FINAL YEAR PROJECT REPORT

SMART METER

Session: 2013-2017

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Abstract

Billing is critical function of the electricity board towards getting meter reading. Meter reading, even though it looks simple, is far from simple and involves processes that can give various problems, most problems currently seen, result from the manual processes followed.

Calculation errors, delay in system updating a fault tracking issues are the major problems that companies find difficult to find answer for this paper suggests a smart electricity billing system to collect process and notify consumers about consumption. This system will be reliable, efficient and accurate to suit the requirement of these companies. The burden on the meter reader is lessened and other new features have been introduced. Customer interaction with the system is improved and customers can easily view their current electricity bill using their respective account. Most of the problems related to electricity billing are addressed through this system and might prove to be best solutions for specific companies to optimize services on low budget.

The technology of e-metering (Electronic Metering) has gone through rapid technological advancements and there is increased demand for a reliable and efficient Automatic Meter Reading (AMR) system. This report presents the design of a simple low cost wireless Bluetooth energy meter and its associated android application, for automating billing and managing the consumption of electricity. The proposed system replaces traditional meter reading methods and enables remote access of existing energy meter by the energy provider. Also they can monitor the meter readings regularly. A Bluetooth based wireless communication module is integrated with electronic energy meter of each entity to have remote access over the usage of electricity. In which we use Ardiuno Uno (microcontroller). Live meter reading from the Bluetooth enabled energy meter is sent back to this billing point periodically and these details are updated in a central database. The complete monthly usage and due bill is messaged back to the customer after processing these data. Smart Meter help to manage the budget of their houses and we can also control the consumption of electricity which is a big problem of our country. Smart Meter can also be applied with individually home appliances like Air conditioner, refrigerator, iron and etc. If you’re amongst two-thirds (68% to be exact) of the population that has access to electricity in Pakistan, then you most certainly receive a monthly electricity bill. This piece of paper, also commonly known as the WAPDA bill, has been full of surprises over the last year for many consumers who couldn’t make head to toe of the exorbitantly high electricity bills and consumption. It is widely believed that electricity supply companies in Pakistan are laced with incompetence, negligence, and other issues. Unfortunately, it’s the consumer who has had to bear the brunt of the laxity and mismanagement of our electricity supply companies in the form of over-billing and disconnections and late payment surcharges. We’ve masked personal details. Although, our electricity companies are to be blamed for not sending out accurate electricity bills from time to time, consumers also need to be more aware and conscious of any discrepancies in their WAPDA bills so that if we use smart meter we should fully know about their electricity unit consumption on daily basis.

Dedication

We dedicate our dissertation work to our teachers and family. A special feeling of gratitude to our loving parents, whose words of encouragement push for tenacity ring in our ears. We also dedicate this dissertation to our many friends and family who have supported us throughout the process. We will always appreciate all they have done, especially Khurram Jilani for helping us develop our technology skills and Dr Abdul Aziz for helping us to master the leader dots. Both of you have been my best cheerleaders.

This thesis is dedicated to my Sir Khurram Jilani, who taught us that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to our parents; they taught us that even the largest task can be accomplished if it is done one step at a time.

Acknowledgments

First and foremost, enormous gratitude is due to Fahad Sabah who has been there as my supervisor and has been unstinting is his support and constructive critique. Many thanks are also due to Khurram Jilani who started us down this road. Fahad Sabah has been the ideal thesis supervisor. His sage advice, insightful criticisms, and patient encouragement aided the writing of this thesis in innumerable ways. I would also like to thanks Khurram Jilani whose steadfast support of this project was greatly needed and deeply appreciated.

I wish to thank my group members who were more than generous with their expertise and precious time. A special thanks to Khurram Jilani, my group advisor for his countless hours of reflecting, reading, encouraging, and most of all patience throughout the entire process. Finally I would like to thank the beginning teachers, mentor-teachers.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

1. Alternate Current Autocorrelation Function
2. Akaike Information Criterion
3. Akaike Information Criterion Corrected
4. Advanced Meter Infrastructure
5. Advanced Meter Reading
6. Artificial Neural Network
7. Autoregressive Integrated Moving Average Autoregressive Moving Average with Exogenous Inputs China Mobile Communication Corporation
8. Critical Peak Pricing Day Ahead Pricing Final Prediction Error
9. Generalized Autoregressive Conditional Heteroscedastic Home Energy Management System
10. Home Area Network In-Home Display
11. Mean Absolute Percentage Error
12. Maximum Absolute Error
13. Maximum Absolute Percentage Error
14. Mean Square Error
15. Normalized Root Mean Square Error
16. Online Transaction Processing Systems
17. Pacific Northwest National Laboratory
18. Partial Autocorrelation Function
19. Real Time Pricing Schwarz criterion
20. Supervisory Control and Data Acquisition System
21. Smart Energy Management System
22. Sum of Squared Errors of Prediction
23. Technology Acceptance Model
24. Time of Use Pricing

1 INTRODUCTION

In the early phase of household technology, delivery of electricity is completely depended on traditional energy meters. These meters play a key role in measuring the consumption of electrical energy in individual households. The usage of these meters has been slowly declining with the advancement in technology as rapid changes has been made to encounter the problems occurred by the traditional meters. The major problem arises when habitants are unaware of their daily behavior. Monthly feedback given to the consumers is not sufficient as the consumers will not have knowledge on how much energy does the individual appliances consume. To overcome the problems of traditional electricity meters, Smart Meters have been upgraded and developed. With the use of Smart Meter data, energy alerts will be provided to the consumers based on hourly utilization of energy. The primary objective of the Smart Meters is to reduce the energy consumption in the households. Our thesis utilizes real time Smart Meter data sets obtained from a Swedish electricity company. A case study is performed on hourly measurement data of 16 households to determine consumption patterns.

With its growing attention in the market the behavior of the consumers can be studied and analyzed. The energy consumption patterns can be facilitated in improving the behavior of users. The electricity market can be restructured with the installation of these meters, as it not only preserves the energy, but also reduces carbon dioxide emissions [4]. Trust and credibility of these meters is established only when the consumers have positive quality of experience. Timely consumption of consumers can be reduced as Smart Meters are connected to online billing [2].

1.1 Motivation

Energy expenditures will be lowered by increasing the possibility of reduced consumption using analyzed Smart Meter data motivated to perform this research work. During the usage of traditional meters, there is involvement of wastage of much energy to man power. As the electricity consumption of the household is known on monthly basis by conventional meters, there is an overall demand for the electricity utilities to explore a new development for benefit of the consumers as well as themselves. However, the study determines to make attempts to replace electricity meter in respective households by minimizing the drawbacks occurred by consumer. The daily electrical usages change with respect to habits and it is mostly dependent on behavior of consumers. By using traditional meters, usages are not flattened as consumers are not aware of the knowledge about how much consumption has been made in an hour or any particular interval of time in a day. The uncertain perception of the consumers can also be falsified as most of the consumers have very low knowledge regarding the Smart Meter and its installation. Lastly, to enable change and read concerns in the market also motivated to perform this study.

1.2 Scope of the Thesis

This thesis work deals with energy consumption values acquired from the energy provider. These standard values help energy utilities and consumers to know their energy consumption which is reported on an hourly basis. In fact, behavior of the consumers can be studied and results obtained can help the consumers in changing their behavior, in particular when correlated with a potentially varying price. This work explains a gap between the consumers and energy utilities so that they can communicate more efficiently through the implementation of conservation strategies. The consumers need to be educated with broader knowledge regarding the meter so that wrong perceptions can be altered. A case study is conducted on the standard data obtained for sixteen sets of households. The variation in change of the usage has been well understood and determined. The research work can also help users to think intelligently when using their power. Moreover, daily patterns for the complete day on hourly basis are examined. Future savings which consists in determining when to use which appliance can be done by using prediction models and flattening techniques.

1.3 Study Prerequisites

The important prerequisites contributed in our research work are as follows:

- The analysis of hourly measurement data of 16 households is necessitated while employing data.
- Statistical modeling knowledge is essential to determine the relation between price, cost, consumption, cumulative consumption and cumulative cost on which statistics are calculated such as lag1 autocorrelation, price-cost correlation, price-consumption correlation, cost-consumption correlation, average, standard deviation and coefficient of variation.
- Efficient knowledge on a calculation tool such as ´Microsoft Excel´ is required to execute statistical calculations while evaluating the graphs.

The importance and evolution of Smart Meters has been studied in research papers and articles. This further contributed in improving the knowledge from traditional meters to advanced meters.

1.4 Structure of Thesis

The flow of the thesis is organized as follows. The first chapter includes a general description of introduction and its segments such as scope of the thesis, motivation and study prerequisites. The second chapter presents background work consisting of evolution of meters from past, traditional meters. It discusses the motions of Smart Grid, Smart Meter, power consumption, people‘s behavior, ARIMA models and ends with a literature survey. Chapter 3 explains aims and objectives, research questions and the methodology to find the answer to research questions. In chapter 4, a case study is performed on Smart Meter data readings and this is followed with an explanation of results in chapter 5.

2 BACKGROUNDS AND RELATED WORK

2.1 Evolution of Electricity Meters from the Past

In early years, electricity is available only to a specific section of affluent society. The advancement in technology over time encouraged meeting the demands of common people in all parts of the world. The history of electricity meter is well connected involving researchers from past. The general usage of electricity in the early 1870's is only confined to telegraphs and arc lamps. With the invention of the electric bulb by Thomas Elva Edison, the power energy market became widely opened to the public in the year 1879. Oliver B. Shallenberger introduced his AC ampere hour meter in the year 1888. Eventually, the progressive development in metering technology leads in enlightening the lives of many common people [33].

2.1 .1 Traditional Electricity Meters and its types

The electrical devices that can detect and display energy in the form of readings are termed as electricity meter. Traditional meters are used since the late 19th century [28]. They exchange data between electronic devices in a computerized environment for both electricity production and distribution. In most of the traditional electricity meter aluminum discs are used to find the usage of power. Today's electricity meter is digitally operated but still has some limitations.

Some of the limitations faced by the traditional electricity meter are as follows:

- Meters are unreliable in nature as consumer has to anticipate for the monthly electricity bill.
- The process of measurement is supported by a specific mechanical structure and hence they are called as electromechanical meters.
- In order to perform meter readings, a great number of inspectors have to be employ-ed.
- Payment processing is expensive and time consuming.
- New type of tariffs on hourly basis cannot be introduced with the corresponding meters for encouraging the consumer.
- Development of meter software applications and supportive network infrastructure is complicated.

Besides the above mentioned limitations, there are also several other elements creating a huge gap between the consumer and distributor because of installation of traditional meters.

Meters are of distinct types. Even though timely development of electricity meters helps the consumer to gain knowledge with respect to electricity consumption, statistics of the consumption couldn't be changed. Some of the basic types of electricity meters are explained as follows:

Different Types	Outline
Electrolytic Meter	The whole current passes through the electrolyte. The major drawback is mechanical considerations and adoption by limited
Commutator Meter	Brush-shifting device is used to vary the current load and commutator's of small diameter facilitates in insulation attention. The major drawbacks are inadequate load characteristics.
Mercury Motor Meter	There is a satisfactory performance with the introduction of this meter. The adoption of rotor made a prominent role in supplying the calibration. The momentary short circuit is reduced or even
D.C Watt Hour Meter	This meter model is developed for heavy current circuits where the temperature coefficient is high. For indication of demand purposes a separate time switch is used. Also, it is a clock -type meter in which
Single Phase Induction Meter	Magnetic conditions are better improved to control the energy consumption and a considerable improvement in performance is also done. Meter inspection is easily assessed as the construction of this
Poly-Phase Watt Hour Meter	Lagging power factors in the meter reflects the characteristics of the current transformer. Attempts for improving high degree of accuracy have been built to avoid troublesome corrections. Interaction effects,

2.2 Smart Grid

Smart Grid is the modern development in electricity grid. Recent electrical grids are becoming weak with respect to the electrical load variation of appliances inside the home. The increase in population is also the indication of electrical grids becoming more fragile. The higher the population, the more load on the grid.

Improving the efficiency of grid by remotely controlling and increasing reliability, measuring the consumptions in a communication that is supported by delivering data (real-time) to consumers, supplier and vice versa is termed as Smart Grid [31]. Automated sensors are used in Smart Grids. These sensors are responsible in sending back the measured data to utilities and have the capability to relocate power failures and avoid heating of power lines. It employs the feature of self-healing operation. Literally, the concept of Smart Meter is commenced from the idea of Smart Grid. A carbon emission reduction of 5% is expected by 2030, annually by its installations and it can show a greater impact on environmental changes [31]. For a sustainable development and establishment of new grid infrastructure, Smart Grids are recommended for many countries.

2.3 Smart Meter

Smart Meter is an environmentally friendly energy meter that is used for measuring the electrical energy in terms of KWh (Kilowatt - hours). It is simply a device that affords a direct benefit to the consumers who want to save money on their electricity bill. They belong to a division of Advanced Meter Infrastructure and are responsible for sending meter readings automatically to the energy supplier. A simple picture of a Smart Meter is shown below.

Accurate meter reading will be provided with the inclusion of firm benefits from the Smart Meter. They record the consumption on the basis of hourly or less than hourly intervals. A Smart Meter has non-volatile data storage, remote connects or disconnects capability, tamper detection and two-way communication facilities. They perform remote reporting of the collected data to the central meter. This central meter monitors the functionality of the Smart Meter. From an operational perspective, use of Smart Metering allows an improved management and control over the electricity grid [6]. Some of the benefits of Smart Meters are as follows:

- Low operational cost.
- Time saving to the consumers and utility companies for reporting the meter reading back to the energy providers.
- Online electricity bill payment is allowed.
- Power consumption can be greatly reduced during the high peaks with an intimation policy.
- Has a feature of automatically terminating the appliances off when they are not in use.

Smart Meter senses all the consumption generated inside the residents. Meter readings give a broader understanding to the energy utilities so that overall energy usage customs of the habitants can be altered. Finally, all the information that is generated by Smart Meter will increase help in noble generation.

2.4 Power Consumption

The total amount of power consumed in an individual household is referred as power consumption. The consumption of power is an important aspect of electricity supply. People should be aware of preserving energy for future use. With daily usage of electricity, the energy patterns have been slowly varying. This variation of consumption patterns can be caused by weather conditions or unnecessary utilization of power by inhabitants such as increase of appliances in respective households and careless attitude in utilization for example not switching OFF the lights or television when not watching it. These factors may show greater impacts on end user. As the power supplied by energy companies is vast, most of the people are neglecting energy and its savings. The importance of consumption is declining in the mindset of utilities. The energy utilities should play a major role in advancing the Smart Meter technology and should make people participate in reducing energy consequences by creating awareness about the impact of their current level of consumption.

2.5 Study of People's Behavior

People‘s behavior is termed as behavior of consumer on appliance consumption in a household. If the consumption of the customer is high then we can empathize that their usage of devices is also high, which means cost is directly proportional to the product of number of uses and the corresponding durations. It is important for energy companies in reaching the anticipation of the customer. In-fact most of the consumers rely on monthly bill they expect for. They usually do not know which appliances are consuming more energy and how they can manage their consumption better. These factors play an important role in influencing the behavior of the customer. The better understanding of the people‘s behavior is only achieved through analyzing how they use their energy. The consumers should be influenced in a smart way while accessing their appliances. An illustration of a Smart Meter installed in a household while measuring the appliances.

The above figure expresses the daily activities of household appliances measured by a Smart Meter in a home. Smart Meter is installed outside the house and its hourly consumption data is measured for lowering consumer electricity bills. This measurement facility converts simple home to a smart home.

2.6 ARIMA model

The acronym of ARIMA stands for Autoregressive Integrated Moving Average. ARIMA model is a standard linear time series model that accepts the present values and predicts the future values in the series. It is represented as ARIMA *(p, d, q)* where parameter *p* is referred as the order for auto-regression, parameter *d* is the order for non-seasonal difference and *q* is the order for the moving average. The ARIMA model accepts time series data as input (combination of past values) and predicts future values as output. Predicting the future values guides in applying many applications such as demand estimations, stock prices estimation, economic estimations and sales.

There are two types of ARIMA processes, seasonal and non-seasonal ones, which are discussed in detail below.

Seasonal ARIMA model: Seasonality is a regular pattern of changes that repeats over *s* time periods. A seasonal ARIMA model is expressed as ARIMA $(p, d, q)\,(P, D, Q)_s$ where *P* is the order of seasonal auto regressive part, *D* is the order of seasonal differencing part, *Q* is the order of seasonal moving average part and *s* is the number of time periods of seasonal cycle.

2.7 Survey of Related Work

The survey is split into four parts, namely socio-economical issues, technological issues, cases and prediction. As we started with literature survey in the initial stage of research, the division of cases is chosen to answer research questions in an organized manner.

Social-economic issues:

The value of customer satisfaction in communication market is trusted with the services provided by service provider. The author explains people‘s behavior towards the Smart Metering system and states the services such as viewing electric consumption in real time, viewing the effect of turning electrical appliances on and off, making estimation of the next bill, or receiving messages directly from the grid operator. The consumption patterns during night and weekends are projected in the paper.

A survey is conducted in different countries over different households and user‘s feedback is obtained so that people become motivated to be energy-conscious. A socio-technical review to promote sustainable energy consumption using Smart Meters is done. Answers are proposed for a set of research questions such as 1: Is feedback useful for energy saving and behavioral change? 2: What presentation of feedback is good and effective? Scientific advice on energy saving instruments for household energy consumption is provided in. A Smart Metering privacy model is implemented to measure the privacy that a Smart Meter will provide with and without involvement of third parties. The advantages of Smart Metering concept are low metering costs, energy efficiency and easier detection of fraud.

A quantitative survey was conducted among various households and results of this survey were presented in paper. The mapping of consumer‘s perception with household appliances is done. A theoretical framework named TAM is proposed for household perception of Smart Appliances. Mean scores and standard deviations for perceived usefulness, perceived ease of use, attitude and intention to use, safety, control and comfort are tabulated.

Technological Issues:

The connection between meter and the household appliances is carried out in different ways. The connection can be dedicated line, wireless connection, web-based communication and power-line communication between the appliances in home and the meter. The secured scenario can be maintained by connecting the meter to the data centre. When Smart Meters are connected with mobile phones, the actual power consumption of a device when it is switched ON/OFF or plugged in/out is observed. An overview of Smart Metering installations, implementations, and functionality which is installed in the Netherland.

Smart Metering involves installation of one or several Smart Meters by continuously monitoring and sending feedback of data to the customer. Consumers, by making use of Smart Meters, will get safe, secure and affordable energy, and a reduction of carbon emissions is possible.

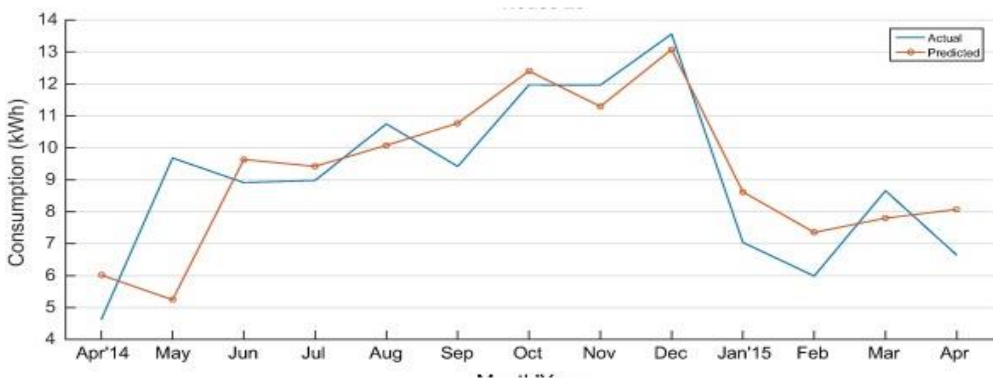
The architecture of Smart Energy Management System was developed to control the transmission capacity and rate generation for the aggregated load conditions of the Smart Appliances. Energy prices, consumption and cost of consumption under different demand conditions i.e. on-peak, mid-peak and off-peak values are tabulated. The energy cost of each appliance is shown in pictorial form.

The importance of Smart Meter in the market with respect to the customer and business organization has been reviewed. Functionalities and benefits of Smart Meters compared to mechanical meters are explained. The authors are curious to find out the hypothesis to the proposed questions in this particular research paper. To make energy efficient society, the customer must be aware of the energy consumed. So, different feedbacks are proposed in this paper to save energy and improve energy efficiency.

The monitoring of Smart Meters in Hungary is discussed. The meter has two-way communication capability for tariff based operation and remote control. The communication tools of the meter such as Zigbee, WIMAX and Home Area Network supporting the energy meter is addressed. Energy Management System with high level application possibility has been proposed.

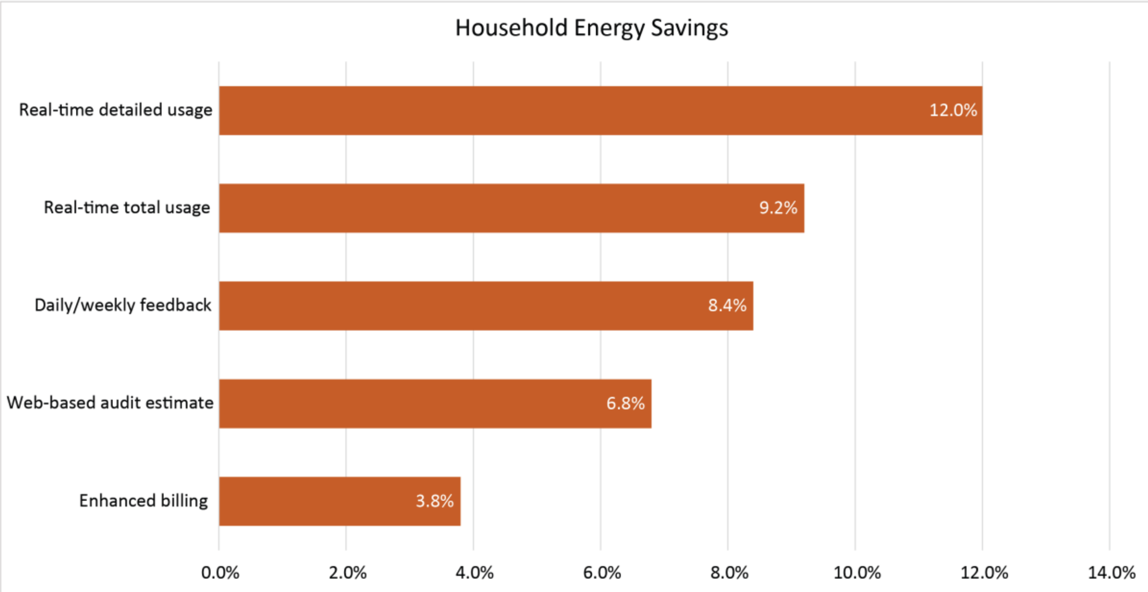
Cases:

Consumption patterns are analyzed in two households and an office in the UK, where real time reporting is done using web. The need for Smart Meters, benefits and how to monitor the power is detailed. Experimental setup is designed in three household premises. The experiment setup contains a section of equipment and software. Graphs are observed on a 24 hour cycle online for weekday, Sunday, before and after the change of appliance. The analysis is also done for heating water, turning on central heating and printing from a laser printer. Direct feedback is suggested to identify the appliances of high burn. The aim of influencing consumer habits has been achieved by indicating where the savings are possible.



A thorough analysis of 15 minute residential meter data of 50 houses were used to derive several target applications such as identifying demand response potentials, abnormal load behaviors and fault diagnosis. The processing of Smart Meter data with the aid of Supervisory Control and Data Acquisition System, billing and weather data is focused. The data collected by the researchers at Pacific Northwest National Laboratory was used. The load profile of two households with highest and lowest energy consumption over 15 minutes during the month of April is plotted. The impact of temperature on the power consumption of a household is demonstrated.

A Smart Metering development system for a residential environment is explained and system monitoring of other countries is reviewed. A pilot demonstration with the developed system is conducted in 77 different sized households located in two different cities. The study is focused on verifying the effectiveness of In-Home Display which is an essential component of Korean Smart Metering system. Many ideas such as Advanced Meter Infrastructure, Smart Grid and Smart Metering system have been proposed. The results interpreted convey that people living in small houses are more sensitive to price-related information. The daily power consumption comparison graphs of two cities before and after using In-Home Display are demonstrated. The impact of temperature on daily power consumption is observed.



Prediction:

Price prediction is done on the basis of Home Energy Management System. The experiment evaluated results in saving 22.2% of electricity expenditure daily. Types of pricing models such as Real Time Pricing, Day Ahead Pricing, Time of Use Pricing and Critical Peak Pricing are specified. Client interface data model for the energy consumption is constructed using XML. The graph for actual price and predicted price, maximum power utilization i.e. peak hours are also compared and observed. Test bed is designed to evaluate the Home Energy Management System.

Simulation model presents a generated load profiles for household to construct flat tariffs. The impact of Smart appliances and variable prices on electricity bills of a household is investigated. Field tests are carried out to estimate the bill saving and other cost estimations. The operations of household appliances are shifted so that users can reduce their cost. The load curves for working days, Saturday and Sunday are demonstrated. Comparison of load curves for flat tariff and time based tariff is shown. The results of the paper show how variable pricing will affect consumer behavior under realistic environment conditions.

An ARIMA approach to forecast short term electricity prices to improve accuracy by forecasting errors is proposed in the paper. Based on the historical data obtained from California power market, ARIMA model is implemented on daily average prices. Forecasting curves after single and double error adjustments are shown in graphical form. Statistical results such as mean, variance, Mean Square Error, Maximum Absolute Error for forecasting price of California and after twice error adjustments are tabulated.

Spot electricity price forecasting has been done using European Energy Exchange data. ARIMA is founded to be the best fitting model for the experiment. From the results, Maximum Absolute Percentage Error and Mean Absolute Percentage Error of the model are rounded.

Results from Spain and California markets are presented in this paper. The differences of both the market has been observed by applying ARIMA model. Time series analysis is explained with steps from identification to forecasting of the model. The outcome of the Spanish market is 5 hours to predict future prices and 2 hours is needed for California market predictions.

Monthly energy data forecasting approach of Provincial Electricity Authority of Thailand is provided to decompose trend cycles and seasonal patterns. Decomposition technique is used for time series forecasting, while correlation coefficients and mean absolute percentage errors are computed to measure fitting accuracy.

Seasonal ARIMA model is used for forecasting the mobile traffic. Analysis is performed based on the real time data obtained from CMCC. NRMSE is calculated for determining and acceptance of forecast errors.

The papers which impacted our research addressed people's behavior towards Smart Metering system, benefits of Smart Meter compared to mechanical meters and feedback to save energy on improving energy efficiency consumption patterns on a 24 hour cycle are analyzed in two households in the U.K.

3. DESIGN AND IMPLEMENTATION

3.1 Aim and Objectives

The main aim of this research is to measure and analyze power consumption using Smart Meter data by conducting a case study on various households. The related objectives are as follows:

Objectives

- To analyze the data on an hourly basis to understand the potential that much line-grained measurements can have on control of electricity consumption.
- To understand how to move demands in time so that the overall power consumption becomes less varying and costly.
- To change people's mind a bit more intelligent during the day for better distribution of energy consumption.
- To select a good prediction model for predicting 24 hour ahead consumption and cost.
- To flatten power distribution graph when abnormal electricity changes occur.

3.2 Research Questions

RQ.1) What are the methods to measure and analyze the power consumption of household applications in a real-time environment?

RQ.2) How can we model the energy consumption of single household and their superposition?

RQ.3) How should power consumption be reduced in household appliances to flatten daily consumption patterns?

The first research question is formulated to retrieve information about methods to measure electricity. More importantly, assumptions and variations with real-time data are accounted and analyzed. The second research question is framed to filter different types of models and select a suitable model for fitting the data. In addition, smart way of superposition of the data is essential to observe behavior of households. The third research question is acquired to find the optimal way to flatten daily consumption patterns.

3.3 Research Methodology

The research methodology involved in our research using case study and stages that are followed for answering the research questions are as below:

1. In the first stage of the research we have to perform a literature review related to Smart Meters. The data which is measured using Smart Meters is obtained from an energy provider. The results which are obtained from data are plotted in the form of graphs and observations are done regarding the consumption, price-cost, cumulative cost of the household and further statistical analysis. Particularly, in this stage the results are statistically summarized from the arrived data. The flow of research methodology is shown in below figure.

2. In the second stage of the research, a prediction model is selected. Model matching should be done after model selection, which is followed by validation. Different household energy consumption and cost patterns can be modeled using ARIMA. Various data sets are processed to obtain price-consumption correlations for observing behavior of households using superposition.

3. In the third stage of research, a method of flattening consumption patterns is identified and developed, aiming at flattening daily patterns and attempting to change the attitude of consumers. Finally, conclusions are drawn from the analysis.

4. CASE STUDY

An analysis of data involving a method of research is called case study. Some steps had been followed in the case study of our research. The steps are as follows:

1. In the first step of our study, the Smart Meter data is obtained from a local energy provider that prefers to remain secret. This data was received by our supervisor.
2. This received data is passed to our team by supervisor for evaluating and

analyzing the results. Smart Meter data is a validated one as it is obtained from an energy utility provider.

3. The received data contains two sets of Microsoft Excel sheets.

a) We considered price values of area 4, south of Sweden, which is named as ³SE4´ in the sheet. The hourly price is varying for each day, i.e. each day has 24 different prices.
b) The second sheet contains Smart Meter consumption data values of 16 households. The 24 hourly consumption values per day and household are included in the Excel sheet. The data in the sheet ranges from day 30 to day 1 of the month of April. We considered time from 1:00 hour to 23:00 hour of the current day in the sheet as it is, and 00:00 hour of next day which is considered as 24:00 hour of present day. This data is carefully observed and noted in a separate Excel sheet. A careful observation is needed when moving the data from one sheet to another, as skipping of data has a great impact on the results. For reasons of anonymity and privacy, the 16 households are referred by a number from 1 to 16.
c) After reading the data, we need to interpret the real Smart Meter data in a new Excel sheet. In the formulated sheet we arranged time (1:00 to 24:00 hour), price, energy consumption and calculation of cost, cumulative cost, cumulative consumption, lag 1 autocorrelations of price, cost, energy consumption and correlations of price-cost, price-consumption and cost-consumption is determined.
d) Based on the results obtained, graphs are plotted for time versus consumption (KWh), time versus price, time versus cost and time versus cumulative cost. The time is plotted on the x-axis and consumption is plotted on the y-axis for time-consumption graph; time on the x-axis and price on the y-axis for time-price graph; time on the x-axis and cost on the y-axis for time-cost graph; and lastly for time-cumulative cost, time is plotted on the x-axis and cumulative cost is plotted on the y - axis.

e) **Correlation:** It is a statistical measure of how two variables move in relation with each other. It ranges between +1 and -1 [29]. They are of two types.

- **Positive correlation:** A relationship between two variables which move in the same direction i.e. as one variable decreases, the other variable also decreases and when one variable increases the other variable increases is called positive correlation. In statistics, the maximal value of positive correlation is represented by +1.

- **Negative Correlation:** A relationship between two variables which move in the opposite direction i.e. as one variable decreases, the other variable increases and as one variable increases, the other variable decreases is called negative correlation. In statistics, the maximal value of negative correlation is represented by -1.

In addition to that computation of price-cost correlation, price-consumption correlation and cost-consumption correlation, average, standard deviation, and coefficient of variation for price, cost and energy consumption is done.

f) The above computed steps are repeated for all days in a month per single household. Similar graphs are generated for all 16 households from the results obtained.
g) The complete analysis can only be achieved with the help of another classified sheet. So, we named those sheets as analysis succeeding with a number representing the household. In this determined sheet, we calculated real cumulative cost, cumulative cost based on average price, difference of real cumulative cost and cumulative cost based on average price. The

correlation of price with consumption is done as positive correlation is expected to yield high cumulative cost. A comparison of cumulative based on hourly price with those based on average price is computed because this reveals when hourly prices are disadvantageous/advantageous for consumers. Two graphs are plotted, one with the number of the day on the x-axis and price-consumption correlation on the y-axis represented as correlation graph, another with difference between real cumulative cost and cumulative cost based on average price on the y-axis and the number of the day on the x-axis representing difference graph.

h) The maximum values of data such as price, peak power consumption and cost are documented independently in sheets of ᵌMicrosoft PowerPoint´ for better understanding. The analysis is performed as a combination of 16 household results and correlation/difference graphs are presented in excel sheets.

Cross correlation: Cross correlation between consumption and price is a measure to know how effective hourly charging was for the customer. It is a measure for interdependencies.

+100%: price and consumption follow each other either up/down : price and consumption are approximately independent -100%: price up implies consumption down and vice versa

- For positive correlation, there is a tendency that low prices occur together with high consumption.
- For negative correlation, there is a tendency that low prices occur together with low cost.

The mentioned correlations in this research help the reader with much easier and quicker analysis.

i) A model search has been done, and the XLSTAT tool [40] is found to fit the combination of model selection and prediction. Various ARIMA models are tested by taking consumption data as a reference of one household and comparison of all models is carried to search for the best fitted model.

j) The identification of ARIMA model that fits best is finally chosen and graphed for different cases. The parameters AIC and SBC of the model are quite low and model is fitted on original graph when compared to other models. According to the standard statistics [24], the mentioned parameter values should be low. The model with lowest AIC and SBC has the tendency to exhibit good results. Moreover, different observation characteristics of the model also displayed various impeccable outcomes. As adequacy, efficiency and accuracy strongly reflects the nature of the model motivated us to use this model in our research work.

k) Finally, flattening of the consumption pattern is observed.

l) By performing the above steps, case study is successfully implemented.

5. RESULTS

RQ. 1) What are the methods to measure and analyze the power consumption of household applications in a real-time environment?

The research question is split into two complementing directions of research as follows:

Methods to Measure:

There are multiple traditional ways of assessing the meter and its data. The better way of assessing the meter is implemented by using Smart electricity meters rather than opting for traditional meters. The ancient and next generation methods of measuring the energy are explained in background work of this thesis paper. A literature review [2] has been performed to answer the question. The presentation of this part of the research question and its answer is mainly invoking an impressive knowledge for the people of various developed and underdeveloped nations regarding the fundamental changes among electricity market. From the literature survey and final suggestions of research, it was found that Smart Meter is the efficient meter to measure power consumption of household in real-time environment.

Analysis:

We acquired real time hourly power consumption data of 16 households and prices for April month from an electricity provider in the form of excel sheets. Time, price, cost, consumption, cumulative consumption, cumulative cost are tabulated in excel sheet. Lag-1 autocorrelation, price-cost correlation, price-consumption correlation, cost-consumption correlation, average, standard deviation and coefficient of variation of price, cost and consumption are calculated. Each and every factor specified above is tabulated for easy understanding. The data is arranged for all the 16 households and graphs are drawn for consumption, price, cost and cumulative cost. The parameters that are required are defined as follows.

- **Power:** Power is defined as the energy consumed per unit time. Power

  = e/t

  - where e is energy consumption in KWh t is time

- **Cost (c):** Cost is calculated as the product of price and energy consumption. The unit of measurement is in monetary units.

  - c = p.e

- where e is energy consumption in KWh p is price in monetary units/KWh
- **Average (m):** It is defined as sum of different quantities divided by the total number of these quantities. It is formulated as follows:
    - $m = 1/n. \quad X_i$
    - Where n is total number of terms

X_i is value of each individual element i = 1, 2, 3,
---------------------- n

- **Standard Deviation *(s):*** A measure of dispersion of a set of data from its mean is called standard deviation. Standard deviation is calculated as square root of the variance [16]. It is formulated as follows:
- Where n is total number of terms X_i is value of i_{th} terms
        - is mean
    - ------------------i = 1, 2, 3, n
- **Autocorrelation:** A mathematical representation of the degree of similarity between a given time series and a lagged version of itself over successive time intervals is termed as autocorrelation [17].
- $rk = ((yi -) (yi+k -)) / \qquad (yi -)2$
- where r_k is lag k autocorrelation
        - --------- i = 1, 2, 3, n
    - ------------------- k = 1, 2, 3, n
    - n is total number of terms
        - is average of n terms

- **Cumulative consumption (E_i):** The cumulative consumption is the sum of hourly consumptions during the first i hours of the day. The first value of cumulative consumption is taken as it is from consumption.

- $E_i = e_i + {}^{E}{}_{i-1}$
- where E_i is cumulative consumption
    - ------------------- i = 2, 3, 4, n
    - e_i is consumption
    - E_{i-1} is previous cumulative consumption
- **Cumulative cost (C_i):** The cumulative cost is the sum of hourly costs during the first i hours of the day. The first value of cumulative cost is taken as it is from cost.

- $C_i = c_i + C_{i-1}$

- ---------------------------- where C_i is cumulative
  cost at i_{th} hour i = 2, 3, 4, n
  - c_i is cost at i_{th} hour
  - C_{i-1} is previous cumulative cost

- **Coefficient of variation:** The ratio of standard deviation to average is called coefficient of variation. It is formulated as follows:

- Coefficient of variation = (Standard deviation / Average)

  - The product of average price and larger value of cumulative consumption is called cumulative cost based on average price. It is formulated as follows:

ACum = E .

Where ACum is cumulative cost based on average price

$E = e_i$

$= 1 / 2 4 \quad p_i$

The sum of product of consumption and price in a particular hour is called cumulative cost based on hourly price. It is formulated as follows:

HCum = $e_i . p_i$

Where HCum is cumulative cost based on hourly price i is hour of the day

E is sum of consumption of a day

e_i is consumption of particular hour p_i is price on particular hour is average price

Three graphs for consumption, price-cost and cumulative cost on a particular day of a household, which are interesting for some specific reasons, are shown below. This is the first step of evaluating multiple graphs for further references.

The energy consumption showed in the above figure 5.1 regarding household 3 declines from hour 8:00 to 12:00 and increases sharply from 12:00 to 13:00. Cumulative cost graph is almost linearly increasing from 1:00 to 24:00 hours. The user should be smart enough to play a safer role in utilizing energy efficiently by avoiding spikes.

Regarding household 5, high energy consumption when compared to other households is recorded at 17:00 hour on April 14. The price on April 14 is much less varying. So the price graph is observed as flat. As the user is consuming much energy, the cost factor is high even though the price is low. From the cumulative cost graph, we infer that the curve is not increasing linearly but becomes much steeper at high consumption hours.

From the below figure 5.3 regarding household 6, complete flatten energy consumption is observed with very low consumption on April 3. As consumption is very low, cost is low as well, as it is a product of price and consumption. Cumulative cost increases almost linearly from 1:00 to 24:00 hours as the cost is not constant over time.

From the below figure 5.4 regarding household 7, consumption shift between 0 and 1 is observed. This behavior is different from the remaining households. This unusual behavior indicates the type of meter that only counts multiples of kw. Here the user is cautioned about the power. The cumulative cost is not increasing linearly but following a stepwise pattern.

The graphs for energy consumption, price-cost and cumulative cost which are generated above can help the users to study their daily electricity usage. As it is difficult to compare time plots, the necessity of understanding the correlation is evaluated. The parameters obtained in the correlation data sheet are defined in chapter 4. For the convenience of readers, we could only present a specific set of household patterns, revealing somehow interesting behaviors.

After analysis, we found that it would be quite interesting to compare the peak consumption of all households during a particular hour in April 2012 on a single graph.

By comparing consumption values of all 30 days in 16 households, high consumption for each household is selected and plotted on a single graph as a reference. From the figure 5.5, household 5 consumed maximum power when compared to other households.

Correlation of 16 Households:

The steps followed to calculate and analyses correlation is as follows:

- The price-consumption correlation, real cumulative cost, cumulative cost based on average price and difference between real cumulative cost and cumulative cost based on average price is calculated for 30 days of all the 16 households.
- Two graphs are generated for each household (correlation and difference graph).
- Correlation graphs are plotted with the correlation on y-axis and number of days on x-axis.
- Difference graphs between real cumulative cost and cumulative cost based on average price on the y-axis and number of days on the x-axis is plotted.
- By analyzing all the graphs and data we came to know that on days during which the correlation between price and consumption is positive, the real cumulative cost is higher than the cumulative cost based on average price, whereas days during which the correlation between price and consumption is negative implies the real cumulative cost is less than the cumulative cost based on average price.

Real cumulative cost i.e. cumulative cost obtained by hourly price is denoted by HCum and cumulative cost based on average price during the day is denoted by ACum. A consumer with hourly pricing benefits, If HCum is less than ACum and loses, if HCum is greater than ACum.

Depending on the sign of the cross correlation between HCum and ACum, we arrive at the following cases. Bad indicates hourly pricing leads to higher cost than average pricing. Good indicates hourly pricing leads to less cost than average pricing.

Positive	HCum > ACum (Bad) HCum
Negative	< ACum (Good) HCum
Disappearing	ACum (Neutral)

The correlation of 16 households is executed, and some of the most interesting results are displayed below.

We observe that days of negative correlation imply that HCum is less than ACum, which means savings with hourly pricing. For this user, this happens on the majority of days.

Household 3, the consumption of user is partially negative and partially positively correlated with the price. Maximum negative difference is observed on April 18, on which the user experiences a moderate step-down of cost.

Household 6, the consumption of user is positively correlated with price. As HCum is greater than ACum results in positive difference, the user mostly loses control over consumption.

Household 10, the consumption of user is mostly experiencing positive correlation with price where he can be advised to change his patterns.

Household 13, the consumption of user is negatively correlated with price. This results in receiving negative differences. This kind of user is an inspiration to rest of the users in controlling the energy.

From the correlation part of results we infer that the more negative the correlation, the lower will be the cost based on hourly readings and vice versa. Here the correlation graph results are useful in allowing the users to think about their way of life and corresponding consumption patterns. The user can reduce cost while targeting negative correlation.

RQ.2) How can we model the energy consumption of single households and their superposition?

It was not possible to see any generic daily pattern between the households. To overcome the challenges and conflicts in the electricity market, future predictions are required to distribute energy economically and sufficiently. Hence, finding a suitable prediction model is essential to predict future consumption and cost. The capture of usage patterns through ARIMA models will be investigated, which will also allow the prediction of usage to a certain extent. The energy consumption of households in our research is modeled using a seasonal ARIMA model. Time series collected on hourly, daily and monthly data has seasonal behavior. As our data is related to hourly measurements of one month, seasonal ARIMA model is chosen. This model has the ability to achieve flexibility of data and deliver accuracy results. Modeling of ARIMA can be exercised in the following stages:

1. Identification
2. Estimation
3. Validation
4. Prediction

A flow chart is formulated below for easy understanding of the model.

Flow Chart:

Start

Input Data

Model
Identification

Model
Estimation

Flow chart of ARIMA Modeling

Graphs are generated to state the performance and analysis of households for consumption, price-cost and cumulative cost. The patterns of graphical analysis suggest consumers to serve a competitive nature among them. With the computation of price-consumption correlation results, we can observe that more negative the correlation, the lower will be the cost while as more the positive correlation higher will be the cost if hourly pricing was applied.

Several models were observed and a precise selection is done on the basis of goodness of fit statistics. An idea and a methodology of using seasonal ARIMA for predicting future electricity prices and cost have been proposed. Resource utilization can be effectively improved with the observation of distributed statistics. The unstable behavior of users is noticed and compared from the prediction analysis. Best fitting graphs are shown in the analysis. The graphs generated for this analysis can bring people to adopt changes requested in the paper.

The correlations in the superposition can make people to imitate and defend to control their future statistics. As it is hard to find a typical user, it is also difficult to predict a typical user‘s behavior.

Therefore to study the patterns of households a flattening technique is proposed to save the cost of the consumer.

6. PROJECT DETAIL

1. Existing Solution

A system can be regarded as a set of interacting elements, producing outputs from a set of inputs. Existing system is completely manual. A meter reader visits a house, does the meter reading and then manually calculates the amount considering the units consumed. Back in the office a data entry officer enters the meter readings into the system manually. There may be a lot of chance of clerical and procedural errors. Existing system has several disadvantages such as Redundancy in stored data, Lack of security, Data is inconsistent, More time required, Waste storage space, Manpower required, Errors may occur, Regular watching and supervision is necessary.

2. Proposed Solution

Smart Electricity Billing System helps to send the electric bill of our monthly consumption to us direct via the test message or through email with the help of a application. This concept provides a cost efficient manner of electricity billing. The working of smart electric billing system is more than the existing system and it is time saving also.

3. Smart Meter

4. Hardware Components Used

a. Ardiuno Uno (microcontroller)

b. Bluetooth

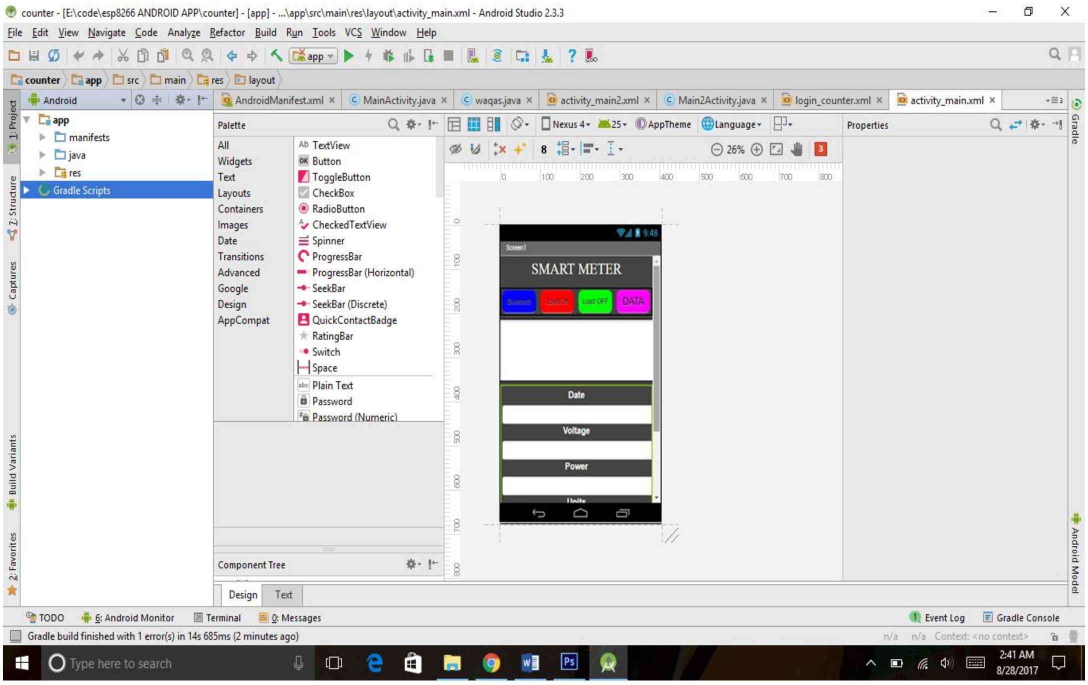
c. Current transformer (sensor)

d. Potential Transformer (sensor)

e. LED Display

f. Application

5. Android App



6. Project Cost

There are the following components used to make this project.

Arduino Uno cost is 1800.

Current transformer cost is 1000.

Potential transformer cost is 1000.

Bluetooth cost is 300.

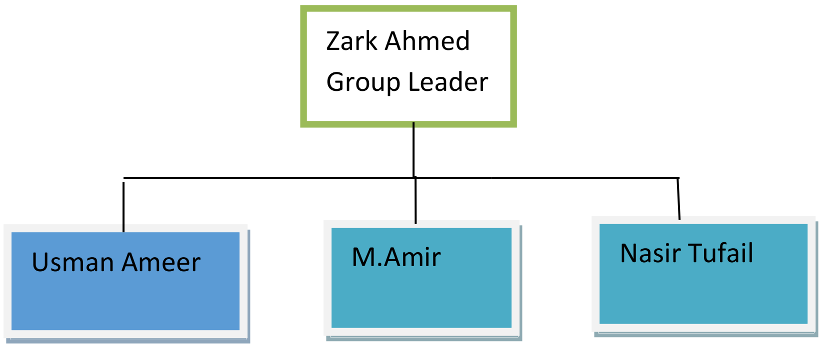
LCD display cost is 500.

12 volt supply 500.

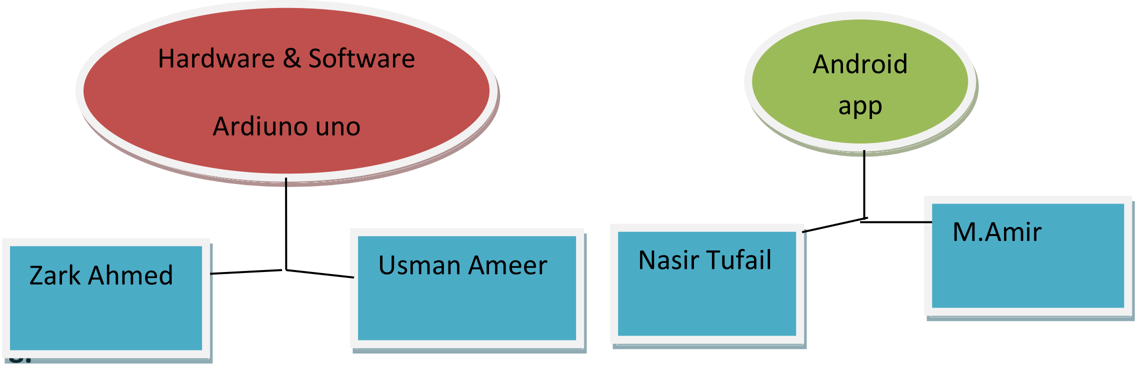
LED and wires 100.

Total cost of the project is 5200.

7. Team Structure



7.1. Role



9. Conclusions

The procedure is far from satisfactory and it is believed a better system using available technology would definitely be an advantage. In this application we can start load on, load off and we can collect data from the Ardiuno uno by sending a message through the Bluetooth. The existing system is manual and prone to defects and ultimately the consumers mentally and financially suffer in such billing system. Therefore to replace the manual and traditional billing techniques, we designed and implemented a cost effective, but still reliable Smart electricity billing system for electricity provider companies. In this way the electricity provider companies would not have to completely replace their existing setup facilities and they would be able to replace their existing billing methods with our Smart electric billing system.

10. Future Enhancement

The term “smart meter” initially referred to the function-ability of measuring the electricity used and/or generated and the ability to remotely control the supply and cutoff when necessary. It was called AMR that used one-way communication and capable of automated monthly reads, one way outage (or last gasp) and tamper detection, and simple load profiling. Over time, the AMR capability was extended into short-term interval (hourly or less) data capture, which on demand reads and linking and reading other commodities. A major upgrade of functionality occurred after integration of the meters with two-way communication technology which has been called advanced metering integrated (AMI). The upgrade included the incorporation of service switching, time-based rates, remote programming, power quality measure, and a dashboard-type user interface for real-time usage monitoring into the AMR. Although the term smart meter started to be used only after the SG initiatives, it can be seen that the features and functionality of the meters evolved from the manually read meters of the past to the AMI meters with dashboard interfaces and two-way communication capability. Therefore in the current metering environment, a meter is expected to have the following capabilities to be categorized as a smart meter

1) Real-time or near real-time capture of electricity usage and possibly distributed generation.

2) Providing the possibility of remote and local reading of the meter.

3) Remote controllability of the meter enabling control and even cut off the supply.

4) Possibility of linking to other commodity supply.

5) Ability to capture events such as device status.

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