Research on the Influence of Distributed Wind Power Access Location on Power Supply Reliability of Distribution Network

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Abstract. In order to study the influence of distributed wind power access location on power supply reliability of distribution network, this paper adopts the method of simulation and comparative analysis. Distributed wind power with the same capacity is connected to 10kV distribution lines at different location on ETAP (Electric Transient Analyzer Program) simulation platform. The reliability indices of distributed wind power at different access location are analyzed. Results show that the accessing of distributed wind power can improve the reliability of 10kV distribution network effectively, and when the distributed wind power is connected to the end of the feeder, the improvement of the reliability of the system is more significant.

1. Introduction

The rapid development of social economy and the improvement of people's living standards require higher power supply reliability. However, electricity is mainly converted from fossil energy such as coal, oil and natural gas. At present, the problems of energy shortage and pollution are becoming increasingly prominent. Under the circumstances, Distribution Generation (DG) technology emerges as the times require. It uses renewable and clean energy such as solar energy, wind energy and tidal energy to generate electricity, which can alleviate the problem of resource constraints effectively. Wind power resources are abundant in some areas of China, and the application of wind power generation is good. But the randomness and non-dispatch of wind power generation bring many uncertainties to the power grid. With the distributed wind power connected, the conventional distribution network is transformed from a single-power radiant network to a network of power supply and user interconnection [1]. How to evaluate the influence of these uncertainties on the reliability of power supply in distribution network is a very meaningful research.

In recent years, experts and scholars have begun to study the impact of distributed wind power accessing to distribution network. In reference [2] the influence of distributed wind farm accessing to distribution network in different conditions on relay protection is studied on ETAP simulation platform. In reference [3] the effect of wind turbine disconnection and interconnection on voltage fluctuation of power grid is studied according to different conditions of energy storage system and wind power permeability. Reference [4] adopts improved genetic algorithm, reference [5] uses minimum voltage stability margin index and reference [6] considers wind power and the timing...
characteristics of load comprehensively, both of them have done research on location and capacity selection of distributed wind power.

In this paper, the reliability evaluation module of ETAP is used to simulate the distributed wind power accessing to 10kV distribution network. The change of power supply reliability after accessing the distributed wind power is analyzed. And the influence of distributed wind power access location on power supply reliability of distribution network is explored.

2. The Reliability Evaluation Module of ETAP

ETAP is complete graphical power system simulation software developed by Operation Technology Inc. (OTI) in the United States, which can be applied on Microsoft Windows 2003/2008/2012/XP and Sever 2003 platforms. It integrates many simulation modules such as power flow calculation, reliability evaluation, short circuit calculation, harmonic analysis, motor start-up analysis, arc flash analysis and relay protection. It can use real-time data to realize advanced monitoring, real-time simulation, optimization and energy management functions. It is a simple and practical power system design and test analysis tool [7, 8].

![Flow chart of Reliability Evaluation based on ETAP.](image)

Its reliability evaluation module uses Failure Mode and Effect Analysis (FMEA) to carry out reliability evaluation. By analyzing the influence of each component fault on each load point in the system, the reliability indices are counted. The flow chart is shown in figure 1, which can carry out reliability of distribution network with various wiring modes. It also can calculate and analyze the power supply reliability of distribution network with distributed generation.

When evaluating, the single-line diagram of distribution network structure is built according to the actual network, and then the reliability parameters of various components (mainly including failure rate, repair time and average repair time) are input. Finally, the Failure Mode and Effect Analysis method is used to evaluate the reliability index.

The module is equipped with wind turbine generation model, which can simulate various wind speed curves and wind power curves in different wind speed conditions. The parameter setting diagram of wind turbine model is shown in figure 2. The output power of wind turbine can be obtained according to the actual wind speed condition. Figure 3 shows the parameter setting diagram of wind speed model. The variation curve is obtained by setting actual wind speed parameters.
3. Distributed Wind Power Model

Wind turbine is a device that converts wind energy into electricity, and its output power is affected by wind speed. In this paper, the distributed wind power is equivalent to a multi-capacity generator. When wind speed reaches the cut-in speed, the fan starts. When wind speed is greater than the cut-in speed and less than the rated speed, the fan power increases with the increase of wind speed. When wind speed increases to the rated speed, the fan output rated power. And if the wind speed increases further than the cut-out speed, the fan power is 0. Figure 4 shows the fan power model.
The relationship between fan power and wind speed can be expressed as:

\[
P(v) = \begin{cases} 
0 & 0 \leq v < v_{ci} \\
(A + Bv + Cv^2)P_r & v_{ci} \leq v < v_r \\
P_r & v_r \leq v < v_{cor} \\
0 & v \geq v_{cor} 
\end{cases}
\] (1)

In the formula, \(P(v)\) is fan power, \(P_r\) is the rated power of the fan, \(v\) is the real-time wind speed, \(v_{ci}\), \(v_r\) and \(v_{cor}\), are cut-in wind speed, rated wind speed and cut-out wind speed of the fan respectively. A, B, C parameters are calculated as:

\[
\begin{align*}
A &= \frac{1}{(v_{ci} - v_r)^2} \left[ v_{ci} (v_{ci} + v_r) - 4v_{ci}v_r \left( \frac{v_{ci} + v_r}{2v_r} \right)^2 \right] \\
B &= \frac{1}{(v_{ci} - v_r)^2} \left[ 4\left( v_{ci} + v_r \right) \left( \frac{v_{ci} + v_r}{2v_r} \right)^3 - 3(v_{ci} + v_r) \right] \\
C &= \frac{1}{(v_{ci} - v_r)^2} \left[ 2 - 4 \left( \frac{v_{ci} + v_r}{2v_r} \right)^3 \right]
\end{align*}
\] (2)

In this paper, the wind speed data in Ashton area, UK [9] are used for calculation. The average hourly wind speed is used to replace the real-time wind speed. The wind speed is divided into several classes. The probability of each class of wind speed is shown in figure 5.

\[
\begin{align*}
&8-20 \text{ (m/s)}, 21.87\% \\
&7-8 \text{ (m/s)}, 6.59\% \\
&6-7 \text{ (m/s)}, 8.76\% \\
&5-6 \text{ (m/s)}, 11.04\% \\
&4-5 \text{ (m/s)}, 13.24\% \\
&0-4 \text{ (m/s)}, 38.51\%
\end{align*}
\]

Figure 5. The probability of each class of wind speed.
The rated power $P_r$ is 3000 kW. The cut-in wind speed, rated wind speed and cut-out wind speed of the fan are 4 m/s, 8 m/s and 20 m/s respectively. These parameters are substituted into equation (2) to calculate $A = -0.3750$, $B = 0.0156$, $C = 0.0195$. Combining these parameters, the average hourly wind speed of each level is substituted into equation (1) to calculate the output power and probability of fan. Results are shown in table 1.

| Power (kW) | Probability | Power (kW) | Probability |
|------------|-------------|------------|-------------|
| 0          | 0.3851      | 1655       | 0.0876      |
| 272        | 0.1324      | 2523       | 0.0658      |
| 905        | 0.1104      | 3000       | 0.2187      |

### 4. Simulation Analysis

In this paper, the reliability evaluation module of ETAP is used to simulate a 10kV feeder system. The wiring diagram is shown in figure 6. The influence of distributed wind power with different access location on power supply reliability of the system is analyzed. Assuming that the electric source and fuse of the system are completely reliable, only the faults of distribution transformers, transmission lines, circuit breakers and switches are considered in the calculation. The basic reliability parameters of various components are shown in table 2.

![Figure 6. The wiring diagram of 10kV feeder.](image-url)
Table 2. Reliability Parameters of Components.

| Component       | Failure Rate | Failure Repair Time (h) | Pre-scheduled Outage Failure Rate | Pre-scheduled Repair Time (h) | Mean Time to Repair (h) |
|-----------------|--------------|-------------------------|----------------------------------|------------------------------|-------------------------|
| Transmission Line | 0.0680       | 4.06                    | 0.0044                           | 3.35                         | 4.01                    |
| Transformer     | 0.0001       | 1.04                    | 0.0003                           | 2.18                         | 1.77                    |
| Circuit Breaker | 0.0019       | 1.83                    | 0.0085                           | 3.69                         | 3.34                    |
| Switch          | 0.0245       | 1.97                    | 0.0566                           | 3.11                         | 2.77                    |

In order to analyze the influence of distributed wind power access location on the reliability of 10kV distribution network, the distributed wind power access schemes with the same capacity and different access location are simulated respectively. The specific schemes are as follows:

Case0: The feeder system is not connected with distributed wind power.
Case1: Connect distributed wind power to the head of the feeder, as shown in figure 6.
Case2: Connect distributed wind power to the middle of the feeder, as shown in figure 6.
Case3: Connect distributed wind power to the end of the feeder, as shown in figure 6.

Simulation results are shown in table 3. Statistical indices include System Average Interruption Frequency (SAIFI), System Average Interruption Duration (SAIDI) and Expected Energy Not Supplied (EENS).

Table 3. Simulation Results with different schemes.

|                | Case0 | Case 1 | Case 2 | Case 3 |
|----------------|-------|--------|--------|--------|
| SAIFI (f / customer.yr) | 1.3078 | 1.0314 | 0.9781 | 0.9616 |
| SAIDI (hr / customer.yr)  | 4.8610 | 4.7246 | 4.4663 | 4.4282 |
| EENS (MW hr / yr)          | 11.988 | 10.995 | 10.227 | 9.903  |

In order to reflect the reliability simulation results of four different schemes intuitively, the SAIFI and EENS of the system are compared and plotted in figure 7.

Figure 7. Comparison of SAIDI and CAIDI indices of different schemes.

As can be seen from the graph, the reliability index of the feeder system has been improved after connecting with distributed wind power. When the electricity failure of the upper power grid occurs, the power supply demand of users can not be satisfied in conventional distribution network. If the fault of the upper power grid occurs, the distributed wind power can supply power to some users after
connecting with the grid. Thus, the scope and time of electricity failure are reduced, and the reliability of power supply is improved effectively.

Compared the indices of Case1, Case2 and Case3, when distributed wind power is connected to the end of the feeder, the average outage frequency of the system can be reduced greatly, and the reliability of power supply can be improved significantly. In case 1, the distributed wind power is connected to the head of the feeder. When component failure causes electricity failure, the distributed wind power occurs on the path from the fault component to the electric source. It is impossible to restore branch line power supply after short-time switching operation. In case 3, the distributed wind power is connected to the end of the feeder. When system outage is caused by the faults of components in the front, distributed wind power can restore branch line power supply after a short period of switching operation, which can improve the reliability of power supply effectively. Therefore, when distributed wind power is connected to the end of the feeder, the effect of improving the reliability of power supply is more obvious.

5. Conclusion
With the general trend that distributed power is connecting with power grid, this paper establishes a reliability evaluation model of 10kV distribution network with distributed wind power based on ETAP. The influence of distributed wind power access location on power supply reliability is analyzed. Results show that the distributed wind power can improve the reliability of 10kV distribution network effectively, and the best access point is the end of the feeder. This provides an important basis for the location selection of distributed wind power in power grid planning, and has good engineering practical value.

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References
[1] TANG Fei, LU Yuping. A New Fault Location Algorithm for Distributed Generation System [J]. Power System Protection and Control, 2010, 38(20):62-68.
[2] BIAN Chaonan, SUN Guokai, GE Tingyou. Impact of Distributed Wind Farms Access Distribution Network on Relay Protection [J]. Journal of Liaoning Technical University (Natural Science), 2016, 35(9):973-977.
[3] YU Huajun, MOU Jinshan, FAN Sanbo. Distributed Wind Power on Distribution Network Voltage [J]. Journal of Shanghai Dianji University, 2016, 19(3):176-181.
[4] MA Junyang, MENG Tao, YI Hang. Locating and Sizing for Distributed Wind Generation in the Distribution Network based on the Improved Genetic Algorithm [J]. Electrical Automation, 2018, 40(6):38-41.
[5] ZHAO Wenjie, CAO Fang, JIN Feng. Distributed Wind Power Locating and Sizing in Distribution Network based on Minimum Voltage Stability Margin [J]. Smart Grid, 2016, 4(2):190-197.
[6] CHU Zhuangqiao, FU Quan. Locating and Sizing of Distributed Wind Generation Considering Wind Generation and the Timing Characteristics of Load [J]. Proceeding of the CSU-EPSA, 2017, 29(10):85-90.
[7] ETAP 12.6.0 User Guide [M]. Operation Technology, Inc., 2015.
[8] TIAN Haixia. Harmonic Characteristic Analysis and Governance Research based on ETAP for the Substation [D]. XIAN Polytechnic University, 2017.
[9] CHEN Shaoan, CHEN Biyun, WEI Hua, etc. Mixed Half-Cloud Modeling Method for Irregular Probability Distribution of Wind Speed [J]. Proceeding of the CSEE, 2015(6):1314-1321.