IAES International Journal of Robotics and Automation (IJRA)
Vol. 14, No. 4, December 2025, pp. 508~517
ISSN: 2722-2586, DOI: 10.11591/ijra.v14i4.pp508-517

Optimal battery sizing using modified spider monkey optimization in grid connected microgrids

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Article Info

Article history:

Received Dec 19, 2024
Revised Aug 16, 2025
Accepted Aug 26, 2025

Keywords:

Battery energy storage system
Microgrid
Modified spider monkey
Optimal sizing
Photovoltaic

ABSTRACT

Microgrids (MGs) must have optimally sized storage and renewable energy sources to operate efficiently, economically, and reliably. MG may benefit from optimization techniques in their scheduling and sizing since they have a variety of energy sources with varying availability conditions and necessary costs. In this research, a novel modified spider monkey-based energy management system (MSM-EMS) has been proposed by increasing the photovoltaic (PV) or battery energy storage system (BESS) module capacity while minimizing grid connectivity dependency. The fundamental idea behind the proposed approach is greater dependability at the lowest feasible cost. By taking into account the BESS utilization factor and PV forced outage rates in a MG, the method becomes more realistic. Despite the absence of renewable energy sources and the grid, the proposed strategy provided critical loads according to schedule while maintaining reserve margins. Experimental findings demonstrate that the modified spider monkey optimization (MSMO)-based algorithm can determine the best BESS size and PV depending on cost. In comparison to particle swarm optimization (PSO) of $2756.1 and ABC of $2912.65, the ideal cost for EMS-MSMO is $2215.77 which is relatively low compared to the existing technique. As a result, the suggested MSMO algorithm and innovative energy management system has been optimized along with PV and battery dimensions.

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1. INTRODUCTION

Fossil fuels like coal, oil, and natural gas are currently the primary sources of energy generation [1]. Nevertheless, these fuels also damage the environment and release greenhouse gases. In particular, wind and solar energy are vital ecological alternatives to nuclear power and fossil fuels. They are infinitely scalable, non-polluting, and ideal for decentralized production. Indeed, in recent years, wind and photovoltaic systems have advanced significantly and seen a notable drop in cost. As a result, the research community is currently investigating these issues in great detail [2]. However, previous studies have shown that the intrinsic unpredictability of wind and solar renewable energy sources (RES) has complicated power grid management, causing concerns about system stability and power quality.

Recently, there has been a growing interest in microgrid systems as one of the worldwide solutions to the energy challenge [3]. You can think of the loads as a group of distributed generation sources (DGs) that can be sent directly to the loads or the utility grid. Batteries energy storage systems (BESS) can now power many parts of the power grid [4], [5]. With its quick and flexible features, the BESS is a solid option for preserving resilience and dependability [6].

One of the main issues in the design of microgrids (MGs) has been determining the optimum BESS size [7]. Improving MGs' dependability and lowering their total cost requires optimizing the size and kind of BESS [8]. Grid-connected and standalone MGs are sized optimally while taking into account two alternative objectives: minimizing the annual total energy losses and the energy cost [9]. This paper aims to improve frequency management and save operating costs by combining the metaheuristic algorithm with the best BESS sizing [10]. Numerous investigations have examined the best way to size BESS in MGs using a variety of techniques, including dynamic programming, mixed integer linear and nonlinear programming, and the meta-heuristic approach [11], [12].

An improved particle swarm optimization (PSO) (I-PSO) is suggested in [13] that optimizes both BESS reactive and active power to reduce voltage fluctuations. MATLAB is used to create and implement the I-PSO, and DIgSILENT Power Factory is used to calculate the time sweep load flow. A day-ahead scheduling technique for an energy storage device in an MG that makes use of the PSO and GA methods was presented in [14]. Microgrids with price variability use a scheduling mechanism that lowers the amount that consumers must pay. In a simulation, the average cost reductions throughout the energy storage system schedule produced by the net energy-based approach were 11.31% for GA and 14.31% for PSO. In addition, three parallel versions of metaheuristic methods are introduced in [15] to find the optimal battery power distribution in DC grids. A multi-objective PSO method is presented in [16] to explore three sustainable MG topologies for the Shiraz climate in Iran. The MG topologies that were considered were CHP and photovoltaic (PV), CHP and wind turbine (WT), and CHP and WT.

Particle swarm optimization for an ideal microgrid system for hybrid renewable energy in the face of uncertainty is introduced in [17]. The proposed method can be used to charge and discharge BESS while keeping sufficient margin to supply important loads if renewables and the grid are not available. Moreover, to improve the efficiency of hybrid energy management systems, [18] presented a revolutionary fuzzy logic-based PSO (FLB-PSO) technique. Hybrid energy storage system (HESS) that combines RES with solar PV systems, batteries, and supercapacitors (SC) in [19]. This research introduces the simulation and improvement of an energy management system (EMS) for a HESS utilizing grey wolf optimizer (GWO), genetic algorithm (GA), and ant colony optimization (ACO). Additionally, the fast transient reaction offered by this control strategy enhances the HESS's charge and discharge performance, lowering battery stress and extending its longevity.

In addition to the literature various optimization techniques like grey wolf [20], artificial bee colony [21], and Cuckoo Search [22] have been employed in the majority of the literature to determine the optimal number of BESS in MGs. Based on maximal iterations and population size, these evolutionary algorithms draw inspiration from nature [23]. Accordingly, the population size, iteration count, and other algorithmic factors all affect the way these approaches and their solutions converge. To reach the global optimal solution, these algorithms could be stuck in local optimum solutions [24], [25]. As a result, the techniques are not appropriate for solving large-scale issues. To overcome these issues, a novel modified spider monkey-based energy management system has been introduced. The research questions for the proposed method are How can the modified spider monkey optimization (MSMO) algorithm enhance energy management in grid-connected microgrids by optimizing PV and BESS sizing? What is the impact of using MSMO on the overall cost reduction in microgrid energy management compared to existing techniques? How does the MSMO-based EMS balance cost minimization and power reliability in microgrid operation? When calculating the optimal PV and BESS sizes for the microgrid, which significant technological and financial restrictions are taken into consideration?

The major contribution of the proposed method is given as follows. The proposed MSMO algorithm is utilized to produce the ideal PV size and energy storage while taking cost minimization. The proposed strategy identifies the proper BESS and PV sizes, presenting reduced costs as an objective function and offering a novel optimal energy management solution for a grid-connected MG. Even in the absence of renewable energy sources and the grid, the proposed method supplied critical loads on time while maintaining reserve margins. As demonstrated by the data, the MSMO-based approach can determine the best PV and BESS size based on cost when combined with the energy management plan. Experimental result shows that the suggested approach in comparison to the current PSO and ABC algorithm considerably lowers the grid cost by 0.7%, and 0.8% respectively.

This is the structure for the remainder of the paper. Relevant work is described in section 2. The system model is introduced in section 3, the enhanced optimization algorithm is introduced in section 3, the findings and discussions are presented in section 4, and section 5 encloses conclusions.

2. PROPOSED MSMO-EMS METHODOLOGY

In this research, a novel MSMO-EMS has been proposed to improve the BESS or PV capacity to reduce dependency on grid connectivity. Figure 1 illustrates the broad flow of the proposed approach.

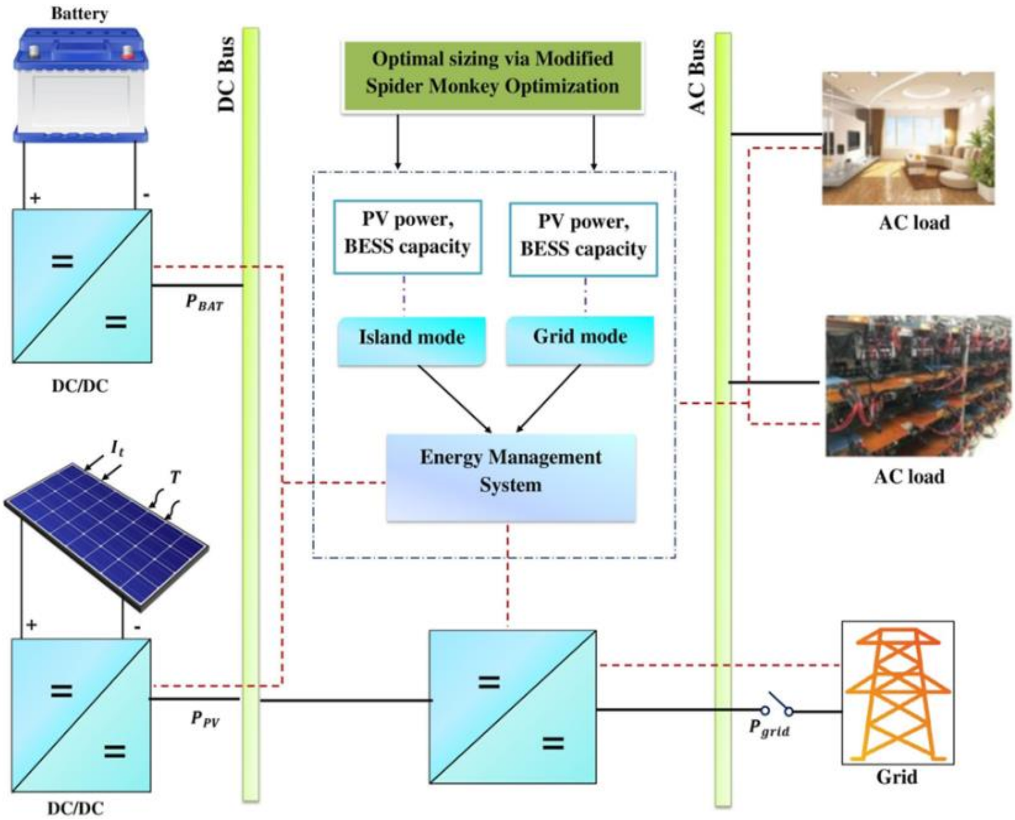


Figure 1. Proposed MSMO-EMS

2.1. Objective function

Energy costs serve as an objective function in this research. The objective is to lower the MG's overall energy costs while maintaining predetermined restrictions. The energy cost is computed as (1).

$$E_C = (PV_{total\ energy} \times PV_{cost}) + (BESS_{total\ energy} \times BESS_{cost}) \quad (1)$$

In this case, the entire output energy of PV and BESS is represented by $PV_{total\ energy}$ and $BESS_{total\ energy}$, respectively. They are produced within a specified time frame by the energy management algorithm. The following limitations apply to the proposed operation difficulty. The following equality and non-equality microgrid constraints are taken into consideration when solving the specified multi-objective function.

a. Equality constraint:

$$P_L(t) = P_{PV}(t) + P_{BESS}(t) \quad (2)$$

b. Inequality constraint
- SoC constraints: $SoC_{min} \leq SoC(t) \leq SoC_{max}$
- Battery energy constraint: $BESS_{min} \leq BESS(t) \leq BESS_{max}$
- Solar PV constraints: $PV_{min} \leq PV(t) \leq PV_{max}$

2.2. Energy management system
Energy flow management is a crucial procedure for system component optimization and effective system functioning. The two components of the suggested energy management strategy are grid-connected mode operation and island mode operation.

2.2.1. Island mode
When the MG is in island mode, it does not have grid support. PV generation or the existing capacity of BESS can meet the required load. The battery is deemed charged after calculating the net energy $(Net_{ery}(t) = PV_{ery}(t) - Load_{ery}(t)$. Island mode functioning prevents any residual power in the PV system from being consumed or sold to the grid if the BESS exceeds its charge limit. It is possible to deplete batteries till their $Min\ Battery_{ery}$ level if BESS has energy available. Lastly, batteries are charged using PV power while there is still some PV power generation available. The energy management flowchart is depicted in Figure 2.

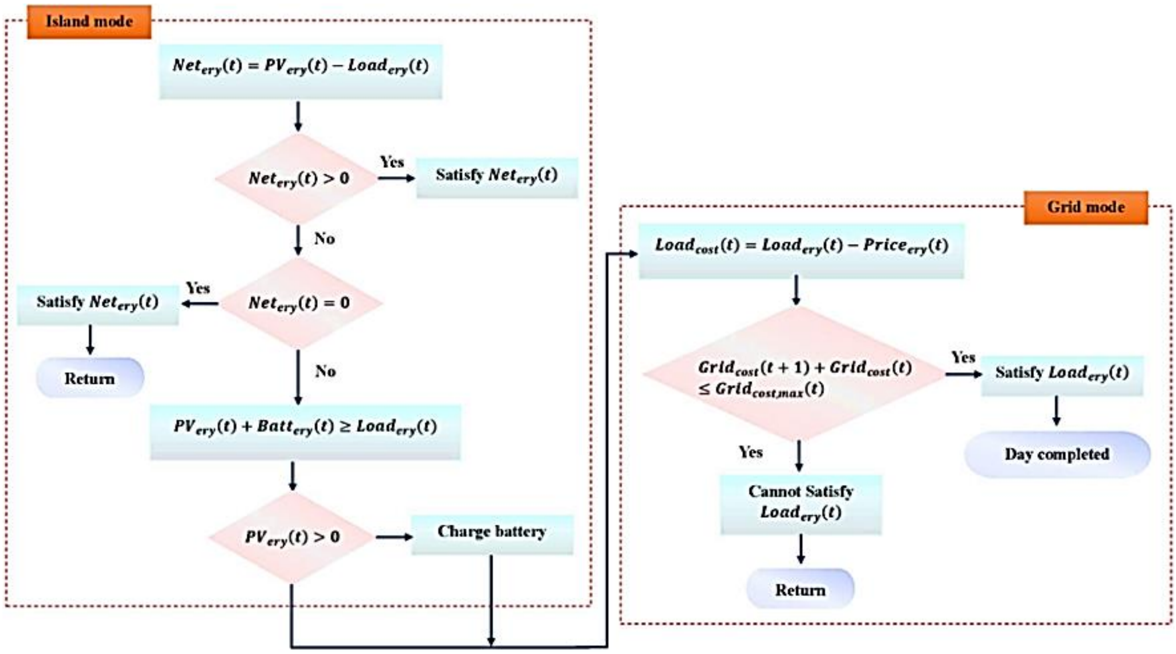


Figure 2. Energy management flowchart

2.2.2. Grid supplied mode
The grid maintains MG while it's functioning in the grid-connected mode. To identify the optimal PV and BESS aspects, a largely self-sufficient MG is analyzed during a one-year period. In situations where solar and battery power cannot meet load needs, the grid turns to electricity. For a short time after the PV and BESS have used up all of their energy, the MG could be able to be supplied entirely or in portion by the grid. MGs may be able to use grid electricity prices in case of insufficient energy supply. The MSMO approach is utilized to determine for increasing capacity of the PV or BESS module.

2.3. Modified spider monkey optimization (MSMO)
MSMO is employed in this study to determine the minimal points, or minimum cost. The numbers of PV and BESS modules are represented by spider monkeys, which are initialized at random. By using a modified spider monkey optimization method, the original SMO technique has been enhanced in terms of convergence time and solution quality. Random PV and BESS sizes are generated by MSMO in each iteration, and the costs of each are contrasted with the optimal solution. The PV and BESS sizes are the area after all iterations, produces the best global cost. In Figure 3, the MSMO flowchart is displayed.

2.3.1. Initialization
The MSMO method starts with an initial population of N spider monkeys (SM). In this case, each SM is initialized and serves as a possible remedy for the issue at hand.

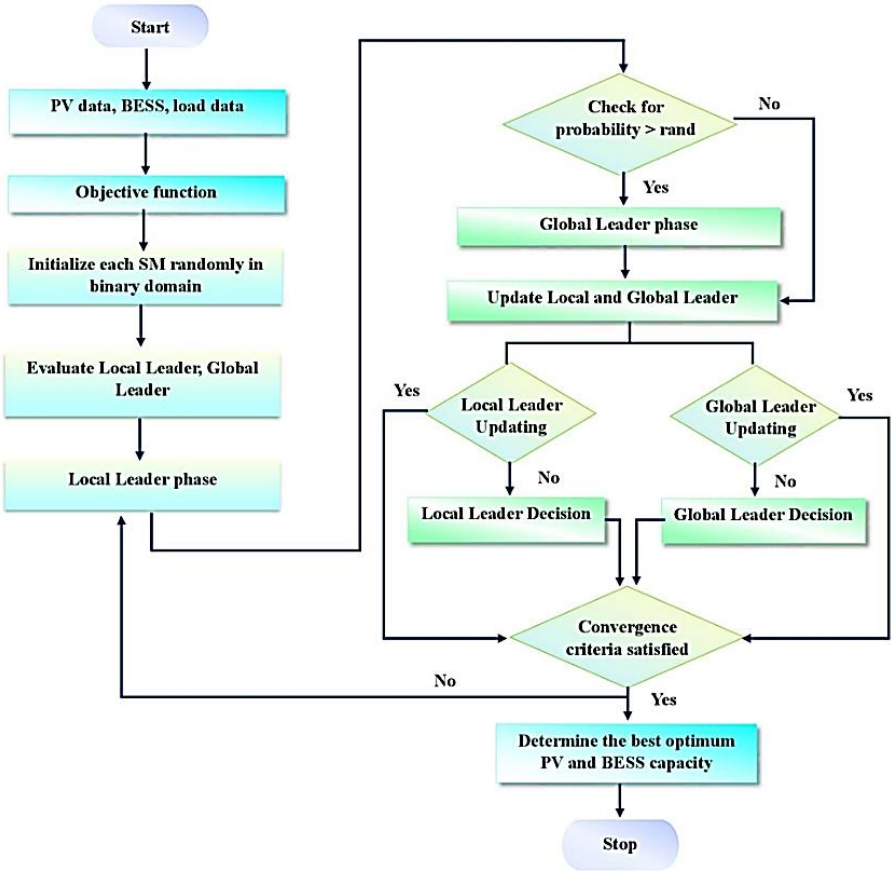


Figure 3. Flowchart of MSMO

$$SpM_{x,y} = SpM_{min,y} + P \cdot (SpM_{min,y} - SpM_{max,y}) \tag{3}$$

The lower and upper boundaries are represented by $SpM_{min,y}$, $SpM_{max,y}$ respectively, where $\{1, \dots SpM\}, y \in \{1, \dots Dim\}$, denote the x^{th} spider monkey in the y^{th} dimension, and P is a number generated at random between [0, 1]. Equation (4) calculates the Fitness function (FF) for the objective function (O_b).

$$FF_x = \begin{cases} 1 + O_b, & O_{b_x} \geq 0 \\ \frac{1}{1+|O_b|}, & O_{b_x} \leq 0 \end{cases} \tag{4}$$

One (of the two) search equation is chosen at random to update the spider monkeys' position:

a. Original SMO

$$SpM_{newx,y} = \begin{cases} SpM_{x,y} + \left(\left(P \cdot (ll_{z,y} - SpM_{x,y})\right) + \left(q \cdot (SpM_{r,y} - SpM_{x,y})\right)\right), & P \geq t_p \\ SpM_{x,y} & Otherwise \end{cases} \tag{5}$$

b. Modified SMO

$$SpM_{newx,y} = ll_{z,y} + P \cdot (SpM_{k,y} - SpM_{i,y}) \tag{6}$$

In this case, k and i are randomly selected spider monkey indexes. $SpM_{newx,y}$ represents the revised spider monkey location or new solution. $SpM_{x,y}$ represents the prior solution; $SpM_{k,y}$ represents the y^{th} dimension of the r^{th} spider monkey; z^{th} represents the local leader of the y^th dimension of the z^th group; q is a random number between [−1, 1]; and t_p represents the perturbation rate.

2.3.2. Global leader phase

During this stage, spider monkey positions are modified based on group member and global leader (GL) experiences. Every member's probability is calculated to update every position. The probability is computed as (7).

$$P_x = 0.9 \cdot \frac{(FF_x)}{max\_FF} + 0.1 \tag{7}$$

a. Original SMO

$$SpM_{x,y} = SpM_{x,y} + \Big(\big(P \cdot (\mathrm{GL}_y - SpM_{x,y}) \big) + q \cdot (SpM_{r,y} - SpM_{x,y}) \Big) \tag{8}$$

b. Modified SMO using artificial bee colony (ABC)

$$SpM_{newx,y} = \mathrm{GL}_y + P \cdot (SpM_{k,y} - SpM_{i,y}) \tag{9}$$

where GL_y is the updated global leader, P denotes the random interval [0, 1], and q is the other random number in the interval [−1, 1].

2.3.3. Local and global leader learning phase

Global leader learning states that the spider monkey with the greatest efficiency value becomes the new global leader. The greedy selection approach is used to pick the local leaders for each group in the local leader learning process.

2.3.4. Global and local leader decision phase

By randomly initializing or merging global and local leaders, the location of local leaders is changed throughout the local leader preference phase up to the predefined threshold, sometimes referred to as the local leader limit. After a certain number of times, if no local leader updates their position, the local leader count is reset to zero and the positions of all group members are updated. The revised equations are as follows.

a. Original SMO equation

$$SpM_{x,y} = \begin{cases} SpM_{x,y} + \Big(\big(P \cdot (SpM_{x,y} - ll_{z,y}) \big) + \big(q \cdot (\mathrm{GL}_y - SpM_{x,y}) \big) \Big), & P \geq t_p \\ SpM_{min,y} + P \cdot (SpM_{min,y} - SpM_{max,y}) & Otherwise \end{cases} \tag{10}$$

b. Modified SMO equation using Artificial Bee colony (ABC)

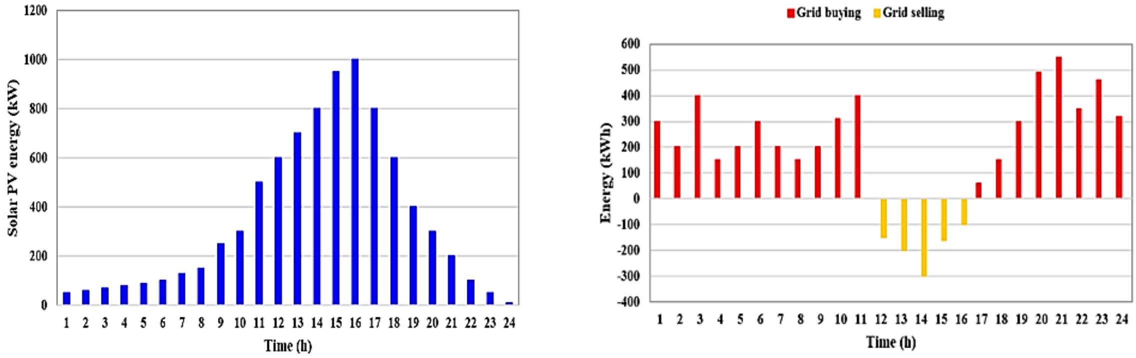
$$SpM_{newx,y} = ll_{z,y} + P \cdot (\mathrm{GL}_y - SpM_{i,y}) \tag{11}$$

However, when the global leader limit is not updated to certain iterations, the decisions made by the global leaders are divided into smaller groups. Lastly, the most fit person provides the solution to the issue at hand. The optimum solution found during this optimization process is then applied to the calculation of dependability indices that are specifically customized for the regulatory framework of choice. The reliability performance of the MG under each policy can be ascertained using this method.

3. RESULT AND DISCUSSION

In this section, the EMS-MSMO algorithm is measured based on performance. The proposed approach with microgrid with PV panels and batteries was configured using MATLAB to implement the technique. The study is conducted using a 33-node IEEE distribution system that includes solar and wind power sources. Figure 4 illustrates the overall energy analysis of the proposed microgrid system. Here, Figure 4(a) shows the average daily solar PV energy generation that highlights the maximum production at around 15:00, and Figure 4(b) shows the primary grid energy sales and purchases throughout a 24-hour period. Despite daily fluctuations, energy purchases peak at night when demand is highest and, in the absence of renewable energy generation, only the battery can provide additional power. When solar PV generation is in excess, grid power sales occur at 12:00, 13:00, 14:00, 15:00, and 16:00.

Within the constraints of the optimization process, which are set at a minimum of 15% SoC and a maximum of 80% SoC, the battery SoC profile is displayed in Figure 5. The 50% SoC battery capacity not only meets daily energy needs but also provides the optimum operational cost and efficiency, ensuring a longer battery lifespan.



(a) (b)

Figure 4. Energy analysis (a) average daily generation of solar PV energy and (b) grid buying/selling energy in 24 h period

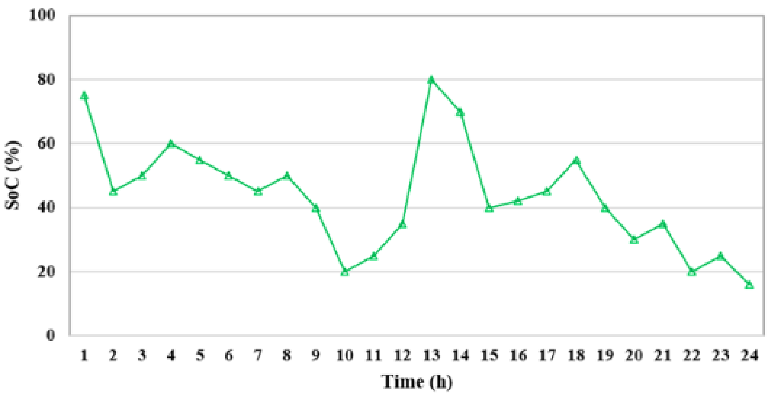
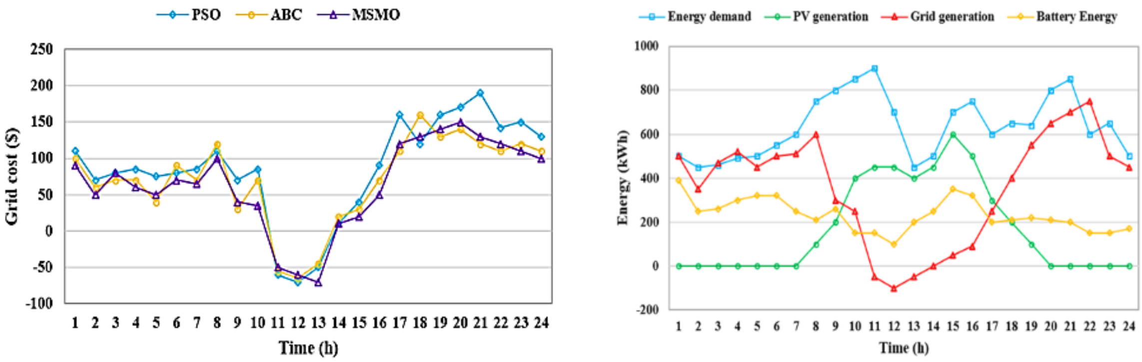


Figure 5. SoC profile

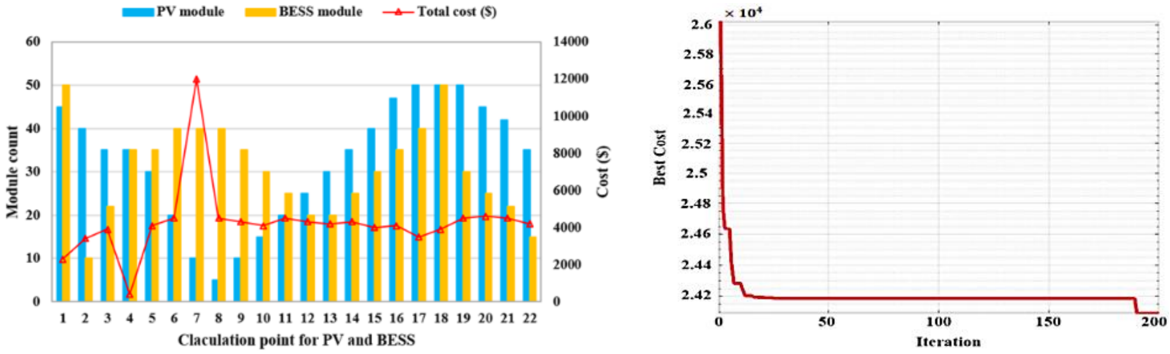
The MSMO prioritizes battery charging during peak renewable generating hours over selling extra energy to the MG. Figure 6 provides the performance analysis of the proposed MSMO-based EMS. Figure 6(a) shows the grid cost variations are compared with existing algorithms, showing that MSMO achieves lower purchases at key time slots such as 13:00, 15:00, and 20:00. Moreover, Figure 6(b) depicts the demand energy profile under a dynamic tariff that shows the renewable generation peaks between 8:00 and 11:00 a.m., leading to excess electricity sales while battery use remains steady.



(a) (b)

Figure 6. Performance analysis of (a) EMS grid cost and (b) demand energy profile over a 24-hour period

Figure 7 presents the cost analysis for different PV and BESS configurations. In Figure 7(a), the system cost fluctuation is shown with respect to varying module numbers, where costs rise sharply at certain points due to inefficiencies. Figure 7(b) highlights the novel energy management method using the MSMO algorithm offers improved cost efficiency. Additionally, the 192nd iteration of the energy management strategy with MSMO estimated a total cost of USD 44.972, with 47 and 28 PV modules, respectively, being the perfect counts. Finding the global point takes longer than the suggested techniques.



(a) (b)

Figure 7. Cost analysis of (a) system cost for different PV and BESS modules and (b) obtained best cost results of proposed MSMO

4. CONCLUSION

This research proposes a novel modified spider monkey-based EMS by increasing the PV or BESS module capacity while minimizing grid connectivity dependency. The fundamental idea behind the proposed approach is greater dependability at the lowest feasible cost. By taking into account the battery energy storage (BES) utilization factor and photovoltaic forced outage rates in a grid-connected microgrid (MG), the method becomes more realistic. Despite the absence of RES and the grid, the proposed strategy provided critical loads according to schedule while maintaining reserve margins. The proposed technique with microgrid with PV panels and batteries was configured using MATLAB to implement the technique. The study is conducted using a 33-node IEEE distribution system that includes solar and wind power sources. Combining the MSMO-based algorithm with the energy management technique, the experimental analysis depicts the MSMO-based algorithm can calculate the optimal PV and BESS size based on the lowest cost. In comparison to PSO of $2756.1 and ABC of $2912.65, the ideal cost for EMS-MSMO is $2215.77 which is relatively low compared to the existing technique. As a result, the suggested MSMO algorithm and innovative energy management system has been optimized along with PV and battery dimensions. Future work is extended by integrating machine learning for predictive energy management to enhance computational efficiency. Additionally, the proposed method is incorporated with wind, hydrogen storage, and electric vehicle charging stations to improve grid resilience and cost-effectiveness.

ACKNOWLEDGMENTS

The author would like to express his heartfelt gratitude to the supervisor for his guidance and unwavering support during this research for his guidance and support.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Manne Rama Subbamma			✓		✓	✓		✓	✓		✓		✓	

C	: **C**onceptualization	I	: **I**nvestigation	Vi	: **Vi**sualization
M	: **M**ethodology	R	: **R**esources	Su	: **Su**pervision
So	: **So**ftware	D	: **D**ata Curation	P	: **P**roject administration
Va	: **Va**lidation	O	: Writing - **O**riginal Draft	Fu	: **Fu**nding acquisition
Fo	: **Fo**rmal analysis	E	: Writing - Review & **E**diting		

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

INFORMED CONSENT

We certify that we have explained the nature and purpose of this study to the above-named individual, and we have discussed the potential benefits of this study participation. The questions the individual had about this study have been answered, and we will always be available to address future questions.

ETHICAL APPROVAL

This manuscript has been reviewed and ethically approved by our research guide for publication in this journal.

DATA AVAILABILITY

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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