All Sciences Proceedings
All Sciences Proceedings
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5th International Conference on Applied Engineering and Natural Sciences
July 10-12, 2023: Konya, Turkey

https://www.icaens.com/

A multi-objective strategy for cost-effective microgrid solutions based on renewable energy sources

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Abstract – With the rapid urbanization and increasing energy demands, microgrids are recognizing renewable energy sources (RESs) as a valuable power generation option. However, efficiently managing the energy cost poses a significant challenge in integrating RESs with microgrids. To address this challenge, this study presents a novel approach utilizing a cost-effective multi-objective genetic algorithm (MOGA) to optimize power allocation among diverse generation units within the microgrid. The proposed MOGA algorithm aims to minimize generation costs by efficiently distributing the generated power from different sources in the microgrid vs the CO_2 emission. By leveraging the genetic algorithm population, MOGA generates a diverse set of non-dominated solutions. Simulation results demonstrate the effectiveness of the proposed approach in reducing the cost of RESs in microgrids, surpassing the performance of other multi-objective optimization methods such as multi-objective particle swarm (MOPSO) and multi-objective wind-driven optimization (MOWDO).

Keywords – Renewable Energy Sources (RESs), Energy Management, Cost Optimization, Multi-Verse Optimizer, Microgrid, Multi-Objective Genetic Algorithm.

1. INTRODUCTION

Microgrids are highly reliable networks operating at low voltage levels, efficiently supplying energy to consumers [1,2]. As the energy sector experiences a rapid increase in power demand, the utilization of renewable energy resources (RERs) becomes crucial to meet this demand effectively. RERs play a vital role in satisfying energy requirements and enabling efficient operation of microgrids. These microgrids comprise diverse distributed energy resources (DERs), including wind power plants, solar power plants, and other sources, along with storage devices and loads [3,4]. Fig 1 illustrates the components of a microgrid, encompassing an energy management system, DERs, a storage system, and various types of loads, such as residential, industrial, and commercial loads. Microgrids are typically operated in either islanded mode or grid-connected mode, depending on the specific circumstances.

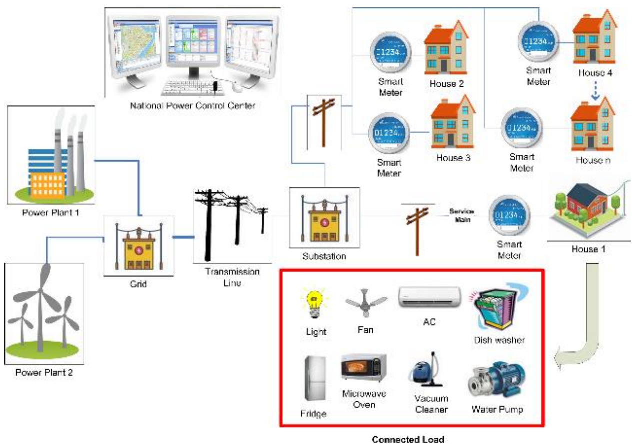

Fig 1. General Structure of a smart microgrid

In islanded mode, a microgrid functions as an independent system, operating autonomously to meet the energy needs of different communities solely through distributed energy resources. On the other hand, a microgrid in grid-connected mode operates in conjunction with the utility grid, enabling efficient use of energy and reducing reliance on fossil fuels [5]. Effective energy management is crucial for ensuring the seamless operation of a microgrid in real-time environments. However, optimizing energy management and solving associated optimization problems in microgrids pose significant challenges [6]. Previous studies have explored the application of various well-known meta-heuristic algorithms to optimize different performance attributes of microgrids.

The literature contains numerous reports on optimization methods used for optimizing various parameters in microgrid energy management. One such study [7] proposed a robust stochastic approach for optimizing hybrid energy systems. This method aims to reduce system losses and the overall operating cost of renewable energy resources and was validated on the IEEE 37 node distribution system. Another study [8] introduced an integrated approach utilizing multi-objective particle swarm optimization to minimize power supply probability loss, levelized energy cost, and greenhouse gas emissions. The authors of [9] presented a cost reduction approach by strategically placing capacitors to mitigate power loss in a radial distribution network. This work was tested on two different IEEE standard networks. In [10], a real-time energy management system was proposed to optimize the performance of a microgrid. The study focused on minimizing energy costs and CO2 emissions using a binary particle swarm optimization approach, and the IEEE 14-bus system was used for analysis.

In this paper, an enhanced algorithm called Multi-Objective Genetic Algorithm (MOGA) is proposed to optimize power scheduling among available generation units in a microgrid and minimize generation costs. The modified version of the original MOGA algorithm ensures a more balanced exploration and exploitation, improving the ability to navigate rugged search spaces and avoid getting stuck in local optima. The proposed MOGA algorithm solves the power scheduling problem for microgrids, aiming to achieve optimal power sharing among available generation units while satisfying the demand at the lowest possible cost.

2. Problem Formulation

This section outlines the cost objective function for the proposed system model, with the aim of reducing operating costs within the system. The subsequent details present the specific characteristics of these objective functions.

2.1. Cost Function

The first objective function in our study focuses on reducing the operating cost associated with the smart grid, as expressed in equation 1.

$$\min OF1 = \sum_{t=1}^{T} (CDG(t) + SUDG(t) + SDDG(t) + CUG(t)) \quad (1)$$

where

CDG = Cost associated with a Diesel Generator (GD)

SUDG = Start Up cost of DG

SDDG = Shut Down cost of DG

CUG = Cost of Utility Grid

2.2. Constraints

To ensure proper working of our proposed smart grid model, certain limits must be implemented and observed. These constraints may include both equality and inequality constraints depending upon the nature of source and objective function. Certain constraints for our model are discussed below:

2.2.1. Power balance

According to this constraint, Power generated from the sources must be equal to power demanded by the consumer's loads.

2.2.2. Power generation constraint

The amount of power produced from a certain source must neither exceed nor fall behind a certain limit. This inequality constraint for DGs, BES and UG.

2.2.3. BES constraint

Battery energy system capacity is limited by the charging and discharging level at a particular hour" t".

BES can be either charged or Discharged at each hour. To keep BES in operating condition, battery capacity must be held within their maximum and minimum capacity limits. Also, the amount of charge stored will be equal to the amount of charge supplied.

3. METHODOLOGY

This section provides an explanation of the multi-verse optimizer algorithm and its utilization in obtaining optimized solutions for the problem at hand. Additionally, a cost-effective variant of the multi-verse optimizer algorithm is discussed and applied specifically for the purpose of cost optimization.

3.1. MOGA

Multi-objective genetic algorithm takes the genetic algorithm population and obtains non-dominated solutions having diversity between these solutions. Proposed solutions closer to the Pareto front are ranked as 1. The rest of the solutions are obtained according to their position. Steps for this algorithm are given as;

Step 1: Provide input data to the algorithm.

Step 2: The initial population is generated.

Step 3: Assigning rank to the population according to their position.

Step 4: Assigning row fitness to each solution by using the linear mapping function.

Step 5: Calculate average row fitness for the rank one solution. Also, finding the number of solutions in rank 1.

Step 6: Performing crossover to produce new solutions.

Step 7: letting the solution mutate.

Step 8: check the stopping condition. If yes, stop; otherwise return to step 1.

Step 9: After termination, the resultant solution is our optimal solution.

4. IMPLEMENTATION AND RESULTS

This section presents the details of the experimental setup and provides a description of the dataset used. Furthermore, the performance of the proposed algorithm is assessed by its implementation on microgrid models of various scales.

4.1. Experimental Setup

The algorithms were implemented utilizing MATLAB, and the experiments were conducted on a computer equipped with an Intel (R) Core (TM) i5 processor, 8 GB RAM, and running the 64-bit version of the Windows 10 operating system. The proposed algorithm was applied to two different test systems, and the obtained results were compared with those obtained by alternative algorithms.

4.2. Results and Discussion

In the first case, the prime objectives of cost and emission of CO_2 are taken as trade-off solutions for these two. Then, the three-optimization techniques, MOGA, MOPSO, and MOWDO, are applied for the best trade-off solution of reduced cost and minimal emissions. It is shown that MOGA, MOPSO, and MOWDO cost values are 339.4Ect, 382.4Ect, and 443.6Ect, respectively. Similarly, for the same set of algorithms, the pollution emissions values are 316.4 Kg/KWh, 336.4kg/KWh, and 316.7kg/KWh respectively, shown in Fig 2, 3, and 4 respectively. It can be deduced from the figures that GA shows the best individual results among all the given algorithms by reducing cost and pollution by 11.91%, and 6.12% as compared to MOPSO and 26.5% and 0.1% as compared to MOWDO, respectively.

Table 1: Cost vs Emission analysis

ALGORITHM	Scenario 1	
	Cost (Ect/MW)	CO2 (kg/MW)
MOPSO	382.4.4	336.4
MOGA	339.4	316.4
MOWDO	443.6	316.7

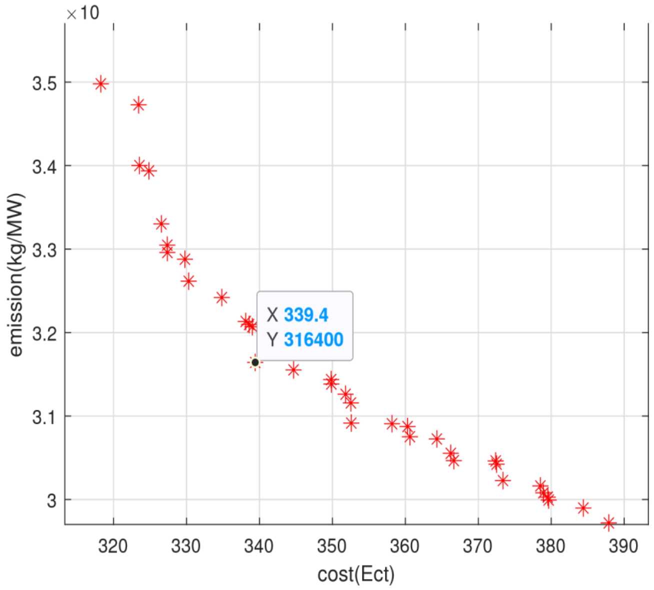

Fig. 2: Cost Vs Emission by MOGA

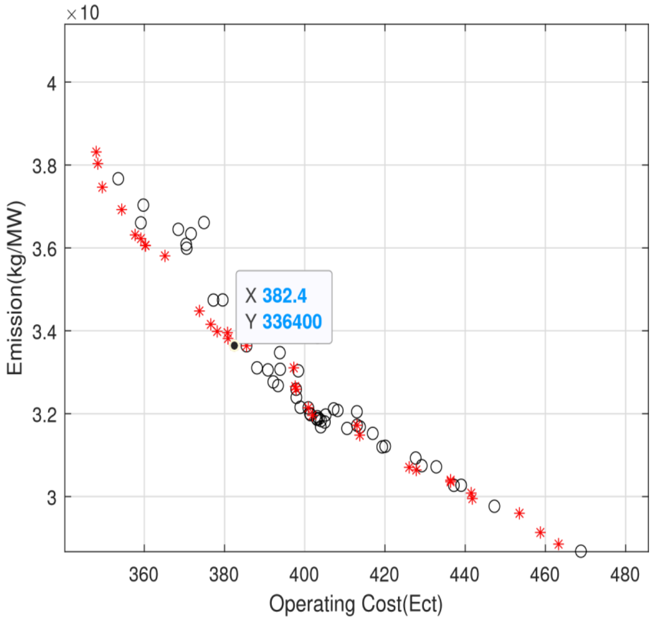

Fig. 3: Cost vs Emission by MOPSO

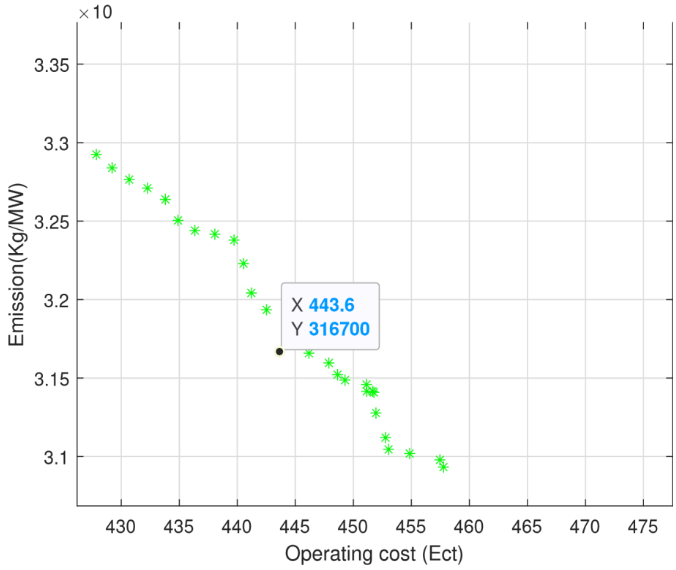

Fig. 4: Cost vs Emission by MOWDO

In fig 2, 3, and 4, the results drawn between Cost and Emission by MOGA, MOPSO and MOWDO algorithm respectively. These graphs shows that when the load is minimum like residential load the power shift from Utility Grid to Renewable Energy sources. In that case the Cost is low and the Emission factor is low that lead us to our optimal value and the optimal value is selected by inspection that mean a close point to the mean value.

5. CONCLUSION

This paper introduces a cost-effective optimization algorithm, Multi-Verse Optimizer (MOGA), designed to optimize power sharing among various generation units. MOGA enhances the local and global search capabilities of Genetic Algorithms (GA) and achieves cost optimization. The proposed algorithm effectively minimizes generation costs and offers a highly cost-effective solution to the power scheduling problem, ensuring stability and effectiveness. The optimization results yield an optimal energy management strategy for smart microgrids based on renewable energy sources.

ACKNOWLEDGMENT

I am grateful to my MS supervisor, Dr. GUL RUKH, for their ongoing support and advice. Without their wonderful encouragement and assistance, I would never have been able to complete this research work.

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