

ORIGINAL RESEARCH ARTICLE

Efficient energy management in microgrid using Zebra Optimization Algorithm

Dodda Aasha Vardhini^{†*}  and **Jayaram Nakka[†]** 

Department of Electrical Engineering, National Institute of Technology Andhra Pradesh, Tadepalligudem,
Andhra Pradesh, India

[†]These authors contributed equally to this work.

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***Corresponding author:** Dodda Aasha Vardhini (dodda.aashavardhini@gmail.com)

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Abstract: The inherent variability of power output from photovoltaic (PV) systems, wind energy resources, battery energy storage systems (BESS), and hydrogen (H₂) fuel cells presents a significant challenge in efficiently integrating these technologies into microgrids. This stochastic nature underscores the necessity of accounting for fluctuations in renewable energy resources (RERs) to optimize energy utilization within the microgrid. This paper proposes a resource-efficient energy management (REEM) framework for a microgrid interconnected with the main power system. By dynamically regulating PV generation, wind power output, BESS discharge, and hydrogen fuel cell operation in response to load variations, the proposed approach enhances energy utilization and grid stability. To address the complexities associated with REEM, this study employs the zebra optimization algorithm (ZOA), a highly efficient metaheuristic technique. The primary objectives of this optimization include cost minimization, voltage profile enhancement, and optimal sizing of RERs. Simulation results demonstrate that the strategic integration of PV units, wind turbines, grid-connected BESS, and hydrogen fuel cells significantly reduces operational costs while improving overall system performance. Comparative analysis further reveals that ZOA outperforms the moth-flame optimization algorithm and stochastic fractal search network in achieving the defined optimization objectives.

Keywords: Energy resources; Photovoltaic system; Wind energy; Zebra Optimization Algorithm; Voltage stability; Cost function

1. Introduction

The incorporation of a wide variety of renewable energy sources and the facilitation of power flow in both directions are two of the most important contributions that alternating current (AC) microgrids make to the improvement of energy dependability, resilience, and efficiency.¹⁻³ They provide flexibility in the management of dispersed generation, the reduction of transmission losses, and the support of grid stability, which

ultimately contributes to the promotion of decentralized and sustainable energy systems. Variations in load demand, the unpredictability of renewable energy resources (RERs), the relationship between the grid and the microgrid, and the capacity for energy storage are all factors that influence the functioning of an AC microgrid. Optimal management takes into account these aspects to achieve a balance between supply and demand, guarantee grid stability, and maximize the

use of renewable energy sources while simultaneously minimizing costs and the effect on the environment.^{4,5}

It is possible to optimize power flow, load scheduling, and resource allocation through the use of AC microgrid energy management (EM). To enhance dependability and lower costs while preserving grid stability, it integrates renewable sources and storage to strike a balance between supply and demand. To guarantee that available resources are used in an efficient manner, intelligent algorithms, and control mechanisms are utilized.⁶⁻⁸ EM for AC microgrids aims to achieve the following goals: optimize the integration of renewable energy sources, maximize grid stability, minimize operating expenses, and effectively balance supply and demand within the system. To guarantee dependable and environmentally friendly power distribution, it requires real-time monitoring, management, and coordination of generation, storage, and consumption.

AC microgrid EM provides significant improvements in terms of flexibility, dependability, and efficiency when it comes to the integration of various energy sources. In addition to facilitating grid stability and supporting dynamic load control, it promotes the effective use of renewable resources. The design of the AC microgrid also makes it simpler to integrate with the infrastructure that is already in place, which helps to improve grid resilience and scalability. In our study, an optimal EM strategy for AC microgrids is proposed to enhance the integration of renewable energy sources.⁹⁻¹⁴

Through extensive simulations, as demonstrated previously,¹⁵ the proposed strategy achieves a significant reduction in overall system costs while ensuring grid stability. Specifically, the optimization algorithm employed, based on particle swarm optimization, minimizes the total energy procurement expenses and maximizes renewable energy utilization. The results indicate that existing methods in terms of both economic benefits and environmental sustainability. A paper by Dey *et al.*¹⁶ presents an adaptive control scheme tailored for AC microgrid EM, integrating demand response mechanisms and energy storage systems (ESS). The proposed scheme optimally schedules energy generation and consumption considering varying load profiles and renewable energy availability. By employing a modified genetic algorithm for optimization, our approach dynamically adjusts energy dispatch strategies to minimize operational costs and maintain grid stability. Simulation results validate the effectiveness of the proposed scheme in achieving optimal operation of AC microgrids under different operating conditions.¹⁷⁻¹⁹

Zebra optimization algorithm (ZOA) was employed in this study due to its superior capability in solving complex optimization problems related to EM in microgrids. ZOA is inspired by the collective movement and foraging behavior of zebras, effectively balancing exploration and exploitation in the search space.²⁰ This characteristic is crucial in microgrid EM, where optimal decisions must be made dynamically to accommodate fluctuations in renewable energy generation and load demand. Unlike conventional optimization techniques, ZOA demonstrates faster convergence rates and avoids local optima more effectively.²¹ This is particularly beneficial when optimizing energy dispatch strategies involving multiple RERs, as it enhances the efficiency and stability of the microgrid. Further, the ZOA is well-suited for handling such multi-objective optimization problems.²²

This work addresses the issues that were described before and presents a method by which ZOA can effectively respond to changing circumstances, hence increasing the resilience of AC microgrids against interruptions and uncertainty. The adaptability of ZOA across microgrids of varying sizes and configurations provides scalability and flexibility, providing answers to a wide variety of problems related to EM. The structure of this paper unfolds as follows: Section 2 elaborates on the problem formulation of the resource-efficient EM (REEM) system. In Section 3, the ZOA system is outlined. Section 4 delves into the simulation results of the proposed ZOA algorithm, comparing its performance with existing algorithms. Finally, Section 5 provides a comprehensive summary of the work conducted in this study.

2. Problem formulation

The management of energy in a microgrid is achieved through the integration of six distinct objective functions within a comprehensive framework that addresses multiple targets. The significant goal is to amplify the utilization of energy while at the same time guaranteeing that microgrid sticks to the furthest reaches that have been set on it.^{23,24} The methodology attempts to harmonize a few components of EM by including various goals to accomplish this equilibrium. These viewpoints incorporate effectiveness, trustworthiness, and supportability. Moreover, the convergence of these objectives into the multi-objective capability makes it conceivable to adopt a comprehensive strategy to the streamlining of energy for the microgrid, which thus makes it simpler to meet the limitations of the microgrid

and works on the general execution of the framework. The microgrid EM framework is displayed in Figure 1, which shows its setup. The wind turbine (WT) and photovoltaic system (PV) are the portion of the sources that are recommended for the microgrid plan.

2.1. Goal function

2.1.1. Measures for cost-saving

Several components increase the total annual cost of electricity produced by a microgrid. They include the annual energy loss cost (R_{loss}), the expenditure associated

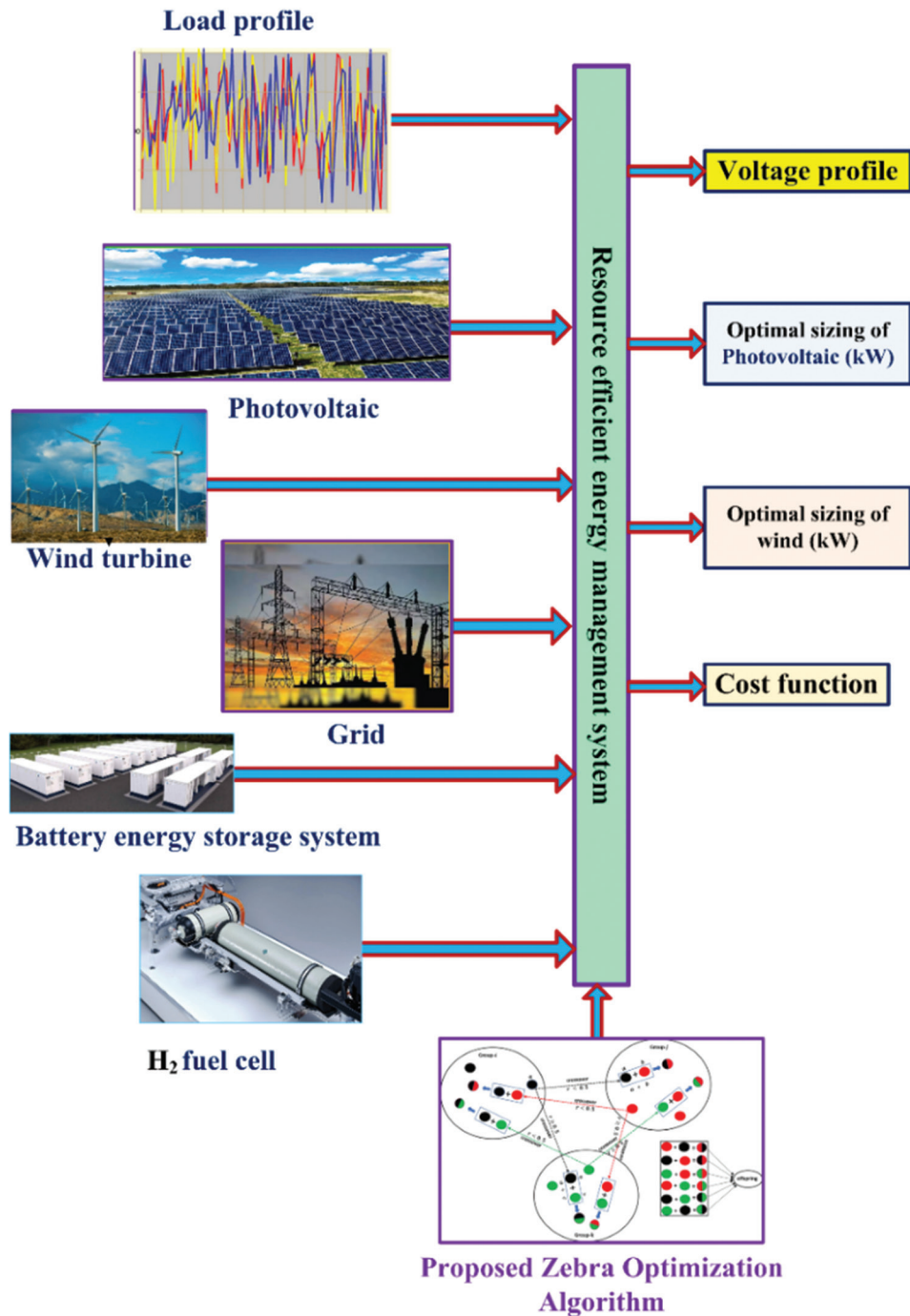


Figure 1. Configuration of microgrid smart energy management system (SEMS)

Abbreviations: BESS: Battery energy storage system; PV: Photovoltaic; ZOA: Zebra Optimization Algorithm.

with transporting electricity from the electric substation (R_{Grid}), the costs of the PV units (R_{PV}), WTs (R_{WT}), battery ESS (BESS) unit (R_{BESS}), and H2 fuel unit (R_{FC}). The above-mentioned components together account for the total cost associated with EM.²⁵ The total cost function scenarios are expressed by Equation I.

$$R = \min (R_{loss} + R_{Grid} + R_{PV} + R_{WT} + R_{BESS} + R_{FC}) \quad (I)$$

Equation I is rearranged as

$$R_{loss} = 365 \times \delta_{loss} \times \sum_{k=1}^{24} P_{loss}(k) \quad (II)$$

$$R_{Grid} = 365 \times \delta_{Grid} \times \sum_{k=1}^{24} P_{Grid}(k) \quad (III)$$

$$\left. \begin{aligned} R_{PV} &= R_{PV}^I + R_{PV}^{O,M} \\ R_{PV}^I &= cf \times \delta_{PV} \times p_{r,PV} \\ R_{PV}^{O,M} &= \delta_{PV}^{O,M} \times \sum_{k=1}^{24} P_{PV}(k) \end{aligned} \right\} \quad (IV)$$

$$\left. \begin{aligned} R_{WT} &= R_{WT}^I + R_{WT}^{O,M} \\ R_{WT}^I &= cf \times \delta_{WT} \times p_{r,WT} \\ R_{WT}^{O,M} &= \delta_{WT}^{O,M} \times \sum_{k=1}^{24} P_{WT}(k) \end{aligned} \right\} \quad (V)$$

$$cf = \frac{\psi \times (1 + \psi_{PV,WT,DG,B,FC})^{np_{PV,WT,DG,B,FC}}}{(1 + \psi_{PV,WT,DG,B,FC})^{np_{PV,WT,DG,B,FC}} - 1} \quad (VI)$$

In Equations I to VI, the cost of obtaining electricity from the grid is represented by δ_{Grid} , and the cost of energy loss is represented by δ_{O} . The costs for maintaining and operating the PV unit and WTs are indicated by $\delta_{PV}^{O,M}$ and $\delta_{WT}^{O,M}$, respectively. The PV system and WTs installation costs are represented by R_{PV}^I and R_{WT}^I , respectively, and are expressed in ₹/kW. The $\psi_{PV,WT}$ represents the combined installed costs of the PV system and the WTs. $np_{PV,WT}$ is the equivalent portion of time that a PV system or WTs operates at full output capacity, and cf stands for the capital recovery factor.

2.1.2. Enhancement of voltage profile

The system's performance would be enhanced by the decrease in voltage fluctuations. N is the total number

of buses in the grid, and V_n is the voltage of the n -th bus. This can be achieved by minimizing voltage level variations, which will enhance the system's overall dependability and efficiency.²⁶

$$\sum VD = \sum_{k=1}^{24} \sum_{m=1}^N |(V_n - 1)| \quad (VII)$$

2.1.3. Voltage stability improvement

The third goal function emphasizes raising the voltage stability index (vs_i) to its maximum value in order to enhance stability. This index serves as a metric to assess and improve the system's overall voltage stability,²⁷⁻²⁹ making it possible for the system to function more dependably and robustly across a range of operating conditions.

$V_{si} =$

$$vs_i = |V_i|^4 - 4(p_i X_{i,j} - q_i R_{i,j})^2 - 4(p_i X_{i,j} + q_i R_{i,j}) |V_i|^2 \quad (VIII)$$

$$\sum vs_i = \sum_{k=1}^{24} \sum_{m=1}^N vs_{i_m} \quad (IX)$$

In Equations VIII and IX, the symbol R_{ij} is the existing resistance of the transmission line between the buses i and j . The code $X_{i,j}$, indicates the transmission line's reactance between buses i and j . At bus i , injective active power is represented by the symbol p_i . The symbol q_i stands for power injection at bus i .

2.2. Constraints of the proposed energy system

2.2.1. Limitations of inequalities

The inequality limitations of the proposed system vary from minimum to maximum of voltage, current, and power. The associated equation for the inequality limitations is given by Equations X to XIII.

$$V_{\min} \leq V_n \leq V_{\max} \quad (X)$$

$$p_{sr} + p_{wr} \leq \sum_{i=1}^n p_{D,i} \quad (XI)$$

$$pf_{\min} \leq pf \leq pf_{\max} \quad (XII)$$

$$I_y \leq I_{\max,y}; y = 1, 2, 3, \dots, T \quad (XIII)$$

$$p_s + p_{PV} + p_{WT} = \sum_{i=1}^T p_{loss,i} + \sum_{i=1}^N P_{D,i} \quad (XIV)$$

$$q_s + q_{PV} + q_{WT} = \sum_{i=1}^T q_{loss,i} + \sum_{i=1}^N q_{D,i} \quad (XV)$$

In Equation XV, the p_s and q_s are active and reactive powers, respectively.

3. Proposed ZOA

Flowchart of ZOA algorithm is shown in Figure 2. The ZOA is used primarily to optimize REEM in microgrids. This strategy minimizes costs and reliance on fossil fuels, thereby minimizing greenhouse gas emissions. ZOA does this by dynamically adjusting energy production, distribution, and consumption. To improve the microgrid resilience and scalability across a variety of configurations, ZOA can adapt to changing circumstances. The findings of the simulation suggest that ZOA is more effective than other algorithms already in use, making it a potentially useful answer to a wide range of situations involving EM. The life cycle of American zebras unfolds through five distinct stages. These stages include the formation of random zebra groups, feeding activity among American zebras, breeding behavior, the establishment of group leadership, and the subsequent stage of leadership transition involving the selection of a new leader. The mathematical representation of these stages is defined as Equation XVI.³⁰

$$Z_j^{\circ k} = \begin{cases} 2R_1 \sin(2\pi R_2) \times (Z_s^k - Z_j^k) + Z_s^k; \text{if } R_3 < 0.5 \\ \forall i \in N_k \\ 2R_1 \cos(2\pi R_2) \times (Z_s^k - Z_j^k) + Z_s^k; \text{otherwise} \end{cases}$$

$$Z_j^k = \begin{cases} Z_j^{\circ k}; f_j^{\circ k} < f_j^k \\ Z_j^k; \text{otherwise} \end{cases}$$

$$R_2 = 1 - t \times \left(\frac{1}{T}\right)$$

(Stage 1 and Stage 2) (XVI)

$$Z_j^q = \text{Crossover}(Z_j^a, Z_k^b); \text{if } r < pc, j \neq k$$

$$Z_k^q = \text{Crossover}(Z_j^a, Z_k^c); \text{if } r \geq pc, j \neq l$$

$$\forall j, k, l \in N$$

$$Z_s^{\circ k} = \begin{cases} 2R_4 \sin(2\pi R_5) \times (WR - Z_s^k) + WR; \text{if } R_6 < 0.5; \\ 2R_4 \cos(2\pi R_5) \times (WR - Z_s^k) + WR; \text{otherwise} \end{cases} \quad (\text{Stage 3}) \quad (XVII)$$

$$Z_s^k = \begin{cases} Z_s^{\circ k}; f_s^{\circ k} < f_s^k \\ Z_s^k; \text{otherwise} \end{cases}$$

$$R_5 = 1 - t \times \left(\frac{1}{T}\right)$$

(Stage 4) (XVIII)

$$Z_s^k = \{Z_j^k, \text{if } F(Z_j^k) < F(Z_s^k); \forall j \in N_k\}$$

(Stage 5) (XIX)

In the described scenario, Z_s^k and Z_j^k denote the positions of the stallion and the j^{th} zebra within the k^{th} group, respectively. N_k represents the total number of members in the k^{th} group. R_1 is uniformly distributed random values ranging from -2 to 2 , influencing the feeding behavior of zebras at various angles around the group leader. R_2 represents an adaptive parameter computed using Equation XVI. R_3 is a random value uniformly distributed between 0 and 1 . The functions \sin and \cos aid in the movement of other members at multiple angles around the family leader. $Z_j^{\circ k}$ represents the updated position of the j^{th} member during feeding, with F_j^k indicating its corresponding fitness value. Furthermore, Z_j^a represents the position of a baby zebra from the j^{th} group, Z_k^b denotes the position of zebra b from the j^{th} group, Z_l^c represents the position of zebra l from the l^{th} group, and Z_k^q and Z_l^q are the positions of zebras q in the k^{th} and l^{th} groups, respectively. R_4 is a uniformly distributed random number between -2 and 2 , while R_5 signifies an adaptive parameter calculated using Equation XIX. R_6 is another uniformly distributed random number ranging from 0 to 1 ; WR represents the water reserves; Z_s^k denotes the current position of the leading stallion in the j^{th} group, while $Z_s^{\circ k}$ represents its next position, with F_s^k representing its fitness value.

4. Simulation results

The goal of this paper's proposed ZOA for microgrid REEM is to minimize the capacity of distributed generators powered by PV, WT, BESS, and H₂ fuel cell. The application considers scenarios with and without uncertainty. In this work, a comparison is made between

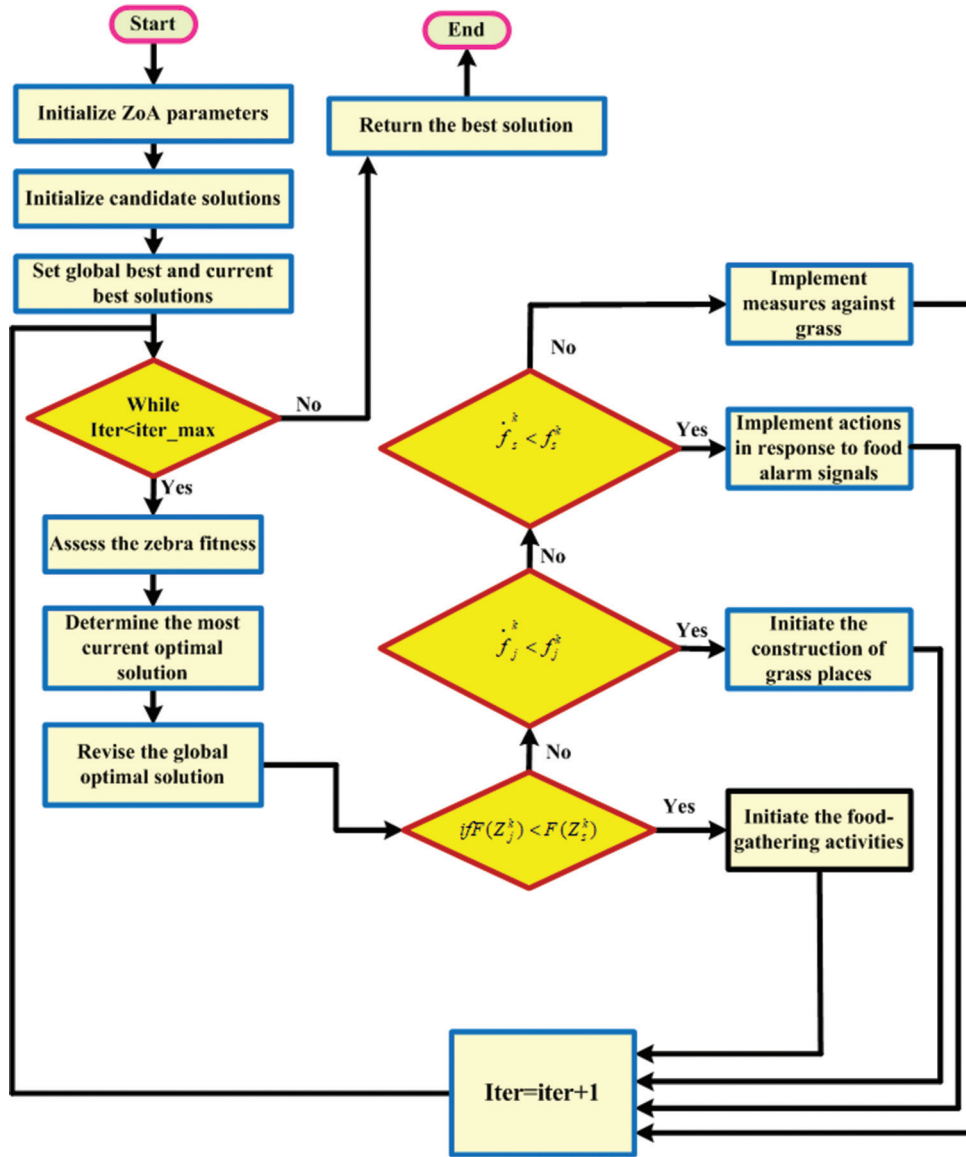


Figure 2. Flowchart of ZoA algorithm

the acquired findings and those from the moth-flame optimization algorithm (MFOA) and stochastic fractal search network (SFSN) to verify the effectiveness of the proposed method. The proposed approach is tested in the IEEE 13 bus system. Table 1 shows parameters for the different algorithms to observe the initial flow of the initial load. Grid specifications are given in Table 2.

4.1. REEM in deterministic conditions

The ZOA solves the REEM problem under deterministic conditions while accounting for input, output, and constraints. An analysis of time-varying market prices, solar irradiance load profile, and wind speed are evaluated for the performance of the proposed algorithm. The various profiles, including

Table 1. Selected parameters for the ZOA, MFOA, and SFSN algorithms

Algorithm	Parameters
ZOA	$T_{max}=150, R_1=10, R_2=20, R_3=30$ and $R_4=50$
MFOA	$T_{max}=150$, search agents=20, $a_1=2, a_2=2, G.p=0.5$
SFSN	$T_{max}=150$, search agents=50

Abbreviations: MFOA: Moth-flame optimization algorithm; SFSN: Stochastic fractal search network; ZOA: Zebra optimization algorithm.

the percentage of load, solar irradiance, wind speed, and market price over a 24-h period, are shown in Figure 3A-D, respectively.

The voltage profiles with and without RERs are shown in Figure 4, and when the RERs were optimally integrated, the voltage profiles significantly improved.

Table 2. Grid specifications

Specification	Value
Voltage in p.u (minimum)	0.9344
Voltage drop in p.u	0.38
Real load in kW	4
Reactive power in KVAR	3.9
Losses in kW of the grid	20

Table 3. Results of MGs under various conditions

Specification	Without RERs	With RERs
Losses (kWh)	1.45688×10^5	9.8650×10^4
Procurement energy (kWh)	3.45787×10^6	2.9501×10^6
PV unit (kW)	0	386
Optimization size of the WT (kW)	0	60
Overall energy loss cost (\$)	8.74149×10^3	5.18867×10^3
Overall cost of procurement energy (\$)	3.54878×10^6	2.0951×10^6
Cost PV (\$)	0	4.83465×10^4
Cost of wind turbine (\$)	0	2.47426×10^4
Total cost (\$)	3.5575×10^6	2.17337×10^6

Abbreviations: MGs: Microgrids; PV: Photovoltaic; RERs: Renewable energy resources; WT: Wind turbine.

In terms of the defined objective functions, ZOA outperformed MFOA and SFSN, as shown in Table 3, which contrasts their results. The simulation results displayed in Table 4 were obtained by applying the Evolutionary ZOA, MFOA, and SFSN.

The losses, ideal sizes of the sustainable power sources and purchase cost of energy taken from the grid, and all-out cost are assessed through proposed calculation and with other standard improvement methods like SFSN and MFOA. The outcomes obviously show that the proposed ZOA calculation outperformed in all previously mentioned angles in any events when RERs were not thought of. Without integrating the environmentally friendly power assets, the general expense of the framework is to be \$89106, simultaneously considering the absolute expenses of sustainable power assets at \$427,700, \$456,700, and \$448,200 for ZOA, MFOA, and SFSN, respectively. In addition, Table 3 records the ideal sizes for PV, and WT units. Figure 5 shows an enhanced power quality in terms of active power loss (kW) with and without RER incorporation through proposed ZOA. When the solar irradiance or the wind speed changed, the PV unit's and WT's power outputs also changed, which can be seen in Figures 6 and 7, respectively. The goal capability union is achieved when ZOA, SFSN, and MFOA were utilized, which is portrayed in Figure 8. By the 30th emphasis, ZOA showed supporting assembly. This demonstrates that ZOA is an amazing asset for tracking down ideal answers for the predefined REEM issue.

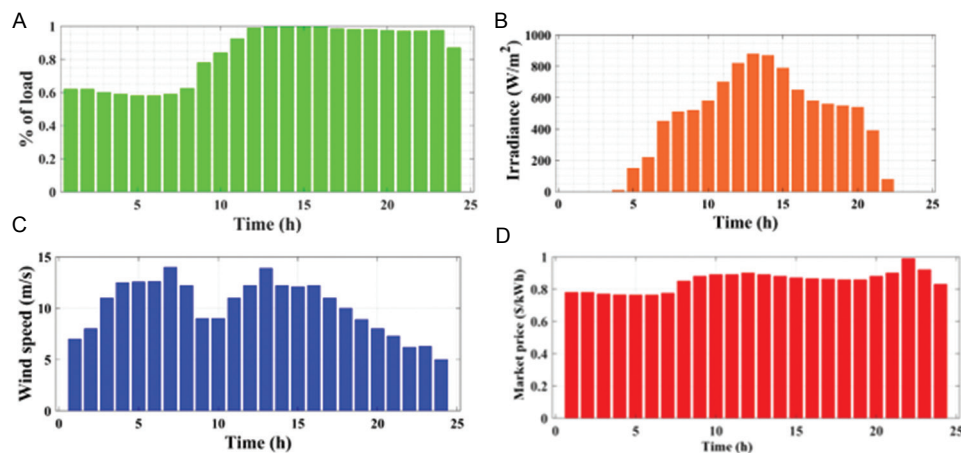


Figure 3. Load profile (A), solar irradiance (B), wind speed (C), market price (D)

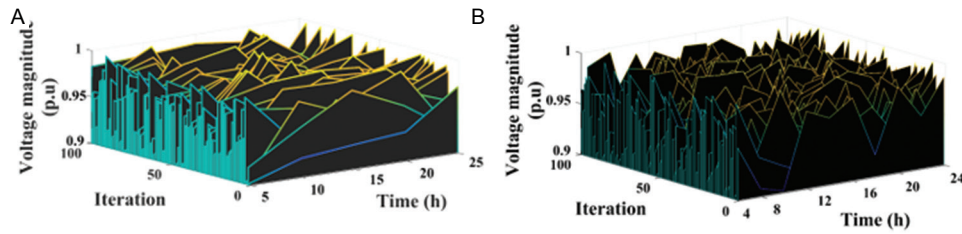


Figure 4. Voltage profiles of a microgrid: (A) Without RER (B) With RER
Abbreviation: RER: Renewable energy resource.

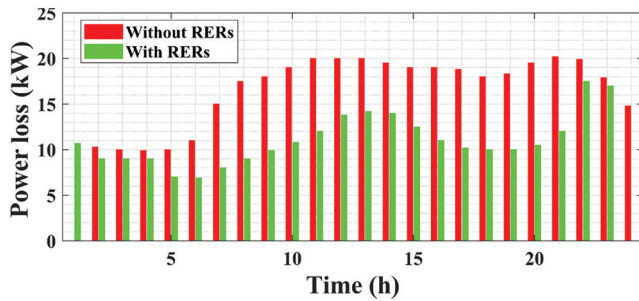


Figure 5. Active power loss (kW)
Abbreviation: RERs: Renewable energy resources.

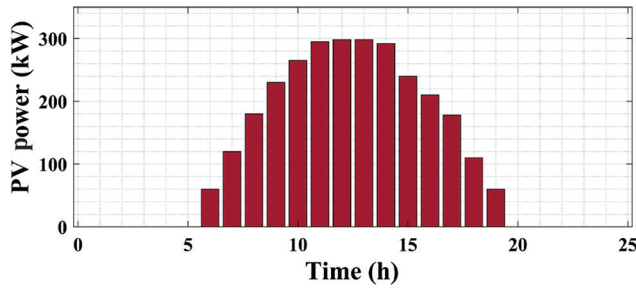


Figure 6. PV power profile
Abbreviation: PV: Photovoltaic.

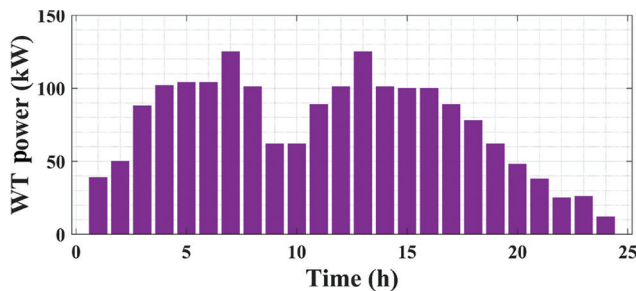


Figure 7. Active power of wind profile
Abbreviation: WT: Wind turbine.

4.2. Microgrid REEM in a probabilistic scenario
In this work, a method for managing microgrid REEM,

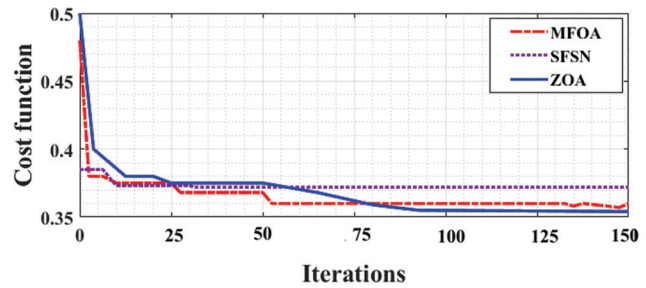


Figure 8. Objective function for MFOA, SFSN, and ZOA

Abbreviations: MFOA: Moth-flame optimization algorithm; SFSN: Stochastic fractal search network; ZOA: Zebra optimization algorithm.

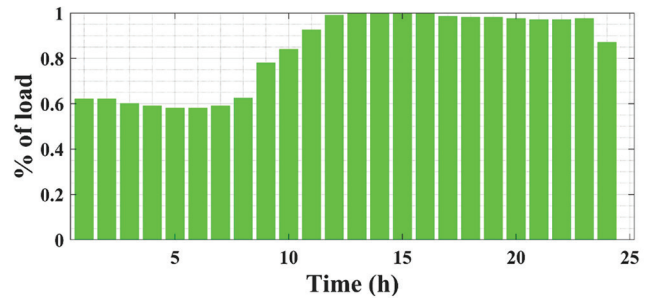


Figure 9. Forecasting of load profile under probabilistic conditions

which includes wind speed, solar power, and energy demand, is presented. Data on hourly energy demand, sunlight, and wind speed from 3 years are available for study. Wind speed, PV, and the heap profile are displayed in Figures 9 and 10, respectively. Table 5 shows the acquired ideal REEM results involving ZOA strategy in both the situations when RERs are incorporated and without even a trace of them. Without RERs, the general expense, absolute energy (kWh), and the cost of procurement energy from the substation are \$3,557,500, \$145,688, and \$3,548,780, respectively. Taking RERs

Table 4. Results of MGs under various conditions

Specification	Without RERs	ZOA	MFOA	SFSN
Energy losses (kWh)	1.4×10^5	7.434×10^4	7.98140×10^4	7.74459×10^4
The amount of procurement energy from substation (kWh)	3.2088×10^6	1.3802×10^6	1.5356×10^6	1.4434×10^6
PV unit (kW)	-	215	295	230
WT unit (kW)	-	147	135	208
Cost of energy loss (\$)	7.0341×10^3	4.7888×10^3	4.6876×10^3	4.6467×10^3
Cost of purchase energy (\$)	8.8403×10^5	3.1426×10^5	2.9426×10^5	3.0915×10^5
Cost PV (\$)	-	3.71928×10^4	3.23764×10^4	2.90563×10^4
Cost of wind turbine (\$)	-	7.15469×10^4	1.25469×10^5	1.05425×10^5
Total cost (\$)	0.89106×10^6	0.4277×10^6	0.4567×10^6	0.4482×10^6

Abbreviations: MFOA: Moth-flame optimization algorithm; MGs: Microgrids; PV: Photovoltaic; RERs: Renewable energy resources; SFSN: Stochastic fractal search Network; ZOA: Zebra optimization algorithm.

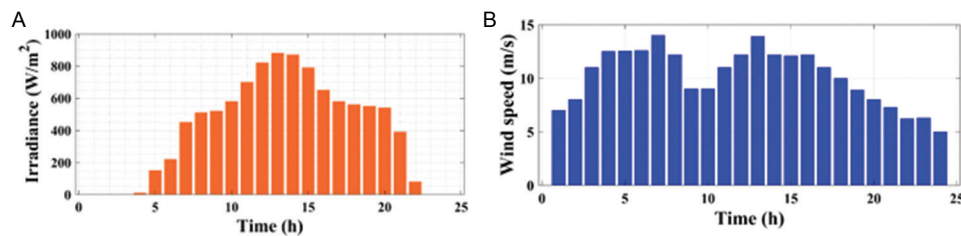


Figure 10. Input profile under probabilistic conditions: (A) PV solar irradiance, and (B) wind speed
Abbreviation: PV: Photovoltaic.

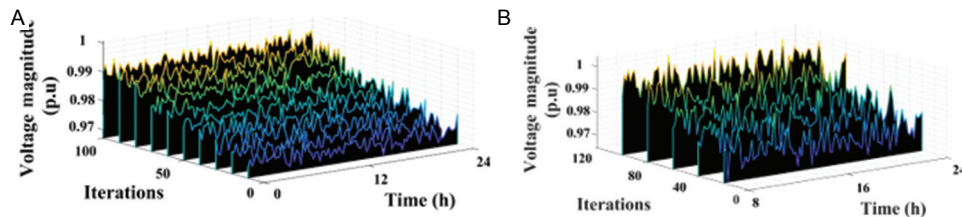


Figure 11. Per unit voltage of a microgrid under probabilistic conditions: (A) without RER, and (B) with RER
Abbreviation: RER: Renewable energy resource.

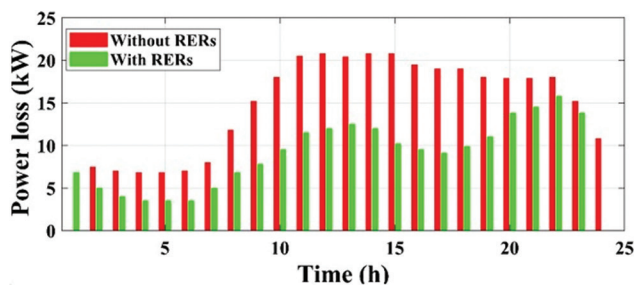


Figure 12. Power losses under probabilistic scenario

into consideration, the ideal sizes (kW) of the PV and WT are 386 and 60, respectively, which are recorded in Table 3. Figure 11 portrays the voltage profiles at various

emphasis with and without considering RERs under probabilistic circumstances. The proposed Ideal REEM, regardless of RERs, prompts a better voltage profile. Figure 12 further shows that RERs essentially cut down on power losses (kW). Figure 13A portrays the PV yield power and Figure 13B shows the WT yield power, with both fluctuating with PV illumination and wind speed (Figure 10). A correlation of the two variables uncovers that PV power changes with contrasts in irradiance while WT power changes with variations in turbine speed. Microgrid framework execution and sustainable asset use are both upgraded by the streamlined EM approach that considers vulnerabilities and the RER combination.

Efficient energy management in microgrid

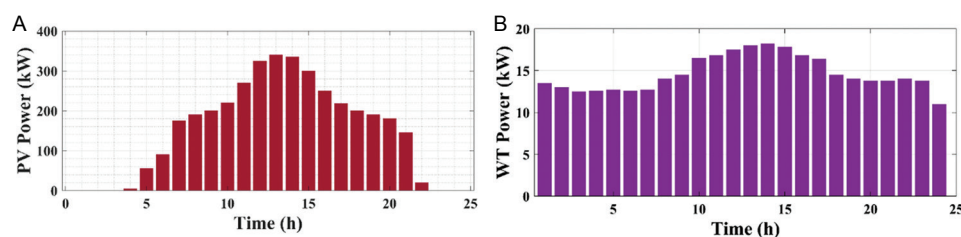


Figure 13. Electric powers for 24-h period: (A) PV, and (B) WT
Abbreviations: PV: Photovoltaic; WT: Wind turbine.

Table 5. REEM simulations of MGs under probabilistic scenario

Parameter	Without RERs	With RERs
The energy losses (kWh)	1.45688×10^5	9.8650×10^4
The procurement energy from the substation (kWh)	3.45787×10^6	2.9501×10^6
Optimization size of the PV unit (kW)	0	386
Optimization size of the WT	0	60
Overall Cost of energy loss (\$)	8.74149×10^3	5.18867×10^3
Cost of procurement energy (\$)	3.54878×10^6	2.0951×10^6
Cost PV (\$)	0	4.83465×10^4
Cost of Wind turbine (\$)	0	2.47426×10^4
Total cost (\$)	3.5575×10^6	2.17337×10^6

Abbreviations: REEM: Resource efficient energy management; RER: Renewable energy resources; MGs: Microgrids; PV: Photovoltaic; RERs: Renewable energy resources; WT: Wind turbine.

5. Conclusion

In this work, a challenge of REEM in a microgrid was addressed by consolidating PV and WT power frameworks in the most successful way. Under deterministic and probabilistic situations, the ZOA – a compelling streamlining strategy – was utilized to analyze changes sought after for loads, wind speed, PV, and market costs. The proposed ZOA approach further develops the voltage and cost profiles simultaneously following an attempt on developing a 12-transport microgrid framework. An examination was made between the ZOA calculation’s result and those of MFOA and SFSN. This examination adds as far as anyone is concerned of the advantages of the ZOA

methodology in microgrid REEM applications and features its better exhibition.

This paper exhibits the adequacy of ZOA in tending to difficulties with REEM in microgrids, providing evidence for its capability in streamlining microgrid tasks and its viability in deterministic and probabilistic situations. This features ZOA’s strength and flexibility in upgrading microgrid execution.

Ideal reconciliation of RERs into smart EM system (SEMS) has decreased by 52% in general expense under deterministic settings. Simultaneously, the absolute voltage profile has fundamentally dropped by 7.4949%. A critical 63.68% decrease in general expense is accomplished in a probabilistic situation by tending to SEMS through effective fusion of RERs. Simultaneously, the total voltage stability index has improved by 7.51 %.

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Conflict of interest

The authors declare that they have no competing interest.

Author contributions

Conceptualization: Dodda Aasha Vardhini
Investigation: Dodda Aasha Vardhini
Methodology: Jayaram Nakka
Writing–original draft: Dodda Aasha Vardhini
Writing–review & editing: Jayaram Nakka

Availability of data

Data are available from the corresponding author on reasonable request.

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