Overall Voltage Level Reliability and Economy Coordinated Analysis in Distribution Network

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Abstract—At present, the reliability assessment of power system are based on their respective voltage grade which have ignored the integrity and coordination of distribution network and it can’t reflect the interaction between transmission and distribution. This paper presented a method of overall voltage level coordinated expansion planning in distribution network. Considering the effect of transmission system and the main connection schemes of substation, a top-down approach about overall voltage level reliability assessment was proposed. Based on Life Cycle Cost (LCC), the assessment of reliability and economy is carried out which select the unit increment cost of average service availability index (ASAI) as the objection function. Finally, the proposed method was well applied to different application fields and the optimum conditions is obtained which serves the long-term interests of power grid.

Index Terms—distribution network, overall voltage level, reliability and economy analysis, the unit increment cost of ASAI, life cycle cost

I. INTRODUCTION

One of the tasks of power grid planning is to coordinate reliability and economy. At present, there is a lot of research on the coordination of reliability and economy in distribution network planning. [1] proposes comprehensive analysis of the economic and reliability of different connection modes of medium voltage distribution network and puts forward suggestions on the choice of connection modes. In [2], the mathematical model of minimum annual income is established and the economic and reliability of the distribution network improvement scheme is analyzed and calculated. [3] without substation fault, from the aspect of economy and reliability, analyzes and compares the connection mode of 110 kV and 10 kV distribution network. [4] based on the comprehensive analysis of the reliability and economy of closed loop operation of distribution network, the outage cost is added to the optimization objective. In the calculation of reliability, the documents mentioned above are calculated separately based on their respective voltage level and assume that the power grid with higher voltage level is completely reliable. It can find out the weak points of each power grid but it cannot reflect the mutual influence of the power grid with higher voltage level and lower voltage level. In [5] which is based on the equivalent model of transformer substation main wiring, the reliability of the overall voltage level is evaluated and compared with the traditional reliability calculation method. Results show the influence of the power grid with higher voltage level has less effort to system power supply availability ASAI but the lack of system supply (Energy Not Supplied, ENS) is affected seriously. Visibly, ignoring the influence between systems but simply calculating subsystem reliability will bring error to power grid reliability and economy coordination research. Billinton R proposed in the overall voltage level reliability evaluation that the reliability parameters of the medium power grid are equivalent to the distribution network power parameter [6], [7] is an effectively method to reduce the difficulty of evaluation.

In order to figure out investment scheme of power grid planning and weak point of power grid. In this paper, we consider the influence of power grid and high voltage distribution network substation main wiring. This paper presents a method for reliability evaluation of overall voltage level of distribution network. The contribution of equipment fault of each voltage level to the user's power supply reliability and the weak points of each voltage level are analyzed. Based on life-cycle cost of the equipment, considering coordinated optimization of reliability and economy, the minimum of the unit incremental cost of power supply availability is established as the objective function of reliability-economy evaluation method. The reliability and economic analysis of different improvement schemes are carried out and then the better scheme is selected.

II. RELIABILITY EVALUATION OF OVERALL VOLTAGE LEVEL IN DISTRIBUTION NETWORK

This paper in medium voltage distribution network reliability evaluation process mainly considers the influence of power grid and high voltage distribution network substation main wiring on inferior power supply reliability [8], [9]. First, a sequential Monte Carlo simulation method is used on the main part (220kV and
higher voltage level) for reliability evaluation. Then the main network reliability calculation results are converted to the high voltage distribution grid power bus. Next, according to the different substation main connection modes, the reliability evaluation of high voltage distribution network is carried out. The reliability parameters are converted to the power bus of the medium voltage distribution network. The reliability evaluation of the medium voltage distribution network is finally carried out.

A. Reliability Evaluation of High Voltage Distribution Network Considering Substation Main Connection

The reliability parameters of grid are equivalent to the power bus A which is the reliability interface of generation, transmission system and high voltage distribution network as shown in Fig. 1. The λ (failure rate), μ (repair rate) of the power bus can be obtained separately. On the basis of this and under the substation main connection mode, the reliability evaluation of high voltage distribution network is carried out. The calculation steps are as follows:

1. To establish the relation diagram of the reliability: the main wiring diagram divert into the diagram of the reliability characterization of the functional relationship between the components.
2. To obtain the minimal path [10] between the power point to the load point.
3. To obtain the minimal path combination based on the system operation mode. The minimal path is the minimal compound path and then the minimum compound path is obtained.
4. To calculate the reliability index of the system.

Then convert the system failure rate λ, to repair rate μ, to the medium voltage distribution network [11], [12].

![Figure 1. Unilateral power and dual feed electricity supply of high voltage distribution network.](image)

III. EVALUATION OF RELIABILITY AND ECONOMY OF DISTRIBUTION NETWORK BASED ON LIFE-CYCLE COST

The reliability cost of distribution network based on life-cycle cost [13], [14] including the investment cost $E_{IC}$. Operation, maintenance cost $E_{OC}$ and network loss cost $E_{NLC}$. Reliability cost $R_c$ can be expressed as:

$$R_c = E_{IC} + E_{OC} + E_{NLC}$$  \hspace{1cm} (1)

A. Investment Costs $E_{IC}$

Assuming the equipment investment costs is $C$. The service life is N years. The discount rate is i. Then:

$$E_{IC} = \sum_i C_i \times (A/P, i, n)$$  \hspace{1cm} (2)

$(A/P, i, n)$ is the conversion factor for the present value of the equivalent annual value.

B. Operation and Maintenance Costs $E_{OC}$

$$E_{OC} = \alpha \times E_{IC}$$  \hspace{1cm} (3)

$\alpha$ is the approximate conversion factor, usual 0.05–0.1.

C. Network Loss Cost $E_{NLC}$

According to the forecast of the annual maximum load, calculate power loss corresponding with the maximum load $\Delta P_{max}$. Then it can calculate the annual power loss. The cost of loss [15] can be obtained by the electricity price:

$$E_{NLC} = \Delta P_{max} \times \tau_{max} \times d$$  \hspace{1cm} (4)

$$\tau_{max} = T_{max} \times \cos \theta$$  \hspace{1cm} (5)

$\Delta P_{max}$ is power loss of the minimum load; $d$ indicates electricity price; $\tau_{max}$ is the time loss of minimum load, $T_{max}$ is the maximum load utilization hours; $\cos \theta$ is the power factor. From the economic perspective, the reduction of average cost of failure loss is equal to the increase of average reliability [16].

So the annual outage loss cost of the system can represent the reliability benefit $R_c$. The average electricity price calculation method can be used to calculate:

$$R_c = E_{NESS} \times b \times d$$  \hspace{1cm} (6)

$$E_{NESS} = \sum_{i=1}^{n} P_i \times U_i$$  \hspace{1cm} (7)

where $E_{NESS}$ (kWh) is the loss of power supply. $b$ is the ratio of unit electricity price of power outage to average electricity price, making it 30. $d$ is average electricity price.

$P_i$ is the active power of load node i. $U_i$ is the annual average outage time of load node i. The annual cost is:

$$C = E_{IC} + E_{OC} + E_{NLC} + R_c$$  \hspace{1cm} (8)

Based on the annual cost, this paper takes the minimum cost of the unit power supply availability as the objective function. Define the incremental cost of unit power supply availability:
International Journal of Electrical Energy, Vol. 6, No. 2, December 2018

\[ I = \frac{C}{\Delta \text{ASAI}} \] (9)

\( \Delta \text{ASAI} \) is the power supply availability variation. With the increase of investment cost, the increment of the power supply availability becomes smaller and smaller. So there is an optimization between the cost of investment and the increment of the power supply availability.

IV. EXAMPLE ANALYSIS

A. Reliability Analysis of Power Grid and High Voltage Distribution Network

Qinghai power grid in 2014 is taken as an example. The highest voltage level of the network is 750kV. The voltage level of the transmission network is respectively 750kV, 330kV, 220kV. Distribution network is composed by high voltage distribution network of 110kV and medium voltage distribution network of 35kV, 10kV. By using a sequential Monte Carlo simulation method to evaluate the reliability of the main network of 220kV and higher voltage level grid. Statistic the load shedding frequency and the load shedding duration of the main network. The reliability indexes of the main network is listed in the Table I:

<table>
<thead>
<tr>
<th>TABLE I. THE RESULT OF TRANSMISSION SYSTEM RELIABILITY ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability index</td>
</tr>
<tr>
<td>Main grid failure rate(time/a)</td>
</tr>
<tr>
<td>Failure duration for one time(h/time)</td>
</tr>
<tr>
<td>Average failure duration for one year(h/a)</td>
</tr>
</tbody>
</table>

Qinghai is characteristic of a wide area and distributed load with 110kV high voltage distribution network mainly based on double radiation. The main wiring forms of substation are single bus bar section (77.36%), double bus (9.43%) and inner bridge connection (8.49%). The calculation results are as shown in Table II:

<table>
<thead>
<tr>
<th>TABLE II. THE RELIABILITY ASSESSMENT RESULT OF HIGH VOLTAGE DISTRIBUTION IN DIFFERENT CONNECTION SCHEMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substation main wiring mode</td>
</tr>
<tr>
<td>double bus</td>
</tr>
<tr>
<td>single bus bar section</td>
</tr>
<tr>
<td>inner bridge</td>
</tr>
</tbody>
</table>

B. Reliability and Economic Coordinated Evaluation of Distribution Network

Taking a line in the B region in Xining area as an example, the voltage level of the power grid is 330/110/10kV. 110kV line is double radiation. The main wiring mode of the substation is single bus bar section. Improve its structure. (As shown in Fig. 2, the switch on line is not marked on the map). 7 cases are designed as shown in Table III.

<table>
<thead>
<tr>
<th>TABLE III. DIFFERENT KINDS OF IMPROVEMENT SCHEMES</th>
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<tbody>
<tr>
<td>scheme</td>
</tr>
<tr>
<td>original case</td>
</tr>
<tr>
<td>case 1</td>
</tr>
<tr>
<td>case 2</td>
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<tr>
<td>case 3</td>
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<tr>
<td>case 4</td>
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<tr>
<td>case 5</td>
</tr>
<tr>
<td>case 6</td>
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<tr>
<td>case 7</td>
</tr>
</tbody>
</table>

The assessment process assumes that there is only one user in each load point. And consider the influence of pre-scheduled power outages on the system reliability.

It can be got from statistical data: pre-scheduled outage rate of line is 6.13 times/100 km/year. Pre-scheduled outage average duration is 7.02h. The load rate of line is 6.13 times/100 km/year. Pre-scheduled power outages on the system reliability.

It can be seen from Table IV that the 7 cases can improve the reliability of the original case in different degree. From the view of reliability, the case 7 is more improved than other cases, so its reliability is the best and the case 3 is the worst. Compared with the case 2 and...
case 3, the average outage duration of the transformed load point can be reduced which is used to transform load and whose reliability is relatively high. The case 2 is with the large load capacity and load concentration at the position of the link line. While the case 3 is with the small load and relatively scattered load at the position of the link line. As a result, the reliability of the case 2 is better than that of the case 3.

The increment cost of unit power supply availability is shown in Fig. 3 and Table V.

Comparing the data of cases, it can be known the case 5 has the lowest increment cost of the unit power availability so it is the best improved case.

V. CONCLUSION

This paper considering the impact of the power grid with higher voltage level on the subsystem with lower voltage level to evaluate overall voltage level reliability of distribution network. Then taking the increment cost of the unit power availability as the objective function. Reliability and economy coordinated evaluation of different improved cases is carried out. The optimized case has the minimum annual cost while increasing the per unit power availability.

REFERENCES

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