Power Supply Reliability Evaluation of Distributed Network with Distributed Generation Considering Load Nodes’ Equivalent Loss of the Electric Quantity

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Keywords: Equivalent loss of the electricity quantity, The value coefficient of power outage consequences, Distributed network with distributed generation, Evaluation of reliability, MONTE Carlo Method.

Abstract. As the network is becoming complicated and two-way interactive, it’s necessary to analyze every user’s power supply reliability based on the operating of the network. The essay evaluated the power supply reliability of different nodes in the distributed network with distributed generation from the perspective of the users’ power outage consequence, according to the equivalent load tree model of distributed network, combining load nodes’ loss of electricity and the value of electricity loss, the concept and computational model of load nodes’ equivalent loss of the electricity quantity was proposed. Combining the concept model of equivalent loss for load nodes’ electricity and the power outage duration index of the reliability of distribution network, the evaluation method of the power supply reliability calculation of Monte Carlo considering the equivalent loss index of the electric quantity was proposed. The efficiency for the method is proved by the example, and the method also provides suggestions for network specific rebuilding and the selection of operation mode of distribution network.

Introduction

The distribution network reliability refers to the ability of continuing to provide the electric power and the electric quantity for electric power users[1]. In the distribution network reliability calculation, If the reliability calculation is combined with the consequences that may be caused by the users’ power outage, that is to quantify the consequences of any users’ power outage and combine this quantitative results with the evaluation results of distribution network operation reliability, the reliability evaluation results of a fixed distribution network operation mode to different users can be obtained. According to this result, the adjustment of local operation or the targeted transformation can be done to the distribution network, which makes the reliability assessment of the distribution network considering the user side more effective and comprehensive, and also provide more theoretical support for improving the reliability level of the distribution network from the user side.

The current reliability assessments of distribution network with distributed generation mainly focus on fault mode analysis and system state analysis, which studied the reliability analysis on overall operation. However, few researches have focused on evaluation of distribution network reliability considering the consequences of power failure to individual users. And it is also inconvenient to calculate the consequences under the existing topology transform of distribution network. Simplified the complex network structure, literature [2,3] proposed a simple radial equivalent distribution network, without calculation considering the user information. In [4], the improved fault mode method has been proposed to re-divide the distribution network and analyze the reliability index of the load-point combined with the failure consequence analysis. This method analyzed the failure consequences through the network simplification, but had indirect connection with the user characteristic, which is short of quantitative results of the failure consequence. [5,6]
studied the classification of user and its reliability needs, proposed the evaluation method of user value, which have analyzed user characteristics factors and given the definition of network reliability requirements. [7,8,9] proposed a reliability calculation method of distribution network with micro-grid based on Monte Carlo method. The lectures consider the distribution network reliability assessment mainly from the network simplification and algorithm improvement, but have not conducted in-depth study of the consequences of user power failure.

Firstly, the paper proposes the concept of equivalent load tree transform of distribution network and puts forward the definition of load nodes’ equivalent loss of the electric quantity, the value of electric quantity loss of users is analyzed and quantified from the point of view of the consequence of users’ power outage combining with the definition of equivalent load tree. Then, the paper calculates the reliability index of power outage duration based on the improved Monte Carlo algorithm, and calculates equivalent loss of the electric quantity according to the value coefficient of users’ electric quantity power outage consequences; Finally, the reliability evaluation for power consumer of the power distribution network with distributed generation is carried out according to the equivalent loss of the electric quantity.

**Equivalent Load Tree of Distribution Network**

Equivalent load tree based on distribution network topology is a tree equivalent transformation graph of distribution network. Since the distribution network operates in the form of open loop, it can be considered as a complex radial network composed of multiple simple radial networks[11]. At the condition that the distribution network operates in a certain way and the direction of power flow is given, the distribution network connection according to the power flow from superior node to subordinate node is similar to a tree diagram, which is the topology of distribution network during the next operation, the tree can be considered as the equivalent load tree of the network with the addition of the injection direction of the power flow of nodes. Figure 1 shows the equivalent load tree of a distribution network.

![Figure 1. Equivalent Load Tree of distribution network.](image)

In the equivalent load tree, each power shunt node reflects the injection direction of load flow and the power supply relationship of network nodes. And each power shunt node is an equivalent load node which is a set of loads with its supply. The leaf nodes are the user nodes of the equivalent load tree. In this way, nodes of the equivalent load tree are divided into equivalent load nodes and user nodes.

**Load Nodes’ Equivalent Loss of the Electric Quantity**

**Definition and Expression of Equivalent Loss of the Electric Quantity**

The loss of electric quantity of each other can be formed if breaking down the electric quantity of users’ power outage corresponding to the distribution network during a power outage to each user, While, the equivalent loss of electric quantity refers to the consequences of improved calculation
for the users’ electric quantity loss combining the results of users’ power outage. The loss of electric quantity has different meanings for equivalent load node and user node. The electric quantity loss of user node is a value measure index for the actual electric quantity loss of each user, that index is the product of the actual electric quantity loss and the value coefficient of power outage results, While the equivalent loss of the electric quantity of the equivalent load point is the sum of equivalent loss of the electric quantity of the set of all user points included in the equivalent load point.

The users’ equivalent loss of the electric quantity is calculated by multiplying the actual electric quantity loss of the user by the value coefficient of its power outage consequences, the expression is as follows:

\[
e_{d}(i,t,M) = \int_{t}^{t+M} U(i,t,M) P_{c}(i,t)dt .
\]

In the formula: \( e_{d}(i,t,M) \) indicates equivalent loss of the electric quantity that the user \( i \) from \( t \) time to start a power outage and the lasting time of power failure is \( M \). \( U(i,t,M) \) indicates the value coefficient of power outage consequences that the user \( i \) from \( t \) time to start a power outage and the lasting time of power failure is \( M \). \( P_{c}(i,t) \) indicates the load demand function for user \( i \).

The expression formula of equivalent loss of the electric quantity for equivalent load point \( R \) is as follows:

\[
e_{d}(R,t,M) = \sum_{i \in D} e_{d}(i,t,M) = \sum_{i \in D} \int_{t}^{t+M} U(i,t,M) P_{c}(i,t)dt .
\]

In the formula: \( e_{d}(R,t,M) \) indicates equivalent loss of the electric quantity of equivalent load point \( R \); \( D \) indicates the set of all user points included in the equivalent load point \( R \).

The Value Coefficient of Power Outage Consequences

In the case that the actual electric quantity loss of different users due to power outage is equal, the consequences of loss of different users due to power outage are not necessarily the same, the reasons resulting in these differences are mainly that the users’ security level, economic losses of power outage of the users’ unit quantity of electricity and the power supply capacity of distributed power installed by users are different. The above factors will affect the value of the loss of users’ electric quantity, so the paper corrects the electric quantity loss using the value coefficient of power outage consequences, then can form the equivalent loss of the electric quantity, its unit is still kWh, but its size reflects the size of the value of the users’ electric quantity loss.

The three factors measuring the value coefficient of power outage consequences are described by the value coefficient of the user security level, the value coefficient of the economic loss of power outage and the value coefficient of power supply capacity of distributed self-provided power supply.

The Value Coefficient of the User Security Level. The value coefficient of user security level refers to the relative value of the user security level index specified for different users from the perspective of the impact of power failure on the users’ security, according to the users’ demand for power supply reliability and the degree of harm when the users stops power supply. There into, the impact of power failure on the user security includes five aspects which caused by power outages: personal injury accidents, environmental pollution and damage, national security being threatened, political effect and the social order being disrupted.

Reference [12] obtains five quantitative indicators by experts 'rating for these five aspects, and then the users’ security level index value can be obtained through the integrated calculation of these five index values based on the objective weighting method and the gray correlative degree method, The greater the value is, the higher the user security level is, and the more severe the consequences of power outage is.

According to the security index value obtained in [12], For all user points, based on the mean of security level index of all users included in power supply area, user security level value coefficient is the relative ratio of the security level index of each user to the mean, as follows:
\[ x_{i1} = \frac{\gamma_i}{\left(\sum_{j=1}^{k} \frac{\gamma_j}{k}\right)}. \] (3)

In the formula: \( x_{i1} \) indicates the value coefficient of security level of the user \( i \); There are \( k \) users in the power supply area.

The above process only applies to the calculation within the same network structure. If the comparison calculation between different networks is needed, using security level indicator value of a typical residential area as a benchmark is necessary. such as \( \gamma_k = 5.021 \), for all user points, user security level value coefficient is the relative ratio of the security level index of each user to the reference value, as follows:

\[ x_{i1} = \frac{\gamma_i}{\gamma_k}. \] (4)

The greater the value coefficient of the user security level is, it shows that the more serious impact of power outages on the users’ security is, the more serious consequences of the users’ power outage are.

**The Value Coefficient of the Economic Loss of Users’ Power Outage.** The economic loss value coefficient of the users’ power outage is used to measure the consequence of the users’ power outage from the economic point of view, and the taking-value method is the proportion that the power outage loss per unit of electricity of the users account for the mean of power outage loss per unit of electricity of the users in the corresponding time length area.

The power outage loss per unit of electricity of the users is the cost value of power outage loss per unit of electricity caused by the users’ power outage, which is due to economic losses caused by power outage and is mainly affected by the power outage duration, that is to say, different power outage durations correspond to different cost value of power outage loss per unit of electricity, the average cost value of power outage loss per unit of electricity of the users in the corresponding time length area refers to the mean of power outage loss per unit of electricity of all users in the area under the specified power outage duration.

[13, 14] Summarizes the model calculation results of the loss of users’ power outage, and obtains the typical value of the common type users’ power outage loss per unit of electricity in different power failure time. According to the results of the study, the value \( C_i(M) \) of power outage loss per unit of electricity for the user can be obtained. The value indicates the value of power outage loss per unit of electricity for the user \( i \) in the power outage duration of \( M \). The average cost of power outage loss per unit of electricity for users is calculated as follows:

\[ C_G(M) = \frac{\sum_{j=1}^{k} C_j(M)}{k}. \] (5)

In the formula: \( C_G(M) \) indicates the average cost value of power outage loss per unit of electricity of all users within the region \( G \) in the power outage duration of \( M \), its unit is yuan/kWh; \( C_j(M) \) indicates the value of power outage loss per unit of electricity of the user \( j \) in the power outage duration of \( M \). There are \( k \) users in the area.

According to formula (4), the value coefficient of economic loss of power outage for the users can be calculated as follows:

\[ x_{i2}(M) = \frac{C_i(M)}{C_G(M)}. \] (6)

In the formula: \( x_{i2}(M) \) indicates the value coefficient of economic loss of power outage for the user \( i \) in the power outage duration of \( M \).

Similar to formula (3), the formula (6) is only applicable to the calculation within the same network structure. If the comparison calculation between different networks is needed, using the
loss value of a typical users’ power outage as a benchmark is necessary, for example, \( C_k(t) \) can indicate the function that power outage loss varies with the the power outage time in a typical residential area, the value coefficient of economic loss of power outage for the users that is the ratio of the power outage loss of each user in the corresponding power outage duration to the reference value can be calculated as follows:

\[
x_{12}(M) = \frac{C_i(M)}{C_k(M)}.
\]  

(7)

It can be seen that the greater the value of power outage loss per unit of electricity is, the more serious the consequences of the users’ power outage are.

The Value Coefficient of Power Supply Capacity of Distributed Self-provided Power Supply. When the power distribution network failure occurs, distributed generation can provide electricity for the users as electric power supply, which improves the users’ own level of reliability, the reliability requirement of the users for distribution network can be relatively reduced. However, due to the random nature of the distributed power output power, the degree of reliability to meet the users is not stable, which has a certain degree of randomness.

The value coefficient of power supply capacity of distributed self-provided power supply reflects the compensation effect of the distributed generation access to the electric quantity of power outage of the users. If the raw date is on the basis of the typical daily load curve of the users and typical daily generation curve of distributed generation (such as wind power or photovoltaic power generation), the power supply capacity coefficient of distributed self-provided power supply can be expressed as a ratio of the user’s demand load at a certain moment to power generation load corresponding to the self-provided power source at that moment, The specific expression is as follows:

\[
x_{13}(t) = \begin{cases} 
\left( \frac{P_{\text{load}}(t)}{P_{\text{DG}}(t)} \right), & P_{\text{load}}(t) > P_{\text{DG}}(t) \\
1 & P_{\text{load}}(t) \leq P_{\text{DG}}(t) 
\end{cases}
\]

(8)

In the formula: \( P_{\text{load}}(t) \) is the load demand of the user \( i \) at time \( t \); \( P_{\text{DG}}(t) \) is the output power of distributed generation connected to user \( i \) at time \( t \); When the output power of distributed generation is sufficient to meet the current user load demand, the user does not do power outage calculation, the value coefficient is 0; When the output power of distributed generation is less than the current user load, it shows that distributed generation alone is not enough to meet the user load demand, and the greater the value of the user load demand is, the higher the reliability demand of the user for distribution network is. If the user does not have access to distributed generation or there is no output of distributed generation at the moment, then the value coefficient is 1.

The Calculation Model of Equivalent Loss of the Electric Quantity

According to the impact factor of the value coefficient of power outage consequences described in 2.2. The value coefficient model of the power outage consequences of a user at a certain time is expressed as follows:

\[
U(i,t,M) = x_{11} \cdot x_{12}(M) \cdot x_{13}(t).
\]

(9)

In the formula: \( x_{11}, x_{12}(M), x_{13}(t) \), respectively, indicates the value coefficient of security level, the value coefficient of the economic loss of power outage and the value coefficient of power supply capacity of distributed self-provided power supply which belong to the user \( i \).

Put the formula (7) into the expression formula (1) of the equivalent loss of the electric quantity described in 2.1, the specific calculation model of equivalent loss of the electric quantity can be expressed as follows:
The equivalent loss of the electric quantity of the users:

\[ e_d(i,t,M) = \int_{t}^{t+M} U(i,t,M)P_e(i,t)dt = x_{i1},x_{i2}(M)\int_{t}^{t+M} x_{i3}(t)P_e(i,t)dt \]  \hspace{1cm} (10)

The equivalent loss of the electric quantity of the equivalent load point:

\[ e_d(R,t,M) = \sum_{i\in D} e_d(i,t,M) = \sum_{i\in D} x_{i1},x_{i2}(M)\int_{t}^{t+M} x_{i3}(t)P_e(i,t)dt \]  \hspace{1cm} (11)

In the formula: \( E_d(i,t,M) \) indicates the equivalent loss of the electric quantity of the user I in the condition of power outage at the current time t and the power outage duration is M; \( E_d(R,t,M) \) indicates the equivalent loss of the electric quantity of the equivalent load point R in the condition of power outage at the current time t and the power outage duration is M; \( D \) indicates the set of all the users contained in the equivalent load point R.

Open-loop configuration is usually adopted for distribution network in practice. During a certain time period, the equivalent load tree of the distribution network will change with the movement of the broken point in the distribution network with a loop configuration, if the operation mode of distribution network needs to be changed because of the reasons such as troubleshooting, the users’ power outage in a short time and so on, So that recalculation will be necessary for equivalent loss of the electric quantity.

The statistics duration can be divided into several sub-periods according to the transformation time and transformation times if there are movement of broken point or change of operation mode in the statistics duration. According to the algorithms presented in this paper, the equivalent loss of the electric quantity in each operation mode can be obtained, and the equivalent loss of the electric quantity of this operation mode can be calculated according to the proportional relationship of the occupied time of different operation modes, the specific formula is described as follows according to the formula (10) and (11):

\[ E_{kd}(i,t,M) = \frac{t_k}{T} E_d(i,t,M) \]  \hspace{1cm} (12)

\[ E_{kd}(R,t,M) = \frac{t_k}{T} E_d(R,t,M) \]  \hspace{1cm} (13)

In the formula: \( E_{kd}(i,t,M),E_{kd}(R,t,M) \) respectively, indicates the equivalent loss of the electric quantity of the users and the load points according to the operating mode k in the statistical time. \( t_k \) is the duration of the operation mode; \( T \) indicates the total statistical time.

Finally, the total equivalent loss of the electric quantity in the statistical time is obtained by summing up the equivalent loss of the electric quantity in all operation modes.

**Power Supply Reliability Evaluation Process of Distribution Network with Distributed Generation**

The main idea of the Monte Carlo Method of calculating the reliability of traditional distribution networks is to get the fault components of the system by sampling, and to determine the running time of the system and the repair time of the faulty components. Then the reliability indexes of the load nodes in the different fault section of distribution network such as power outage duration and power outage frequency can be respectively accumulated. The paper obtains the reliability index of users’ power outage time by the Monte Carlo Method. The equivalent loss of the electric quantity of the users and the equivalent load nodes based on the index, So as to evaluate the reliability of the distribution network with distributed generation[15] from the perspective of the power loss value of the users.
The Solving Process of Equivalent Loss of the Electric Quantity by Monte Carlo Method

The power outage time index can be obtained by the reliability algorithm of traditional distribution network, and the actual electric quantity loss of the users can be calculated according to the users’ load curve, the equivalent loss of the electric quantity is the product of the actual electric quantity loss and the value coefficient of the users’ power outage consequences. Combined with the comparison of the equivalent loss of the electric quantity of different users in the case that the power outage time and the electric quantity loss are the same, It is feasible to evaluate the reliability of distribution network with distributed generation from the perspective of the power loss value of the users.

The paper is based on the Monte Carlo Method. The solving steps of calculating the equivalent loss of the electric quantity are as follow:

A. Based on the Monte Carlo Method, first, initialize the system, combining with the user's basic information in the original data, according to 2.2, the user security value coefficient $x_{i1}$ can be calculated by expert scoring method and gray correlation degree method

B. According to the results of the Monte Carlo simulation sampling, for each kind of fault, divide the power outage area according to the fault point location and the power supply situation of distributed generation, Calculate the power outage time $M$ of each power outage user; Calculate the user’s economic value coefficient $x_{i2}$ on the basis of $M$.

C. Calculate the value coefficient of power supply capacity $x_{i3}$ of each user’s distributed self-provided power supply according to whether the user uses distributed generation, the distributed generation’s output power and the user’s load level.

D. Calculate the equivalent loss of the electric quantity of the users and the equivalent load nodes in the current power failure state according to the formula (10) and (11), user's load curve, the reliability index of current power outage time and the value coefficient of power outage consequences of the users.

Reliability Assessment Process of Distribution Network with Distributed Generation

From the calculation procedures, the equivalent loss of electric quantity of users and the equivalent load point in every power outage period can be accessed. Through the accumulation of calculation results step by step in the statistical time, the equivalent loss of electric quantity of users and the equivalent load point in the statistical period can be accessed.

The equivalent loss of electric quantity can be used as the criterion for evaluating the reliability level of different users or load points. For the users and the equivalent load points, the greater the equivalent loss of electric quantity indicating the greater value of power outage and the higher demands for the reliability of distribution network. Therefore, the equivalent loss of electric quantity of whole network can evaluate the value of power outage consequences of the reliability level of all load points. By comparing the equivalent loss of electric quantity of different load points of the same user and the equivalent loss of electric quantity of the same load points of different users, the reliability of distribution network included power sources which can provide the reference for the reliability construction of the distribution network can be assessed.

Figure 2 is a reliability assessment process of distribution network with distributed generation considering the value of the users’ power outage consequences.
The transformation of the network’s Equivalent load tree; System initialization; User information collection

Calculate the value coefficient of each user’s security

Faulty component sampling; Determination of system operating time; Output power sampling of DG

Determine whether the user has electricity or not according to the power outage area

Accumulate the reliability index M of the User’s power outage duration; Calculate the value coefficient of the user’s economy

Calculate the value coefficient of power supply capacity of the user’s distributed self-provided power supply according to each user’s load level and the connectivity condition of DG

Calculate the equivalent loss of the electric quantity of the users and the load points in the current power outage state

Judge: T<Trun?

The cumulative calculation results of the equivalent loss of the electric quantity

Reliability evaluation of distribution network with distributed generation

Don’t accumulate the power outage duration

Figure 2. Reliability Assessment Process of Distribution Network with Distributed Generation.

**Numerical Example Analysis**

Distribution network structure diagram is shown in Figure3, figure3 is the transformation chart of the equivalent load tree of the distribution network’s first branch. The separating isolating switch is installed at the front of each equivalent load point. The circuit breaker is at the beginning of each branch in three branches. There is a loop switch between the two substations. The load information of the user uses the load data (24 points) of a province power grid. Assuming that the local average wind speed is 6.7 m/s, the wind speed adopts the two parameters of the Weibull model: k=2.10, c=7.58, the cut-in wind speed of distributed generators is 3m/s, rated wind speed is 13.5m/s, the cut-off wind speed is 25m/s, rated capacity is 1MW. Conversion efficiency of the solar panels: $\eta_c = 0.10$, $K_c = 200W/m^2$, rated capacity is 1MW.
Plan 1: Different user points are connected to the same user without considering the access situation of distributed generation under the condition of the same network structure. For example, a large-scale commercial user A is respectively connected to the load point 14 and 16, the results are shown as follows. Thereinto, $\gamma$ is the cumulative time of the load point’s power outage (its unit is hour), $E_d$ is the equivalent loss of the electric quantity of the load point (its unit is kWh).

Table 1. The calculation results of the user A in plan 1.

<table>
<thead>
<tr>
<th>The users</th>
<th>connected to the node 14</th>
<th>connected to the node 16</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma$ (hour/year)</td>
<td>$E_d$ (kWh)</td>
</tr>
<tr>
<td>User A</td>
<td>1.6883</td>
<td>2532.5107</td>
</tr>
</tbody>
</table>

As can be seen from Table 1: 1) the equivalent loss of the electric quantity of the large-scale commercial user A that is connected to node 16 is greater than the equivalent loss of the electric quantity of the large-scale commercial user A that is connected to node 14 by 1812.9370. The results show that under the condition of different connection structures of the distribution network, the conclusion can be obtained by judging the same user-changed equivalent loss of the electric quantity that if the equivalent loss of the electric quantity is smaller, it shows that the network structure is more favorable to the distribution network reliability, if the equivalent loss of the electric quantity becomes larger significantly, it shows that this network structure reduces the level of network reliability. 2) Try not to install the important users at the end of the line as far as possible, if the important users must be installed at the end of the line, power supply reliability level needs to be improved through the transformation of lines.

Plan 2: Network structure remains unchanged, different users are connected to the same node, connection method ①: node 13, 15, 16 are resident users, node 12 is a government unit, node 14 is an important factory; connection method ②: node 12 is an important factory, node 13 is a government unit, nodes 14, 15, 16 are community public facilities or hospitals. The calculation results are as follows.
As can be seen from Table 2: 1) under the condition of the same network structure, the equivalent loss of the electric quantity of the same load point is different when connection users are different. The greater the equivalent loss of the electric quantity of the user connected to the same load point is, the greater the power outage value of the user is. That is, if connection method ② is implemented, the reliability construction strength of the network end needs to be increased to ensure the power supply of public facilities. If connection method ① is implemented, the power supply of important plant needs to be guaranteed significantly, so for all the upper parts of the load point 14, the reliability construction strength needs to be increased to ensure the power supply. 2) The change of connection users in the example, especially different connection methods of the important users (industrial users), directly leads to obvious difference of the equivalent loss of the electric quantity of node 12 and node 14. What’s more, the equivalent loss of the electric quantity is different under the condition that the important users is connected to node 12 and 14, which indicates that in addition to the change of connection users, the equivalent loss of the electric quantity is also related to the reliability of its own line components. So the reliability construction of load node 12 and 16 needs to be improved, such as the improvement of line connection and the addition of double-circuit transmission line to improve the power supply reliability under the condition that the users has greater power loss value.

Plan 3: Network structure remains unchanged, the same users are connected to the same load point, compare the changes between before and after the DG's connection to the distribution network. Based on the data of connection method ① in plan 2, the distributed generation is connected to load 14. The results are shown as follows:

As can be seen from Table 3: 1) the equivalent loss of the electric quantity of load node 14 is obviously reduced by 1257.9315 after the distributed generation is connected to the distribution network, the reason is that the power loss value of load node 14 has been reduced after the distributed generation is connected to the distribution network, which enhances the role of obviously improving the reliability security level of the load nodes. 2) The access of the distributed generation not only protects the power supply of load node 14, but also makes the equivalent loss of the electric quantity of the upper load nodes that are connected to load node 14 reduced, which indicates that the power supply of load node 14 is guaranteed through the access of the distributed generation, the reliability demand of the load node 14 to distribution network structure is reduced as well, So the investment of the load node 14 provided by distribution network can be reduced appropriately.

<table>
<thead>
<tr>
<th>The load points</th>
<th>The distribution network without DG</th>
<th>The distribution network with DG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>γ (hour/year)</td>
<td>E_k (kWh)</td>
</tr>
<tr>
<td>R14</td>
<td>1.4002</td>
<td>2107.9685</td>
</tr>
<tr>
<td>R1</td>
<td>0.4508</td>
<td>2212.7803</td>
</tr>
<tr>
<td>R2</td>
<td>1.0034</td>
<td>2114.6312</td>
</tr>
<tr>
<td>R3</td>
<td>1.3862</td>
<td>2274.9226</td>
</tr>
</tbody>
</table>
Plan 4: The original network structure is changed appropriately, assuming that the load point 4 and 11 are connected by a loop switch, and the load point 7 and 9 are directly connected without passing through the bus. One of the two loop switches needs to be closed to ensure the power supply between the load node 8 and 11. Assuming that operation mode 1: the first 32.5% of the duration of the statistic time is the time in which the loop switch between the load node 6 and 8 is closed; operation mode 2: the loop switch between the load node 4 and 11 is closed in the remaining time. Observe the change of the equivalent loss of the electric quantity of the load node 9, 10 and 11.

Table 4. The comparison of Part node calculation results of plan 4.

<table>
<thead>
<tr>
<th>The load points</th>
<th>operation mode 1 $E_{d1} (kWh)$</th>
<th>operation mode 2 $E_{d2} (kWh)$</th>
<th>The final value $E_{d} (kWh)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>R9</td>
<td>852.3317</td>
<td>144.7036</td>
<td>314.6827</td>
</tr>
<tr>
<td>R10</td>
<td>312.7539</td>
<td>489.2294</td>
<td>431.8748</td>
</tr>
<tr>
<td>R11</td>
<td>231.9863</td>
<td>508.9736</td>
<td>413.1027</td>
</tr>
<tr>
<td>R21</td>
<td>668.9934</td>
<td>299.3387</td>
<td>419.4765</td>
</tr>
<tr>
<td>R22</td>
<td>101.2038</td>
<td>81.2904</td>
<td>87.7622</td>
</tr>
<tr>
<td>R23</td>
<td>99.1771</td>
<td>150.0090</td>
<td>133.5887</td>
</tr>
<tr>
<td>R24</td>
<td>110.2010</td>
<td>197.3920</td>
<td>169.0549</td>
</tr>
</tbody>
</table>

As can be seen from Table 4: 1) For several above-mentioned load nodes, the operating mode 2 makes the equivalent loss of the electric quantity of them small as a whole, operation mode 2 is suitable for the dispatching of distribution network under the condition that power outage consequences of the user-side are mainly considered. 2) The end value of the equivalent loss of the electric quantity is between the results of two operation modes by observing the change of it, and it is more closer to the result of the operation mode that has a longer occupation time, which indicates that operating mode switching is a must if the scheduling needs, and the operation mode which has a smaller result of power outage of the user-side should be chosen, and it runs a little longer.

Conclusions

The transformation of the equivalent load tree in distribution network reflects the relationship between load points and users in the distribution network, and better covers the user information in the range of load points. Based on the Monte Carlo method to calculate the equivalent loss of the electric quantity of the load point, the value of the users’ power outage loss is quantified and the reliability evaluation of distribution network is carried out from the perspective of the value of power outage consequences, which provides a reference for the construction and investment of reliability of distribution network. The following conclusions can be drawn by analyzing the reliability evaluation of the distribution network with distributed generation combining equivalent loss of the electric quantity:

1) Equivalent loss of the electric quantity index can not only be used to assess the reliability of power supply of the distribution network to different users, but also can be used to compare the advantages and disadvantages of different distribution networks’ operation in the same operation of the supply of the user; This indicator can be used to make decisions about the mode of operation of the distribution network and the location of the connected users.

2) The greater the value coefficient of power outage loss is, the greater the equivalent loss of the electric quantity is, when the network architecture is the same and the users connected to the terminal are different, which indicates that the influence of the user’s power outage consequences is even bigger, that is, the reliability demand of the user to the distribution network is even higher, the distribution network also requires greater reliable investment at the same time;

3) With the access of distributed generation in distribution network, the power outage time of the users or load points with distributed generation is reduced in the statistical time, the equivalent loss of the electric quantity compared to the condition that there is no distributed generation in distribution network is also reduced as well. It shows that the access of the distributed generation provides the backup for the reliability of the user side, which not only improves the reliability level.
of the users or the load nodes effectively, but also reduces the value of the power outage loss of the users. So the reliability of the network in which the investment and construction of reliability is relatively low can be increased through the access of distributed generation in distribution network.

References


