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# EMTDC Modeling Method of DC Reactor type Superconducting Fault Current Limiter

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***Abstract*-- As electric power systems grow to supply the increasing electric power demand, short-circuit current tends to increase and impose a severe burden on circuit breakers and power system apparatuses. Thus, all electric equipment in a power system has to be designed to withstand the mechanical and thermal stresses of potential short-circuit currents. Among current limiting devices, Fault Current Limiter (FCL) is expected to reduce the short-circuit current. Especially, Superconducting Fault Current Limiters (SFCL) offer ideal performance: in normal operation the SFCL is in its superconducting state and has negligible impedance, in the event of a fault, the transition into the normal conducting state passively limits the current. The SFCL using high-temperature superconductors offers a positive resolution to controlling fault-current levels on utility distribution and transmission networks. This study contributes to the EMTDC based modeling and simulation method of DC Reactor type SFCL. Single and three phase faults in the utility system with DC reactor type SFCLs have been simulated using EMTDC in order to coordinate with other equipments, and the results are discussed in detail.**

## 1. INTRODUCTION

In electric power systems short circuits might be caused by aged or accidentally damaged insulation, by lightning stroke on overhead line, or by other unforeseen events. The short-circuit current can exceed the normal current by up to 100 times, and will lead to high mechanical and thermal stresses. All components of the power system have to be designed to withstand these stresses for a certain time period, which is usually determined by the time needed for circuit breakers to interrupt the fault currents. The higher the prospective fault currents, the higher will be the cost for all equipment, especially for the breakers. In all cases the resulting current surges can easily damage transmission line and substation components. Under certain conditions faults can destabilize a regional power grid producing blackouts extending over several regions [1-2].

Conventional alternative methods for fault current limiting include; replacing the existing circuit breakers and other equipments with higher short circuit ratings, splitting and reconfiguring the system and consequently reducing the operational flexibility and system stability; using cost ineffective transformers with higher short circuit impedance; using series reactors which incur losses during the normal system operation; and using single operation devices, such as fuses and pyrotechnic current limiters, which have to be replaced after each operation [3].

These measures, however, are inconsistent with the increasing demand for higher power quality, which asks for strongly interconnected grids with low impedances.

To date, utilities have been lacking an affordable fault current limiter that can not only automatically detect and limit fault currents, but also intelligently disconnect itself anytime current flows do not exceed those required for normal operation of the loads. Traditionally, large resistors or series reactors have been used to limit short circuit currents to safe levels. Unfortunately, these brute-force fixes limit current not only during disturbances, but also under normal operating conditions causing unnecessary losses and poor regulation, thus weakening the system [4].

An ideal FCL has to have characteristics of zero resistance or zero impedance at normal operation, no power loss during normal operation as well as current limitation, large impedance under fault condition, a quick appearance of impedance at an occurrence of faults, fast recovery to normal state after a fault removal, reliable current limitation at the defined fault current and low voltage operation besides reliability and cost performance [5].

The SFCLs are corresponds to the ideal FCLs. There is a big demand for the SFCLs, which under normal operation have negligible influence on a power system, but in case of a fault will limit the fault current to a value close to the normal current. Attempts to realize the SFCLs have been based on fast current interruption.

The SFCLs with High Temperature Superconductor (HTS) are expected to be introduced into electric power system as an effective countermeasure for the conventional alternative methods. With respect to cost, reliability and compatibility, the SFCLs have to fulfill the same requirements as conventional devices. They must be cost effective, as reliable as conventional devices for limiting short-circuit currents and compatible to existing power systems [6].

Before the commercialization of the SFCL, at first, the simulation study of the SFCL in the hypothetical power system is needed. In this paper, DC reactor type of SFCL modeling and simulation methods using PSCAD/EMTDC is presented. Single and three-phase faults in the utility system with DC reactor type SFCL have been simulated using PSCAD/EMTDC in order to coordinate with other equipments, and the results are discussed in detail.

## 2. PRINCIPLE OF DC REACTOR TYPE SFCL

Fig.1 shows the specific diagram of the single-phase dc reactor type SFCLs. A high temperature superconducting coil is used and connected in the diode bridge. In the case of a line fault, the diode bridge switches it and the fault current flows through the dc reactor coil. Thus, the increase rate of a fault current can be limited to a determined value by the inductance of this coil. The load current is usually flowing through the dc reactor coil and the current change is limited by the coil inductance.

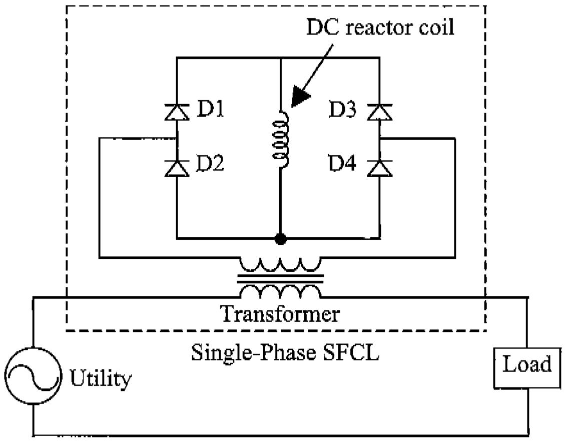


Fig. 1. Specific diagram of single DC reactor type SFCL

Fig. 2 represents the specific diagram of three-phase DC reactor type SFCLs. In this diagram, a three-phase transformer is inserted in series between utility and load. Three-phase power converter is incorporating with one dc reactor coil. It is possible to limit a fault current by only one superconducting coil. At the occurrence of a line to ground fault, the primary current in the transformer will increase to fault current and the primary voltage will rise to the line voltage. The secondary currents and voltages will also increased to the values corresponding to the transformer ratio.

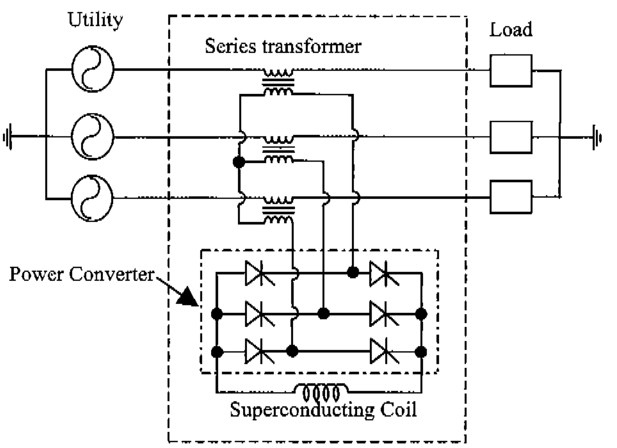


Fig. 2. Specific diagram of three-phase DC reactor type SFCL

The necessary DC reactor inductance for a fault current limitation is calculated as follows. The DC reactor coil current and the DC reactor voltage are defined $I_d$ and $V_d$, and the primary line voltage and current are defined by $V_s$ and $I_s$ respectively.

$$I_d = \sqrt{2} a I_s \tag{1}$$

$$V_d = \frac{3\sqrt{2}}{a\pi} V_s \tag{2}$$

Neglecting the short-circuit impedance and resistance of the circuit across the reactor, after the occurrence of a fault, $L$ is coil inductance

$$L\frac{di}{dt} = V_d \tag{3}$$

The reactor current increase after the fault per cycle is given by

$$\delta_i = \frac{3\sqrt{2}V_s}{\pi f L} \tag{4}$$

Assume that the fault current has to be interrupted within $n$ times that of steady-state current in $m$ cycles after the occurrence of a fault

$$I_d + m\delta_i \le n I_d \tag{5}$$

The necessary inductance L of the dc reactor can be derived from (1) ~ (5).

$$L \ge \frac{3mV_s}{\pi(n-1)fI_s} \tag{6}$$

Substituting $V_s$ and $I_s$ and frequency $f$ into (6), respectively, then the necessary coil inductance is obtained as

$$L \geq \frac{0.105m}{n-1} \ [H] \tag{7}$$

Equation (7) gives the necessary inductance of the reactor coil to limit the fault current to less than $n$ times within $m$ cycles, where $n$ is the ratio of fault current to normal current, and $m$ is interruption time [7].

## 3. SIMULATION OF THREE-PHASE DC REACTOR TYPE SFCL

Table 1 shows the simulation parameters. For this simulation, the utility voltage of 6.6 [kV], load resistance of 3.81 [Ω] and the ratio of transformer 1:1 are used, respectively.

DC reactor coil capacity is calculated by (7), and it is 52.5 [mH] ($m = 4$, $n = 9$).

Fig. 3 depicts the fault current and DC reactor coil current during the fault. The result shows that the dc reactor coil current increases at certain rate after fault inception. The peak of the fault current coincides with the inductor current and both have the same rising rate.

TABLE I Simulation parameters

| | |
|---|---|
| DC reactor coil | 52.5 [mH] |
| Ratio of transformer | 1:1 |
| Fault resistance | 0.1 [Ω] |
| Source Voltage | 6.6 [kV] |
| Source Current | 1000 [A] |

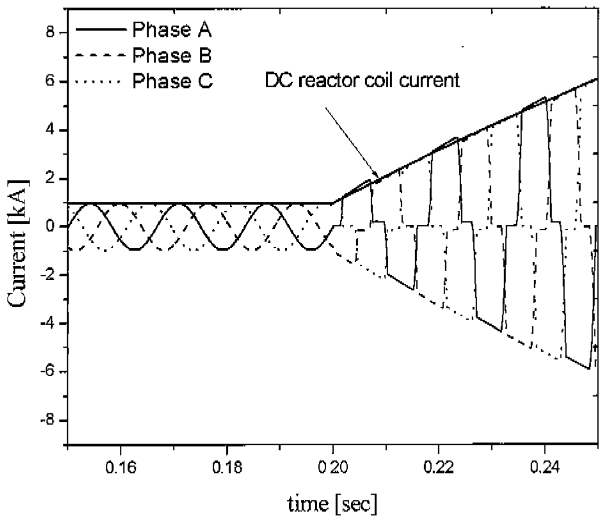
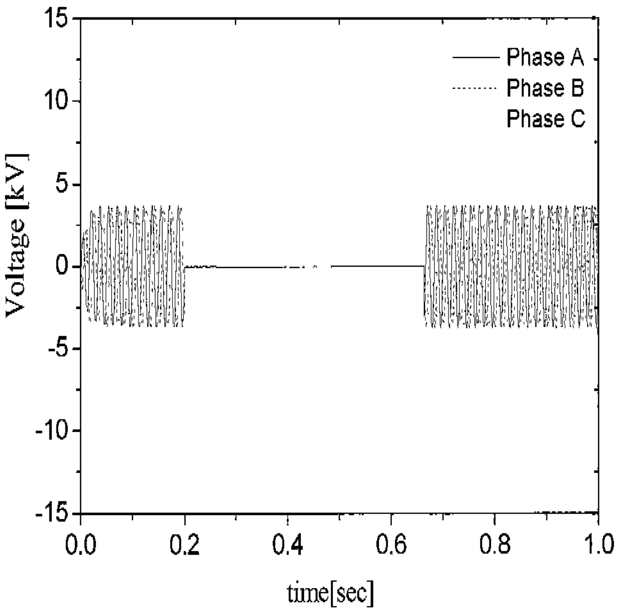


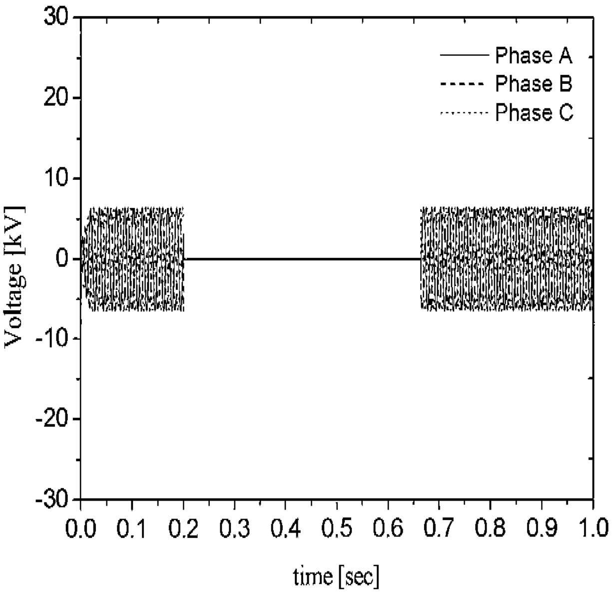
Fig. 3. Current waveforms during the fault

Fig. 4 shows the long-term simulation result of the voltage and the current waveforms due to circuit breaker operation of the reclosing. In this case, the fault occurred at 0.2 [sec]. After 4 cycles, the circuit breaker was opened, and reclosed at 0.664 [sec].

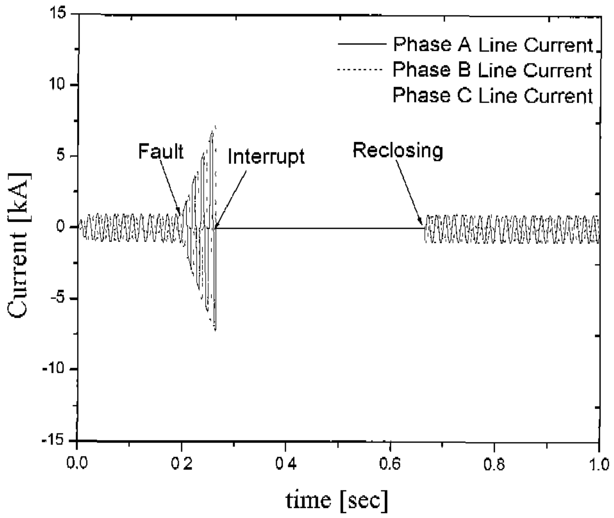
Fig. 5 shows the DC reactor coil current and line current. The line current increases due to the fault, and the DC reactor coil current increases with the same shape. After the circuit breaker is opened at 0.264 [sec], the inductor current remains at higher value and slowly decreases to the steady state value.



(a) Line-Line Voltage



(b) Line-Line Voltage (RMS)



(c) Line Current

Fig. 4. Voltage and current waveforms for the simulation period

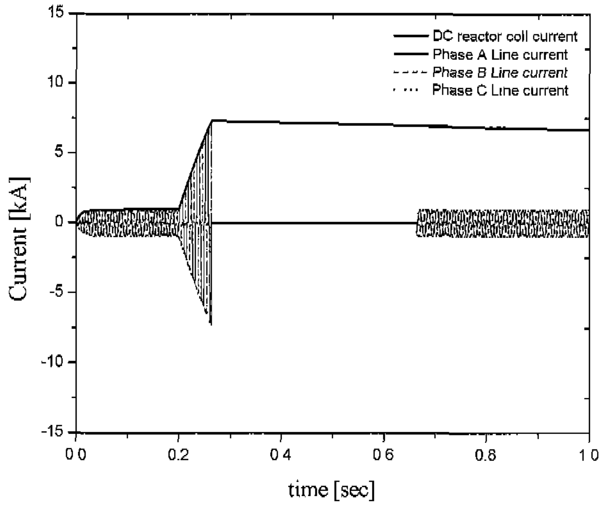


Fig. 5. DC reactor coil current and line current

## 4. CONCLUSIONS

In this study, reasonable and valuable test results of DC reactor type SFCL connected to the utility grid are obtained using PSCAD/EMTDC modeling and simulation, which means that this work contributes to the modeling and simulation method of DC reactor type SFCL. The effectiveness of the modeling and simulation has been demonstrated through the single and three phase fault in the utility system with DC reactor type SFCLs and the results are discussed in detail.

## ACKNOLEDGEMENTS

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