TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

A

FINAL YEAR PROJECT REPORT

ON

HOURLY LOAD SHIFTING APPROACH FOR DEMAND SIDE MANAGEMENT

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ABSTRACT

The generation capacity of power stations is limited, and electricity consumption varies throughout the day, with high demand during peak hours and lower demand during off-peak hours. Balancing the supply of electrical power according to the load is essential, and simply increasing the number of generation units is not the sole solution to meet the increasing demand.

Demand Side Management (DSM) offers a solution by optimizing load patterns instead of solely relying on increasing power output. DSM enables customers to save on energy bills while ensuring network operators maintain network reliability and avoid unexpected surges in demand that can lead to power outages. By scheduling usage, DSM allows for better load balancing.

This report proposes a load shifting-based demand side management strategy to reduce peak hour demand. The objective is to minimize peak demand through an optimization problem formulated in the MATLAB R2021a environment. The proposed strategy seeks to find an optimal solution that maximizes efficiency.

Results demonstrate a 9.28% reduction in total peak demand through load shifting, accompanied by a 69.57% increase in base load. This optimization approach improves the utilization of electrical energy, enhancing DSM and proving cost-effective for both consumers and utility providers.

In summary, demand side management through load shifting offers a more reliable, environmentally friendly, and economically efficient power system. By effectively managing load patterns, DSM contributes to a more sustainable and balanced electricity grid.

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LIST OF ABBREVIATIONS

ANN	:	Artificial Neural Network
CC	:	Cycle Charging
CD	:	Combined Dispatch
COE	:	Cost of Energy
CVR	:	Conservation Voltage Reduction
DED	:	Dynamic Economic Dispatch
DER	:	Distributed Energy Resources
DESS	:	Distributed Energy Storage System
DLC	:	Direct Load Control
DR	:	Demand Response
DSM	:	Demand Side Management
DSR	:	Demand Side Response
ECC	:	Energy Consumption Controlling
EV	:	Electric Vehicles
GA	:	Genetic Algorithm
GOA	:	Grasshopper Optimization Algorithm
GSA	:	Gravitational Research Algorithm
HEMS	:	Home Energy Management Systems
HES	:	Hybrid Energy Systems
kWh	:	Kilowatt-hour
LF	:	Load Following
MW	:	Megawatt
NPC	:	Net Present Cost
OSG	:	On-site Generation

PAR	:	Peak to average ratio
PSO	:	Particle Swarm Optimization
PSO	:	Particle Swarm Optimization
RESs	:	Renewable Energy Systems
SG	:	Smart Grid
SGNs	:	Smart Grid Networks
T&D	:	Transmission and Distribution
TOU	:	Time of Use

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Electrical energy has played inseparable parts in domestic, commercial and industrial due to its finer points. Electrical energy can easily and economically convert from other forms of energy such as hydropower, thermal power, chemical power, solar power, wind power, etc. In the same way, electrical energy could be concerted back to some other form of energy. The electrical energy is transmitted very long distance cheaply and efficiently. Therefore, electrical energy has become an alliable part all around the development of socio-economic and industrial fields.

Electricity is an inseparable part of human life. Electricity is an essential part of modern life and important to the economy of the nation. People use electricity for lighting, heating, cooling, and refrigeration and for operating appliances, computers, electronics, machinery, and public transportation systems.

The generation of electrical energy is limited. The capacity to generate electricity is limited for the power station. But due to increasing population, varied population density, standard of living of people of certain area, the electrical consumption is uneven throughout the day. During peak hours, electrical energy demand is high and during off-peak hours, electrical demand is low. This is to say, during peak hours, the generated electrical energy is insufficient to handle the load. But during off-peak hours, the demand is so low that the electrical energy is not fully generated according to its capacity. The process of generation-consumption of electricity is a dynamic one. So, we need to balance the supply of electrical power in a power system network according to the load or power demand by adjusting the load instead of the power output of power plants. This is simply known as demand side management.

Presently, Nepal’s power industry is confronting the following difficulties – supply shortfalls, high peak power demand, high transmission & distribution (T&D) losses, power theft, wastefulness in metering and income accumulation and poor access to electricity in rural areas.

A smart grid should be the answer for every one of these difficulties and one of the critical functional areas of the smart grid is the demand side management (DSM). DSM methods are relied upon to be a noteworthy advance in the acknowledgement of the smart grid systems. The key objective of DSM techniques is to enable the utility services to deal with the consumer side electrical burdens. It can be said that the DSM will be a critical venturing stone towards practical behavior of the smart grid. *More generation unit is not the only solution for meeting the increasing demand as there are different asset limitations to generation*, for example restricted land, fuel, water, social and ecological worries in the setting of new power plants.

Distribution part in the Nepalese power sector is the weakest link in the power system network. In order to establish the balance between demand and supply, an appropriate action needs to be taken on both sides i.e. the supply side and the demand side. To achieve an effective operation of a smart grid, variables such as an expanded electricity demand, behavior of sustainable power resources, an expanded peak load demand and advancement in system framework play a crucial role. These smart grids are believed to be the up and coming generation of electric grids. The behavior of electrical consumption is the main idea behind the DSM. *The generated electricity ought to be used proficiently to take care of the demand and additionally to enhance the dependability of the electric supply framework*. There is need to acknowledge the importance of Demand Side Management in Power system.

1.2 PROBLEM STATEMENT

- Energy consumption is uneven throughout the day due to increasing population, varied population density, standard of living of people, etc. **During peak hours, electrical energy demand is high and during off-peak hours, electrical demand is low.**
- One of the solutions to fulfill high load demand might be increase in generation units. But during off peak period, the generated electricity will not used proficiently and the utility will have to encounter heavy loss. So, increasing only the generation units doesn’t solve it.
- For this, hourly load shifting might be the best solution.

1.3 OBJECTIVES

The general objective(s) of our project are:

- To reduce system peak load (Load Leveling)

The specific objective(s) of our project are:

- To reduce the peak demand of a certain city of India as the data is taken from research article.

1.4 SCOPE AND LIMITATION OF THE PROJECT:

The scopes of the project are as follows:

- Cost savings: By consuming energy during off-peak hours when energy rates are lower, consumers can reduce their energy bills.
- Grid stability: Hourly load shifting can help to prevent blackouts and brownouts, and ensure that the grid is able to meet demand during periods of high usage.
- Environmental benefits: By reducing overall energy demand, hourly load shifting can help to reduce greenhouse gas emissions and promote a more sustainable energy system.
- Energy security: Hourly load shifting can help to improve energy security by reducing reliance on imported energy sources and promoting a more stable and self-sufficient energy system.
- Renewable energy integration: Hourly load shifting can help to integrate renewable energy source into the grid (coordinating energy consumption with the availability of renewable energy.)

The limitations of the project are as follows:

- The project considers that all the consumers shift the considered secondary loads to the time suggested.
- It requires a well-developed and reliable energy grid with the infrastructure to support this type of demand side management strategy.
- Consumers must be aware of the benefits of this strategy and have access to the information and resources.

- Hourly load shifting may not always be feasible, particularly for consumers who have limited control over their energy usage, such as those living in multi-unit dwellings.
- For some consumers, shifting their energy consumption to off-peak periods may be inconvenient or disruptive to their daily routines.

1.5 ORGANIZATION OF THE REPORT

a. Chapter one embodies the general background of the project, problem statement of the project, objectives of the project, scope of the study and its limitations and organization of the document.

b. Chapter two reviews different articles in the field of demand side management. It depicts various techniques of DSM along with the related algorithm. It also mentions various tools and softwares used for the demand side management of the specific city. It also contains theoretical background and required theoretical information for understanding the project.

c. Chapter three contains a methodology on how the objective of the project is fulfilled. Besides, it mentions the software used for the implementation of the project.

d. Chapter four includes the result before and after demand side management in graphical form with its description.

e. Chapter five summarizes the results of the project as the conclusion.

CHAPTER TWO

LITERATURE REVIEW

2.1 REVIEW OF RESEARCH ARTICLES:

During our project, we had been through various research papers based on demand side management. The various papers explained different methods to solve energy demand.

In their 2014 technical report titled “A New Scheme for Demand Side Management in Future Smart Grid Networks,” A. Mahmood et al. from the Institute of Information Technology, Islamabad, Pakistan proposed an autonomous energy consumption scheduling scheme for household appliances, aimed at enabling Demand Side Management (DSM) in future Smart Grid Networks (SGNs). The paper highlights the integration of advanced information and communication technologies, facilitating environmentally friendly and cost-effective energy generation along with efficient consumption to meet the increasing qualitative and quantitative requirements of consumers. The scheme assumes that each user possesses a smart meter equipped with an Energy Consumption Controlling (ECC) unit. Through a local area network, these ECC units are interconnected with neighboring units to share power consumption information. Employing a distributed algorithm, the ECC units collaboratively work to minimize peak loads by shifting shiftable loads from peak hours to off-peak hours. This strategy ultimately reduces the total energy consumption cost. By leveraging smart grid technologies and the real-time data provided by smart meters, the proposed scheme offers an intelligent and automated solution for demand-side energy management in future SGNs. It addresses the goals of the smart grid paradigm, including grid reliability enhancement, optimized resource utilization, and sustainability promotion. The effective implementation of this scheme allows for a more balanced load profile, decreased peak demand, and optimized energy consumption, meeting the evolving needs of consumers while considering environmental and economic factors. [1]

In 2017, a paper titled “Grasshopper Optimisation Algorithm: Theory and Application” was published by Shahrzad Saremi, Seyedali Mirjalili, and Andrew Lewis from the School of Information and Communication Technology, Griffith University, Australia. The paper introduced the Grasshopper Optimisation Algorithm (GOA) as an effective solution for challenging structural optimization problems. Inspired by the collective behavior of grasshopper swarms, GOA is mathematically modeled and applied to optimize the shape of trusses and cantilever beams. The study demonstrated the superior performance of GOA compared to other algorithms such as Particle Swarm Optimization (PSO) and Gravitational Research Algorithm (GSA). The findings highlight the practical applicability of GOA in solving optimization problems in various domains. [6]

In 2018, L. Mellouk, M. Boulmalf, A. Aaroud, K. Zine-Dine, and D. Benhaddou published a paper titled "Genetic Algorithm to Solve Demand Side Management and Economic Dispatch Problem." The paper presented the application of the Genetic Algorithm (GA) method to address the optimization challenges of Demand Side Management (DSM) and Dynamic Economic Dispatch (DED). Instead of treating DSM and DED as separate processes, the authors considered them as complementary stages in the optimization process. To tackle the problem, the authors adopted a discrete approach, treating the energy consumption profile of each user as an individual discrete problem. The GA was developed to determine the optimal scheduling for users' electrical devices and allocate the optimal contribution of each energy source to meet the needs of individual users during specific time slots. The primary objectives of the study were to minimize consumer bills through time pricing of different energy sources, reduce the degree of energy consumption during peak hours, and minimize energy losses in the grid. The proposed GA-based scheduling scheme was compared with unscheduled schemes, and the results demonstrated significant performance improvements of more than 10%. By employing the GA approach, the authors successfully addressed the challenges of DSM and DED, optimizing the consumption profile and energy allocation for individual users. The findings of the study emphasize the potential of GA as a powerful optimization tool for demand-side management and economic dispatch problems, contributing to improved energy efficiency, cost reduction, and grid stability. [4]

In January 2019, A. S. Aziz, M. F. Naim Tajuddin, M.R. Adzman, Makbul A. M. Ramli, and S. Mekhilef published a paper titled "Energy Management and Optimization of a PV/Diesel/Battery Hybrid Energy System Using a Combined Dispatch Strategy." The paper highlights the advantages of optimally designed hybrid energy systems (HESs) compared to single-source systems in terms of reliability and cost-effectiveness. The study focuses on the feasibility of a combined dispatch (CD) control strategy for a photovoltaic (PV)/diesel/battery HES. This strategy combines the load following (LF) strategy and cycle charging (CC) strategy to ensure optimal system performance. The researchers employed HOMER software as a tool for optimization analysis, examining the techno-economic and environmental aspects of the proposed system. Simulation results demonstrate that the CD strategy outperforms the LF and CC strategies in terms of net present cost (NPC) and cost of energy (COE). The CD strategy achieves lower NPC values compared to LF strategy-based systems and lower COE values compared to CC strategy-based systems. From an environmental perspective, the CD strategy exhibits the best performance among the considered strategies. Overall, the study emphasizes the benefits of the CD strategy in achieving improved economic and environmental performance in PV/diesel/battery HESs. By optimizing the energy management and dispatch strategies, the proposed approach provides valuable insights for the design and operation of hybrid energy systems, promoting cost efficiency and sustainability. [2]

In August 2019, E. Sarker, M. Seyedmahmoudian, S. Mekhilef, and A. Stojcevski published a paper titled "Optimal Scheduling of Appliances in a Smart Grid Environment Using BPSO Algorithm." The paper introduces the use of the Binary Particle Swarm Optimization (BPSO) algorithm for implementing Demand Side Management (DSM) in a smart grid (SG) environment. The study focuses on the application of load shifting techniques in both residential and industrial areas, aiming to shift the electricity demand from peak hours to off-peak hours. The load shifting technique is mathematically formulated and implemented as a minimization problem. The paper clearly demonstrates that the BPSO-based load shifting method can efficiently handle a large number of devices with varying characteristics, outperforming traditional DSM methods. The primary objectives of the research include reducing peak load demand, electricity cost, and Power Affordability Ratio (PAR) while achieving significant cost savings. Comparative analysis with the Genetic Algorithm (GA)-based DSM approach indicates that the BPSO-based load shifting method yields superior results in terms of peak load reduction. The findings highlight the effectiveness of the BPSO algorithm in optimizing the scheduling of appliances, thereby enabling efficient load management and cost savings in a smart grid environment. Overall, the study underscores the advantages of utilizing the BPSO algorithm for DSM implementation in a smart grid context. By optimizing load shifting strategies, the proposed approach contributes to peak load reduction, cost optimization, and improved energy affordability, fostering the goals of sustainability and efficiency in smart grid operations. [11]

In their November 2019 paper titled "Hourly Load Shifting Approach for Demand Side Management in Smart Grid Using Grasshopper Optimization Algorithm," Majid Jamil and Sonam Mittal discuss the transformative impact of the smart grid on the power system network. They emphasize the importance of demand side management (DSM) or demand side response as a crucial element of the smart grid, enabling intelligent capabilities within the traditional grid infrastructure. The paper introduces a novel approach for demand side management that focuses on load shifting, specifically shifting the load from peak to off-peak hours. The primary objective of their work is to reduce peak hour demand and utility bills for consumers. To achieve this goal, the authors propose and apply two optimization algorithms: the Particle Swarm Optimization (PSO) algorithm and the Grasshopper Optimization Algorithm (GOA). These algorithms are utilized for three distinct load sectors in the smart grid: residential, commercial, and industrial. Through simulation results, the authors demonstrate the effectiveness of their approach, showcasing a significant reduction in peak hour demand and utility bills. The integration of the PSO and GOA algorithms with load shifting strategies offers promising solutions for efficient demand side management within the smart grid context. Overall, this research contributes to advancing the field of demand side management, providing valuable insights and practical approaches for reducing peak hour demand and improving cost savings for consumers. By harnessing the potential of optimization algorithms, load shifting techniques, and the intelligence of the smart grid, the proposed approach paves the way for more sustainable and economically viable energy consumption practices. [10]

In their 2019 research article titled "Ensuring the Reduction in Peak Load Demands Based on Load Shifting DSM Strategy for Smart Grid Applications," Mande Praveen and G. V. Sivakrishna Rao address the highly variable behaviors of prosumers, who both produce and consume energy, in the context of the smart grid. The dynamic nature of prosumer behavior, influenced by factors such as price and incentives, has made peak load management a critical issue. Demand response has gained significant attention, particularly in smart and microgrid systems. The paper focuses on the role of Demand Side Management (DSM) in peak load management within a residential community. The study employs a load shifting-based DSM technique and conducts a simulation analysis. Daily consumption patterns of electricity across four types of electric loads are considered on an hourly basis. The results indicate a substantial decrease in the peak load when compared to the load patterns observed prior to implementing DSM. By investigating the impact of DSM on peak load reduction, this research sheds light on the effectiveness of load shifting strategies in managing electricity demand within residential communities. The findings emphasize the significance of DSM in smart grid applications, offering potential solutions to optimize peak load demands and enhance the overall stability and efficiency of the grid. [5]

In their 2020 research paper titled “Effect of Demand Side Management on the Operation of PV-Integrated Distribution Systems,” J. A. Sa’ed, Z. Wari, F. Abughazaleh, J. Dawud, S. Favuzza, and G. Zizzo from the Department of Electrical and Computer Engineering at Birzeit University, Palestine, investigate the implementation of smart grids alongside distributed generation from renewable energy sources to enhance the reliability and controllability of the grid. The paper emphasizes the mutual benefits of Demand Side Management (DSM) for users, utilities, and the market. DSM methodologies such as Conservation Voltage Reduction (CVR) and Direct Load Control (DLC) are explored as means to reduce plant generation and overall costs. The algorithms of CVR, DLC, and their combination are implemented using OpenDSS and MATLAB, and their effectiveness is evaluated on the IEEE 30-Bus test system. Multiple integration scenarios between Photovoltaic (PV) systems and DSM schemes are analyzed, focusing on optimizing energy consumption reduction for both users and utilities. The results demonstrate that the implemented DSM algorithms lead to significant reductions in energy losses and consumed energy. By effectively integrating PV and DSM schemes, the study highlights the potential to achieve enhanced energy efficiency and cost savings in distribution systems. This research contributes to the understanding of the operation and benefits of DSM in PV-integrated smart grid environments, providing valuable insights for grid operators, policymakers, and researchers aiming to optimize the operation of renewable energy-based distribution systems. [7]

In their November 2020 research paper titled “Demand Side Residential Load Management System for Minimizing Energy Consumption Cost and Reducing Peak Demand in Smart Grid,” Md. A. Rahman, I. Rahman, and N. Mohammad from the Department of Electrical and Electronic Engineering at Chittagong University of Engineering and Technology, Bangladesh, present a system designed for efficient demand-side management in the context of the smart grid. The primary objective of the research is to optimize load scheduling in order to minimize energy costs and reduce peak loads. The study employs a demand response technique specifically for load scheduling optimization, aiming to minimize the overall cost of power consumption for residential household loads while ensuring customer satisfaction. To achieve this, a detailed load scheduling model is developed, enabling the Home Energy Management System (HEMS) to compute optimized power consumption by considering dynamic price variations and customer preferences. The results demonstrate the effectiveness of the proposed dynamic pricing-based HEMS, as it significantly reduces peak loads and achieves a remarkable 22.55% reduction in total energy costs for customers. This research contributes to the advancement of demand-side management strategies in the smart grid, offering a practical solution for minimizing energy consumption costs and addressing peak demand challenges. By integrating dynamic pricing and customer satisfaction considerations, the proposed system enhances the efficiency and affordability of electricity usage in residential settings. [12]

In their 2021 research paper titled "Demand Side Management Techniques for Home Energy Management Systems for Smart Cities," M. M. Hussain, R. Akram, Z. A. Memon, M. H. Nazir, W. Javed, and M. Siddique explore various demand side management (DSM) techniques for home energy management systems (HEMS) in the context of smart cities. The paper introduces three distinct modules based on DSM and distributed energy resources (DERs): load shedding, grid penetration reduction with renewable energy systems (RES), and implementation of HEMS. These approaches offer promising opportunities to enhance demand side efficiency and minimize energy demand during peak hours. The researchers utilized the Electrical Power System Analysis (ETAP) software to model and assess the integration of distributed generation, specifically RES, and local power storage. They investigated how the energy consumption of smart home appliances can be minimized to optimize the utilization of photovoltaic (PV) systems. Additionally, the study examined the impact of integrating wind turbines into power networks to reduce the load on the main power grid. The findings of the study indicate that smart grids contribute to improved energy efficiency, security, and management. Moreover, they raise consumer awareness regarding power usage and foster environmental consciousness. By implementing DSM techniques and leveraging DERs, such as RES and HEMS, in smart cities, it becomes possible to achieve a more sustainable and efficient energy infrastructure. [8]

In their September 2022 research article titled "Demand response modeling with solar PV as a panacea to the Nigerian electricity distribution conundrum: A case study of Sierra Leone," Ima Okon Essiet and Yanxia Sun from the Department of Electrical and Electronic Engineering Science at the University of Johannesburg, South Africa, presented an optimization model based on a case study conducted in Sierra Leone. This model can be adapted for the Nigerian distribution system, as both countries are located in the same region (West Africa) and have similar power systems. The paper focused on two demand response

(DR) scenarios: price-based and incentive-based. By comparing these DR schemes to a situation without DR utilization, the authors examined the impact of DR on peak load reduction and financial benefits for participants. Furthermore, they investigated the impact of renewable energy dispatch during peak and off-peak periods on financial benefits. The simulation results demonstrated that both time-based and incentive-based DR strategies effectively reduce peak load demand. This finding highlights the potential of DR in addressing the challenges faced by the Nigerian electricity distribution system. By implementing DR and integrating renewable energy sources such as solar PV, significant improvements can be achieved in reducing peak loads and providing financial benefits to participants. The insights gained from the case study in Sierra Leone offer valuable lessons for the Nigerian context and contribute to finding sustainable solutions for the electricity distribution conundrum in the region. [3]

In their July 2022 paper titled "Neural Network-Based Demand-Side Management in a Stand-Alone Solar PV-Battery Microgrid Using Load-Shifting and Peak-Clipping," Godiana Hagile Philipo, Josephine Nakato Kakande, and Stefan Krauter from Paderborn University, Germany, addressed the challenges of electrifying African rural communities with microgrid systems in the absence or unreliability of a centralized electricity grid. These microgrids face complexities in control and stability due to intermittent energy generation and increasing demand. Demand side management (DSM) techniques provide an opportunity to enhance flexibility on the demand side by optimizing users' consumption patterns in response to supply. The paper proposed a demand-side management strategy based on load shifting and peak clipping. The approach was implemented using a MATLAB/Simulink R2021a environment and optimized with an artificial neural network (ANN) algorithm. Simulations were conducted to evaluate the efficacy of the proposed model in a stand-alone PV-battery microgrid scenario in East Africa. The results demonstrated that the algorithm effectively reduced peak demand, achieved desired load profile smoothing, and improved the peak to average ratio (PAR) of the system. Furthermore, the incorporation of deferrable loads increased the flexibility of demand-side management. The findings indicated that peak clipping led to a decrease in peak demand and PAR, while load shifting offered additional flexibility for customers. Overall, the proposed DSM strategy showed promising results in optimizing energy consumption and enhancing the performance of stand-alone microgrid systems. [9]

2.2 RELATED THEORY

2.2.1. DEMAND CURVE / LOAD CURVE

The graph which shows the variation of load on the power station with respect to time is called the load curve of the power station.

The load on a power station does not remain constant; it changes from time to time. These changes in the load on a power station during whole day (i.e. for 24 hours) are recorded half-hourly or hourly and are plotted with respect to time on the graph. The obtained graph is called the daily load curve of the power plant.

a. The daily load curve illustrates the electricity demand patterns over a 24-hour period, capturing the variations from minimum to maximum load. It helps in analyzing the peak demand periods and planning power generation and distribution accordingly. Typically, the daily load curve exhibits two peaks, known as the morning peak and evening peak, which correspond to the times of highest electricity consumption during the day. The load curve usually shows lower demand during the late-night and early morning hours when electricity usage is minimal. Figure 2.1 illustrates the daily load curve.

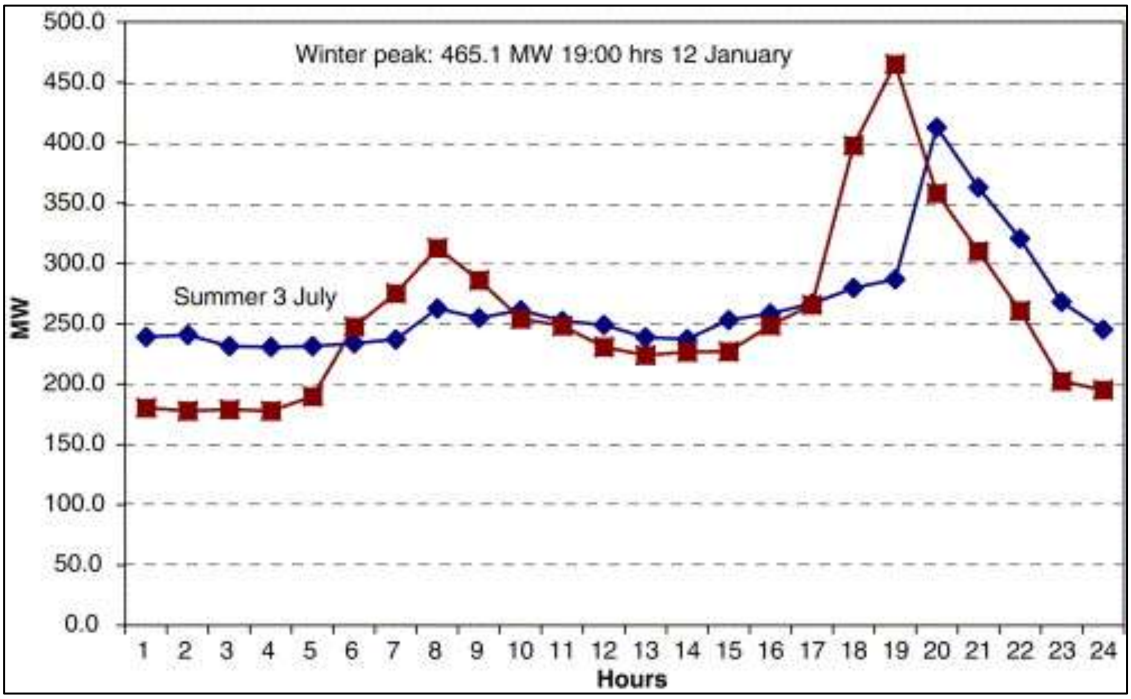

Figure 2.1: Daily Load Curve [13]

b. The monthly load curve provides an overview of electricity demand patterns over a specific month. It helps in identifying the seasonal variations in electricity consumption.

c. The yearly load curve represents the electricity demand patterns over a full year. It provides a comprehensive view of the seasonal, monthly, and daily variations in energy consumption. The yearly load curve is crucial for long-term planning, infrastructure development, and capacity expansion decisions.

Importance of Load Curves

Load curves play a crucial role in various aspects of the electricity industry and energy management. Some of the key importances of load curves are:

i. Grid Planning and Operation:

   Load curves provide valuable insights into the electricity consumption patterns, allowing grid operators and planners to optimize the operation of the power grid.

ii. Energy Market Operations:

   Load curves are used in energy markets for pricing and trading electricity. They help determine the supply and demand dynamics, influencing electricity prices.

iii. Demand Response Programs:

   Load curves aim to incentivize consumers to adjust their electricity usage during peak demand periods. By analyzing load curves, grid operators and utilities can identify critical periods and implement demand response initiatives, such as time-of-use pricing or load shedding programs.

iv. Renewable Energy Integration:

   Load curves help in integrating renewable energy sources, such as solar and wind, into the grid. These sources are variable and depend on weather conditions, which can be forecasted by analyzing historical load curves.

v. Infrastructure Planning:

   Load curves assist in infrastructure planning and development, such as transmission and distribution systems. By analyzing load curves, engineers can identify areas with high demand and plan for infrastructure upgrades to meet future load growth.

The demand/load of a power station is not same throughout a day. During off-peak hours, demand is low and too high during on-peak hours. Balance in demand throughout the day is good for the economic condition of the nation.

2.2.2. TYPES OF ELECTRICAL LOAD

The electrical energy consumption depends on the nature of area, population of the area, population density and standard of living of the people.

- Domestic (Residential) Load:

  Domestic loads refer to the electrical power consumption in residential households. These loads include lighting, heating and cooling systems, kitchen appliances, entertainment devices, home electronics, and other equipment used in homes.

- Commercial Load:

  Commercial loads are associated with non-industrial businesses and establishments. These loads encompass a wide range of electrical equipment and systems used in offices, retail stores, restaurants, hotels, and other commercial buildings. Examples of commercial loads include lighting, air conditioning, refrigeration, computers, printers, cash registers, and other office equipment.

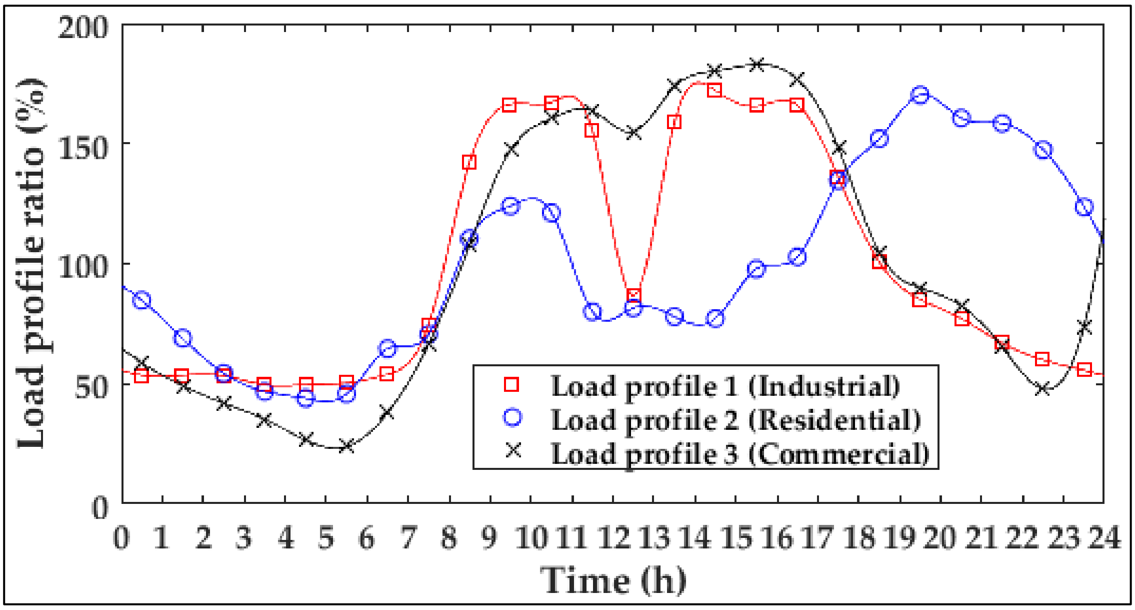

Figure 2.2: Demand curve of different sectors

Figure 2.2 shows that different types of loads have different peak demand in different time.

- Industrial Load

  Industrial loads pertain to the electrical power consumption in industrial facilities and manufacturing plants. These loads are typically more demanding and can include heavy machinery, motors, pumps, compressors, conveyors, welding equipment, and various process equipment used in manufacturing, mining, and other industrial processes.

- Municipal Load

  Municipal loads are related to the power consumption by public facilities and services provided by local governments. These loads include street lighting, traffic signals, water pumping stations, wastewater treatment plants, public buildings (such as libraries and community centers), and other infrastructure managed by municipalities.

- Agriculture loads, irrigation loads, and traction loads are other less common types of load.

Therefore, different types of load have different peak demand.

On the basis of controllable nature of devices, loads are classified as:

a. Primary loads: These are the loads which must run at specific time. They cannot be shifted to flexible period of time for its operation.

b. Shiftable/Controllable devices: Controllable devices are characterized by their ability to be shifted or having lower priority, making them flexible in terms of their operation time. A comprehensive list of shiftable devices for residential, commercial, and industrial areas is provided. These devices have the potential to be adjusted and scheduled based on demand and grid conditions, contributing to effective load shifting and demand side management strategies.

   i. Residential area: Among the three zones of the smart grid, the residential area offers the highest number of controllable gadgets that can be managed. However, it is important to note that these gadgets typically have lower power utilization ratings and shorter task durations compared to those in commercial and industrial areas.

   ii. Commercial area: The controllable gadgets available for control in the commercial region have slightly higher utilization ratings compared to those in the residential area.

   iii. Industrial area: Among the three zones of the smart grid, the industrial area has the lowest number of controllable gadgets available for control. However, it is noteworthy that these gadgets have the highest consumption ratings compared to the gadgets in both residential and commercial areas.

2.2.3. DEMAND SIDE MANAGEMENT

Demand Side Management (DSM) refers to the planning, implementation, and coordination of various strategies and techniques aimed at influencing the patterns and levels of electricity consumption by end-users. It involves actively managing and modifying electricity demand to achieve specific goals such as reducing peak load, improving grid reliability, enhancing energy efficiency, and promoting sustainable energy practices.

The key objective of demand side management is to optimize the use of electricity resources and infrastructure by balancing the supply and demand of electricity. By strategically influencing consumer behavior and consumption patterns, DSM helps to align electricity demand with the available generation capacity, reducing the need for additional power generation and infrastructure investments.

There are several approaches and techniques employed in demand side management:

a. Load Shifting: Encouraging consumers to shift their electricity usage from peak demand periods to off-peak hours when demand is lower. This can be achieved through time-of-use pricing, incentives, or real-time feedback.

b. Peak Load Reduction: Implementing measures to reduce or manage electricity consumption during peak demand periods, which helps to alleviate stress on the grid and prevent potential blackouts or brownouts.

c. Energy Efficiency Programs: Promoting energy-efficient practices, technologies, and equipment to reduce overall electricity consumption. This can include energy audits, efficiency incentives, and education campaigns.

d. Demand Response: Enabling consumers to voluntarily adjust their electricity usage in response to signals or incentives provided by the utility or grid operator. This can involve temporarily reducing or shifting electricity consumption during times of high demand or supply constraints.

e. Dynamic demand: It includes advance or delay appliance operating cycles by a few seconds to increase the diversity factor of the set of loads. The concept is that by monitoring the power factor of the power grid, as well as their own control parameters, individual, intermittent loads would switch on or off at optimal moments to balance the overall system load with generation, reducing critical power mismatches. As this switching would only advance or delay the appliance operating cycle by a few seconds, it would be unnoticeable to the end user. This type of dynamic demand control is frequently used for air-conditioners.

f. Distributed Energy Resources: Distributed generation, also distributed energy, on-site generation (OSG) or district/decentralized energy is electrical generation and storage performed by a variety of small, grid-connected devices referred to as distributed energy resources (DER). Conventional power stations, such as coal-fired, gas and nuclear powered plants, as well as hydroelectric dams and large-scale solar power stations, are centralized and often require electric energy to be transmitted over long distances. By contrast, DER systems are decentralized, modular and more flexible technologies, that are located close to the load they serve, albeit having capacities of only 10 megawatts (MW) or less. These systems can comprise multiple generation and storage components; in this instance they are referred to as hybrid power systems. DER systems typically use renewable energy sources, including small hydro, biomass, biogas, solar power, wind power, and geothermal power, and increasingly play an important role for the electric power distribution system. A grid-connected device for electricity storage can also be classified as a DER system, and is often called a distributed energy storage system (DESS). By means of an interface, DER systems can be managed and coordinated within a smart grid. Distributed generation and storage enables collection of energy from many sources and may lower environmental impacts and improve security of supply.

g. Smart Grid Technologies: Utilizing advanced metering, communication systems, and control devices to enable real-time monitoring and management of electricity consumption, allowing for more precise demand-side interventions.

The benefits of demand side management are multifaceted. For consumers, it can result in reduced energy bills, improved comfort and control over electricity usage, and increased awareness of energy conservation. Utilities and grid operators benefit from improved grid stability, optimized resource allocation, and enhanced operational efficiency. Additionally, demand side management contributes to environmental sustainability by reducing the need for new power plants, minimizing greenhouse gas emissions, and promoting the integration of renewable energy sources.

Overall, demand side management plays a crucial role in achieving a more balanced, efficient, and sustainable electricity system by actively managing and optimizing electricity consumption at the consumer level.

2.2.4. DEMAND SIDE MANAGEMENT TECHNIQUES

There are various techniques of demand side management.

a. Peak Clipping:

   It refers to the reduction of utility loads during peak demand periods. This can differ the need of additional generation capacity. The net effect is reduction in both peak demand and total energy consumption.

b. Valley Filling:

   It is a form of load management that entails building of off-peak period loads. It is often the case when there is under-utilized capacity that can operate on low cost fuels. The net effect is an increase in total energy consumption, but no increase in peak demand.

c. Load Shifting/ Hourly Load Shifting:

   It involves shifting load from on-peak to off-peak periods. The net effect is a decrease in pad demand but no change in total energy consumption. Typical methods use for load shifting are time of use (TOU) rates and use of storage device.

d. Load Growth:

   It consists of increase in overall sales. The net effect is an increase in both demand and total energy consumption.

e. Load Conservation:

   It refers to the reduction in end-use consumption. These are net reduction in both peak demand (depending upon coincidence factor) and total energy consumption.

f. Flexible Load Curve:

   It refers to variations in reliability or quality of service. Instead of influencing load shape on permanent basic, the utility has the option to interpret load when necessary. There may be net reduction in peak demand and little in any change in total energy consumption.

The above techniques are illustrated in figure 2.3 and figure 2.4 in next page.

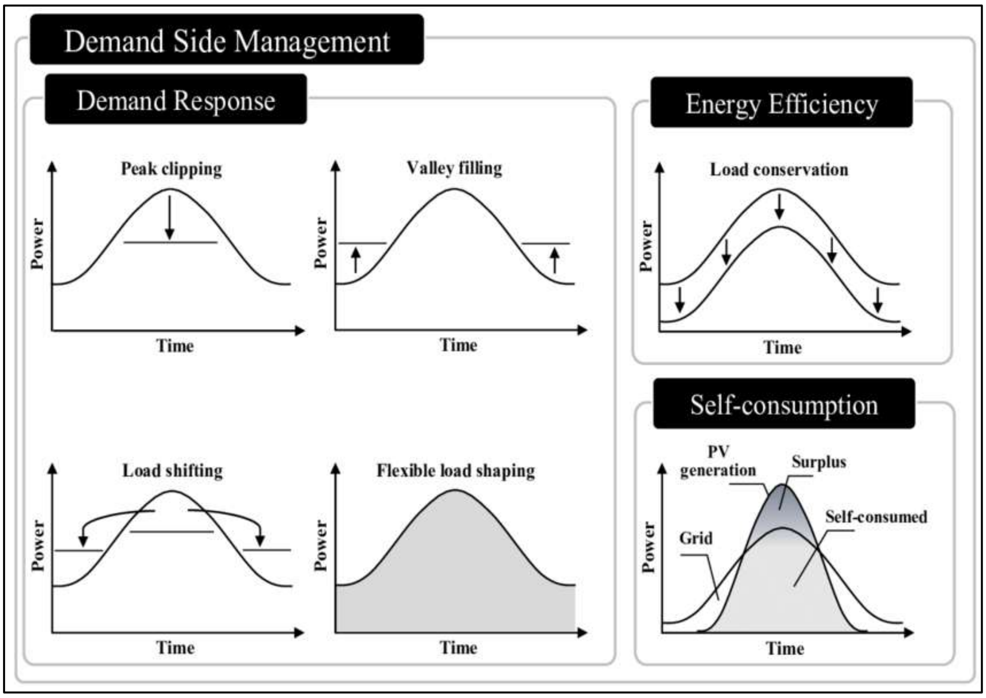

Figure 2.3 : Demand Side Management [25]

Figure 2.3 illustrates the various techniques of demand side management.

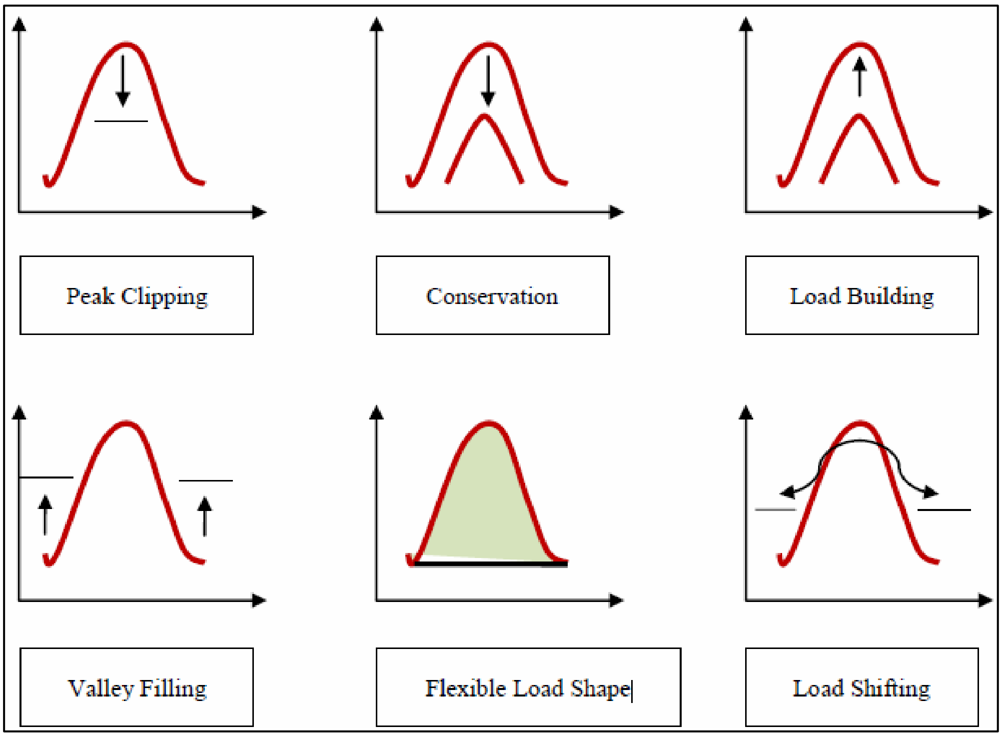

Figure 2.4 : Load Leveling techniques [26]

Figure 2.4 illustrates various load leveling techniques used for demand side management.

2.2.5. SOME COMMONLY USED DSM TECHNIQUES

After we reviewed some of the research articles related to Demand Side Management, we found several ways for the management of demand side. Some of the methods are as follows:

a. Load Scheduling

Load scheduling is a process that involves strategically planning and managing the timing and sequencing of electricity consumption for various loads within a system. It aims to optimize energy usage, minimize peak demand, and achieve operational efficiency. Load scheduling is an essential component of demand side management (DSM) strategies, which focus on balancing electricity supply and demand.

The main objective of load scheduling is to distribute the energy load more evenly throughout the day, reducing the strain on the electrical grid during peak demand periods. By shifting the timing of energy-intensive activities to off-peak hours, load scheduling helps to flatten load profiles and maximize the utilization of available energy resources. This can result in cost savings, improved grid stability, and reduced environmental impact.

b. Demand Response

Demand response is a strategy or program implemented to actively manage and adjust electricity consumption in response to changes in the supply-demand balance within the electrical grid. It involves modifying energy consumption patterns based on price signals, grid conditions, or specific requests from grid operators. The goal of demand response is to achieve a more balanced and efficient electricity system by aligning electricity usage with available supply. Demand response programs typically involve incentives, price signals, or contracts that encourage electricity consumers to voluntarily adjust their energy consumption during periods of high demand or supply constraints. Participants may receive financial incentives, reduced electricity rates, or other benefits for participating in demand response activities.

c. Combined Dispatch Strategy

A combined dispatch strategy refers to an approach in energy management that integrates and optimizes the dispatch of multiple energy resources, such as power plants, renewable energy sources, and energy storage systems, to meet the electricity demand efficiently. This strategy involves coordinating the operation of different energy resources in a unified manner to achieve specific objectives, such as cost minimization, emission reduction, or grid stability. The combined dispatch strategy takes into account the availability, capabilities, and constraints of each energy resource to determine the most optimal and cost-effective combination of resources to meet the current demand. It considers factors such as fuel costs, renewable energy availability, storage capacity, and system constraints to make informed decisions on resource allocation and utilization. By combining and optimizing the dispatch of various energy resources, a combined dispatch strategy can offer several benefits like enhanced flexibility, cost optimization, improved grid stability, etc. Overall, a combined dispatch strategy provides a comprehensive and integrated approach to energy management, allowing for efficient utilization of diverse energy resources while achieving cost savings, grid stability, and environmental sustainability.

d. Grasshopper Optimization Algorithm (GOA)

The process of finding the best values for the variables of a particular problem to 21ehavior or 21ehavior an objective function is called optimization.

Grasshopper are insects. The life cycle of grasshoppers has three stages: eggs, nymph and adult. Although grasshoppers are usually seen individually in nature, they join in one of the largest swarm of all creatures. The size of the swarm may be of continental scale and a nightmare for farmers. The unique aspect of the grasshopper swarm is that the swarming 21ehavior is found in both nymph and adulthood. Millions of nymph grasshoppers jump and move like rolling cylinders. In their path, they eat almost all vegetation. After this 21ehavior, when they become adult, they form a swarm in the air. This is how grasshoppers migrate over large distances. Food source seeking is important characteristic of the swarming of grasshoppers.

Nature-inspired algorithms logically divide the search process into two tendencies: exploration and exploitation. In exploration, the search agents are encouraged to move abruptly, while they tend to move locally during exploitation. These two functions, as well as target seeking, are performed by grasshoppers naturally. Therefore, if we find a way to mathematically model this 21ehavior, we can design a new nature-inspired algorithm.

e. Genetic Algorithm (GA)

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. You can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic, or highly nonlinear. The genetic algorithm can address problems of mixed integer programming, where some components are restricted to be integer-valued.

f. Particle Swarm Optimization(PSO)/Binary PSO (BPSO):

Particle Swarm Optimization (PSO) is a population-based optimization algorithm inspired by the collective behavior of bird flocking or fish schooling. It is a metaheuristic algorithm used to solve optimization problems by iteratively improving a population of candidate solutions.

In PSO, a population of candidate solutions, called particles, move through the search space in search of the optimal solution. Each particle represents a potential solution and has a position and velocity vector. The position represents a potential solution, and the velocity determines the particle's movement direction. At each iteration, particles update their positions and velocities based on their own experience and the best experience of their neighboring particles. The position update is influenced by two factors: the particle's previous best position (personal best) and the global best position found by any particle in the population.

PSO has been widely applied to various optimization problems, including engineering design, data clustering, image processing, scheduling, and function optimization. It is known for its simplicity, efficiency, and ability to handle both continuous and discrete optimization problems.

g. Artificial Neural Network (ANN)

Artificial Neural Network(ANN) uses the processing of the brain as a basis to develop algorithms that can be used to model complex patterns and prediction problems.

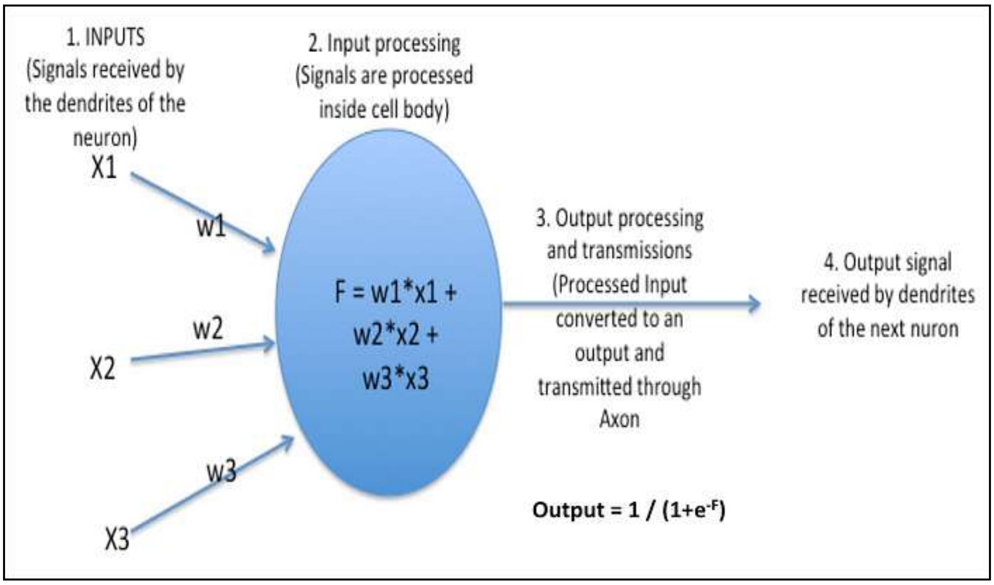

Figure 2.5 : Working of ANN algorithm analogy to neuron [21]

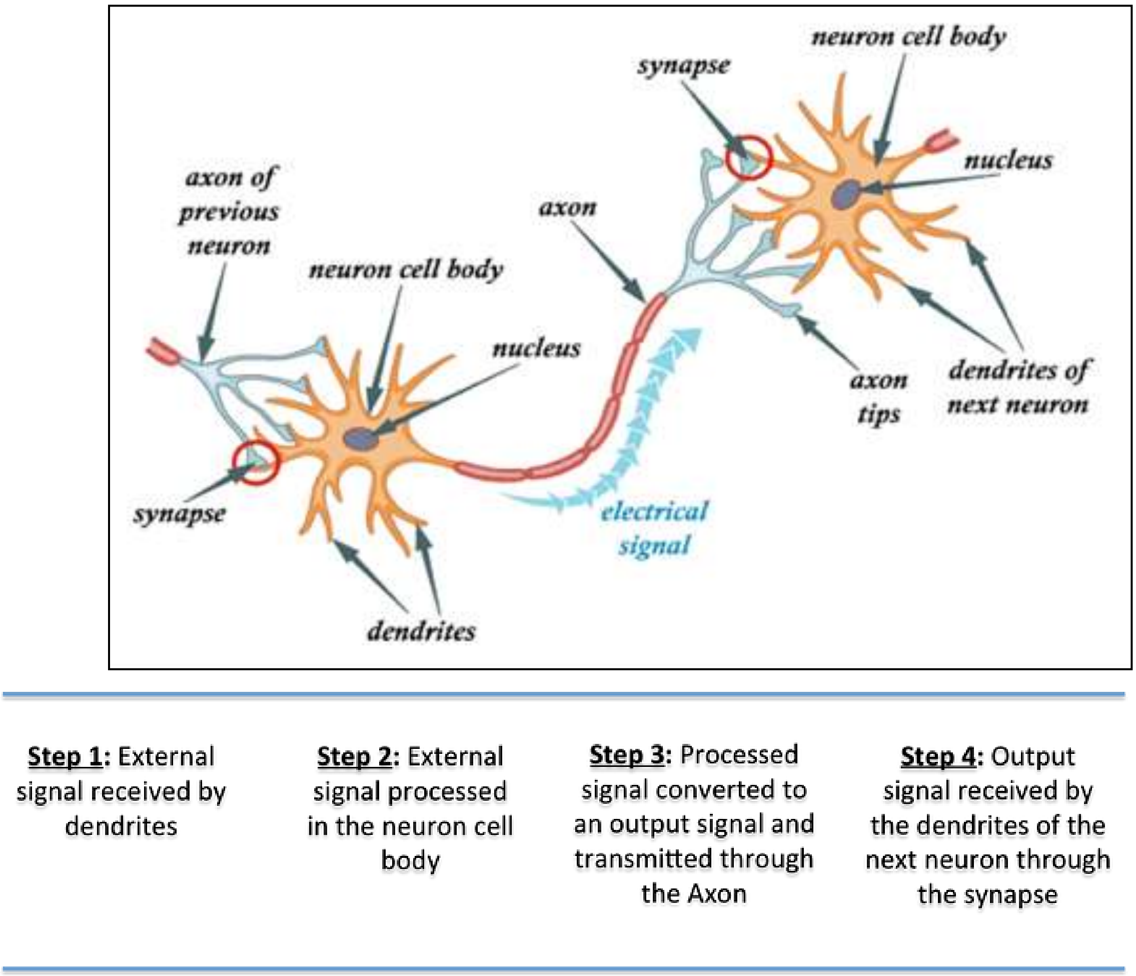

Figure 2.6 : Working of human nerve cell (neuron) [21]

Figure 2.5 (in previous page) illustrates the working of ANN in similar manner with the human nerve cell. ANN receives the signal as input, processes it and then generates output. The generated output is used as input signal for another system until the desirable result is obtained.

The function of ANN is analogy to human nerve cell which is illustrated in figure 2.6 (in previous page). The human nerve cell receives different input signals through dendrites, processes in nerve cell body and the output signal is transmitted to axon. The axon transmits the signal to dendrites of another neuron. In this way, ANN works.

CHAPTER THREE

METHODOLOGY

3.1 FLOW CHART OF PROPOSED MODEL:

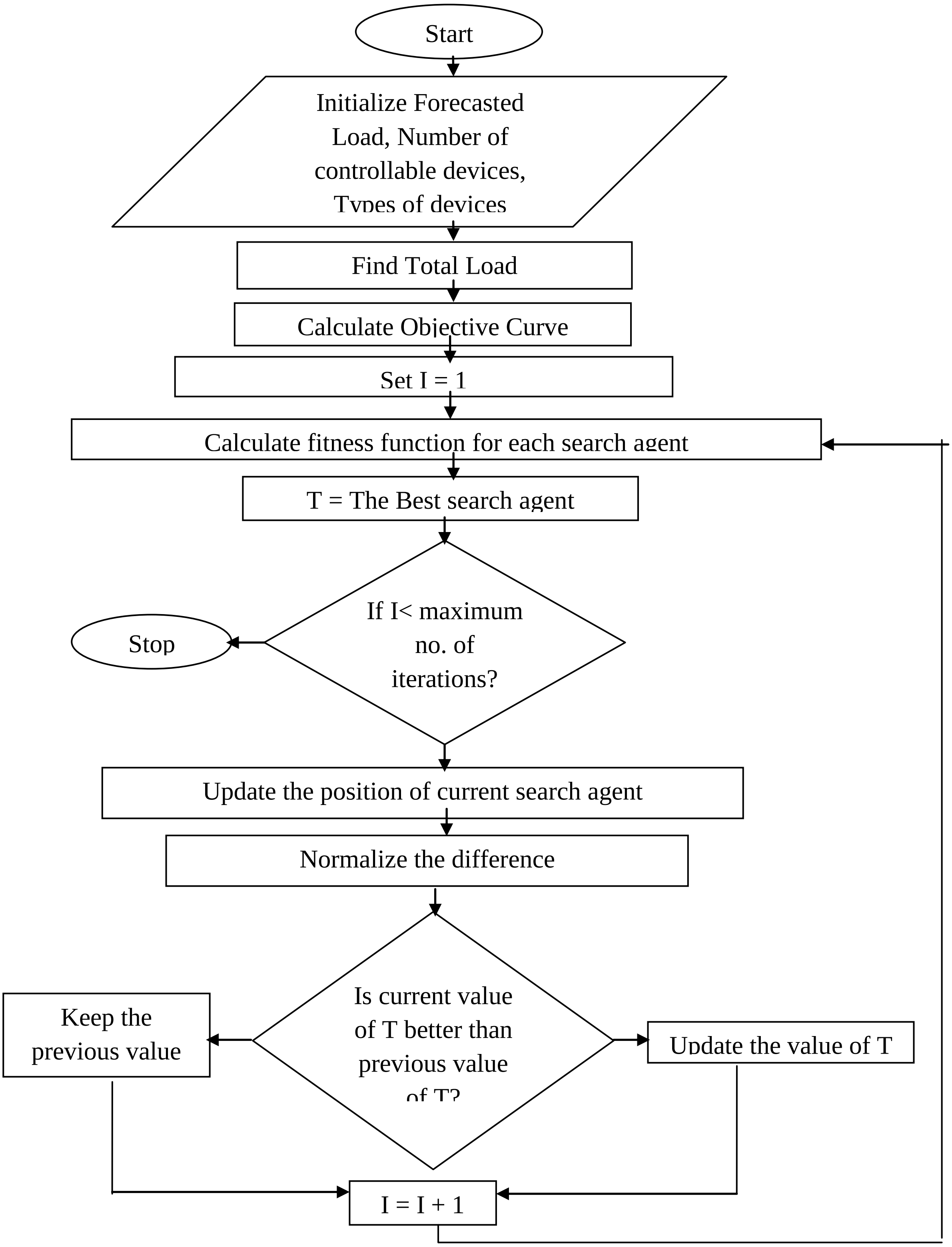

Figure 3.1 : Flowchart of proposed model

Figure 3.1 in the previous page shows the working diagram of the proposed model to implement demand side management. Initially, demand of a certain city in a particular year is forecasted using the data available. The number and types of secondary devices are assumed as necessary. The total load of the city is calculated and an objective curve is determined. For each sector (domestic, commercial, industrial, etc) and for each time period, the fitness function is calculated.

The process is repeated until the maximum number of iterations is achieved. The difference is normalized and the fitness function is updated. The whole process is repeated for the best search agent.

3.2.FORMULATION OF THE PROBLEM:

The proposed DSM technique aims to optimize the connection times of controllable devices, which can be shifted, in order to align the actual demand curve with the target demand curve. This involves formulating the DSM strategy as a numerical minimization problem, expressed as follows:

Minimize = (Target Demand Curve - Actual Demand Curve)^2 …………………. (i)

By minimizing the squared difference between the target and actual demand curves, the DSM technique strives to achieve a close match between them. This optimization process involves determining the optimal scheduling of controllable devices to minimize the deviation between the actual and desired demand profiles.

Solving this minimization problem requires the application of suitable algorithms and optimization techniques. The proposed approach offers an effective means of load management, contributing to the successful implementation of Demand Side Management within the smart grid network.

The actual power consumption at any given time can be calculated by considering the forecasted load, as well as the contributions from controllable and non-controllable loads at time t. The equation for calculating the actual power consumption is formulated as follows:

Actual Power Consumption (at time t) = Forecasted Load + Controllable Loads + Non-Controllable Loads …………………………. (ii)

This equation takes into account the predicted load, the power consumed by controllable devices, and the power consumed by non-controllable devices at a specific time t. By summing these components, the actual power consumption can be accurately estimated.

This calculation provides valuable information for monitoring and managing power consumption, enabling effective load balancing and optimization strategies within the smart grid network.

Alternatively,

$$P_{ac}(t) = \text{Forecasted}(t) + \text{Connected}(t) - \text{Disconnected}(t) \text{ -------------- (iii)}$$

here Forecasted(t) is the fixed energy consumption of non-controllable loads, connected(t) is the consumption of that controllable loads which were shifted to time t and disconnected(t) is the consumption of that controllable loads which were switched-off during the process with time t.

$$obj = \sum_{t}^{T=24} Forecasted(t)) \text{ ------------------ (iv)}$$

Power consumed by connected devices is calculated as:

$$\text{Connected}(t) = \sum_{i=1}^{t-1} \sum_{j=1}^{D} C_{jit}.P_{1j} + \sum_{l=1}^{k-1} \sum_{i=1}^{t-1} \sum_{j=1}^{D} C_{ji(t-1)}.P_{(1+l)j} \text{ ------------- (v)}$$

where C_{jit} shows the total devices of type j shifted from the time i to t. The total device types that are available is given by D, P_{1j} and $P_{(1+l)\,j}$ with the power consumption at time 1 and $1 + l$:

$$\text{Disconnected}(t) = \sum_{d=t+1}^{t+a} \sum_{j=1}^{D} C_{jtd}.P_{1j} + \sum_{l=1}^{k-1} \sum_{t=t+1}^{i+a} \sum_{j=1}^{D} C_{j(t-1)d}.P_{(1+l)j} \text{ --------- (vi)}$$

where C_{jtd} is the total number of devices of type j which were delayed from time t to d and a is limit to the permissible delay. Equations from (1) to (5) are taken from [12] but the abbreviation is changed. There are some limitations and the paper characterized these limitations by the following mathematical equations. The number of displaced devices cannot be negative:

$$C_{jit} > 0 \ \forall i, j, k \text{ ------------------------------ (vii)}$$

The total number of shifted devices cannot exceed the total secondary devices available at a particular time step. A condition can be numerically formulated as

$$\sum C_{jit} \leq Controllable(i) \text{ ----------------------- (viii)}$$

here Controllable(i) represents secondary devices available at i^{th} time step. The shifting can be delayed but never be advanced. The mathematical representation is as follows.

$$C_{jit} = 0 \; \forall i > t \text{ ------------------ (ix)}$$

At last, a restriction is imposed on optimum allowable time delay for the secondary devices, formulated as:

$$C_{jit} = 0 \; \forall \; t - i > m \text{ ------------------ (x)}$$

3.3. SYSTEM UNDER CONSIDERATION, TOOLS AND SOFTWARE:

A. Tools and Software

For the optimization of demand, we used following tools and softwares, viz:

- Microsoft Excel
- MATLAB R2021a

B. System Under Consideration

For hourly load shifting of the forecasted demand, the following data are taken from one of the research article, "Hourly Load Shifting approach for demand side management in smart grid using grasshopper optimization algorithm," by M. Jamil and S. Mittal. [10]

Table 3.1: Forecasted load demand with energy prices [10]

Time (hr)	Price (Rs./kWh)	Hourly forecasted energy, kWh		
		Residential	Commercial	Industrial
8-9	12	729.4	923	2045.5
9-10	9.19	713.5	1154	2435
10-11	12.27	713.5	1443	2629
11-12	20.69	808.7	1558	2727
12-13	26.82	824.5	1673	2435
13-14	27.35	761.1	1673.9	2678
14-15	13.81	745.2	1673	2678
15-16	17.31	681.8	1587	2629
16-17	16.42	666	1558	2532
17-18	9.83	951.4	1673	2094.5
18-19	8.63	1220.9	1818	1704.5
19-20	8.87	1331.9	1500	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	1120.1
23-24	8.87	761.6	377	1022.7
00-1	8.65	475.7	404	974
1-2	8.11	412.3	375	876.6
2-3	8.25	364.7	375.2	827.9

3-4	8.1	348.8	404	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	1120.1
7-8	9.35	539.1	663	1509.7

Table 3.2: Controllable residential devices [10]

Device type	Hourly consumption of device, kW			Number of devices	Starting time
	1st hour	2nd hour	3rd hour		
Dryer	1.2	-	-	189	4
dishwasher	0.7	-	-	288	8
washing machine	0.5	2.5	-	268	10
oven	1	-	-	279	12
iron	1	2	-	340	15
vaccum cleaner	0.4	3	-	158	13
fan	0.2	3.5	3	288	11
kettle	2	-	-	406	10
toaster	0.9	-	-	48	4
rice cooker	0.85	-	-	59	6
hair dryer	1.5	-	-	58	7
blender	0.3	-	-	66	9
frying pan	1.1	-	-	101	10
coffee maker	0.8	-	-	56	12
total	-	-	-	2604	

Table 3.3: Controllable commercial loads [10]

Device type	Hourly consumption of device, kW			Number of devices	Starting time
	1st hour	2nd hour	3rd hour		
water dispenser	2.5	-	-	156	10
dryer	3.5	-	-	117	14
kettle	3	2.5	-	123	15
oven	5	-	-	77	11
coffee maker	2	2	-	99	9
fan/AC	2.5	3	3	93	12
air conditioner	4	3.5	3	56	13
lights	2	1.75	1.5	87	16
total	-	-	-	808	

Table 3.4: Controllable industrial devices [10]

Device type	Hourly consumption of device, kW						Number of devices	Starting time
	1st hour	2nd hour	3rd hour	4th hour	5th hour	6th hour		
water heater	12.5	12.5	-	-	-	-	39	4
welding machine	25	25	25	25	25	-	35	8
fan/AC	30	30	30	30	30	30	16	10
arc furnace	50	50	50	50	50	50	8	12
induction motor	100	100	100	100	100	100	5	15
DC motor	150	150	150	-			6	13

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. BEFORE DEMAND SIDE MANAGEMENT

A daily load curve of residential, industrial and commercial area before demand side management is plotted in the figure 4.1.

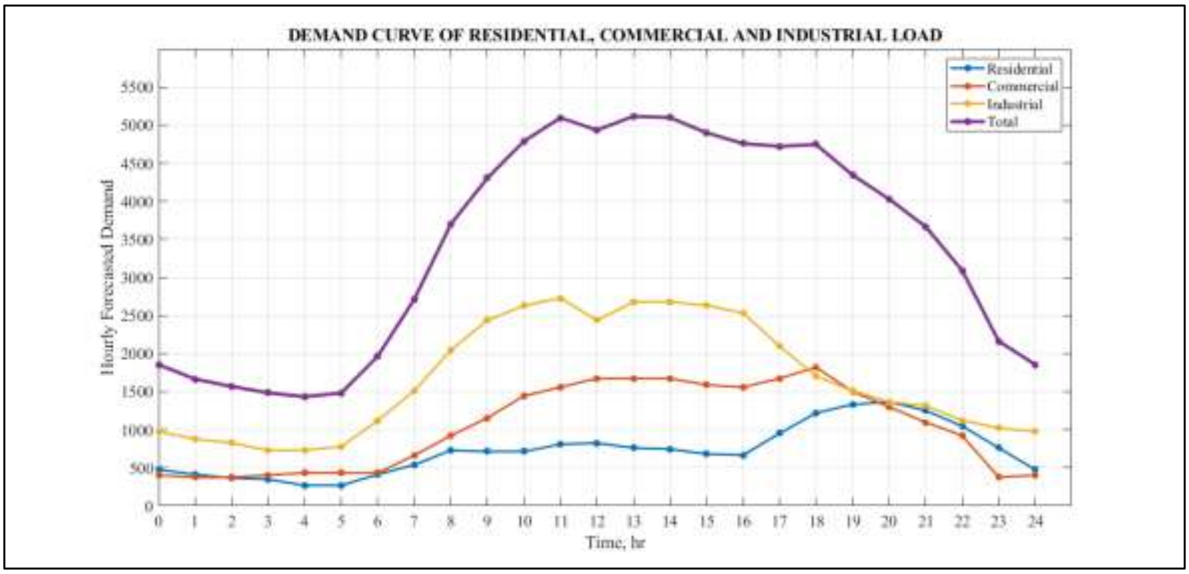

Figure 4.1 : Load Curve before demand side management

In the figure 4.1, residential area, commercial and industrial areas have their peak demand at different point of time.

- Residential loads mostly operate during evening time. Such loads also operate during the morning time. It consists of light loads. The consumers are given single phase supply up to 5kW and three phase supply for loads exceeding 5 kW. Demand factor for such loads is low (around 0.5).
- The commercial loads generally operate from 10 am to evening time of the day. The demand factor is fairly high.
- The industrial loads generally operate from dawn to dusk. Such loads are generally provided with three phase supply.
- So, there is huge demand of power during the day time and low demand of power during night time.

4.2. AFTER DEMAND SIDE MANAGEMENT

The data obtained after demand side management is summarized in the following table 4.1.

Table 4.1: Data obtained after DSM

Time	Residential	Commercial	Industrial	Total	ResDSM	ComDSM	IndusDSM	TotalDSM
0	475.7	404	974	1853.7	475.7	404	3229	4108.7
1	412.3	375	876.6	1663.9	412.3	375	3131.6	3918.9
2	364.7	375.2	827.9	1567.8	364.7	375.2	3082.9	3822.8
3	348.8	404	730.5	1483.3	348.8	404	3885.5	4638.3
4	269.6	432.9	730.5	1433	269.6	432.9	2523	3225.5
5	269.6	432.9	779.2	1481.7	534.4	432.9	2571.7	3539
6	412.3	432	1120.1	1964.4	1782.15	432	1120.1	3334.25
7	539.1	663	1509.7	2711.8	1209.1	663	1509.7	3381.8
8	729.4	923	2045.5	3697.9	708.85	923	1170.5	2802.35
9	713.5	1154	2435	4302.5	1033.7	1154	1560	3747.7
10	713.5	1443	2629	4785.5	615.4	1443	1274	3332.4
11	808.7	1558	2727	5093.7	808.7	1173	1372	3353.7
12	824.5	1673	2435	4932.5	500.7	2256	680	3436.7
13	761.1	1673.9	2678	5113	697.9	1871.9	898	3467.8
14	745.2	1673	2678	5096.2	271.2	1847	898	3016.2
15	681.8	1587	2629	4897.8	341.8	1739.25	2617.8	2430.05
16	666	1558	2532	4756	30.8	1514.5	1632	3177.3
17	951.4	1673	2094.5	4718.9	951.4	1520.75	1194.5	3666.65
18	1220.9	1818	1704.5	4743.4	1220.9	1687.5	1204.5	4112.9
19	1331.9	1500	1509.7	4341.6	1331.9	1500	1009.7	3841.6
20	1363.6	1298.7	1363.6	4025.9	1363.6	1298.7	863.6	3525.9
21	1252.6	1096.7	1314.9	3664.2	1252.6	1096.7	1314.9	3664.2
22	1046.5	923	1120.1	3089.6	1046.5	923	1607.6	3577.1
23	761.6	377	1022.7	2161.3	761.6	377	1510.2	3523.8

When the data obtained after DSM in table 4.1 is plotted, the following curve is obtained.

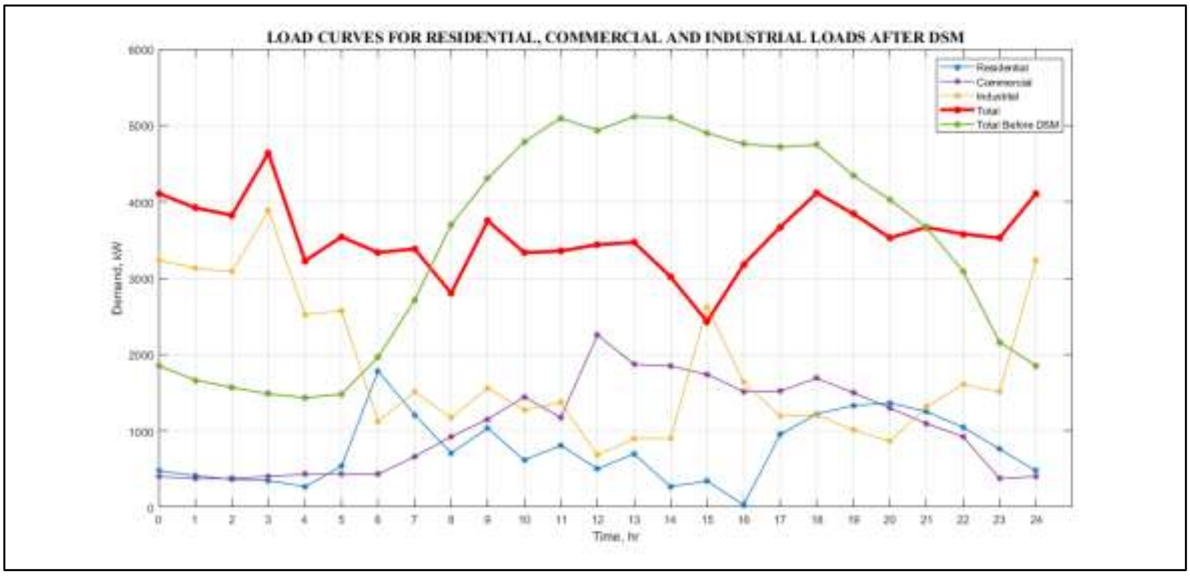

Figure 4.2: Combined Load Curve after DSM

In the figure 4.2, it is clear that the peak load has been reduced after hourly load shifting technique. With the help of table 4.1, we can say that,

- The total peak load has been reduced from 5113 kW to 4638 kW. This means the peak load has been reduced by 9.28%.

  This decrease in peak load means the utility can fulfil the same demand (load) by reducing the plant output by that percentage.

- The base load has increased from 1433 kW to 2430.05 kW. This increase in base load is almost 69.57%.

  This increase in base load means the consumer loads during off-peak hours have increased and the revenue can be increased as well.

- The total demand before and after Demand Side Management is same, i.e. 83579.6 kW. This verifies that the total electrical energy consumed in a day is constant.

The following curve is obtained when we plot total demands against time.

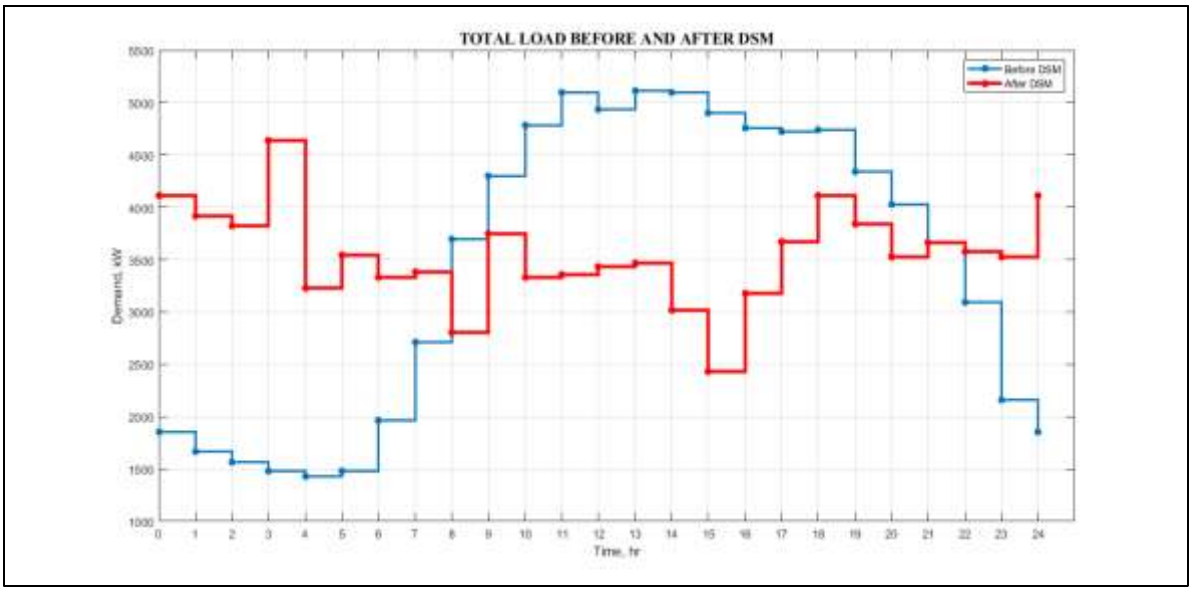

Figure 4.3: Total load curve before and after DSM

- In the figure 4.3, the total demands before and after DSM are plotted against time. This indicates that the peak load has been greatly reduced and the base demand has increased from 1433 kW to 2430.05 kW. This increase in base load is almost 69.57%.

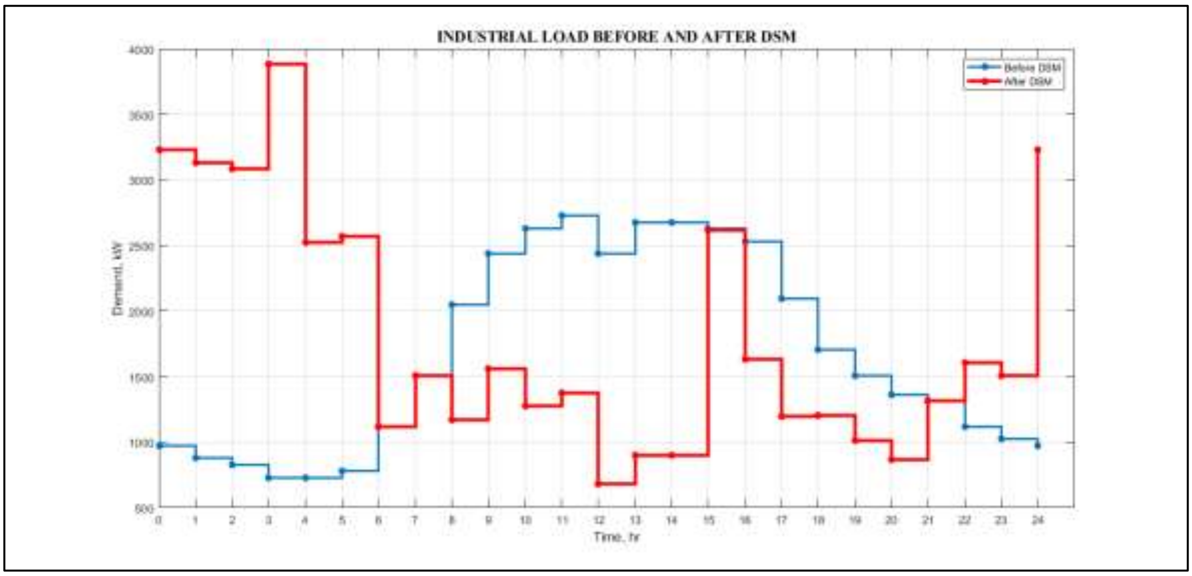

Figure 4.4: Industrial Load Curves before and after DSM

In the figure 4.4, the industrial demand before and after DSM is plotted against time. It illustrates that the demand during the day is shifted to the night time. Since commercial loads cannot be shifted from daytime to night time and residential loads also cannot be shifted from morning/evening to night hours, shifting of industrial loads can be a good solution. This ultimately decreases the total peak load.

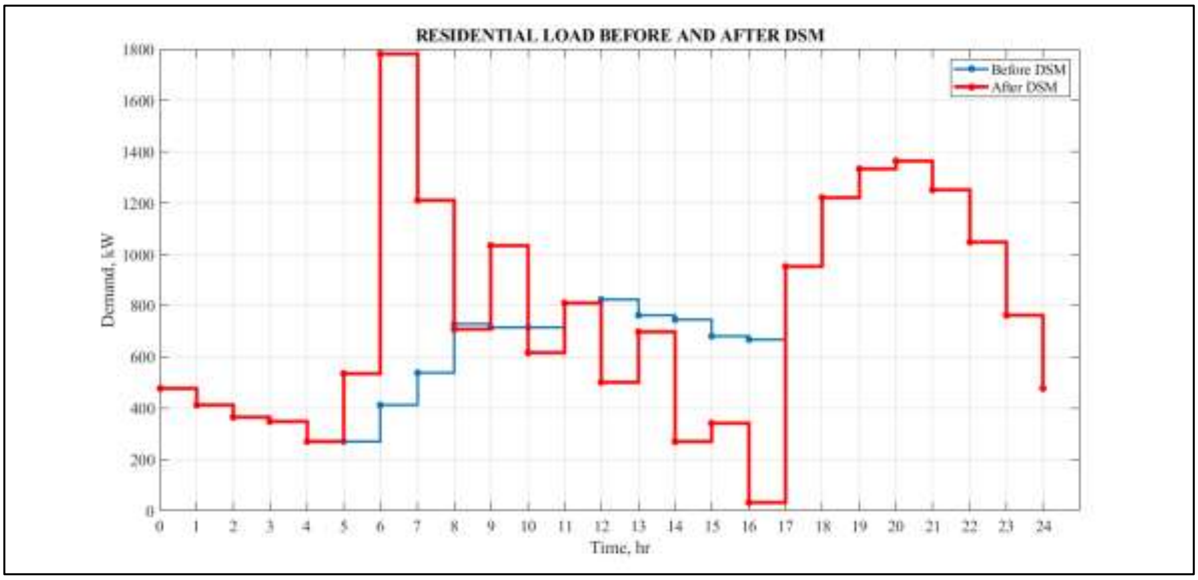

Figure 4.5: Residential Load Curves before and after DSM

The figure 4.5 shows the residential demand before and after DSM. The residential loads is shifted from day-time to morning and evening time. This decreases residential peak load and total peak load.

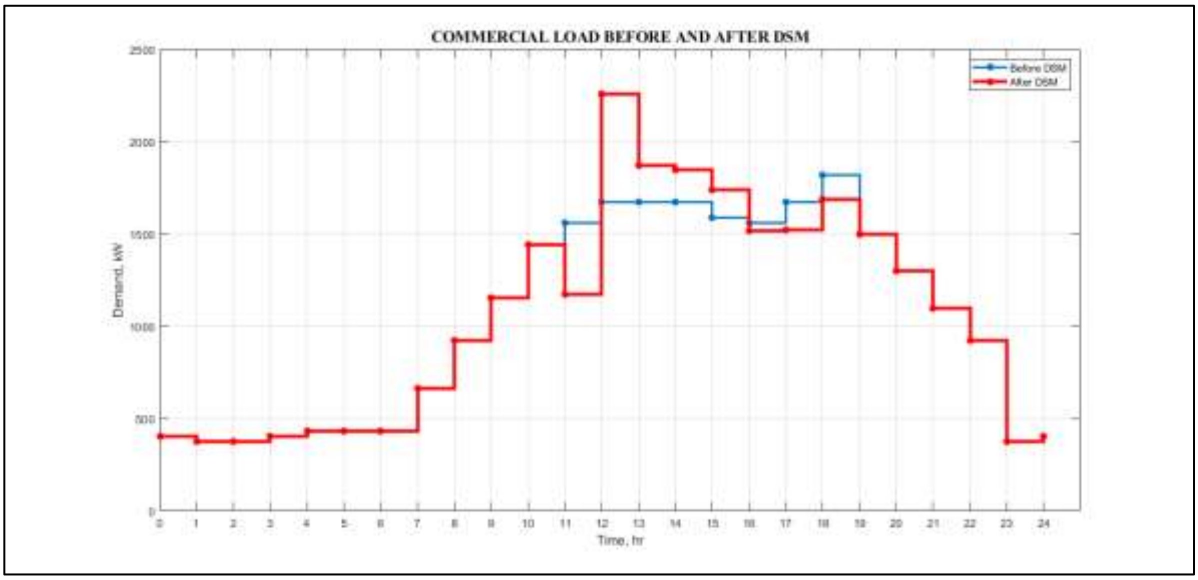

Figure 4.6: Commercial Load Curves before and after DSM

The figure 4.6 shows the commercial load curve before and after DSM. It illustrates that the commercial loads should run during the day time.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

Electrical energy plays a vital role in various sectors, including domestic, commercial, and industrial, due to its versatility and cost-effectiveness. It can be easily converted from and to other forms of energy such as hydropower, thermal power, chemical power, solar power, wind power, etc. Moreover, electrical energy can be transmitted over long distances efficiently and economically, making it indispensable for the socio-economic and industrial development.

However, energy consumption patterns exhibit significant variations throughout the day due to factors like population growth, population density, and standard of living. This leads to high demand during peak hours and low demand during off-peak hours. Simply increasing the number of generation units to meet peak demand is not a sustainable solution, as it results in underutilization of generated electricity during off-peak periods and financial losses for utility providers.

To address this issue, demand side management (DSM) emerges as an effective solution. DSM encompasses various approaches, and one of them is the hourly load shifting technique, which focuses on reducing peak demand. Our project successfully achieved this objective by implementing a minimized optimization problem that resulted in a significant reduction in peak demand from 5113 kW to 4638 kW (9.28% reduction), while maintaining the overall energy consumption at 83579.6 kW.

The implementation of hourly load shifting brings several benefits. Customers, especially large businesses and industries, can save on their energy bills by shifting their demand to off-peak hours. This approach also reduces the costs associated with managing the electricity grid and ensures a more efficient and reliable electricity network by smoothing out demand fluctuations. Additionally, network operators can maintain network reliability by avoiding the need for costly backup or fossil-fuel plants to cope with peak demand. Moreover, DSM helps in lowering market prices for electricity by reducing the burden on utilities during peak demand periods.

In conclusion, demand side management, particularly through techniques like hourly load shifting, is crucial in optimizing energy consumption, reducing peak demand, and achieving financial and operational benefits for customers, utility providers, and the overall electricity grid.

5.2. RECOMMENDATION

It is the nature of every project in the field of engineering and technology to get modified and advanced. New technology is emerging day by day. So, every project can be continued for future enhancement. We strongly recommend considering these recommendations to further improve the effectiveness and impact of our demand side management initiatives.

a. Advanced Data Analytics:

   To further enhance the effectiveness of the demand side management project, it would be beneficial to invest in advanced data analytics capabilities. This would involve leveraging technologies such as machine learning and artificial intelligence to analyze large amounts of data collected from various sources, including smart meters, IoT devices, and energy management systems. By applying sophisticated algorithms to this data, we can gain deeper insights into energy consumption patterns, identify optimization opportunities, and make data-driven decisions to improve our demand side management strategies.

b. Demand Response Programs:

   Consider implementing demand response programs as part of the demand side management project. These programs involve incentivizing consumers to reduce their electricity consumption during peak demand periods by offering them financial incentives, rewards, or other benefits. By collaborating with customers and engaging them in demand response initiatives, we can effectively manage peak loads, reduce strain on the grid, and achieve greater energy efficiency.

c. Smart Grid Integration:

   Integrate the demand side management project with a smart grid infrastructure. By connecting our energy management systems with smart grid technologies, we can enable real-time communication and coordination between energy producers, consumers, and grid operators. This integration would allow for more accurate load forecasting, automated demand response, and optimized energy distribution. It would also pave the way for the adoption of innovative solutions such as dynamic pricing and time-of-use tariffs, which encourage consumers to shift their energy consumption to off-peak hours.

d. Consumer Education and Engagement:

   Enhance consumer education and engagement initiatives to raise awareness about the benefits of demand side management and encourage active participation. Educate consumers about energy conservation practices, smart appliances, and energy-efficient technologies that can help them reduce their electricity consumption. Provide regular feedback and personalized energy usage reports to consumers to empower them with the knowledge to make informed decisions about their energy usage.

e. Collaboration and Partnerships:

   Foster collaborations and partnerships with relevant stakeholders, including local utilities, energy service providers, technology vendors, and regulatory authorities. By working together, we can leverage their expertise, resources, and industry insights to further strengthen our demand side management project. Collaborative efforts can also facilitate the development of innovative solutions and the sharing of best practices across the industry.

In conclusion, by implementing these future enhancements, we can maximize the benefits of our demand side management project, achieve greater energy efficiency, and contribute to a more sustainable future.

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APPENDIX : MATLAB CODE

BEFORE DSM:

```
time = [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24]';

Residential = [475.7 412.3 364.7 348.8 269.6 269.6 412.3 539.1 729.4 713.5 713.5 808.7 824.5 761.1 745.2 681.8 666 951.4 1220.9 1331.9 1363.6 1252.6 1046.5 761.6 475.7]';

Commercial = [404 375 375.2 404 432.9 432.9 432 663 923 1154 1443 1558 1673 1673.9 1673 1587 1558 1673 1818 1500 1298.7 1096.7 923 377 404]';

Industrial = [974 876.6 827.9 730.5 730.5 779.2 1120.1 1509.7 2045.5 2435 2629 2727 2435 2678 2678 2629 2532 2094.5 1704.5 1509.7 1363.6 1314.9 1120.1 1022.7 974]';

plot(time, Residential,'DisplayName','Residential');hold on; plot(time, Commercial,'DisplayName','Commercial');plot(time, Industrial,'DisplayName','Industrial');hold off;

 xlabel('time,hr');

ylabel('forecasted energy deman');

grid on;

title('DEMAND CURVE OF RESIDENTITAL, COMMERCIAL AND INDUSTRIAL LOAD');
```

AFTER DSM:

```
load dsm.mat

>> tableS10

tableS10 =

  25×9 table

   Time    Residential    Commercial    Industrial    Total     ResDSM    ComDSM    IndusDSM    TotalDSM

   ____    ___________    __________    __________    ______    ______    ______    ________    ________
```

0	475.7	404	974	1853.7	475.7	404	3229	4108.7
1	412.3	375	876.6	1663.9	412.3	375	3131.6	3918.9
2	364.7	375.2	827.9	1567.8	364.7	375.2	3082.9	3822.8
3	348.8	404	730.5	1483.3	348.8	404	3885.5	4638.3
4	269.6	432.9	730.5	1433	269.6	432.9	2523	3225.5
5	269.6	432.9	779.2	1481.7	534.4	432.9	2571.7	3539
6	412.3	432	1120.1	1964.4	1782.1	432	1120.1	3334.2
7	539.1	663	1509.7	2711.8	1209.1	663	1509.7	3381.8
8	729.4	923	2045.5	3697.9	708.85	923	1170.5	2802.4
9	713.5	1154	2435	4302.5	1033.7	1154	1560	3747.7
10	713.5	1443	2629	4785.5	615.4	1443	1274	3332.4
11	808.7	1558	2727	5093.7	808.7	1173	1372	3353.7
12	824.5	1673	2435	4932.5	500.7	2256	680	3436.7
13	761.1	1673.9	2678	5113	697.9	1871.9	898	3467.8
14	745.2	1673	2678	5096.2	271.2	1847	898	3016.2
15	681.8	1587	2629	4897.8	341.8	1739.2	2617.8	2430.1
16	666	1558	2532	4756	30.8	1514.5	1632	3177.3
17	951.4	1673	2094.5	4718.9	951.4	1520.8	1194.5	3666.6
18	1220.9	1818	1704.5	4743.4	1220.9	1687.5	1204.5	4112.9
19	1331.9	1500	1509.7	4341.6	1331.9	1500	1009.7	3841.6
20	1363.6	1298.7	1363.6	4025.9	1363.6	1298.7	863.6	3525.9
21	1252.6	1096.7	1314.9	3664.2	1252.6	1096.7	1314.9	3664.2
22	1046.5	923	1120.1	3089.6	1046.5	923	1607.6	3577.1
23	761.6	377	1022.7	2161.3	761.6	377	1510.2	3523.8
24	475.7	404	974	1853.7	475.7	404	3229	4108.7

```
>> stairs(tableS10.Time, tableS10.Total,'DisplayName','Before DSM');
```

```
>> hold on;
>> stairs(tableS10.Time, tableS10.TotalDSM,'DisplayName','After DSM');
>> hold on;
>> title(' TOTAL LOAD BEFORE AND AFTER DSM');
>> xlabel('Time, hr');
>> ylabel('Demand, kW');
>> grid on;
>> hold off;

stairs(tableS10.Time, tableS10.Residential,'DisplayName','Before DSM');
>> hold on;
>> stairs(tableS10.Time, tableS10.ResDSM,'DisplayName','After DSM');
>> hold on;
>> title('RESIDENTIAL LOAD BEFORE AND AFTER DSM');
>> xlabel('Time, hr');
>> ylabel('Demand, kW');
>> grid on;
>> hold off;

>> stairs(tableS10.Time, tableS10.Commercial,'DisplayName','Before DSM');
>> hold on;
>> stairs(tableS10.Time, tableS10.ComDSM,'DisplayName','After DSM');
>> hold on;
>> title('COMMERCIAL LOAD BEFORE AND AFTER DSM');
>> xlabel('Time, hr');
>> ylabel('Demand, kW');
>> grid on;
```

```
>> hold off;

stairs(tableS10.Time, tableS10.Industrial,'DisplayName','Before DSM');
>> hold on;
>> stairs(tableS10.Time, tableS10.IndusDSM,'DisplayName','After DSM');
>> hold on;
>> title('INDUSTRIAL LOAD BEFORE AND AFTER DSM');
>> xlabel('Time, hr');
>> ylabel('Demand, kW');
>> grid on;
>> hold off;

>>plot(tableS10.Time, tableS10.ResDSM,'DisplayName','Residential'); hold on;
plot(tableS10.Time, tableS10.ComDSM,'DisplayName','Commercial'); hold on;
plot(tableS10.Time, tableS10.IndusDSM,'DisplayName','Industrial'); hold on;
plot(tableS10.Time, tableS10.TotalDSM,'DisplayName','Total'); hold on;
plot(tableS10.Time, tableS10.Total,'DisplayName','Total Before DSM'); hold on;
title('LOAD CURVES FOR RESIDENTIAL, COMMERCIAL AND INDUSTRIAL LOADS AFTER DSM');
xlabel('Time, hr');
ylabel('Demand, kW');
grid on;
>> hold off;
```

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