periods of time. This reality implies that digital media channels may increase feedback effectiveness to the extent that the classification of direct or indirect feedback would become immaterial. In the long term, direct feedback options would have better use than indirect approaches.

Central to all these developments is the smart meter device whose importance cannot be gain said. This is the primary device that would be used to offer premise level real time feedback. The smart device allows the linking of the usage data and production measurements within a specified time frequency. Such an arrangement is quite a game changer in the way legacy billing has worked in decades for billing along flat pricing.

Early smart meter adopters included European countries such as Italy and Sweden who were among the first countries in to complete smart meter rollouts in the late 2000s. Finland easily followed the same approach at the end of the year 2013. A second batch of countries have equally gone ahead in Europe to embrace smart meters with rollouts cascaded over several months and years. Such countries have included France, the Netherlands, Spain, the UK and several others in Western Europe whose deployments have set targets to be achieved by the year 2020. As an example, the country of Estonia is doing the first nationwide rollout in Eastern Europe, where other markets with a high level of activity also include Poland and Latvia (Berg Insight, 2015).

Appliance level feedback has also emerged as the next level real time approach that is proving quite useful. To encourage use of energy-efficient operations in residential and office buildings, non-intrusive load monitoring systems have been suggested to infer the fine-grained power consumption and usage patterns of household appliances from power-line measurement data. Fine-grained monitoring of everyday home appliances like toasters, coffee makers, and washing machines can not only promote energy-efficient building operations, but also provide unique insights into the context and activities of residential individuals (Nirmalya, Nilavra & Archan, 2016).

2.3 Empirical Literature

According to Ehrhardt-Martinez et al. , (2010), the provision of direct context relevant feedback and other usage saving tips to the consumer, has a great potential in achieving the best results at scale, with large scale programs aimed at achieving saving targets from past programs being able to achieve between 4 to 12 percent in savings. Exceptions have also been noted to offer even higher levels of savings. More important is the fact that feedback provision is generally required at scale as it creates usage visibility to a large consumer base allowing for even further extension considerations to extend the same practice to consumer usage groups beyond residential users.

The EEA (2013), through the EU's Energy Efficiency Directive noted that in October 2012, a number of EU Member States were not on the anticipated trend to be able to reduce primary energy usage by 20 percent by the year 2020. According to the EEI, the implementation of this directive, and other relevant policies would require significant changes to an old industry not used to change, specifically in consumer behaviour and energy usage practices. Indeed, a growing body of relevant knowledge in academia seems to demonstrate that there is huge potential for energy usage savings due to feedback measures targeting behaviour. This is illustrated in the Table 1.3 below:

Table 2.1: Possible Energy Savings due to Measures Targeting Behaviour (EEA, 2013).

Intervention	Range of energy savings
Feedback	5–15 %
Direct feedback (including smart meters)	5–15 %
Indirect feedback (e.g. enhanced billing)	2–10 %
Feedback and target setting	5–15 %
Energy audits	5–20 %
Community-based initiatives	5–20 %
Combination interventions (of more than one)	5–20 %

According to Ehrhardt-Martinez et al. (2010), in the US, a mix of new consumer feedback approaches are making energy resources visible to residential energy consumers. As summarized in the figure below, this mix of initiatives has made it possible to check other potential energy usage savings that, on average, could help reduce individual residential consumption by between 4% - 12%. If such savings can be achieved, then this would underscore the important fact that consumer feedback is proving to be critical as an initial step of engagement and empowerment to consumers.

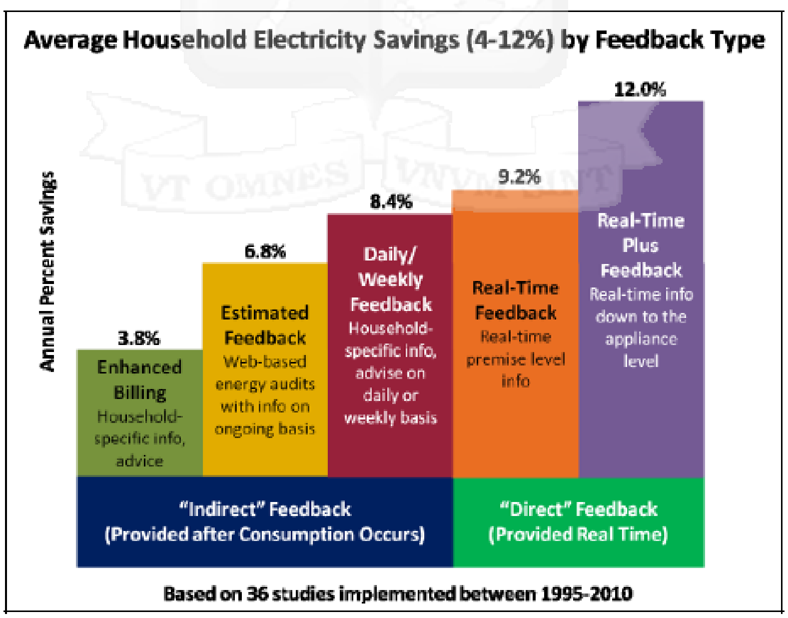


Figure 2.2: Noted Household Electricity Usage Savings. (Ehrhardt-Martinez et al., 2010).

2.3.1 European approach to Smart Meters rollout

In 1995, a research in Norway was done to check on the impact of using an informative usage invoice as a key component of consumer feedback. The research that lasted close to 36 months and was conducted on close to 1,200 residential households was made to consider the possibility that could be achieved from using a higher billing frequency, clearer presentation of information and making use of relevant usage comparisons. Three experimental groups were setup and presented with more frequent bills. On experimental group 1, frequent feedback was dispatched with actual consumption while on experiment group 2, graphical feedback concerning their current usage was dispatched and compared to the group's previous consumption. Finally on group 3, feedback was dispatched concerning their current usage as compared to some established standard.

At the end of the study in 36 months, it was noted that the experimental groups averaged a saving of 10% over the control group, up from the saving of 7.6% at the end of the 24th month, showing a positive trend of the effects induced. Notable, these results suggested that the crucial factor in this particular study was the billing frequency and which determined invoice presentation. (Ford, 2009).

Governments within the Eurozone have continued to play an important role for the adoption of smart metering technologies ushering a technological shift towards demand-side management at scale. Berg Insight (2015), noted that the Eurozone has close to 280 million metered electricity customers and the annual demand for electricity meters for new installations and reticulations is in the range of 12–16 million devices. The intended new installations of these new smart meters, while providing more comprehensive usage monitor and control functionality than basic meter data collections, was 24 percent at the end of the year 2014. By year 2020, the Eurozone projects that the penetration rate could increase to over 55 percent. This large increase in last mile smart meter rollouts could be driven mainly by large rollouts in anchor countries of Spain, France and the UK, in combination with nationwide rollouts in several smaller countries.

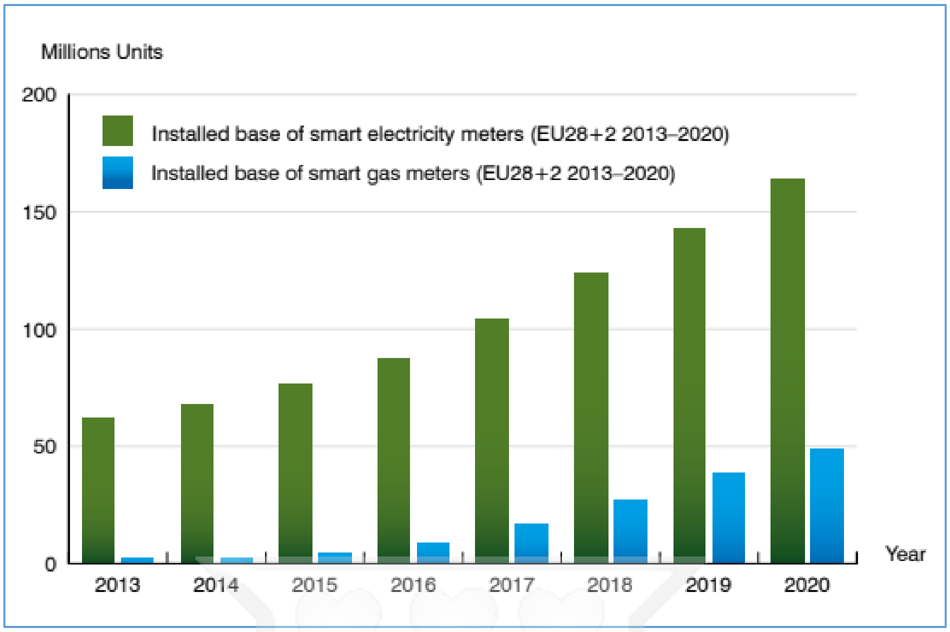


Figure 2.3: Installed Smart meters in Europe (Berg Insight, 2015)

2.3.2 British approach to Smart Meters rollout

In Great Britain, the Department of Business, Energy & Industrial Strategy (2018), noted that the Smart metering project had been planned for delivery in two phases. Phase one began in the year 2011, where the government engaged industry stakeholders with key among them being industry and consumer groups. Commercial and regulatory frameworks were then put in place to support smart metering project phases, systems trial and test runs, offer consumers protection and learn vital lessons from early phase installations. Phase two of the project was the main installation phase running from the year 2016 to year 2020 and it was within this period when most residential and small businesses would have smart metes installed. As of March 2018, around 12 million smart meters had been rolled out in residential and business premises across Great Britain.

2.4 Techniques and Models Used in Usage Management

Traverse LLC (n.d), observed that consumption-based pricing and billing seems straightforward yet the mechanics are quite different than supporting one-time or subscription-based offerings. Although these mechanisms are deeply intertwined in the telecommunication or utilities proprietary systems historically, usage processing could occur in batch or in near real-time, depending on the need.

Further, Traverse LLC, (n.d), defined eight core concepts of usage-based billing as shown in the Figure 1.3 below and enumerated as follows:

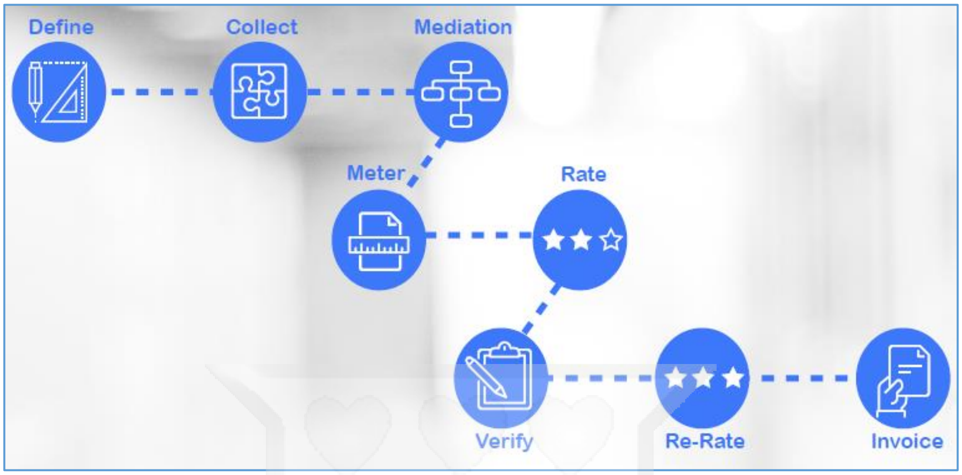


Figure 2.4: Eight Concepts of Usage-based Billing. (Traverse LLC, n.d.).

i) **Define the Quantifiable Metric(s):** A measurable unit that can be defined/calculated and tracked must exist. Examples of quantifiable metrics include: number of transactions, number of hours, number of API calls, amount of storage used, etc. Metrics that could be billed by consumption are often called 'events.'

ii) **Collect the Data:** Mechanisms to track, collect and, if necessary, store the data.

iii) **Normalize the Data (Mediation):** This process formats, enriches, aggregates and de-dupes raw event data from disparate sources in multiple formats. The result is normalization for validation, rating, billing and reporting.

iv) **Meter the Data:** Metering is the continuous monitoring of event data for thresholds and notifications. It is associated with a rate of data collection (per sec/min/hour/day/etc.).

v) **Rate the Data:** This process determines the costs applied to the event and applying a charge to them. A rating engine controls rules for rate plans, rollovers, allowances, balances, quality of service (QoS), time-of-day, 'special' days, etc. The ability to rate multiple variables on one usage type prevents usage unit proliferation.

vi) **Verify the Data:** Quality assurance steps including voiding, editing or preparing the data for re-rating.

vii) **Re-Rate the Data:** A critical step that quickens processing time for rating and invoicing. The re-rate function is typically invoked as part of the requirements for usage pooling, shared allowances or tiered pricing. In these scenarios, the usage must be re-evaluated across many services based on complex rating parameters, and crossing into higher tiers requires the re-rating of all previous events with the new rate.

viii) **Invoice:** Produce an itemized bill that includes the consumption amounts, rates, individual charges and total charges with corresponding terms to be paid.

Data rating approaches differ from one country to another. In principle, the major guiding factor for the differences in rating are whether these markets are regulated or non-regulated markets.

2.4.1 Usage Rating Models Used in the United States

Edison Electric Institute (EEI) (2007) documented a conclusive list of pricing models onto which usage was subjected for the United States market. In the case of the US, retail prices have been modelled alongside wholesale prices since the market was a de-regulated model. In this model, it was the norm that usage prices are computed hourly to reflect real time pricing of peak and off-peak periods.

i) Hourly Pricing

a) The basic hourly model. In this pricing model, direct wholesale prices were applied with little markup to the retail consumers.

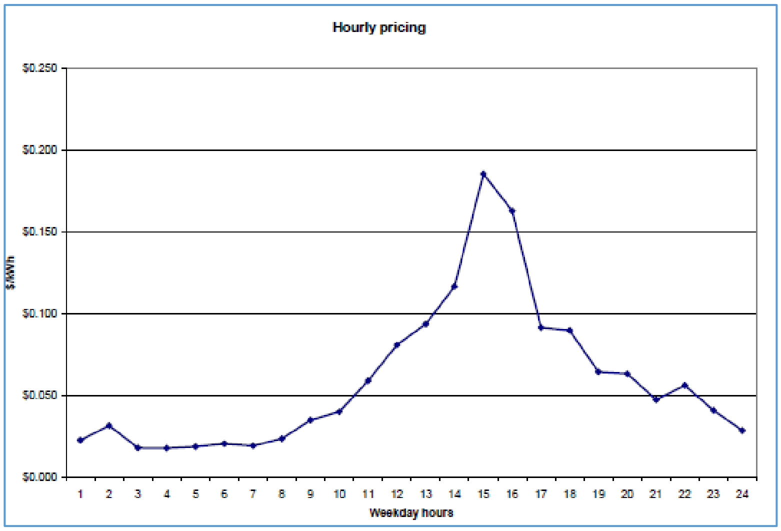


Figure 2.5: Hourly Pricing (EEI, 2007)

b) Block and index pricing model. This combined model charged consumers on an hourly basis and this charge was indexed to a reference wholesale energy usage market. A key component involves price contracting such that a certain fixed amount would be charged during peak hours and this protects both parties from any further load fluctuations.

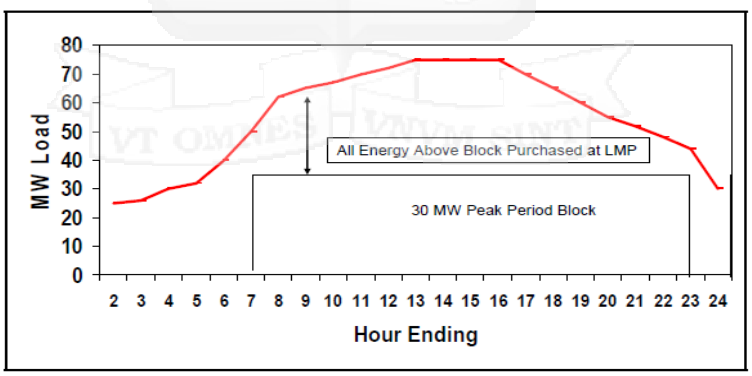


Figure 2.6: Block and Index Pricing. (EEI, 2007).

ii) Daily Pricing

a) TOU pricing per day. In this pricing model, multiple TOU price references were put in place in advance to reflect expected wholesale prices by time period on different price day-types. The applicable price profile was announced a day ahead of time. An example is the Tempo residential tariff offered by EdF, which consisted of three TOU price profiles, with limits on the number of times that the medium and high prices could be called.

b) Variable peak pricing. Under this model, a static fixed off-peak pricing was put in place, but at the same time, a dynamic pricing model was put in place for high peak periods and this was determined on a daily basis to reflect energy market prices, and was announced a day ahead of time. This price structure could be thought of as a simplified version of hourly pricing, in which hourly prices were averaged into pricing periods.

c) Critical peak pricing model. Under this pricing model, the rating was established such that it consisted of a base TOU rate plus a pre-specified critical price that was considerably higher than the TOU peak price. When combined with CPP, the corresponding TOU peak price could be offered at a discount relative to a standard TOU rate, because the peak price did not have to cover the expected cost of the highest-cost hours. The utility could announce a critical day on a day-ahead or same-day basis, in which case the critical price applies during all or part of the peak period instead of the normal TOU price. The rate typically contains a restriction on the number of times that the critical price could be called.

d) Variable CPP. This pricing model established multiple critical prices prior to billing execution. This design would address two practical issues in implementing a CPP rate, which were setting the critical price level and establishing the criteria to be used for calling a critical event. That is, if a single CPP price was set very high, then it could send an accurate price signal on rare, very high-cost days that could not occur in every year.

Table 2.2: Variable CPP. (EEI, 2007).

	Hours ending	Price ($/kWh)
On-peak	14 - 19	$ 0.063
Mid-peak	11 - 13; 20 - 22	$ 0.048
Off-peak	1 - 10; 23 - 24; and all weekend	$ 0.025
Critical	(see below)	
High		$ 0.125
Emergency		$ 0.250

Critical events involved events that lasted from 1 to 6 hours during On-peak period. Critical events were considered high when announced by 4 p.m. of previous day. Critical were said to be emergency events when announced with 1 - 2 hour notice. Similarly there could be no more than 15 events per season and no more than 30 emergency hours.

e) CPP linked standard pricing model. This pricing model made use of critical price feature as an add-on to the standard non-TOU rate. This design would offer the benefit of not having to first design and offer a new TOU rate in conjunction with the critical price option. This could help address potential bill impact and revenue erosion problems that could arise from voluntary TOU rates (see Section 3.2), and could simplify the option for consumers. Like CPP/TOU, the critical price, or prices, which would apply during a pre-determined peak period, could be announced on a limited number of days, and would depend on wholesale market conditions. Also like CPP/TOU, the standard tariff price would be discounted to account for the fact that it did not have to cover the cost of the highest-cost hours, as well as to provide an incentive for consumers to choose the rate.

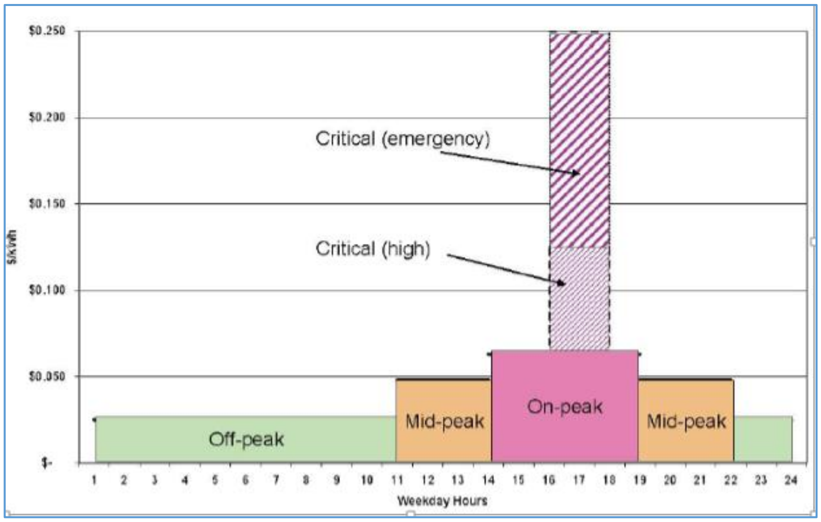


Figure 2.7: Variable CPP/TOU Rate. (EEI, 2007).

f) Peak-day rebate pricing model**.** This pricing model linked the critical pricing model to the standard pricing model. The model had features that were associated with demand response programs. A voluntary approach was used when faced with a critical price response decision, i.e., consumers would be charged on the standard price, even during critical times, but they would have the opportunity to receive a discounted payment for any load reductions below an estimated baseline.

iii) Fixed time of use pricing

In this price structure, prices were fixed within each TOU pricing period. Pricing periods would be defined according to time of day (e.g., on-peak, mid-peak, and off-peak), day of week (e.g., weekday and weekend), and/or season. Demand charges as well as energy prices could vary by time of day. TOU rates represented one of the oldest forms of efficient time-based pricing in the industry, and were relatively common as standard tariffs at many utilities for large commercial and industrial customers.

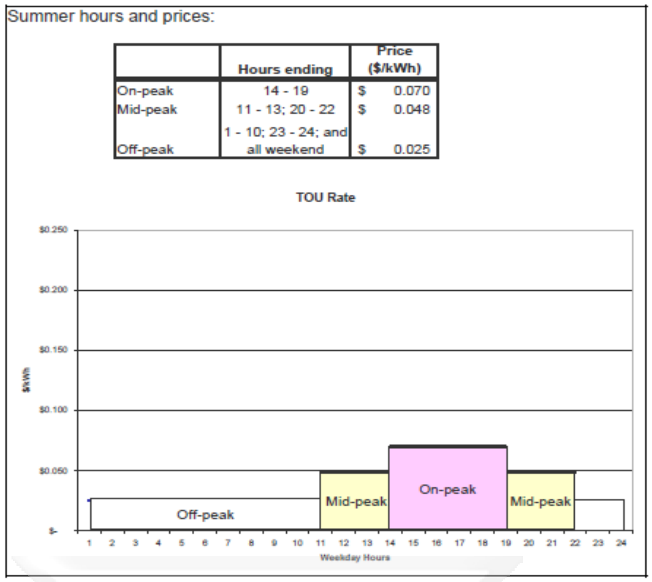


Figure 2.8: Sample TOU usage rate. (EEI, 2007).

iv) Seasonal Flat Pricing

In this structure, prices were fixed within a season but could vary between seasons. The prices represented average differences between power costs in the designated seasons. Because they were announced months in advance, they provided customers with signals regarding differences in expected power system costs by season, and could thus provide weak incentives about, for example, the cost of air conditioning or space heating.

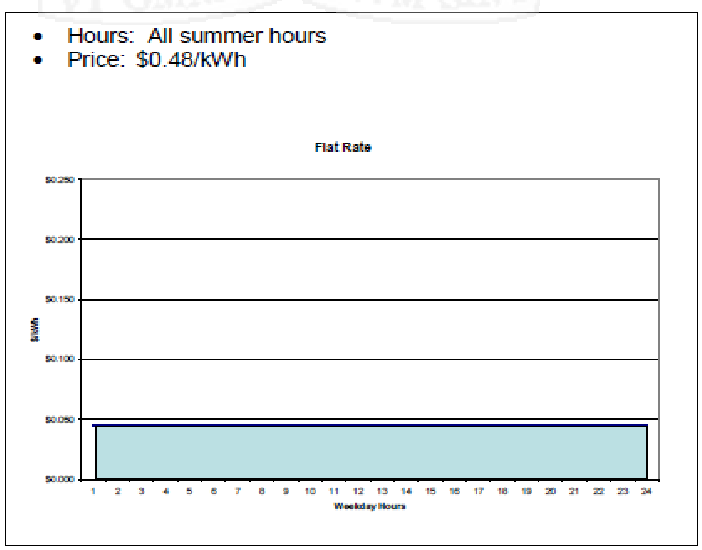


Figure 2.9: Flat Seasonal Rate. (EEI, 2007).

Most of the pricing implementations had dynamic rating which implied that a dynamic amount was charged for every kilowatt hour and this pricing changed with the seasons of winter and summer being the most common seasons in use. (Coughlin, K., White, R., Bolduc, C., Fisher, D. & Rosenquist, G., 2006).

Table 2.3: Seasonal Definitions Table, S=summer, W=winter (Coughlin et al. 2006).

Utility	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Beauregard Electric	W	W	W	S	S	S	S	S	S	S	S	W
Idaho Power	W	W	W	W	W	S	S	S	W	W	W	W

2.4.2 Usage Rating Models Used in Australia

Carbon and Energy Markets (CME), an economics consultancy focused on Australia's energy and utility industries observed that while production and retailing of electricity in Australia was operated in a non-regulated market, the grid components that consisted of transmission and distribution were operated in a regulated market. Most retailers were also producers of most or a large part of the electricity they sell (CME, 2015). The distribution network service providers (DNSP) charged the following sample prices to retailers.

Table 2.4: Tariff structures by DNSP. (CME, 2015).

	Two Part	Inclining Block Tariffs	Time of use
SA Power Networks (SA)		X	
Ausgrid (NSW)	X	X	X
Endeavour Energy (NSW)		X	X
Essential Energy (NSW)	X		X
CitiPower (Vic)		X	X
Jemena (Vic)	X		X
Powercor (Vic)		X	X
Ausnet (Vic)	X	X	X
United Energy (Vic)	X		X
Energex (Qld)	X		X
Ergon Energy (Qld)	X		X
Aurora (Tas)	X		X

This pricing model consisted of two part pricing models with monthly or quarterly fixed prices in use. A single variable charge was also applied. Another key feature was the use of inclining block pricing which referred to a pricing approach with progressive increasing charges per unit of usage billed.

2.4.3 Usage Rating Models Used in Kenya

The core tariffs set by the Kenya Power as of December 2017 are shown below.

Table 2.5: Tariff Schedule from December 2017 (Kenya Power, 2017)

Tariff code/description	**Charges - Ksh**		
	Fixed charge price	**Energy charge - per kWh**	**Demand charge - per kVA**
DC (240 V)	150	First 50 kWh: 2.5 50 to 1 500 kWh: 12.75 Beyond 500 kWh: 20.57	N/A
SC (240 V)	150	13.50	N/A
CI1 (415 V)	2 500	Peak: 9.20 Off-peak: 4.60	800
CI2 (11 kV)	4 500	Peak: 8.00 Off-peak: 4.00	520
CI3 (33 kV)	5 500	Peak: 7.50 Off-peak: 3.75	270
CI4 (66 kV)	6 500	Peak: 7.30 Off-peak: 3.65	220
CI5 (132 kV)	17 000	Peak: 7.10 Off-peak: 3.55	220
IT (Residential Water Heater)	150	13.50	N/A

In Kenya, the power utility announced special off-peak prices for commercial consumers with effect from December 2017. Off-peak prices were then set as follows:

Table 2.6: Off-peak pricing for commercial consumers (Kenya Power, 2017)

Day	**Off-peak hours**
Weekdays	From 22:00 to 00:00 and From 00:00 to 06:00
Saturdays and public holidays	From 14:00 to 00:00 and From 00:00 to 08:00
Sundays	All day, that is from 00:00 to 00:00

Faced with multiple pricing models, the EEI summarized options that could simplify pricing and determine a reasonable amount to charge. According to EEI, the simplest pricing model would be to adopt a case where the consumer was charged on an hourly pricing that directly reflected the actual cost to service them on the grid. Where consumers needed simplicity and certainty of a flat pricing model, the best options to offer would be either a consumer specific monthly, seasonal or annual pricing model which would be based on the expected cost to serve each individual consumer on the grid.

Finally, consumers could also be charged on a fixed-bill pricing model with an appropriate risk premium. While every situation could warrant the use of a different model suiting its operational conditions, the simplest rule would be that the simpler and certain a price was, the better it would be for the end consumer; even though this could sometimes have greater administrative cost and risk to the utility operator, and thus the greater the risk premium. This risk matrix that swung in different directions for consumer and the utility was presented as shown in Figure 1.8 below.

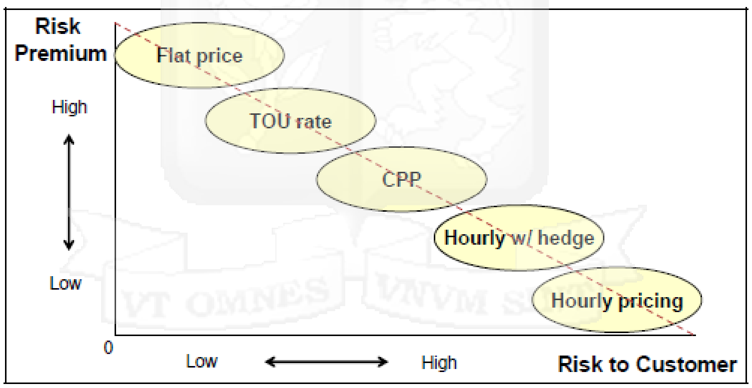


Figure 2.10: Risk Premiums and Risk-based Retail Pricing. (EEI, 2007).

2.5 Challenges of Current Usage Management Approaches

Challenges of timely and accurate usage detection other than prejudicing the consumers also leads to commercial losses to the utilities. In its yearly report for the year 2016-2017, Kenya power pointed out that, Commercial losses occurred due to specific technical and non-technical losses. Sample of these losses were electricity equipment theft, faulty meters and inaccurate usage detection. Further, the utility noted that it was investing in major system management tools and digital meter solutions that would allow real time data gathering to accurately understand and monitor consumer usage behaviour (Kenya Power, 2017).

In a study analyzing ways to reduce non-technical losses in Kenya, Njenga (2011), noted the challenges below which had a bearing on accurate usage detection:

2.5.1. Illegal Tapping of Electricity from the Feeder.

An electricity connection is considered illegal when it is connected to the utility's network without utility's permission. This was the most common and simplest way of pilfering electricity. According to Njenga (2011), poverty levels and unemployment led to vandalism of transformers and theft of copper conductors for sale, and competition in manufacturing and production industries which pushed some to minimize their production costs through power theft. These issues were the major causes of electricity theft which in turn contributed largely to non-technical electricity losses. Poverty due to unemployment pushed people to steal electricity since they couldn't afford but they needed it. They also engaged in acts of vandalism where they sold electricity equipment like oil and copper found in the transformers.

2.5.2 Bypassing and Tampering with the Energy Meter.

According to Depuru (2012) this method of theft was found as difficult to detect and could only be confirmed by a random audit. This tamper and physical damage occurred across all consumer groups such as industrial, commercial and residential. Several other tamper actions have been noted and these present huge challenges for non-technical losses. Key among these illegal actions are meter exposure to strong magnetic fields to wipe out the memory, frequency tamper which affects integrated circuits.

2.6 Usage Information Flow

Jiang (2010) proposed an architecture model that consisted of three layers namely: data sensing, data delivery and representation, and applications and services. He demonstrated that this layering methodology allowed the system designers to isolate low-level details of the system hardware, communication channels, protocols from the software layer which helps implement the data movement a logic.

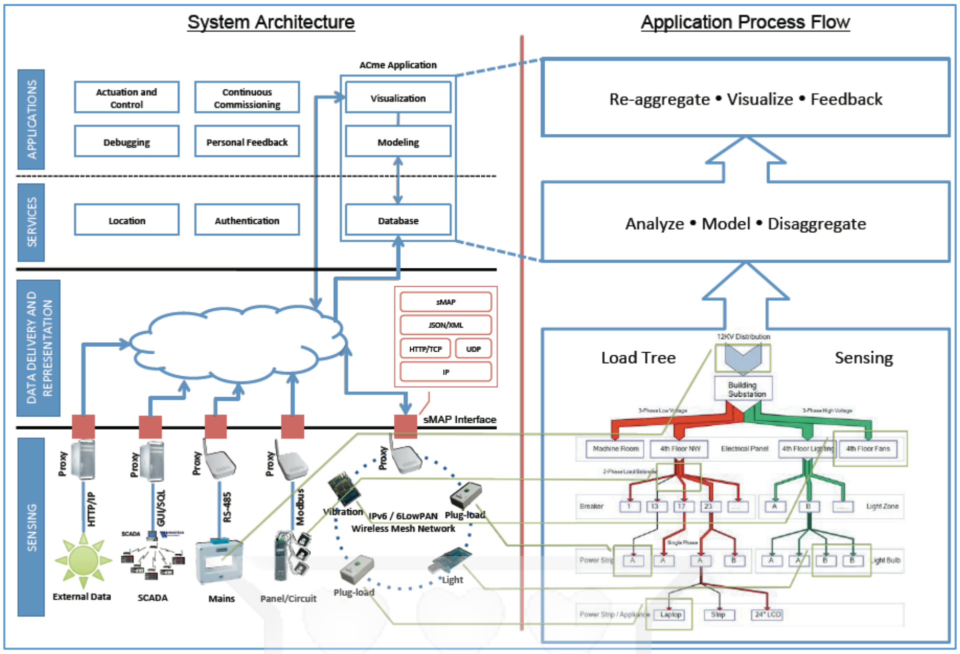


Figure 2.11: Smart Usage System Architecture and Application Process Flow. (Jiang, 2010).

Electric Power Research Institute - EPRI (2007) presented a usage measurement and collection system that included meters recording at the consumer premise, a robust communication channel between the premise and a utility servers, and a data receiving module and reporting systems that availed the information on time.

As illustrated in the Figure 2.13 below, these meters could transmit the recorded usage information through several data channel options such as Broadband over Power Line (BPL), Radio Frequency (RF) networks, and public networks to the utilities' central meter data management system (MDMS) that managed data storage and usage analysis to provide the information in useful form to the utility.

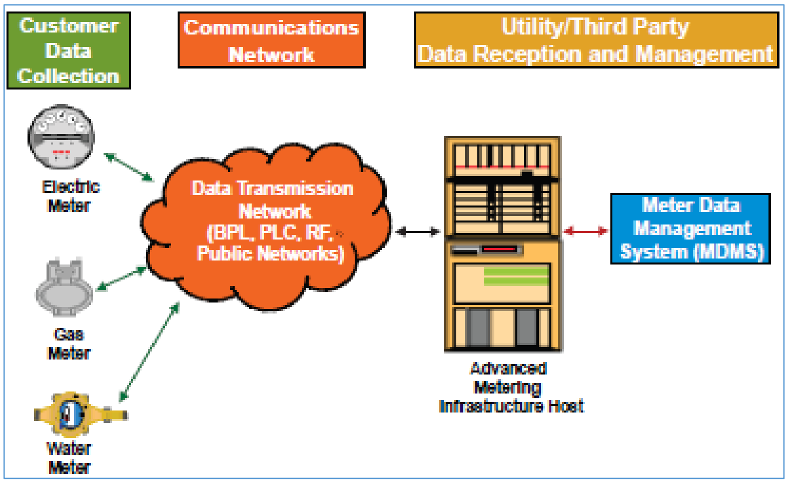


Figure 2.12: Advanced Meter Infrastructure Model. (EPRI, 2007).

Information flow in the proposed system has three distinct sections namely: Data Acquisition: This could involve data acquisition from residential meters; Services: This could handle the data authentication, storage, Email server setup and SMS gateway setup and Applications: This could handle the data modelling, visualization, applications development and feedback on Email, SMS and Web.

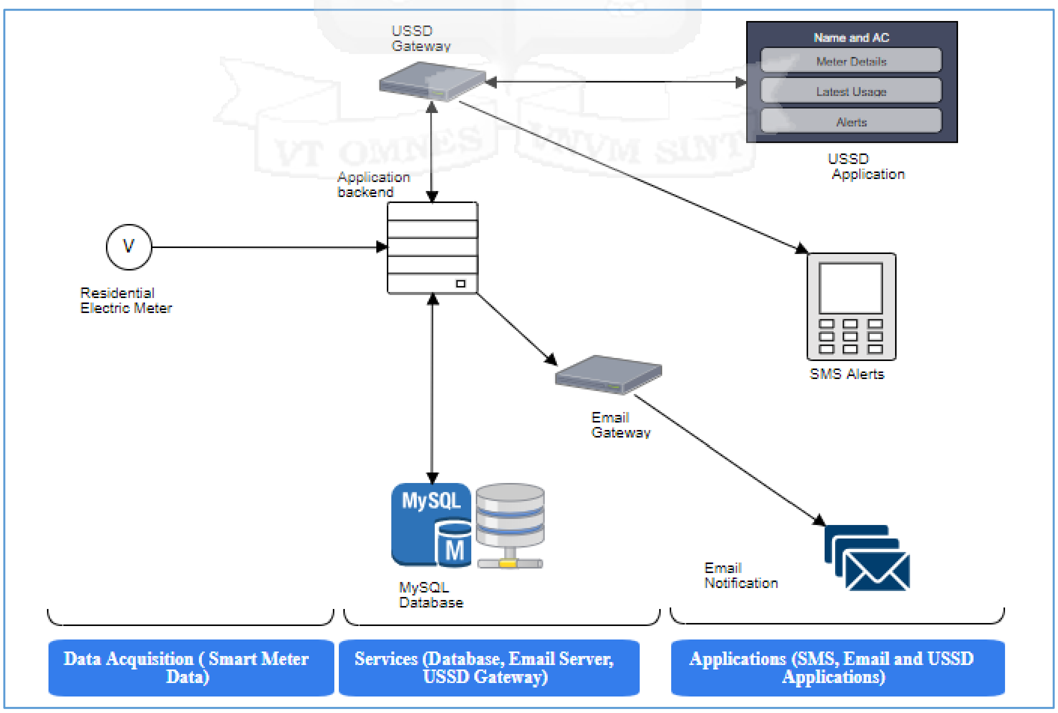


Figure 2.13: Information Flow for Smart Usage Monitor System

2.7 Conceptual Framework

The Figure 2.14 illustrates the conceptual framework that was used to develop the application prototype. As the figure shows, the consumers' contact information was be collected and stored in a database as a one off exercise. Thereafter, the consumers' electricity usage was collected on an hourly basis; matched to the recorded consumer meter, analyzed against historic consumption and the alert generated. Where the alert generated denoted an over-consumption against the previous average, then the SMS or Email was generated and forwarded to the appropriate gateway for onward transmission.

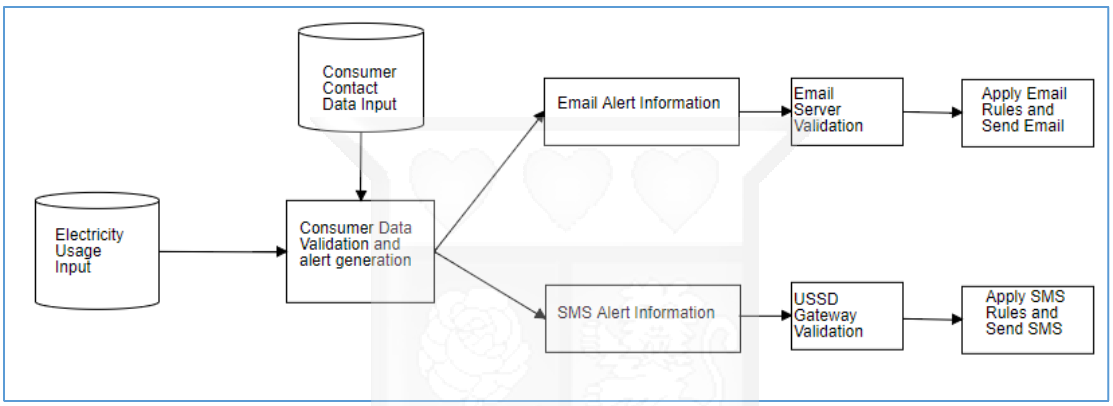


Figure 2.14: Conceptual Framework

Chapter 3: Research Methodology

3.1 Introduction

This research work dwelt on designing an energy usage and alerts system that acquired real time electricity usage from consumers and analyzed the data to provide an immediate feedback to the consumer. The data acquisition was done using a smart electricity meter, in semi-connected mode. The goal of the research was to provide to the consumer feedback that they could link to their energy use in order to drive change and savings in energy use at domestic level.

3.2 System Development Methodology

The development methodology used involved an approach that hinged on data collection and analysis using an iterative and reflective approach that improved on the overall understanding of the problem at hand. Specifically, this approach involved concept design, system architecture construction, system prototyping and eventual development.

According to Flora, Chande, and Wang (2014), iterative and incremental approach was seen as a natural fit for iterative systems development as these methodologies follow an iterative path to build software faster, breaking down the entire development and output life cycle into portions. This approach was risk averse and allowed the project to adapt quickly to emerging modifications without necessarily stopping the entire process.

3.3 Research Design

According to Thomas (2010), research design can be described as the realization of a specific logic in a set of procedures. This action usually optimizes the validity of data for a noted study problem. It gives directions from the underlying philosophical assumptions to research design, and data collection. Research design then remains an action plan that shows how to get to Point A from Point B with resultant answers to specific queries.

In this study, empirical research methodology was used as it allowed the researcher to use data evidenced from the smart meter device and experience. Perry, Porter, and Votta (2000), noted the many forms that such research could take by enumerating that such are realized not only as formal experiments, but also as prototypes and case studies. The attempt to learn something useful by comparing theory to a realistic outcome was the essence of an empirical approach to research. Evidently so, such research could improve our theories as well. Empirical studies have involved the following key steps: formulating a hypothesis to test, observing a given situation, converting noted observations into data, analyzing the collected data, and drawing conclusions based on the hypothesis test outcome.

As this research addressed each of the set objectives, this study used the usage data collected over several days and analyze the data based on established patterns while building appropriate abnormality scores. This abnormality scores and related charts or graphs formed the basis of deploying targeted Email and SMS to the selected customers with an objective that such precise messages could help them take actions to reduce electricity use and limit on wastage.

3.3.1 Location of the Study

This research study was done within the city of Nairobi, Kenya. The sample data to be used came from smart meter device running on a test kit with residential consumers whose usage is currently billed on the Postpaid Tariff. A smart meter was be fitted with sample load and was used for testing usage in real time.

3.3.2 Target Population and Sampling

The usage of analysis in this study was data component recorded from residential electricity consumers. According to Kenya Power (2017), the total number of customers by close of year 2017 was 6,121,854 (Six Million, One Hundred and Twenty One Thousand, and Eight Hundred and Fifty Four). Of these number, the Domestic Tariff category had a total number of 5,781,466 (Five Million, Seven Hundred and Eighty One Thousand, Four Hundred and Sixty Six) customers. This tariff category represents 94% of the total customers' base. This was our target population.

Table 3.1: Number of Customers by Tariff for Year 2017 (Kenya Power, 2017)

Consumer Tariff Code	Consumption category description	Total No of Consumers
DC	Domestic	5,781,466
SC	Small Commercial and Small Industrial	326,548
CI	Commercial Industrial	3,686
IT	Off-peak (Interruptible)	799
SL	Street Lighting	9,355
TOTAL		**6,121,854**

In this study, we used purposive sampling, where we are purposely decided to gather electricity usage data from Postpaid Tariff residential consumers only. Purposive sampling as a technique is a non-probability sampling type that is effective when one needs to study a certain domain with knowledgeable experts within. The efficiency of the method was realized due to the existing inbuilt bias. Further, the method remains robust even when tested against random probability sampling.

Alvi (2016) concurred that in purposive sampling, the sample is approached having a prior purpose in mind; and that the criteria of the elements who are to be included in the study is predefined. Therefore, we do not include everyone who is available to us rather those available are included who meet the defined criteria. According to Ali (2014), the sample usage recorded size that was of interest to this study was calculated as follows:

$$n = \frac{z^2 p q}{d^2}$$

Where:

n = the desired sample size

z = the standard normal deviate usually set at 1.96 (which corresponds to the 95% confidence level)

p = the proportion of the target population to have a specific characteristic. If estimates are not available, then this is set at 50 percent.

q = 1-p

d = absolute precision or accuracy, normally set at 0.05.

n =384

This then suggests that out of the possible 5,781,466 customers or 5,781,466 usage readings per month (assuming that each meter reading is done once a month), we took a minimum of 384 usage readings. Tongco (2007) mentioned that since a better understanding of a theoretical framework is necessary, proper data gathering is critical in research. It was then necessary that the chosen data collection approach be informative and be done with sound judgment, since no amount of post usage collection analysis can make up for collected data errors and anomalies. This research study aimed at reaching the target size of 384 recorded usages and even surpass this as more data proved useful for accuracy at analysis stage.

3.3.3 Data Collection Procedure

Electricity usage data was recorded by means of smart electricity meters. The meter was configured to read load usage on a periodic frequency of either 30 or 60 minutes. This device was used to take precise usage readings within an established frequency. Since the scale of the meters in use was limited by the numbers, attention was taken to ensure that more usage readings are recorded for purposes of statistical analysis.

3.3.4 Data Analysis

Data analysis can be described as a process of bringing order, structure and meaning to the mass of collected data (Vosloo, 2014). It was noted that this can be messy, ambiguous and a time-consuming exercise, but an equally creative and rewarding process. Right from the point of collection, the electricity usage data was recorded and validated by the application before storage. A usage reading was considered valid if the value captured had greater value than the previously recorded usage.

All readings submitted were accepted only if they were accompanied by a previously registered meter number. Against the valid time series usage data recorded for each day, an abnormality score was computed be based on both the average usage and the standard deviation. The set upper and lower limits were based on the system requirements and denoted the maximum and minimum values allowed. The standard deviation used for the sample was as shown below:

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

Where:

s = Standard deviation

N = The Number of the usage data samples.

x_i = The individual value in the sample.

$\overline{x}$ = The average of mean of the samples.

$\sum$ = Summation

3.5 System Analysis

This study used a real-world dataset to evaluate the electricity usage readings detected from readings taken from a smart meter and transmitted in real time to a central database. The dataset contained power consumption readings of a residential consumer.

3.5.1 Entity Relationship Diagram

This was used as a data modelling tool to show the relationships of the various entities within the database. It showed the database structure of the application highlighting the tables and/or views used.

3.5.2 Context Diagrams

Context diagram was used to show the web portal and USSD application in high level design. It showed the relationship these applications have with other entities such as Application backend, USSD gateway and Email Server.

3.5.3 Data Flow Diagrams

Data flow diagrams was modeled to show the flows of data through the system and to show a general overview of the system. Data input came through the smart meter reading module, manually recorded into the application database. This data was then analyzed by the application back-end logic to come up with an abnormality score. Based on the score established, consumption reports were generated and availed to the report tables for web viewing; alerts generated for both SMS and Email dispatch purposes.

3.5.4 Use Case Diagrams

Use case diagrams were drawn to depict system interaction with all the actors. For this system, there existed two level of actors namely: actors that provide input and actors that receive or query output. The diagram clearly showed these relationships, their impact on the system and all the use cases.

3.5.5 Sequence Diagrams

Sequence diagrams were used to show the progression of events and related processes from one system unit another. Since the main event trigger was the detected usage, these diagrams showed the events progression from the usage input through the application back-end analysis, data scoring and outputs of Email or SMS.

3.6 System Implementation

In the absence of Smart Meter data input at scale, development was first done for the application backend with usage rules processing to ensure that we have accurate readings submission and that constraints are put in place to block erroneous data entry. Iterative development was then used to further ensure that the incoming usage, appropriate validation and abnormality scores generation was accurate. Development was done at the database level to equally ensure that based on the score generated, automatic alert generation is done for both Email and SMS. The system further generated report data and chart/graphical representation for further reference using the web portal.

3.7 System Testing

Since this system incorporated several modules working independently of each other, testing was done at two levels. Unit testing was done for each of the units such as usage readings processing backend, abnormality generation logic, email alert generation and SMS alert generation components. At the second level, system testing was done to ensure that in concert, input is injected that can give the correct Email or SMS alerts. This level of testing checked for accuracy of the abnormality score. Finally, User Acceptance Testing was done to ensure that the consumers understanding of the output could be accurate when deployed at scale.

3.8 System Evaluation and Validation

The cardinal objective in validation of software requirements and design specifications is to identify and resolve software problems and high-risk issues early in the software life-cycle. Validation seeks to establish the fitness or worth of a software product for its operational mission with possible validation activities occurring throughout the software life-cycle, including the development phase (Boehm, 1979).

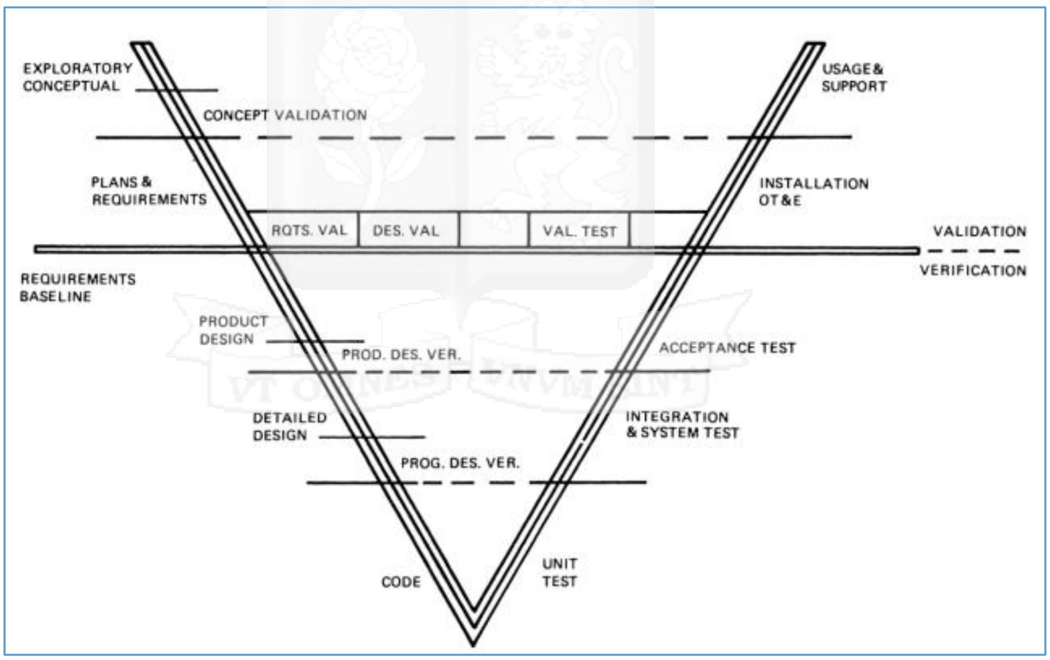


Figure 3.1: Verification and Validation through the Software Life-Cycle. (Boehm, 1979).

As depicted in the **Figure 3.1,** above, validation occurred throughout the software life-cycle. The validation activities included: Requirements validation, Design validation and Validation testing. In other words, the whole exercise sought to check for and confirm:

Completeness, that is, the extent to which the system parts were present and each part was fully developed; Consistency, that is, the extent that the system's capabilities did not have conflict with one other and Testability, that is, the extent that one could identify an economically feasible technique for determining whether or not the developed software could satisfy the specification. In order to be testable, specifications were specific, unambiguous, and quantitative wherever possible. This exercise was important to establish how well the usage detection system handled usages submitted with or without errors and under different stress tests.

Chapter 4: System Design and Architecture

4.1 Introduction

This section describes the general architecture of the usage system as well as a comprehensive design of the proposed solution depicting a USSD functionality, SMS and Email alerts system and web-based front-end. All these models were presented side by side with the design taking a user centric approach to ensure that whichever model a user would interact with, they would be in a position to find it usable.

The design diagrams enumerated in this section followed the Unified Modelling Language approach and included the use case diagram which detailed user interaction with the system, class diagram which showed how different class objects in the proposed model interacted, system sequence diagram which illustrated the sequential flow of processes within the model, a data flow diagram showing how data flowed within processes and a database to show the tables, views, triggers and functions or procedures that were used to power the backend processing.

4.2 Requirements Analysis

In line with the research objectives set out at the beginning of this research, requirement analysis offered capability needed by the user to solve a problem or to achieve an objective. Specifically, requirement in this case was a software capability that has to be met by a system or system component to satisfy the formally noted problem of electricity usage management. The usage model designed and translated into the needed system met the usability requirements that were needed for the model to be deemed usable by the electricity consumer.

4.2.1 Functional Requirements

Looking at the noted challenges experienced by both the utility companies and the users in an environment where most usage billing information did not offer an immediate feedback into the usage consumed, the following requirements were used as the appropriate functional requirements for the proposed usage system.

i) The system could be able to receive the usage data sent remotely by smart meters and securely store the same on a relational database.

ii) The system could be able to use the usage stored, compare with the latest usage information and compute abnormality scores for insight and decision making.

iii) The system could be able to send timely SMS where the user phone number has been provided and Email where the user email address has been provided.

iv) The system could be able to avail latest usage information where such is queried by the users either by SMS, Email or from the USSD platform. Such would be provided whether the customer's usage information is within normal usage or not.

4.2.2 Usability Requirements

The intended users of the proposed solution in this study were the utility energy users on Domestic or Small Commercial tariff and the utility company that is providing the service. The utility company has the mandate to ensure that the customer receives timely feedback in a manner that can link information to the customer's action. Therefore, the interaction between these users and the solution was made simple and interactive whether the user uses the web portal application to make inquiry, SMS or USSD to make inquiry or whether the user was sent feedback whenever their usage score exceeded the calculated average. Since the design of the system had put the user at the center of all interactions, simplicity from the front end had been factored in the buildup.

4.2.3 Supportability Requirements

The electricity usage received was analysed and the results of that analysis availed on platforms that are readily accessible to the users, namely: USSD platform for access by any mobile phone device that can process text messages and web based application for ease of access on desktop computers or laptop computers through any browser of user's choice. Users could choose to use any of the above platforms for query purposes. By default, the system information was availed on all the platforms.

4.3 System Architecture

The Usage Monitor application was based on a client-server architecture model where the web based application was composed of two primary components: the client and server components. The client component had the web application that accessed the remote server via a secure tunnel that allowed data to be sent to and from the remote server. Similarly, the user could use a text based phone to request basic usage information using text messaging service. In this scenario, the client prompts were passed through the USSD gateway that enabled the message request to be passed to the application program in the remote backend server.

Finally, a user with a web browser could sign in to see the dashboard provided and presents information relevant to the user's monthly, 2 months or past 3 months usage together with the latest electricity pricing. On this portal, the user could be able to download and print their service Statement. Different from an Invoice or payment receipt, a statement provides all the monetary transactions to the user in a manner that is easy to add up and know their latest debt position. The system architecture on which this system has been built is illustrated below.

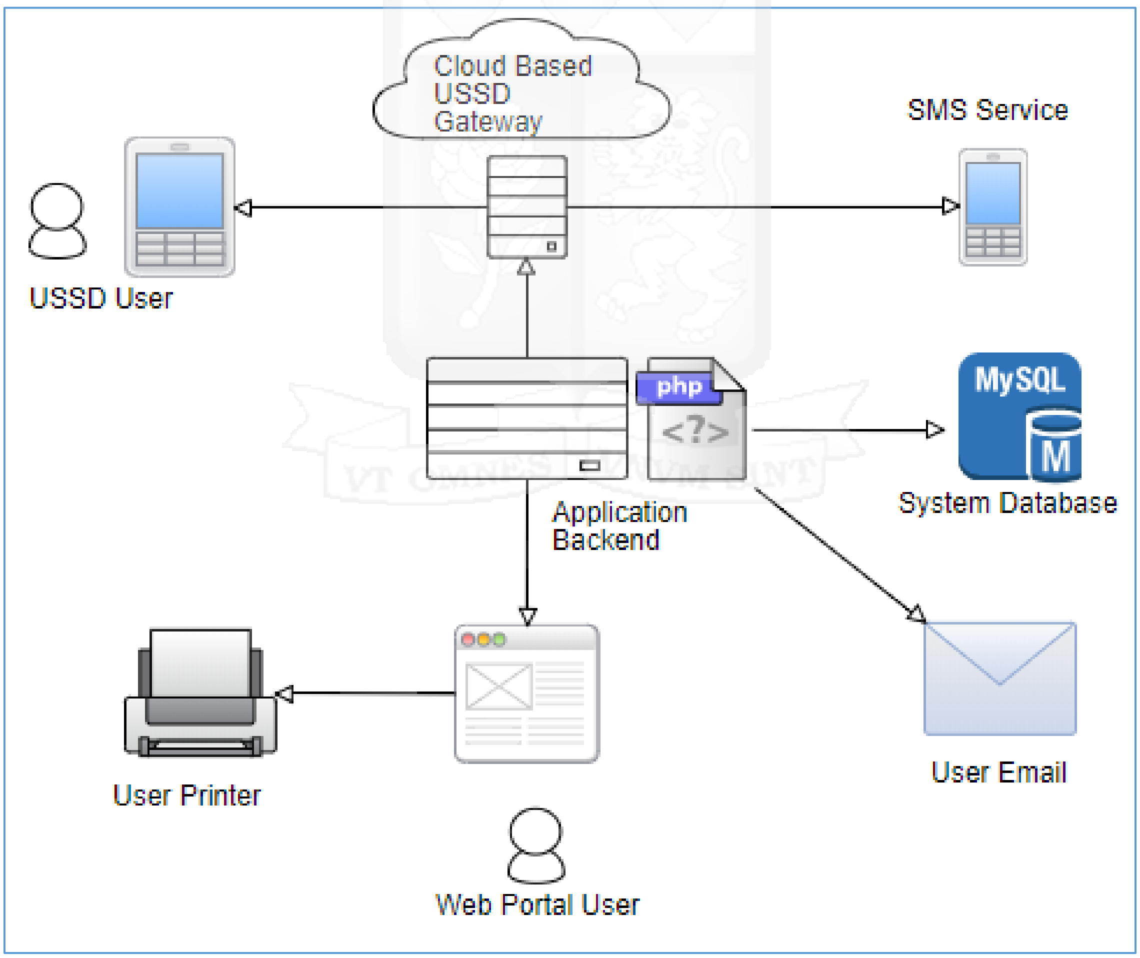


Figure 4.1: Usage System Architecture.

4.4 Application Wireframes

The system functionalities from the user point of view were divided into two, namely: the web portal and the USSD & SMS application. The wireframes discussed then are an illustration of these two functionalities.

4.4.1 Web portal Wireframe

The web portal was further divided into two sub-sections. The main application dashboard and menus that are accessible by the system administrators and other users assigned to roles such as Contracting, Readings, Billing and Payments roles.

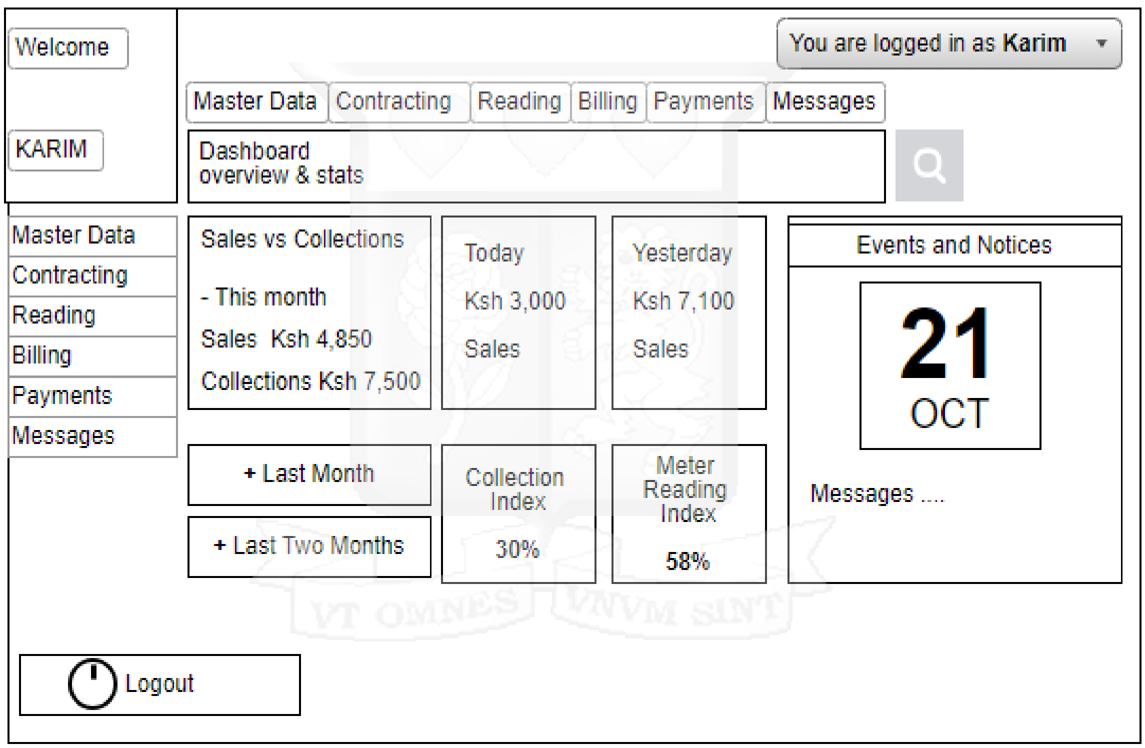


Figure 4.2: The Web Application Wireframe

The other part of the system consisted of the customer dashboard that provides a customer with a single point of truth regarding both their usage data and usage cost. The customer was also capable of accessible the statement, which is a single document that provides the tally of bills, payments and net debt.

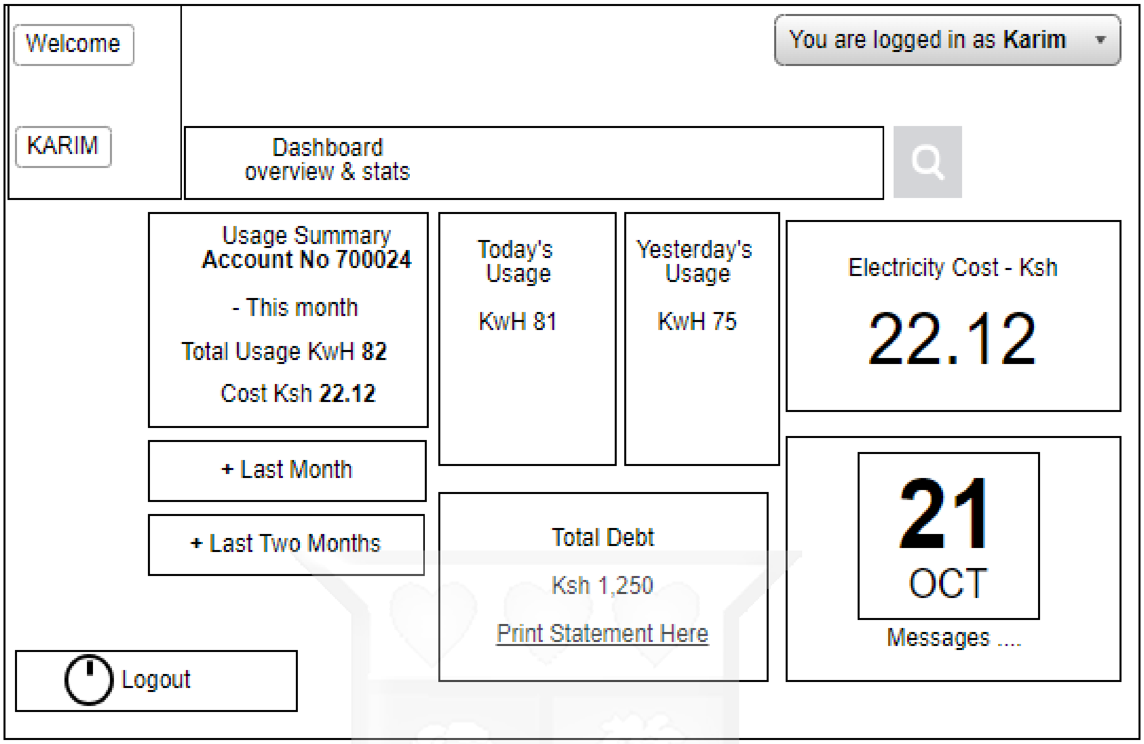


Figure 4.3: The Customer Dashboard Wireframe

4.4.2 USSD application wireframe

The USSD application provided the customer the means to initiate queries with the system. By this system option, the customer was able to check their account balance, register complaints, register their personal details to allow accurate update and manage their password.

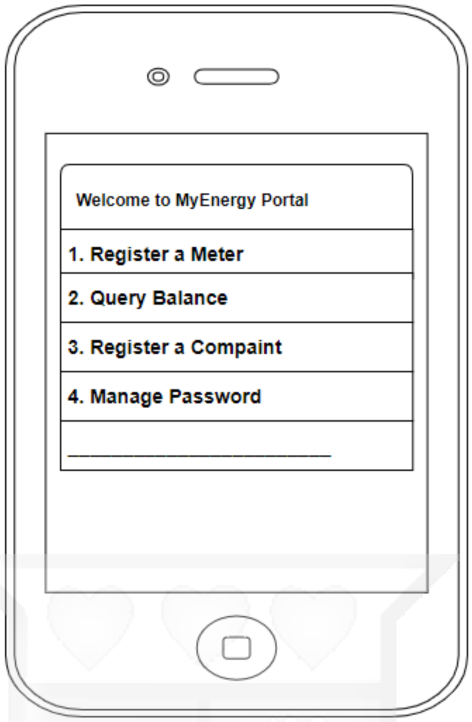


Figure 4.4: USSD Wireframe

4.5 Use Case Diagram

This is a behavior diagram that illustrated the main functions of the system and how those functions related to the existing actors. The breakdown unit that described these functions are the Use cases and their dependencies. The table below lists the Use cases of the system.

Table 4.1: Main System Use Cases

Use case	Description
Use case UC1	Query Real Time Usage
Use case UC2	Query Monthly Usage
Use case UC3	Query 2 Months Usage
Use case UC4	Query 3 Months Usage
Use case UC5	Change Password

Use case UC6	Register a Complaint
Use case UC7	Record and Upload Usage data
Use case UC8	Receive and Validate Periodic Usage
Use case UC9	Calculate averages
Use case UC10	Validate latest usage against a running average
Use case UC11	Generate and issue Email/SMS alerts

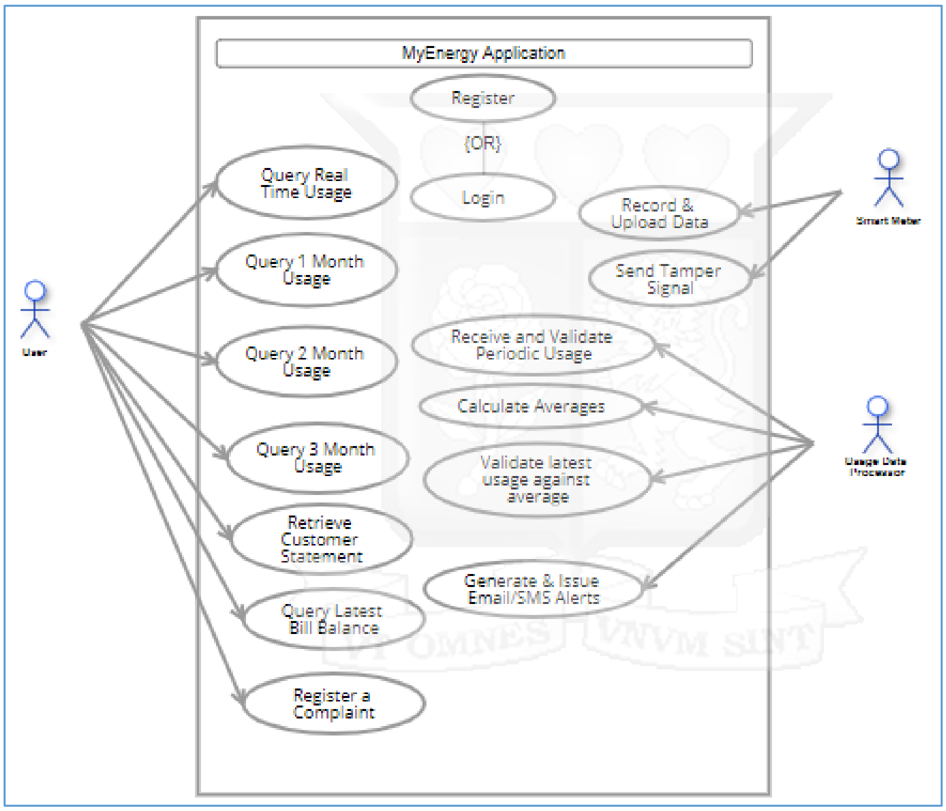


Figure 4.5: Main System Use Case Diagram

4.6 Data Flow Diagram (DFD)

The DFD shows the interactions between the system user and system sub-processes. As shown below, Figure 4.6 shows the various sub processes. Specifically, the system user could retrieve daily usage data, weekly usage data and monthly usage data. To each of these retrieval requests, the system user could be able to print out a daily usage report, weekly usage report and monthly usage report respectively. On the other hand, SMS alerts are system generated depending on the usage patterns and when generated, the alerts are automatically sent to the user email address.

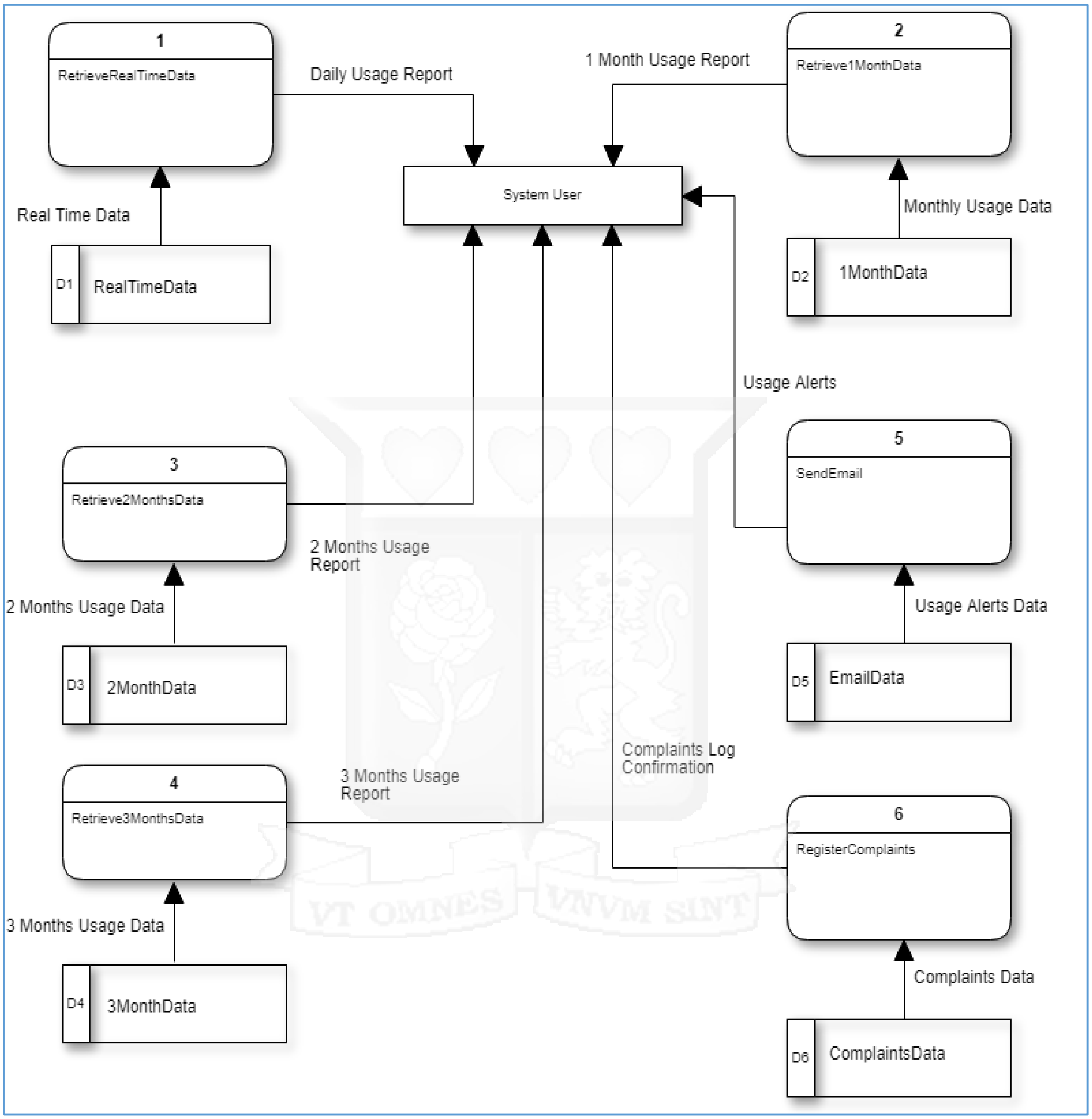


Figure 4.6: The System Data Flow Diagram

4.7 System Sequence

The sequence diagram in Figure 4.7 shows the events flow between the system user and system components. When a user first signs to use the system, they are presented with a form which has mandatory input. Upon successful sign up, the user could then sign in and either decide to retrieve and view daily, weekly or monthly usage data. Similarly, Usage Data Processor continuously run analysis on data to establish the usage to average correlation. Whenever the usage was below or above the know average, the system would automatically generate alerts and send to the user's email address.

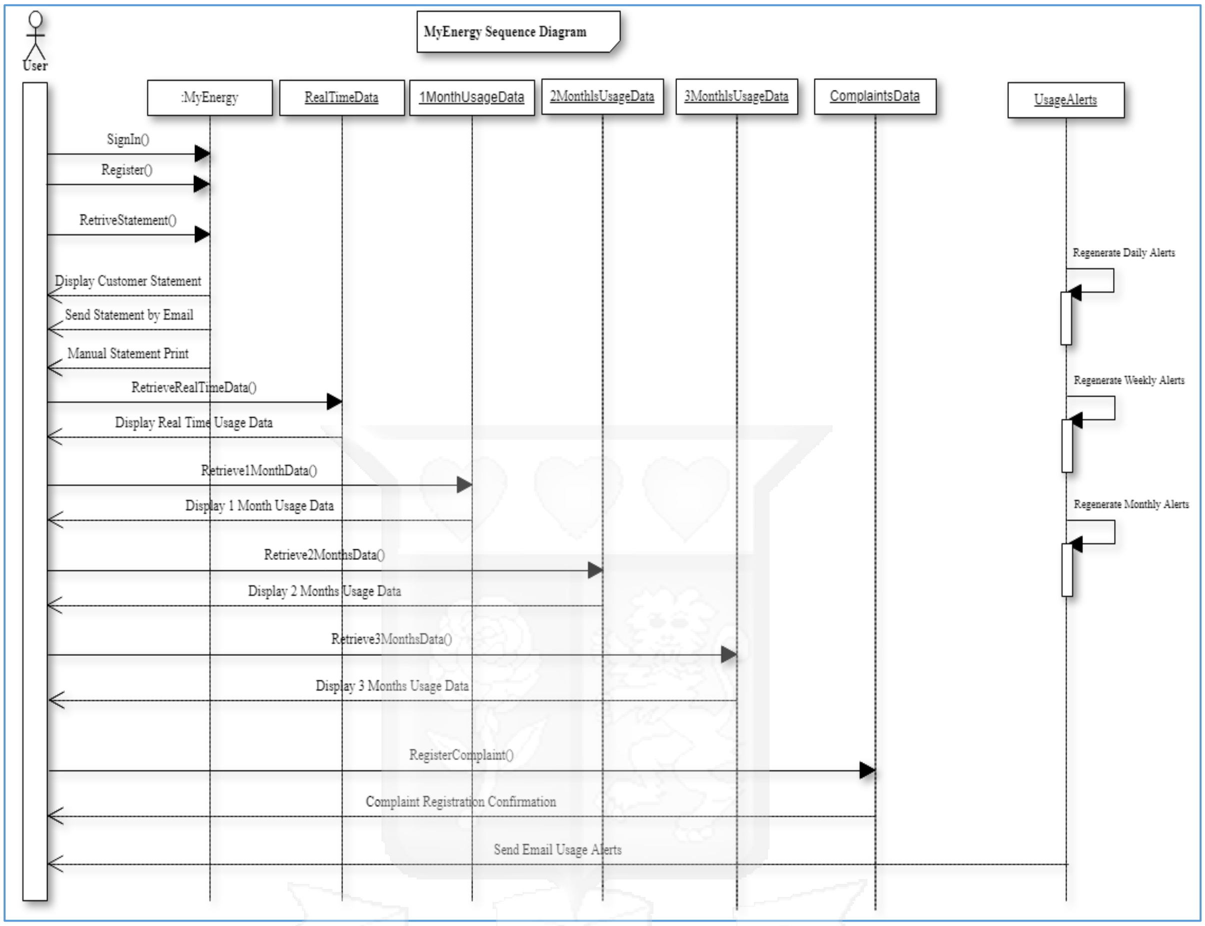


Figure 4.7: The System Sequence Diagram

4.8 Class Diagram

The system class diagram describes the structure of the system by showing its classes, attributes and the relations among the classes. MyEnergy class diagram shows the interaction between different entities of the system and their relationships. The class diagram is illustrated below:

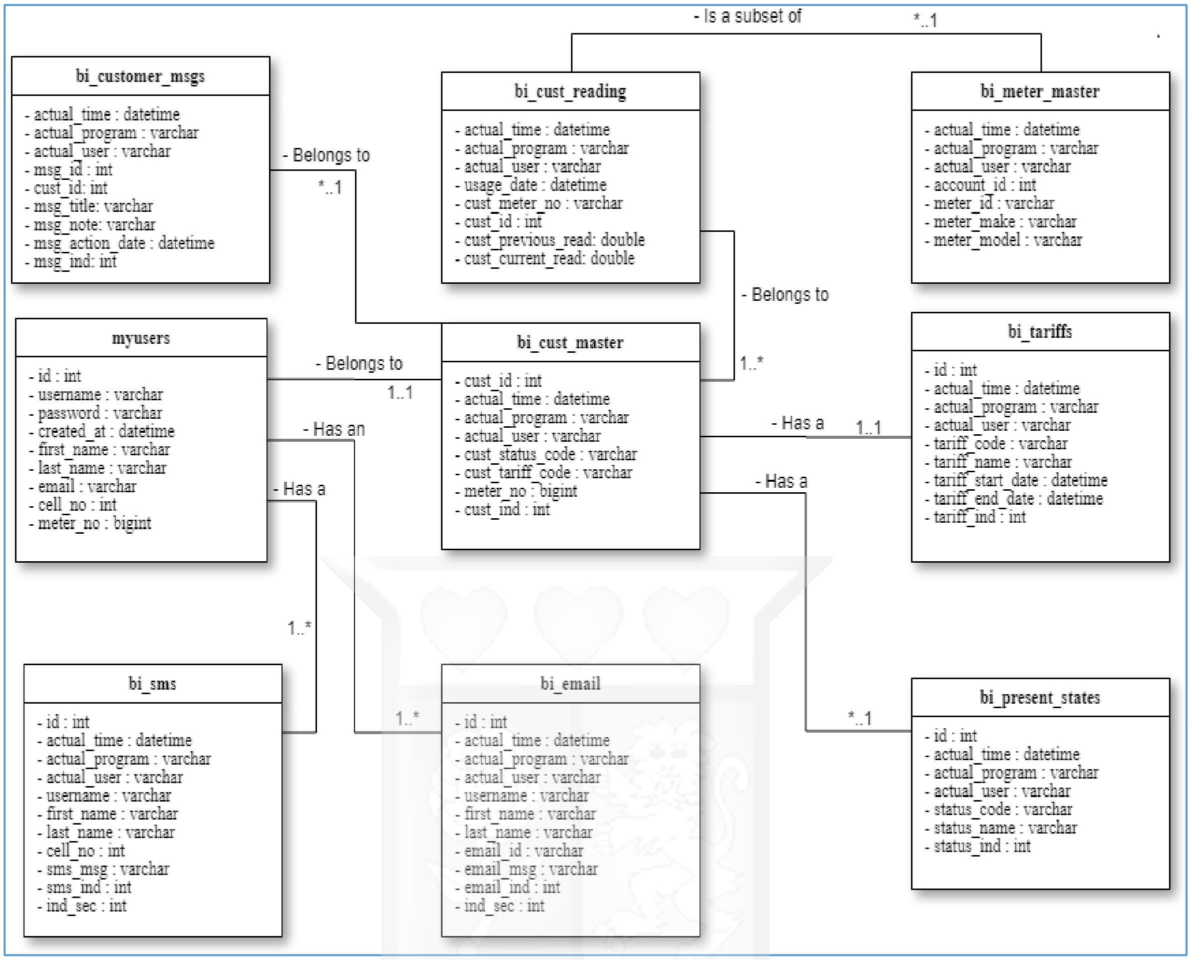


Figure 4.8: The System Class Diagram

4.9 Database Design

Logical design

At logical level, the utility company that uses MyEnergy application already has customers enrolled and active on its service. Upon enrolling a customer to the customer management platform, the system makes it mandatory to input phone number. The customer's mobile phone number is then registered and a default profile automatically created for the customer with the phone number being used as both the username and password. By design, the web platform was designed to have more information displayed than the SMS or Email service combined.

Entity Relationship Diagram

The diagram below shows the Entity Relationship Diagram (ERD) for the system.

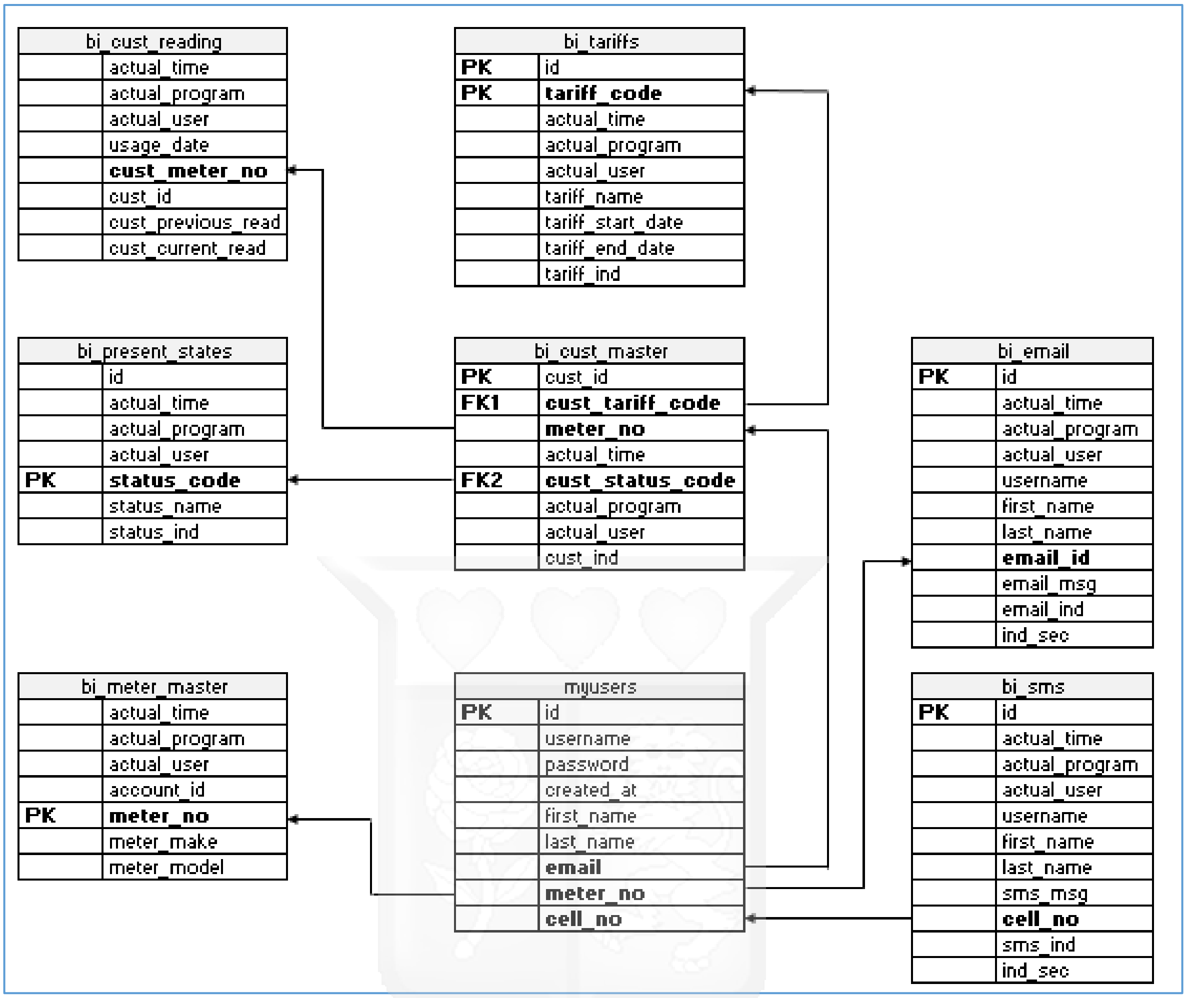


Figure 4.9: Schema Diagram.

4.10 Security Design

Security is key to the way the system operates. All users of the system must access the system using provided usernames and secure passwords. From the moment a customer was registered and provided with an electricity meter, their electricity meter number became their username and password with an option to change the password whenever they wished to. All passwords were encrypted before storage in the database.

The system used an in built API password_hash() that created a new password hash using a strong one-way hashing algorithm. The system made use of PHP encryption mechanism, PASSWORD_DEFAULT or PASSWORD_BCRYPT algorithm to encrypt the password before storage. According to Cuppi (2017), PASSWORD_DEFAULT and PASSWORD_BCRYPT are similar. Alternative algorithms could be supported in future with PASSWORD_DEFAULT eventually getting replaced. The advice at this point in time is to always use PASSWORD_DEFAULT.

Encryption works as illustrated below:

password_hash("37155455358", PASSWORD_DEFAULT)

Decryption then works as shown below:

password_verify('37155455358', $hash)

Chapter 5: System Implementation and Testing

5.1 Introduction

This chapter focuses on the implementation technique and the testing mechanism of the proposed Smart Usage Management system. The implementation dwelt on multiple functions of the system as well as providing an understanding of the software and hardware environments under which they were implemented at either test or production level.

5.2 Software Environment

The software has been developed in a Windows Operating System environment. Windows 10 Pro operating system has been used as the base upon which installation for development tools were done. The development tools of use were PHP 7, MySQL database, Apache Web Server for both local and remote application hosting.

PHP 7 is the latest version of PHP that was release on December 2015 and it is a version that offers versatile performance for robust website and online applications. Compared to the previous version, PHP 5.6, it is estimated that PHP 7 offers extreme improvement in performance speed over its predecessor (Habib, 2016). The Usage Monitor is a USSD application designed to work on any phone, both smart phones and feature phones. It is built on the principle of a hybrid application where records are retrieved directly from the application and displayed on the application.

5.3 Hardware Environment

The hardware specification used in the development environment are a computer running on a minimum of 2 gigabytes of RAM on a minimum of 50 gigabytes of storage. The USSD and SMS application runs on any mobile phone device with at least 128 megabytes of main memory and 100 megabytes of storage.

5.4 Roles Based Design

The system has been in built with user roles in mind by ensuring that system users are created and assigned roles. The web portal then renders specific menu list items depending on the role a user is assigned. A user assigned a Super Admin Role will be able to see all menu lists, such as, Master Data, Contracting, Readings, Billing, Payments and Message Management options. A user assigned a Billing Role will only see billing role menu items.

Finally, the customer was given an End User role which restricted the customers' view of the system to the customer dashboard.

5.5 System Modules

5.5.1 Web Application

The application web portal was designed with a user friendly interface. The following web portal screens shows the main web-portal features of the application.

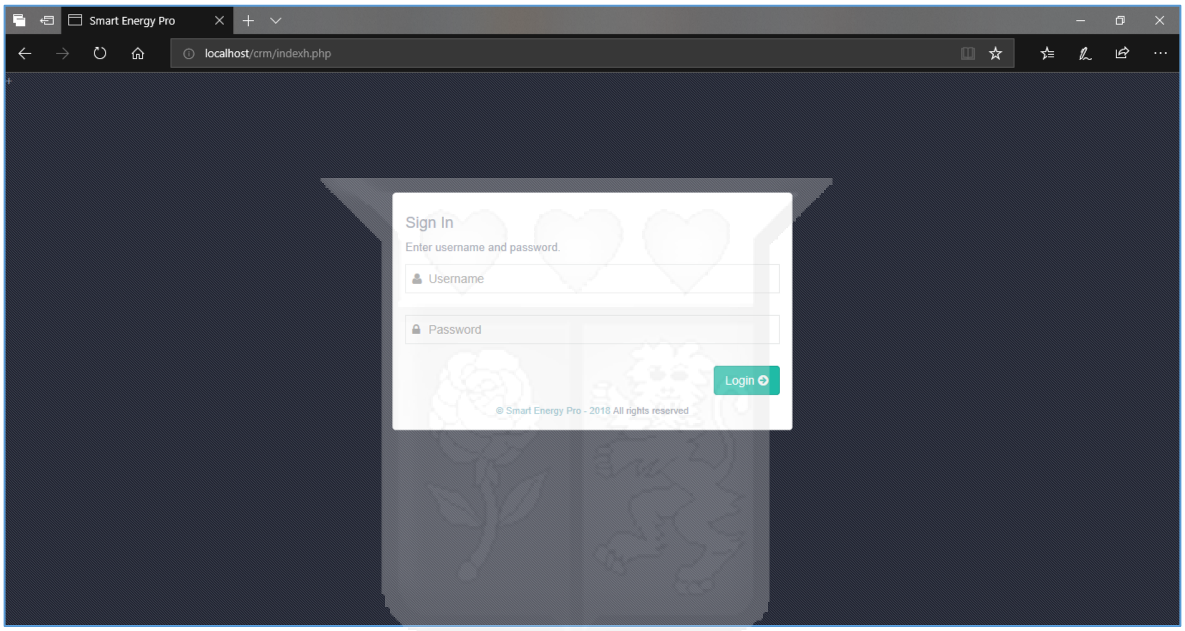


Figure 5.1: Login Page

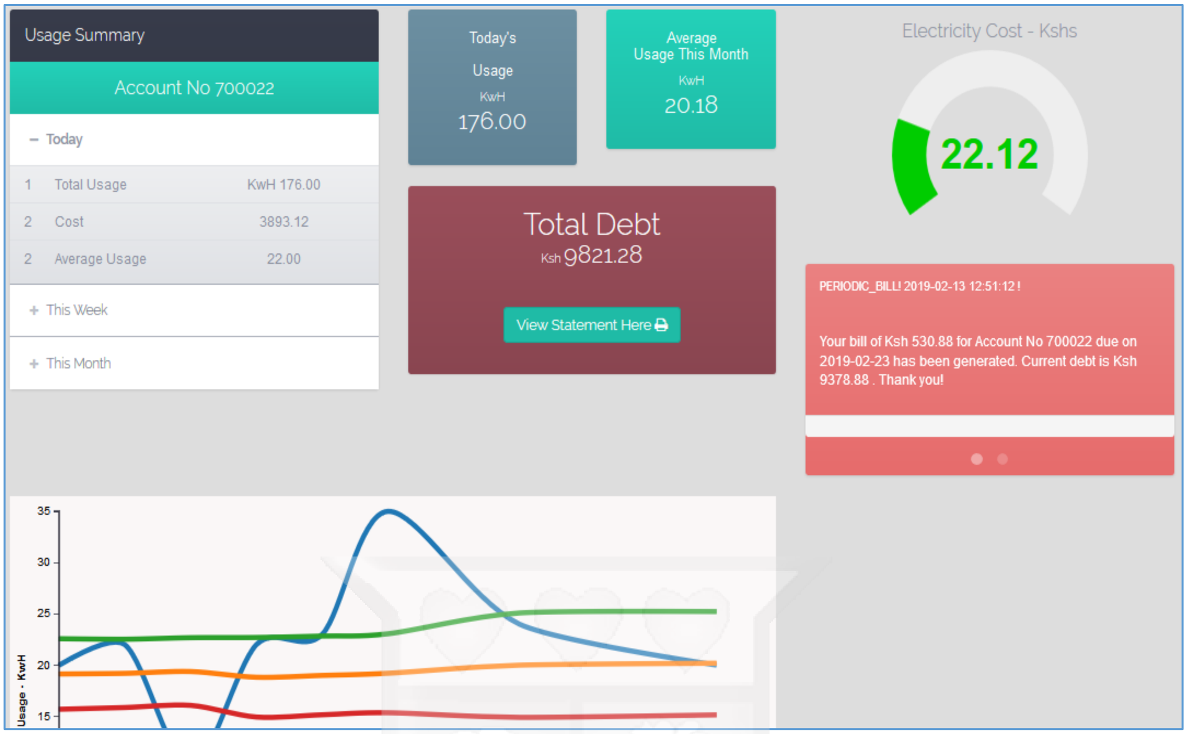


Figure 5.2: Customer Dashboard

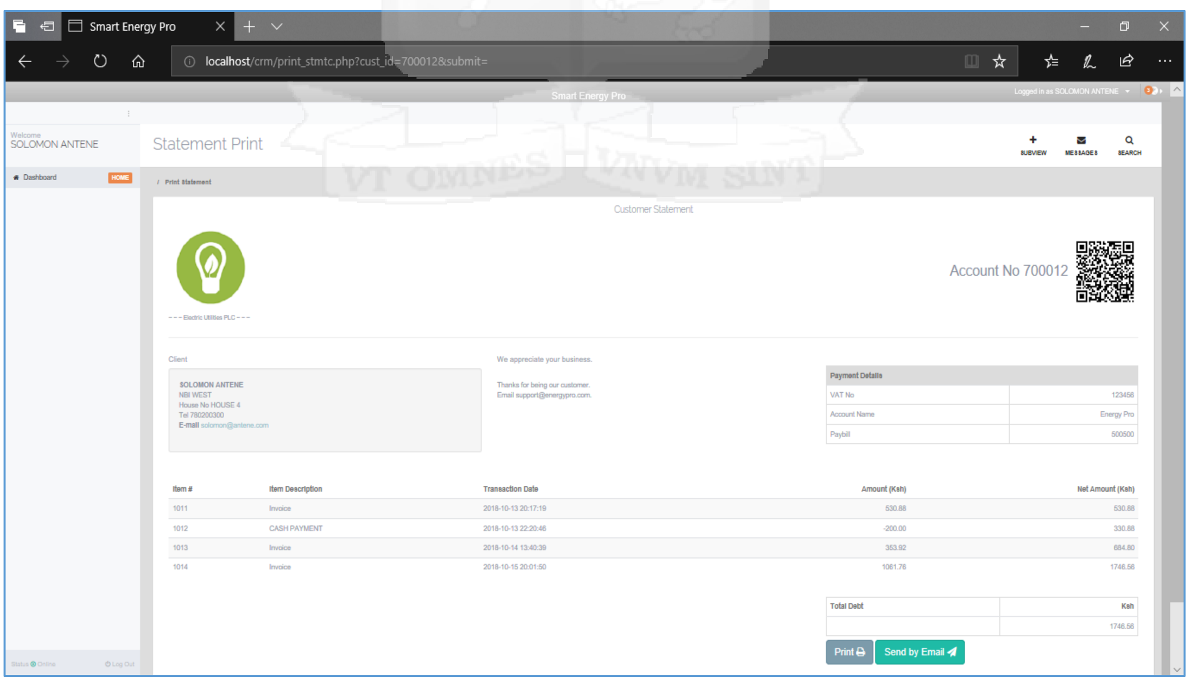


Figure 5.3: Customer Statement

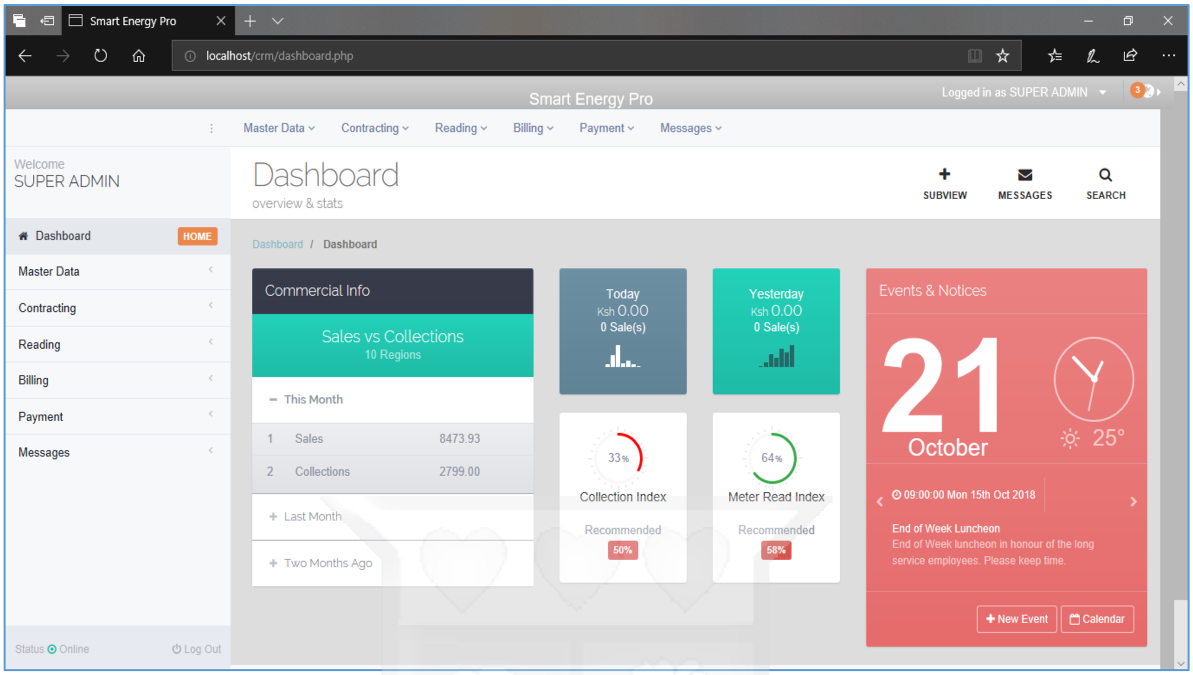


Figure 5.4: Administrator Dashboard

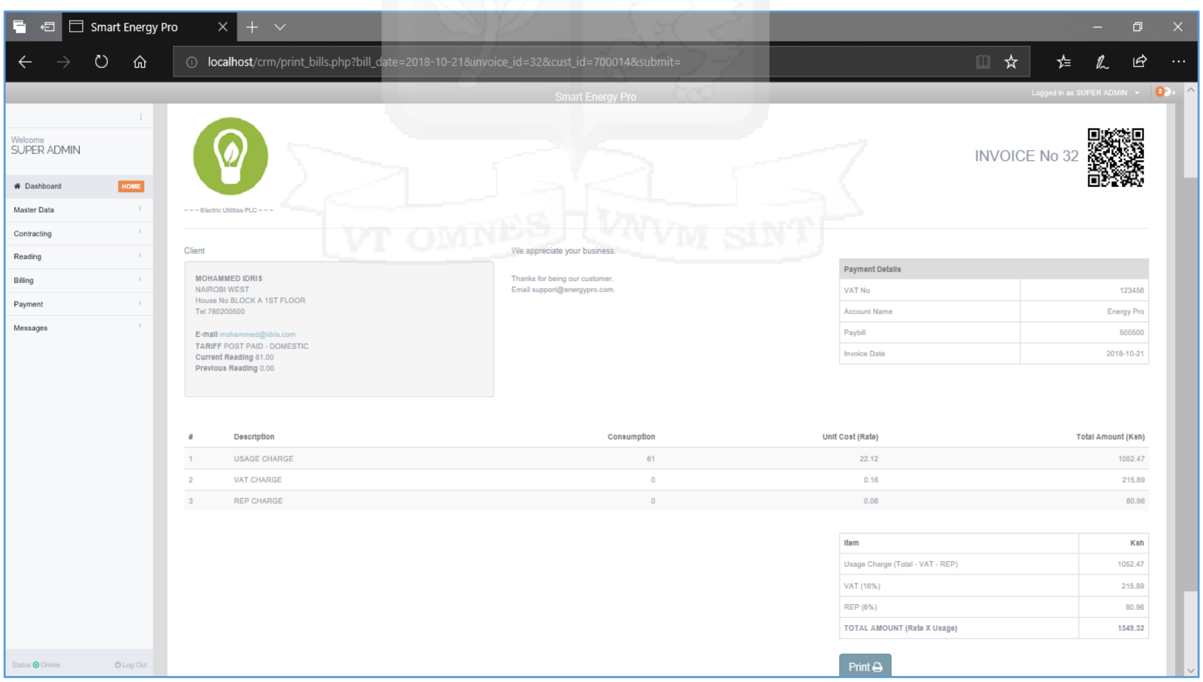


Figure 5.5: Sample Invoice Copy

5.5.2 USSD Application

The USSD application was designed to manage specific user-centered actions that would make the user informed of their usage situation. Central to the operation of the USSD application is the USSD gateway running from the URL: https://simulator.africastalking.com:1517/simulator/ussd

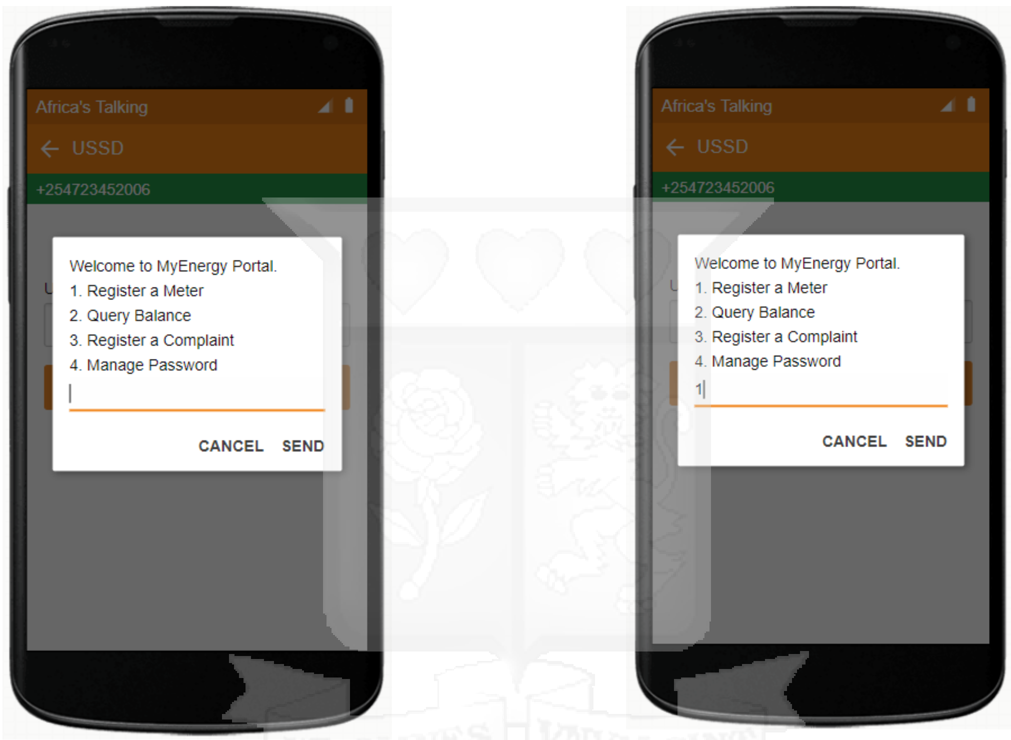
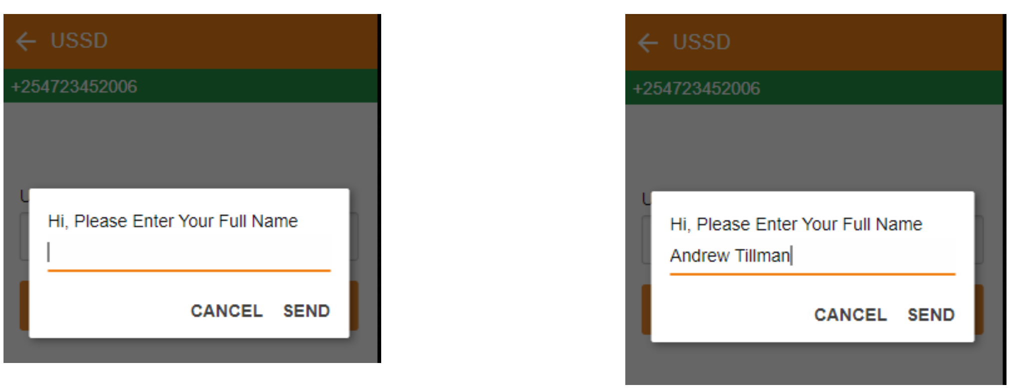


Figure 5.6: The Applications Options



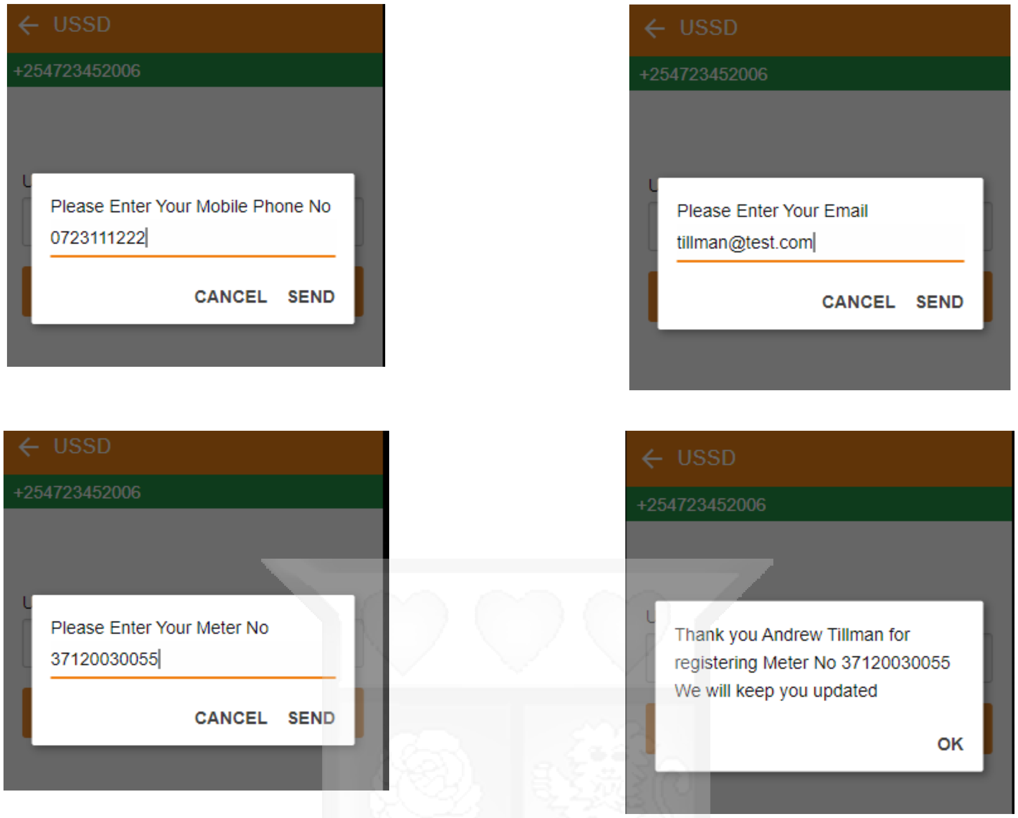


Figure 5.7: Option 1. Register a Meter

5.5.3 SMS Alert Dispatch Application

The system design also incorporated an SMS dispatch for sending alerts of either warnings or information. Upon new customer registration, bill generation or payment processing, the system would dispatch an SMS alert to keep the customer informed. Equally, when a user's invoices were due, the system would send an SMS to alert the customer of the due date and the impending disconnection. The figure below illustrates an SMS dispatch upon registration.

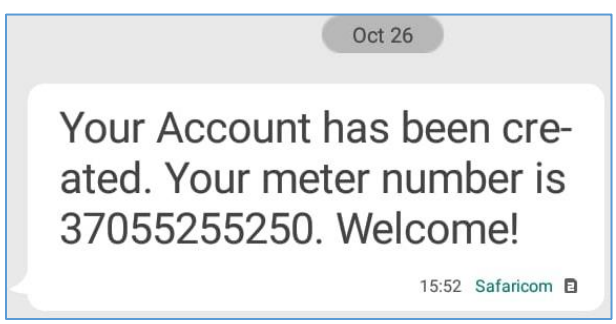


Figure 5.8: SMS information display after registration.

5.5.4 Email Alert Dispatch Application

The system design also incorporated an electronic mail dispatch for sending alerts of either warnings or information. Upon new customer registration, bill generation or payment processing, the system dispatched an email alert to keep the customer informed. Equally, when a user's invoices were due, the system would send an email to alert the customer of the due date and the impending disconnection. It is noted that not all consumers would have an email account. In this case, the equivalent alert would be generated and dispatched to the cell phone number by SMS. The figure below is a sample of the email received upon registration.

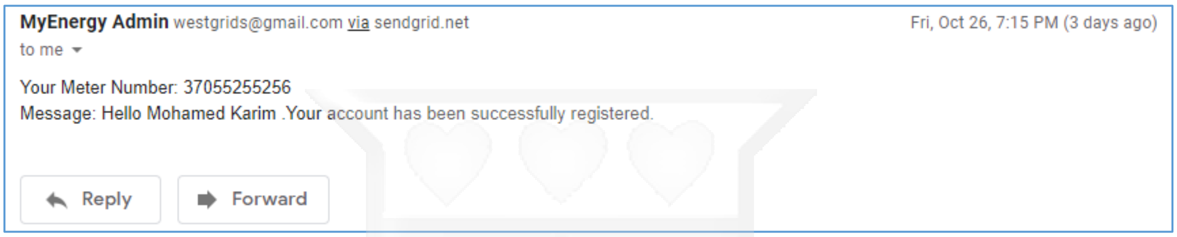


Figure 5.9: Email information display after registration.

5.6 System Testing and Validation

5.6.1 Functional Testing

Using actual data being read from a smart meter, functional testing was done to check that customer information and alerts were generated and dispatched during account creation, bill generation and payments processing. Similarly, customer usage was analysed as they are generated and a comparisons done based on average usage and statistical standard deviation. A sample test kit used is shown below:

Figure 5.10: Smart Meter Test Kit

While the average usage provided a baseline value, the standard deviation was used by the system to determine the upper and lower value ranges within which the customer's usage values ought to be. Any usage value that was found to be comparably higher than the upper limit or lower than the lower limit was considered an out control value and an alert issued to the consumer. The figure and table below illustrates:

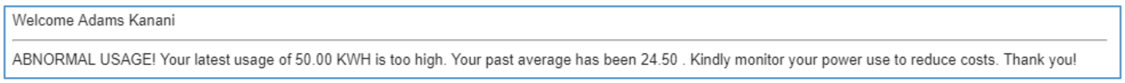


Figure 5.11: Abnormal Usage Alert

Table 5.1: Functional Testing Results

No	Component	Description	Expected Behavior	Observed Behavior	Error	Conclusion
1	Registration	Testing if the system generates informative alert to the consumer	The system should inform the consumer of their account information.	The consumer is sent an email and SMS with relevant account data.	None	OK
2	Usage Entry	Testing if the system accepts and validates usage.	The system should only accept a usage higher than the previous value.	The system properly validates the usage entry.	None	OK
3	Billing Processing	Testing if the system accurately bills the usage.	The system should bill the usage immediately and dispatch the bill alerts.	The system produces the bill and send the alert by email and SMS.	None	OK
4	Payment Processing	Testing if the system accepts the payment and processes it for a particular invoice.	The system should process the payment and alert the consumer of the payment received and the debt position.	The system processes the payment and sends the email and SMS alert.	None	OK

5	Abnormal Usage Alert	Testing if the latest usage is out of the average range.	The system should determine the average usage and range of previous usages for comparison with the current usage.	The system determines the average usage and range and compares with latest usage with an alert issued for usage out of expected range.	None	OK

5.6.2 Compatibility Testing

This test was done to ensure that the applications run on different Web browsers for compatibility. The browsers tested included Google Chrome, Mozilla Firefox and Microsoft Edge. The table below illustrates:

Table 5.2: Compatibility Testing Results

No	Browser	Compatibility
1	Google Chrome browser (Version 71 and above)	Yes
2	Mozilla Firefox browser (Version 64 and above)	Yes
3	Microsoft Edge browser (Version 42 and above)	Yes

5.6.3 Usability Testing

This test has been used to show that the flow of the application is user friendly and consistent. From the onset, the web portal layout of the menus, buttons and other widgets has been shown to be consistent in its design and colour scheme to provide user predictability and ease of use. Similarly, the SMS messages that delivered alerts were designed with specific and brief messages that informed the consumer of the result of their high usage action. This system is considered usable to the extent that it is considered easy to use and understand across the multiple channels of the web-portal, email, USSD and SMS.

5.6.4 Load Testing

For this testing purpose, actual smart meters were acquired and used to record usage over a period of time, enabling the study to use data generated and recorded every 30 minutes. The system has proven that it can handle data generated at this interval and produce bills and alerts immediately as expected after the required consumption analysis. While we may not have been able to do mass testing of hundreds or thousands of smart meters, the extent of load testing here was limited by the number of smart meters availed.

5.6.5 Integration Testing

The system tested the integration between the web application and the USSD application, the web application and the SMS alerts system, and between the web application and the email alert system. In these tests, confirmation of success showed by display of the correctly generated messages/alerts as shown in the figures 5.7, 5.8 and 5.9.

5.6.6 Validation

At this point in time, the system was tested using manually input data read from a smart meter device. Further tests and validation using smart meters with automatic data upload could be done in future.

Chapter 6: Discussion of Usage Analysis Results

6.1 Introduction

Following the collection and analysis of the electricity usage data gathered through the use of a smart meter, it was noted that accurate billing to the customers is possible. The use of smart meters as the main tool to record usage further illustrated that billing estimation can be eliminated. Further, the periodic usage recorded demonstrated that irregular usage patterns can be detected using a dynamic control tool. Any such irregularity is flagged and an alert is generated by way of both Email and SMS and dispatched to the customer. This allows the system to link the customers' action to the result, ensuring that he/she is informed on time to enable consumption behavior change.

6.2 Discussion of Sample Data and interpretation of results

The usages recorded for each customer were recorded every hour. Once this was done, the following usage metrics were computed by the system in real time to help in visualization and chart generation. With reference to the Figure 6.1 shown below, the values of importance were:

i) Usage: This is the customer usage recorded at the time. It was computed as the difference between Current Reading and Previous Reading.

ii) Average Usage: This is average usage taken for all the usages ever recorded for this consumer. This value established our control line, that is, the value against which all succeeding usages are compared.

iii) Upper limit: This is the limit above the control line, that is, the upper value beyond which a usage was considered abnormal. It was computed by adding the Standard deviation value to the average. In this case we used twice the value of the Standard deviation. This was purely an administrative choice.

iv) Lower limit: This is the limit below the control line, that is, the lower value below which a usage was considered abnormal. It was computed by subtracting the Standard deviation value from the average. In this case we used twice the value of the Standard deviation. This was purely an administrative choice.

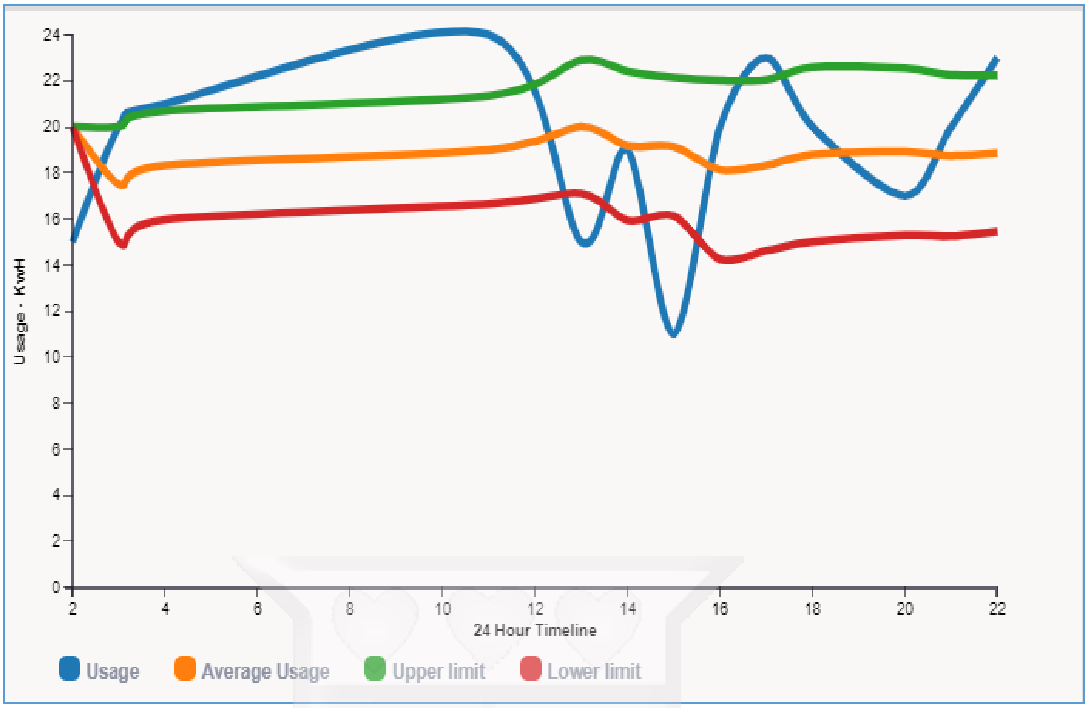


Figure 6.1: Customer Usage Control Chart

In the sample shown in the figure above, the usage line is the blue line. It is the usage recorded every hour. In interpretation, any time this line goes above the green line or below the red line, then the consumer would be alerted by Email and SMS. Should they have access to the web portal, then it is hoped that this single tool would help them change consumption patterns.

6.3 Efficiency benefits of the system as compared to existing systems

In Kenya, many of the electricity consumers are billed on the prepaid or postpaid tariff but none of these is metered using smart devices. This implies that as compared to the proposed system, estimate billing is still occurring as evidenced by several complaints from customers. The proposed system could eliminate billing by way of estimation, an undertaking that has been used in Kenya before and which has given rise to debts in dispute. (The Star, 2018).

Change in billing criteria from the current flat rate approach to a Time of Use (TOU) model was made possible by use of a smart meter. In operational terms, TOU billing makes use of the usage recorded and the time of that recording. As such, the proposed system is then able to record billing hourly and the rate to be used will either be an off-peak or a high-peak rate. The current systems in use do not provide this capability of billing. It is envisaged that a TOU billing will offer high revenue returns to utilities that adopt smart devices.

The EEA (2013) cites that the onboarding of widespread smart meter initiatives brought the reality that dynamic usage pricing may be explored more widely. Dynamic usage pricing allows the electricity market to reflect actual and near real-time system costs associated with changes in the supply and demand. This is the scenario that utilities must embrace in a deregulated market.

A key pillar of the proposed system is having the customer at the center of all operations. This implies that no system action that affects their debt happens without an information alert to the customer. This provides a major operational difference between the current system and the proposed system since the current system does not provide on time alerts to operations such as billing, payments and abnormal usage. The real time alerts system is envisaged to be the key behavior change motivator for the new system.

Adnane, Nathalie and Kevin (2017) found that unlike other household commodities that can be purchased for later use, energy purchases are done for immediate use and remain invisible to the usage consumer. This fact underscores one of the main reasons smart metering as a technology is proposed to ensure that the consumer is aware of their usage impact and price.

6.4 Limitations of the proposed system

The designed system used a limited number of smart meters due to high acquisition cost. This limited the magnitude of usage data that could be collected and by extension the insight was limited. The system relied on data link to ensure continuous usage upload. This suggests that the system would have a data cost whose impact could be passed to the consumer by the utilities.

Chapter 7: Conclusions and Recommendations

7.1 Conclusion

This electricity usage study reveals the challenges that electricity consumers face when they are presented with usage and bills whose makeup is not clear and late in time when no action can be taken to address the anomaly as when it is detected. Similarly, many consumers end up with huge costs for electricity whose consumption fairness cannot be established. In any case, the invisibility of electricity usage makes it difficult for consumers to seek redress. This study has then resulted in a system; designed, built and tested to meet the formal software standards of enterprise systems that are in use within the utilities while being customer-centric.

At the center of the design is the use of smart meters to monitor and record electricity usage, bill the usage, inform the consumer of the usage and bill and ultimate flag abnormal usages by way of alerts. The study has established that where such alerts are presented to consumers, the urge to take action and address the abnormal usage is immediate.

7.2 Recommendations

The study has shown that automation can be used to bring efficiency while cutting costs to the utility entities that are currently using systems whose operation mechanisms have remained unchanged for decades. The approach demonstrated here indicates that a modern electricity grid system that is in tune with the current technological and environmental challenges is necessary for an efficient economy. It is the recommendation of this study:

i) That utilities take advantage of the cost reduction of telecommunication costs and put in place smart meters and vending systems to help them mitigate against current losses and increase their revenues on both on-grid and off-grid installations.
ii) That to be able to scale such a system, pilot project approaches should be considered as means to learning in phases and using learned lessons to use in procuring both smart meter devices and the core systems that run them.
iii) That utilities consider partnerships with telecommunication companies that are critical to the smooth operation of a truly smart grid system. This would provide

the opportunity test several connectivity options like GPRS Internet, broadband over powerline and wireless mesh.

iv) That researchers partner with institutions and policy makers within the energy industry in Kenya to debate and agree on modalities of the sector modernization.

v) That further usage studies be considered to confirm effect of feedback reports in Kenya; and that extra engagement initiatives be done between researchers, utility companies and public institutions.

7.3 Suggestions for Future Work

This research has been designed and tested on a limited number of smart meters. Future research and work in this line ought to address scalability of the system. This will address the capacity of the utility entities to manage the massive data growth as well as putting in place a robust communication backbone to support data upload and remote capabilities. While this study has demonstrated smart meter usage recording by reading individual meters, a future approach would require an application backend connecting to an enterprise portal and feeding the portal with periodic usages automatically.

Similarly, while connectivity using GPRS enabled internet link was used in this study, it will be important to model and test the system connectivity using such alternatives as Power line carrier (PLC) or broadband over powerline and Radio frequency (RF) mesh; with a clear comparative approach to the advantages and disadvantages of each. The study also noted that hourly smart meter usage for a single customer point would increase annual data growth from 12 usage readings in a year to 8,760 usage readings, an increase of 72,900%. This massive data would usher the utilities to the big data industry where continuous data analysis would generate new insights into customer behaviour, help monitor outage and reduce both technical and non-technical losses and even help contain fraud. Kenya power would have to be bold enough to setup facilities to contain such data and walk into a future guided by data analytics.

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Appendices

Appendix A: Introduction Letter

Dear Respondent,

This questionnaire is designed to gather information on "A REAL TIME ELECTRICITY USAGE MONITORING SYSTEM USING SMART METERS FOR WASTAGE DETECTION IN KENYA''. This electricity usage analysis is being carried out for an ongoing thesis project as partial fulfillment of the degree in Masters of Science in Information Technology of Strathmore University, Kenya.

The information you avail will be held in strict confidence and remain anonymous. Such information provided shall be used for this research purpose only.

On request, a copy of this usage research paper will be availed to you without any reservations.

Many thanks,

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Joseph Oduor Obonyo	**Professor Ismail Ateya Lukandu**
MSc IT Degree Scholar	**Associate Professor –**
	Strathmore University

Appendix B: Questionnaire to Post-paid Electricity Customers

This questionnaire is intended to collect usage data to examine an approach for the **A REAL TIME ELECTRICITY USAGE MONITORING SYSTEM USING SMART METERS FOR WASTAGE DETECTION IN KENYA**. The outcome of your usage analysis will be solely used for academic research purposes. Your identity will remain anonymous throughout this exercise.

Please provide us feedback by answering 6 questions below as you see appropriate.

1. Does the meter reader come monthly for your electricity usage reporting?

    Yes [ ]   No [ ]

2. No of years you have had electricity connection:

    Below 1 year [ ]   1-5 years [ ]   6-10 years [ ]   11-15 years [ ]   Above 15 years[ ]

3. How do you currently receive your bills?

    By Email [ ]   By SMS [ ]   Manual Printout [ ]

4. How would you rate your satisfaction with the means of bill reception picked above? (1 is lowest, 5 is highest)

Satisfaction Query	**1**	**2**	**3**	**4**	**5**
We are fine with the current bill reception mode					

5. Do you own and operate a mobile telephone?

    Yes [ ]   No [ ]

6. Do you own and operate an email account?

    Yes [ ]   No [ ]

THANK YOU FOR YOUR TIME AND PARTICIPATION