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Analysis of cut-off characteristics of transformer-type superconducting DC circuit breaker according to reactance of superconductor and transformer turns ratio

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Abstract

- In this paper, we proposed a transformer-type superconducting DC circuit breaker(TS-DCCB) for reliably interrupting faults.
- It consists of a transformer-type superconducting element, a DC circuit breaker. The transformer-type superconducting DC circuit breaker reduce initial fault current, the DC circuit breaker interrupt the fault current by reaching the zero-point through the LC resonant.
- We designed a simulation circuit using the PSACD/EMTDC, and the cut-off characteristics were analyzed by applying the TS-DCCB.
- As a result, the time for the DC circuit breaker to reach the zero point could be accelerated by changing the transformer turns-ratio, and the power burden on the superconducting element was also reduced.

The transformer-type superconducting DC circuit breaker

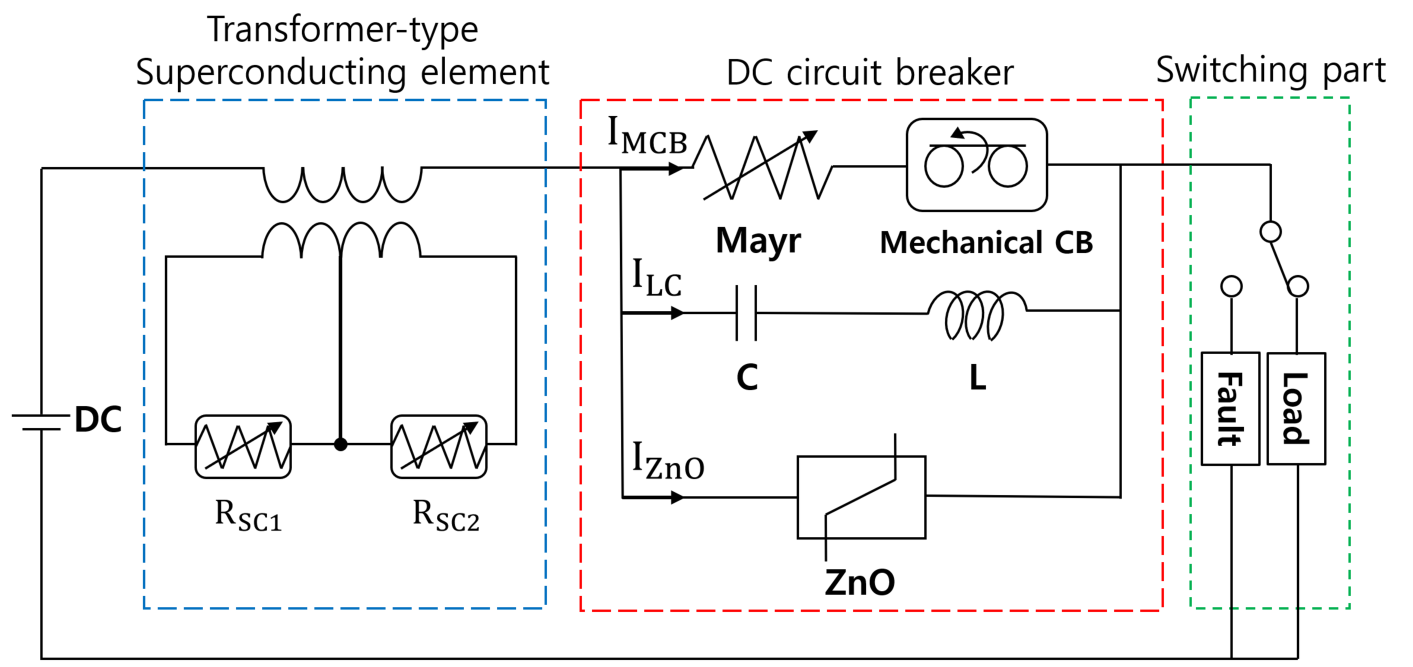

Fig. 1. Circuit of the TS-DCCB

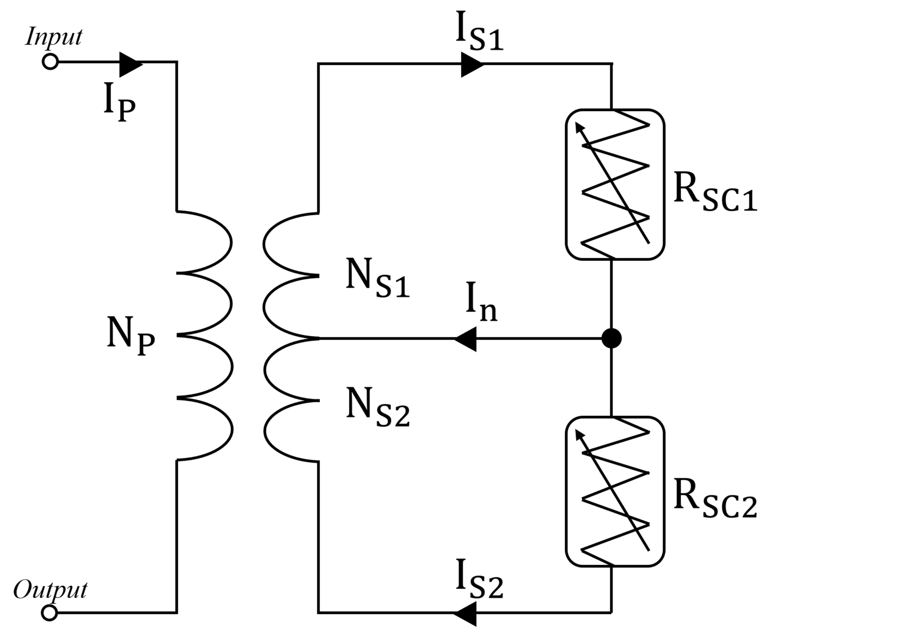

Fig. 2. Equivalent circuit of the transformer superconducting element

Characteristics presence or absence of a neutral

- We connected the neutral line to the secondary side of the transformer to solve the inequality of the superconductor critical current occurring during the manufacturing process.
- LC circuit of the DC circuit breaker causes the fault current to reach zero-point through resonance. After that, the mechanical circuit breaker is completely opened.
- We confirmed that the superconducting element was quenched at almost the same time due to the presence of the neutral line. In addition, there was no significant difference in the quenching operation time of the superconductor even when the number of turns ratio of the transformer was changed.

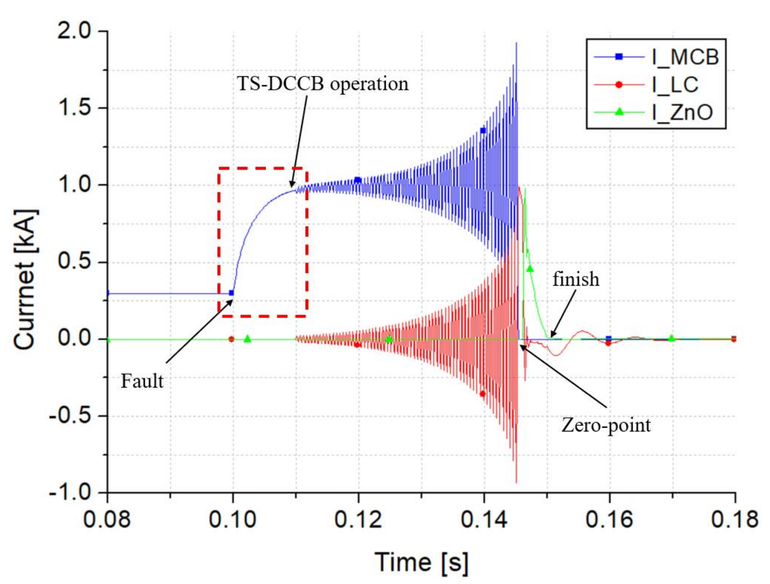

Fig. 3. Characteristics of the DC circuit breaker

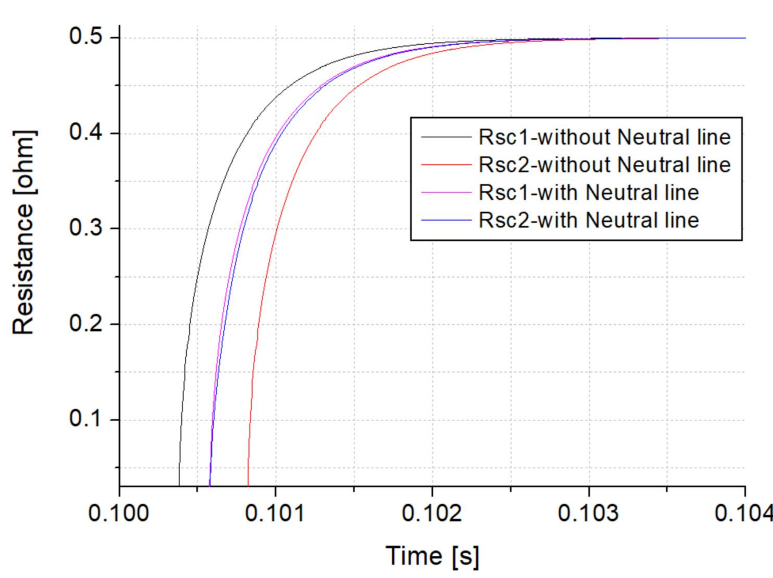

Fig. 4. graphs of the superconducting element resistance generation

Table 1. Operation time through turns-ratio of the transformer

Turns-ratio	Superconducting element operating time [s]	
	$I_c = 400\ A$	$I_c = 500\ A$
1.4 : 1	0.10007	0.10007
1.3 : 1	0.10018	0.10017
1.2 : 1	0.10028	0.10029
1.1 : 1	0.10042	0.10041
1 : 1	0.10056	0.10056
1 : 1.1	0.10074	0.10075
1 : 1.2	0.10093	0.10093
1 : 1.3	0.10112	0.10112
1: 1.4	0.10130	0.10131

Simulation

1) Design

Table 2. Parameters of the simulation

Division	Value
DC source	1.5 kV
Transformer capacity	1 [MVA]
Turns-ratio	1.4:1 ~ 1:1.4
L (LC circuit)	20 μH
C (LC circuit)	350 μF
R_{sc1} critical current	400 A
R_{sc2} critical current	500 A

- The resistance of the superconducting element applied to the secondary side of the transformer is applied through Equation (1). it occurs when the threshold current flowing through the superconducting element exceeds.

$$R_{sc} = \begin{bmatrix} 0 & (t < t_{quenching}) \\ R_m\sqrt{1 - e^{(t/T_{sc})}} & t_{quenching} < t \end{bmatrix} \quad (1)$$

R_{sc} : resistance of the superconducting element, $t_{queching}$: quenching time
R_m : maximum resistance of the superconducting element

1) Results

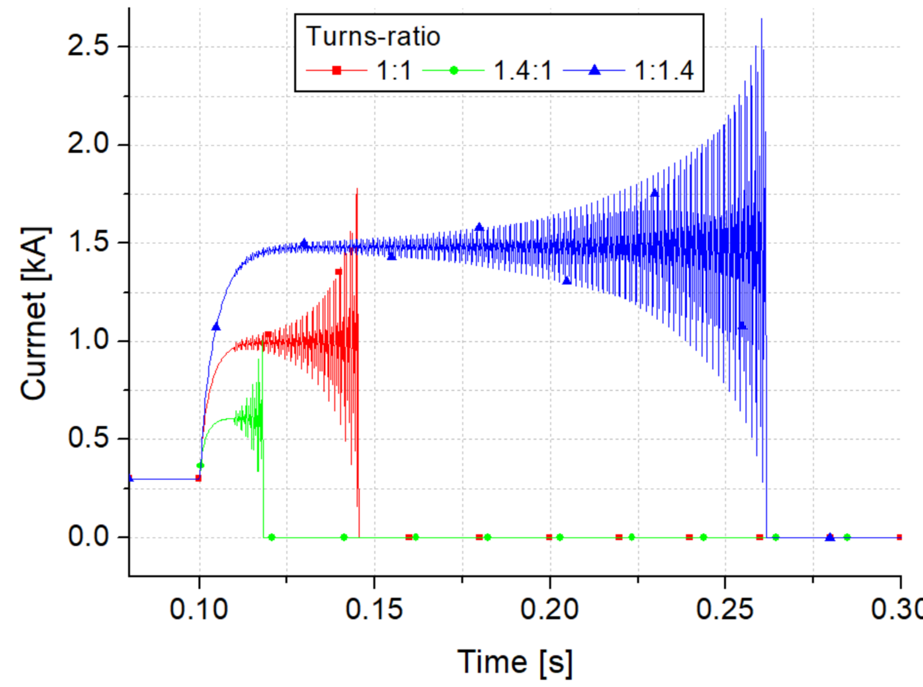

Fig. 5. Comparison of the DC circuit breaker operating characteristics according to the turns-ratio

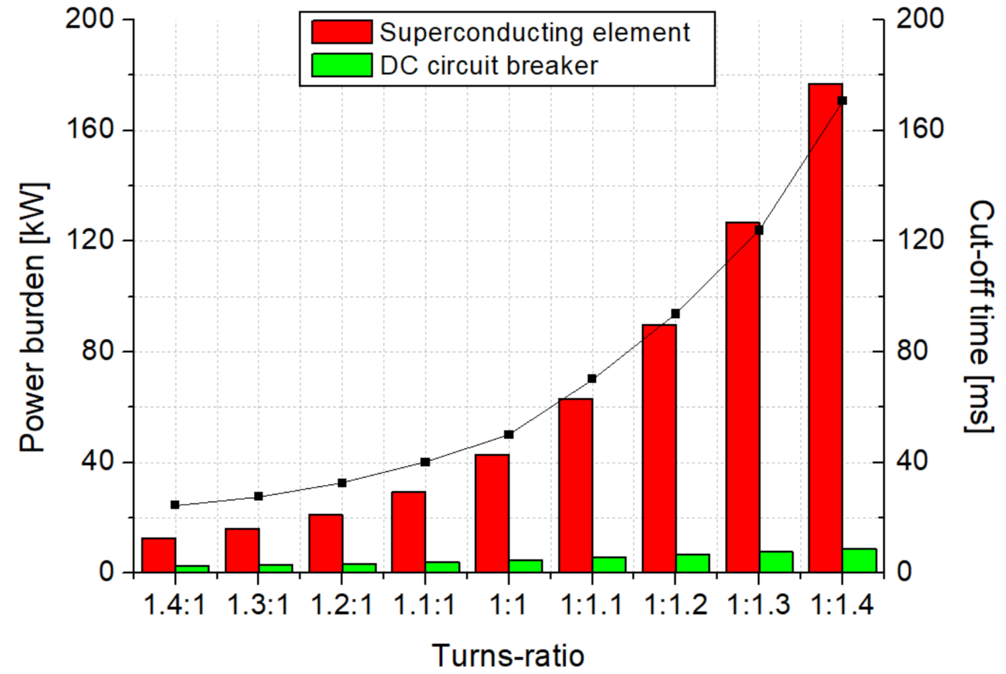

Fig. 6. Power burden and cut-off time of the DC circuit breaker through the turns-ratio

Table 3. Power burden through turns-ratio

Turns-ratio	Power burden [kW]		Cut-off time [ms]
	SC- element	MCB	
1.4 : 1	12.67	2.62	24.5
1.3 : 1	16.06	2.94	27.64
1.2 : 1	21.11	3.37	32.52
1.1 : 1	29.18	3.96	40.06
1 : 1	42.79	4.74	50.01
1 : 1.1	62.84	5.69	70.15
1 : 1.2	89.73	6.7	93.65
1 : 1.3	126.61	7.78	123.8
1: 1.4	177.02	8.87	170.6

- In the simulation, the normal current was about 0.3 kA and the fault current was about 3 kA.
- The current of transformer primary side flows through the DC circuit breaker. The rise of the voltage of the transformer primary side reduced the fault current flowing through the DC circuit breaker and reduced the power burden delivered to the DC circuit breaker and the superconducting element.
- Our goal is to equalize the power burden on the circuit breaker and the superconducting element, and we confirmed that the power burden proportion lowered by increasing the number of turns on the primary side through Fig. 6.

Conclusion

- We simulated a transformer-type superconducting DC circuit breaker by applying it to a single DC system. And the presence or absence of the neutral line on the secondary side of the transformer and the operating characteristics of the DC circuit breaker according to the change in the number of turns were confirmed.
- As a result, the application of the neutral wire quenched the superconductor uniformly. In addition, the current delivered to the circuit breaker was lowered by increasing the number of turns on the primary side of the transformer. And it is judged that this can equalize the power burden of the DC circuit breaker and the superconducting element. And we expect the economic effect of controlling the number of turns of the transformer-type superconducting element.

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