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초전도 코일을 이용한 DC 회로 차단기의 차단 능력 특성

Characteristics of Interruption Ability in DC Circuit Breaker using Superconducting Coil

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Abstract - Development of DC interruption technology is being studied actively for enhanced DC grid reliability and stability. In this study, coil type superconductor DC circuit breaker was proposed as DC interruption. It is integration technology that combined current-limiting technique using superconductor and cut-off technique using mechanical DC circuit breaker. Superconductor was applied to the coil type. In simulation, Mayr arc model was applied to realize the arc characteristic in the mechanical DC circuit breaker. PSCAD/EMTDC had used to model and perform the simulation. To find out the protection range of coil type superconductor DCCB, the working operation have analyzed based on the rated voltage of DCCB. The results confirmed that, according to apply the limiting device, the protection range was increased in twice. Therefore, the probability of failure of interruption has lowered significantly.

Key Words : Direct Current(DC), Direct Current Circuit Breaker(DCCB), Superconductor, Arc, Coil

1. Introduction

Recently, there has been a huge increase in power demand in the world. Not only the steady usage of power apparatus, but also new devices such as smart-phone, electric vehicle have developed as new demands. It is urgent that measures to supply the electric power for the growth are established. There is a method using direct current electricity as a measure of energy measures. Unlike existing AC, DC has a lot of advantages like high stability and low power dissipation. By using this, many researches have been performed as HVDC or MVDC, high voltage transmission, or the dc system for power supply. Also due to environmental issues, renewable energy, such as wind and solar power, is growing rapidly. These kinds of power sources generated in DC is connected to the large system as distributed generation system[1].

Using DC as transmission and distribution has many benefits, but there is a problem to commercialize. The AC current has 2 zero current points in one cycle. This makes the interruption easily. However the DC current has no zero current point, and a high arc voltage appears across the DC circuit breaker when it conducts breaking operation. If a high arc voltage damages the insulation or exceeds the capacity of the breaker's circuit cut off, it can lead to blackout, or in the worst, to the collapse of the entire grid. It is critical to make DC grid because of the variety of DC power sources and DC demanding electric apparatus. To make the grid, DC circuit breaker is the most core technology. Only if the development of the DC circuit breaker should proceed, DC current and the grid will use efficiently and stably[2].

In this study, the coil-typed superconductor DC circuit breaker was proposed to improve the interruption performance of DC current. In prior to construct in real, an in-depth determination of DCCB applying to a superconductor is essential. Accordingly, operation and protection range of DCCB was analyzed depending on each input voltage. EMTDC/PSCAD had used to design the simulation.

2. Coil type Superconductor DC circuit

DC circuit breaker simply consisted of two parts; coil type superconductor for the current limitation and mechanical DC circuit breaker for interrupting the fault current. Fig. 1 represents the configuration of coil type superconductor DC circuit breaker. In normal operation, current flows without any disturbance. When the fault occur, the superconductor limits the initial fault current.

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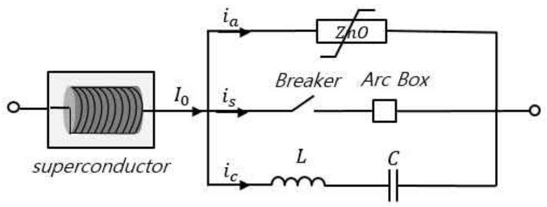

Fig. 1 Configuration of coil type superconductor DC circuit breaker

After the operation, mechanical DC circuit breaker cut off the current with L-C oscillation.

2.1 Superconducting coils

In normal superconducting state, there is no impedance in superconductor. By this reason, power could supply without any electric losses or power burden. Upon the occurrence of a fault, however, when the amplitude of fault current exceeds the critical current of the superconductor, it generates a specific high impedance in a few milliseconds according to their unique characteristic. This behavior is named as quenching. Equation (1) represents the quenching characteristics of the superconductor. The value Rm is the maximum resistance of the superconductor in the quenching state. Tsc is the time constant of the superconductor during transition from the superconducting state to the normal state. To is the time to start the quenching [3].

In coil type superconductor, the constant for Rm= 8Ω and Tsc = 0.75 msec. The reason is the peak resistance value of the superconductor was modeling to be within 2 msec. Fig. 2 represents the coil type superconductor quenching characteristic graph of coil type superconductor [4].

$$\begin{pmatrix} 0 & t_0 > t \\ R_m[1-\exp(-\frac{t-t_0}{T_{sc}})^{1/2} & t_0 \le t \end{pmatrix} \tag{1}$$

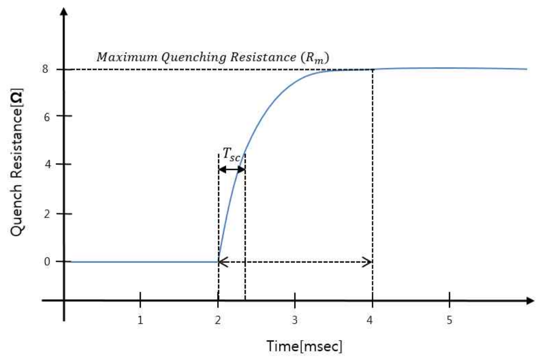

Fig. 2 Coil type superconductor quenching characteristic graph

2.2 Configuration of circuit

The mechanical DC circuit breaker is comprised of 3 circuits; breaking circuit, commutation circuit and absorber circuit.

First, there are mechanical contact and arc box in the breaking circuit. Arc box is placed for arc characteristics in the circuit breaker. As previously stated, DC interruption is usually accompanied with arc. To implement the arc characteristics in the simulation, arc modeling is indispensable. Mayr arc model had used to apply arc box modeling. Coil type superconductor DCCB is aimed to adapt to the DC links between the distributed power systems. This part is suited for high voltage. Mayr arc model has selected to arc model because it is appropriate in high voltage and low current.

Also Mayr assumed that the arc has fixed across-sectional area losing energy only by radial thermal conduction. The Mayr model is suited for modeling of the arc in the vicinity of current zero when the temperature of the plasm is below 8000 K[5]. Arc box was modeled based on equation (2).

$$\frac{1}{g}\times\frac{dg}{dt}=\frac{1}{T_W}\times\frac{u_{\mathrm{arc}}i_s}{p_o}-1 \tag{2}$$

g : Arc conductance, u_{arc} : Arc voltage, i_s : Arc current
T_W : Arc time constant, p_o : Arc power loss

Second, inductance (L) and capacitance(C) are the elements of the commutation circuit. The momentary mechanical contact is opened, the current flows into commutation circuit and induces oscillation. By the function of the oscillation current, zero current could be induced. Equation (3) is the arc current occurred in between the mechanical contact in the breaking circuit.

The arc time constant is 0.3 uF and arc cooling power is 50 MW. The constants for the commutation circuit were set at L = 300 uH and C = 30 uF [6].

$$i_s = I_0\left[1+\exp\left(-\frac{1}{2L}\times\frac{du_{\mathrm{arc}}}{di_s}t\right)\times\sin w_c t\right] \tag{3}$$

At this point, $w_c = \sqrt{1/LC}$.

Lastly, an arrester was placed in the absorber circuit. The residual current was discharged through the arrester. 120 kV of arrester voltage rating was inserted into the simulation [7-8].

3. Simulation Analysis

3.1 Simulation modeling

In this paper, we would like to confirm the protection range of DCCB according to coil type superconductor. Mechanical DCCB were designed by rating voltage of 120 kV. The DC sources that were applied to the simulation were 120 kV, 180 kV and 240 kV in 60 kV interval each. The fault occurred at 1 second after beginning of the simulation, and the fault duration was 0.5 sec. As the circuit breaker had mechanical contacts to operates, accordingly the opening operation would have of 10ms delay time. It works at 1.010 sec. The figures showed that the line resistance was set at 2.5 Ωand load resistance was set at 24.77Ω

3.2 Simulation results

Fig. 3 shows the current characteristics when the applied voltage is 120 kV DC. It shows behaviors of CB with and without coil type superconductor. When the power was applied to the without superconductor, a 4.39 kA steady-state current flowed into the circuit. Through the simulated fault at 1 sec, fault current of 12.6 kA was generated. After 10 msec, mechanical contact in the breaking circuit was operated and oscillation current flowed with commutation circuit. At this moment, oscillation current increased maximum 21.2 kA. It took 13.08 sec for breaking operation. In the end, the residual current discharged through the arrester in 4~5ms. On the other hand, when the DCCB had applied superconductor, fault current was limited to 7.3 kA by quenching operation of superconductivity. After 10ms mechanical circuit breaker worked and whole interruption operation ended in 10.08 msec.

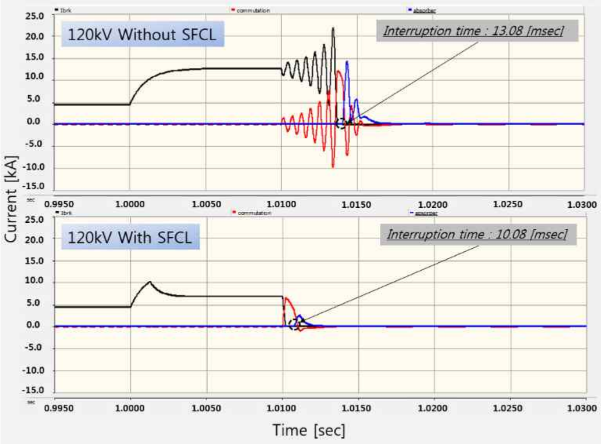

Fig. 3 DC current characteristics between with and without superconductor when the input voltage is 120 kV

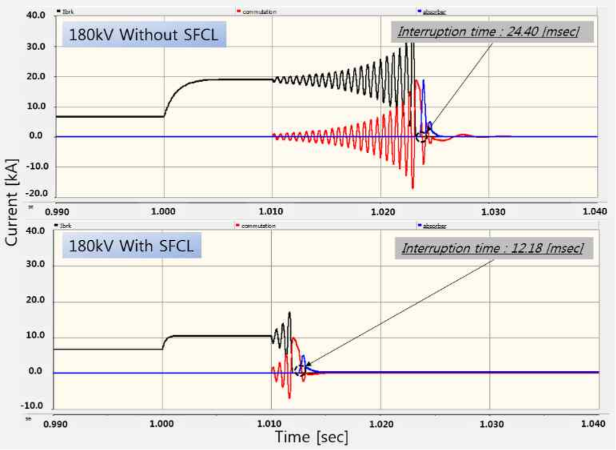

Fig. 4 DC current characteristics between with and without superconductor when the input voltage is 180 kV

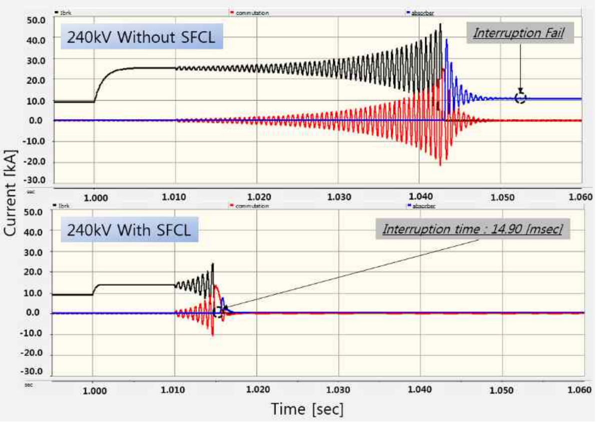

Fig. 5 DC current characteristics between with and without superconductor when the input voltage is 240 kV

Fig. 4 represents the current characteristics in 180kV. At first 6.59 kA of steady state current flowed in normal condition. When the fault occurs, 19.2kA of fault current was generated in the DC circuit breaker which is composed without superconductor. After the operation of the contact, oscillation fault current increased until 35.1kA. And the whole interruption was done in 23.40 msec. When the DC circuit breaker applied a superconductor, the fault current that limited by superconductivity was generated about 10.8 kA. As aforementioned mechanism, it took only 12.18 msec to cutoff the fault current.

Fig. 5 shows characteristics in input voltage of 240 kV. The figure of 8.79 kA steady state current flowed in normal state. In the without superconductor, 25.22 kA of fault current was generated. After it took same mechanism as above-mentioned. In breaking circuit, there is no current flow after oscillation, however, 10.3 kA of current flows through absorber circuit. Indeed interruption had failed.

Whereas in the case with superconductor, 13.7 kA of limited fault current was generated. The whole interruption operation has done in 14.9 msec.

Results show that when the input voltage was 120 kV, fault current was interrupted stably without superconductor. However, when the input voltage was 180kV, the both fault current and interruption time was increased than before. At last interruption has failed in 240 kV. On the other hand, when the superconductor has applied to DC circuit breaker, the whole three cases were cut-off stably within 16 msec.

3.3 Consideration

Fig. 6 shows the interruption time and power burden graph according to rise of input voltage. The power burden represents energy that generates in the circuit breaker which is calculated by integration of the rated voltage and rated current. This is the case of 120 kV rated DC circuit breaker with the coil type superconductor. It could find that although the input voltage had increased, cut-off operation worked in a very high speed. Also it only took 14.9 msec when the input voltage was 240 kV. Therefore protection range could enlarge at least 2 times when superconductor applied. According to AC circuit breaking standard, fault current should cut-off in 3~5 cycles. But the figure represents the interruption time in the full grid with all electric devices. When we check the operation speed of current limiter only, it should have to operate within 8 msec. However, this is the case of DC circuit breaker with coil type superconductor. Therefore the maximum interruption time was computed at 16 msec in this paper. As follows the standard, the figure in the data represents that interruption time is appropriate.

Fig. 6 Interruption time and power burden of coil type superconductor applied DC circuit breaker according to increase of input voltage

When the massive power burden had occurred, the heat generated within the circuit increases and resulted electric breakdown and deterioration as breaker failure. Thus, a stable cut-off criterion was calculated as a point where it would take twice as much power as the initial power burden. At least 4.35 MVA was imposed on the approval of 120 kV. At 240 kV, approximately twice the 8.3 MVA power burden was generated. Therefore, if superconductor applied to 120 kV rated DC circuit breaker, the maximum protection range was calculated at 240 kV that twice as much as the rated.

At last, depending on the maximum resistance and capacity of coil type superconductor, the protection range can be increased.

4. Conclusion

In this study, coil-type superconductor DC circuit breaker was proposed which is combined with coil-type superconductor and mechanical DCCB. Protection range had checked with or without superconductor in the same DCCB capacity.

The result is telling that in the without superconductor DCCB system, the tolerable cutoff voltage of DCCB was within 20 to 30 % of the rated cutoff voltage. However, when the superconductor applied, the range of the protection has enlarged within 150 to 200 %.

If the coil type superconductor DCCB is commercially available in the future, the possibility of blocking failure will be significantly lowered and the DC grid reliability will be enhanced. Further tests are to be demonstrated by actual experiment of coil-type superconductor DCCB.

감사의 글

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