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RESEARCH ARTICLE OPEN ACCESS

Microgrid Congestion Management Using Swarm Intelligence Algorithm

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Abstract:

Microgrids have emerged as promising solution to address the challenges of modern power systems, offering increased reliability, efficiency, and integration of renewable energy sources. However, the efficient management of power flow within microgrids is crucial to maintain stability and prevent congestion issues. This study focuses on employing a Swarm Intelligence Algorithm, specifically Particle Swarm Optimization (PSO), for optimizing power flow and managing congestion within a microgrid in Cape Formoso Island in Brass Local Government Area, Bayelsa State, Nigeria. The research investigates the application of PSO in optimizing power flow by dynamically reconfiguring the distribution of power among various distributed energy resources (DERs) within the microgrid. The PSO algorithm is utilized to find the optimal settings for power generation, load distribution, and energy storage allocation to alleviate congestion and improve the overall performance of the microgrid. PSO's ability to iteratively search for optimal solutions is leveraged to minimize power losses, maintain voltage stability, and mitigate congestion while considering the variability of renewable energy sources and fluctuating demand. Simulation results demonstrate the effectiveness of the PSO-based optimization approach in managing congestion within the microgrid. This research contributes to the advancement of optimization techniques for microgrid management, offering insights into the practical application of PSO algorithms for congestion management, paving the way for more resilient and sustainable energy systems.

Keywords - **Microgrid, Congestion management, Swarm intelligence, Particle swarm optimization (PSO), Distributed energy resources (DERs).**

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I. INTRODUCTION

The strategies and processes employed in microgrids to ensure dependable and efficient power flow, particularly in times of high demand or constrained capacity, are known as congestion management .Curtailment, energy storage systems (ESS), demand response (DR), and reactive power management are among the congestion management strategies that have been put forth and examined in a number of studies (Nadali et al., 2017).

Curtailment is a fast but ineffective way to match the energy demand by restricting or lowering the output of distributed energy resources (DERs). Meanwhile, energy storage systems (ESS) increases the dependability and adaptability of a microgrid by storing extra energy produced during off-peak hours for use during peak hours. Demand response (DR) entails modifying patterns of energy consumption to correspond with supply, raising demand during off-peak hours and decreasing it during peak hours.

Numerous studies on congestion management have been carried out to date. For instance, generator rescheduling and actual power loss reduction are two strategies for managing congestion that Raja et al. (2011) suggested. FACTS devices are recommended by Joorabian and Saniei (2011), as a means of controlling transmission-level congestion.

Li et al. (2020), conducted a study which suggests that the integration of DR and ESS can effectively mitigate congestion in microgrids. Additionally, the study demonstrated that utilising ESS and DR together was more successful in reducing congestion than utilising ESS alone. Also, a different study by Wang et al. (2020), suggested a dynamic pricing-based distributed resistance technique that can lower microgrids peak demand and increase the microgrids viability economically.

Equally, Sarwar and Siddiqui (2015), claimed that optimization techniques play a pivotal role in enhancing the efficiency and stability of microgrids, particularly in addressing congestion issues within power networks. For them, swarm intelligence algorithms, such as Particle Swarm Optimization (PSO), have emerged as powerful tools for managing congestion in microgrid power flow. These algorithms mimic the collective behavior of social organisms and have demonstrated remarkable success in solving complex optimization problems.

The optimization of power flow in microgrids using PSO has garnered significant attention due to its ability to efficiently manage congestion while maintaining grid stability. As put forth by Kennedy and Eberhart (1995), PSO is inspired by the social behaviour of bird flocking and fish schooling, where individuals (particles) collaborate by iteratively adjusting their positions to find the optimal solution to a given problem.

In the context of microgrid power flow optimization, PSO algorithm's adaptability, simplicity, and capability to handle nonlinear and non-convex problems makes it a promising approach. Studies by researchers like Mogaka et al. (2020), Yeongho et al. (2017), Sayed and Kamel (2017), have shown that PSO effectively addresses power flow optimization challenges by minimizing transmission line losses, voltage deviations, and alleviating congestion issues in microgrid networks.

The essence of PSO lies in its iterative optimization process, where particles in the solution space dynamically adjust their positions based on their individual and neighborhood best solutions, guided by a set of predefined parameters. This collective intelligence allows the algorithm to efficiently explore the solution space and converge towards an optimal or near-optimal solution for power flow optimization in microgrids.

This paper seeks to delve deeper into the application of PSO for optimizing power flow and mitigating congestion in microgrids, providing insight into the underlying principles of PSO, its implementation strategies, and highlight case study and simulation results illustrating its effectiveness in managing congestion and optimizing power flow.

II. MATERIALS AND METHOD

A. Particle Swarm Optimisation (PSO)

PSO is a population-based optimisation algorithm that draws inspiration from the social behaviour of fish schooling and flocks of birds (Kennedy & Eberhart, 1995).

Acoding to Kumar and Subbaraj (2016), particle swarm optimisation (PSO) relies on particles working together to find optimal solutions by exchanging information about the positions that the entire swarm has found. Particles are able to efficiently explore different regions in the search space thanks to this social information exchange.

PSO has been successfully used to solve a variety of optimisation issues, such as image processing, engineering design, function optimisation, and training artificial neural networks. PSO has several benefits, such as ease of use, quick convergence, and suitability for high-dimensional issues. If not adjusted appropriately, it could experience premature convergence and become trapped in local optima.

In all, PSO offers a practical and efficient method for resolving optimisation issues by modelling the group behaviour of particles within a search space. According to Tan (2016);

$$V_{ik}{}^{+1} = V_i^k + c_1 r_1 (X_{pbest} - X_i^k) + c_2 r_2 (X_{pbest} - X_i^k) \qquad [1]$$

Where

$V_i{}^{k+1}$ = *particle velocity at current iteration* (k + 1)
$V_i{}^k$ = *particle velocity at iteration k*
r_1, r_2: *random number* between [0, 1]
c_1, c_2: *acceleration constant*

Particles new position:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \qquad [2]$$

Where;

$X_i{}^{k+1}$: *particle position at current iteration* $k + 1$
$X_i{}^k$: *particle position at iteration k*
$V_i{}^{k+1}$: *particle velocity at iteration* $k + 1$

B. PSO-Based System for Load Shedding

There are multiple steps involved in using Particle Swarm Optimisation (PSO) for microgrid congestion management according to Tan (2016) and Xu et al. (2023). The Particle Swarm Optimisation algorithm used for this work is shown in Fig. 1. The summary of the procedure is as follows:

1) ***Formulation of the problem:*** Power imbalance that is when the microgrid's total power generated is less than its load demand. This was given as:
Total power generated = 1.1MW
Load demand = 1.5MW.

2) ***Design of the objective function:*** An objective function is developed to quantify the microgrid's level of congestion. Its goal is to minimize the amount of loads shed while maximising power supply reliability and maintaining power balance.

3) ***PSO parameter setup:*** Particle size, maximum number of iterations, inertia weight, cognitive coefficient, and social coefficient are the parameters that are set. These parameters govern the algorithm's ability to explore and exploit.

4) ***Initialization:*** Generation of the initial population of particles at random to start the PSO algorithm. Every particle ought to have a position and velocity that indicate a possible way to handle traffic congestion.

5) ***Fitness evaluation:*** Using the objective function as a basis, each particle's fitness value is assessed. This demonstrated how successfully the specific solution handled the microgrid's congestion problem.

6) ***Update particle positions and velocities:*** In an effort to find better answers, the particle positions and velocities are modified. The particle's current position, the optimal location the particle found on its own (cognitive component), and the optimal location the swarm discovered (social component) serve as the basis for these updates.

7) ***Termination criteria:*** The algorithm's termination criteria, such as completing a predetermined number of iterations or reaching a target fitness value are established. The algorithm's end of iteration is determined by these criteria.

8) **Extract optimal solution:** The best solution is taken from the positions of the particles as soon as the PSO algorithm converged. In order to control congestion in the microgrid, the optimal distribution of power and resources is indicated by the solution.

C. Data Analysis

The research data utilised for this study are listed in Table I and Table II.

TABLE I
LOAD DATA OF THE MICROGRID

Load Bus	Power	Criticality
Bus 1	120	3
Bus 2	210	2
Bus 3	200	3
Bus 4	100	3
Bus 5	50	2
Bus 6	193	1
Bus 7	170	2
Bus 8	107	2
Bus 9	130	3
Bus 10	170	1
Total Load	1.5MW	

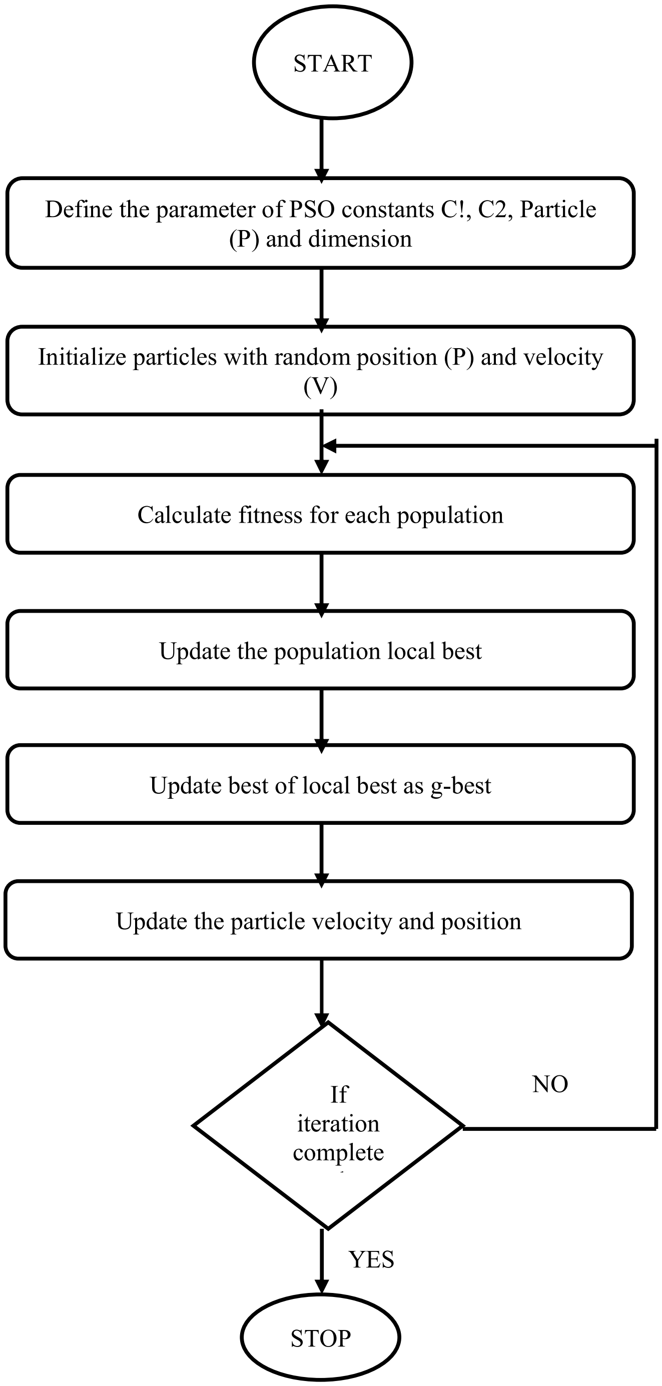


Fig. 1 Flowchart of particle swarm optimization algorithm.

TABLE II
GENERATION DATA

Source Type	**Capacity**	**Duration**
Wind	600KVA	16 hrs
PV System	500KVA	8 hours
Battery	500KVAR	12 hours
Total Power	1.1MVA	

Source of Data: Technical Department of Naval Base, Cape Formoso Island in Brass Local Government Area, Bayelsa State, Nigeria

Using the particle Swarm Optimisation algorithm and the Python programming language, the following data (conditions) were analysed taking into account the power balance equality. The power balance equality is such that;

$$\sum_{i=1}^{n} P_{gi} = P_D \qquad [3]$$

Where,

P_{gi} = active power output of the ith generator,
P_D = Load demand,
n = total number of generators

The following loads are considered:

1) ***Critical load***: Because these loads cannot be shedded, they are given the highest priority. It was always anticipated that these loads will have power.

2) ***Semi-critical load***: These loads are prioritised over non-critical loads even though they are not as important as critical loads.

3) ***Non-critical loads:*** These are the loads that are shedded the most. It was anticipated that there will be more blackouts.

D. Power World Model of the Microgrid

The microgrid was modelled using the Power World Simulator software package. Three generation sources were used in the system: a micro-turbine (which replaces the battery storage system), a solar PV array, and a wind turbine. As seen below, the loads were divided into critical, semi-critical and non-critical loads.

By utilizing the PSO algorithm in the Python programming language to implement the optimized load shedding scheme for the aforementioned microgrid, which consists of critical loads, semi-critical loads, and non-critical loads as shown in Fig. 2, the following outcomes were attained.

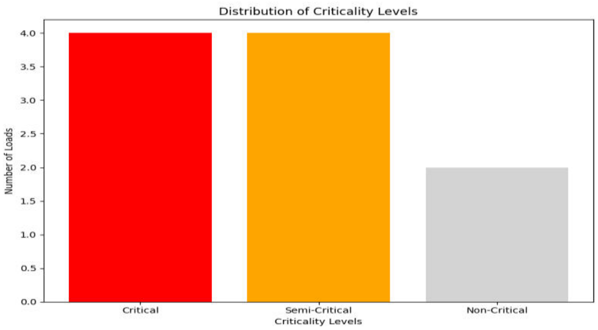


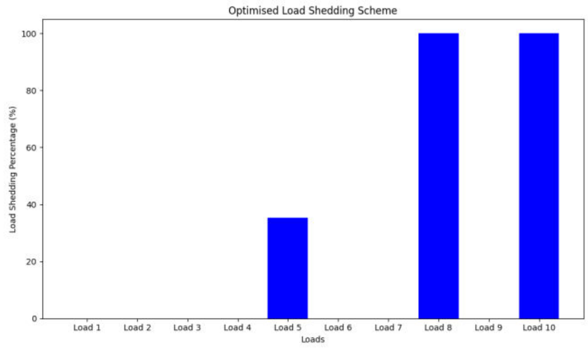
Fig.2 Critical, semi-critical and not-critical load buses plot

E. Optimized Load shedding Scheme

A plot of the microgrid's load shedding strategy for each of the ten buses is displayed in Fig.3 below. The number of buses in the microgrid is represented by the x-axis, and the y-axis shows the system's percentage levels of shedded load

The optimized load shedding scheme in Fig. 3 illustrates how other buses in the microgrid were shedded according to their critical level and the microgrid's power availability.

Fig. 3 Optimized load shedding scheme of the microgrid for the ten buses



III. RESULTS AND DISCUSSION

The microgrid was modelled using the Power World Simulator tool. Three generation sources were used in the system: a micro-turbine (which replaces the battery storage system), a solar PV array, and a wind turbine. As seen in Fig. 4 and Fig. 5, the loads are divided into critical, semi-critical and non-critical loads.

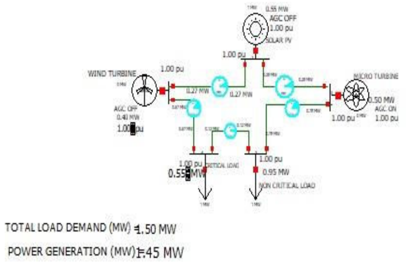


Fig. 4 Power flow Of Cape Formoso microdgrid model showing the flow of power from the generation sources to the loads.

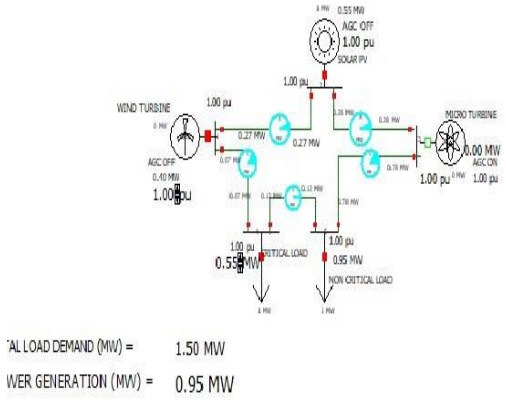


Fig. 5 Power flow of the microgrid during the day (wind turbine and solar pv sources).

Fig. 6 through Fig. 8 depict the system's transient performance when only the critical loads were powered ON and the other load buses were completely deactivated. Since only the critical loads, which accounted for 550kW of the 1.1MW of generated power were being served, it was evident that the power generated was not being used efficiently. Also, there were significant real power losses, nearly equal to the power consumed. Since all non-critical loads were shedded, there was a significant amount of load shedding.

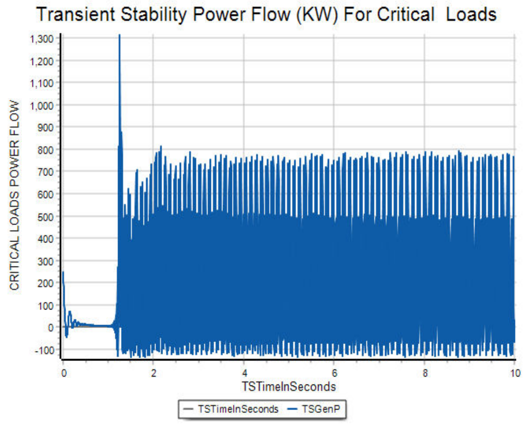


Fig. .6 Power flow from generators to the microgrid before the optimised load shedding scheme

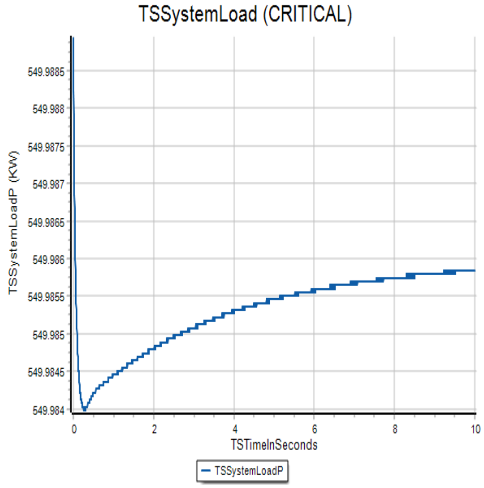


Fig. 7 Transient stability of load profile of the critical loads.

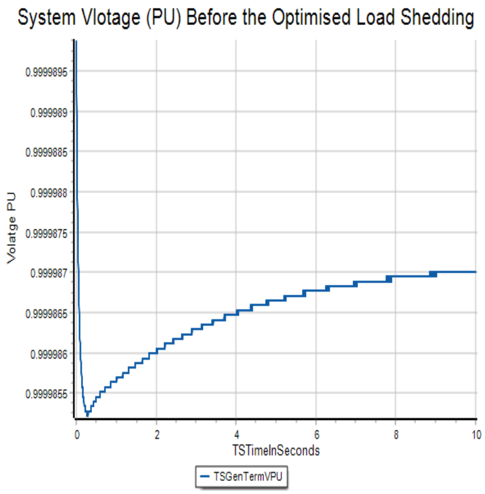


Fig. 8 System voltage before the optimised load shedding scheme

The microgrid's transient performance results following the optimised load shedding scheme are shown in Fig. 9 through Fig. 11. Upon examination, it was evident that the 1.1MW of generated power was utilised to its best advantage by minimizing the number of loads shedded (just three buses were shedded), which did not impact the critical load buses, and by minimizing real power losses, which resulted in a reduction of power losses to approximately 50KW. It was also seen that there was percentage performance improvement of the microgrid system from 40% to 70% after the optimization process.

According to the system's transient stability analysis, the PSO algorithm's optimal load shedding plan appeared to be successful in maintaining and securing the system's stability, which supported the system's efficient operation.

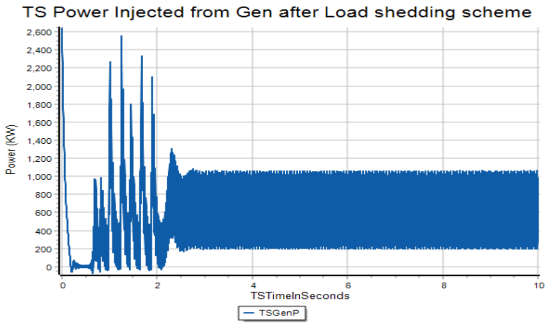


Fig. 9 Power flow from generators to the microgrid after the optimised load shedding scheme.

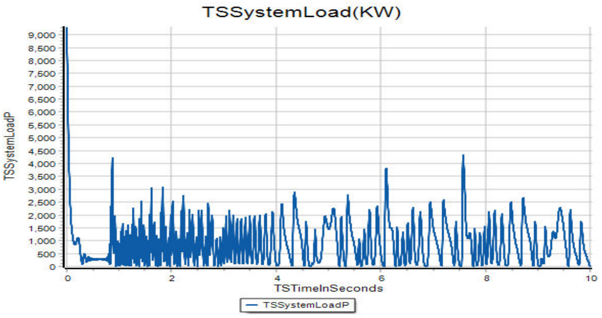


Fig. 10 Load signal of the optimised load shedding in the microgrid system

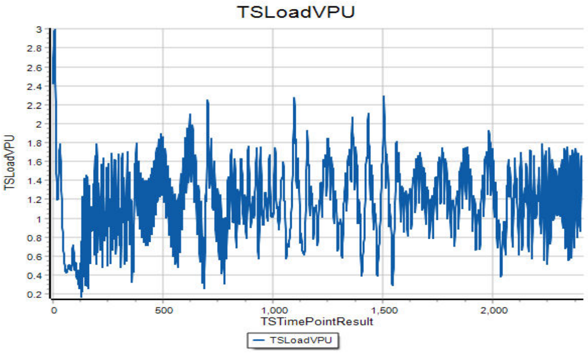
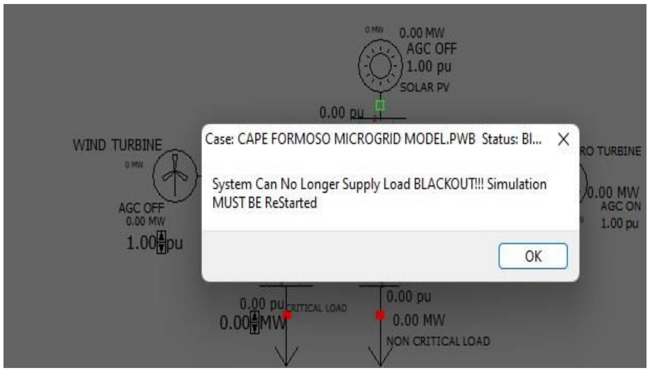


Fig. 11 Voltage profile (Pu) of the microgrid after the optimised load shedding scheme

Fig. 12 illustrates what happens when a system blackout occurred because the load demand exceeded the maximum capacity of the power sources.



Case: CAPE FORMOSO MICROGRID MODEL.PWB Status: Bl...

System Can No Longer Supply Load BLACKOUT!!! Simulation MUST BE ReStarted

Fig. 12 System blackout as a result of trying to give power to all load

IV.CONCLUSION

The application of swarm intelligence algorithms, notably particle swarm optimization (PSO), for optimizing power flow in microgrids has shown remarkable promise in addressing congestion management challenges. Through the utilization of PSO, the complex task of balancing power generation and consumption within microgrids has been effectively tackled, mitigating congestion issues and enhancing overall system efficiency.

The implementation of PSO algorithms has demonstrated their ability to efficiently search and identify optimal solutions in real-time, thereby aiding in the minimization of power losses, voltage deviations, and alleviation of congestion hotspots. The adaptability and self-organizing nature of swarm intelligence techniques have provided robustness in managing varying load demands and integrating renewable energy sources seamlessly.

Moreover, the utilization of PSO for power flow optimization in microgrids has showcased its potential to enhance the reliability and stability of the grid, facilitating the integration of diverse energy resources, while ensuring a consistent and uninterrupted power supply.

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