Overall Voltage Level Reliability and Economy Coordinated Analysis in Distribution Network

Wenxia Liu[1], Xiaoxing Zheng[1], Qi Chen[2], and Pengcheng Xu[3]
[1]State Key Laboratory of Alternate Electrical Power System with Renewable Energy Source/North China Electric Power University, Beijing, China
[2] State Grid Ningbo Electric Power Supply Company, China
[3]State Grid Fujian Fuzhou Electric Power Supply Company, Fuzhou, China
Email: {liuwenxia001, qichantd, ncepuxpc}@163.com, 359932335@qq.com

***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 improved planning in Qinghai province, 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 Evalution 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

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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_s and repair rate μ_s to the medium voltage distribution network [11], [12] power bus.

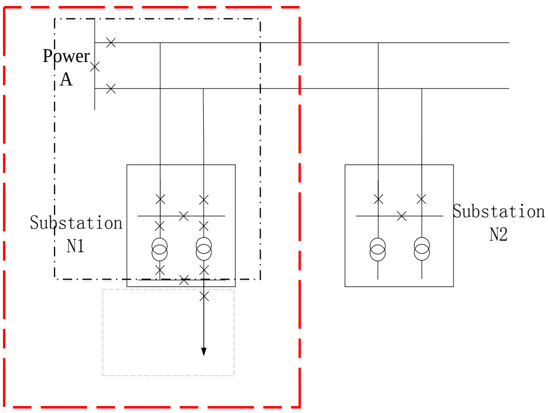

Figure 1. Unilateral power and dual feed electricity supply of high voltage distribution network.

III. Evalution 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:

$$R_C = E_{IC} + E_{OC} + E_{NLC} \tag{1}$$

A. Investment Costs E_{IC}

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

$$E_{IC} = \sum_i C_i * (A/P, i, n) \tag{2}$$

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

B. Operation and Maintenance Costs E_{OC}

$$E_{OC} = \alpha * E_{IC} \tag{3}$$

α 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 ΔP_{max}. Then it can calculate the annual power loss. The cost of loss [15] can be obtained by the electricity price:

$$E_{NLC} = \Delta P_{\max} * \tau_{\max} * d \tag{4}$$

$$\tau_{\max} = T_{\max} * \cos\theta \tag{5}$$

ΔP_{max} is power loss of the minimum load; *d* indicates electricity price; τ_{max} is the loss time of minimum load, T_{max} is the maximum load utilization hours; cosθ 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_E. The average electricity price calculation method can be used to calculate:

$$R_E = EENS * b * d \tag{6}$$

$$EENS = \sum energy\ not\ supplied\ of\ users = \sum_{i=1}^{N} P_i * U_i \tag{7}$$

where *EENS* (*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:

$$C = E_{IC} + E_{OC} + E_{NLC} + R_E \tag{8}$$

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:

$$I = \frac{C}{\Delta ASAI} \tag{9}$$

$\Delta ASAI$ 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 I. The Result of Transmission System Reliability Assessment

Reliability index	Index value
Main grid failure rate(time/a)	0.1123
Failure duration for one time(h/time)	113.24
Average failure duration for one year(h/a)	12.717

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 II. The Reliability Assessment Result of High Voltage Distribution in Different Connection Schemes

Substation main wiring mode	Failure rate λ time/a	Repair time(h)
double bus	1.4867	15.23
single bus bar section	1.8565	14.86
inner bridge	2.1752	14.91

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.

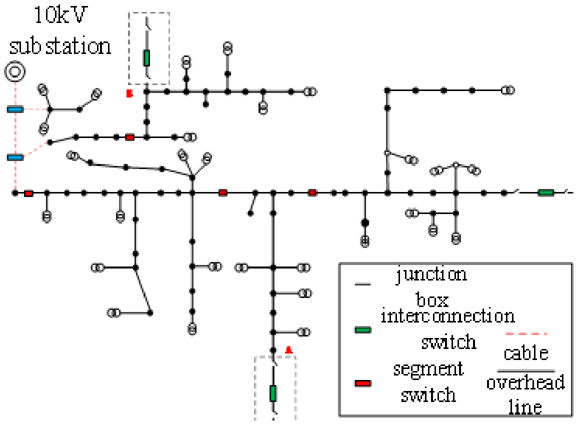

Figure 2. The network structure of original grid

TABLE III. Different Kinds of Improvement Schemes

scheme	110kV substation main wiring	Link line added at A point	Link line added at B point
original case	—	—	—
case 1	Y	—	—
case 2	—	Y	—
case 3	—	—	Y
case 4	—	Y	Y
case 5	Y	Y	—
case 6	Y	—	Y
case 7	Y	Y	Y

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 basically between 10%~35%.Therefore, when considering the load transfer it is assumed that the load margin of the adjacent transfer line can meet the load transfer of the line. The fault located isolation time is 0.5h.The transformed time is 1h.The reliability calculation results of different schemes are shown in Table IV:

TABLE IV. The Reliability Assessment Result of Different Improvement Schemes

scheme	SAIDI h/a	ASAI(%)	SAIFI time/a	ENS kWh/a
original case	5.8517	99.9332	0.6163	41147.545
case 1	5.2745	99.9398	0.5763	37057.4566
case 2	5.2868	99.9396	0.6143	37692.0844
case 3	5.6678	99.9353	0.6154	40419.619
case 4	5.2058	99.9406	0.6097	36935.7166
case 5	4.7096	99.9462	0.5743	33480.256
case 6	5.1816	99.9409	0.5914	36207.7906
case 7	4.6286	99.9472	0.5694	32845.6282

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.

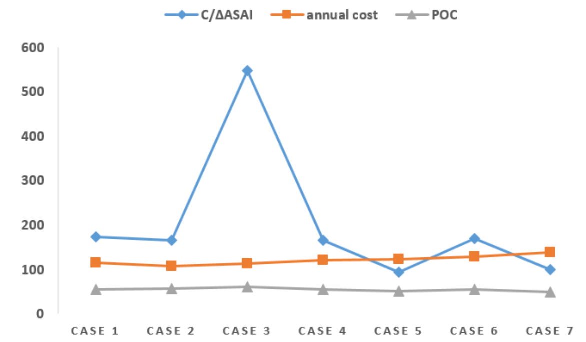

Figure 3. Reliability and economy analysis

TABLE V. THE RESULT OF UNIT COST OF ASAI INCREMENT

case	1	2	3	4
C/ΔASAI (10^5kRMB)	172.97	165.41	546.9	164.63
case	5	6	7	
C/ΔASAI (10^5kRMB)	94.05	168.20	98.57	

According to the reliability indexes calculated in Table IV. The economy parameters of power network are as follows: contact switch 6.5 kRMB/group, section switch 2 kRMB/set, the operation and maintenance cost is 5% of the annual investment cost. Discount rate is 10%. The average electricity price is 0.5 RMB/kWh, the service life of the switch and circuit is 20 years. The service and expansion life of substation is 30 years. Because several cases only transform substation main wiring or add the link line and the distribution network structure doesn't change. So that the cost of network loss is considered consistent. From statistical data from 2014: the maximum load of the line is 4.13MW. The maximum load utilization hours is 3623h. Taking the power factor 0.8, the maximum load loss hours were found to be 2457h. The net loss cost is 361.2 kRMB. According to the cost of equipment in Table III and the loss power of system in Table IV, we can get investment cost, operation and maintenance cost, Power Outage Cost (POC) and Annual Cost (AC) (units are ten thousand) as shown in Table VI:

TABLE VI. RELIABILITY AND ECONOMY EANALYSIS

cases	IC	OC	RNLC	POC	AC
case1	21.21	1.0605	36.12	55.58	113.9705
case2	13.33	0.6665	36.12	56.54	106.6565
case3	15.21	0.7605	36.12	60.63	112.7205
case4	28.44	1.422	36.12	55.40	121.3820
case5	34.54	1.727	36.12	50.22	122.6070
case6	36.42	1.821	36.12	54.31	128.6710
case7	49.75	2.4875	36.12	49.27	137.6275

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.

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Wenxia Liu received B.S. degree in Radio technology from Nanjing University of Science and Technology in 1990, and obtained M.S. degree and PhD degree in electric power system and its automation from Northeast of China Electric Power University and North China Electric Power University in 1995 and 2009 respectively. She is currently professor in the School of Electrical and Electronic Engineering, North China Electric Power University, Beijing, China. Her research interests include risk assessment in power system, power system dispatch and management automation.

Xiaoxing Zheng received the B.S. degree from North China Electric Power University in 2016. Currently, she is working toward M.S. degree in the School of Electrical and Electronic Engineering, North China Electric Power University, Beijing, China. Her major interest lies in the reliability evaluation in power system.