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A multi-objective scheduling of renewable energy sources in a smart grid system

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***Abstract* –** The demand for electricity is increasing as our global population grows. The shift towards renewable energy sources (RESs) is unavoidable.

RESs have cost benefits and are also eco-friendly. However, effectively regulating the energy cost presents a notable challenge when incorporating RESs into microgrids (MG). To tackle this issue, this work presents a novel approach utilizing a cost-effective multi-objective particle swarm optimization (MOPSO) to optimize electricity distribution among different generation units within the MG system. The proposed MOPSO algorithm will optimally allocate the power produced from various sources in the MG, aiming to minimize operational costs, carbon emissions, and LOLE (Loss of Load Expectation). MOPSO utilizes the heuristic technique to produce a wide range of non-dominated solutions. The simulation results depict the efficiency of our proposed model in reducing the cost, emissions, and LOLE in MG under two distinct scenarios.

Keywords – RESs, MG, PV, WT, MOPSO

I. INTRODUCTION

Using fossil fuels for electricity production has significantly increased global warming. The alarming increase in carbon dioxide production and resource depletion are critical. A new approach must be adopted for the production of electricity. This includes using RESs, as conventional energy systems have high emission rates. Thus, a shift towards clean energy is inevitable. These include wind, solar, biogas, etc. [1]. They are readily available in nature. Combining these resources makes a microgrid (MG) system. The concept that makes the MG intelligent and innovative is a two-level data communication between the source and sink. This data is collected from users' load profiles aggregated and sent back to the control center for decision-making [2]. The data communication involves an advanced infrastructure called AMI, which transfers data through GSM technology. This data is beneficial in making decisions for the utility to balance its supply and energy demand. The end user is offered price incentives to shift the load from high-demand hours, where the price is high, to low-demand hours, where the price is low [3].This allows consumers to shift their loads and rely on RESs for cost optimization and emission reduction.

In the literature study various relevant work has been discussed.In the past decade, researchers have made significant progress in improving the reliability and cost-effectiveness of smart grid (SG). The demand for reliable energy is important, and MG allows RESs to integrate. Using RESs helps supply eco-friendly energy, reduces operational costs, and minimizes CO2 emissions. MILP technique is adapted by the author in [4] to optimize cost, emissions, and LOLE, and load factor. Still, it needs to consider using a power-optimizing technique that optimally schedules sources, such as GA and MOPSO techniques. Two scenarios of using MOPSO have been identified: reducing cost and increasing availability, but pollution emission has not been considered. Researchers in [5] used three cases to minimize emissions and reduce costs by applying the MOPSO technique to the problem. However, LOLE should have been considered a crucial describing entity in energy management and scheduling. In [6], the author developed an SG energy system that enables a bi-level data line between the supplier and consumer sides with demand response. However, the cost is not minimized. In their study [7], the authors introduced the NSGA III algorithm to optimize an energy management system to minimize costs, emissions, and PAR (Peak-to-Average Ratio). Nevertheless, the technique failed to enhance the load factor. Another algorithm, the Advanced Gray Wolf Optimization (AGWO), was proposed in a separate study. This algorithm was handled as a MILP model with given constraints to minimize cost and reduce pollution emissions. The convergence and optimality of this algorithm proved to be the best for solving the energy management problem [8]. Authors in [9] used demand response on a price-based mechanism to reduce peaks in demand cost and emissions for the microgrid. Different meta-heuristic optimization algorithms were used to control energy exchange between shiftable load and generation systems. To maximize the competence of distribution networks, the DSOs used strategies of DSM in the optimal patterning problem of the sources. In [10], the Lyapunov optimization method is studied with joint scheduling of BESs (battery electrical storage systems) having loads on the residential side utilizing the optimal load shifts. The vigorous optimization with the help of the DA distributed algorithm is utilized to overcome the total amount of the MG with high diffusion of renewable energy sources and the optimal usage of (demand side management) DSM. [11]. In [12], the Manto Carlo simulation (MCS) through robust scheduling is utilized to raise the high penetration of RESs in a BESs system.

The contribution of this work is to optimize grid energy and schedule the sources for effective and reliable grid operation with cost benefits and environmental sustainability. An enhanced optimization technique, MOPSO, is used to find the optimal trade between contrasting objectives like cost, emission, and LOLE in the presence of BESs and RESs. The effectiveness of the model shows that MOPSO is the best suited for optimizing stochastic energy problems.

II. PROBLEM FORMULATION

This part presents various objective functions, such as cost, pollutant emission, and LOLE (Loss of Load Expectation), which will be further detailed in the following section.

A. *First function to be optimized(cost):*

The initial objective of our study is to analyze the Operating cost function, which is employed to minimize the expenses associated with the operations of the smart grid, as represented by equation (1).

$$minF1 = cost_{Dg} + cost_{Bess} + cost_{Ug} \qquad (1)$$

The above equation models the operational costs associated with diesel generator illustrated as $cost_{Dg}$, Where as $cost_{Bess}$, and $cost_{Ug}$ represents the cost of battery storage system and cost of utility grid respectively as depicted above.

B. *Second function to be optimized(Emissions):*

The second objective of this paper is to reduce the emission of harmful gases in terms of the function of pollution emission. The function for the proposed model is given by equation (2).

$$minF2 = Emiiss_{Dg} + Emiiss_{Ug} \qquad (2)$$

The second function to be minimized is carbon footprints, which is elaborated in the equation mentioned above in (2), where the emission caused by a diesel generator and emission caused by a utility grid is represented as $Emiiss_{Dg}$ and $Emiiss_{Ug}$ respectively as shown.

C. *Third function to be optimized(LOLE):*

LOLE, or Loss of Load Expectation, refers to the load lost during a smart grid's operation. Our goal is to minimize the Loss of Load Expectation (LOLE) to decrease the number of hours of load-shedding, as stated in equation (3).

$$minF3 = Pow_{Sch} \times Time_{out} \qquad (3)$$

In the above equation, $Time_{out}$ represents the duration during which the power generated by the smart grid does not match the power demanded. At the same time, the scheduled power Pow_{Sch} is determined by summing the power generated and exchanged from various sources, including DGs, PVs, WTs, EESSs, and the utility grid.

D. *Constraints:*

It is necessary to establish and adhere to specific boundaries to verify the functionality of the proposed smart grid architecture. The constraints may consist of both equality and inequality constraints, which vary based on the characteristics of the source and objective function. The following limitations of our model are discussed below:

1. Balance of power:

Based on this restriction, the power produced by the sources must equal the power required by the consumer's loads.

2. Power generation constraint:

The term refers to the quantity of energy generated by a specific source, which must remain within a specified threshold and neither surpass nor fall below it.

3. BESSs constraint:

A storage system typically saves the energy generated from RESs when the source cannot produce electricity. We utilized batteries to carry out the specified activity, monitoring the state of charge (SoC) within the designated timeframe. The SoC indicates the level of charging or discharging at every hour. To maintain batteries in optimal working condition, it is important to monitor the SoC within the specified upper and lower limits during the processes of charging and discharging. Furthermore, it is important to note that batteries cannot be charged and drained concurrently.

4. DGs constraint:

These constraints include the modeling of diesel generators with technical aspects. Minimum start-up time, downtime, and ramp up and down are modeled in this.

III. METHODOLOGY

Particle swarm optimization is chosen for multi-objective optimization problems because it has a better convergence ratio and offers greater accuracy than other optimization techniques. Multi-objective problems involve the optimization of multiple objective functions and constraints simultaneously. MOPSO can optimize these functions.

A. *MOPSO:*

MOPSO, a multi-objective problem optimizer, seeks to optimize many competing objectives with constraints simultaneously. The MOPSO algorithm will produce two solutions for any multi-objective problem: either one solution will dominate the other, or no solution will be dominated. The solutions are saved in the repository and are continuously compared until the stopping requirement is satisfied. The subsequent procedures demonstrate the functionality of the MOPSO algorithm:
Step 1: Initiate the algorithm by inputting objective functions, sources, and customer details.
Step 2: Create the initial set of individuals in the population.
Step 3: The fitness function is determined using a power dispatch algorithm for the created populations.
Step 4: Determining the solutions that are not dominated by other solutions.
Step 5: Adding the obtained solution to the memory.
Step 6: Choosing the leader as the most suitable particle from the population.
Step 7: Modify the velocity and position of each particle according to the updated particle's position and velocity.
Step 8: Replicate the particle's changed position by comparing it with its previous position.
Step 9: Storing the improved non-dominated solution into the memory.
Step 10: Eliminating members that are dominating.
Step 11: Excess members from the repository are removed.
Step 12: Validating the termination criteria.

IV. DISCUSSION AND ANALYSIS

This section provides an analysis of the proposed model and a discussion of the outcomes. The suggested model comprises distributed generators (DGs), photovoltaic systems (PVs), wind turbines (WTs), and BESs to fulfill the energy demand of three distinct types of end users: domestic, commercial, and industrial.

A. *Experimental setup:*

The proposed system was implemented using MATLAB 2020a on a computer equipped with an Intel (R) Core (TM) i5 processor with 8 GB RAM. Our strategy was examined on two different test systems, and the subsequent outcomes were reviewed to confirm the usefulness of our technique.

B. *Describing and analyzing results:*

The primary goals of cost and CO2 emissions are key trade-off solutions in the initial scenario. The optimization technique known as Multi-Objective Particle Swarm Optimization (MOPSO) is utilized to identify the optimal solution that achieves the most favorable balance between minimizing costs and reducing emissions. The optimal values of the first and second objective functions are 1733$/MW and 12.8 kg/MW, respectively, as shown in Figure 1. At the same time, the optimal scheduling in this case is depicted in Figure 2.

The MOPSO algorithm represents the operation cost of the smart grid, loss of load expectation, and EESSs in this case. The results obtained are then examined to determine the optimal solution. The optimal solution was chosen from the non-dominated solutions identified by MOPSO, as shown in figure 3, and the optimal scheduling in this case is represented in figure 4. The decision-making process aims to achieve the closest approximation to the ideal solution. The operational cost for this system is 2785$/MW, and the expected power loss value for this scenario is 41.9 kW.

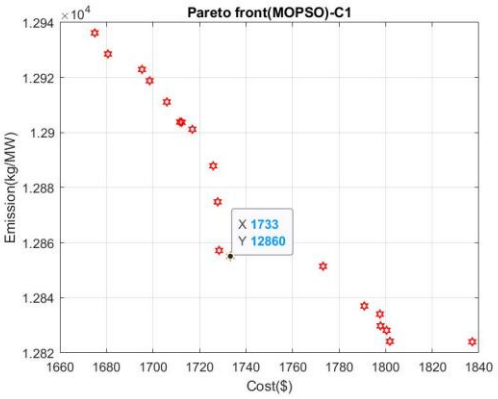

Figure 1: Cost Vs. Emission

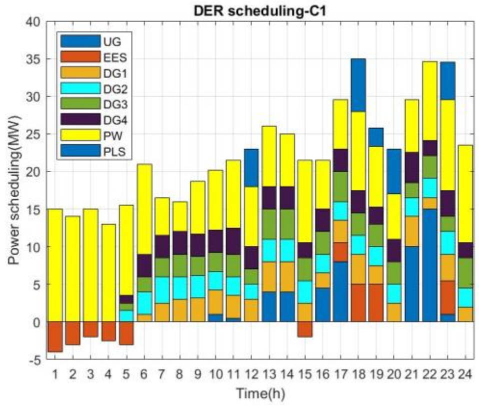

Figure 2: Scheduling for case 1

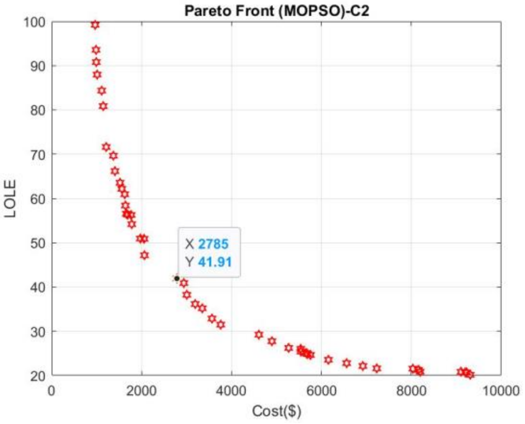

Figure 3: Cost Vs. LOLE

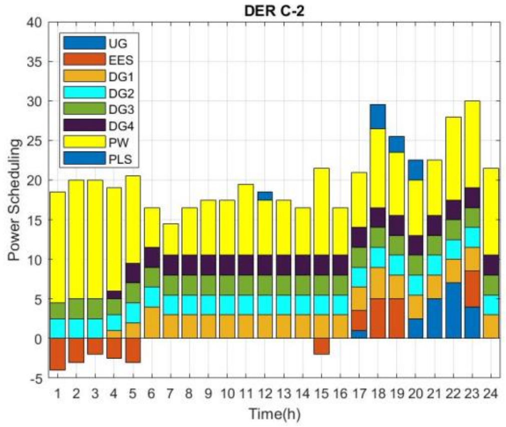

Figure 4: Scheduling for case 2

V. CONCLUSION

The study introduces an optimization model for effectively controlling energy in intelligent power networks, encompassing renewable energy sources, distributed generators, energy storage technologies, and the utility grid. The objective was to develop a highly effective power scheduling methodology while reducing emissions, LOLE, and operational expenses. The most efficient approach was determined using decision-making techniques, specifically the MOPSO algorithm. In the first scenario, the MOPSO algorithm was employed to reduce costs and emissions by integrating renewable energy resources and optimizing the scheduling of EESS. The second scenario aimed to enhance the efficiency of operational costs and LOLE for the smart grid. Power scheduling was performed for different sources in distributed systems, guaranteeing the most efficient provision of electricity to residential, commercial, and industrial demands. The study determined that the suggested method effectively reduced operational expenses, pollution, and LOLE while guaranteeing appropriate scheduling of power sources.

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