The Configuration Scheme of Reactive Power Compensation Capacity on the 110kv Substation

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ABSTRACT: When the main transformers need to be uprated on the 110kV substation of Mian Cheng, we need to analyze the long-term flow calculation and determine reactive power compensation capacity. On the basis of the current program on the 110kV substation to determine, we proposed two configurations about reactive power compensation capacity for the long term program. The voltage fluctuation and reactive power compensation capacity are analyzed by theoretical analysis and simulation for verification. And combining with the requirements of the relevant regulations, the optimal reactive power compensation scheme is selected reasonably.

Keywords: reactive power compensation; configuration; voltage fluctuations

1 INTRODUCTION

It’s closely related to the economy of the power system operation and reactive power, and the reactive power is indispensable in the power system. Many inductive loads and reactive power losses in the grid require the power system to provide adequate reactive power. Otherwise, the grid voltage will drop and the power quality can’t be guaranteed. Meanwhile, the irrational distribution of reactive power will also result in the increased line losses and reduce power system economic operation. When the main transformers need to be uprated or the new substation need to be built because of the growth of loads in the power system, the reactive power compensation capacity should be rationally determined. When the reactive power is insufficient or excess, it will all affect the operation of the power system. When there is not enough reactive power, the voltage will drop and the normal operation of the equipments will be affected; Reactive excess will deteriorate the system voltage, and reduce the active transport efficiency of the line, which does not only meet the requirement of the grid power factor, but also increase the additional investment of the reactive equipments. Therefore, the reasonable allocation of reactive power will directly affect the stable operation of the power system, and further affect the economic operation of the grid. The reactive power compensation capacity configuration of the substation has an important influence for safe and economic operation of power systems. According to procedures required, the reactive power compensation configuration should satisfy the layering and zoning balance of the reactive power in the grid. Between the voltage level, the reactive power exchange should be reduced and meet the needs of reducing losses and adjusting the voltage. The reactive power balance is the basic condition of ensuring the voltage stability. The reactive power shortage will cause low voltage. On the contrary, it will make high voltage. That ensuring reactive power balance and suppressing voltage fluctuation of the substation must rely on the reactive power compensation devices.

In this paper, take the 110kV substation of the Cotton City in Guangdong as an example. On the basis of the current reactive power compensation configuration of the substation determined, from the perspective of power flow calculation, the long-term reactive power shortage of the substation is analyzed. Considering the over-voltage and harmonic situation, the reasonable long-term reactive power compensation configuration is chosen, so that the power factor and voltage fluctuations on each side of the substation meet the requirements.

2 THE INFLUENCE OF VOLTAGE FLUCTUATION ON REACTIVE POWER

For a specific power network, it’s known that the head
line voltage is $U$ and power is $S = P + jQ$. The calculation formula for the first to end of the line voltage drop is:

$$dU = \Delta U + j\delta U \quad (1)$$

$$\Delta U = \frac{PR + jQX}{U} \quad (2)$$

$$\delta U = \frac{PX - QR}{U} \quad (3)$$

In general, the phase difference between the two ends of the line is small. When estimating the voltage drop approximately, we can ignore the horizontal component of the voltage drop, namely that $\delta U = 0$, so $dU \approx \Delta U = \frac{PR + jQX}{U}$.

When there is lack of reactive power in the power system, the shunt capacitor or reactor is usually used to improve the power factor. In order to accurately analyze the relationship between voltage and reactive power fluctuation, it’s shown in Figure 1.

![Figure 1. The analysis chart of reactive power compensation capacity.](image)

The voltage of the first side of the line before reactive power compensation is

$$U_2 = U - \frac{PR + jQX}{U} \quad (4)$$

If the load side of the power system is put into a capacitor with a capacity of $Q_c$, the voltage of the first side is increased from $U$ to $U'$ after compensation, at this time, the voltage of the end side of the system is

$$U_{2c} = U' - \frac{PR + j(Q - Q_c)X}{U'} \quad (5)$$

Combining the formula (5) and (6), we can know that the voltage variation before and after the input capacitor is

$$\Delta U = U_{2c} - U_2 = (U' - U) + \left[\frac{PR + jQX}{U} - \frac{PR + j(Q - Q_c)X}{U'}\right] \quad (6)$$

In terms of the power grid, the voltage fluctuation is generally small before and after the reactive device inputs. It is assumed that $U \approx U'$, and therefore, the voltage change before and after putting in the capacitor is

$$\Delta U \approx \frac{QcX}{U} \quad (7)$$

Therefore, the voltage fluctuation before and after the compensation is

$$\Delta U% = \frac{\Delta U}{U} \times 100% = \frac{QcX}{U} \times 100\% \quad (8)$$

From the formula (9), we can know that the greater the investment capacity we put in, the greater the voltage fluctuates. But when the capacity is too small, the equipment units of the reactive power compensation units will be more input and greatly increasing the area. Therefore, it is very important to choose an appropriate reactive power compensation optimization scheme for the capacity expansion of the main transformer.

### 3 THE SCHEME OF THE PARALLEL REACTIVE POWER COMPENSATION

According to the planning scheme of the power grid in Guangdong province, considering the situation of the power grid nearby of 110kV and the load of 10kV line, it is proposed to increase the reactive power compensation devices in the two 110kV/10kV main transformers in the substation of the cotton city to achieve comprehensive control of the voltage and reactive power of the substation.

According to the Management Regulations of the Voltage Quality and Reactive Power in the State Grid Corporation Power System of China (National Grid (2009) 133), the capacity of reactive power compensation device should be reasonably determined when building the new transformer substation and increasing the main transformer capacity to ensure that at the maximum load of 35~220kV substation in the main transformer, the power factor in the high voltage side should not be less than 0.95; at the minimum load the power factor should not be higher than 0.95, and should not be less than 0.92. The calculation results in the long-term 240MVA of the main transformer show that the power factor is 0.93, which is not satisfied with requirement. For this purpose, the power factor of the system can be satisfied by switching the capacitor or reactor, and the calculation results of reactive power balance after switching reactive power compensation device are shown in Table 1. According to the calculation results of Table 1, combining with the consideration of long-term 110kV outlet part of the cable type, reactive power compensation capacity is required to configure 6Mvar of the low voltage shunt reactor. When configuring 24Mvar or 18.16Mvar of the shunt capacitor (with a series of resistance), the power factor all meets the requirements. Therefore, there are three schemes for the capacity allocation of reactive power compensation in the Cotton City:

- **Scheme A:** The low voltage side of each main transformer configure 2*6Mvar parallel capacitors and 1*3Mvar shunt reactors;
- **Scheme B:** The low voltage side of each main transformer configure 1*6 (12% of the series reactance...
rate) + 1 * 4 (5% of the series reactance rate) Mvar of shunt capacitors and 1 * 3 Mvar shunt reactor;
Scheme C: the low voltage side of each main transformer configure 3 * 4 Mvar parallel capacitors and 1 * 3 Mvar of shunt reactor.

3.1 Theoretical calculation

In order to simplify the calculation and analysis, we will make the equivalent analysis of cotton city outside the system. To this end, the system can be simplified as shown in Figure 2.

![Figure 2. A simplified diagram of the power system.](image)

According to the existing data, it can be known: the positive sequence impedance p.u. of the 110kV power system is 0.05021 (the base capacity is 100MVA) and the positive sequence reactance of the transformer is 34.054 ohms. In the high-voltage power grid, the reactive power compensation device is generally switched on the low voltage side of the transformer in the substation. That is, the device is switched in the low-voltage side of the 10kV, and the voltage fluctuation in the low-voltage side of the 10kV is the biggest. This section is mainly the analysis of the voltage fluctuations of the low-voltage side. So on the basis of the simplified analysis and calculation of the power system, the voltage fluctuation of the low voltage side can be gotten when the reactors with different capacity are put into by analysis and calculation of system parameters. As shown in the Table 2.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Capacitance (-) / reactance (+) input</th>
<th>The reactive power loss of the main transformer</th>
<th>The reactive surplus (+) deficit (-) of the substation</th>
<th>The power factor of the primary side of the main transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>6.52</td>
<td>-28.92</td>
<td>0.94</td>
</tr>
<tr>
<td>B</td>
<td>-1 * 8</td>
<td>6.96</td>
<td>-5.36</td>
<td>0.99</td>
</tr>
<tr>
<td>C</td>
<td>-1 * 6</td>
<td>6.72</td>
<td>-10.39</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Table 1. The calculation results of the long-term reactive power balance in Yaoqiao Substation.

3.2 Simulation verification

In order to better analyze the voltage fluctuation in power system, we use MATLAB/Simulink simulation software to analyze the power flow of the system. The voltage fluctuation of the low-voltage side of the system is obtained by the result of power flow calculation. According to the results, the feasibility of the scheme is verified. According to the simulation calculation of the above parameters, we can set up the simulation diagram, as shown in Figure 3, which is the voltage fluctuation of the low-voltage side of the system when 6Mvar capacitor is switched. At this time, the voltage fluctuation is 1.9% and all the results of the voltage fluctuation are shown in table 4 when different reactive power compensation devices are put into.

![Figure 3. A simulation program of scheme A.](image)
According to the simulation results of Table 3, the capacitor of 8Mvar is put into the power system, and the voltage fluctuation of the low-voltage side of the system is 2.6%, which exceeds the required ±2.5% voltage fluctuation rate. However, when the capacitor of 6Mvar is switched, the voltage fluctuation is 1.99%, which meets the requirement of voltage fluctuation. Therefore, from the simulation results can be obtained: when the long-term reactive power compensation in the Yaoqiao substation configures 2*6Mvar capacitors and 1*3Mvar reactor, the voltage fluctuation within the specified range meets the requirements.

Similarly, in order to better verify the feasibility of scheme B, we used another kind of power flow calculation software PASAP to calculate and analyze the power flow and voltage of the system. According to the calculation results, the low-voltage side voltage fluctuation of the system is obtained, which is used to analyze the feasibility of the scheme B and scheme C. According to the above parameters, simulation results of the long term program can be calculated, which is shown in Table 4.

According to the simulation results of Table 4, when a group of 10Mvar capacitor is switched, the voltage fluctuation at the low-voltage side of the system is 2.95%, which exceeds the required ±2.5% voltage fluctuation rate. However, when a single set of 6Mvar capacitor (12% series reactance rate) is put into, the voltage fluctuation is only 1.75%, which meets the requirement. In addition, because of 4Mvar capacitor switched, the voltage fluctuation is 1.35%, which is within the specified range. So, the voltage fluctuation also meets the requirement when a group of 4Mvar capacitor (5% series resistance rate) is switched. Therefore, from the simulation results can be obtained: when the long-term reactive power compensation in the Yaoqiao substation configures 1*6Mvar (5% series reactance rate) +1*4Mvar (12% series resistant rate) capacitors and 1*3Mvar reactor, the voltage fluctuation within the specified range meets the requirement. So the scheme B and scheme C meet the requirement.

### 3.3 The comparative analysis of different schemes

In the project, due to the circuit breaker of the capacitor of 10kV voltage level using the way of intelligent phase controlled. The intelligent phase controlled technology can realize zero switching and effectively avoid the happen of the inrush current and over voltage and transient harmonics, which makes the inrush current inhibition of 1.18 times and the overvoltage suppression within 1.17 times when closing capacitor, so that the reactive power compensation device can be safely and reliably invested and removed. Therefore, from the perspective of suppressing overvoltage, these three schemes are desirable.

Due to the series reactance rate of the switched parallel capacitance has two types of 5% and 12%, it not only can play a role in reducing the voltage fluctuation, but also eliminate the system harmonics, which the 10Mvar capacitor with 12% reactance rate can elimi-
nate three harmonic and the 8Mvar capacitor with 5% reactance rate can eliminate five harmonic in the power system. And the two types of capacitors with reactance ratio in the three harmonic and five harmonic externally are sensible, so three resonance and five resonance will not occur. From this perspective, scheme B is better than scheme A.

Although the single set of switched capacitor capacity is the smallest in scheme C, but the installing points in the three schemes are the most, so the scheme C covers the largest area and the largest construction and it is not suitable. Comprehensive comparison of the three schemes in the long term program to identify the scheme that each transformer configuration a group of 4Mvar capacitor (reactance rate of 5%), a group of 6Mvar capacitor (reactance rate of 12%) and a group of 3Mvar reactor.

4 CONCLUSIONS

This paper mainly analyzes the long-term reactive power compensation capacity allocation of 110kV substation in Shantou Cotton City. Combining with the current scale, research and analysis are performed through two aspects of theory and simulation and a reasonable scheme of long-term optimal reactive power compensation configuration is chosen. The main conclusions are as follows:

(1) The voltage fluctuation is proportional to the input reactive power, and is inversely proportional to the square of the bus voltage. The bigger reactive power is, the smaller the bus voltage is and the bigger the voltage fluctuation is.

(2) Through the long-term power flow calculation of 110kV substation of Cotton City in Shantou, two schemes of reactive power compensation are determined. Considering the switching over-voltage and harmonics in the power system, the scheme B for optimal reactive power configuration is determined finally.

REFERENCE