Cost-Centric Energy Management of a Test Grid System Considering Load Flexibility for DSM

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***Abstract*—Demand-Side Management (DSM) adjusts load demand by rebuilding the load demand model of a distribution system and thus reduces operating costs. One potential approach to achieving cost savings is the redistribution of flexible loads to time periods characterized by lower utility expenses per unit, or alternatively, the elimination of nonessential loads. The primary objective of this research is to examine the use of DSM approaches in the scheduling of domestic appliances. The aim is to effectively minimize operating expenditures, the peak-to-average demand ratio (PADR), and any associated problems. Domestic appliances may be categorized into three distinct types based on their ability to adjust to variations in time, temperature, and light: time-flexible, temperature-flexible, and light-flexible. The second step of the study focuses on modelling the power consumption scheduling issue for demand-side clients. This is done by including operating cost priorities and modes of operation while taking into account both demand and supply factors. This research optimizes an IEEE 33 bus test grid system using load scheduling, fossil fuel generators, and renewable energy. The primary objective of this optimization is to minimize operating costs. In order to optimize the load model, it was necessary to restructure it according to the DSM participation level. After considering the restructured load demand models, distributed load scheduling ideas are disseminated to reduce test grid system power distribution costs.**

***Index Terms*—demand side management, IEEE 33 BUS, optimal power flow, power flow optimization**

I. Introduction

As the world's population and standard of living continue to rise, so does the need for energy [1]. This massive need for resources has exacerbated energy and environmental issues, which jeopardize the further progress of human civilization, especially excessive use of fossil fuels to produce energy. As a result of scientific and technological progress, contemporary lifestyles have become more complicated and resource-intensive. Increasing energy supply utilities is a common strategy used by many nations that are struggling to strike a balance between their energy demand and supply [2]. Due to the rising quantity of renewable resources and their inherently top-down, one-way energy flow, complex, real-time management of dispersed energy resources is essential. A different approach to achieving equilibrium between supply and demand is provided by DSM [3, 4]. The DSM method is used to reduce the need for additional power and keep the system's vulnerability within an acceptable range. Before designing and implementing DSM within a power system, its stability and performance must be analyzed [5, 6].

An important feature of an energy management system in power delivery networks, demand-side management is an integral part of a grid design that allows consumers to control their load consumption patterns [7]. Changing the electric load consumption profile may be accomplished by different methods. Energy efficiency reduces overall consumption rather than just during peak use times. Efficiency improvements are further analyzed in Chowdhury *et al*. [8] and Tronchin *et al*. [9]. Time of use is a method for charging customers different rates depending on their energy consumption patterns throughout the day [10, 11]. This method divides fixed utility rates into multiple time intervals across a 24-hour period. Using the differential tariff of electricity units, this method may assist in limiting the impact of peak load rates and seasonal fluctuations in pricing tariffs. According to Rebours and Kirschen [12], in the event of an unexpected drop in generation, the electric grid system's spinning reserve can be activated by the distribution network operator (DNO) to make up the difference between consumption and generation. During times of high tariffs in the electricity wholesale market or when the grid stability is unstable, demand response refers to the deviations in load consumption by end-user consumers from their typical usage patterns in response to the change in unit tariffs over time or based on incentivized programs offered to reduce load consumption [13].

Restructuring the load model by optimally moving the elastic or dispatchable loads to hours when the electricity market price is lower is the goal of DSM, an economic technique. DSM is not only essential for lowering peaks, but also for increasing load factors. While there are many studies on the topic of reducing the generation cost of a distributed system, very few of them make use of an economic technique like DSM. Using DSM, the authors of [14] dynamically scheduled residential loads to reduce the system's generating cost, while the authors of [15] used DSM to do dynamic economic emission dispatch. Using a similar multi-objective harmony search method, the

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authors of [15] constructed DSM to solve the dynamic optimum power flow algorithm. If the power market price remains static across the scheduling horizon, DSM will not be cost-effective since its principal driver is a time-of-use based pricing structure.

Power grids have expanded to accommodate increased renewable production capacity, mostly from wind turbines (WTs) and solar photovoltaic (PV) units. This is because these units have various benefits, including lowering pollution levels, and because they may be placed closer to users, decreasing line congestion, power losses, and voltage dips. Additionally, their relatively modest sizes have encouraged private sector investment in their growth [16]. However, the fundamental difficulty with these units is the uncertainty associated with their production. There will be numerous operational issues with power networks that will slow the growth of renewable energy if these uncertainties are not controlled appropriately.

Increasing interest in the application of power optimization techniques to electrical system engineering has opened the door to the use of various optimization techniques. In contrast to strict mathematical methods, these techniques appear to be able to accommodate the nonlinearities and discontinuities that are prevalent in electrical systems. The Optimal Power Flow (OPF) approach represents the challenge of determining the optimum operational values for electrical power facilities to meet the demands of a power transmission grid network, typically with the goal of minimizing operating costs [17, 18]. This paper utilizes OPF to tackle the optimization problem.

A. Gap in Recent Studies and Novelty of Contribution

Every day, a large number of new studies reporting a wide variety of operations to assess the economic management of energy in electrical grid systems are published in reputable journals. The current study analyzes some recent literature [19, 20] streams that help comprehend the effectiveness of the initial phases of the power flow optimization process, with recent technological advancement and the complexity that remains contained to the constraints of different distributed energy resources used, in order to identify the research gap. A systematic literature review was used to analyze the current research, and it was discovered that load shedding is an efficient technique to prevent a complete breakdown of the grid's ability to deliver energy. However, no comparative studies have been conducted with DSM. Second, there is no study of how DSM would affect the classified loads and there is no research on classification-based load scheduling for DSM as an alternative to load shedding for developing nations. This article's original contribution is:

Developing a DSM load scheduling method that uses a categorized load model.

To integrate the load model into the system and compute the simulation-based DSM objective for reduce peak time consumption.

To compare the costs and benefits of the planned load shifting-based DSM and load reduction base DSM.

B. Outline of Paper

Here are the remaining parts of the paper: Section II organizes the formulation of the issue. The DSM framework is detailed in Section III, followed by case studies, findings, and debate in Section IV, and finally, the work is wrapped up in Section V.

II. Focusing on a Problem

Creating electrical energy with a test grid at the lowest possible cost while satisfying all equality and inequality requirements is the primary goal of optimum power flow.

A. Optimum-cost Function

For a typical load modeling scenario, Considering N_T samples in a capture period, the acquired samples are sequences of length N_T as shown in Eq. (1) and (2):

$$V_{\text{load}} = \left[V_{\text{load}}(n)\right]_{n=1}^{N_T} \tag{1}$$

$$i_{\text{load}} = \left[i_{\text{load}}(n)\right]_{n=1}^{N_T} \tag{2}$$

where V_{load} and i_{load} are the instantaneous values of voltage and current consumed by the system load.

The energy consumption P_{load} for any load number can be obtained from

$$P_{\text{load}} = \frac{1}{N}\sum_{n=1}^{N} V_{\text{load}}(n) i_{\text{load}}(n) \tag{3}$$

The three types of loads—flexible load (FL), light-dependent load (LL), and temperature-dependent load (TCL)—are separated for convenience of calculation. According to the DSM plan, managers must reduce a grid's overall cost by offering a variety of incentives, and consumers must reduce their load in accordance with that.

Thus, considering FL load as $P^k_{\text{FL\_load}}$, LL load as $P^k_{\text{LL\_load}}$, TCL load as $P^k_{\text{TCL\_load}}$ and thus total active power $P^k_{\text{Total\_load}}$ can be calculated for k time period,

$$P^k_{\text{Total\_load}} = P^k_{\text{FL\_load}} + P^k_{\text{LL\_load}} + P^k_{\text{TCL\_load}} \tag{4}$$

Similarly, we can consider $Q^k_{\text{Total\_load}}$ as total reactive power for k time period,

$$Q^k_{\text{Total\_load}} = Q^k_{\text{FL\_load}} + Q^k_{\text{LL\_load}} + Q^k_{\text{TCL\_load}} \tag{5}$$

If any aggregator is responsible for coordinating at L number of loads in a power network then real power demand P^k_D and reactive power demand Q^k_D can be expressed as,

$$P^k_D = \sum_{l=1}^{L} P^{k,l}_{\text{Total\_load}} \tag{6}$$

$$Q^k_D = \sum_{l=1}^{L} Q^{k,l}_{\text{Total\_load}} \tag{7}$$

The standard version of AC optimal power flow, the power equation expressed as number of test grid node if the n number of nodes, where the load injections are assumed constant and given. Thus, the overall power consumption by the grid P_{Grid}^{t} can be expressed as the function of real demand and reactive demand power:

$$P_{\text{Grid}}^{t} = \sum_{i=1}^{n} \left[f_{P}^{i,k}\left(P_{D}^{i,k}\right) + f_{Q}^{i,k}\left(Q_{D}^{i,k}\right) \right] \quad (8)$$

Here the objective function for the power grid network with n_g generator is

$$\text{Cost}^{\text{Total}} = c_{\text{grid}}^{t} P_{\text{Grid}}^{t} = \sum_{t=1}^{24} \sum_{g=1}^{N_G} \left(a_g P_{g,t}^2 + b_g P_{g,t} + c_g \right) \quad (9)$$

According to Eq. (9), the total cost for 24 hours is $\text{Cost}^{\text{Total}}$, where t is the hour indication. Diesel generator (DG), photovoltaic (PV), and wind turbine (WT) are represented by a_g, b_g, and c_g, respectively, as cost coefficients where the value c_g is the fuel cost dependent fixed cost. The grid's pricing for energy on the market is denoted by the symbol c_{grid}^{t}.

B. Inequality Constraint

Below is an equation that may be used to express the system's inequality restriction.

$$P_{D,\text{Min}}^{i} \le P_{D}^{i} \le P_{D,\text{Max}}^{i} \quad (10)$$

For the lower and upper limit of ith unit.

$$P_{\text{Grid,Min}}^{i} \le P_{\text{Grid}}^{i} \le P_{\text{Grid,Max}}^{i} \quad (11)$$

For the lower and upper limit of Grid system.

C. Equality Constraint

The overall power generation should be meet the power balance equation expressed as functions of the voltage angles θ^k and magnitudes V_m^k and generator injections P_g^k and Q_g^k, where the load injections are assumed constant and given.

$$P_{\text{bus}}\left(\theta^k, V_m^k\right) + P_D^k - C_g^k P_g^k \quad (12)$$

$$Q_{\text{bus}}\left(\theta^k, V_m^k\right) + Q_D^k - C_g^k Q_g^k \quad (13)$$

D. Uncertainty Modelling

Since renewable energy sources are inherently unpredictable and stochastic, uncertainty modelling is a kind of probabilistic and predictive research that finds the greatest variance that may be achieved from predicted data [21, 22].

In the section, we model the uncertainty of solar and wind power using the following graphic.

$$\text{PV}^U = d\text{PV}^U n_1 + \text{PV}^f \quad (14)$$

$$d\text{PV}^U = 0.7\sqrt{\text{PV}^f} \quad (15)$$

where PV^U represents the PV output variance and PV^f represents the PV output prediction for the next day. n_1 indicates the standard distribution function.

$$W^U = dP^W n_2 + W^f \quad (16)$$

$$dP^W = 0.8\sqrt{W^f} \quad (17)$$

where W^U denotes wind unpredictability, dP^W denotes wind power variation, and n_2 designates the standard distribution function.

For demand variation counted for different node can be expressed as

$$P_d^U = dP_d^u n_3 + P_d^f \quad (18)$$

$$dP_d^U = 0.9\sqrt{P_d^f} \quad (19)$$

where P_d^f is the historical power consumption, dP_d^U is the deviation of daily demand and n_3 states the standard distribution function of the demand curve.

III. Methodology Used

First, a test electrical grid with three power plants and renewable energy has been taken into consideration. Various power plants have varying cost functions, but since doing so is advantageous economically, the lowest cost generation always comes first. Since the generating and renewable energy systems are located in separate nodes, various transmission constraints might occur. It has been and will continue to be the goal of grid energy management to provide the most affordable electricity to the area's users. The economic operation of a grid system is initially basically nonexistent if DSM strategy is ignored, and customers must pay high prices during peak hours. All of the research discussed in the literature review section would be much more cost-effective if DSM had been taken into account. DSM particularly targets the flexible loads on the network in question and best relocates them during off-peak hours. Even when the peak demand is greatly reduced, the load factor increases even while the total load demand at the conclusion of the scheduling period (typically a day) remains constant.

Some load shaping techniques used by DSM include peak clipping, load shifting, strategic growth, valley filling, strategic conversion, variable load shape, etc. [23-25]. For ease of computation, loads are divided into three categories: flexible load (FL), light dependent load (LL), and temperature dependent load (TCL). The analysis of composite demand data involves examining several literature sources on surveys and adjusting the power consumption trend. In their publication, Vinh Tien et al. [26], examined the power consumption and demand curve of Tuy Hoa city in Vietnam. Additionally, references [27] and [28] provide insight into the trajectory of power demand in typical residential usage. In his study, Imran Khan performed a survey in Bangladesh to investigate the use of household demand, as discussed in article [29]. For the DSM plan, management must lower the total cost of a grid by providing various incentives, and customers must decrease load in line with that. Also, LL can be reduced by offering day light saving type offer whereas TCL can be changed by imposing high price during summer.

Fig. 1 depicts the flow chart of the system model. There are several iterations, both with and without the DSM, from which one may derive an analogy by referring to the flow chart. Fig. 2 depicts the redesigned version of the IEEE 33 bus test grid system, taking into account the relevant system considerations [30]. Additionally, node bus 16 and 24 are equipped with a renewable energy source.

Each frequent load consumed by residential, semi-industrial, and industrial consumers has to be carefully simulated to optimize the cost and reliability of the power grid system. Following load-modelling and categorization, there are two available methodologies to compute the load combination.

A. Top-down approach
B. Bottom-up approach

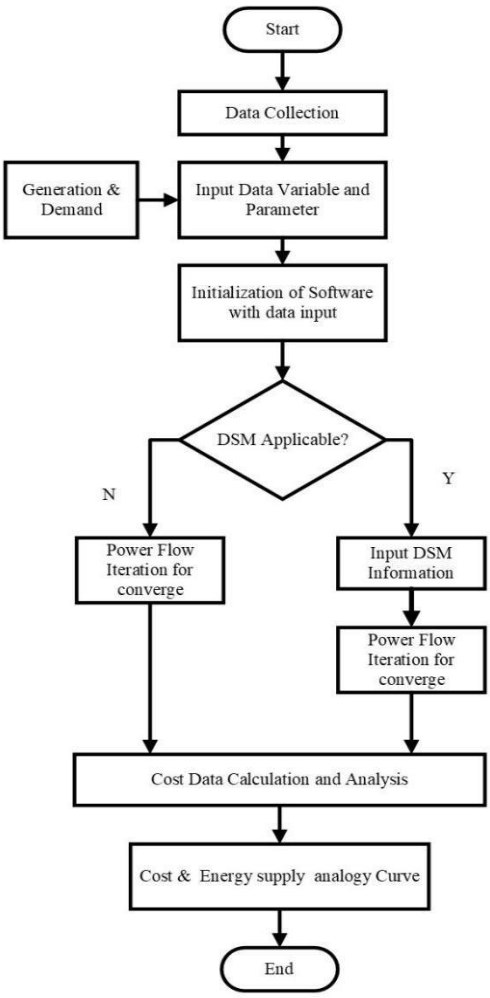


Fig. 1. Process of test grid system calculation.

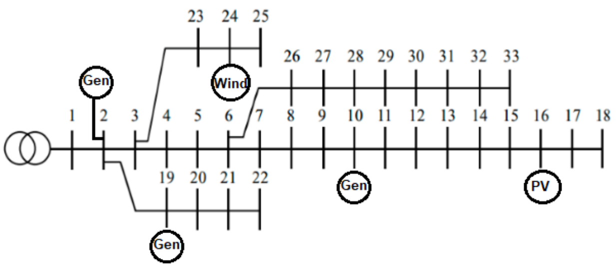


Fig. 2. A 33-bus test grid presentation.

The top-down strategy is employed to aggregate the power consumption units of a unit, resulting in the knowledge of only the overall energy consumption of a certain local region [31]. In contrast to the top-down approach, the bottom-up methodology examines the individual power consumption of each appliance. The regular load curve for a base station or multiple base stations can be easily obtained by aggregating the consumption of all devices [32].

In order to determine the energy usage on an hourly basis, historical data is analyzed using a bottom-up approach for various appliances during a 24-hour period.

The steps for implementing the assumed DSM are as follows:

Step 1: Enter the hour wise load.

Step 2: Input the cost of generating.

Step 3: Enter the percentage of DSM applied in the variable load share.

Step 4: Calculate the hourly flexible and base loads in the grid.

Step 5: Determine the TCL and LL load's minimum, maximum, and total. For the FL load requirement, the control variables must be adjusted.

Step 6: Applying optimization methodology, minimize $c^t_{\text{grid}} P^t_{\text{Grid}}$.

Considering the temperature control loads (TCL) as a different category. As these loads depend on temperature, and a percentage of user avail DSM sacrificing their comfort. Here D is the percentage of consumer availing DSM for consuming power $P_{\text{TCL\_load}}$ suitable modeling equation can be expressed as,

$$N_{\text{TCL}_{n'}} = \text{USE} \cdot N_{\text{TCL}_o}, \text{ for } \begin{cases} \text{USE} = 1, & \text{Normal time} \\ \text{USE} = 1 - D, & \text{DSM time} \end{cases} \tag{20}$$

$$P_{\text{TCL\_load}} = \frac{1}{N} \sum_{n=1}^{N} T_{\text{TCL}_{n'}} v_{\text{load}}(n) i_{\text{load}}(n) \tag{21}$$

Considering the lighting loads (LL) as a different category. As these loads depend on light, and during daylight saving time of user avail DSM by keeping the lighting load off. Here the percentage of consumers availing day light saving is counted by difference in differences (DID) method [33]. Such DSM for consuming power $P_{\text{TCL\_load}}$ suitable modeling equation can be expressed as,

$$N_{\text{LL,new}} = \text{USE} \cdot N_{\text{LL,old}}, \quad \text{for } \begin{cases} \text{USE} = 1, & \text{Normal time} \\ \text{USE} = 1 - D, & \text{Day light saving time} \end{cases} \tag{22}$$

$$P_{\text{LL\_load}} = \frac{1}{N} \sum_{n=1}^{N} T_{\text{LL\_load}} v_{\text{load}}(n) i_{\text{load}}(n)$$

Flexible loads can be considered as the loads that can be shiftable to another time period like washing machine, water pump, telecom rectifier etc. As a result, then the energy demand at this time will reduce by the energy that would have been consumed by it. As these loads depends on time, for consuming power $P_{\text{FL\_load}}$ suitable modeling equation can be expressed as

$$N_{\mathrm{FL,new}} = \mathrm{USE} \cdot N_{\mathrm{LL,old}},\ \text{for} \begin{cases} \mathrm{USE}=1, & \text{Shifted time} \\ \mathrm{USE}=0, & \text{Peak time} \end{cases} \quad (23)$$

$$P_{\mathrm{FL\_load}} = \frac{1}{N}\sum_{n=1}^{N} T_{\mathrm{FL\_load}} v_{\mathrm{load}}(n) i_{\mathrm{load}}(n) \quad (24)$$

Step 7: Using the DSM technique and the optimal flexible load values, the other load demand for each hour is added to the newly organized load demand model.

IV. Descriptive Analysis and Discussion

For the analysis, a 33-bus test grid system is taken into account. With added two other generation of wind and renewable energy, the system is considered run by three generation system. The 33-bus grid system using renewable energy is shown in Fig. 2. The generation parameters are shown in Table I and are primarily taken from the Bangladesh Power Development Board's annual report.

TABLE I: Type of Generation Parameter

Unit	Max (MW)	Min (MW)	A ($/KW)^2	B ($/KW)	C ($)
Gen1	2.70	1.00	0.0007	20	0.000454
Gen2	0.69	0	0	37	0
Gen3	1.00	0	0	117	0
PV	0.30	0	0	11	0
WG	0.15	0	0	15	0

The currency has been converted to the US dollar. The prioritization of renewable energy sources for power generating is of paramount importance, with cost-effective generation techniques being afterwards considered. The calculation of the total demand factor was based on a representative dataset of daily demand from the electricity system in southern Bangladesh. The demand curve has been segmented into three distinct categories of loads to facilitate computational convenience, and the amount of load has been computed as seen in Fig. 3. The analysis of composite demand data involves examining several literature sources on surveys and making adjustments to the power consumption trend. In their publication, Vinh Tien *et al*. [34], examined the power consumption and demand curve of Tuy Hoa city in Vietnam. Additionally, references [35] and [36] provide insight into the trajectory of power demand in typical residential usage. In his study, Imran Khan performed a survey in Bangladesh to investigate the use of household demand, as discussed in article [37].

In the context of DSM implementation, it has been taken into account a flexible market approach, whereby the Independent Service Operator (ISO) manages a day-ahead market. This market facilitates the bidding of electricity by aggregators, as seen in Fig. 4. Additionally, aggregators get compensation from the ISO for achieving goal load reduction.

Total power has been calculated from the curve using a straightforward bottom-up method, occasionally adding an uncertainty function for load verification. Fig. 5 shows the usual load demand and the cost of electricity depending on time of use (TOU).

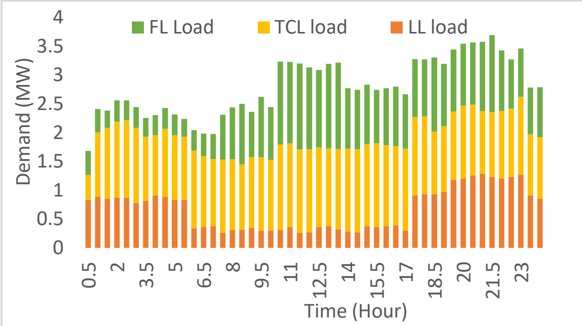


Fig. 3. Demand curve with classified load.

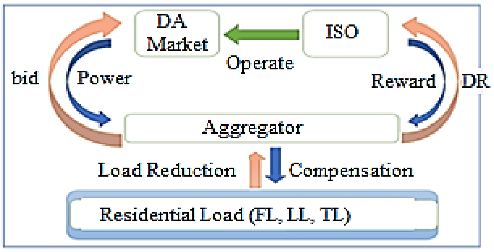


Fig. 4. Market mechanism considered for research.

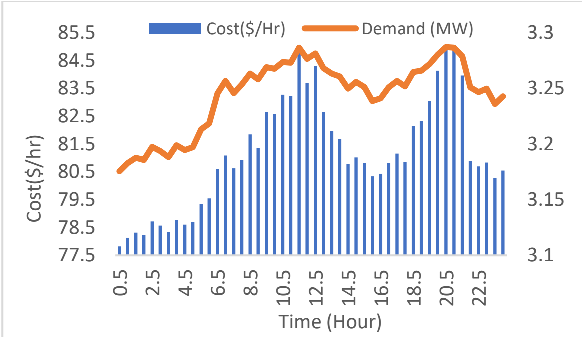


Fig. 5. A typical day demand Vs cost representation

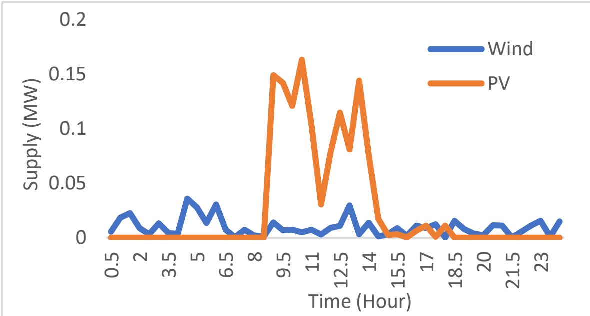


Fig. 6. Renewable energy supply with uncertainty model

Fig. 6 shows the anticipated hourly output of the solar and wind farms for the aforementioned test grid model. The Matlab® M-file package for solving power flow and optimal power flow problems, MATPOWER, has an optimization tool for the study of optimal power flow that has already proven to be superior in solving a number of power system optimization problems, including reactive power problems. Additionally, a fundamental Matlab® method has been created to determine hourly usage. Table II shows the algorithm's executive summary.

When considering the market, a typical market is one in which the aggregator receives compensation from an independent service provider. This market is controlled by minimizing system costs as a whole.

Algorithm 1: Determining hourly usage

Input→ Gen Data/ Cost Data
Loop (0.30 hr. to 24 hr.)
Input→ Load data (LL/TCL/FL)
Iteration up to Converge
end
Output Store
Loop (0.30 hr. to 24 hr.)
Input→ Load data (LL/TCL/FL)/ DSM Scheme
Iteration up to Converge
end
Output Store
Print Curve

No financial analysis is added for simplicity of study, and only system minimization is given attention.

It is assumed that the aggregators are actively buying and selling electricity to and from the test grid system in this scenario. A DSM-based fuel cost reduction strategy for the test grid system is calculated using an ideal power flow optimization process. The cost reduction due to TCL and LL load is finally examined in Case Study 1, and the cost minimization due to a change in time of usage for flexible load is examined in Case Study 2.

A. Case Study 1: DSM by Load Reduction

According to different DSM participation percentages, the expected load demand for each hour in the first level was separated into three types of loads. Loads are optimized in accordance with the incentive-based energy market and mainly LL and TCL loads are targets for DSM pricing in order to provide a revised load demand model for various levels of DSM involvement.

Under the premise that 5% to 15% of the total hourly load demand may be lowered and participate in DSM modelling, the electrical load demand model has been redesigned for the aggregator level and the electricity market pricing. Without changing the average or total electrical demand for the distribution system, DSM reduces the peak of the demand curve.

The production cost for the test grid system is reduced as normal for all load demands. The hourly output of the DERs with generation system for the 5% DSM, 10% DSM, and 15% DSM schemes, respectively, are shown in Fig. 7. It should be noted that the reduction in grid producing costs is significantly influenced by the hourly output of the grid. When the grid controls power usage, objective costs go down.

The cost change in relation to the change in load brought on by the DSM application is shown in Fig. 8. For greater demand reduction, there is enough cost minimization that can be accomplished. Table II provides a summary of the entire situation.

TABLE II: DEMAND CHARACTERISTICS

	Without DSM	5% reduction	10% reduction	15% reduction
Peak (MW)	3.2843	3.2834	3.2816	3.2778
AVG (MW)	3.2421	3.2420	3.2417	3.2416
Peak reduction (%)		0.09	0.27	0.65
Load factor	0.8826	0.8828	0.8831	0.8838

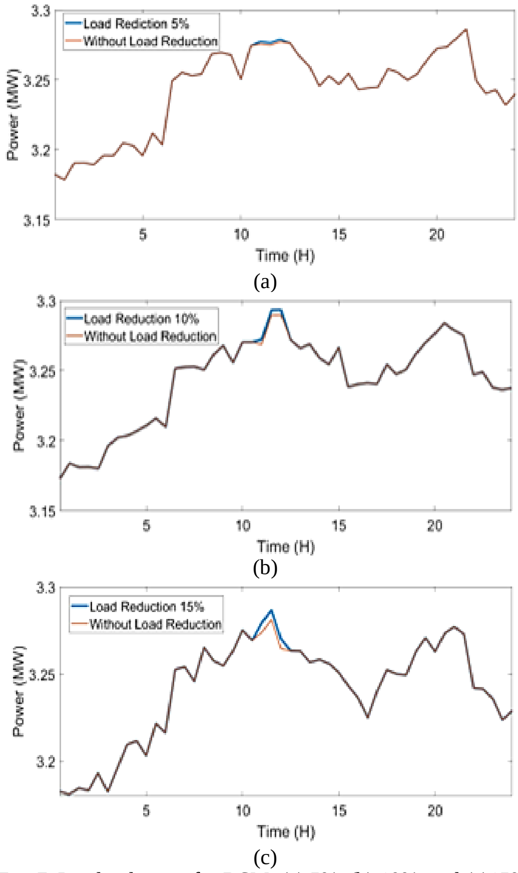


Fig. 7. Load reduction for DSM: (a) 5%, (b) 10%, and (c)15%.

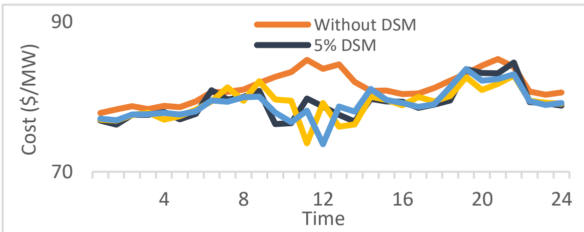


Fig. 8. Costing variation with different DSM condition.

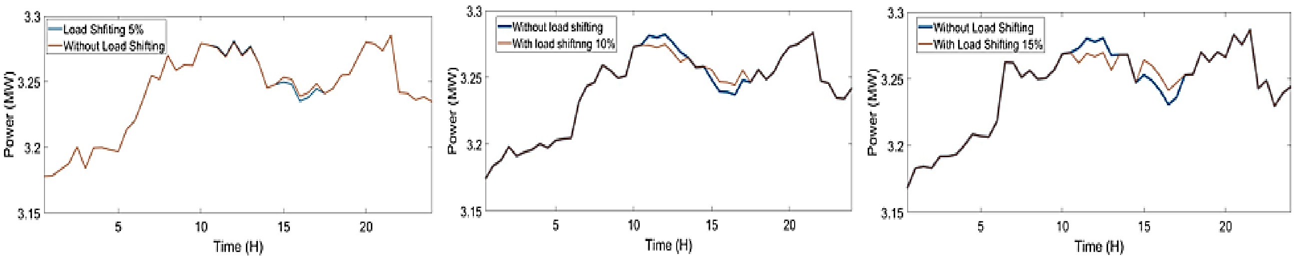
B. Case Study 2: Demand Shifting

In this case, it is thought that supplying TOU-based energy market pricing, which encourages the aggregator to sell power to the customer while providing some compensation, shifts the grid demand.

The assumed demand response will be sufficient to change the test grid system's overall load demand during this hour. To study the effects of the FL load shift, the minimal generation cost is calculated without taking LL and TCL into consideration.

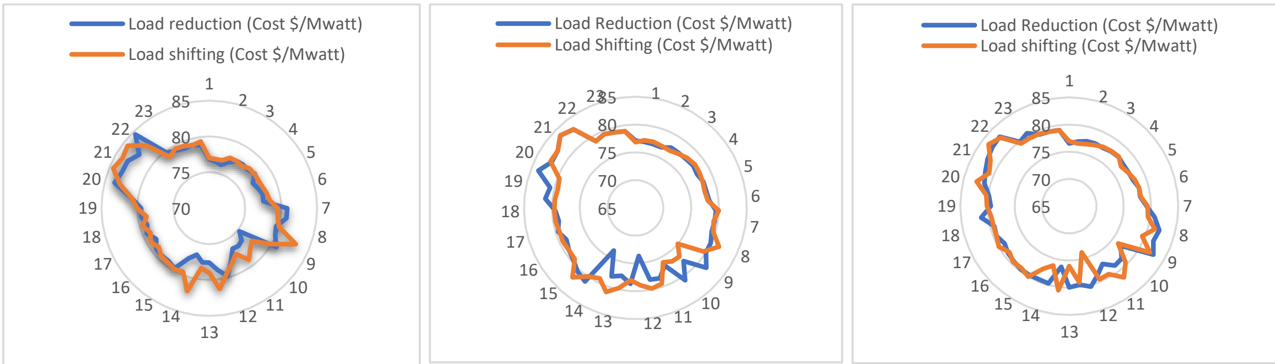
C. Discussion

The cost of producing one hour's worth of production increases significantly when the FL is not taken into account by the grid system. The price is decreased when shifting is considered Due to the grid's changing involvement and the investigation of generating costs under DSM plans, it is not necessary production the grid to acquire energy from high-cost production. On the other side, Fig. 9(b) and (c) depict the possibility of an alternative peak, which might raise the cost of producing in comparison to Case 1.



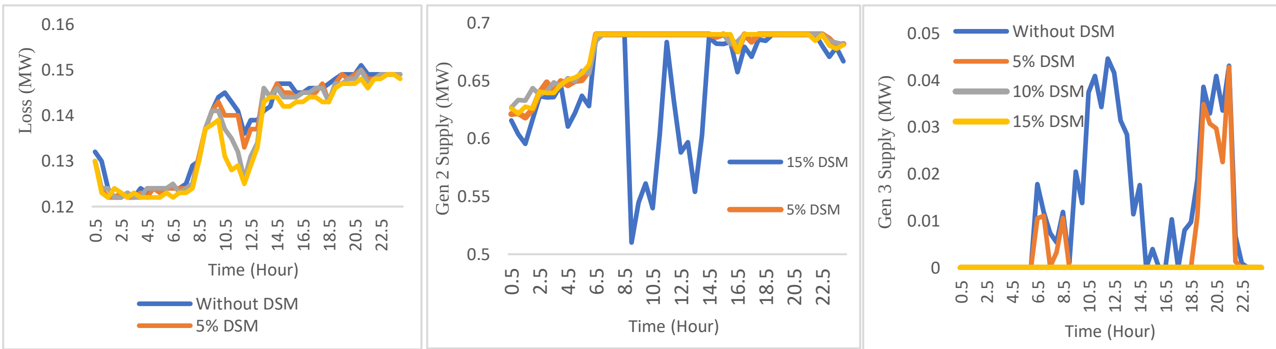
(a) (b) (c)

Fig. 9. Load shifting for DSM: (a) 5%, (b) 10%, (c)15%.



(a) (b) (c)

Fig. 10. Load shifting vs load reduction: (a) 5%, (b) 10%, (c) 15%.



(a) (b) (c)

Fig. 11. Impact of DSM: (a) Losses, (b) Gen 2, (c) Gen 3.

The grid's best strategy for transferring grid users is to utilize a TOU-based power market pricing model, according to a comparison of prices in Fig. 10. In this case, the grid controls the market price of power, allowing customers to maintain their standard of living while perhaps lowering prices overall.

Fig. 11 illustrates the influence of the DSM on the generation system. Generation 1 remains unchanged as it continues to function as a base load supplier. However, Generation 2 and 3 at this point operate as peaking power plants. This shift in power supply is significantly influenced by the alteration in DSM value.

Fig. 11 (a) represents the overall influence of DSM alterations on power flow and the subsequent losses. It is evident that a higher percentage of DSM implementation will decrease the overall losses in the network. Both consumers and the power generation authority benefit from cost reduction through the decrease of system losses. While the impact may not be considerable during periods of lesser consumption, it becomes important during the picking period.

Fig. 11. (b) and (c) indicate that Generation 2 has a reduced impact on the load as the DSM value increases, but Generation 3 does not require to even produce power for a DSM value of 10% or 15%.

Fig. 7 illustrates the relationship between the increase in DSM value and the corresponding change in operating cost. It can be seen that a higher percentage of load reduction achieved by DSM would result in a decrease in the total cost of the system.

D. Limitation of the Study and Possibility of Practical Implications

Nevertheless, it is important to acknowledge the limitations of the system model. It should be noted that in real-time case studies, there may be variations in the total power consumption patterns. Essentially, the DSM models used in this work depend on base load modelling as a fundamental basis. This can provide a constraint as it presupposes a generally stable and unvarying pattern of electricity demand. Electricity consumption can fluctuate considerably in actuality, owing to variables such as weather conditions, economic volatility, and shifts in consumer behavior. Template-based load modelling may inaccurately reflect these changes.

Furthermore, the precision of DSM modelling depends on the use of reliable and current data, which encompasses past consumption trends and consumer actions. The modelling process can be compromised by data restrictions or mistakes, leading to errors that undermine the dependability of the conclusions. Further-more, energy markets are susceptible to fluctuations in fuel costs, alterations in policies, and the development of grid infrastructure. The presence of these variables can inject a level of unpredictability into the planning of DSM.

The research on template-based DSM provides useful insights for policymakers and energy management. The document offers guidance on how to execute DSM techniques in practical environments and emphasizes the possible obstacles that may occur. Policymakers and energy managers can receive guidance in formulating policies and implementing DSM in real-world situations. Policymakers and energy managers should give highest priority to making decisions in DSM implementation based on data analysis. Timely and precise information regarding energy usage trends, consumer habits, and the adoption of technologies is crucial for efficient planning. Additionally, it is crucial to guarantee that the regulatory structure is conducive to DSM activities. Policymakers should focus on establishing a conducive climate that promotes the incorporation of demand-side resources into the energy market. This entails considering the effects on energy expenditures and ecological advantages, both in the immediate and distant future. This study aims to investigate and use incentive mechanisms that motivate consumers and enterprises to engage in demand-side management (DSM) programs, such as time-of-use pricing or demand response incentives.

V. Conclusion and Future Work

A test grid setup using an IEEE 33 bus was utilized to conduct an economic analysis. This study highlights the benefits of grid integration, grid pricing, and demand-side management (DSM) participation. The subsequent section provides a concise overview of the primary discoveries derived from the study. Enhancing active grid involvement is necessary in order to mitigate the generation costs of the system. The comparative analysis reveals that the producing costs of Cases 1 and 2 exhibit a notable similarity. However, the incorporation of Demand Side Management (DSM) results in a reduction in costs ranging from 15% to 31% in comparison to the costs computed in the absence of DSM. Furthermore, the implementation of Demand Side Management (DSM) offers various advantages, such as reducing the demand during peak periods and increasing the load factor, all while ensuring the overall load and average load of the demand are maintained.

Both time-of-use (TOU) based and incentive-based power market pricing play a crucial role in the efficacy of demand-side management (DSM). Consequently, it is necessary for the cost of energy to vary on an hourly basis in accordance with the level of demand. The influence of a fixed electricity price on demand-side management (DSM) load modeling is minimal. The expenses associated with the generation of the system are reduced when an effective demand-side management (DSM) strategy is determined. The superiority of load shifting as a method becomes evident due to its lack of hindrance in load consumption. However, load reduction exhibits notable advantages in terms of power conservation and environmental benefits, as demonstrated by a comparison of Case 1 and Case 2.

Investigating cost-centric energy management in test grid systems, specifically focusing on load flexibility for Demand-Side Management (DSM), is a crucial and promising subject for future research. Create and improve sophisticated optimization algorithms to efficiently oversee and regulate the grid system, taking into account load flexibility. Exploring machine learning and AI-based techniques, such as reinforcement learning and deep learning, could enhance the accuracy of forecasts and decision-making processes. Examine the function of energy storage systems, such as batteries, in relation to load flexibility and cost control. Investigating the most efficient dimensions, positioning, and management techniques for energy storage can yield significant benefits. Examine the regulatory and policy structures that can support the efficient management of energy costs and the ability to adjust energy usage. Engage in cooperation with policymakers and industry stakeholders to discern obstacles and potential advantages. Subsequent research in this domain should strive to tackle the obstacles and possibilities arising from the changing energy environment, emphasizing the reduction of expenses, the promotion of sustainability, and the enhancement of dependability. The cooperation of researchers, industry, and government organizations will be crucial to stimulate innovation and facilitate beneficial transformations in energy management systems.

Conflict of Interest

There is no conflict of interest.

Author Contributions

Conceptualization—S.M.S. and N.M.; methodology—S.M.S. and N.M; software—S. M. S.; investigation—S.M.S.; writing—original draft preparation— S.M.S.; writing—review and editing— S.M.S. and N.M. All authors had approved the final version.

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