pISSN 1229-3008 eISSN 2287-6251
Progress in Superconductivity and Cryogenics
Vol.23, No.3, (2021), pp.51~54
https://doi.org/10.9714/psac.2021.23.3.051

Operating characteristics of a superconducting DC circuit breaker connected to a reactor using PSCAD/EMTDC simulation

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(Received 26 February 2021; revised or reviewed 5 July 2021; accepted 6 July 2021)

Abstract

The DC system has less power loss compared to the AC system because there is no influence of frequency and dielectric loss. However, the zero-crossing point of the current is not detected in the event of a short circuit fault, and it is difficult to interruption due to the large fault current that occurs during the opening, so the reliability of the DC breaker is required. As a solution to this, an LC resonance DC circuit breaker combined a superconducting element has been proposed. This is a method of limiting the fault current, which rises rapidly in case of a short circuit fault, with the quench resistance of the superconducting element, and interruption the fault current passing through the zero-crossing point through LC resonance. The superconducting current limiting element combined to the DC circuit breaker plays an important role in reducing the electrical burden of the circuit breaker. However, at the beginning of a short circuit fault, superconducting devices also have a large electrical burden due to large fault currents, which can destroy the element. In this paper, the reactor is connected to the source side of the circuit using PSCAD/EMTDC. After that, the change of the fault current according to the reactor capacity and the electrical burden of the superconducting element were confirmed through simulation. As a result, it was confirmed that the interruption time was delayed as the capacity of the reactor connected to the source side increased, but peak of the fault current decreased, the zero-crossing point generation time was shortened, and the electrical burden of the superconducting element decreased.

Keywords: superconducting fault current limiter, DC circuit breaker, LC resonance, reactor capacity

1. INTRODUCTION

As the DC system gradually increases, the reliability of the DC circuit breaker is required. The DC system is divided into HVDC(High Voltage Direct Current), MVDC(Medium Voltage Direct Current), and LVDC(Low Voltage Direct Current). HVDC and LVDC technologies are commercially available, but MVDC technology is still actively developing [1]. In addition, it is also important to develop the most suitable DC circuit breakers used in the system MVDC [2]. Unlike the AC system, the DC system has difficulty in interruption because the fault current does not pass through the zero-crossing point in case of a short circuit fault, and various DC circuit breaker technologies have been proposed so far [3].

In this paper, a simulation was performed using a Superconducting DC circuit breaker. It is combined SFCL(Superconducting Fault Current Limiter) to the LC resonance DC circuit breaker. The superconducting LC resonance DC circuit breaker limits the initial fault current by using the quench resistance of SFCL. After that, the fault current passes through the zero point under the influence of the LC resonance and then interruption. SFCL is subjected to strong stress by the initial fault current, which may lead to device destruction, making maintenance difficult. To solve such a problem, a reactor is connected of the source side to limit the rapid rise of the initial fault current to protect SFCL. Therefore, PSCAD / EMTDC simulation was used to change the reactor capacity connected to the source side and compare and analyze the electrical burden on the SFCL and the circuit breaker in the event of a short circuit according to the stepwise change.

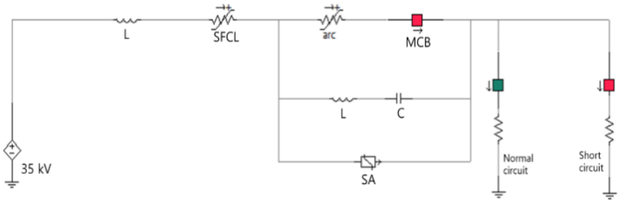

Fig. 1. Circuit diagram (PSCAD/EMTDC).

2. SIMULATION

2.1. Superconducting DC circuit breaker

Superconducting DC circuit breaker allows current to flow without loss in normal state, and in case of falut occurs, the fault current can be interrupted by the quench resistance of the superconductor and LC resonance. In addition, the internal circuit of LC resonant DC circuit breaker is composed of MCB(Mechanical Circuit Breaker), LC circuit, SA(Surge Arrester) in parallel.

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Fig. 1 is a circuit diagram used for simulation. The quench resistance of the superconducting DC circuit breaker used in the simulation can be obtained through equation (1) with data obtained through experiments [4]. The maximum resistance of SFCL is 1.0 Ω and the critical current is set to 2 kA, so that when the fault current flows over 2 kA, the SFCL generates resistance. Equation (2) is the Mayr's arc model of the MCB.

$$R_{SFCL}(t) = \begin{Bmatrix} 0 \\ R_m \sqrt{\left[1 - \mathrm{EXP}\left(-\frac{t}{T_{SC}}\right)\right]} \end{Bmatrix} \begin{matrix} (t<t_{quenching}) \\ (t_{quenching}<t) \end{matrix} \tag{1}$$

$R_{SFCL} = SFCL\ resistance$ $R_m = maximum\ resistance$
$T_{SC} = time\ constant\ for\ displacement$
$t = time\ to\ quenching$

$$\frac{1}{g_m}\frac{dg_m}{dt} = \frac{1}{\tau_m}\left(\frac{u_{arc} \cdot i_{arc}}{P_0} - 1\right) \tag{2}$$

$g_m = arc\ conductance$ $\tau_m = arc\ time\ constant$
$u_{arc} = arc\ voltage$ $i_{arc} = arc\ current$
$P_0 = arc\ power$

2.2. Modeling

The impedance of the reactor connected to the source side is affected by frequency and inductance as shown in equation (3). Since there is no frequency in direct current, the impedance becomes zero and the current flows without loss. When a short circuit fault occurs, the initial fault current is limited by generating a back electromotive force as shown in equation (4) in proportion to the rapidly increasing fault current. The current and voltage flowing through the inductor can be obtained from equation (5). After that, resistance in SFCL can be explained from equation (1), it limited the fault current and creating a zero-crossing point with the resonance circuit and then MCB is opened to complete the interruption [5].

Fixed values are source voltage, SFCL quench time, MCB operation time, LC resonance circuit value, and fault current occurrence time. The variable value is the capacity value of the reactor connected to the source side.

Table I shows the settings applied to the simulation. The range of MVDC is from 1.5 kV to 100 kV DC voltage. The source voltage was set to 35 kV, and the value of the LC resonance circuit was set to 0.1 mH and 500 μF. In addition, A delay time of 0.01 s was considered for the MCB. The source side reactor capacity was changed from 1 to 20 mH to observe the interruption characteristics.

$$X_L = 2\pi f L \tag{3}$$

$$e = -L\frac{di}{dt} \tag{4}$$

$$I = \sqrt{2}i,\ V = L\frac{di}{dt} \tag{5}$$

2.3. Result and Analysis

Table II shows the detail names of the curves in the graphs of Fig. 2 ~ Fig. 4

Fig. 2 is a graph of voltage and current when the reactor capacity of the source side is 1 mH.

TABLE I
SETTINGS APPLIED TO THE SIMULATION.

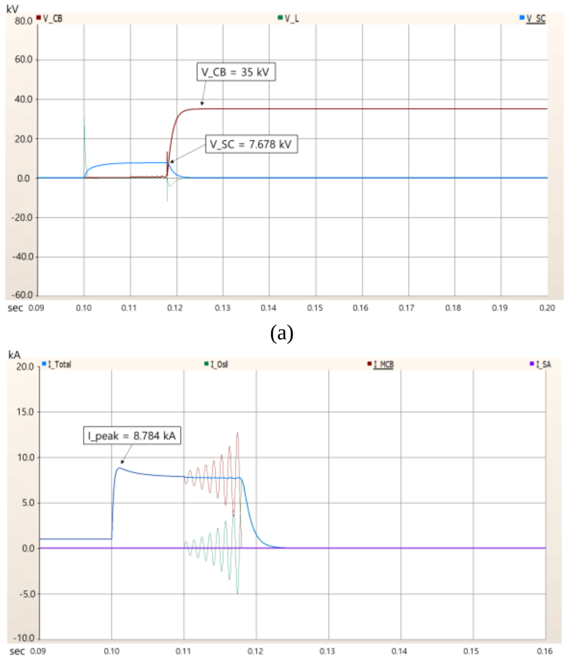
Source voltage	Resonance circuit setting value	Reactor capacity
35 kV	L = 0.1 [mH], C = 500 [μF]	L = 1 ~ 20 [mH]

TABLE II
DETAIL NAMES OF THE CURVES IN THE GRAPHS.

	Full name
V_L	Reactor voltage of source side
V_SC	SFCL Voltage
V_MCB	MCB Voltage
I_Total	Fault current
I_Osil	LC resonant current
I_ MCB	Current flowing in MCB
I_SA	Current discharged to SA

TABLE Ⅲ
RESULT TABLE ACCORDING TO REACTOR CAPACITY CHANGE.

	1 [mH]	5 [mH]	10 [mH][	15 [mH]	20 [mH]
SFCL Voltage [kV]	7.67	7.66	7.66	7.65	7.57
MCB Voltage [kV]	35.00	42.64	54.28	63.74	71.55
Fault current [kA]	8.78	8.08	7.84	7.69	7.61
Zero-crossing point time [s]	-	0.0210	0.0216	0.0221	0.0226
Interruption time [s]	0.0243	0.0326	0.0529	0.0733	0.0996

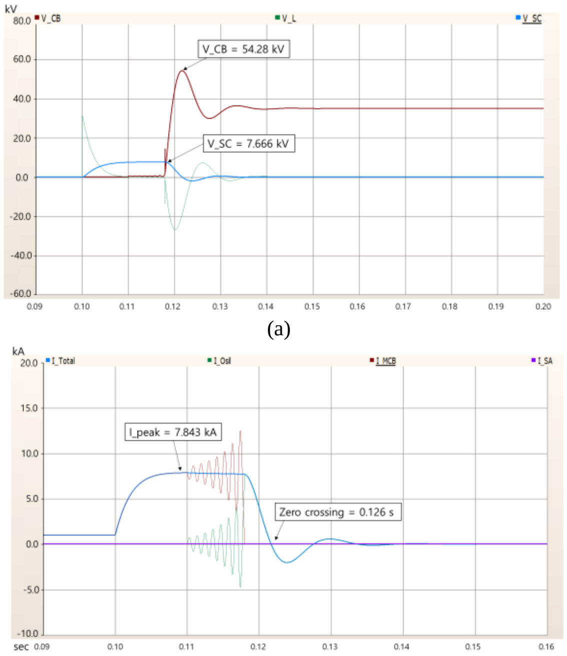


(a)

(b)

Fig. 2. The graphs of simulation for the reactor capacity 1 mH.

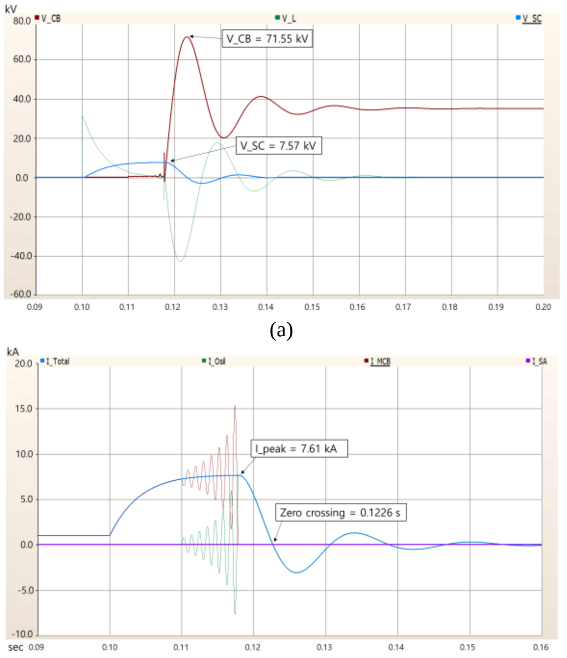
A fault current occurred at 0.1 s, and the rise of the initial fault current was suppressed by the back electromotive force of the source side reactor and the quench resistance of the SFCL.



(a)

(b)

Fig. 3. The graphs of simulation for the reactor capacity 10 mH.



(a)

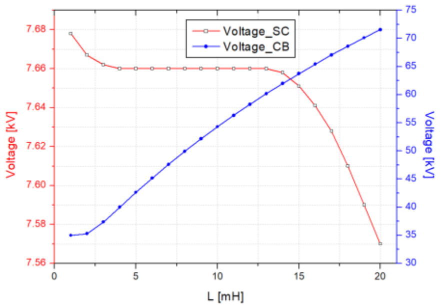
(b)

Fig. 4. The graphs of simulation for the reactor capacity 20 mH.

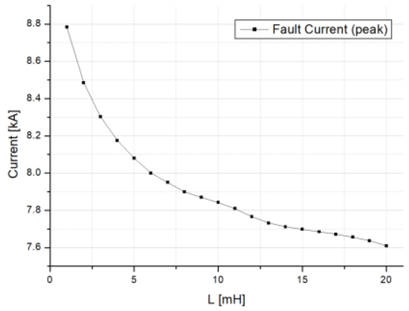
Fig. 2 (a), the maximum of about 7.67 kV was applied to the SFCL and the maximum of about 35 kV was applied to the MCB.

Fig. 2 (b), the maximum fault current was about 8.78 kA, and the interruption time was about 0.0243 s. When the reactor capacity was 1 mH, the fault current did not cross the zero point.

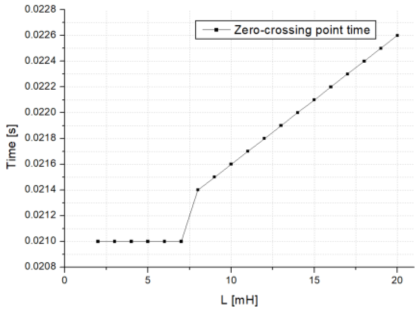
Fig. 3 and Fig. 4 are graph of voltage and current when the source-side reactor capacity is 10 mH and 20 mH.



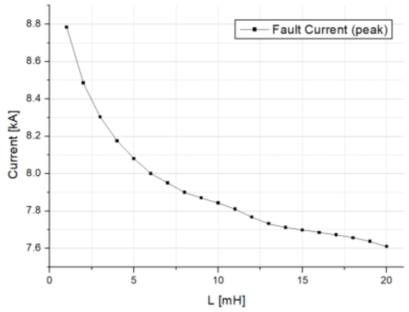
(a) Graphs of the Superconductor Voltage and Breaker Voltage



(b) Graphs of the fault current



(c) Graphs of the zero-crossing point time



(d) Graphs of the interruption time

Fig. 5. Graphs according to the change in reactor capacity on the source side.

Table Ⅲ shows the simulation results of interruption according to the change in reactor capacity. Voltage and current are the peak values.

Fig. 5 shows the graph as the reactor capacity of the source side changes from 1 mH to 20 mH. Fig. 5 (a) shows graph of SFCL voltage and MCB voltage according to reactor capacity change. As the source side reactor capacity increased, the voltage applied to the SFCL decreased. This is because as the capacity of the reactor connected to the source side increases, the back electromotive force increases according to Equation (4), thereby suppressing the rise of the fault current. However, the voltage applied to the MCB increased. This is the transient voltage caused by the energy release of the reactor when shutting off. Fig. 5 (b) shows the graph of the peak current during a short circuit fault. As the reactor capacity of the source side increased, back electromotive force was generated according to the change of the fault current according to equation (4), and the peak current gradually decreased in case of a short circuit fault. Fig. 5 (c) and (b) shows the generation time of the zero-crossing point and time of the interruption completion according to the reactor capacity change. As the capacity of the source-side reactor increased, the time at which the zero-crossing point occurred was delayed. This is because the quench time of the superconductor changes as the fault current rises slowly. In addition, the interruption time was delayed due to the generation of back electromotive force and transient voltage for the LC resonance current.

3. CONCLUSION

Superconducting DC circuit breaker is a combination of LC resonance DC circuit breaker and SFCL. SFCL has a large electrical burden due to rapid resistance generation due to quenching during a short circuit fault. To solve this problem, the reactor was connected of the source side using PSCAD/EMTDC simulation, and the electrical burden according to the reactor capacity change was analyzed. As the reactor capacity increased, the maximum value of the voltage applied to SFCL and the initial fault current decreased. However, the time to generate the zero-crossing point of the fault current was delayed and the interruption time was delayed due to the generation of back electromotive force and transient voltage for the LC resonance current. The generation time of the zero-crossing point is related to the quench time of the superconductor.

The superconducting DC circuit breaker connected to a reactor can reduce the initial current and lower the rating of the circuit breaker. However, the interruption time is delayed due to the transient voltage. This is a problem that needs to be solved for the circuit breaker to be commercialized, and research on ways to suppress the back electromotive force of the reactor is currently in progress.

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