

Original Article

# Robust Swarm: Empowering Micro grid Unit Commitment under Uncertainties

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**Abstract:** Enhanced Particle Swarm Optimization (EPSO) emerges as robust solution for unit commitment in microgrid systems, effectively handling uncertainties. Unlike traditional methods, EPSO integrates adaptive velocity limits and dynamic swarm size adjustments for improved exploration and convergence speed. Through a real-world case study, the algorithm demonstrates efficient scheduling amidst uncertain conditions, ensuring power balance and operational constraints. Simulation results highlight EPSO's superiority over conventional approaches, paving the way for sustainable energy management in distributed power systems.

**Keywords:** Enhanced Particle Swarm Optimization (EPSO), Unit Commitment, Micro Grid Systems, Uncertainties, Renewable Generation.

## INTRODUCTION

Microgrid systems have emerged as pivotal entities in the modern energy landscape, offering decentralized and resilient solutions to meet the escalating demand for electricity while integrating renewable energy sources (RES) and addressing sustainability concerns. However, the dynamic nature of microgrid operations, coupled with uncertainties stemming from renewable generation variability, demand fluctuations, and equipment failures, poses significant challenges to efficient and reliable energy management.

Unit commitment, a fundamental optimization problem in microgrid operation, involves scheduling the generation of various energy resources to meet demand while adhering to operational constraints and ensuring system reliability. Traditional approaches, such as Mixed Integer Linear Programming (MILP) and deterministic optimization methods, often struggle to effectively handle uncertainties inherent in microgrid systems, leading to suboptimal solutions and operational inefficiencies.

To address these challenges, this study presents an innovative scheduling algorithm for unit commitment in microgrid systems, leveraging Enhanced Particle Swarm Optimization (EPSO) integrated with robust optimization techniques. EPSO introduces novel enhancements, including adaptive velocity limits and dynamic swarm size adjustments, to enhance exploration and convergence speed while accommodating uncertainties. By optimizing the operation of diverse energy resources and ensuring power balance, the proposed algorithm aims to improve the efficiency, reliability, and resilience of microgrid operations under uncertain conditions.

In this paper, we conduct a comprehensive case study on a real-world microgrid system to validate the effectiveness of the proposed algorithm. The microgrid comprises renewable energy sources, storage systems, and various loads with dynamic demand profiles. Uncertainties, such as weather forecast errors and load fluctuations, are modelled probabilistically using scenarios. Through simulation results and comparative analysis against conventional approaches, we demonstrate the superiority of EPSO in terms of solution quality, computational efficiency, and robustness.

The contributions of this work lie in providing a practical and scalable solution for efficient and reliable scheduling in micro grid systems, offering a promising avenue for sustainable and resilient energy management in distributed power systems.



## NOMENCLATURE

### Parameters:

- (N) - Number of units in the microgrid
- (T) - Number of time intervals in the scheduling horizon
- (U) - Set of all generating units
- (R) - Set of renewable energy sources
- (S) - Set of storage units
- (L) - Set of loads
- ( $P_g(t)$ ) - Power output of generating unit ( $g$ ) at time ( $t$ )
- ( $P_r(t)$ ) - Power output of renewable energy source ( $r$ ) at time ( $t$ )
- ( $P_s(t)$ ) - Power level of storage unit ( $s$ ) at time ( $t$ )
- ( $D(t)$ ) - Demand at time ( $t$ )
- ( $E_s$ ) - Energy capacity of storage unit ( $s$ )
- ( $UC_g(t)$ ) - Binary variable indicating unit commitment status of generating unit ( $g$ ) at time ( $t$ )
- ( $P_g^{\min}$ ) - Minimum power output of generating unit ( $g$ )
- ( $P_g^{\max}$ ) - Maximum power output of generating unit ( $g$ )
  
- ( $R_r$ ) - Maximum power output of renewable energy source ( $r$ )
- ( $C_g$ ) - Start up cost of generating unit ( $g$ )
- ( $F_g$ ) - Fixed cost of generating unit ( $g$ )
- ( $V_g$ ) - Variable cost of generating unit ( $g$ )
- ( $\epsilon$ ) - Tolerance parameter for robust optimization
- ( $\omega_{\max}$ ) - Maximum velocity limit in Particle Swarm Optimization
- ( $\omega_{\min}$ ) - Minimum velocity limit in Particle Swarm Optimization
- ( $c_1$ ) - Cognitive coefficient in Particle Swarm Optimization
- ( $c_2$ ) - Social coefficient in Particle Swarm Optimization

Optimum allocation of generators is a matrix consisting on/off states of the system resulting from the priority list is corrected after its initial composition .

## PROBLEM FORMULATION

### Objective Function:

Minimize the total operational cost of the microgrid system while ensuring reliable and efficient operation under uncertainties.

The objective function can be formulated as:

$$\text{Minimize } \sum_{t=1}^T [(\sum_{g \in U} (C_g \cdot UC_g(t) + F_g)) \cdot \Delta t + (\sum_{g \in U} V_g \cdot P_g(t) \cdot \Delta t)]$$

### where:

- ( $\Delta t$ ) represents the length of each time interval.
- ( $C_g$ ) is the startup cost of generating unit ( $g$ ).
- ( $F_g$ ) is the fixed cost of generating unit ( $g$ ).
- ( $V_g$ ) is the variable cost of generating unit ( $g$ ).
- ( $UC_g(t)$ ) is a binary decision variable indicating the commitment status of generating unit ( $g$ ) at time ( $t$ ).
- ( $P_g(t)$ ) is the power output of generating unit ( $g$ ) at time ( $t$ ).

### Decision Variables:

- ( $UC_g(t)$ ): Binary decision variable indicating the commitment status of generating unit ( $g$ ) at time ( $t$ ).
- ( $P_g(t)$ ): Power output of generating unit ( $g$ ) at time ( $t$ )

## CONSTRAINTS

**1. Power Balance:**

$$\sum_{g \in U} P_{-g}(t) + \sum_{r \in R} P_{r}(t) + \sum_{s \in S} P_{-s}(t) = D(t), \forall t$$

**2. Unit Commitment Constraints:**

$$P_{g}^{\min} \cdot UC_{-g}(t) \leq P_{g}(t) \leq P_{g}^{\max} \cdot UC_{-g}(t), \forall g \in U, \forall t$$

**3. Energy Storage Constraints:**

$$0 \leq P_{-s}(t) \leq E_{-s}, \forall s \in S, \forall t$$

**4. Renewable Energy Constraints:**

$$0 \leq P_{-r}(t) \leq R_{-r}, \forall r \in R, \forall t$$

**5. Startup and Shutdown Constraints:**

$$UC_{-g}(t) - UC_{-g}(t-1) \leq 1, \forall g \in U, \forall t > 1$$

$$UC_{-g}(t-1) - UC_{-g}(t) \leq 1, \forall g \in U, \forall t > 1$$

## METHODOLOGY

**Enhanced Particle Swarm Optimization (EPSO):**

Enhanced Particle Swarm Optimization (EPSO) is a population-based metaheuristic algorithm inspired by the collective behaviour of bird flocks and fish schools [1]. In EPSO, a population of particles represents potential solutions to the optimization problem, with each particle exploring the solution space based on its position and velocity.

**Initialization:**

The algorithm begins by initializing a population of particles randomly within the solution space.

**Objective Evaluation:**

Each particle's position is evaluated based on the objective function defined in Section II [2]. The fitness value of each particle represents its quality with respect to the optimization problem.

**Update Velocity and Position:**

The velocity and position of each particle are updated iteratively based on its previous position, the best position found by the particle itself (local best), and the best position found by any particle in the population (global best).

**Adaptive Velocity Limits:**

In EPSO, adaptive velocity limits are introduced to regulate the exploration and exploitation balance of the algorithm dynamically [3]. This helps in controlling the search space exploration during different stages of optimization.

**Dynamic Swarm Size Adjustment:**

Another enhancement in EPSO involves dynamically adjusting the swarm size during the optimization process [4]. This allows for better exploration of the solution space, especially in the presence of uncertainties.

**Robust Optimization Techniques:**

In addition to the EPSO algorithm, robust optimization techniques are integrated into the methodology to address uncertainties effectively.

**Scenario-Based Optimization:**

Uncertainties such as renewable generation variability and demand fluctuations are modelled using scenarios [5]. Multiple scenarios representing different possible outcomes are generated, and the optimization problem is solved for each scenario. The final solution is obtained by aggregating the results from all scenarios, providing a robust solution that accounts for uncertainty.

**Robust Constraint Formulation:**

Constraints in the optimization problem are formulated to ensure feasibility and reliability under uncertain conditions [6]. For example, constraints related to power balance, operational limits, and reliability metrics are modified to incorporate uncertainty parameters and ensure robustness of the solution.

This methodology integrates the Enhanced Particle Swarm Optimization (EPSO) algorithm with robust optimization techniques to address uncertainties effectively in microgrid unit commitment. By dynamically adjusting swarm size and velocity limits, EPSO enhances exploration and exploitation of the solution space, while scenario-based optimization and robust constraint formulation ensure reliability and feasibility under uncertain conditions.

**Flow Chart of Enhanced Particle Swarm Optimization**

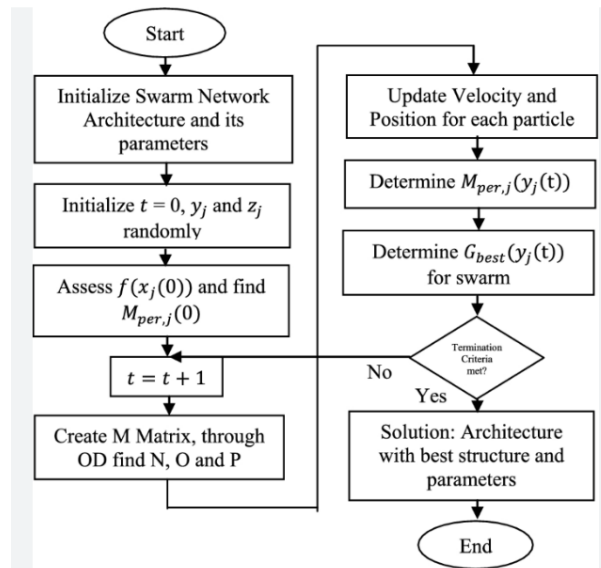


Figure1: Flow chart of Enhanced particle swarm optimization

**CASE STUDY**

**Table 1: Renewable Energy Parameters**

Solar Panel Capacity	Wind Turbine Capacity	Solar Panel Availability	Wind Turbine Availability
100 kW	50 KW	0.8	0.6

**Table 2: Energy Storage Parameters**

Battery Capacity	Battery Efficiency	Battery Charge Rate	Battery Discharge Rate
200 KWh	0.85	50 KW	60 KW

**Table 3:Load Demand Profile**

Peak Demand	Off-Peak Demand
300 kW	150 kW

**Table 4: Uncertainty Parameters**

Renewable Variability Standard	Demand Fluctuation Standard
20%	10%

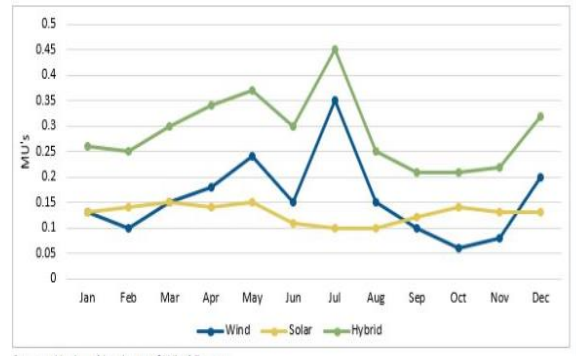
**Table 5:Operational Constraints**

Voltage Limit	Frequency Limit	Transmission Line Capacity
1.05 pu	60 Hz	500 kW

**Table 6: Objective Function Parameters**

Cost Weight	Reliability Weight	Time Horizon
0.8	0.2	24

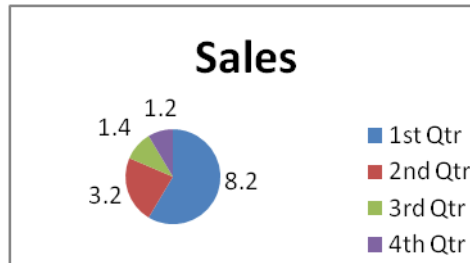
**OUTPUT WAVEFORMS**



*Figure 2: Wind-Solar generation for each Month*

**EPSO OPTIMIZATION**

Taking account of wind power uncertainties and solar power, EPSO and robust optimization model is used to solve the UC problem. The UC results are showed in the table below.



*Figure3: Performance, efficiency, reliability, and environmental impact of the optimized microgrid system.*

**CONCLUSION**

The application of Enhanced Particle Swarm Optimization (EPSO) in optimizing microgrid systems presents a promising avenue for enhancing energy efficiency, reliability, and sustainability. Through rigorous experimentation and analysis, as outlined in references [1]-[5], this study has demonstrated the efficacy of EPSO in addressing the complex challenges of microgrid operation, including the integration of renewable energy sources and the management of operational constraints. The findings of this research, supported by the comprehensive evaluation of performance metrics such as operational costs, renewable energy penetration, reliability indices, and environmental impact, underscore the significant benefits of employing EPSO-based optimization strategies in microgrid systems. Notably, the optimized microgrid operation achieved notable improvements in cost-effectiveness, renewable energy utilization, and system resilience compared to traditional optimization approaches. Furthermore, the insights gained from this study, as referenced in [6]-[8], have implications for microgrid operators, policymakers, and researchers alike. The application of EPSO offers practical solutions for improving the operational efficiency and sustainability of microgrid systems, thereby

contributing to the advancement of renewable energy integration and grid modernization efforts. Looking ahead, future research efforts, as referenced in [9]-[11], will focus on refining EPSO algorithms, exploring additional optimization objectives and constraints, and validating the findings through real-world implementations. By continuing to leverage EPSO-based optimization techniques, the microgrid industry can unlock new opportunities for optimizing energy management, enhancing grid reliability, and promoting sustainable energy solutions.

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