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Design and Accomplishment of AI Control Platform for Reactive Power Cloud Compensation System

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***Abstract*—The balance of active and reactive power in the power system is very important for the normal operation of the whole system, the correct method is to inject the corresponding reactive power where much of the reactive power is consumed to maintain the balance. it is of great positive significance to develop a device with integrated new switching technology that can realize non-impact switching of capacitor banks and be controlled by better algorithms. In this paper， an artificial intelligent (AI) control platform for reactive power cloud compensation system is designed and achieved, by switching capacitors on the load side, the requirements of capacitor switching conditions are analyzed, the requirements of capacitor bank and capacitor controller are put forward, and the theoretical analysis is carried out. Results of the installation operation in site show high performance of the designed system.**

Keywords-control platform; reactive power; artificial intelligent; cloud compensation system

I. INTRODUCTION

The balance of active and reactive power in the power system is very important for the normal operation of the whole system and equipment. Since the transmission of active power in a power system requires phase Angle difference between two nodes, it can be realized in a wide range. However, the flow of reactive power depends on the voltage difference between nodes, so its regulation range is relatively small, so it is impossible to balance the reactive power of the whole network by relying on the power generation equipment. Thus, a variety of reactive power compensation equipment came into being. In a grid, the reactive power consumed by any load must correspond to one or more sources that emit the corresponding reactive power. It is obviously unreasonable for a generator to deliver such reactive power over a long distance. The correct method is to inject the corresponding reactive power where much of the reactive power is consumed to maintain the balance. In general, reactive power compensation has the following functions: reducing the long distance of reactive power and reducing transmission loss. The voltage at all levels can be stabilized, and the transmission capacity and system stability can be improved by increasing the intermediate voltage of long-distance transmission. Balance three-phase load. Therefore, it is necessary to make local reactive power compensation for specific load in each part of the power system and to control the reactive power of nodes in each substation. Among the many methods, the use of capacitor switching for reactive power compensation is the main method of lower cost compensation at present.

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The installation uses the capacitor to send out reactive power after being connected to the network to supplement the reactive power consumed by other inductive loads in the network to realize the purpose of compensation. Switching capacitor is also widely used because of its simple principle, high reliability, convenient use and maintenance, and easy realization of large capacity and high voltage. To sum up, before the mature application of low-cost, high-capacity and high-reliability power electronic reactive power compensation devices, it is of great positive significance to develop a device with integrated new switching technology that can realize non-impact switching of capacitor banks and be controlled by better algorithms. In this paper, design and accomplish AI control platform for reactive power cloud compensation system.

II. AI Control Strategy of Voltage and Reactive Power

The research of capacitor switching reactive power compensation mainly involves the selection of compensation mode, the calculation of capacitance, the discharge circuit of shunt capacitor, device protection, harmonic suppression and automatic switching control strategy. It can be said that after a long time of accumulation, all aspects have been quite mature and accumulated a lot of practical experience. Reactive power compensation and voltage regulation are a pair of interrelated quantities, so the processing of this coupling relation will be the key and difficult point in the design of this kind of device. For capacitor switching compensation of reactive power, the key technology is reflected in two aspects: the switching impact is as small as possible. In order to reduce the impact of cutting, on the one hand, we can choose the right time to input or cut; On the other hand, the redundant movement of the device should be avoided. On the one hand, the interference caused by the coupling of reactive power and voltage to the device is shielded as much as possible. On the other hand, under the premise of no loss of rapidity, an optimal control scheme is sought on a large time scale as far as possible.

A. Reactive Power Demand Theoretical Analysis

In the power system, electromagnetic induction is involved in most loads, such as motor. When the load is working, a certain amount of energy is needed to establish a magnetic field with the same frequency as the AC voltage. This kind of alternating magnetic field needs to absorb or release a certain amount of power, but this power does not do external work, it is only used to form a magnetic field, and the power absorbed and released in a cycle is equal. This power is called reactive power. The relationship among apparent power, active power and reactive power is shown in Fig. 1.

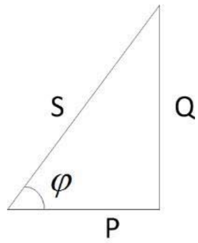

Figure 1. Power relationship.

From the Fig. 1 we get the equation (1),

$$\begin{cases} S^2 = P^2 + Q^2 \\ Q = S * \sin(\varphi) \\ P = S * \cos(\varphi) \\ Q = P * \tan(\varphi) \end{cases} \tag{1}$$

The voltage, active power, reactive power and power factor of the line are obtained by data acquisition of the power system of the offshore platform. The relationship between data is as equation (2).

$$\begin{cases} \varphi = \arccos(PF) \\ Q = P * \tan(\varphi) \end{cases} \tag{2}$$

When the active power is constant, the reactive power and the power factor cos (φ) are negatively correlated. In the platform, the reactive power is high. If the reactive power needs to be provided by the generator on the grid, then in each cycle, the equipment will exchange power with the generator. The power flows on the grid, resulting in great network loss and huge economic loss. Reactive power compensation is to connect the corresponding reactive power compensation source at the load, so that the reactive power required by the equipment can be exchanged between the compensation source and the equipment, without the need to flow power on the grid. Reactive power compensation effectively improves the power factor in the circuit, reduces the current used for reactive power compensation in the grid, and improves the load capacity of the generator and the network. The higher power factor increases the output of the equipment and the load capacity of the generator. Reactive power compensation plays a certain role in the stability of grid voltage.

B. The Influence of Reactive Power Flow on Node Voltage

As shown in Fig.2, the system voltage source voltage is $\dot{U}$, the node voltage is $\dot{V}$, the transmission line impedance is $R + jX$, the current flowing through the line is $\dot{I}$, the transmission line voltage drops to $\Delta\dot{U}$, the active power output at the node is P, and the reactive power is Q.

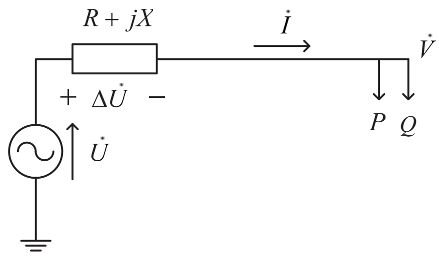

Figure 2. Power system and load equivalent circuit diagram.

Set the Angle between the supply voltage $\dot{U}$ and the node voltage $\dot{V}$ as φ, as shown in Fig.3, and the accurate relationship between the effective value of the node voltage and the reactive power flow can be calculated.

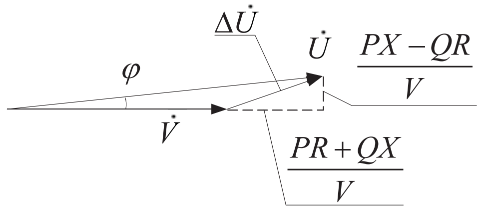

Figure 3. The node voltage via the reactive power flow.

When the voltage drop of the transmission line is small, the interaction between the system voltage and reactive power can be locally linearized. Moreover, this is guaranteed by other system voltage regulation mechanisms.

C. The Influence of Transformer Ratio on Reactive Power Flow

When the reactive power compensation cannot control the node voltage within the normal range, the substation generally adjusts the transformer tap to affect the node voltage. However, the adjustment of the node voltage will lead to the change of reactive power and active power flow. At the same time, the reactive power equivalent will be injected into the system after the same capacitor bank is put in. In this part, we will focus on the variation of the parameters of the converted system due to the variation of the transformer ratio. Consider the relationship between the corresponding quantities when the system is converted from high voltage side to secondary side without considering the loss of the transformer core and leakage reactance, as shown in Fig.4 and Fig.5. For the regulation of the on-load switch, the essence is to change the secondary side flux chain, that is, to change the node voltage by changing k. As a matter of fact, if the line transmission impedance is very small relative to the load impedance, then the conclusion will be very simple. Therefore, when the line impedance is very small relative to the load, it can be considered that the transformer ratio has a linear relationship with the node voltage.

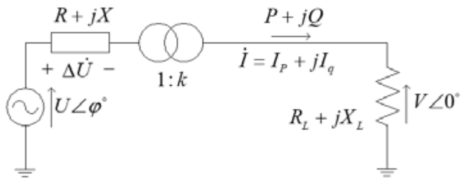

Figure 4. Before converted from high voltage side to secondary side.

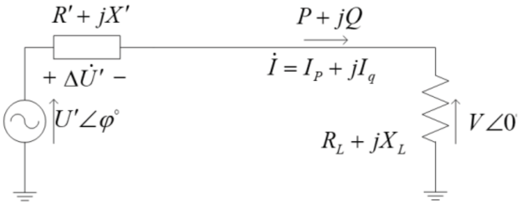

Figure 5. After converted from high voltage side to secondary side.

D. Control Strategy of Node Voltage and Reactive Power

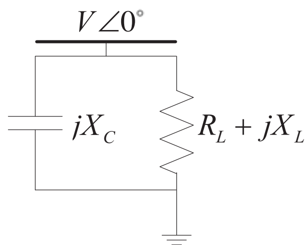

Figure 6. The combined effect of transformer ratio and active power flow on nodal voltage.

The change of the node voltage will also affect the reactive power inflow equivalent of the fixed capacitor bank and the active and reactive power consumption of the load, which should also be considered. Refer to Fig.6. For convenience of discussion, this figure can be considered as a balance node (or node) of the power system. It can be known that when the node voltage increases, the reactive equivalent consumed by the same load will increase, and at the same time, the reactive equivalent of the capacitor bank injection system will also increase. Since the reactive power flow can't be fixed near a certain value relative to the node voltage, the process of linearization must consider the current reactive power flow. The influence of node voltage on reactive power flow is a quadratic function, and the current reactive power flow must be considered in the linearization process.

III CLOUD CONTROL PLATFORM FOR CAPACITOR BANK

A. The Best Time to Put in a Capacitor Bank

In the three-phase system shown in Fig.7, the capacitors C_1, C_2 and C_3, are connected by current-limiting inductors in a star style, and are put into the grid or cut off from the grid by controlling the on-off of K_A, K_B, K_C. The reason why this star-connected three-phase capacitor bank with ungrounded neutral points is special is that depending on the state of each switch, the three capacitors will be connected to the grid in different forms -- either suspended, or in series, or in parallel. Suppose the circuit breaker closes in the order of K_A, K_B, K_C. When K_A closed, K_B disconnected, and K_C disconnected, the three capacitor banks are suspended and connected to the grid. The only difference is that u_1, u_2, u_3 will be the same as the instantaneous voltage in phase A. When K_A is closed, K_B closed and K_C disconnected, the voltage u_1, u_2 at each point, respectively, is consistent with the two-phase voltage of A and B. Because there is no current flowing through, the potential u_3 is the same as the N' point. When the parameters of the three-phase capacitor are symmetrical, it can be considered that $u_3 = (u_1 + u_2)/2$.

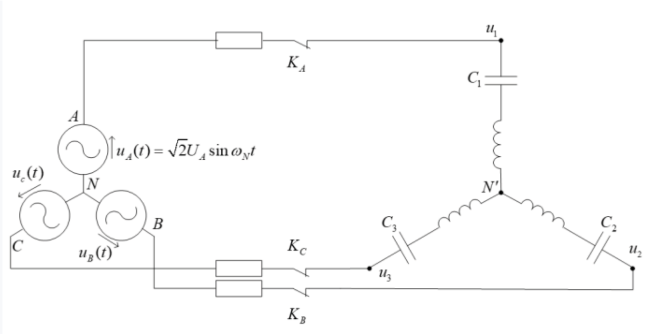

Figure 7. Schematic diagram of three-phase capacitor compensation structure.

The next step is to calculate the switching time of the three-way capacitor bank. As shown in Fig.7, it is assumed that none of the three capacitors is invested in the initial state, that is, the circuit breaker K_A, K_B, K_C is in the disconnected state. Close K_A first, though not necessarily, and in order to unify the operation, it can be put in when the a-phase voltage crosses zero $t_1 = 0ms$. At this time u_1, u_2, u_3 and will be consistent with the instantaneous voltage of phase A, so the time t_2 when the second set of capacitors is cut into shall be when $u_A(t_2) = u_B(t_2)$. Similarly, when K_A make, K_B make and K_C break, the voltage at each point u_1, u_2, and u_3, respectively, are consistent with the two-phase voltage of A and B. Because there is no current flowing through, the potential is the same as the point N'. When the parameters of the three-phase capacitor are symmetrical, it can be considered that $u_3 = (u_1 + u_2)/2$, according to the above discussion, the input time of the third capacitor group t_3 should meet the conditions $u_C = (u_A + u_B)/2$. The above results give the optimal switching time of the three capacitors, but please note that the switching time of the third capacitor is determined based on the three phase parameter pairs. In the actual operation process, the optimal switching time of each capacitor can be determined by taking the corresponding k values: $t_1 = 0ms$, $t_2 = 8.67ms$ and $t_3 = 13.33ms$

B. *Main Circuit for Reactive Power Compensation*

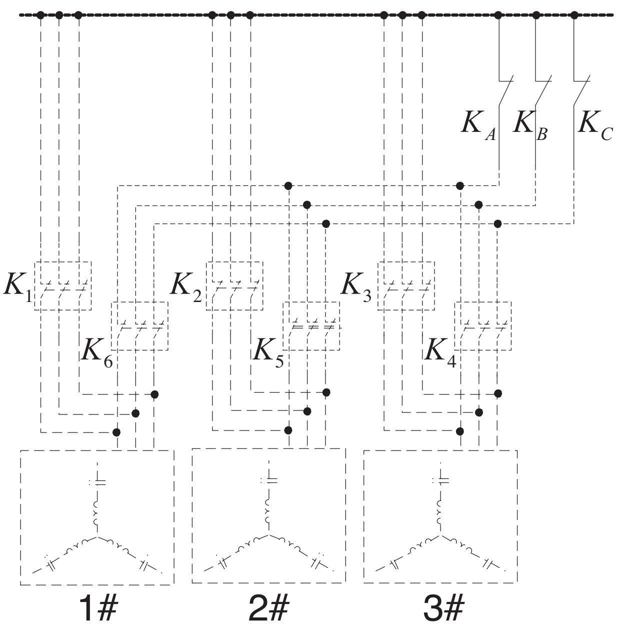

Figure 8. Design of main circuit for multi-bank capacitors switching.

Circuit breakers that can accurately control the switching time often cost a lot more than general circuit breakers. Therefore, in order to reduce the engineering cost as little as possible, this paper discusses how to design the main switch circuit to minimize the use of high-performance circuit breakers.

According to the above ideas, the switching main loop as shown in Fig. 8 can be adopted. Where, K_A, K_B, K_C is the high performance circuit breaker that can be operated separately, and is the general contactor. The idea of action execution is: use K_4, K_5, K_6 as a gate switch, and K_1, K_2, K_3 as a bypass switch.

C. *Design of Zero - Crossing Signal Capture Circuit*

Both voltage and current signals will eventually be output from the sensor terminal as voltage signals. The circuit that can be used to detect the zero-crossing moment of voltage or current based on the above voltage signals is called zero-crossing detection circuit. The zero-crossing detection circuit applied in the industrial field should have the functions of filtering and shaping to ensure the anti-interference performance of filtering and the accuracy of zero-crossing detection. In the device, a basic filter and comparison circuit is constructed by means of an operational amplifier, and a circuit with zero-crossing detection function is constructed by means of a voltage clam protection, which shown in Figure 9.

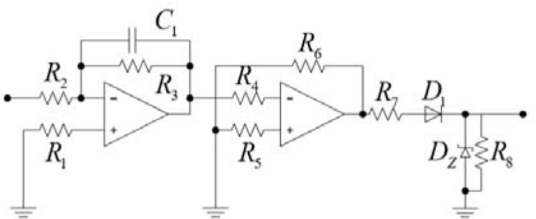

Figure 9. Zero - crossing signal capture circuit.

D. *Realization of Cloud Platform for Reactive Power Switching*

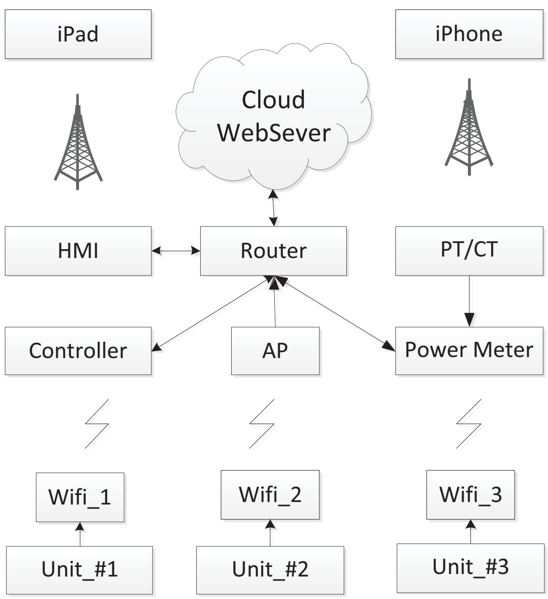

Figure 10. Schematic diagram of circuit principle of intelligent reactive power compensation device.

In the process of switching capacitor, if it is not switched on at voltage zero crossing or switched off at current zero crossing, impulse current and voltage fluctuation will occur on the power grid. The utility model relates to an intelligent power saving device at the end of a low-voltage distribution network, which comprises an air switch, an intelligent measurement and control unit, an electronic switch circuit and a capacitor. The air switch is an opening and closing switch of an intelligent power saving device paralleled to the power grid and used for the over-current protection of the capacitor. The intelligent measurement and control unit receives the signals from the power grid, the thyristor switch circuit and the temperature sensor of the capacitor through receiving the electric parameters of low-voltage grid meters, reactive demand and other control and protection parameters are calculated, control and protection signals are output to the electronic switch circuit to execute signal instructions, and capacitor switching is completed. The intelligent measurement and control unit is equipped with 485 bus interface for communication control, which is used to connect with external controller. The capacitor can be a compensation capacitor bank with two built-in temperature sensors and each phase series inductance or a sub compensation container with a built-in temperature sensor and each phase series inductance. The intelligent measurement and control unit is connected to HMI, communication interface and control interface. The electronic switch circuit is composed of zero crossing trigger unit, double thyristor anti parallel, high power magnetic holding relay and zero crossing measurement and control over-voltage protection module. The intelligent power saving device is divided into three-phase common compensation module and three-phase sub compensation module.

In the integrated module composed of two three-phase capacitors, one phase of one capacitor is connected directly with the corresponding phase of the power grid or power supply after paralleling with the other, and the other two phases of each capacitor are respectively connected with a thyristor switch circuit to complete the switching on and off of the capacitor. In the integrated module composed of a three-phase shunt capacitor, each phase is connected with a thyristor switch circuit to realize the on / off of the capacitor. The intelligent power saving device has the functions of environmental temperature over value, over-voltage, over-current, no-load, power failure, phase loss, maloperation protection, which can be used independently by a single set, or can be used in a system composed of multiple networks. During the process of capacitor switching, there is no over-voltage, no inrush current; at the same time, it has smaller volume, less power consumption, more reasonable structure, frequent switching, lower price, better heat dissipation, production and group Easy to install and maintain. The intelligent energy-saving device can replace the controller, display instrument, indicator light, change-over switch, fuse (or air switch), composite switch (or AC contactor), thermal relay and other loose components in the low-voltage reactive power compensation system after assembly. It has the functions of environmental temperature over value, over-voltage, over-current, no-load, power failure, phase loss, maloperation protection, and has no over-voltage in the process of switching No inrush current generation, fast compensation of superior performance.

IV CONCLUSION

Through terminal reactive power compensation, the power factor of power system can be effectively improved, the loss of power grid can be reduced, and the voltage of power grid can be stabilized. The power factor of the system is stabilized at an ideal level by measuring the real-time power grid data and switching out the capacitors according to the judging conditions. In this paper，an artificial intelligent control platform for reactive power cloud compensation system is designed and achieved, results of the installation operation in site show high performance of the designed system.

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