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# Characteristics of the magnetic flux-offset type FCL by switching component

**Byung-Ik Jung[a] and Hyo-Sang Choi[*,b]**

[a] *Dongkang Collage, Gwangju, Korea*
[b] *Chosun University, Gwangju, Korea*

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**Abstract**

The study of superconducting fault current limiter (SFCL) is continuously being studied as a countermeasure for reducing fault-current in the power system. When the fault occurred in the power system, the fault-current was limited by the generated impedance of SFCLs. The operational characteristics of the flux-offset type SFCL according to turn ratios between the primary and the secondary winding of a reactor were compared in this study. We connected the secondary core to a superconductor and a SCR switch in series in the suggested structure. The fault current in the primary and the secondary winding of the reactor and the voltage of the superconductor on the secondary were measured and compared. The results showed that the fault current in the load line was the lowest and the voltage applied at both ends of the superconductor was also low when the secondary winding of the reactor had lower turn ratio than the primary. It was confirmed based on these results that the turn ratio of the secondary winding of the reactor must be designed to be lower than that of the primary winding to reduce the burden of the superconductor and to lower the fault current. Also, the suggested structure could increase the duration of the limited current by limiting the continuous current after the first half cycle from the fault with the fault current limiter.

*Keywords* : Superconducting fault current limiter (SFCL), flux-offset type FCL, Silicon controlled rectifier (SCR), Turn ratio of a reactor

## 1. INTRODUCTION

Various studies are under way for the empirical analysis on the SFCL. The SFCL can simultaneously detect and limit the fault current, and is considered one of the promising future power devices. The most critical issue in the empirical analysis on the SFCL is its recovery time. The fast recovery as well as the fast response of the SFCL is very important in improving the supply reliability and transient stability of a system [1-3].

Currently, domestic demonstration projects are also experiencing recovery delay [4-5]. This problem must be resolved for the stable field application of the SFCL.

The ways to reduce the recovery time of the SFCL will be suggested in this study.

## 2. EXPERIMENTAL PRINCIPLE AND DESIGN OF PROPOSED SFCL

2.1. Experimental Design and principle

Fig. 1 shows the experimental circuit of the SFCL suggested in this study. In the figure, the primary winding of the reactor is connected to the load line, and the secondary to the superconductor and SCR switch. The load line at the primary winding of the reactor is connected to a vacuum interrupter, which is a mechanical switch for fault current bypass, and to a CLR, which is a limiting device for fault current. The current transformer (CT) detects the fault. If the detected fault current exceeds the set value of the SCR control system, power is applied to the solenoid to operate the vacuum interrupter [4].

The source switch at the power supply is a switch for power application, and the fault switch is for fault simulation. In normal conditions, the current is supplied as R-Load through the primary winding of the reactor and the b-contact of the vacuum interrupter. At fault, on the other hand, the flow of fault current is divided into the first half cycle of the fault and after. The initial fault current from the start of fault through the end of the first half cycle is limited by the impedance caused by the quench of the superconductor on the secondary winding of the reactor and the opening of the SCR switch. The fault current after the first half cycle, however, is detoured to the CLR connected to the a-contact of the vacuum interrupter and

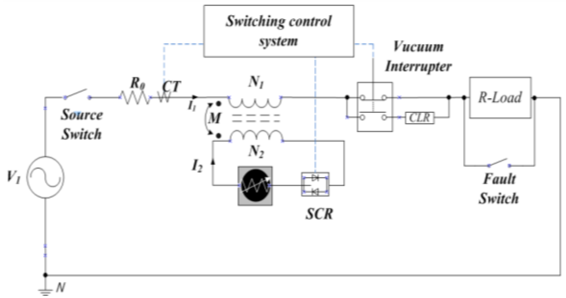


Fig. 1. Schematic diagram of experimental circuit.

* Corresponding author: hyosang@chosun.ac.kr

limited. Table 1 show the appearance and inductance values for turns of the reactor used in this study. The test voltage used in the experiment was 120 volts and the load resistance was set 50 ohm. The superconducting elements etched in meander lines were fabricated using 300nm thick YBCO thin films, its critical current are 18~20 ampere.

2.2. Fault Current Comparison on the Primary winding of the Reactor

Fig. 2 shows the values of the fault current that flows through the primary winding of the transformer, i.e. load line at fault. As shown in Fig. 2, the initial peak current during the first half cycle of the fault was significantly low when the turn ratio of the primary and the secondary winding of the reactor was 4:2. The accurate values of the initial peak current were listed in table 2. It was confirmed that the initial peak current can be adjusted through the comparison of turn ratios. Limiting the fault current in a load line is the essential role of the SFCL that is required along with the existing circuit breaker for protection. Since limiting the current on the primary winding of a reactor can relatively increase the current on the secondary winding that is connected to a superconductor, the values of the fault current on the secondary winding were also compared.

2.3 Fault Current Comparison on the Secondary winding of the Reactor

Fig. 3 compared the currents that flow through the secondary winding of the reactor, i.e. the superconductor. The initial peak current on the secondary winding of the reactor was not much different from the peak current on the primary winding. The accurate values were listed in table 2.

TABLE 1
THE VALUE OF THE REACTOR'S INDUCTANCE.

| Turns ratio | Inductance (mH) | |
|---|---|---|
| | Primary winding | Secondary winding |
| 4 : 2 | 21.72 | 5.51 |
| 2 : 4 | 5.46 | 21.89 |
| 4 : 4 | 21.72 | 21.89 |

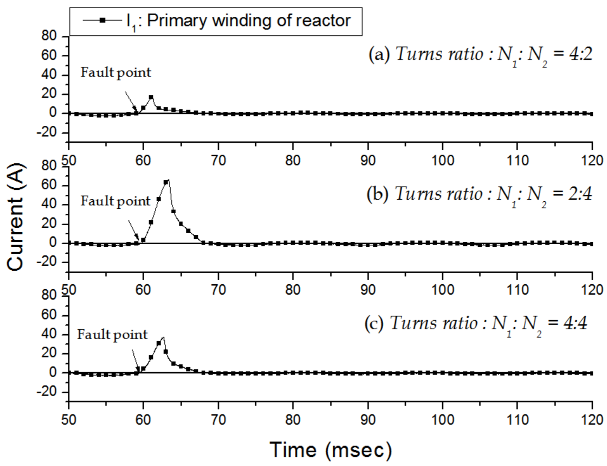


Fig. 2. Fault current curves of the primary side of reactor.

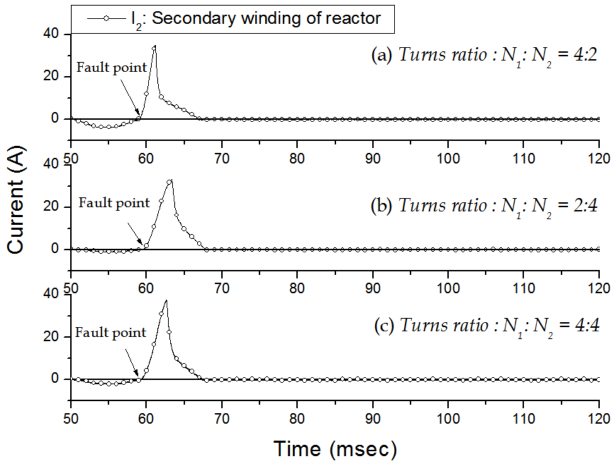


Fig. 3. Fault current curves of the secondary side of reactors.

TABLE 2
THE VALUE OF PEAK FAULT CURRENT AND VOLTAGE OF AN SFCL.

| Turns ratio | Peak fault current (A) | | Peak voltage (V) |
|---|---|---|---|
| | Primary winding | Secondary winding | Superconducting unit |
| 4 : 2 | 17.8 | 35.36 | 30.63 |
| 2 : 4 | 67.32 | 33.55 | 115.63 |
| 4 : 4 | 38.43 | 37.41 | 104.38 |

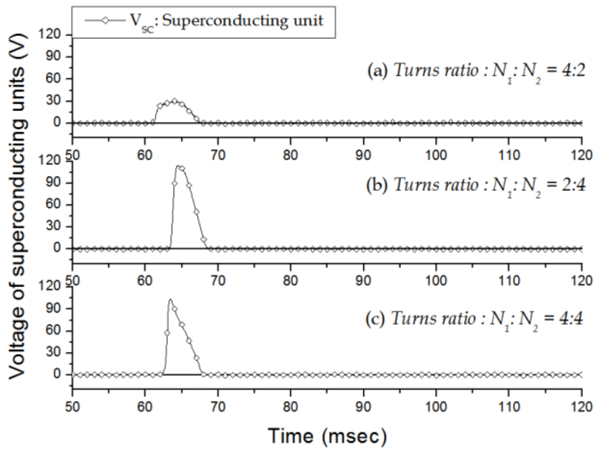


Fig. 4. Voltage curves of superconducting units.

The quench of the superconductor seems to restrict the fault current under the specified value. For the existing SFCLs, when the fault current increases, the burden of a superconductor tends to increase proportionally to the square of the current.

For the SFCL suggested in this study, however, the fault current in the load line of the primary winding was reduced and the fault current through the superconductor was maintained on the similar level. Thus, the SFCL is considered advantageous to capacity increase for real applications.

2.4. Voltage Comparison of the Superconductor on the Secondary winding of the Reactor

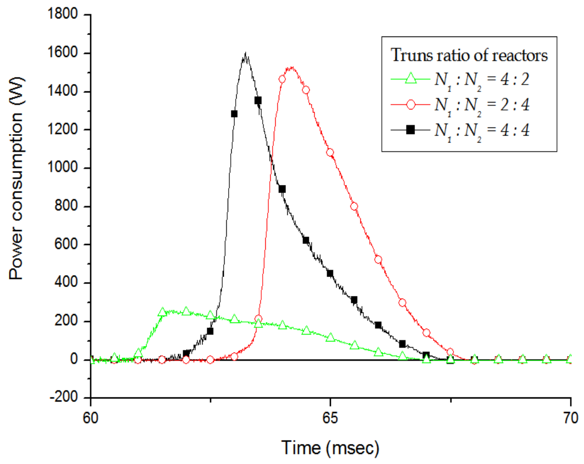


Fig. 5. Power consumption of the superconducting unit.

Fig. 4 shows the voltage values applied at both ends of the superconductor connected to the secondary winding of the reactor at initial fault. If the fault current exceeds the critical current of the superconductor, the superconductor quenches. The generated impedance of the superconductor limits the fault current, operates the SCR switch, and opens the secondary winding. This opening causes magnetic flux imbalance between the primary and the secondary winding of the reactor, and the reactance generated by the imbalance limits the initial fault current in the load line on the primary winding. The voltage comparison of the superconductor also showed that the superconductor had the lowest burden at the turn ratio of 4:2.

Fig. 5 shows electric power comparison data calculated from the applied voltage and current to the superconductor. The area formed by the instantaneous power curve and x-axis represents the total electric power applied to the superconductor. It is significantly low under the turn ratio of 4:2 as shown in fig. 4. Thus, it is believed to be beneficial to maintain lower turns for the secondary winding of the reactor than the primary winding for improving the limitation of the initial fault current and reducing the burden of the superconductor. Also, the duration of the limited current is expected to be extended by limiting the consistent fault current after the first half cycle with the CLR connected to the load line. These results are considered useful in future application to the actual systems.

## 3. CONCLUSION

The recovery time of the SFCL and the way to improve the limited current duration were suggested in this study. In the existing flux-offset type SFCL, the superconductor takes all burdens at fault, however, the suggested structure makes that the superconductor limits the fault current during the first half cycle only, and opens the SCR switch later to minimize the burden of the fault. Also, enough duration of the limited current could be secured by limiting the consistent fault current after the first half cycle with the CLR connected to the load line. These performance improvements are considered advantageous in cooperation with the existing protective devices. Structural improvements are required in the future as the structure of the system still remains complicated.

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## REFERENCES

[1] Hyo Sang Choi, Byung -Ik Jung and Young-Sun Cho, “Transient Characteristics of a Flux-Coupling Type Superconducting Fault Current Limiter According to Winding Direction,” *IEEE Trans. Appl. Supercond.*, vol. 19, no. 3, pp. 1827-1830, 2009.

[2] H. S. Choi, O. B. Hyun, H. R. Kim and K. B. Park, “Switching properties of a hybrid type superconducting fault current limiter using YBCO stripes,” IEEE Trans. Appl. Supercond., vol. 12, no. 3, pp. 1833-1838, 2002.

[3] B. I. Jung, H. S. Choi, Y. S. Cho and D. C. Chung, “Current Limitation and Power Burden of a Flux-Coupling Type SFCL in the Three-Phase Power System According to Turn’s Ratio and Fault Type,” IEEE Trans. Appl. Supercond., vol. 21, no. 3, pp. 1225-1228, 2011.

[4] B. I. Jung and H. S. Choi, “Combined Effect of the SFCL and Solenoid Coils,” IEEE Trans. Appl. Supercond., vol. 24, no. 3, pp. 5600404, 2014.

[5] Y. S. Cho and H. S. Choi, “The current limiting effects of a matrix-type SFCL according to the variations of designed parameters in the trigger and current-limiting parts,” Physica C, vol. 468, pp. 2054-2058, 2008.