Demand Response of Smart Grid using Dynamic Pricing

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Submitted By

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Certificate

I hereby certify that the matter which is being presented in the thesis report entitled, *"Demand response of smart grids using dynamic pricing"*, in partial fulfillment of the requirements for the award of degree of Masters of Engineering submitted in Computer Science and Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of *Dr. Neeraj Kumar*.

The work presented in this thesis has not been submitted for award of any degree of this or any other university.

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ABSTRACT

In flat-tariff structures we are free to use all of our electronic devices at the same per unit price throughout the day. Due to which, we fail to get the true cost of electricity generation and distribution. Dynamic pricing is a solution to this problem, where a consumer is charged various prices depending upon the demand load curve. Recent researches and Implementation of dynamic pricing of electricity is mostly restricted to block pricing in which the per unit rate of electricity increases or sometimes decreases after the consumption of a certain amount (block) of electricity. Since electricity consumption of every consumer is not same but the impact of increased price due to load shifting during peak hours affects each consumer equally. Hence we are proposing a new model of dynamic pricing where the increased price will be shared only among those users, who actually participate in unbalancing the demand supply curve, and not the one, whose electricity usage is bare minimum or below average.

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Chapter 1

Introduction

1.1 Traditional Electric Grid

An electrical grid comprises of an interconnected network for providing electricity from supplier end to consumers. It comprises of generating stations that provide electrical power, high-voltage transmission lines carrying power from distant sources to demand centers, and distribution lines connecting individual customers. The power stations are generally built near to a fuel source or a dam site, to access renewable energy sources, so they are generally away from places that have a heavy population. These are usually quite huge for taking advantage the economies of scale. The generated electric power is stepped up to a higher voltage and then connects to the electric power transmission network. The bulk power transmission network moves the power long distances, as far as international boundaries so as to reach the wholesale customer (generally the company owning local electric power distribution network). As it arrives at the substation, power is stepped down from transmission level voltage to distribution level voltage. It enters the distribution wiring on exiting the substation. After arriving at the service location, power is again stepped down from the distribution voltage to the service voltage(s) desired. Conventional electric power generation is done at central generating stations which are designed to produce electricity in a very efficient way. Despite its universal success, there are a number of drawbacks associated with this method. The traditional system needs a lot of transmission and distribution apparatus making use of 6-7% of all transmitted electrical power. Only 40% of the fossil fuels calorific value gets converted to electrical energy; the rest 60% is dispersed in the form of heat. A large proportion of the dispersed heat is of potential use but that is impractical because of the central location. To resolve the issues of the conventional power grid, a new concept known as smart grid has arisen.

1.2 Smart Grid

A smart grid is an electrical grid which makes use of a variety of operational and energy measures for example, smart meters, renewable energy resources, and energy efficient resources. Electronic power conditioning, production control and distribution of electricity are essential facets of the smart grid. It is a policy designed to keep up with the modernization our country's electricity transmission and distribution system so that reliability and security electricity infrastructure are maintained and future demand growth can be met to achieve the following objectives:

- Improvement in electric grid's efficiency by using digital information with control of technology.
- Complete cyber-security with dynamic optimization of grid resources.
- Deployment and incorporation of distributed resources along with their generation, with the use of renewable energy sources.
- Development and integrating demand response, demand-side resources, as well as resources which are energy efficient.
- Use of `smart' technologies (which are real-time and automated so as to optimize physical operation of consumer devices) for distributing automation, metering, communication operations related to the grid and status.
- Merging of `smart' appliances with consumer devices.
- Deployment along with merging of advanced electricity storage with peak shaving technologies, making use of plug-in electric and hybrid electric vehicles, and thermal storage air conditioning.
- Consumers are provided with up to date information.
- Development of communication standards as well as interoperability of appliances and equipment that are connected to electric grid, also involving the infrastructure concerning the grid.
- Identification along with reduction of the present hurdles to adopt smart grid technologies and practices.

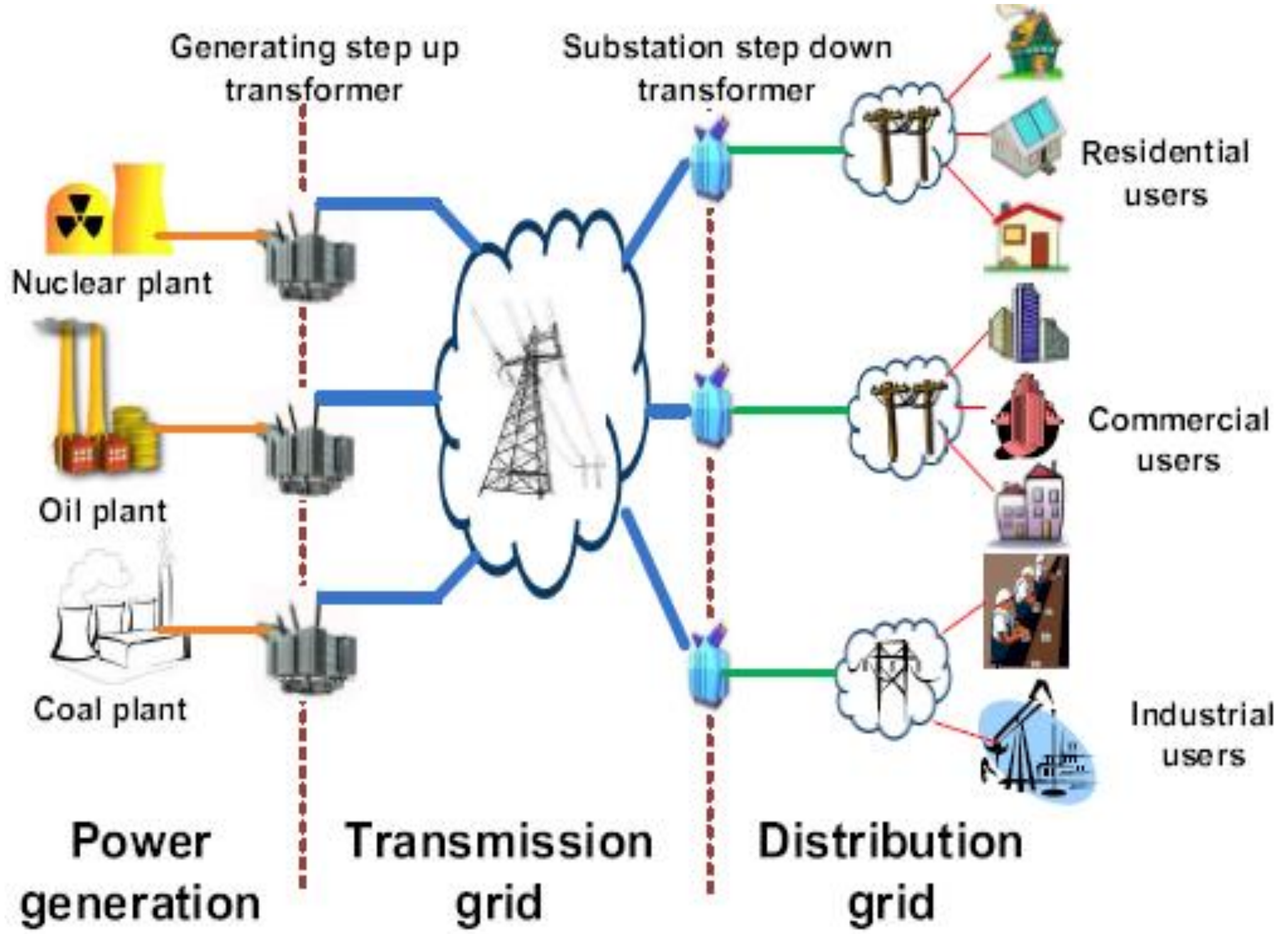

Fig 1: Smart Grid

1.2.1 Available Communication Technologies for Smart Grid

A communications system is an essential component of smart grid infrastructure. Using advanced technologies so that a smarter infrastructure infrastructure is attained, a lot of data from various applications is made use of for analyzing and applying real time pricing techniques. Hence, it is important that electric utilities predefine their communications requirements and apply the best cpossible infrastructure to monitor output data,making the system reliable, cost-efficient and secure. Two media of communication, i.e., wired and wireless that provide various technologies for communication can be used to transmit data between smart meters and electric utilities. For many cases, wireless communications have benefits over wired solutions, for example, Infrastructure cost is low and it is easier to connect to difficult areas. But signals may get attenuated owing to the path of transmission. Whereas, wired solutions have no interference problems and batteries do not define their functions, like wireless solutions. Information flow is defined by using two kinds of information infrastructure in a smart .The first kind of flow makes use of sensor and electrical appliances to smart meters while the second flow is from smart meters to utility data centers. Some of the technologies related to smart grid and their merits and demerits are summarized in the following section.

A. ZigBee

ZigBee is a wireless technology solution which has lesser power usage and complexity. It is ideal for monitoring energy, automating homes, automating meter readings etc. ZigBee Smart Energy Profiles (SEP) have been identified as the most appropriate standards of communication by the National Institute for Standards and Technology (NIST), U.S for the domain of smart grid residential network. ZigBee incorporated smart meters communicate with ZigBee integrated devices to control them. ZigBee SEP has options to send messages to the home owners who can obtain details about their real-time energy consumption.

Advantages: ZigBee uses a 2.4 GHz band with 16 channels, each having a bandwidth of 5 MHz. ZigBee is ideal for metering and other available options of energy management since it is simple, robust, deployment is less costly , requires less bandwidth, operates within unlicensed spectrum and network implementation is easy. ZigBee SEP provides benefits like load control, real time pricing, demand response, real time monitoring of systems for utilities gas, water and electricity.

Disadvantages: There are some restrictions in the implementation of ZigBee like smaller size of memory, lesser capability of processing, interference with those appliances which lie in that particular transmission medium, small delay requirements, license-free industrial, scientific and medical (ISM) frequency band varying from IEEE 802.11 wireless local area networks (WLANs), Wi-Fi, and Microwave. These troubles faced by ZigBee and noisy conditions make the channel prone to corruption because of the interference of 802.11/b/g in the circle of ZigBee. There is a need to implement detection and avoidance schemes for implementation by making use of energy efficient routing protocols. This helps to improve network performance and increase the network life-time.

B. **Wireless Mesh**

A mesh network comprises of a group of nodes such that new nodes can join and each one can act as an independent router. This network has a self healing character which helps signals to trace routes via other nodes in case a node drops out of the network. Every meter behaves as a repeater for the signal till data finds the electric network access point. The communication network helps to transfer data to the utility.

1) **Advantages**: Mesh networking is a cost effective solution with dynamic self-organization, self-healing, self configuration, high scalability services, which provide many advantages, such as improving the network performance balancing the load on the network, extending the network coverage range. Good coverage can be provided in urban and suburban areas with the ability of multi-hop routing. Also, the nature of a mesh network allows meters to behave as signal repeaters and addition of some repeaters to the network can be used to extend the network coverage and capacity. Some applications of wireless mesh technology are advanced metering infrastructures and home energy management.

2) **Disadvantages**: Network capacity and interference are some of the major issues faced by wireless mesh systems. These networks face a coverage

challenge in urban areas as the meter density is unable to give full coverage of the network. For reliable and flexible routing, a balance has to be created using enough quantity of smart nodes, taking node cost into consideration. These aspects are essential for mesh networks. Third party intervention is needed for network management, and as the metering information transmits through all access points and various encryption methods are used to provide security to data. Also, there could be loop problems when data packets move around many neighbors, leading to more hurdles in the communications channel, leading to in lowering of the available bandwidth.

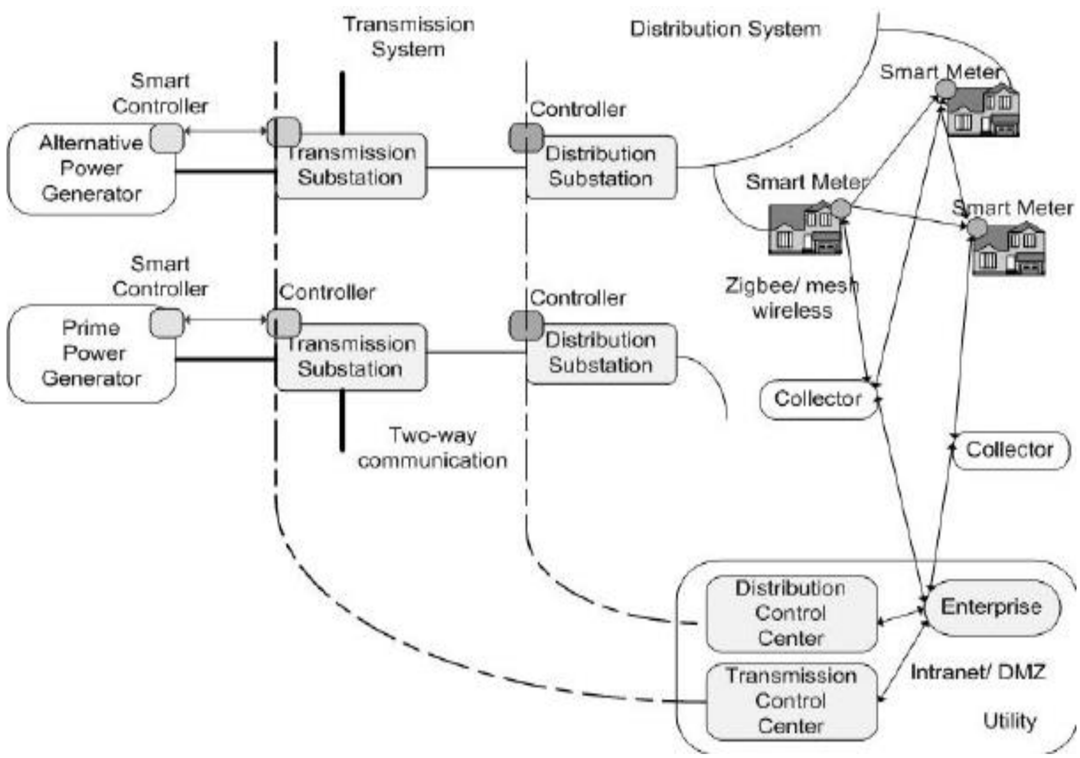

Fig 2: Smart Grid Communication

1.2.2 SMART GRID COMMUNICATIONS REQUIREMENTS

A two way communication is needed between the generation, transmission, distribution and consumption of energy. End to end secure communication, interoperability between applications and sufficient bandwidth are the prerequisites to this infrastructure. The system must be robust so that there are no cyber attacks and the whole system is in a stable and reliable state. The following section gives a summary of communication requirements for smart grid.

A) Security

Two important parameters for power utilities like billing and grid control are transportation and secure information storage[24]. Reliable security measures are needed to prevent cyber attacks. Various standardization measures related to the power grid security are needed.

B) System Reliability, Availability and Robustness

System reliability has become an important commodity of power utilities. Unreliability in power grid arises due to aging power infrastructure, peak demand and rising energy consumption. System reliability and robustness can be strengthened by using secure communication protocols, embedded intelligent devices(IEDs) for substations, feeders and consumer resources and robust control devices. The communication technology used affects the availability of such a communication structure. For large scale smart grid deployment, wireless technologies using restricted bandwidth and lower installation costs are a good option. Wired technologies with enhanced capacity and security are very expensive. Thus a hybrid communication technology is required to provide a balance of robustness, security, availability, appropriate costs and reliability. These hybrid systems are a mixture of wired and wireless technologies.

C) Scalability

A smart grid needs to be scalable to carry out the power grid operations. It can handle scalability by incorporating reliable protocols, web services,security aspects and improved functionalities lie self configuration.

D) Quality-of-Service (QoS)

One of the main issues in power grid is communication between power suppliers and customers. In case of performance degradation like delay or outage, there could be a compromise with stability. So a QoS mechanism is needed to fulfill requirements of communication (for example,high-speed routing) . A QoS routing protocol should be made use of in the communications network. The following questions are to be importantly answered in a smart grid.

- Defining QoS requirements with regard to smart grid.
- Ensuring that QoS requirement is fulfilled by the appliance in communication network.

The answer to the first problem lies in investigating mechanisms of power price on the basis of load dynamics. Using power price and appliance's utility function, a reward system is created for that appliance. The effect of delay and outage on the appliance's reward are calculated. Next, optimization of the reward is done is to find the QoS requirements.

Routing methodologies fulfilling the QoS requirements are made use of to answer the second question. As the heterogeneity of the smart grid requires high computing and storage capability, more than one QoS aware routing must be implemented within numerous(more than 2) boundaries and constraints. For the second question, routing methodologies satisfying the inferred QoS requirements are worked upon). A QoS requirement makes use of specifications such as average delay, probability of connection outage and jitter. For this, probabilistic dynamics of the system are needed to fulfill the QoS requirement. This helps to measure the impact various QoS specifications have on the smart grid system and hence QoS requirements can be gauged from the impact.

1.3 Demand Response

Demand Response programs are in existence for a long time and are perceived to be a very effective tool for organizations to monitor and manage system peaks by controlling customer loads. For non-industrial consumers, the demand response programs needed the direct load control of high load appliances at home namely AC systems, water heaters, and high voltage water pumps. These were mostly one -way systems working on signals sent via various channels e.g. power line communications, pager, energy management system and telephone etc. to the controlling devices. Upon receipt of controlling signals the controllers eventually turn off or cycle the identified appliance during peak usage. This mechanism helps the suppliers by offering them a better means to manage demand and supply, and in parallel the consumers profit from financial incentives for coordinating with the supplier through enrolling for program. The program has been successful in effectively managing the demand and is in wide practice. When we talk of Smart Grid, Department of Energy and other electricity suppliers clearly realize that an active participation from consumers towards Demand Response is a key variable contributing to its success. The Smart Grid systems are coupled with Advanced Metering Infrastructure (AMI) systems, these AMIs provide sound operational platforms for linking consumer response to Demand Response events. With the capability of communication over Internet, electricity-supplying companies can now empower consumers to manage system capacity by themselves. AMI deployment is one way to symbiotically work with the customers; companies are also using Smart Meter to connect to residential customers and are making sure that their distribution systems support Demand Response Program so that the consumers participate actively. Since last few years, AMI vendors have been aligning their existing systems to support this functionality through joint initiatives such as the ZigBee Alliance. The idea is to intelligently infuse into the meters a technological fusion of control network technology and wireless sensors so that the meters transform into a communicating gateway to all home devices connected to it. These devices serve two purposes at a time- notifying the customer of current energy usage and controlling any significant electrical loads in the house. Consequently, the Smart Meters and AMI networks working in tandem successfully offer monitoring and verification functionalities that allow suppliers to know which controlling devices were part of a Demand Response event and how much load was eliminated as a control measure.

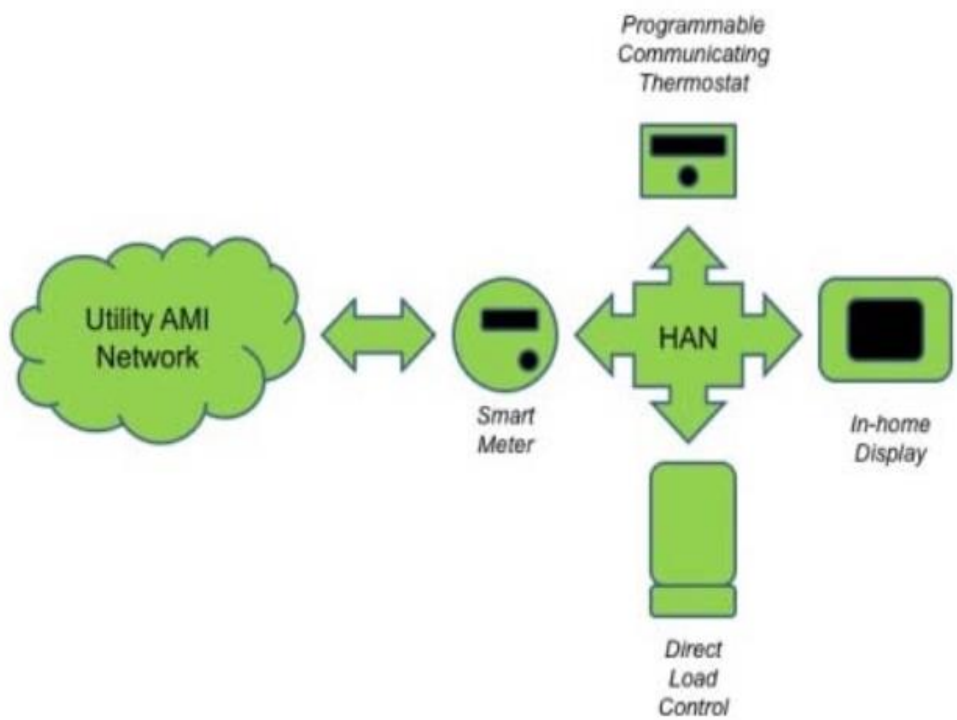

Figure: 4

There are many products easily available in the market, which enables residential customers to participate in such Demand Response programs. One can get these products from the local electricity supplying body or sometimes from consumer electronics outlets. An equipped and smart Home Area Network (HAN) can be created by installing direct load control devices primarily connected to high power consuming home appliances, programmable communicating thermostats (PCT) to manage various cooling and heating systems, and in-home displays (IHD) to show real-time energy consumption. These IHD also lets the user know of real-time electricity pricing if it's part of Demand Response program, they act like a multi-info device for them. Once the consumers setup HAN, utilities can connect to consumers in multiple ways. Prevailing Smart Grid implementations send signals to the meter through deployed AMI network, and then connect to the devices at home. Since it's a relatively new technology and utilities have been trying to involve more collaboratively with consumers as a breakthrough shift, quiet understandably it needs a significant effort and time to build trust and gain visible acceptance from consumers. Currently, limited trials are being conducted to validate its capabilities, various interconnectivity, and error free performance. Few early trials have actually used AMI vendor's in-house technology to communicate between the meter and HAN devices since there were not any industry standards available from governing bodies. Several Demand Response trials have been executed using ZigBee low - power wireless technology integrated into the Smart Meter, which then acts as the entry point into the HAN. The challenge with few trials was they were manufacturer specific, which means manufacturers control how data is defined and displayed for the HAN. A better alternative is to connect to the HAN without any system dependency on the AMI or on the Smart Meter. These alternate solutions can have gateway device connected to the consumer's Internet. In such arrangement, the HAN gateway can talk to the Smart Meter via ZigBee (or other commonly supported communication path), but the Smart Meter does not act as the gateway or HAN controller. With this solution, the Smart Meter only provides usage information to the HAN. Rest of the information, which may include control of devices for Demand Response events, or information provided to the consumer via an IHD may traverse directly to the HAN through this alternative Internet gateway. Figure - 4 demonstrates an example of a network showing connectivity from the AMI through an electric meter, and alternatively through a broadband gateway device.

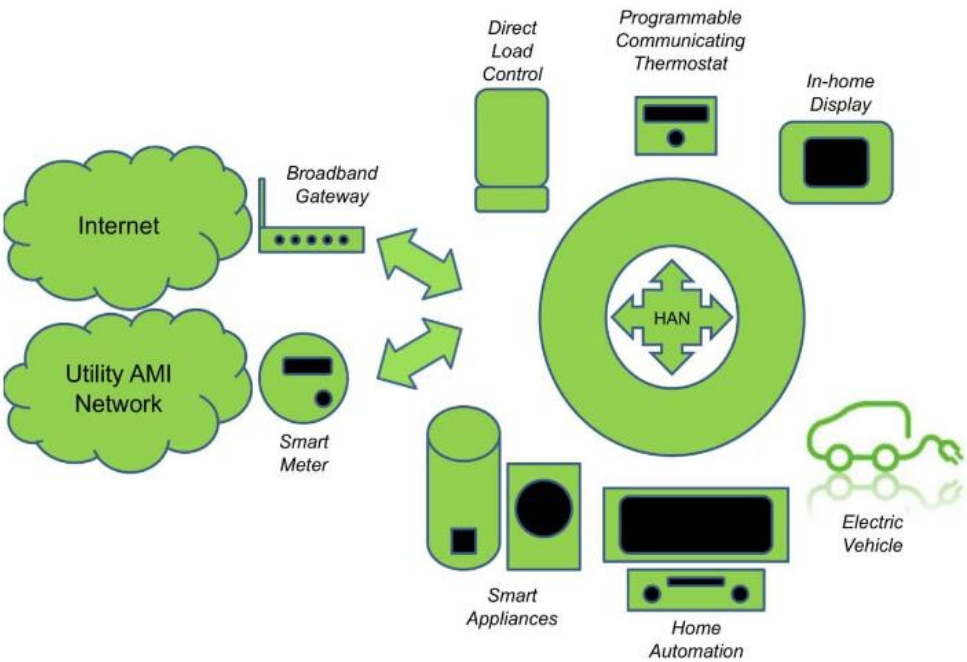

Figure 4: Connectivity from the AMI

1.4 Dynamic Pricing

Electricity prices can be broadly categorized into two types - static prices that do not change with a change in demand and dynamic prices that change with hanging demand situation. Although flat rates offer uncertainty-free electricity bills to customers, it may require costly capacity additions, most of which are environmentally harmful. Dynamic tariff structures have the potential to flatten demand profiles and thus help power suppliers to reduce expenditure on capacity addition and efficiently plan electricity generation and distribution. Dynamic tariffs also provide each consumer with an opportunity to reduce his/her electricity bill at a constant consumption level**.** Effective scheduling of electrical load can help consumers to reduce their electricity bills by increasing consumption when prices are low and reducing consumption when prices are high. Demand patterns and elasticity of demand vary from consumer to consumer and thus segmentation of the electricity market can prove to be helpful. Suppliers can offer suitable pricing schemes in properly segmented markets to boost their revenue. There are several issues related to dynamic pricing of electricity that are important in the event of a practical application of the concept. This section includes retail and wholesale pricing, demand and price forecasting, demand elasticity, consumer's willingness-to-pay, enabling technologies, market segmentation, and consumption scheduling. [12],[13],[14] and [15] describe various pricing schemes as mentioned below.

- **Flat tariffs**: Price remains static even though power demand changes. Consumers under such a scheme don‘t face the changing costs of power supply with a change in aggregate demand. Thus, consumers have no financial incentive to reschedule their energy usage. They don‘t face any risk of high value electricity bills for any unavoidable or unplanned electricity consumption. Hence this scheme is often used as a welfare pricing scheme.

- **Block Rate tariffs**: This scheme differentiates between customers based on the quantity f electricity consumption. The scheme consists of multiple tiers characterized by the amount of consumption. Inclining rate schemes increase the per-unit rate with increasing consumption and declining schemes do the opposite.

- **Seasonal tariffs**: These schemes observe different rates in different seasons to match the varying demand levels between seasons. Energy is charged at a higher rate during high demand seasons and the price lowers during low demand seasons.

- **Time-of-use (TOU) tariff:** These are pre declared tariffs varying during the different times of the day, that is, high during peak hours and low during off-peak hours. Such schemes can stay effective for short or long terms. This is also known as time-of-day (TOD) tariff.

- **Super peak TOU:** It is similar to TOU but the peak window is shorter in duration (about four hours) so as to give a stronger price signal.

- **Critical peak pricing (CPP):** This is a pricing scheme in which consumers are charged a high fixed rate during a few peak hours of the day and a discounted rate during the rest of the day. It gives a very strong price signal and enhances the reduction of excessive peak load.

- **Variable peak pricing (VPP):** This is quite similar to CPP with the only difference that the peak prices are not fixed, and vary from day to day. The consumers are informed about such peak prices beforehand.

- **Real time pricing (RTP):** This is the purest form of dynamic pricing and the scheme with the maximum uncertainty or risk involved for the consumers. Here the prices change at regular intervals of one hour or less and the consumers are made aware of the prices beforehand as per the design of the scheme.

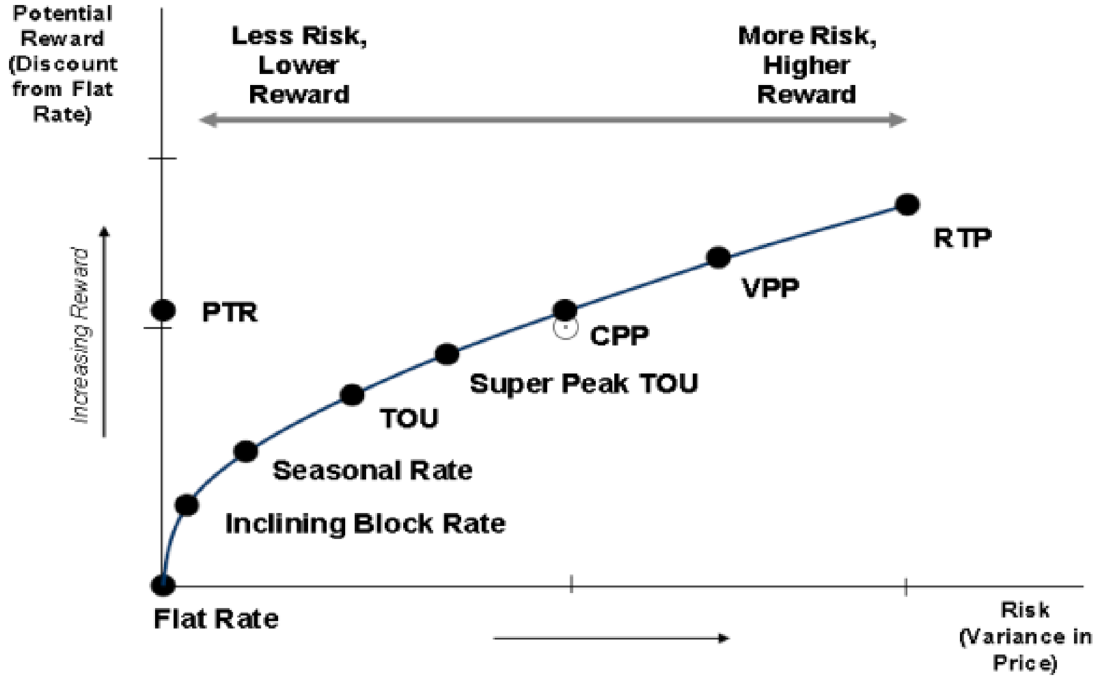

Fig 5: Time-Of-Use

Chapter 2

Literature Review

Electrical power grid has experienced no change in its structure since a 100 years. Hierarchical, centrally controlled grid and other conventional grids do no satisfy the needs of 21st Century. To handle issues of the traditional power grid, the novel approach known as smart grid has arisen. Smart grid is a modern electric power grid infrastructure which achieves better efficiency and reliability using automated control, better communication infrastructure, metering, sensing technologies and new techniques to manage energy using demand optimization, network availability etc. Though the existing power systems need solid information and communication infrastructure, a different and complicated approach is used for smart grids, since it works on a larger dimension [1]. Authors address important issues on smart grid technologies using information and communication technology (ICT) issues as well as opportunities. The author gives a look at the present scenario in smart grid communication. According to [2], smart grids are used to create an automated and distributed network of delivery using smart meters to allow two-sided flow of information as well as electricity between energy providers and consumers. This conversion provides greater demand response and gives a good flexibility to demand shaping with the help of time-dependent pricing (TDP). Electricity providers transfer all the price related information from the database to Energy Consumption Controller (ECC) unit placed at smart meters of consumers, as depicted in Fig. 1. Device activities can be scheduled by ECC to control energy consumption of consumer at reduced prices. A number of devices like vacuum cleaners, smart washing machines are becoming “intelligent” as they can be scheduled using manual as well as automatic means by ECC, and can be switched on or off based on the price ranges at different times. These innovations help electricity providers to obtain access to dynamic pricing effectively to match cost and revenues by attuning the peak demand , thus using resources better. Many works focus on the total demand across users at different times, but heterogeneity is not taken into consideration at device level [2]. Various time sensitivities are associated with different devices in shifting their electricity consumption (e.g. smart washing machines can stand a longer delay in the activity of scheduling, while smart ovens can stand very little delay). Also, author uses day-ahead time-dependent pricing against real time pricing, as consumer is very uncertain in the latter and this approach is not very attractive from the perspective of user adoption. Day-ahead time-dependent pricing helps them to plan what they want ahead of them and automated lightweight scheduling of activities can be done in an automated manner. Here author focused on pricing problem which sells energy to consumers directly rather than generation of electricity. Further, it is shown that his formulation of this problem is highly scalable a huge numbers of users overpricing periods. Moreover, the user behavior predictions help to determine formulations. [3] proposed a generic day-ahead demand side management (DSM) strategy for upcoming smart grid. In this paper, author makes use of load shifting to be used by smart grid's central controller. Objectives of the demand side management are maximizing the number of renewable energy resources being used, minimizing power obtained from main grid, and lowering peak load demand. Smart grid manager creates an objective load curve as per demand side management. The aim of proposed algorithm aims is to get the final load curve closer to the objective load curve in the best possible manner . For example, if the objective of DSM is to reduce the utility bill, an objective load curve inversely related to electricity market prices will be selected. According to [3], DSM has input as objective load curve and it computes required load control actions to satisfy required load consumption. A pre-defined control period is done in the beginning, which is typically a day. Then, real time execution is done based on the results. The proposed demand side management strategy schedules the connection moments such that load consumption curve and objective load consumption curve come closer to each other.

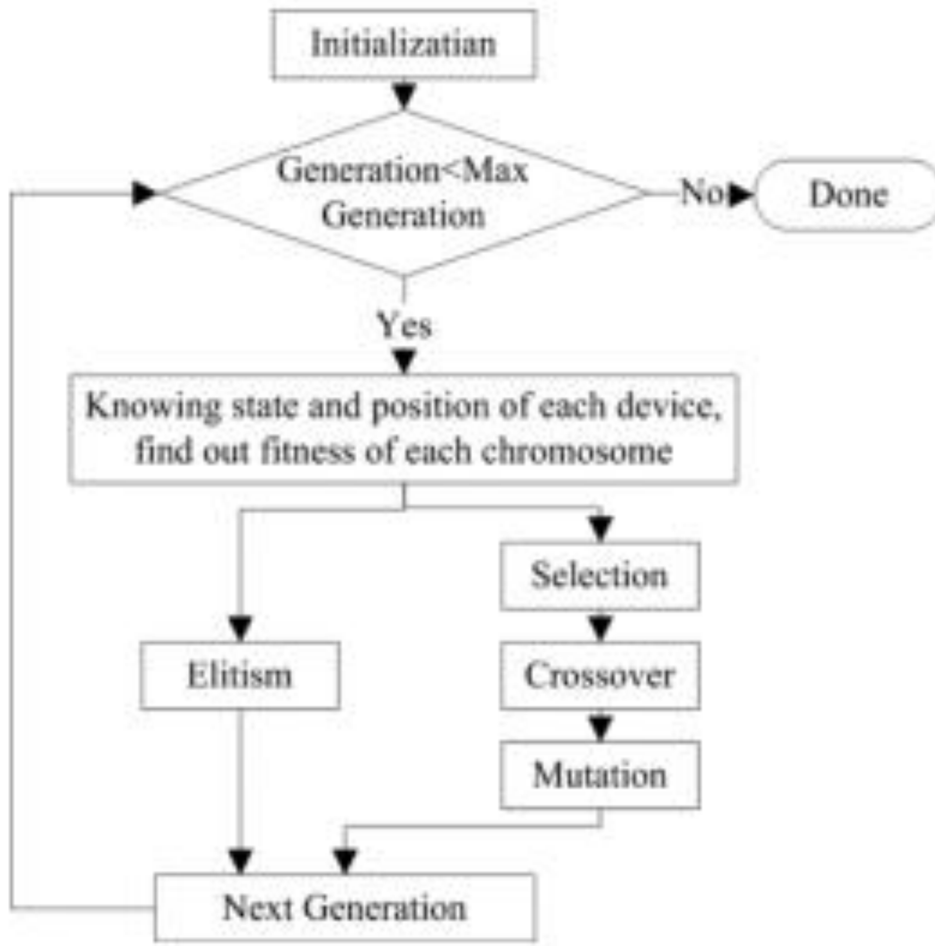

Figure 6. Proposed evolutionary algorithm

While in [4], demand response scheme of the second type was considered. Here author focused on a specific kind of dynamic pricing known as the day-ahead hourly pricing (DAHP). Under DAHP, the hourly retail prices of electricity are set one day ahead of the actual consumptions, thus giving a price certainty to consumers. DAHP also allows day-to-day adjustment of retailer prices. Also, the interactions between a retailer and its customers are also analyzed. A Stackelberg game model is used to obtain retailer-consumer interactions where retailer is the leader who sets the DAHP and the consumers adjust individual consumption. Apart from the demand response scheme using DAHP, [4] also they incorporated renewable energy and energy storage to see the effects. Further, when renewable sources are integrated, the retail profit at the social welfare optimizing DAHP is positive, making social welfare maximization potentially a viable operation objective. When the capacity of renewable integration is small then more benefit of renewable integration is obtained by retailer. Benefit increases as capacity increases. Authors of [5] mentioned smart pricing is one of the most efficient techniques among DSM tools which can help users to consume wisely. With the increase in energy prices,users take part in DSM programs and make an attempt to that the schedule of energy consumption of high-load household appliances gets shifted to off-peak hours to minimize cost. In [5], authors gave a new approach for DSM to consume energy efficiently to attain social objectives. But high compuattional complexity makes it hardto achieve them, if all appliances of users have joint schedules. Thus a top-down approach is given to control it.

First, every user's power consumption in every time slot is calculated. This is called user level control. Every user attempts to arrange his appliance's operation to match the desired consumption level of power. That is called appliance level control. This problem of scheduling power consumption is considered in [5]. They showed that attaining these targets is difficult also for user level control and needs gathering information related to energy consumption pattern of the users, the advantage user gets by consuming a specific quantity of energy. Generally users do not wish to share this information. So various design rules are needed to generate user's self interest. Authors of [5] give a VCG mechanism for DSM programs to for efficient energy consumption. Each user places his demand to energy provider. Using a centralized mechanism, the energy provider calculates the energy consumption level which is optimal for every user, and electricity payment is computed for each user. Many possible efficient management technique arise as smart grid takes shape. One of them is pricing of electricity. Presently, rate designs are not very flexible thus hiding the temporal variations in the electricity cost. Thus excess consumption at peak times, and very little consumption at off-peak times lead to inefficiencies. Matching demand and supply becomes difficult, affecting grid stability.In [6], the authors stated that Dynamic pricing of electricity helps to solve this issue by motivating consumers to delay their non-critical loads. Customers can delay the start time of dish-washers which has this option. But still a very little proportion of users make use of this and make use of the appliance late at night i.e. during the off-peak times. This is when dynamic pricing can make consumers cautious about the amount of electricity they consume and time, thus potentially flattening out peak-time system loads, increasing efficiency. In[6], a progression of concerned models was analyzed by considering how optimal dynamic prices are characterized in Smart Grid. It analyzed how optimal demand and supply could be achieved by interactions with spot market. While system reliability is a crucial factor affected by it, the requirement for regulation is increasing as mismatches between supply and demand are introduced by renewable variability. In [6], authors also handle payment for regulation by using conceptual pricing methodologies that enhance good performance. In [8], authors proposed a new load shaping strategy based on dynamic pricing in smart grids. In the proposed strategy, a consumer obtains required energy (i.e., quota) from the grid. As the real energy demand deviates, the consumer has to give a greater price of electricity. Using energy storage, consumer draws less electricity by discharging energy from grid at a reduced price as soon as demand becomes greater than quota and draws more electricity by charging energy when demand is much lesser than quota, at a lower price. Thus load shifting can be implemented and energy cost can be saved. Moreover, this strategy offers low complexity and works in a distributed manner, which provides scalability as number of consumers increase. Authors of [9] gave an intelligent pricing policy to obtain an optimal real-time price. As soon as real time price is obtained from micro-grids, a *plug-in hybrid electric vehicle* (PHEV) selects a micro-grid in an optimal way for the purpose of energy consumption. As the pricing policy is evaluated on home-price and roaming-price, an approach for decision making is selected to choose the optimal micro-grid thus maximizing the utilities of PHEVs. They also discuss how individual utilities can be maximized using the discharging process of the PHEVs. While in [10], a real-time DR algorithm is kept forward which helps to attain optimal load control for a number of devices by using rapidly updated Real Time Prices (RTPs). Devices purchase energy virtually from the Energy Management Center EMC who becomes virtual retailers and act in response to the announced Virtual retail prices (VRPs). The objective is to lower the daily expenses on electricity by formulating energy-consumption such that planning can be done in advance (e.g., for the next day). While in [11], it is shown that incorporation of different energy resources is a feasible option to improve performance of present DR programs. Coupling between various energy carriers helps customers to take part in DR programs by using load shifting and switching the consumed source of energy . It is known as integrated DR (IDR). This program is used in an energy hub in smart grids. This is known as smart energy (S. E.) hub. A modernized two sided communication network as well as technologies are used to shift data between the customers and respective utility companies. Customers can be active in the S.E hubs as they can convert one type of energy to the other in the IDR programs, say, the natural gas to some other form of energy, e.g., the electricity by making use of converters like micro turbine and gas furnace. From company's perspective, electrical load demand is minimized. From the customers' perspective, the amount of electricity consumed remains constant, but the source is switched to natural gas.

Chapter 3
Problem Statement

3.1 Gap Analysis

Implementation of dynamic pricing of electricity is mostly restricted to block pricing in which the per unit rate of electricity increases or sometimes decreases after the consumption of a certain amount (block) of electricity. Increased prices during the high demand can prevent the low income group from using the electricity even for small consumption like bulb, fan, etc. Current research lacks in providing a dynamic tariff scheme which can meet the requirement of all the class of groups. We must design the dynamic pricing scheme in a way where the low income group can also avail the minimum electricity even in the peak hours.

3.2 Problem Statement

Electricity consumption per month of every consumer is not same but the impact of load shifting during peak hours affects each consumer equally. Due to flat-tariff structures we are free to use all of our electronic devices at the same per unit price throughout the day. In turn, we fail to get the true cost of electricity generation and distribution.

3.3 Objective

We must design a new tariff plan which can help in maintaining the demand response curve. In case of peak hours where the curve is likely to unbalance, the class of users should not be affected who hardy contribute in increased load. The increased price should be shared among only those users whose electricity usage is more than the average for that particular time. There must be a mechanism to assure that the low income users should avail the minimum electricity to fulfill their daily need of electricity at the same price even in the peak hours where the chances of increasing the price is quite high.

3.4 Methodology

Main focus of the thesis is to improve the current pricing scheme which may help in maintaining the demand response curve for electricity used in homes using Dynamic Pricing. Additionally the use of dynamic pricing should not affect the class of users who don't contribute in unbalancing the curve. Our approach consist of the following steps:

- Classify the users on the basis of their monthly electricity usage
- Monitor the available load and required demand at a interval of 2 hours
- Calculate the current price for every class of users based on the demand load curve
- Distribute the increased price to the class of users whose usage for particular hour has unbalanced the curve

Chapter 4
Implementation and Results

We have classified the consumers in a different categories depending uppon their monthly usage. This classification can be further modified as per the need of the retailer and provider based on the loaction to location. This classification will provide us a brief idea about the total required consumption for a month. Which further, can help us in forcasting of the generation of electricity so that we can use the resources accordingly.

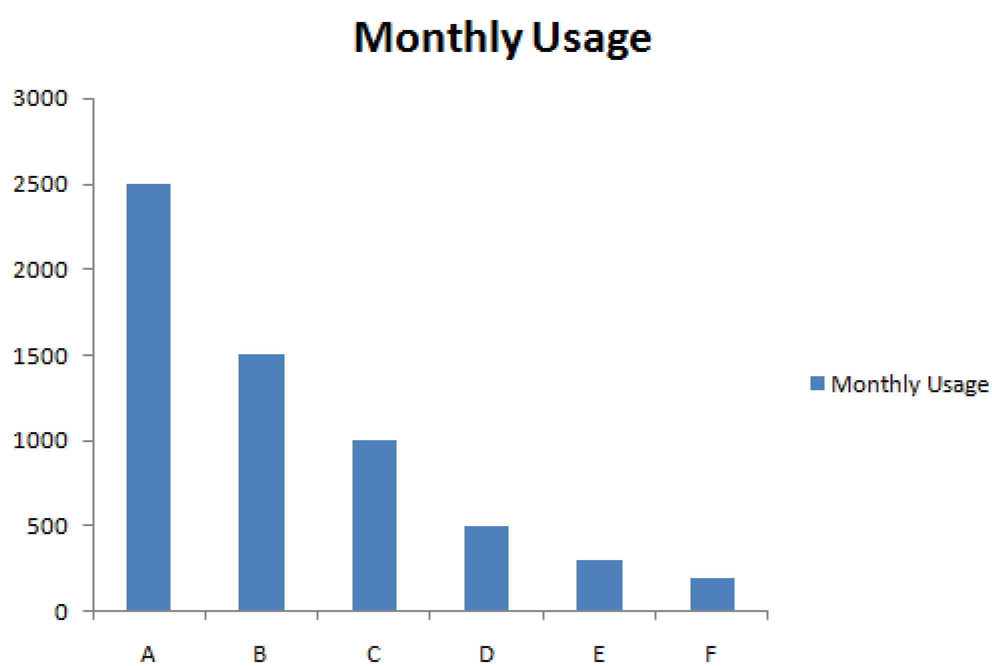

Fig: classification of users

4.1 Proposed Methodology

- The Base Price will be initialized by the electricity provider based on the cost of generation and distribution. It may change time to time.

- Every customer has to select their class before using the electricity, which can be modified in later stages
- Once the class has been selected, it has to be maintained for at least a period of one month
- Consumers will not be able to use the electricity beyond their limits of each class, which is predefined.
- The customers of higher class will be affected more due to change in price as compared to the customers of lower class
- Class F will be unaffected from any change in the price due to their low consumption
- The dynamic price will be calculated once in every two hours based on the demand response curve and it will remain unchanged.
- Consumers can further sell or purchase the electricity units from any users

4.2 Algorithm

Step1: Calculate the available *Load* **and requested** *Demand*

Step 2: Initialize *BasePrice*

Step 3: Calculate the *difference* **between** *load* **and** *demand*

Step 3: If *difference* **is equal to 0,**

CurrentPrice = *Base Price*

Step 4: If *difference* **is less than 0**

CurrentPrice = **reducedPrice(***load, demand, Class, member***)**

Step 5: If *difference* **is greater than 0**

CurrentPrice = **increasedPrice(***load, demand, Class, member***)**

Step 6: Print *CurrentPrice*

Step 7: *END*

Let T, D, B, ML, MP, SP and CP are the variables used for storing the values of Total Available Load, Total Demand, Base Price, Margin of loads, Margin of price, Share in Increased Price and Current Price respectively.

T = Total Load available, D = Total Demand

Demand can be calculated as follows, where the total demand for any particular hour is calculated by summing up the demands of each member of the respective class and then the summation of all the classes.

$$D = \sum \text{class A} + \sum \text{class B} + \sum \text{class C} + \sum \text{class D} + \sum \text{class E} + \sum \text{class F} \ldots\ldots \quad \text{(i)}$$

$$ML = T - D \quad \ldots\ldots \quad \text{(ii)}$$

$$MP = ML * B \quad \ldots\ldots \quad \text{(iii)}$$

$$\text{CP of class A} = \frac{MP * SP}{\text{Total members in class}} \quad \ldots\ldots \quad \text{(iv)}$$

4.3 Test Case: 1

Assumptions:

- *Total Available Load = 1000*
- *Current Demand = 1100*
- *Base Price = Rs. 5.00/unit*
- *There are 50 members in each class*

- *Consumers under Class A will be charged 30% more of the exceeded load*
- *Consumers under Class B will be charged 25% more of the exceeded load*
- *Class C users will be charged 20% more of the exceeded load*
- *Class D users will be charged 15% more of the exceeded load*
- *Class E users will be charged 10% more of the exceeded load*
- *Class F users will be exempt from increased price*

Total exceeded load will be multiplied by the base price in order to distribute the excess amount into various users of different classes as per the assumptions mentioned above.

$$\textbf{CP of class A} = \frac{MP * 0.30}{\textbf{50}}$$

$$\textbf{CP of class B} = \frac{MP * 0.25}{\textbf{50}}$$

$$\textbf{CP of class C} = \frac{MP * 0.20}{\textbf{50}}$$

$$\textbf{CP of class D} = \frac{MP * 0.15}{\textbf{50}}$$

$$\textbf{CP of class E} = \frac{MP * 0.10}{\textbf{50}}$$

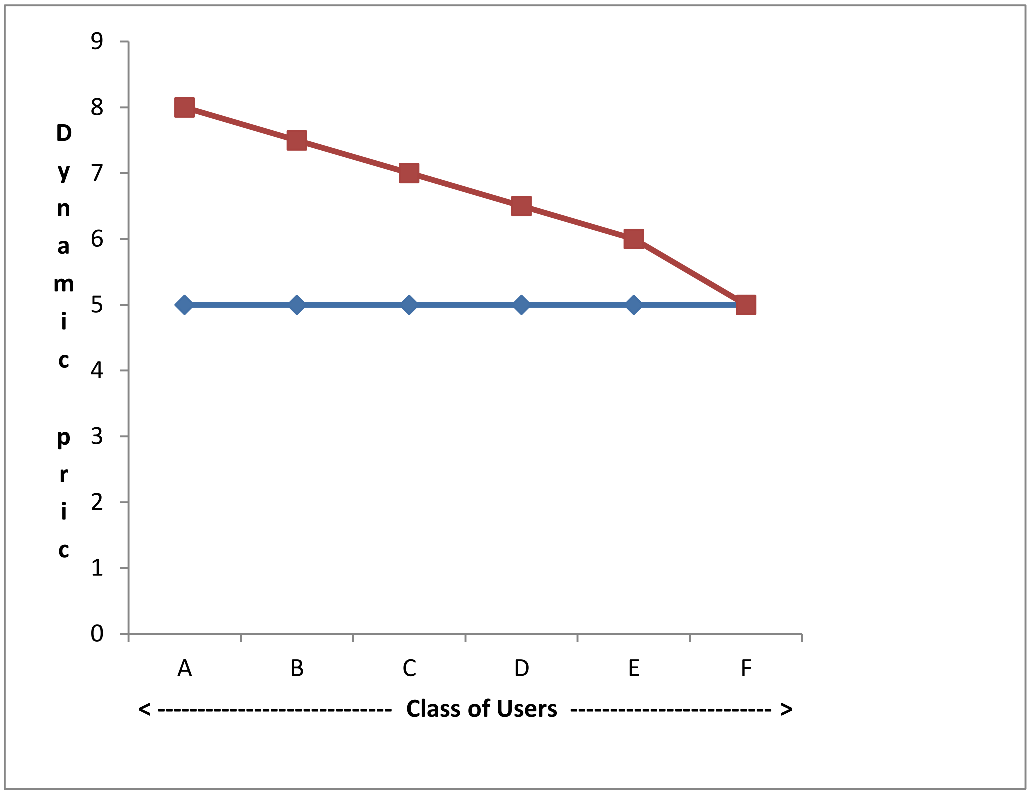

Fig 8: Dynamic price at peak time

4.4 Test Case 2

Assumptions:

- *Total Available Load = 1000*
- *Current Demand = 800*
- *Base Price = Rs. 5.00/unit*
- *There are 50 members in each class*
- *Consumers under Class A will get reduction of 30% of the demand supply load difference*
- *Consumers under Class A will get reduction of 25% of the demand supply load difference*
- *Consumers under Class A will get reduction of 20% of the demand supply load difference*
- *Consumers under Class A will get reduction of 15% of the demand supply load difference*
- *Consumers under Class A will get reduction of 10% of the demand supply load difference*
- *Class F users will have no effect on the decreased price as well*

ML = 1000 – 8000

= 200

MP = ML * B

= 200 * 5 = 1000

Total reduced load will be multiplied by the base price in order to distribute the saved amount into various users of different classes as per the assumptions mentioned above.

CP of class A = A - (MP * 0.30)/50

CP of class B = B - (MP * 0.25)/50

CP of class C = C - (MP * 0.20)/50

CP of class D = D - (MP * 0.15)/50

CP of class E = E - (MP * 0.10)/50

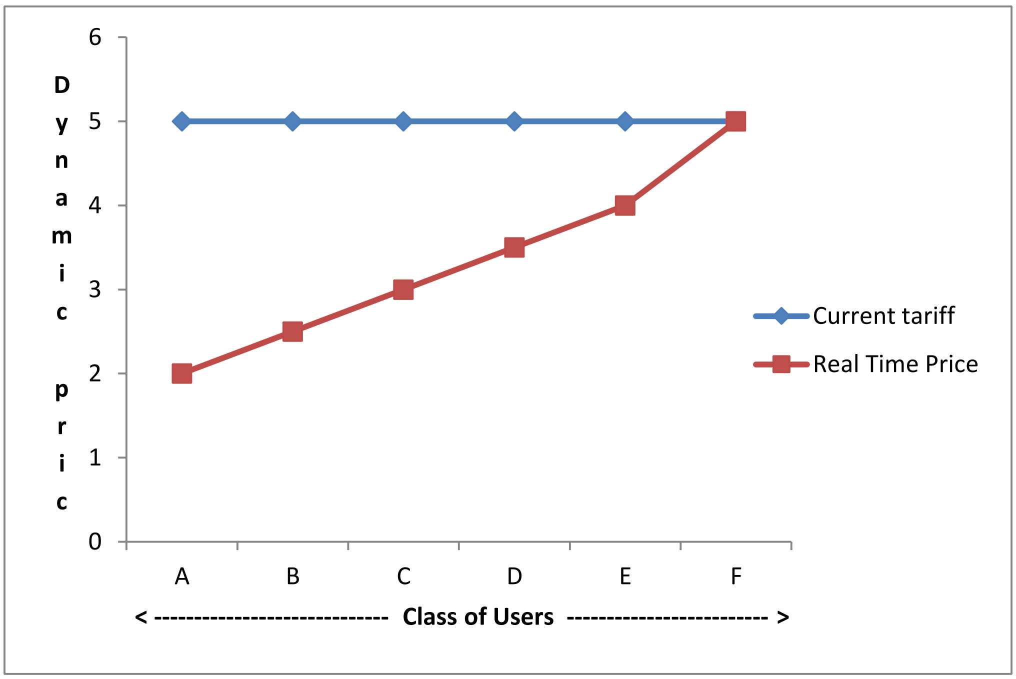

Fig 9: Dynamic price at off-peak time

Chapter 5
Conclusion & Future Scope

6.1 Conclusion

The discussions in this paper reveal the importance of dynamic pricing of electricity and its effects on demand response. Dynamic pricing has the potential to modify load profiles. The development and testing of enabling technologies is an ongoing process and there are several studies that reveal the usefulness of such technologies. This paper can help in drawing the attention of policy makers and electricity market players to the benefits of dynamic and customized pricing, demand mapping, segmentation for electricity markets and automation technologies.

6.2 Potential Areas for Future Research

There are interesting future research challenges that evolve from this study. These are noted in this section.

- Understanding the customer's willingness to adopt dynamic tariffs can be very helpful for further progress in this field. Dynamic prices have never been experienced in many electricity markets. Such markets can provide interesting research opportunities for discovering consumer's willingness-to-pay for electricity within a dynamic pricing environment. Results from such studies can help promote the idea to more number of customers and suppliers.

- The impact of dynamic pricing increases with the increase of elasticity and hence the most elastic portion of the demand curve in any electricity market is worth identifying. Determination of the demand price relationship for consumers is challenging, especially when such efforts are to be made at the individual household level. Factors influencing electricity demand change from consumer to consumer. Identification of such factors in different markets is necessary for implementing dynamic prices. Experiments to identify electricity market segments and suitable pricing schemes for each segment are necessary to get more benefits from dynamic pricing.

- Academic research on electricity market segmentation in India and many other economies is rare. Such efforts can open up avenues for better revenue management in electricity markets. Discovery of market segments must be followed by development of suitable pricing schemes. Possibilities need to be analyzed to shift from segment based pricing to individual customized pricing, thereby enabling the markets to better absorb consumer surplus.

- Carefully designed retail pricing schemes can appropriately link the wholesale and retail markets. Pricing schemes should be researched to form the standard for pricing designs so that neither are the customers exploited nor do suppliers experience loss.

- Smart grid technology can enable automated scheduling of household loads. Automation is possible with the development of scheduling algorithms. Researchers can keep on developing more realistic scheduling algorithms with different objectives for different customers. On the technological side, the type of enabling technology required in any particular market and the technological and financial feasibility study for the same can be studied.

- The environmental and social impacts of shifting from a flat rate tariff to a dynamic tariff scheme are worth studying in order to popularize the idea of dynamic pricing. The advantages and disadvantages of introducing dynamic pricing to different classes of society must be studied before practical implementation.

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