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Analysis of Interruption Characteristics According to Application Position of Inductor-Combined Superconducting DC Fault Current Limiter

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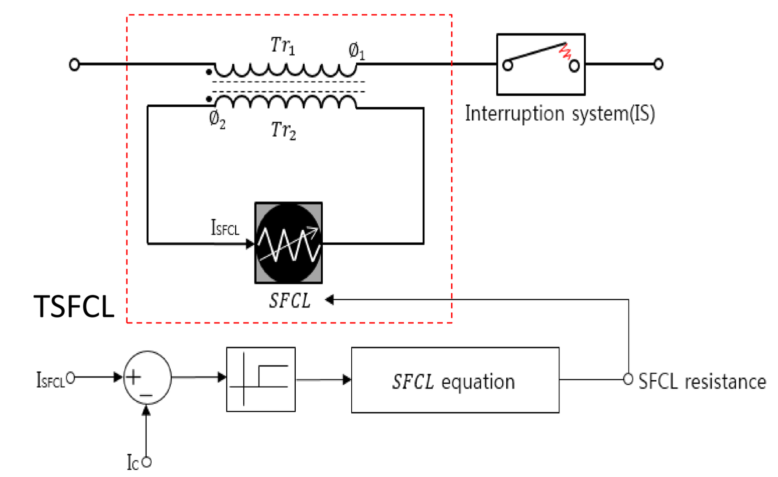
Abstract

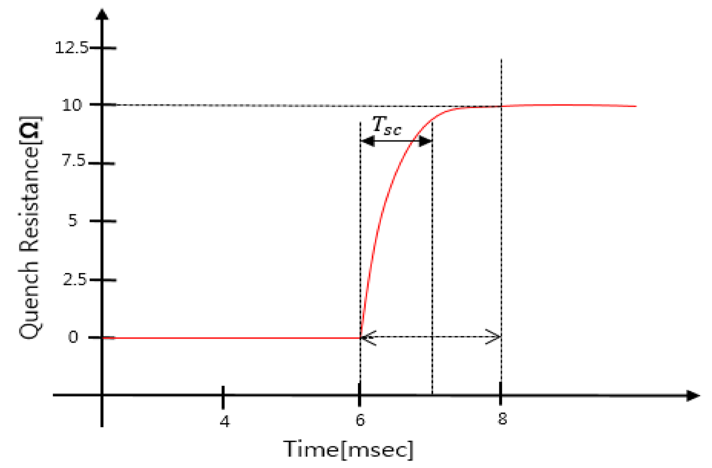
A transformer-type superconducting fault current limiter (TSFCL) interruption system is proposed in this paper. The TSFCL interruption system is a technology that maximizes the interruption function of a mechanical DC circuit breaker using a transformer and a superconducting fault current limiter. In the case of a fault, the proposed system uses TSFCL to limit the maximum value of the fault current. The limited fault current is then introduced into the mechanical DC circuit breaker. As a result, the mechanical DC circuit breaker performs stable and fast. The DC test circuit and TSFCL interruption system were designed using PSCADTM/EMTDCTM. In addition, the TSFCL interruption system was applied to the DC test circuit to analyze its current-limiting and interruption operation characteristics. The simulation results showed that the TSFCL interruption system interrupted the fault current in a stable and fast manner when a fault occurred. The current-limiting rate of the TSFCL interruption system was approximately 62.5%, and the interruption time was less than 16 ms.

TSFCL(Transformer-type Superconducting Fault Current Limiter) interruption system

A. TSFCL



TSFCL interruption system circuit diagram



Characteristics of superconducting fault current limiter applied to TSFCL

- TSFCL is a combination of magnetic flux change and superconducting fault current limiter technology.
- TSFCL consists of a transformer and a superconducting fault current limiter.
- Normal state
  Transformer and SFCL operate as lossless devices.
  <Because the Frequency is zero>
- Fault state
  Current flows through the transformer secondary coil
  Operation of SFCL and secondary coil current is limited
  Primary coil current limit with secondary coil current limit

$$a = \frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{I_2}{I_1} \quad (1)$$

a = turns ratio
N_1 = primary winding, E_1 = primary voltage, I_1 = primary current
N_2 = secondary winding, E_2 = secondary voltage, I_2 = secondary current

$$X_L = 2\pi f L[\Omega] \quad (2)$$

X_L = reactance, f = frequency, L = inductance

$$E = n\frac{\Delta\Phi}{\Delta t}[V] \quad (3)$$

E = induced electromotive force, n = number of turns, t = time

$$e_1 = 4.44 f N_1 \Phi_m [V] \quad (4)$$

e_1 = primary induced electromotive force, Φ_m = magnetic flux

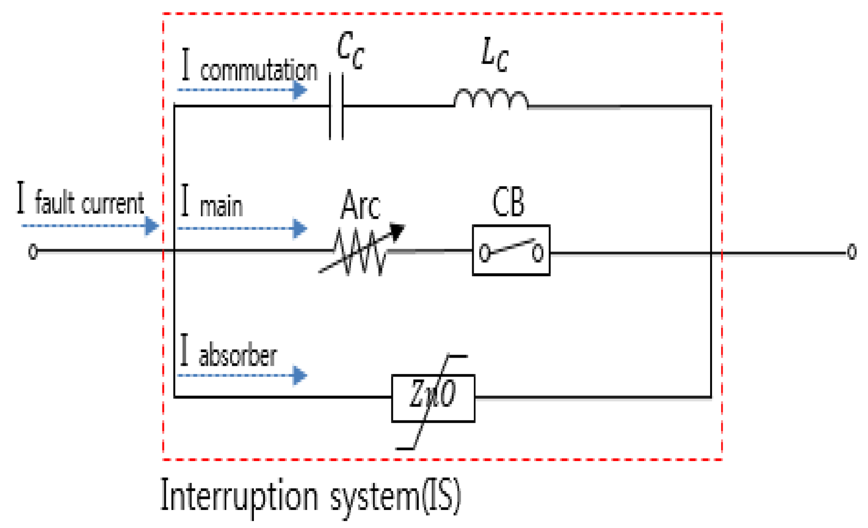
$$e_2 = 4.44 f N_2 \Phi_m [V] \quad (5)$$

e_2 = secondary induced electromotive force

$$R_{SFCL}(t) = \begin{bmatrix} 0 & (t < t_{quenching}) \\ R_m\left(1-\exp\left(-\frac{t}{T_{sc}}\right)\right)^{1/2} & (t_{quenching} < t) \end{bmatrix} \quad (6)$$

R_{SFCL} = superconductor resistance, R_m = maximum quench resistance
t = time, T_{SC} = time constant

B. Mechanical DC breaker



Mechanical DC breaker applied to TSFCL interruption system

1) Main part

- The main part consists of an arc box and a mechanical DC breaker.
- The arc box is applied to the mayr equation.
- Mechanical DC breaker contacts open at 8 ms after a fault.
- Arc current with high frequency is generated.

$$\frac{1}{g}\frac{dg}{dt} = \frac{1}{\tau}\left(\frac{U_{arc} I_{main}}{P} - 1\right) \quad (7)$$

g = arc conductance, τ = time constant, U_{arc} = arc voltage
I_{main} = main part current, P = arc powerloss

2) Commutation part

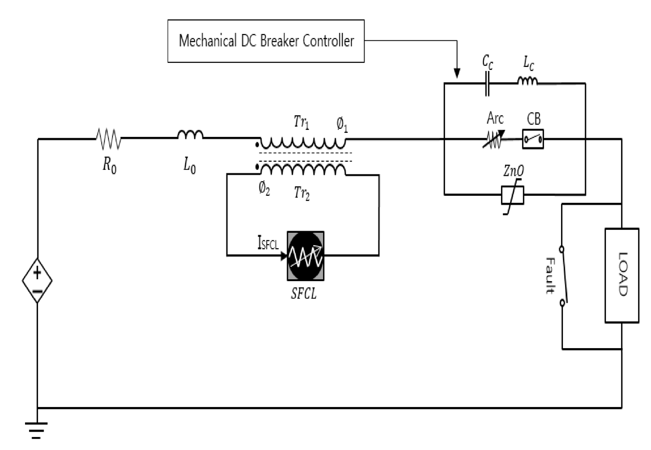
- The commutation part consist of a capacitor(C_C) and an inductor(L_C).
- Divergence oscillation current generated by equation (8).

$$I_{main} = I_{faultcurrent}\left[1 + e^{-0.5L_c(dU_{arc}/dI_{main})t}\sin\left(\frac{1}{\sqrt{L_c C_c}}t\right)\right] \quad (8)$$

3) absorber part

- A gap-less ZnO was used for the absorber part.
- The ZnO is modeled as a non-linear resistor in series with a variable voltage source.

TSFCL interruption system test circuit and parameters



TSFCL interruption system test simulation circuit diagram

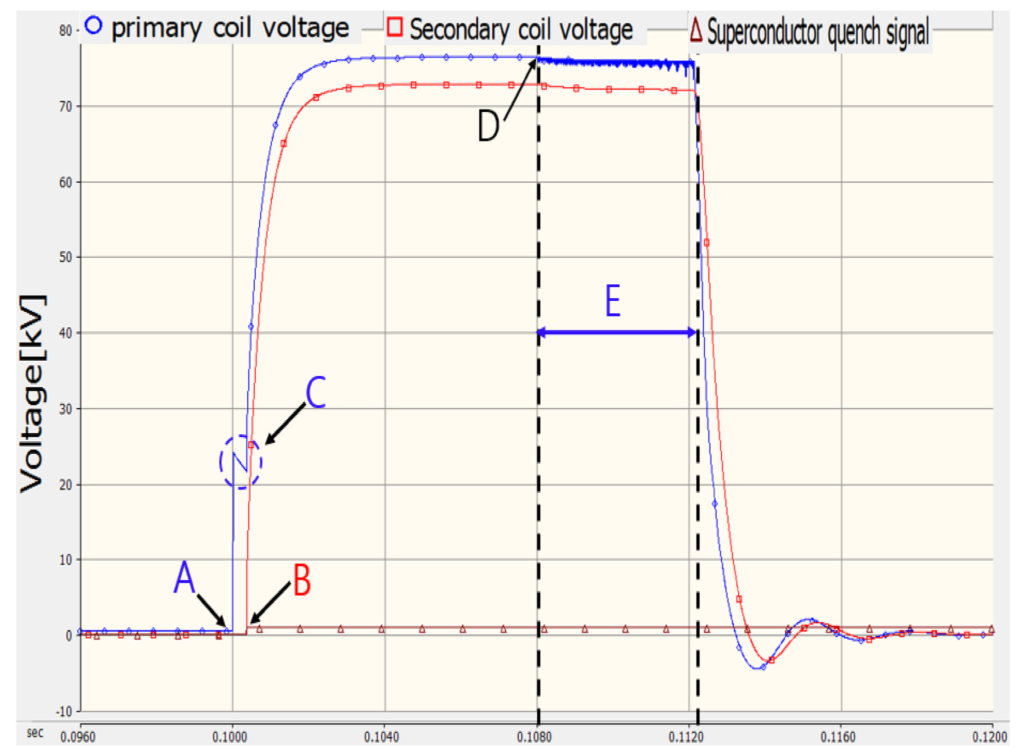
TABLE I
TS-type FCL DC parameter

Transformer			Superconducting fault current limiter		
Transformer capacity	120	MVA	Maximum quench resistance	10	Ω
Leakege reactance	0.1099	pu			
Primary winding voltage	120	kV			
Secondary winding voltage	120	kV	T_{sc}	0.75	ms

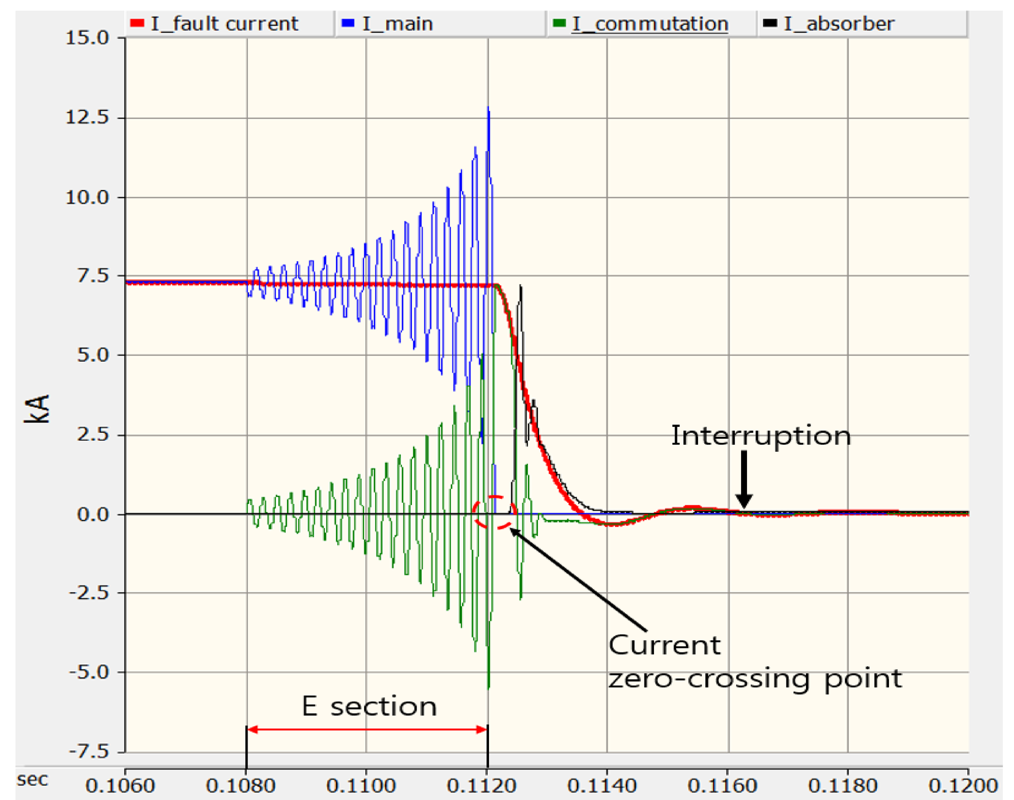
TABLE II
Mechanical DC breaker and arc box parameters

Part	Quantity	Unit	Value
Main part	Breaker capacity	kA	1.2
	Arc cooling power	kW	8000
	Time constant	us	0.3
Commutation part	CC	uF	13
	LC	uH	100
Absorber part	ZnO	kV	80

Simulation and analysis of the TSFCL interruption system

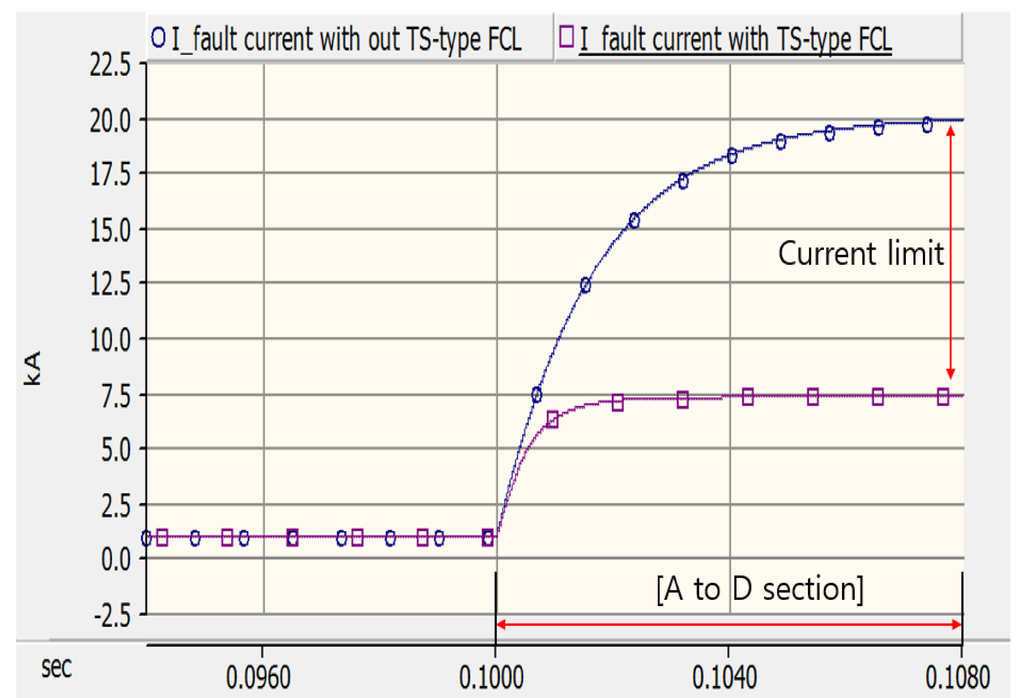


Voltages in the primary and secondary coils of the transformer in the TSFCL and the superconductor quench



Interruption characteristics graph of the TSFCL interruption system [section E]

- Fault time
  0.1 s
- Breaker operating time
  0.108 s
- Maximum Failure Current
  13 kA



Current-limiting characteristics graph of the TSFCL interruption system [sections A-D]

CONCLUSION

- This study proposed a transformer-type superconducting fault current limiter (TSFCL) interruption system for the reliability and stable operation of voltage source converter high-voltage direct-current (VSC-HVDC) transmission systems.
- Arc and capacity of mechanical DC circuit breaker can be reduced by applying TSFCL.
- The fault current was limited about 0.6 times and the interruption speed of the circuit breaker was within 8 ms.
- Applying the TSFCL interruption system to the DC grid may significantly decrease the possibility of interruption failure.
- The capacity of the equipment can be reduced.

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