Energy Management System in Micro Grid and Smart Grid

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Abstract - The increasing need for energy due to the growing global population has resulted in a greater dependence on coal. There are issues with economy, efficiency, and the environment as a result of this spike in electricity use. In the context of the energy market paradigm, this study presents an efficient energy management system called Smart Micro grids (SMG) that attempts to address these problems by providing practical solutions and encouraging environmental sustainability. Control agents (CAs), energy management controllers (EMMCs), and home energy controllers (HEMCs) are used to accomplish these goals. Distributed Generators (DGs), user comfort, local generation, storage systems, and links to service providers are just a few of the elements that load system management must consider. This study's energy management solutions center on delivery and transportation management at the local and commercial rates.

I. INTRODUCTION

In shaping the social and economic fabric of a nation, energy plays a crucial role by directly impacting the economy and contributing to the improvement of the living standards of the population. As the global population continues to grow, the demand for energy naturally increases, underscoring the urgency to address energy needs. Simultaneously, the escalating emissions of greenhouse gases pose adverse effects on the environment. Confronted with these energy challenges, especially in developing countries, the adoption of Smart Energy Management (SEM) emerges as a valuable strategy to address both technical and economic issues. SEM revolves around the integration of local generation sources like Photovoltaic (PV), Wind, and Fuel Cell, fostering efficient energy trading between providers and consumers. Additionally, the integration of optimal storage systems proves pivotal in mitigating techno-economic challenges within Smart Micro-Grids (SMG).These problems can be solved by using different optimization techniques like grey wolf optimization, particle swarm optimization, ant bee colony technique, etc. Also the concept of demand response can be adopted for proper load scheduling and the prosumers should be encouraged to use their local generation which is renewable energy resources.

II. LITERATURE REVIEW

In 2020, V. V. S. N. Murty et al. [1] formulated micro grid energy management (MGEM) using mixed-integer linear programming. They introduced a novel multi-objective solution for MGEM, incorporating a demand response program. The optimization problem included demand response to showcase its impact on optimal energy dispatch and techno-commercial benefits. A fuzzy interface was developed for the optimal scheduling of Energy Storage Systems (ESS). Simulation results were obtained for various parameters, including converters, Battery Energy Storage (BES), power exchange with the grid, annual net present cost, initial cost, operational cost, fuel cost, and penalties for greenhouse gas emissions. The findings revealed a 51.60% reduction in CO2 emissions in the standalone hybrid micro grid system compared to the traditional system with the grid alone. The proposed method's simulation results were compared with various evolutionary algorithms to validate its effectiveness.

In 2020, David Romero-Quete and collaborators presented a mathematical formulation for an Energy Management System (EMS) designed for isolated micro grids. This system effectively addresses uncertainty by employing the affine arithmetic method. The proposed EMS algorithm is rooted in an Affine Arithmetic (AA) unit commitment problem for day-ahead dispatch. It utilizes uncertainty intervals for both load and renewable energy, generating robust commitment and dispatch solutions in AA form. These solutions remain feasible for all potential realizations within predetermined uncertainty bounds. Simulation results demonstrated that the proposed EMS offers robust and cost-effective solutions without the need for frequent recalculations, as required in Model Predictive Control (MPC)-based approaches, or reliance on assumptions regarding statistical characteristics of uncertainties, as seen in stochastic optimization approaches.

In 2018, Sheraz Aslam and colleagues introduced a system wherein a smart home autonomously determines whether to purchase or sell electricity to the commercial grid, aiming to minimize electricity costs while maximizing earnings through Power Availability and Reduction (PAR). This decision-making process is informed by factors such as electricity prices, demand, and the generation output from the home's micro grid, which comprises a wind turbine and solar panel. Given the intermittent nature of electricity generation from these renewable sources, the scheme incorporates an Energy Storage System (ESS) to ensure stable and reliable power system operation. Simulation results validated the effectiveness of the proposed scheme in terms of reducing electricity costs and PAR while maximizing profits. Additionally, a comparative analysis was conducted to underscore the legitimacy and productivity of the proposed Comparative Study Analysis (CSA) and Sensitivity Analysis (SA).

Dhanapala Prudhviraj and colleagues created a stochastic paradigm for micro grid energy management in 2020 with the intention of lowering grid-related energy costs. To increase computational feasibility, the created scenarios were simplified using Monte Carlo simulations, which were used to model uncertainty. Micro grid scheduling previously employed substation (source node) prices as a standard; however, these costs varied between nodes. This paper so proposes nodal price-based energy management for micro grids to increase scheduling accuracy. The study included four case scenarios that replicated a modified 15-node radial distribution network connected to solar PV and a battery energy storage system (BESS) in order to evaluate the efficacy of the micro grid energy management framework utilizing nodal pricing.

In 2019, MD Shahin Alam and collaborators conducted a comprehensive literature review focusing on recent advancements in energy management systems. The review systematically categorizes research based on factors such as energy management goals, the methodologies employed for energy management, and the algorithms utilized for solutions. Additionally, the paper critically examines highly effective techniques and methodologies developed or adopted to tackle energy management challenges, presenting a comparative table of these approaches. The document also elucidates the existing challenges and limitations within energy management systems, concluding with insights into potential future research directions.

In 2018, Guangzhong Dong and colleagues introduced a data-driven energy management approach utilizing the Bayesian Optimization Algorithm (BOA) for a singular grid-connected home micro grid. This innovative solution addressed the optimization problem without a predefined objective function expression, employing a BOA-based data-driven framework for resolution. Characterized as a black-box function sequential global optimization strategy, the proposed solution eliminates the need for derivative operations on the objective function. Moreover, it adeptly handles uncertainties related to microgrid operation and parameter prediction. Simulation results compellingly validated the efficacy of this proposed approach.

To mitigate consumer discomfort and enhance energy cost savings, Hafiz Majid Hussain et al. (2018) proposed an effective home energy management controller (EHEMC) employing the genetic harmony search algorithm (GHSA). This study considers EHEMC incorporating critical peak pricing (CPP) and real-time electricity pricing (RTEP) for both individual residences and multiple residences. Various heuristic algorithms, including wind-driven optimization, harmony search algorithm (HSA), genetic algorithm (GA), and the proposed GHSA method, are employed to address the constrained optimization problem. The GHSA algorithm, when compared to other algorithms, exhibits superior search efficiency and dynamic potential in discovering optimal solutions. Simulation results further demonstrate that the suggested GHSA algorithm outperforms existing algorithms in minimizing human discomfort, reducing electricity costs, and addressing peak to average ratio (PAR).

In 2020, Muhammad Haseeb and colleagues [8] introduced an effective energy management strategy to address challenges within a smart micro grid (SMG). The objective is to provide a solution that is both cost-effective and environmentally friendly within the energy market paradigm. The achievement of these goals is facilitated through the utilization of the Home Energy Management Controller (HEMC), Energy Market Management Controller (EMMC), and Control Agent (CA). The management of individual loads is orchestrated considering local generation, storage systems, user comfort, distributed generators (DGs), and utility interactions within the energy market paradigm. The proposed two-level energy management approach proves instrumental in accomplishing the specified objectives, as evidenced by simulation results in this study.

In 2018, Mingfu Li and collaborators [9] introduced an algorithm aimed at reducing peak load and electricity bills. This algorithm achieves its goal by postponing the starting times of delay-tolerant appliances from peak to off-peak hours, regulating the temperature settings of heating, ventilation, and air conditioning (HVAC), and strategically planning the discharging and charging periods of an electric vehicle (EV). The paper evaluates user comfort through Quality of Experience (QoE) functions. To uphold the user's QoE, constraints are applied to the delay of the starting time of a home appliance and the temperature setting of HVAC using a QoE threshold. Furthermore, in comparison to the optimal scheduling method for appliances found in existing literature, the proposed scheme demonstrates significantly superior performance in peak load reduction and user QoE`s.

Kobylinski and colleagues [10] presented a comprehensive depiction of an artificial neural network (ANN)-based model created for forecasting short-term high-resolution (15-minute intervals) micro-scale residential net load profiles. The study involved a real micro-neighborhood consisting of 75 single-family houses. The achieved average prediction error corresponded to 5.4% of the maximal measured net load. The paper addresses several issues such as the feasibility of micro-scale residential load forecasting considering renewable energy penetration, the ability to predict net load with a dense temporal resolution of 15 minutes, the challenge of feature selection, and the proposed presumption and comparison-oriented prediction model key performance measure. These aspects are likely to be of interest to engineers involved in designing energy balancing systems for local smart grids.

In 2018, Shengnan Zhao and collaborators [11] introduced an integrated energy transaction mechanism based on block chain technology. This innovative approach segregates the trading process into two distinct stages: the call auction stage and the continuous auction stage. To illustrate the intricacies of the trading process, the authors employed transactions involving electricity and heat market participants as examples. Subsequently, smart contracts for these transactions were devised and implemented on the E there um private block chain platform to showcase the effectiveness of the proposed transaction scheme.

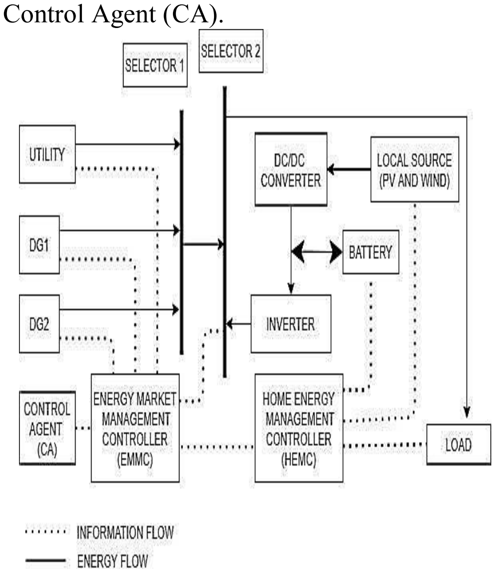
In 2020, Vivek Nikam et al. [18] provided a concise overview of cutting-edge operation and control strategies for managing distributed energy resources, energy storage systems, and electric vehicles within a micro grid. The control of a micro grid with a significant number of distributed energy resources, small energy storage units, and electric vehicles demands adaptable and scalable control approaches. The paper aimed to review the latest centralized, decentralized, and competitive control strategies for effectively governing and coordinating distributed energy resources, energy storage systems, and electric vehicles in a micro grid. It also delved into internet of things-based control strategies within micro grids. Ultimately, the paper introduced a conceptual framework featuring intelligent agents.

MATERIALS AND METHODS

The escalating energy demand within traditional grids is becoming increasingly intricate, less viable, detrimental, and characterized by high power losses. Simultaneously, the rising population is leading to a surge in electricity demand, intensifying the need for coal, which becomes economically impractical. For this, demand response based on optimal planning can be followed and optimization technique will help us for proper load scheduling and optimal planning.

BLOCK DIAGRAM OF PROPOSED SYSTEM

The block diagram illustrating the proposed system is presented in Figure 3.1. Within this diagram, the dotted line signifies the flow of information, while the straight line signifies the flow of energy. The attainment of goals is facilitated by three controllers: Home Energy Management Controller (HEMC), Energy Market Management Controller (EMMC), and Control Agent (CA).



Block diagram of proposed system

EMMC collects all the necessary data from energy providers, sending a request signal to all available energy providers to obtain information on their energy capacities, limits, prices, and gas emission rates. Subsequently, the individual controller of each energy provider sends back a data signal to EMMC, containing all requested information. Once EMMC has gathered all the required details from energy providers, it shares Time-of-Use (ToU) pricing information with each HEMC, enabling them to manage their load and schedule their storage. These priorities are pre-defined for each home based on their economic condition and personal preferences. Now EMMC will send the information to selector 2 to make a choice where the energy should be traded either from energy providers i.e., selector 1 or from the local generation. If the energy is traded from energy providers, the selector 2 will get energy from selector 1 and send the energy to load. If it is from local generation, then selector 2 will get the energy from local generation and share it to the load.

SYSTEM MODEL

The microgrid (MG) within the smart grid paradigm establishes clear electrical and communication boundaries to facilitate the sharing of power and communication signals. The proposed framework has been implemented on a singular MG. In this envisioned structure, each load possesses its independent local generation. The energy market incorporates various sources such as distributed generations (DGs) and the utility. Initially, the Energy Market Management Controller (EMMC) gathers power and price data from DGs, including the utility, and disseminates this information to the Home Energy Management Controller (HEMC). The purpose is to schedule the load and storage system efficiently. Subsequently, HEMC reciprocates by sharing the energy difference with EMMC for energy trading.

MODELING OF RER (RENEWABLE ENERGY RESOURCES)

Renewable Energy Resources (RER), including photovoltaic (PV) and wind turbines (WT), are explored for local generation, providing a cost-effective solution for end users. Equation (1) represents the output power of the PV system:

$$P_{pv} = (R_p / 1000) \times P_{pv,rated} \times \eta_{MPPT} \quad (1)$$

In this equation, Rp signifies perpendicular radiations at the PV array surface, measured in (W/m^2), and η denotes the efficiency of the PV system's DC/DC converter at maximum power point tracking (MPPT). Equation (2) is employed to ascertain the mechanical and electrical powers of the wind turbine.

$$P_w = \begin{cases} 0, & if\ v < v_{cut_{in}} \\ P_n(v), & if\ v_{cut_{in}} < v < v_{ref} \\ 1, & if\ v_{ref} < v < v_{co} \\ 0, & if\ v > v_{co} \end{cases}$$

(2)

The wind turbine relies on the force of blowing wind as its primary source, and its mechanical power is contingent on the wind speed and direction, as specified in equation (2).

Table 3.1 Ratings of renewable energy resources

Renewable energy resources	Ratings	Renewable energy resources
Solar power	10kW	Solar power
Wind power	10kW	Wind power

ENERGY PROVIDERS

The energy providers utilized in this proposed work include a thermal power plant, a solar power plant, and a wind power plant. The thermal power plant supplies power to the load when solar power is insufficient. Additionally, in cases where wind power cannot meet the demand, either thermal power or solar power will fulfill it. These energy providers are considered utility providers to meet the demand. The energy providers and their respective ratings are detailed in Table 3.2.

Table 3.2 Ratings of energy providers

Energy providers	Ratings
Thermal power	1MW
DG1	30kW
DG2	30kW

MODELLING OF LOAD

The implemented system applies to a community comprising three areas, each featuring distinct types of loads with varying ratings. Each area is configured to accommodate a total demand with a rating of 10 kW.

MODELING OF BATTERY ENERGY STORAGE SYSTEM

The weather outside determines how much power photovoltaic cells and wind turbines can produce, and its unpredictable nature throws off forecasts for local generation. An additional resource in the form of an ancillary service is needed to handle these variations. One source of regulatory reserves is the Battery Energy Storage System (BESS). By regulating active power to regulate frequency and reduce deviations brought on by abrupt changes in Renewable Energy Generation (REG), it can operate as a sort of supplementary service. Battery configuration, backup time, depth of discharge (DoD), and life are all directly impacted by the storage system rating.

Storage is essential to the planned project since it lowers costs and makes managing electricity for emergency use easier. Equation (3) uses emergency consumption (Ee) to show how the battery responds to an abrupt and unforeseen load. Equation (4) shows how the battery charges when a scheduled load (Eε) is abruptly disconnected.

$$P_{batt_{ch}}(t) = P_{ch}(t) \quad if \begin{cases} P_{loca_{gen}}(t) > P_{load}(t) \\ C_{source}(t) = min\,(C_{source}) \\ E_e = 0 \end{cases}$$

$$P_{batt_{dis}}(t) = P_{disch}(t) \quad if \begin{cases} P_{loca_{gen}}(t) < P_{load}(t) \\ C_{source}(t) = min\,(C_{source}) \\ E_{\varepsilon} = 0 \end{cases}$$

Subject to

$$SOC_{min} < SOC(t) < SOC_{max}$$

P battch and P battdis here stand for the battery's charging and draining, respectively. P locagen expresses the entire local generation of each home, and P load the load of each home. Equation (5) illustrates the battery's observable state of charge (SOC).

CONTROLLER FOR MANAGING HOME ENERGY

The literature indicates that the primary concerns for a Smart Micro grid (SMG) include the peak-to-average ratio (PAR), user comfort, and optimal energy consumption. Different authors have proposed various efforts to address these issues. Real-time critical peak pricing aids in maximizing user comfort, reducing PAR, and lowering energy expenses for the load. The Home Energy Management Controller (HEMC) aims to optimize shiftable time-controllable loads and schedule storage system charging and discharging while minimizing costs. Equation (6) outlines the cost objective function.

$$Cost = Minimize\left(\sum_{t=1}^{24}((\sigma(t) + \varsigma(t)) \times EP_s(t))\right)$$

Where,

$$\sigma(t) = \sum_{x'=1}^{N'_a} \sum_{y=1}^{N_{t'}} E'_{x'y'}(t)$$

$$\varsigma(t) = \sum_{x=1}^{N_a} \sum_{y=1}^{N_t} E_{xy}(t) \times S_{xy}(t)$$

CONTROLLER FOR ENERGY MARKET MANAGEMENT

The traditional grid facilitates only unidirectional power flow from generation to the consumer, lacking feedback options. In contrast, a Smart Micro Grid (SMG) enables two-way power flow and communication, allowing for load and generation adjustments.

MULTI OBJECTIVE GREY WOLF OPTIMIZATION

Multi-Objective Grey Wolf Optimization (MOGWO) is a powerful meta heuristic optimization technique. This optimization surpasses others due to its high accuracy in solutions, minimal computational efforts, and prevention of premature convergence. Inspired by grey wolves, this technique mimics their pack behavior.

The optimal location in the suggested optimization technique is thought to be alpha (α) wolf, followed by beta (β) as the second best option and delta (δ) as the third best position. Figure 3.3 displays the suggested system's flow chart.

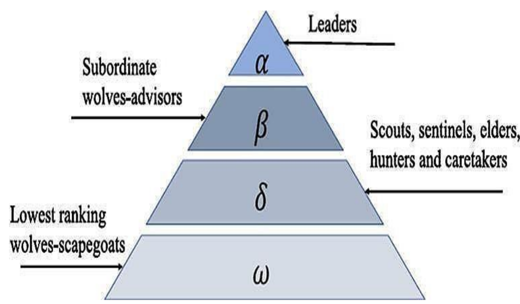


Figure 3.2 Hierarchy of grey wolves

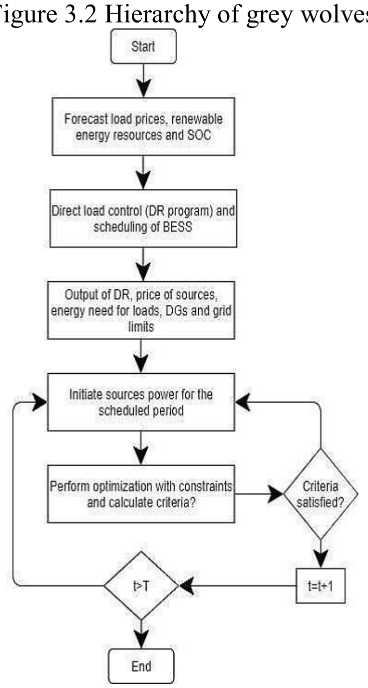


Figure 3.3 Outlining the Proposed System Flow Chart

SOFTWARE IMPLEMENTATION

These days, simulation is an extremely effective tool for both academic and industry applications. One of the best ways to examine the behavior of a system or circuit without causing damage is through simulation. It should be mentioned that in the power system, a lab-based proof of hardware prototype and computer simulation work in tandem. This chapter primarily uses the MATLAB program to simulate the energy management system in micro grids and smart grids.

SIMULATON DIAGRAM

The diagram illustrating the proposed work is presented in Figure 4.1. In this study, renewable energy resources, specifically solar and wind power, are employed. Initially, the controller segment involves two controllers: the Energy Market Management Controller (EMMC) and the Control Agent (CA).

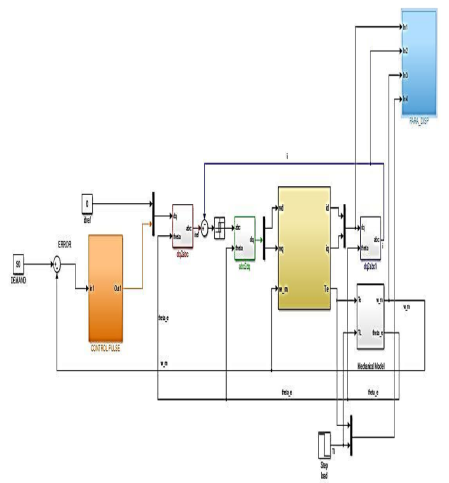


Figure 4.1 Simulation diagram of proposed work

EMMC will get all the information from energy providers about the energy capacities, cost of trading and gas emission rate. And also the load details like demand rate, energy capacity of local generation are received from Home Energy Management Controller (HEMC). After receiving all the information the CA, it will decide from which energy provider (either from local generation or from energy providers) the energy should be transferred to meet the demand.

For this information sharing between the controllers, the optimization algorithm called Multi Objective Grey Wolf Optimization (MOGWO) algorithm is coded within the controllers. So that it will get all the details about source of energy and load and then the energy flow will get started. This procedure will repeat until the demand is met.

SIMULATION RESULTS

The simulation output of reduction of cost in trading energy, reduction of pollution and energy support of load from energy providers and renewable energy resources are shown and discussed below. Figure 5.1 shows the percentage of energy shared by the grid. In this diagram, the green color represents the sharing of energy by renewable energy resources, and the red color represents the sharing of energy by the thermal power plant.

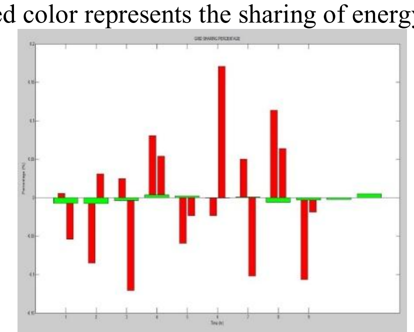


Figure 5.1 Percentage of energy shared by the grid

The reduction of pollution of area1, area2 and area3 are shown in Figure 5.2, 5.3 and 5.4 respectively. In all these three graphs, green bar represents the pollution caused in micro grid with energy management system and red bar represents the pollution caused in grid without energy management system.

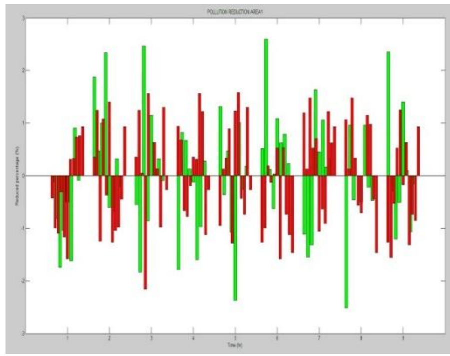


Figure 5.2 Percentage of pollution reduction in area 1

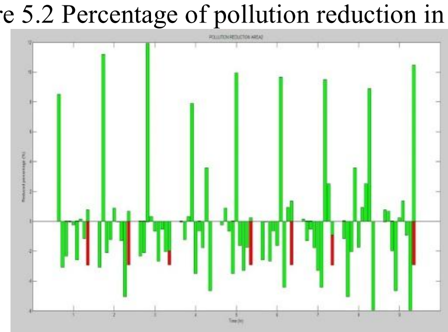


Figure 5.3 Percentage of pollution reduction in area 2

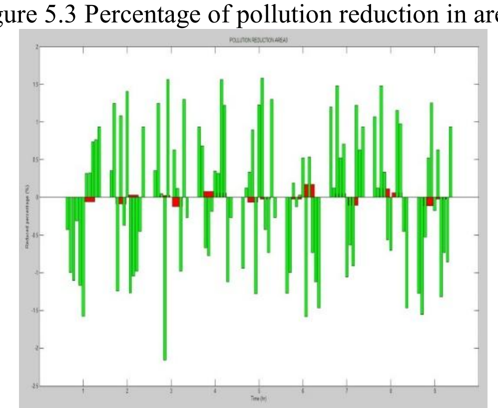


Figure 5.4 Percentage of pollution reduction in area 3

The overall percentage of pollution reduction i.e., average percentage of pollution reduction in all areas in shown in Figure 5.5. Here green bar represents the pollution caused in micro grid with energy management system and red bar represents the pollution caused in grid without energy management system.

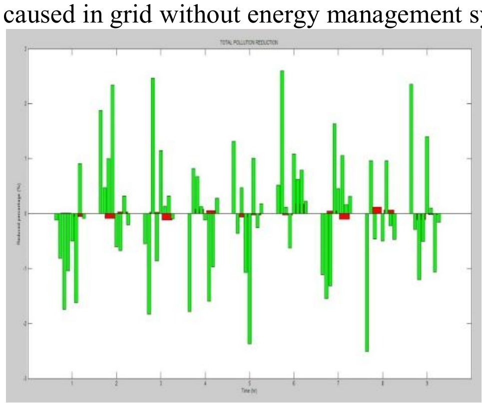


Figure 5.5 Overall percentage of pollution reduction

Percentage of pollution reduction in each area and overall percentage of pollution reduction is shown in Figure 5.6

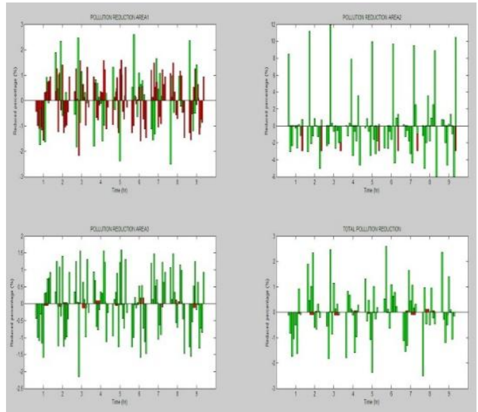


Figure 5.6 Pollution reduction percentage in each area and overall percentage

Power supplied by energy providers to area1, area2 and area3 are shown in Figure 5.7, 5.8 and 5.9 respectively. In this graph, green bar represents the power delivered by the renewable energy resources and red bar represents the power delivered by the thermal power plant.

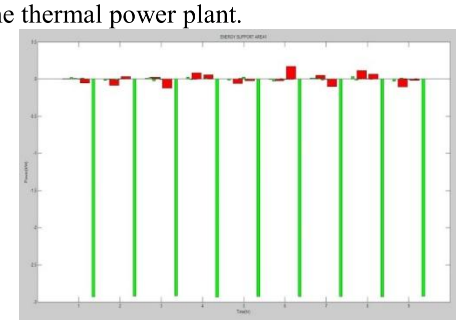


Figure 5.7 Power delivered in area 1

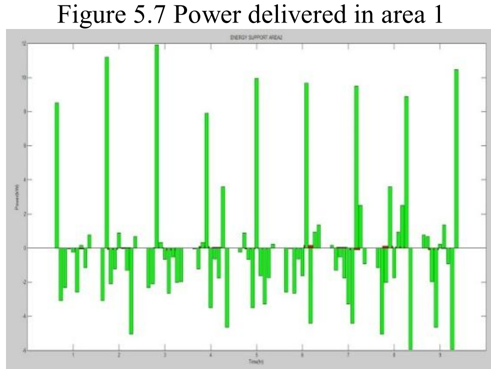


Figure 5.8 Power delivered in area 2

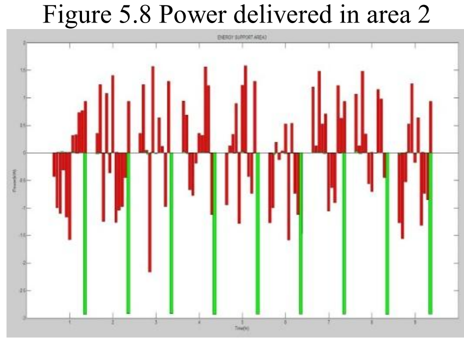


Figure 5.9 Power delivered in area 3

The power distribution across all regions, illustrated in Figure 5.10, demonstrates that the power supplied to the load from renewable energy sources surpasses that delivered by thermal generation. This accomplishment is facilitated through the utilization of an optimization algorithm.

III. CONCLUSION

Renewable energy is becoming a significant contributor to electrical power generation, especially in wind and solar energy. It is poised to play a noteworthy role in the grid's power supply. Efficiently managing challenges such as cost, user comfort, local generation penetration, and energy market pricing requires a sophisticated energy management system for micro grids. A two-stage process has been developed to address multi-objective issues. Two distinct controllers have been introduced to oversee each stage. The Home Energy Management Controller (HEMC) operates at the community level, while the Energy Market Management Controller (EMMC) functions at the energy market level, regulating energy transactions among areas, distributed generators (DGs), and the utility. Each zone within the intelligent micro grid community is equipped with an HEMC, tasked with managing forecasted loads while minimizing expenses and maximizing the utility of local resources. At the community level, the second controller collects data from HEMCs, DGs, and the utility regarding local generation, loads, and prices. A meta-heuristic method, namely multi-objective grey wolf optimization (MOGWO), is suggested to optimize the multi-objective function. Pollution levels can be lowered by up to 39–55% by putting these controllers and optimization strategies into practice.

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