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Research on switching overvoltage suppression of 35 kV shunt reactor

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Abstract. In recent years, a number of equipment abnormal events caused by operating overvoltage have occurred during the interruption of 35 kV shunt reactors, which jeopardizes the safe and stable operation of the grid. In order to explore the mechanism of operating overvoltage when 35 kV shunt reactor is cut off and the effect of various suppression measures, this paper carries out simulation analysis and research, mainly considers several factors to the effect of overvoltage, such as bus outlet, circuit breaker switching position and overvoltage protector.

1. Introduction

During shunt reactor switching, especially when the empty bus system is switched, is prone to interception, arc re-ignition and equivalent interception [1-3], which in turn generates operating overvoltage, causing bus-to-phase short-circuit, reactor phase-to-phase short-circuit and failures such as damage to the insulation of the reactor, threatening the safety of electrical equipment and affecting the safe operation of the system. In recent years, 220 kV substations frequently occur in switching (mainly breaking) equipment failure caused by 35 kV shunt reactor, which seriously affects the safe and stable operation of the power grid [4-6].

The operation overvoltage generated by switching 35kV shunt reactors is serious and involves a wide range of equipment, which is urgently needed to be improved. Therefore, this paper analyzes the formation mechanism and several suppression measures of the overvoltage of the shunt reactor.

2. Overvoltage mechanism of interrupting shunt reactor

Two kinds of overvoltage occur during the interruption of the reactor: the interception overvoltage and the re-ignition overvoltage [7-8]. The interception causes energy to be stored in the reactor to cause an overvoltage, which is called an interception overvoltage. After no re-ignition break, single-frequency load side oscillation occurs, and the maximum overvoltage on the circuit breaker is about 2.0 p.u. The main cause of the switching overvoltage of the shunt reactor is re-ignition and the equivalent interception of the non-first opening phase caused by re-ignition [9-10].

The formation mechanism of the re-ignition of the circuit breaker when breaking a small current is shown in Figure 1. I is the current flowing through the circuit breaker, the system issues a trip command at T_C, and the circuit breaker operating mechanism starts to operate. After the opening time t_0, the breaker contacts begin to separate at T_S, and the fracture dielectric insulation begins to recover (as shown by the fracture dielectric insulation recovery curve). After the arcing time t_a, the arc is extinguished at the time T_0 due to the current zero-crossing (the ideal state has no interception), and

the transient recovery voltage begins to appear at the fracture. If the arcing time t_a is short, the contact between the contacts of the circuit breaker is not completely broken, and the distance between the moving and static contacts is not large. At this time, if the amplitude of the recovery voltage at both ends is too large, breakdown may occur, resulting in arcing. The re-ignited arc is quickly forced to extinguish near the zero crossing point, and the recovery voltage is regenerated between the contacts. If the recovery voltage exceeds the medium withstand capability of the gap at this time, the arc re-ignition will be triggered. The re-ignition process until the gap between the contacts is sufficiently large to withstand the recovery voltage.
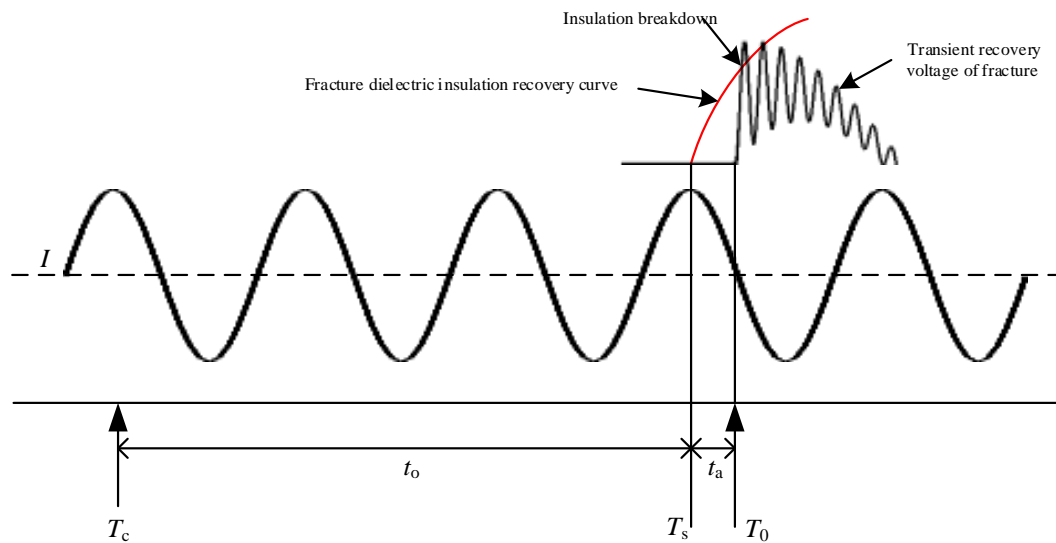

Figure 1. Re-ignition mechanism diagram.

Re-ignition mainly depends on the transient recovery voltage of the fracture and the insulation recovery characteristics of the fracture medium [11-13]. The dynamic insulation strength of the fracture has a certain dispersion, so the re-ignition of the arc also has a certain randomness. Once the re-ignition continues, the overvoltage will rise, which may cause harm to other equipment in the system [14].

It is impossible to completely eliminate the re-ignition of any kind of circuit breaker. If there is no special measure of voltage suppression, regardless of the switching device, the re-ignition overvoltage may occur when the reactor is turned off.

3. Breaking shunt reactor overvoltage suppression ideas

The occurrence of re-ignition is mainly due to the intersection of the fracture dielectric insulation recovery curve and the fracture transient recovery voltage. Therefore, the idea of eliminating or reducing re-ignition can be summarized into three types, as shown in Figure 2.

The "re-ignition window" is formed between the corresponding arcing time and the zero-crossing point T0 when the dielectric insulation recovery curve of the circuit breaker and the fracture transient recovery voltage are tangent. When the arcing time ta is sufficiently large that the circuit breaker separation timing TS can avoid this re-ignition window, re-ignition will not occur.

Use high-performance circuit breakers with faster dielectric insulation recovery to avoid transient recovery voltage or reduce the number of times the dielectric insulation recovery strength curve intersects the transient recovery voltage. If SF6 circuit breaker is used instead of vacuum circuit breaker Device. But it does not completely eliminate re-ignition.

The transient recovery voltage of the fracture is affected by the performance of the circuit breaker itself and the system parameters at both ends of the fracture. The fracture transient recovery voltage can be reduced by changing the system parameters at both ends of the fracture, and the transient

recovery voltage curve and the medium recovery characteristic curve are avoided as much as possible. First, the position of the circuit breaker can be changed, and the capacitive effect of the connecting cable can be used to select the front circuit breaker switching or the neutral point circuit breaker switching. Second, the recovery speed of the transient recovery voltage can be reduced and the damping can be increased by adding a RC absorber on the bus side or the reactor side.
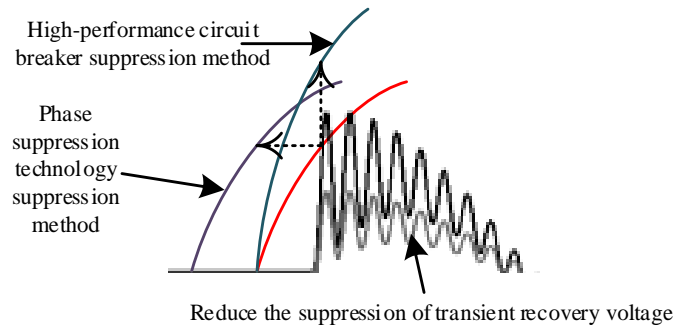

Figure 2. Extend arcing time t_a - phase control technology.

In addition, various overvoltage protection devices can be selected to effectively discharge energy and reduce overvoltage after overvoltage is generated. For the new station, it is also possible to order the reactive power compensation device without switching to replace the shunt reactor in an orderly manner.

4. Breaking shunt reactor overvoltage simulation model

The PSCAD electromagnetic transient simulation software was used to simulate the overvoltage of the 35 kV shunt reactor. The simulation model mainly consists of 220 kV power supply, 220 kV/35 kV transformer, bus (ground capacitance), bus lightning arrester, bus PT, home position circuit breaker, connecting cable, pre-circuit breaker, reactor arrester, shunt reactor (including stray capacitance). And the composition of the neutral point circuit breaker, in addition to the simulation requirements to add equipment models such as RC absorbers and overvoltage protectors.

4.1. Circuit breaker model

The single-phase circuit breaker model constructed by three factors: cutoff value Ic, fracture medium recovery strength Ud, and high-frequency current arc-extinguishing capability ΔI is adopted. When the circuit breaker receives the opening command and the absolute value of the current is less than the cutoff value Ic, the circuit breaker is disconnected. If the fracture medium recovery strength Ud is less than the fracture transient recovery voltage Ut, the breaker breaks through (not considering the arc model). If the rate of change of the high-frequency current is less than the high-frequency current-extinguishing capability ΔI and the current is less than the cut-off value Ic, the fracture is re-opened. This cycle is repeated until the current is broken (no insulation breakdown of the device is set in the model).

4.2. Reactor model

The rated voltage of the reactor is 35 kV (37.5 kV), the rated capacity is 10000 kvar, the star connection, the neutral point is not grounded, set by 0.38 H per phase inductance, and the winding resistance is 1 Ω. Parallel reactors are distributed between phases, relative to each other, and between turns, the dry air reactance is set at 500 pF, and the oil immersed reactor is set at 1500 pF.

4.3. Connection cable model

In the actual substation, the YJV22-26/35 kV single-core cable is mostly used for the connecting cable of the reactor. The actual laying length is in the range of 60~270 m, and the typical value is 100 m.

The side-to-ground capacitance of the shunt reactor is mainly provided by the cable, so the cable model is the key to the overvoltage simulation of the shunt reactor.

4.4. Lightning arrester model
The relative overvoltage strength of the shunt reactor operation depends on the voltage limiter of the arrester. The arrester is configured according to the main transformer, bus, and shunt reactor side where the actual substation is located.

4.5. Bus outlet model
According to the "Power Engineering High-voltage Transmission Line Design Manual", the overhead line is different according to the cross-sectional area and geometrical distance, and the length of the outgoing line is different, and the capacitance value of the bus-to-ground is estimated.

5. Research on overvoltage treatment of open shunt reactor

5.1. Overvoltage simulation in a typical system configuration
In the typical configuration, the bus is an empty bus reactance selection dry reactor, and the original position vacuum circuit breaker is switched. The breaking shunt reactor simulation was performed by selecting 100 breaking time points at intervals of half a cycle (10 ms).

In a typical configuration, the probability of re-ignition when breaking a shunt reactor is 93%. The relative peak voltage has a maximum value of 89.62 kV, a 2% statistical voltage of 103.78 kV, a phase-to-phase peak voltage of 172.51 kV, and a 2% statistical voltage of 208.78 kV. It can be seen that the overvoltage condition is very serious and poses a great threat to the insulation of the equipment.

The first open phase transient recovery voltage waveform (without re-ignition breaking) is shown in Figure 3. The probability that the dielectric insulation recovery curve escapes the transient recovery voltage peak is very low.
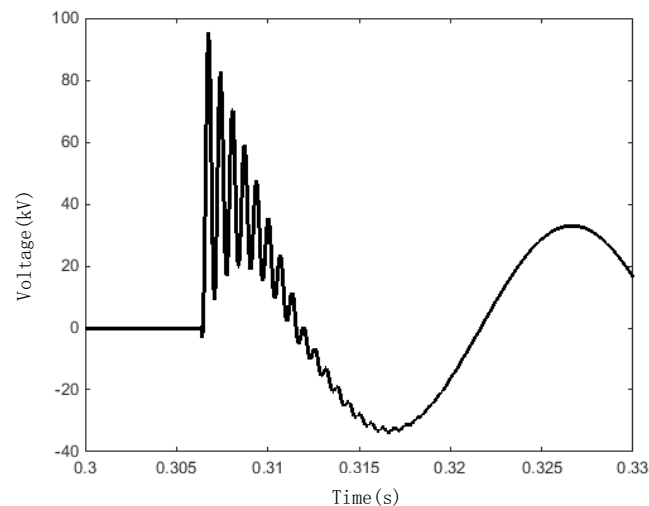

Figure 3. Transient recovery voltage.

The analysis shows that if the initial arcing time of the 35 kV vacuum circuit breaker can be controlled to exceed a certain value, it can ensure that the dielectric insulation recovery curve and the transient recovery voltage waveform does not intersect, thus eliminating re-ignition. The arcing time exceeding 3.3 ms must be realized by a three-phase phase-separated independent operating mechanism to suppress the re-ignition overvoltage generated by the circuit breaker operation by controlling the initial phase angle of the voltage or current when the circuit breaker is opened.

5.2. Effect of bus outlet condition on overvoltage

Changing the bus-to-ground capacitance value simulates the operation over-voltage waveform when the shunt reactor is turned off, and the bus-side voltage waveforms at the time of the empty bus (0.01 μF) and 0.5 μF are shown in Figures 4 and 5.
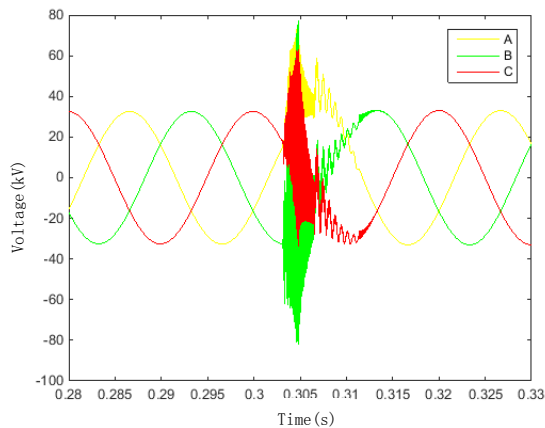

Figure 4. Bus voltage 0.01 μF, bus voltage waveform when the arcing time is 1ms.
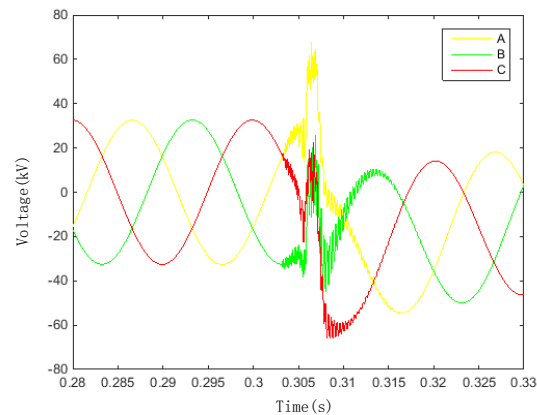
Figure 5. Bus voltage 0.5 μF, bus voltage waveform at 1ms arcing time.

After the bus-to-ground capacitance increases, the oscillation frequency decreases, and the effect of re-ignition on the voltage is significantly reduced. When the bus side capacitance is increased to 0.5 μF, the bus side overvoltage is mostly caused by waveform distortion, and the equivalent oscillation frequency is low, and the hazard is reduced.

As the bus-to-ground capacitance increases, the relative overvoltage of the bus side and the reactor side decreases, but there is no significant suppression of the phase-to-phase overvoltage voltage. When the bus takes out the line, the vacuum reactor is used to switch the shunt reactor. It is necessary to pay attention to the phase-to-phase overvoltage, especially the phase-to-phase overvoltage of the shunt reactor.

5.3. The influence of the switching position of the circuit breaker on the overvoltage

The switching position of the circuit breaker is divided into the original position circuit breaker switching, the front circuit breaker switching and the neutral point circuit breaker switching. Simulate the transient recovery voltage of the fracture when the three types of circuit breakers are switched to open the shunt reactor.

According to the simulation results, the switching mode of the front circuit breaker and the neutral point circuit breaker can significantly suppress the overvoltage. The pre-circuit breaker and neutral point breaker breaking mode on the one hand reduces the transient recovery overvoltage of the fracture and its rising speed, and reduces the possibility of re-ignition; on the other hand, the capacitance of the cable to the ground, and the cable and the parallel connection are utilized. The high-frequency filtering effect of the reactor can effectively reduce the operating overvoltage when the shunt reactor is turned off.

When the front circuit breaker is switched, it is recommended to add a set of lightning arresters at the connection point between the circuit breaker and the connecting cable in the switch cabinet when conditions permit. When the neutral point circuit breaker is switched, a set of lightning arresters must be installed between the reactor and the neutral point circuit breaker to suppress the hazard of the steep pulse or high frequency oscillation to the inter-turn insulation at the neutral point of the reactor. The SF6 circuit breaker is recommended. The additional lead-out cable has no significant effect on the voltage waveform when the neutral point breaker is turned off.

5.4. Effect of overvoltage protector on overvoltage

The overvoltage protector (interphase arrester) is essentially equivalent to a special structure of lightning arrester.

The overvoltage protector is usually installed on the side of the switchgear reactor. Four-column and six-column overvoltage protectors were used in the simulation to calculate the peak value of the phase-to-phase overvoltage in half a cycle.
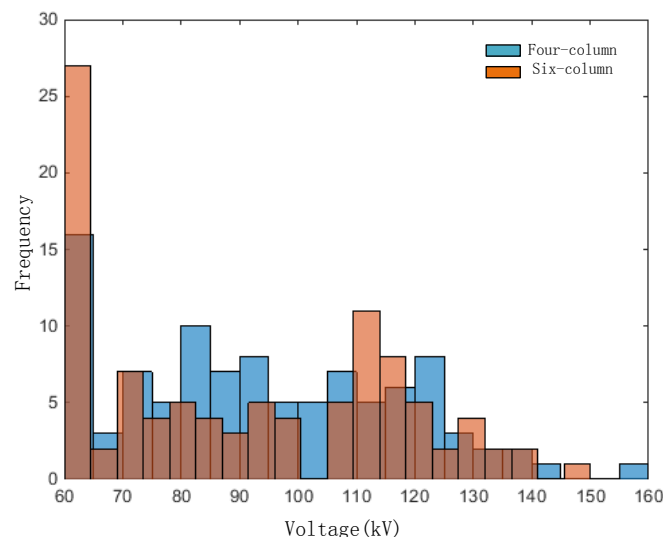

Figure 6. Input overvoltage protector 100 times breaking maximum phase voltage histogram.

It can be seen from the histogram of Figure 6 that the six-column full-phase protector has a slightly better suppression effect, and the inter-phase overvoltage strength of the bus side may still reach 160 kV after inputting the four-column overvoltage protector. The six-column full phase protector suppresses the maximum phase-to-phase overvoltage to less than 150 kV. Both overvoltage protectors have a bus suppression effect on the operating overvoltage, which can suppress the overvoltage to 40~70%. The four-column protector has a slightly better over-voltage suppression on the bus side, and the six-column over-voltage protector has a more obvious effect on suppressing the over-voltage on the side of the reactor.

The overvoltage protector needs to be installed in the switchgear. Under the miniaturization design requirements of the switchgear, there is a potential threat to the insulation. The effect of suppressing the overvoltage by installing the phase arrester on the outdoor reactor side is equivalent to that of the six-column full-phase protector, but it is necessary to ensure sufficient insulation distance between the devices. When the overvoltage protector or the phase arrester is used to suppress the overvoltage, if the re-ignition lasts for a long time, the protector needs to bleed the current frequently, which puts a test on the heat dissipation in the device and the switchgear. Field trials and network operations are used to make decision support.

6. Conclusions

The PSCAD electromagnetic transient simulation software was used to simulate the overvoltage condition of the 35 kV shunt reactor under various working conditions, and the suppression effect of various overvoltage suppression measures was compared.

1) The probability of re-ignition at break in a typical configuration is 93%, and the maximum value of the peak-to-phase voltage is 172.51 kV. The overvoltage condition is very serious, which poses a great threat to equipment insulation.

2) Increasing the capacitance of the bus to ground can reduce the oscillation frequency and reduce the influence of re-ignition on the voltage.

3) The switching mode of the front circuit breaker and the neutral point circuit breaker has a good suppression effect on the operating overvoltage.

4) The overvoltage protector has obvious suppression effect on the overvoltage of the open shunt reactor, especially the six-column full-phase overvoltage protector. The protection performance in the simulation is the best among the existing products.

Acknowledgement

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