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A techno-economic optimization of Renewable energy sources within a smart grid and battery system through evolutionary algorithms

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Abstract – The contemporary economy is partially reliant on the electricity supply. The demand for an accessible and enduring energy supply is unavoidable. Due to the depletion of conventional energy sources, energy sectors are transitioning their generation units from traditional sources to renewable energy sources (RESs). These sources are abundant in nature; nevertheless, energy derived from these sources exhibits unpredictable patterns, which can present a potential danger to the regular functioning of the system. To address this problem, this study introduces an innovative method that utilizes heuristic optimization approaches, such as the multi-objective genetic algorithm (MOGA), to efficiently optimize cost and emissions in battery energy storage systems (BESSs) scenarios. Genetic Algorithm (GA) stands out among the several available methodologies since it consistently delivers superior outcomes for many case studies.

Keywords – RESs, MG, PV, WT, MOPSO

I. INTRODUCTION

Recent studies on energy optimization have shown that, by improving the power generation and usage system, energy consumption can be reduced from 25% to 35% without requiring any changes to the system infrastructure that has already been established [1]. RESs, such as wind and solar power, which produce pollution and encourage user meetings economically, are among the various ways to reduce power loss. An emerging phenomenon in the postmodern era is the smart grid (SG) with penetration of RESs, and energy optimization has become critical. In the meantime, forecasting is a necessary component of energy optimization. However, the main and difficult issues with optimizing the energy of RESs, such as solar and wind power, are the unpredictable conditions surrounding these resources and the discrepancies between the predicted and actual performance of the generations [2]. In particular, because energy generation from RESs is unpredictable, it is the operator of the SGs duty to maintain equilibrium between energy.

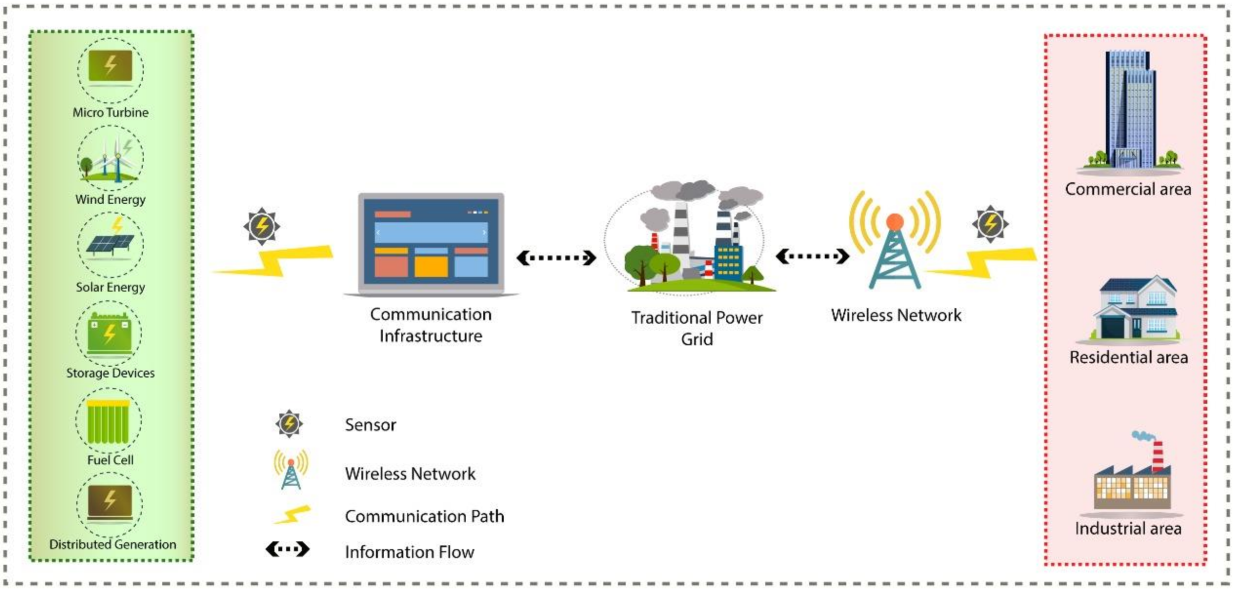

Figure 1: Flowchart of a typical Microgrid System

generation and potential consumption issues [3]. To reduce the uncertainty in energy generation and maintain the necessary level of security, SG operators maintain a reserve amount for backup. By purchasing more energy from independent power producers for backup needs, such as fuel-based and fast-ramping generators, the operators of the SG can reduce the problems mentioned above. Remember that the above solutions to the problems mentioned come with problems like higher operating costs and pollution emissions [4]. Another perfect answer to the issues raised concerning the maintenance of energy generation and consumption within a short time frame is the least precise prediction of RESs. The SG operators employ the leading strategy for energy-saving technologies to preserve energy scarcities and maintain a balance between generation and consumption.

A lot of work has been done in this field.The existing models have limitations regarding optimization techniques and objectives handled in trade-off solutions. Some of the dominant in the field of energy management in microgrids with the same niche are described below. Also, the limitations are mentioned in this study:A multi-objective smart grid is more useful than a single source-based renewable energy system. Authors in [5] proposed that a single-source SG energy system is not plausible and has many limitations regarding their power distribution, i.e., they are unpredictable and have intermittent behavior. SG energy systems with multiple integrated energy sources are proposed to mitigate these limitations. In [6], the author devised an SG energy system that operated in two-way communication between the load and generation sides to ensure demand responses (DR); however, the cost is not minimized. Authors in [7] have proposed an optimal power scheduling method for a home energy management system under DR that effectively reduces peak-to-average ratio (PAR) and operating cost by combining real-time pricing with an inclined block rate model. However, they have not considered pollutant emissions (CO2) from RESs. In [8], real-time two-way communication is focused between utility companies and multiple domestic users. A distributed real-time algorithm finds optimal energy management for maximum social welfare. However, operating cost and PAR are not considered. A model is represented for optimal DR programming in [9]. The Artificial Bee Colony algorithm (ABC) and the Quasi-static technique (QST) are used for multi-objective optimization. Stochastic methods have dealt with uncertainties. An economic operation model is implanted in a General Algebraic Modelling System (GAMS) to study the optimal operation of a BESSs, solar unit, and combined heating [10]. Furthermore, an optimization strategy is induced to minimize the operating cost and maximize the efficiencies of RESs utilization. However, the BESSs is not focused. The authors of [11], who control the multi-class appliances, effectively minimize

PAR and consumer's bill, develop a multi-objective distributive optimization strategy. It also looks to the user's comfort. However, operating cost is increased due to peak hour load [12].

The literature derived and methods calculated can cater to uncertainties accompanied by RES and the uncertain attitude of demand side participants (DSPs). Furthermore, their achieved results are not worth satisfaction; therefore, a different kind of mechanism is needed to optimize optimal energy, enabling the performance of energy optimization by tackling all prospects simultaneously and deriving a solution to minimize uncertainties caused by RESs and the attitude of DSPs. Hence, we propose a heuristic-based optimization model with three algorithms, e.g., MOGA, multi objective particle swarm (MOPSO), and wind driven optimization (MOWDO), to reduce operational costs and carbon dioxide emissions with the involvement of BESSs.

II. PROBLEM FORMULATION

In this section, we will elaborate further on the objective functions optimized in this study. The bi-objective optimization comprises two scenarios of cost vs. emission without BESSs and cost vs emission with BESSs through the available techniques. Objective function formulation is further discussed in the coming subsections.

A. *1st objective function (Operational cost):*

The first objective employed in this study is to cut down the operational expenses of the MG system, as presented in the below equation (1).

$$objF1 = Costs_{DG} + Costs_{BESs} + Costs_{UG} \qquad (1)$$

The operation costs of the MG system are expressed in terms of expenses caused by the diesel generator operation, elaborated as $Costs_{DG}$. In contrast, the cost associated with the energy backup system is represented by$Costs_{BESs}$. Finally, the electricity borrowed from the utility provider is expressed as $Costs_{UG}$ as given in the above equation (1).

B. *2nd objective function (Carbon emissions):*

In the second objective function, we opt to reduce the carbon footprints produced from various generation sources. The equation for the pollution function is modelled in the given equation (2).

$$objF2 = Emiission_{DG} + Emission_{BESs} + Emiission_{UG} \qquad (2)$$

The equation above (2) expresses the relation between various sources and their participation in overall emissions. The emission associated with the diesel generator is represented by $Emiission_{DG,}$ whereas $Emission_{BESs}$ and $Emiission_{UG}$ depicts the pollution criteria by BESs and utility grid respectively as given.

C. *Constraints:*

It is imperative that specific constraints must be implemented and enforced to guarantee the correct operation of our proposed smart grid model. This may include equality and inequality constraints, contingent upon the nature of the power-generating sources and objective functions. Here, we present certain constraints in our model.

The limitations associated with our proposed system are listed below:

1. Power balance:

As per this constraint, the power generated by all power-producing sources must be equivalent to the power required by the end user's load demand.

2. Constraint on power generation:

The quantity of power that a specific source can generate must not exceed or fall below a predetermined limitation.

3. BESSs constraint:

The charging and discharging levels at a specific hour "t" are the limiting factors for the capacity of the battery energy system. Each hour, the BESSs can be either charged or discharged. To maintain the functionality of BESSs, it is necessary to maintain the battery capacity within the maximum and minimum capacity limits. Additionally, the quantity of charge stored will be equivalent to the quantity supplied.

III. METHODOLOGY

The multi-objective genetic algorithm utilizes the population of the genetic algorithm to obtain non-dominated solutions that exhibit variation among them. Solutions closer to the Pareto front are assigned a ranking of 1. The remaining solutions are derived based on their respective positions. The algorithm follows the following steps:

A. *MOGA:*

• Step 1Input data is provided.
• Step 2: The starting population is formed.
• Step 3: Allocating a rank to each member of the population based on their position.
• Step 4: Calculate the row fitness of each solution by applying the linear mapping function.
• Step 5: Compute the mean row fitness; the quantity of solutions is determined in rank 1.
• Step 6: Implementing crossover to provide novel solutions.
• Step 7: Allowing the solution to undergo mutation.
• Step 8: Verify the termination condition. If the answer is affirmative, stop; return to step 1.
• Step 9: The resulting solution is our ideal answer upon termination.

IV. DISCUSSION AND ANALYSIS

This study carries out a test system of RESs. In addition to wind and solar energy systems, the system includes diesel generators, microturbines, and fuel cells to fulfill consumers' energy requirements. There are three distinct categories of consumers: commercial, industrial, and domestic.

A. *Experimental setup:*

This study was carried out on the operating system Windows 10 in the MATLAB 2021a software environment, with specifications of 8 GB RAM and a 64-bit system. We have examined two case studies to simulate the unpredictability of RESs and optimize the multi-objective problem.

B. *Describing and analyzing results:*

In the first scenario, the primary functions of cost and carbon emissions without BESS's involvement of BESSs are considered alternative solutions that involve making trade-offs between the two. Next, the three optimization strategies, MOGA, MOPSO, and MOWDO, are utilized to obtain the most optimal solution that balances cost reduction and minimizing emissions. The cost values for MOGA, MOPSO, and MOWDO are 349.4Ect, 382.3Ect, and 408.9Ect, respectively. Similarly, the pollutant emissions values for the same set of algorithms are 331.3 kg/kWh, 355.5kg/kWh, and 367.1kg/kWh, as depicted in Figure (1). It can be seen that MOGA have the least cost and emission values as compared to other techniques. Using the three techniques that are currently available, the second scenario addresses cost and emissions without

Table 1: Comparison of competing scenarios

ALGORITHM	Scenario 1 (without BESSs)		Scenario 2 (with BESSs)	
	Cost(Ect/MW)	Emission(kg/MW)	Cost(Ect/MW)	Emission(kg/MW
MOGA	382.4	336.4	438.4	1.342
MOPSO	339.4	316.4	333.4	1.131
MOWDO	443.6	316.7	352.6	0.5513

the involvement of the BESS system. As illustrated in Figure (2), the optimal values for the trade-off of costs and emissions when utilizing MOGA, MOPSO, and MOWDO are 406.6Ect, 433.5Ect, and 434.2.5Ect, respectively. In contrast, for carbon dioxide production, the values are 268.5kg/kWh, 329.1kg/kWh and 413.2kg/kWh. It can depicted through the results comparison in Table (1) that MOGA offers superior results in both cases and, hence, is best suited for such complex engineering problems.

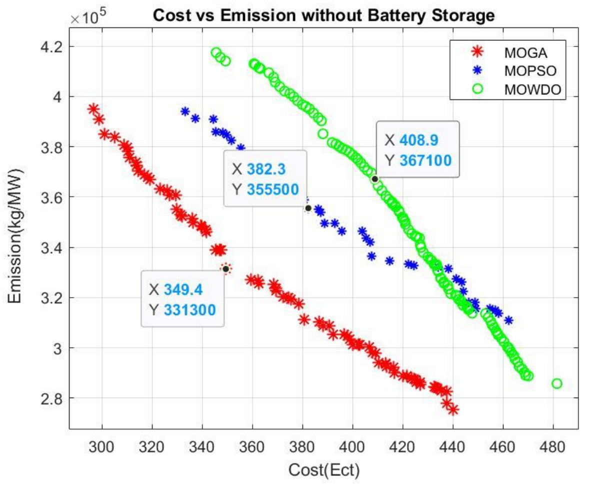

Figure 1: Cost Vs. Emission without BESSs

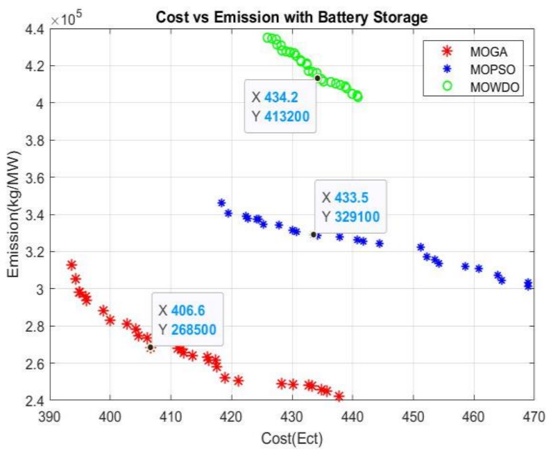

Figure 2: Cost Vs. Emission with BESSs

V. CONCLUSION

This study focuses on the multi-objective optimization of RESs. The objectives are to decrease operational costs and minimize CO2 emissions with and without the involvement of BESSs. Three optimization strategies are employed, namely MOPSO, MOWDO, and MOGA. These three algorithms are utilized in two different scenarios. In the first scenario, the focus is on considering cost and emission without considering the battery bank. In the second scenario, the goal is to optimize operational expenses and emissions with the involvement of a backup system. The simulation results indicate that MOGA is the most effective algorithm in all three circumstances. It outperforms other cost and pollution reduction strategies, as shown in Table (1). The results and performance of MOGA indicate that GA has a high convergence ratio compared to other current approaches. It has a faster solving time than other algorithms, making it the optimal choice for this optimization issue.

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