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Bus-voltage Sag Suppressing and Fault Current Limiting Characteristics of the SFCL Due to its Application Location in a Power Distribution System

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Abstract – The application of the superconducting fault current limiter (SFCL) in a power distribution system is expected to contribute the voltage-sag suppression of the bus line as well as the fault-current reduction of the fault line. However, the application effects of the SFCL on the voltage sag of the bus line including the fault current are dependent on its application location in a power distribution system. In this paper, we investigated the fault current limiting and the voltage sag suppressing characteristics of the SFCL due to its application location such as the outgoing point of the feeder, the bus line, the neutral line and the 2nd side of the main transformer in a power distribution system, and analyzed the trace variations of the bus-voltage and fault-feeder current. The simulated power distribution system, which was composed of the universal power source, two transformers with the parallel connection and the impedance load banks connected with the 2nd side of the transformer through the power transmission lines, was constructed and the short-circuit tests for the constructed system were carried out. Through the analysis on the short-circuit tests for the simulated power distribution system with the SFCLs applied into its representative locations, the effects from the SFCL's application on the power distribution system were discussed from the viewpoints of both the suppression of the bus-voltage sag and the reduction of the fault current.

Keywords: Superconducting fault current limiter (SFCL), Power distribution system, Voltage-sag suppression, Fault-current reduction

1. Introduction

The continuous enlargement of the power facilities including the power transmission line has caused the short-circuit current in a power system to be increased, which has resulted in the excess of the available cut-off ratings of the circuit breakers installed for the protection of the power system [1-3]. To effectively suppress the more increased fault current in a power system, the superconducting fault current limiter (SFCL) has been suggested and the various types of the SFCLs have been developed [2-5].

Though the suppressing countermeasure of the bus-voltage sag together with the reduction of the fault current in the practical power distribution system has been noticed as one of the important issues, most of the studies on the SFCL, however, have been focused on the development of the SFCL model to minimize its power burden for the generation of its higher limiting impedance [5-9].

Therefore, for the effective application of the SFCL in a power distribution system, the studies on the bus-voltage sag suppressing characteristics of the SFCL together with the fault current limiting ones, especially dependent on its application location in a power distribution system, are primarily required to be progressed.

In this paper, the outgoing point of the feeder, the bus line, the neutral line and the 2nd side of the main transformer were selected as the representative application locations of the SFCL in a power distribution system and the bus-voltage sag suppressing and the fault current limiting characteristics of the SFCL due to its application location in a power distribution system were investigated through the short-circuit tests for the simulated power distribution system. Through the analysis on the trace variations of the bus-voltage and fault-feeder current obtained from the short-circuit tests, the bus-voltage sag suppressing and the fault current limiting characteristics of the SFCL in each application location were discussed.

2. Experimental Circuit Configuration for Simulated Power Distribution System

Fig. 1 shows the schematic configuration of a simulated power distribution system with four feeders and two main transformers, operated in parallel. As the candidate for the application location of the SFCL, the entrance point of each feeder, the secondary side of the main transformer, the neutral line of the main transformer with the delta-wye structure and the bus line were considered.

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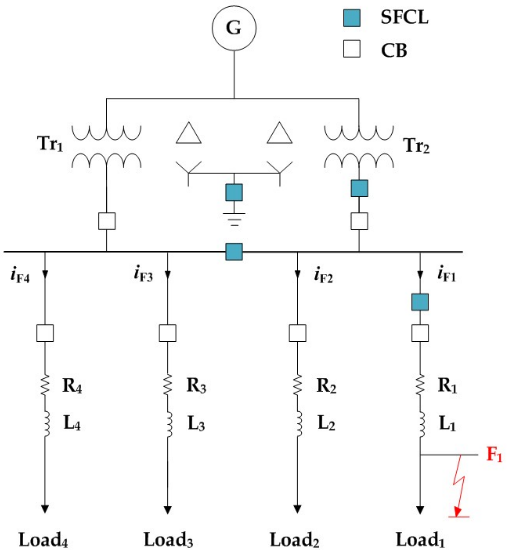

Fig. 1. Schematic configuration of a simulated power distribution system with two main transformers

Table 1. Specifications of components comprising power distribution system with SFCL

Transformer 1, 2 (Tr_1, Tr_2)	Value	Unit
Capacity	3	kVA
Voltage of primary side	200	V
Voltage of secondary side	60	V
Distribution line	**Value**	**Unit**
$R_1 + X_1$, $R_3 + X_3$	0.097 + j0.686	Ω
$R_2 + X_2$, $R_4 + X_4$	0.140 + j1.033	Ω
Load	**Value**	**Unit**
$Load_1$	41.2 + j1.885	Ω
$Load_2$	10.3 + j1.885	Ω
$Load_3$	20.6 + j1.885	Ω
$Load_4$	30.9 + j1.885	Ω
SFCL	**Value**	**Unit**
Material	YBCO	
Manufactured form	Thin film	
Critical current	19	A
Critical temperature	87	K
Shunt resistance	6.9	Ω

For the comparative analysis in consideration of the different installation number of the SFCL in each candidate for the application location of the SFCL, one representative SFCL's application location near the fault point was selected respectively, which was indicated with the filled rectangular box as shown in Fig. 1. The detailed specifications of the components comprising the simulated power distribution system were shown in Table I. The detailed fabrication process of the SFCL using YBCO thin film was described in references [8-10].

3. Experimental Results and Discussions

Fig. 2 shows the current of the fault feeder (i_{F1}), the currents of the 2^{nd} side of two main transformers (i_{tr1}, i_{tr2}) and the bus voltage (v_{bus}) including the voltage across the

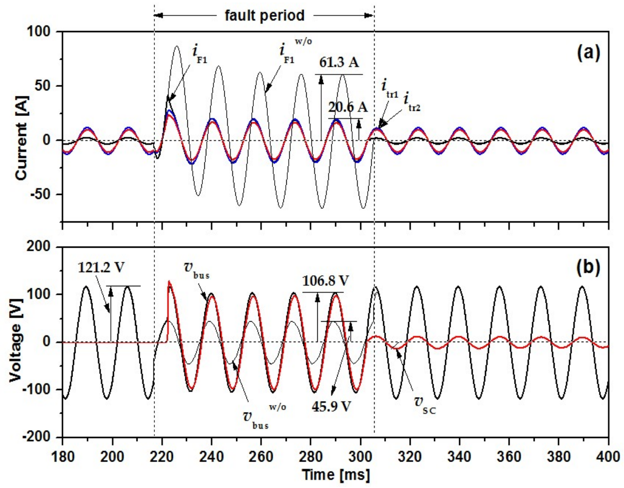

Fig. 2. Current and voltage waveforms in a power distribution system with a SFCL installed in the outgoing point of the fault feeder: (a) Currents of the fault feeder and two main transformers; (b) Bus voltage and voltage across SFCL

SFCL (v_{SC}) in case that the fault removes 5 periods after the fault occurs in a power distribution system with a SFCL installed in the outgoing point of the fault feeder. For comparative analysis, the current of the fault feeder ($i_{F1}^{w/o}$) and the bus voltage ($v_{bus}^{w/o}$) in case that the fault occurred in a power distribution system without the SFCL were displayed together with the narrow line.

As seen in Fig. 2, the excess of the fault current over the critical current of the SFCL immediately after the fault occurrence has brought about its fast limiting operation, which had have the initial peak value of the fault current to be limited largely. About 5 periods after the fault occurs, the fault current can be observed to be limited into 20.6 A from 61.3 A, which corresponds to the amplitude of the fault current in a power distribution system without the SFCL. In addition, the bus-voltage can be seen to be kept to be 106.8 V from 121.2 V in a normal time, not falling down into 45.9 V ($v_{bus}^{w/o}$), which occurs in a power distribution system without the SFCL as shown in Fig. 2(b).

As the other application location of the SFCL, in case that the SFCL was applied into the 2^{nd} side of the main transformer comprising the power distribution system, the fault current limiting and the bus-voltage sag suppressing characteristics of the SFCL were analyzed as shown in Fig. 3. Among the current components from two main transformers contributed to the total fault current, the current only from the transformer Tr_2 (i_{tr2}) can be seen to be limited by the SFCL installed in the 2^{nd} side of the Tr_2 and, on the other hand, the current from the transformer Tr_1 (i_{tr1}) not limited, which is expected to be effectively limited through the application of another SFCL into the 2^{nd} side of the main transformer Tr_1. Unlike the fault current, the bus-voltage (v_{bus}) during the fault period in case of the SFCL's application into the 2^{nd} side of the main transformer can be seen to be not suppressed, which is rather more dropped into 35.1 V compared to 45.9 V ($v_{bus}^{w/o}$) in a power distribution system without the SFCL. From above analysis, the suppression of the bus-voltage sag in case that the SFCL was applied into the 2nd side of the main transformer in a power distribution system could be confirmed to be not improved, which agreed with the previous studies by us [5].

As the third candidate location for the SFCL's application in a power distribution system, the bus line was selected and the fault current limiting and the bus-voltage sag suppressing effects by the SFCL were investigated, and the analysis results obtained from the short-circuit tests for the third candidate location of the SFCL were shown in Fig. 4. On the contrary to the case that the SFCL was applied into

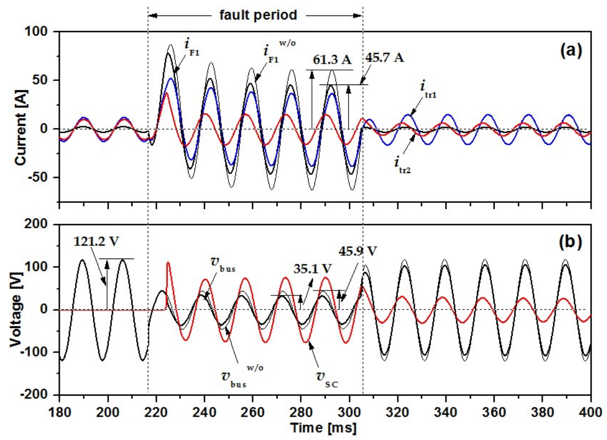

Fig. 3. Current and voltage waveforms in a power distribution system with a SFCL installed in the 2nd side of one main transformer: (a) Currents of the fault feeder and two main transformers; (b) Bus voltage and voltage across SFCL

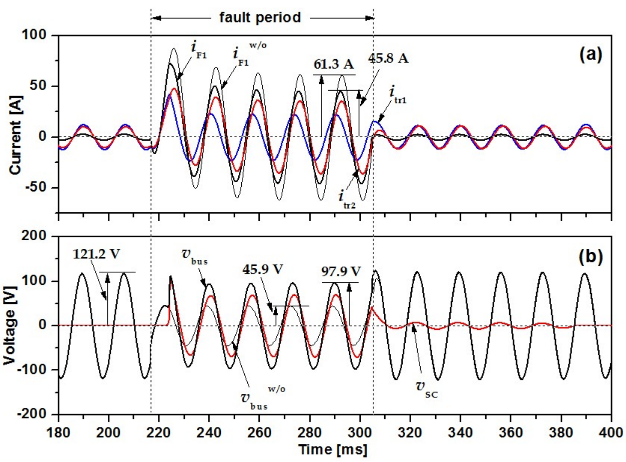

Fig. 4. Current and voltage waveforms in a power distribution system with a SFCL installed in the bus line between two main transformers: (a) Currents of the fault feeder and two main transformers; (b) Bus voltage and voltage across SFCL

the 2nd side of the main transformer (Tr_2) as described in Fig. 3(a), the current only from the transformer Tr_1 (i_{tr1}) can be seen to be limited by the SFCL as seen in Fig. 4(a). The bus-voltage (v_{bus}), which is required to be not deviated from the rated voltage, could be seen to be suppressed through the application of the SFCL into the bus line in a power distribution system, and the bus-voltage (v_{bus}) five periods after the fault happens as shown in Fig. 4(b) could be observed to be kept to be 97.9 V, not dropped into 45.9 V($v_{bus}^{w/o}$), which corresponds to the case without the SFCL.

As the last application location of the SFCL, the SFCL was applied into the neutral line of the main transformer, which was previously suggested by us as more effective application location for the quench and recovery operation of the SFCL [11]. Fig. 5 shows the current and the voltage waveforms in a power distribution system with a SFCL installed in the common neutral line of the 2nd side of two main transformers. The fault current in the fault feeder (i_{F1}) can be seen to be divided into two equal currents of the 2nd side of main transformers (i_{tr1}, i_{tr2}) and limited into 48.8 A after 5 periods since the fault occurs as seen in Fig. 5(a). The bus-voltage (v_{bus}) in case that the SFCL was applied into the common neutral line of the main transformers, however, was not suppressed but dropped into 37.0 V as indicated in Fig. 5(b), which was rather more dropped compared to the case without the SFCL ($v_{bus}^{w/o}$, 45.9 V). On the other hand, the recovery of the SFCL into the superconducting state after the fault removed, which could be analyzed from the voltage across the SFCL (v_{SC}), could be observed to be most quickly operated compared to the other location.

From above analysis, the suppression of the bus-voltage sag through the application of the SFCL into the common neutral line of the 2nd side of two main transformers could be confirmed to be not effective, which is similar to the

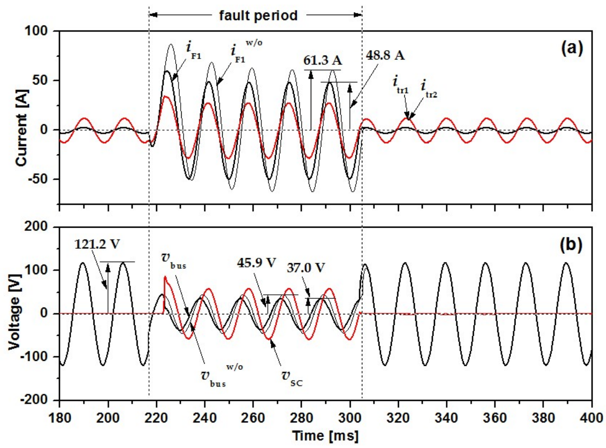

Fig. 5. Current and voltage waveforms in a power distribution system with a SFCL installed in the common neutral line of the 2nd side of two main transformers: (a) Currents of the fault feeder and two main transformers; (b) Bus voltage and voltage across SFCL

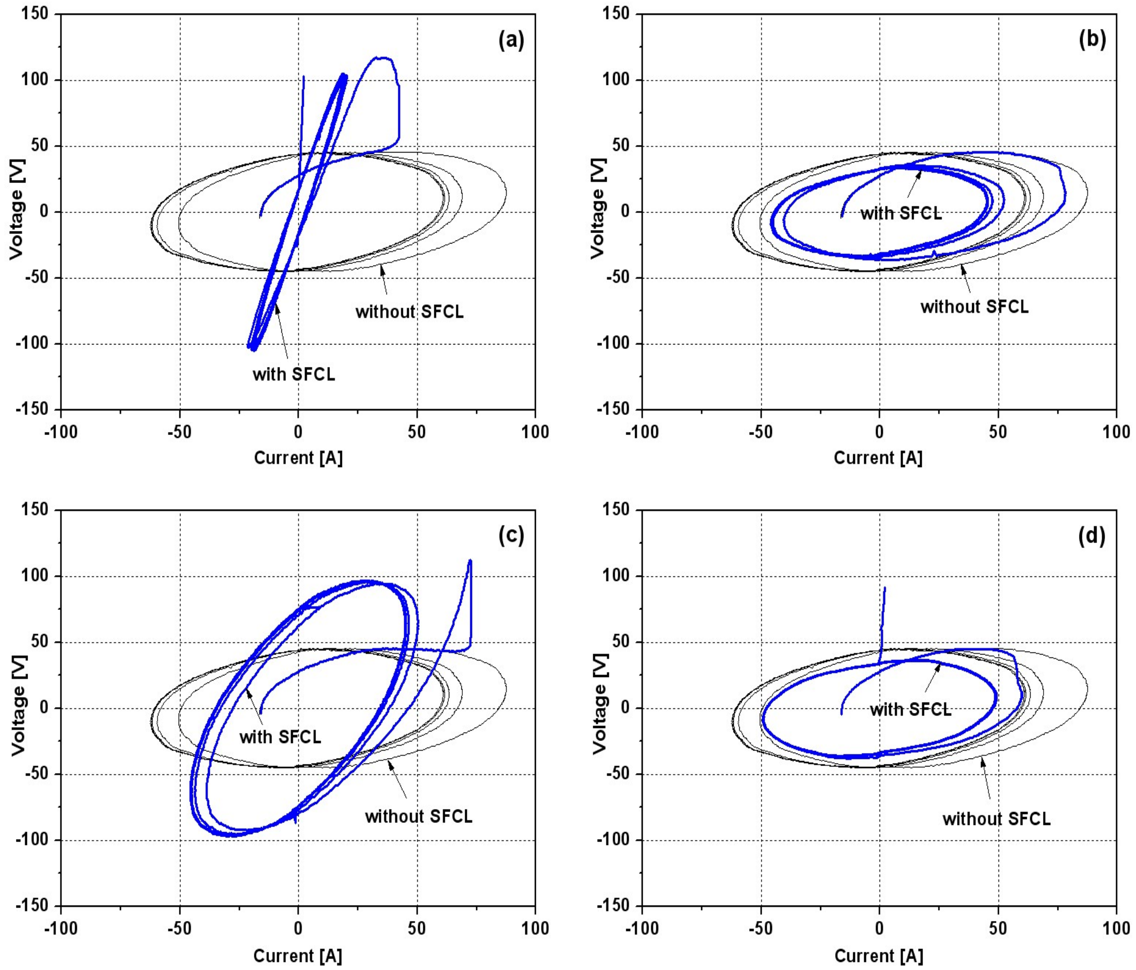

Fig. 6. Trace variations of bus-voltage and fault-feeder current during the fault period in case that the SFCL is installed in (a) the outgoing point of the fault feeder; (b) the 2nd side of one main transformer; (c) the bus line between two main transformers; (d) the common neutral line of the 2nd side of two main transformers

case that the SFCL was applied into 2^{nd} side of the main transformer Tr_2 as analyzed in Fig. 3(b).

For the comparison of both the fault current limiting and the bus-voltage sag suppressing operations of the SFCL with the case without the SFCL in each its application location in a power distribution system, the trace of the bus-voltage and the fault-feeder current during the fault period in each application location of the SFCL was examined and displayed in Fig. 6 together with the case without the SFCL.

As compared in Fig. 6, through the application of the SFCL into the outgoing point of the fault feeder (Fig. 6(a)) and the bus line (Fig. 6(c)), both the fault current limiting and the bus-voltage sag suppressing operations by the SFCL could be analyzed to be more effectively performed, especially, most effectively performed in case of the application of the SFCL into the outgoing point of the fault feeder. However, for the application of the SFCL into either the 2nd side of the main transformer (Fig. 6(b)) or the common neutral line of the main transformers' 2nd side (Fig. 6(d)), the fault current only could be observed to be effectively limited. For the effective suppression of the bus-voltage sag together with the limitation of the fault current, in case that the SFCL was applied into either the 2nd side of the main transformer or the common neutral line of the main transformers' 2nd side, the additional installation of the SFCL into other location such as the outgoing point of the fault feeder or the bus line is thought to be inevitable.

4. Conclusion

In this paper, as the typical application locations of the SFCL in a power distribution system, the outgoing point of the feeder, the bus line, the common neutral line and the 2nd side of the main transformer were selected and, the simulated power distribution system, which was comprised of four feeders and two main transformers operated in parallel, was constructed and the short-circuit tests for the simulated power distribution system with SFCL in its each location were executed.

Through the short-circuit tests for the simulated power distribution system with the SFCL applied in its each location, the bus-voltage sag suppressing and the fault current limiting operations of the SFCL were compared. Through the analysis on the short-circuit tests due to the application location of the SFCL in a power distribution system, the most effective application locations of the SFCL in a power distribution system were discussed from the viewpoints of both the suppression of the bus-voltage sag and the limitation of the fault current and the SFCL applied into the outgoing point of the fault feeder among its application locations in a power distribution system could be analyzed to most effectively perform both the bus-voltage sag suppressing and the fault current limiting operations.

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References

[1] H. Kadoe and M. Ichikawa, "Performance of a high-Tc superconducting fault current limiter-design of a 6.6 kV magnetic shielding type superconducting fault current limiter," *IEEE Trans. Appl. Supercon*., vol. 7, no. 2, pp. 993-996, Jun. 1997.

[2] S. H. Lim, J. C. Kim, and B. W. Lee, "Improvement of Recovery Characteristics of a Flux-Lock Type SFCL Using a Superconductor's Trigger," *IEEE Trans. Appl. Supercon*., vol. 2010, no. 3, pp. 1182-1185, Jun. 2010.

[3] S. H. Lim and I. K. You, and J. C. Kim, "Study on peak current limiting characteristics of a flux-lock type SFCL using its third winding," *IEEE Trans. Appl. Supercon*., vol. 21, no. 3, pp. 1275-1279, Jun. 2011.

[4] I. K. You, S. H. Lim, and J. C. Kim, "Operational Characteristics of Hybrid SFCL with First Half Cycle Non-Limiting Operation Considering Its Design Parameter," *IEEE Trans. Appl. Supercon*., vol. 21, no. 3, pp.1271-1274, Jun. 2011.

[5] J. S. Kim, S. H. Lim, and J. C. Kim, "Analysis on fault current limiting and bus-voltage sag suppressing operations of SFCLs using magnetic coupling of two coils according to their application locations in a power distribution system," *Phys. C*, vol. 471, pp. 1358-1363, Oct. 2011.

[6] J. F. Moon, S. H. Lim, J. C. Kim, and S. Y. Yun, "Assessment of the Impact of SFCL on Voltage Sags in Power Distribution System," *IEEE Trans. Appl. Supercon*., vol. 21, no. 3, pp. 2161-2164, Jun. 2011.

[7] S. H. Lim, Y. S. Cho, H. S. Choi, and B. S. Han, "Improvement of current limiting capability of HTSC elements in hybrid type SFCL," *IEEE Trans. Appl. Supercon*., vol. 17, no. 2, pp. 1807-1810, Jun. 2007.

[8] S. H. Lim and J. C. Kim, "Quench and recovery characteristics of series-connected resistive type SFCLs with magnetically coupled shunt-reactors," *IEEE Trans. Appl. Supercon*., vol. 18, no. 2, pp. 729-732, Jun. 2008.

[9] S. H. Lim, "Operational characteristics of flux-lock type SFCL with series connection of two coils," *IEEE Trans. Appl. Supercon*., vol. 17, no. 2, pp. 1895-1898, Jun. 2007.

[10] S. H. Lim, "Study on current limiting characteristics of SFCL with two trigger current levels," *Phys. C*, vol. 470, pp. 1631-1635, Oct. 2010.

[11] S. H. Lim, J. C. Kim, J. F. Moon, S. B. Rhee, C. H. Kim, and O. B. Hyun, "Quench and Recovery Characteristics of a SFCL Applied Into Neutral Line of a Three-Phase Power System," *IEEE Trans. Appl. Supercon*., vol. 19, no. 3, pp.1835-1838, Jun. 2009.

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