MT 26
International Conference
on Magnet Technology
Vancouver, Canada | 2019

Conceptual design of a saturated iron-core superconducting fault current limiter for a DC power system

Wed-Mo-Po3.08-06 [58]

V. Q. Dao*, C. S. Kim*, J. Lee* and M. Park*
Changwon National University*

capta.paper@gmail.com
Tel : +82-55-213-2866
CAPTA

1 Introduction

A superconducting fault current limiter can significantly reduce the stress on the DC circuit breaker in DC power systems due to its inherent physical characteristics that can quickly limit the fault current. This paper presented the conceptual design of a saturated iron-core superconducting fault current limiter (SI-SFCL) for DC power systems. First, the electrical characteristics of the SI-SFCL were investigated. Then, a detailed design process and corresponding configuration of the SI-SFCL for a 15 kV, 3 kA DC power system were presented. A PSCAD/EMTDC simulation model was built to analyze the operating and fault current limiting characteristics of the SI-SFCL. To demonstrate the effectiveness of the conceptual design parameters and configuration, a lab-scale SI-SFCL for a 500 V, 50 A DC power system was designed in detail. The fault current limiting capability of the lab-scale SI-SFCL was confirmed by the 3D finite element method (FEM). As a result, the lab-scale SI-SFCL has a high current limiting capability, which can reduce the magnitude of the fault current by up to 75%. The next step is to fabricate a lab-scale SI-SFCL hardware and test its actual performance to verify the fault current limiting effect in DC power systems.

2 Conceptual design of the SI-SFCL

A. Configuration of the SI-SFCL for a DC power system

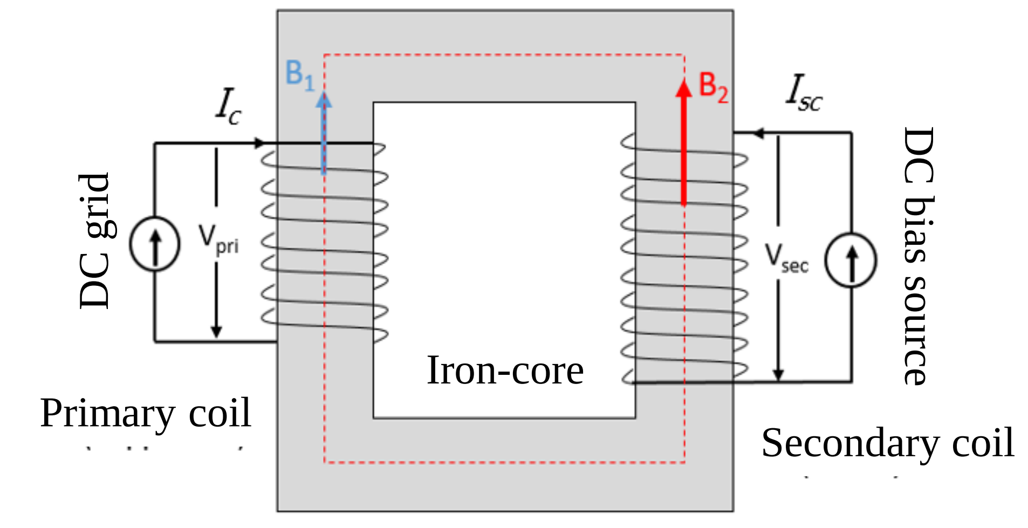


Fig. 1. Configuration of the SI-SFCL for a DC power system

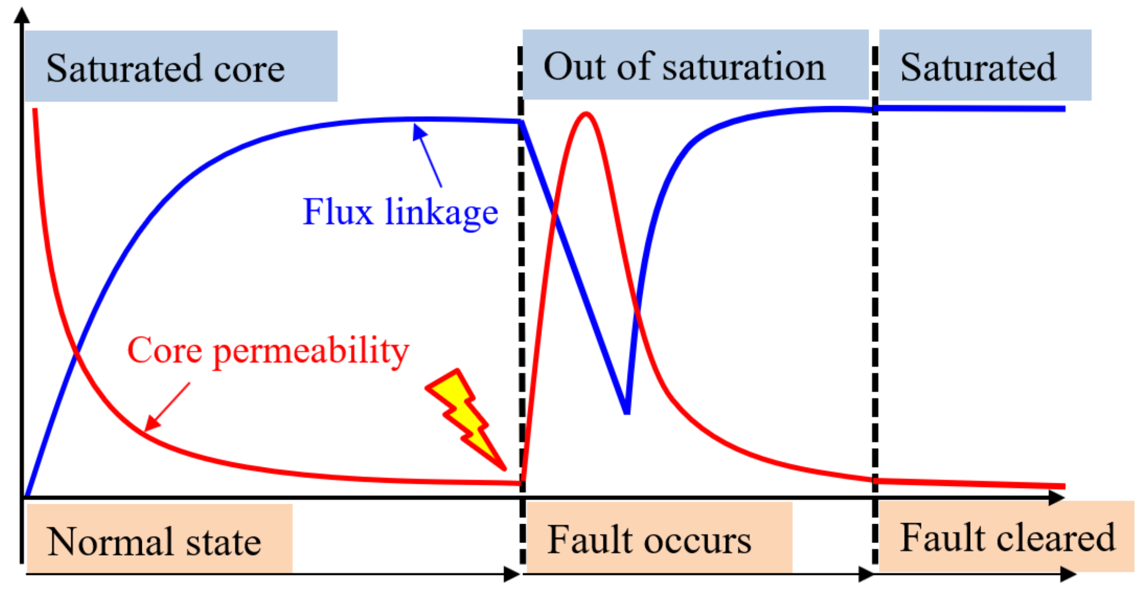
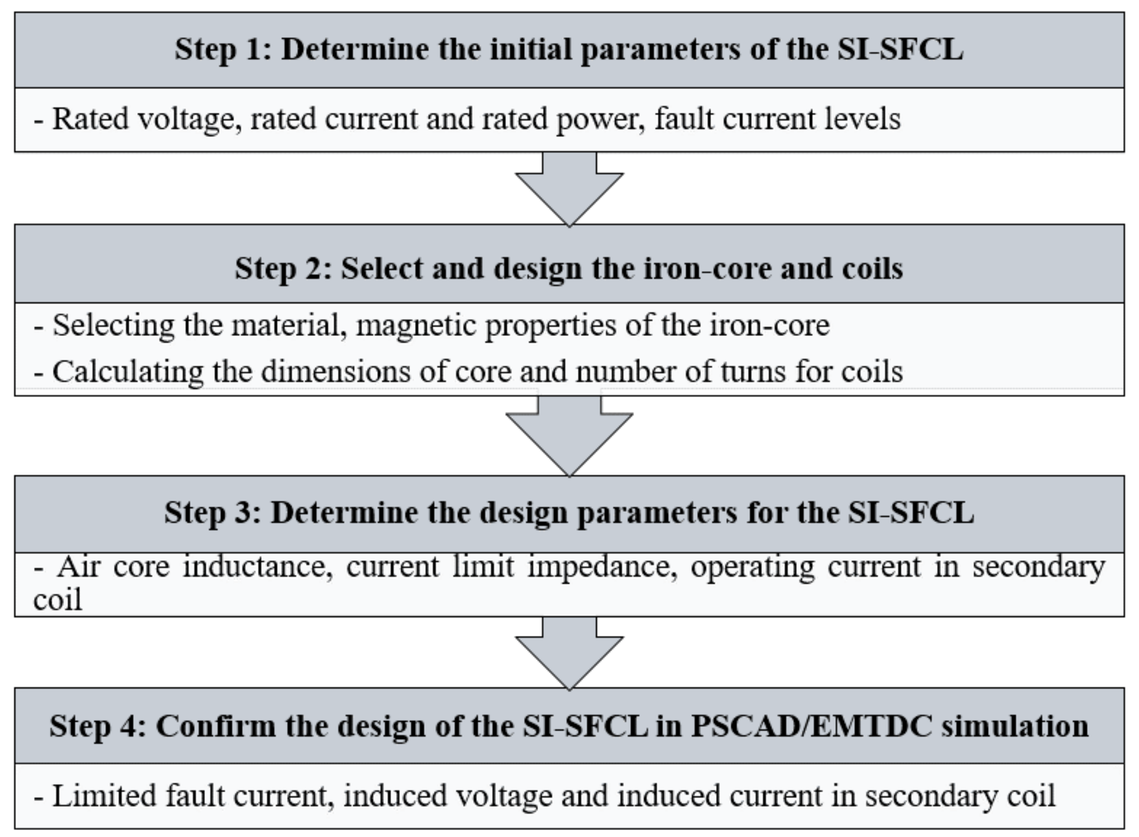


Fig. 2. Saturation characteristics of the SI-SFCL in fault condition

B. Detailed design process of the SI-SFCL



Step 1: Determine the initial parameters of the SI-SFCL
- Rated voltage, rated current and rated power, fault current levels

Step 2: Select and design the iron-core and coils
- Selecting the material, magnetic properties of the iron-core
- Calculating the dimensions of core and number of turns for coils

Step 3: Determine the design parameters for the SI-SFCL
- Air core inductance, current limit impedance, operating current in secondary coil

Step 4: Confirm the design of the SI-SFCL in PSCAD/EMTDC simulation
- Limited fault current, induced voltage and induced current in secondary coil

Fig. 3. Design process of the SI-SFCL for the DC power system

This design process was applied to design the SI-SFCL for the 15 kV, 3 kA DC power system. The cross-sectional area A_{core} of the iron-core was calculated by the following equation:

$$A_{core} = 1.2 \times \sqrt{P_m}$$

Basically, the SI-SFCL could be considered as a single-phase transformer model. Thus, the number of turns N_{pri} in the primary coil was determined by the equation:

$$N_{pri} = \frac{V_{pri}}{4.44 \times f_{base} \times B_{\max} \times A_{core}}$$

TABLE I
Specifications of the SI-SFCL for the 15 kV, 3 kA DC power system

Items	Value
Rated voltage, V_c	15 kV
Rated current, I_c	3 kA
Rated power, P_m	45 MW
DC cable resistance, R_c	0.9095 Ω
DC cable inductance, L_c	10 mH
Fault current without SFCL	16.35 kA
Target of fault limiting rate	70%
Core material	50PN470
Saturated magnetic field of the iron-core, B_{max}	1.7 T
Cross-section area of the core, A_{core}	0.805 m^2
Length of the magnetic path in the core, l_{core}	6.4 m
Number of turns in the primary coil, N_{pri}	140 turns
Number of turns in the secondary coil, N_{sec}	327 turns
Saturated magnetic flux in the primary coil, Φ_{sat}	0.21 Wb
Operating current of the secondary coil, I_{sc}	1.5 kA
Air core inductance of the primary coil, L_{air}	3.1 mH

C. Fault current limiting characteristics of the SI-SFCL

A PSCAD/EMTDC simulation model was built to confirm the designed parameters and analyze the operational characteristics of the SI-SFCL. A single-phase transformer model was used to simulate the SI-SFCL. The maximum fault current without the SI-SFCL was 16.38 kA.

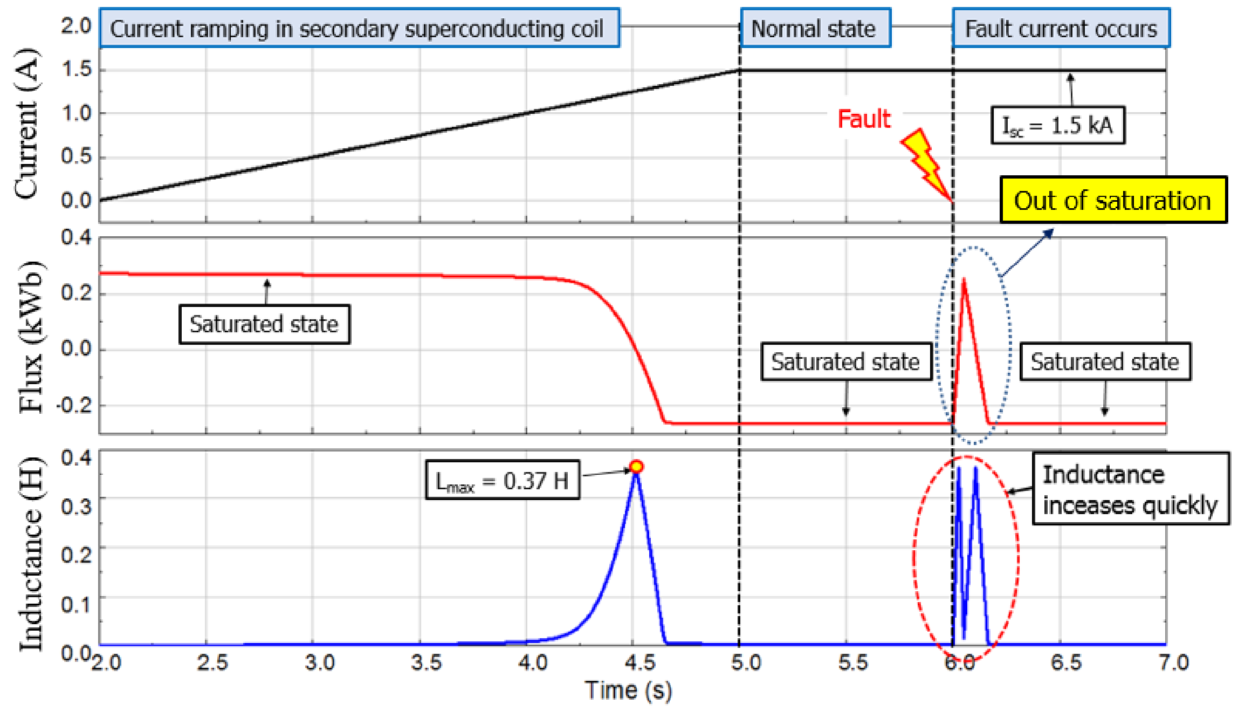


Fig. 4. Saturated state and transient inductance of the primary coil during the fault

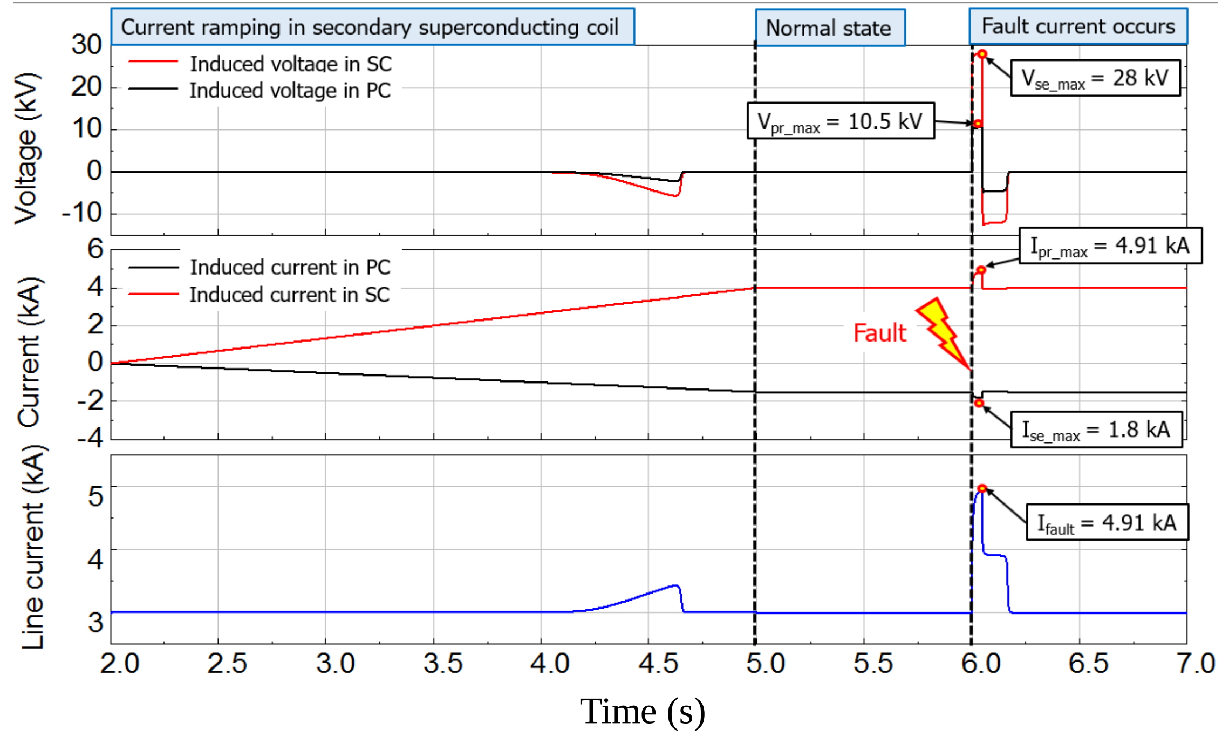


Fig. 5. Induced current and voltage of the secondary coil during the fault

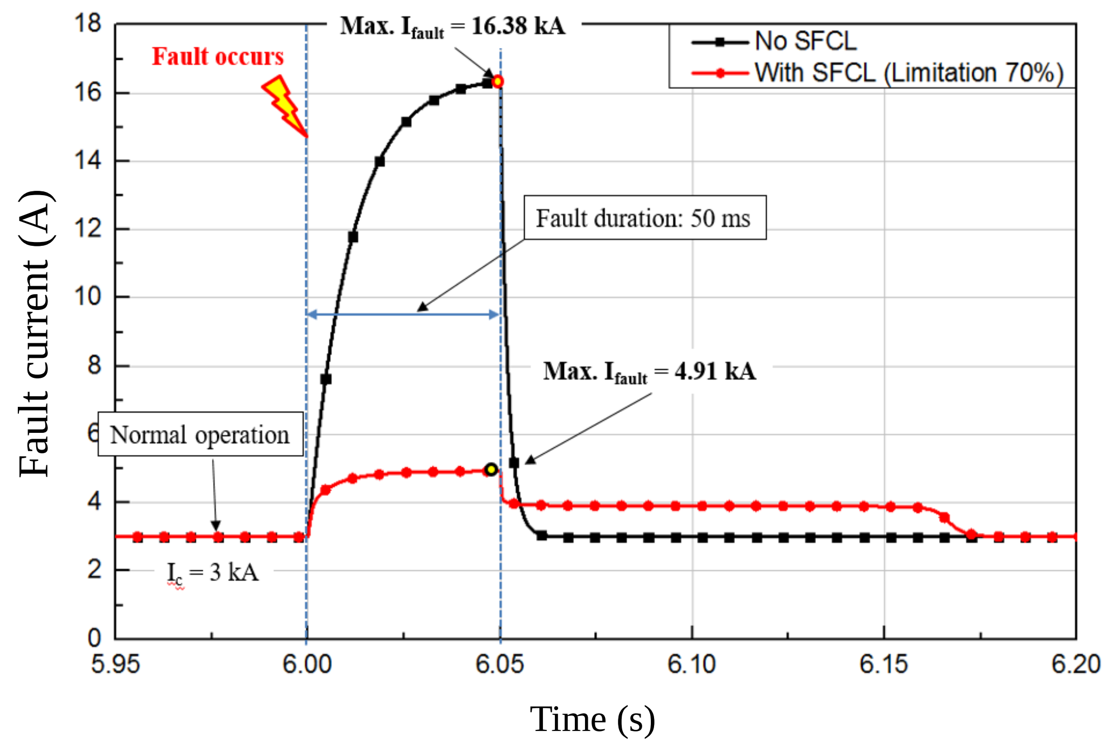


Fig. 6. Fault current levels with and without the SI-SFCL

3 Design and analysis of a lab-scale SI-SFCL

A. Specifications of the lab-scale SI-SFCL for a 500 V, 50 A DC power system

A lab-scale SI-SFCL was implemented in the 500 V, 50 A DC power system to verify the effectiveness conceptual design.

TABLE II
Specifications of the lab-scale SI-SFCL

Items	Value
Rated voltage, V_c	500 V
Rated current, I_c	50 A
Rated power, P_m	25 kW
DC cable resistance, R_c	0.5 Ω
DC cable inductance, L_c	1.651 mH
Capacitor bank	5,300 μF
Fault current without SFCL	550 A
Target of fault limiting rate	70%
Core material	50PN470
Saturated magnetic field of the iron-core, B_{max}	1.7 T
Cross-section area of the core, A_{core}	0.01 m^2
Length of the magnetic path in the core, l_{core}	1.6 m
Number of turns in the primary coil, N_{pri}	198 turns
Number of turns in the secondary coil, N_{sec}	150 turns
Saturated magnetic flux in the primary coil, Φ_{sat}	3.2 Wb
Operating current of the secondary coil, I_{sc}	200 A
Air core inductance of the primary coil, L_{air}	6 mH

B. Detailed structure design of the lab-scale SI-SFCL

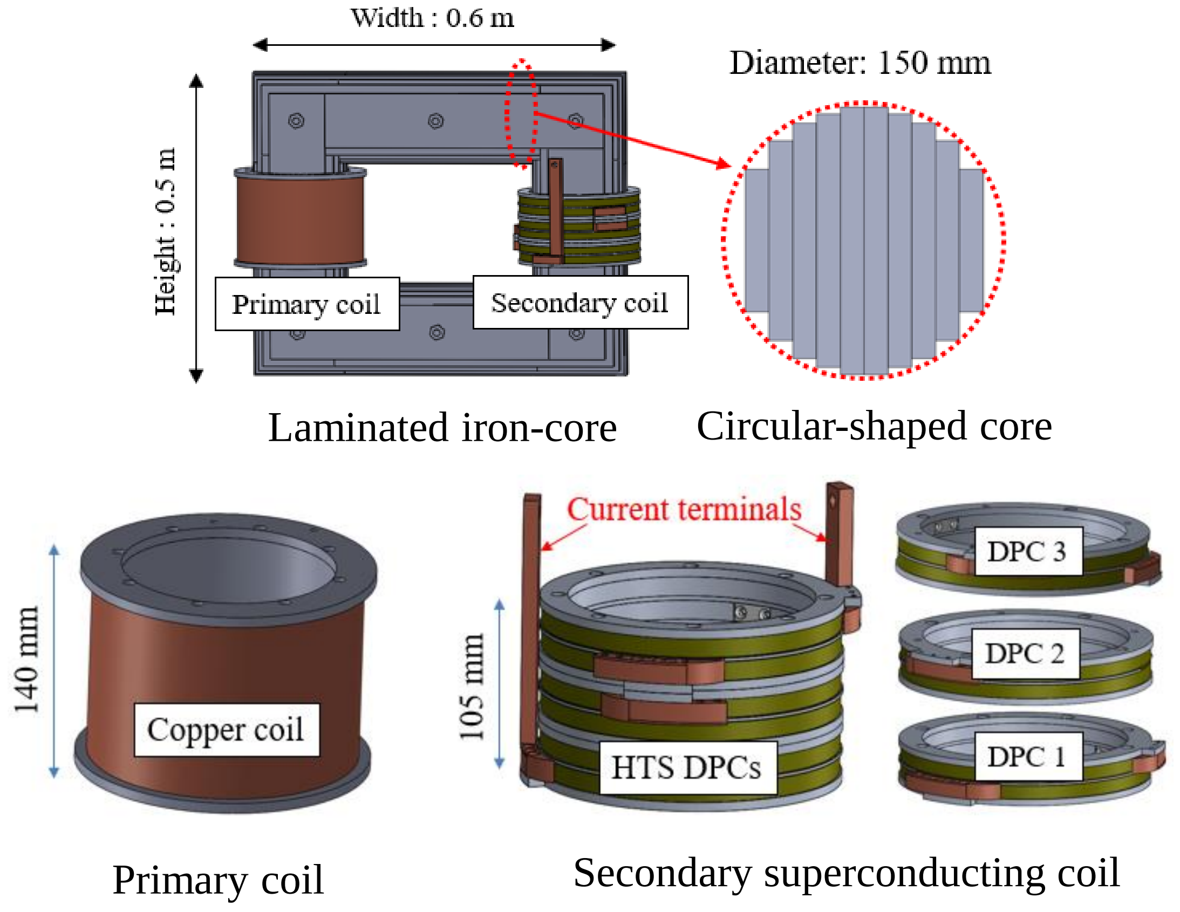


Fig. 7. Detailed structure design of the lab-scale SI-SFCL

C. 3D FEM simulation results and discussions

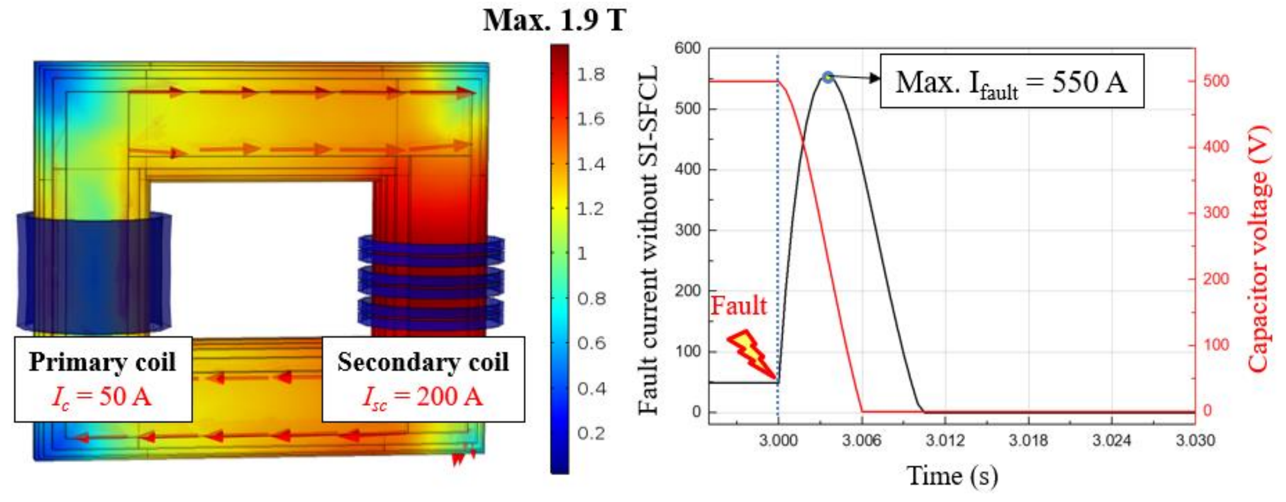


Fig. 8. 3D FEM simulation model of the lab-scale SI-SFCL

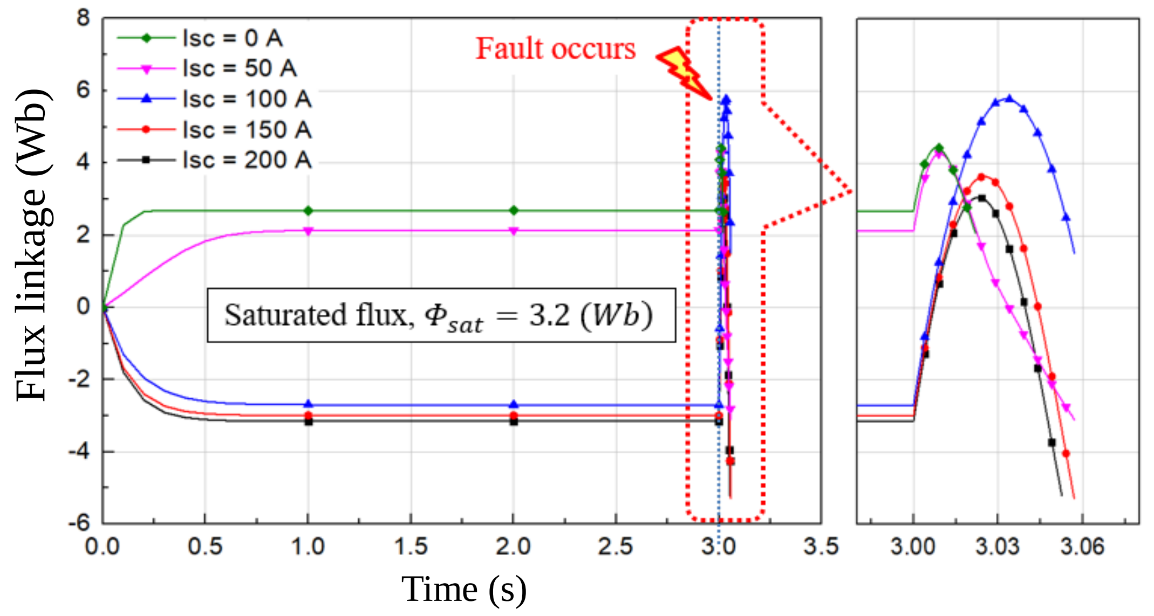


Fig. 9. Flux linkages of primary coil with different secondary currents

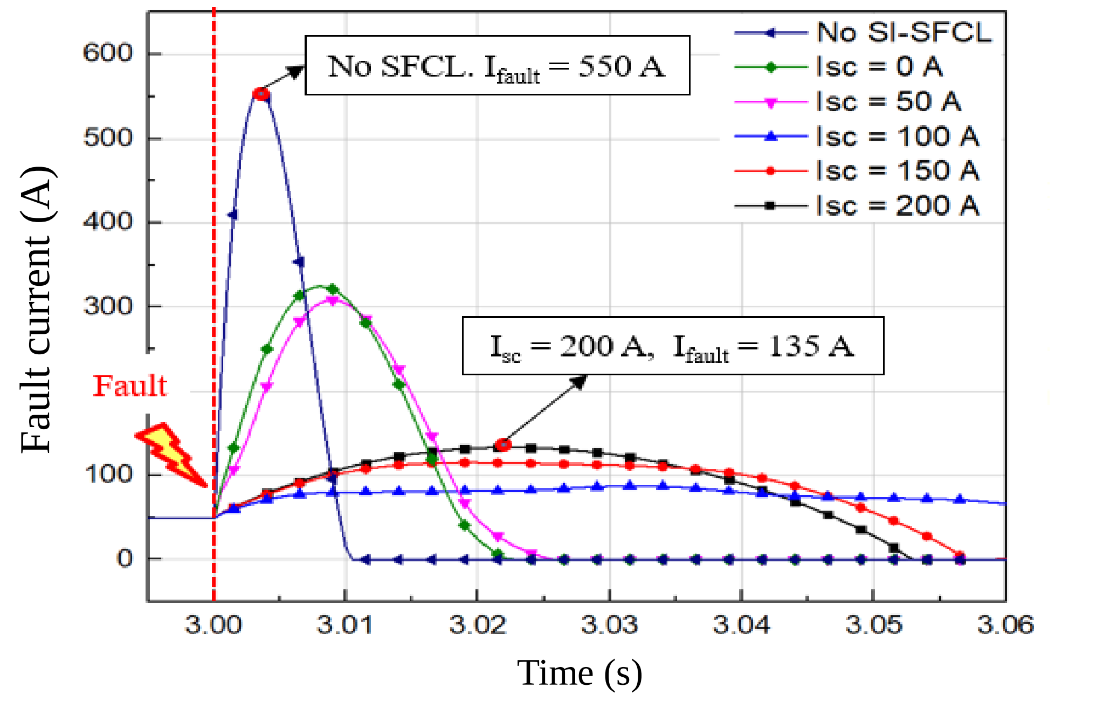


Fig. 10. Fault current limiting with different secondary currents

In normal operation, the primary side was saturated with the secondary current of 200 A. When the fault occurred, the fault current was reduced to 135 A, the limitation rate was up to 75%. These results show that the lab-scale SI-SFCL has high current limiting performance, which can effectively reduce the rate of rise and magnitude of the fault current.

4 Conclusions

The authors presented the conceptual design of a SI-SFCL for DC power systems. Detailed design process and the corresponding configuration of the SI-SFCL were determined. First, the conceptual design was applied to a 15 kV, 3 kA DC power system to confirm the design process, operation and fault current limiting characteristics of the SI-SFCL. In normal operation, the secondary coil fully saturated the iron-core and the primary inductance was very small. When a fault occurred, the iron-core went out of saturation state, resulting in increased the inductance of the SI-SFCL and limited the magnitude of the fault current to 70%. A lab-scale SI-SFCL for a 500 V, 50 A DC power system was designed in detail to implement the SI-SFCL design concept in a hardware-based experiments. The magnetic properties and current limiting ability of the lab-scale SI-SFCL were confirmed in the 3D FEM simulation. As a result, the lab-scale SFCL was able to effectively reduce the rate of rise and the magnitude of the fault current, with a limitation rate of up to 75%. This confirms that the design of the lab-scale SI-SFCL is accurate and can be manufactured for future physical experiments.

Acknowledgement

This research was supported by Korea Electric Power Corporation. (Grant number: R16XA01)