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Demand Response-Based Energy Management Strategy for University Micro Grid Using Modified Optimization Algorithm

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Abstract: **Scheduling university appliances, energy batteries, and distributed generation like PV in a stochastic setting required the development of an optimization model. The research proposes an optimization approach to the micro-grid of the university campus considering various loads. Research considers that the energy management system can work with renewable energy sources like PV and storage. The merged approach of MILP and PSO has been used to solve the optimization problem, and the results have been presented comprehensively. This research investigation explores the process of creating an EMS for a prosumer microgrid with a centralized energy storage system and distributed generation (DG) installed on-site. The proposed EMS optimizes energy flow between µG and the utility network and schedules energy storage charging and discharging to minimize energy costs. The operational optimization of the energy hub has been modelled using MATLAB software, and the approach could be modified to find the optimal solution for various energy hubs with little modifications.**

Key Words: **PSO, MILP, DSM, Optimization of Hub, Distributed Generation, Energy Hub, Smart Grid**

I. INTRODUCTION

Due to climate change and increased demand for energy in a technologically sophisticated era, fossil fuels are becoming increasingly expensive and limited. Nations increasingly turn to RERs (renewable energy resources) to meet their energy needs [1]. Several issues are plaguing our current electrical infrastructure, such as rising energy costs due to GHG emissions and the depletion of fossil fuels. Utilities, customers/prosumers, and microgrid operators are all affected by these problems to varying degrees. Possible solutions to this problem include increasing the use of renewable energy sources and employing various energy management methods, like demand response and demand-side management [2]. High energy costs are associated with campus microgrids among major energy users in the United States [3]. This paper describes a novel energy management system for microgrids on campus that uses onsite solar photovoltaic & ESS and functions in a grid exchange scenario.

Although traditional grids may not solve these challenges, resource scheduling via demand response programs can overcome them in emerging smart grids with a smart distribution system equipped with energy storage and distributed generators. Having defined electrical borders, centralized loads, on-site DGs, & storage systems all form a microgrid (G). It may function both on the mains and independently. Because sensors have been placed strategically across the emerging grid, they can be easily monitored & and have the potential for self-healing, remote control, & and pervasive control [4].

By combining energy management systems (EMSs), the smart grid provides several prospects for prosumer Gs to conserve energy and integrate renewable energy sources. For intelligent control devices to function within the context of this type of energy management technique, secure communication between utility and prosumer is required [5]. Since the distribution network comprises µGs, each of which acts as the distribution node, energy storage, µGs with the onsite DGs, and DR programs can reduce energy costs and network overloading. The above advantages will be more noticeable for Gs carrying much weight [3].

As a result of their varied energy needs, institutional buildings are considered a heavy load G, or mixed load consumer [3]. Due to their on-site generators, these structures may sell their extra energy to the utility grid and become prosumers. When local DGs and storage are inadequate, they can also import electricity from the grid to fulfill peak demand [6]. The operating energy cost of such Gs is reduced, and the distribution network is supported when they actively participate in grid operations. Grid operators provide different incentive and price-based DR programs to encourage large-scale users to participate in electricity markets. A cost-effective energy management plan that guarantees their efficient involvement in grid operations and satisfies their demand is essential [7]. Projected EMS's photovoltaic energy generation and storage have economic and environmental impacts.

The following are the key contributions of the research:

- The proposed framework provides an optimized solution for campus microgrids by applying the merged approach of PSO and MILP.
    - The research would provide a generic solution to optimize the microgrid using particular constants.
    - The operational optimization of the energy hub has been modelled using MATLAB software, and the results have been optimized using the novel approach of incorporating PSO.

II. Literature Review

Microgrids are decentralized energy systems that can operate independently or in connection with the main grid. Microgrids have received significant attention from researchers due to their potential to increase energy efficiency and reduce carbon emissions [27]. This literature review focuses on microgrid models and optimization techniques.

Microgrids using solar panels, diesel generators, combined heat and power (CHP), and batteries were presented by Waqar et al. [*8*] for many cities in Pakistan. The goal was to maximize yearly waste heat recovery from the thermal units and grid sales while minimizing energy generating costs, net cost, and annual GHG emissions. According to the research, each municipality has its optimal goal function. Ultimately, it is up to the responsible authority to determine which city is most suited to accomplish its goal. According to the research, Lahore had the lowest greenhouse gas emissions at 1000.214 tons/year, while Quetta had the most at 8,322,268 kWh/year.

In another study, Rehman et al. [*9*] developed a microgrid model for residential customers that included PV units, batteries, the national grid, & critical & responsive loads. Using net present and levelized costs, the model attempted to verify the system's feasibility (LCOE). Based on the research, a home with a 2 kW PV system, 1200 Ah of battery storage, and a 1 kW power converter would be optimally set up. The initial investment in the system was $7610; the cost to replace it was $2833; and the cost to operate and maintain it was $6522. Li et al. [*10*] introduced a chance constraint programming-based probabilistic spinning reserve solution for decentralized microgrids [24]. The goal was to offer a trade-off method for the microgrid's cost and dependability to cut costs and computing time. Compared to a hybrid intelligence algorithm, the suggested solution decreased costs by 0.5 percent, from $396.5 to $394.3, and decreased computing time by 673.5 seconds to 2 seconds (HIA) [18].

Perković et al. [*11*] analyzed the energy management of a microgrid and presented a model for optimal scheduling. The model was tested on a real microgrid in Croatia and compared to two other models. The study found that the proposed model had a 4% lower energy cost than the others. Zhang [*12*] presented a microgrid testbed project at Georgia Tech. With 200 structures and 400 net meters in mind, the model was examined on the OpenDSS platform. Building-grid interaction was improved with the addition of demand response mechanisms. The research also looked at the future needs of campus microgrids, including the planning of generation growth [25].

The literature review discusses various research works related to scheduling energy resources & appliances in smart homes, microgrids (μGs), and prosumer-based systems [*13*,*14*]. The works discussed in the review [*15*] proposed different models and algorithms for optimizing cost, load deviation, profit, and efficiency while considering uncertainties, renewable resources, and storage systems such as battery energy storage systems (BESS), compressed air, flywheels, and ultracapacitors [*16*].

Most of the research focused on the optimal scheduling of photovoltaic (PV), ESS, and load. Some works considered the financial feasibility and cost savings of integrating the PV and the ESS in μGs. However, few works have considered economic analysis, including Levelized energy cost, energy exchange with grid, PV uncertainties, and DR simultaneously [*9*]. Microgrid models and optimization techniques have been researched extensively to enhance energy efficiency, reduce carbon emissions, and improve grid reliability [*15*]. Microgrid models and optimization techniques can provide cost-effective and efficient solutions for energy management in microgrids [26].

III. METHODOLOGY

This research aims to create energy management models for end-use loads, DG sources such as photovoltaic panels, and energy storage devices and then schedule them efficiently. As shown in Fig.1, the operator system and the smart house form the backbone of the proposed Energy Management System (EMS). The smart house's main components are the smart meter, scheduling decision device, energy storage device, distributed generating resources, and consumer loads.

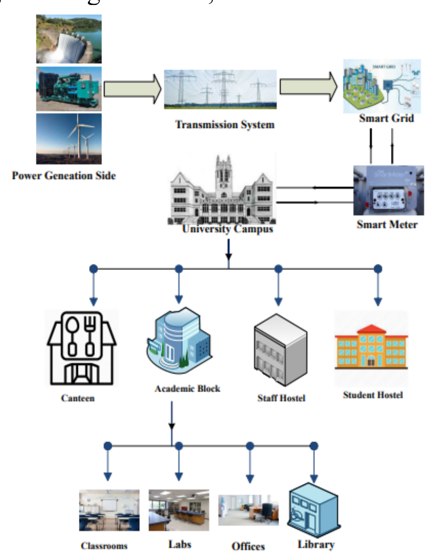


Figure 1. The Analyzed Energy Hub Model

Stochastic models were established first for consumer loads, energy storage, PV, utility, etc. Next, an evolutionary optimization strategy will combine these emerging models and create a more economical consumption policy [28].

Mathematical Model of Energy Management Problem

µG's total operational cost (J) includes energy exchange, diesel generator, and energy storage degradation costs. In equation (1), we see how various expenditures add up.

As shown in equation (4), the battery's lifespan is affected by various factors, including its initial cost, the number of cycles it undergoes, and its overall capacity.

$$\text{Cost} = min \sum_{t=1}^{24} \left(c_{t}^{0} + c_{t}^{dg} + c_{t}^{es}\right) \quad (1)$$

Where,

$$c_{t}^{0} = \left(p_{t}^{g}\right)\lambda_t \quad (2)$$

$$c_{t}^{dg} = \boldsymbol{\alpha} T_G + \beta \boldsymbol{\rho}_t^{dg} \quad (3)$$

$$c_t^{es} = \left(\frac{capital_{cost}}{No.of\ cycles * total\ capacity * 2}\right) * \left(\eta_{ch}\ \rho_t^{ch} + \frac{\rho_t^{dch}}{\eta_{dch}}\right) \quad (4)$$

$$\rho_t^{bat} = \eta_{ch}\ \rho_t^{ch} - \frac{\rho_t^{dch}}{\eta_{dch}} \quad (5)$$

Where ${}_{t}^{0}$, ${}_{t}^{dg}$, $and\ c_{t}^{es}$ are the energy exchange costs, DG cost, & the battery degradation cost at any time t respectively [20]. Power purchased from the grid and sold to consumers are represented by p_{t}^{g} & respectively at any given hour t.

Equation 5 depicts the charging efficiency, discharging efficiency, charging power, and discharging power of the battery storage, as well as the net power of the battery represented by $\eta_{ch}\ \eta_{dch}\ \rho_t^{ch}\ and\ \rho_t^{dch}$ charging & discharging efficiency, charging & discharging power of battery storage is represented by $\eta_{ch}\ \eta_{dch}\ \rho_t^{ch}$ & ρ_t^{dch}respectively & net power of battery $\rho_t^{bat}$is represented in eq. 5.

Load Balance Constraints

The supply-and-demand constraint is analogous to the equality constraint. Equation (6) must be met to strike this equilibrium.

$$p_t^g + p_t^{pv} + p_t^{bat} + p_t^{dg} = p_t^l \quad (6)$$

Where $p_t^{pv}\ and\ p_t^l$ are output power of solar PV in kW & load demand of prosumer respectively.

ESS Constraints

Supporting supply loads in the event of grid failure makes ESS an essential part of the energy management system. Since an ESS cannot be quickly charged or discharged, its power constraints are reflected in restrictions (7)-(11). Equation (12) incorporates the prior state $BS0C_{(t-1)}$ into the calculation of the battery state of charge (BSOC) in ESS at any given time interval t BSOCt. In expression (13), the maximum and lower limits of BSOC are specified by (BSOCmax) and (BSOCmin), respectively, to prevent overcharging and total discharge of ESS [21]. Since the beginning of the day's charge ($BSOC_0$) is considered to be equal to the end of the day's charge ($BSOC_t$) in equation (14), it follows that the battery's charge level at midnight is also equal to its charge level at midnight [19].

$$\frac{BSOC_{(t-1)} - BSOC_{(\max.)}}{100}\ C^{ES} \le p_t^{bat} \quad (7)$$

$$p_t^{bat} \le \frac{BSOC_{(t-1)} - BSOC_{(\max)}}{100}\ C^{ES} \quad (8)$$

$$0 \le \eta_{ch}\ \rho_t^{ch} \le u_t^{ch}\ p_{ch,max}^{bat} \quad (9)$$

$$0 \le \frac{\rho_t^{dch}}{\eta_{dch}} \le u_t^{dch} p_{dch,max}^{bat} \quad (10)$$

$$u_t^{ch} + u_t^{dch} \le 1 \forall t \quad (11)$$

$$= BSOC_{t\text{-}1} - \frac{100 * \eta_{ch}\,\rho_t^{dch}}{C^{ES}} - \frac{100\ \rho_t^{dch}}{C^{ES}\eta_{dch}} \quad (12)$$

$$BSOC_{min} \le BSOC_t \le BSOC_{max} \quad (13)$$

$$BSOC_T = BSOC_0 \quad (14)$$

PSO

The DSM optimization is performed in the research using Particle Swarm Optimization (PSO). The main objective function of PSO is stated in the equation below [22]:

$$F_{un} = \sum_{t=1}^{T} Pr\,(t)\left[q_{ac}(t) + q_{ewh}(t) + q_{ewp}(t)\right]$$

$$+ \sum_{t=1}^{T} Pr\,(t)[q_{ev}(t) + q_{inv}(t)] + P_1(soc_{ev}^{on} - soc_{ev}^{max})$$

$$+ L_1(soc_{ev}^{off} - soc_{ev}^{max}) + P_2(soc_{inv}^{on} - soc_{inv}^{max}) +$$

$$+ L_2(soc_{inv}^{off} - soc_{inv}^{max}) + H_1(T_{wh}^{t_1} - T_{wh}^{t_{96}}) +$$

$$H_1(v_{wh}^{t_1} - v_{wh}^{t_{96}}) \quad (15)$$

The equations of PSO are listed in the equations below [23]

$$v_i(t+1) = w \times v_i(t) + c_1 \times r_1 \times \left[p_{best_i} - x_i(t)\right] +$$

$$c_2 \times r_2 \times [(g_{best} - x_i(t)] \quad (16)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (16)$$

The methodology that has been adopted in the research is the combination of MILP and PSO approaches using MATLAB. The results have been deduced considering the cases and the analysis has been presented in the research. .

IV. RESULTS AND DISCUSSION

The smart campus prosumer microgrid (SCPM) in Punjab is used to test the suggested concept stated in Section III. It comprises six faculties, fourteen departments, and eight dormitories. A comprehensive rooftop PV installation study reveals the campus's 4 MW rooftop capability.

CASE STUDY

This case study schedules µG in winter and summer, Pakistan's two primary seasons. To simplify the study, normal summer and winter load patterns are used. Winter and summer peak loads are in January and August. Two further scenarios are considered in the research analysis and are presented as Scenario A and Scenario B. The detail of these scenarios is presented below:

Scenario A:

The scenario considers the case in which PV, Grid, ESS is considered while DGen is not connected to the system. The results of the scenario are evaluated separately for summer and winter in the research.

Scenario B:

The scenario considers the case in which PV, Grid, ESS, and DGen are connected to the system. The results of the scenario are evaluated separately for summer and winter cases and are stated in the table. Savings achieved in Scenario A compared and Scenario B was 40% and 37% respectively

. The obtained results are explained separately in the graphs and figures that are presented below:

TABLE 1
SUMMER SCENARIO

Summer Case 1	Energy imported from the grid (kWh/day)	Energy Generated (kWh/day)	Net cost of electricity /day ($)	LCOE ($/kWh)	%Saving
Scenario A	5570.4	8889.7	870.6	0.062	40
Scenario B	4561.6	8889.7	935.7	0.069	37

Scenario 2A: In this situation, the suggested approach optimizes ESS charging & discharging patterns, & net energy cost is $870.6 after considering all component prices. Table 2 shows the best BESS scheduling under a TOU-based tariff LCOE of $ 0.062/kWh. Figure 2 shows that ESS intelligently stores energy in off-peak hours and discharges in peak hours to reduce energy costs.
Scenario 2B: This scenario assumes campus µG has an onsite diesel generator (DGen) with PV & the BESS to relax the grid network during peak hours (19:00–23:00 for summer). LCOE obtained is 0.062 $/kWh which is 35% less as compared to the case in which only the grid has been connected.

TABLE 2
WINTER SCENARIO

Winter Case 2	Energy imported from grid (kWh/day)	Energy Generated (kWh/day)	Net cost of electricity/day ($)	LCOE ($/kWh)	%Saving
Scenario 2A	8590.54	8657.8	1108.8	0.071	33
Scenario 2B	8134.77	8657.8	1133.4	0.073	30

Scenario 1A: Table 2 shows winter peak hours as 17:00–21:00. To improve utility energy exchange, energy storage is included. The current scenario has a net electricity cost of $1108.8. To maximize cost savings, the suggested strategy is implemented to schedule ESS charging and discharging efficiently (see Figure). LCOE obtained is 0.071 $/kWh which is 31% less as compared to the case in which only the grid has been connected.
Scenario 1B: In this case, the running expenses amount to $1133.4 per day. For the winter, the recorded processing/execution time is 2.4 seconds. From these conversations and analyses, the ideal solution for the existing system is solar PV, scheduled ESS with a utility grid. The savings achieved in Scenario A compared and Scenario B was 33% and 30% respectively. The graphical representation of results has been demonstrated in Fig. 2,3 and 4.

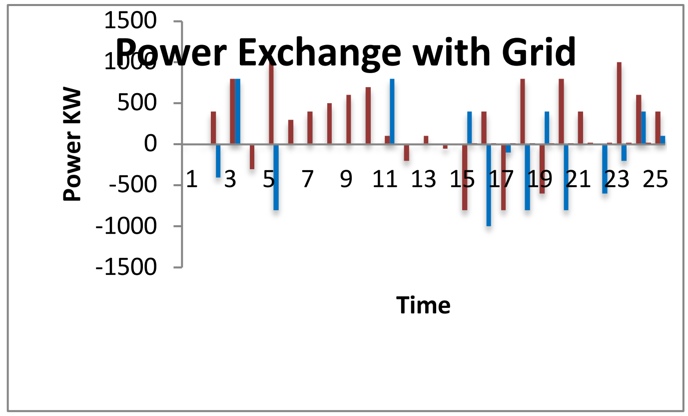
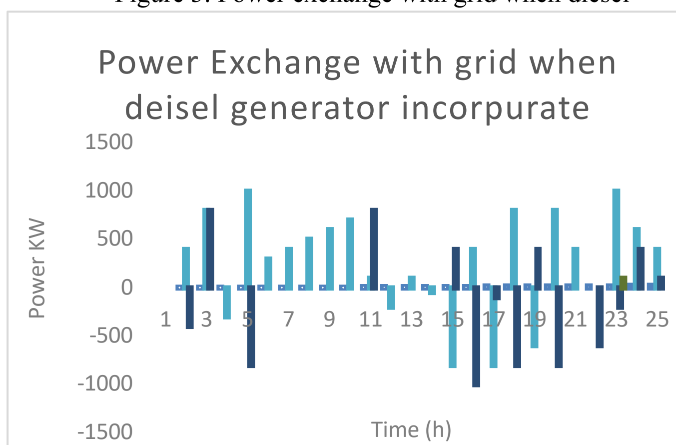


Figure 2. Power Exchange with Grid

Figure 3. Power exchange with grid when diesel



generator incorporate

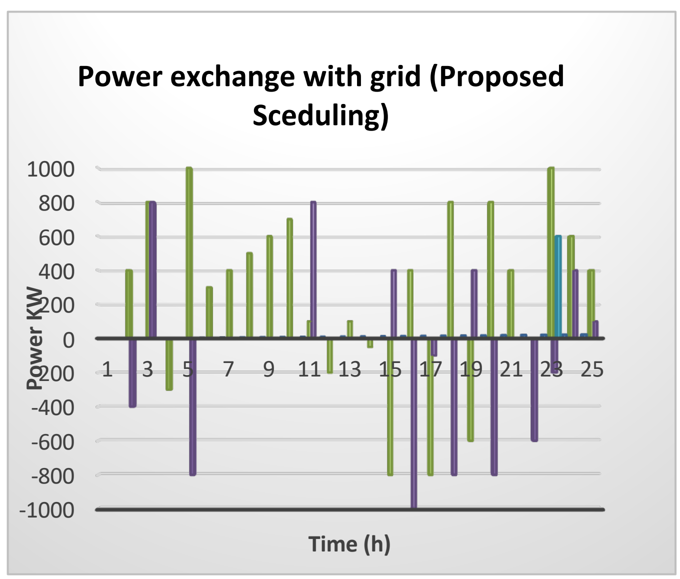


Figure 4. Power exchange with grid (Proposed scheduling)

V. CONCLUSION

In this research, the merged approach of MILP and PSO has been used to solve the optimization problem, and we use actual load data to examine how a university's campus μG may benefit from PV and optimally timed ESS to reduce the operating energy cost for the commercial prosumer. The consequences of using solar PV, a diesel generator, and a battery storage system were analyzed using the suggested model. To evaluate the scheduling issue while considering battery life, we transformed it into a mixed-integer linear optimization problem and ran simulations in MATLAB. As price-based DR (Time-of-adopt), ESS was taken into account, and it was decided to adopt ESS as a flexible DR system that could be intelligently charged and discharged at different times to save costs without reducing the system's lifespan. Prices to run the campus were higher since no DGs or ESSs were installed to supplement the energy needs of the G. Percentage of daily savings of 33% and 40% were seen in winter and summer, respectively, when DGen, PV, & ESS were combined with prosummer. The effectiveness of these improved results is evident by comparison with other methods. It may also be used to solve optimal power flow and optimization problems at a larger scale.

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