

Transient Characteristics Analysis of 500kV Parallel Circuit Breaker Based on Highly Coupled Split Reactor

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Abstract. With the continuous expansion of power system capacity, parallel high-voltage circuit breakers with a Highly Coupled Split Reactor (HCSR) have a potential application for limitation of high short-circuit current. However, as the parallel circuit breakers open at different time, the residual voltage of the split reactor on the post-open circuit breaker is higher and the stray capacitors of HCSR form high-order oscillating circuits, which may lead to serious transient recovery voltage (TRV). Therefore, it is necessary to analyze and simulate the transient characteristics of 500kV HCSR. Firstly, the equivalent model of HCSR circuit breakers is built in EMTP simulation platform, and its TRV generation is analyzed. Then, the TRV of parallel circuit breakers under different operating conditions and fault types is simulated and calculated. Finally, according to the statistical calculation results, the protection measure of 0.2 μ F shunt capacitance to limit rise rate of TRV is proposed.

1 INTRODUCTION

With the fast development of grid, the short-circuit currents of many central nodes of power grids are approaching or even exceeding the regulation standard seriously, endangering security and stability problems of power grid [1]. In addition to superconducting fault current limiter, current limiting reactor, high voltage fuse, thyristor-based fault current limiter and bus splitting operation [2-5], the parallel technology of circuit breaker is one of the ways to solve high current interruption [6],[7].

Compared with other current limiting methods, the current limiter based on Highly Coupled Split Reactor (HCSR) has the advantages of simple principle, low cost and small space occupation. In stable operation, the coupled series reactance has lower energy consumption, and the working conditions are lower [8]. The resonance of capacitors in resonant current limiter is not considered. The control signal of the power electronic component is not needed, which improves the accuracy and economy of its action.

However, as the parallel circuit breakers open at different time, the residual voltage of the split reactor on the post-open circuit breaker is higher and the stray capacitors of HCSR form high-order oscillating circuits, which may lead to serious transient recovery voltage (TRV). At present, the HCSR current limiter [9],[10], which is mainly developed in domestic 252kV system, has little research on the transient characteristics of HCSR when circuit breaker breaks in 500kV system. It is necessary to provide reference for equipment parameter selection and insulation manufacturing.

The purpose of this paper is to study the electromagnetic transient of 500 kV shunt circuit breaker based on HCSR. Firstly, the model of parallel circuit breaker is built on EMTP simulation platform relying on 500 kV system in engineering example. Then, the overvoltage of parallel circuit breaker under different operating conditions and fault types is simulated and analysed in depth. Finally, according to the statistical calculation results, the optimization suggestions for overvoltage protection measures and series reactance technology are put forward.

2 EXPERIMENTAL SETUP

The key of parallel connection technology based on HCSR is to realize shunting of shunt branch in the process of breaking and current limiting of reactor operation after unbalanced breaking, so as to ensure that the fault current borne by each branch of circuit breaker does not exceed its limit breaking capacity [11]. Among them, L1 and L2 are a pair of HCSR in reverse parallel, which are connected in series with CB1 and CB2 respectively. C1, C2, C3, C4, C5 and C6 are stray capacitors.

The inductance of the two arms should be the same in theory, and $L1=L2$. When the system runs steadily, the current flowing through the two branches is equal, and the impedance value of the HCSR is very small. The influence of its access on the system can be neglected. When a short-circuit fault occurs in the system, ideally, when the current of the double circuit breaker of the device is zero, only 50% of the short-circuit current of each group of circuit breakers will be cut off at the same time. Considering the dispersion of the breaking time of

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parallel circuit breakers, when one of the circuit breakers first breaks, the single-arm inductance in the HCSR can effectively limit the fault current of the other circuit breaker. Short-circuit current can be separately interrupted by opening branch after syndrome.

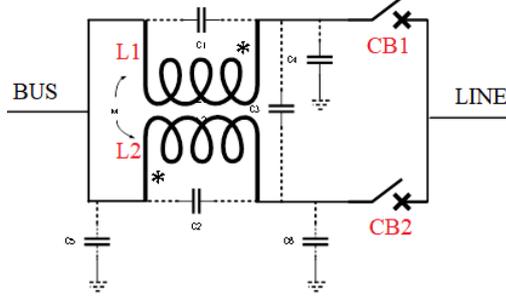


Fig. 1. The structure of HCSR

It's suggested that series reactance L1 and L2 are taken as 4Ω, and the coupled coefficient is considered as 0.98. The mutual inductance M=3.9Ω, and the overall reactance of HCSR in normal operation is 0.04Ω, which is equivalent to a circuit reactance of about 0.16km. It is suggested that the basic rated parameters of 500kV shunt circuit breakers based on HCSR are shown in Table 1.

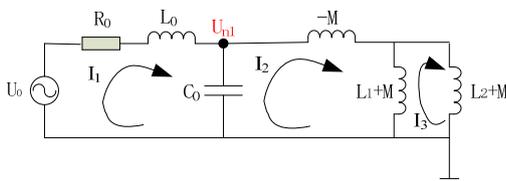
Table 1. The basic rated parameters of each branch

Inductance of HCSR	4 Ω
Coupled coefficient	0.98
Rated current	4 kA
Rated voltage	84 kV

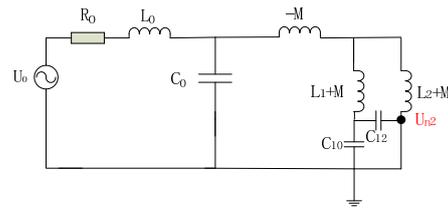
3 SIMULATION MODEL AND METHOD

This paper mainly considers the over-voltage generated by the asynchronous interruption of two arms of HCSR. The equivalent circuit of the interruption process is shown in Figure 2. When one phase of the system is short-circuit grounded, the circuit breaker switches off according to the instruction of relay protection. The voltage on both sides of the contacts at the instant of extinguishing is TRV [12].

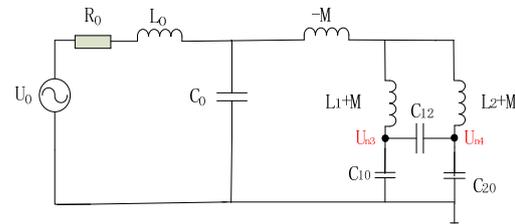
3.1 Equivalent Circuit Equation



(a) As grounding fault occurs, breaking voltage Un1 of CB1



(b) Breaking voltage Un2 of CB2



(c) As fault clearing, the TRV (Un3 and Un4) of CB1 and CB2

Fig. 2. The voltage of HCSR as parallel breakers opening differently

In view of the fact that TRV does not appear for a long time, usually within a few hundred micro-seconds, during this period, the power supply voltage with a frequency of 50 Hz is basically unchanged. In order to simplify the calculation, the voltage can be set to U_0 , $U_0 = U_s \sin \varphi$. The arc quenching time is t , the circuit equivalent inductance is L , and the equivalent capacitance is C . Assuming that t is the origin of time coordinate, i.e. $t=0$, KVL equation can be obtained from Kirchhoff's law:

$$U_0 = Ri + L \frac{di}{dt} + u_c \quad (1)$$

$$\text{For } i_1 = C \frac{du_c}{dt}, \frac{di_1}{dt} = C \frac{d^2 u_c}{dt^2} \quad (2)$$

$$\text{i.e. } U_0 = RC \frac{du_c}{dt} + LC \frac{d^2 u_c}{dt^2} + u_c \quad (3)$$

Usually, the equivalent power supply resistance R is small. Solution (3) can be obtained:

$$u_c = U_0 (1 - e^{\delta t} (\alpha_1 \cos \omega_0 t + \alpha_2 \sin \omega_0 t)) \quad (4)$$

When the two arms of the circuit breaker move in succession, the maximum time difference of three-phase opening is 3ms, the stray capacitance C between the phases of the access circuit increases, and the amplitude and rise rate of the voltage change greatly. The rate of rise is as follows:

$$\left(\frac{du}{dt} \right)_{\max} = u_0 \omega_n = \frac{u_0}{\sqrt{LC}} \quad (5)$$

Due to the introduction of current limiting reactor, the stray capacitance of the stray capacitance current limiting reactor on the line side forms a resonant circuit, which results in higher frequency oscillation. Therefore, according to the derived theoretical formula, the influence method of restraining TRV rise rate can be obtained. The mathematical expressions obtained provide a theoretical basis for optimizing the parameters

of current limiting reactor and selecting the breaking characteristics of high voltage circuit breaker.

3.2 System Model

In this paper, EMTP simulation software is used to accurately simulate the physical characteristics of each equipment in the system from the angle of electromagnetic field. The calculation step is 10us. According to the actual operation characteristics, the simulation calculation model of each equipment is established. Random switches are used for both arm circuit breakers and short circuit faults.

This paper verifies the influence of HCSR on TRV of circuit breaker relying on 500 kV Zongjiang-Guancheng(ZJ-GC) line in Guangdong Province. According to the preliminary calculation results, if no measures are taken, the three-phase short-circuit current of ZJ Station will be 69.3 kA and the power flow will be 1330 MW in 2020. After installing HCSR on the bus side of ZJ Station, the three-phase short-circuit current will be 49.5 kA and the power flow will be 1322 MW. Basic wiring diagram of substation as shown in Figure 3.

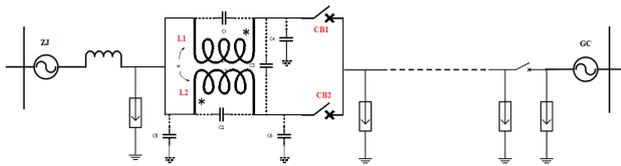


Fig. 3. Basic wiring diagram of substation

4 EXPERIMENT RESULTS

The types of short-circuit faults in HVAC transmission lines in power system mainly include three-phase short-circuit, two-phase short-circuit, single-phase short-circuit grounding and two-phase short-circuit grounding, among which single-phase short-circuit fault has the highest incidence and three-phase short-circuit fault is the most serious. Three-phase short-circuit fault is an important basis to determine the reliability of power system and the breaking performance of circuit breaker under fault conditions.

4.1 TRV of HCSR in Different Fault

When grounding faults occur at the end of ZJ Substation, the TRV of HCSR in various faults is shown in Table 2. The simulation results can be seen that the three-phase grounding fault is the most serious in short circuit fault, the peak value of transient recovery overvoltage of circuit breaker is 783.1 kV, and the corresponding rise rate of TRV is 11.9 kV/us. The peak value meets the standard of T60[13]. The rise rate of TRV is far beyond the standard range.

Table 2. TRV of HCSR as grounding faults occur at the end of ZJ Substation.

Circuit	Fault	TRV(kV _{peak})	TRV(kV/us)	Current (kA)
Single	1LG	716.2	6.2	31.2
	2LG	766.0	10.0	32.3
	3LG	783.1	11.9	34.2
Double	1LG	702.5	7.2	31.0
	2LG	751.8	8.1	32.1
	3LG	770.3	10.1	32.9

When grounding faults occur at different point of the line, the simulation results of TRV in double lines single-phase fault is shown Table 3. The simulation results show that the TRV of end fault is higher than that of near-zone fault. The rise rate of TRV doesn't have clear trend and exceed the standard range. So, some restrictive measures should be taken.

Table 3. TRV of HCSR as fault at different point of line.

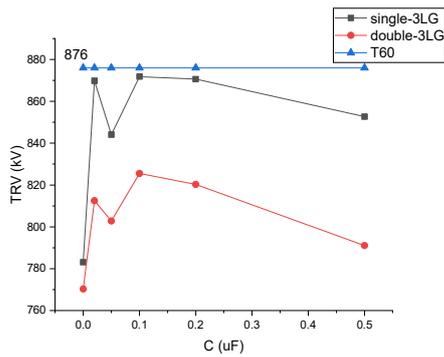
Fault place	TRV (kV _{peak})	TRV (kV/us)
ZJ side	702.5	7.3
Quarter	627.4	6.1
Middle	656.4	5.6
Three-quarter	673.3	5.2
GC side	770.3	5.7

4.2 Restrictions on TRV

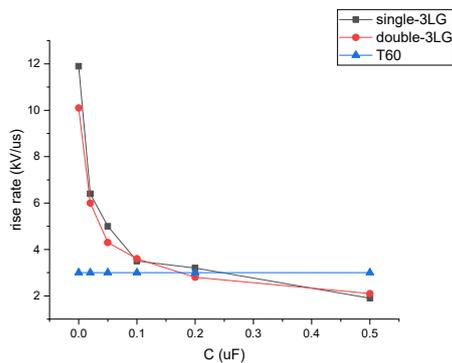
According to the analysis of the reasons for the steepness of TRV caused by series reactor, it is necessary to reduce the rise rate of TRV by reducing the residual voltage at the line side at the breaking time or the natural frequency of the oscillating circuit participating in the series reactor after quenching arc. After analysis, it is difficult to reduce the residual voltage at the line side at the breaking time, and measures to reduce the extinction need to be found. The natural frequencies of oscillation loops with the participation of back-arc series reactor. At present, the commonly used way to restrain the rise rate of TRV is shunt capacitance of series reactor [14]. This paper simulates the TRV level of three-phase grounding fault circuit breaker on the ZJ station side after the parallel capacitor is 0.02~0.5uF. The results are as Table 4 and Figure 4.

Table 4. TRV in three-phase grounding fault with various parallel capacitors

Fault	C(uF)	f(kHz)	TRV(kV)	TRV(kV/us)
single	non	10	783.1	11.9
	0.02	5.9	869.8	6.4
	0.05	4.1	844.1	5.0
	0.10	3.3	871.8	3.5
	0.20	2.2	870.6	3.2
	0.50	1.4	852.7	1.9
double	non	10	770.3	10.1
	0.02	5.9	812.5	6.0
	0.05	4.1	802.8	4.3
	0.10	3.0	825.5	3.6
	0.20	2.1	820.3	2.8
	0.50	1.4	791.1	2.1



(a) The peak of TRV with stander



(b) The rise-rate of TRV with stander

Fig. 4. the TRV in three-phase grounding fault with various parallel capacitors

According to the simulation results, if the shunt capacitance of the series reactor is the larger, the TRV steepness of the circuit breaker will be the lower, and the low frequency oscillation will be more serious due to the interaction between stray capacitance and inductance. Because the shunt capacitance is much larger than series reactor [15-17], the shunt capacitance has no effect on short circuit current. Considering comprehensively, the selection of 0.2uF shunt capacitor can effectively reduce the rise rate of TRV.

5 CONCLUSION

In this paper, the transient process of 500 kV line circuit breaker after installing HCSR is studied, and the overvoltage protection measures are put forward. The main conclusions are as follows:

- 1) The structure and parameters of HCSR device are put forward. It's suggested that coupled series reactors are 4Ω with coupling coefficient of 0.98.
- 2) After installing HCSR on 500 kV transmission line, there are high amplitude and high frequency oscillations on the line side when the circuit breaker breaks short circuit fault, which results in the rise rate of TRV exceeding the standard value.
- 3) Experiments show that the 0.2uF parallel capacitance at both ends of the current limiting reactor can effectively limit the rise rate of TRV to the specified value (3kV/us).

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