Rapid assessment method for reliability of distribution network

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Abstract. In the early stage of power system reliability research, society is in a new stage of rapid development. The primary task of power system is to meet the required power generation, and the impact of unreliable power distribution system on users is increasing. Based on the Newton-Raphson method, the mathematical reference model of power flow calculation is established. The set of protection components and their corresponding motion vectors are redefined, and the objective function and network constraints are calculated and passed through the countercurrent in the power flow calculation. The detailed overview of transmission, downstream transmission and reliability assessment, combined with the calculation of relevant values in the relevant examples, further validates the characteristics of downstream and countercurrent transmission, providing a numerical reference for future concrete construction.

1. Introduction
Based on the Newton-Raphson algorithm, this paper systematically studies the rapid assessment method of distribution network reliability for power flow calculation through the established mathematical reference model, and calculates the constraints of the set objective function and related power flow calculation. The best fault isolation and recovery mode, finally through the calculation of relevant examples, corroborates the characteristics of downstream transmission and countercurrent transmission, and provides assistance for future design and construction.

2. Establishment of mathematical model
2.1. Modeling
The mathematical model of the power flow calculation refers to the relationship between the operating state parameters such as power and voltage and the network parameters in the power system, which is expressed as:

\[ Y_B U_B = \left( \frac{S_B}{U_B} \right) \] (1)

In the formula, \( Y_B \): node admittance matrix; \( U_B \): node voltage column vector; \( S_B \): power.

The objective functions solved are the user’s minimum power outage economic loss and the minimum number of power outages, respectively, which are expressed as public:
\[
\begin{align*}
\text{min } \text{Cost} &= \sum_{i \in U} L_i \times CDF_i \left( d_i \right) \\
\text{Min } \text{RCI} &= e^{\frac{N_R}{N_c}}
\end{align*}
\] (2)

In the formula, Cost: user power loss; U: power outage user set; N R: power supply number during normal operation of the distribution network; N c: number of users who still fail to supply power after fault isolation.

2.2. Newton Lawson Method
The system of nonlinear equations:

\[
F_i(x_1, x_2, \ldots, x_n) = 0 \quad (i=1, 2, \ldots, n) \tag{3}
\]

Expand into a Taylor series to get the correction for the first iteration:

\[
\Delta x^{(0)} = -\left[f'(x^{(0)})\right]^{-1} f'(x^{(0)})
\] (4)

Repeat the above process and apply the Newton method to solve the iterative format:

\[
\begin{align*}
&f'(x^{(k)}) \Delta x^{(k)} = -f'(x^{(k)}) \\
&x^{(k+1)} = x^{(k)} + \Delta x^{(k)}
\end{align*}
\] (5)

It can be seen from the above that the core of the Newton-Raphson method is to repeatedly solve the modified equation.

3. Rapid assessment of distribution network reliability considering power flow calculation

3.1. Fault isolation and recovery mode considering power flow calculation
When a component in the power distribution system fails, the influence of the positioning factor is ignored. The system will restore the normal power supply in the non-faulty area in time, locate and isolate the fault location, and research and analyze the recovery and fault isolation strategy.

The mutual assistance of the protection components enables timely isolation of faulty components in the power distribution system and subsequent fault recovery. The specific correlation algorithm flow is: (a). List all the sets of protection elements s corresponding to the faulty component; (b). Search for non-faulty power failure areas corresponding to each protection component to ensure timely access to the network structure after backup power; (c). The operation state of the non-faulty power failure area after the component failure is solved by the power flow calculation; (d). If the constraint is met, enter (g), and if the constraint is not met, enter (e); (e). The load shedding operation of the fault area is based on the objective function set for the power company; (f). Calculate the network after load shedding using the power flow calculation in (c); (g). If the non-faulty power failure area corresponding to all the protection component sets s has been checked, the process proceeds to step (h), and if not, the operation state of the next non-faulty power failure area is calculated; (h). List the vector S corresponding to the set s; (i). Calculate the reliability of the vector S; (j). Have all the vectors been calculated? Yes, the reliability index of the protection component is passed, otherwise the reliability index of the next vector is calculated; (k). Compare the vectors in (j) and select the best vector from them.
3.2. Consider the counter current flow of power flow calculation

When a fault occurs downstream of the distribution network, the degree of influence on the upstream area is the reverse flow transmission process of the reliability indicator. Its related characteristics are:

$$\begin{cases}
\lambda_{d, non-E}^u = \lambda_{o, non-E}^u P_j \\
I_{o, non-E}^{u'} = I_{o, non-E}^{u''}
\end{cases} \quad (6)$$

After the power flow calculation, the reverse flow transmission process of the reliability index of the distribution network is: (a). The reliability index of each component is transmitted to the end of the first protection component in the direction of the main power source in a reverse manner; (b). Use the power flow calculation to calculate the optimal fault isolation and recovery mode of the protection component; (c). The counter current transfer process of reliability indicators is improved by optimal isolation and recovery mode; (d). According to the reverse transfer characteristic, the reliability index at the end of the protection element is transmitted to the front end; (e). Pass the front-end reverse flow reliability indicator to the end of the first protection element; (f). Have all components been checked? If yes, proceed to step (g), otherwise continue the reverse flow reliability index transmission of the protection element; (f). Have all the levels in the component model been checked? If yes, pass the reliability index downstream, otherwise continue to pass the upstream reliability index of the protection element.

3.3. Downstream calculation considering power flow calculation

When a distribution online game fails, the degree of impact on the downstream area is the downstream transmission process of the reliability indicator. Its transfer characteristics are:

$$\begin{cases}
\lambda_{o, non-E}^d = \lambda_{p, non-E}^d \\
I_{o, non-E}^d = I_{o, non-E}^{d''}
\end{cases} \quad (7)$$

In the formula, d is the downstream reliability index; o is the end of the protection component; p is the front end of the protection component; non-E is the reliability indicator. Then, the downstream transmission process considering the optimal reliability index of the power flow calculation is: (a). Master the downstream transfer characteristics of reliability indicators and improve them with the best fault isolation and recovery mode of the protection components; (b). Using the downstream transmission characteristics, the reliability index of the distribution network is transmitted downstream; (c). Pass the reliability indicator back to the front end of the protection element in the direction of the main power supply; (d). Has the protection component been fully checked? If yes, proceed to step (e), otherwise continue to pass the downstream reliability indicator; (e). If the level in the component model has been checked, the reliability index of the load point is calculated. If not, the downstream reliability index is passed to the lower level.

When evaluating the reliability of the protection components of the distribution network, first establish the relevant protection component model to reduce the redundancy calculation in the transmission process, and combine the power flow calculation to carry out the trend of all the protection components corresponding to each component listed. Calculate, find the corresponding optimal fault isolation and processing vector S; then improve the reverse current transfer characteristic according to the optimal fault isolation and recovery vector S to reduce unnecessary calculation; secondly, by vector S, The flow transfer characteristics are improved to realize the full network transmission of reliability indicators. Finally, in order to obtain the reliability index of the load point, the downstream reliability
transfer and the reverse flow reliability transfer are combined, and then the system reliability index is obtained through calculation.

4. Case analysis

4.1. Experimental procedure

This paper selects the distribution network of 355 nodes in a certain city to verify the enforceability of the algorithm. The distribution network consists of 6 tie switches, 176 transformers, 255 lines, 5 12kV feeders, and 123 segment switches and 15 circuit breakers. The upper limit voltage of the feeder is 1.05 and the lower line voltage is 0.93. The value, its capacity and length are shown in the length and capacity of the feeder of Table 1.

| Table 1. Feeder length and capacity |
|------------------------------------|
| Feeder number | 1 | 2 | 3 | 4 | 5 |
| length /km     | 7.33 | 16.89 | 6.21 | 7.32 | 8.55 |
| capacity /MVA  | 4.1 | 28.6 | 3.6 | 6.9 | 7.8 |

In addition, there are many shopping malls, office buildings and other users in the distribution network. The corresponding power outage losses and the relationship between transformer capacity and reliability indicators in the network are as shown in Table 2 for different users' power outage losses and Table 3 transformers and related reliability. The indicators are shown.

| Table 2. Power outage losses of different users |
|-----------------------------------------------|
| user                                | Power outage loss($/KW) |
|                                    | 2min | 30min | 70min | 360min | 550min |
| Office building                  | 5.123 | 8.968 | 22.360 | 67.256 | 125.365 |
| store                           | 0.532 | 3.256 | 9.256 | 33.215 | 84.189 |
| factory                        | 2.325 | 4.568 | 10.235 | 28.562 | 58.641 |
| school                          | 0.531 | 1.256 | 8.265 | 24.531 | 42.879 |

| Table 3. Transformer and related reliability indicators |
|--------------------------------------------------------|
| transformer /kNA | λ/*10^-3f/yr | r/hr | λ/*10^-6f/yr | r/hr.km |
| 60-180           | 4.3          | 50.4 | 1.16         | 11.8    |
| 180-320          | 4.5          | 31.2 | 1.08         | 12.6    |
| 320-480          | 4.8          | 66.5 | 1.21         | 13.8    |
| 480-860          | 5.2          | 71.3 | 1.52         | 18.9    |
| 860-1160         | 5.8          | 76.2 | 8.24         | 4.1     |
| 1160             | 6.5          | 80.1 | 6.33         | 5.4     |

In this example, consider four scenarios: case (a): considering the power flow calculation, the objective function is the user's minimum economic loss; case (b): regardless of the power flow calculation, the objective function is the user's minimum economic loss; c): Considering the power flow calculation, the objective function is the minimum power outage user; the situation (d): the power flow calculation is not considered, and the objective function is the minimum number of power outage users.
Table 4. System reliability indicators in four scenarios

| Case | SAIFI/int/cus.yr | CAIDI/hr/int. | SAIDI/hr/cus.yr | ASAI |
|------|------------------|---------------|-----------------|------|
| 1    | 1.625            | 6.325         | 0.999224        | 4.012|
| 2    | 1.625            | 6.251         | 0.999314        | 3.568|
| 3    | 1.625            | 6.405         | 0.999342        | 4.054|
| 4    | 1.625            | 7.289         | 0.999351        | 3.957|

| Case | EENS/GWh/yr | AENS/MWh/cus.yr | ECOST/$/yr | IEAR/$/MWh |
|------|-------------|-----------------|------------|------------|
| 1    | 213256      | 1235.05         | 452165     | 3.201      |
| 2    | 236589      | 1152.24         | 564218     | 3.125      |
| 3    | 236589      | 1435.15         | 553126     | 2.158      |
| 4    | 235627      | 1761.04         | 678421     | 3.012      |

The reliability indicators obtained based on the above four cases are shown in the system reliability indicators in the four cases in Table 4. According to the data in the table, the SAIFI indicators in the four cases are the same, regardless of whether the objective function is the same or whether the trend is considered. The calculation does not affect the average power outage frequency of the system. Explain that both the objective function and the power flow calculation provide a reference for the isolation and recovery of faults.

Comparing the reliability indicators of case (a) and case (b), it is found that the indicators such as AENS, SAIDI and IEAR of case (a) are smaller than case (b), indicating that after the failure of the distribution system, the backup power supply The power supply capacity is insufficient, and in the process of power flow calculation, the load of the non-faulty power failure area is small, and the voltage is too low, so that the power demand of all users cannot be met. The situation of case (d) and case (c) is similar to the former, so the basic factor that cannot be ignored in the actual distribution network is the power flow calculation.

Comparing case (d) with case (b), it is found that a change in the objective function leads to a change in the reliability index. It can be seen from the table that the indicators such as EENS and CAIDI of case (d) are lower than case (b), indicating that the goal of case (b) is to reduce the economic loss of users. The IEAR and ECOST indicators of case (b) are lower than case (d), indicating that the purpose of case (d) is to minimize the users in the non-faulty power outage area, so in the process involving power flow calculation, different The objective function will cause different fault isolation and recovery effects, and finally it will be reflected in the reliability index of the system.

Comparing the reliability indicators of case (c) and case (a), it is found that compared with case (d) and case (b), the difference is small, indicating the different setting of the objective function, in the case where the power flow calculation is not involved. The next will lead to differences in the reliability of the system.

With the development of automation level of distribution network, the traditional series operation mode cannot meet the requirements of power grid system. The new parallel operation mode greatly improves the reliability index of the system.

Comparing the changes of case (c) and case (a), it is found that as the number of operations increases, the distance between the two gradually decreases, and finally returns to zero. Explain that whether the number of affected users is targeted or the economic loss of the user is targeted, the order of operations is taken as the primary measure for improvement, so the increase in the number of operations can be reduced without considering the calculation of the power flow. The gap in system reliability indicators. Similarly, there is a difference between case (d) and case (b). When the running state does not satisfy the network constraint, different objective functions will make the load shedding different. Therefore, the setting of the objective function is on the distribution network. Reliability assessment plays a crucial role.
5. Conclusion

Based on the Newton-Raphson method, this paper considers the power flow calculation of the distribution network system through the established mathematical model, and proposes a fast reliability algorithm with strong applicability. The distribution network of a certain city proves that the algorithm can be implemented. Sex, got the following conclusion:

(a). The applicable mathematical model is established, and the complex structure of the distribution network is simplified by setting the relevant objective function. The layered transfer characteristic of the reliability index is used to greatly reduce the calculation amount of the index; the relationship between fault isolation and recovery is a detailed description of the components of the rapid assessment of distribution network reliability.

(b). Considering the power flow calculation factors, all possible fault isolation and recovery modes are listed. Combined with the setting of the objective function, when the power supply capacity is insufficient, the load shedding operation is guided. The power flow calculation is applied to the distribution network. The importance of reliability index assessment, different objective functions, and system reliability indicators have different focuses. The automation of power distribution is quantified, and the segmentation switch operand is used to further verify the influence of the actual distribution network index on the power flow calculation, its power flow calculation and the objective function to quickly assess the reliability of the distribution network.

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