Electrical design of 4×50MW small thermal power plant

X J Feng, J Luo
Department of Architectural Engineering, Dongguan University of Technology, Dongguan, 523808, China
Fengxianjie@126.com

Abstract. The paper is the primary and secondary electrical design of a 4×50MW small-scale power plant. We selected the number and type of main transformers of our factory, plan to design two alternatives for main electrical wiring. The equivalent circuit diagram is simplified, and each short-circuit point is calculated in order to provide data protection for the subsequent selection, and then combined with the calculation results of each short-circuit point to select and verify the types of various equipment in the power plant.

1. Introduction
After entering the new era of the 21st century, people's demand for energy is growing rapidly not only in material and cultural life, but also in daily production and life. Although a variety of new energy generation technologies such as wind power, solar power, fuel cell power, biomass power, nuclear power are developing rapidly[1][2], the traditional thermal power generation still occupies the dominant position in China at present. Due to the exhaustion of traditional energy, thermal power technology must adapt to the natural environment, and comprehensive use of various conditions, design some small and medium-sized thermal power generating units.

This paper is to design a 4 × 50MW small power plant electrical system. The electrical system consists of power plant, substation, line and user, and four 50MW generator units supply power to the power plant. The overview of each generator is as follows:

- Model: QF-50-2
- Rated voltage: 10.5KV
- Maximum continuous output power: 50MW
- Rated power factor: 0.8
- Line reactance: 0.02
- The power consumption rate is 10%
- Minimum load on the generator voltage bus: 25 MW
- Generator Efficiency: 98%
- Rated current: 2864A
- Rated speed: 3000r/min
- Load power factor: 0.8
- Times transient reactance: 12.9%
- The annual utilization hours are 5500h
- Transient reactance: 17.5%

The highest annual temperature in this region is 37℃, the lowest temperature is 5℃, and the average annual temperature is 25℃.

2. Selection of main transformer
Because the scale of this power plant is 4×50WM, considering investment, efficiency, maintenance and other factors, we decided to adopt three-winding transformer.

The connection of transformer windings, including "star" and "triangle" two forms, different connection forms and different winding groups, will produce different effects.
2.1. Connection mode of main transformer windings
In our country, in general, the connection mode of the three windings of the transformer will vary according to the different voltage:

- Less than 35KV: triangular connection mode.
- 35KV: star connection, and the neutral point through the arc suppression coil to ground.
- Higher than 110kV: star connection mode.

2.2. Main transformer load calculation
When the load on the voltage bus is at its minimum, the maximum residual power is transferred to the system. At this time, the minimum load can be ignored. The load power at this time is [3]:

\[ S_N = \frac{\sum P_{NC}(1-K_f)}{\cos \varphi} - \frac{P_{min}}{\cos \varphi_G} / n \]  

then

\[ S_N = \frac{\sum P_{NC}(1-K_f)}{0.8} - \frac{25}{0.8} / 4 \approx 48.4 \text{MVA} \]

Therefore, two SFPS7-50000 / 110 main transformers with three windings are selected.

3. Design of main electrical wiring diagram
When we design the main wiring diagram, we must make the requirements concise and clear, and improve the reliability of the system as much as possible. When the power grid fails, try to minimize the loss. The main wiring mode can be changed quickly and conveniently regardless of the normal working state or the fault state. And choose cost-effective equipment to save money. It must have a long-term development perspective to facilitate expansion.

The final electrical main wiring scheme is as shown in figure 1,10kV terminal double bus-bar three-section wiring, reactors are installed at the sections to limit the short-circuit current, 10 loops outgoing, an average of 3MW each loop is transmitted, and the maximum load is 35MW. The 35kV terminal single bus-bar is connected in sections, with 6 outgoing lines, and the average transmission is 13MW each time, and the maximum load is 80MW. The 110kV terminal is connected to the infinite large-capacity system to receive the surplus power. It adopts a single bus-bar segmented connection, 4 circuits of outlets, and a maximum load of 25MW.

As shown in the main wiring diagram in figure 1, double-bus and three-section connection is selected for the low-voltage side, which is more reliable and flexible and can effectively reduce the impact range in case of failure. However, single-bus and three-section connection is selected for the middle and high-voltage side out of economic considerations.

4. Short circuit calculation of main wiring scheme
The purpose of calculating short circuit current is to limit the harm of short circuit and reduce the influence range of fault.

4.1. Calculation of reactance of each element
The equivalent reactance of the main electrical connection is shown in figure 2. Select \( S_B = 100 \text{MVA}, U_B = U_{av} \), impact coefficient \( K_{sh} = 1.9 \), the following calculation results are standard unit values

QF-50-2 generator: \( X_1 = X_2 = X_3 = X_4 = X'_k \cdot \frac{S_j}{S_N} = 0.145 \times \frac{100}{62.5} = 0.232 \)  

SFPS7-50000/110 transformer:

\[ X_5 = X_6 = \frac{U_{k1} \%}{100} \cdot \frac{S_j}{S_N} = \frac{18 + 6.5 - 10.5}{100} \times \frac{100}{50} = 0.29 \]
\[ X_7 = X_8 = \frac{U_{k2} \%}{100} \cdot \frac{S_j}{S_N} = \frac{10.5 + 6.5 - 18}{100} \times \frac{100}{50} = -0.02 \]
\[ X_9 = X_{10} = \frac{U_{k3} \%}{100} \cdot \frac{S_j}{S_N} = \frac{18 + 10.5 - 6.5}{100} \times \frac{100}{50} = 0.44 \]

Line reactance: \( X_{11} = 0.02 \)
Figure 1. Electrical main wiring scheme diagram

Figure 2. Equivalent reactance diagram

Figure 3. Short-circuit contour map at K1 point
4.2. Draw the equivalent reactance diagram of the system

According to the diagram of the selected main electrical wiring scheme, the reactances of the four generators are \( X_1, X_2, X_3 \) and \( X_4 \) respectively, and they are all connected to the bus of the low voltage side. The reactance of the two three-winding transformers \( (X_5, X_6, X_7 \) and \( X_9, X_{10} \) ) are respectively connected to the bus of the low, medium and high voltage measurement. The line impedance is \( X_{11} \), while the reactance of the finite current reactor at the bus section on the low voltage side is \( X_{12} \). In summary, the reactance equivalent circuit diagram can be drawn as shown in figure 2. Then, three short circuit points (K1, K2 and K3) are selected to calculate the name and unit value of each short circuit point respectively, and the short circuit impulse current can be calculated according to the calculation results.

4.3. Short-circuit current calculation, equivalent reactance diagram analysis

This project has three short circuit points, namely: 110kV short circuit point K1, 35kV short circuit point K2, 10kV short circuit point K3. Because the space is limited, this paper calculates a short circuit point K1.

The reactances of the four generators are all equal, and they are all connected to the same bus, so they can be connected in parallel to \( X_{13} \), as shown in figure 3, the value of \( X_{13} \) is one-fourth of the reactance of each generator[4]:

\[
X_{13} = \frac{1}{4} X_1 = \frac{1}{4} X_2 = \frac{1}{4} X_3 = \frac{1}{4} X_4 = \frac{1}{4} \times 0.232 = 0.058
\]

\( X_5 \) and \( X_9 \) are connected on the same line, \( X_6 \) and \( X_{10} \) are connected on the same line, so these two groups can be connected in series to obtain \( X_{14} \) and \( X_{15} \) respectively. The series value is the addition of the two values:

\[
X_{14} = X_5 + X_9 = 0.29 + 0.44 = 0.73
\]

\[
X_{15} = X_6 + X_{10} = 0.29 + 0.44 = 0.73
\]

Since \( X_{14} \) and \( X_{15} \) are connected in the same way, as shown in figure 4, which can also be connected in parallel to get \( X_{16} \) as shown in figure 5.

Then connect \( X_{13} \) and \( X_{16} \) in series to get \( X_{17} \). Finally, we can use \( X_{17} \) and \( X_{11} \) to calculate the short-circuit current per unit value of this short-circuit point, and then calculate the famous value and the impulse current value in turn:

\[
X_{17} = X_{13} + X_{16} = 0.058 + 0.365 = 0.423
\]

\[
I^* = \frac{1}{X_{11}} + \frac{1}{X_{17}} = \frac{1}{0.02} + \frac{1}{0.423} = 52.36
\]

\[
I^* = I^* \cdot \frac{S_B}{\sqrt{3} \cdot U_{av}} = \frac{52.36 \times 100}{\sqrt{3} \times 115} = 26.29kA
\]

Short circuit impulse current:

\[
i_{sh \, k1} = \sqrt{2} \cdot I^* \cdot K_{sh} = \sqrt{2} \times 26.29 \times 1.9 = 70.72kA
\]

Similarly, we can calculate the short-circuit impulse current at K2 and K3 respectively:

\[
i_{sh \, k2} = 41.89kA
\]

\[
i_{sh \, k3} = 293.13kA
\]
5. **Longitudinal differential protection of generator**

Choose BCH-2 type relay, and make setting calculation[5]:

\[
I_{k,\text{max}} = \frac{S_N}{\sqrt{3}U_N \cos \varphi} \times 1 = \frac{50 \times 10^3}{\sqrt{3} \times 10.5 \times 0.8} \times \frac{1}{0.129} = 26640.4A
\]

Sensitivity check:

\[
I_{k,\text{min}}^{(2)} = \frac{\sqrt{3}}{2} I_{k,\text{max}} = 23071A
\]

\[
K_{sen} = \frac{I_{k,\text{min}}^{(2)}}{I_{op}} = 6.197 > 1.5
\]

So it meets the criteria.

6. **Conclusion**

Based on the original data, considering the local power supply environment, load properties, user needs and other factors, the main electrical wiring scheme is designed, the number of main transformers is determined, and important parameters such as short-circuit current are calculated, which provides effective help for the construction of power plants and has practical guiding significance.

**References**

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