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초전도 한류기를 주변압기 접지선에 설치시 배전계통의 순간전압품질 분석

Voltage Quality Analysis in Power Distribution System with Superconducting Fault Current Limiter at Grounding Line

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Abstract – In this paper, voltage quality improvement is analyzed in case of Superconducting Fault Current Limiter (SFCL) installed in grounding line of main transformer in power distribution system. First, a resistive-type SFCL model is used. Next, Korean power distribution system is modeled. Finally, when SFCL is installed in the starting point of feeder and grounding line of main transformer, voltage qualities are evaluated according to various fault locations and resistance values of SFCL using PSCAD/EMTDC. The voltage quality results in case of grounding line are compared with the voltage in case of feeder.

Key Words : Grounding line, Power distribution system, Superconducting fault current limiter, Voltage quality

1. Introduction

Superconducting Fault Current Limiter (SFCL) has been developed in the world and applied to substation of power distribution system in Korea. SFCL can limit the fault current in power system using the increased resistance caused by quenching characteristics of superconducting elements. In addition, SFCL can improve voltage quality not only in faulted phase but in non-faulted phase when a 1 phase to ground fault is occurred.

The assessment method of voltage sag using the Information of Technology Industry Council curve is presented in Reference [1] when SFCL is applied to power distribution system. The parallel connection of radial systems via the SFCL which can make voltage dips less severe is presented in Reference [2]. The improvement of voltage sags caused by decreased fault current is presented in References [3] and [4]. These studies dealt with the voltage sags in the power distribution system with SFCL. However, voltage quality such as voltage sag and overvoltage in faulted and non-faulted phase has been not dealt with.

In this paper, we assess the impact of SFCL on voltage quality when SFCL is installed in the starting point of feeder and grounding line. In Section 2, a resistive-type SFCL used in this paper is explained. In Section 3, power distribution system model is explained. In Section 4, we evaluate the voltage quality of each case according to the fault location and resistance of SFCL. In conclusions, finally, we propose the location of SFCL considering voltage quality.

2. Superconducting Fault Current Limiter

Many types of SFCL has been developed such as resistive-type, reactive-type, hybrid-type, and so on. In this paper resistive-type of SFCL is used because this model can decrease fault current effectively [1]. The used resistive-type SFCL model is represented as eq. (1) where R_n and T_F represent the impedance being saturated at normal temperature and time constant, respectively[1,5-11]. Also t_0, t_1, and t_2 represent quench-starting time, the first recovery-starting time, and the secondary recovery-starting time, respectively.

$$R(t)=\begin{cases} 0 & (t<t_0) \\ R_n\left[1-\exp\left(-(t-t_0)/T_F\right)\right]^{1/2} & (t_0 \le t < t_1) \\ a_1\left(t-t_1\right)+b_1 & (t_1 \le t < t_2) \\ a_2\left(t-t_2\right)+b_2 & (t \ge t_2) \end{cases} \tag{1}$$

Fig. 1 represents quenching and recovery characteristics of the SFCL modeled by PSCAD/EMTDC using equation (1) and Table 1 represents the related parameters

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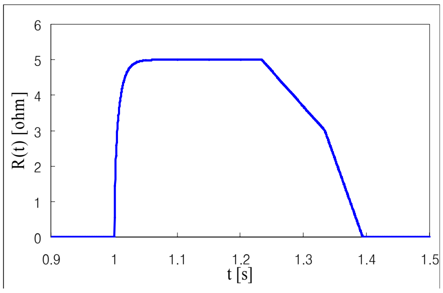


Fig. 1 Quenching and recovery characteristics of SFCL

Table 1 Parameters of modeled SFCL

Parameter	R_n [Ω]	T_F	a_1 [1/s]	a_2 [1/s]	b_1 [Ω]	b_2 [Ω]
Value	variable	0.01	-80	-160	R_n	$R_n/2$

3. Power Distribution System for Assessment of Voltage Quality

Fig. 2 represents a conventional power distribution system in Korea. Transmission system of 154[kV] is connected to distribution system of 22.9[kV] through main transformer of 45[MVA]. The connection of main transformer is △-Y. The Circuit Breaker (CB) is operated by Over Current Realy (OCR, 50) and Over Current Ground Relay (OCGR, 51)

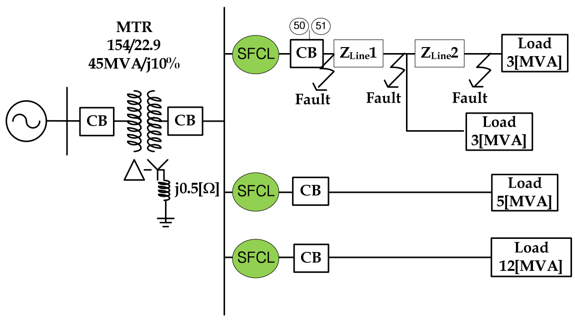


Fig. 2 Power distribution system with SFCL in starting point of feeder

When a 1 line-to-ground fault is occurred, OCGR decides to the fault and trips the CB. However, the fault current is very large. Thus, the secondary side of transformer has grounding line with j0.5[Ω] to decrease fault current when a 1 line-to-ground fault occurred.

Until now, the location of SFCL is proposed to the starting point of feeder or the secondary side of main transformer in many papers. Thus, we first install the SFCL to the starting point of feeder.

Fig. 3 represents the power distribution system with SFCL in grounding line of main transformer eliminating the SFCL of feeder.

Generally, 1 line-to-ground fault make up for about 70-80% of the entire faults. Thus, if the SFCL in grounding line can effectively limit the fault current caused by 1 line-to-ground fault, SFCL installed in feeder can be eliminated and the number of the eliminated SFCL of 3 phases is about 7-10 in each substation. In the study hereafter, we select the location of SFCL; the starting point of feeder limiting fault current for all types of faults or the grounding line of main transformer limiting fault curret for 1 lint-to-ground fault. Also these problems are related economic analysis.

Table 2 represents the power distribution system data used in case studies

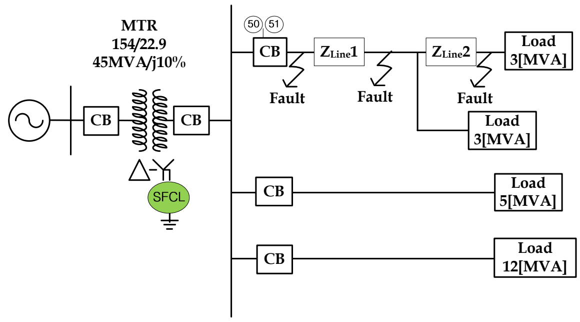


Fig. 3 Power distribution system with SFCL in grounding line of main transformer

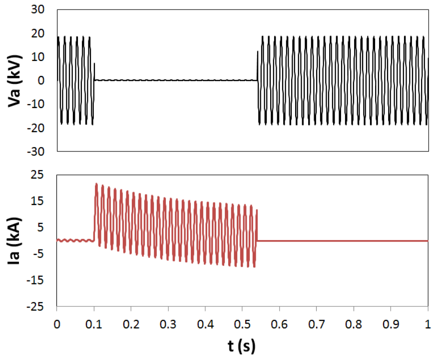
Table 2 Power distribution system data

	Data
Source	154 [kV], 100 [MVA], j4 [Ω]
M. Tr	154/22.9 [kV], 45 [MVA], j10 [%]
Line impedance	Z0=10.8+j23.6 [%/km]
	Z1=3.48+j7.44 [%/km]
Line length	F1 : 0, 3, 6 [km]
Load	F1 : 3 [MVA], 3 [MVA] F2 : 5 [MVA] F3 : 12 [MVA]

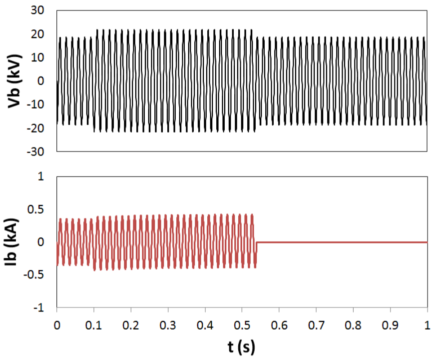
4. Voltage Quality Analysis through Case Studies

Total 9 cases of contingency analysis are studies. Case 1, 2, and 3 are faults without SFCL. Case 4, 5, and 6 are faults with SFCL at starting points of feeders. Case 7, 8, and 9 are faults with SFCL at grounding line. All cases are 1 line-to-ground faults of 0, 3, and 6 km from the secondary bus. Fig. 4 represents the voltage and current waveform of (a) faulted line (b) non-faulted line when a 1 line-to-ground fault is occurred at 0 km from the bus.

At Fig. 4, when a 1 line-to-ground fault is occurred at



(a) Faulted line



(b) Non-faulted line

Fig. 4 Voltage and current waveform for fault at 0 km without SFCL (Case 1)

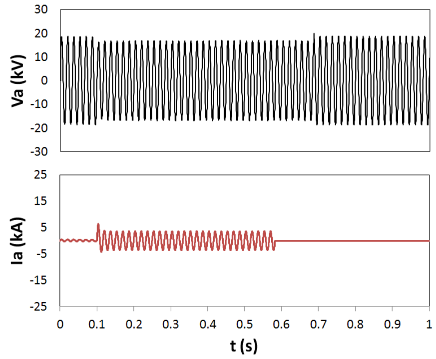
phase a, the fault current flows and the voltage becomes 0 (temporary interruption) at faulted line. Also, the voltage at non-faulted line increases (overvoltage).

Fig. 5 and 6 represent case 4 and 7, respectively; the voltage and current waveform of (a) faulted line with SFCL of 5 [Ω] at feeder (b) non-faulted line with SFCL of 5 [Ω] at grounding line when a 1 line-to-ground fault is occurred at 0 km from the bus.

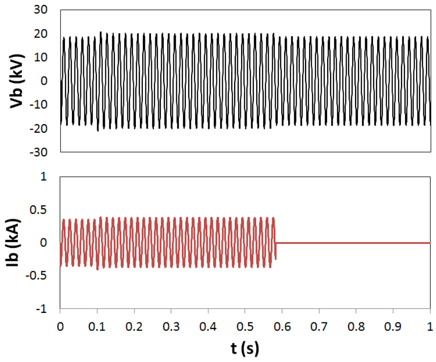
At Fig. 5, the voltage at faulted line comes to increase compared to case 1 (voltage sag) and the voltage at non-faulted line comes to decrease (overvoltage) because of SFCL of 5 [Ω] at feeder

The voltage and current waveform in case of SFCL installed at grounding line as Fig. 6 is similar to Fig. 5 with SFCL at feeder.

That is, both the voltage sag at faulted line and the overvoltage at non-faulted line are improved cording to the resistance value of SFCL rather than the location of SFCL. It is represented at Fig. 6. Fig. 7 represents the RMS value of voltage at faulted and non-faulted line according to resistance of SFCL when a 1 line-to-ground

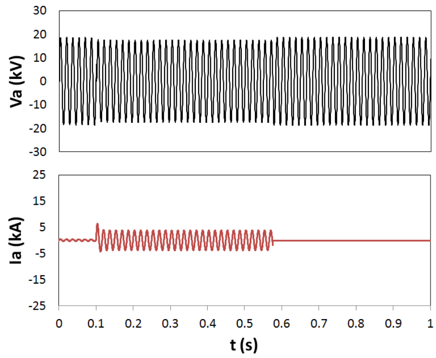


(a) Faulted line

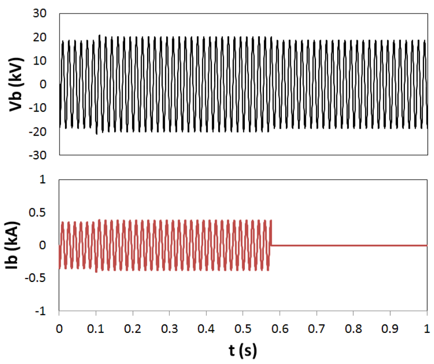


(b) Non-faulted line

Fig. 5 Voltage and current waveform for fault at 0 km with SFCL of 5 [Ω] at feeder (Case 4)

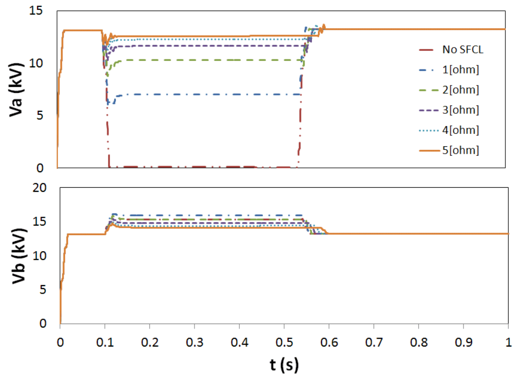


(a) Faulted line

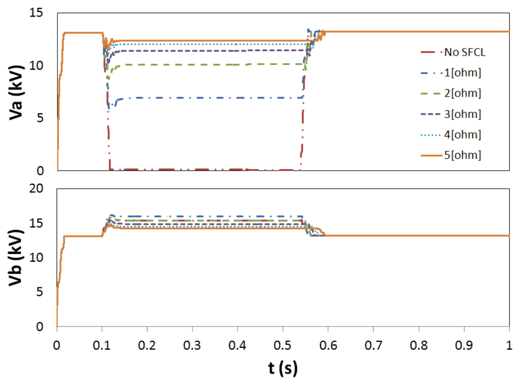


(b) Non-faulted line

Fig. 6 Voltage and current waveform for fault at 0 km with SFCL of 5 [Ω] at grounding line (Case 7)



(a) SFCL installed at feeder



(b) SFCL installed at grounding line

Fig. 7 RMS voltage for fault at 0 km according to the resistance value of SFCL

is occurred at 0 km from bus in case of (a) SFCL at feeder (b) SFCL at grounding line

Table 3~6 represent the voltage at faulted and non-faulted line according to resistance of SFCL and fault location when SFCL is installed in feeder and ground line. Where, sag represents the remaining voltage.

Above tables, the voltage sag and overvoltage are improved according to the resistance of SFCL. However,

Table 3 Voltage of faulted line at fault location of 0 km from bus

SFCL	Grounding line		Feeder		Error
Voltage at faulted line	Voltage [kV]	Sag [%]	Voltage [kV]	Sag [%]	
No SFCL	0.1	0.7	0.1	0.7	0.0
1[ohm]	6.9	52.4	7.0	53.2	-0.8
2[ohm]	10.1	76.5	10.3	78.0	-1.5
3[ohm]	11.4	86.4	11.6	88.1	-1.7
4[ohm]	12.0	91.0	12.3	92.8	-1.8
5[ohm]	12.4	93.6	12.6	95.2	-1.7
Normal	13.2	100	13.2	100	

Table 4 Voltage of non-faulted line at fault location of 0 km from bus

SFCL	Grounding line		Feeder		Error
Voltage at non-faulted line	Voltage [kV]	Over-voltage [%]	Voltage [kV]	Over-voltage [%]	
No SFCL	15.4	116.2	15.4	116.2	0.0
1[ohm]	16.0	120.7	16.0	120.7	0.0
2[ohm]	15.4	116.5	15.4	116.3	0.2
3[ohm]	14.9	112.5	14.8	112.0	0.4
4[ohm]	14.5	109.6	14.4	109.1	0.6
5[ohm]	14.2	107.7	14.2	107.1	0.7
Normal	13.2	100	13.2	100	

Table 5 Voltage of faulted line at fault location of 6 km from bus

SFCL	Grounding line		Feeder		Error
Voltage at faulted line	Voltage [kV]	Sag [%]	Voltage [kV]	Sag [%]	
No SFCL	9.84	71.3	9.84	71.3	0.0
1[ohm]	10.30	74.7	10.35	75.0	-0.4
2[ohm]	10.76	78.0	10.85	78.6	-0.7
3[ohm]	11.16	80.9	11.28	81.8	-0.9
4[ohm]	11.49	83.2	11.64	84.3	-1.1
5[ohm]	11.75	85.2	11.92	86.4	-1.2
Normal	13.2	100	13.2	100	

Table 6 Voltage of non-faulted line at fault location of 6 km from bus

SFCL	Grounding line		Feeder		Error
Voltage at non-faulted line	Voltage [kV]	Over-voltage [%]	Voltage [kV]	Over-voltage [%]	
No SFCL	13.80	104.4	13.80	104.4	0.0
1[ohm]	13.83	104.6	13.83	104.6	0.1
2[ohm]	13.83	104.6	13.81	104.5	0.1
3[ohm]	13.80	104.4	13.77	104.2	0.2
4[ohm]	13.76	104.1	13.72	103.8	0.3
5[ohm]	13.72	103.7	13.67	103.4	0.3
Normal	13.2	100	13.2	100	

the location of SFCL does not influence on voltage sag and overvoltage. The maximum error is only 1.7 %.

5. Conclusions

In this paper, voltage quality such as voltage sag and overvoltage is analyzed in power distribution system with SFCL at the starting point of feeder and grounding line of secondary side of main transformer at substation according to resistance value of SFCL when a 1 line-to-ground fault is occurred.

Fault current is decreased and voltage quality is improved as fault is occurred far from bus. That is, when a fault is occurred at starting point of feeder, fault current, voltage sag, and overvoltage are maximized. If SFCL is installed at feeder, fault current is decreased and voltage quality is improved as the resistance of SFCL is increased. Furthermore, the decreasing of fault current and the improvement of voltage quality is approximately equal to the case of SFCL installed in grounding line.

Thus, to prevent the 1 line-to ground fault, which make up for about 70-80% of faults, SFCL installed at ground line is more effective than SFCL at feeder. Also, SFCL installed at ground line is one-phase, whereas SFCL installed at feeder is three-phase. In future studies, it should be considered that various types of faults, protective coordination, and so on.

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