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Power Loss Reduction in Distribution System Via ETAP Analysis and PSO Algorithm

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ABSTRACT

This paper proposes a power flow optimization method for distribution networks using the Particle Swarm Optimization (PSO) algorithm. The primary objective is to determine the optimal placement and sizing of distributed generation (DG) units to minimize active power losses and improve voltage profiles across the system. The IEEE 33-bus test system is simulated in MATLAB/Simulink, and the results are compared with conventional load flow analysis conducted in ETAP software. The PSO-based approach demonstrates superior performance in reducing total power losses and enhancing voltage stability, while also achieving faster computational time. These results highlight PSO as a promising tool for planning and operating modern power distribution systems. Furthermore, the paper discusses the advantages, limitations, and practical applicability of the algorithm in real-world power systems.

Keywords: ETAP software, distributed generation, power system, particle swarm optimization.

1. INTRODUCTION

The problem of optimizing the placement and sizing of distributed generation (DG) units in distribution systems has been the focus of extensive research over the past decades and will likely remain relevant as long as energy demand continues to grow. Most existing approaches aim to determine the optimal DG configuration with the primary objectives of minimizing power losses and enhancing voltage profiles [1]. Various studies have demonstrated that the integration of DG can significantly reduce energy losses and improve power quality, including voltage regulation, waveform integrity, and frequency stability [2], [3]. To prevent economic losses and mitigate voltage distortions that may compromise system stability, minimizing power loss and maintaining voltage quality are critical considerations in distribution system operation. Therefore, ongoing research into determining the optimal location and capacity of DG units in distribution networks remains essential.

The study in [4] highlights that integrating distributed generation (DG) into radial distribution systems, which were originally designed without local generation, can considerably affect power flow and voltage conditions for both consumers and utility assets. Depending on the characteristics of the DG units and the operational features of the distribution network, these impacts may be either positive or negative [5], [6]. As a result, researchers have extensively investigated optimal DG placement and sizing within distribution systems to achieve various technical and operational objectives.

To simulate power flow and current distribution across the transmission lines of a distribution network, several software tools are commonly employed for research and analysis, such as MATLAB/Simulink, PowerWorld, and ETAP. Among them, MATLAB/Simulink is widely used in academic and advanced research, while ETAP stands out for its practical and industry-oriented applications [7]. In this paper, the author investigates and compares the characteristics and responses of both MATLAB/Simulink and ETAP in simulating the IEEE 33-bus distribution system.

ETAP is a comprehensive software platform that offers an integrated suite of solutions for power system analysis, ranging from arc flash studies, load flow, short-circuit analysis, and transient stability, to relay coordination, cable ampacity, optimal power flow, and beyond. Its modular structure allows flexible customization to meet the requirements of organizations of all sizes, from small facilities to large-scale power networks.

The computational capabilities of ETAP include:

- Performing short-circuit analysis under various fault scenarios.
- Simulating the startup and shutdown processes of motors and generators.
- Assessing the influence of harmonics and disturbances on transmission lines.
- Investigating power system stability under dynamic conditions.
- Integrating protection devices to ensure system safety.
- Improve the efficiency of power flow in the system.
- Evaluate the reliability of power supply.
- Adjust reactive power to achieve maximum efficiency.
- Perform grounding system design calculations.
- Carry out calculations for underground cable projects.
- Develop control circuits for the system.
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2. DETERMINING THE OPTIMAL LOCATION AND CAPACITY OF DG USING THE PSO ALGORITHM

Particle Swarm Optimization (PSO) is a population-based algorithm that models swarm intelligence, inspired by the collective foraging and social behavior observed in birds, fish, and other biological populations [8], [9].

Input the data and collect the required parameters for the problem, then initialize a population of particles with random positions and velocities [10]-[12].

$$\theta_i = \theta_{\{i,\backslash min\}} + \backslash text\{random\}\left(\theta_{\{i,\backslash max\}} - \theta_{\{i,\backslash min\}}\right) \ (1)$$

$$\Omega_j = \Omega_{\{j,\backslash min\}} + \backslash text\{random\}\left(\Omega_{\{j,\backslash max\}} - \Omega_{\{j,\backslash min\}}\right) \ (2)$$

Where: $\theta_{i,min}$ and $\theta_{i,max}$ are the minimum and maximum position limits of a particle, respectively; $\mho_{i,min}$ and $\mho_{i,max}$ are the minimum and maximum velocity limits of a particle, respectively.

Through the process of evaluating the solution quality based on the objective function, the velocity and position of each particle are updated according to equations (3) and (4):

$$\Omega_{\{j,i\}}^{\{new\}} = \omega, \Omega_{\{j,i\}} + c_1 r_1\left(P_{\{best,i\}} - \theta_i\right) + c_2 r_2\left(G_{\{best,i\}} - \theta_i\right) \ (3)$$

$$\theta_i^{\{new\}} = \theta_i + \Omega_{\{j,i\}}^{\{new\}} \ (4)$$

Where: $\theta_{i,new}$ is the updated velocity of particle i in the current iteration; θ_i is the velocity of particle i in the previous iteration; ω is the inertia weight; c_1, c_2 are the coefficients; r_1,r_2 are random numbers in the $\mho_{i,new}$ range; is the updated position of particle i in the current iteration.

The fitness function is shown as:

$$\sum P_{loss} = \min\left(\sum_{i=1}^{n} R_i I_i^2\right) \qquad (1)$$

Where: R_i is the resistance of branch i; I_i is the current flowing through branch i; P_{loss} is the active power loss in the distribution network.

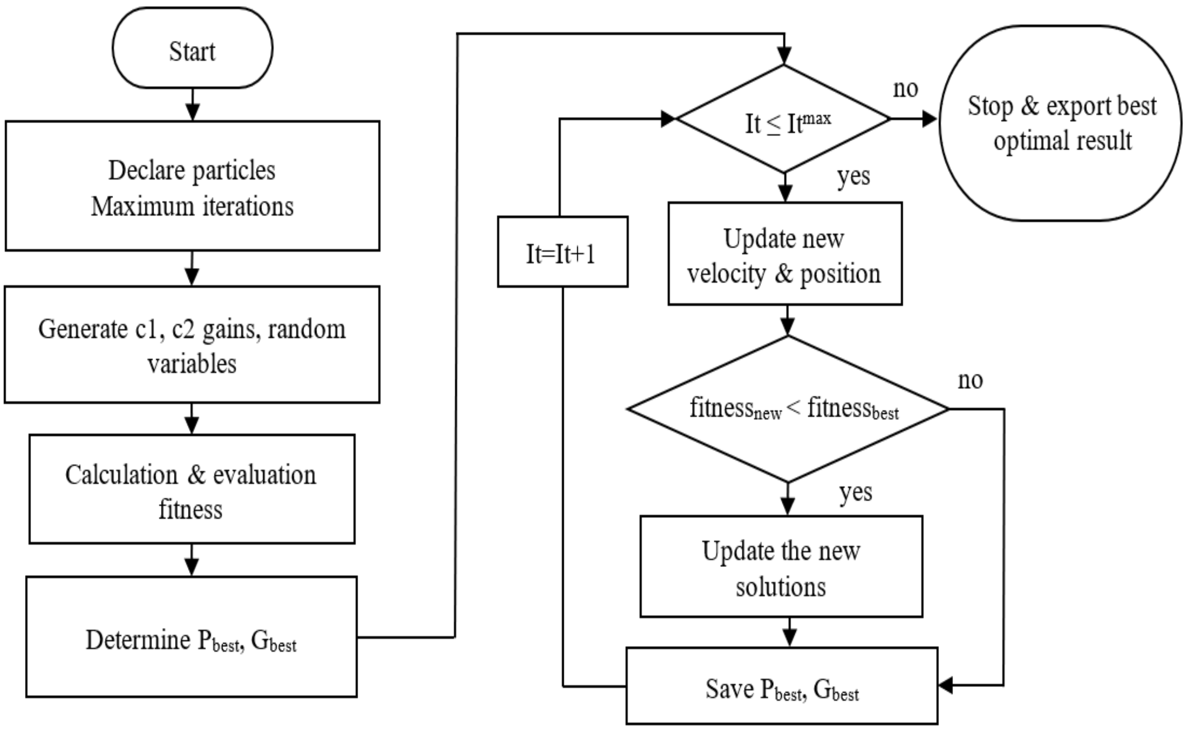

Fig. 1. Flowchart of finding optimal solution of PSO algorithm

3. SIMULATION RESULTS

3.1 Case study 1: Simulation of the power system on ETAP software without DG

The simulation is carried out by dragging and dropping the power system components in ETAP. The parameters of each component are then entered, and the elements are interconnected to form a complete 33-bus distribution network.

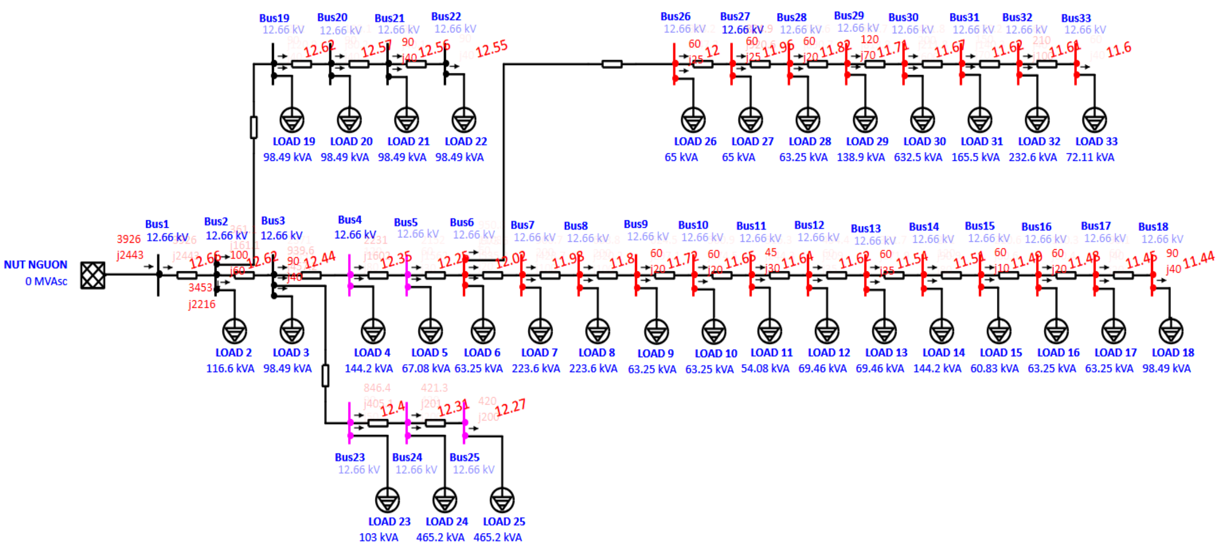

Fig. 2. Simulation of the IEEE 33-bus system on ETAP software

As shown in **Fig.3**, the bus voltages vary across different nodes due to the influence of conductor cross-sections and the length of each line.

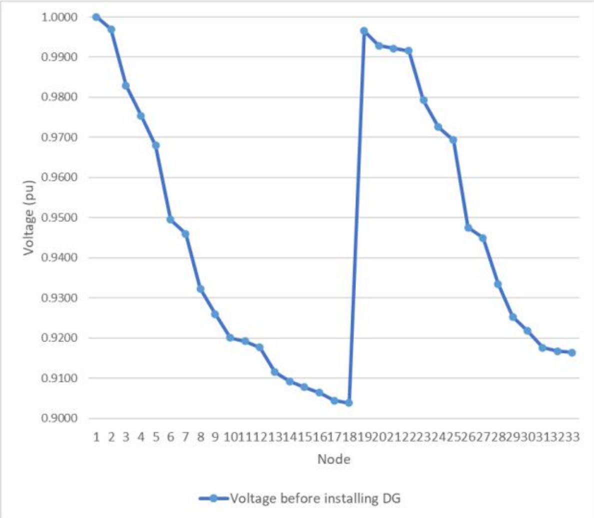

Fig. 3. Voltage graph at 33 nodes without DG

Fig.4 illustrates the distribution of active power on each line, from which the total active power loss is calculated to be 211 kW. This loss value will later be compared with Case 2, where a DG is integrated into the system to reduce overall losses.

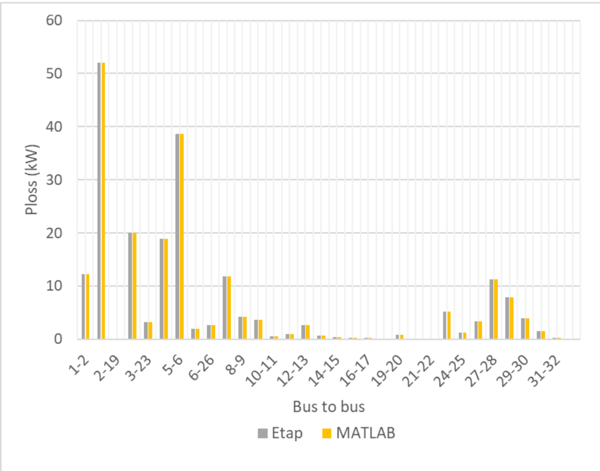

Fig. 4. Active power loss on each line without DG

Furthermore, the figures indicate that power losses are greater on lines closer to the source, whereas bus voltages decrease as the distance from the source increases.

3.2 Case study 2: Simulation of the power system on MATLAB/Simulink with one DG

The accuracy of PSO results depends on the number of particles, iterations, and runs defined. Too few values may lead to large errors, while excessively large values significantly increase computation time. Therefore, several cases are examined to balance accuracy and efficiency, and the optimal values are selected accordingly. The results are presented in **Table 1**.

Table 1. Convergence with different number of solutions and iterations

Scenario	1	2	3	4
Number of run	50			
Solutions, iterations	20 & 20	20 & 30	30 & 40	50 & 50
DG (kW)	2590,92	2589,73	2589,88	2590,21
P_{loss} (kW)	111,643	111,296	111,126	111,044
Deviation	0,775	0,421	0,314	0,059

It can be observed that the total active power loss of the system is 111.044 kW with 50 runs, using 50 particles and 50 iterations of the algorithm. In this case, the total DG capacity obtained is 2590.21 kW. Scenario 4 is identified as the most optimal case, with the smallest standard deviation. The results of the four scenarios are presented in **Table 1** and **Fig.5**.

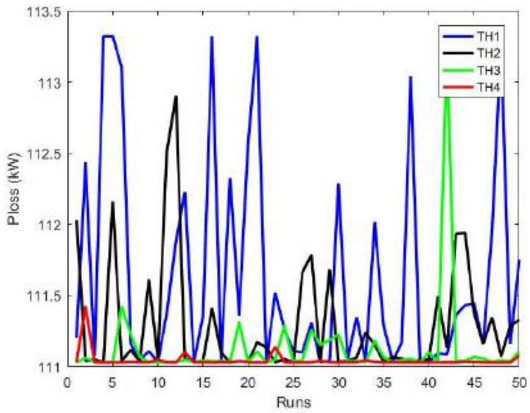

Fig. 5. P_{loss} plot with different number of solutions and iterations

The case 4 is selected to determine the optimal bus and capacity of the IEEE 33-bus system with the installation of one DG. In addition, the convergence characteristics of Case 4 are examined and illustrated in **Fig.6**.

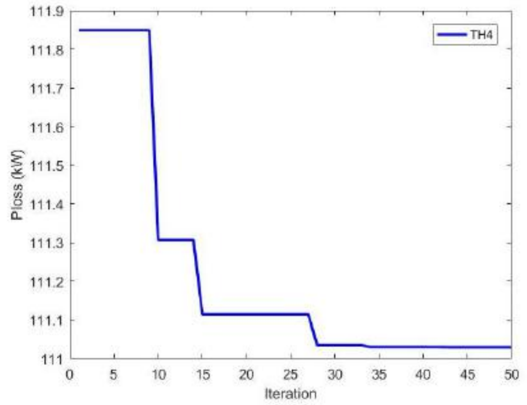

Fig. 6. The graph of convergence process at the optimal value of the PSO algorithm

After running the PSO algorithm, the optimal location is identified as Bus 6, with an optimal capacity of 2590.21 kW. The bus voltages before and after installing one DG are presented in **Fig.7**.

Fig. 7. Voltage graph at 33 nodes before and after installing 1 DG

After installing a DG in the power system, it can be observed that the total power losses on the distribution lines are significantly reduced, while the voltage profile is also improved compared to the pre-installation condition. This demonstrates the effectiveness of the PSO algorithm in optimizing the distribution system.

To further validate the accuracy of the results, the outcomes obtained from the PSO algorithm are compared with those calculated using ETAP. The comparison demonstrates a consistent and reasonable agreement between the two methods, providing additional evidence of the effectiveness and reliability of PSO in improving distribution system performance. The results are presented as:

Table 2. Results of P_{loss} on MATLAB and ETAP

DG location	DG capacity	P_{loss} (kW)	
		ETAP	PSO
6	2590,2099	111,12	111,0299

4. CONCLUSIONS

This paper has presented the application of the Particle Swarm Optimization (PSO) algorithm to optimize the performance of a distribution system by determining the optimal location and capacity of distributed generation (DG). The IEEE 33-bus system was modeled in MATLAB/Simulink, and the results were compared with those obtained from ETAP software.

The findings indicate that PSO effectively reduces active power losses and improves the voltage profile of the system. In particular, installing a DG at the optimal bus significantly enhanced network performance, with power losses reduced and bus voltages maintained within acceptable limits. The comparison with ETAP results demonstrated strong consistency, validating both the accuracy and reliability of the proposed approach.

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