Reliability Analysis of Distribution Network with Distributed Power Supply

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Abstract. In this paper, the reliability index calculation method of power equipment, load and system dispatching is studied. According to the location of the circuit breaker and disconnecting switch, the fault is partitioned, and the load reliability index is the same in each minimum distribution area, so that the reliability evaluation of the distribution network can improve the efficiency. On this basis, the partition coding table is also established, and the calculation of the minimum distribution area can be directly transformed into the calculation of the corresponding coding area. Combined with monte carlo method, the correctness of the method used in this paper is proved by comparing the example analysis with other literatures.

1. Introduction
During the operation of power grid, the reliability evaluation of power system is indicated by various calculation indexes. When calculating each reliability index, the influential factors of all aspects of the system must be taken into account, which is also a necessary condition for reliability evaluation. The system reliability index can describe the reliability degree of the power system from all directions and angles[1]. The reliability parameters of the components themselves and the load point index are closely related to them, and the location and direction of the component fault point can also affect the reliability index of the power grid. The indicators that usually represent the reliability of the power grid include: System Average outage Duration (System Average Interruption Duration Index, SAIDI), System Average power Frequency (System Average Interruption Frequency Index, SAIFI), the Average power supply availability (business Service Availiability Index, ASAI) as well as the battery is low expectations (Expect Of Energy, Not Supplied, EENS) et al.

2. Reliability analysis of distribution network based on minimum distribution area
The data were randomly simulated to get what might happen. The idea of this article is to divide the partition into automatic and manual isolation zones based on feeder partitioning. If the automatic isolation zone includes a manual isolation zone, the manual isolation zone can be called the smallest power distribution zone. Then combined with Monte Carlo simulation method to calculate the system reliability index.

Because the distribution system is directly connected with users, it has the characteristics of complex structure, large number of components and uncertain parameters. The feeder structure in China is generally designed for closed-loop open-loop operation, but in this state of operation, once the main feeder fails, all the loads connected downstream will be suspended accordingly[2].
Figure 1. Schematic diagram of distribution network structure

Figure 1 shows a typical structure of a distribution network. The main feeder is connected to the main power supply through a circuit breaker. The feeder sections numbered 1, 2, 3, and 4 are the main trunks and numbered 5, 6, 7, 8, 9, 10. The feeder section is a branch line; the load point number is LP1, LP2, LP3, LP4, LP5; the distribution transformer is T1, T2; the circuit breaker number is B1, B2; S1, S2, S3 are normally closed isolation switch numbers, S4 It is a normally open isolating switch number, also called a contact switch; F is a fuse, which is used to isolate the branch line component when it fails, so as to prevent the fault from affecting other lines.

If the feeder section 2 fails at this time, the circuit breakers B1 and B2 on the main feeder line will trip first. At this time, the entire feeder line will be powered off. Then open S1 and S2 to isolate and find the fault point. Then close the circuit breaker B1. Restore the normal power supply of lines 1 and 5, close circuit breaker B2 and contact switch S4, and supply power to lines 3, 4, 9, 10 through the backup power supply. Finally, after the fault point is found and repaired, switch the switch and the system resumes normal operation[3].

It can be seen that the switch configuration affects the system power outage time. In the area composed of the disconnector, the reliability index is basically the same. For example, take the area with isolation switches S1, S2, and S3 as an example. No matter which component in the area fails, the area will be powered off, and the power failure time depends on the fault repair time.

3. Monte Carlo reliability assessment process

As shown in Figure 2 and Figure 3, \( \lambda \) represents the failure rate, \( \mu \) represents the repair rate, both of which are in years; TTF represents the operating time before failure, and TTR represents the repair time.

\[
\begin{align*}
MTTF &= \frac{1}{\mu} \\
MTTR &= \frac{1}{\lambda}
\end{align*}
\]

MTTF -- the average running time;
MTTR -- the average repair time.

Figure 2. Repairable component outage model
For a distribution system with \( n \) components, the sequential Monte Carlo method reliability assessment process based on state duration sampling is as follows:

1) The clock is initialized to zero. Generate \( n \) random numbers between the interval \([0,1]\), find the failure rate \( \lambda \) in each component status model, and then get \( n \) \( \text{TTF} \) (\( \text{TTF}_i \)) of the \( i \)-th component.
Find the minimal \( \text{TTF}_i \), and generate a random digit for the element. Then according to its repair rate \( \mu \), it can get \( \text{TTR} \) and generate \( S_r \) and \( S_s \) in the meantime, and advance the analog clock by \( \text{TTF}_i \);

2) Call the FMEA table to seek the load points involved by component \( i \) failure and record the related information, for example, the number of power outages[4];

3) Produce a new random digit, and then switch it to a new \( \text{TTF}_i \) of element \( i \) through calculation;

4) If it does not span the year, calculate the power outage information at that load point into the reliability index for that year;

5) Determine whether the analog clock has achieved the requested accuracy of the time span, and if it achieves, execute the first;

6) If not reachable, return to step 2;

### 4. Example Analysis

In this paper, the network structure, network nodes and network elements are used to measure the characteristics of distribution network nodes, and then the system strength is analyzed.

1) Network architecture

For a network, cohesiveness is the minimum number of links to be removed when the network disconnects all the links between a pair of network nodes. The high degree of cohesion indicates that the network has strong toughness and strong ability to resist destruction, and vice versa, the network is weaker. If the cohesion of a network is 1, it means that a pair of nodes in the network need to remove only one link, such a network is more fragile. Connectivity is similar to cohesion. For a network, connectivity is the minimum number of nodes to be removed when the network disconnects all paths between a pair of nodes. If the connectivity of a network is 2, the minimum number of nodes to be removed in order to disconnect all paths between a pair of nodes is 2.

According to the actual situation, the values of network cohesion and connectivity are both natural numbers, and the values are generally less than or equal to 4. In the early warning index classification, the cohesion and connectivity are divided into four grades according to the actual situation, 0.5-1.5, 1.5-2.5, 2.5-3.5, 3.5-4.5, respectively.

2) Network nodes

Node degree is a physical quantity used to describe the importance degree of a distribution network node. Too much node degree will lead to too much node degree. In fact, the node degree of distribution network is a natural number and the value is less than or equal to 4. In the early warning index classification, the degree of node is divided into four grades: 0.5-1.5, 1.5-2.5, 2.5-3.5, 3.5-4.5 respectively.

By analyzing the classification of voltage grade and transmission power in the national standard, the voltage grade and transmission power grade are classified according to the actual situation. Usually the distribution network voltage level has 0.4 Kv, 6 Kv, 10 Kv, 35 Kv. The corresponding transmission power for each voltage level is shown in Table 1.
Table 1. Voltage class and load capacity

| Voltage class / Kv | 0.4 | 6.6 | 10   | 35  |
|-------------------|-----|-----|------|-----|
| Load bearing power / MW | 0-0.1 | 0.1-1.2 | 0.2-2 | 0.9-10 |

According to the relationship between node voltage and transmission power, and the evaluation criterion that the higher power is, the more important the line is, the voltage equivalent is divided into four grades in the early warning index classification, they are 100v-400v, 400v-8Kv, 8Kv-20Kv and 20Kv-40Kv. The transmission power is divided into four grades: 0 MW-0.5 MW, 0.5 MW-1.5 MW, 1.5 MW-5.5 MW and 5.5MW-15 MW.

3) Network components

Service life does not fully represent the use of components, components in service life will be subject to environmental, animal or lightning discharge factors such as interference, will shorten the normal service life of components, that is, the aging of components. The anti-aging degree of components is related to many factors, such as design scheme, raw material use, production process, human error operation and use environment, etc. In the grading early warning index, the degree of aging is divided into four grades: 0-25% , 25-50% , 50-75% , 75-100% . In summary, the distribution network parameters of the early warning indicators as shown in Table 2.

Table 2. Early warning index of distribution network parameters

| Grade       | Cohesion | Connectivity | Node degree | Voltage level / Kv | Load bearing power / Mw | Component Life / year | Degree of aging |
|-------------|----------|--------------|-------------|--------------------|-------------------------|-----------------------|----------------|
| Level one   | 0.5-1.5  | 0.5-1.5      | 3.5-4.5     | 20-40              | 5.5-15                  | 0.25                  | 75%-100%       |
| Level two   | 1.5-2.5  | 1.5-2.5      | 2.5-3.5     | 8-20               | 1.5-5.5                 | 25-45                 | 50%-75%        |
| Level three | 2.5-3.5  | 2.5-3.5      | 1.5-2.5     | 0.4-8              | 0.5-1.5                 | 45-55                 | 25%-50%        |
| Level four  | 3.5-4.5  | 3.5-4.5      | 0.5-1.5     | 0.1-0.4            | 0-0.5                   | 55-65                 | 0%-25%         |

Simulation is carried out in Matlab software, the distributed power supply with different permeability is connected to IEEE33 node system, and the disturbance degree of distribution network with different permeability is analyzed, the degree of disturbance is reflected by the following four indicators.

1) Static voltage stability index

The voltage level of distribution network nodes is measured by the bus voltage level, and the bus voltage level is also the main reference to ensure the user voltage to maintain a stable level. In this paper, the static voltage stability index of distribution network is introduced to measure the static voltage characteristics of distribution network with source. According to the simulation results of section 2.3.1, the fluctuation range of the static voltage index is 0-0.16%. In the early warning index classification, the node voltage deviation is divided into four grades: 0-0.04% , 0.04%-0.08% , 0.08%-0.12% , 0.12%-0.16% .

2) Network loss rate of change

The network loss is an unavoidable loss of the system, and the magnitude of the network loss depends on the power flow of the distribution system. The distribution system loss value of
non-distributed power supply mainly depends on the load power. In the process of loss calculation of dgs connected to distribution network, the rate of loss change is the index of loss change before and after Quantitative analysis connected to distribution network. According to the simulation result of 2.3.2, the value range of the loss change rate of distribution network is 1. In the early warning index classification, the loss change rate of distribution network is divided into four grades, which are 30% -15%, 15% -0, 0 -15%, -15% -30% respectively.

3) harmonic occupancy

It will bring serious harmonic pollution to the distribution network when the inverter distributed power supply is connected to the distribution network. A large number of harmonics will produce serious resonance effect in the line, increase line loss and, to a certain extent, too high harmonic voltage, the misoperation of relay protection device will harm the system operation safety. According to the simulation analysis of section 2.3.4, it can be seen that the harmonic occupancy is proportional to the access capacity of the distributed power supply, and the harmonic occupancy increases with the increase of the access capacity of the distributed power supply, the share of harmonics in distribution networks up to and including 35 kV shall not exceed 4%. In the early warning index classification, the harmonic occupancy rate is divided into four levels, respectively 1%-0, 2%-1%, 3%-2%, 4%-3%.

4) Short circuit current rate of change

The short-circuit current in the line will change with the change of the permeability, which makes the relay protection device refuse to move or not to move, this paper describes the influence of distributed generation access on relay protection by using short circuit current rate of change. According to the simulation analysis of section 2.3.4 of this paper, the short-circuit current rate of change in the range of ±10% will not affect the relay protection work, beyond this value will appear protection do not move. In the early warning index classification, the short-circuit current rate of change is divided into four levels, respectively 30% -40%, 20%-30%, 10%-20%, 0-10%.

Distribution Network operating parameters early warning indicators classification as shown in Table 3.

Table 3. Early warning index of distribution network operation parameters

| Class     | static voltage stability | loss rate         | harmonic occupancy rate | short circuit current rate |
|-----------|--------------------------|-------------------|-------------------------|---------------------------|
| Level one | 0.12% - 0.16%            | -15% - -30%       | 3% - 4%                 | 30% - 40%                 |
| Level two | 0.08% - 0.12%            | 0 - -15%          | 2% - 3%                 | 20% - 30%                 |
| Level three | 0.04% - 0.08%          | 15% - 0          | 1% - 2%                 | 10% - 20%                 |
| Level four | 0 - 0.04%                | 30% - -15%       | 0 - 1%                  | 0 - 10%                   |

5. Conclusion

In this chapter, based on the quasi-sequential Monte Carlo method, the reliability evaluation of the distribution network is performed after adding the distributed power of the wind turbine to the F4 feeder model in IEEEERBTSBUS6. And the load adopted a normal distribution model. In an island, if the distributed power output is insufficient, the load is reduced. The data results show that after adding distributed power and considering the island formation time, although the failure rate of the load point is not greatly improved, it can effectively reduce the annual outage time of the load point, thereby improving the reliability index of the load point.
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