Analysis of Interruption Ability in Coil Type superconductor DC circuit Breaker

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Background

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 be established. DC is the solution. Using DC as transmission and distribution has many benefits yet there is a problem to commercialize. DC current has no zero current point, and a high arc voltage appears across the DC circuit breaker when it conducts breaking operation. 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.

Objectives

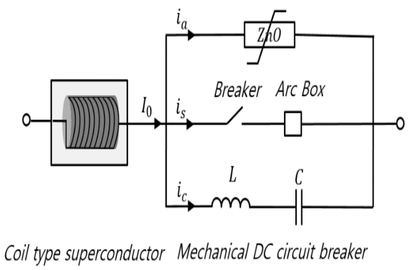
- In prior to construct in real, an in-depth determination of DCCB applying to superconductor is essential.
- operation and protection range of DCCB is analyzed depending on each input voltage.

Conclusion

- This study, coil-type superconductor DC circuit breaker was proposed which is combined model between coil-type superconductor and mechanical DCCB.
- Protection range had checked with or without superconductor in the same DCCB capacity
- The result is telling that the without superconductor DCCB system, the tolerable cutoff voltage of DCCB was within 20 to 30 % of the rated cutoff voltage.
- 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 the failure of the prevention failure will be significantly lowered and the DC grid reliability will be enhanced.

Proposed system

Configuration of Coil Type superconductor DC Breaker

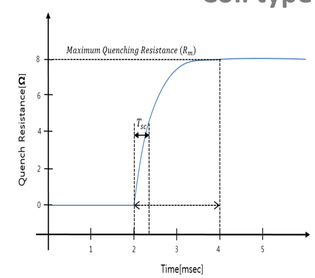


Two parts;
- Coil type superconductor
- Mechanical DC circuit breaker

In normal operation, current flows without any disturbance. When the fault occur, the superconductor limits the initial fault current. After the operation, mechanical DC circuit breaker cutoff the current with L-C oscillation.

Modelling

Coil type superconductor



Quenching Characteristics of Coil type superconductor

- Coil type superconductor was used.
- The constant for Rm = 8 Ω & Tsc = 0.75 msec.
- Peak resistance value of the superconductor was modeling to be within 2 msec.

<Quenching Characteristics>

$$R_{SFCL}(t) = \begin{cases} 0, & (t_0 > t) \\ R_m[1 - exp(-\frac{t-t_0}{T_{sc}})]^{\frac{1}{2}}, & (t_0 \le t) \end{cases}$$

Rm : the maximum resistance of the superconductor in the quenching state
Tsc : the time constant of the superconductor during transition

Mechanical DC circuit breaker

- To implement the arc characteristics , Mayr arc model had used to apply arc modeling.
- The constants for the commutation circuit were set at L = 300 μH and C = 30 μF
- The residual current is discharged through the arrester. 120 kV of arrester voltage rating is inserted into the simulation.

<Mayr Arc Model>

$$\frac{1}{g} * \frac{dg}{dt} = \frac{1}{T_w} * \frac{u_{arc} i_s}{p_0} - 1$$

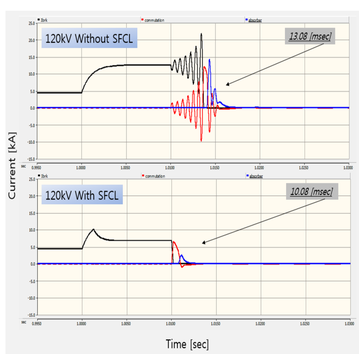
g: Arc conductance, u_{arc} : Arc voltage i_s: Arc current
T_w : Arc time constant p_0 : Arc power loss

<Arc Current>

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

Results

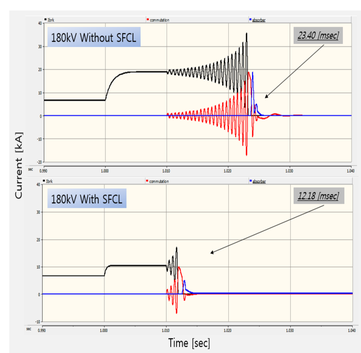
Simulation Results



<Without superconductor>
- Steady state current : 4.39 kA
- Fault current : 12.6 kA
- Interruption time : 13.08 msec

<With superconductor>
- Steady state current : 4.39 kA
- Fault current (Limited) : 7.3 kA
- Interruption time : 10.08 msec

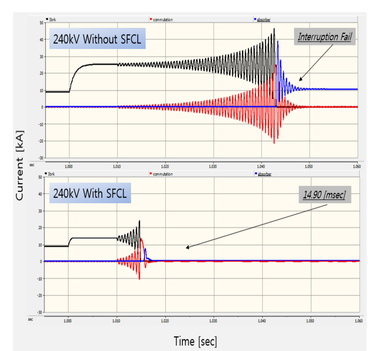
DC current characteristics between with and without superconductor when the input voltage is 120 kV



<Without superconductor>
- Steady state current : 6.59 kA
- Fault current : 19.2 kA
- Interruption time : 23.40 msec

<With superconductor>
- Steady state current : 6.59 kA
- Fault current (Limited) : 10.8 kA
- Interruption time : 12.18 msec

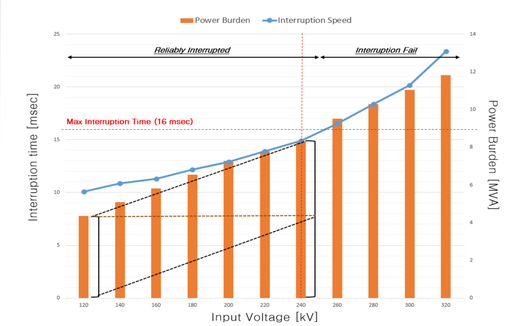
DC current characteristics between with and without superconductor when the input voltage is 180 kV



<Without superconductor>
- Steady state current : 8.79 kA
- Fault current : 25.22 kA
- Interruption time : ***Failed***

<With superconductor>
- Steady state current : 8.79 kA
- Fault current (Limited) : 13.7 kA
- Interruption time : 14.9 msec

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



- It is interruption time and power burden of coil type superconductor applied DC circuit breaker according to increase of input voltage.

As you can check in the figure, protection range was calculated at 240 kV. The interruption speed was 14.9msec and the power burden was 8.3MVA.

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