RESEARCH ON THE IMPROVED FAULT CURRENT LIMITER BASED ON HIGH COUPLED SPLIT REACTOR

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ABSTRACT

As the short circuit current increases sharply, the application of fault current limiter (FCL) becomes more and more extensive. The FCL based on high coupled split reactor (HCSR) has many advantages compared with other types of FCL. As the key component of FCL based on HCSR, HCSR only exhibits a small leakage inductance to power system in the normal operation condition, and it will change role to a current limiting reactor once fault occurs. Due to the reverse coupling characteristics between two windings of HCSR, it puts big pressure on the insulation design of HCSR when FCL is applied in high voltage or ultra high voltage power system. In order to solve the above problems, an improved FCL topology is proposed and retains the advantages of HCSR, eliminating the need to transfer full-capacity fault currents, and on the other hand reducing the insulation requirements for HCSR. In this paper, focusing on the improved FCL topology, a simulation model is established to analyse the voltage and current changes under working condition, which can provide reference for the selection of HCSR and fast mechanical switch.

INTRODUCTION

With the rapid development of the power system, the short circuit current level has increased sharply. If no measures are taken, the busbar short-circuit current of some 500kV substations in Guangdong power grid has exceeded 80kA, which has exceeded the breaking capacity of existing circuit breakers[1]. In order to ensure security, stability and reliable operation of power system, it is necessary to take effective measures to limit short-circuit current, and the fault current limiter (FCL) is one of the important means to solve the above problems.

The FCL exhibits low impedance in normal operation condition of power grid, and changes to a high impedance limiting short circuit current when fault occurs. There are many types of FCL, each one has its own characteristics and advantages. Among them, the FCL based on high coupled split reactor (HCSR) is a relatively economical solution. The use of HCSR to achieve limit and interruption of large current is a new technique emerged in recent years[2-4]. HCSR consists of two highly coupled windings, which exhibits low reactance in normal conditions and is transferred to large reactance when fault occurs. The FCL based on HCSR has many advantages compared with other types of FCL.

This paper analyses the current transfer and current limiting process of the FCL with HCSR, and points out the problems exist in topology. In order to solve the problems, an improved FCL topology is proposed and the current transfer process is analysed through simulation[5-8], which can provide reference for the selection of HCSR and fast mechanical switch.

WORKING PRINCIPLE OF FCL BASED ON HCSR

HCSR is a kind of split reactor which has two reverse coupled windings. When the current pass through two coupled windings of the HCSR simultaneously, HCSR only presents a small leakage inductance to the system. When the HCSR has only one winding connected to the grid, it is presented as a large inductance that could limit the fault current. The current sharing/current limiting characteristic of HCSR can meet the requirements of power system for FCL, therefore HCSR can be applied to compose a new type of FCL.

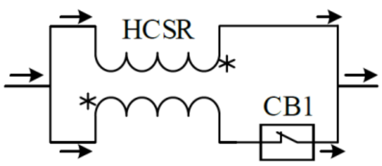

Fig.1 Schematic of FCL based on HCSR

The topology principle of FCL based on HCSR is shown in Figure 1. The FCL based on HCSR composed of

HCSR and a fast mechanical switch. As HCSR consists of two highly coupled windings, the fast mechanical switch is connected in series with a winding of HCSR, thus forming two paralleled branches. In the normal operation condition, the current is proportionally distributed between two branches, and the magnetic field of HCSR's two windings have opposite direction and almost identical value, which means the magnetic flux generated by two windings of HCSR cancel each other out and only exhibit a small leakage inductance to the system. Once fault occurs, the fast mechanical switch in series with one winding of HCSR disconnects at first current zero point, thus HCSR will change role to a current limiting reactor, which could limit the fault current and make sure the main circuit breaker in the system interrupts the limited fault current successfully. The total current and branch current changes during the application of the current limiter are shown in Figure 2. In the normal working condition, the current in two branches is half of the total current. The total current increases sharply when short circuit occurs. Meanwhile, the fast mechanical switch of FCL is disconnected, and one winding of HCSR is put into power system to limit short circuit current.

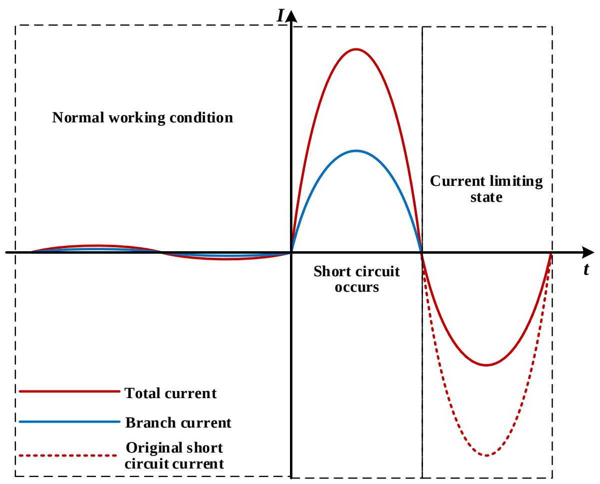

Fig.2 Transformation of current in the FCL based on HCSR

The advantage of topology is that the fast mechanical switch does not need to interrupt the full capacity short-circuit current to achieve current transferring. When the inductance of HCSR two windings is equal, the fast switch only needs to interrupt half of the total short-circuit current. The problem with the topology is that since the two windings of HCSR is tightly coupled, when the fast mechanical switch in series with one winding is turned off, the induced voltage of the disconnected winding exists, which puts big pressure on the insulation design of HCSR, and affects the recovery voltage of fast mechanical switch. As shown in Figure 3, when the fast switch CB1 is disconnected, suppose that the potential at the input end of HCSR is U, and the potential at output end is 0, the highest voltage that needs to be tolerated between encapsulations of HCSR is 2U. When HCSR is applied to high voltage or ultra high voltage power system, the insulation requirement of HCSR is very high. Taking 500kV system as an example, suppose the short circuit current is 90kA and the inductance of single arm in HCSR is 8mH, the highest voltage between encapsulations of HCSR is up to 120kV(RMS), which makes it difficult to design HCSR as two windings of HCSR need to be highly coupled.

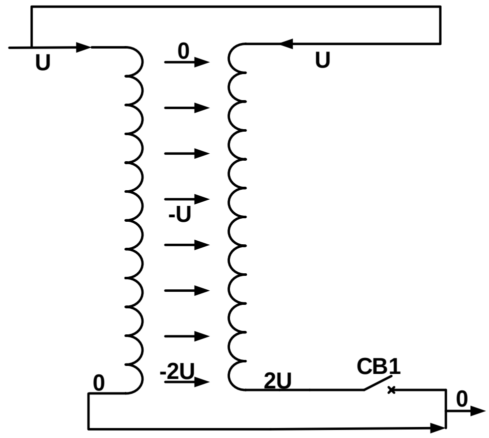

Fig.3 Diagram of potential distribution in HCSR

IMPROVEMENT OF FCL BASED ON HCSR

In order to solve the problems above, an improved FCL topology is proposed as shown in Figure 4. The improved FCL consists of a HCSR and two fast mechanical switches, wherein one arm of the HCSR is connected in series with two fast switches, and then connected in parallel with the other arm of the HCSR. When the fault occurs, the fast mechanical switches (CB1 and CB2) are disconnected at the same time, and the fault current is limited by a winding of HCSR.

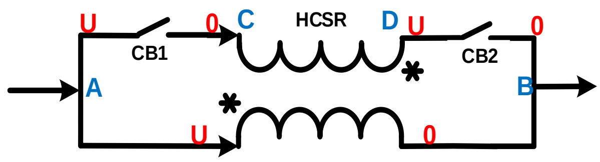

Fig.4 Schematic of the improved FCL based on HCSR

In order to reduce the insulation requirements for HCSR, the way of inlet and outlet of HCSR two-arm windings is adjusted. In this situation, the requirement of withstand voltage between the windings of HCSR is small. As shown in Figure 5, when CB1 and CB2 are disconnected, suppose that the potential at point A is U and the potential at point B is 0, if the voltages across two switches are fully equalized during the breaking process, the potential at point C is 0 and U at point D. Therefore the voltage that needs to be tolerated between encapsulations of HCSR is approximately equal to 0. Compared with the original topology of FCL, the insulation requirement of HCSR has dropped from 2U to 0. Figure 6 shows the longitudinal section of the HCSR with four encapsulations. It can be clearly seen that the encapsulations are substantially equipotential in the horizontal direction.

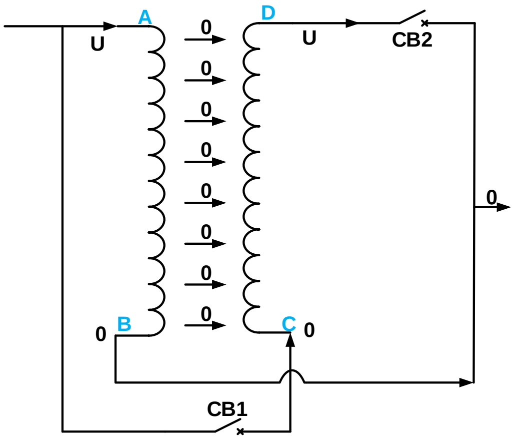

Fig.5 Diagram of potential distribution in the improved FCL

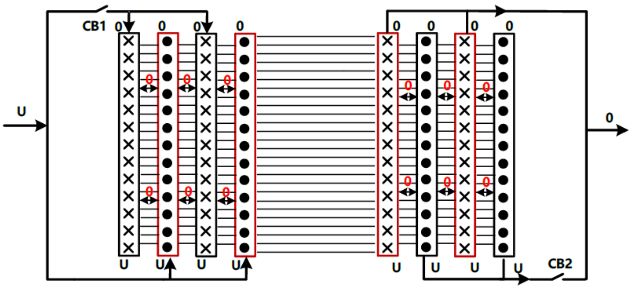

Fig.6 Longitudinal section of the HCSR with 4 encapsulations

The improved FCL topology retains the advantages of current sharing/current limiting characteristics based on HCSR, eliminating the need to transfer full-capacity fault currents, and on the other hand reducing the insulation requirements for HCSR. Focusing on the improved FCL topology, a simulation model is established based on PSCAD-EMTDC to analyze the voltage and current changes of various components under working condition, which can provide reference for the design of FCL based on HCSR.

SIMULATIONS AND RESULTS

The simulation is based on PSCAD-EMTDC, and the ideal circuit breaker model in PSCAD is adopted to simulate the fast mechanical switch. Therefore, the transient recovery voltage (TRV) obtained by the simulation is only related to the parameters of system components. In order to simulate the operating conditions when FCL connected to the 500kV system, firstly the system equivalent circuit model is established[9-10].

Taking a single-phase circuit as an example, suppose short circuit occurs in the load-side terminal of the main circuit breaker in power grid, the equivalent circuit model is shown in Fig. 7. The supply voltage and frequency of the system are set to be 317kV (corresponding line to line voltage of 550kV) and 50Hz respectively, while the short circuit current is set to 90kA. The inductance L_S represents equivalent inductance of the source-side circuit, CB represents the main circuit breaker in power grid, and components in series and parallel composition (R_1, C_1, L_2, R_2, C_2) are to simulate the overvoltage condition during the interruption of fast switches in FCL, which refer to the frequency modulation circuit in synthetic test.

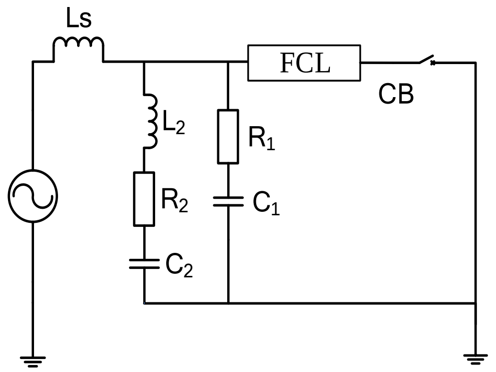

Fig.7 Schematic of single-phase equivalent circuit model

A three-phase equivalent circuit model of 500kV system is established in PSCAD, suppose that the short circuit current is 90kA, the equivalent inductance of the system is 11.23mH, the inductance of each arm in HCSR is 8mH, and the coupling coefficient of HCSR is set to 0.97.

Three-phase short circuit to ground

It is assumed that a three-phase short circuit to ground occurs. The FCL is set to operate at t=0.11s, and the impedance of single arm in HCSR is put into the system. The FCL in B-phase is the first to complete the current transfer and limiting process. The waveform of short-circuit current and the TRV across fast switches in the B-phase FCL are shown in Figure 8.

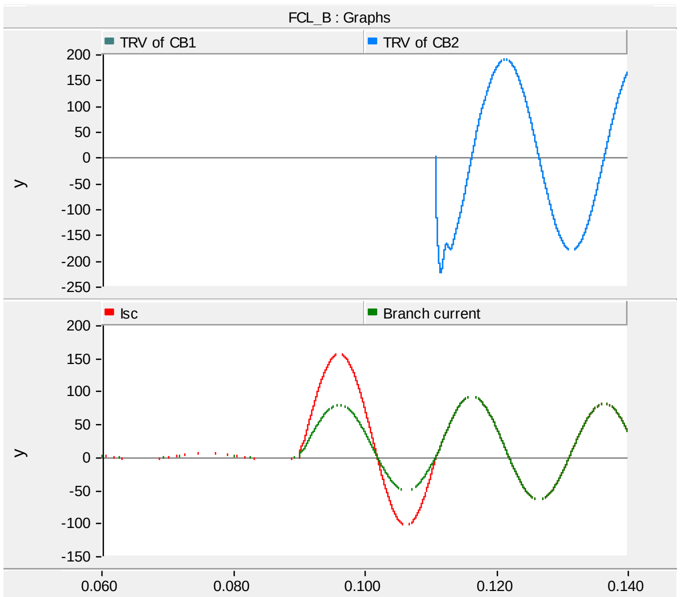

Fig.8 Current and TRV waveform in B-phase FCL

The improved FCL limits the fault current from 90kA to 52kA, which is in line with the expected results. When fault occurs, the fast switches (CB1 and CB2) need to break 45kA short-circuit current to complete current transfer process, and the recovery voltage waveforms of two switches are basically the same. Figure 9 shows the voltage across B-phase FCL, which proves that HCSR exhibits a small leakage inductance before two fast switches disconnect, and change role to limit fault current when fast switches interrupt branch current successfully. Comparing the simulation results with figure 3 and 5, it could be found that the improved FCL based on HCSR uses two fast switches to share the induced voltage caused by the anti-coupling characteristic of HCSR. The peak of TRV and RRRV of two fast switches are basically the same.

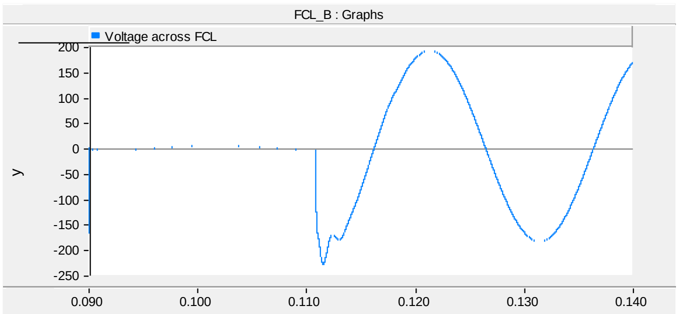

Fig.9 Waveform of voltage across B-phase FCL

Multi-module application of FCL

Since a single fast switch is difficult to meet the TRV requirements in some cases, it is considered to reduce the requirement of breaking capacity for fast switch by connecting multiple modules of FCL in series, which also benefits the design and manufacture of HCSR. As shown in Figure 11, two modules are connected in series with two HCSR and four fast switches. The inductance of single arm in each HCSR is 4mH, and the coupling coefficient is 0.97. As to three-phase short circuit to ground, the simulated current and TRV waveform are shown in Figures 10. The current limiting effect is the same as FCL with 8mH inductance of single arm in HCSR. The recovery voltage waveforms of four fast switches are identical, which successfully reduces the breaking capacity requirement for each switch.

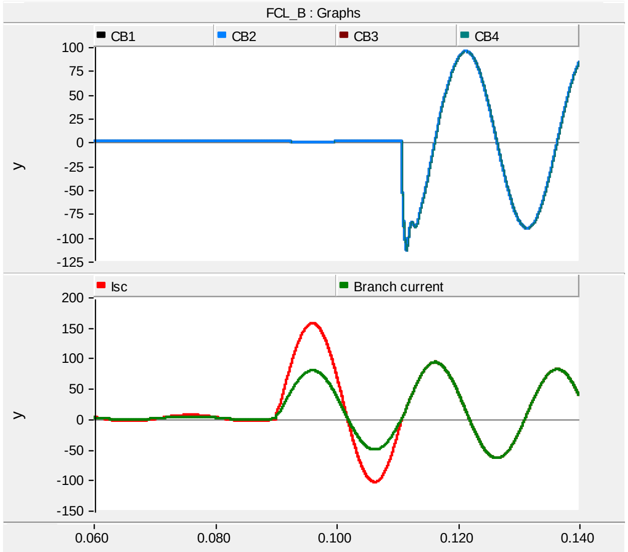

Fig.10 Current and TRV waveform in B-phase FCL

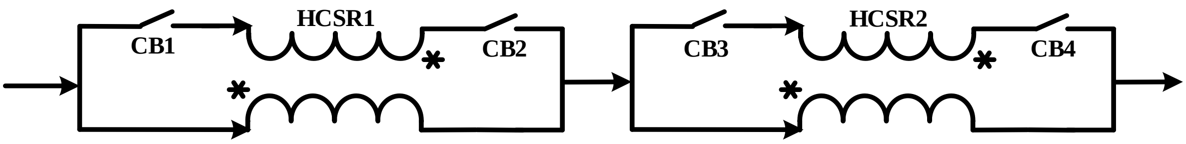

Fig.11 Schematic of two modules in series

CONCLUSION

According to the improved FCL based on HCSR, the equivalent circuit model is established in PSCAD and the current transfer and limiting process is analysed through simulation. It can be concluded that:

1) The improved FCL based on HCSR retains the advantages of HCSR, eliminating the need to transfer full-capacity fault currents, and on the other hand reducing the insulation requirements for HCSR.

2) In the improved FCL based on HCSR, the two fast switches share the effect of HCSR on the recovery voltage caused by induced voltage, which reduces the requirements for fast switches.

3) Since a single fast switch is difficult to meet the TRV requirements in some cases, it is considered to reduce the requirement of breaking capacity for fast switch by connecting multiple modules of FCL in series, which also benefits the design and manufacture of HCSR. Meanwhile, it is also conceivable to complete current transfer process with multiple low voltage levels of fast switches in series.

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