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Managing Demand in Commercial and Industrial Sectors: A Comprehensive Review

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Abstract

Demand Side Management (DSM) is an economical method of managing power networks with the goal of lowering expenses and capacity requirements. DSM has emerged as a pivotal strategy in the energy sector, offering industrial and commercial entities the means to optimize costs and enhance sustainability by intelligently shifting their energy consumption profiles. This review paper provides a comprehensive exploration of DSM's application in the context of industrial and commercial loads. This review paper offers a thorough analysis of DSM methods and how they are used to optimize energy costs in the commercial and industrial sectors by shifting loads. The paper explores the basic ideas of DSM, highlighting how it can save energy costs and lessen environmental effects.
Keywords: - Demand Side Management, Demand Response, Industries, Commercial, Constraints.

1. Introduction

The commercial and industrial sectors represent significant contributors to global energy consumption and carbon emissions. It is becoming more and more important for these sectors to increase their energy efficiency and lessen their environmental impact as the world struggles with the consequences of climate change and need to turn to more sustainable energy practices. In order to accomplish these objectives, demand-side management, or DSM, has become a crucial technique. It includes a broad range of strategies and tactics meant to maximize energy use, reduce peak demand, and eventually promote a more effective and ecologically conscious energy system.

DSM refers to actions taken to change the amount or rhythm of energy consumption [1]. Given the depletion of conventional energy resources and the recent advancements in DSM technologies in the secondary distribution system, the primary goal of the research is to reduce energy consumption. Numerous studies have been conducted to improve energy efficiency and lower operating costs at the same time. Over 60% of all energy used globally is consumed in the industrial and commercial sectors [2]. Demand Response (DR) is one type of DSM in which power consumption is purposefully changed to adjust demand in order to take into account supply or any other constraints, sometimes referred to as load shifting, valley filling, and peak shaving, respectively [3, 4]. DSM can maximize its use of electricity from renewable resources by timing the increase in demand for electricity to align with times of surplus supply [5, 6]. Consequently, DSM can aid in resolving intermittency and unpredictability problems, encourage more renewable energy installations, and lower greenhouse gas emissions from the production of electricity. Furthermore, DSM has the capacity to reduce peak electricity demand, ensuring it remains within the limits of the transmission and distribution network. This, in turn, extends the lifespan of components and reduces electricity distribution costs for both consumers and businesses. [7, 8].

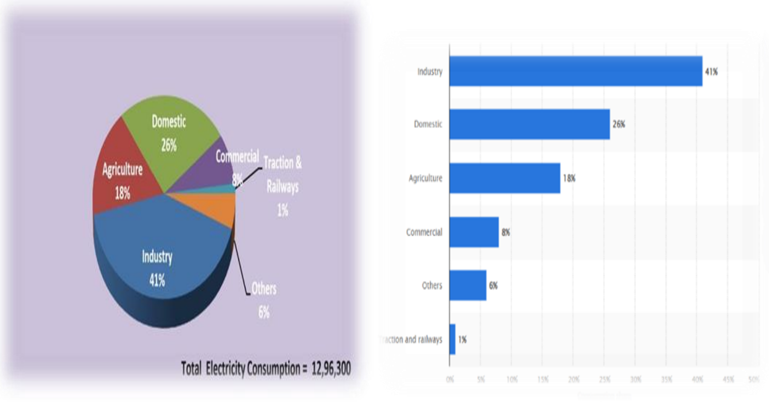

Figure-1 Sector-wise consumption.

The three main categories of electricity demand are usually determined by the end user: residential, commercial, and industrial [9, 10]. In developed nations, the share of each sector in electricity consumption is roughly one third [11, 12, 13]. DSM implementation may be hampered by financial and technical issues in all sectors [15] and is essentially limited by the requirements of humans that the energy use fulfils. Technically speaking, there are various levels of adjustability available for electric appliances with regard to power consumption and usage duration. For instance, a stable power supply is necessary for sensitive processes that cost a lot to start up in many industrial processes. From an economic perspective, certain electricity demands cannot be changed without incurring losses, like for commercial loads necessary to properly serve clients. On the other hand, certain loads—like the electricity required by devices used in vital medical applications—cannot be changed without jeopardizing human welfare. Hence, for the successful implementation of DSM and to effectively guide policy and technical initiatives aimed at overcoming barriers to DSM adoption, it is essential to comprehend the technical and economic constraints within each sector.

Human behavior can also impose limitations on the DSM's implementation [16]. As an example, energy usage for charging an electric car is constrained by driving habits. Charging can only occur when the car is connected to a power source, and the required amount of energy is contingent on the distance the vehicle needs to travel. Furthermore, DSM can affect human outcomes because, for example, limiting electricity use in the winter can significantly lower indoor temperatures, raising the risk of respiratory illnesses [17, 18, 19]. Human outcomes ultimately drive the demand for electricity because people are not inherently drawn to electricity; rather, they are drawn to the numerous things that electricity makes possible, like thermal comfort and travel.

However, people rarely behave like healthy economic actors [20] and might not react to DSM programmes in the way that conventional economic theory suggests. For instance, high income households are less affected by changes in the price of electricity than are low-income households [21], since the way people use energy is influenced by a variety of intricate processes that include psychological, environmental, and financial factors [22], and as a result, its price elasticity is nonlinear. Therefore, for DSM to be successful, it is necessary to comprehend both the more logical and easily quantifiable economic and technical constraints as well as human outcomes and the behaviors motivated by the desire to achieve those outcomes. To put it briefly, comprehending the constraints imposed by both human behavior and reason is necessary for effective DSM.

2. Overview of DSM Approaches

Electricity utilities have implemented the DSM program to encourage customers to adopt beneficial practices [9]. DSM includes various endeavors aimed at reshaping load profiles by influencing consumers' electricity consumption patterns [23]. However, integrating DSM into power systems adds complexity, requiring the monitoring of generators and power system loads [24], resulting in additional costs for sensor installation, incentives, and operational activities.

DSM consists of three main components: demand response, strategic load growth, and energy efficiency [9]. Demand response strategies, such as load-shifting, peak-clipping, or valley filling, adjust consumption patterns to respond to pricing or reliability changes. Strategic load growth initiatives aim to increase consumption strategically through methods like dual-fuel heating or thermal storage. Energy efficiency measures focus on reducing overall demand by promoting more efficient use of energy resources.

Demand response, often known as flexible load shaping, is adaptable to varying system requirements and market conditions. Load-shifting redistributes usage to off-peak hours, peak-clipping reduces consumption during high-demand periods, and valley filling increases consumption during low-demand times.

Strategic load growth stimulates demand in specific areas to optimize system utilization and revenue generation. Energy efficiency measures aim to lower overall demand by upgrading appliances, implementing energy-efficient practices, and enhancing building insulation.

In essence, DSM strategies aim to optimize system performance, enhance reliability, and promote sustainable energy practices by reshaping electricity consumption patterns.

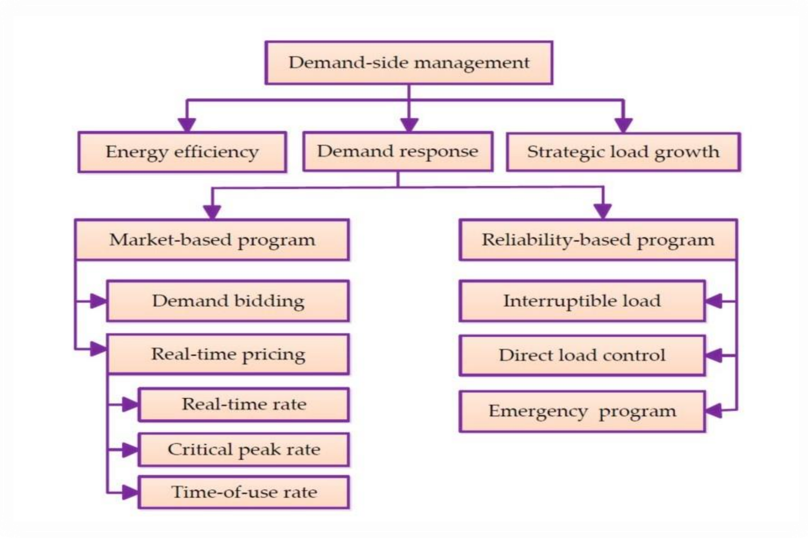

Figure-2 Different approaches to demand-side management.

2.1 Energy Efficiency

A long-term conservation strategy called energy efficiency seeks to lower demand and save energy through the use of energy-efficient procedures. Enhancing the efficiency of household appliances and weatherization are two examples of energy-efficiency initiatives [25]. By implementing energy-efficiency programmes, power system costs can be averaged down, and on-peak demand can be reduced. Additionally, an extension of power system capacity can be delayed [26]. Among the energy-efficient tactics are:

1. Encouraging energy-conscious behavior among users and implementing energy-efficient buildings and appliances can optimize energy consumption [27].
2. Enhancing and carrying out routine maintenance on electrical apparatus [25] by using contemporary machinery with efficient designs, recovering heat waste, improving maintenance practices, and engaging in cogeneration [27].

2.2 Demand Response

Demand response (DR) is a programme that manipulates loads temporarily with the goal of influencing how much energy people use. The definition of DR is "the deviations in end-users' electric usage from their typical consumption patterns in response to variations in the price of electricity over time, or to incentive payments intended to induce lower electricity use at times of high wholesale prices or when system reliability is jeopardized"[28]. In the evolving electricity market landscape, DR programs are progressively superseding other DSM methods. This shift is attributed to the distinct advantage of DR, which directly influences and impacts the load. [29]. Valley filling or other methods are used in DR to build loads during off-peak times [30]; peak trimming, which lows loads during on-peak times peak trimming to lower loads when things are at their busiest [31] or load shifting, it incorporates peak-clipping and valley-filling tasks [9].

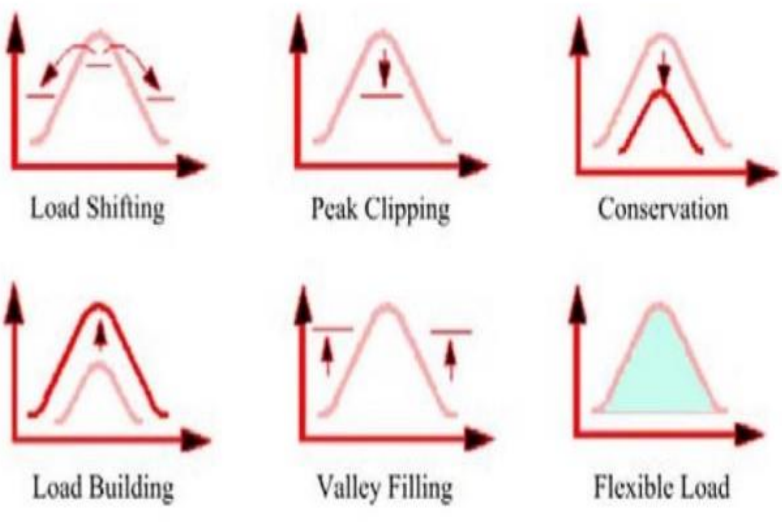

Figure-3 DR Techniques.

2.3 Strategic Load Growth

Utilities commonly stimulate strategic load growth by employing methods such as dual fuel heating, heat pumps, thermal storage (storing energy during off-peak hours for later use during on-peak hours), and promotional rates to increase the electrical energy load. Due to the overall rise in energy consumption, particularly with the introduction of electric vehicles into contemporary power systems, strategic load growth is occasionally unavoidable [9] or air conditioning in warm nations [32].

3. DSM Reviews

A review of DSM in heavy industries is found in [33], with an emphasis on the financial and technical limitations in oil refineries, smelting facilities for aluminum, and cement manufacturing facilities. How industrial DSM is applied using the idea of enterprise-wide optimization is examined by Zhang and Grossmann [34], where inventory and expenses are decreased through the optimization of manufacturing, supply, and distribution [35]. The study delves into the application of energy storage for industrial Demand-Side Management (DSM), analyzing the advantages and disadvantages of different storage solutions, including magnetic, mechanical, electrochemical, and thermal storage. The comparison is based on their technical and financial capabilities. [36]. An analysis of industrial DSM is carried out in [37], which is concentrated on putting DR programmes into action, offering utility companies services while taking industrial processes' technical limitations into consideration. An examination of commercial and industrial DSM is carried out in [38], which emphasizes the significance of technical limitations and the influence of economics on DSM in the electricity markets.

Furthermore, an exploration was conducted on initiatives in "smart grids," which refer to advanced electrical networks incorporating networked communication systems capable of adjusting to fluctuating supply and demand. The examination includes a comprehensive review of techniques and mathematical models used to simulate distributed resistance in smart grids. [4]. An overview of the pricing techniques and optimization approaches used to simulate disaster recovery programmes in smart grids, emphasizing market-based deployment provided by [39]. Examination of DR programmes in smart grids that use renewable energy sources and provide a comparison and economic analysis of the various DR initiatives, [40].

Though more measurable and quantifiable than behavioral constraints, the main focus of all these reviews is on the technical and economic barriers affecting the implementation of DSM. The only review that specifically discusses behavioral restrictions [16], excludes the use of electricity for commercial or industrial purposes. Furthermore, technical and financial limitations are overlooked in this review, despite the fact that they can have significant interactions with behavioral constraints. Therefore, the combined effects of technical, economic, and behavioral constraints on DSM as well as the ways in which these constraints interact and vary in importance depending on the different sectors of the electricity consumption market have not been reviewed.

4. DSM of Industrial Loads

In industrial contexts, demand-side management, or DSM, refers to a collection of tactics and procedures meant to maximize energy use, lower peak demand, and improve overall energy efficiency in the manufacturing and industrial domains. Since industrial processes frequently contribute significantly to energy use and greenhouse gas emissions, DSM is crucial for increasing sustainability and economy.

Numerous industries use electricity for various processes, such as the production of metals, oil refining, chemicals, cement, and pulp and paper [41]. The amount of electricity used is frequently a significant factor in the operating costs of industries [42, 43]. Furthermore, as more industrial processes—like process heat—become electrified, it is anticipated that industrial electricity consumption and costs will rise [44, 45, 46 47, 48, 49].

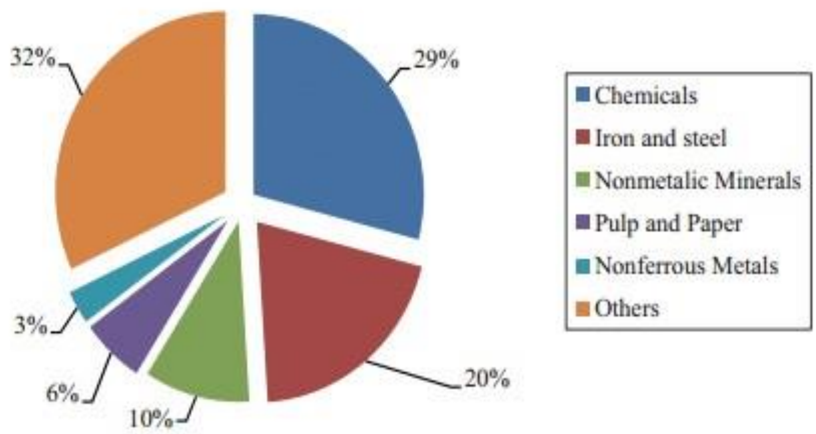

Figure-4 Industrial sector energy consumption by major energy-intensive industry shares.

4.1 Technical and Economic Constraints

Industry-specific and consumer-specific technical constraints for electricity consumption can differ significantly based on a variety of factors, including equipment, schedules, and processes. For this reason, industrial DR programmes are usually customized to meet the needs of each customer [34, 36, 37]. While industrial consumers vary greatly in terms of flexibility, many industrial processes cannot be interrupted at all, and others cannot be interrupted without prior notice. Therefore, it is widely accepted that industrial energy demand is far less flexible than in other sectors, and therefore stoppages or decreases will result in more immediate negative consequences. [33, 38]. The cost and difficulty of stopping many industrial processes make electricity a relatively insignificant portion of the overall expenses incurred by industrial consumers [50, 51, 52, 53, 54]. To promote participation, incentives for DR are typically greater for industrial consumers than for residential or commercial consumers [33, 55].]. But because their procedures are so rigid, many customers are still unable to participate even with these incentives [33].

4.2 Behavioral Constraints

Industrial electricity demand is normally determined solely by the financial and technical limitations of the industrial process during normal operation [33]. Human behavior therefore has minimal impact. When it comes to operational scheduling and the potential need for electricity at the plant, behavioral constraints like employees' willingness to work overtime can be crucial factors to take into account [45]. The overall amount of electricity consumed and the amount of people participating in DR are, however, generally unaffected by these behavioral factors, and the costs associated with stoppages or reductions may make hiring more employees the more economical course of action.

5. DSM of Commercial Loads

In the commercial sector, demand-side management, or DSM, refers to a group of tactics and procedures meant to maximize energy use, lower peak demand, and improve overall energy efficiency in commercial structures. Office buildings, retail stores, lodging facilities, dining establishments, and other non-industrial commercial properties are included in this sector. In the commercial sector, DSM aims to minimize environmental impact, promote energy sustainability, and lower operating costs.
Lighting, water heating, electronic devices, and space heating and cooling are just a few of the many uses of electricity in the commercial setting. Space conditioning accounts for a quarter to a third of the electricity used in office, service, and retail buildings. Nonetheless, retail buildings are distinguished by their high percentage of electricity consumption (35– 40%) for refrigeration [56].

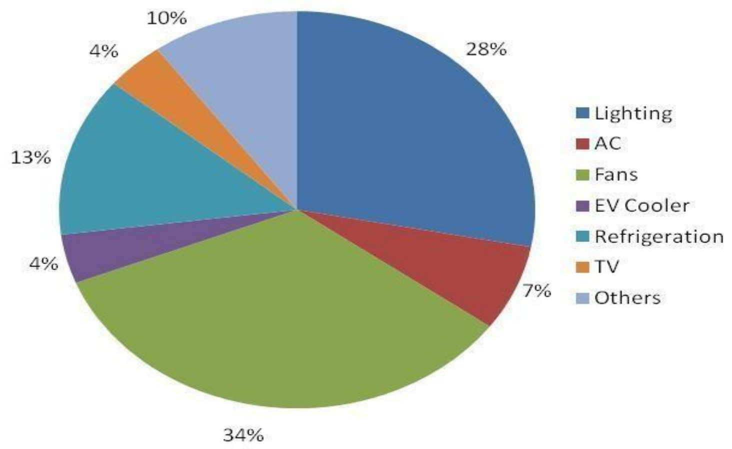

Figure-5 Energy consumption in different sectors of a commercial building.

5.1 Technical and Economic Constraints

Space conditioning accounts for a quarter to a third of the electricity used in office, service, and retail buildings. Nonetheless, retail buildings are distinguished by their high percentage of electricity consumption (35–40%) for refrigeration [57]. Commercial customers' electricity consumption is regulated in large part for things like space heating, lighting, and refrigeration. For instance, task-specific illumination levels in the workplace should be met while the business is open, which are set by standards. As a result, the amount of electricity that can be used for lighting is flexible. Because of these restrictions, a sizable amount of the electricity demand is variable throughout business working hours, and many businesses use very little electricity after these hours. Furthermore, compared to building costs, labor costs, and material costs, electricity demand might not account for a significant portion of operating costs. As a result, the financial incentive for DSM adoption is less important than other financial factors.

Economic limitations pertaining to business operations also affect the demand for commercial electricity. Since most commercial electricity loads are necessary for operations, there is little demand for elasticity for them. For instance, a restaurant that uses electric cooking appliances is unlikely to change how they use them in response to fluctuations in the cost of electricity because doing so would make it more difficult for them to provide for their patrons and make money. Water heaters and space heaters, among other appliances with thermal storage, therefore, perform the majority of commercial DR [58]. Because of their thermal storage, these appliances' electricity loads are more flexible than those of most other commercial loads because the demand for electricity can be separated from the demand for heating and cooling. Technical limitations, like the building's thermal insulation, and behavioral limitations, like the thermal comfort of employees and customers, still apply to these loads.

5.2 Behavioral Constraints

The majority of the demand for commercial power is driven by technical and economic restrictions, making human behavioral constraints very negligible. Since most commercial power consumption is for equipment that are mandated by laws (like lighting standards) or by business operations (like the capacity to serve customers), human behavior often plays a little role in this demand. Nonetheless, applications that support thermal comfort consider human behavior. Individuals may have different preferences for thermal comfort, which may have an impact on the amount of electricity needed for space heating and cooling. These varying preferences can affect the demand for electricity even though not all commercial consumers have the means or the desire to modify their consumption of electricity in accordance with them [59].

6. Summary

A significant portion of consumer operating expenses and the demand for electricity suppliers and distributors can be attributed to industrial electricity consumption. Industrial DR is therefore advantageous to electricity utility companies as well as to consumers. DR is widely used in the production of cement, in cold storage warehouses, in pulp and paper mills, in electrolysis facilities, and in electric furnace metalworking. Industries with longer operational shifts, large inventory buffers, and/or processes involving heat storage are generally the greatest candidates for industrial DR.

There are, however, a number of obstacles preventing increased industrial DR adoption: (1) As small consumers have a lower DSM potential than larger consumers, they are frequently ignored;(2) Although adopting DR requires both in-depth understanding of an industry's procedures and an understanding of DR incentives, these skill sets are rarely found in the same organization;(3) Because DR programmes are typically tailored to a single customer, industry-wide process-specific applications with significant DSM potential—like compressed air systems—are frequently disregarded.

Industrial DR generally takes place through customized contracts that utility companies and consumers enter into, acknowledging the needs of the consumer's processes. This is due to the fact that industry and the types of electricity-dependent operations are major determinants of industrial DR. Thus, overall human behavioral restrictions are generally not important for industrial DR.

When considering employee wages, material costs, and facility costs, electricity costs typically make up a smaller portion of the overall costs associated with running a business. As a result, commercial consumers typically place less emphasis on managing their electricity demand than do industrial consumers. Most commercial electricity demand is constrained by economic and/or technical factors, making it less flexible. Examples of these factors include workplace lighting regulations and customer service requirements. Commercial DR programmes therefore concentrate on uses that have built-in storage, like battery storage in electric vehicles and thermal storage in refrigerators. The commercial DSM sector has comparatively less research conducted than other sectors. This could mean that there is a significant research gap in this area or that the sector has little potential for DSM because of its lower share of overall costs from electricity consumption. Enhancement prospects for commercial distributed refrigeration DR encompass enhanced comprehension of consumer demand flexibility, more accurate modelling of building occupant preferences and comfort levels, and expansion of DR initiatives to smaller consumers. Technical and financial limitations should be the main focus of improvements in commercial DR since human behavior is usually not significant in determining commercial electricity demand.

Conflict of Interest

Authors declares that no conflict of interest in the manuscript.

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