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Optimum Coordination of Overcurrent Relays with Active Superconducting Current Controller in Distribution Systems

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Abstract *– The Active Superconducting Current Controller (ASCC) is a new type of Fault Current Limiters which can limit the fault current in different modes and also has the particular abilities of compensating active and reactive power for AC main circuit in the normal state. The use of the ASCC disturbs the operation of Over Current Relays (OCR) used in the distribution system. In this paper, an optimum method is proposed for protective coordination of OCR when the ASCC is applied in the system and operates in different modes. By adjusting the magnitude and phase angle of compensation current and also by adjusting the setting parameters of OCR such as Time Dial and Pick up Current in the optimum values, the protective coordination is obtained. By using MATLAB, the model of the distribution system with the ASCC is built and the impact of this type of FCL on the over current relays protection is studied in detail under different current-limiting modes.*

Keywords: *Superconducting fault current limiter, Voltage compensation, Over current relay, Power distribution system.*

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INTRODUCTION

With the increase of power demand in recent years, the structure of power network is more complicated and the short circuit capacity may be increased which can damage to the circuit breakers and other equipment used in the power system. The fault current limiters (FCL) are suitable equipment's to solve these problems and to reduce the fault current to appropriate level [1]. The Active SCC based on voltage series compensating is a novel typology of SFCL that can limit the fault current in different levels by controlling the magnitude and phase angle of compensation current. Fig. 1 shows the circuit structure of the three phase ASCC, which is consisting of three air-core superconducting transformers and a three-phase voltage source converter. The primary winding of the superconducting transformers is connected in series with the main circuit and the second winding is connected through a voltage source converter [2-4].

In this paper the ASCC is used to decrease the short-circuit current due to the replacement of the main power transformer with higher capacity transformer in Power Distribution System. However, decrease of fault current in different levels influences the over current relays used in the system and impedes the operation of these relays.

An optimum method is proposed for protective coordination of OCR when the ASCC is applied to network and operates in different modes. By adjusting the magnitude and phase angle of compensation current and also by adjusting the setting parameters of OCR such as Time Dial(TD) and Pick up Current (Ip) through analysis on the TCC curves the protection coordination of ASCC under the different current limiting modes is done and the results are confirmed using the simulation by MATLAB.

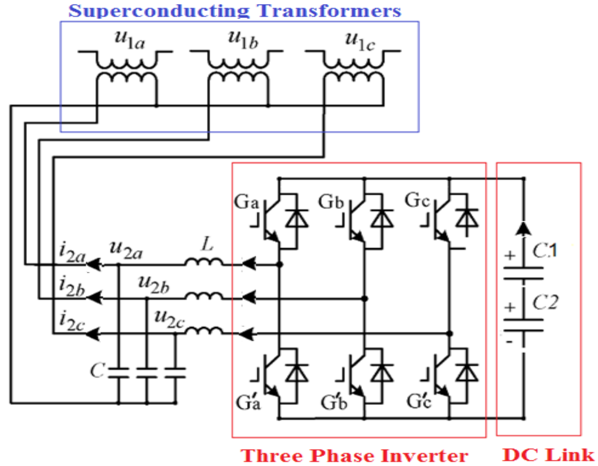

Fig. 1 - The structure of the three-phase ASCC

STRUCTURE AND PRINCIPLE OF THE ASCC

The structure of a distribution system with ASCC is shown in Fig. 2. The OCR installed at the secondary side of the main transformer to generate the trip signals for circuit breakers [5].

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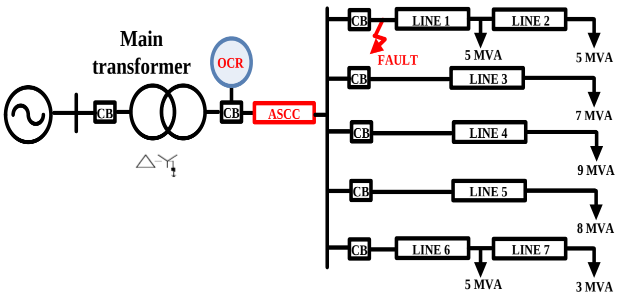

Fig. 2 - Schematic configuration of distribution system

Taking phase A for an example to study, in normal state and in per unit, Eq. (1) can be achieved [6-7].

$$U_{SA} = (Z_S + Z_{Tr})i_{1a} + u_{1a} + Z_{eq}i_{1a} \quad (1)$$

That:

$$u_{1a} = j\omega L_{S1}i_{1a} - j\omega M_S i_{2a} \quad (2)$$

In normal operation mode, the primary voltage must be compensated to zero $j\omega L_{S1}i_{1a} - j\omega M_S i_{2a} = 0$. Therefore, the Active SFCL will have no influence on main circuit, and i_{2a} can be set as:

$$i_{2a} = \frac{L_{s1}}{M_S} i_{1a} = \frac{L_{s1}}{M_S}\left(\frac{u_{SA}}{Z_S + Z_{Tr} + Z_{eq}}\right) \quad (3)$$

When the Three-phase fault happens, the primary current and voltage and the secondary voltage of the superconducting transformer will increased to i_{1af} , u_{1af} and u_{2af} respectively:

$$i_{1af} = \frac{u_{SA} + j\omega M_S i_{2a}}{Z_S + Z_{Tr} + j\omega L_{S1}} \quad (4)$$

$$u_{1af} = \frac{u_{SA}(j\omega L_{S1}) - (j\omega M_S)(Z_S + Z_{Tr})i_{2a}}{Z_S + Z_{Tr} + j\omega L_{S1}} \quad (5)$$

$$u_{2af} = (j\omega M_S)\left(\frac{u_{SA} + (j\omega M_S)i_{2a}}{Z_S + Z_{Tr} + j\omega L_{S1}}\right) \quad (6)$$

The limiting impedance of Active SFCL (Z_{ASCC}) can be obtained in Eq. (7):

$$Z_{ASFCL} = \frac{u_{1af}}{i_{1af}} = j\omega L_{S1} - \frac{j\omega M_S i_{2a}(Z_S + Z_{Tr} + j\omega L_{S1})}{u_{SA} + j\omega M_S i_{2a}}$$

(7)

According to the Eq. 4 by regulating the amplitude and phase angle of i_{2a} , there are three operation modes: [8]

Mode1: Making i_{2a} remain the original state, and

$$Z_{ASCC-1} = \frac{(Z_{eq}\, j\omega L_{S1})}{(Z_S + Z_{Tr} + Z_{eq} + j\omega L_{S1})} \quad (8)$$

Mode2: Controlling the amplitude of i_{2a} to zero, and

$$Z_{ASCC-2} = j\omega L_{S1} \quad (9)$$

Mode3: Regulating the phase angle of i_{2a} to make the angle difference between u_{SA} and $j\omega M_S i_{2a}$ be 180^0 by setting: $j\omega M_S i_{2a} = -Ku_{SA}$

$$Z_{ASCC-3} = \frac{K}{1-K}(Z_S + Z_{Tr}) + \frac{1}{1-K} j\omega L_{S1} \quad (10)$$

Modeling of Overcurrent Relay

For the modeling of OCR to protect the power distribution system, the operational equations of OCR can be obtained as follows:

$$Time_{trip} = \left(\frac{A}{M^P - 1} + B\right) * TD \quad (11)$$

$$\text{That: } M = \frac{I_{input}}{I_{pickup}} \quad (12)$$

In the above equation A, B and P are constants which are determined based on the type of relay. In this paper the constants are decided by U.S. Very inverse type and shown in Table 1. According to equation 12 the multi-rate of current (M) is made up of I_{input} and I_{pickup}, that I_{input} is equal to fault current and I_{pickup} is one of the setting parameters of OCR. TD is the other setting parameter of OCR that is set for protective coordination [9-11].

Simulation Using MATLAB

To investigate the impact of the ASCC on the fault current limiting and OCR operation, the model shown in Fig. 2 is created in MATLAB. The detailed parameters of the distribution system and the setting values of the OCR are shown in Tables 1.

Fig. 3 shows curves of fault current without Active SFCL in the case of 45MVA and 100MVA transformers are used in power distribution system, when the setting of OCR is equal. In the case of 45MVA transformer, the OCR is set to operate in 0.4 seconds. After the replacement of the 100MVA transformer, the fault current will increase and the relay operating time is reduced to 0.16 seconds.

According to equation 13, to meet protection coordination without changing in the setting parameters of OCR, the fault current in the presence of 45MVA transformer must be equal to the fault current in presence of 100MVA transformer with Active SFCL.

$$\frac{u_{SA} - u_{1A}}{Z_S + Z_{Tr2}} = \frac{u_{SA}}{Z_S + Z_{Tr1}} \quad (13)$$

Table 1
Detailed specifications of distribution system and OCR

Z_{SFCL}	U_A (KV)	I_A (KA)	U_a (KV)	I_a (KA)
0.697i	9.13 ∠3	7.56 ∠-87	0.54 ∠-177	0.59 ∠-87

TABLE 2
SETTING OF ASCC TO PROTECTION COORDINATION WITH OCR

Configuration Components	Parameters
Source	154KV , 1.75%
Transformer	Before:154/22.9(KV),45MVA , j15[%] After:154/22.9(KV),100MVA , j20[%]
Distribution Line	Z_0=8.68+j22.86[%] , [100MVA] Z_1=Z_2 =3.48+j7.44[%] , [100MVA]
Loads	Feeder1: 10MVA , pf=0.95 Lag Feeder2:7MVA , pf=0.95 Lag Feeder3:9MVA , pf=0.95 Lag Feeder4:8MVA , pf=0.95 Lag Feeder5:8MVA , pf=0.95 Lag
Over Current Relay	Load Current: 1.13[KA_{rms}] Full Load Current: 1.51[KA_{rms}] Pickup Current of Time Delay Operation: 2.1[KA_{rms}] Lever: 1
	Parameters of very inverse type OCR: A=3.88, B =0.0963 , P =2, TD=0.4
SFCL Parameters	L_{s1}=L_{s2}=5mH , M_s=4mH

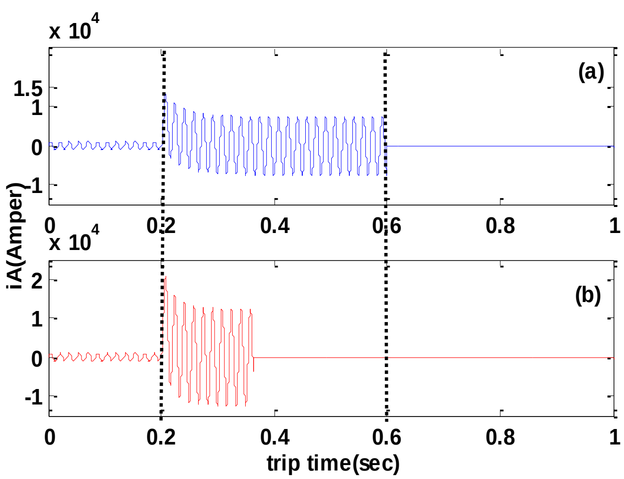

Fig. 3 - Fault current without SFCL.
(a) with45MVAtransformer; (b)with100MVAtransformer

The Primary and secondary voltage and current values of the superconducting transformer with limiting impedance to protection coordination without changing in the setting parameters of OCR are given in Table 2.

The comparison of the fault current waveforms without SCC and with SCC in the operation modes are shown in Fig. 4. According to Fig. 4, it can be seen that mode3 shows the best effect of current limiting. Figure 5 shows the superconducting transformer Characteristics in presence of the Active SCC, from time t=0.2s to t=0.23s (time delay for action of PWM converter and fault detection), the line current limited to 8078 A by current limiting mode 1, from time t=0.23s to t=0.4s by setting the phase angle of compensating current (I_a) to 90 the fault current limited to 6637 A by current limiting mode 3. The values of the SCC parameters when the fault occurs at the point F in Figure 2 are expressed in Table 3.

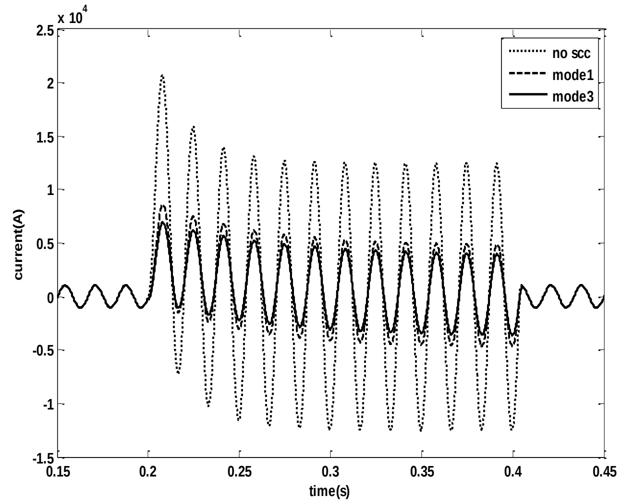

Fig. 4 - The comparison of the fault current characteristics

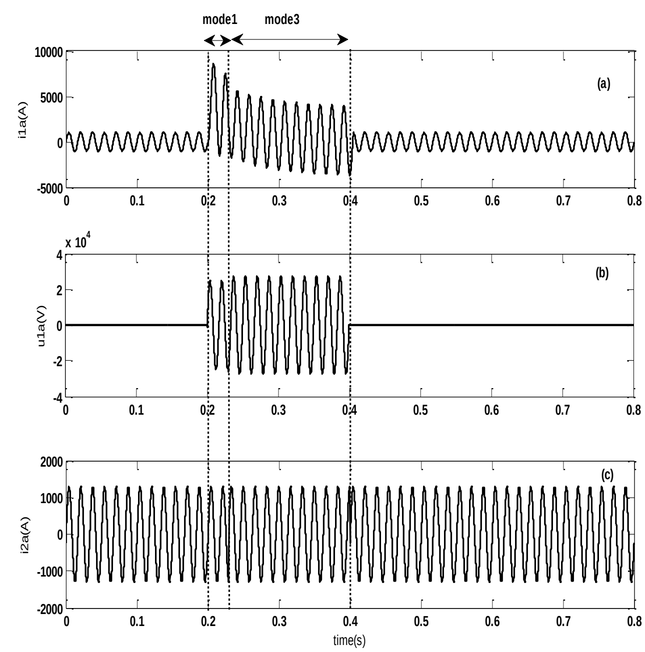

Fig. 5 - Waveforms of primary and secondary currents and voltages of superconducting transformer (a-Primary current, b-Primary Voltage, c-secondary current)

THE VALUES OF THE SCC PARAMETERS

The Time-Current Curve (TCC) of OCR in this case is shown In Fig. 6.

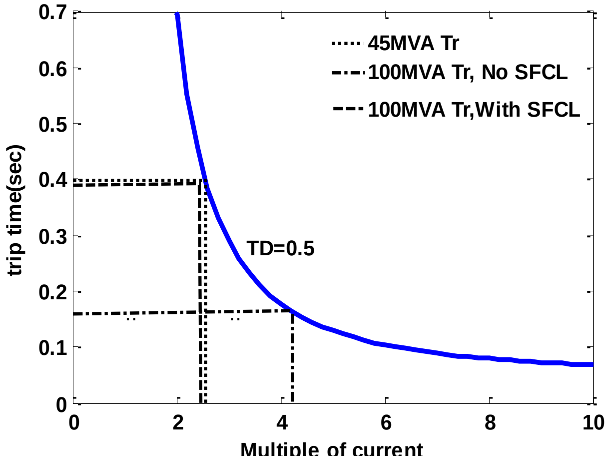

Fig. 6 - Time current curve In case that the ASCC impedance was modified to meet the coordination time

TABLE 3

	u_A	i_A	Zscc	Ia
Mode1	0.63∠-2.8	1.85∠-80.2	0.074+0.33j	0.513∠-10.84
Mode2	0.64∠1.8	1.79∠-88.2	0.359j	0
Mode3	0.69∠1.42	1.52∠-88.2	0.003+0.46j	0.513∠90

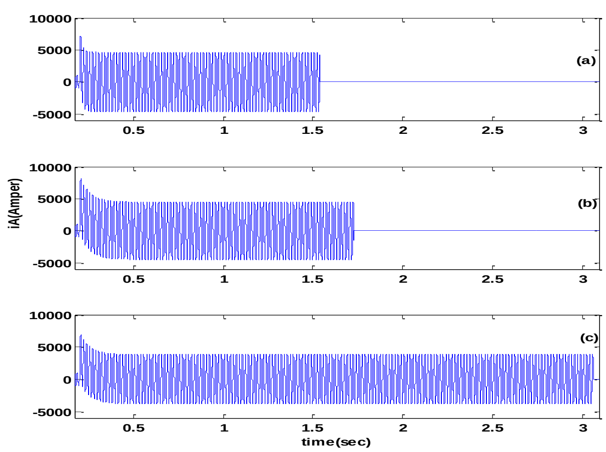

Fig. 7 - Fault current in presence of ASCC (a) mode1, (b) mode2, (c) mode3

Fig. 7 shows waveforms of fault current after replacement of the 100MVA transformer when the SFCL was applied into the power test grid and operate in modes 1, 2 and 3.

When the SFCL operates in mode1 (Fig. 5-a) the multi-rate was decreased to 1.58 and the operation time of OCR was increased to 1.34s. In mode2 and mode3, the multi-rate also decreased to 1.52 and 1.3 respectively and the operation time of OCR increased to 1.53s and 2.86s respectively. The Time Current Curves of OCR with the operation points by applying the SFCL in different operation mode are shown in Fig. 8.

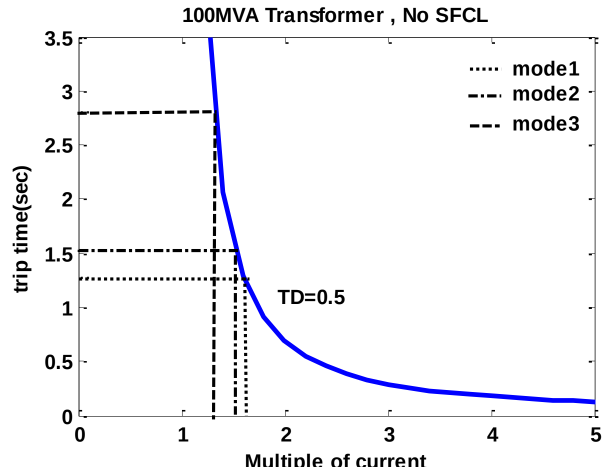

Fig. 8 - Time current curve In case that the ASCC was operated in mode1, mode 2 and mode 3

Figures 9 and 10 show the TCC of the OCR With different values of TD when the Active SFCL operate in mode 1 and mode 2. To meet the protection coordination in mode1 and mode 2, the modification of TD value from "0.5" to "0.1" is needed. The operation times of OCR in this case are reduced to 0.27s and 0.3 s respectively.

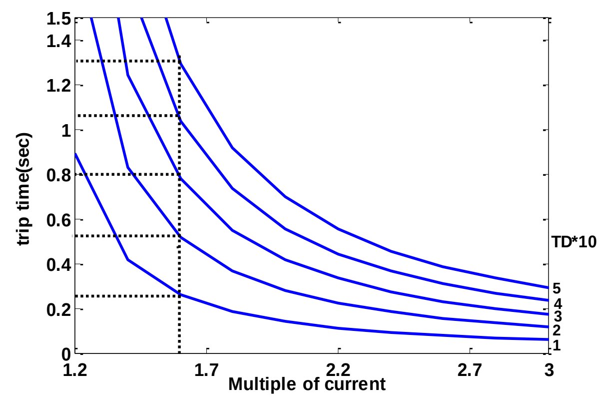

Fig. 9 - Time current curves in case that the TD was adjusted to meet the coordination time in mode1

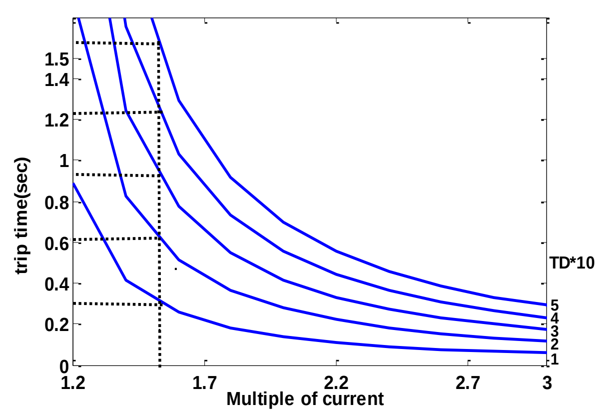

Fig. 10 - Time current curves in case that the TD was adjusted to meet the coordination time in mode 2

When the ASCC operates in mode 3, with modification of the TD value to "0.1" the operation time of OCR is decreased to 0.57s, thus in this mode the other technique for protection coordination is reduction of the pickup current of relay. According to Fig. 11 when the TD value of the OCR is modified from "0.5" to "0.1" and the Pickup current modified from "2.1" to "1.9", the protection coordination in three operation modes is confirmed.

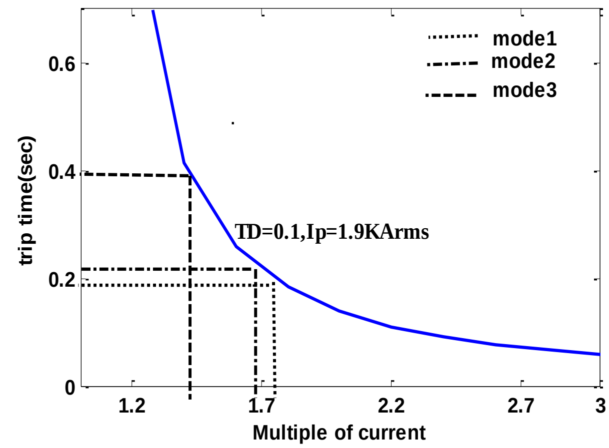

Fig. 11 - Time current curves in case that the TD and Ip were adjusted to meet the coordination time in mode 3

Fig. 12 shows the optimal coordination by modifying both setting parameters of OCR in three operation modes. According to the Figure 10 with modification of the TD and Pick up Current value to "0.2" and "1.9" respectively, the optimal coordination in mode1 and mode2 are confirmed. The optimal coordination in mode3 is confirmed with modification of the TD and Pick up Current value to "0.1" and "1.9" respectively.

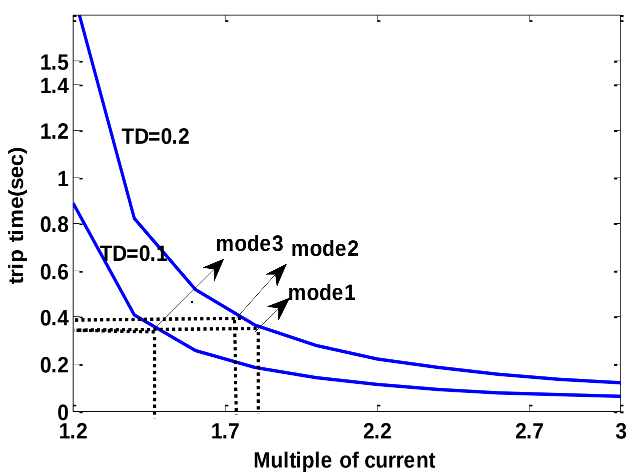

Fig. 12 - The optimal coordination in three operation modes

The trip time of OCR based on the different setting parameters values of OCR (TD, Ip) are shown in table 4.

. TABLE 4

OCR Parameters		MODE1	MODE2	MODE3
Ip=2.1 KArms	TD=0.5	tt=1.34s	tt=1.53s	tt=2.86s
	TD=0.4	tt=1.07s	tt=1.22s	tt=2.28s
	TD=0.3	tt=0.807s	tt=0.92s	tt=1.71s
	TD=0.2	tt=0.54s	tt=0.61s	tt=1.14s
	TD=0.1	tt=0.27s	tt=0.305s	tt=0.57s
Ip=1.9 KArm	TD=0.1	tt=0.19s	tt=0.2s	tt=0.38s
	TD=0.2	tt=0.38s	tt=0.4s	tt=0.76s

THE TRIP TIME OF OCR BASED ON DIFFERENT VALUES OF SETTING PARAMETERS OF OCR

CONCLUSIONS

In this paper the active superconducting fault current limiter type of series voltage compensation is introduced to reduce the fault current when the main transformer is replaced with a higher capacity transformer and the effects of this compensator on Overcurrent Relay protection in a Power Distribution System is investigated. In the first step, for the protection coordination of OCR without changing in the setting parameters of OCR, by setting the Secondary winding current of superconducting transformer the range of the impedance of Active SFCL is obtained. In second step, the optimal values of Time Dial and Pick up Current for the optimal protection coordination are obtained through analysis of TCC curves in three operation modes of Active SFCL. The results show that the optimal coordination is confirmed with modification of the both TD and Pick up Current value in three operation modes.

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