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NEW ACTIVE TYPE OF SFCL DURING UNBALANCED FAULTS ALLOCATED IN INCOMING AND OUTGOING FEEDERS OF DISTRIBUTION NETWORKS

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Abstract- As a practical solution, this paper aims to introduce and compare Superconducting Fault Current Limiter (SFCL), the new type named active-type SFCL and conventional resistive-type; it especially refers to unbalanced Faults. Active-type SFCL is a type of Superconducting Fault Current Limiter that has been recently introduced. Proposed SFCL type is consisted of air-core superconducting transformer and PWM converter. Impact of two types of SFCLs during unbalance faults is performed through MATLAB/SIMULINK. This paper focused on the new active-type SFCL for specification of current limiting behavior including limiting period, Index of fault reduction and distortions. Even more important than of investigation of new active-type specification, using of combinational approach of resistive and new active-type SFCL together in outgoing feeders of distribution network provides acceptable values of current limiting. Simulation results illustrate the efficiency of the hybrid approach new active and resistive SFCL application in comparison with individual conventional type whenever they were placed in optimal allocation based on recent cited research of SFCLs.

Keywords: Distribution Network, Superconducting Fault Current Limiter (SFCL), Short Circuit Fault, Unbalanced Fault.

I. INTRODUCTION

Increasing the production capacity may lead to increased level of fault current in power systems. Also, increased fault current may impose additional expenses to the system [1]. When new resources are installed, proper utilization of SFCL can not only decrease the maximum fault current, but also improve the overall performance of the system [2-3]. In normal conditions, fault current limiter embeds negligible resistant to the network. When a fault is occurred, the Impedance of SFCL is rapidly increased and hence the fault current is decreased [4].

In recent years, SFCL has become a forefront topic in the technology of fault current limiters in the world. Various studies have been undertaken in the field of practice of some superconducting fault current limiter in distribution networks [5-7] and their comparison [8-9]. Suitable performance of fault current limiter depends on their speed and position. Changing the position of fault current limiters may lead to increase the transient of short circuit current. Hence, finding a suitable position for its installment has a great importance [10]. The Effect of active-type SFCL on the fault current and the over-voltage has been studied on a distribution network [11].

In this study, the effect of installing new type named active-type SFCL and the conventional resistive-type is studied in the existence of unbalanced faults. Also, by analyzing them in a distribution network, they are compared. Furthermore, by presenting a combinational structure, the effect of limiting the current of SFCL is evaluated in various positions.

II. PRELIMINARIES OF RESISTIVE AND NEW ACTIVE-TYPE SFCLs PERFORMANCE AND OPERATION

A. Resistive-Type SFCL

Due to simple structures, quick response and lack of requirement to foreign excitation, Superconducting fault current limiters are increasingly noted. These limiters work on superconducting materials from the superconducting state to normal state transition [12]. The transition from superconducting state to resistive state is possible to be achieved by three factors, current density, temperature and magnetic field. In the normal model of this limiter, with short circuit current from, due to the excess of temperature from critical temperature, the transition from superconducting state to normal state is done in several milliseconds. In its second type which is known as flux coupling, the feature current density increase is used for the transition the superconducting state to resistive state instead of heat. In this study the second type is simulated [5-7].

Flux-coupling type SFCL using transformer is consisted of coils and the current limiting element as shown in Figure 1. The primary coil of a flux-coupling type SFCL is connected in series with secondary coil and the secondary coil is also connected in parallel with the current limiting element [13].

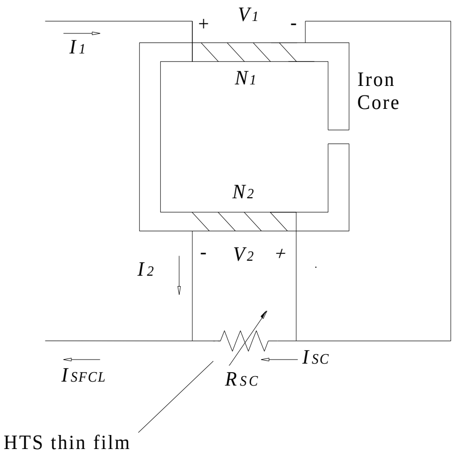


Figure 1. Basic configuration of Flux-coupling type SFCL [13]

B. Active-Type SFCL

The operation principle of this SFCL is similar to the fault current limiter based on flux compensation. Active-type SFCL introduces the new concept controlling the amplitude and the phase of the second winding's current, which can finally increase the limiting capacity of SFCL. The circuit structure of the active-type SFCL is shown in Figure 2, which is composed of an air-core superconducting transformer and a voltage-type PWM converter [11]. The air-core superconducting transformer has some advantages such as absence of iron losses and magnetic saturation, and it has greater possibility of reduction in size and weight than the conventional and the iron-core superconducting transformer. By neglecting the losses of the transformer, the active-type SFCL's equivalent circuit is shown in Figure 3 [11].

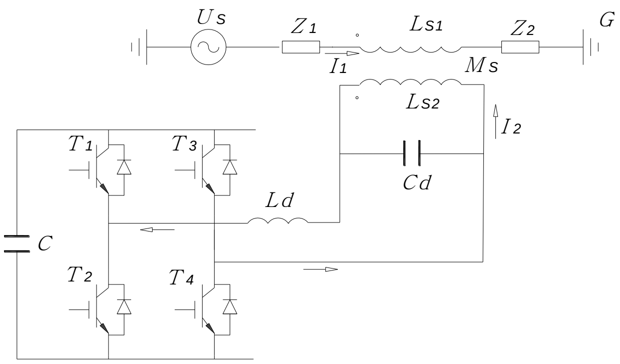


Figure 2. Circuit structure of active-type SFCL

In the case that there is no fault in network, active-type SFCL has no effect. In this case, Current I_2 in secondary winding of the transformer is controlled in a way that the magnetic field of air core would be zero. Considering the equivalent circuit, we have:

$$\dot{U}_s = \dot{I}_1(Z_1 + Z_2) + j\omega L_{s1}\dot{I}_1 - j\omega M_s \dot{I}_2 \tag{1}$$

$$\dot{U}_P = j\omega M_s \dot{I}_1 - j\omega L_{s2}\dot{I}_2 \tag{2}$$

Controlling I_2 to make $j\omega L_{s1}\dot{I}_1 - j\omega M_s \dot{I}_2 = 0$ and the primary voltage will be regulated to zero. $\left(Z_{SFCL} = U_1/I_1\right)$

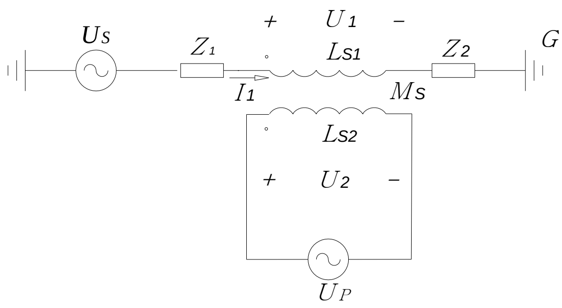


Figure 3. Equivalent circuit of active-type SFCL [11]

In fault state, current I_2 is controlled proportional to time in terms of amplitude or phase angle so that the initial voltage of series-installed superconducting transformer is controlled and hence reduces fault current. In this case Z_2 is short-circuited; from Equation (1):

$$\dot{I}_{1f} = \dot{U}_s + \frac{j\omega M_s \dot{I}_2}{Z_1} + j\omega L_{s1} \tag{3}$$

$$\dot{U}_{1f} = j\omega L_{s1}\dot{I}_{1f} - j\omega M_s \dot{I}_2 \tag{4}$$

$$Z_{SFCL} = \frac{U_{1f}}{I_{1f}} = j\omega L_{s1} - j\omega M_s \dot{I}_2 \left(\frac{Z_1 + j\omega L_{s1}}{\dot{U}_s + j\omega M_s \dot{I}_2} \right) \tag{5}$$

I_2 is indicated in different operating modes. They are as follows [11]:

1. I_2 in original state

$$Z_{SFCL-1} = Z_2 \left(\frac{j\omega L_{s1}}{Z_1 + Z_2 + j\omega L_{s1}} \right)$$

2. $I_2 = 0$

$$Z_{SFCL-2} = j\omega L_{s1}$$

3. Regulating the phase angle of I_2 to make the angle difference between $\dot{U}_s$ and $j\omega M_s \dot{I}_2$ be $180°$.

$$Z_{SFCL-3} = \left(\frac{cZ_1}{1-c} \right) + \left(\frac{j\omega L_{s1}}{1-c} \right)$$

The cost of making flux coupling type superconducting fault current limiter would increase considering the high volume of superconducting material. Also, these limiters have superconducting transformer with iron core [6]. In comparison with active-type SFCL, no transformer saturation is occurred in air core, and according to it, the linearity of Z_{SFCL} can be easily proved. Active-type superconducting fault current limiter with the air-core superconducting transformer has advantages such as lack of iron losses and magnetic saturation and possibility to decrease size, weight and more harmonic compared with iron core superconducting transformers.

III. MODELING TYPES OF ACTIVE AND RESISTIVE SFCLs

In Figure 4, the application of SFCL in a distribution network is demonstrated. In this network, an industrial load is 6 megavolts ampere, and each domestic load is 1 megawatt. Output power is reached to 20 kilovolt by a transformer and is connected to network.

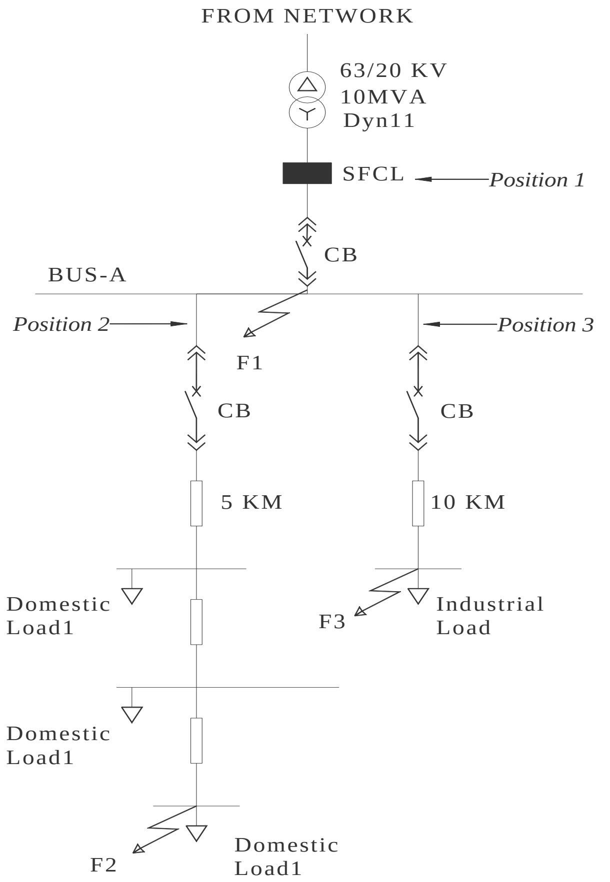


Figure 4. Circuit structure of SFCL in a distribution system

When a short-circuit fault occurs in the feeder, the first state is automatically activated in active-type SFCL, and the increasing rate of fault current is controlled. During switching, its amplitude is further limited. In the normal state of this model, SFCL resistant is minimized, but whenever the effective current of SFCL exceeds from triggering current (pre-determined), SFCL resistance is maximized after the duration of transition time to limit the fault current at a certain level. After the elimination of fault or the return of current to a certain level, the resistance of SFCL is then minimized after recovery time.

Compared with the common technologies of fault current limiters, SFCL can have quicker response time and shorter return time. Active-type SFCL has the ability of adjusting the response time as well.

In this model, by considering changing the position of SFCL and fault locations, special impacts of over-currents are analyzed and studied in computer simulations.

To analyze the limiter features, current and voltage, of SFCL, an active-type SFCL distribution system and also resistive-type SFCL, are shown in the Figures 1 and 2, are simulated by MATLAB software. Main parameters of the system are shown in Table 1.

To study this network, 3 scenarios are considered. Firstly, it is considered that active-type SFCL is installed in position 1. Next, the resistive-type SFCL is installed in position 1. Finally, to study the effect of positioning in SFCL, two SFCLs are simultaneously installed; active-type SFCL is placed in position 2, and resistive-type SFCL is placed in position 3, so that a comparison is made and its results are evaluated.

Table 1. Main simulation parameters of the system model [10-11]

Active-Type SFCL	
Primary Inductance	50 mH
Secondary Inductance	30 mH
Mutual Inductance	32.9 mH
Resistive-Type SFCL	
Transition or Response Time	2 ms
Minimum Impedance	0.01 Ω
Maximum Impedance	20 Ω
Triggering Current	270 A
Recovery Time	10 ms
Distribution Transformer	
Rated Capacity	10 MVA
Transformation Ratio	63/20 KV
Feeder Line	
Line Parameter	0.128+j0.098 Ω/km
Power Load	
Industrial Load	6 MVA
Each Domestic Loads	1 MW

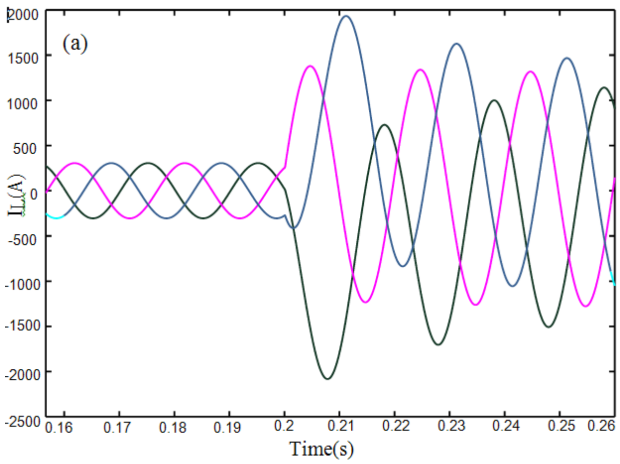
A. Analysis of Current Limiting Performance of Active-Type SFCL

To investigate the effect of fault current limiters, it is supposed that three-phase short-circuit current to ground is occurred $t=0.2$ seconds in F1, F2 and F3, respectively. As a result, Bus-A current curve is simulated without SFCL and with active-type SFCL in position 1, Figures 5, 6, and 7 illustrate the fault current waveforms in the mentioned positions.

Figures 5, 6, and 7 illustrate a comparison between fault current in SFCL-less state and with placing in power distribution network during occurrence of three-phase grounded fault in F1, F2 and F3 positions. During short-circuit occurs for positions F1, F2 and F3, fault current is decreased 43%, 41% and 47% respectively.

Figures 8, 9, and 10 illustrate the SFCL's current-limiting characteristics and the waveforms with and without active-type SFCL in the cases of two-phase-to-ground, phase to phase and single-phase-to-ground faults are initiated (F1 in Figure 4).

When a short circuit is occurred in F1, reduction in fault current in cases of two-phase-to-ground, phase to phase and single-phase-to-ground faults will be 50%, 51% and 22%, respectively.



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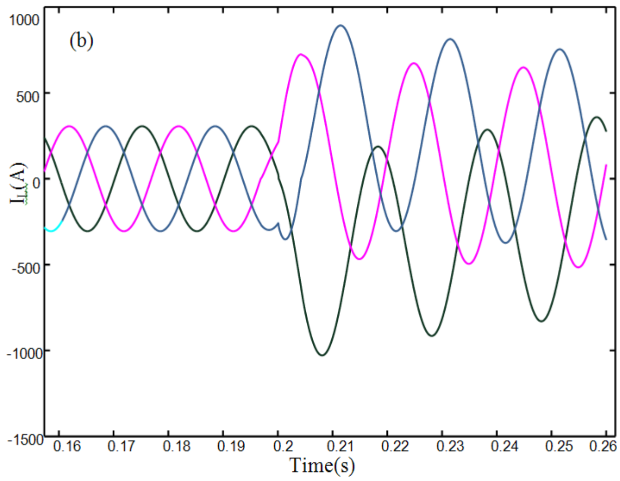
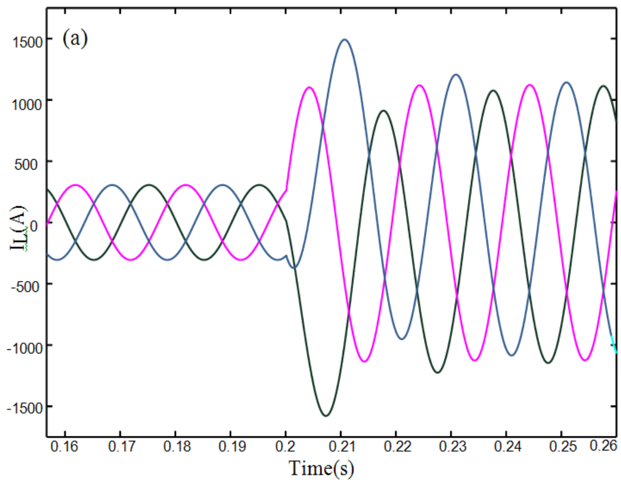


(b)

Figure 5. Current waveforms during the three-phase grounded short circuit occurs at F1 (a) Without SFCL (b) With active-type SFCL in position 1



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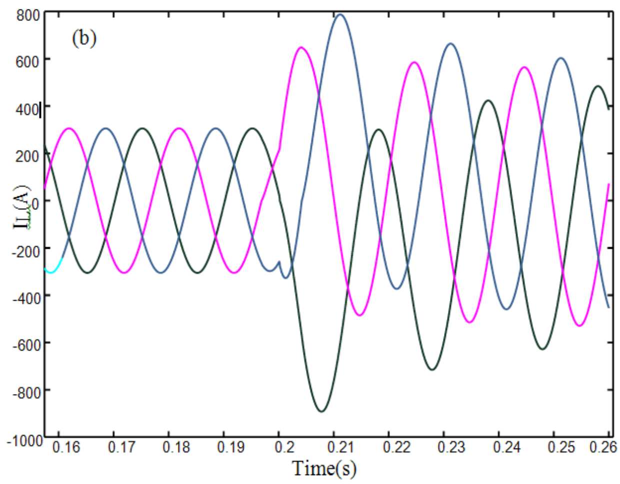

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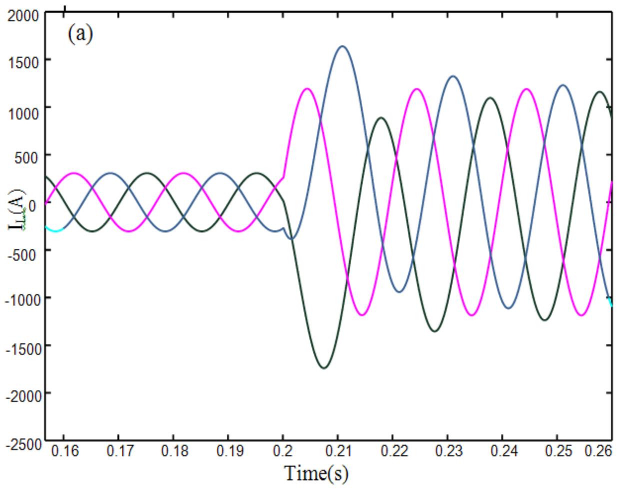
Figure 6. Current waveforms during the three-phase grounded short circuit occurs at F2 (a) Without SFCL (b) With active-type SFCL in position 1



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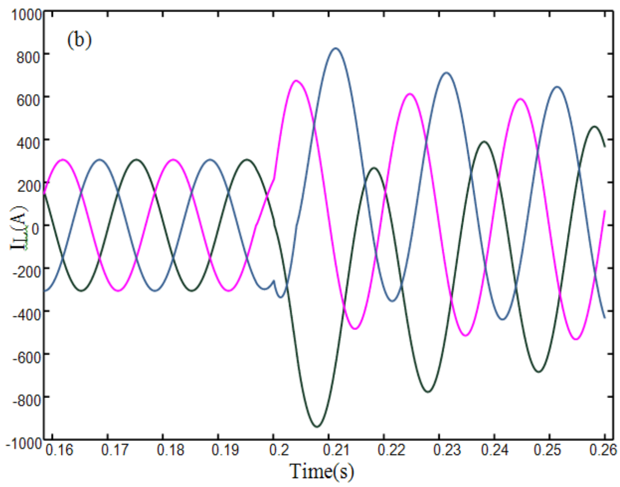
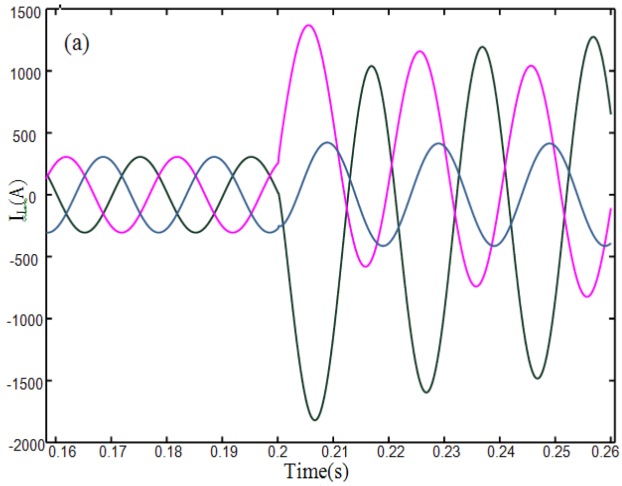


(b)

Figure 7. Current waveforms during the three-phase grounded short circuit occurs at F3 (a) Without SFCL (b) With active-type SFCL in position 1



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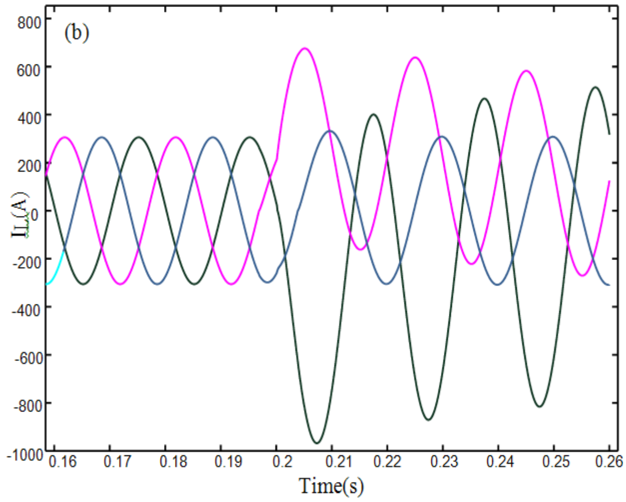
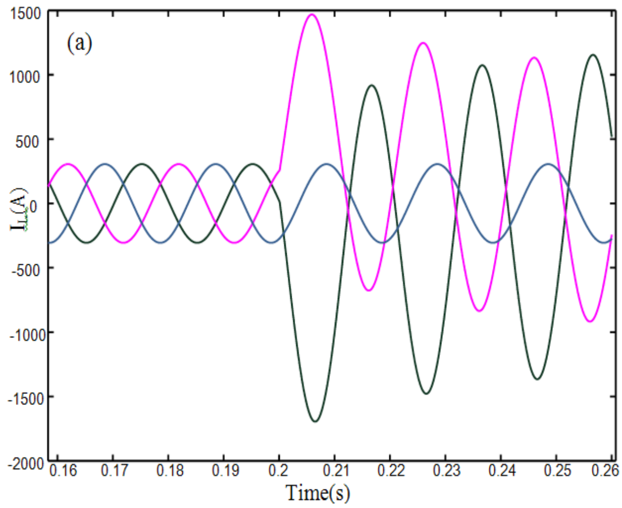


(b)

Figure 8. Current waveforms during the two-phase grounded short circuit occurs at F1 (a) Without SFCL (b) With active-type SFCL in position 1



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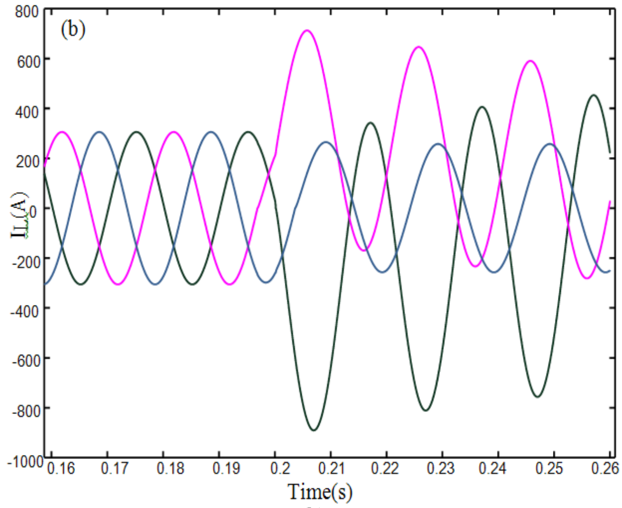
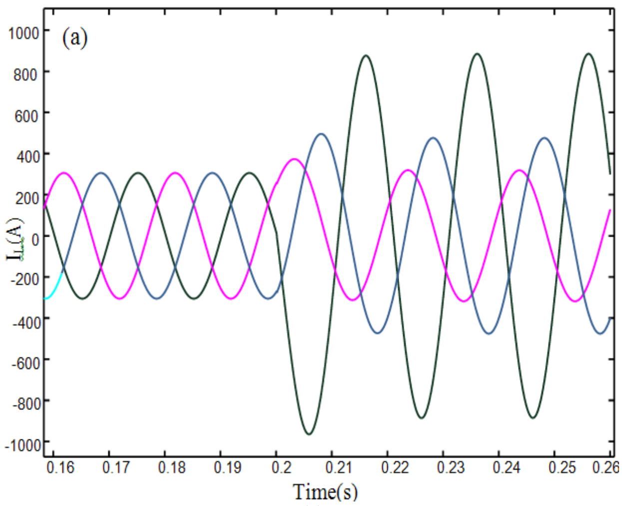


(b)

Figure 9. Current waveforms during the two-phase short circuit occurs at F1 (a) Without SFCL (b) With active-type SFCL in position 1



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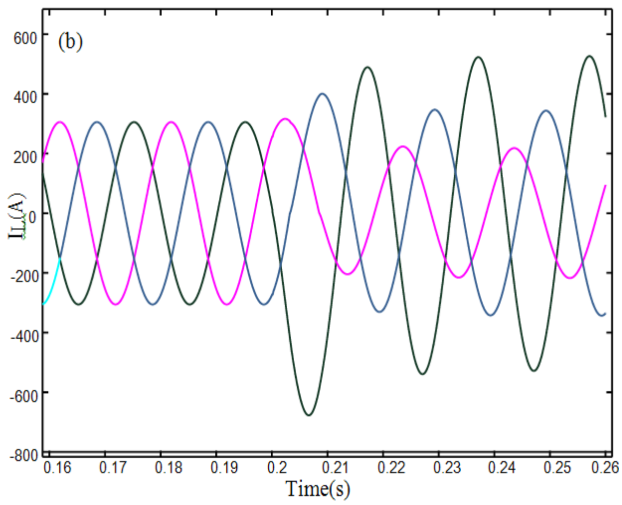

(b)

Figure 10. Current waveforms during the single-phase grounded short circuit occurs at F1 (a) Without SFCL (b) With active-type SFCL in position 1

B. Presentation of Combinational Structure: Current Limiting Performances in Active-Type and Resistive-Type SFCL in Simultaneous Usage in Various Positions

In this case, Bus-A current is simulated by considering simultaneous use of active-type SFCL in position 2, and resistive-type SFCL in position 3at a same time. Figures 10 and 11 indicate the performance of fault current limiters when the fault is in points F2 and F3.

The reduction rate of fault current in the case of simultaneous use active-type and resistive-type fault current limiters in comparison with lack of using a limiter in positions F2 and F3 are 38% and 21%, respectively.

Tables 2, 3 and 4 indicate the summary results of reducing fault current for sort of unbalanced faults. There are results in 3 different scenarios assessed active-type SFCL in position 1, resistive-type SFCL in position 2 and simultaneous active-type and resistive-type SFCL in positions 2 and 3, respectively.

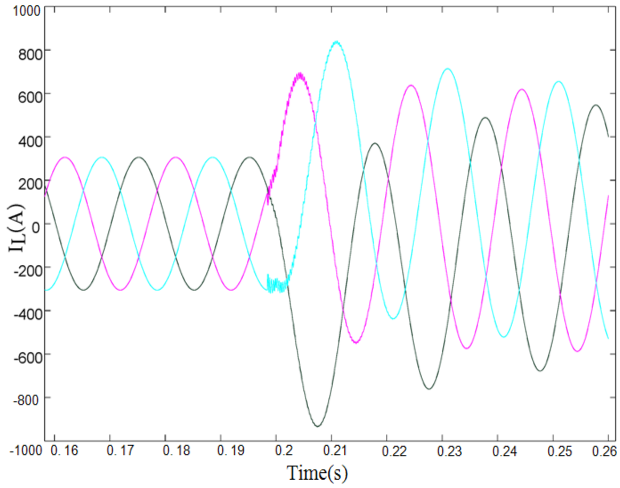

Figure 10. Current waveforms during the three-phase grounded short circuit occurs at F2 by considering simultaneous use of active-type SFCL in position 2, and resistive-type SFCL in position 3

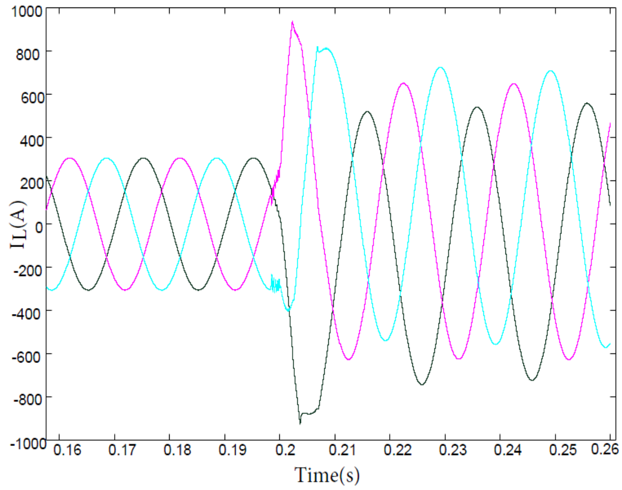

Figure 11. Current waveforms during the three-phase grounded short circuit occurs at F3 by considering simultaneous use of active-type SFCL in position 2, and resistive-type SFCL in position 3

Table 2. Reduction in fault current due to active-type SFCL in position 1

	SLG	LL	LLG	LLLG
F1	-22%	-51%	-50%	-47%
F2	-19%	-44%	-43%	-41%
F3	-21%	-47%	-46%	-43%

Table 3. Reduction in fault current due to resistive-type SFCL in position 1

	SLG	LL	LLG	LLLG
F1	+4%	-43%	-39%	-36%
F2	0	-31%	-27%	-25%
F3	+2%	-35%	-31%	-29%

Table 4. Reduction in fault current by considering simultaneous use of active-type SFCL in position 2, and resistive-type SFCL in position 3

	SLG	LL	LLG	LLLG
F2	-7%	-42%	-40%	-38%
F3	+1%	-26%	-22%	-21%

Analyzing the results indicate that active-type SFCL has a faster response time in comparison with the resistive-type, and reduces more fault current in first cycle. Furthermore, single-phase-to-ground fault current is not reduced in first cycle while using resistive-type SFCL. Also, by implementing active and resistive-type SFCL simultaneously in the early part of outgoing feeders, it can be concluded that the best case for installing fault current limiter is to place it in input feeder in position 1. On the other hand, since one of the component of fault current is an exponential decay DC wave which has an initial value directly proportional to fault angle. Different initial fault angles have different peak amplitude of short-circuit current as well.

IV. CONCLUSIONS

In this paper, the application of active-type and resistive-type SFCL in distribution network is studied and their performance is compared in terms of unbalanced faults. Results indicate higher limiting speed, improved damping during distortion, and less noise for new active-type limiters in comparison with the more conventional resistive-type. Additionally, reducing the distance of fault location and installment position improves the performance of fault current limiters. Also, results emphasis the best performance for fault current reduction of distribution network will be achieved if new active-type SFCL is placed in incoming feeder.

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