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Optimization and reliability analysis of the main wiring in power plant —— Take 2400mw thermal power plant as an example

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ABSTRACT

With the rapid development of economy, the power industry is facing a more severe test. How to ensure the reliability of power supply is the primary consideration of every power plant and substation. This paper will introduce an improved method of main wiring, which can improve the reliability of main wiring. At the same time, it will also introduce several algorithms commonly used in the reliability analysis of electrical main wiring in power plant substation - minimum cut set method, GO method, and so on. Select a typical example for analysis and calculation. Finally, through the introduced reliability calculation method and the mathematical model of the main wiring, through the calculation and analysis, the reliability of the main wiring before and after the optimization is compared, which proves that the optimized main wiring form is more reliable.

Keywords: electrical main wiring; reliability analysis; GO method;

At present, the problem of energy shortage in our country is becoming more and more serious, and the unstable operation of electric energy often occurs (for example, substation failure leads to a wide range of power outage). As the power is not easy to store, there is the need for timely use of power generation characteristics, if a certain area of power supply failure, will be a lot of waste of energy. In the reality of energy shortage, how to use limited energy more reliably is an urgent problem.

This paper mainly introduces the reliability analysis of the main wiring and the improvement method of the main wiring in the thermal power plant. The substation can be used as a reference.

1. MAIN WIRING OPTIMIZATION SCHEME

In the analysis of current conventional thermal power plants, we find that most of the electrical main wiring in large and medium-sized thermal power plants usually adopts the form of one and a half circuit breaker or double bus with bypass wiring, in which the high-voltage side often uses one and a half circuit breaker wiring, and the low-voltage side often uses the form of double bus with bypass wiring. Through the research, we will take a 2400MW thermal power plant as an example, and use the algorithm to calculate the reliability of its main electrical wiring. The simplified main wiring diagram of the thermal power plant is shown in Figure 1.

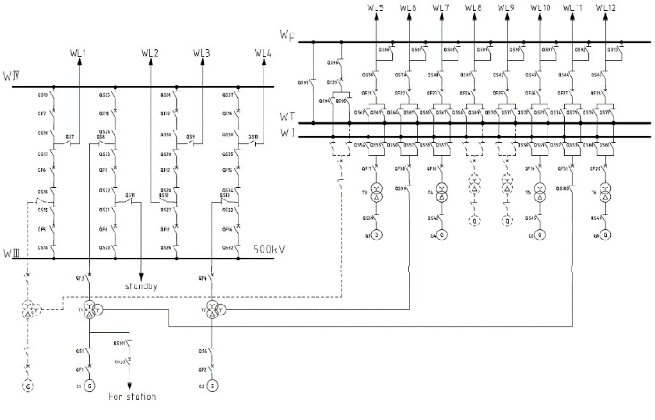


Figure 1 main wiring diagram of 2400mw thermal power plant

As shown in the main wiring diagram, the thermal power plant uses 2 × 600MW units to supply 500kV voltage level; 4 × 300MW units to supply 220kV voltage level. The 500kV side adopts the wiring form of one and a half circuit breakers, while the 220kV side adopts the wiring form of double bus with bypass.

Through investigation and analysis, in the previous main wiring form, the generator outlet is connected with the bus in the plant after being boosted by the unit wiring, and then the power is supplied to each outgoing line through various forms of main wiring in cooperation with the outlet circuit breaker (as shown in Figure 1). This connection mode is widely used in large power plants. In the process of my research and learning, I found a more reliable improved connection mode. Therefore, the author puts forward a special application of the classical connection form of double bus with bypass bus, that is, unit connection directly supplies power to the bypass bus. The schematic diagram is shown in Figure 2.

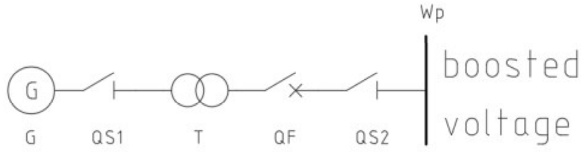


Figure 2 Schematic diagram of power supply from unit wiring to bypass bus

In order to analyze the reliability of the power supply form and facilitate the comparison of the reliability differences before and after the use of the wiring form, this paper takes the main wiring in Figure 1 as an example, and combines the improved scheme with the main wiring form of 2400MW fire power above. The optimized main wiring diagram is shown in Figure 3.

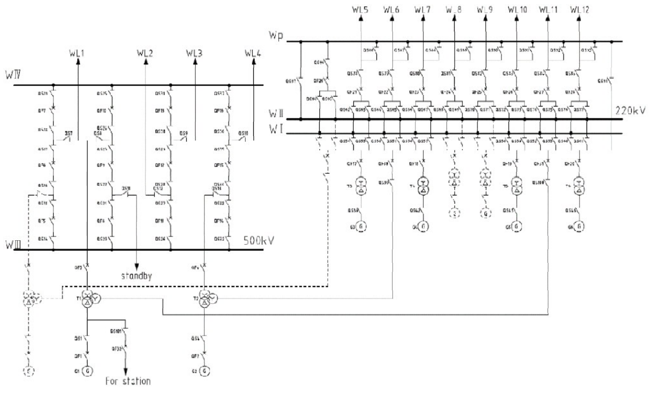


Figure 3 main wiring diagram after optimization

Through the optimization diagram, we can know that in the 2400mw thermal power plant, we have improved the main wiring form of 220kV side double bus wiring with bypass, and the partial enlarged diagram of 220kV side is shown in Figure 4. At the same time, in order to make a better analysis later, we also enlarge the 500kV side, as shown in Figure 5. Through comparison, an isolation switch QS98 is added to the right side of the main wiring of the optimized 220kV side, so that the generator G6 can directly transmit the electric energy to the bypass bus Wp through the step-up transformer, similar to the direct power supply to the bus, and there is no need for a breaker here.

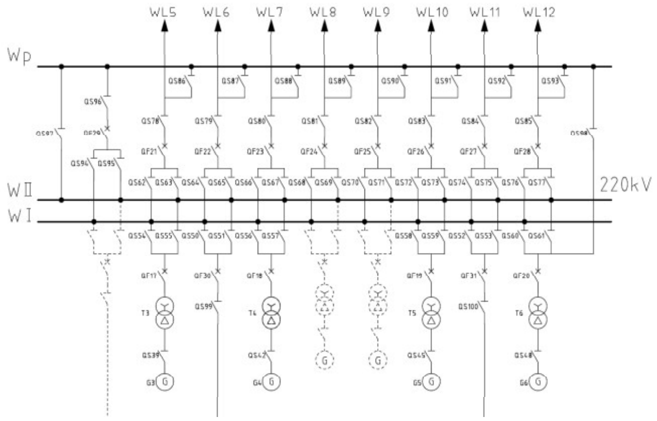


Figure 4 partial drawing of 220kV side

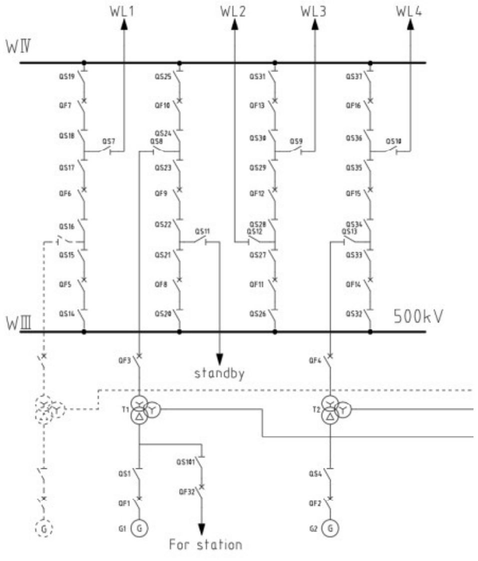


Figure 5 partial drawing of 500kV side

2. RELIABILITY ANALYSIS METHOD

In the process of reliability analysis of main wiring, if the main wiring system is relatively simple, the main wiring can be idealized into series or parallel system for analysis.

However, for the medium and large-scale thermal power plants as mentioned above, the system is complex and cannot be directly reduced to parallel or series system. For this system, there are many different analysis methods, such as minimum cut set method, GO method, fault tree method, etc.

Among them, the minimum cut set method and the fault tree method are based on the fault introduction oriented analysis method, while the GO method is based on the stability probability oriented analysis method. Because the analysis process of fault tree method is greatly affected by human subjective factors, this paper will use the minimum cut set method and GO method which are commonly used in the reliability analysis of main wiring, two different types of analysis methods to analyze the reliability of the main wiring. Four analytical methods are described below.

2.1 Series system

As long as any part of the system is out of line fault, it will lead to the failure of the whole system. This system is called series system. For the ideal system in series, the reliability Rs of each component is often multiplied, that is:

$$R_s = R_1 \cdot R_2 \cdot \cdots \cdot R_n = \prod_{i=1}^{n} R_i \qquad \text{Formula(1)}$$

Where $R_1, R_2, \cdots, R_n$ are the reliability of each element and system in the series system. It should be noted that the series system mentioned here is not a series system in the common sense. For example, the capacitor parallel shown in Figure 6, because any one capacitor fails, the whole system will not work normally, so the capacitor parallel system is also called a series system.

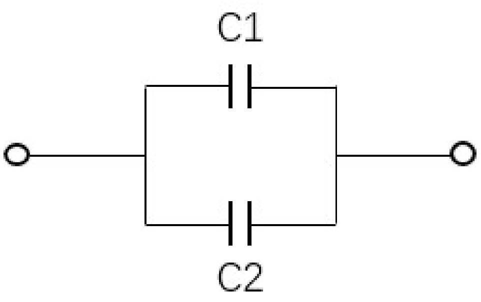


Figure 6 parallel connection of capacitors

2.2 Parallel system

When all parts of the system fail at the same time, the whole system will fail. This kind of system is called parallel system. For the ideal parallel system, it is often used to multiply the unreliability F_i of each component, and then calculate the reliability R_s by $R_s = 1 - F_i$, that is:

$$F_s = F_1 \cdot F_2 \cdot \cdots \cdot F_n = \prod_{i=1}^{n} F_i \qquad \text{Formula(2)}$$

$$R_s = 1 - \prod_{i=1}^{n} F_i \qquad \text{Formula(3)}$$

$F_1, F_2, \cdots, F_n$ in the formula are the unreliability of each component and the whole system in the series idealized system.

2.3 Introduction to minimum cut set method

For the more complex main wiring system, that is, non series parallel system, the most commonly used analysis method is the minimum cut set method. In a complete system, the minimum subset of the set of components that will lead to system failure is defined as the minimum cut set. In the minimum cut set, as long as any component in the set is not failed, it will not cause system failure. This also shows that all components in the minimum cut set must be failed in order to cause system failure. Through the definition, we can analyze that the components of each minimum cut set are connected in parallel. Because of the failure of any minimum cut set, the system will fail, and there is a series relationship between the cut set and the cut set.

For a typical non series parallel system bridge type network, as shown in Figure 7, since this type of network cannot be reduced to series or parallel system, the minimum cut set method is required. There are four minimum cut sets in this system .

Table 1 minimum cut sets in bridge networks

Serial number	Components in cut set	Serial number	Components in cut set
1	AB	2	AED
3	CD	4	BEC

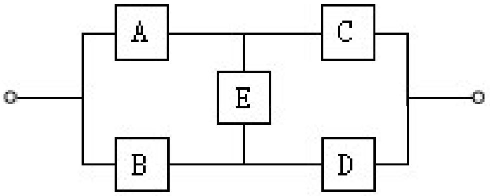


Figure 7 bridge network

If A and B fail at the same time, that is, if the first minimum cut set fails, the whole bridge network will fail; similarly, if A, E and D fail at the same time, that is, if the second minimum cut set fails, the whole bridge network will fail, as will the third and fourth minimum cut sets. Therefore, the bridge network can be simplified as follows:

Firstly, the components in each minimum cut set are connected in parallel, because the components in the minimum cut set will fail only when they fail at the same time. At the same time, each minimum cut set is connected in series, because the failure of any minimum cut set will lead to the failure of the whole system. By analyzing the bridge network in Figure7, it can be simplified as follows:

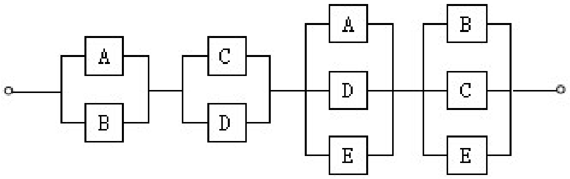


Figure 8 equivalent reliability diagram of bridge network

In order to calculate the reliability of the system, we will combine the minimum cut sets. In the calculation process, we use C_m to express the m-th cut set. If the probability of failure $P(C_m)$) is, then the system's unreliability$\overline{A_s}$ is

$$\overline{A_s} = P(C_1 \cup C_2 \cup C_3 \cup \cdots \cup C_m \cup \cdots \cup C_n)$$

Formula(4)

2.4 GO method introduction

GO method is a new concept of system reliability analysis technology. Its analysis method can be approximated to graphic solution. The main principle of GO method is to take function flow as the guide, analyze the system first, list the minimum path set that meets the conditions one by one, then analyze and merge the circuit, list the logical relations of different components in different situations, and then draw the equivalent go of the system Figure, so as to calculate the input source of the system from go to the output unit, so as to obtain the reliability of the system. By using GO method, the reliability analysis of the whole system can be transformed into the reliability analysis of the corresponding equivalent units in the system. In addition, GO method can be used to analyze the minimum cut set that leads to system obstacles.

In using GO method, we must understand the establishment of go graph,GO method, operator and signal graph. In the process of building a GO diagram, you must first understand the common operators in the go diagram, as shown in Figure 9. In addition, there are many operators of GO graph, which will not be specifically introduced in this article. In the power plant main wiring analysis, the detailed use method will be introduced in the next section.

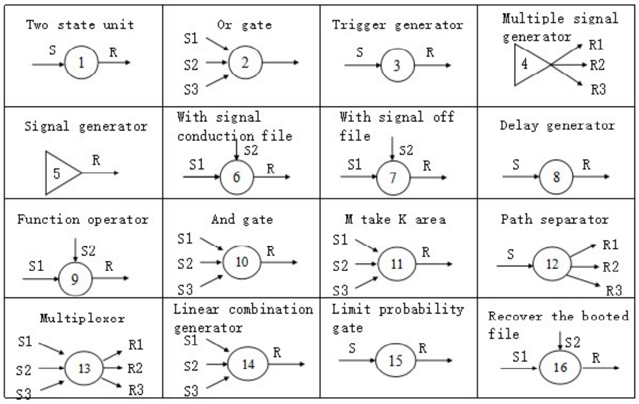


Figure 9 standard operators of go chart

The meta components or subsystems in the system can be called cells. The functions of cells and their logical relations are represented by operators. For different cell functions, different types of operators are used. Each operator has its own operation rules, functions and requirements.

Signal flow represents the input signal and output signal between each unit and door component of the system and the relationship between each unit component. It is composed of two attributes: state value and state efficiency. When the system diagram is equivalent to GO diagram, the number and signal flow of operators and operators must be marked well, and all marked out must be unique, and the drawn diagram cannot be less than part of the input and output. GO operation is through the probability data of each different operator and the probability state of this operator, through the input end of the system to the output end, and finally get the state of the system output signal.

It can be seen from the above analysis that in a simpler system, parallel system analysis and series system analysis are often used, but in a more complex system such as a power plant, the minimum cut set method and go method should be used for reliability analysis.

3. MATHEMATICAL MODEL OF RELIABILITY OF MAIN WIRING EQUIPMENT

Reliability is defined as: “the probability that components, equipment, systems, etc. complete their specified functions under specified conditions and within a predetermined time.” Generally, reliability indexes are measured by numerical value. Generally, four kinds of indexes of power system reliability are as follows:

(1) Probability index for the system or main wiring equipment to complete the indicating function.

(2) The expected failure days in the middle of a year are failure indicators.

(3) The frequency index of the failure in unit time.

(4) Time indicator of the duration of the failure.

In the main wiring, the reliability of the electrical components directly affects the reliability of the main wiring of the power plant. Before calculating the reliability of the main wiring, the mathematical model of the reliability of the equipment (circuit breaker, disconnector, transformer, generator, etc.) in the main wiring should be established first. The reliability model of each equipment is as follows, in which the reliability of each equipment is represented by P_N.

3.1 Transfer probability matrix

Before studying the reliability model of electrical equipment, it is necessary to know the state transition probability matrix. Every element of the matrix is nonnegative, and the sum of all elements is equal to 1. Each element is represented by probability, which is transferred to each other under certain conditions, so it is called transfer probability matrix. The transition probability matrix method can be used to calculate the state of a system when the state changes, and the transition probability can be used to calculate the state after the system changes. In short, if there are three states of some articles, A, B and C, and the number is n_A、n_B、n_C respectively. In the discrete-time system, if the state changes after Δt time, and the corresponding transition probability is shown in the table2 below

Table 2 Transfer probability

After transfer Before transfer	A	B	C
A	P_{AA}	P_{AB}	P_{AC}
B	P_{BA}	P_{BB}	P_{BC}
C	P_{CA}	P_{CB}	P_{CC}

Note: it indicates the probability of transition to state B after time for an object with initial state A.

If the number of objects in state A, B and C after Δt time is N_A、N_B、C_C, then it can be calculated by the following formula

$$[N_A \quad N_B \quad N_C] = [n_A \quad n_B \quad n_C] \times \begin{bmatrix} P_{AA} & P_{AB} & P_{AC} \\ P_{BA} & P_{BB} & P_{BC} \\ P_{CA} & P_{CB} & P_{CC} \end{bmatrix}$$

Formula(5)

Through the above analysis, we can get the number of a certain kind of goods after state transition through the probability matrix of state transition. For the continuous time system of electrical equipment, when tends to 0, the above analysis will be applicable to the continuous time system.

3.2 Reliability model of circuit breaker

As the circuit breaker is an operable equipment, it can be divided into the following five states according to its actual operation condition according to its influence on the components within the protection scope: non operation, non expansion fault, expansion fault, planned maintenance and normal operation state. In addition to the normal operation state, the other four states have the same impact on the system. However, the planned maintenance state and the rejected action state are non random, and they will only occur under specific circumstances, in which the planned maintenance state will occur within the specified time, and the rejected action will appear only when there is a command to require its action, and will not appear when there is no command action. In addition, the extended faults and non extended faults are random. Therefore, these states need to be treated differently, and the failure modes of the circuit breaker are various, so the five state reliability model is proposed. In conclusion, the reliability mathematical model of the circuit breaker is shown in Figure 10. The probabilities of the five states are P_F、P_M、P_s、P_R、P_N respectively.

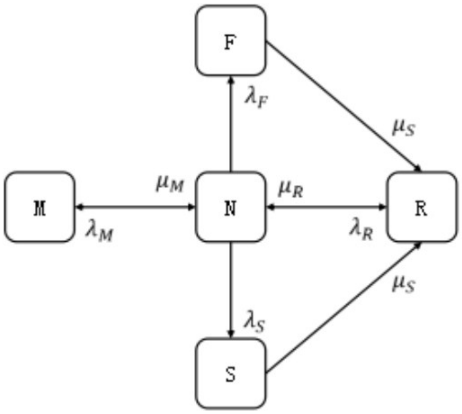


Figure10 Mathematical model of circuit breaker reliability

Among them:

F - refuse to move;

M - planned maintenance status;

S-extended fault state;

R-non expanded large fault state;

N - normal working state;

λ and μ is the transition probability between various states, where is the failure rate and is the repair rate. As shown in Figure 5, the specific meaning is as follows:

λ_M- maintenance rate from normal operation to planned maintenance;

λ_F- failure rate from normal operation state to non operation state;

λ_s- failure rate from normal operation state to extended failure state;

λ_R- failure rate from normal operation state to non expansion fault state;

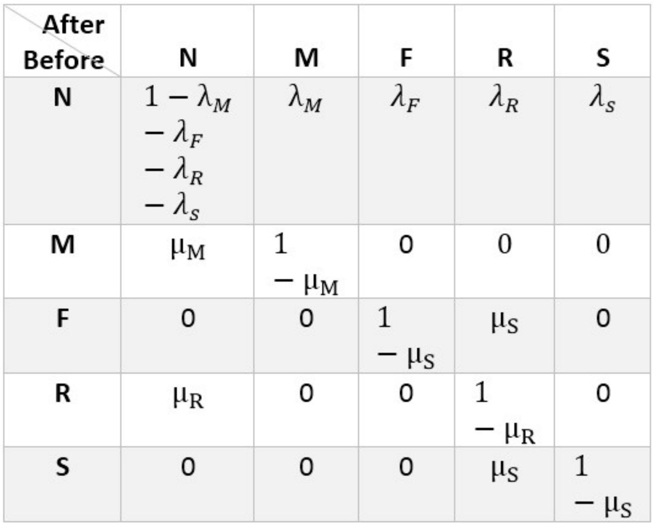
μ_M- repair rate from normal operation state to planned maintenance state;

μ_S- switching rate from fault to non extended fault state;

μ_R- repair rate from non expanded fault state to normal state;

For the establishment of the reliability model, the transfer probability matrix method described above will be used in this paper. The transfer probability matrix of the circuit breaker can be obtained from the mathematical model of the circuit breaker in Figure 5 as shown in the following table 3

Table3 Transfer probability matrix of circuit breaker



After / Before	N	M	F	R	S
N	$1-\lambda_M-\lambda_F-\lambda_R-\lambda_s$	λ_M	λ_F	λ_R	λ_s
M	μ_M	$1-\mu_M$	0	0	0
F	0	0	$1-\mu_S$	μ_S	0
R	μ_R	0	0	$1-\mu_R$	0
S	0	0	0	μ_S	$1-\mu_S$

Because the probability of the circuit breaker in five states is P_F、P_M、P_S、P_R、P_N respectively, and the probability will not change when the circuit breaker has state transfer, that is, the probability of the circuit breaker in five states after state transfer is P_F、P_M、P_S、P_R、P_N. The following formula can be listed

$$[P_N \quad P_M \quad P_F \; P_R \quad P_S] = [P_N \quad P_M \quad P_F \; P_R \quad P_S] \times \begin{bmatrix} 1-\lambda_M-\lambda_F-\lambda_R-\lambda_s & \lambda_M & \lambda_F & \lambda_R & \lambda_s \\ \mu_M & 1-\mu_M & 0 & 0 & 0 \\ 0 & 0 & 1-\mu_S & \mu_S & 0 \\ \mu_R & 0 & 0 & 1-\mu_R & 0 \\ 0 & 0 & 0 & \mu_S & 1-\mu_S \end{bmatrix}$$

Formula(6)

The equations can be obtained:

$$\begin{cases} (-\lambda_M-\lambda_F-\mu_R-\lambda_s)P_N+P_M\mu_M+P_R\mu_R=0 \\ P_M\lambda_M-P_F\mu_M=0 \\ P_M\lambda_F-P_F\mu_S=0 \\ P_N\lambda_R+P_F\mu_S-P_R\mu_R+P_S\mu_S=0 \\ P_N\lambda_s-P_S\mu_S=0 \end{cases}$$

Formula(7)

Among $P_F+P_M+P_S+P_R+P_N=1$

The probability of the circuit breaker under the normal working condition can be obtained by combining (6) and (7):

$$P_N = 1/(1+\frac{\lambda_M}{\mu_M}+\frac{\lambda_S+\lambda_f}{\mu_S}+\frac{\lambda_S+\lambda_f+\lambda_R}{\mu_R})$$

Formula(8)

3.3 Reliability model of transmission line, generator and transformer

The mathematical model of transmission line, generator and transformer reliability is similar to that of circuit breaker, but compared with circuit breaker, transmission line, generator and transformer will not refuse to operate, and will only have extended fault. According to the analysis, the normal operation reliability model is shown in Figure 11

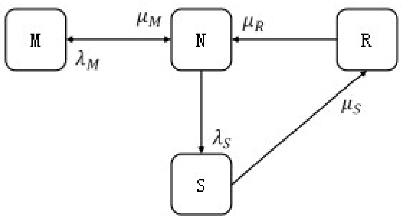


Figure 11 Transmission line reliability mathematical model

The transfer probability matrix is analyzed as follows:

Table 4 Transition probability matrix

After transfer Before transfer	N	M	R	S
N	$1-\lambda_M-\lambda_s$	λ_M	0	λ_S
M	μ_M	$1-\mu_M$	0	0
R	μ_R	0	$1-\mu_R$	0
S	0	0	μ_S	$1-\mu_S$

The formula and the analysis process are the same as the reliability model of the circuit breaker, and the probability of transmission line, generator and transformer under normal working condition can be obtained through the equation group

$$P_N = 1/(1+\frac{\lambda_M}{\mu_M}+\frac{\lambda_S}{\mu_S}+\frac{\lambda_S}{\mu_R})$$

Formula(9)

3.4 Bus reliability model

For the bus with switching operation, the reliability model can be analyzed by the reliability model of transmission line, generator and transformer, such as formula (10). For the bus without switching operation, three state model can be used for analysis, and its reliability model is shown in the figure12 Shown

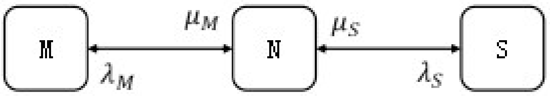


Figure 12 Three-state reliability model

The transfer probability matrix is analyzed as follows:

Table 5 Transition probability matrix

After Before	N	M	S
N	$1-\lambda_M-\lambda_s$	λ_M	λ_s
M	μ_M	$1-\mu_M$	0
S	μ_S	0	$1-\mu_S$

Similarly, by analyzing the equations, we can get the probability of normal working state of bus without switching operation as follows:

$$P_N = 1/(1+\frac{\lambda_M}{\mu_M}+\frac{\lambda_S}{\mu_S})$$

Formula(10)

3.5 Summary of electrical equipment reliability model

For circuit breakers, the probability of reliable operation P_N is

$$P_N = 1/(1+\frac{\lambda_M}{\mu_M}+\frac{\lambda_S+\lambda_f}{\mu_S}+\frac{\lambda_S+\lambda_f+\lambda_R}{\mu_R})$$

Formula(11)

For transmission lines, generators, transformers and buses with switching operation, the probability of reliable operation is P_N

$$P_N = 1/(1+\frac{\lambda_M}{\mu_M}+\frac{\lambda_S}{\mu_S}+\frac{\lambda_S}{\mu_R})$$ Formula(12)

For the bus without switching operation, the probability of reliable operation is P_N

$$P_N = 1/(1+\frac{\lambda_M}{\mu_M}+\frac{\lambda_S}{\mu_S})$$ Formula(13)

4. RELIABILITY ANALYSIS AND CALCULATION OF EACH OUTGOING LINE

In the process of reliability analysis of main wiring, because the wiring form is not completely symmetrical, the reliability calculation process of different outgoing lines is slightly different. Therefore, the 12 circuit outgoing line and one circuit standby outgoing line of main wiring in Figure 8 are divided into three groups, WL1-WL3, WL5-WLl12,WL4 and standby outgoing line, and two different reliability calculation methods are used for analysis.

Among them, the reason why wl1-wl3 is divided into one group is that in the 500kV side, one and a half circuit breaker wiring, the electrical energy of the three groups of outgoing lines can not be directly obtained from the power supply through the disconnector circuit breaker. Power must be obtained from the bus on the 500kV side.

The reason why WL5 WLl12 is divided into one group is that they are all on the 200kV voltage level side, and they are all powered through the wiring form of double bus with bypass, and they all pass through the same bus, so they are considered to be the same type of outgoing line.

The reason why WLl4 and standby outgoing line are divided into one group is that on 500kV side, two outgoing lines of them can be obtained from the bus, and they can also be obtained directly from the power supply through the disconnector breaker without passing through the bus.

At the same time, in this chapter, the difference between the reliability of the main wiring after optimization and before optimization will be analyzed and calculated rigorously. Because the optimization is carried out in the form of 220kV side double bus belt bypass wiring of the main wiring, there is no impact on the outgoing line of one and a half circuit breakers at 500kV side. That is to say, it only has a significant impact on the reliability of wl5-wl12 outgoing line. The reliability comparison before and after optimization will be analyzed and calculated in Section 3.3.

In the process of analysis and calculation, the letter R is used as the reliability coefficient.

4.1 Reliability coefficient of primary electrical equipment

Reliability coefficient can also be called probability of reliable operation. In order to facilitate subsequent calculation, reliability coefficient R_s is used later in this chapter to represent probability of reliable operation. By referring to the manual of electrical primary side equipment and substituting the parameters into the reliability model of electrical components introduced in Chapter 8, it can be concluded that in the main wiring of Figure 3, the reliability coefficient of each component is as follows:

- Reliability coefficient of generator $R_{sG} = 0.99$;
- Reliability coefficient of circuit breaker $R_{sQF} = 0.9926$;
- Reliability coefficient of disconnector $R_{sQS} = 0.9981$r;
- Reliability coefficient of transformer $R_{sT} = 0.9968$;
- Reliability coefficient of bus $R_{sW} = 0.9991$.

4.2 Reliability analysis of outgoing line WL1-WL3 (minimum cut set method)

4.2.1 Analysis and calculation process

In this section, the minimum cut set method of complex network algorithm will be used to analyze the reliability of wl1-wl3 three circuit outgoing line. At the same time, within the error range, some equipment will be combined for analysis.

Analyze the power source of the three groups of outgoing lines. Combined with the form of main wiring in Figure 8, the reliability equivalent diagram as shown in Figure 13 can be obtained. Through the diagram, the reliability of the three groups of outgoing lines can be analyzed.

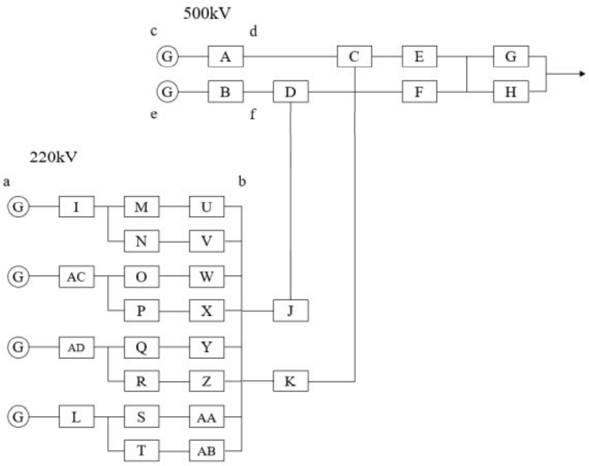


Figure 13 WL1, wl2 and wl3 equivalent

Note: in Figure 13, the following four generators are from 220kV side; modules a and B are circuit breakers at 500kV side. C. Module D is the equivalent component of three winding transformer; modules E and F are the equivalent components of disconnector circuit breaker before electric energy flows into 500kV bus; modules I, AC,AD and L are the equivalent components of 220kV side transformer and circuit breaker; modules U ~ AB are the equivalent components of 220kV bus; the equivalent component diagram conforms to the error range.

Where R_A、 R_B、 $R_C \cdots R_{AC}$、 R_{AD} is the reliability of each equivalent element in the figure

Simplify figure 13:

It is assumed that the electric energy can flow out of the generator, and the reliability of passing through the equivalent element I-M-U or I-N-V is R_{ab}. That is to say, the reliability of any generator at 220kV side that can enter into the bus at 220kV side is . So in 220kV side, the reliability can be considered as four reliability in parallel. At the same time, through the above analysis, the value of reliability can be obtained:

$$
\begin{aligned}
R_{ab} &= R_G \cdot R_I \cdot ((R_M \cdot R_U)//(R_N \cdot R_V)) \\
&= 0.99 \times 0.9968 \times 0.9926 \\
&\quad \times (0.9981 \times 0.9991 \times 2 \\
&\quad - 0.9981^2 \times 0.9991^2) \\
&= 0.979522
\end{aligned}
$$

Formula(14)

In parallel with four R_{ab}, all the equivalent elements on the 220kV side can be combined into one equivalent element, which is represented by I module, and its reliability coefficient is R_I.

$$
\begin{aligned}
R_I &= R_{ab}//R_{ab}//R_{ab}//R_{ab} \\
&= 1-(1-R_{ab})^4 \\
&= 0.9999998241
\end{aligned}
$$

Formula(15)

Combine the generator at 500kV side with the equivalent component A, which is represented by a module, with a reliability of R_A. combine the other generator at 500kV side with the equivalent component B, which is represented by B module, with a reliability of R_B

$$R_A = R_B = 0.99 \times 0.9926 \times 0.9981 = 0.980807$$

Formula(16)

Through the simplification of the above two steps and the analysis of the minimum cut set method in the previous chapter, the equivalent reliability diagram of the system is shown in Figure14.

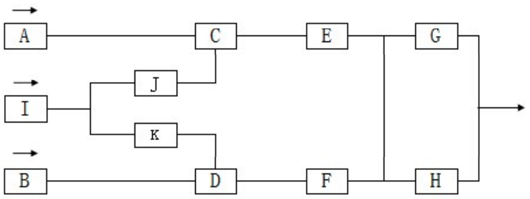


Figure 14 equivalent reliability diagram of WL1, wl2 and wl3 outgoing lines

At this point, the equivalent circuit diagram can no longer be simplified, and it needs to be analyzed by the minimum cut set method. The minimum cut set of the equivalent reliability is shown in table.

Table6 WL1, WL2, WL3 minimum cut set

Minimum cut set number	Components in cut set	Minimumcut set number	Components in cut set
1	AIB	2	AID
3	CIB	4	AJKB
5	CKB	6	AJD
7	CD	8	EF
9	GH	10	CF
11	DE		

From the principle of using the minimum cut set method, we can know that only when all components of the minimum cut set fail at the same time, the whole system will lose its function, so there is a parallel relationship between the components of the minimum cut set; at the same time, any failure of the minimum cut set will lead to the failure of the whole system, so the minimum cut sets are in series. From the above analysis, we can get the following simplified graph of minimum cut set reliability.

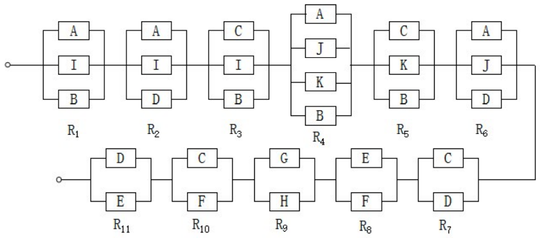


Figure 15 reliability diagram of equivalent minimum cut set of WL1, LW2 and WL3 outgoing lines

It can be seen from figure15

$$R_1 = R_A//R_I//R_B = 1-(1-R_A)\cdot(1-R_I)\cdot\ (1-R_B) = 0.999999999935203$$

Formula(16)

$$R_2 = R_A//R_I//R_D = 0.999999999989197$$

Formula(17)

$$R_3 = R_C//R_I//R_B = 0.999999999989197$$

Formula(18)

$$R_4 = R_A//R_J//R_K//R_B = 0.999999968211093$$

Formula(19)

$$R_5 = R_C//R_k//R_B = 0.999999429457797$$

Formula(20)

$$R_6 = R_A//R_J//R_D = 0.999999429457797$$

Formula(21)

$$R_7 = R_C//R_D = 0.99998976$$

Formula(22)

$$R_8 = R_E//R_F = 0.999585859869482$$

Formula(23)

$$R_9 = R_G//R_H = 0.999751931328175$$

Formula(24)

$$R_{10} = R_C//R_F = 0.999934878308541$$

Formula(25)

$$R_{11} = R_E//R_D = 0.999934878308541$$

Formula(26)

From the above data and applying $R_s = R_1 \cdot R_2 \cdot \cdots \cdot R_n = \prod_{i=1}^{n} R_i$, the reliability R_{s1} of WL1, wl2 and wl3 can be obtained.

$$R_{s1} = R_1 \cdot R_2 \cdot \cdots \cdot R_n = \prod_{i=1}^{n} R_i = 0.999196333236071 \approx 99.92\%$$

Formula(27)

4.2.2 Conclusion

Through the above analysis and calculation, it can be seen that the reliability of WL1, wl2 and wl3 outgoing lines has reached 99.92%ÿ. In the 500kV outgoing lines, the power plant is designed to supply two outgoing lines to a 500kV substation at the same time. In a complex large-scale thermal power plant, the three outgoing lines can be considered reliable.

4.3 Reliability analysis of outgoing line wl5-wl12 (GO method)

4.3.1 Analysis and calculation process

The main wiring diagram is shown in Figure8. Considering that the main wiring before and after the improvement affects the reliability of this type of outgoing line, a comparative analysis will be conducted in the following analysis. For WLl5-WLl12 outgoing line, take wl5 as an example to analyze its minimum path set (in order to make the minimum path set simple and clear, no isolation switch is added in this analysis, just add it in the subsequent calculation), as follows:

L1:(G1,QF1,T1,QF31,W1,QF21,WL5)

L2:(G1,QF1,T1,QF31,W1,QF29,Wp,WL5)

L3:(G1,QF1,T1,QF31,W1,QF29,Wp,W2, QF21,WL5)

L4 / L5 / L6 supplies power to another 600MW generator, which is similar to the last three path sets;

L7:(G3,T3,QF17,W1,QF21,WL5)

L8:(G3,T3,QF17,W1,QF29,Wp,WL5)

L9:(G3,T3,QF17,W1,QF29,Wp,W2, QF21,WL5)

L10 / L11 / L12, L13 / L14 / L15 and L16 / L17 / L18 supply power to the other three 300MW generators on the 220k ide, similar to the last three path sets;

L19:(G6,T6,Wp,WL5).

The L19 path set is the minimum path set of the new disconnector in the optimized main wiring. It can be seen from the minimum path set that all 18 sets of minimum path sets except L19 pass through W1. Therefore, it is considered to consider L19 as an additional consideration, and finally parallel it with the first 18 sets of systems.

The bus W1 in the main wiring is taken as the node, and the minimum path set is analyzed separately.

The minimum path set from power supply to bus W1 is:

LW1: G1,QF1,T1,QF31,W1;
G2,QF2,T2,QF30,W1;
G3,T3,QF17,W1;
G4,T4,QF18,W1;
G5,T5,QF19,W1;
G6,T6,QF20,W1.

The minimum path set from bus W1 to load outgoing line wl5 can be divided into the following

LL1: W1,QF21,WL5;
W1,QF29,Wp,WL5;
W1,QF29,Wp,W2, QF21,WL5.

After the system is disassembled, the go model of the system with bus W1 as the node can be built. As shown in Fig. 16 and Fig.17.

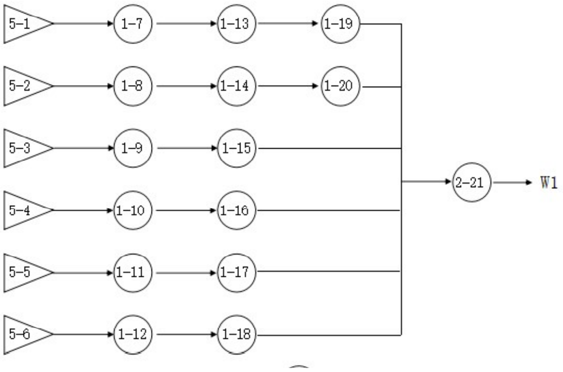


Figure 16 go model from power supply to node W1

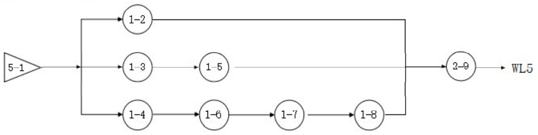


Figure 17 go model of W1 node to wl5 outgoing line

Based on the reliability analysis of equipment components in Section4.3.1 and the construction of system go, the GO model can be combined and simplified as follows.

In the W1 node GO model, 5-1 ~ 1-7 ~ 1-13 ~ 1-19 lines are in series, which can be reduced to the multiplication of reliability coefficients of each component:

$$R_{s1} = R_{sG} \cdot R_{sQF} \cdot R_{sQS} \cdot R_{sT} \cdot R_{sQS} \cdot R_{sQF} \cdot R_{sQS} = 0.99 \times 0.9926 \times 0.9981 \times 0.9968 \times 0.9981 \times 0.9926 \times 0.9981 = 0.966749447179541$$

Formula(28)

The reliability of 5-2 ~ 1-20 line is consistent with that of 5-1 ~ 1-19 line, so no need to analyze again. Next, the reliability of 5-3 ~ 1-15 lines is analyzed.

$$R_{s2} = R_{sG} \cdot R_{sQS} \cdot R_{sT} \cdot R_{sQF} \cdot R_{sQS} = 0.975810767417130$$

Formula(29)

5-4 ~ 1-16 line, 5-5 ~ 1-17 line, 5-6 ~ 1-18 line and 5-3 ~ 1-15 line have the same reliability, no need to analyze again.

It can be seen from figure 6-4 that the six lines on the left are in parallel, so the reliability of the six lines on the left can be obtained as follows:

$$R_{s3} = 1 - (1 - R_{s1})^2 \cdot (1 - R_{s2})^4 = 0.999999999621482$$

Formula(30)

Considering the reliability of bus W1, we can get

$$R_{s4} = R_{s3} \cdot R_{sW} = 0.999099999621823$$

Formula(31)

So far, the go model of W1 node has been calculated, and in the wl5 outgoing go model, the reliability of signal source 5-1 isR_{s4}. Next, the reliability of wl5 outgoing go model is analyzed.

The reliability of 1-2 line is

$$R_{s5} = R_{sQS} \cdot R_{sQF} \cdot R_{sQS} = 0.988831703286000$$

Formula(32)

The reliability of 1-3 ~ 1-5 line is

$$R_{s6} = R_{sQS} \cdot R_{sQF} \cdot R_{sQS} \cdot R_{sW} \cdot R_{sQS} = 0.986064665419012$$

Formula(33)

The reliability of 1-4 ~ 1-8 line is

$$R_{s7} = R_{sQS} \cdot R_{sQF} \cdot R_{sQS} \cdot R_{sW} \cdot R_{sQS} \cdot R_{sW} \cdot R_{sQS} \cdot R_{sQF} \cdot R_{sQS} = 0.974174455854030$$

Formula(34)

From diagram15 It can be seen that the above three lines are connected in parallel, so the reliability after parallel connection is

$$R_{s8} = 1 - (1 - R_{s5}) \cdot (1 - R_{s6}) \cdot (1 - R_{s7}) = 0.999995980668517$$

Formula(35)

The reliability of the go model can be obtained by connecting the signal source 5-1 in series

$$R_{s9} = R_{s4} \cdot R_{s8} = 0.999095983907740$$

Formula(36)

Finally, the reliability of L19 special circuit is considered

$$R_{L19} = R_{sG} \cdot R_{sQS} \cdot R_{sT} \cdot R_{sQF} \cdot R_{sQS} \cdot R_{sW} = 0.974932537726454$$

Formula (37)

L19 loop and go model are in parallel

$$R_s = R_{s9} // R_{L19} = 0.999977338610713$$

Formula (38)

4.3.2 Conclusion

Through analysis and calculation, the reliability of wl5-wl12 outgoing line at 220kV side before optimization is 99.91%, and the reliability after optimization is99.99%.Through the comparison betweenR_{39} and R_{3}, we can know the importance of QS98 in 220kV side of the main line.

4.4 Reliability analysis of outgoing line wl4 and standby outgoing line

The above has spent a lot of time on the analysis process of two reliability analysis methods in the power plant to be designed. Here, the reliability analysis of wl4 and standby outgoing line will not be repeated, and the final reliability calculated by the minimum cut set method is 99.94%.

4.5 Main wiring reliability summary

Through the analysis of sections 3.2, 3.3 and 3.4, the reliability of each outgoing line in the optimized main wiring in Figure8 can be summarized as the following table, in which qs98 is the reliability after optimization and no QS98 is the reliability before optimization.

Table 7 reliability of outgoing lines of power plant

type	WL1-WL3	WL4	备用
Reliability	99.92%	99.94%	99.94%
type	WL5-WL12(无QS98)	WL5-WL12(有QS98)	
Reliability	99.91%	99.99%	

From this statistical table, QS98 plays a very important role in the reliability of the whole power plant. At the same time, the reliability of all circuits is over 99.90%. In the main wiring without disconnector QS98, the wiring mode of one and a half circuit breakers is more reliable than that of double bus with bypass, which conforms to the theoretical analysis results.

5. EXAMPLE OF SWITCHING OPERATION

After the optimization of the main wiring, it will inevitably lead to some changes in the classic switching operation. In this chapter, we will introduce some common switching operations of the improved main wiring. The partial enlarged drawing is shown in Figure9 and figure 10. There is a big safety risk in the switching operation. In the operation process, it must conform to the safety standard process, be strict and meticulous, and strictly abide by the operation ticket operation system.

Switching operation principle:

- It is forbidden to turn off and close the disconnector when the load is not cut off
- It is forbidden to disconnect and close the disconnector under the condition of grounding
- Do not close the ground wire with electricity
- Do not open or close the circuit breaker by mistake
- Do not enter the live safety interval

5.1 Switching line

When the line needs to be switched on and off, it involves the switching operation of the line. Here, take the outgoing line WL1 as an example to make a simple switching operation introduction.

Input WL1: close QS19 → QS18 → QS7 → QF7
Remove WL1: openQF7 → QS7 → QS18 → QS19

5.2 Inverted bus bar

At 220kV side, when bus I needs to be overhauled, it is necessary to turn the right standby of bus II into the working state, and the switching operation is as follows.

1. OpenQS98 → QF29
2. When QS97 →QF29 is closed, bus II is charged
3. Close all disconnectors on the power side connected to bus II, close all disconnectors on the load side connected to bus II, disconnect all disconnectors on the load side connected to bus I, and disconnect all disconnectors on the power side connected to bus I.
4. When QS97 → QF29 is opened, bus I is not electrified, and it exits from the working state and can be repaired.

5.3 Maintenance of a circuit breaker

For 500kV voltage level side, take maintenance QF13 as an example (affecting outgoing line Wl3), close QF12, ensure that the outgoing line Wl3 is not affected, open QF13 → QS30 → QS31, at this time, there is no voltage at both ends of QF13, and maintenance can be carried out.

For 220kV voltage level side, take maintenance QFf21 as an example (affecting outgoing line wl5), close QS86, ensure that the outgoing line Wl5 is not affected, open QF21 → QS78 → QS62, at this time, there is no voltage at both ends of QF21, and maintenance can be carried out.

5.4 QS97 fault (ground)

Disconnect all circuit breakers (QF20, QF29, etc.) and disconnectors connected to the bypass bus, bus II, to ensure that bus II and bypass bus are not live, and only bus I is live. At this time, the fault isolation switch QS97 can be repaired.

6. SUMMARY

This paper first discusses a new way of improving the main wiring unit wiring directly supplies power to the bypass bus, at the same time introduces the mathematical model of the electrical equipment in the main wiring and several commonly used reliability analysis methods, and uses practical examples to analyze and calculate, so as to make the theory fully practical, in order to provide a better introduction for the readers. The reliability of each outgoing line of the main connection before and after optimization is calculated by a reasonable reliability algorithm. It can be known that in the form of double bus belt bypass connection at 220kV side, the reliability before and after optimization is 99.91% and 99.99% respectively. Because the power is not easy to store in case of fault, and the unbalanced current generated in case of fault will cause great damage to the power system, and even a larger area of power failure may occur. Therefore, the optimization of the main wiring described above is more effective for the reliability of the whole power plant and even the whole power system.

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