A current compensation type superconducting fault current limiter

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Current compensation type superconducting fault current limiter is a novel topology of FCL, which consists of an equivalent AC current source with a limiting resistor in parallel. It connects power systems in series with a transformer. At normal state, the current of equivalent AC current source is consistent with the system current and the limiter has no effect on the system. But under fault condition, the system current is greater than the current of equivalent AC current source and the limiting resistor takes effect immediately. The application circuit and its control system are presented. Simulation results show that the SFCL can reduce both transient and steady-state fault currents significantly.

INTRODUCTION

Fast growing networks with increasing fault levels require the use of FCL techniques. Many investigations to develop the FCL have been carried out. Recently, superconducting FCL and solid state FCL attract more attentions. In this paper, a new topology of FCL named current compensation type superconducting fault current limiter [1] that combines superconducting technology and power electronic technology is proposed. It is a promising device because of following several features. 1) It is possible to limit the current at once. 2) It can reduce both transient and steady-state fault currents. 3) Low losses and high current reduction rate.

PRINCIPLE

Model

Figure 1 shows principle diagram of a current compensation type SFCL. It consists of an equivalent AC current source with a limiting resistor in parallel and then it connects power systems in series with a transformer.

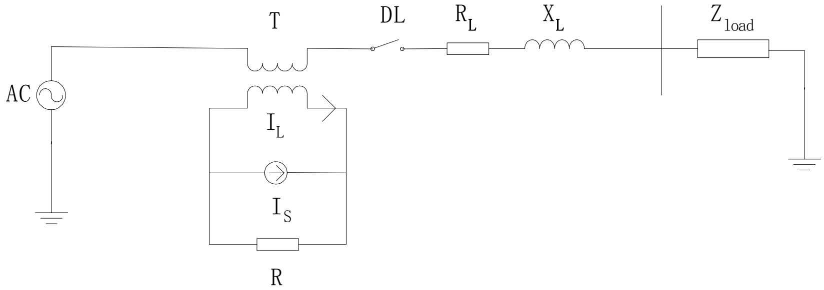


Figure 1 Principle diagram of a current compensation type SFCL

Figure 2 shows circuit diagram of a current compensation type SFCL. A superconducting reactor HTS-L is used because of its advantages such as with a larger inductance, smaller volume and lower losses. The inductance of HTS-L is so large that we can consider the current through the coil to be invariable, which makes it work as an equivalent constant current source. The superconducting reactor and a fully controlled bridge constitute a current source inverter (CSI). Then the CSI is in parallel with a limiting resistor and a transformer.

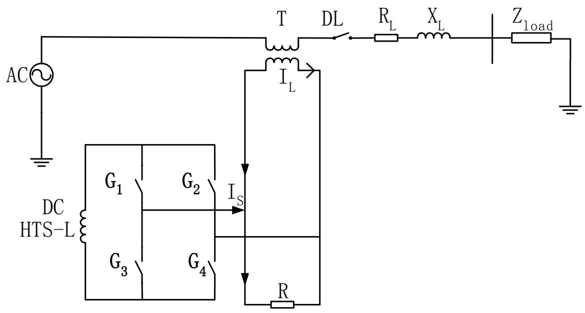


Figure 2 Circuit diagram of a current compensation type SFCL

Operating principle

Figure 3 shows the operating principle scheme of a current compensation type SFCL.

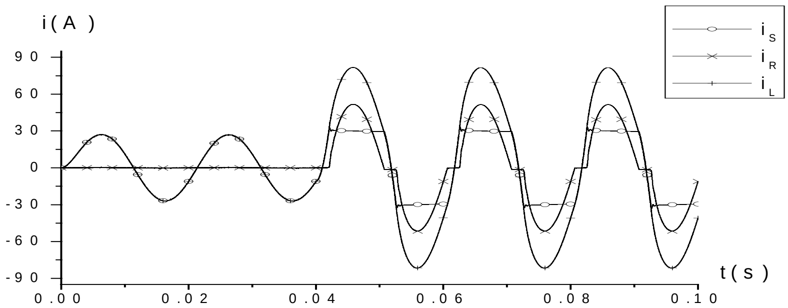


Figure 3 Operating principle scheme of a current compensation type SFCL

The value of superconducting reactor current is set to I_d. I_d is kept larger than the value of normal system current but much smaller than fault system current.

At normal state, the CSI generates equivalent AC current source i_s which is consistent with the system current i_L and there is no current through the limiting resistor (i_R=0). The transformer's secondary winding becomes shorted and the limiter has no effect on the system.

During fault, the peak value of the output current of the CSI is I_d, so I_L becomes greater than I_s and the difference current passes through the limiting resistor. Correspondingly, there is a voltage drop on the transformer and the voltage on R_L and X_L becomes lower, which effectively limits the short current.

Control strategy

Current source inverter has many advantages such as inherent short circuit protection and ruggedness, but received less attentions because of the difficulties associated with gating the switches. In this paper, we use on-line generation of gating signals for the CSI [2]. The control system is shown in Figure 4.

The power switches in the CSI must be operated so as to avoid an open circuit on the dc link or a sudden short circuit on the output capacitor. An alternate way is to add the required shorting pulse to obtain the gating signals. These pulses create a dc bus short through one leg of the inverter whenever either all top or all bottom switches are open.

SIMULATION

Analysis conditions

Simulation studies were carried out with the circuit shown in Figure 4. Each IGBT was in series with a diode. The short circuit was supposed to occur at the end of the transmission line. Table 1 shows parameters for the simulation.

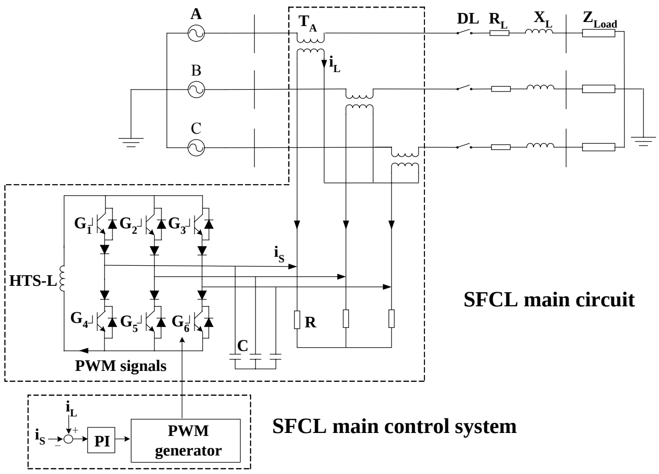


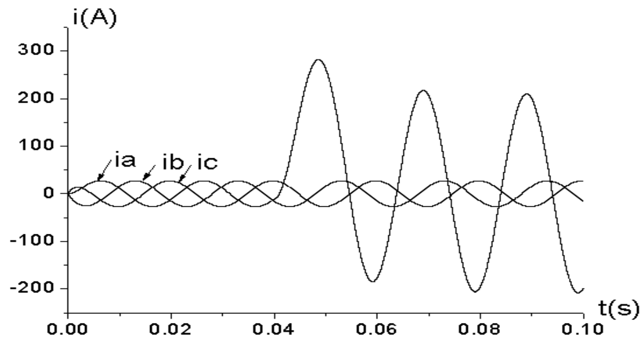
Figure 4 Application circuit and its control system of a current compensation type SFCL

Table 1 System simulation parameters settings

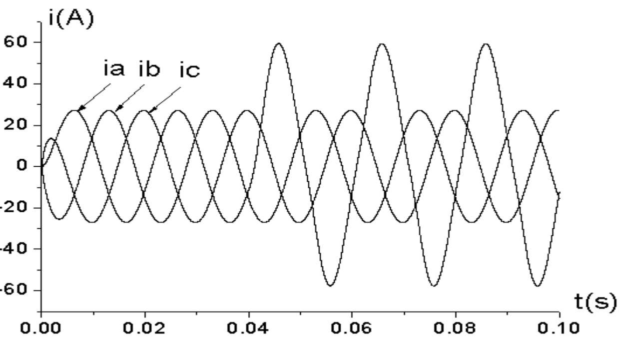
Power supply	220V	System frequency	50Hz
Line resistance	0.47Ω	Line inductance	4.49mH
Load resistance	10Ω	Load inductance	10.468mH
Limiting resistance	5Ω	Filter capacitance	50μF
Initial current of HST-L	30A	HST-L inductance	0.5H

Simulation results

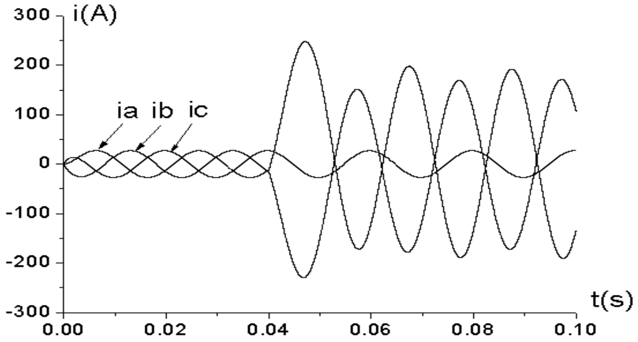
Figure 5 shows the simulation results. Figure 5(a) shows a single-phase-to-ground short circuit without SFCL. Figure 5(b) shows a single-phase-to-ground short circuit with SFCL. Figure 5(c) shows a phase-to-phase short circuit without SFCL. Figure 5(d) shows a phase-to-phase short circuit with SFCL. Figure 5(e) shows a three-phase short circuit without SFCL. Figure 5(f) shows a three-phase short circuit with SFCL.



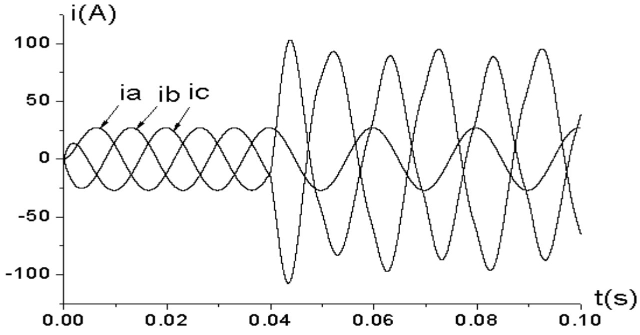
(a) Single phase-to-ground short circuit without SFCL



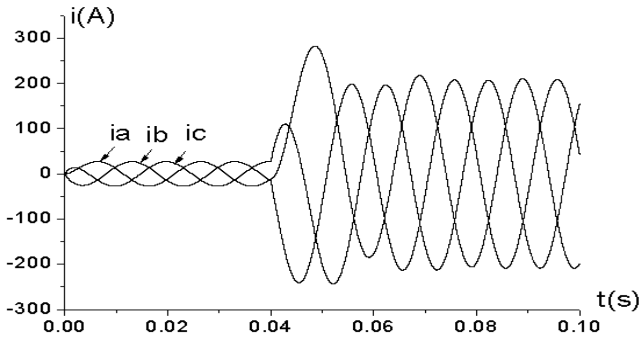
(b) Single phase-to-ground short circuit with SFCL



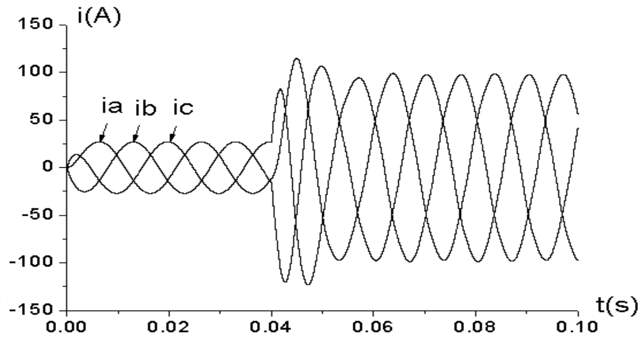
(c) Phase-to-phase short circuit without SFCL



(d) Phase-to-phase short circuit with SFCL



(e) Three-phase short circuit without SFCL



(f) Three-phase short circuit with SFCL

Figure 5 Simulation results of different faults in the three-phase system

We easily noticed that there was a great contrast between the short circuit currents with and without SFCL. The current compensation type SFCL could limit the faulted current to a desired level. The fault current reduction rate of the first peak short circuit current was between 50% and 80%.

For example, three-phase system worked without SFCL. At normal state, the peak current of A phase was 27.1A, THD was 1.8%. When a single line-to-ground short circuit happened, the first peak fault current of A phase was 281A and the steady-state fault current was 209A. By contrast, three-phase system worked with SFCL. The normal peak current of A phase is 27A, THD was 1.95%, The first peak fault current of A phase was limited to 59.5A and the steady-state fault current was limited to 57A. The current loss was only 0.37% and the harmonics that came from the CSI was very small when the system operated normally. The first peak fault current reduction was 79% and the steady-state fault current reduction was 73%. All above showed that the SFCL had a good current limiting characteristic.

CONCLUSION

It is verified that the current compensation type SFCL is an efficient device for reducing fault current under different fault conditions by the analysis and simulation in the paper. The superconducting characteristics have been used in the current compensation type SFCL, which produce low energy losses at normal state. With the development of superconducting material and power electronics, it will become a promising application device in the future.

REFERENCES

1. Caihong Zhao, Liye Xiao, Liangzhen Lin, A Kind of Circuit of FCL, Patent Application Number, 021568251

2. Espinoza, J. and Joos, G., On-line Generation of Gating Signals for Current Source Converter Topologies, IEEE International Symposium (1993), 674-678