Research on Intelligent Control Technology of Reactive Power Compensation

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ABSTRACT

In the distribution network, reactive power is an important factor influencing voltage stability, and it is related to the safe and stable operation of whole power system. Reactive power compensation is to improve the reactive power, and it is one of the effective measures to ensure the high-efficiency and reliable operation of the power system. In order to improve the power supply capacity of equipment, improve the voltage quality, improve the power factor, reactive power compensation scheme is designed. The realization of reactive power compensation uses the parallel compensation capacitor and takes the ways of low-voltage centralized compensation. To the compensation control strategy, an improved Nine–zone diagram is used. Then choose a reasonable capacity of parallel capacitor according to the calculation of formula. Thus capacitor switching is controlled by software to complete real-time control of the transformer reactive power compensation.

INTRODUCTION

In the power generation, transmission, distribution and utilization of the AC power system, the variation of reactive power affects power factor and power supply quality. When reactive load is greater than reactive capacity of the power output, the power factor and the power supply voltage will decrease. On the contrary, the power factor and the voltage will increase. during the operation of the power network, the active power loss is generally no more than 10% of the load, while the reactive power loss accounts for 30%~50% of reactive load. Therefore, reactive power compensation is an important part of power system [1]. In this paper, through the study of reactive power compensation, a complete set of compensation strategy is proposed, i.e., shunt capacitor bank compensate the reactive power of transformer, which controlled by intelligent terminal. The remainder of this paper is organized as follows. Section II describes the principle of reactive compensation control. Section III and section IV demonstrate the control strategy of reactive compensation and computation of reactive compensation capacity, respectively. Software design of reactive compensation control is presented in Section V and the conclusions are given in Section VI.
PRINCIPLE OF REACTIVE COMPENSATION CONTROL

Because most of the equipment in power grid are inductive load (e.g. the motor, transformer etc.), it is necessary to use capacitive power to balance the inductive reactive power load. For the purpose of reducing the reactive power of power grid, we use capacitive current phase shifting capacitor to balance part of the inductive current in the power network.

Shunt compensation capacitor is the most common method of reactive power compensation. The method is to directly connect the capacitor in parallel to the power equipment which needs to be compensated in order to improve the power factor. The parallel compensation capacitor is widely used in many countries [2].

According to the location of the capacitor in the power supply system installation, reactive power compensation mainly includes 10kV bus centralized compensation, 10kV line distribution compensation, low voltage 380V side centralized compensation and low voltage load side distributed compensation. Currently, to carry out centralized compensation in the 380V side of distribution transformer is a common reactive power compensation method in China [3] (as mode 2 shown in Fig. 1).

In this way, the low voltage shunt capacitor group, which is controlled by microcomputer, is usually used to track the compensation according to the fluctuation of the load level of the user. Its main purpose is to improve the power factor of the user and achieve reactive power in situ balance. It is helpful to ensure the user's voltage level and reduce loss of the distribution network and distribution transformer. The principle of reactive power compensation control signal of capacitor is shown in Fig. 2.

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![Figure 1](image1.png)

**Figure 1.** Reactive power compensation scheme for distribution system.

![Figure 2](image2.png)

**Figure 2.** Reactive power compensation capacitor control signals schematic diagram.
The capacitor group is divided into two modes, and divided into three groups, namely, the "mixed up" mode [4], which adopts the three-phase co compensation capacitor and the three-phase capacitor, and is equipped with an indicator light. The three-phase reactive power gap is completed by three-phase co compensation, and the three-phase reactive power unbalance part is completed by the three-phase dispersion compensation.

Based on the principle of capacitor group signal control, the design of the intelligent non-reactive power compensation control module is a part of the intelligent distribution terminal, connected with the smart distribution terminal through the European style motherboard socket. The intelligent distribution terminal realizes the real-time acquisition of low-voltage side voltage and current of distribution transformer, and calculates the parameters such as active power, reactive power and power factor. The control output signal of the reactive power compensation controller is isolated by the photoelectric coupler, the control mode is level control and 485 control, and the structure is shown in Fig. 3. The control signal of the photoelectric coupler is driven by the latch and the driving circuit. Reactive power compensation control panel can control up to 6 groups of co compensation capacitors and 3 groups of dispersion compensation capacitor. Co compensation control is completed by optical coupler 1 to optical coupler 6, while dispersion compensation is controlled by optical coupler 7 to optical coupler 16.

THE CONTROL STRATEGY OF REACTIVE COMPENSATION

The judgment of voltage reactive power control is generally based on the fuzzy control algorithm of the voltage and reactive power boundaries, i.e. the nine-zone diagram which is shown in Fig. 4. The control principle of nine-zone diagram makes the system run in a normal region by the control algorithm of reactive compensation [5].

The principle of traditional nine-zone diagram is simple, the control is convenient and reliable, but all the control strategies are static and not predictive, what’s more, it does not consider the impact of reactive power regulation on voltage and voltage regulation on reactive power. In fact, this will bring about oscillations and frequent moves of devices, which may cause the voltage instability of the system. This article is
based on an improved algorithm about the traditional nine-zone diagram method, as is shown in Fig. 5.

The control strategy of the traditional standard nine-zone diagram divides the reactive power plane into nine regions according to a fixed voltage and reactive power (or the line-side power factor of substation). Since the value of the upper and lower limits is given, it is proved that the actual operation can’t get the best control effect. In this paper, both operational limits have been improved. The define of the upper and lower limits of voltage adopts the principle of time-sharing control [6], and the determine of the upper and lower limits of reactive power adopts the sub-station control principle, and the optimized nine-zone diagram is used to modify and perfect the control strategies [7].

The basic regulation of shunt compensation capacitor is: when the transformer tap is up-regulated (or down-regulated), the bus voltage $U$ will become larger (or smaller), and the line power factor $\cos \phi$ will become smaller (or larger), while the adjustment of the tap generally has little effect on reactive power; when the capacitor is put in (or removed), the reactive power $Q$ absorbed from the system will become smaller (or larger), the $U$ will become larger (or smaller), and the $\cos \phi$ will become larger (or smaller).

In a word, we can get an improved action strategy.

Zone 1: If the capacitor does not exceed the upper limit value of the power factor, the priority will be put into the capacitor; if the voltage is still not qualified, then adjust the main transformer.
Zone 2: If switching in the capacitor does not make the voltage and the power factor exceed the upper limitation, only switch in the capacitor.

Zone 3: If the voltage is high and the power factor is low, only adjust the main transformer tap to drop the voltage, and the next decision after action depends on operation condition.

Zone 4: If the voltage is high, but switch off a group of capacitors will lead to the power factor exceeding the lower limit value, switch off the main transformer tap.

Zone 5: If switching off the capacitor does not make the power factor lower than the lower limit, switch off the capacitor first; if the voltage of the capacitor is still not qualified, adjust the main transformer tap to drop the voltage.

Zone 6: If switching off the capacitor does not make the voltage and the power factor lower than the lower limit, only switch off the capacitor.

Zone 7: If the voltage is low and the power factor is high, adjust the main transformer tap to boost the voltage, the next decision after action depends on operation condition.

Zone 8: If the voltage is low, but switching in a group of capacitors will lead to the power factor exceeding the lower limit value, switch the main transformer tap to boost the voltage.

Zone 3’: If the voltage is detected over the upper limit value after switching in the capacitor and there is a capacitor can be switched in, adjust the main transformer tap to drop the voltage first, and then detect whether the capacitor need to be switched in; if other operation condition occurs, make a new decision. If there is no capacitor can be switched in this zone, maintain the status quo and do not operate the main transformer tap.

Zone 7’: If the voltage is detected over the lower limit value after switching off the capacitor and there is a capacitor can be switched off, adjust the main transformer tap to boost the voltage first, and then detect whether the capacitor need to be switched off; if other operation condition occurs, make a new decision. If there is no capacitor can be switched off in this zone, maintain the status quo and do not operate the main transformer tap.

Considering the same action strategy, zone 3 and zone 3’ can be merged into an integrated area, and zone 7 and zone 7’ can be merged into an integrated area.

Control device makes comprehensive judgment according to factors such as voltage, reactive power, harmonic content, time, load rate, information switch and load regulating transformer tap position. It judges the operating region according to the real-time data, and then switches in or off the shunt compensation capacitor and adjusts the load voltage regulating transformer tap according to a predetermined control scheme making operating points get into the normal workplace with the optimal control sequence and the least action time.

**COMPUTATION OF REACTIVE COMPENSATION CAPACITY**

The purpose of calculating reactive power compensation is to select the capacity of shunt capacitors reasonably. The calculation method for the capacity of the compensation capacitor is as follows:

The capacity of reactive power required to compensate reactive power is \( Q_{\Delta,\text{load}} \), load active power is \( P \), the power factor of no capacitance compensation is \( \cos \phi_{\text{circuit}} \), circuit
power factor after compensate reactive is \( \cos \varphi \), reactive power is \( Q \). As known by the power triangle (as shown in Fig. 6) :

![Power Triangle](image)

Figure 6. Power triangle.

Reactive power when no capacitance compensation is

\[
Q_i = P \tan \varphi_i
\] (1)

\[
Q_k = Q_i - Q = P \tan \varphi_i - P \tan \varphi = P(\tan \varphi_i - \tan \varphi)
\] (2)

In the formula:

\[
\tan \varphi_i = \frac{\sin \varphi_i}{\cos \varphi_i} = \frac{\sqrt{1 - \cos^2 \varphi_i}}{\cos \varphi_i}
\] (3)

\[
\tan \varphi = \frac{\sin \varphi}{\cos \varphi} = \frac{\sqrt{1 - \cos^2 \varphi}}{\cos \varphi}
\] (4)

So it can be deduced:

\[
Q_k = P\left(\frac{\sqrt{1 - \cos^2 \varphi_i}}{\cos \varphi_i} - \frac{\sqrt{1 - \cos^2 \varphi}}{\cos \varphi}\right)
\] (5)

Take the specific load of 10000kw as an example, calculate the compensation capacity and the power factors before and after compensation, and the results are shown in table 1.

In the table, the power factor of no capacitance compensation is \( \cos \varphi \), the power factor after compensate reactive is \( \cos \varphi \), reactive power is \( Q \).

<table>
<thead>
<tr>
<th>Number</th>
<th>power factor before Compensation</th>
<th>power factor after Compensation</th>
<th>Compensation capacity [kvar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.74</td>
<td>0.91</td>
<td>4533</td>
</tr>
<tr>
<td>2</td>
<td>0.76</td>
<td>0.92</td>
<td>4292</td>
</tr>
<tr>
<td>3</td>
<td>0.78</td>
<td>0.93</td>
<td>4071</td>
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<tr>
<td>4</td>
<td>0.80</td>
<td>0.94</td>
<td>3871</td>
</tr>
</tbody>
</table>
SOFTWARE DESIGN OF REACTIVE COMPENSATION CONTROL

The design idea of reactive power compensation control software is to adopt values such as voltage, current, reactive power of the system and power factor on the transformer status acquisition board after the initialization of system electrification and self-check, compare these values with those set by the users, and then judge the switch condition of capacitor bank according to the voltage of system. Normally, switching in or off the capacitor bank depends on the reactive power flow of system, load power factor, voltage, time delay and so on. The software flow chart is shown in Fig. 7.

CONCLUSION

This paper describes the control technology of reactive power compensation based on 380V low-voltage side of transformer in detail. Compensation equipment adopts shunt compensation capacitor bank to compensate, three-phase co compensation capacitor group and the three-phase capacitor "fill up" mode are selected as connection mode. Reactive power compensation control algorithm uses the improved nine-zone diagram method, and then through the calculation and control of the controller software, finally completes real-time control of the transformer reactive power compensation.
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REFERENCES

1. A.D. Lu: Power factor and reactive power compensation (Shanghai science and Technology Publishing House, China 2004).