



Optimal placement of distributed products to improve network reliability under network operation conditions

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Abstract: Considering the study of optimal location of distributed units to improve network reliability under network operation conditions and the focus on using the genetic algorithm method for locating distributed generation units in the distribution system, there is no comprehensive and relevant research in this field. In this research, to improve network reliability, location with variable numbers and sizes of distributed generation resources is performed. In the proposed method, multi-objective optimization using weight coefficients to combine two objective functions as the overall objective function is used.

Keywords: Positioning, Reliability, Disteributed Generation, Bus.

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1. Introduction

In today's electricity distribution networks, especially with the growing trend of privatization and competitiveness of the electricity market, the primary goal of electricity distribution companies is to reduce the costs related to operation, maintenance, and network construction while increasing reliability [1]. One of the most effective ways to respond to load growth and also provide a certain level of reliability is to use distributed generation resources. With the advancement of technology, increasing the efficiency and reducing the cost of distributed generation technologies, as well as harmonizing these products for the economic criteria of reconstructed power systems such as low risk and competitive market, the role of distributed generation resources is expected [2]. The use of distributed generation resources can be one of the effective ways to get rid of some problems such as high losses, poor power quality, and density in power systems. In addition, the low capacity of distributed generation resources makes it easier to design and install these units in a short period of time compared to using large and centralized units. Dispersed products can be used as active power compensation in the network, just as a capacitor is used to compensate reactive power [3]. Given the nature of distributed generation, distribution networks are the most suitable part for connecting these sources to the power system. Also, given the increasing penetration of distributed generation sources in distribution systems, one of the important goals is to achieve their maximum value by optimally locating distributed generation

sources, reducing losses and improving the network voltage profile. Studies show that the wrong choice of location and capacity of distributed generation sources can cause more network losses than before the installation of the distributed generation source. Also, optimal placement and determination of the appropriate capacity of the distributed generation source can free up line capacity. Hence the new investment costs, which are both heavier and have a longer period than the installation of the distributed generation source [4].

In this research, a new hybrid algorithm based on GA and PSO is used to optimally locate distributed units based on the cost function measurement related to the installation and commissioning of distributed generation sources in order to improve network reliability under network operating conditions. This estimation is investigated with the help of quantitative and qualitative level of network losses, quantitative and qualitative level of network voltage profile and optimal location of distributed units in order to improve network reliability under network operating conditions. The studied systems are also structurally asymmetric and the number of distributed generation sources to be located is also considered variable. In addition, multi-objective optimization concepts (Parato) are used to locate distributed generation sources in the studied networks.

2. Simulation

This section uses the IEEE-RBTS 6 test system to check if the research method works and is accurate. A diagram shows the

updated active distributed network, which has 23 load branches. These branches include circuit breakers, distribution transformers, and loads. The system also contains 30 lines, 4 circuit breakers, and 1 segment switch. Four identical distributed generation sources, each with a 10 MW wind turbine (WT) and an 8 MW distributed unit, are connected to nodes 13, 19, 24, and 28. Also, the installed capacity of WT and distributed unit in each distributed generation source is 10 and 8 MW, respectively.

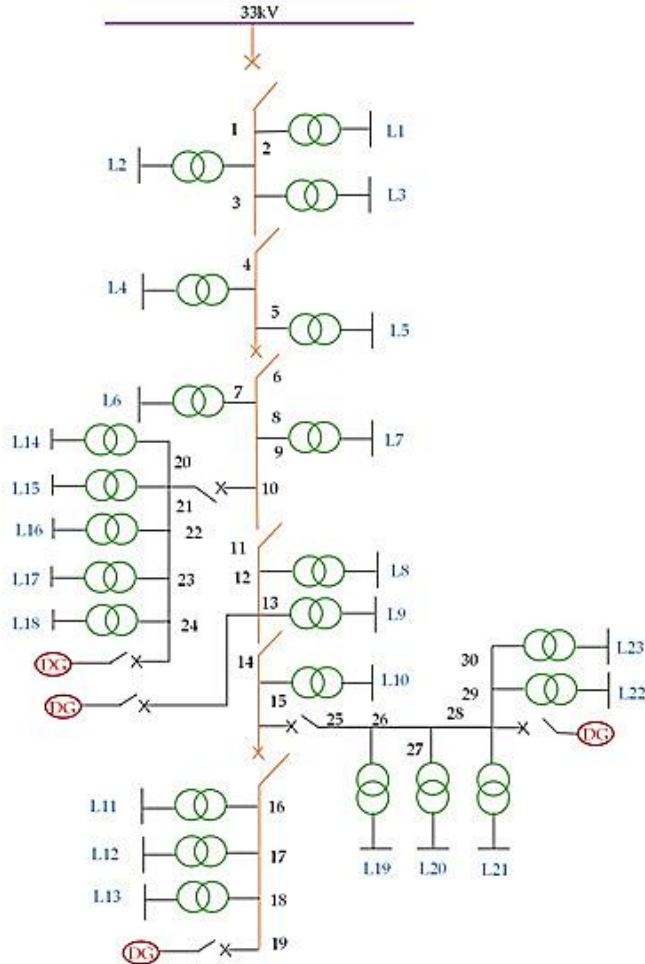


Figure 1. Distribution network reliability testing system diagram

Table 1 presents the raw load data, which is categorized by importance into Class I (safe load), Class II, and Class III (mostly auxiliary load). Class I is the highest priority and is shed last, while Class III is shed first if power is insufficient. The system's feeder failure rate is 0.048 times/(year*km), and the switch failure rate is 0.006 times/year, with a 3-hour average repair time for both. Feeder lengths are detailed in Table 2. MATLAB was used for simulations.

Table 1: Loading data

Load Level	Number of Load Points	Number of Users
First Class Load	L ₅	132
First Class Load	L ₇ , L ₂₃	1
First Class Load	L ₉ , L ₂₁	1
Second Class Load	L ₁ , L ₆	147

Second Class Load	L ₁₅ , L ₂₀	1
Second Class Load	L ₁₀ , L ₁₂ , L ₁₆ , L ₂₂	76
Third Class Load	L ₂	126
Third Class Load	L ₄ , L ₁₈	1
Third Class Load	L ₁₇ , L ₁₃ , L ₇	1
Third Class Load	L ₁₄ , L ₁₉ , L ₈ , L ₁₁	79

Table 2: Feeder section length

Length / km	Feeder number
0.5	7,13,30
0.75	1,4,6,9
0.8	2,3
0.85	5,8,10,15,18,20,23,24,28
1.0	11,12,16,22
1.3	14,17,19,27
1.5	21,25,26,29

3. Research scenarios

Figure 2 illustrates four likely scenarios, selected by an improved PSO algorithm, that represent typical daily load patterns. These scenarios are numbered 1 through 4, with scenario 1 having the highest probability and scenario 4 the lowest. Scenario 0 does not include renewable energy. While the distributed generation resources have the same capacity across all scenarios, their operational modes vary.

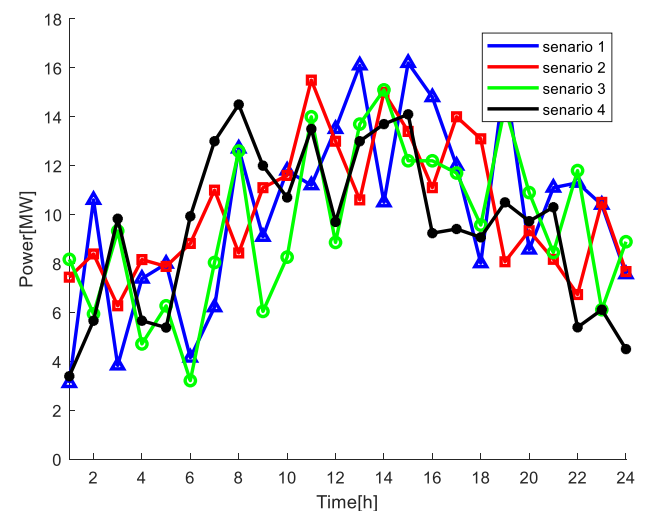


Figure 2. Loading under typical scenarios

Scenario 1's results are important because it's the most probable. Daily electrical load magnitudes were measured by dividing the day into 24 hourly intervals. The load curves show significant fluctuations throughout the day in typical scenarios, with a noticeable peak-to-valley difference between scenarios. Low

electricity consumption occurs between 4 am and 6 am, while peak load power is between 12 pm and 5 pm. Many load power points overlap across different scenarios, indicating the representativeness of the chosen typical scenarios.

An improved PSO algorithm also generated typical daily scenarios for wind generation (WG) and distributed unit output, characterizing their output uncertainty. Unlike load, distributed generation resource output sampling considers both operational and power states to simulate this uncertainty. Figures 4-3 and 5 show these typical scenarios. Figure 5a shows significantly higher WG power output from 0 to 4 o'clock due to wind speed variations, with similar fluctuations across scenarios. Figure 5b shows concentrated distributed unit output between 10 am and 2 pm, coinciding with high light intensity. Distributed unit output is zero between 1 am and 5 am and after 7 pm due to zero light intensity.

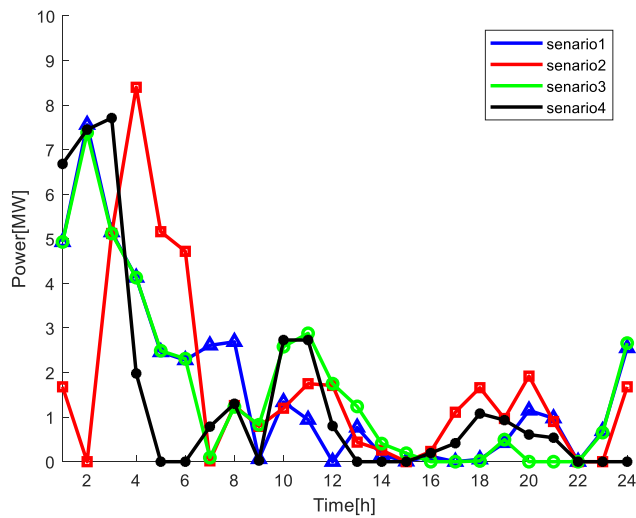


Figure 3. Output power under typical scenarios: (WG)

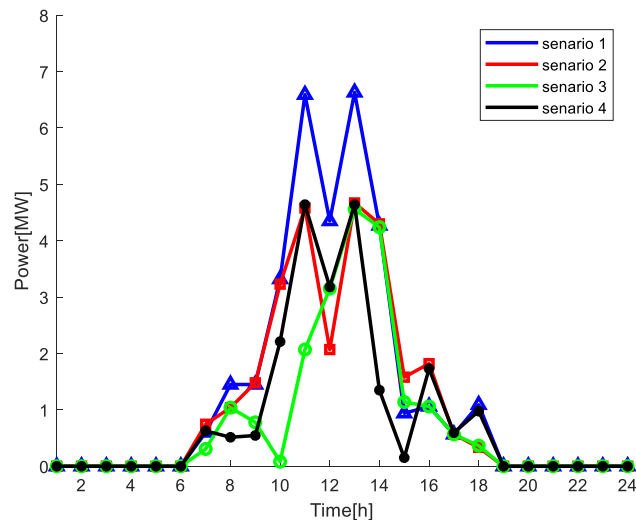


Figure 4. Output power under typical distributed unit scenarios.

To fully assess how uncertainty affects active distribution network reliability, four typical scenarios were created based on load, wind generation (WG), and distributed unit combinations. Figures 5 and 6 present these scenarios, ordered from highest probability to lowest, with Scenario 1 being the most likely.

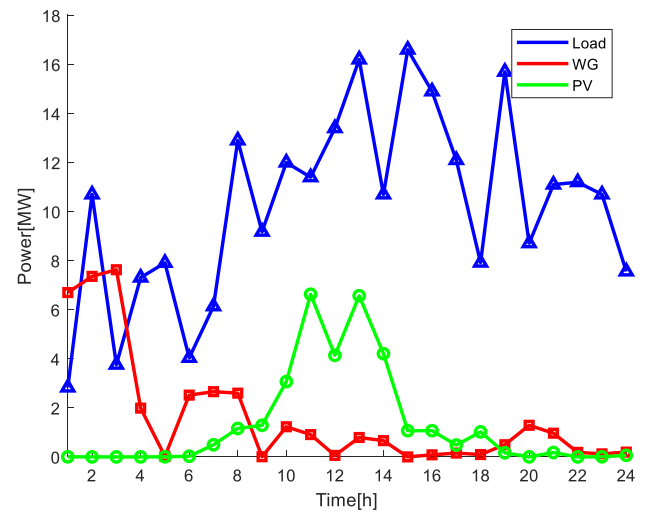


Figure 5. Distribution network under typical scenarios: Scenario 1

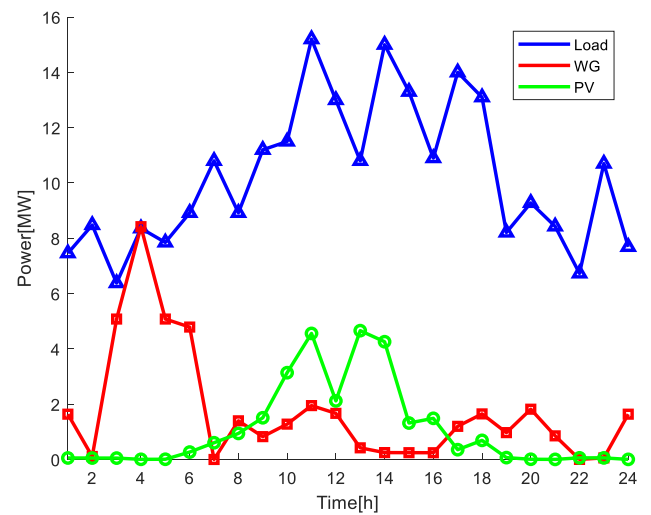


Figure 6. Distribution network under typical scenarios: Scenario 2

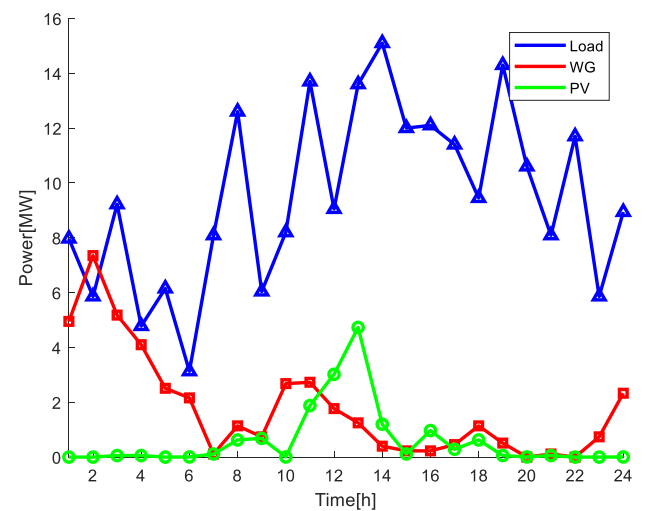


Figure 7. Distribution network under typical scenarios: Scenario 3

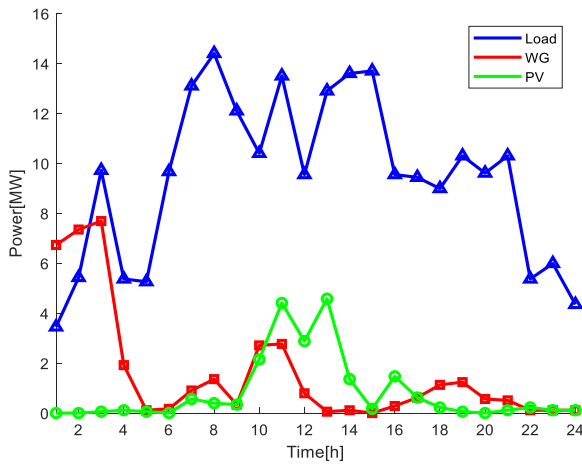


Figure 8. Distribution network under typical scenarios: Scenario 4

Figure 6 shows that wind generation (WG) and distributed unit output are insufficient to meet load demands in various scenarios, necessitating power purchases from the main grid. WG output is notably high from 1 to 4 o'clock, while distributed unit output peaks between 10 am and 2 pm. WG and distributed unit outputs complement each other regarding load. During faults within these peak generation periods, more renewable energy is available on the island, resulting in fewer disconnected load points and a greater positive impact on distribution network reliability.

4. Analysis of reliability indicators

This study uses a 50-year simulation period to ensure accurate and stable results. Both four typical scenarios (with renewable energy) and one scenario (without renewable energy) were analyzed. Reliability indices were calculated to assess network reliability, and the impact of renewable energy integration was determined by comparing these scenarios. Figure 9 shows the average annual number of outages per load point, and Figure 10 shows the average annual outage duration. Both metrics are generally higher in the scenario without renewable energy compared to the four with renewable energy. However, for some load points, the values are nearly equal. This occurs because these load points lack nearby distributed generation, preventing islanding after a fault and thus limiting the reduction in affected load points. Therefore, connecting distributed power improves grid reliability by providing energy support and enabling islanding in active distribution networks.

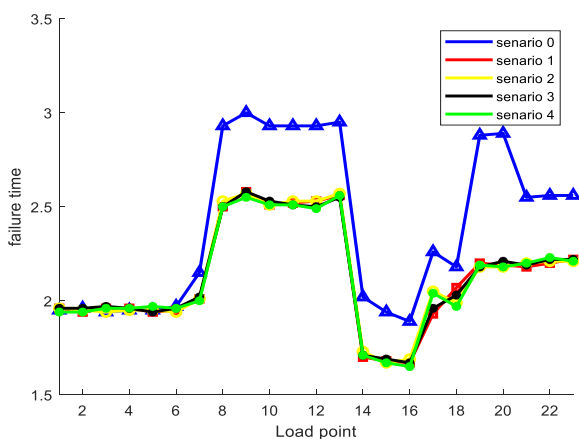


Figure 9. Load point reliability indicators: (a) Average annual number of outages

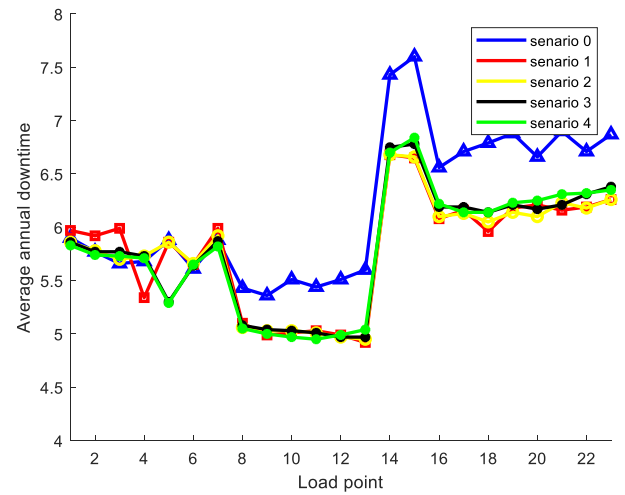


Figure 10. Load point reliability indices: (b) Average annual outage time

The reliability of the distribution network under different scenarios has obvious differences. Scenario 1 should focus on high probability. Compared with scenario 0, SAIFI and SAIDI are clearly improved in scenario 1.

In general, if renewable power generation is considered under fault, some load points can form planned islands to meet part of the load demand. The reliability of load points in islands is significantly increased. The use of new energy capacity improves the reliability indicators and has a positive impact on the reliability of the active distribution network.

5. Comparison of network reliability calculation among three algorithms

In addition, reliability indices are calculated using other common algorithms, including the minimum path (MP) algorithm and the non-sequential improved particle swarm algorithm (NMC) in Scenario 1. The results and calculation times obtained by the three algorithms are compared in Table 3.

Table 3: Comparison of calculations by three algorithms in scenario 1

Indexes	MP	NMC	Proposed Method
SAIFI (times/household* year)	2.5134	2.068	1.9479
SAIDI(h/household* year)	6.2348	6.0916	5.7969
ENS (MW ·h /year)	0.9998719	0.99994171	0.9993825
Calculation time (s)	25.3	18.7	19.5

The reliability indices calculated by the proposed method are lower than those from the MP and NMC algorithms. The NMC algorithm has the fastest computation time, while the NP algorithm is the slowest. However, the NMC algorithm's results contain errors due to its simplified handling of distributed generation and load resource states. Therefore, the proposed method is considered effective and advanced.

6. Conclusion

This research presents a comprehensive reliability assessment method for active distribution networks, accounting for the uncertainty of distributed generation and load resources. A detailed uncertainty model, based on probability statistics, is developed, considering both the operational mode and output power of these resources. An improved PSO algorithm generates representative scenarios to manage this uncertainty. Reliability indices for the active distribution network are then calculated for these scenarios. The IEEE-RBTS 6 standard test system validates the proposed method. Key reliability metrics, including average load point failure rate, energy not supplied (ENS), and average service availability index (ASAI), are calculated. Results demonstrate that integrating new energy sources improves the availability and reliability of the active distribution network by enhancing its ability to meet load demands.

The study in this research is useful for connecting renewable energy to the grid and improving power quality through assessing the reliability of the active distribution network. In addition, the study can provide useful assistance for network topology reconstruction and network planning based on reliability calculation.

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