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Research on Reliability Evaluation Method of AC/DC Hybrid Micro-Grid

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Abstract. AC/DC hybrid micro-grid combines the advantages of DC and AC micro-grids, and it is one of the future development directions for micro-grid. Five kinds of typical structures of AC/DC hybrid grid are introduced, and the functions and characteristics of those structures are analyzed. Considering the influence of micro-grid structure on the power supply reliability, three kinds of AC/DC hybrid power grid reliability evaluation methods are established, which are the Minimal Path Method, the Convolution Method and the Monte-Carlo Simulation Method. The reliability of five typical structures is analyzed and compared by using three kinds of reliability evaluation methods.

1. Introduction

Micro-grid is an effective way to solve many problems in the future development of power grid. It is a self-controlled and self-management system consists of distributed power supplies, loads, energy storage systems, reactive power compensation devices, power conversion devices and monitoring and protection systems. Micro-grid can improve the utilization efficiency of renewable energy, improve the reliability of power supply and reduce the network loss [1].

At present, the research on the micro-grid structures include the AC micro-grid, the DC micro-grid and the AC/DC hybrid micro-grid. Comparing with the AC micro-grid structure or the DC micro-grid structure, the AC/DC hybrid micro-grid structure has the following advantages: AC/DC hybrid micro-grid can reduce AC/DC, DC/AC and other conversion, thereby it can reduce the number of power electronic converters; AC/DC hybrid micro-grid can provide two forms of power supplies (AC power supply and DC power supply), then it can reduce the frequency conversion converter and equipment manufacturing costs [2].

The reliability of the grid structure of micro-grid directly determines whether the micro-grid system is stable [3-6]. In this paper, according to the number of the AC/DC hybrid distribution device and the differences of the functions and the characteristics, five kinds of AC/DC hybrid micro-grid network structure are introduced, which are single-terminal radiation structure, double-terminal ring network structure, double-terminal double-ring network structure, three-terminal ring network structure and three-terminal double-ring network structure. The reliability of five typical structures is analyzed and compared by using three kinds of reliability evaluation methods.

2. AC/DC Hybrid Micro-grid Structure
According to different functions and features, five kinds of micro-grid grid structure with AC/DC hybrid power distribution devices are introduced in this paper.

2.1. *Single-terminal radiation structure*
Figure 1 shows a single-terminal radiation structure. The distributed power load is connected to the AC bus and DC bus of the AC/DC hybrid power distribution device in this structure.

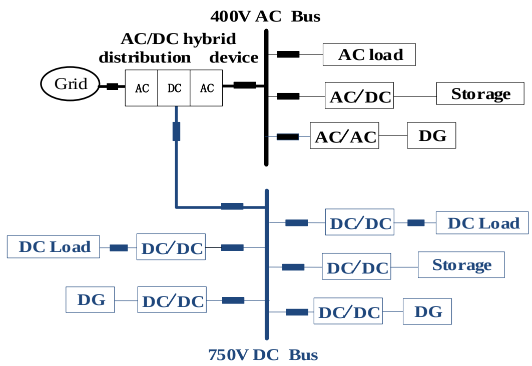
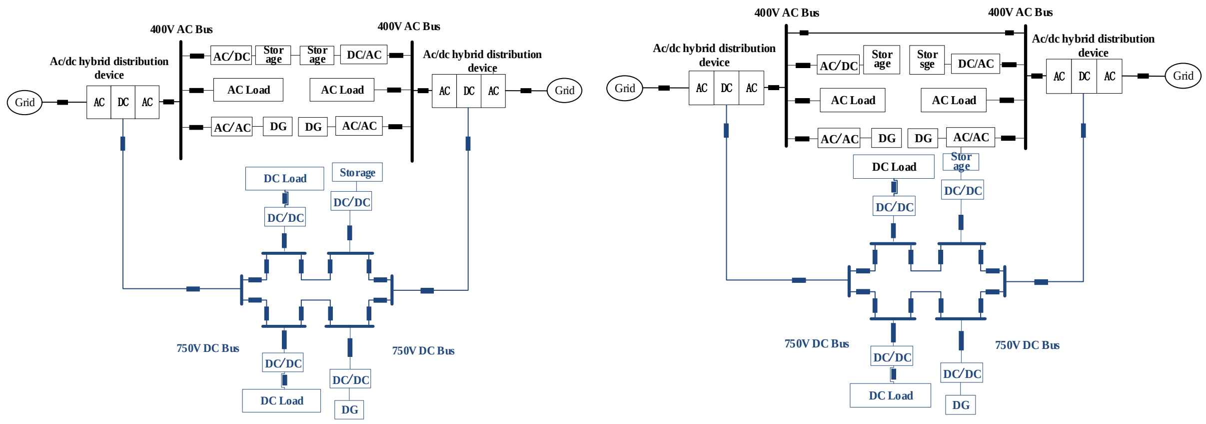


Figure 1. Single-terminal radiation structure

2.2. *Double-terminal ring network structure*
Figure 2(a) shows the double-terminal ring network structure, the structure contains two AC/DC hybrid power distribution devices which are connected to different 10kV power grids. The double-terminal structure is formed through the connected DC bus. In the double-terminal ring network structure, two AC/DC hybrid power distribution devices are used as standby for each other. When there is an operation fault in one of AC/DC hybrid power distribution devices, the continuous DC power supply can be obtained from the other one.



(a) Double-terminal ring network structure (b) Double-terminal double-ring network structure

Figure 2. Double-terminal structure

2.3. *Double-terminal double ring network structure*
Figure 2(b) shows the double-terminal double-ring network structure, the structure is combined with two 10kV distribution networks, and the AC/DC micro-grid is connected to two 10kV networks through two AC/DC hybrid power distribution devices. The double-terminal structure is formed through the DC bus and the AC bus. In the double-terminal double-ring network structure, when there

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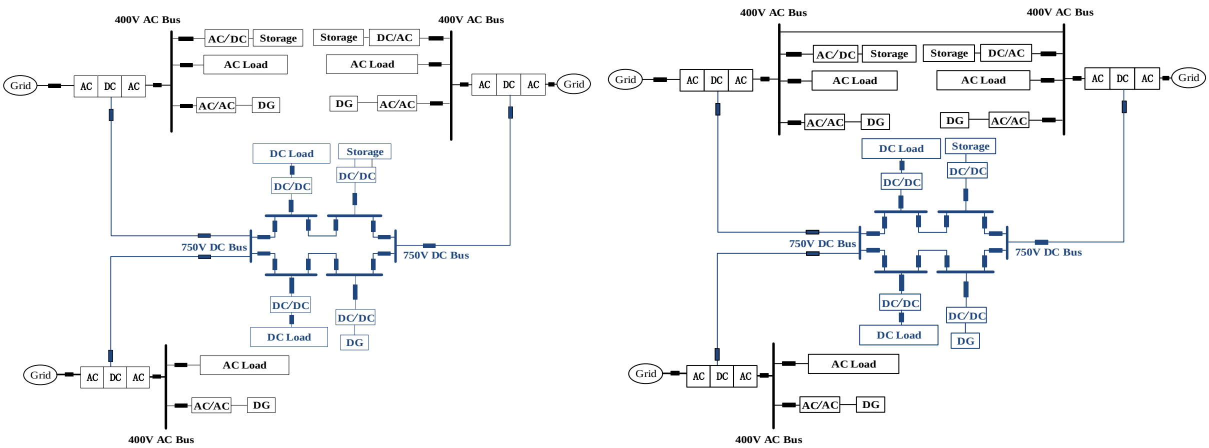
is an operation fault in one of AC/DC hybrid power distribution devices, the continuous DC power supply and AC power supply can be obtained from the other one.

2.4. Three-terminal ring network structure

Figure 3(a) shows a three-terminal ring network structure, the structure is combined with three 10kV distribution networks, and the AC/DC micro-grid is connected to different 10kV networks through three AC/DC hybrid power distribution devices. The three-terminal structure is formed through the DC bus. In the three-terminal structure, when there is an operation fault in one of AC/DC hybrid power distribution devices, the continuous DC power supply can be obtained from the other two AC/DC hybrid power distribution devices.



(a) Three-terminal ring network structure (b) Three-terminal double-ring network structure

Figure 3. Three-terminal structure

2.5. Three-terminal double-ring network structure

Figure 3(b) shows the three-terminal double-ring network structure, the structure is combined with three 10kV distribution networks, and the AC/DC micro-grid is connected to different 10kV networks through three AC/DC hybrid power distribution devices. The three-terminal double-ring network structure is formed through the DC bus and the AC bus. In this structure, when there is an operation fault in one of AC/DC hybrid power distribution devices, the continuous DC power supply and AC power supply can be obtained from the other two AC/DC hybrid power distribution devices.

3. Reliability Evaluation with Minimal Path Method

For the reliability evaluation, the basic idea of the Minimal Path Method [7-9] is to find the minimum path for each load point, so the components of the whole system are divided into two types: the minimum path component and the non-minimum path component.

For the minimal path components, the reliability evaluation principle is:

(1) If there is no standby power supply or the power can not reach the requirement of the system, each component on the minimal path will cause the load point fault.

(2) If the system has standby power supply which can supply the power for whole system, the fault happening in front of the switch or the breaker will influence the load point, and the fault time of the load point behind the switch or the breaker is only max$\{t_B, t_F\}$. In which, t_B is the standby power source switching time, t_F is the operation time of the switch or the breaker. And, the maintenance of the component in front of the switch or the breaker will not influence the operation of the load behind the switch or the breaker.

For the non-minimum path components, the influence of non-minimum path components on the load point should convert to the influence of minimum path components on the load point.

By using the network equivalent method to simplify the network, the reliability calculation formula can be written by using the Minimal Path Method. Then, the component reliability parameters can be applied into the formula. The reliability rate of the grid power supply can be calculated.

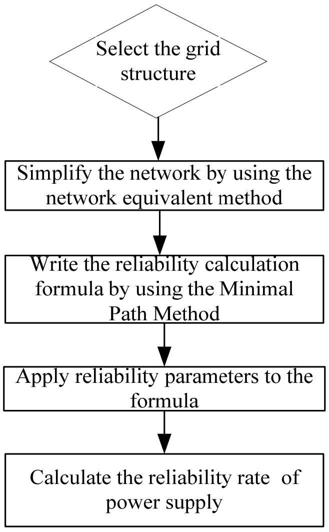


Figure 4. Calculation process of reliability evaluation

The reliability parameters of each component in the micro-grid are shown in Table 1.

Table 1. Component Reliability Parameters Statistics Table

Component type	Fault frequency (times/year)	Average maintenance time(h)
DG	0.4	4
Line	0.05	5
Inverter	0.67	0.5
Breaker	0.002	4
Element type	Operation time/h	
Standby power	0.17	
Isolating switch	0.5	

The average interruption time of load is calculated as follows.

$$u = (1-q)(u_d - u_e) + u_e \tag{1}$$

Where, u is the load interruption time, q is the probability that the distributed power output can satisfy the load power supply, u_d is the total power interruption time before adding distributed power, u_e is the power interruption time caused by the fault at the load point, and the distributed power supply can not eliminate the interruption time caused by the fault of the load point.

For example, if the Average Service Availability Index (ASAI) of power system is not less than 99.99%, the ASAI calculation formula is shown below.

$$ASAI = \frac{8760 - (\sum_{j=1}^{N} u_j) / \mathrm{N}}{8760} \cdot 100\% \geq 99.99\% \tag{2}$$

N is the number of load points, u_j is the annual power interruption time of point *j*.
From equation (3), the ASAIs of five types of network structures are shown in Table 2.

Table 2. The ASAIs of five types of network structures

Name of the structure	ASAI
Single-terminal radiation structure	99.8778%
double-terminal ring network structure	99.9898%
double-terminal double-ring network structure	99.9904%
double-terminal double-ring network structure	99.9904%
three-terminal ring network type	99.9889%
three-terminal double-ring network structure	99.9914%

4. Reliability Evaluation with Convolution Method

Convolution Method is often used to calculate the system reliability based on the generator power output and the load power requirement [10-12]. In the reliability calculation of micro-grid, the power grid reliability rate can be calculated by the ratio of supply power of source and power requirement of the load. The system model is shown below.

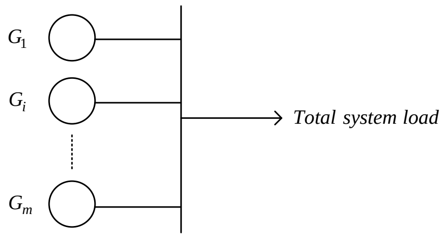


Figure 5. Generator-load system model

Reliability calculation of Micro-grid with AC/DC hybrid power distribution device based on the Convolution Method includes the following four parts:
(1) Establish the models of distributed generators;
(2) Establish discrete probability models of power generators;
(3) Establish discrete probability models of loads;
(4) Establish a convolution operation between the distributed generators and the loads.
When the probability table of the distributed generators and the load is established, the Convolution Method can be used to estimate the reliability of power generation system. The Loss of Load Expectation (LOLE) represents the expected value of the time of insufficient electricity supply.

$$LOLE = \sum_{j=1}^{N_G}\sum_{i=1}^{N_L} P_i P_j I_{ij} \cdot T \tag{3}$$

Where, P_i is the probability of the i-th load level, N_L is the load level classification in the load-level probability table, P_j is the probability of the j-th generation, N_G is the number of generation capacity rating in the distributed power output rating table, T is the total time of load duration curves. I_{ij}=1, when the level of the load power is higher than the output power of distributed generator, I_{ij} =0, when the output power of distributed generator is higher than the load power.

5. Reliability Evaluation with Monte Carlo Simulation Method

For the reliability evaluation, the Monte Carlo Simulation Method can be used [13-15]. The basic principle of Monte Carlo Simulation Method is to estimate the probability of events based on the

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frequency of events in a large number of experiments. First, we must establish a probability model or random process. And then find their parameters and some mathematical solutions. And then analyze the characteristics of parameters through the test. At last, using its arithmetic average as the approximate solution. Monte Carlo algorithm solves the difficulty of structural reliability analysis in mathematics, that is, only the linear normal distribution functions can be accurately planned. It only needs to enough experiments to get a more accurate result.

The flow chart of reliability evaluation based on the Monte Carlo Simulation Method in AC/DC Hybrid Micro-grid is shown in the figure below.

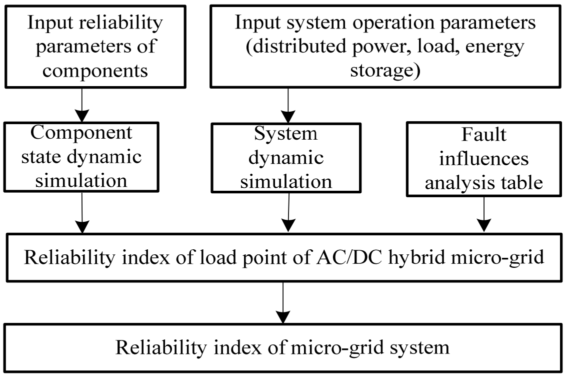

Figure 6. Reliability calculation flow chart of Monte Carlo Simulation Method

The reliability parameters of each component in micro-grid are presented in Table 1.

The Monte Carlo Simulation Method is adopted to simulate and analyze the above five kinds of grid structures, and the reliability of five kinds of structures is calculated. Through dynamic simulation, the power supply reliability during grid connection operation is shown in the following figure.

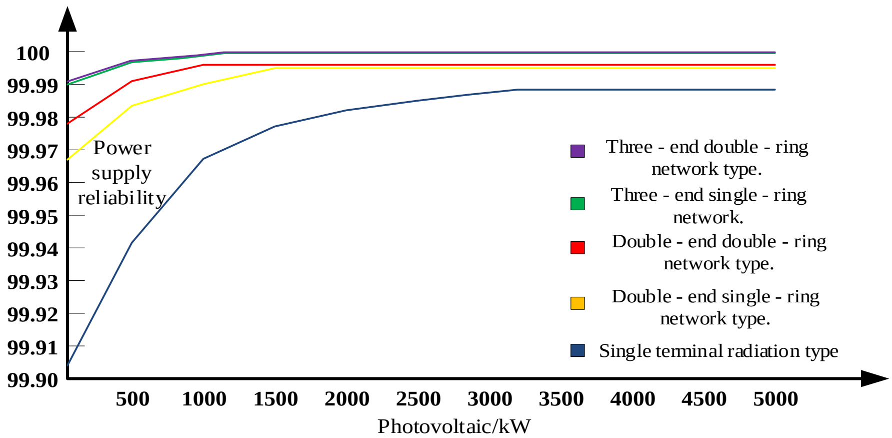

Figure 7. Simulation results of reliability calculation using Monte Carlo Simulation Method

6. Conclusion

Three kinds of reliability evaluation methods are proposed in AC/DC hybrid micro-grid. The reliability of five types of AC/DC hybrid micro-grid structures with AC/DC distributed devices is analyzed by using aforementioned three kinds of evaluation methods.

The Minimal Path Method can get a certain formula, the idea is simple and clear, but the relationship between reliability and distributed power capacity is not considered in this method; Convolution Method analyzes the relationship between reliability and distributed power capacity, but does not consider the reliability parameters of each component in micro-grid; And Monte Carlo

Simulation Method can take into account various factors such as distributed power supply, load, weather characteristics, component fault rate and so on, but it is a complicated process.

Different types of AC/DC hybrid micro-grid structures have different reliability. With three reliability evaluation methods, the reliability characteristics can be obtained.

Acknowledgments
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