Research on reliability evaluation method of active distribution network

Chao Yue*, Qiumin Qi, Yu Wang, Bojun Wang, Xilong Zhang
Qinghai Electric Power Design Institute Co., Ltd., Power China, Xining 810008, China
*E-mail: yuechao0516@126.com

Abstract. The operation time of active distribution network is affected by distributed power supply, which brings complex problems including power quality, power supply reliability and relay protection, among which the reliability problem is particularly prominent. This paper discusses the component mathematical model, evaluation index and evaluation method for the reliability evaluation of active distribution network.

1. Introduction
Active distribution network is defined as a distribution network that can spontaneously control the controllable energy in distributed power supply, flexible load and other systems, and manage the power flow of the distribution network by flexibly changing the network topology to play a supporting role in the system. The research on reliability evaluation methods of active distribution network plays an increasingly important role in planning, production and operation, which plays an important role in power network planning, improvement of power network operation mode and improvement of system operation reliability [1].

2. Basis for reliability evaluation of active distribution network

2.1. Reliability model

2.1.1. Component reliability model
The sampling value of the state duration of the element follows the exponential distribution:

\[ t_1 = -\frac{MTTF}{x_1}\ln(x_1) \]  
\[ t_2 = -\frac{MTTR}{x_2}\ln(x_2) \]

Type:

MTTF: mean trouble-free working time of components;
MTTR: Average repair time of components;
t_1: Duration of normal operation of components;
t_2: Component repair time;
x_1, x_2: a random variable obeying uniform distribution on the interval of [0, 1].
2.1.2. timing load model

When analyzing the reliability of power network, considering that the active distribution network is connected with distributed power supply, the output of the system becomes unstable. If a constant load is adopted, there will be a big difference in reliability evaluation [2]. Therefore, it is necessary to use the time series load curve for evaluation.

\[ P_L(t) = P_A \cdot P_{rate}(t) \]  \hspace{2cm} (3)

Type:
\( P_L(t) \): demand of load at time \( t \);
\( P_A \): the load peak at a load point during the simulation period of the evaluation algorithm;
\( P_{rate}(t) \): the rate of load at time \( t \).

2.1.3. output model of wind turbine

(1) Wind speed simulation based on Weibull distribution

As a continuous distribution, Weibull distribution is generally used in the field of wind speed simulation because it has a relatively simple functional form in the calculation of probability density. The Weibull two-parameter distribution function is as follows:

\[ F(v) = P(V \leq v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \]  \hspace{2cm} (4)

Type:
\( V \): actual wind speed at each time \( t \);
\( C \): scale coefficient, which reflects the average wind speed;
\( k \): shape coefficient, reflecting the skewness of Weibull distribution, generally \( k=2 \);
\( F(v) \): Probability density function of wind speed.

(2) Wind speed simulation based on autoregressive sliding average

With auto-regressive Moving Average (ARMA) time series simulation method, time series can be generated with linear regression model. The difference equation is as follows:

\[ x_t = \sum_{i=1}^{m} \phi_i x_{t-i} + \sum_{j=1}^{m} \theta_j \alpha_{t-j} + \alpha_t \sim NID(0, \sigma_a^2) \]  \hspace{2cm} (5)

Type:
\( \phi_i \) (\( i=1,2,\cdots,m \)): autoregressive parameter;
\( \theta_j \) (\( j=1,2,\cdots,m \)): sliding average parameter;
\( \alpha_t \): Mean, variance of 0 for "sigma"\( \sigma_a^2 \) of gaussian white noise process.

In order to ensure the calculation accuracy of the ARMA model, the original data shall be processed first, denoted by\( \{x_t\} \) as the original data, and the processing process is as follows:

\[ x_t = \frac{X_t - \mu_t}{\sigma_t} \]  \hspace{2cm} (6)

Type:
\( \mu_t \), \( \sigma_t^2 \): respectively \( \{X_t\} \) of the mean and variance.

\[ \mu_t = \frac{1}{N} \sum_{t=1}^{N} X_t \]  \hspace{2cm} (7)

\[ \sigma_t^2 = \frac{1}{N-1} \sum_{i=1}^{N} (X_t - \mu_t)^2 \]  \hspace{2cm} (8)

Through the above method to the original wind speed data for standardization process, can be forecast wind speed sequence\( \{x_t\} \):

\[ x_t = \sigma_t x_t + \mu_t \]  \hspace{2cm} (9)
(3) Wind Turbine Generator

The relationship between the real-time output of the wind turbine and the wind speed is described quantitatively through the output curve of the wind turbine, and a representative curve is selected to describe the relationship. The real-time output power of the wind turbine is regarded as a random function [3].

\[ P_t = \begin{cases} 
0 & 0 \leq V_t \leq V_{ci} \\
(A + B \times V_t + C \times V_t^2) \times P_r & V_{ci} < V_t \leq V_r \\
P_r & V_r < V_t \leq V_{co} \\
0 & V_t > V_{co} 
\end{cases} \]

(10)

Type:
P_t: The output power of the wind turbine at time t;
P_r: Wind turbine rated power;
V_{ci}: Wind turbine starting speed;
V_r: Wind turbine rated speed;
V_{co}: wind turbine cutting out wind speed.

A, B, C are the output power characteristic curve parameters of the wind turbine generator set, which are calculated by formula (11):

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

(11)

2.1.4. Charging and discharging model of energy storage system

When the energy storage system is connected to the active distribution network, the fluctuation of the output power of the wind turbine can be smoothed, the impact of the wind turbine's unstable output on the power grid can be reduced, and the reliability of the active distribution network can be improved. The charging and discharging model of the energy storage system is as follows:

Charging model:

\[ \begin{align*}
P_{bat}(t)\leq P_{ch\text{-}max} \\
E_{bat}(t) + P_{bat}(t) \leq E_{max} \\
E_{bat}(t+1) = E_{bat}(t) + P_{bat}(t) 
\end{align*} \]

(12)

Discharge model:

\[ \begin{align*}
P_{bat}(t)\leq P_{dch\text{-}max} \\
E_{bat}(t) - P_{bat}(t) \leq E_{min} \\
E_{bat}(t+1) = E_{bat}(t) - P_{bat}(t) 
\end{align*} \]

(13)

Type:
P_{bat}(t): charging and discharging power of the energy storage system at hour t;
E_{bat}(t): energy stored in the energy storage system at the hour t;
P_{ch\text{-}max}: maximum charging power of energy storage system;
P_{dch\text{-}max}: Maximum discharge power of energy storage system;
E_{min}: Minimum capacity limit of energy storage system;
$E_{\text{max}}$: Maximum capacity limit of energy storage system.

2.2. System reliability index
In the analysis of reliability, by establishing a series of reliability indicators, the degree and trend of quantitative analysis indicators under different operation modes of the system can be evaluated more intuitively. Because the failure rate of each component and load makes the comprehensive reliability of the system change, it is necessary to analyze the comprehensive reliability of the distributed power supply after it is connected to the system. The reliability indexes used to analyze active distribution network are mainly shown in figure 1:

![Figure 1. reliability evaluation index of active distribution network](image)

3. Reliability evaluation method of active distribution network

3.1. Analytical method
The analytical method is mainly used to evaluate the simple power system. By setting all the components in the system as ideal components, a mathematical model is established for the components according to the different logical relations between the system and components, and the reliability index of the system is calculated. The analytical method has a high accuracy and the mathematical model has a clear logical expression [4]. However, if the network is complex and the number of components is large, the data input into the mathematical model will increase correspondingly and the calculation amount will also increase, so only a limited number of loads can be considered.

3.2. Simulation
When the power system is composed of a complex network, and the system contains multiple branches, it is impossible to establish a suitable mathematical model for analysis. Therefore, simulation method is needed to analyze reliability. This method uses the computer to generate random numbers, iterates repeatedly according to the accurate probability model, conducts the random simulation test, and calculates the reliability of the system.

3.3. Application of Monte Carlo simulation method in reliability evaluation
In the aspect of power grid reliability evaluation, the analytical method has higher accuracy. According to different indexes of various components of the system, a multi-level model is established, and various indexes are obtained through a series of rigorous numerical calculations. However, when the scale of power system is large, the calculation amount of analytical method also increases rapidly. Therefore, when analyzing the reliability of complex power systems, we generally use the Monte Carlo simulation method.

When the failure rate and repair time of each component in the system are known, but the system is complex, contains many branches, and it is difficult to establish an accurate evaluation model, the Monte Carlo simulation method, also known as the random sampling method, can be used. Monte Carlo simulation method used in large-scale power system [5], can be relatively easy to simulate the system operating conditions before failure, failure after shutdown state, Monte Carlo simulation method and
analytic method of the difference is that it is not affected by the size of the power system constraints, in large scale power system can also be relatively easy to analyze its reliability, so this method is suitable for the evaluation of complex systems.

Sequential monte-carlo simulation method was used to evaluate the reliability of active distribution network. Firstly, according to the random faults and repair models of various components such as distributed power supply and energy storage system, the faults or operation states of various components in a year were determined, and the faults and normal operation states of the system in each time period were tested. Monte Carlo simulation method can classify loads according to different demands of loads, determine failure rate according to years of failure simulation, and then calculate various reliability indexes. This method can effectively simulate the fault and running state of the system and analyze the running mode of the system in different time periods during the simulation. Applying this method in the planning stage of active distribution network can guide the system planning.

4. conclusion
As the development trend of smart power grid, active distribution network plays an important role in absorbing clean energy. People pay more and more attention to the reliability evaluation of active distribution network, and its reliability research plays an increasingly important role in power grid planning, production and operation. Therefore, the reliability assessment of active distribution network plays an important role in power network planning, power production technology improvement and system operation reliability improvement.

References
[1] Fan Mingtian, Zhang Mingming, discussion on issues related to active distribution network planning [J]. Power supply technology. 2014; 22 to 26
[2] Wang Haiqiao. Study on power system reliability with large-scale renewable energy [D]. Huazhong university of science and technology, 2012.
[3] Cheng Lin, chang ji, liu manjun et al. Evaluation of reliability of power system with stored energy based on pseudo-time-sequence state transfer sampling method [J]. Power system automation, 2014,(07):53-59
[4] Zhang Yejie, Ge Shaoyun, Liu Hong et al. Comprehensive evaluation system and method of smart distribution network [J]. Power grid technology, 2014, 38(1):40-46
[5] Ge Shaoyun, Wang Haoming, Xu Dong. Reliability evaluation of distributed wind-solar power storage system based on monte carlo simulation [J]. Power grid technology, 2012, 36(4):39-44