Study on the Optimal Planning of Distributed Renewable Power Generation Based on Long-Term Sequence Simulation in Regional Distribution Network

Kaihui Feng¹, Wenwen Sun², Bibin Huang¹, Jing Hu¹, Dan Du¹ and Dan Wang³

¹State Grid Energy Research Institute Co., LTD, Beijing, China
²China Electric Power Research Institute Co., LTD, Beijing, China
³North China Electric Power University, Beijing, China

E-mail: fengkhui@163.com

Abstract. Distributed renewable power generation has obvious volatility and randomness. It has different impacts on voltage, power loss, power quality and so on with different integration schemes in distribution network. It could improve the distribution network voltage level and reduce the power loss with reasonable integration scheme. Conversely, if the integration scheme is not reasonable, it will have bad impacts on power loss and voltage level of the distribution network. To achieve the optimal planning scheme of Distributed renewable power Generation, a optimal planning method has been proposed in this paper. In the method, the minimum power loss of region distribution network as the optimization objective, long-term sequence simulation with wind energy, solar energy and load actual dates for at least one year in a row has been used to get the annual power loss and voltage qualified rate on different integration schemes. A model is verified by an actual case, which is a large-scale distribution network including multiple feeders. It is shown that the feasibility of the integration scheme. Secondly, the operation requirements of Distributed renewable power generation have been proposed based on the simulation analysis of impacts on voltage distribution of Distributed renewable power generation with PQ and PV operation mode. It is shown that appropriate voltage control strategy could be used to enhance voltage qualified rate.

1. Introduction

Distributed renewable power generation has obvious volatility and randomness. It has different impacts on short-current, reactive power/voltage distribution, and voltage stability and so on with different integration schemes in distribution network [1,2,3,4]. It could improve the distribution network voltage level and reduce the power loss with reasonable integration scheme. Conversely, if the integration scheme is not reasonable, it will influence the safe and stable operation of the distribution network. So it is very important to solve the layout and capacity selection of distributed renewable power generation in the planning stage.

The impacts on power loss and voltage distribution of distributed renewable power generation are closely related with loads, capacity and layout of distributed renewable power generation and topology of distribution network. Aimed at the minimum power losses of distributed power generation, the literatures carried out the optimal configuration analysis based on its flexible and controllable, in which the generated output and load distribution were assumed to be stable or simplified numerous. However, their randomness was ignored during the distributed new energy power generation
The integration scheme of distributed renewable power generation based on a static moment or a typical day values is not optimal because of the volatility of loads and output of distributed renewable power generation. So a planning method of Distributed renewable power Generation has been proposed in this paper to reduce the annual power loss. The method based on long-term sequence simulation with wind energy, solar energy and load dates for at least one year in a row. A model is verified by an actual case, which is a large-scale distribution network including multiple feeders. It is shown that the feasibility of the integration scheme. In addition, the voltage control requirements of distributed renewable power generation have been proposed based on the simulation analysis of impacts on voltage distribution of distributed renewable power generation with PQ and PV operation mode to enhance the security and stability of distributed renewable power generation and distribution network.

2. The time sequence of distributed renewable power generation and load [10]

2.1 Time sequence of distributed renewable power generation

The distributed renewable power generations mainly include wind power and PV power. The influence factor of output of wind power is mainly wind speed. Wind speed has volatility and variability. So output of wind power also has volatility and variability. The influence factors of output of PV power are irradiance and temperature, and the irradiance is main factor. So output of PV power has volatility, randomness and intermittent. The output of wind power and PV power in different seasons as shown in Fig.1 and Fig.2.

![Figure 1. Output of wind power](image1)

![Figure 2. Output of PV power](image2)

2.2 Time sequence of load

The loads in actual power grid are not constant they also have characteristics of volatility, irradiance and time sequence. The curves of typical load as shown in Fig.3.

![Figure 3. Curves of typical load](image3)

It can be seen that integration scheme of distributed renewable power generation based on a static moment or a typical day values is not optimal for long-time. So in planning of distributed renewable power generation, it is important to consider the volatility and irradiance of generation and loads to ensure stability and economy of power grid after distributed renewable power generation integration.
3. Objective of planning

3.1 Optimization objective
The optimization objective of distributed renewable power generation integration is power loss of region network. So the minimum power loss of region distribution network as the optimization objective.

\[
\min f = C_{\text{loss}}
\]

Where \( C_{\text{loss}} \) is the annual power loss of distribution network, it can be get by:

\[
C_{\text{loss}} = \sum_{k=1}^{8760} \sum_{j=1}^{1} I_{kj}^2 R_j
\]

Where \( I_{kj} \) is the first k hour current of year on the branch j of distribution network. \( R_j \) is resistance of the first j branch of distribution network. J is the number of branch.

3.2 Constraint condition
(1) Inequality constraints
1) Nodes voltage constraints
\[
U_{\text{min}} \leq U_i^k \leq U_{\text{max}}
\]
Where \( U_{\text{min}} \) is nodes lower voltage. \( U_{\text{max}} \) is nodes upper voltage. \( U_i^k \) is nodes voltage amplitude. As shown in type.3 the first k hour voltage deviation of year on node i must be in constraints abound.

2) Branch power flow constraints
\[
S_{ij}^k \leq S_{ij}^{\text{max}}
\]
Where \( S_{ij}^k \) is branch power flow between node i and j. \( S_{ij}^{\text{max}} \) is branch rated capacity between node i and j. As shown in type.4 the branch power flow can’t exceed branch rated capacity.

(2) Equality constraints
3) Power flow equation constraint
\[
\begin{align*}
P_{Gi}^k - P_{Li}^k &= U_i^k \sum_{j=1}^{N} U_j^k (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \\
Q_{Gi}^k - Q_{Li}^k &= U_i^k \sum_{j=1}^{N} U_j^k (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij})
\end{align*}
\]
Where \( P_{Gi}^k \) and \( Q_{Gi}^k \) is respectively the first k hour active power and reactive power output of year of generation at node i. \( P_{Li}^k \) and \( Q_{Li}^k \) is respectively the first k hour active power and reactive power output of year of load at node i. \( U_i^k \) and \( U_j^k \) is respectively the first k hour voltage amplitude of node i and j. \( \theta_{ij} \) is the first k hour voltage phase angle difference between node i and j. N is number of node. K is in between 1 and 8760. \( G_{ij} \) and \( B_{ij} \) is admittance of line which between node i and j.

4. Planning method
A planning method of Distributed renewable power Generation has been proposed in this paper. The method based on long-term sequence simulation with wind energy, solar energy and load dates for at least one year in a row to get the distributed renewable power generation planning scheme which could reduce annual power loss.

4.1 Simulation modeling
(1) Building model of generation, grid and load in simulation software which has functions such as reactive voltage, power flow, power quality, short-current and long-term sequence analysis. The load distribution must be built in the model.
(2) Building model of distributed renewable generation which could respond generation characteristics in simulation software.
(3) Compiling optimized code in optimization software. The optimization object is interconnected location and capacity of distributed renewable power generation. The optimization objective is annual power loss and voltage qualification rate.

4.2 Processing resource and load data
(1) Processing load data based on power system load forecast in level years of distributed renewable generator configuration, the time resolution is 15 minute or 1 hour. 
(2) Processing resource data of year. The resource and load data is corresponding in time.

4.3 Steps of distributed renewable power generation integration scheme
(1) Determining the transformer substation of distributed renewable power generation integrated. Getting initial integration scheme based on annual mean of load.
(2) Carrying out long-term sequence simulation based on resource and load data of year. Analyzing the impacts on region network annual power loss and voltage qualification rate of distributed renewable power generation.
(3) Analyzing the annual power loss and voltage qualification rate results in optimization software to get the further integration scheme.
(4) Repeating step (2) and (3) according to the further integration scheme. Getting the optimized distributed renewable power generation integration scheme consideration to minimum annual power loss.

4.4 Implementation scheme
In this paper combined with DIgSILENT/PowerFactory and MATLAB to realize distributed renewable power generation planning. DIgSILENT/PowerFactory is in charge of long-term sequence simulation. MATLAB is in charge of optimization treatment. The process of distributed renewable power generation planning based on DIgSILENT/PowerFactory and MATLAB as shown in Fig.4.

Figure 4. The process of distributed renewable power generation planning based on DIgSILENT/PowerFactory and MATLAB
5. Analysis of example

5.1 Basic situation
An actual system is selected as example for simulation analysis. The actual system has 17 10kV lines which power supplied by 220kV substation. It’s electric diagram as shown in Fig.5. The annual mean load is 21.3MW, maximum load is 51.9MW, and minimum load is 1.3MW. The distributed renewable power generation is planned in 10kV level. 8 10kV lines are selected for distributed renewable power generation integration, as shown red in Fig.5.

![Electric diagram of typical example](image)

5.2 Simulation result
Selecting PV power to calculate. Carrying out simulation analysis based on solar resource and load data of year. The power loss result at different PV power capacity as shown in Fig.6.

![The power loss result at different PV power capacity](image)

It can be seen that the power loss will be reduced when the PV power capacity is between 20MW to 50MW. The largest power loss amount in the region can be reduced by about 12%. The operation economy of distribution network will be enhanced. The distributed PV power integration scheme when power loss is minimum as shown in Table.1.
Table 1. The distributed PV power integration scheme when power loss is minimum unit: MW

| Solution | L3 | L7 | L11 | L12 | L13 | L14 | L15 | L17 |
|----------|----|----|-----|-----|-----|-----|-----|-----|
| Capacity | 3.2| 3.2| 4.4 | 3.4 | 3.4 | 4.2 | 4.8 | 3.2 |

It will have impacts on voltage because of distributed PV power integration. The voltage fluctuations of bus L12 before and after PV power integration in one week are as shown in Fig.7. It could be seen that voltage fluctuation was enhanced after distributed PV power integration. It will influence stable operation of grid.

![Figure 7](image-url)

**Figure 7.** The voltage fluctuation of bus L12 before and after PV power integration

To analyze the impacts on voltage of distributed PV power integration, the voltage deviations of bus L12 before and after PV power integration for one year are as shown in Fig.8. The red column is annual average voltage. Blue columns are voltage deviation relative to the annual average voltage. The right of red is positive deviation. The left of red is negative deviation.

It can be seen that, the voltage deviation of bus L12 is 2% before PV power integration. After PV power integration, the voltage deviation increased to 3%. It will have adverse effect on voltage stability because of PV power integration. The reactive-voltage control ability of PV power should be used to reduce voltage fluctuation range. The voltage deviation of bus L12 used PV power reactive-voltage control ability (within ±0.95 power factor) as shown in Fig.9. It will reduce voltage fluctuation range and enhance voltage stability of grid.

![Figure 8](image-url)

**Figure 8.** The voltage deviations of bus L12 before and after PV power integration

(a) Before PV power integration  (b) After PV power integration
6. Conclusions

The integration scheme of distributed renewable power generation based on a static moment or a typical day values is not optimal because of the volatility of loads and output of distributed renewable power generation. A planning method of Distributed renewable power Generation based on long-term sequence simulation with wind energy, solar energy and load dates for at least one year in a row has been proposed in this paper. First processing resource and load data. Secondly, building model of generation, grid and load in simulation software and analyzing the simulation results in optimization software. Finally getting the optimized integration scheme. The feasibility of the integration scheme is verified by an actual case, Secondly. And proposing to enhance operation stability of grid and distributed renewable power generation using reactive-voltage control ability of distributed renewable power generation.

Acknowledgements

The work in this paper is supported by Science and Technology Project of State Grid Corporation of China "Research on key technologies of distribution network optimal operation and planning for distributed generation, micro-grid and multiple load".

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