FEASIBILITY FOR IMPLEMENTATION OF SMART GRID BY SURVEY QUESTIONAIRE BASED RESEARCH

THESIS

Submitted

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By

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DEDICATION

To my grandmother, parents, my wife, my brother, my in-laws and everyone else for supporting me during my studies and shouldering the extra burden.

Names OF GEC Members

1. **Dr. Salman Nisar**

2. **Dr. Tariq Mairaj Rasool Khan PN**

3. **Dr. Syed Sajjad Haider Zaidi PN**

DECLARATION

None of the material contained in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institution of learning.

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THESIS ABSTRACT

The increase in urbanization and industrialization has resulted in massive increase in demand for power. Fossil fuel based power generation is becoming costly by the day. The existing electricity delivery system requires huge investment to cater to the increased power demand. Further, the power demand has a very irregular profile, which necessitates the requirement of additional generation resources at the time of peak demand. Such consequences require extensive implementation of energy efficient and sustainable initiatives to avoid huge investment in expanding conventional power generation resources and electricity delivery infrastructure. Smart Grid provides an excellent solution to address all these issues. Consumer perceptions about Smart Grid in context of Pakistani environment have been investigated in this research. The results show that Pakistani consumers are willing to curtail their load demand in return of a monetary benefit, and hence have a positive perception for Smart Grid.

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CHAPTER 1

INTRODUCTION

Electrical Power energy is one of the novel inventions of the 20th Century. Electrical power has entirely changed the lives of people. It is just a carrier of portable energy which can be converted into any form of energy very easily. For example light, mechanical or computational energy. The system of electrical power consists of Power Generation, Transmission, Distribution, and Consumption by end user [16]. Power Generation consists of transformation of thermal, Hydro, Nuclear or Wind Energy into electrical energy. The generated power in the power plants is then transmitted on long distance transmission lines till it reaches Grid Stations where voltage is stepped down and then further distributed to different areas. The end user uses power from the nearby mains which is further stepped down to usable voltage.

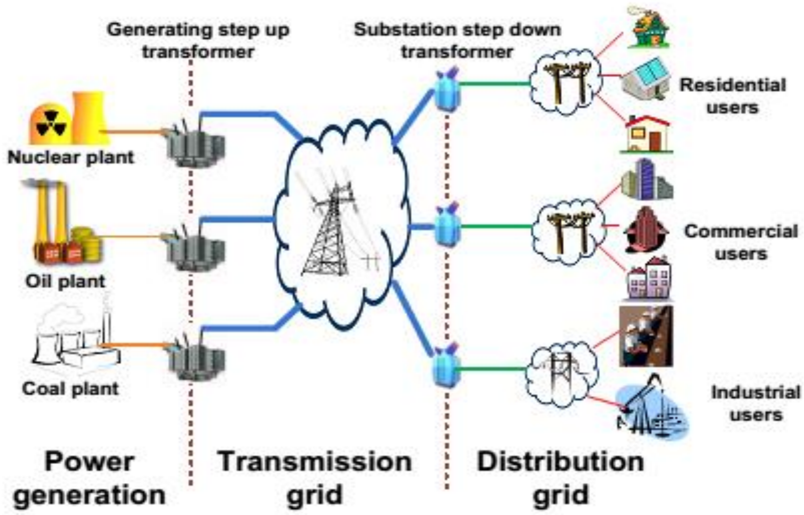


Figure 1.1 An example of a traditional Grid [18]

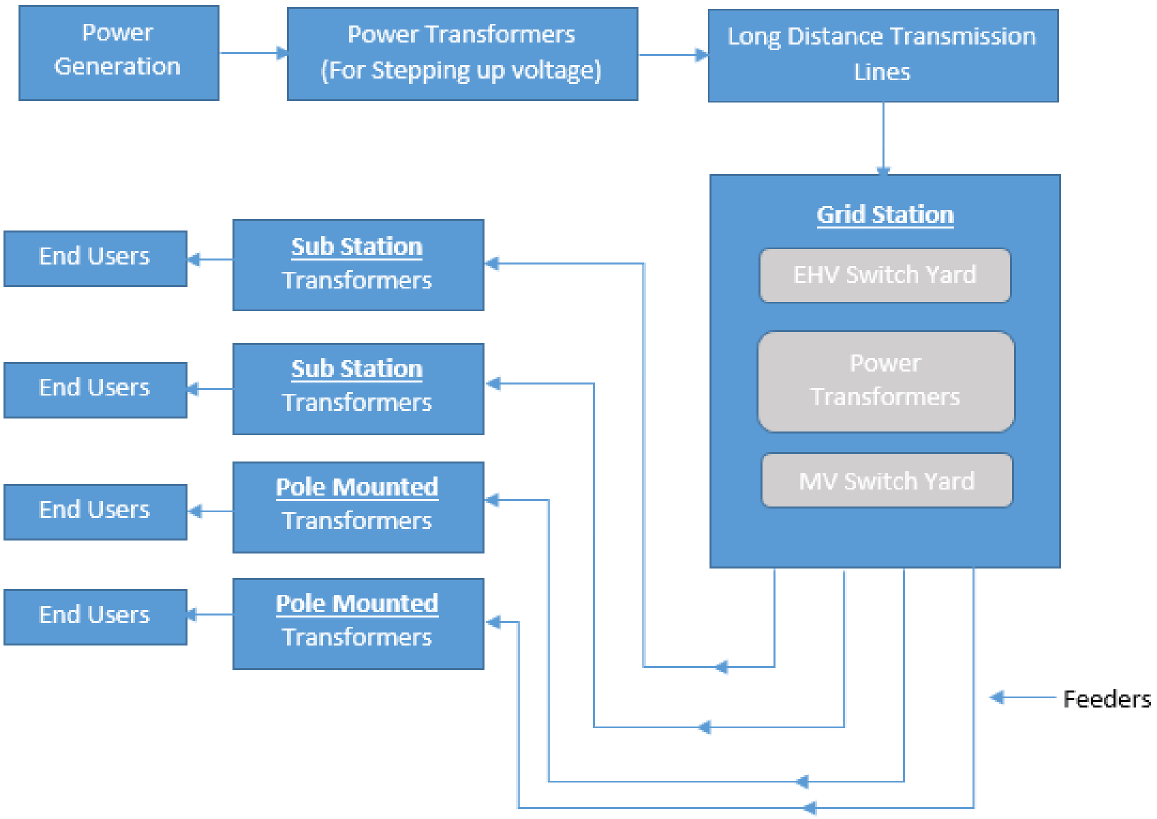


Figure1.2 Block Diagram of Electrical Distribution System [47]

1.1 Grid Interconnection

The Electrical Distribution System as depicted in Figure 1.2 is further interconnected to other similar topology electrical distribution system across thousands of miles. In this way, Electrical Delivery and supply is centralized and synchronized in order to attain efficiency and to maintain uninterruptible power supply. The power generation across one region may be surplus, meanwhile, at any other region the supply is less, so in this way, with a centralized power generation and interconnectivity, the supply of power reaches to all interconnected regions. This also further add to Power distribution reliability.

On the other hand, owing to the interconnectivity, the transmission cables are becoming heavily loaded, with the passage of time and ever increasing urbanization. Due to the centralization of grid, more power has to flow from the transmission lines. The enhancement of transmission lines requires a big investment, as per one study, the approximate cost for

225 KV Transmission Line having a capacity of 750 KVA costs around 4 Billion Rupees for every 10 KM length.

The cost of transmission lines varies with the land geography and is highly dependent on the loading capacity. As the loading capacity is increased the number of circuits have to be increased which add to the cost. Moreover, the installation of Over Head Transmission lines also requires adequate right of ways. For instance a 400 KV transmission line requires a 40 meter wide corridor. So such requirements of transmission lines add to various complications in a highly dense urban environment.

All such issues lead to the development of highly efficient energy saving technologies. Governments around the globe are now focusing on energy efficiency and smarter ways of delivering and transmitting electricity.

1.2 Energy Management

Managing the way electricity is generated, transmitted and distributed is a very interesting topic and it is gaining a lot interest among researchers. There are two types of energy management, as discussed by Babar [8]:

(a) Supply Side Management

(b) Demand Side Management

1.2.1 Supply Side Management

Supply Side Management focus on initiatives and actions which ensure the generation of Power. Also, it covers the development of new transmission lines and its operations and maintenance of transmission lines [8].

The Supply Side Management (SSM) ensures that the Power Generating Plants are delivering the required amount of power being demanded, efficiently and without interruption. Secondly, SSM also ensures that the transmission lines are not getting overloaded. SSM plans for the development of new Transmission Line Circuits, by optimum resource utilization.

The Generation of power is centralized in the Supply side Management. Emphasis is given on controlling the amount of power being generated by the Power Generation Plants. The amount of Power is following the demand for power, for e.g as the demand for power shoots in the summers, the amount of power being generated in the Power Plants is correspondingly increased. Similarly, in the transmission of power segment, the focus is on increasing the capacity of transmission lines. This is also complemented by diverting the excess power from one circuit, whose capacity has exhausted to any other circuits, which has some available capacity.

Figure 1.3 depicts the maximum capacities and peak load demands of different interconnected transmission circuits. As one circuit approaches to exceed its operating capacity, then the supply side management comes into play. This scenario triggers the network operators to divert load to any other interconnected circuits.

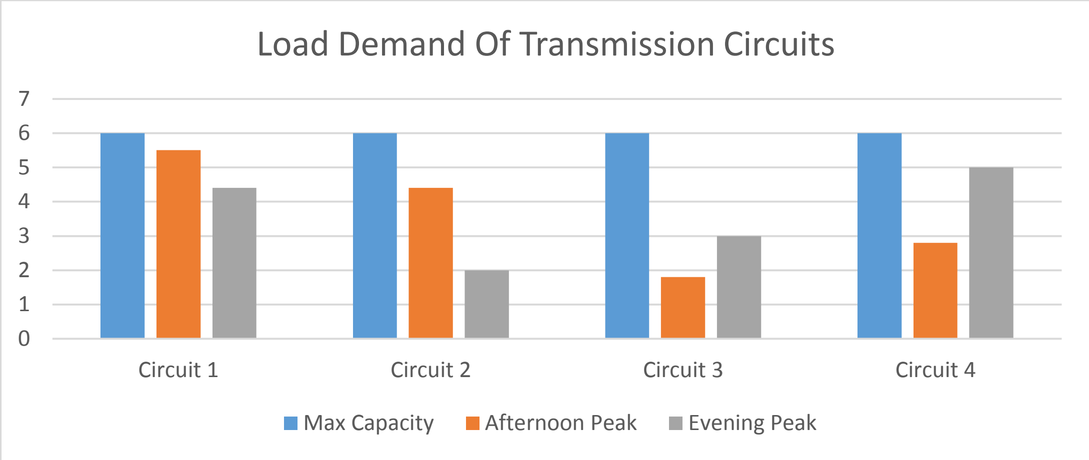


Figure 1.3 Load Demands of Transmission Circuits [49]

The overloading of Transmission circuits may cause sagging in the lines. This is because of the heating of the conductors which triggers thermal expansion and results in increased sagging [9]. SSM supervise the monitoring of temperatures of the conductors, and allow overloading of the circuit beyond its capacity till a threshold level of sagging is attained. Beyond the hazardous limits of sagging, the load of circuit is diverted.

1.2.2 Demand Side Management

Demand Side Management (DSM) focuses on the actions which reduce or increase the consumption of power by the consumer to an extent that it matches with the quantum of power being generated [8]. DSM lays emphasis on the areas of unnecessarily high and inefficient power consumption and tries to make the consumption of power equal the amount of power being generated or power capacity available. DSM also facilitates the consumption of power in a more efficient way, and also guide the end users to consume power in a way that the resources are utilized optimally.

Demand Side management is more economical, since it does not require investing in the infrastructure. It allows maximum utilization of the Power Generating assets. The requirement of additional Transmission lines and Distribution system is mitigated.

1.3 Smart Grid

Demand side management is one of the features available in the concept of SMART Grid. It is due to the inherent capability of Smart Grid to effectively utilize the generation and network assets optimally, that is why it is gaining a lot of popularity among the researchers and Electric Utility Operators [47].

With the advent of industrialization and urbanization there has been an exponential demand for cheap electrical power. Owing to depleting energy resources, researchers all around the globe are looking for alternate means for generating electricity. One of the latest concepts in modernizing the way electrical power is generated, transmitted and distributed is of the SMART GRID. Following is the visual depiction of the concept of SMART Grid [47].

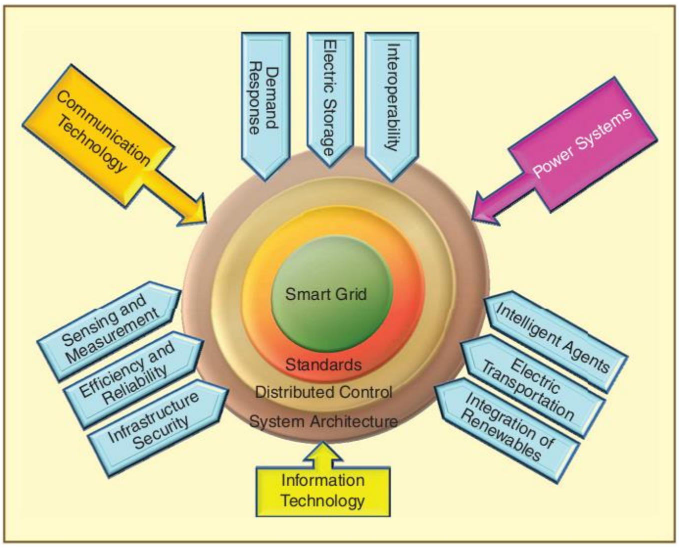


Figure 1.4 Visual Depiction of SMART Grid [47]

SMART GRID comprises of various technologies integrated to perform various functions at different stages. US department of Energy has defined SMART GRID as, "A modernized electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity."

1.4 The Concept of Smart Grid

What constitutes a Smart Grid is still an emerging concept as discussed in San Diego Smart Grid Study Report [3]. Utility and Technology experts have highlighted the need for substantial changes in how Power Generation and delivery system is operated, designed and built. The objectives of Smart Grid, as discussed by US department of Energy [2] are:

1. Enabling informed participation by customers.
2. Accommodating all generation and storage options.
3. Enabling new products, services and markets.
4. Introduction of a third party company to work as an aggregator between the consumers and utility.
5. Optimizing asset utilization and operating efficiently.
6. Addressing disturbances through automated prevention, containment and restoration.

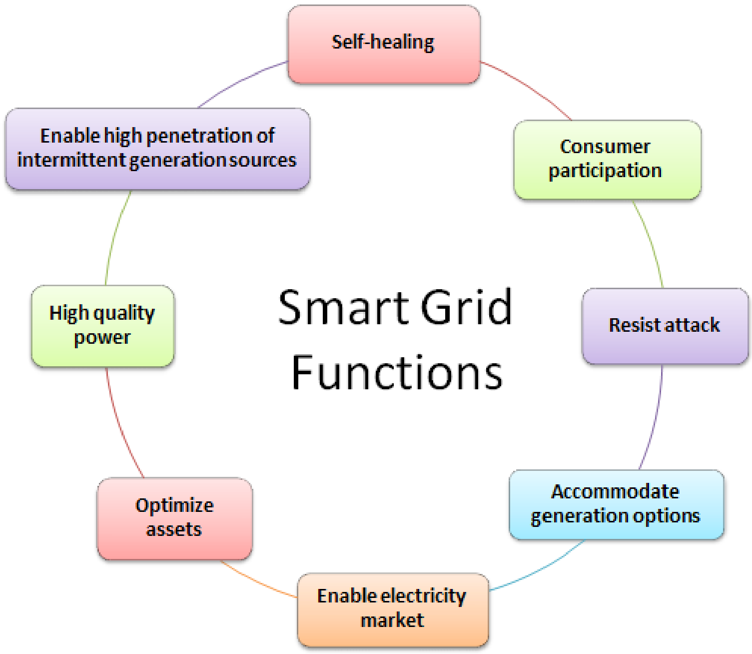


Figure 1.5 Functions of Smart Grid [54]

1.4.1 Enabling informed participation by customers

The conventional electricity distribution system only emphasize on delivering power to the end user, without any active involvement of the consumer[2]. Smart Grid will enable participation of consumers in the electricity distribution. For instance, one consumer informs the Distribution Company, its expected load demand for the next day, and offers some of its appliances to be switched off in times of peak load demand. Meanwhile, another consumer informs the distribution company that it has some standby generation, which may be switched on to deliver power. Hence, the distribution company is receiving information from the potential consumers as well as potential generation resources. And hence, it may trigger a generation resource to start delivering power in times of peak load demand. On the other hand it may also signal a consumer's appliance to switch off in times of peak load demand.

1.4.2 Accommodating all generation and storage options

Various consumers of electricity have standby power generation capability [2]. While, there are some consumers who have renewable energy resources for e.g. Solar Electric Cells, Wind Power etc. There are some consumers who have storage options, for e.g. some consumers have battery powered appliances (battery powered vehicles) or Battery powered inverters. Such battery powered appliances / devices have a capability of energy storage to some extent. Such stored energy in the battery may be utilized in times of high peak load demand, meanwhile such batteries may be re-charged in times of low load demand. Similarly the available standby generators may be switched on and connected to the grid to deliver power in order to cope up with sudden rise in the load demand. The intermittent generation resources like Wind Turbines may be utilized when there is wind available, and in such times the consumers may be encouraged to consume more power.

1.4.3 Enabling new products, services and markets

In the conventional electricity grid, there is no provision of distributed generation, neither is there any capability in the system to allow consumers to curtail their load in times of high load demand. There is one way interaction between the electrical grid and the consumer. With the implementation of Smart Grid, a new product or service may be introduced, wherein there will be a capability to allow consumers to interact with the electrical grid, by curtailing their load [2]. Meanwhile some consumers will be able to dispatch power from their standby generators or battery resources to cope up with the peak load demand. Such services of load curtailment and dispatch of power may be provided by an intermediary company which may function between the electricity distribution company and the end user. Apart from that, such companies may enter into a contract with the distribution company to maintain a certain amount of load demand. To ensure, this load demand, it may take initiatives to persuade consumers to change their consumption pattern in return of a monetary incentive. Such initiatives by the intermediary company will generate income for the intermediary at the same time a percentage of the income will be transferred to the end user, on the basis of participation extent.

1.4.4 Optimization of Asset Utilization and Operating Efficiently

In the conventional distribution system, the components are usually underutilized. The components are utilized to their maximum capacity only in times of peak load demand. Smart Grid has this capability to shave off the peak by encouraging consumers to vary their consumption pattern accordingly. In the same time, encourage consumers to consume power, so that the power demand is maintained to the level it is in line with the capacity. Thus asset utilization is optimized.

1.4.5 Self-Healing Capability

In times of power breakdown, due to cable faults or tripping of the switches, a modern distribution system is expected to have an inherent capability to normalize itself without human intervention. With the availability of superior technology, it has become possible to incorporate such technology to obtain such self- healing objectives in the electricity distribution system. A distributed control system gives guidance to the operators in tracing cable faults. Smart Grid has such capabilities of Self-Healing.

1.4.6 Network Resilience

Owing to the availability of electricity to the masses and with massive expansion in the electricity distribution network, it has become highly prone to terrorist attacks and sabotage. Self-Healing capability as discussed above and resilience are increasingly becoming essential features of a Electricity Distribution Network. It is expected from a modern Electricity Distribution Network to resist collapse, if one essential component is damaged. This has become possible by incorporating distributed generation in the network and greater controllability.

1.5 Comparison of Smart Grid with Traditional Grid

The traditional grid and smart grid may be compared as under:

Existing Grid	Intelligent Grid
Electromechanical	Digital
One-Way Communication	Two-Way Communication
Centralized Generation	Distributed Generation
Hierarchical	Network
Few Sensors	Sensors Throughout
Blind	Self-Monitoring
Manual Restoration	Self-Healing
Failures and Blackouts	Adaptive and Islanding
Manual Check/Test	Remote Check/Test
Limited Control	Pervasive Control
Few Customer Choices	Many Customer Choices

Table 1.1 Comparison of Smart Grid with Traditional Grid [47]

1.6 Problem Statement

The implementation and the success of Smart Grid is greatly dependent on the will of consumers to actively participate in load curtailment in times of peak power demand. If Smart Grid is implemented in Karachi, would the consumer be willing to curtail their load in times of peak load demand? Would it be feasible to implement Smart Grid in K-Electric which shall pave the way for Voluntary Load curtailment by consumers in times of peak load demand?

1.7 Overview of the Thesis

In this thesis we have investigated the consumer preference pertaining to the implementation of Smart Grid in K-Electric Limited. How consumers perceive Smart Grid? What consumers expect from this new technology? Would the consumers be willing to implement Smart Grid and participate in voluntary load curtailment?

Chapter 1. gives an introduction of Smart Grid. The features available in the Smart Grid Technology. The capabilities of Smart Grid are discussed, and its advantages and importance is described. The problem statement is defined

Chapter 2 Literature Review is conducted and research papers are discussed where in the research is carried out to investigate consumers' consumption patterns as well as their preferences for smart grid and various other power generation technologies. Research methodologies were also reviewed. Then Smart Grid implementations in various countries were studied. Consumer behavior pertaining to the acceptance of new technologies were also reviewed in the literature.

Chapter 3 discussed the Data Collection. How the sample size was selected and what type of sampling technique was used. Graphical representation of the research method was described. How the respondents were encouraged to fill the research questionnaire and how the data was recorded.

Chapter 4 discuss the results and gives analysis on the results. Data collection technique is also discussed.

Chapter 5 Conclusion and Future Work

CHAPTER 2

LITERATURE REVIEW

Consumers have a major role in making the Smart Grid Technology successful. Without the participation of consumers in Energy Decision Making, the efficiency cannot be attained. Until now, the major research was on the technology, how it will be implemented. What modifications in the network are required to convert to SG, but little was known about the consumer behavior, consumer acceptance of Smart Grid technology and the consumers' inclination towards energy efficiency by compromising on privacy and comfort. One research pertains to Honk Kong consumers wherein it has been surveyed that consumers are willing to implement Smart Grid and keen on adopting energy efficient initiatives. Meanwhile, they are reluctant to allow government to install Nuclear Power plants to increase generation [5].

As per 2012's estimate of European Commission's Joint Research Centre [10] the estimated budget spending on Smart Grid initiatives country wise is as under:

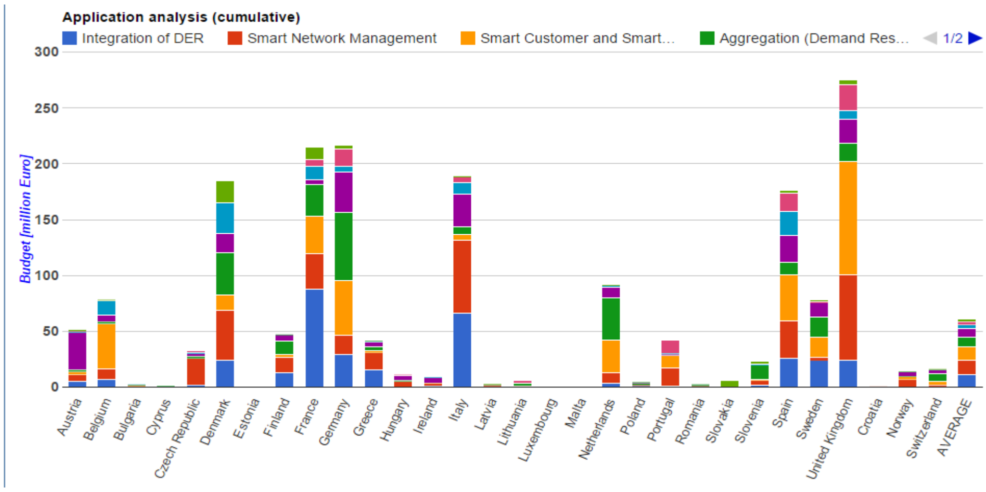


Figure 2.1 Budget Allocation Table Country wise

United Kingdom tops the Budgetary spendings in Smart Grid over all in Eurpoe. Whereas Germany is coming second. It is also observed that more densely populated a country is, the more likely it is to implement Smart Grid so as to inculcate efficiency in the Electricity Distribution Network.

Smart Grid is a new technology and it requires considerable awareness among its end users[11]. A research was conducted in Europe comprising of a sample of consumers of Yogoslavia, Germany and Switzerland on technology acceptance of Smart Grid. This research reveals that, Smart Grid Technology may be acceptable to the consumers if the consumers are ensured that not much additional effort would be required by the end users, if SG is implemented. Secondly, this research also reveals that consumers must have adequate education pertaining to environment concerns, this will also add to SG accepatability [11].

With the increase in the education and awareness on sustainable energy, more people are having concerns over environment. This has resulted in to a requirement to seriously think over to re-invent the grid. How electricity is generated, distributed and transmitted needs to be re-structured. There is an arising need to integrate the intermittent energy resources and consumers into a Smart Grid. The renewable energy resources are intermittent. They generate power only when the sun is shining or the wind is blowing or when the rivers are flowing.

2.1 Smart Grid

As discussed earlier, the traditional Electrical grid, consists of interconnected electrical transmission network, which consists of generators, transformers and conductors. The modern electrical grid also known as a Smart Grid consists of all the basic infrastructure of the traditional grid, but with the incorporation of intelligence, efficiency, and reliability in to the system. These advanced features are incorporated by modern digital technology [17]. Xi Fang suggests that Smart Grid can also be termed as smart elecrical grid, future grid, intra grid, intelligent grid or intelligrid [18]. Fang also discuss that the traditional grid consists of centralized power generation, which is then transmitted on long distance carriers and distributed to the end user [18]. Whereas the smart grid enables two way power flow along with two way flow of information in order to bring more efficiency, reliability and cost effectiveness.

Smart Grid uses the concept of a virtual power plant which controls the distributed generation resources as discussed by Xi Fang [18]. The virtual power plant is a centralized control station which has access of conrolling all distributed generation resources. The control center of the virtual power plant can trigger the most optimized generation resource on the basis of optimization algorithms as investgated by R. Caldon [28].

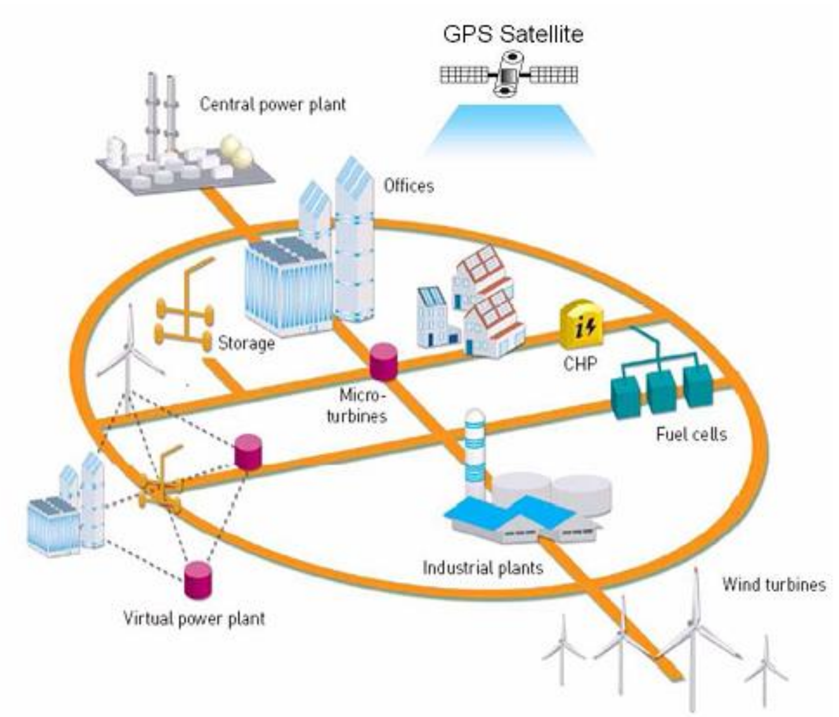


Figure 2.2 Smart Grid [29]

The efficiency in Smart Grid is obtained by straightening the load demand profile. Smart Grid enables the voluntarily curtailment of load in times of peak load demand [18]. And in a similar way it encourages the higher load consumption in times low peaks. In this way the load demand profile is straighten up and Generation resources are optimaly utilzed.

The authors of [20], reviewed the existing SG standardizations and gave concrete recommendations for future SG standards. Vasconcelos [21] outlined the potential benefits of smart meters, and provided a short overview of the legal framework governing metering activities and policies in Europe. Brown and Suryanarayanan [22] determined an industry perspective for the smart distribution system and identified those technologies that could be applied in the future research in the smart distribution system. Baumeister [23] presented a review of the works related to SG cyber security. Chen [24] explored the security and privacy issues in SG and related these issues to cyber security in the Internet. Gungor and Lambert [25] explored communication networks for electric system automation and attempted to provide a better understanding of the hybrid network architecture that can provide heterogeneous electric system automation application requirements. Akyol et al. [26] analyzed how, where, and what types of wireless communications are suitable for deployment in the electric power system.

From a technical perspective Smart Grid can be divided into three sub-systems as discussed by Xi Fang, Satyajayant Misra, Guoliang Xue and Dejun Yang [18]. These sub-systems are:

1. Smart Infrastructure System
2. Smart Management System
3. Smart Protection System

Smart Infrastructure System comprises of the Power Generating Plants, Transformers, Transmission Lines, Distribution Network and the point of consumption, information systems and the communication systems. This infrastructure is the main skeleton of the Smart Grid. These components are the most expensive part of the Smart Grid. These components are also present in the traditional grid, but the information and the communication systems are not advanced and intelligent enough. Moreover, the distributed generation resources at the distribution network as available in a Smart Grid are also not available in the traditional grid.

Smart Management system provides the advanced management and control services over the smart infrastructure system. One of the most important and significant functionality provided by smart management system is that it can re-shape the load demand profile, and reduce the peak load demand. Further, through the smart management system the Utilization of existing resources could be optimized by using optimization algorithms as discussed by V. Bakker in [27] and by Babar in [8].

Smart Protection Systems not only address issues pertaining to the failure of grid infrastructure but it also counters cyber-attack and the malicious activities which could alter the billing mechanism as discussed by Xi Fang in [18].

2.2 Aggregator and Demand Response

Aggregator is a third party entity between the Utility and the consumer. It is emerging as a key player for curtailing the aggregated load demand in front of the Utility as discussed by Babar [55]. Load curtailment in comparison to increasing the generation capacity is more economical, efficient and cost effective [56]. Demand response is a terminology used in load curtailment, where by the load is curtailed by the end user in response to price signal, or response to the request from the Utility in order to manage the peak load.

Aggregator works as an intermediary between the Utility Service provider and the consumer. Since, it is very difficult for the Utility alone to interact with so many consumers for load curtailment and load utilization, therefore the framework of adding aggregator makes easier for the utility to deliver power and at the same time shave off the peak. For the Utility, aggregator is just like a large consumer, which buys electricity from the Utility and sells it to individual consumers. Aggregator informs the utility about its day-ahead power requirement. On which the utility communicates the price of electricity which is dependent on the time of use. Now, aggregator bids for a price and day-ahead power requirement in the form of a Power demand curve. A deal or contract is settled at a particular price and power demand curve between the aggregator and utility. Aggregator communicates the price and power demand, down the line to its individual consumers. This framework, where by an aggregator is added in the power supply chain, the entire process of load curtailment becomes more manageable and cost effective [8].

Demand Response is defined as the changes in the electricity use by the end user from their normal use in response to a price signal by the utility service provider in order to coincide the generation resources with consumption [55]. Demand Response refers to the curtailment of load or scheduling of load by the end user. Babar has designed a load scheduling algorithm which utilizes the services of an aggregator to bring the aggregated load demand to the required levels [8]. Dynamic programming technique was used to develop the load curtailment algorithm.

2.2 Survey questionnaire based research

Survey research is defined as a systematic way of asking people about certain traits, preferences, behaviors, opinions or beliefs as explained by Ronald [30]. Most of the literature published using survey based research pertains to medical science, however, there is credible evidence of using this technique in the energy consumption surveys [1, 5]. The success of a survey research is dependent upon how closely the responses recorded in the survey matches with the actual facts.

The design of survey questionnaire is the most crucial part of survey questionnaire based research. As discussed by Miller [31], the design of questionnaire should start with the

Development of hypothesis and research questions. The research parameters, like the sample size, type of research methodology, statistical technique etc. should be determined beforehand. The questions should be structured on the basis of above mentioned parameters. Further, to above [33] suggests that questionnaire design helps in translating various key features or characteristics of a concept into measurable constructs. A bad design of a questionnaire is unable to provide measurable constructs to perform analysis. The internet has also provided a media for questionnaire design with programs available at websites for 'Adobe Acrobat', 'Google Docs' and 'Survey Monkey'.

2.1.1 Question wording

Several studies have examined the effect of the types of questions and their design on response rates. Sudman and Bradburn [34] categorised questions into 'knowledge questions' and 'attitude questions', which could be further divided into 'threatening' (have you ever subjected to line Disconnection owing to non-payment of bill) and 'non-threatening' questions (e.g. Do you use Dish washer Machine). Sudman and Bradburn recommended the use of [34, 35]:

- filter questions to filter out respondents lacking sufficient information
- open-ended questions
- a 'don't know' response category to reduce perceived threat

- several questions on the same topic to reduce guessing
- avoidance of double barreled questions
- standardized questions
- including a middle response category
- general questions should precede specific ones

Open-ended questions require a narrative reply whilst closed-ended questions provide the respondent a choice of several pre-defined options to respond. Open-ended questions are useful in the pilot phase of a survey to identify key responses [36]. They can also be used for ‘cognitive interviewing’ in order to determine how a respondent arrives at a particular answer during the pilot phase. Conversely with postal questionnaires, some respondents may still include responses other than those offered in the closed-ended question format. This problem can be overcome by including a ‘don't know’ (closed response) or ‘other, please specify’ (open response) as a further category; this is termed partial-closed response. Griffith et al. [37] studied the effects of open versus closed questions and found no significant difference in the response rate, but did report almost 50% greater completed questionnaires in the closed compared to an open-ended format.

Questions determining opinion can either be designed as a question with an ‘agree/disagree’ format (e.g. I like visors? Agree/disagree) or as two options (please specify whether you (a) like visors, or (b) do not like visors?). Studies have shown that there is a higher response rate with questions worded giving two options rather than the ‘agree/disagree’ format [38].

Questions can be classified as ‘elliptical’ if they lack a verb or noun (e.g. Hamstring ACL reconstructions fail) or ‘non-elliptical’ (e.g. I think hamstring ACL reconstructions fail). Whilst no difference has been found in response rates comparing the two types of question structure, elliptical questions were found to produce more polarised responses than non-elliptical questions [39].

Response set bias occurs when the same closed category is chosen for each question set. Acquiescence response bias occurs when respondents answer ‘yes’ to all queries. Educational level can affect acquiescence bias with less educated respondents more likely to answer ‘yes’ than highly educated respondents [37]. Questions should therefore contain an equal number of positive and negative (or neutral and non-neutral) options.

Respondents can feel pressurized into answering all questions presented to them. The use of filter questions can ‘weed out’ respondents who would otherwise give fictitious answers [38]. The wording of filter questions can also affect response rates with respondents more likely to pick the ‘don't know’ option of a filter question if it is strongly worded [38]. Addition of prestige names (e.g. Newton) to a question has also been shown to introduce bias by polarizing opinion and reducing the number of ‘don't know’ responses given [40].

2.1.2 Question order

Several studies have investigated the effect of question order on response rate and quality, with no clear agreement in the literature as to the optimal question order. Question order is determined by importance of the response, content area and perception of threat [41]. Easy, general, salient questions should be presented first to interest the respondent in order to increase the chances of questionnaire completion [42,44,43]. In contrast, some studies argue that demographic questions should come last as they can be perceived as threatening (e.g. age and qualifications) [41].

General questions should be followed by specific questions (funnelling) to minimise questions order effects [41]. Filter questions encourage completion and prevent the respondent's time being wasted on inapplicable questions. Questions should be grouped and instructions provided for each new group of questions. A chronological flow can also enhance response rates and speed by making it easier to complete [44].

Response order effects occur when the order of listed options rather than their content affects the choice of response. Primacy effects occur when the respondent is more likely to pick the first option and recency effects occur when the respondent is more likely to pick the last option presented. The mode of questionnaire administration has an effect where telephone or interview completions are more susceptible to recency effects, whilst self completion postal questionnaires are more prone to primacy effects [41].

2.3 Survey based Research to evaluate consumer perception of the Smart Grid Technology

Survey based research has been utilized in the evaluation of consumer perceptions and acceptability of Smart Grid as per the work of Daphne [5]. A research was carried out to investigate the consumer perception in Honk Kong, regarding the existing Power Generation and Distribution Systems and Energy Technology and its possible up-grade to Smart Grid technology.

In Honk Kong context, the results show a general preference for the Smart Grid and energy efficiency technologies [5]. One of the reason for this preference was the meltdown of Nuclear Power Plant of Fukushima, Japan in 2011. The people of Honk Kong have shown a strong opposition for Nuclear Power Plants and have thus preferred on energy efficient technologies. While these results are in line with many consumer surveys which show very positive attitudes towards renewable energy and green electricity [51,52] they should be interpreted with caution. It is noteworthy that renewable energy in urban settings such as in the form of building-integrated solar power has been emerging [53], but most of these Initiatives are in the R&D stage and are small in scale. In the context of Hong Kong, the deployment of renewable would need to overcome major problems of physical and cost constraints, and that would also require major institutional changes.

There is a strong evidence of consumers agreeing to modify their consumption patterns and lifestyle in response to monetary benefits offered by the Utility company, in times of high load demand and low load demand, in order to optimize the Generation resources [5]. There is a need to formulate policies at institutional level to pave the way for incorporation of Smart Grid Technologies at country level [5].

CHAPTER 3

DATA COLLECTION

To obtain the consumer perception and the acceptability of Smart Grid technology in K-Electric, a sample of domestic consumers was obtained, which represented the entire upper middle class population. The consumers were asked a set of questions whose results were recorded. The recorded data was analyzed using statistical techniques. And a final conclusion was drawn from the recorded data.

3.1 The Design of Survey Questionnaire

Questionnaire design is the heart of this thesis. The entire research depends on the questions which are being put up to the sample population. The questions were dependent on the objectives of the research. Following are the objectives of the research:

Research Objectives

1. To determine the extent to which the consumers would allow penetration of their privacy in order to control the appliances for demand response.
2. To determine consumers' desirability to install Automatic Meter Reading system as available in Smart Grid.
3. To determine the consumer satisfaction pertaining to price & service quality of electricity
4. To determine the level awareness pertaining to renewable energy resources.
5. To determine the consumers' electricity consumption pattern.

Questionnaire Design

On the basis of mentioned objectives, past literature was reviewed, and investigated how a question should be put fourth so that the targeted objectives could be obtained. Based on past literature [31], the questions were of Multiple Choice type. First 3 questions determined the basic information pertaining to type of consumer, amount of Sanctioned load, and usage of electricity. The next three questions determined the consumer satisfaction pertaining to price and quality of service. While the remaining questions were focused to determine the objectives of the research.

The questions were kept as simple as possible, so that the questionnaire is comprehensible to the masses. Also, the questionnaire was designed to put up straight questions, so that the respondent does not feel much difficulty.

A covering letter was prepared with each questionnaire to explain the purpose of the questionnaire, its projected benefits and outcome. This motivated the respondent to fill the questionnaire. This technique was adopted by most of the well known research companies which are carrying out survey research [46].

A pilot questionnaire was executed on some respondents to obtain feedback about the questionnaire as discussed by Miller [31]. Based on the feedback, the questionnaire was amended. This cycle was repeated three to four times until a final questionnaire was developed.

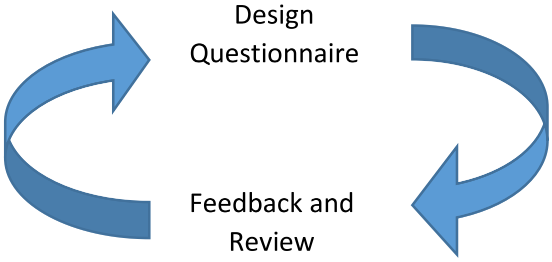


Figure 3.1 Questionnaire Design Cycle

3.2 Determination of Sample Size

The size of sample should be such that it represents the entire population with minimum bias. The sample size is increased in order to reduce the bias. Further, there are some other considerations as well which determine the size of sample. For example the budget of research, the effect size, and the sensitivity of the outcome.

In this research the outcome is not sensitive enough that it creates a life death situation as is experienced in medical statistical experiments, where the outcome may result in death or extreme consequences. So, this possibility is ruled out. Then the budget of this research is minimum only 25000 RS. So in this budget, and also on the basis of literature, wherein a research was conducted to determine the most appropriate sample size in a building energy survey. In this research a relationship between sample size, population size, confidence interval and population variance was developed and verified. It was observed that by keeping other parameters constant and on plotting sample size with the total population, revealed that on reaching a threshold, further increase in population did not result in the increase in the sample size [1].

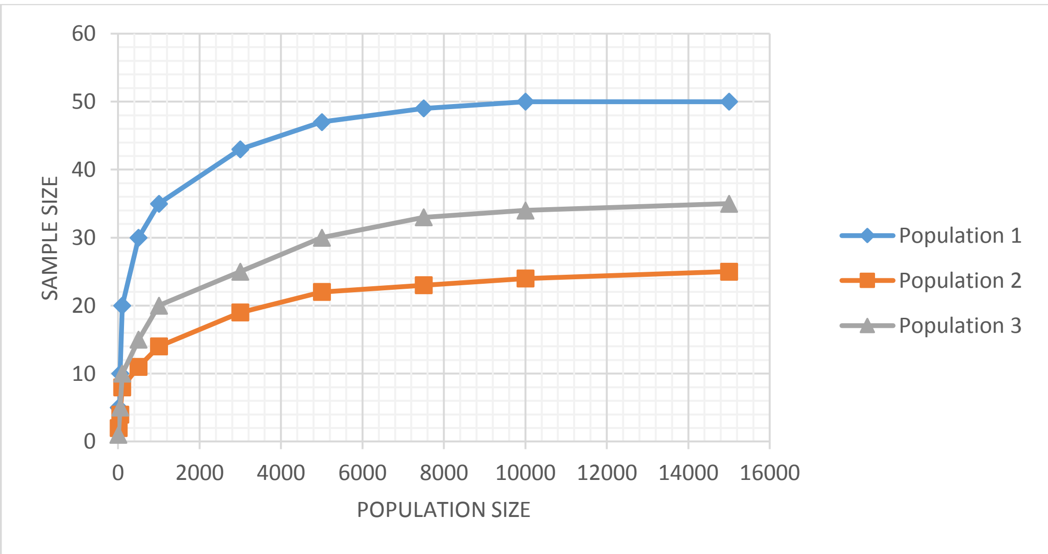


Figure 3.2 Relationship between Sample Size and Size of Population

Therefore, 50 is the most appropriate size of sample based on the works of Zeng Liang & Heng-gen Shen [1]. It has also been verified in the works of Zeng Liang & Heng-gen Shen [1] that if the population is increased further, the size of sample reaches a threshold beyond which the size of sample is not required to be increased.

The size of sample is dependent upon the population size, as a rule of thumb 1 % of the population represents the sample. But in the case of consumer electricity consumption surveys, the consumption patterns and behavior, the above relationship determined in [1] suggests that 50 is an adequate sample size. In this research, the sample size selected is 55.

3.3 Data Collection

Survey questionnaire was executed and launched online on Google Forms. The respondents were subjected to the questionnaire by means of personal contact, telephones and emails. The respondents were requested to submit their responses online on the provided link. Some data was obtained manually by printed questionnaire from the respondents. This exercise continued for a month till the required number of samples were obtained.

Hurdles Faced During Data Collection

1. The respondents showed lack of interest.
2. The appropriate respondents having the preliminary knowledge pertaining to Utility Company, technology and Smart Grid were not easily available.
3. Delay in recording response by respondents.

Measures taken to address the issues faced

1. Personal Meetings and telephone calls were made to persuade the respondents.

2. The questionnaire was referred on social media, so that the appropriate respondents, which qualify for the research sampling could be approached.

3. A brief background, aims and perceived benefits of this research were explained on the covering letter of each questionnaire, this educated the respondents, also the right responses were obtained in this way with minimum bias.

CHAPTER 4

ANALYSIS & RESULTS

Survey questionnaire consisting of 21 questions was posted online to obtain data. The data obtained from the questionnaire form was tabulated and a sample size of 55 respondents was selected. The size of sample was determined from the work of Zeng Liang, Heng-gen Shen [1]. The tabulated data was used to perform statistical analysis. The frequencies, percentages, valid percentages, and cumulative percentages were determined.

Frequency: It specifies the number of times a particular event has occurred in an experiment [12].

Cumulative Frequency: It is defined as the running total of frequencies. It is also defined as the sum of the occurrences of a particular event irrespective of its inclusion in any other set or class. The frequency of an element in a set refers to how many of that element there are in the set. Cumulative frequency can also defined as the sum of all previous frequencies up to the current point [13]. Cumulative frequency at particular point is calculated by summing all the frequencies up to that point.

Valid Percentage: It is the proportion of data that is valid. It is obtained by excluding the missing values or invalid values [14].

Cumulative Percentage: It is the percentage of cumulative frequency. It describes the accumulated total of an occurrence on the scale of 100, in order to better describe the occurrences/frequencies of an event. Cumulative frequency is determined by dividing the cumulative frequency by the total number of samples / observations, then multiplying by 100 [15].

4.1 Income of the respondents:

The income of the respondents determined in the survey questionnaire is tabulated as under:

What is your monthly income?				
Income	Frequency	Percent	**Valid Percent**	Cumulative Percent
Less than 20,000 per month	8	14.5	**14.5**	14.5
20,001 to 100,000 per month	28	50.9	**50.9**	65.5
100,001 to 300,000 per month	13	23.6	**23.6**	89.1
Above 300,000 Per Month	1	1.8	**1.8**	90.9
Don't want to share	5	9.1	**9.1**	100.0
Total	55	100.0	**100.0**	

Table 4.1 Income Group

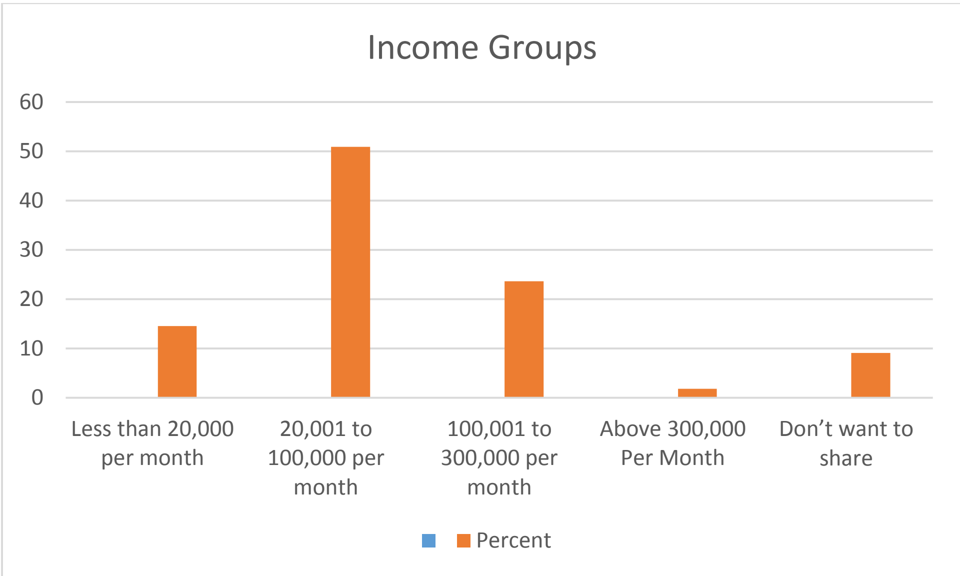


Figure 4.1 Representation of Income group

The above statistics show more than 50% of the respondents lie in 20,000 to 100,000 rupees per month group. Which is also valid as per data published by Pakistan Bureau of statistics [2], which reports that average income of an urban Pakistani household is 26000 rs per month for the 5th quartile. In this research the sample is taken from the upper middle class as the same is also evident from [2].

4.2 Type of Usage (Residential or Commercial):

The type of usage either residential or commercial determines the nature of consumption for which the consumer pays the electricity bill i.e Residential or commercial or industrial as defined in NEPRA consumer service Manual [50]. The sample was obtained from domestic consumers. The data obtained also shows relevancy in sampling, as most of the consumers were of residential nature.

Type of Usage				
	Frequency	Percent	Valid Percent	Cumulative Percent
Commercial	2	3.6	3.6	3.6
Residential (Domestic user.)	`53	96.4	96.4	100.0
Total	55	100.0	100.0	

Table 4.2 The Type of Electricity Consumption

4.3 Sanctioned Load:

The quantum of sanctioned load determines the authorized amount of power which a consumer may use at any instant of time. The data pertaining to sanctioned load is segmented into 3 groups Below 50 KW, Above 50 KW and Above 1500 KW.

Sanctioned Load				
	Frequency	Percent	Valid Percent	Cumulative Percent
Less than 50KW	32	58.2	58.2	58.2
Above 50 KW	2	3.6	3.6	61.8
Above 1500 KW	1	1.8	1.8	63.6
Don't Know	20	36.4	36.4	100.0
Total	55	100.0	100.0	

Table 4.3 Sanctioned Load

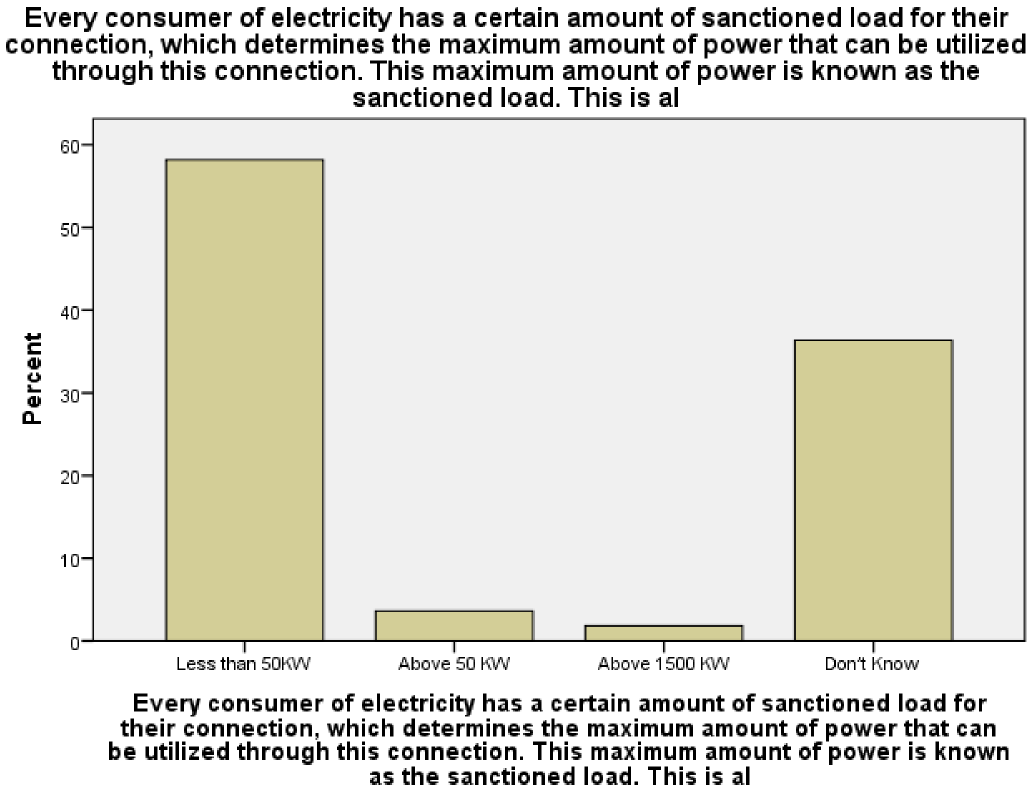


Figure 4.2 Sanctioned Load

The survey results show that more than 55% of the respondents pertained to Less Than 50 KW sanctioned load category. 35% of respondents were not aware of their sanctioned load. This reveals a major deficiency of understanding in electricity consumers regarding sanctioned load. This also results in consumption of load beyond the sanctioned load, which is an un-authorized act on the part of consumer. The consumer is liable to a penalty from Utility company on increasing his load beyond the sanctioned load.

4.4 Consumers Satisfaction on the Price of Electricity:

The satisfaction of the respondents on the electricity price was determined on Likert scale from highly not satisfied to highly satisfied. The data reveals that more than 60% of the respondents were not satisfied with the price, meanwhile only 23% of the respondents were satisfied with price. This result is however contrary to the works of Daphne Ngar-yin Mah [5] which pertains to the area of Honk Kong.

What is your satisfaction level on the price of electricity? Please select from following				
	Frequency	Percent	Valid Percent	Cumulative Percent
Highly Not Satisfied	11	20.0	20.0	20.0
Not Satisfied	23	41.8	41.8	61.8
Neutral	9	16.4	16.4	78.2
Satisfied	10	18.2	18.2	96.4
Highly Satisfied	2	3.6	3.6	100.0
Total	55	100.0	100.0	

Table 4.4 Satisfaction on Price of Electricity

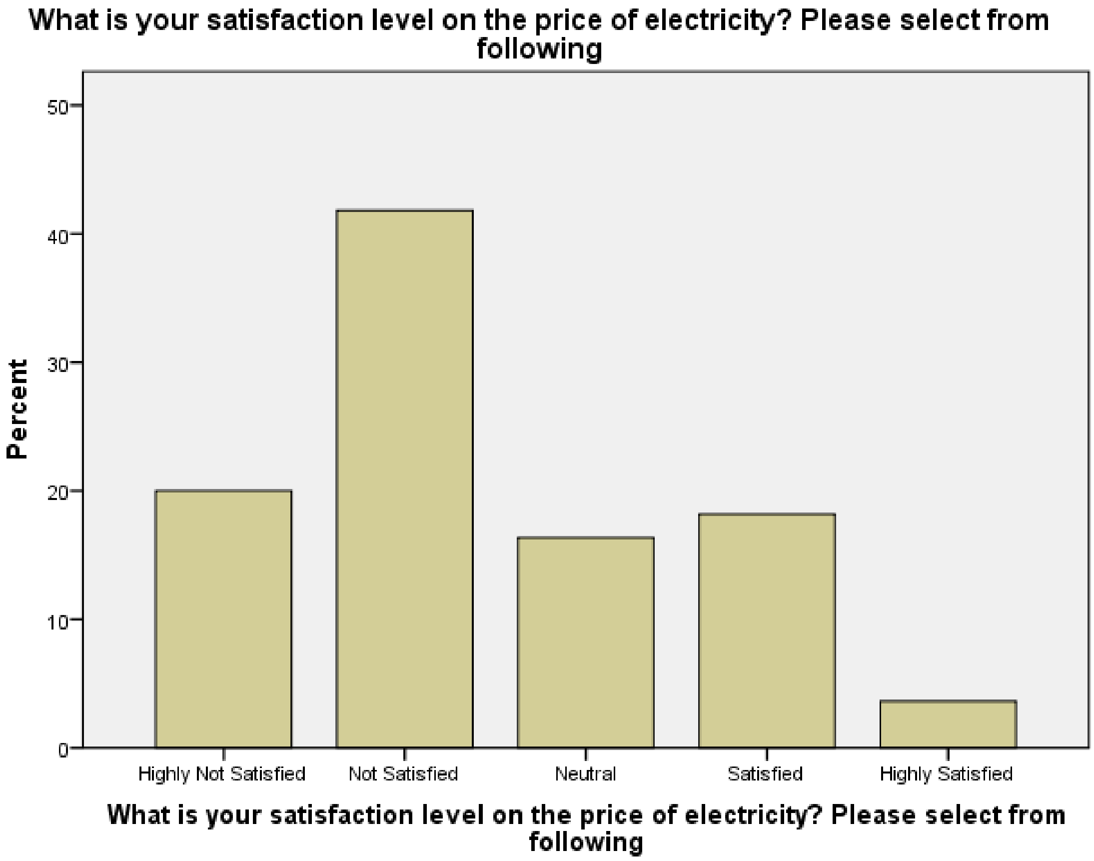


Figure 4.3 Satisfaction on Price of Electricity

4.5 Consumer Satisfaction on the Service Quality of Electricity:

The service quality of electricity is determined on various factors, which includes voltage fluctuations, Power break downs, frequency, complaint response and customer services etc. However in this survey questionnaire, a general perception of consumers pertaining to service quality is evaluated based on a sample of 55 respondents.

What is your satisfaction level on the service quality of electricity provided by the Utility Company?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Highly Not Satisfied	6	10.9	10.9	10.9
Not Satisfied	7	12.7	12.7	23.6
Neutral	16	29.1	29.1	52.7
Satisfied	22	40.0	40.0	92.7
Highly Satisfied	4	7.3	7.3	100.0
Total	55	100.0	100.0	

Table 4.5 Satisfaction on the service quality of electricity

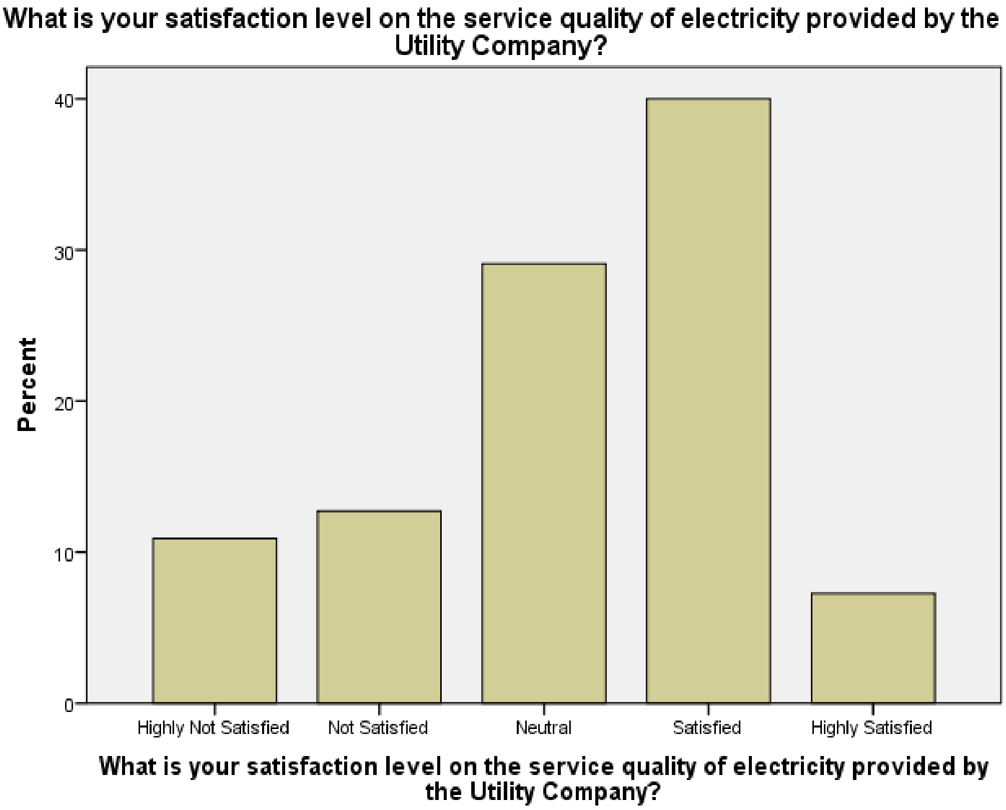


Figure 4.4 Satisfaction on the service quality

The results reveal that 47% of the consumers are satisfied with the service quality. Only 23% were not satisfied with the service quality. This also shows that the high income group are having a better perception of service quality than lower income, the same is also evident from following cross tabulations

What is your monthly income?	**What is your satisfaction level on the service quality of electricity provided by the Utility Company?**					Total
	Highly Not Satisfied	Not Satisfied	Neutral	Satisfied	Highly Satisfied	
Less than 20,000 per month	6	2	0	0	0	8
20,001 to 100,000 per month	0	5	16	7	0	28
100,001 to 300,000 per month	0	0	0	13	0	13
Above 300,000 Per Month	0	0	0	1	0	1
Don't want to share	0	0	0	1	4	5
Total	6	7	16	22	4	55

Table 4.6 Comparison of Monthly income with Satisfaction on Service Quality

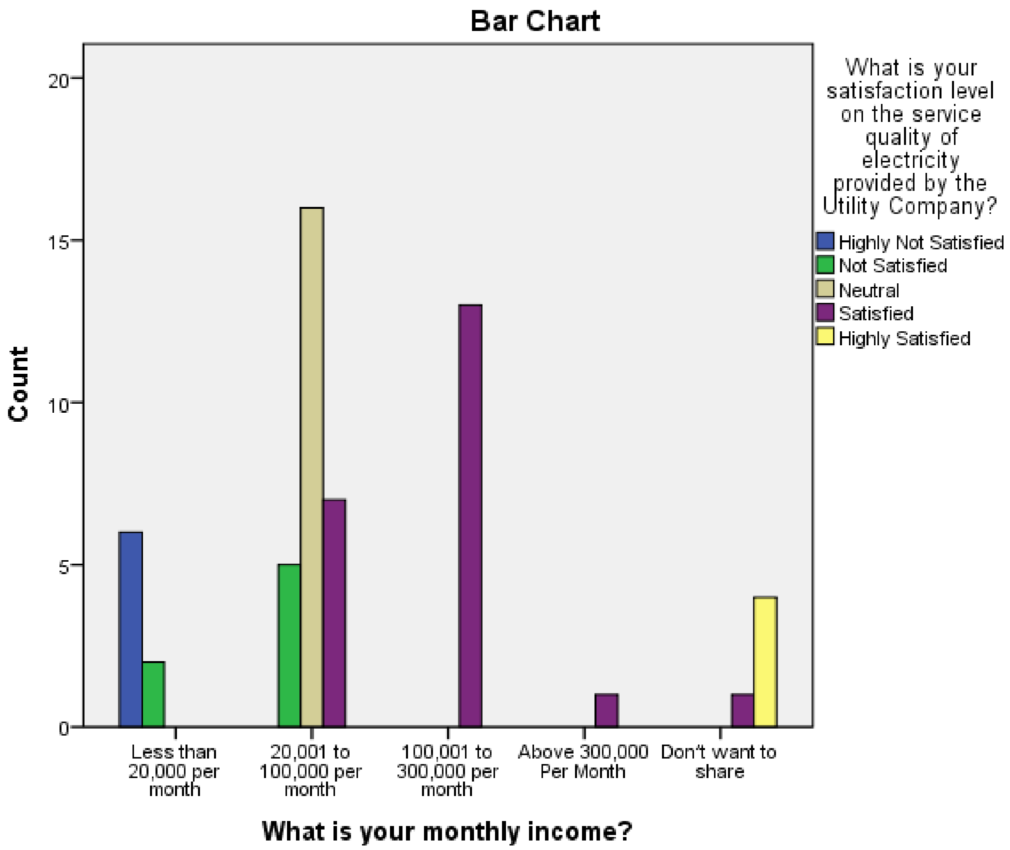


Figure 4.5 Graphical Representation of Comparison of Income with Satisfaction on Service Quality of Electricity

It is evident from the above depiction that higher income group was more satisfied with the service quality. This is because, that higher income groups reside in areas which are posh, and in such localities the load shedding is minimum due to better recovery of dues by the utility service provider. K-Electric has implemented a policy of classifying high loss, medium loss and no loss areas depending upon the recovery of bills from consumers in that area. The utility service provider has put the high loss areas on max load shedding with No loss areas being load shedding free. The results show a strong validity in terms of K-Electric current practice of providing a better services to those areas, which pay their Bills on time and refrain from electricity theft.

4.6 Genuineness of the Bills Received From Utility:

Consumer perception regarding the genuineness of the bill received was evaluated by this survey questionnaire. Consumer agreement on the genuineness of bills was measured on a 5 point Likert scale. The data is tabulated as under:

Do you think the bills received from Utility company are justified? Please select from following.				
	Frequency	Percent	Valid Percent	Cumulative Percent
Strongly disagree	3	5.5	5.5	5.5
Disagree	20	36.4	36.4	41.8
Neutral	20	36.4	36.4	78.2
Agree	11	20.0	20.0	98.2
Strongly Agree	1	1.8	1.8	100.0
Total	55	100.0	100.0	

Table 4.7 Genuineness of Bills

The above results show that almost 40% respondents believe that the bills are not justified. Bills not being justified is a negative argument, which mostly the respondents would not be willing to give a negative response, but 40% have given as such, it shows that respondents are not much satisfied with the billing mechanism. Moreover, it needs to be explored what type of consumers' income group responded negatively, against positively. This shall further describe the thinking and satisfaction among the income groups.

Figure 4.6 Genuineness of Bills

The data shows that around 22% agreed that the bills received from the utility are genuine and justified. Meanwhile, 40% respondents believe that the bills are not justified. On cross tabulation of above response with the income group, following results are obtained.

Do you think the bills received from Utility company are justified? Please select from following. * What is your monthly income? Cross tabulation

Do you think the bills received from Utility company are justified. Please select from following.	What is your monthly income?					Total
	Less than 20,000 per month	20,001 to 100,000 per month	100,001 to 300,000 per month	Above 300,000 Per Month	Don't want to share	
Strongly disagree	3	0	0	0	0	3
Disagree	5	15	0	0	0	20
Neutral	0	13	0	0	0	20
Agree	0	0	1	4	4	11
Strongly Agree	0	0	0	1	1	1
Total	8	28	13	1	5	55

Table 4.8 Cross Tabulation of Income with perceived genuineness of bills

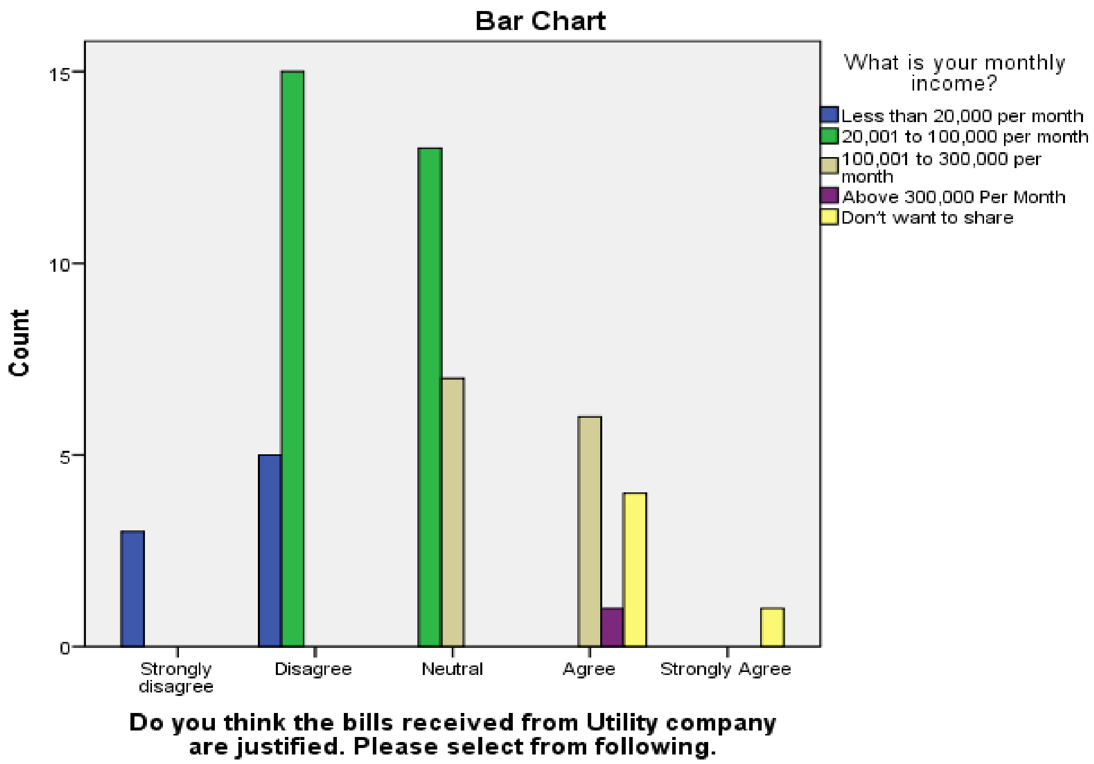


Figure 4.7 Graphical representation of the comparison of income with perceived genuineness of bill

Above visual depiction shows that the lower income group has a perception, that the utility company do not provide them a justified bill. Whereas high income group is agreed that the bills received from the utility are justified.

4.7 Comparison of Bills received on Seasonal Basis:

The questionnaire data pertaining to billing slab was analyzed by cross tabulation method. It revealed that there was a general trend of lower bills in the winters, meanwhile a higher trend of bills are received during summers. This is because of higher use of air conditioning in the summers, but the use of heaters in the winters are not as much to balance the bills of summers with winters. Now this trend, makes the power consumption curve to rise in the summers only, this results in lower capacity utilization in the winters. Such trends may be curtailed if a large scale energy storage campaign is launched at national level, in which the underutilized generation capacity is utilized in the large-scaled energy storage systems [6].

Please select the slab of bill you receive from the utility company during winters * Please select the slab of bill you receive from the utility company during summers. Cross tabulation						
Please select the slab of bill you receive from the utility company during winters	**Please select the slab of bill you receive from the utility company during summers.**					Total
	Rs. 500 – Rs. 1000	Rs. 1000 – Rs. 3000	Rs. 3000 – Rs. 9000	Rs. 9000 – Rs. 25000	Rs. 25000 and above	
Rs. 500 – Rs. 1000	3	3	0	0	0	6
Rs. 1000 – Rs. 3000	0	5	16	0	0	21
Rs. 3000 – Rs. 9000	0	0	4	17	0	21
Rs. 9000 – Rs. 25000	0	0	0	3	3	6
Rs. 25000 and above	0	0	0	0	1	1
Total	3	8	20	20	4	55

Table 4.9 Comparison of Bill on seasonal basis

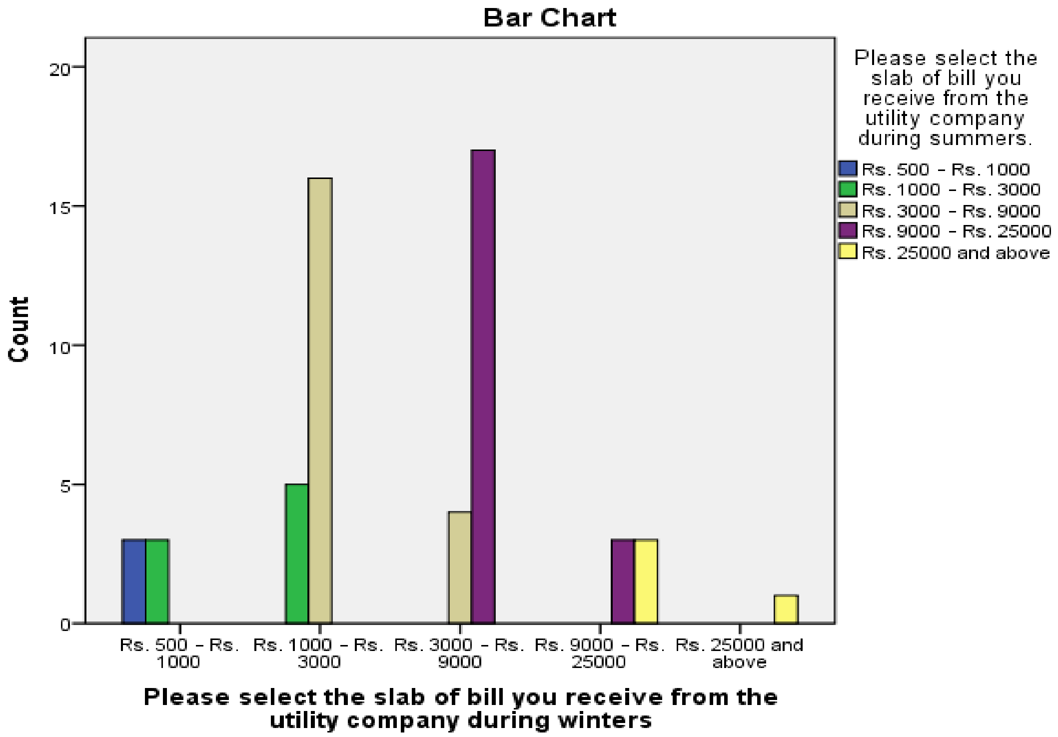


Figure 4.8 Graphical Representation of comparison of bills on seasonal basis

4.8 Awareness on Renewable Energy:

Awareness of renewable energy was determined by asking the respondents when they think they will invest in a renewable energy solution for their home. The respondents were provided options in terms of time frame to invest. Following data is obtained from the questionnaire:

When do you expect to invest on the Renewable Energy Solutions (e.g wind turbine, solar panels) for Your Premises?				
	Frequency	Percent	Valid Percent	Cumulative Percent
0 – 3 years	16	29.1	29.1	29.1
3 – 6 years	20	36.4	36.4	65.5
never	19	34.5	34.5	100.0
Total	55	100.0	100.0	

Table 4.10 Expected time of investment in renewable energy solutions

Above data reveals that more than 60% of the respondents had plans to invest in the renewable energy solutions for their home in next 6 years. Meanwhile, only 35% of the respondents selected, they would never invest in the renewable energy solutions.

There is a smaller extent of consumer interest in an immediate investment in a renewable energy solution. Only 29.1% respondents had plans to invest immediately within 3 years in a renewable energy solution. Whereas, 36.4% of the respondents were planning to invest in a renewable energy solution in the next 3-6 years. 34.5% consumers, however, had no plans to invest in RES.

In Pakistan, there is a need to create more awareness regarding environment protection and energy efficiency. An awareness campaign should be launched by environmental protection agencies. Schools and colleges should educate students in energy efficiency practices.

4.9 Consumers acceptability of the Smart Grid Technology:

The consumer acceptability of the smart grid technology was evaluated by following question in the questionnaire. ***"Would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit"***. It is observed that 49% of the respondents accepted to allow Utility to switch off their electric supply in return of a monetary benefit. However, 29% respondents did not accept this new technology. There may be various reasons for not accepting a technology as suggested by Davis [7] it is stated that a consumer would accept a technology if he perceives it as it is easy to use, secondly if he perceives it as it has a good impact or effect on his own goals. Then it is also suggested in literature that there is always a room for creating adequate awareness of the new upcoming technology, so a requirement is there to increase awareness, only then the users would be able to accept it.

Smart Grid technology is still in its infancy stage. There are no proper standards developed yet for the technology. Various companies are using and classifying it in their own tailored made solutions. So a lot of awareness campaigning is required at this stage of the technology.

Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit?				
	Frequency	Percent	Valid Percent	Cumulative Percent
No	16	29.1	29.1	29.1
Not Sure	12	21.8	21.8	50.9
Yes	27	49.1	49.1	100.0
Total	55	100.0	100.0	

Table 4.11 Smart Grid Acceptability

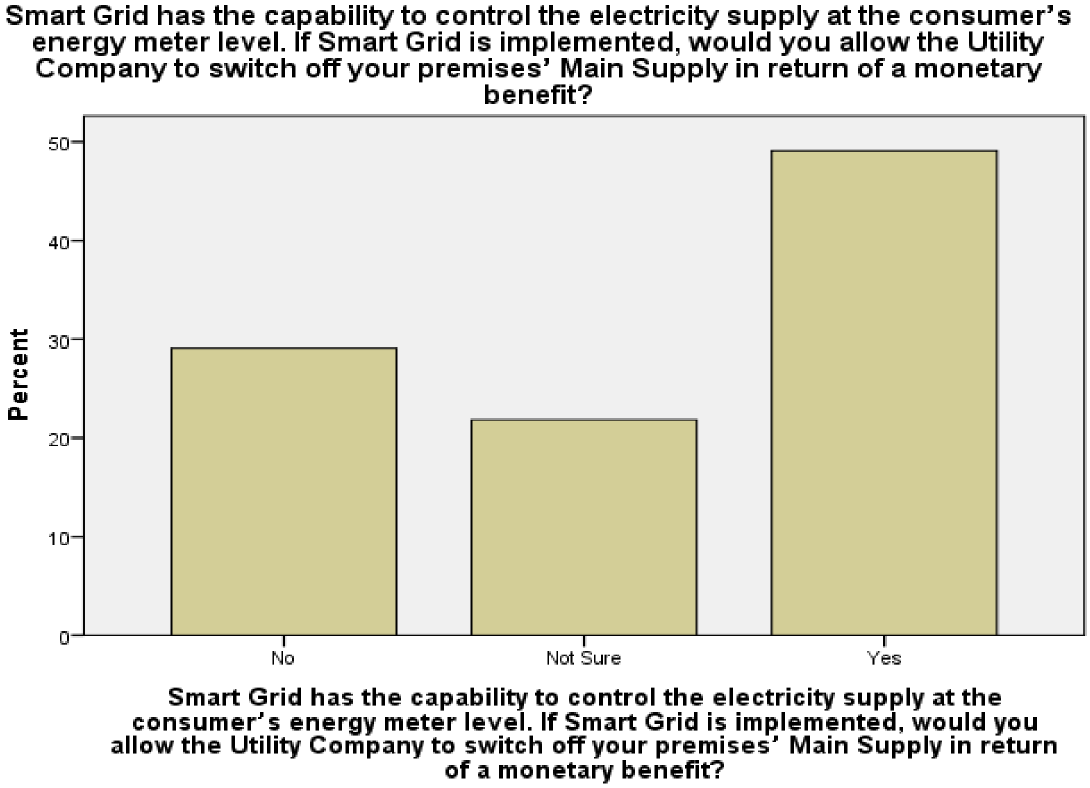


Figure 4.9 Graphical Representation of Smart Grid Acceptability

The acceptability of smart grid was further elaborated by cross tabulating the acceptability with the income group and then cross tabulation with the time of investment in renewable energy. Following table describes the relationship of income group with the smart grid acceptability. The higher income group had more preference for Smart Grid, against lower income group. As discussed earlier, the higher income group has more awareness and education pertaining to environment protection, energy efficiency and smart grid technology. Therefore, the higher income group is more likely to readily accept the Smart Grid Technology.

The lower income group has various other domestic issues to address, therefore he is not much interested in such initiatives.

Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit? * What is your monthly income? Crosstabulation							
Count							
Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit?		What is your monthly income?					Total (%)
		Less than 20,000 per month (%)	20,001 to 100,000 per month (%)	100,001 to 300,000 per month (%)	Above 300,000 Per Month (%)	Don't want to share (%)	
	No	14.5	14.5	0.0	0.0	0.0	29.1
	Not Sure	0.0	21.8	0.0	0.0	0.0	21.8
	Yes	0.0	14.5	23.6	1.8	9.1	49.1
Total		14.5	50.9	23.6	1.8	9.1	100.0

Table 4.12 Comparison of Smart Grid Acceptability with Income Group

The smart grid acceptability was compared with awareness in renewable energy solutions and its expected installation at their homes. This showed that those who had a preference for Smart Grid Technology had more of a negative opinion for installing a renewable energy solution at their home.

Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit? * When do you expect to invest on the Renewable Energy Solutions (e.g wind turbine, solar panels) for Your Premises? Crosstabulation Count					
		When do you expect to invest on the Renewable Energy Solutions (e.g wind turbine, solar panels) for Your Premises?			
		0 – 3 years	3 – 6 years	never	Total
Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit?	No	29	0	0	29
	Not Sure	0	22	0	22
	Yes	0	15	35	49
Total		29.0	36	35	100

Table 4.13 Comparison of Smart Grid Acceptability with the expected time for investment in renewable energy solutions

This shows that installation of wind turbine and solar panels is not having much preference in the group which is preferring smart grid technology to voluntarily curtail load against a monetary benefit. This again shows a lack of education of people pertaining to smart grid technology and its capabilities. As discussed by Farhangi [47], the renewable energy solutions like wind, solar and many other distributed generation resources can be utilized for pumping KWs in the Grid, with the help of Smart Grid Technology and supplement the net generation resources. Such capabilities and features of Smart Grid will in turn give monetary benefits to the consumers. But our results show that the respondents owing to their lack of education and lack of awareness have shown lack of interest and preference for renewable energy solutions.

Apart from above, the acceptability of smart grid is also dependent upon following considerations as well:

(1) Incentive to consumers for Smart Grid Acceptability.

(2) Acceptable Switch Off Time and the length of switch Off Interval.

(3) Extent of control tolerable by Consumers, incase SMART Grid enables Utility to go beyond the "***Premises' Main Supply Level Control***" to ***"Appliances Level Control"***.

(4) Extent of consumers' acceptability on shifting the time of use of their appliances.

(5) Consumers' wish to upgrade the current billing mechanism of Utility from manual to ***"Online Automatic Billing"*** which has more visibility.

4.9.1 Incentive to consumers for Smart Grid Acceptability

The survey data reveals that almost 70% of the respondents agreed to have their electric supplies switched off during the peak hours if required by utility in return of some monetary benefit. This benefit is over and above the month end bill, which is dependent on the monthly units of energy consumed. Meanwhile 30% of the respondents did not agree to give away their comfort of enjoying uninterruptible power supply from the utility and they chose not have any incentive from the utility, in return they expect to be served with uninterruptible power supply.

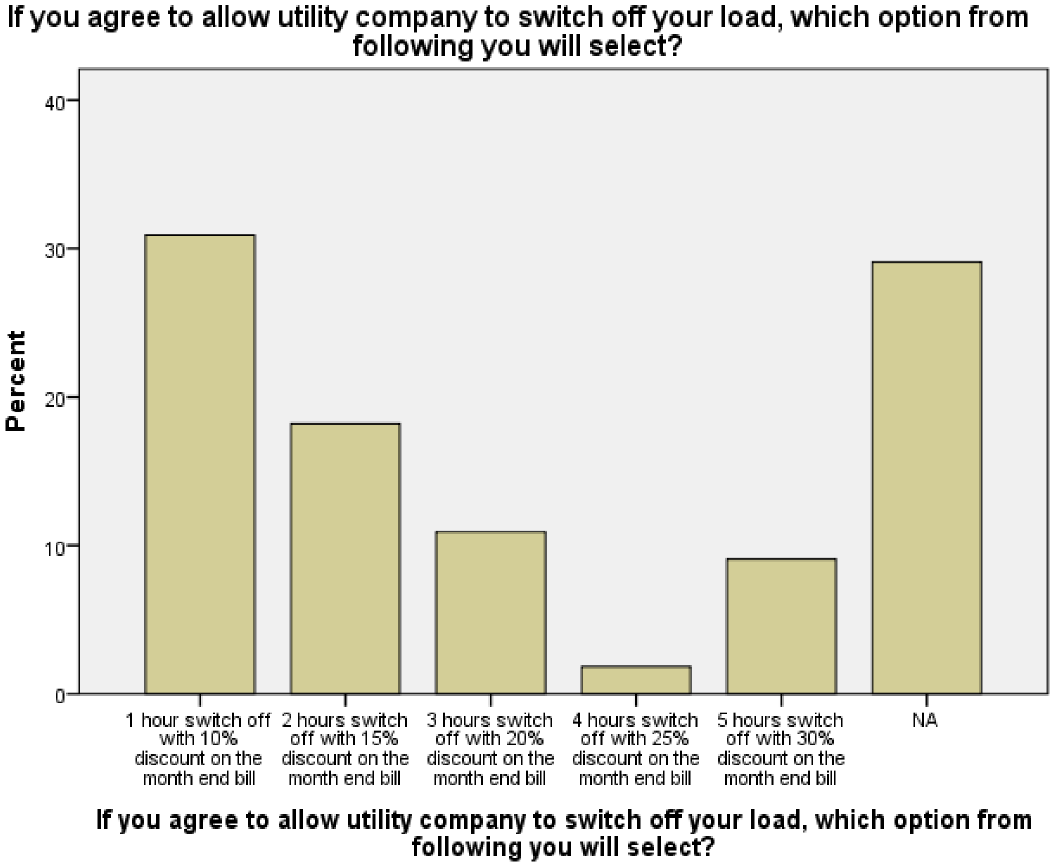


Figure 4.10 Graphical representation of acceptable incentive for switching off the Electricity

From this data, it is evident that if the consumers are offered a benefit, they readily agree to give away their comfort and gain some monetary benefit. This is also because Pakistan is a third world country and the people of upper middle class areas (who are sampled in the survey) are inclined towards gaining some benefit due to bad economic and financial conditions of people. Further, it is also noted that enjoying uninterruptible power supply is not considered as life's necessity. People in Pakistan are quite prone to living without electricity and our quite used to it. So, gaining a monetary benefit against switching off is a very good offer.

4.9.2 Acceptable Switch Off Time and the length of switch Off Interval:

The data from the survey questionnaire reveals that almost 35% of the respondents chose not to have any switch off time. There was almost equal concentration of responses in the night slot (12 am – 9 am), i.e. 21% respondents agreed to have their power supplies switched off at night as well as day slot i.e. 25% respondents agreed to have their power supplies switched off during the day time.

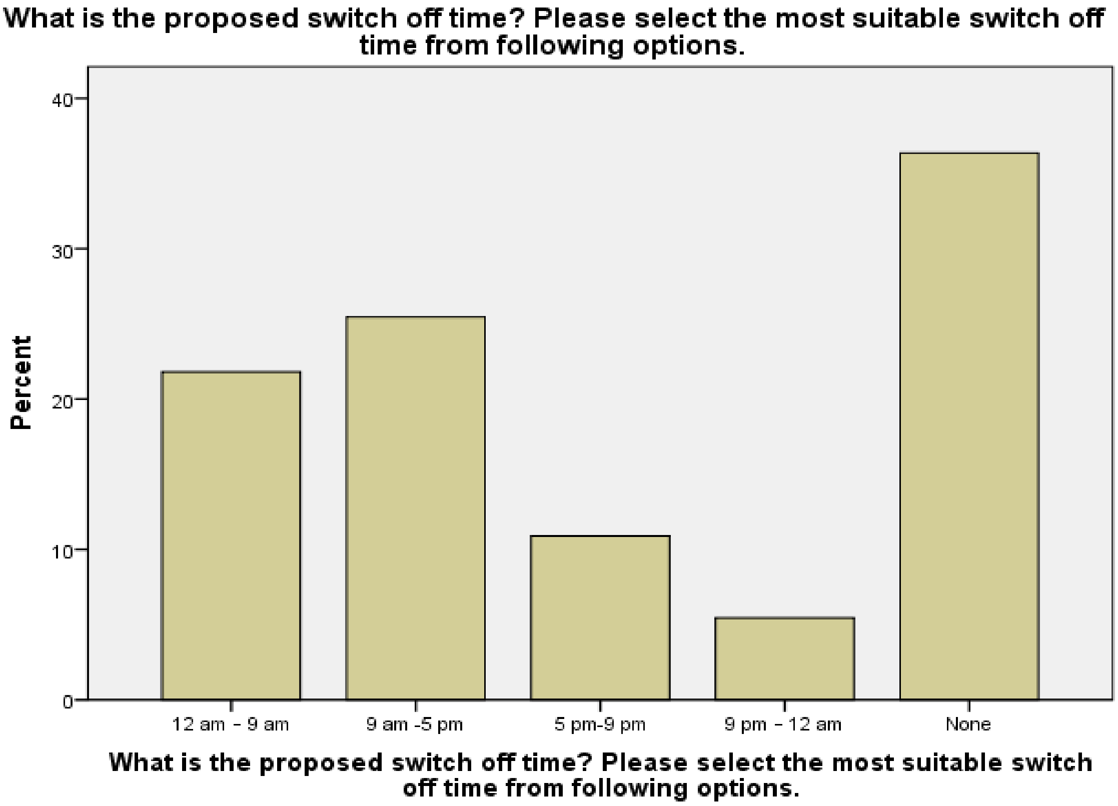


Figure 4.11 Preferred switch off time

Overall, it is observed that although the consumers are agreed to switch off their supplies but different consumers have different preference for the switch off time slot. Hence, the utility cannot force all consumers into a single switch off time interval. Therefore, in order to comply with the consumers' preference, utility company must make use of the smart grid technology which has this capability to control the main supply of the individual consumers.

The conventional distribution system is only capable to switch off the Area Feeder in case of load management, they do not have access to control the electricity of individual consumers. So such capabilities of Smart Grid, make it a more valuable technology for the Utility company to implement and adopt.

The acceptable switch off interval was also evaluated by the questionnaire. The data obtained for this consideration is depicted graphically as under:

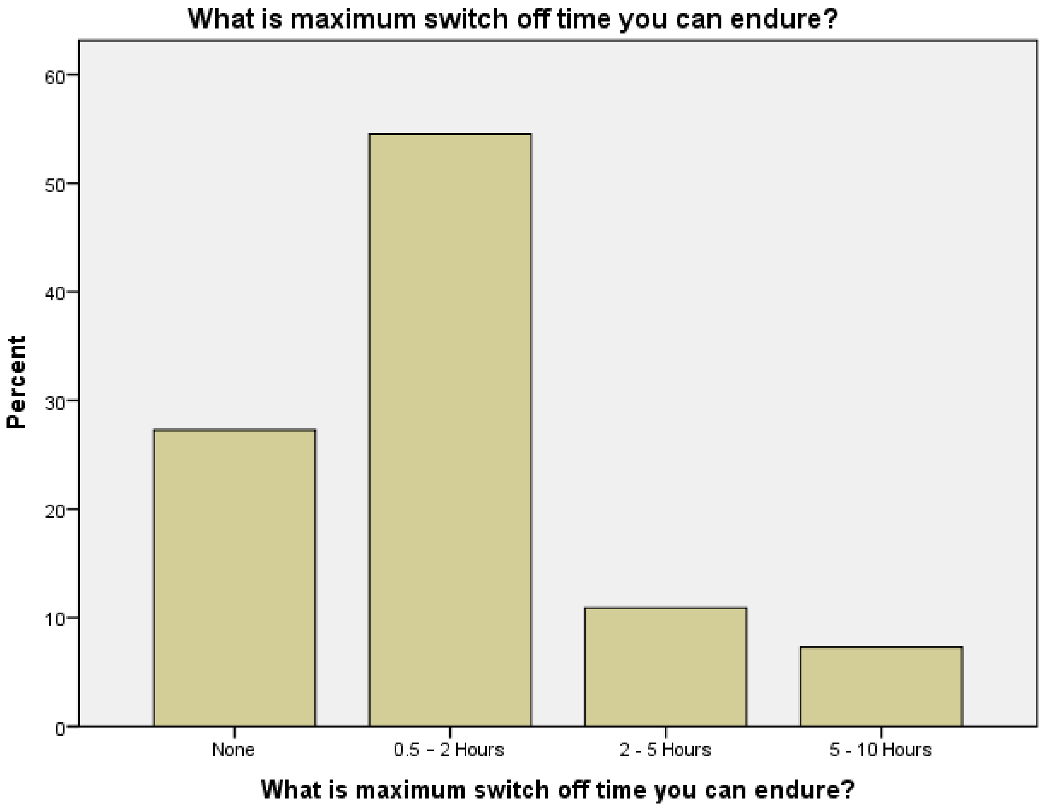


Figure 4.12 Acceptable length of Switch off interval

The maximum number of respondents, almost 54% could endure 0.5 to 2 hours long switch off interval. Whereas 28% respondents cannot endure any switch off time and wanted no switch off time at all. 11% and 8% respondents could endure 2-5 hours long and 5-10 hours long intervals respectively, without electricity. From this data it is evident that if smart grid technology is implemented then it must cater for those consumers as well who are reluctant to switch off, by eliminating such consumers from load shedding. This can be made possible by first asking the consumers through any communication media about their preference for switching off, its duration, time of switching off and the monetary benefit. Once, an agreement is made, between the consumer and the utility, then the utility company switch off those consumers accordingly. Such features are available in the Smart Grid Technology [18, 47].

4.9.3 Extent of control tolerable by Consumers, incase SMART Grid enables Utility to go beyond the "Premises' Main Supply Level Control" to "Appliances Level Control".

Consumers' acceptability to allow Utility Company to control their appliances was evaluated by the survey questionnaire. It is found that 60% of the respondents were agreed to allow Utility to control their appliances with Smart Grid Technology. This shows a higher percentage of respondents have no problems if their privacy is penetrated to the extent that the Utility company control their appliances remotely in order to cater for peak load management.

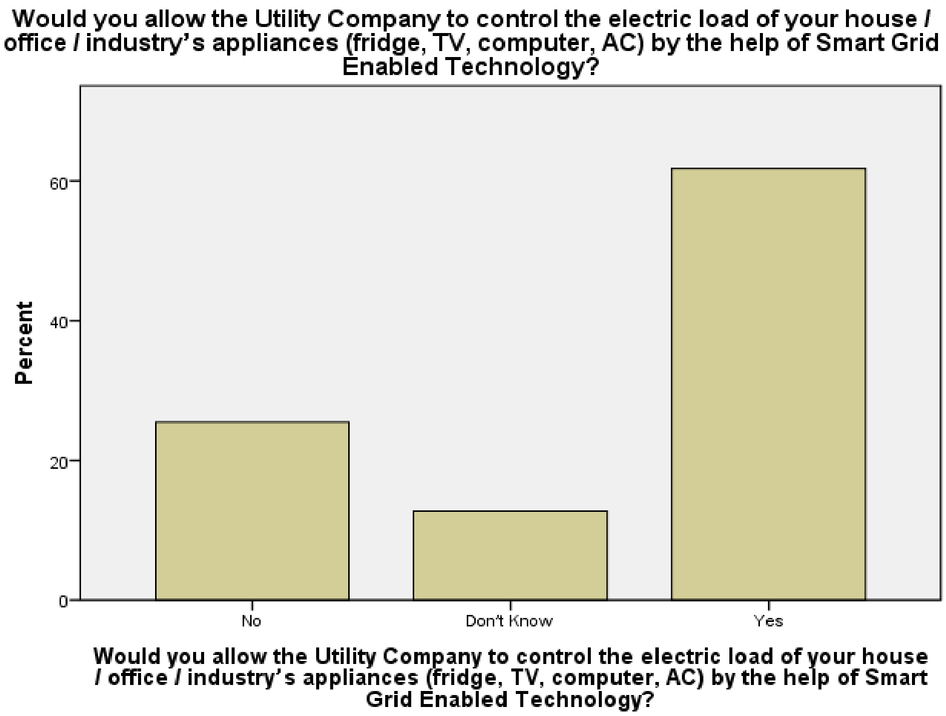


Figure 4.13 Acceptability of appliance's level control

From above data, it is evident that 22% of the respondents did not agree to accept such penetration of their privacy, and denied allowing utility to control their appliances. So, if Smart Grid is implemented then its design should cater to the preference of such consumers also who are not willing to allow control of their appliances. However, the percentage of such consumers is less, only 22%. This feature may be incorporated by first obtaining an agreement from the consumers, and then enrolling only those consumers who are willing to allow control of their appliances. The same results and conclusions were drawn on Honk Kong based survey, wherein [5] Daphne suggests that the consumers have a preference to Smart Grid Technology in order to save environment and obtain energy efficiency in their living.

It is also observed from the questionnaire data, that at least 10% of the respondents were still not sure about this technology and were confused whether they should allow such control or not. Hence, there is strong need to educate consumers regarding renewable energy initiatives and the importance of sustainable energy and its key technology, which is Smart Grid.

4.9.4 Extent of consumers' acceptability on shifting the time of use of their appliances:

Time of use shifting of electricity consumption is very beneficial in terms of shaving off the peak from the power curve. This feature of Smart Grid requires the consumers' acceptability and willingness to shift the use of their appliances like electric cattle, washing Machines, electric geysers and microwave ovens, AC etc. to some other time slot. Following graph shows the consumers acceptability to shift the use of their appliances to any other time slot, 65% of the respondents agreed to shift the use of their appliances in return of a monetary benefit. Meanwhile, 35% of the respondents did not agreed to shift the use of their appliances.

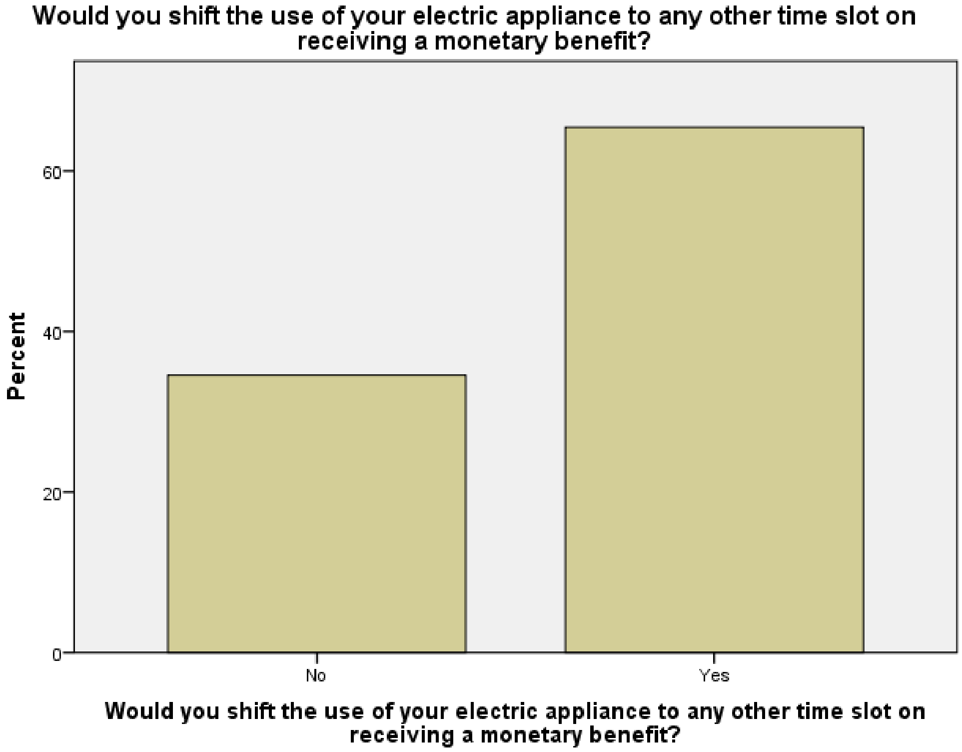


Figure 4.14 Preference to shift the time of consumption

Here in again it is suggested to obtain the consumer preference for time of use shifting, with the help of a communication medium. Enrolling only those consumers who have a preference meanwhile eliminating all such consumers who are not willing. If only the willing consumers are enrolled only for time of use shifting, this would also make a significant impact on the Peak load shaving.

The same is evident from this research that if there are 0.5 million consumers having an average load consumption of 1 KW. If 0.2 million consumers shift the use of their appliances from the peak hours to any other then, if 50% of the load is shifted, this translates into 0.5 KW x 0.2 million = 100 MW.

We can say that 100 MW of power saved is equivalent to 100 MW power generated. Further, in context of environment, the latter is more environmentally friendly and an energy efficient initiative, hence is better.

4.9.5 Consumers' wish to upgrade the current billing mechanism of Utility from manual to "Online Automatic Billing" which has more visibility

With the advancement in technology, various features may be incorporated into SG platform in order to provide consumers with more value. One of the features whose requirement was evaluated by the survey was of ***online automatic billing***. From the survey results It is found that the consumers have little trust on the manual procedure, due to the existence of human involvement while meter reading. This creates more chances of misappropriation by the billing department and the meter reader. Due to this, a very high percentage of respondents have shown a desire that the manual procedure should be replaced by an online automatic billing system. Almost 90% of the respondents were of the view that the current manual procedure in which a meter reader physically reads the meter reading and the company send the bills as per the reading provided by the meter reader, should be abandoned and replaced by an online system. Such features can easily be incorporated on a SG platform, whereas on the conventional system it is not possible.

Do you think the manual method/procedure currently adopted by the utility company to receive bills from consumers should be replaced by an online automatic meter reading system				
	Frequency	Percent	Valid Percent	Cumulative Percent
Strongly disagree	1	1.8	1.8	1.8
Disagree	1	1.8	1.8	3.6
Neutral	3	5.5	5.5	9.1
Agree	21	38.2	38.2	47.3
Strongly Agree	29	52.7	52.7	100.0
Total	55	100.0	100.0	

Table 4.14 Preference for online automatic billing

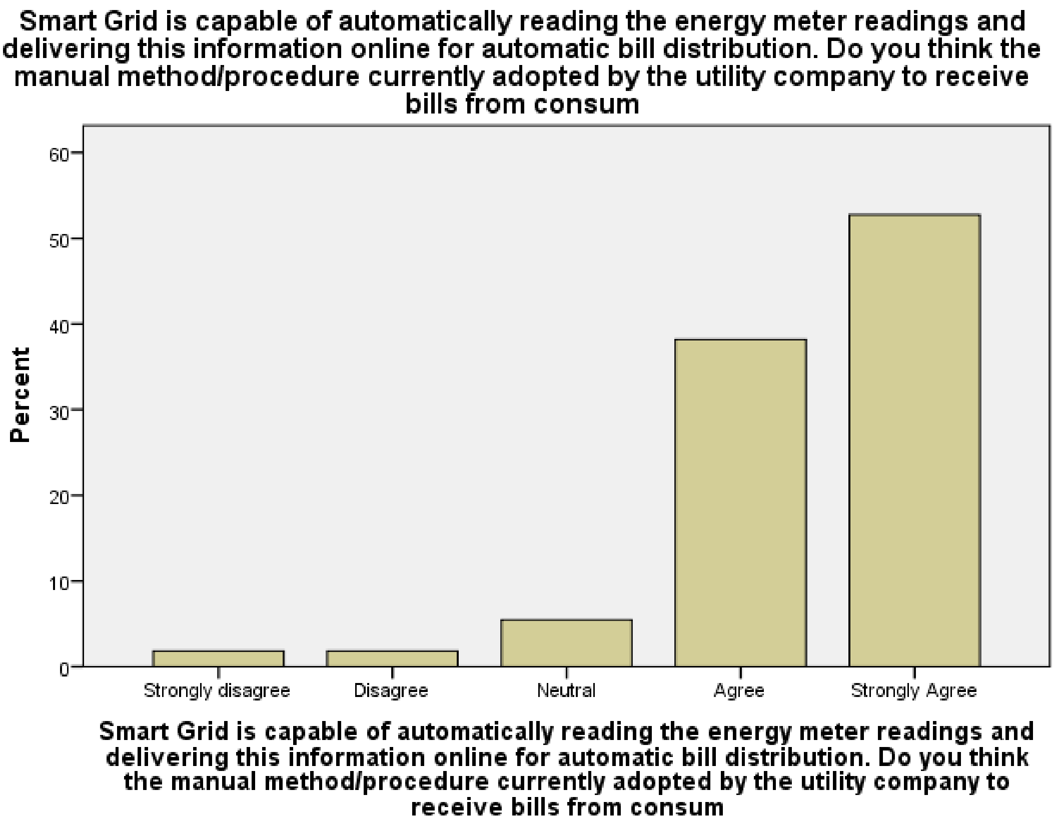


Figure 4.15 Graphical representation of the preference for online automatic billing

4.10 Dependency of Smart Grid Acceptability on Income

It is worth noting that if a relationship is developed between the income groups and acceptability of Smart Grid, this will support the decision makers to decide which income group should be targeted for smart grid deployment in full throw.

The questionnaire was designed such that, the specific features of smart grid were asked in separate questions, in order to mitigate the error in questionnaire responses [5]. The questions which were put forth to check the acceptability of Smart Grid in context of that feature or characteristic available in Smart Grid, are as under:

1. Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit?

2. Would you allow the Utility Company to control the electric load of your house / office / industry's appliances (fridge, TV, computer, AC) by the help of Smart Grid Enabled Technology?

3. Would you shift the use of your electric appliance to any other time slot on receiving a monetary benefit?

4. Would you reduce the thermostat of your AC for a particular time slot on receiving a monetary benefit?

5. Would you switch off your AC for a particular time slot on receiving a monetary benefit?

6. Would you agree that Utility company should replace the manual meter reading system with an online automatic meter reading system as available in Smart Grid?

Considering the mentioned smart grid features, six hypothesis were developed, which were tested from the collected sample and performed chi-square statistical test to check the dependency of income groups on above mentioned acceptable characteristics of Smart Grid. In the end, an average of all the acceptability proportions in each income group was obtained, thereby showing how the acceptability is related to income.

Hypothesis 1: Income group is independent of the acceptability of Smart Grid in context of switching off the main supply against a monetary benefit

This hypothesis was tested and was examined whether the observations reflect any significant variation from the expected results. Based on the book by Earl K. Brown & Martin [56], significance level was 5% which translates to an alpha value of 0.05 as shown in table 4.15.

Chi square statistic = 47.288 Degree of freedom = 8 Significance = 5% Critical Value = 15.5		Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit?			Total
		No	Not Sure	Yes	
What is your monthly income?	Less than 20,000 per month	8	0	0	8
	20,001 to 100,000 per month	8	12	8	28
	100,001 to 300,000 per month	0	0	13	13
	Above 300,000 Per Month	0	0	1	1
	Don't want to share	0	0	5	5
Total		16	12	27	55

Table 4.15 Dependency of income on acceptability to switch off the main supply

The degrees of freedom for this test was 8. The Value of Chi-Square Statistic was 47.288. On comparing the obtained Chi-Squared Statistic with the chi-square table of values at the required parameters, the Chi-square critical value was 15.5 at a significance level of 5%. Whereas, the obtained chi-square statistic is well above the critical value, which showed that a significant variation from the expected results. Hence, it can be concluded that the acceptability of Smart Grid in context of switching off the main supply is dependent on the income.

Hypothesis 2: Income group is independent of acceptability to allow the Utility company to control your appliances with Smart Grid enabled technology

This hypothesis was tested at a significance of 5% and observed that the value of chi-square statistic was 38.964. The degree of freedom was 8, and alpha value was 0.05. On comparing this chi-square statistic with the critical value i.e 15.5 at the significance of 5%, it was found that 38.964 was well above the critical value as shown in table 4.16.

Chi square statistic = 38.964 Degree of freedom = 8 Significance = 5% Critical Value = 15.5		Would you allow the Utility Company to control the electric load of your house / office / industry's appliances (fridge, TV, computer, AC) by the help of Smart Grid Enabled Technology?			Total
		No	Don't Know	Yes	
What is your monthly income?	Less than 20,000 per month	8	0	0	8
	20,001 to 100,000 per month	6	7	15	28
	100,001 to 300,000 per month	0	0	13	13
	Above 300,000 Per Month	0	0	1	1
	Don't want to share	0	0	5	5
Total		14	7	34	55

Table 4.16 Dependency of income on the acceptability of appliances level control

Based on the results shown in table 4.16 the value of our chi-square statistic was well above the critical value. Hence, it was concluded that the observed results had a significant variation from the expected results, and thus the hypothesis was rejected. The alternate hypothesis is true, which translates in to that the income has an effect on the acceptability to allow appliances level control.

Hypothesis 3: Income group is independent of acceptability to shift the use of appliance to any other time slot.

Above stated hypothesis was tested at a significance of 5%. The value of chi-squared statistics was 25.46 at 4 degree of freedom. This chi-squared statistics was compared with the critical value of 9.488 and found that 25.26 was well above the critical value of 9.488 as shown in table 4.17. Hence, it was concluded that there was a significant difference between the expected and the observed values, which implies that the hypothesis is rejected. Hence, it is concluded that income has an effect on the acceptability to shift the use of appliance to any other time slot.

Chi square statistic = 25.46 Degree of freedom = 4 Significance = 5% Critical Value = 9.488		Would you shift the use of your electric appliance to any other time slot on receiving a monetary benefit?		Total
		No	Yes	
What is your monthly income?	Less than 20,000 per month	8	0	8
	20,001 to 100,000 per month	11	17	28
	100,001 to 300,000 per month	0	13	13
	Above 300,000 Per Month	0	1	1
	Don't want to share	0	5	5
Total		19	36	55

Table 4.17 Dependency of acceptability to shift the time of use of appliance on income

Hypothesis 4: Income group is independent of acceptability to reduce the thermostat of Air-condition

This hypothesis was tested by performing chi-squared statistics at a significance of 5%. The results are shown in table 4.18.

Chi square statistic = 68.57 Degree of freedom = 12 Significance = 5% Critical Value = 21.026		Would you reduce the thermostat of your AC for a particular time slot on receiving a monetary benefit?				Total
		Not Sure	Never	Yes sometimes	Yes any time.	
	Less than 20,000 per month	7	1	0	0	8
	20,001 to 100,000 per month	0	6	11	11	28
	100,001 to 300,000 per month	0	0	0	13	13
	Above 300,000 Per Month	0	0	0	1	1
	Don't want to share	0	0	0	5	5
Total		7	7	11	30	55

Table 4.18 Dependency of acceptability to reduce thermostat of AC on income

The value of chi-squared statistic was 68.57, with a significance of 5% and degree of freedom of 12. On comparing the obtained chi-squared statistic 68.57 with the critical value of 21.026, it was observed that 68.57 was well above the critical value of 21.026. Hence, the hypothesis is rejected, and it is concluded that there is a dependence of acceptability to reduce AC's thermostat on income.

Hypothesis 5: Income group is independent of acceptability to switch off the Air-condition

In the above hypothesis it is stated that the acceptability to switch off the AC is independent of income. This hypothesis was tested by obtaining the chi-squared statistics of the observed values and then comparing it with the critical value. The extent of variation from the critical value described how much the observed values deviated from the expected values.

Chi square statistic = 69.851 Degree of freedom = 12 Significance = 5% Critical Value = 21.026		Would you switch off your AC for a particular time slot on receiving a monetary benefit?				Total
		Not Sure	Never	Yes sometimes	Yes any time.	
What is your monthly income?	Less than 20,000 per month	8	0	0	0	8
	20,001 to 100,000 per month	6	11	11	0	28
	100,001 to 300,000 per month	0	0	3	10	13
	Above 300,000 Per Month	0	0	0	1	1
	Don't want to share	0	0	0	5	5
Total		14	11	14	16	55

Table 4.19 Dependency of acceptability to switch off AC on income

The chi-squared statistics of the observed results shown in table 4.19 is 69.851, with a 12 degree of freedom and 5% significance. Whereas, the critical value at a degree of freedom of 12 is 21.026. The calculated chi-squared statistic of 69.8551 based on the observed values, shown in table 4.19 is well above the critical value, which shows that there is a significant variation from the expected results. Hence, the hypothesis is rejected. Hence, it is concluded that the acceptability to switch off AC is dependent on the income.

Hypothesis 6: Income group is independent of acceptability towards online automatic meter reading.

The above stated hypothesis was tested on a significance level of 5% by obtaining the actual observed values from the surveyed data against the expected results.

Chi square statistic = 55.435 Degree of freedom = 16 Significance = 5% Critical Value = 26.296		Smart Grid is capable of automatically reading the energy meter readings and delivering this information online for automatic bill distribution. Do you think the manual method/procedure currently adopted by the utility company to receive bills from consum					
		Strongly disagree	Disagree	Neutral	Agree	Strongly Agree	Total
What is your monthly income?	Less than 20,000 per month	1	1	3	3	0	8
	20,001 to 100,000 per month	0	0	0	18	10	28
	100,001 to 300,000 per month	0	0	0	0	13	13
	Above 300,000 Per Month	0	0	0	0	1	1
	Don't want to share	0	0	0	0	5	5
Total		1	1	3	21	29	55

Table 4.20 Dependency of acceptability for Online Automatic Billing on income

The chi-squared statistics for observed results shown in table 4.20 is 55.435 at degree of freedom of 16. The critical value of chi-squared statistics at a degree of freedom of 16 and significance of 5% is 26.296. The obtained chi-squared statistics is 55.435 is well above the critical value, hence the hypothesis is rejected. Therefore, it is concluded that income has an effect on the acceptability towards online automatic meter reading.

4.10.1 The Relationship of Income and Smart Grid Acceptability

The relationship of income and Smart Grid acceptability is developed by obtaining an average of the percentage acceptance of the various features of smart grid across the income groups. Following features of smart grid contribute towards the acceptability of Smart Grid [18,5].

1. Percentage acceptance of Switching off the main supply
2. Percentage acceptance of allowing appliances control to Utility.
3. Percentage acceptance of allowing load scheduling.
4. Percentage acceptance of reducing the AC thermostat
5. Percentage acceptance to switch off the AC
6. Percentage acceptance of Automatic meter reading in Smart Grid

Each percentage acceptance of smart grid feature was obtained by dividing the number of positive responses and then dividing it by the total number of responses to obtain the acceptance [57].

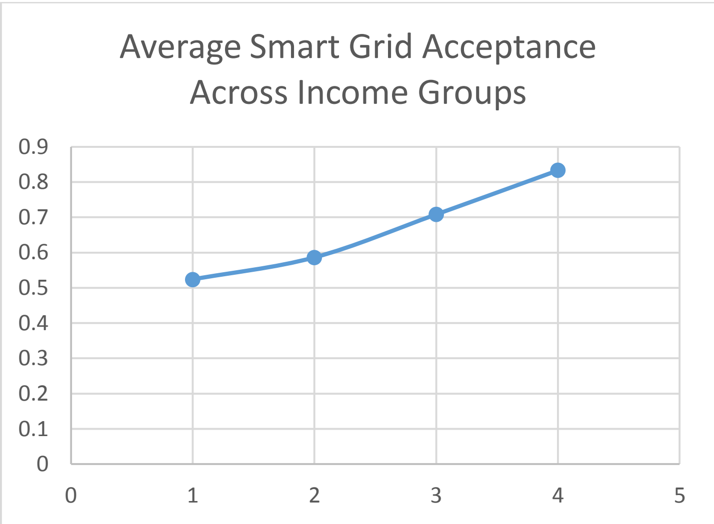
$$Percentage\ Acceptance = \frac{No.\ of\ positive\ responses}{Total\ number\ of\ responses}$$

Then, an average of all the percentage acceptances of all smart grid features across that income group was obtained to get an average acceptance of Smart Grid across that income group.

Income Groups in PKR	Percentage Acceptance on switch off the Main supply	Percentage Acceptance appliances	Percentage Acceptance load scheduling	Percentage Acceptance on reducing AC	Percentage Acceptance on switching off AC	percentage acceptance of Automatic meter reading	Average Acceptance
Less than 20K	0.714285714	0.714285714	0.571428571	0.142857143	0.125	0.875	0.52380952
20K to 100 k	0.428571429	0.52173913	0.652173913	0.52173913	0.535714286	0.857142857	0.58618012
100 k to 300 k	0.5	0.75	0.666666667	0.666666667	0.666666667	1	0.70833333
300 K and above	0	1	1	1	1	1	0.83333333
	0.410714286	**0.746506211**	**0.722567288**	**0.582815735**	**0.581845238**	**0.933035714**	**0.66291408**

Table 4.21 Acceptance percentage of Different Smart Grid Features across income Groups

The average was plotted across the rising income groups which showed following relationship between income group and Average Smart Grid Acceptability.



Increasing Income Groups →

Figure 4.16 Average Smart Grid Acceptance across Income Groups

From the above graph it can be concluded that as the income of respondents increase, there is a rising acceptability of Smart Grid.

CHAPTER 5

CONCLUSION & FUTURE WORK

5.1 Conclusion

The survey research reveals that consumers pertaining the domestic class of Pakistan in general and Karachi in particular have shown a strong preference for energy efficient technologies and especially the smart grid technology. The results reveal that on offering a certain amount of incentive, the consumers get convinced to curtail load. This may have a significant impact on the Grid if properly utilized. However, still there is a need to spread more awareness pertaining to the use of energy efficient initiatives and create better understanding of the benefits of smart grid technology. However, our results show that the consumers are not generally happy with the price of electricity. Further, we have observed that the consumers are also not satisfied with the existing billing mechanism based on manual meter reading. From, all these indicators it is highly recommended to implement Smart Grid having capability to allow voluntary load curtailment against a monetary benefit. And provide improved electricity services to the consumers.

5.2 Future Work

- Development of a framework for incorporation of Smart Grid compliant appliances may be carried out to pave the way for legislation and policy making at government level.
- The concerning government institutions are suggested to prepare such policies and implement them on whose basis the electric supply may become more efficient and environment friendly.

- The same research may be carried out on the industrial consumers or commercial consumers of electricity and study their preferences, consumptions patterns and satisfaction etc.
- Research on the technological framework and the selection of communication systems, smart network topology may be carried out. Compatibility issues may be further explored and characterized, thereby making grounds for their solutions and deployment in future.

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ANNEXURE A

SURVEY QUESTIONAIRE FOR SMART GRID IMPLEMENTATION

INTRODUCTION

A research is being conducted to determine the feasibility and the right time to implement Smart Grid in Pakistan. A survey questionnaire is being delivered to you, your cooperation in filling this survey questionnaire would enable us to determine the right time to invest in the SMART Grid infrastructure. Your effort and engagement in helping us in this research would be very beneficial for the society in general and environment in particular. We would once again appreciate, for showing interest and taking time to fill this questionnaire.

What is Smart Grid

SMART Grid is a modern concept on the Electrical Utility Distribution Network. The conventional electrical Utility system has only one way interaction between the electricity grid and consumer. And it has very limited control on the distribution network resources. Whereas SMART Grid introduces a bidirectional interaction between consumers and electrical grid. Smart grid uses latest digital and communication technologies to improve the operational efficiency of electrical grid and minimize the overall cost of electricity for the consumers.

Smart Grid enables the consumer to allow utility service provider to have control of the consumer's power supply at consumer's energy meter level as well as appliances level. It encourages the consumers of electricity to voluntarily reduce the electricity load by switching off their appliances in times high power demand, in return of a monetary benefit. On the other hand, in times of low power demand, Smart Grid encourages the consumer to utilize more power on lower tariffs. Such features improves the capacity utilization which overall reduces the cost of electricity.

Smart Grid Benefits

1. It enables online automatic meter reading and billing.
2. It improves the operational efficiency of electrical utility service provider.
3. It reduces the cost of electricity.
4. It is more environment friendly.
5. It introduces "Time of use" billing. *(Rate of electricity price is dependent on the time of using electricity.)*

Monetary Benefits

1. The cost implied on meter reading and distributing bills is eliminated.

2. Per unit cost of electricity can be reduced by 10%.

Survey Questionnaire

1. Please write Your Name below:

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2. What is your monthly income?

(1) Less than 20,000 per month
(2) 20,001 to 100,000 per month
(3) 100,001 to 300,000 per month
(4) Above 300,000 Per Month
(5) Don't want to share

2. Electricity bill is based on, the amount of energy consumed and the rate at which one unit of energy is charged. The rate is dependent on the type of activity for which electricity is used i.e commercial, industrial or domestic/residential. Please select from the following the type of activity on which you receive bill from the utility company.

(1) Residential (Domestic user of electricity at home.)
(2) Commercial
(3) Industrial
(4) Don't Know

3. Every consumer of electricity has a certain amount of sanctioned load for their connection, which determines the maximum amount of power that can be utilized through this connection. This maximum amount of power is known as the sanctioned load. This is also mentioned on the electricity bill. Please select the sanctioned load of your connection from following options.

(1) Less than 50KW
(2) Above 50 KW
(3) Above 1500 KW
(4) Don't Know

4. What is your satisfaction level on the price of electricity? Please select from following

(1) Highly Satisfied
(2) Satisfied
(3) Neutral
(4) Not Satisfied
(5) Highly Not Satisfied

5. What is your satisfaction level on the service quality of electricity provided by the Utility Company?

   (1) Highly Satisfied
   (2) Satisfied
   (3) Neutral
   (4) Not Satisfied
   (5) Highly Not Satisfied

6. Do you think the bills received from Utility company are justified. Please select from following.

   (1) Strongly Agree
   (2) Agree
   (3) Neutral
   (3) Disagree
   (4) Strongly disagree

7. Please select the slab of bill you receive from the utility company during winters
   (1) Rs. 500 – Rs. 1000
   (2) Rs. 1000 – Rs. 3000
   (3) Rs. 3000 – Rs. 9000
   (4) Rs. 9000 – Rs. 25000
   (5) Rs. 25000 and above

8. Please select the slab of bill you receive from the utility company during summers.
   (1) Rs. 500 – Rs. 1000
   (2) Rs. 1000 – Rs. 3000
   (3) Rs. 3000 – Rs. 9000
   (4) Rs. 9000 – Rs. 25000
   (5) Rs. 25000 and above

9. When do you expect to invest on the Renewable Energy Solutions (e.g wind turbine, solar panels) for Your Premises?
   (1) 0 – 3 years
   (2) 3 – 6 years
   (3) never

10. Smart Grid has the capability to control the electricity supply at the consumer's energy meter level. If Smart Grid is implemented, would you allow the Utility Company to switch off your premises' Main Supply in return of a monetary benefit?
   (1) Yes
   (2) No
   (3) Not Sure

11. If you agree to allow utility company to switch off your load, which option from following you will select?

(1) 1 hour switch off with 10% discount on the month end bill
(2) 2 hours switch off with 15% discount on the month end bill
(3) 3 hours switch off with 20% discount on the month end bill
(4) 4 hours switch off with 25% discount on the month end bill
(5) 5 hours switch off with 30% discount on the month end bill

12. What is the proposed switch off time? Please select the most suitable switch off time from following options.

(1) 12 am – 9 am
(2) 9 am -5 pm
(3) 5 pm-9 pm
(4) 9 pm – 12 am
(5) None

13. What is maximum switch off time you can endure?

(1) None
(2) 0.5 – 2 Hours
(3) 2 - 5 Hours
(4) 5 - 10 Hours
(5) Unlimited

14. Would you allow the Utility Company to control the electric load of your house / office / industry's appliances (fridge, TV, computer, AC) by the help of Smart Grid Enabled Technology?

(1) Yes
(2) No
(3) Don't Know

15. Would you shift the use of your electric appliance to any other time slot on receiving a monetary benefit?

(1) Yes
(2) No

16. For how many hours a day you use Air-conditioning?

(1) none
(2) 3-5 hours
(3) 5-10 hours
(4) 10-16 hours
(5) all day

17. At what time of day you use AC?

(1) (9 pm – 6 am) Night only

(2) All day
(3) Occasionally

18. Would you reduce the thermostat of your AC for a particular time slot on receiving a monetary benefit?

(1) Yes any time.
(2) Yes sometimes
(3) Not Sure
(4) Never

19. Would you switch off your AC for a particular time slot on receiving a monetary benefit?

(1) Yes any time.
(2) Yes sometimes
(3) Not Sure
(4) Never

20. What type of lights you use for general lighting?

(1) Normal bulbs
(2) Energy Savers
(3) LED Bulbs
(4) Tube Light

21. Smart Grid is capable of automatically reading the energy meter readings and delivering this information online for automatic bill distribution. Do you think the manual method/procedure currently adopted by the utility company to receive bills from consumers should be replaced by online automatic meter reading system?

(1) Strongly Agree
(2) Agree
(3) Neutral
(3) Disagree
(4) Strongly disagree