Enhanced cheetah optimizer for demand side management in smart grids with demand response and renewable energy

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ABSTRACT

For the effective operation of smart grids, it is critical to ensure that demand side management (DSM) includes strong two-way communication and addresses significant security and privacy issues. DSM success depends on the participation of customers who need a just system. The recent fairness studies in DSM have identified different definitions of fairness while this study presents an enhanced cheetah optimizer algorithm (ECOA) for solving complex dynamic economic dispatch (DED). The ECOA targets at minimizing operational costs as well as improving power system security. This research tests the ECOA performance by examining DED problem independently from DSM, and demonstrates its applicability on 10-unit and 20-unit test systems. These figures clearly show that ECOA decreases operational costs by about 0.24% and 0.43% respectively, once DSM is used. Thus, it is possible to conclude that DSM has the possibility of bringing down costs and enhancing economic efficiency. Considering the integration of renewable energy sources into microgrids with electric vehicles, ECOA's adaptivity and dependability make it a potential approach to multi-objective energy management within such kind of networks.

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1. INTRODUCTION

The power system's capacity may soon reach its limit since annual increases in electricity usage are pushing them to the brink of operation. Furthermore, the power system's dependable operation depends on the supply and demand being in balance. Maintaining minimal variations between the peak and off-peak loads improves system efficiency. Demand side management (DSM) is crucial for addressing the issues in power networks since it balances supply and demand [1]. DSM includes control over the consumer side of the power system, such as initiatives to encourage consumers to move non-essential power use to off-peak hours in order to lower their bills and manage peak demand, which has a significant influence on provider side generation costs and system reliability. A multitude of DSM approaches exist [2]. The majority of DSM applications in the past were utility-driven, such as those that used direct load control (DLC). Under residential DLC, the utility can remotely regulate the energy usage and operation of certain household equipment in accordance with a contract between the utility and customers [3].

In order to efficiently control residential loads, day-ahead load shifting techniques were used as a component of a DSM methodology. The primary objective was to lower the utilities' energy expenses. In a microgrid situation, the problem of economic load dispatch was resolved by applying the Interior Search Algorithm. The harmony search approach is used to tackle this multi-objective power flow issue.

A day-ahead shifting of loads DSM technique was implemented using a day-ahead pricing plan and an energy consumption game [4].

Additionally, the traditional boundary intersection approach handled a core multi-objective economic dispatch including demand side management for specific residential loads and electric vehicles, successfully. Costs associated with generation, energy loss, and pollution are regarded as objective functions. To address a variety of intricate problems pertaining to energy management systems, a collection of cutting-edge optimization algorithms was created [5]. Certain characteristics, including future home load demand, appliance user preferences, and solar energy production, have been directly assumed in certain research. It is known that with certain presumptions, the DSM problem is reduced to a straightforward optimization problem.

These studies neglected to account for uncertainty in the real world [6]. Now that processing capacity has increased, huge data can be properly analysed. The preferences of users for their home appliances at any given time can therefore be investigated for a variety of homes and users. In order to accomplish energy conservation, load management is conducted after analysing the power consumption reduction strategies [7]. Voluntary load management programs are another kind of DSM programs. Utilizing systems that encourage users financially to become more engaged contributors is a novel approach to DSM. It is important to keep in mind, nevertheless, that consumers may not be motivated to consistently participate in the programs or to react to price adjustments. As a result, DSM should take automatic load scheduling techniques into account. Users are encouraged to control their loads automatically via the smart power grid through the use of smart pricing in DSM and two-way communication technology in meters [8]. However, there are a number of difficulties in integrating autonomous DSM in a future smart grid.

This necessitates a careful analysis of the dynamic characteristics that result from the grid's integration of various renewable sources. It is essential to comprehend the intricacies of using solar and wind power to attain their optimal integration into the entire energy system as the conversation about sustainable energy grows [9]. These realisations are crucial for advancing the conversation about sustainable energy use and creating practical plans to match the transition to green energy with the requirements of a stable and dependable electrical system. The unpredictable nature of wind speed and solar radiation has little effect on the load variation [10].

One of the quickest, cleanest, and most economical methods to satisfy our expanding energy needs is through demand side management (DSM) and energy efficiency. Our future demand trajectories will be lowered, the demand-supply gaps will be greatly closed in a shorter amount of time, and these efforts will be substantially less expensive than constructing new power plants and transmission and distribution infrastructure. It would seem that encouraging consumption and hence raising sales would be a prudent corporate strategy from a utility point of view [11]. This would be the case in an energy supply system where revenues were the only significant driver and there was excess capacity.

Nevertheless, bigger revenues do not always equate to better profits, and in some circumstances, implementing DSM measures could prove to be more profitable than investing in new generating capacity when using a least-cost planning method. Therefore, utilities could be better advised to encourage energy conservation and DSM. From an environmental standpoint, the environmental effect of energy consumption linked with a specific level of production or other activity is lessened when energy demand declines as a result of increased efficiency [12]. Based on the lowering of the guided wavelength at a factor of square-root of the substrate's effective dielectric constant, this can be accomplished [13]. In order to optimize the nonlinear minimum multiplication model, a third-order polynomial function is used to approximate the link between sample entropy and lithium-ion battery capacity [14]. Systems for energy management EMSs are crucial to electrifying these rural villages because of their harsh conditions [15].

A thorough economic system serves as the foundation for the constrained-nonlinear optimization structure used to formulate this problem [16]. In order to allow the so-called smart grid, new technologies are now being developed [17]. The hooke hinge is used to connect each set of mechanical arms between the top dynamic platform and the bottom static platform [18]. Compared to other sectors, the built environment has nearly twice as much potential for cost-effective carbon reduction [19]. Through load scheduling, the suggested algorithm under the price-based DR encourages residents to participate in DSM [20]. The productivity and efficacy of the suggested DA-GmEDE-based approach to effective energy management [21]. Additionally, to increase sustainability, smart appliances, plug-in hybrid electric vehicles (PHEVs), energy storage systems, and renewable energy sources (RESs) may be introduced into residential structures [22]. Large-scale historical scenarios are reduced or optimized using both data mining and scenario reduction approaches in the classical scenario generating methods, which produce a set of classical scenarios that encompass the entire region that needs to be solved [23]. These results suggest that star-shaped unfused ring electron acceptors (SSUFREAs) can be used as third components to enhance the open-circuit voltage and optimize morphology [24]. The complexity of the optimization model presents challenges for demand response (DR) [25]. Energy management systems are unable to give their consumers a choice between ensuring their comfort and offering a sustainable solution that lowers carbon emissions [26].

In modern power systems, balancing cost efficiency, security, and fairness in DSM remains a significant challenge. While DSM enhances economic efficiency, its success depends on fair customer participation and effective two-way communication. Additionally, integrating renewable energy sources and electric vehicles into microgrids adds complexity to energy management. This study addresses these challenges by introducing the enhanced cheetah optimizer algorithm (ECOA) for solving dynamic economic dispatch (DED) problems. By demonstrating ECOA's potential to reduce operational costs and improve system reliability, this work provides valuable insights for advancing sustainable and efficient energy management strategies.

DSM plays a crucial role in modern smart grids by enhancing economic efficiency and ensuring fair consumer participation through two-way communication. Recent studies on DSM fairness highlight the need for balanced energy management, while optimization techniques continue to evolve for improved cost reduction and system security. This study introduces ECOA to address DED challenges, aiming to minimize operational costs and enhance grid reliability. Tested on 10-unit and 20-unit systems, ECOA demonstrates its effectiveness, particularly in DSM scenarios, and shows promise for managing renewable energy integration in microgrids with electric vehicles.

This paper is organized as section 1 introduction, sections 2 and 3 describe the proposed methodology of DMS block diagram with the enhanced cheetah optimization algorithm proposed, section 4 discusses results and discussion, and finally, the conclusion of this paper is given in section 5. Thus, this methodology is used in the suggested research. The contribution of the paper:

- In this work, we employ the ECOA, demand side management, and renewable energy sources to manage economic dispatching. A levy fly mechanism and chaotic sine map have been added to the approach, which will produce a better and faster solution.
- The goal of this learning technique is to more effectively refine the current candidate solution by taking into account both an estimate and its opposite counterpart at the same time.
- The most dependable probability density functions are used to illustrate the intrinsic unpredictability of solar and wind power producers.
- The ECOA algorithm is crucial for figuring out when to pump water from the higher reservoir, including releasing it for power generation. This algorithm takes into account variables including demand trends, power pricing, and the selling price of renewable energy suppliers.
- We thoroughly examined how well our proposed algorithm performed in solving demand side management and unconventional energy source economic dispatch problems.

2. PROPOSED METHODOLOGY

Traditionally, DSM has been viewed as a way for utilities to postpone adding more capacity by lowering peak electricity demand. In actuality, DSM has a lot of positive benefits by lowering the overall load on an energy network, such as minimizing electrical system emergencies, decreasing blackout frequency, and boosting system dependability. Reduced reliance on costly fuel imports, lower energy costs, and a decrease in environmentally harmful pollutants are further potential advantages. Ultimately, DSM plays a significant part in postponing large investments in networks for distribution, transmission, and generation. Hence, the application of DSM to electrical systems offers noteworthy advantages in terms of economy, dependability, and ecology.

2.1. Demand side management

Since demand-side management enables consumers to modify their load consumption habits, it is a crucial component of the architecture of a smart grid. It is an essential part of an authority delivery network's energy management system. As illustrated in Figure 1, DSM gives integration of power-saving methods, use of dynamic or adjustable modular pricing, and implementation of DR-based programs top priority in order to reduce peak load. DSM oversees the most senior employees general to create an adequate power balance rather than relying on more generating to fulfil demand. The four methods that follow and are depicted in Figure 2 can be employed for organizing various adjustments that are made to define and form the electrical load profiles.

2.1.1. Energy efficiency

This comprises controls designed specifically for end users and appliances that gradually lower load usage by implementing energy-saving techniques at the gadget level. Energy conservation is the reduction of overall load consumption achieved by offering better power delivery for every component in relation to the provided input power for the device, reducing use over time, as opposed to depending on an event-triggered technique for use profile minimization. An extensive examination of the measures, barriers, and characteristics related to energy efficiency improvements is accessible.

2.1.2. Time of use (ToU)

Employing the ToU billing technique, a utility divides its set tariffs into 24-hour intervals. A parameter billing characteristic is then employed for each period. Because this method is based on an hour block-based indicator tariff of electricity units, it can aid in the control of high demand rates and seasonal variations in pricing tariffs.

2.1.3. Spinning reserve

The spinning reserve is generally believed to serve as the electric power method's back power in the case of a sudden fall in generating levels. The spinning reserve is something that the distribution system operator (DNO) may employ to cover any gaps in generating supply and demand. Numerous things, such as harm to the producing units, poor demand forecasting, and dispatch scheduling, can result in power outages. Primary and secondary spinning reserves are the two main varieties. The former uses frequency regulation to restrict the amount of active power output, while the latter injects more active power.

2.1.4. Demand response

When unit rates change over time or incentive schemes are introduced, energy consumers deviate from their typical patterns of usage. When grid stability is unclear or during important tariff periods in the energy wholesale market, lowering the profile of load is the primary goal. DR is especially interested in short-term modifications during the important peak pricing/usage phases of the day because there is little demand or limited spinning capacity for reserves during these times. For DSM, long-term load projections are increasingly crucial, which can be attained by increasing demand-side energy efficiency or implementing consumer-centric consumption habits.

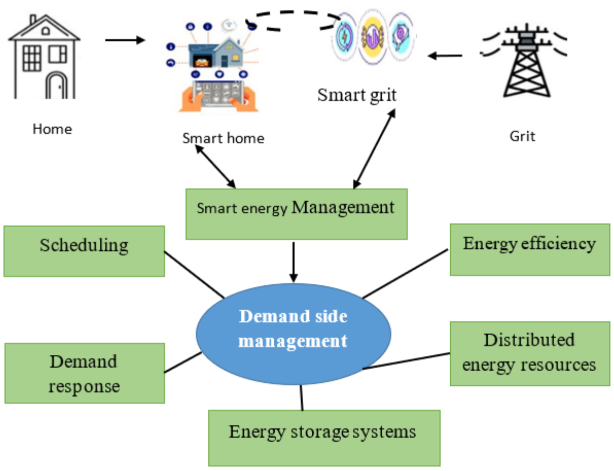

Figure 1. Block diagram of DSM in the smart grid environment

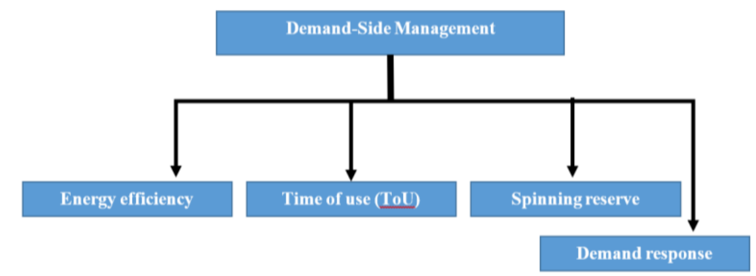

Figure 2. Basic principle of DSM

2.2. Demand side management techniques

As shown in Figure 3, load-shaping strategies for demand side management (DSM) include strategic load growth, load moving, peak trimming, valley filling, or load shaping. In underdeveloped nations, max clipping is a tactic used to lessen the effects of peak demand at peak hours, when it would be expensive to install additional power units. A structure is needed for valley filling in order to maintain system balance during off-peak hours, particularly when the typical price is less than the load cost. This frequently happens when a plant has low operating costs and produces less power than it consumes. This results in a rise in the total consumption of energy even in the case of constant peak demand.

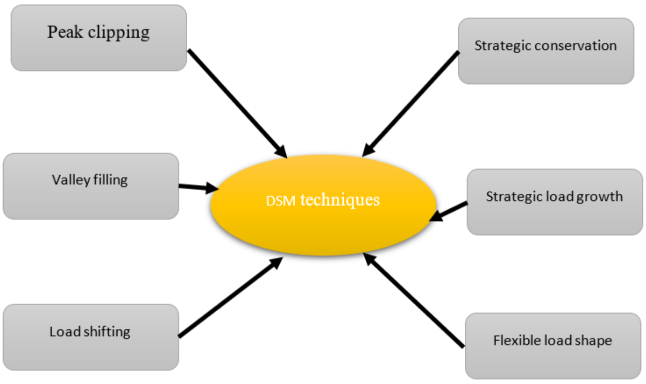

Figure 3. Demand side management techniques

Due to the fact that this approach includes a decrease in sales that is not always accompanied by a drop in peak, it is relatively extensive and is not as often used as other load control techniques. By controlling the seasonal energy usage, strategic load expansion raises peak demand in a certain season and results in a sharp increase in peak demand and energy usage. To achieve their goal, the utilities, however, employ more sophisticated systems, particularly when it comes to the electrification of commercial and industrial heating operations. When it's required to reduce peak demand and change total energy usage, the power company interrupts the loads. Load limitation devices are used in flexible load form to lower user energy consumption without affecting the actual system conditions. Using DSM to formulate the DED problem involves specifying the resulting objective function and the constraints that go along with it. After taking into consideration the valve-point impact, With the i_{th} steam generator at time t, the fuel expense function is as follows:

$$F(P_G) = \sum_{i=1}^{N_{TH}} \left(a_i + b_i P_{Gi} + c_i P_{G_i}^2\right) + |e_i \sin\left(f_i * (P_{Gimin} - P_i)\right)| \quad (1)$$

Where P_{G_i} is the i^th generator's output power in megawatts, k is the total amount of electricity-producing units, a_i, b_i and $c_i$are the fuel expenditure coefficients of the i^th generator. The producing expense factors of the i^{th} unit, represented by $e_i$and f_{ire}, are used to model the valve point packing effect in this instance.

$$C_w(P_w) = K_W P_W \quad (2)$$

In this case, generated power is denoted by P_W and the immediate expense coefficient associated with the wind turbine is denoted by K_W. Regarding this, the following equation represents the direct cost of solar P_V given scheduled power P_{PV} along with the expense coefficient K_{PV}:

$$C_{Pv}(P_{PV}) = K_{PV} P_{PV} \quad (3)$$

In this context, P_{PV} denotes the generated power, while K_{pv} represents the direct cost coefficient associated with solar photovoltaic generation.

Because wind energy is erratic and intermittent, there are expenses and penalties associated with it. These are assessed in order to determine the wind power reserve cost and penalty cost. When organising the operation of wind-generating plants and carrying out an economic assessment, reserve charges and penalty costs are crucial factors to take into account.

$$C_{R_W}, i\left(P_{W_{sh}}, i - P_{W_{ac}}, i\right) = K'_{rw}, i\ (P_{W_{sh}}, i - P_{W_{ac}}, i) \quad (4)$$

$$= K'_{rw}, i\ \int_0^{P_{wsh},i} (P_{Wsh}, i - P_w, i) f_w(P_w, i) dp_w, i \quad (5)$$

When the extra power produced by wind generators surpasses the scheduled output power, the ISOs must pay the price by reducing the power generated by their thermal power plants when they are not utilizing it.

$$C_{pW}, i(P_{W_{ac}}, i - P_{W_{sh}}, i) = K'_{rw}, i\ (P_{W_{ac}}, i - P_{W_{sh}}, i) \quad (6)$$

$$= K'_{pw}, i \int_{P_{Wsh,i}}^{P_{wr,i}} (P_W, i - P_w, sh, i) f_w(P_w, i) dp_w, i \quad (7)$$

Here, $P_{W_{sh_i}}$ stands for the anticipated solar energy and $P_{W_{ac}}, i$ for the actual power generated by the wind turbine. This makes it possible to compute reserve and penalty costs for generators that run only on solar power or in combination with hydropower. The six pieces of instruments used in this investigation are outlined in Table 1, together with information on their electrical capacity ratings.

Table 1. Simulation results

Appliance	Power rating	Appliance	Power rating
Air conditioner	70-130 W	Electric vehicles	200 W
Washing machine	100 W	Battery storage	50-120 W
Cloth dryer	100 W	Iron	250 W

2.3. Distributed generations in smart grid

As illustrated in Figure 4, a distributed energy provider (DER) is a collection of dispersed generators of controlled loads (conventional and smart) linked to a distribution system of a smart grid. Distributed generation, or DER, units frequently combine multiple energy sources. Basically, they fall into two categories of sources according to their type of source of generation and dispatch capacity.

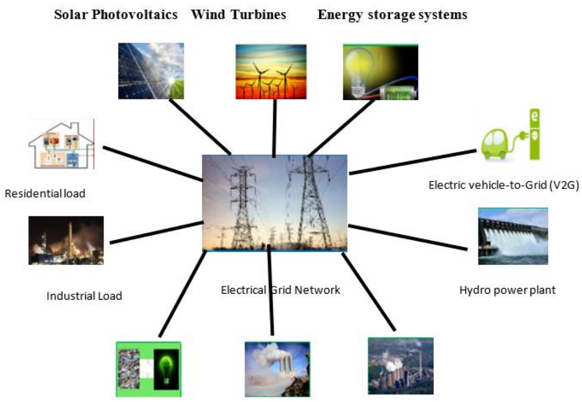

Figure 4. The smart grid uses a variety of energy source types

2.3.1. Solar photovoltaics

The main renewable energy source used worldwide is the conversion of solar radiation into electrical energy using installed semiconductor panels. It can generate energy on any scale, either large-scale (centralized power plants) or small-scale (rooftop photovoltaic systems in residential areas). It can also operate independently or in conjunction with the grid. Production possibilities are increased by scheduling according to weather condition forecasts.

2.3.2. Solar thermal

Solar thermal energy facilities heat fluids to an extremely high temperature in order to generate energy. The water absorbs the heat from this fluid and becomes superheated steam. In a power plant, a generator converts mechanical energy into electrical power while steam powers turbines. With the exception of using sunlight to heat steam instead of burning fossil fuels, this method of producing electricity is comparable to one which uses fossil fuels.

2.3.3. Hydropower plants

Depending on the water's availability and water head, the flowing capacity of water can rotate a turbine to produce power in a centralised or decentralised style of operation. DSM operations are often carried out by small-scale hydropower stations, which are explained in section.

2.3.4. Wind turbines

In situations when there is sufficient wind reach, wind energy conversion systems, or WECs, are also an important part of distributed generation (DGs). Only smaller, lower-capacity generation units can use this unit. This makes it feasible for customers to deploy small-scale WT units without interfering with the overall power system's ability to function.

2.3.5. Geothermal energy

The earth's core is where the energy for geothermal energy is extracted. DGs can be positioned in close proximity to naturally occurring geothermal sources of energy, such as hot springs, lava flows, geysers, or places where water directly contacts surfaces with high thermal conductivity. Geothermal sources are a viable means of generating renewable energy as part of the cycle of evaporation and replenishment.

2.4. Proposed enhanced cheetah optimizer algorithm

Figure 5 shows the suggested enhanced cheetah optimizer algorithm's flowchart. A cheetah's ability to scan its environment allows it to identify possible prey, which it may then either attack right away or wait for the prey to get closer. The actual attack is divided into two stages: a quick approach and capture. The cheetah may, however, give up the chase for a variety of reasons, including limited energy reserves or an overly agile target. In these situations, the cheetah may withdraw to its den in anticipation of new hunting territory. The cheetah carefully evaluates the distance, the state of its prey, and the surrounding conditions before deciding on one of these strategies. The COA algorithm, which relies on the purposeful application of different techniques over multiple hunting cycles or iterations, captures this entire hunting process. In essence, the COA algorithm uses these clever hunting techniques repeatedly while the hunt. Searching: In order to find prey in the search space, cheetahs either actively explore or scan their territories and the surrounding region.

- Sitting and waiting: When cheetahs spot prey but the weather isn't ideal, they could decide to wait patiently for the prey to get closer or for an alternative chance to present itself.
- Attacking: There are two essential stages to this tactic.

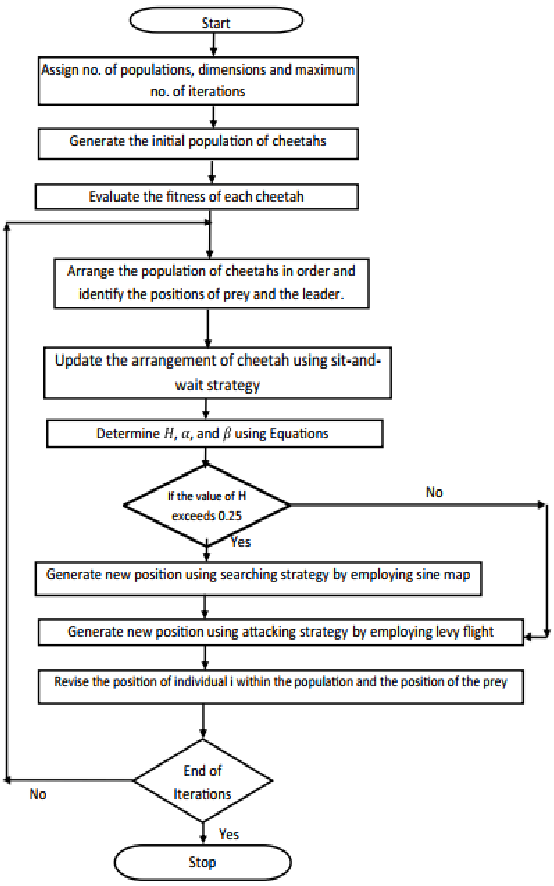

Figure 5. The proposed enhanced cheetah optimizer algorithm's flowchart

3. RESULTS AND DISCUSSION

The relationships between the micro grid's total power demand, the amount of power to be purchased, and the DG's power output are displayed in Figure 6. The users' power consumption is not entirely restricted during these periods. All that is known is that the microgrid operator will purchase a specific amount of power to ensure the lowest possible operational cost.

The impact of Figure 7 shows wet load category's reformed power curve on the winter aggregate power curve. In order to relieve stress on the electrical network, power has been cut during peak hours by approximately 11.9% into 22.7%. Additionally, the length of the morning peak has been shortened. Figure 8 displays the output and load projection for renewable energy for the next day.

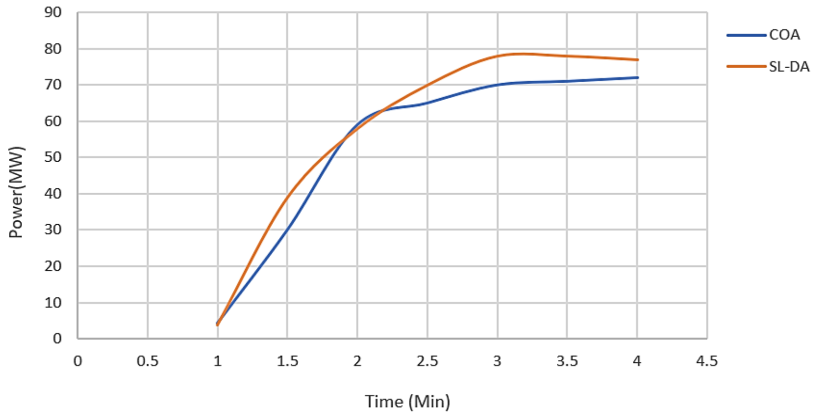

Figure 6. DG output, rigid loads, and maximum power utilization

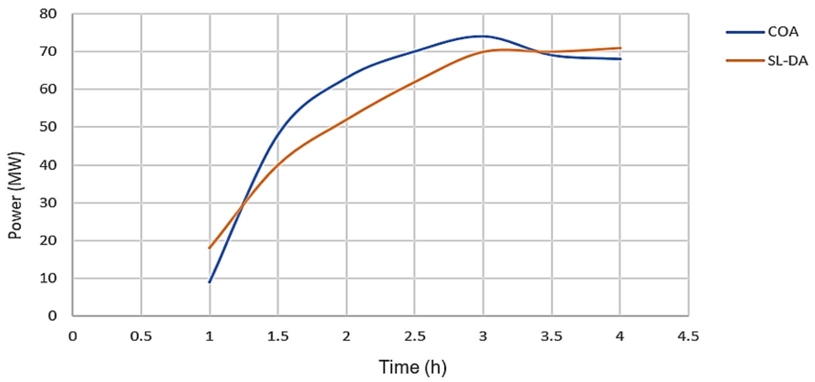

Figure 7. The lowest daily cost, the current electrical demand of the entire residential demand both before and following load shifting

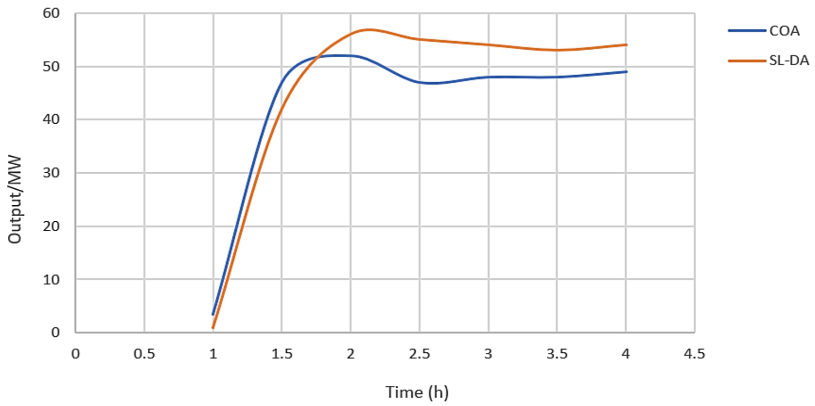

Figure 8. Day-ahead forecasting of the load and output of renewable energy

Figure 9 shows that as robustness increases, the rate at which renewable energy is used gradually declines and the operational costs of the grid show a distinct upward trend. As a result, system robustness increases with the unpredictability of the DR & renewable energy output. In the extreme conditions of energy from renewable sources output and DR output, robust scheduling is required to invoke more DR resources, which increases the system's operating costs but ensures that renewable energy is successfully absorbed into the grid.

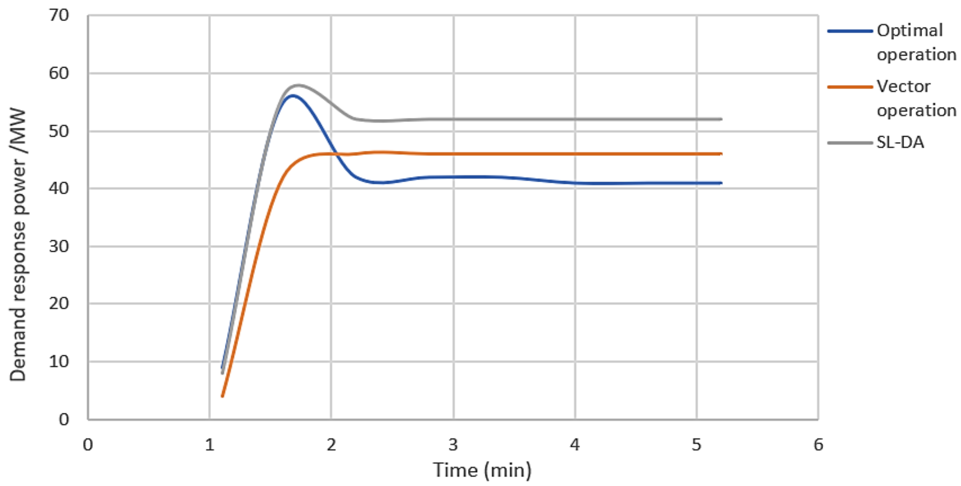

Figure 9. DR power under maximum renewable energy utilization

4. CONCLUSION

DSM initiatives are becoming more popular in India and have shown success in many other nations. There is nothing that will prevent Discos and customers from implementing DSM programs if the value proposition of DSM is clearly understood, despite the fact that the Discos have immediate responsibilities including power purchase, tariff rationalization, and distribution operations. Together with supply augmentation, demand side resources can help to fulfil the goal of making the electricity industry more environmentally friendly and dependable. The real costs of power must be represented across all consumer segments in order to develop value for each unit of power generated for such interventions to be successful. In order to prevent customers from turning to expensive and environmentally harmful alternatives like diesel generator sets or from refusing to pay their electricity bills, Discos should be required to serve loads and improve supply quality and standards at the same time. The moment has come to establish the institutional frameworks and policies that are required, as well as to begin executing extensive projects centred around non-traditional resources like DSM, renewable energy, and energy efficiency. Demand-side resource development will be necessary to optimize infrastructure investments by ensuring clean and efficient growth; if not now, then at a later date and on par with current power generators.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT
Authors state no conflict of interest.

DATA AVAILABILITY
Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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