RELIABILITY SIMULATION AND CALCULATION FOR 1000 MW UNIT AUXILIARY POWER SYSTEM

SUN Shu-qin[1], ZHOU Lei[2], LIU Bing[1], WANG Jun[1], WANG Duo[1] ,YANG Nan[1]

[1]College of Instrumentation Science and Electrical Engineering, Jilin University,

[2]Northeast Electric Power Design, Changchun, China

Abstract: *Power system reliability and stability determine power system quality. The reliability of auxiliary power systems can affect the reliability, stability, and security of the overall power system. Currently, the main components of auxiliary power systems consist of large-capacity 1000 MW power units. These systems involve heavy electro-loads and complex wiring systems. A reliable and stable auxiliary power system is integral to the normal operations of a power plant, so correctly simulating the auxiliary power system is essential to inspect and/or to improve the reliability of the units both in the design and operation. We used the latest engineering design software (ETAP) to model the auxiliary power system for 1000 MW units, simulated its operating state, and tested the reliability of the system. The resulting data are credible and can provide a basis for system planning and optimal design in the future.*

Key words: *1000 MW unit, auxiliary power system, reliability, simulation*

1. Introduction

In recent years, large-scale blackouts have occurred in many countries worldwide [1-2], such as the "8.14" USA blackout, the London blackout, the India blackout, the Moscow blackout, and the blackout caused by a snow disaster in southern China in 2008. These blackouts caused serious social and economic losses, so power workers are more concerned with the reliability and stability of power systems [3-7]. In power system planning and actual operations, evaluating the reliability of power systems is important because many large power outages were triggered by uncertainty in power system operation. The power plant is part of the entire power system, and the auxiliary power system plays an important role in the overall reliability and stability of the system [8-11]. Much research work has been actualized and published about the reliability analysis of electric distribution system or substation, the basic reliability modeling and evaluation techniques have been discussed [12-16]. But seldom work is performed for the large capacity units of power plant, the 1000 MW power units comprise rather complex systems, the reliability analysis of the units as well as their components or sub-systems is necessary in order to inspect and/or to improve the reliability of the units both in the design and operation.

The latest engineering design software for power plants, ETAP, was used in this report [17-19]. We used ETAP to design a power plant running two auxiliary 1000 MW power units and a 10 kV wiring system. All of the electrical equipment of the two generating units was designed using ETAP. Other parameters were assigned, and offline simulations were made according to the Plant Technical Regulation [20-21]. Using ETAP, the reliability data of the load points (buses) and the entire system were calculated, giving us the reliability index. These data can be used for design and optimization of the follow-up system.

The distribution system reliability employs a new analytical algorithm that assesses the reliability indices of radial distribution systems. This algorithm basically uses an algorithm for a radial distribution system, which is first converted to a radial network. Therefore, the employed algorithm is quite efficient and suitable for a large-scale distribution system with general configurations.

2. Wiring form for high-voltage auxiliary power system

There are two high-voltage split transformers, T1 and T2, with a rating of 65/38-38 MVA and a voltage of 27 ± 2 × 2.5%/10.5 kV-10.5 kV for the two plant units. A high-voltage start-up/standby transformer, T, with a rating of 65/38-38 MVA and a voltage of 500 ± 8 × 1.25%/10.5-10.5 kV is used as the start-up/standby source, which receives power from 500 kV power switchgear. Two high-voltage, two-winding transformers with a rating of 38 MVA are used to supply power for the common loads, such as coal handling and desulfurization parts, and they are also used as standbys for each other. The high-voltage, start-up/standby transformer supplies power for high common buses as the temporary source during unit start-up.

The power for motors with a rating of ≥ 200 kW is supplied by the 10 kV bus. The motors with a rating of ≥ 1500 kW and transformers with a rating of 2000 kVA use vacuum breakers, and the others use an F-C circuit. The wiring form for the high-voltage system is shown in Fig. 1.

3. Reliability Evaluation

Three basic reliability indicators are normally used to predict or assess the reliability of a distribution system. These include load point average failure rate (λ), average outage duration (r), and annual unavailability (U). To better describe the dangers of a system during power outages using these three basic indicators, including the number of users connected to each load point of the system, average load, and cost to users during an interruption, the following two sets of indices can be determined. One set is the system reliability index, including the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), and Average Service Unavailability Index (ASUI). These can be used to estimate the overall performance of a distribution system. The other set is the cost of reliability index, including Expected Energy Not Supply (EENS), Estimated Cost of Interruption (ECOST), and Interruption Energy Assess Rate (IEAR). EENS, ECOST, and IEAR can be the indices of each load point or the overall system. All of these indices can be used to estimate the reliability of existing distribution systems and provide useful information to improve existing systems and design new distribution systems. Additionally, to analyze the failure rate of different devices and the sensitivity to the reliability indices EENS and ECOST, the contributions of the equipment to the indices, or grades, are used. A grade can refer to a load point or the overall system.

4. Selecting the model and parameters for each systematic device

ETAP is a tool for comprehensive analysis and can be used to design and test power systems. Using the offline simulation module that is IEC-standard, ETAP can also run real-time data to achieve high-level monitoring, real-time simulation, optimization, energy system management, and high-speed intelligent features such as load rejection. In this study, a simulation of auxiliary power system [11] reliability is conducted using ETAP.

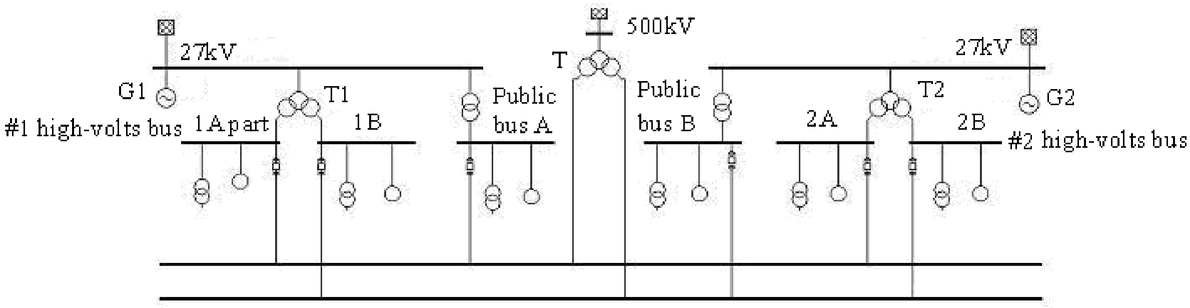

Fig. 1. Wiring project for high-voltage auxiliary power system.

4.1 Selecting transformer parameters

The short-circuit impedance of the transformer is determined by the short-circuit level of the bus and the voltage level of the motor starting the bus. The resistance of the transformer is determined by the actual transformer winding material and other factors. According to the production capacity of transformer plants and the parameters of real running transformers, the high-voltage winding rating capacity of a three-winding split transformer is 65 MVA. The impedance of the transformer (based on the winding on the high-voltage side) can be determined as the following: $U_{k(1-2)} = U_{k(1-3)} =$ 18%， $U_{k(2-3)} = 2.7 \times U_{k(1-2)}$, and high and low resistance R_2 = R_3 using formulas (1)-(4), converting the data of the transformer's brand into Z% and X / R values, and setting them into the model. The three-winding split transformer and two-winding split transformer are τ models. The high-voltage, standby transformer's parameters were chosen based on the maximum value of each parameter of the high-voltage transformer. Each parameter of the two-winding transformers is shown in Table 1.

$$X_{(1-2)} = \frac{U_{k(1-2)}\% \times U_N^{\ 2}}{100 S_N} \tag{1}$$

Table 1. Parameters of two-winding transformers.

Rated Capability (kVA)	High Voltage (kV)	Low Voltage (kV)	Short-circuit Voltage percent(%)	Impedance Ratio (X/R)
160	6.3	0.4	4.5	3.45
	10.5	0.4		
400	6.3	0.4	4.5	4.7
	10.5	0.4		
500	6.3	0.4	4.5	4.7
	10.5	0.4		
800	6.3	0.4	6	5.79
	10.5	0.4		
1250	6.3	0.4	6	7.1
	10.5	0.4		
1600	6.3	0.4	8	7.1
	10.5	0.4		
2000	6.3	0.4	10	7.1
	10.5	0.4		
2500	6.3	0.4	10	10.67
	10.5	0.4		

$$R_{(1-2)} = R_1 + R_2 \tag{2}$$

$$Z_{(1-2)} = \sqrt{X_{(1-2)}^{\ 2} + R_{(1-2)}^{\ 2}} \tag{3}$$

$$X_{(1-2)} / R_{(1-2)} = \frac{U_{k(1-2)}\% \times U_N^{\ 2}}{100 S_N} / (R_1 + R_2) \tag{4}$$

where S_N, U_N are transformer ratings.

4.2. Motor parameter selection

In auxiliary power systems, the motors are all inductive motors (i.e., they are asynchronous motors). A constant-resistance model is used in the simulation. In the network of positive and negative sequences, the asynchronous motor impedance is the following:

$$Z_M = \frac{1}{I_{LR}/I_{RM}} \times \frac{U_{RM}}{\sqrt{3} I_{RM}} = \frac{1}{I_{LR}/I_{RM}} \times \frac{U_{RM}^2}{S_{RM}} \quad (5)$$

where U_{RM} is the motor-rated voltage, I_{RM} is the rated current for the motor, S_{RM} is the rated capacity of the motor, and I_{LR}/I_{RM} is the ratio of the locked-rotor current and the rated current, which are set to 400 at the high voltage (6.3 kV, 10.5 kV) and 500 at the low voltage (0.4 kV, 0.38 kV).

4.3. Setting cable parameters

When setting cable length, approximately 50 m of cable is connected to the motors, and approximately 150 m of cable is connected to the transformers. The cross-sectional area of the cable depends on the rated current of the connecting line. Generally, these areas are 95 mm^2 for high-voltage cables and 185 mm^2 for low-voltage cables. Other parameters can be selected according to the ETAP library. The cable lines are π model.

4.4. Selecting parameters for circuit breakers, disconnecting switches, and F-C circuits

Under normal circumstances, the initial short-circuit current of the high-voltage bus is limited to 40 kA, and the peak current is in the range of 110-165 kA. The simulation shows that the initial short-circuit current of the high-voltage bus can only be limited to approximately 50 kA, so the model of the high-voltage circuit breaker is 15-3 AH-40, the minimum delay time is 0 seconds, the rated current and power are 1250 A and 15 kV, respectively, and the peak current and breaking current are 100 kA and 40 kA, respectively.

According to the actual situations of low-voltage auxiliary power plants, the initial value of the three-phase symmetrical short-circuit current is greater than 50 kA, the peak current is not less than 143 kA, the model of the low-voltage circuit breaker is S7H, the minimum delay time is 0.007 seconds, the rated current and power are 1250 A and 0.415 kV, respectively, and the peak current and breaking current are 143 kA and 65 kA, respectively.

A low-voltage isolation switch is used to cut the circuit reliably to ensure safety for examination and repair. The low-voltage isolation switch is used when the PC section connects to the MCC section using the low-voltage circuit breakers with a rated current of 1200 A and rated voltage of 13.8 KV.

As a general practice, an F-C circuit is used to protect a motor with a rated power of 1500 kW or less and a transformer with a rated power of 2000 kVA or less. This type of load is generally concentrated in high-voltage plants, and the initial current should be limited to 40 kA, so the parameter selection is the same as the high-voltage circuit breaker.

5. Simulation and calculation of reliability for auxiliary power system

Reliability indicators can be estimated using ETAP. The procedure simulates different power system equipment and their role in the reliability of the power distribution system (e.g., by turning on/off the equipment's fault isolation and load recovery operations). ETAP is suitable for general configuration of large-scale system reliability analysis and estimating the reliability of a distribution system and the benefits of different options to ensure maximum system reliability with limited resources.

The indices used to measure the reliability of a distribution system are usually defined as the following:

A. Average failure rate of load point I, λ_i (f/yr)

$$\lambda_i = \sum_{jeNe} \lambda_{e,j}$$

where $\lambda_{e,j}$ is the average failure rate of the equipment j and N_e is the total number of devices that make an interruption of the load point I.

B. Annual average outage duration of load point I, Ui (hr/yr)

$$U_i = \sum_{jeNe} \lambda_{e,j} \gamma_{ij}$$

where γ_{ij} is the duration of failure of load point I caused by failure of equipment j.

C. Average outage duration of load point I

$$\gamma_i = U_i / \lambda_i$$

D. Index of Expected Energy Not Supply (EENS) of load point I

$$EENSi = P_i U_i$$

where P_i is the average load of load point I

E. Index of Estimated Cost of Interruption (ECOST) of load point I

$$ECOST_i = P_i \sum_{jeNe} f(\gamma_{ij}) \lambda_{e,j}$$

where $f(\gamma_{ij})$ is Sector Customer Damage Function (SCDF).

F. Interruption Energy Assess Rate of load point I (IEARi, $\$/kWhr$)

$$IEAR_i = \frac{ECOST_i}{EENSi}$$

G. System Average Interruption Frequency Index (SAIFI, f/annual users)

$$SAIFI = \frac{\sum \gamma_i N_i}{\sum N_i}$$

where N_i is the number of users of load point I and $\sum$ is the sum of all load points.

H. System Average Interruption Duration Index (SAIDI, hr/annual users)

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i}$$

I. Customer Average Interruption Duration Index (CAIDI, hr/interruption of customer)

$$CAIDI = \frac{\sum U_i N_i}{\sum N_i \lambda_i}$$

J. Average Service Availability Index (ASAI, pu)

$$ASAI = \frac{\sum Ni \times 8760 - \sum NiUi}{\sum Ni \times 8760}$$

where 8760 is the number of hours in a year.

K. Average Service Unavailability Index (ASUI, pu)

$$ASUI = 1 - ASAI$$

L. System Expected Energy Not Supply (EENS, $MWhr / yr$)

$$EENS = \sum EENS_i$$

M. System Estimated Cost of Interruption (ECOST, $k\$ / yr$)

$$ECOST = \sum ECOST_i$$

N. Average Energy Not Served (AENS, $MWhr / customer.yr$)

$$AENS = \frac{\sum EENS_i}{\sum N_i}$$

O. System Interruption Energy Assess Rate (IEAR, $\$ / kWhr$)

$$IEAR = \frac{ECOST}{EENS}$$

In this study, we mainly consider the load point reliability indices: average failure rate of load point *I*, λ_i (f/yr) annual average invalidity, U_i (*hr/yr*); and annual average outage duration of load point I, γ_i (*hr*). The reliability parameters of electrical

Table 2. Reliability parameter of electrical equipments

Equipment	Source	Type	Grade	Annual Initiative Failure rate	Annual Passivity Failure rate	Average Repair Time	Switch Time	Replacement Time
Electromotor	IEEE STD493-1990	Steam Turbine	All kV	0.3200	0.3047	234.00	200.00	201.00
Diesel engine	IEEE STD493-1990	Gas Turbine	All kV	0.6380	0.3047	190.00	200.00	400.00
High-voltage Transformer	IEEE STD493-1990	LqdFill >15 kV	>15kV	0.0130	0.1524	367.00	186.00	71.50
Low-voltage Transformer	IEEE STD493-1990	Dry	0-15kV	0.0036	0.3047	67.00	120.00	39.90
Bus	IEEE	Typical	0.00-33kV	0.0010	0.0000	2.00	1.00	1.00
Cable 1	IEEE STD493-1990	A/G Conduit	0.601-15kV	0.0150	0.1524	50.00	8.00	19.80
Cable 2	IEEE STD493-1990	A/G Tray	0.601-15kV	0.0028	0.1524	49.40	8.00	119.00
High-voltage Breaker	IEEE STD493-1900	Fixed	>0.6kV	0.0176	0.1524	44.50	96.00	12.00
Low-voltage Breaker	IEEE STD493-1990	Metalclad	0-0.6kV 0-600A	0.0023	0.3047	75.60	72.00	1.20
Switch	IEEE STD493-1900	Disconnect	Enclosed	0.0061	0.1524	50.10	20.00	13.70

equipment in the system are shown in Table 2. The simulation and calculation results of reliability are shown in Tables 3-5.

Table 3. High-voltage bus reliability basic stability index

High-voltage Bus	Average Failure Rate $\lambda(f/yr)$	Average Outage Duration γ (hr)	Annual Unavailability U(hr/yr)
#1 high -voltage bus 1A part	1.3796	153.11	211.2269
#1 high -voltage bus 1B part	1.4032	151.22	212.1901
Public bus A part /#1 high-voltage bus 2A part	1.2460	191.02	238.0023
#2 high -voltage bus 2A part	1.3826	152.84	211.3169
#2 high -voltage bus 2B part	1.4062	150.96	212.2801
Public bus B part /#1 high-volt bus 1A part	1.2490	190.63	238.0923

According to the results in Tables 3 and 4, the stable reliability indices of the high-voltage load point show that the average failure rate λ is between 1.2 f/yr and 1.5 f/yr, the annual average unavailability of load point *I* is between 211 hr/yr and 238 hr/yr, and the annual average outage duration γ is between 150 hr and 190 hr. The stable reliability indices of the low-voltage load point show that the average failure rate λ is between 2.0 f/yr and 2.5 f/yr, the annual average outage duration γ is between 114 hr and 131 hr, and the annual average unavailability of load point *I* is between 257 hr/yr and 297 hr/yr. All of the stable indices above meet the system requirements. Table 5 shows that the reliability indices of the overall system also meet the requirements.

6. Conclusions

In order to inspect and/or to improve the reliability of the large-capacity units of power plant both in the design and operation. An auxiliary 1000 MW unit power system, which is found for practical systems, is modeled by ETAP software in this study. The reliability indices of every bus and the overall system are calculated, and the results show that the reliability indices are optimal. The wiring form of the system is simple, easy to maintain, and inexpensive, and the results of the simulation are consistent with the actual situation. The results and data provide good

Table 4. Low-voltage bus reliability basic stability index

High-voltage Bus	Average Failure rate $\lambda(f/yr)$	Average Outage Duration γ (hr)	Annual Unavailability U(hr/yr)	High-voltage Bus	Average Failure rate $\lambda(f/yr)$	Average Outage Duration γ (hr)	Annual Unavailability U(hr/yr)
Boiler PC A part	2.1898	117.17	258.1104	Boiler PC B part	2.2134	117.05	259.0735
Chemistry disposal PC A part	2.2180	116.96	259.4213	Chemistry disposal PC B part	2.2210	116.84	259.5113
Security PC A part	2.1829	118.00	257.5887	Security PC B part	2.2065	117.17	258.5519
Plant former Section PC A part	2.0670	131.45	271.7224	Plant former Section PC B part	2.0700	131.31	271.8123
Repair PC part	2.2006	117.43	258.4149	Illume PC part	2.2242	116.61	259.3781
Pretreatment PC A part	2.2242	116.61	259.3781	Pretreatment PC B part	2.2272	116.50	259.4680
Boiler remove Dirt PC A part	2.1748	121.02	263.2024	Transport coal PC A part	2.4412	117.65	287.2031
Boiler remove Dirt PC B part	2.1984	120.16	264.1656	Transport coal PC B part	2.4429	117.53	287.1201
Steam motor PC A part	2.1921	117.82	258.2842	Transport coal PC C part	2.4412	117.65	287.2031
Steam motor PC B part	2.2157	117.00	259.2474	Transport coal PC D part	2.4429	117.53	287.1201
Replenishment water Supply PC A part	2.3683	114.96	295.9325	Replenishment water Supply PC B part	2.3683	114.96	295.9325
Decoke PC A part	2.4376	117.71	286.9308	Decoke PC B part	2.4416	117.56	287.0217
Decoke PC C part	2.4376	117.71	286.9308	Decoke PC D part	2.4416	117.56	287.0217
Waste water disposal PC A part	2.4389	117.69	287.0292	Waste water disposal PC B part	2.4383	117.61	286.7724
Public PC A part	2.2111	117.09	258.5997	Public PC B part	2.2141	116.97	258.9897
Cycle water pump PC A1 part	2.0670	131.45	271.7224	Cycle water pump PC B1 part	2.0700	131.31	271.8123

Table 5. Reliability of the overall system

Index	**Result**
System Average Interruption Frequency Index (SAIFI)	2.17 f/customer yr
System Average Interruption Duration Index (SAIDI)	267.1931 hr/customer yr
Customer Average Interruption Duration Index (CAIDI)	123.132 hr/customer interruption
Average Service Availability Index (ASAI)	0.9695 pu
Average Service Unavailability Index (ASUI)	0.0305 pu
Expected Energy Not Supply (EENS)	46573.29 MW hr/yr
Average Energy Not Supply (AENS)	222.8387MW hr/customer yr

references for designing and planning auxiliary power systems in the future.

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