Research on Reactive Power Optimization Method of DG Accessing Distribution Network Based on Genetic Algorithm

Junxing Wu, Yang Hu*, Dongliang Wang
NARI-TECH Nanjing Control Systems Ltd., Nanjing, China

*Corresponding author e-mail: huyang@sgepri.sgcc.com.cn

Abstract. While developing distributed generation, a large number of distributed power sources will affect the voltage stability of the grid. Firstly, the combination of theoretical analysis and formula deduction is adopted to study the factors affecting the voltage of the distributed power supply grid. Then the IEEE 33-node system is used as the simulation model to optimize the reactive power distribution of the distributed power distribution network. Search for the optimal reactive power output of the single power supply and achieve the minimum system voltage fluctuation.

1. Introduction
In the current economic society, resource-conserving societies want long-term sustainable development, traditional energy can no longer meet this requirement; in addition, large-capacity, long-distance transmission has some shortcomings.

Compared with traditional power generation methods, DG has the advantages of cleaner environmental protection, flexible power generation mode, high power supply reliability, and low investment [1-2]. However, the grid is not considered for the large-scale access of the DG. After the distributed power is connected to the distribution network, the distribution system changes from a radial structure to a multi-power structure [3-5]. Therefore, in order to ensure the stability of the operation of the power system, it is necessary to conduct an in-depth analysis of the influence of the distributed power supply grid-connected on the grid voltage.

This paper first introduces the concept and formula of voltage fluctuation and voltage deviation, and then analyzes the influence of distributed power supply on voltage quality through theoretical analysis and formula deduction method. Then the distributed power supply will increase the reactive power and lead to the voltage drop. Therefore, the genetic algorithm is used to optimize the reactive power of the distribution network. The IEEE 33-node system is used as the simulation model for verification.

2. Analysis of the Influence of DG on Voltage Quality of Distribution Network

2.1. Voltage fluctuation
The voltage fluctuation value is the ratio of the difference between the maximum value and the minimum value of the actual voltage fluctuating within a period of time to the rated voltage [6]:

\[ dU = \frac{U_{\text{max}} - U_{\text{min}}}{U_{\text{r}}} \times 100\% \] (1)
Where $dU$ represents the voltage fluctuation value. $U_{\text{max}}$ is the maximum value of the actual voltage. $U_{\text{min}}$ is the minimum value of the actual voltage.

2.2. Voltage deviation
The change of the operation mode of the power distribution system and the slow change of the load will cause the voltage of each point of the power distribution system to deviate. This phenomenon is a normal operating state. At this time, the difference between the actual voltage at each point and the nominal voltage of the system is called the voltage deviation [7-8]:

$$\Delta U = \frac{U_x - U_N}{U_N} \times 100\%$$  

(2)

Where $\Delta U$ is the voltage deviation. $U_x$ is the actual operating voltage. $U_N$ is the rated voltage.

2.3. Theoretical analysis
After the distributed generation is connected to the distribution network, it will be changed from the original single-supply and radiation-type structure to the multi-source complex network with small and medium-sized power supply [9-10]. The ideal distribution network model is shown in Figure 1:

![Ideal distribution network model](image)

Figure 1. Ideal distribution network model.

The node where $U_0$ is located is a balanced node, and its voltage level is kept constant. $U_N$ is the rated voltage of the system.

The voltage drop on $R_2+jX_2$ can be determined as:

$$\Delta U_2 = \frac{P_2R_2 + Q_2X_2}{U_N}$$  

(3)

Similarly, the voltage drop on $R_1+jX_1$ is:

$$\Delta U_1 = \frac{P_1R_1 + Q_1X_1}{U_N}$$  

(4)

Therefore, the total voltage drop of the entire line is:

$$\Delta U = \Delta U_1 + \Delta U_2$$  

(5)

The voltage of node 2 is:

$$U_2 = U_0 - \Delta U = U_0 - \frac{P_1R_1 + Q_1X_1}{U_N} - \frac{P_2R_2 + Q_2X_2}{U_N}$$

(6)
If a distributed power supply with active power $P_G$ and reactive power $Q_G$ is input at node 1, the voltage of node 2 becomes:

$$ U_2 = U_0 - \Delta U = U_0 - \frac{(P_1 - P_G) R_1 + (Q_1 - Q_G) X_1}{U_N} - \frac{P_2 R_2 + Q_2 X_2}{U_N} \tag{7} $$

If a distributed power supply with active $P_g$ and reactive power $Q_g$ is input at node 2, the voltage of node 2 becomes:

$$ U_2 = U_0 - \Delta U = U_0 - \frac{P R_1 + Q X_1}{U_N} - \frac{(P_2 - P_g) R_2 + (Q_2 - Q_g) X_2}{U_N} \tag{8} $$

According to the above formula, when the distributed power supply is connected to the grid, the node voltage level of the system itself will be greatly changed [11-13], so that the voltage deviation and voltage fluctuation will increase, and the power quality and operational reliability of the power system will be reduced. In general, the system node voltage will rise before the distributed power supply is not connected. As the power output and the incorporation position change, the degree of voltage rise also changes.

3. Reactive power optimization based on genetic algorithm

3.1. Purpose of reactive power compensation

After accessing the distributed power supply, the load level of the distribution network increases and the operating state is constantly approaching the limit operating state. A large amount of reactive power in the power grid will cause the voltage of each node to decrease, which seriously affects the performance of various electrical equipment. The reactive power should be compensated in time [14-15].

There are many ways to adjust the reactive power in the system: adjusting the excitation regulator of the generator, setting the synchronous compensator, shunt capacitor, shunt reactor, changing the transformer tap, using on-load voltage regulating transformer. Each distributed installed capacity is small and the position is dispersed, so it is not suitable for installing a centralized large-capacity reactive power compensation device. By adopting a method of inputting a flexible parallel capacitor bank at each access point, the optimal input amount of the parallel capacitor bank of the compensation node is found by the genetic algorithm, so that the economy is optimal while ensuring the stability of the system operation.

3.2. Reactive power optimization process of distributed power based on genetic algorithm

The essence of genetic algorithm is to select the optimal individual through the survival rule of the fittest. It is an intelligent search algorithm, which contains a variety of behaviors, action methods and goals of each behavior. Reactive power optimization of distributed power supply distribution network is a multi-objective complex optimization problem. Genetic algorithms can be used [16-18]. Its multi-objective function can be expressed as:

$$ \begin{cases} F_1 = \min (L) \\ F_2 = \min \sum_{i=1}^{n} Q_i \end{cases} \tag{9} $$
L represents voltage fluctuation, and n represents the number of reactive compensation points. Qi represents the reactive power input by the reactive power compensation node.

The process of reactive power optimization of distributed power supply using the specific operation rules of the above genetic algorithm [19-20] is as follows:

1. Input system raw parameters.
2. Perform initial power flow calculation.
3. Perform coding operations and initial population generation.
4. Decoding operation and power flow calculation.
5. Calculate the fitness value of the objective function.
6. Compare and select good individuals based on fitness function values.
7. Select, cross, and mutate operations.
8. Loop through the above operations until the set number of iterations is reached to output the optimal solution.

The flowchart of reactive power optimization of distributed power supply based on genetic algorithm is shown in figure 2.

4. The simulation verification
This paper uses the IEEE 33-node system as a simulation model as shown in Figure 2. The IEEE 33-node system is a radial power distribution network with a reference power of 10 MVA, a voltage rating of 12.66 KV, a total active load of 3715 kW, and a total reactive load of 2300 KVar. Access the distributed power at node 17.

![Figure 2. IEEE 33 node network structure diagram.](image)

The active output is 743KW, and the reactive output QD is used as the amount to be optimized. The constraint condition is: 0 ≤ QD ≤ 0.006. Each node voltage Ui is a state variable. The constraint condition is: 0.9 ≤ Ui ≤ 1.1.

In this example, the genetic algorithm uses a crossover probability of 0.8, a mutation probability of 0.01, an iteration number of 90 times, a population size of 50, and the number of binary coded bits is 8. The voltage values of system nodes before and after reactive power optimization are shown in table 1. The voltage distribution comparison chart is shown in Figure 3.
| Node number | Initial voltage | Optimization Results | Node number | Initial voltage | Optimization Results |
|-------------|----------------|----------------------|-------------|----------------|----------------------|
| 1           | 1              | 1                    | 18          | 0.9717         | 1.0354               |
| 2           | 0.9975         | 0.9979               | 19          | 0.997          | 0.9973               |
| 3           | 0.9933         | 0.9956               | 20          | 0.9934         | 0.9938               |
| 4           | 0.9877         | 0.9915               | 21          | 0.9927         | 0.9931               |
| 5           | 0.9823         | 0.9875               | 22          | 0.9921         | 0.9924               |
| 6           | 0.9683         | 0.9789               | 23          | 0.9897         | 0.9921               |
| 7           | 0.9658         | 0.9812               | 24          | 0.9831         | 0.9855               |
| 8           | 0.9645         | 0.9815               | 25          | 0.9798         | 0.9822               |
| 9           | 0.9633         | 0.9857               | 26          | 0.9664         | 0.977                |
| 10          | 0.9627         | 0.9905               | 27          | 0.9638         | 0.9745               |
| 11          | 0.9628         | 0.9911               | 28          | 0.9526         | 0.9634               |
| 12          | 0.9631         | 0.9922               | 29          | 0.9445         | 0.9555               |
| 13          | 0.9642         | 1.0018               | 30          | 0.941          | 0.952                |
| 14          | 0.9646         | 1.0075               | 31          | 0.937          | 0.948                |
| 15          | 0.966          | 1.0128               | 32          | 0.9361         | 0.9471               |
| 16          | 0.9682         | 1.0189               | 33          | 0.9358         | 0.9468               |
| 17          | 0.9723         | 1.036                |             |                |                      |

**Figure 3.** Comparison of voltage distribution before and after reactive power optimization

After reactive power optimization of the distribution network, it can be obtained that the reactive power output of distributed power supply required by node 17 is 0.0057 (57KVar). After reactive power optimization, the average voltage fluctuation of distribution network is 1.9275%. Compared with 2.9597% before optimization, it has a great improvement. The voltage fluctuation of the system is significantly reduced, and its operation safety and stability are also greatly improved. The evolution curve of the objective function value in the reactive power optimization process is shown in figure 4.
5. Conclusion
The massive grid-connection of DG alleviates the problems of environmental pollution, energy shortage and electricity demand, but also brings many problems to the traditional distribution network. Therefore, a large number of distributed power supply access will cause the voltage quality does not meet international standards. Firstly, this paper analyzes the influence of DG on the voltage quality of distribution network. By establishing a simplified ideal distribution network model, the influence of grid-connection of distributed power on voltage fluctuation and voltage deviation is theoretically expounded. Then the IEEE 33 node system is used as the simulation model, and the optimal reactive power output of distributed power supply under certain constraints is calculated by genetic algorithm to ensure the lowest average voltage fluctuation of the system.

Acknowledgments
This work was financially supported by Research on Physical Asset Management and Intelligent Operation and Maintenance of Power Grid Based on Internet of Things and Mobile Technology (524608190024).

References
[1] Distributed generation in liberalized electricity market [M]. France: IEA Publications, 2002.
[2] Multi-objective optimization of two stage thermoelectric cooler using a modified teaching–learning-based optimization algorithm [J]. R. Venkata Rao, Vivek Patel. Engineering Applications of Artificial Intelligence . 2013 (1).
[3] Power Flow Simulation and Reactive Voltage Optimization Strategy for Active Distribution System [D]. Huaide Lin. South China University of Technology Guangzhou, China, 2018.
[4] Research on Reactive Power Optimization of Distribution Network with Distributed Generation [D]. Xu Xiongfeng. AnHui University of Science and Technology. No.168, Shungeng Road, Huainan, 232001, P.R. CHINA, 2018.
[5] Enhanced Utilization of Voltage Control Resources With Distributed Generation. Andrew Keane, Luis (Nando) F. Ochoa, Ek Nath Vital. IEEE Transactions on Power Systems. 2011.
[6] Effective method for optimal allocation of distributed generation units in meshed electric power systems. Akorede, M.F., Hizam, H., Aris, I., Ab Kadir, M.Z.A. IET Generation, Transmission and Distribution . 2011.
[7] Reactive Power Optimization for Distribution Network with Distributed Generations. TAO Zhidong, ZHAO Meng, CHENG Meng, HU Chuansheng. College of Energy and Electrical Engineering, Hohai University, Nanjing 211100, China. 2015.
[8] Wang Baoyaqiong, Chen Hao. Overview study on improving protection methods of distribution network with distributed generation [J]. Power System Protection and Control, 2017, 45 (12): 146-153.

[9] Ma Xiaobo. Study on maximum penetration level of distributed generation in distribution network by considering current protection [J]. Electric Power, 2016, 49 (4): 88-92.

[10] A new modeling and placement of shunt FACTS devices in the secondary voltage regulation environment [J]. R. Benabid, A. Berizzi, C. Bovo, V. Ilea, M. Boudour. Electrical Engineering. 2014 (4).

[11] Multi-objective optimization of two stage thermoelectric cooler using a modified teaching–learning-based optimization algorithm [J]. R. Venkata Rao, Vivek Patel. Engineering Applications of Artificial Intelligence, 2013 (1).

[12] A benchmark test system for testing frequency dependent network equivalents for electromagnetic simulations [J]. Y.P. Wang, N.R. Watson. International Journal of Electrical Power and Energy Systems. 2013 (1).

[13] Optimal reactive power dispatch with wind power integrated using group search optimizer with intraspecific competition and lévy walk [J]. Yuanzheng Li, Mengshi Li, Qinghua Wu. Journal of Modern Power Systems and Clean Energy. 2014 (4).

[14] A Review of Active Management for Distribution Networks: Current Status and Future Development Trends [J]. Junhui Zhao, Caisheng Wang, Bo Zhao, Feng Lin, Quan Zhou, Yang Wang. Electric Power Components and Systems. 2014 (3-4).

[15] A stochastic simulation model for reliable PV system sizing providing for solar radiation fluctuations [J]. E. Kaplani, S. Kaplanis. Applied Energy. 2011.

[16] Power system reconfiguration and loss minimization for an distribution systems using bacterial foraging optimization algorithm [J]. K. Sathish Kumar, T. Jayabarathi. International Journal of Electrical Power and Energy Systems. 2011 (1).

[17] "Modelling and Design of Wind Power Forecast Error Estimation System". Guoqiang Yang, Hanyi Chen, Kaifeng Zhang, Ying Wang. 2014 IEEE Workshop on Advanced Research and Technology in Industry Applications (WARTIA). 2014.