Research on Key Technologies of Intelligent Control Switches in Distribution Networks

Fusheng Guo¹, Weihan Zhou², Yongqing Wang³, Yongzhi Su³, Weiping Wu⁴ and Weichao Li⁵*

¹ Yantai Power Supply Company State Grid, Shandong Electrical Power Company, Yantai, Shandong, 264000, China
² Laizhou Power Supply Company State Grid, Shandong Electrical Power Company, Laizhou, Shandong, 261400, China
³ Shandong Electrical Power Company, Jinan, Shandong, 250001, China
⁴ Muping Power Supply Company State Grid, Shandong Electrical Power Company, Muping, Shandong, 264100, China
⁵ School of Electrical Engineering, Shandong University, Jinan, Shandong, 250061, China

*Corresponding author’s e-mail: weichao_li@mail.sdu.edu.cn

Abstract: With the development and widespread application of high-power power electronics technology, there is an interaction between distribution network voltage and reactive power and power quality. It is prone to operating over-voltage and closing inrush when closing, and reignition often occurs during opening. The voltage is too high, which far exceeds the voltage and insulation performance that the equipment can withstand, resulting in damage to the equipment. In response to the above problems, this article proposes an intelligent control switch closing and opening strategy to reduce the impact on the equipment during the reactive power compensation switching process. Considering the different dispersion of the intelligent control switch, the process of closing the parallel capacitor is simulated, and the effect of the intelligent control switch on the overvoltage and inrush current limitation is compared, which proves that the strategy is effective.

1. Introduction

With the development and universal application of high-power power electronic technology, the proportion of DC transmission, new energy grid-connected and new power loads is increasing [1]. With the rise of new energy sources, some harmonics have large content and have impacts. Characteristic large-capacity installations, such as electric arc furnaces, wind turbines and photovoltaic equipment connected to the grid, have a serious impact on the power quality problems of the distribution network. The research on the problems of power quality control measures including reactive power compensation is relatively lagging, not only in theoretical research blind spots, but also lack of follow-up in device improvement and research and development. The impulse overvoltage caused by the backward compensation equipment and the large number of harmonics generated by the system are intertwined, which not only endangers the reactive voltage regulating equipment, but also brings greater safety hazards to the main network side equipment, such as equipment oscillation overvoltage,
heat overload. Such failures occur from time to time, thereby affecting the reliability of the distribution network power supply.

As users have higher and higher requirements for power quality [2], the development of compensation has experienced synchronous adjustment of cameras, shunt capacitors, static var compensators, static var generators [3-4]. However, due to the mutual influence between the voltage and reactive power of the distribution network and the power quality, there are often many problems that are not conducive to the operation of the system and the safety of the equipment during the switching process of the adjustment. The phenomenon of operating over-voltage and closing inrush current is prone to occur during closing, and reignition often occurs during opening to cause excessive voltage, which far exceeds the voltage and insulation performance of the equipment, which leads to equipment damage [5].

In response to the above problems, this article proposes an intelligent control switch closing and opening strategy to reduce the damage to the equipment during the reactive power compensation switching process, and consider the different dispersion of the intelligent control switch to simulate the process of closing parallel capacitors, comparative analysis of the effect of the intelligent control switch on the overvoltage and inrush current limitation, proves that the strategy is effective.

2. Intelligent control switch switching strategy

The intelligent control switch adopts the principle of phase selection and switching to control the closing and opening phases, thereby reducing the damage to the equipment in the process of reactive power compensation switching. Aiming at the switching operations of capacitors and reactors in the neutral point ungrounded system such as 35kV, through theoretical analysis, the following strategies are proposed for the phase selection, closing and opening of the intelligent control switch.

2.1. Closing process

The main goal of the intelligent control switch during the closing operation is to select the appropriate phase to reduce the closing impact, thereby reducing inrush current and overvoltage. For capacitor banks and reactor banks, there are certain differences in their principles.

1) Put in parallel capacitors: Its main goal is to suppress inrush current and overvoltage, including the following two strategies. The first strategy is: closing the two-phase switches at the same time when the voltages of the two phases are equal; closing the third phase when the neutral point and the third phase voltage cross zero at the same time after 1/4 power frequency period.

![Figure 1. Phase selection strategy of putting in parallel capacitors (1)](image1)

![Figure 2. The phase selection strategy of putting in parallel capacitors (2)](image2)
The second strategy is: the first phase is closed at its voltage zero-crossing point, the second phase is closed when its phase voltage is equal to the first-phase voltage, and the last phase is closed at its subsequent self-zero-crossing point.

2) Put in shunt reactor: each phase is closed at the peak voltage at both ends of the circuit breaker. Its main goal is to suppress inrush currents.

![Figure 3. Phase selection strategy for shunt reactor](image)

3. Simulation

3.1. Simulation of capacitor switching process
Considering the different dispersion of the intelligent control switch, the process of closing the parallel capacitor is simulated, and the effect of the intelligent control switch on the limitation of overvoltage and inrush current is compared and analyzed. The switch closing strategy used in the simulation is as described above. The simulation results are shown in Table 1 and Table 2.
Table 1. Simulation results of using intelligent control switch to input parallel capacitors (Strategy 1)

|                                | No measures | Phase selection and closing (No deviation) | Phase selection and closing (Deviation ±0.5ms) | Phase selection and closing (Deviation ±1ms) |
|--------------------------------|-------------|-------------------------------------------|-----------------------------------------------|---------------------------------------------|
| Closing inrush current (kA)    | 8.38        | 3.64                                      | 3.82                                          | 4.29                                        |
| 35kV bus-to-ground voltage (p.u.) | 1.25        | 1.09                                      | 1.09                                          | 1.11                                        |
| Series resistance bus side voltage to ground (p.u.) | 1.25 | 1.09                                      | 1.09                                          | 1.11                                        |
| Capacitor-to-ground voltage (p.u.) | 2.40        | 1.47                                      | 1.50                                          | 1.59                                        |
| Capacitor neutral point to ground voltage (p.u.) | 1.00 | 0.51                                      | 0.63                                          | 0.75                                        |
| Voltage across series reactance (p.u.) | 1.18 | 0.38                                      | 0.41                                          | 0.48                                        |
| Voltage between capacitors (p.u.) | 2.42 | 1.47                                      | 1.50                                          | 1.59                                        |
| Bus arrester current (A)       | <1          | <1                                        | <1                                            | <1                                          |
| Energy consumption of bus arrester (KJ) | <1 | <1                                        | <1                                            | <1                                          |

Table 2. Simulation results of using intelligent control switch to input parallel capacitors (Strategy 2)

|                                | No measures | Phase selection and closing (No deviation) | Phase selection and closing (Deviation ±0.5ms) | Phase selection and closing (Deviation ±1ms) |
|--------------------------------|-------------|-------------------------------------------|-----------------------------------------------|---------------------------------------------|
| Closing inrush current (kA)    | 8.38        | 3.65                                      | 3.88                                          | 4.40                                        |
| 35kV bus-to-ground voltage (p.u.) | 1.25        | 1.09                                      | 1.10                                          | 1.11                                        |
| Series resistance bus side voltage to ground (p.u.) | 1.25 | 1.09                                      | 1.10                                          | 1.11                                        |
| Capacitor-to-ground voltage (p.u.) | 2.40        | 1.47                                      | 1.51                                          | 1.61                                        |
| Capacitor neutral point to ground voltage (p.u.) | 1.00 | 1.00                                      | 1.00                                          | 1.00                                        |
| Voltage across series reactance (p.u.) | 1.18 | 0.38                                      | 0.42                                          | 0.50                                        |
| Voltage between capacitors (p.u.) | 2.42 | 1.47                                      | 1.52                                          | 1.61                                        |
| Bus arrester current (A)       | <1          | <1                                        | <1                                            | <1                                          |
| Energy consumption of bus arrester (KJ) | <1 | <1                                        | <1                                            | <1                                          |
It can be seen that there is no significant difference in the calculation results under the two strategies. Taking into the closing time deviation within 1ms, the use of intelligent control switches can still significantly reduce the closing inrush current and overvoltage.

3.2. Simulation of reactor switching process
Considering the different dispersion of the intelligent control switch, the process of closing the shunt reactor is simulated, and the effect of the intelligent control switch on the limitation of overvoltage and inrush current is compared and analyzed. The switch closing strategy used in the simulation is as described above. The simulation results are shown in Table 3.

| Table 3. Maximum inrush current and overvoltage of the shunt reactor |
|---------------------------------------------------------------|
| Closing inrush current (kA) | No measures | Phase selection and closing (No deviation) | Phase selection and closing (Deviation ±0.5ms) | Phase selection and closing (Deviation ±1ms) |
|------------------------------|-------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 35kV bus-to-ground voltage (p.u.) | 1.25 | 1.09 | 1.10 | 1.11 |
| Capacitor-to-ground voltage (p.u.) | 2.40 | 1.47 | 1.51 | 1.61 |
| Capacitor neutral point to ground voltage (p.u.) | 1.00 | 1.00 | 1.00 | 1.00 |
| Bus arrester current (A) | <1 | <1 | <1 | <1 |
| Energy consumption of bus arrester (KJ) | <1 | <1 | <1 | <1 |

It can be seen that considering a certain closing time deviation, phase selection and closing can significantly reduce the closing inrush current.

4. Conclusion
The intelligent control switch can effectively limit the inrush current and overvoltage when the reactive power compensation device is switched on and off, and suppress the reignition phenomenon when the circuit breaker is opened. It is suitable for the frequent switching on and off of the reactive power compensation device. In addition, the switch has the advantages of fast opening and closing speed, small bounce, stable performance, no power consumption, low price, simple combined structure and long service life.

Acknowledgment
This work was supported by State Grid Shandong Electric Power Company Science and Technology project (Grant No.5206051900CA).

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