LOAD SCHEDULING ALGORITHM BY USING TIME OF USE AND REAL TIME PRICING METHODS TO MINIMIZE PEAK LOAD AND ELECTRICITY COST

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of

Master of Electrical Engineering, 2016

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CERTIFICATE

This is to certify that this dissertation entitled “**Load Scheduling Algorithm by Using Time of Use and Real Time Pricing Methods to Minimize Peak Load and Electricity Cost**” has been carried out by **SUBHO PAUL** under our guidance and supervision and be accepted in partial fulfilment of the requirement for the degree of **Master of Electrical Engineering.** The project, in our opinion, is worthy of its acceptance.

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CERTIFICATE OF APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject and presented in a manner satisfactory to warrant acceptance as pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn there in but approve the thesis for which it is submitted.

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I certify that except where due to acknowledgement has been made; the work is that of the candidate alone. This thesis is a presentation of my original research work and has not been submitted previously, in whole or in part, to qualify for any other academic award. Furthermore, the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program.

The work was done under the guidance of Professor (Dr.) Swapan Kumar Goswami and Assistant Professor Madhumita Mandal, Electrical Engineering Department of Jadavpur University, Kolkata.

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ABSTRACT

As the electricity demand is increasing day by day but in contrary the amount of fuel is reducing, so it becomes very critical to supply the total demand and the losses. As the transmission and distribution losses are negligible compared to the total demand so proper load scheduling is a very essential work to be done for every utility to minimize their electricity production cost and also to maintain certain spinning reserve. Also the load profile in a particular day is not a flat curve so the generators will not run economically and this would increase the start up and running costs of the units. Sometimes cases may occur when the total demand is much higher than the total available generation and that time load curtailment is the traditional way adopted by the utilities to solve this situation but load shedding always increases the customers' dissatisfaction, so it is not a user friendly solution for the excess demand problem.

In this work instead of using load shedding operation we use load shifting method, used by utilities, to just shift the amount of peak load to the off-peak hours to flatten the load curve. Load shifting operation of the controllable loads is done in time of use (TOU) pricing environment and the objective is to reduce electricity cost and the peak load demand by using Differential Evolution (DE) Optimization Technique.

As in case load shifting the utilities will not consider the customers' preference to use their appliance at their suitable time and customers' cannot participate into the DSM strategy we proposed a load scheduling algorithm in real time pricing environment where customers' will schedule their controllable appliances in such a manner by using Harmony Search (HS) optimization technique which results a reduced electricity bill. The utilities will be also benefitted because due to this algorithm the peak to average ratio is also reduced.

Both the proposed load scheduling methods are implemented into a real time data of a smart grid with residential, commercial and industrial load data. Here it is investigated which of the above two methods is best in which area and how much the electricity cost and peak load have been reduced in both cases in each area.

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LIST OF SYMBOLS USED

1. DSM: Demand Side Management
2. PAR: Peak-to-Average Ratio
3. TOU: Time of Use Pricing
4. RTP: Real Time Pricing
5. ANN: Artificial Neural Network
6. $Pload(i)$: Actual Load at any time interval 'i'
7. $forecasted(i)$: Forecasted Load at any time interval 'i'
8. $Objective(i)$: Objective load at any time interval 'i'.
9. $connect(i)$: Connected load at time interval 'i'
10. $disconnect(i)$: Disconnected load at time interval 'i'
11. P_{1j} = Power Consumption by device type j at its 1st hour of operation
12. X_{cji} = Number of devices of type j shifted to time interval i.
13. X_{dji} = Number of devices of type j shifted from time interval i.
14. DE: Differential Evolution Optimization Technique
15. Cr : Cross-over rate
16. F : Mutation Rate
17. L_{peak} : Peak Load of the System
18. L_{Avg} : Average Load of the System
19. HS: Harmony Search Optimization Algorithm
20. HM: Harmony Memory
21. HMS: Harmony Memory Size
22. HMCR: Harmony Memory Consideration Rate
23. par : Pitch Adjustment Rate
24. N I: Maximum Number of Iterations
25. rand: Random Number Generation

CHAPTER 1: INTRODUCTION

1.1Thesis Motivation:-

The utility power sector in India has an installed capacity of 298 GW as of 31 March 2016. Renewable power plants constitute 28% and non-renewable power plants constitute the remaining 72% of total installed capacity. The gross electricity generated by utilities is 1,106 TWh (1,106,000 GWh) and 166 TWh by captive power plants during the 2014–15 fiscal. During the fiscal year 2014-15, the electricity power generated in utility sector is 1,030.785 billion KWh with a short fall of requirement by 38.138 billion KWh (-3.6%) against the 5.1% deficit anticipated. The peak load occurred was 141,180 MW with a shortage of requirement by 7,006 MW (-4.7%) against the 2.0% deficit anticipated. In a May 2015 report, India's Central Electricity Authority anticipated, for the 2015–16 fiscal year, a base load energy deficit and peaking shortage to be 2.1% and 2.6% respectively. Southern and North Eastern regions are anticipated to face energy shortage up to 11.3%. The marginal deficit figures clearly reflect that India would become electricity surplus during the 12th five-year plan period. By the end of calendar year 2015, India has become power surplus country despite lower power tariffs.

Now this power deficit occurs due to unplanned load scheduling. If the demand increased from the present generation, utilities used to adopt two ways- first they will increase their generation capacity by either starting a new unit or increasing fuel supply to the already running units, not running at their rated value, secondly utilities go for load curtailment. First method increases overall electricity production cost and second one increases the customers' dissatisfaction. To get rid of this unwanted situation proper planning of load is needed that the peak demand of the system is reduced and also the overall electricity production cost will be minimum.

To achieve this aim load scheduling options have come out where the utilities will take certain measures to keep the system load in a prescribed limit by fulfilling all the generation and load side constraints and this measure should also be acceptable to the users. Load scheduling means properly manage the use time of the loads whose operation is not strictly depends on use time.

1.2 Thesis Objective:-

The objective of this work is to design algorithms for proper load scheduling. Here two algorithms have been proposed.

First one is only for utilities and the load scheduling is done by load shifting operation i.e. the utilities will schedule the loads and shift the loads from peak hours to off-peak hours to reduce their electricity generation cost as they are using time of pricing technique and to reduce the system peak to flatten the load curve, that the generation scheduling will be easier.

Second algorithm is established on data interchanging between the users and the utilities and the success of this algorithm is dependent upon both. Here real time pricing technique is used to bill the users and the cost function is a convex one. Here also a new penalty imposing criteria has been introduced which is applicable to every load pattern. Here the utility will inform the user about their current electricity bill and to minimize it user itself will reschedule its appliances.

The proposed methods have been implemented on a smart grid load data where residential, commercial and industrial users are present to mainly minimize system peak load and electricity cost. The effect of applying the above mentioned algorithms have been studied in those three areas.

1.3 Thesis Outline:-

This thesis is divided into 6 chapters-

The motivation for this thesis and the objectives that are aimed to be achieved are addressed in Chapter 1.

Chapter 2 presents an overall idea of the theoretical aspects used in this thesis like conventional power system followed by the new modified smart grid system, a brief idea on demand side management technique, electrical loads and different pricing techniques.

Chapter 3 describes some research works that has already been done on this research area.

The 4th chapter describes about the proposed load shifting algorithm for load scheduling adopted by utilities using time of use pricing technique. The proposed algorithm is then applied to a smart grid load data to minimize system peak and electricity cost by using Differential Evolution Optimization technique.

Chapter 5 deals with the second type of load scheduling algorithm using real time pricing technique which is adopted by both users and the utilities. Utilities accept it to reduce system PAR and users accept it to reduce their total electricity bill by using Harmony Search Optimization Technique. The designed algorithm is tested on the same smart grid load data.

The final part of the thesis, Chapter 6, provides conclusion of the total thesis work and offers suggestions for future research work.

CHAPTER 2: THEORETICAL OVERVIEW

2.1 Conventional Power System:-

2.1.1 Introduction:

An electric power system is a network of electrical components used to supply, transfer and use electrical power. An example of an electric power system is the network that supplies at homes and industries of a region with power—for sizable regions, this power system is known as the grid and can be broadly classified into the generators that supply the electrical energy, the transmission system that carries the same from the generating centres to the load centres and the distribution system that feeds the power to nearby customers. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. The major portion of these systems is based on three phase AC power—standard for large-scale power transmission and distribution across the modern world. Specialised power systems that do not always rely upon three-phase AC power are found in aircraft, electric rail systems, ocean liners and automobiles.

Electrical power system is mainly divided into major three stages- Generation, Transmission and Distribution as shown in Fig. 2.1

Generation- Electricity is produced at power plants (also referred to as generating station) by converting any form of energy (mechanical, thermal, solar etc.) into electrical energy. A prime mover, such as a turbine, provides the mechanical power to a synchronous generator in order to produce electricity. Nuclear power plants use nuclear fuel. Some other plants use non thermal sources such as hydraulic, wind turbines and photovoltaic cell. Thermal, Hydro and Nuclear power are the main source of electricity on current days and generally located away from the load centre in the rural areas. These plants generally produce electricity at 11 KV voltage level. Electricity is generally produced at low voltage due to insulation requirement and practical design limitations. The generation plants are then connected to transmission networks through generating substations, where electrical power is stepped up to a higher voltage to be transported over long distance through transmission lines.

Transmission- The transmission level is divided into two parts: primary transmission and secondary transmission systems. The generation voltage is too low for transmission over long distance. It is therefore stepped up by means of step-up transformers. The primary transmission system transfer power from generating substation to secondary transmission systems at voltage levels of 220 KV and above. The operation of secondary transmission system is similar to distribution system. It differs from a distribution system in a way that secondary transmission system operates at higher voltage of 66KV to 132 KV and supplies bigger loads. From secondary transmission level power is transmitted to distribution sub-station. High Voltage transmission is needed as it will increase the power delivery level and also reduce the transmission loss as transmission loss is inversely proportional with the voltage level.

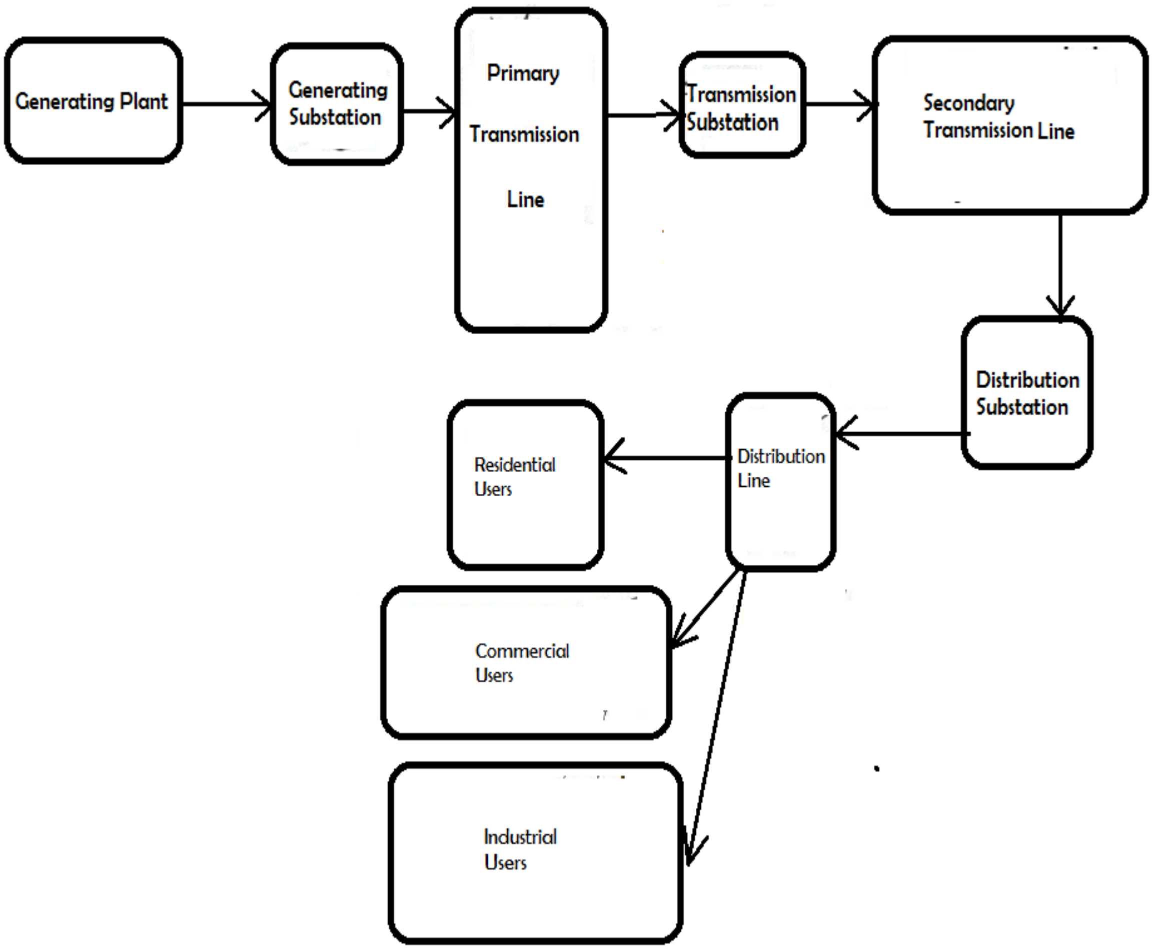


Figure 2.1: Lay-out of Conventional Power System

Distribution- The component of an electrical power system connecting all the consumers in an area to the bulk power source is called a distribution system. It is totally an interconnected system and may be of single phase and three phase. It is the stage of delivering electricity to consumers. This stage is divided into two parts, primary distribution and secondary distribution. At primary distribution stage, voltage is stepped down from 66KV or 132KV to 11KV or 33KV. Then, it transmits the power from the distribution substation to the distribution transformers. Some industrial customers are served directly from the primary distribution system. At secondary distribution level, the distribution transformers step down the voltage again to utilization levels i.e. 415V for 3 phases and 230V for single phase. The secondary distribution network is either overhead or underground.

2.1.2 Drawbacks:

Today's electrical grid suffers from various types of problems, such as-

1. **Old-** The average age of a thermal power plant is 35 years, so now the running plant units become very old.
2. **Dirty-** As most of the electricity demand is fulfilled by thermal power plants where coal is the main fuel increases more carbon emission, ashes.
3. **Inefficient-** As the transmission and distribution losses are increasing the delivered efficiency is only 35%.
4. **Vulnerable-** As the total grid is an interconnected system so any disturbance at any place may affect at other place also.

2.2 Modern Power System-Smart Grid:-

2.2.1 Introduction:

Smart Grid [1], [2] & [3], is the modernization of the electricity supply system so that it automatically monitors, protects and optimizes the operation of its interconnected elements-from the centralized and distributed generator through the high and/or voltage transmission and low voltage distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices. Smart grid integrates the information and communications system into electric transmission and distribution networks. The smart grid in large sites is the intersection of energy, IT and telecommunication technologies. The smart grid (Fig. 2.2) supplies electricity to consumers using two-way digital communication technology to enable the more efficient management of consumers' end uses of electricity as well as the more efficient use of the grid to identify and correct supply demand-imbalances instantaneously and detect faults in a "Self-healing" process that improves service quality, enhances reliability and reduces expenditure.

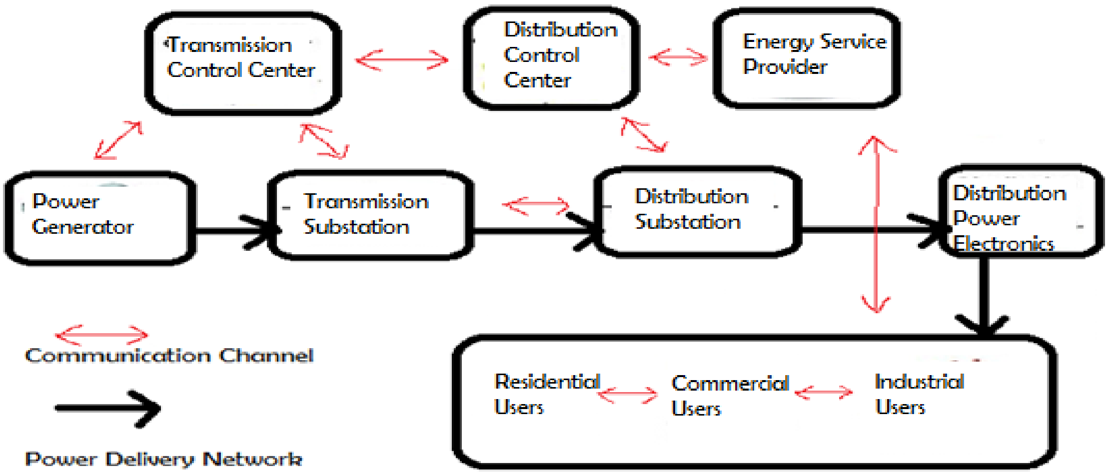


Figure 2.2: Schematic Diagram of Smart Grid

2.2.2 Components:

a. **Intelligent Appliances-** capable of deciding when to consume electricity based on pre-set customers' preferences. This can lead a long way toward reducing peak demand which has a major influence on electricity generation cost- reduce the need of new power plants and cutting down on damaging greenhouse emissions. Early tests with smart grids have shown that consumers can save up to 25% on their energy usage by simply providing utilities with information on that usage and the tools to manage it.

b. **Smart Power Meters-** featuring two way communications between consumers and power suppliers to automate billing data collection, detect outages, wastage of power and dispatch repair crews to the correct location faster.

c. **Smart Substations-** that include monitoring and controlling of critical and non-critical operational data such as power factor performance, breaker, transformer and battery status, security, etc.

d. **Smart distribution-** it is self-healing, self-balancing and self-optimizing including superconducting cables for long distance transmission, and automated monitoring and analysis of tools capable of detecting or even can predict cable and line failures based on real-time data about weather, outage history etc.

e. **Smart generation-** capable of "learning" the unique behaviour of power generation resources to optimize energy production, properly evaluating the optimum generation schedule and to automatically maintain voltage, frequency and power factor standards based on feedback from multiple points in the grid.

f. **Universal access-** to afford, low-carbon electrical power generation (e.g., wind generators, concentrating solar power systems, photovoltaic panels) and storage (e.g., in batteries, flywheels or super-capacitors or in plug-in hybrid electric vehicles).

2.2.3 Technologies:

a. **Integrated Communications-** includes data acquisition, protection, control, and enable customers to interact with intelligent electronic devices in an integrated system. Communication infrastructure would comprise of-

- Power line carrier (PLC) communication system
- Wireless radio
- Advanced metering infrastructure (AMI)
- Home Area Network (HAN)/ Local Area Network (LAN)
- Fibre optic network

b. Sensing and Measurement- It supports acquiring data to evaluate the health and integrity of the system and support automatic meter reading, elimination of billing estimates, and prevent energy theft. Sensing and Measurements include-

- Current Transformer (CT)
- Voltage Transformer (VT)
- Phasor Measurement Unit (PMU)
- Smart Meter
- Temperature, Pressure and acoustic and so on.

c. Advanced Components- are used to determine the electrical behaviour of the grid and can be applied in either standalone applications or connected together to create complex systems such as micro grids. The success, availability, and affordability of these components will be based on fundamental research and development (R&D) gains in power electronics, superconductivity, materials, chemistry, and microelectronics. These components are-

- FACTS Controller
- HVDC
- New Energy Storage Technologies
- Distributed Generation
- Reclosoures, automatic switches, breakers, switchable shunts, on load tap changers and so on

d. Advanced Control Methods- are the devices and algorithms that will analyze, diagnose, and predict grid conditions and autonomously take appropriate corrective actions to eliminate, mitigate, reduce wastage of power, loss and prevent outages and power quality disturbances. Advanced control algorithm includes-

- Wide area monitoring and control,
- Micro grid management
- Distribution load balancing and reconfiguration
- Demand Response
- **Demand Side Management**
- Optimal Power Flow
- Voltage and VAR optimization

- Fault detection, identification and recovery
- Automatic Generation Control
- Inter area oscillation damping

e. **Improved Interfaces and Decision Support-** converts complex system data into information that is more useful for grid operators. Improved interfaces and decision supports will utilize instantaneous measurements from PMUs and other sources to drive fast simulations and advanced visualization tools that can help system operators to access dynamic challenges.

2.2.4 Advantages:

a. **Self-Healing-** A smart grid automatically detects and responds to routine problems and quickly recovers if they occur, minimizing downtime and financial loss.

b. **Motivates and Includes the Consumer-** A smart grid gives all type of consumers like industrial, commercial, and residential, visibility into real-time pricing, and affords them the opportunity to choose the volume of consumption and price that best suits their needs.

c. **Resists Attack-** A smart grid has security built-in from the ground up for security purpose.

d. **Provides Power Quality for 21st Century needs-** A smart grid provides power free of sags, high voltage spikes, noise disturbances and current or voltage interruptions. It is suitable for use by the data centres, computers, electronics and robotic manufacturing that will power our future economy.

e. **Accommodates All Generation and Storage Options-** A smart grid enables "plug-and-play" interconnection to multiple and distributed sources of power and storage (e.g., wind, solar, battery storage, etc.)

f. **Enables Markets-** By providing consistently dependable coast-to-coast operation, a smart grid supports energy markets that encourage both investment and innovation.

g. **Optimizes Assets and Operates Efficiently-** A smart grid enables us to build less new infrastructure, transmit more power through existing systems, and thereby spend less to operate and maintain the grid.

2.3 Demand Side Management (DSM):-

2.3.1 Definition:

Demand side management strategy is a modern control technique of smart grid. This helps the utility to control its load pattern and also helps the customers to use the electricity in an efficient way to minimize the electricity payment bill. This process depends on two-way communication where user will inform the utility about their load pattern over a certain period of time and the utility will reschedule the load on his own or with the help of users. The main objectives of demand side management is reducing the peak load during peak hours to flatten the load curve by various methods and reducing the total electricity cost to minimize the electricity bill of the users and maximize the profit of the suppliers. The impacts of DSM is forecasted based on various factors like environmental conditions, economic approach, customers' attitude etc. and it is better illustrated in [4].

2.3.2 Different DSM Methodologies:

Reduction of peak load or smoothening of the non-uniform distribution of load among the time period can be done either by reduction of the load at peak load period or by increasing the load at off-peak load period. Based on the required objective [5], of the utility the DSM can be done by following six methods-

a. **Peak Clipping-** Peak clipping [6] is the mostly used and conventional method among all DSM methodologies. This is also known as direct load control (DLC) scheme used by the utility to reduce the system peak and the electricity purchase at the time of peak load. One of the DLC methods adopted by utilities is load shedding. This method is only used when the peak of the load occurs by clipping the peak.
b. **Valley Filling-** It is the second type of DSM method used when the long run incremental cost is more than the electricity charges. Here also a direct load control scheme applied to add more load during off-peak load by introducing storage systems.

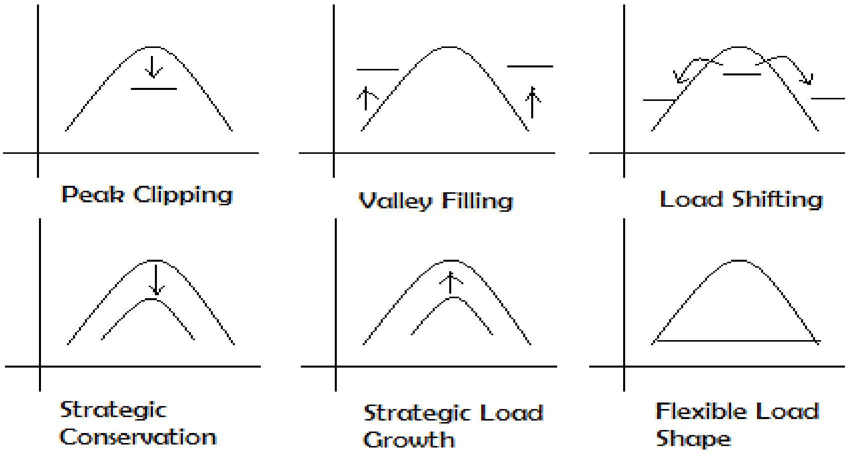


Figure 2.3: Demand Side Management Methodologies

c. **Load Shifting-** Load shifting is the third and most efficient DSM method in the distribution networks where the load is shifted from the peak hours to the off-peak hours. Here the load is shifted to reduce the electricity production cost and to fulfil the demand with the existing power installation keeping the required spinning reserve during the peak hours.

d. **Strategic Conservation-** Strategic Conservation is the load-shape change that results from utility-stimulated programs directed at end-use consumption. The change shows a modification of the load pattern involving a reduction in sales. In employing energy conservation, the service provider must consider what conservation actions would occur naturally and then evaluate the cost effectiveness of possible intended utility programs to accelerate or stimulate those actions. Examples include weatherization and appliance efficiency improvement.

e. **Strategic Load Growth-** Strategic Load Growth is the load-shape change that refers to a general increase in sales, stimulated by the utility, beyond the valley filling. Load growth may involve enhanced market share of loads that are, or can be, served by competing fuels, as well as economic development in the service area. Examples include dual fuel heating, heat pumps, and promotional rates. In the future, load growth may include electrification like industrial process heating, automation, electric vehicles. This rise in intensity may be motivated by reduction in the use of fossil fuels and raw materials resulting in improved overall productivity.

f. **Flexible Load Shape-** Flexible Load Shape is a concept related to reliability, a planning constraint. Once the anticipated load shape, including demand-side activities, is forecast over the planning horizon, the power supply planner studies the final optimum supply-side options. Among the many criteria he uses is reliability. Utility will identify the flexible loads whose scheduling variation is possible for some incentives. The programs involved can be variations of interruptible or curtail able load; concepts of pooled, integrated energy management systems; or individual Customers load control devices offering service constraints.

2.4 Power System Loads:-

2.4.1 Introduction:

Definition- A device which uses electrical energy is said to impose load on the system. Load in a power system is defined as the total electric power consumed by all users connected to the distribution network of a system, and also the power used to compensate for losses in all parts of the network (transformers, converters, and transmission lines & also in distribution lines).

Maximum Demand or Peak Load- The maximum demand of an installation or system is the greatest of all demands which have occurred during the specific period of time.

Average Load- It is the ratio of energy consumed in a given period of the time in hours.

$$\text{Average Load} = \frac{\text{Energy consumed in a given period}}{\text{Hours in that time period}}$$

Load Curve- Load Curve is a graphical representation between load (kW or MW) in proper time sequence in hours. It shows the variation of load at the power station. When it is plotted for 24 hours a day, it is called daily load curve. If the time considered is one year then it is called yearly load curve. It is to be noted that the daily load curve of a system is not same for all days. It differs from day-to-day and season-to-season. A distinction is made between individual and group load curves (for individual users and groups of users, respectively). Loads determined by the rated power of the users are random quantities that may assume various values with a certain probability. Consumers usually do not operate simultaneously and are not all at their full rated power; therefore, the actual power system loads are always less than the sum of the rated powers of all individual users. The ratio of the maximum consumed power to the connected power is called the coincidence factor, and the ratio of the maximum load of a given group of consumers to their rated power is called the demand factor.

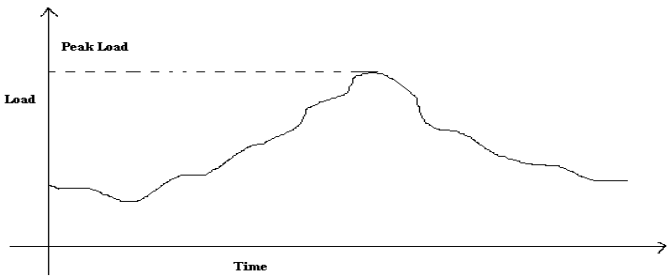


Figure 2.4: A Typical Load Curve

The following information are obtained from load curves-

(i) Load variation between different hours of a particular day, month or year.

(ii) The peak load indicated by the load curve gives the maximum demand on the power station.

(iii) The area under the load curve gives the total energy generated in the period under consideration

(iv) The area under the load curve divided by the total number of hours gives the average load.

On the basis of the above information load curves are useful as follows-

(i) To decide the installed capacity of a power station.

(ii) To choose the most economical sizes of various generating units.

(iii) To estimate the generating cost.

(iv) To decide the operating schedule of the power station, i.e., the sequence in which different generating units should run.

(v) To decide the operating schedule of various types of loads.

Peak-to-Average Ratio (PAR) - It is defined as the ratio of the peak load and average load of a given period of time. The value of PAR is greater than '1'.

$$PAR = \frac{\text{Peak load}}{\text{Average load}}$$

2.4.2 Types of Loads:

A. Depending upon the flexibility of using time the electrical loads can be classified into three types of loads-

1. **Uncontrollable Load-** Those types of loads whose operating time is fixed in a total time period and cannot be altered at any cost is known as uncontrollable load or non-shift-able load. Shifting of this type of load creates more discomfort to the consumers. These loads never participate in DSM plans. Refrigerator, TV, Computer systems, Mobile phones are few examples of this category.
2. **Semi-controllable Load-** This type of load can participate in the DSM plans but their operation schedule cannot be delayed for a long time. Lights, cooking appliances etc are this type of loads.
3. **Controllable Load-** This type of load fully participates to DSM plans and their operating schedule can be delayed as per the requirement of the utility. Delay of operation of these loads introduces a little discomfort into the customers' life style but their delayed operation will significantly minimizes the operating cost and smooth the load curve. Air-conditioning system, Electric vehicles, Water heaters, Water pumps etc. are some examples of controllable loads.

B. Depending upon the load operating sector in the power system the consumers can be divided into three categories-

1. **Residential Loads-** This is mainly household appliances which are of small power rating but the variation in this type is very large. Residential loads mostly participate into DSM methods as these loads are very flexible in time of use. Lights, coffee maker, dryer, fans, refrigerators etc. are under residential loads. Domestic consumers are given single phase supply up to 5kW and 3- phase supply for more than 5kW load.
2. **Commercial Loads-** This type of loads are imposed due to schools, shopping malls, offices etc. Rating of commercial loads are comparatively high than residential loads and most of these type loads are not controllable. Fans, Air-conditioners, heaters, computers etc are under commercial loads.
3. **Industrial Loads-** It is a very high rated load and positioned at big industries like automobile industries, steel plants etc. The operations of these loads are very time restricted and very few loads can participate in DSM plans. Three phase induction motor, DC motor, Electric Furnace, Welding machine, Electric Heaters, cooling

systems etc. are under industrial loads. Industrial customers are supplied by 3-phase supply from 415 Volt to 33kV with a load demand of 10kW to more than 100 kW.

2.5 Electricity Costs:-

2.5.1 Type of Costs:

The generating cost per unit of electrical energy can be divided into following three categories-

1. **Fixed Cost-** This cost is independent of maximum demand and energy output. It is due to the annual cost of central organisation, interest on the capital cost of land, and salaries of high officials. The annual expenditure on central organisation and salaries of high officials is fixed since it has to be met whether the plant has high or low maximum demand or it generates more or less energy. Further, the capital investment on the land is fixed and hence the amount of interest is also fixed.
2. **Semi-Fixed Cost-** The semi-fixed cost is due to the annual interest and depreciation on the capital cost of the generating plant, transmission and distribution network, building and other civil works, all types of taxes and insurance charges and salaries of management and clerical staff. The semi-fixed cost is approximately proportional to the maximum demand as the size and cost of the installation is governed by the maximum demand on the power plant. The greater the maximum demand on the power plant, the greater is its size and cost of installation. Further, the taxes, insurance charge and the strength of clerical staff depend upon the size of the plant and hence upon the maximum demand.
3. **Running or Operating Cost-** This cost depends upon the number of hours the plant is in operation or upon the number of units of electrical energy generated. The running cost is due to annual cost of fuel, lubricating oil, water, maintenance and repair cost of equipments and wages and salaries of operational and maintenance staffs. The operating cost is approximately proportional to units generated.

Hence the total electricity cost is expressed as,

$$C=a+b\times f_1(kW)+c\times f_2(kWh)$$

Where, a= Fixed Cost,

$b \times f_1(kW)$ =Cost due to maximum demand,

$c \times f_2(kWh)$ = Cost due to total number of units generated.

2.5.2 Different Types of Pricing Methods:

1. Simple Pricing- This is the simplest type of tariff plan according to which the cost of energy is charged on the basis of units consumed. The rate can be derived as-

$$Cost / kWh = \frac{\text{Annual operation cost}}{\text{Total number of units delivered}}$$

This method is free from the use time of the load. The cost per unit is fixed irrespective of the operating time of use of the load whether it is operating on peak hours or off-peak hours.

2. Dynamic or Time-Differentiated Pricing- This type of pricing method is applied in case of DSM plans as in this case the cost of electrical energy not only depends on the total number of units used by the consumers but also the time period of the day when they had used it. More cost will be introduced if the load is operating under peak time region and bill is less if it is operating under off-peak time period. This type of pricing is more real and cost effective for both the utilities and the users. The time differentiated pricing method can be sub-divided into following groups-

- **Time-of-use pricing** (**TOU pricing**) - Where electricity prices are set for a specific time period on an advanced or forward basis, typically not changing more often than twice a year. Prices paid for energy consumed during these periods are pre-specified and known to consumers in advance, allowing them to vary their usage in response to such prices and manage their energy costs by shifting usage to a lower cost period or reducing their consumption overall;
- **Critical peak pricing-** Whereby time-of-use prices are in effect except for certain peak days, when prices may show the costs of generating and/or purchasing electricity at the wholesale level
- **Real-time pricing (also: dynamic pricing)/RTP** - Whereby electricity prices may change as often as hourly (exceptionally more often) basis. Price signal is provided to the user on an advanced or forward basis, showing the utility's cost of generating and/or purchasing electricity at the wholesale level.

- **Peak load reduction credits-** For consumers with large loads who enter into pre-established peak load reduction agreements that reduce a utility's planned capacity obligations.

2.6 Summary:-

In this chapter we have discussed about the conventional power systems with its drawbacks and also how the modern power systems named Smart Grid has overcome those limitations. After that the basic principle of Demand Side Management method, a brief overview of power system loads and the type of cost for electricity production and different types of pricing methods imposed on the consumers have also been narrated. This chapter gives a theoretical overview of all the technical terms and concepts, used in this thesis work.

CHAPTER 3: LITERATURE REVIEW

3.1 Related Works:-

- As discussed in chapter-2 that the DSM can be done by six different methodologies out of which peak clipping and valley filling, commonly known as direct load control (DLC) strategy, are conventional methods as by this methods the load management is done by directly shedding a portion of peak load or increasing the load consumption during off-peak hours aiming to flatten the load curve. In this strategy mainly TOU tariff plan is used for cost minimization. Only the utility is the controller of the load and consumer has no such direct involvement to gain the objective. Depending upon the per unit cost at the time interval utility will decide whether the load is allowed to turn on or not. Various research works have been done to implement DLC strategy.

1. **Ryan** et al. [9] introduced a method based on duty cycle approach for direct load control (DLC) programs. They have shown that that DLC programs will get load and energy reduction by controlling the duty cycle of the consumers' appliances. Hare duty cycle is taken as a beta density function and they have shown that it is very useful for determining consumers' usage pattern in a specific time period. But it is a very old method which leads to load shedding and thus increased consumers' discomfort.
2. **Kurucz** et al. [10] approached a system model to reduce the system peak by using linear programming solution method. They have proposed separate direct load control programs for commercial/industrial load and residential load and also for various control appliances in residential area. Instead of controlling the whole time period they have only applied their control strategy when the peak load is subjected and also a payback effect is considered when the load control is released.
3. **Hoe Ng** et al. [11] proposed a direct load control approach where they have decided the number of customers to be controlled. Instead of minimizing the cost of the utility they have considered the profit done by the utility as their objective function, which is a non-linear function. The profit has been maximized by using linear programming optimization technique.

4. **Hsu and Su** [12] designed a direct load control (DLC) model where they have combined the DLC problem with the unit-commitment problem to reduce the electricity production cost. DLC scheme is applied here on the air-conditioning loads during the summer time only and a optimized load pattern with reduced peak and production cost have been achieved by using Dynamic Programming based optimization technique.
5. **Faranda** et al. [13] told that the difference between the total demand and total power generation is often less than 1% of the total produced power so by their methodology load shedding is a very good method for reducing the total peak demand and the cost too. They have proposed a new Distributed Interruptible Load Shedding (DILS) technique where the load is divided into two categories- interruptible and non-interruptible. The proposed model is done by modelling the total distributed interruptible load as a Gaussian probability distribution and a signal is sent to the interruptible loads to cut out a portion of the load by a probability of failure method and the general cost equation which is again a Gaussian distribution function.
6. **Gomes** et al. [14] proposed a direct load control program in multi-objective environment where minimization of peak demand, maximization of profit, minimization of loss factor and minimization of the consumer’s discomfort is taken as the objective functions and the optimization is done by Evolutionary Algorithm (EA) based on the users’ preference to the objectives as some objectives are contradictory with each other. As many objectives have been considered, so the overall result is much better.
7. **Yao** et al. [15] proposed a new method named Iterative Deepening Genetic Algorithm (IDGA) whose main objective is to find out the proper scheduling of some load groups comprises of only air-conditioning load. IDGA not only controls the load shedding program at each sampling interval but also minimizes the amount of shedding load such that the revenue loss of the utility will also be minimized. IDGA also helps to distribute the whole shedding time uniformly among each load group for avoiding the complaints about fairness of load shedding. IDGA is composed of a master GA and a sequence of slave GA. The function of master GA is to call a slave GA and slave GA finds the possible forward combinations.
8. **Pedrasa** et al. [16] used binary particle swarm optimization (BPSO) to schedule interruptible loads over a period of time using load curtailment operation. It combines

a number of objective functions into a single objective function to minimize both the payment due to that interruptible load and also the number of interruptions imposed on them while satisfying the system constraints like total available interruptible loads.

9. **Ashok** et al. [17] present a model for industrial load management to reduce the total electricity cost and also system peak under time of use tariff plan. The objective function is optimized by integer linear programming method by considering the system constraints like total production capacity, storage capacity, sequence of operating machines , maximum permissible demand and electrical load estimation etc.
10. **Torriti** [18] proposed a demand side management strategy based on time-of-use (TOU) pricing method. The method is applied on residential customers of Trento in Northern Italy to reduce electricity price, shift of peak load and reduction of peak electricity demand at substations.
11. **Arthur I. Cohen** et al. [19] proposed a successive dynamic programming control method to reduce the objective function, cost or the peak load, which is a function of the forecasted load and diversified load. They have told that if any load is disconnected then its energy demand will increase and it leads to customers' dissatisfaction. So the energy demand is a constraint of the optimization problem. Here also the maximum control time and the time between two successive control periods of a device is taken as constraint. A main drawback of this method is that the run time will increase with increase of allowed cycle rates. Here the cost function is fixed irrespective of the time of operation of the device.
12. **Babu** et al. [20] introduced a non-linear model for an electrolytic process industry depending on the time of use (TOU) tariff plan. They have proposed a cost function considering the load at the time period and as well as the maximum demand in kVA at that time period. If it is peak load period then penalty will be charged for reduction of the peak and if it is off peak period then incentive is provided for valley filling. The cost equation is minimized by using mixed integer non-linear programming (MINLP) technique to reduce peak load too.
13. **Lee** et al. [21] proposed an analytical load control model for controlling water heater type of loads during winter time. They have considered more than one objective such as demand reduction, peak reduction; energy cost reduction and net payback and solved the problems by using linear programming method.

14. **Ramanathan** et al. [22] proposed a direct load control mechanism for air-conditioning load. The mechanism is formulated as optimization problems where minimization of the amount of load control and as well as the minimization of customers' discomfort due to load control are taken into consideration. The optimization problem is done by Monte Carlo-based Dynamic Programming Approach. The effect of this algorithm on system load parameters, ambient parameters and artificial constraints on the load control is also studied.

- As the load shedding or peak clipping method increases the customers' dissatisfaction and because of valley filling the power generation amount is increased which increases operating cost. Because of those reason direct loads control scheme is not so good from both customers and utilities point of view. To overcome the above situation load shifting method is used in [23]. And load scheduling is done in [24].

1. **Logenthiran** et al. [23] uses load shifting method to optimize the cost and peak load of a system. The cost at any time period is pre-defined and a day-ahead load shifting method is proposed in this work. Here a heuristic based evolutionary algorithm is used for solving the minimization problem. They have also showed that load shifting method also reduces the generation cost of various generating companies like thermal, PV, wind etc.
2. **Cohen** et al. [24] proposed a load management system for utilities for residential area load, mainly air conditioners and water heater load. Here a forecasted load data without load management and a load data with full load management are taken as reference data and the controllable loads are scheduled such as the final result should not exceed the target peak load. A dynamic programming optimization is used to get the optimum schedule.

- Another DSM strategy is used now a day which is done by the utilities and the customers both by their mutual understanding. In this strategy utilities will charge the electricity bill on the users depending upon the real time power consumption by the users and to reduce the electricity bill users would reschedule their appliances use time. This method is based on real time pricing technology and researchers are now advancing this method.

1. **Schweppe** et al. [25] designed a spot price based algorithm for residential users and the control logic is dependent upon the attitude of the customers and the acceptance of the customers to the control mechanism and also the man machine interface. The algorithm is specially designed for EPRI supported hardware/software system.
2. **Luh** et al. [26] proposed a real time pricing scheme named load adaptive pricing and designed the problem as a closed loop Stackelberg game problem. The main aim of this game is to choose the proper incentive and/or pricing strategies so that the customers would be induced to achieve the optimum solution with low peak system. They also told that at steady state the system will be stable and the solution converges.
3. **Mohsenian** et al. [27] proposed a game theory among the residential consumers that the consumers will schedule their appliances in a day by minimizing their pay off, which is its electricity bill. Authors modified the convex cost function as for any user the cost function is only depends upon the energy consumption of that user instead of taking it as a whole and it has been solved by Interior Point Method (IPM). As the cost has been minimized the peak to average ratio (PAR) also been minimized automatically. Authors also told that no other user will be benefited if it violates its schedule from the optimum schedule.
4. **Qian** et al. [28] proposed a method based on real time pricing model on residential users. The problem has been sub-divided into two stages, in one stage users maximizes their usage quality and on the other hand in the next stage the supplier maximizes its profit by considering a non-convex cost function and solving it by Simulated Annealing based Price Control (SAPC) method. The process has been done by a exchanging data between suppliers and the users.
5. **Liu** et al. [29] proposed a distributed energy scheduling algorithm for the scheduler and the residential customers to minimize the energy cost by taking peak to average ratio (PAR) as a fundamental constraint that the PAR of the optimum schedule should not exceed a certain upper limit.
6. **Mohsenian-Rad** et al. [30] proposed a load management technique based on real time pricing model to minimize the electricity payment and as well as the waiting time of the residential appliances. It formulates the cost function by combining real time pricing model and inclining block rates pricing model. A cost function is also

formulated to calculate the waiting time of each appliance according to their energy consumption at a specific hour in a day. This multi objective optimization problem is solved by linear programming method. By this proposed method PAR is also reduced.

7. **Z. Md. Fadlullah** et al. [31] have innovated a game theory to minimize PAR by scheduling the appliances of the customers. This game theory is an interaction between the supplier and the customer. A newly proposed objective function is used in this paper which is the difference between the value of energy and the cost of energy which is also a function of the consumed energy of the respective customer. In this model the customer will reschedule its appliances by knowing the energy cost parameter and the present scheduling vector to minimize the objective function by using interior point optimization technique.
8. **Gkatzikis** et al. [32] proposed a method for reduction of the cost of the supplier and the electricity payment of the residential users. They have introduced a middle man concept, named aggregators, between the utility and the users. Aggregators will offer their DR scheme to the supplier and the supplier gives incentives if the offered DR scheme is better than other aggregators. On the other hand the aggregators provide compensation to the end users in order to modify their load consumption by allowing some discomfort. That way with the help of suppliers, aggregators and users are benefitted at the same time.
9. **Kunwar** et al. [33] proposed an area load based pricing method where the load scheduling data of unmanaged loads are predicted using Artificial Neural Network (ANN) prediction technique. The cost, which is a continuous function of load consumption at any specific time of the area, according to this prediction is shown to the users' network. Users will schedule their loads to minimize the cost and the PAR of the network by using NSGA II optimization technique to obtain a smooth load profile.
10. **Gottwalt** et al. [34] proposed a demand side management model based on the load curve created by the generators considering the type, number of household appliances and the time of use of those appliances over a year. One appliance is modelled over the year by considering whether the day of use is a working day or holiday and the number of family member present in this house. Then the load model of every appliance is added up and the whole load profile is shown in-front of the user. Now the user will optimally shifts their fully automatically controlled devices and semi-

automatically controlled devices to reduce the cost based on the given time based tariff plan.

11. **Samadi** et al. [35] proposed Vickery-Clarke-Groves (VCG) mechanism for the smart grid to maximize the user utility and reduce the energy cost. Using real time pricing method where the cost function is a convex type VCG mechanism encourages the users to reveals their actual power consumption data to get incentives. The efficiency and truthfulness of this mechanism is also shown in this literature and was proven a better solution to the peak load and more energy cost problem. By this mechanism both the energy providers and the users will be benefitted.
12. **Koutitas** et al. [36] introduced a new concept other than the dynamic pricing method. They have showed that the operation of all typical energy consuming devices can be accurately described by any periodic pulse wave. Based on this approach they have used gradient descent optimization technique to synchronize the periodic loads by providing a minimum delay on the duty cycle of the devices and due to that continuous on/off command flow between user and supplier was also reduced. By this approach three main objectives were fulfilled- peak reduction, overall cost reduction and flattening the load curve over the time period. The total optimization problem has been solved in centralized and also in distributed manner.
13. **Pipattanasomporn** et al. [37] proposed an intelligent home energy management algorithm and also a simulation tool used at demand response analysis. This method is capable of managing the total household demand below a specified limit while considering the consumers' priority to the load and the comfort level of the customers. This algorithm is able to overcome the limitation of the demand response (DR) analysis that a high peak can occur at the off-peak period when the DR operation is over. This has shown that DR event is a function of the customer comfort preference and the maximum demand limit that will not cause any high load after DR event.
14. **Gatsis** et al. [38] proposed a load control algorithm for residential loads. They have mentioned that residential load is comprises of mainly two types of load- first type whose total power consumption is fixed but operation time can be altered and the second type which don't have any specific power consumption but their operating time changing causes more dissatisfaction to the consumers. So this two type of loads lead to a distributed algorithm where total electricity cost and customers' dissatisfaction both have been minimized by using Lagrangian Multiplier method and

a convex type cost function is chosen which is sent to the users as the Lagrangian Multiplier and the user provide the utility with their total power consumption at any time interval. This algorithm is also capable to provide the near-optimum schedule in case of loss of original data transmitted by the communication line.

15. **Yu** et al. [39] proposed a parametric utility model named statistical demand price model based on the theory that the responsive behaviour electric loads under different pricing methods depends on the interaction between their utilities and the users as a function of the electricity price and the time of use. This developed model is used to real time pricing environment to maximize the social welfare, difference function of the electricity utilization and the production cost. A 6-bus test system is considered for implementing the proposed model.
16. **Lopez** et al. [40] proposed a centralised method of Demand Side Management where the schedules for charging of electric vehicle batteries are taken into consideration. In the proposed method it was assumed that customers would provide their original charging schedule and based on that utility would minimize the peak load and consumers' energy cost by using stochastic optimisation evolutionary algorithm.
17. **Chen and Leu** [41] designed an incentive rate structure for interruptible loads so that would influence the customer to reschedule the interruptible loads on off-peak hours. Because of that the peak load demand is reduced and also the load curve would be configured properly. The proposed structure was applied by Taiwan Power Company and a significant reduction in peak demand had been achieved.
18. **Paschalidis** et al. [42] developed a market-based method for a building smart micro-grid operator (SMO) to meet the regulation service (RS) reserve and other obligations done by the wholesale market independent system operator (ISO). The SMO would control the behaviour of the load by sending a signal of internal pricing. The objective of this model is to derive an optimal SMO pricing or incentive policy towards respective building occupants so that they consent to the sale of RS reserves to the ISO and collaborate in meeting the ISO's RS requirements in longer time scale and during this period of time ISO follows shorter time scale stochastic dynamics to repeatedly request from the SMO to decrease or increase its consumption.

- Some authors also investigated the proper location of DSM use and as well as some of its limitations and how it influences the generation scheduling.

1. **Hayes** et al. [43] have proposed that the location of applying DSM is very important in case of a radial and as well as for a meshed distribution system. Here they have used optimal power flow (OPF) for determining the location of the DSM to be applied taking the maximum power flow through the line and bus voltage limits as the constraints. After finding out the location they have decomposed the total available load into residential 'wet' load and commercial refrigeration load and applied time – sequential OPF at every half an hour interval taking cost as the optimization function. Here it is demonstrated that the location and as well as the composition of the available load at any time interval has a significant impact on applying DSM scheme at any distribution network.
2. **Shi** et al. [44] introduced a distributed OPF method for demand response (DR) of any distribution network. They have told that the residential appliances are not isolated from each other but they are connected by a distribution network and the effect of the demand response cannot be solved by centralized OPF method for any AC distribution network. Applying the proposed method into IEEE radial 13 bus distribution system , the conclusion was made that the location of the load at any network is very important in DR as the load far away from the feeder reduces more demand. Another effect named as rebound effect was proposed that if the parameters of the OPF are not chosen carefully then another peak in demand may arise after applying the DR scheme.
3. **Li** et al. [45] investigated that if Demand Response scheme is applied to every home then most of the schedulable load would be scheduled at night to reduce the electricity bill and because of that a peak demand may occur at the night time named rebound peak. They have showed that if the electricity cost is a homogeneous function of the electricity consumption over a time period and if the electricity consumed by multiple users is flat over that time period then the total electricity cost is lesser. They have proposed certain DR schemes for the users to reduce rebound peak like flat price model at night, different price model for different users at night and defining maximum power supply allowed for each home to get same bill reduction and a flat load profile.

4. **Moura and Almeida** [46] proposed a multi-objective optimization problem for renewable energy resources. They have considered various numbers of renewable sources, so named as mixed renewable system. The applied demand side management strategy is used to maximize the contribution of the mixed renewable system to peak load, minimizing the combined intermittence and minimizing total cost.
5. **Pina** et al. [47] showed that use of demand side management or load shifting strategy helps the generation companies to fulfil the required demand with the current installed capacity other than introducing new generating units. As the use of renewable energy resources create problems because of their share into the energy mix and the use of storage systems to overcome this limitation is a very expensive remedy so the use of DSM strategy is a helpful solution to this challenge as DSM reduces the new installation.

3.2 Summary:-

This chapter discussed about the related works done in this research area. The research works has been sub-divided into three main categories. First where the research papers on direct load control or load curtailment strategies of suppliers for load management is taken into consideration. In the second portion researches on the system load control by both users and utilities are considered and in the last slot some limitation and the proper place of use of load control are described.

CHAPTER 4: LOAD SCHEDULING BY UTILITY USING TIME OF USE PRICING METHOD

4.1 Introduction:-

As we have discussed in chapter 2 that the load is subdivided in major three categories out of which only controllable and semi-controllable loads can participate in DSM methodologies. As the load management is a serious concern from supplier point of view because the total generation should fulfil the total demand and line losses at a specific point of time so they are main controller of the demand to regulate their generation economically and to fulfil the required demand at any time period by the running units present at that time without turning on any extra unit as this will increase the starting cost and as well as the running cost. So it is very essential to manage the load in a proper way. Other objective of a utility is to maintain a flat load profile on a particular day that the load fluctuation level will be minimized. So their main aim to fulfil the above mentioned objectives is to reduce the load at peak hours and increase the load at off-peak hours.

One way may be the load shedding or load curtailment but it is not a good solution as it will increase the discomfort level of the consumers. Other DSM methods like valley filling, load building, flexible load shape is not good from economical point of view.

The most efficient solution technique adopted by the utilities is load shifting method as this will shift the peak loads to the off peak hours and thus reduces the customers' dissatisfaction level compared to load shedding method. Load shifting method will just change the time of use of the appliance of a particular user unlike load shedding as it totally cut out the load. By load shifting only the controllable and semi-controllable loads are shifted.

4.2 Objective of the Work:-

The main objective of this work is to properly schedule the loads with the help of time of use (TOU) pricing technique adopted by the utilities to implement the load shifting operation in such a manner that it will bring the actual load curve close to the objective load curve and thus the total cost and the peak load will be reduced. Here Differential Evolution optimization algorithm is used to optimize the result. The proposed algorithm is implemented on residential, commercial and also industrial consumers and the effect on these three major customers is investigated.

4.3 System Model:-

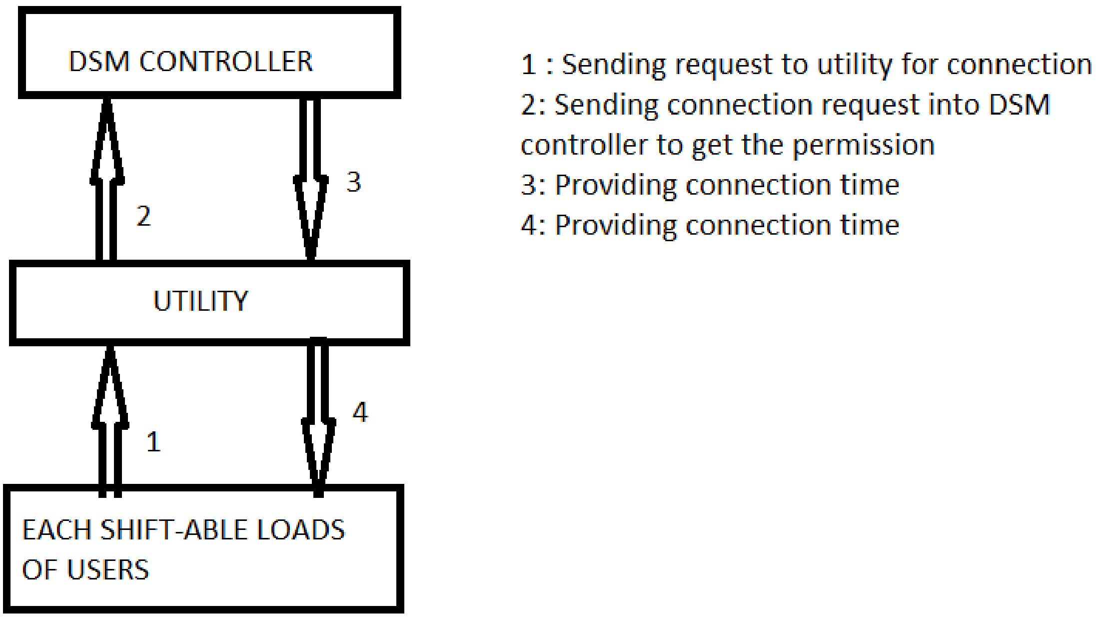


Figure 4.1: System Architecture for Load Shifting Method

The proposed system architecture is shown in the above figure. Here the system model of [23] is implemented. Here the scheduling algorithm is stored in the DSM Controller unit which divides total time span into several time intervals. The algorithm is designed by mainly three major inputs- forecasted load data, objective load data and cost per unit at a specific time period. The cost per unit at any time period is decided by the forecasted load at that time period.

Now the load may be forecasted depending upon the previous load data. In [33] ANN prediction technique is used to forecast load. [48] proposed a load forecasting method for DSM based on both black and gray box linear and non-linear model where active demand (AD) is taken as an input to the model. The proposed model is only for residential and small commercial consumers. Knowledge based short term load forecasting method is proposed in [49]. Fuzzy multi-objective logic is used for spatial load forecasting in [50].

The next step is to set the objective load curve. The objective load curve is selected based on the available power generation and the main objective to achieve. [51] proposed a load curve model for analyzing DSM methods by considering peak load, base load and/or energy demand as three variables. An erroneous selection of objective load data will lead the optimization problem to a wrong decision. On the basis of physical characteristics of elemental load devices a class of load model for DSM is proposed in [52].

The utility specify the operating time of every controllable appliances. If the appliance is turned on at peak hours then a delayed signal will be passed on to the appliance and the new operating time is assigned. The advantage of this method is that the optimum result is stored into the controller previously and the controlling action is done on real time by using the connectivity advantage of smart meter. When any appliance under DSM is turned on the request signal is sent to the controller and then the controller processes the request and compares the output with its saved result. If the result matches with the saved one then an acceptance signal will be sent otherwise a rejection signal is sent which also contain the next feasible operation time of the appliances. That way unlike the load shedding operation the appliance schedule is only shifted but not shed.

4.4 Problem Formulation:-

The proposed DSM strategy has the main aim to reduce the deviation of the forecasted load data from the objective load data. So the objective function of the optimization problem is

$$\text{Minimize} \quad \sum_{i=1}^{H}\left(Pload(i)-Objective(i)\right)^{p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here, $Pload(i)$ is the actual load at a time interval i. $Objective(i)$ is the set load data at the objective curve for the same time interval i. H is the total number of time intervals. p is 2 or any positive even integer. Here we will consider p=2 as here we are concerned about the modulus value of the difference between objective and real load curve but not the sign.

Now at a specific time period the actual load will be the resultant load of load that has been shifted to that time period from its past and shifted from that time period to its future and the total forecasted load. So $Pload(i)$ can be numerically represented as follows;

$$Pload(i) = forecasted(i) + connect(i) - disconnect(i) \quad \text{....................................... (2)}$$

Where,

$forecasted(i)$ = Forecasted load at any time interval i

$connect(i)$ = Connected load at any time interval i

$disconnect(i)$ = Disconnected load at any time interval i

Now the $connect(i)$ is comprises of two part i.e., load connected at the time interval i by load shifting and load connected at time interval i due to load shifting at the time interval before i as some appliance may run more than one time interval from its operational point of view. Hence,

$$connect(i) = \sum_{j=1}^{n} X_{cji} P_{1j} + \sum_{l=1}^{i-1} \sum_{j=1}^{n1} X_{cjl} P_{(l+1)j} \quad \text{..........................(3)}$$

Where,

j= Type of device that is to be shifted

n= Total number of device type

P_{1j} = Power Consumption by device type j at its 1^{st} hour of operation

X_{cji} = Number of devices of type j shifted to time interval i.

Similarly $disconnect(i)$ also combination of two parts, one due to disconnection of load from time interval i due to load shifting operation and other is due to disconnected load from time interval i for the load disconnection from time before the time interval i. Hence,

$$disconnect(i) = \sum_{j=1}^{n} X_{dji} P_{1j} + \sum_{l=1}^{i-1} \sum_{j=1}^{n1} X_{djl} P_{(l+1)j} \quad \text{……………………(4)}$$

Where,

X_{dji} = Number of devices of type j shifted from time interval i.

Now while doing the load shifting operation the utility should consider some of operational constraints along with the constraints in [23], that the consumers' discomfort level will not be enhanced too much. Such constraints are,

1. $X_{cji} \geq 0$ and $X_{dji} \geq 0$
2. Total number of shifted devices at time interval i should be lesser than the total number of controllable devices available of that particular type j i.e., $X_{cji} \leq controllable(j)$
3. Load shifting can be done by a maximum delay of 12 hours otherwise it will increase discomfort level i.e. $m \leq 12$.
4. For residential load, that type of devices whose shifting increases more uncomforted level like cooking appliances should not be shifted more than one time and the shifting delay should be as low as possible
5. For commercial and industrial load the controllable devices' time of operation is shifted only once and the delay is as low as possible.

Hence the total optimization problem can be summarized as,

Minimize $\sum_{i=1}^{H}\left(Pload(i)-Objective(i)\right)^{p}$

Subject to,

1. $X_{cji} \geq 0$ and $X_{dji} \geq 0$
2. $X_{cji} \leq controllable(j)$
3. $m \leq 12$.
4. Urgent devices cannot be shifted more and/or with a longer delay

4.5 Scheduling Algorithm:-

The steps of the proposed load shifting algorithm is as follows-

Step 1: Read forecasted load data and set objective load data. Set per unit cost according to the forecasted load i.e., at higher load period per unit electricity cost is also high. Calculate the initial total electricity cost and find the amount of peak load.

Step 2: Read total number of controllable appliances of each type of device and also their hourly load consumption data.

Step 3: Utility operator will shift some amount of devices of a particular type from its original operating time to a new time and it is done in such a manner that load should shift from excess load hour to less load hour by considering the operational constraints listed in last section.

Step 4: Calculate $connect(i)$ and $disconnect(i)$ for all time interval i (i=1,2,……….,H) using equation (3) and (4).

Step 5: Calculate $Pload(i)$ for all time interval i (i=1,2,……….,H) using equation (2).

Step 6: Optimize the equation (1) by performing Differential Evolution (DE) optimization technique.

Step 7: Get the modified load data for every interval of time. Calculate the total cost and find the new peak load.

Step 8: Calculate percentage reduction of the total electricity cost and the peak load.

4.6 Differential Evolution (DE) Optimization Technique:-

Storn proposed DE algorithm,[53], is used in this case to find the optimal solution. DE has a good and faster convergence property compared to other global optimization techniques. Here a modified version of DE, proposed in [54], is used. In [54] the original differential evolution algorithm has been modified in order to increase the convergence speed of the optimization algorithm. These modifications can increase the probability of selection of evolved individuals and consequently can increase the performance of differential evolution algorithm. The performance characteristics of the modified differential evolution algorithm have been compared with those of the original differential evolution algorithm. Results obtained show that the modified differential evolution algorithm is able to converge and find the optimum point faster compared to the original algorithm.

The algorithm of the modified DE is stated as follows-

Step 1: Create the total population of Np members of vector X using equation (2). Set initial mutation operator's value F_1 between 0 and 1. Every member of X has dimension of $(n \times 1)$.

$$X=\{X_1,X_2,................,X_{N_p}\}$$

Step 2: Put every population member to the objective function (1),

$$f_i = f(X_i),\ i=1,2,\ldots\ldots\ldots\ldots.Np$$

Step 3: Divide the total population into two equal parts.

$$m=Np/2, \text{ if Np is even}$$
$$=(Np+1)/2, \text{ if Np is odd}$$

Step 4: Find the best solution (Xbest) from the population which gives the minimum value of the objective function.

$$f_{Xbest} = \min(f(\mathrm{X_i}))$$

Step 5: While the total iteration has not completed or the convergence criterion not met do steps 6 to 9.

Step 6: Set the Mutation and Crossover operation for the iteration 'g'–

Find $f_{\max g} = \max(f(\mathrm{X_{ig}}))$ and $f_{\min g} = \min(f(\mathrm{X_{ig}}))$

Now mutation operator for iteration number 'g' is given by,

$$F_g = \max\left(F_1, 1 - \left|\frac{f_{\max g}}{f_{\min g}}\right|\right), \text{ if } \left|\frac{f_{\max g}}{f_{\min g}}\right| \langle 1$$

$$= \max\left(F_1, 1 - \left|\frac{f_{\min g}}{f_{\max g}}\right|\right), \text{Otherwise}$$

The value of the cross-over operator for iteration number 'g', $Cr_g = 0.5 \times (1 + rand)$

Step 7: The better and worse solutions of total population are separated and stored in equal two parts. First half contains the better solution from where global solution would come out and the second half contains the rest solutions.

This is done by following way-

1. For i = 1 to Np do 2 and 3
2. For j = i to Np do 3
3. If $f_j > f_i$ then swap $\mathrm{X_{jg}}$ with $\mathrm{X_{ig}}$ and f_j with f_i.

Step 8: Perform three main operation of DE technique i.e., mutation, cross-over and selection only on the member of the first half of the population to generate new population and this will reduce the operation time unlike traditional DE. Here we will use DE/best/1/bin type mutation operation.

1. For i = 1 to m do 2 to 6
2. Select two random variables r_1 and r_2 between 1 to Np such that $i \neq r_1 \neq r_2$.
3. **Mutation-** Perform DE/best/1/bin type mutation operation and find the mutant vector for iteration 'g'

$$V_g = X_{best,g} + F_g\left(X_{r1,g} - X_{r2,g}\right)$$

4. For j = 1 to n do 5 & 6

5. Randomly select a number $r_j \left(0 \le r_j \le 1\right)$ and an index $j_{rand} \left(1 \le j_{rand} \le n\right)$.
6. **Cross-over-** Perform cross-over operation and find the new chromosome,

$$u_{j,i,g} = v_{j,i,g} \text{, if } r_j \le Cr_g \text{ or } j = j_{rand}$$

$$= x_{j,i,g} \text{ , } \quad \text{otherwise}$$

7. **Selection-** The selection process is done by following way

$$X_{i,g,new} = U_{i,g} \text{ , if } f(U_{i,g}) \le f(X_{i,g,old})$$

$$= X_{i,g} \text{ , } \quad \text{Otherwise}$$

Step 9: For other half of the population no modification is done. The old values are just passed on to the new generation.

$$X_{i,g,new} = X_{i,g,old}$$

Step 10: Find the best solution which gives minimum value of objective function.

4.7 System Data:-

The proposed load shifting algorithm is performed on the data of a smart grid taken from [23]. As the load shifting cannot be done to a time which is previous of the scheduled operating time and in most of the cases the valleys are before the peak hours so the load shifting operation is not possible if the time window is taken from 0 hr to 24 hr., to avoid this situation the control period is taken from 8th hr of the present day to the 8th hr of the next day. The system data is tabulated in the following given tables-

Time span in a day (Hours)	Wholesale Price (ct/kWh)	Hourly Forecasted Load (kWh)		
		Residential Area	Commercial Area	Industrial Area
8-9	12.00	729.4	923.5	2045.5
9-10	9.19	713.5	1154.4	2435.1
10-11	12.27	713.5	1443.0	2629.9
11-12	20.69	808.7	1558.4	2727.3
12-13	26.82	824.5	1673.9	2435.1
13-14	27.35	761.1	1673.9	2678.6
14-15	13.81	745.2	1673.9	2678.6
15-16	17.31	681.8	1587.3	2629.9
16-17	16.42	666.0	1558.4	2532.5
17-18	9.83	951.4	1673.9	2094.2
18-19	8.63	1220.9	1818.2	1704.5
19-20	8.87	1331.9	1500.7	1509.7
20-21	8.35	1363.6	1298.7	1363.6
21-22	16.44	1252.6	1096.7	1314.9
22-23	16.19	1046.5	923.5	1120.1
23-24	8.87	761.1	577.2	1022.7
24-1	8.65	475.7	404.0	974.0
1-2	8.11	412.3	375.2	876.6
2-3	8.25	364.7	375.2	827.9
3-4	8.10	348.8	404.0	730.5
4-5	8.14	269.6	432.9	730.5
5-6	8.13	269.6	432.9	779.2
6-7	8.34	412.3	432.9	1120.1
7-8	9.35	539.1	663.8	1509.7

Table 4.1: Forecasted Load Demand & Wholesale Energy Prices

Now the smart grid also contains different types of controllable appliances. The details of such appliances for residential, commercial and industrial area is listed below-

Sl No.	Device Type	Hourly Consumption of Device (kW)			Number of Devices
		1st Hr	2nd Hr	3rd Hr	
1	Dryer	1.2	-	-	189
2	Dish Washer	0.7	-	-	288
3	Washing Machine	0.5	0.4	-	268
4	Oven	1.3	-	-	279
5	Iron	1.0	-	-	340
6	Vacuum Cleaner	0.4	-	-	158
7	Fan	0.2	0.2	0.2	288
8	Kettle	2.0	-	-	406
9	Toaster	0.9	-	-	48
10	Rice-Cooker	0.85	-	-	59
11	Hair Dryer	1.5	-	-	58
12	Blender	0.3	-	-	66
13	Frying Pan	1.1	-	-	101
14	Coffee Maker	0.8	-	-	56
	Total	-	-	-	2604

Table 4.2: Data of Controllable Devices in the Residential Area

Sl No.	Device Type	Hourly Consumption of Device (kW)			Number of Devices
		1st Hr	2nd Hr	3rd Hr	
1	Water Dispenser	2.5	-	-	156
2	Dryer	3.5	-	-	117
3	Kettle	3.0	2.5	-	123
4	Oven	5.0	-	-	77
5	Coffee Maker	2.0	2.0	-	99
6	Fan/AC	3.5	3.0	-	93
7	Air Conditioner	4.0	3.5	3.0	56
8	Lights	2.0	1.75	1.5	87
	Total	-	-	-	808

Table 4.3: Data of Controllable Devices in the Commercial Area

Sl No.	Device Type	Hourly Consumption of Device (kW)						Number of Devices
		1st Hr	2nd Hr	3rd Hr	4th Hr	5th Hr	6th Hr	
1	Water Heater	12.5	12.5	12.5	12.5	-	-	39
2	Welding Machine	25.0	25.0	25.0	25.0	25.0	-	35
3	Fan/AC	30.0	30.0	30.0	30.0	30.0	-	16
4	Arc Furnace	50.0	50.0	50.0	50.0	50.0	50.0	8
5	Induction Motor	100.0	100.0	100.0	100.0	100.0	100.0	5
6	DC Motor	150.0	150.0	150.0	-	-	-	6
	Total	-	-	-	-	-	-	109

Table 4.4: Data of Controllable Devices in the Industrial Area

A. **Residential Area-** The controllable devices data of residential area is tabulated in Table 4.2. These appliances are of small rating and have lesser operation time. Total 2604 numbers of appliances are available from 14 types of devices.
B. **Commercial Area-** Table 4.3 contains the data of controllable devices of commercial area of the smart grid. There are total 808 appliances of 8 types have taken into consideration whose power consumption is slightly higher than that of residential area.
C. **Industrial Area-** The devices subjected to load control under industrial area are listed in Table 4.4. Only 109 numbers of appliances of total 6 types of devices are available as controllable load in industrial area as most of the loads under industries are very much critical and cannot be shifted as per requirements. These loads are of very high power rating and have a long duration of power consumption.

Objective Load Data- As our main goal is to reduce the cost so we have to select our objective load data in such a manner that it possesses lesser load during time when the cost per unit of electricity is higher and greater load when cost per unit of electricity is lower. So the objective load data at any time interval is chosen to be inversely proportional to the per unit electricity cost at that time interval.

4.8 Simulation Result & Discussion:-

4.8.1 Software Tools Used:

The proposed load scheduling by utility using time of use pricing method algorithm is coded in MATLAB 8.3 (R2014a). MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Programmers and users of MATLAB can analyze data, develop algorithms and create models and applications using the language, tools, and built-in math functions to explore multiple approaches and solve technical computing problems faster than with spreadsheets or traditional programming languages such as C, C++ and Java.

4.8.2 Simulation Criteria:

Specifications of DE Algorithm

1. **Initial Mutation Rate-** As a high value of mutation rate will cause loss of good solution so initially mutation rate is chosen to be 20% (0.2) and it is changing in every iteration with the value of the objective function as indicated in step 6 of the DE algorithm.
2. **Cross-over Rate-** If cross-over rate is very large then the algorithm will converge very fast. Cross-over rate with a value '1' means 100% cross-over and this may lead the solution to a local optimum position other-than the global one. So it is feasible to take 80%-90% the cross-over rate. But here we have considered that the cross-over rate is adjusted in every iteration using the formula mentioned in step 6 of DE algorithm.
3. **Population Size-** If the population size is very small then the result will stick to a local optimum value and this will produce an erroneous result. On the other hand if the population size is too large then the algorithm will take too much time to converge. So a moderate size of population with a total of 250 chromosomes is selected in this work.
4. **Maximum Number of Iterations-** 500 iterations is taken as limit in this work as large number of iterations will unnecessarily increases the computation time.
5. **Stopping Criteria-** One stopping or terminating criteria may be the maximum number of iterations and the other stopping criteria is when the value of the objective function, of the best solution after every iteration, does not vary more than 10^{-10} for last 50 iterations then the algorithm will be terminated.

4.8.3 Results-

The simulation result curve for all three areas are shown below-

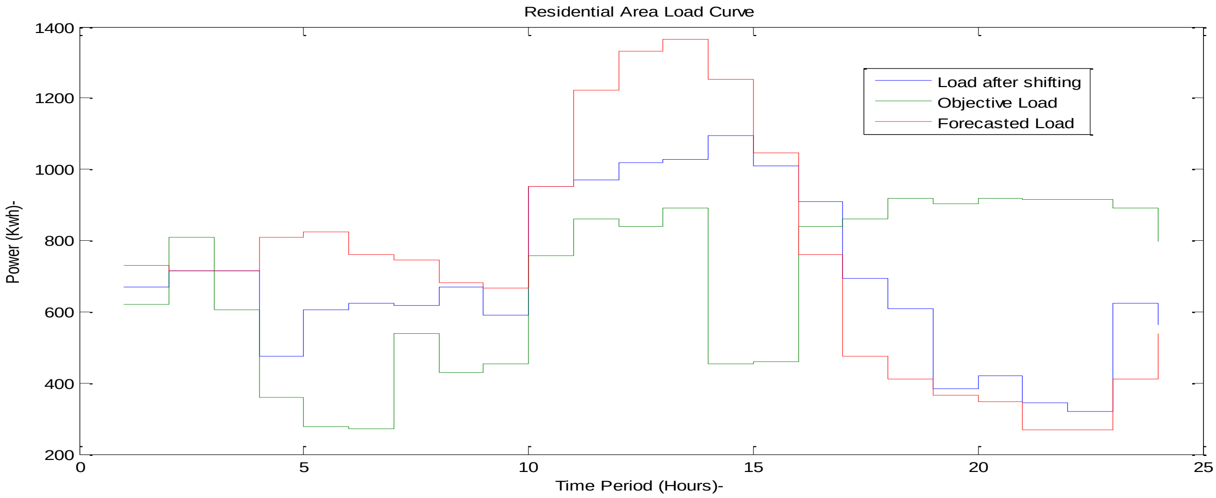


Figure 4.2: DSM Result for Residential Area using Load Shifting

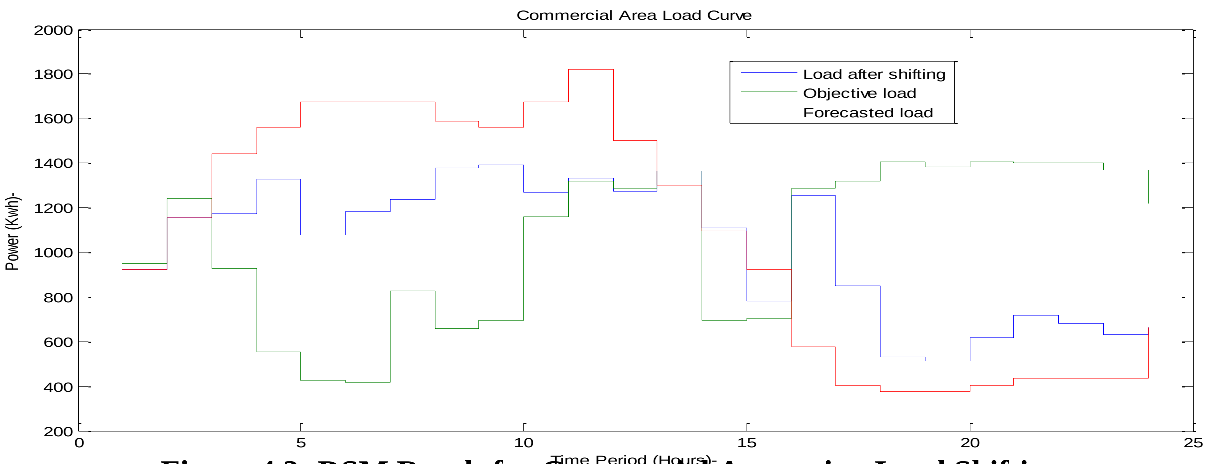


Figure 4.3: DSM Result for Commercial Area using Load Shifting

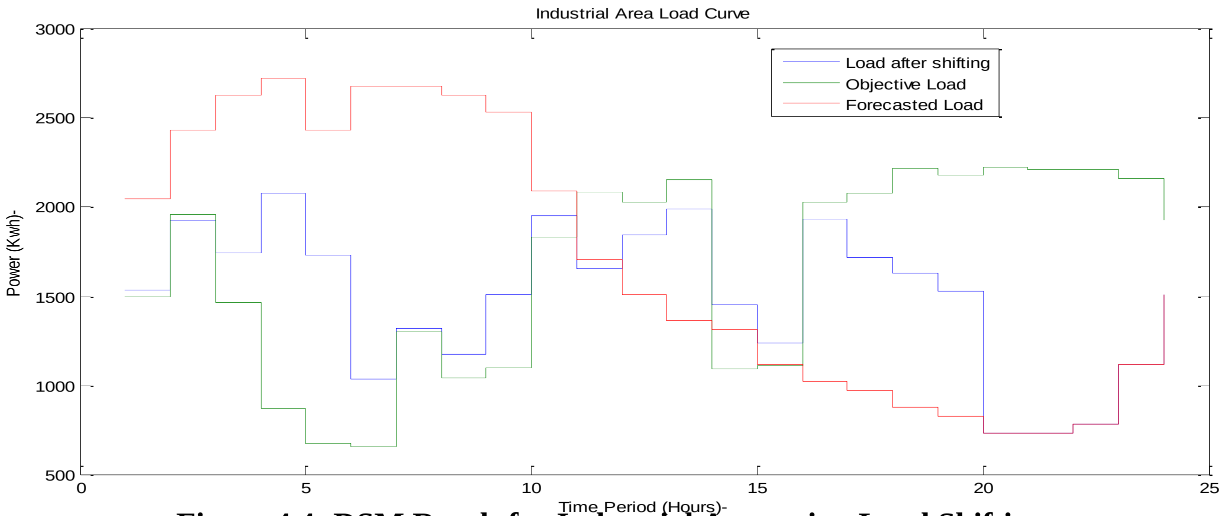


Figure 4.4: DSM Result for Industrial Area using Load Shifting

The total cost and peak reduction is listed in the following tables-

Area	Peak Load before DSM (kW)	Peak Load after DSM (kW)	Percentage Reduction
Residential Area	1363.600000	1095.085928	19.692%
Commercial Area	1818.200000	1393.806014	23.341%
Industrial Area	2727.300000	2079.866078	23.739%

Table 4.5: Peak Load Reduction Results

Area	Cost before DSM ($)	Cost after DSM ($)	Percentage Reduction
Residential Area	2302.879280	2073.865423	9.945%
Commercial Area	3626.639600	3208.508859	11.529%
Industrial Area	5712.047460	4483.954747	21.500%

Table 4.6: Total Cost Reduction Result

Total number of iterations required to converge the solution in each area is listed below-

Area	No of iteration required to converge
Residential Area	127
Commercial Area	142
Industrial Area	197

Table 4.7: No. of Iterations for each Area

4.8.4 Discussion-

In all the three cases (Fig. 4.2-4.4) it can be observed that the load from peak hours is shifted to the off-peak hours and due to that the load under peak time is reduced and the load under off-peak time is increased and because of that the resultant load curve is mostly nearer to the objective load curve.

It can be seen from the listed result of table 4.5 that for residential area initial peak load was 1363.6 kW and it is reduced by almost 20% after applying DSM and reaches a value of 1095.08 kW. For commercial area initial peak load was 1818.2 kW and final is 1393.8kW, so total reduction is almost 23.3%. Similarly for industrial area initial and final peak load is 2727.3 kW and 2079.87 kW respectively, reduction is almost 24%.

Now from the data of Table 4.6 it can be seen that for residential area total electricity cost is reduced from 2302.88 $ to 2073.86 $, reduction is of almost 10%. For commercial area this reduction is almost 3626.64 $ to 3208.51 $, i.e. 11.5%. In case of industrial area cost is reduced from 5712.05 $ to 4483.95 $, 21.5% reduction is possible.

Table 4.7 shows the total computation time required for each area load scheduling. 127, 142 and 197 iterations are required for residential, commercial and industrial area respectively.

Thus it can be concluded from the above simulation result that for industrial area total cost and peak reduction is much more than the other two areas though it has lowest number of controllable devices. On the other hand computation time required for industrial area is also high. Though the residential area has highest number of controllable appliances but it results lowest cost and peak reduction percentage but its computation time is also lesser compared to commercial and industrial area. Commercial area has a moderate result in between residential and industrial area. Thus it is not practicable to predict that if the total number of controllable loads increases or more number of appliances participate into DSM strategy, this will appreciably reduce the system peak or the total cost. It is also important that the load participating in DSM should have a high power consumption rating. Though the residential area has a lot of controllable loads the ultimate result is worse than commercial and industrial areas which have lesser number of loads but commercial and industrial loads' power rating is very much higher than the residential loads. So the shifting of residential loads has lesser impact on system performance compared to that of commercial and industrial loads.

So it is feasible to conclude that load shifting by utilities is a useful strategy of demand side load management for mainly commercial and industrial users.

4.9 Summary:-

This chapter discussed about the demand side management technique using load shifting method adopted by the utilities. A simple load shifting algorithm along with the system architecture is proposed in this chapter to reduce the peak load and as well as the total electricity cost, time of use pricing method. The optimization is done by Differential Evolution Optimization Algorithm. At the end of this chapter the proposed technique is implemented on a sample smart grid data containing three types of users, residential, commercial and industrial, and a comparison is drawn on the basis of the performance of the algorithm on these three users.

CHAPTER 5: LOAD SCHEDULING USING REAL TIME PRICING TECHNIQUE

5.1 Introduction:-

Chapter 4 discussed about the load scheduling algorithm based on the load shifting method by using time of use pricing technology. The limitation of the previous method is that the utility will schedule the controllable loads as per their requirements without considering the customers' preference. Though the load shifting is good for industrial and commercial area but it will increase more dissatisfaction level in case of residential and as well as commercial and industrial customers. So it is more preferable if the consumers can also participate in the DSM technique.

In this type of modelling the load scheduling is done by the mutual understanding between the utilities and the users. Here the customers' will reschedule their appliances use time unlike the load shifting operation. This method is based on the energy usage awareness among the users and utilities do that work. Utilities encourage the customers to modify their load pattern by their electricity pricing structure and because of that the total load pattern of the whole area gets modified and the peak of the system is reduced.

So this methodology is beneficial for both utilities and the customers. By modifying the load schedule users can reduce their electricity bill and utilities can reduce their system peak load or the peak to average (PAR) ratio.

5.2 Objective of the Work:-

The main objective of this work is to design an algorithm in a centralize manner where both utility and users can participate. Utilities will select a consumer based on the present load consumption and will send signal to the user to modify its load consumption schedule and as a result its peak load will reduce. Users will be charged on real time pricing technique or the electricity cost per unit will depends on the amount of load consumed at that point of time. To reduce their electricity bill users will modify their appliances use time. Here Harmony Search Optimization technique is used by the users for bill reduction.

5.3 System Model:-

We consider the smart grid infrastructure as the base of our system. Here it is assumed that only one energy supplier is supplying multiple users. All users are equipped with smart meter which has bi-directional communication capability and also can reschedule the consumers' appliances according to their demand. All the smart meters are connected to the main power grid control centre. The smart meters can also monitor and collect the data of all connected appliances and also have the capability to on or off a particular device and can send the users load schedule to the utility. For further knowledge on smart meters please refer to [55].

Assuming all of the above mentioned conditions the system is modelled in three aspects- power system model, appropriate cost model and load model of consumers.

1. **Power System Model-** Here we will consider the power system model described in [27] and [31]. The model assumes that total N number of users are getting power from the one supplier as shown in the figure-

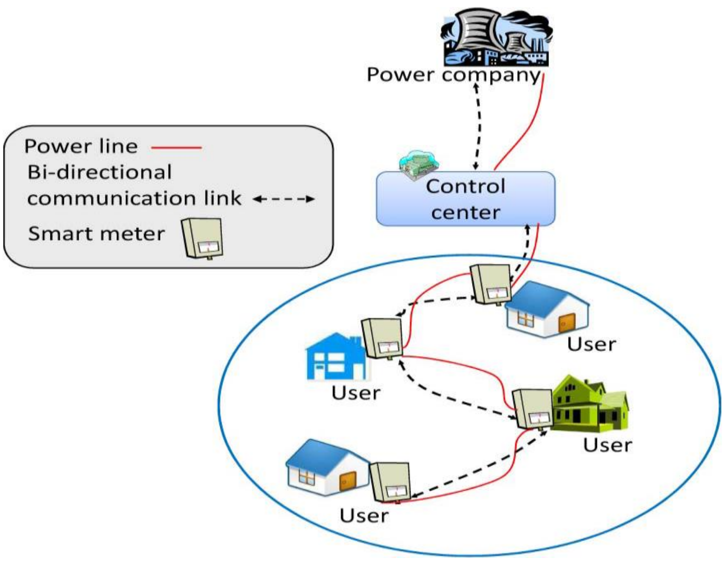


Figure 5.1: Considered System Architecture, [31]

Let for every user, $n \in N$, l_n^h be the load consumption by user n at hour $h \in H \triangleq \{1, 2, \ldots\ldots\ldots, \mathrm{H}\}$, where H is the total hour in a day (H=24).

Hence load consumed by the nth user during the whole day is denoted as-

$$l_n = \{l_n^1, l_n^2, l_n^3, \ldots\ldots\ldots\ldots, l_n^{\mathrm{H}}\}$$

Now if L_h denotes the load consumed by all the users at any hour h, hence

$$L_h = \sum_{n=1}^{N} l_n^h \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Hence the peak load and the average load of a day is given by,

$$L_{peak} = \max_{h \in H} L_h \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$L_{Avg} = \frac{1}{\mathrm{H}} \sum_{h=1}^{\mathrm{H}} L_h \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Therefore the Peak-to-Average Ratio (PAR) of the system is as follows-

$$PAR = \frac{L_{peak}}{L_{Avg}} = \frac{\max_{h \in H} L_h}{\frac{1}{\mathrm{H}} \sum_{h=1}^{\mathrm{H}} L_h} = \frac{\mathrm{H} \max_{h \in H} L_h}{\sum_{h=1}^{\mathrm{H}} L_h} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

2. **Appropriate Cost Model-** Here we will consider real time pricing technique where the per unit electricity cost will be proportional to the amount load consumed at a particular hour. In that way users will get incentives if they shift their load to off-peak hours and thus the system peak will reduce. The cost function should be an increasing function i.e., if the power consumption L_h increases the cost will also increase.

   So, $h \in H$, $C_h\left(L_{h1}\right) < C_h\left(L_{h2}\right)$ if $L_{h1} < L_{h2}$

   Another condition for selecting cost function is that the energy cost function should be a convex one.

   In other words for every $h \in H$, $C_h\left(\theta L_{h1} + (1-\theta) L_{h2}\right) < \theta C_h\left(L_{h1}\right) + (1-\theta) C_h\left(L_{h2}\right)$.

   Where, L_{h1}, L_{h2} and θ are real numbers such that $L_{h1}, L_{h2} \geq 0$ and $0 < \theta < 1$.

3. **Load Model of Consumers-** Here we will consider that every user has only one appliance of a particular type of device. Let $A_n = \{a_1, a_2, \ldots\ldots\ldots, a_A\}$ be the set of the appliances of a user $n \in N$. Now for every appliance of the nth user the energy consumption scheduling vector at every time interval is given by,

$$x_{n,a} = [x_{n,a}^{1}, x_{n,a}^{2}, ..., x_{n,a}^{H}] \text{ ………………………….. (5)}$$

Where $x_{n,a}^{h}$ is the energy consumption of 1-h time interval for appliance a of a user n.

Now the power level of each appliance $a \in A_n$, it needs a minimum and maximum standby power level, so

$$\gamma_{n,a}^{\min} \le x_{n,a}^{h} \le \gamma_{n,a}^{\max}, \forall h \in H_{n,a} \text{ …………….. (6)}$$

$$x_{n,a}^{h} = 0, \forall h \in H \setminus H_{n,a} \text{ ……………….(7)}$$

Now for every user $n \in N$ and each appliance $a \in A_n$, $E_{n,a}^{\min}$ and $E_{n,a}^{\max}$ denotes the minimum and maximum energy consumption during the whole day. Now the load shifting for energy consumption reduction is also bounded by the time interval in between the appliances should be run. Users must select the time interval $H_{n,a}$ between which the appliance can be scheduled. Let the upper and lower time to use the appliance be $\beta_{n,a} \in H$ and $\alpha_{n,a} \in H$, where $\alpha_{n,a} < \beta_{n,a}$. Now this upper and lower limit will be chosen in such manner that the appliance can operate fully in between the total specified time span i.e., for an example if an appliance require 3 hours to complete its operation totally, then $\beta_{n,a} - \alpha_{n,a} \ge 3$. On the other hand in case of uncontrollable loads it is assumed that its scheduling interval is full day with a constant energy consumption (e.g.- Refrigerator) or equal to normal required time to avoid further change in the plan.

So the total power consumption of an appliance is given by,

$$\sum_{h=\alpha_{n,a}}^{\beta_{n,a}} x_{n,a}^{h} = E_{n,a} \text{ …………………… (8)}$$

And $E_{n,a}$ is constrained to its upper and lower limit

$$E_{n,a}^{\min} \le E_{n,a} \le E_{n,a}^{\max} \text{ ………………………… (9)}$$

Now the total energy consumed by the nth user at any time interval $h \in H$,

$$l_n^h = \sum_{a \in A_n} x_{n,a}^{h} , \; h \in H \text{ ……………………………… (10)}$$

Then the main function of the smart meter is to optimally schedule the $x_{n,a}$ vector for the customer.

Finally the optimum feasible energy consumption scheduling set of the user n is given as follows,

$$\chi_n = \left\{ \begin{array}{l} x_n \mid E_{n,a}^{\min} \le E_{n,a} \le E_{n,a}^{\max}, \\ \gamma_{n,a}^{\min} \le x_{n,a}^{h} \le \gamma_{n,a}^{\max}, \forall h \in H_{n,a} \\ x_{n,a}^{h} = 0, \forall h \in H \setminus H_{n,a} \end{array} \right\} \quad \text{.............................. (11)}$$

5.4 Proposed Strategy:-

The proposed strategy is mainly dependent upon the cost function chosen by the utility. As the electricity cost is the main driving force which helps the user to modify its load pattern. In this section we will propose a cost function for the electricity bill imposed on the users. As [27] here we consider the cost function as a convex one.

The cost function is given by,

$$C_h(L_h) = a_h L_h^2 + b_h L_h + c_h \quad \text{....................................... (12)}$$

Where $a_h > 0$ and $b_h, c_h \ge 0$ are the constants.

Now the optimization problem is solved for mainly to satisfy two objectives- reduction of system PAR and reduction of electricity bill.

1. **PAR Reduction-**

   Equation (1) to (4) denotes the system PAR. As low per is preferred so PAR should be minimized,

$$\text{Minimize } PAR = \frac{\mathrm{H} \max_{h \in H} L_h}{\sum_{h=1}^{\mathrm{H}} L_h} \quad \text{.................................... (13)}$$

   Now we can re-write the equation (13) in-terms of $x_{n,a}^{h}$ as,

$$PAR = \frac{\mathrm{H} \max_{h \in H} \left(\sum_{n \in N} \sum_{a \in A_n} x_{n,a}^{h} \right)}{\sum_{n \in N} \sum_{a \in A_n} E_{n,a}} \quad \text{........................... (14)}$$

So the equation (13) can be written as,

$$\text{Minimize } PAR = \frac{\mathrm{H}\max_{h \in H}\left(\sum_{n \in N}\sum_{a \in A_n} x_{n,a}^{h}\right)}{\sum_{n \in N}\sum_{a \in A_n} E_{n,a}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

2. **Cost Reduction-**

Cost reduction is the main objective of this algorithm. The users will be charged on real time pricing basis which follows the cost function (12). So the objective of the users is to reduce their net electricity bill. So the objective function is given by,

$$\text{Minimize } C = \sum_{h=1}^{\mathrm{H}} C_h(L_h) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Now if we consider from the utilities' point of view to fulfil the demand of the present time interval it runs those units whose total generation will be equal to the sum of the total demand, total transmission and distribution losses and the total required spinning reserve. As transmission and distribution losses for a particular system is constant and the spinning reserve is a fixed amount of power that should be available for security constraints. As losses and spinning reserve is constant so change in total generation is proportional with the change in total demand. Now if in the next time interval the total load demand is reduced from the previous time load value then also this amount of load can be supplied by the present running generators. But in case of increase in the demand at next time the demand cannot be supplied with the present available generation and the solution of this situation is either to increase the fuel consumption of those generators which are not running at their rated value or to start a new generator. In the first case the fuel cost of the generation company will be increased and in the second case the start-up cost is also needed with the fuel cost to start and run the new generator. So for both the cases total electricity production cost is increased and because of that the users are penalized for load increment.

So a penalty charge with the regular electricity charge is added to the billing amount if the total load demand including all the users of the current time interval is increased from that of the just previous time interval. And the amount of penalty will depend upon how much the load is excess from its previous value.

So the penalty charge can be formulated as,

$$C_{h,p} = \lambda \times \left(L_{h,i} - L_{h,i-1} \right), \text{ if } L_{h,i} > L_{h,i-1}$$
$$= 0, \text{ Otherwise} \quad \text{.................................. (17)}$$

Here λ is known as penalty factor and it is calculated as the ratio of current and previous load demand i.e. the physical significance of λ can be stated as the current load demand is λ times of that of the just previous time interval.

So the total electricity cost can be written from equation (16) and (17) as,

$$C = \sum_{h=1}^{\mathrm{H}} C_h(L_h) + C_{h,p} \text{ ………………………………..(18)}$$

Or, $$C = \sum_{h=1}^{\mathrm{H}} \left[(a_h L_h^2 + b_h L_h + c_h) + \begin{Bmatrix} \lambda \times \left(L_{h,i} - L_{h,i-1} \right), L_{h,i} > L_{h,i-1} \\ 0, Else \end{Bmatrix} \right] \text{…… (19)}$$

This cost function has a unique feature as the penalty can be charged on the users without knowing the system load pattern previously i.e. only knowing about the available generation and whether it can fulfil the present demand or not, the supplier can penalize the users when the load consumption increases. This cost function also helps to minimize the occurrence of an unwanted peak at the off-peak hours.

So now the objective function is to minimize the cost at equation (19).

$$\text{Minimize } C = \sum_{h=1}^{\mathrm{H}} \left[(a_h L_h^2 + b_h L_h + c_h) + \begin{Bmatrix} \lambda \times \left(L_{h,i} - L_{h,i-1} \right), L_{h,i} > L_{h,i-1} \\ 0, Else \end{Bmatrix} \right]$$

Now as we can see that system peak is also considered as a factor in our cost function so if only cost is minimized then automatically the PAR will be minimized and extra optimization calculation for PAR minimization is not needed.

Hence the optimization objective function to get the optimum load schedule for each user is given by,

$$\text{Minimize } C = \sum_{h=1}^{\mathrm{H}} \left[(a_h L_h^2 + b_h L_h + c_h) + \begin{Bmatrix} \lambda \times \left(L_{h,i} - L_{h,i-1} \right), L_{h,i} > L_{h,i-1} \\ 0, Else \end{Bmatrix} \right] \text{……… (20)}$$

Subject to,

1. $\sum_{h=\alpha_{n,a}}^{\beta_{n,a}} x_{n,a}^{h} \geq E_{n,a}$ ……………………… (21)

2. $E_{n,a}^{\min} \leq E_{n,a} \leq E_{n,a}^{\max}$ ………………… (22)

3. $\gamma_{n,a}^{\min} \leq x_{n,a}^{h} \leq \gamma_{n,a}^{\max}, \forall h \in H_{n,a}$
   $x_{n,a}^{h} = 0, \forall h \in H \setminus H_{n,a}$ ……………….. (23)

This optimization problem is solved by using Harmony Search (HS) optimization technique. But before describing the optimization technique we will discuss about the proposed algorithm.

5.5 Scheduling Algorithm:-

As the success of this strategy depends upon interchange of the data between the utilities and the users, so two separate algorithms are used by utilities and the users. The main objective of the utilities is to reduce system PAR by reducing system peak and the objectives of the users are to minimize their electricity bill. So the equation (20) is minimized in a distributed manner i.e. every user will modify their load scheduling to reduce the total load consumption of the system at any time interval while the load schedule of other users remain same. The algorithms are as follows-

1. **Algorithm 1 (Followed by the Utilities)-**

   Step1: Get the initial load scheduling vector of each user $n \in N$, $\delta_n = [\delta_n^1, \delta_n^2, ..., \delta_n^{\mathrm{H}}]$. Hence the initial scheduling vector of all the users is given by

$$\delta = \begin{bmatrix} \delta_1 \\ \delta_2 \\ . \\ . \\ . \\ \delta_n \end{bmatrix} = \begin{bmatrix} \delta_1^1, \delta_1^2, \ldots\ldots, \delta_1^H \\ \delta_2^1, \delta_2^2, \ldots\ldots, \delta_2^H \\ . \\ . \\ . \\ \delta_n^1, \delta_n^2, \ldots\ldots, \delta_n^H \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

Step2: Do steps 3 to 6 until best result is obtained.

Step3: Calculate total electricity cost for the customers using equation (19) and the system PAR using equation (10) and (1) to (4).

Step4: Randomly select any user $n \in N$ and inform the user about the total electricity cost and send signal to modify its load schedule, keeping load schedule of all other users fixed.

Step5: Perform Algorithm 2 by the selected user.

Step6: Get the new revised schedule of the user n, δ_n . Substitute the new value of δ_n to the old value of δ_n in the load scheduling vector δ .

Step7: Calculate the total electricity cost including all the customers using equation (19) and the system PAR.

2. Algorithm 2 (Followed by the users)-

Step1: Get the total electricity cost data including all users and the signal from the utility to modify load scheduling.

Step2: Reschedule the controllable load in such a manner to minimize the objective function given by the equation (20) subject to fulfilling the operational constraints from equation (21) to (23). The minimization is done by implementing Harmony Search (HS) optimization technique. At the time of minimization all users' load schedule other than the selected one are kept fixed.

Step3: Get the new revised load schedule, δ_n , for the selected user $n \in N$ and inform it to the algorithm 1.

Algorithm 1 and 2 describes the control operation done by the utility (mainly control centre) and the users. At the start of the day, say 8 am, the utility send request to every user to send their load schedule. Users appropriately schedule their loads by satisfying the system constraints and then send it to the control centre. Utility then based on this knowledge calculate the total electricity bill payable by the users and send this information to a randomly selected user and tell them to reschedule their appliance if the user is willing to reduce its electricity bill. Then the user modify its load schedule to minimize its net payable by using Harmony Search optimization technique and then inform the utility about its modified load schedule. Utility then save that new schedule by discarding the old one. This process continues until the equilibrium occurs when both the utilities and the users will not change their load strategy.

In this method users don't have to inform all the information about its load nature, how many appliance he/she is using. They just inform the total load consumption at any particular time interval. So the users' privacy is also maintained.

5.6 Harmony Search (HS) Optimization Technique:-

Harmony Search algorithm is first proposed by Zong Woo Geem et al. in [56]. It is first proposed in 2001 and it is modified as a metaheuristic search algorithm as stated in [57]. The harmony search algorithm is an optimization technique inspired by music phenomenon. Just as musical instruments are played with certain discrete musical notes based on musicians' experiences or randomness in an improvisation process, so design variables can be assigned with certain discrete values based on computational intelligence or randomness in the optimization process. Just as musicians improve their experiences based on an aesthetic standard, design variables in computer memory can be improved based on objective function. It was inspired by the observation that the aim of music is to search for a perfect state of harmony. This harmony in music is analogous to find the optimality in an optimization process. Since its first appearance in 2001, it has been applied to solve many optimization problems including function optimization, engineering optimization, water distribution networks, ground water modelling, energy-saving dispatch, truss design, vehicle routing and others.

As here we are concerned about the use time of the appliances of each user so the HS algorithm is used on the index of the load scheduling vector instead of applying to the value stored at any particular index.

5.6.1 Parameters:

The parameters of the HS algorithm is briefly discussed, after that the algorithm is stated-

1. **Harmony Memory Size (HMS)-** It denotes the total number of harmony or member in the population.
2. **Harmony Memory (HM)-** Harmony is defined as the each member, randomly generated, of the population and the total existing population is known as harmony memory. Let x_j be the j^{th} harmony, of size 'n', of the memory ($j = 1, 2...., HMS$), so the total HM is as follows-

$$HM = \left[x_1 x_2 ....x_{HMS} \right] = \begin{bmatrix} x_1^1 x_2^1 ....x_{HMS}^1 \\ x_1^2 x_2^2 ....x_{HMS}^2 \\ . \\ . \\ . \\ x_1^n x_2^n ....x_{HMS}^n \end{bmatrix}$$

3. **HMCR-** Harmony Memory Considering Rate or HMCR is defined as the probability to select a member from the HM. The value of the HMCR lies between 0 to 1 ($0 \le HMCR \le 1$).
4. **Distance Bandwidth-** It is an arbitrary value and may take any value in between 0 to ∞. Thus $bw \in (0, \infty)$.
5. **Pitch Adjustment Ratio-** Pitch Adjustment Rate or par is defined as the probability to be mutated of a particular member of the HM vector. The member is only mutated if it is considered for next generation so the total probability of a member to be mutated is given by HMCR$\times$ par.
6. **Maximum Number of Iteration (NI)-** It denotes the maximum number of new generated harmonies for improvisation of the old population.
7. **Objective Function-** Every harmony is evaluated by an objective function, $f\left(x_j\right)$, which denotes its fitness. A harmony with weak fitness may not be chosen for the next generation. So objective function is the essential parameter for HS algorithm. In our problem we take equation (20) as our objective function.

In case of traditional HS algorithm HMCR, PAR and bw are kept constant for all iterations. But to get better convergence this values are so modified that it change their values in each iteration. The new modified values of the parameters can be evaluated by following way,

$$HMCR = HMCR_{\min} \times \exp\left[\frac{g \times \log\left({HMCR_{\max}}/{HMCR_{\min}} \right)}{NI} \right] \qquad (25)$$

$$par = par_{\min} + \frac{g \times \left(par_{\max} - par_{\min} \right)}{NI} \qquad (26)$$

$$bw = bw_{\min} + \frac{g \times \left(bw_{\max} - bw_{\min} \right)}{NI} \qquad (27)$$

Where,

$HMCR_{\max}, HMCR_{\min}$ are maximum and minimum value of HMCR respectively between 0 to 1.

$par_{\max}, par_{\min}$ are maximum and minimum value of par respectively between 0 to 1.

$bw_{\max}, bw_{\min}$ are maximum and minimum value of bw respectively between 0 to ∞.

g is the number of the iteration and NI is the maximum number of iterations.

5.6.2 Algorithm:

The steps for the HS algorithm is as follows-

Step1: Create the total harmony memory, HM, by randomly choosing HMS number of members. Here every member of the HM vector is also a vector of size (n1$\times$n). So HM is 3-dimensional matrix. Where in this case 'n1' is the number of type of devices present to each user and 'n' is the total number of time intervals.

Step2: Put every population member to the objective function $f\left(x_j\right)$, $j = 1, 2...., HMS$, and determine the fitness or their objective function value.

Step3: Sort the total population in ascending order according to their objective function value.

Step4: Set the values of $HMCR_{\max}, HMCR_{\min}$, $par_{\max}$, $par_{\min}$, $bw_{\min}$, NI parameters.

Step5: While the total number of iterations is not completed do steps 6 to 10.

Step6: Calculate the value of HMCR and PAR by using equation (25) and (26).

Step7: For i = 1 to n1 do 1 to 2

1. $bw_{\max} = 1 / \beta_{n,i} - \alpha_{n,i}$

   Then the bw is calculated by using equation (27).

2. Formation of the new harmony vector-

   a) **Harmony Memory Consideration-**

      if $rand \le HMCR$

      (i) Select randomly a variable r_i between 1 to HMS.

      (ii) Set $x_{new}(i,1:n,1) = HM(i,1:n,r_i)$

(iii) **Pitch Adjustment-**

if $rand \le par$

(1) Select a random number between '-1' to '1'.

(2) For j =1 to n

$$x_{new}(i, j, 1) = x_{new}(i, round(j + bw \times e), 1) ,$$

if $(j + bw \times e) \le \beta_{n,i}$ and $(j + bw \times e) \ge \alpha_{n,i}$

b) Randomization-

Randomly select any operating time of the appliance of user i, in between the maximum and minimum use time of the appliance.

Step8: Put the new evaluated harmony, x_{new}, to the objective function of equation (20).

Step9: If the value of the objective function of the new evaluated harmony is better than that of the worst member of the previous memory then the new harmony will replace the previous worst member otherwise the new harmony will be discarded.

Step10: Again sort the new memory members according to their objective function value in ascending order.

Step11: Select the best solution which gives the best (minimum) value of the objective function.

5.7 System Data:-

Here the smart grid data of [23] is taken but here it is considered that all the users have same type of devices. The load data of residential, commercial and industrial area is listed as follows-

Sl No.	Device Type	Hourly Consumption of Device (kW)		
		1st Hr	2nd Hr	3rd Hr
1	Dryer	1.2	-	-
2	Dish Washer	0.7	-	-
3	Washing Machine	0.5	0.4	-
4	Oven	1.3	-	-
5	Iron	1.0	-	-
6	Vacuum Cleaner	0.4	-	-
7	Fan	0.2	0.2	0.2
8	Kettle	2.0	-	-
9	Toaster	0.9	-	-
10	Rice-Cooker	0.85	-	-
11	Hair Dryer	1.5	-	-
12	Blender	0.3	-	-
13	Frying Pan	1.1	-	-
14	Coffee Maker	0.8	-	-

Table 5.1: Data of Controllable Devices in the Residential Area

Sl No.	Device Type	Hourly Consumption of Device (kW)		
		1st Hr	2nd Hr	3rd Hr
1	Water Dispenser	2.5	-	-
2	Dryer	3.5	-	-
3	Kettle	3.0	2.5	-
4	Oven	5.0	-	-
5	Coffee Maker	2.0	2.0	-
6	Fan/AC	3.5	3.0	-
7	Air Conditioner	4.0	3.5	3.0
8	Lights	2.0	1.75	1.5

Table 5.2: Data of Controllable Devices in the Commercial Area

Sl No.	Device Type	Hourly Consumption of Device (kW)					
		1st Hr	2nd Hr	3rd Hr	4th Hr	5th Hr	6th Hr
1	Water Heater	12.5	12.5	12.5	12.5	-	-
2	Welding Machine	25.0	25.0	25.0	25.0	25.0	-
3	Fan/AC	30.0	30.0	30.0	30.0	30.0	-
4	Arc Furnace	50.0	50.0	50.0	50.0	50.0	50.0
5	Induction Motor	100.0	100.0	100.0	100.0	100.0	100.0
6	DC Motor	150.0	150.0	150.0	-	-	-

Table 5.3: Data of Controllable Devices in the Industrial Area

5.8 Simulation Result and Discussion:-

Here we solve the total optimization problem in a centralized manner i.e. the users will perform the rescheduling operation to reduce the total electricity bill including all the users. If the users are only concerned about their own electricity bill then the algorithm should be solved in distributed manner but this will lead to a serious problem that is if all the customers will reschedule their appliance to the off-peak hours to reduce their own bill then a peak may occur at the off-peak hours and this peak cannot be avoided. So instead of bothering about their own profit only here the users are concerned to minimize the electricity bill as a whole that every user will be benefitted.

5.8.1 Simulation Tool Used:

The proposed load scheduling algorithm by using real time pricing method is coded in MATLAB 8.3 (R2014a). MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Programmers and users of MATLAB can analyze data, develop algorithms and create models and applications using the language, tools, and built-in math functions to explore multiple approaches and solve technical computing problems faster than with spreadsheets or traditional programming languages such as C, C++ and Java.

5.8.2 Simulation Parameters:

The value of the parameters to run the proposed algorithm of section 5.5 is listed below-

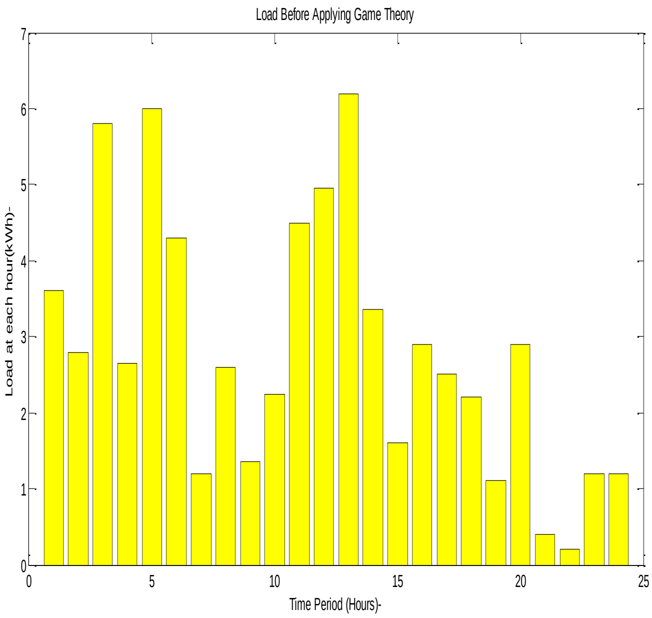
Name of the Parameter	**Set Value**
$HMCR_{\min}$	0.0001
$HMCR_{\max}$	0.7
$PAR_{\min}$	0.0000001
$PAR_{\max}$	0.1
$bw_{\min}$	0.000001
NI	500
HMS	250
Maximum number of selecting user at algorithm 1	For 5 users- 30 For 10 Users- 50 For 20 Users- 70 For 40 Users- 80
a_h	0.3
b_h	0
c_h	0

Table 5.4: Simulation Parameter

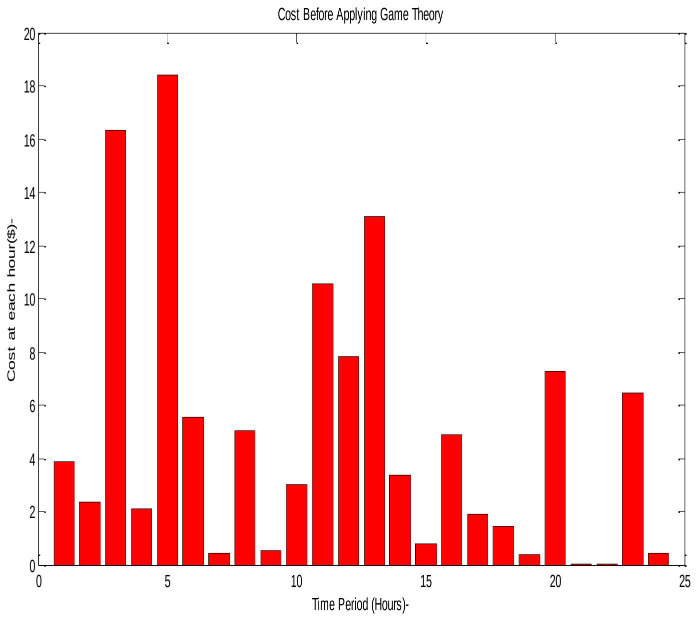
5.8.3 Results and Discussion:

Here we first implement our algorithm on 5 users having the loads listed above of each area. It is assumed that the users have specified the range of their time of use of each appliance. The result is investigated on each area and the cost and PAR reduction is studied and a comparison between their results is also drawn.

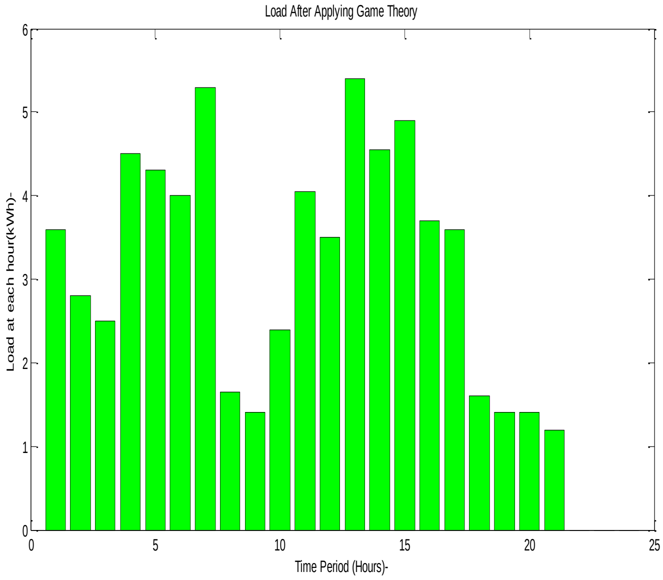
The simulation result curve for residential area is shown below-



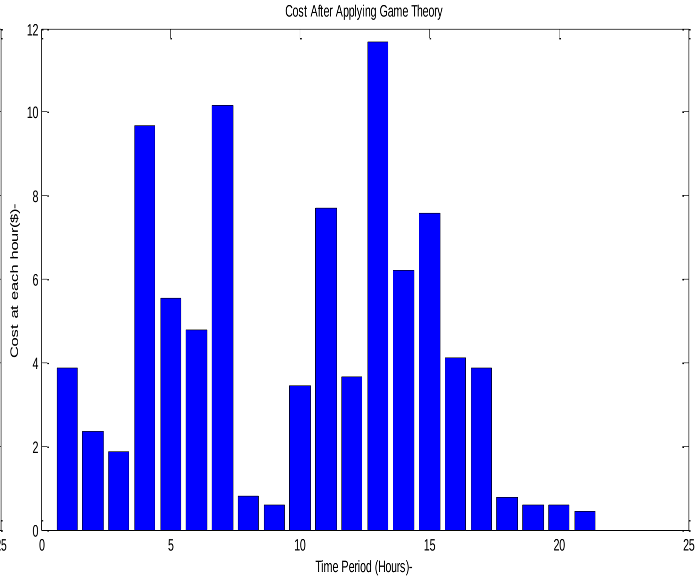
(a)



(c)



(b)



(d)

Figure 5.2: Residential Area Load Data- (a) Load Data before Applying Algorithm, (b) Load Data after Applying Algorithm, (c) Cost before Applying Algorithm, (d) Cost after Applying Algorithm

The simulation result curve for commercial area is shown below-

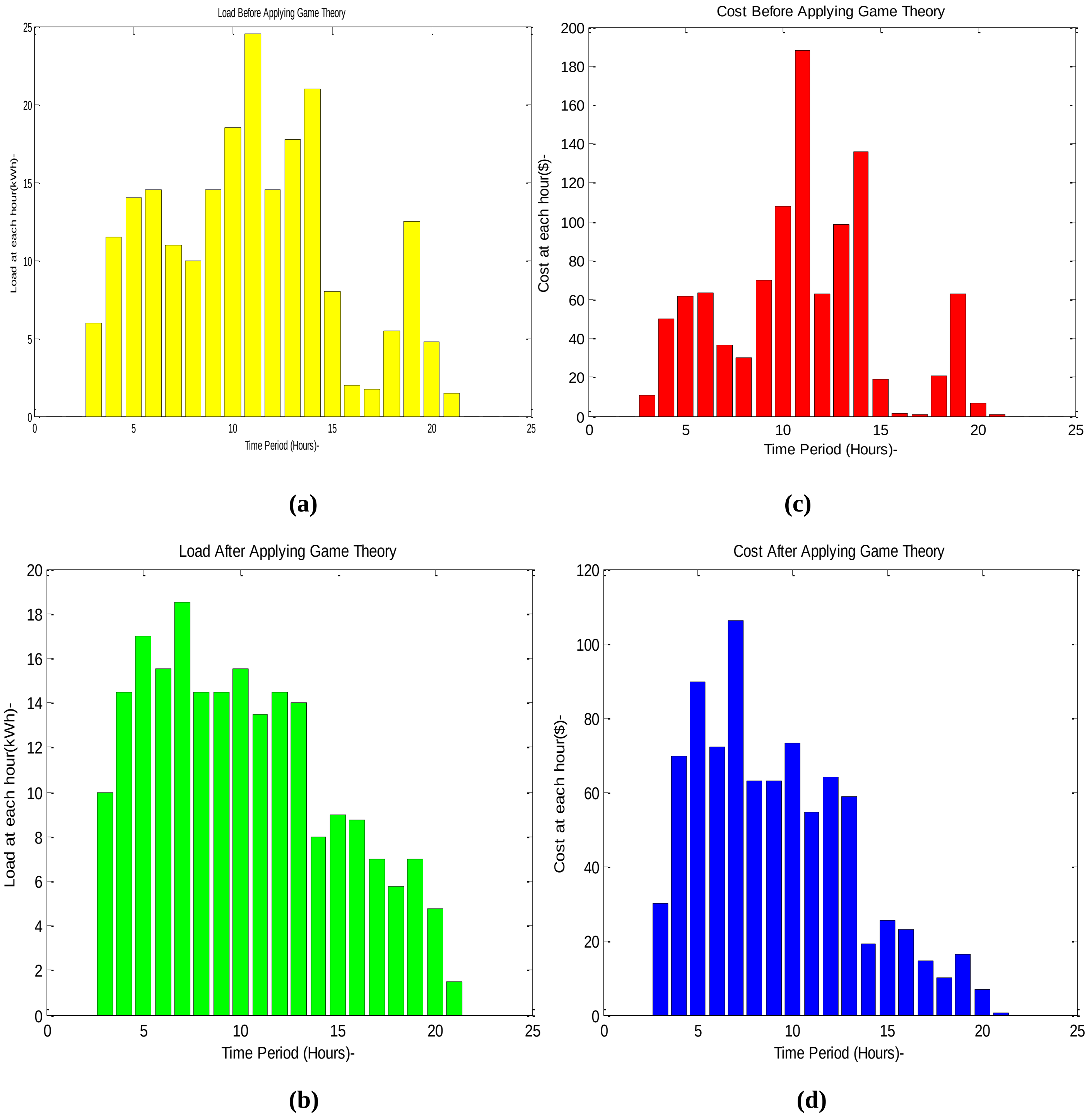
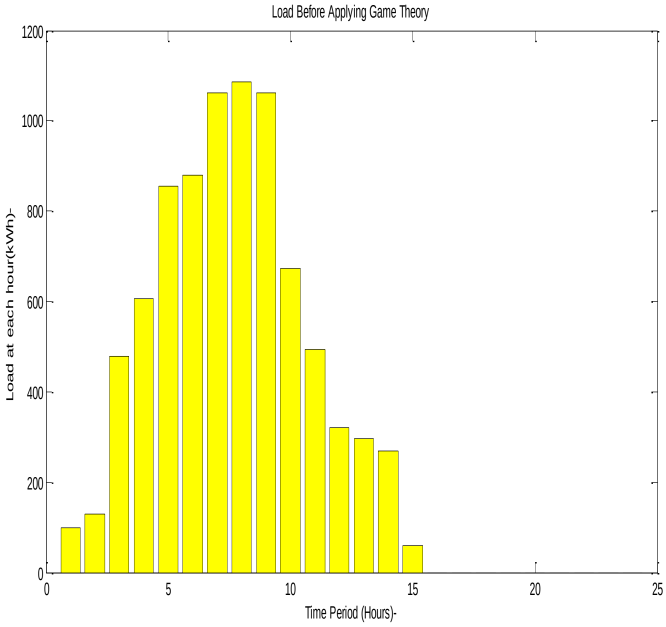
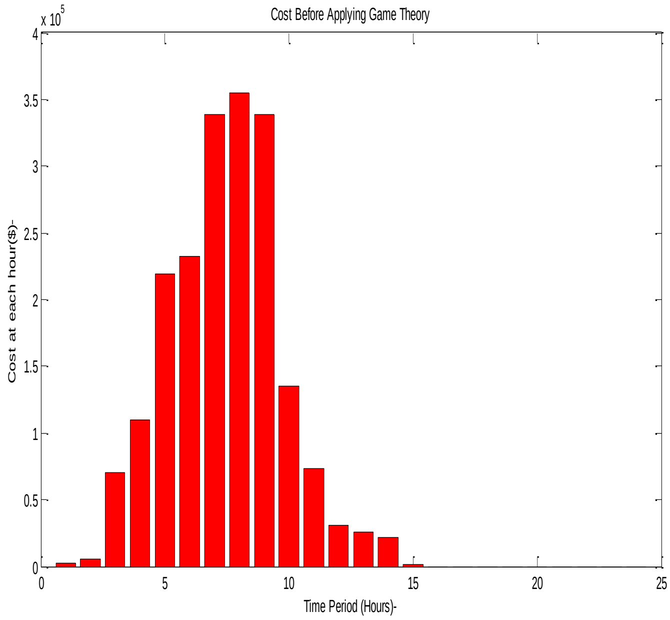


Figure 5.3: Commercial Area Load Data- (a) Load Data before Applying Algorithm, (b) Load Data after Applying Algorithm, (c) Cost before Applying Algorithm, (d) Cost after Applying Algorithm

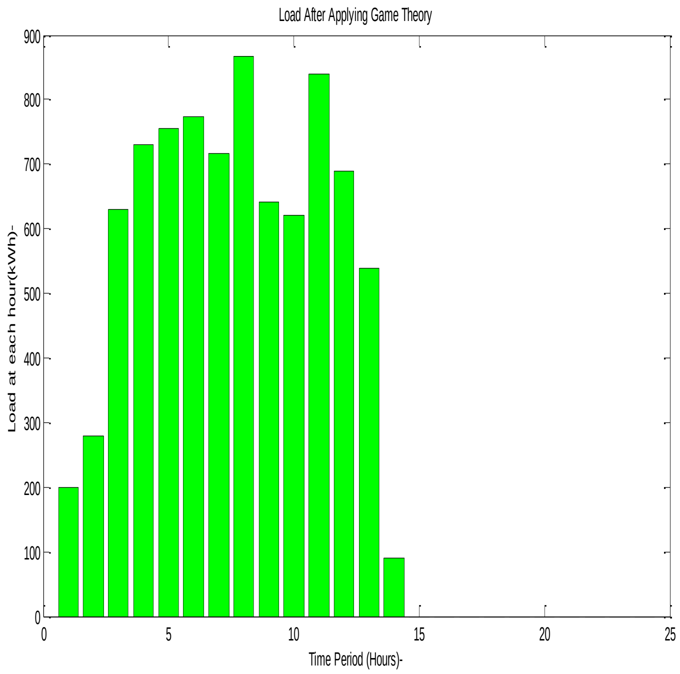
The simulation result curve for industrial area is shown below-



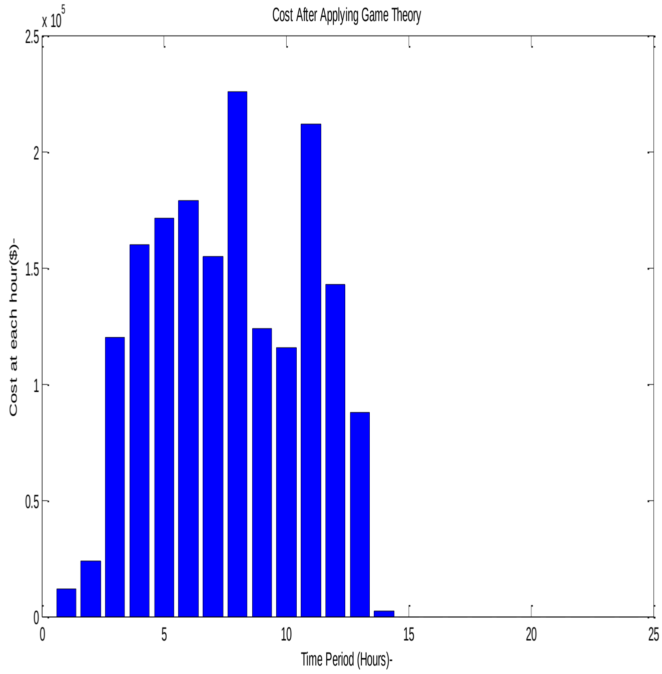
(a)



(c)



(b)



(d)

Figure 5.4: Industrial Area Load Data- (a) Load Data before Applying Algorithm, (b) Load Data after Applying Algorithm, (c) Cost before Applying Algorithm, (d) Cost after Applying Algorithm

It can be seen from fig. 5.2 to 5.4 that for each area after applying the load control algorithm the load at peak hours is reduced while the load at off-peak hours have been increased. Thus it can be concluded that the customers have rescheduled their appliances and because of that the load has been shifted from peak to off-peak hours. As a result of this load rescheduling the total electricity payment bill of all the customers also reduced.

Now the total cost and PAR reduction of each area is tabulated below-

Area	**Total Cost before applying game**	**Total Cost after applying game**	**Percentage Reduction**
Residential	116.058636	90.354762	22.15%
Commercial	1028.276970	860.357708	16.33%
Industrial	1961841.332802	1729823.558211	11.83%

Table 5.5: Cost Reduction Data of Real Time Pricing Technique

Area	**PAR before applying game**	**PAR after applying game**	**Percentage Reduction**
Residential	2.196310	1.912915	12.90%
Commercial	2.750877	2.077193	24.49%
Industrial	3.116418	2.485970	20.23%

Table 5.6: PAR Reduction Data of Real Time Pricing Technique

From the data of table 5.5 and 5.6 it can be shown that in case of residential area electricity bill reduction of users and PAR for utilities system is 22.15% and 12.9% respectively. For commercial area those values are 16.33% and 24.5% respectively and for industrial area 11.8% and 20.2% respectively.

Thus it is concluded that in case of residential area customers the electricity bill reduction is higher than the users belongs to commercial and industrial area. So this method is very much beneficial for residential users as far as electricity bill reduction is concerned. But if we see from utilities point of view we observe that the PAR reduction in residential area is lowest and it is only of 13% approximately but for other two areas it is more than 20%. So for utilities this method is beneficial for commercial and industrial area.

Now we will study the cost and PAR reduction phenomena when the number of users in each area is increased.

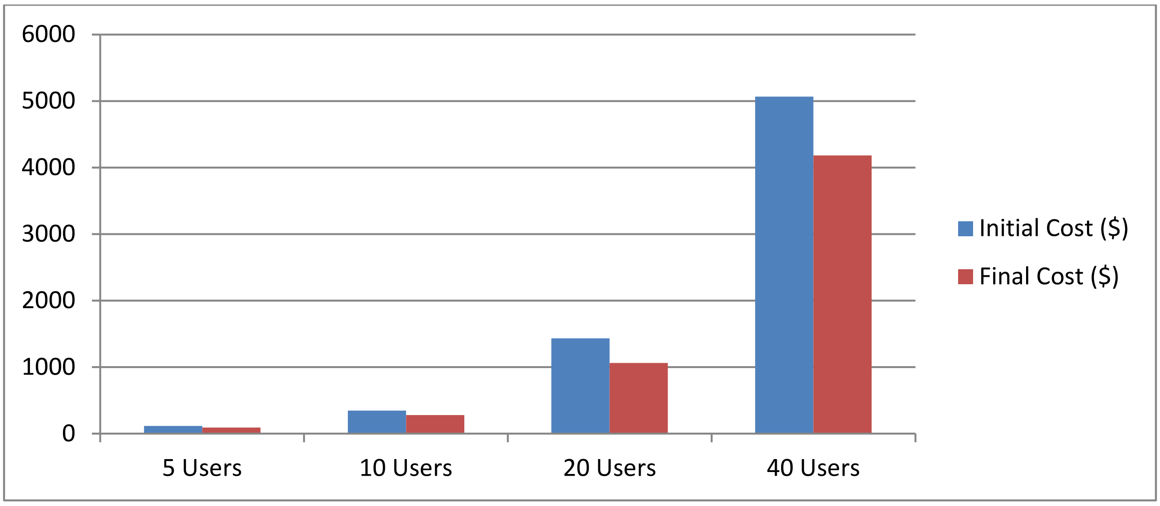


Figure 5.5: Residential Area Cost Data for More Number of Users

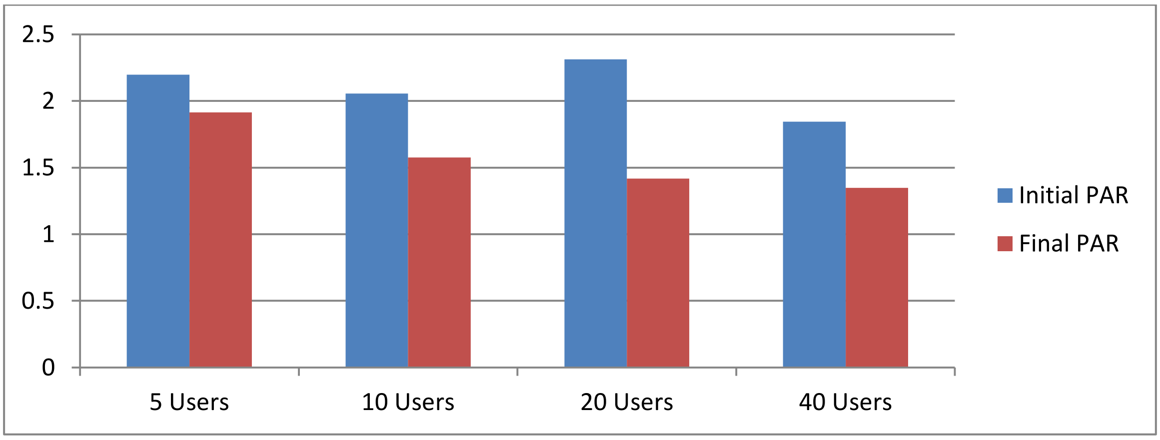


Figure 5.6: Residential Area PAR Data for More Number of Users

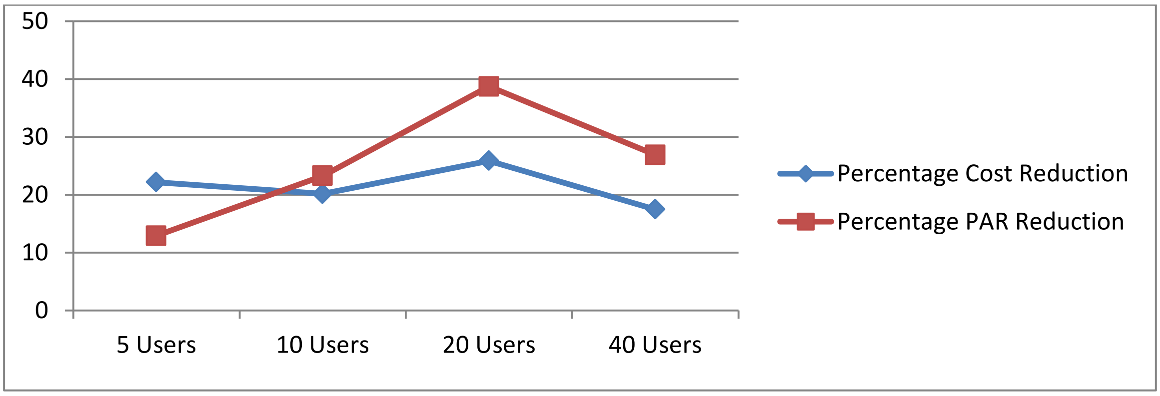


Figure 5.7: Percentage Reduction of Cost and PAR for More Number of Users in Residential Area

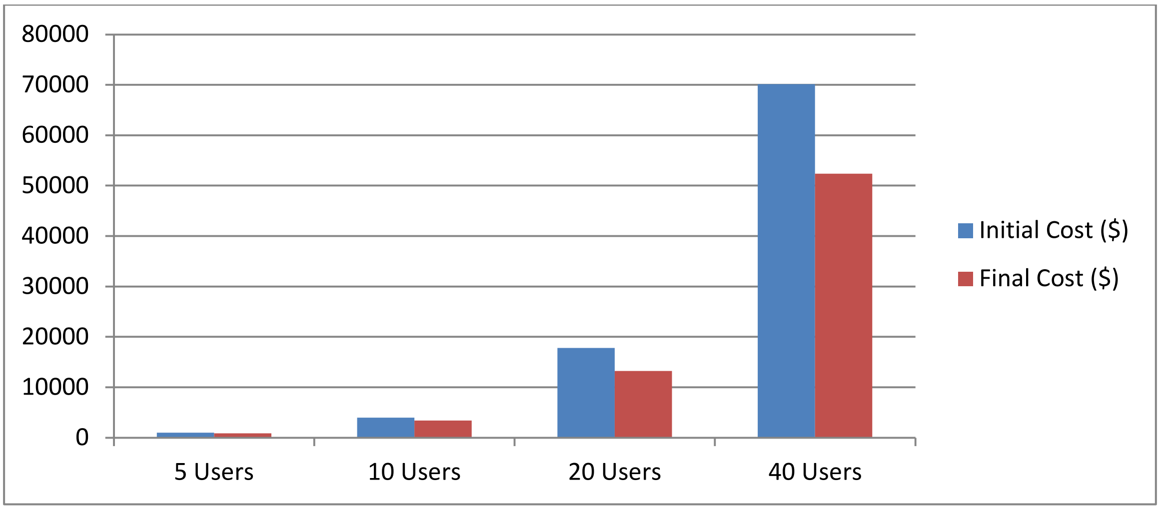


Figure 5.8: Commercial Area Cost Data for More Number of Users

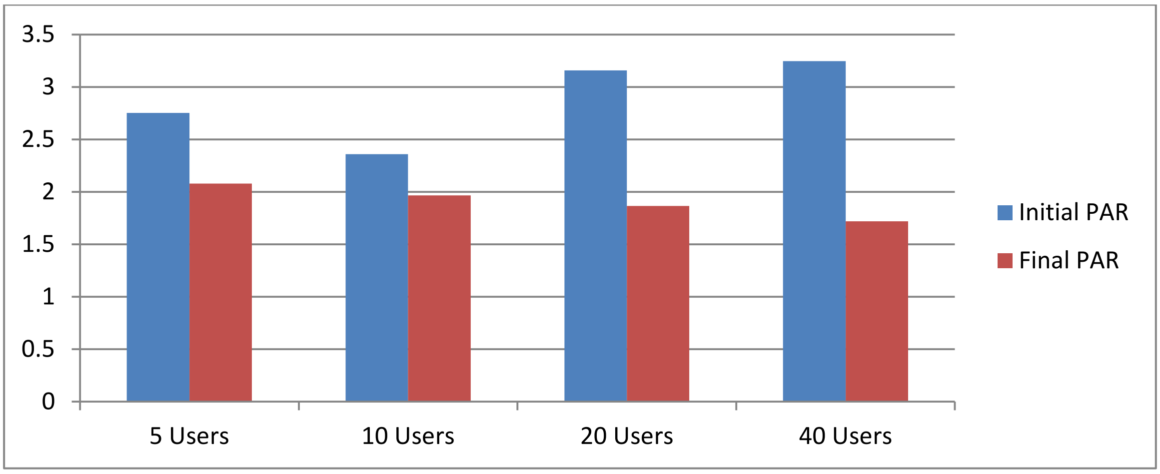


Figure 5.9: Commercial Area PAR Data for More Number of Users

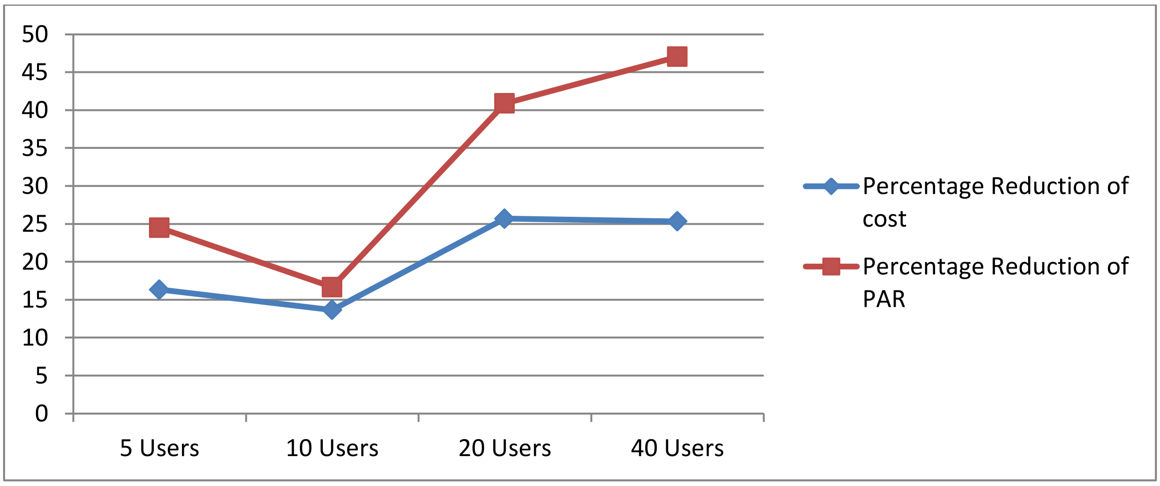


Figure 5.10: Percentage Reduction of Cost and PAR for More Number of Users in Commercial Area

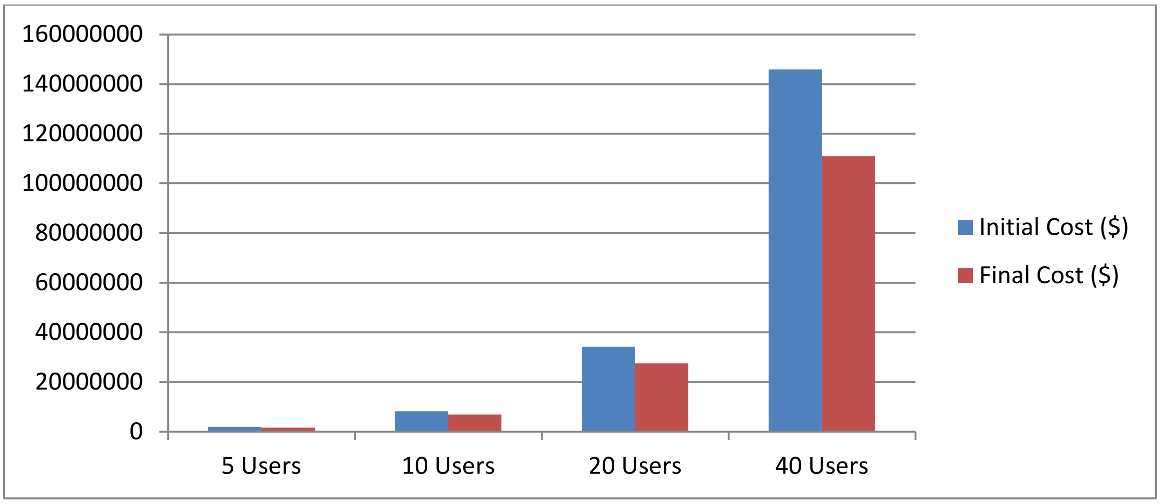


Figure 5.11: Industrial Area Cost Data for More Number of Users

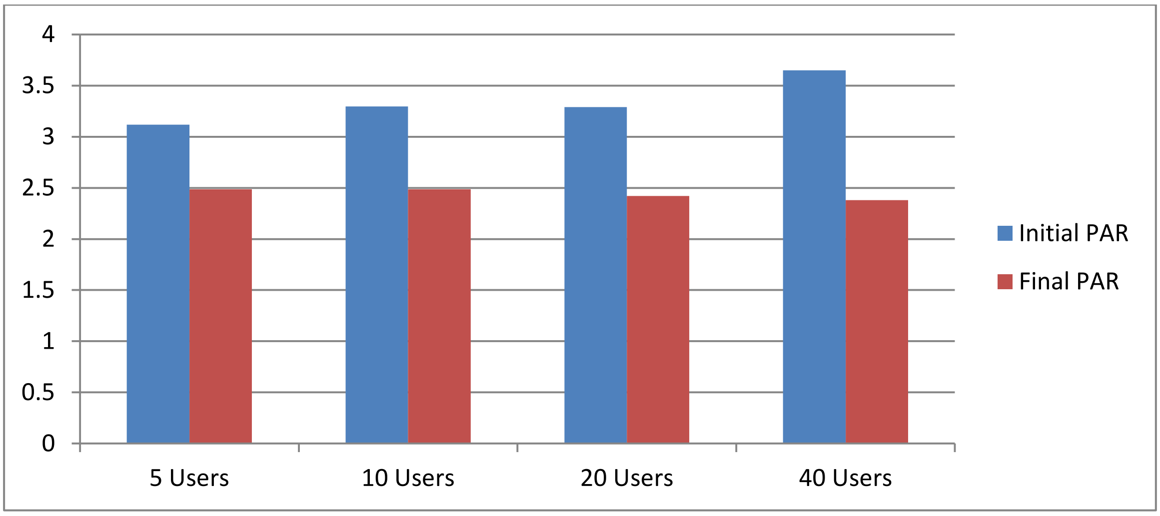


Figure 5.12: Industrial Area PAR Data for More Number of Users

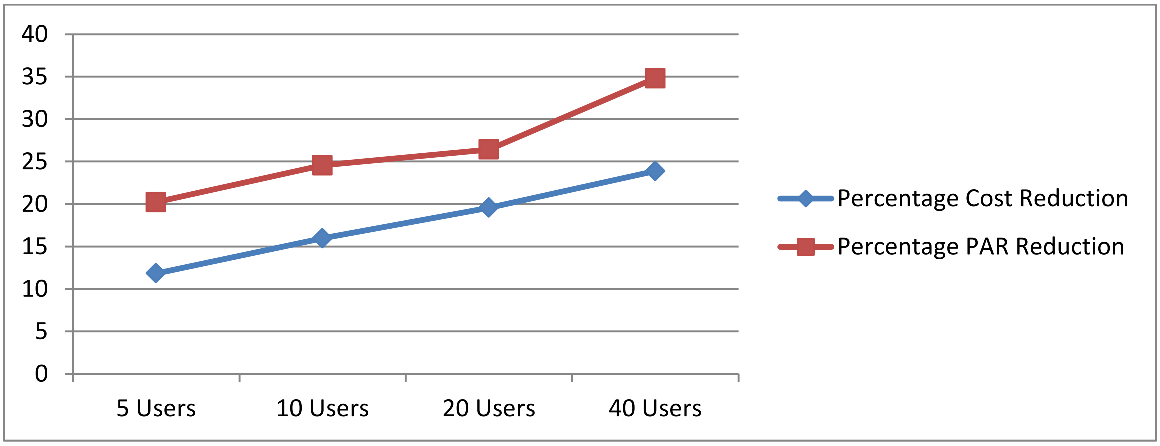


Figure 5.13: Percentage Reduction of Cost and PAR for More Number of Users in Industrial Area

Now it can be seen from Fig. 5.7 that for residential loads if the number of user increases from 5 to 20 the cost reduction and PAR reduction also increases but for 40 numbers of users the reduction in both the fields are lower than that of the 20 users. So for residential area this method is beneficial for lower and medium number of users and not very much efficient when number of users increases.

Now for commercial area users (Fig. 5.10) for lower number of users like 5 and 10 the PAR and cost reduction is not so much but it increase satisfactorily when the number of user is more like 20 or 40. So for large number of users in commercial area this method is useful.

In case of industrial area (Fig. 5.13) the PAR and cost reduction almost linearly increase with the increase of total number of users. For lesser number of users the reduction is not so much significant but as the number of users increases the reduction is much higher.

As the power consumption of the residential users are very low so the effect of the proposed strategy is not so much shown when the number of users increased as the shifting of low power rated loads does not alter the system load so much if the total load is high. So it can be concluded from both users and utilities point of view that this real time pricing algorithm is useful for medium number of residential users and large number of commercial and industrial users.

5.9 Summary:-

In this chapter a load scheduling algorithm based on real time pricing technique is proposed. The electricity cost function used here is a convex type and a new type of penalty function is established which is depends upon the available generation at that time interval. The customer will be only penalized if the current available generation is lower than the current demand. The algorithm is solved by using Harmony Search Algorithm in a centralized manner that the total electricity bill of the consumers and the system peak-to-average ratio will be minimum and every user schedule their loads at the optimum result. The proposed algorithm is tested on a smart grid load data and its effect is studied in case of residential, commercial and industrial users.

CHAPTER 6: CONCLUSION AND FUTURE WORK

6.1 Conclusion:-

In this research work, algorithms to get an optimum load scheduling have been performed under different operating conditions. The main objective of this work is to minimize the peak load of a system to flatten the load curve and due to that the electricity cost will also be minimized. As the cost and load consumption is proportional to each other so here we are mainly concerned to reduce the cost and due to that system peak load will be automatically reduced. Here we have mainly adopted two methods to achieve our goal.

First method is the load shifting method which mainly uses time of use pricing technique to charge the customers. In this method utilities will set the price per unit of electricity on the basis of the forecasted load data, when load is more per unit cost is also more, and then to reduce the total electricity cost they shift the operation of the controllable loads by satisfying the system constraints from peak load hours to the off-peak load hours. To know whether this schedule is optimum or not Differential Evolution Algorithm is used to minimize the total cost. This optimum schedule is stored into the DSM controller of the utilities and whenever the users switch on any of its load DSM controller will match the new schedule with the stored one, if it matches then controller permits the load to turn on, otherwise suggests another schedule time for it.

Second load scheduling algorithm is based on real time pricing technique. In case of previous load shifting algorithm utilities don't consider the customers' preference for load scheduling and that may lead to more dissatisfaction in the users. So to consider the customers' choice, in this algorithm users are also included into the load scheduling algorithm. Here utilities use a convex cost function along with a penalty function, charges when the present demand is more than the previous demand, for the billing process of the users. The utilities will get the schedule from the users at the start of the day and then send signal to the users to modify their schedule to reduce the total electricity payment. In this way the users' itself will modify its power consumption schedule according to their choice. As a result of this system PAR will also be reduced.

The following points are the major contributions of this work-

1. System peak load will be reduced.
2. Electricity generation cost is also reduced.
3. If load scheduling is optimum then the generators will run efficiently.
4. Load scheduling is also advantageous from environmental aspects, i.e. as the peak load is reduced so the generation and thus the fuel consumption is also reduced which will minimize the carbon emission to the nature.

6.2 Future Work:-

The research work can be further extended in the following mentioned area-

1. Here we have considered the residential, commercial and industrial areas separately. An algorithm can be established which can consider all the loads of each area together.
2. The loads can be placed in a standard distribution network and the investigation is carried out whether the DSM strategy will maintain the voltage profile at the distribution system.
3. Investigation can be carried out whether the DSM strategy will obey the power flow constraints from line to line power flow of the distribution system.
4. Performance of the DSM strategy when any disturbance or fault occurs at the distribution system.
5. Implementation of the same algorithms using other optimization techniques like Mixed-Integer Linear programming (MILP), Particle Swarm Optimization (PSO), Bat Algorithm, Genetic Algorithm etc.

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