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Modeling of Active SFCL for Reduction of Fault Current and Over Voltages in Distribution System

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Abstract: The small renewable resources is becoming one of the major systems to generate electricity in distribution generation systems to feed electrical loads. Fault current level has become a major problem in distribution system operations. The effect of short circuit current and induced over voltages under abnormal conditions should be avoided for reliable operation .That abnormal conditions effect can be limited by applying an active type Super conducting Fault Current Limiter (SFCL) in distribution system. Effects of a voltage compensation type active SFCL on that abnormal conditions are studied through theoretical derivation and simulation. The active SFCL mainly consists of an air-core superconducting transformer and converter. During the study process, by changing the locations of the DG units and the fault locations, the current-limiting and overvoltage suppressing characteristics by active SFCL are simulated in MATLAB /SIMULINK. The simulation results show that the active SFCL can regulate the fault current and overvoltage in the presence of distributed generation, and it can nullify the damage of the distribution equipment and improve the system reliability and safety.

Keywords: Overvoltage suppressing, fault circuit current limitation, active SFCL (Superconducting Fault Current Limiter) and Distributed Generation.

I.INTRODUCTION

The government incentives accelerated the renewable energy sector growth in nation. Renewable energy source (RES) integrated with distribution systems at distribution level is named as distributed generation (DG). To fulfil present demand, distributed generation (DG) units are connected to conventional grid. This integration of distributed generation and grid not only effect on operation of distribution grid but also show effect on grid planning. If the introduction of DG is larger it causes increase in fault current level. With the increasing of short-circuit current of the power grid respective system equipments may damage. To restrain short-circuit current use of series reactor is feasible, but the introduction of series reactor having effect on the circuit breakers arc quenching performance.

For solving these difficulties SFCL has been introduced [1-4]. It is an element, inter-metallic compound or alloy that will carry out electricity with negligible resistance below a certain temperature. SFCL is new and an innovative fault current limiter. It works on the principle of Superconducting Property. It is in active under fault condition; it inserts some resistance into the line to limit the fault current. It is inactive under normal condition. It suppresses the fault current within first half cycle only. It operates greater than Circuit breakers, because the Circuit breaker takes minimum 2-3 cycles before they getting activated. The effect of SFCL on grid fault current observed. The optimal place to SFCL is determined. Next short circuit current limiting and over voltage suppressing characteristics of bus under faulted conditions with and without SFCL are to be studied.

II.MODELING OF ACTIVE SFCL

The main advantage of proposed active type SFCL technology is the ability to remain invisible to the grid under nominal operation, offering negligible impedance in the power system until any fault occurs. Ideally, once the limiting action is no longer require, that quickly returns to its normal low impedance state.

Fig.1 shows the circuit structure of three phase voltage compensation type SFCL, which consists of PWM converter and air core superconductingtransfomer. L_{s1}, $L_{s2}$are the self inductances of primary and secondary superconducting windings [5] [6]. M_s is the mutual inductance between two windings. Z_1 and Z_2 are the circuit and load impedances respectively. Converter results the higher order harmonics that are eliminated by using L_d and C_d in

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circuit. Since the voltage type converter's capacity of controlling power exchange is implemented by keeping up the voltage of AC side, the converter can be treated as a controlled voltage source U_p. To analyze the SFCL impedance values, equivalent circuit of the SFCL is drawn with neglecting the losses.
First, in normal state that is without any fault two equations can be achieved. Those equations are

$$\dot{U}_S = \dot{I}_1(Z_1 + Z_2) + jwL_{S1}\dot{I}_1 - jwM_S\dot{I}_2 \qquad (1)$$

$$\dot{U}_P = jwM_S\dot{I}_1 - jwL_{S2}\dot{I}_2 \qquad (2)$$

To control the I_2 the term $j\omega L_{s1}\dot{I_1} - j\omega M_s\dot{I_2} = 0$ in the equation1 make equal to zero, and the primary voltage of superconducting transformer U_1 will be controlled to zero. Thereby, SFCL limiting impedance Z_{SFCL} $(U_1/I_1)$is zero, and I_2 can be written as

$$\dot{I_2} = (\dot{U}_s\sqrt{L_{s1}/L_{s2}})/(Z_1 + Z_2)k$$

Where k is the coefficient of coupling and it can be shown as $k=Ms/\sqrt{L_{s1}L_{s2}}$.
When fault occurred ($Z_2$is shorted), the main current will rise to I_{1f} fromI_1, and the primary voltage will increase toU_{1f} from U_1.

$$\dot{I}_{1f} = \frac{\dot{U}_S + jwM_S\dot{I}_2)}{(Z_1 + jwL_{S1})}$$

$$\dot{U}_{1f} = jwL_{S1}\dot{I}_{1f} - jwM_S\dot{I}_2$$

$$= \frac{\dot{U}_S(jwL_{S1}) - \dot{I}_2Z_1(jwM_S)}{Z_1 + jwL_{S1}}$$

The SFCL current-limiting impedance (Z_{SFCL})can be controlled in:

$$Z_{SFCL} = \frac{\dot{U}_s}{\dot{I}_{1f}} = j\omega L_{s1} - \frac{j\omega M_s\dot{I_2}(Z_1 + j\omega L_{s1})}{\dot{U}_s + j\omega M_s\dot{I_a}}$$

According to the difference in the regulating objectives of I_2, there are three operation modes:
1) Making I_2 remain the original state, and the limiting impedance
$Z_{SFCL-1}=Z_2\,(j\omega L_{S1})/(Z_1+Z_2+j\omega L_{S1})$.
2) Controlling I_2 to zero, and
$Z_{SFCL-2}=j\omega L_{s1}$
3) Reducing the phase angle of I_2 to make the angle difference between $\dot{U}_S$ and $jwM_S\dot{I}_2$ be 180^0.By setting $jwM_S\dot{I}_2 = -c\dot{U}_S$, and
$Z_{SFCL-3}=\frac{cZ_1}{1-c} + \frac{j\omega L_{s1}}{(1-c)}$

The advantages of air-core superconducting transformer over iron-core superconducting transformer are absence of iron losses and magnetic saturation, air core has more possibility of reduction in size, weight and harmonic [7], [8]. The air-core transformer can be more suitable for working as a shunt reactor because of the large magnetizing current [9], and it can be used in an inductive pulsed power supply to decrease energy loss for larger pulsed current [10]. In the air core saturation does not exist and linearity of ZSFCL is well.

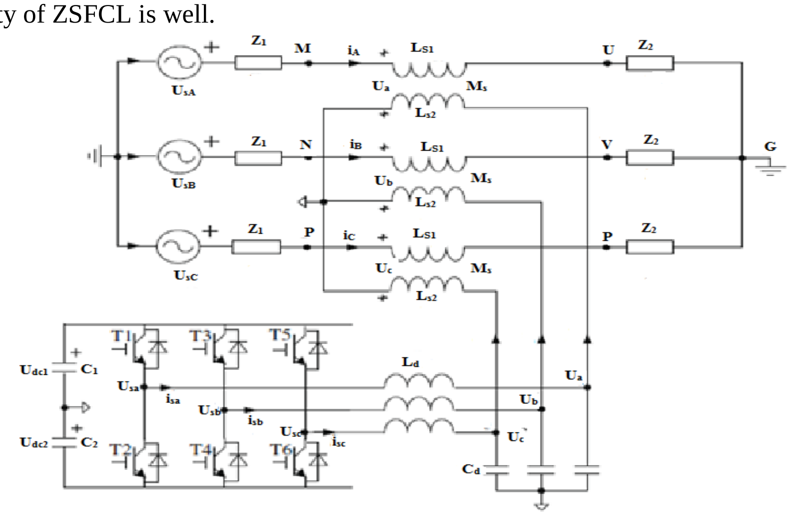

Fig.1.Line diagram Three-phase active type SFCL.

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III.DISTRIBUTION SYSTEM WITH ACTIVE TYPE SFCL

Fig.2 shows proposed distribution system line diagram with distributed generating systems including active type SFCL. The application of the active SFCL in a distribution network with number of DG units, and probable installation locations of DG units at buses B,C,D,E. When a single-phase ground fault occurs in distribution system feeder line 1 (phase A, k_1 point), the SFCL's mode 1 can be automatically triggered, and the fault current's increasing rate can be timely controlled. Along with the different mode switching, its amplitude can be limited further. In consideration of the active type SFCL's effects on the overvoltage, the analysis is presented.

Furthermore, by changing locations of the distribution generation units connected into the distribution system and the fault positions, effects of the SFCL on the fault current and overvoltage may be different, and that are clearly explained through simulation analysis.

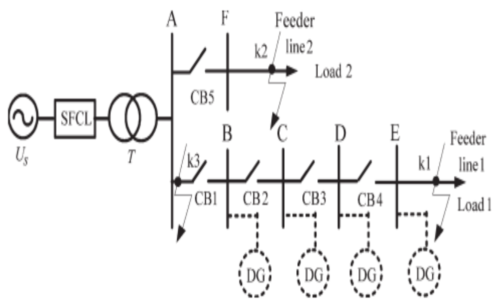

Fig.2.Single line diagram of distribution system with distribution generation units including active type SFCL

IV. SIMULATION RESULTS

The proposed distribution system with and without active type SFCL in the presence of distributed generation is simulated through MATLAB/SIMULINK. First the distribution system is studied under no fault conditions that is healthy system is simulated. The output is same as given. And then it is studied without SFCL under single line to ground fault from unsymmetrical nature for over voltage suppressing characteristics and triple line to ground fault from symmetrical nature for current limiting characteristic. Next by using of SFCL the fault currents at different buses are reduced. All characteristics are explained through Simulink as follows.

A) Overvoltage-Suppressing Characteristics of the SFCL

To simulate the over voltage suppressing characteristics following considerations are taken.[11] First the fault location is k_1 point(single line to ground fault), and the fault time is t=0.2s,the simulation is done whenDG_1 is fixed at bus B and the DG_2 is installed at the Buses C, D, and E, and the three cases are named as

case I, II, and III respectively. Fig.3 Shows the Simulink Model of Proposed Distribution System with Distributed Generation Units without Active SFCL for the case I. Fig.6 shows the same but with SFCL for the same case.Fig5and Fig.8shows the SFCL's overvoltage-suppressing characteristic waveforms without and with the SFCL at bus-A under different locations of DGs.

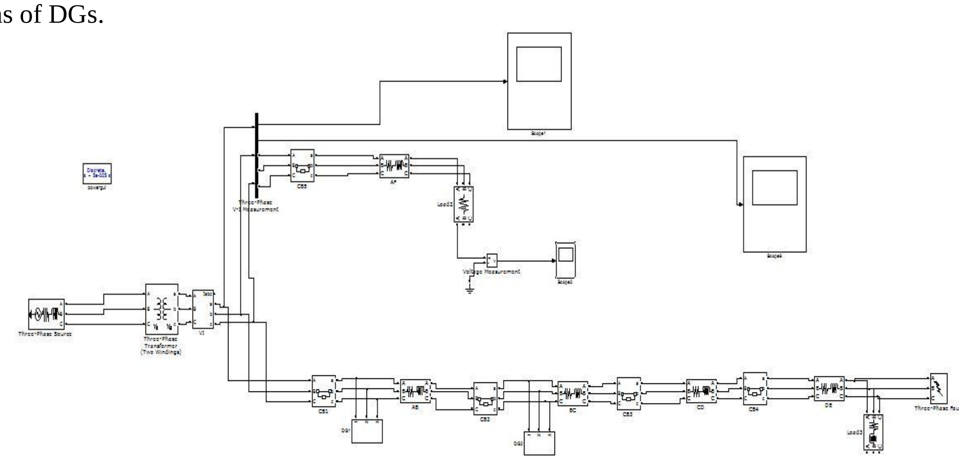

Fig.3.Simulink Model of Proposed Distribution System without Active SFCL

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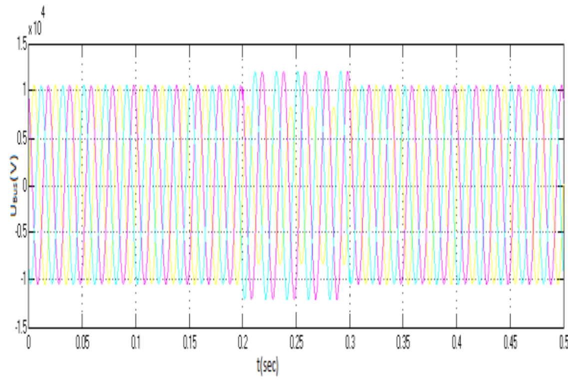

Fig.4 Phase voltage characteristics under single line to ground fault without SFCL

In the same way for the cases I, II, and III, the overvoltage's peak value without SFCL will be respectively 1.19, 1.35, 1.29 times of normal value, and when the active SFCL is applied, the corresponding times will drop to 1.02, 1.05, and 1.04.If the active SFCL is put into use, the limit-exceeding problem can be solved effectively.

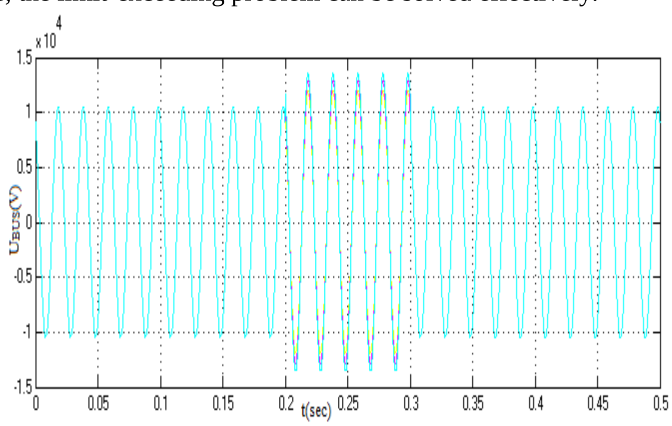

Fig.5 Voltage characteristics of the Bus A under different locations of distributed generation units without SFCL

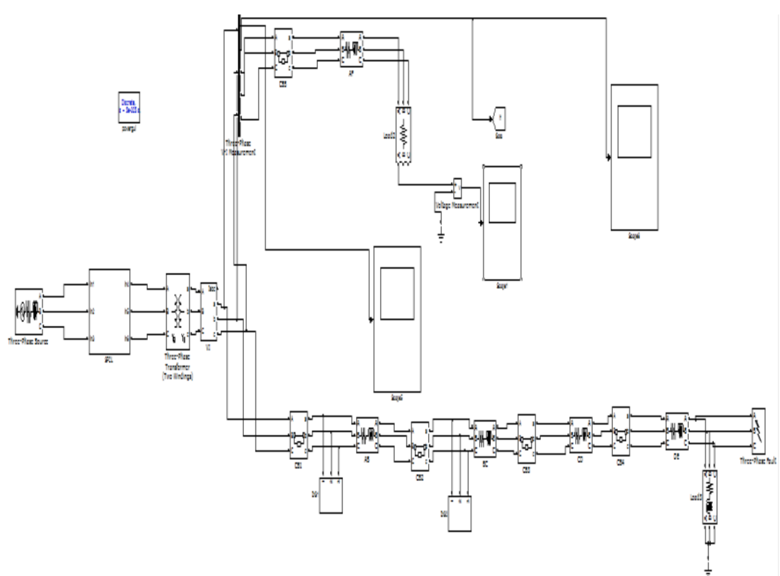

Fig.6.Simulink Model of Proposed Distribution System with Active SFCL

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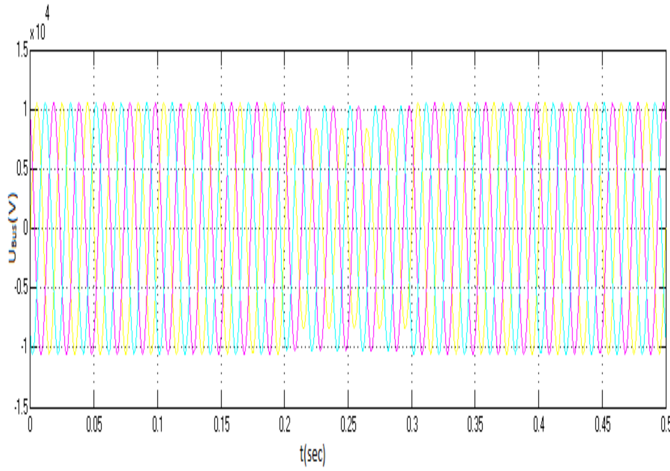

Fig.7 Phase voltage characteristics under single line to ground fault with SFCL

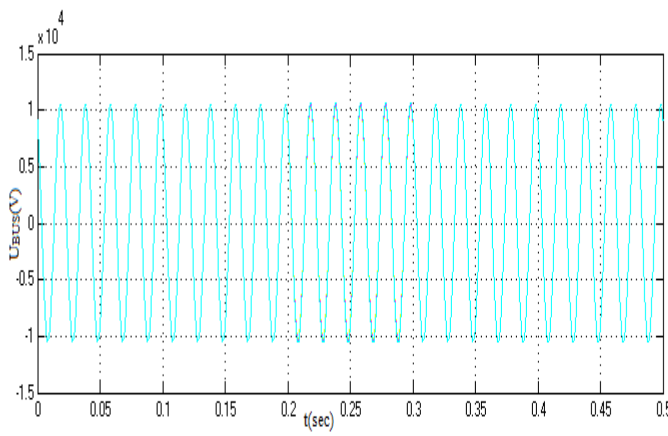

Fig.8.Voltage characteristics of the Bus A under different locations of distributed generation units. with the Active SFCL

B) Current-Limiting Characteristics of the SFCL

To simulate the current limiting characteristics following conditions are designed[11]. Each DG injection capacity is about 100% of the load capacity (load 1), and the two DG units are separately installed in the Buses B and C. Current limiting characteristics with and without the active SFCL when the three-phase short circuit occurs at k_3 point are simulated. Three phase fault introduces more current than that of normal value. Moreover, the three-phase fault occurs at k_1, k_2, and k_3 points and the fault occurring time t_{st}=0.2s. Fig.9 shows the Simulink Model of Proposed Distribution System with Distributed Generation Units without Active SFCL with DG units at the two buses.

Fig.10 shows the distribution system with SFCL Simulink diagram. After installing the active SFCL, the first peak value of the fault currents (i_{Af},i_{Bf},i_{Cf})can be limited to 1.14kA, 1.03kA, 1.05kA, respectively, in compare with 2.6kA, 2.4kA, 2.5kA under the condition without SFCL.Fig.11(a) and 11(b) shows the current waveforms when the three-phase short-circuit occurs at k_3 point Without and with the active type SFCL respectively.

Fig.12(a) and 12(b) are the current limiting characteristics of active type SFCL when the faults placed at the K_1 and K_2 locations in the distribution system.

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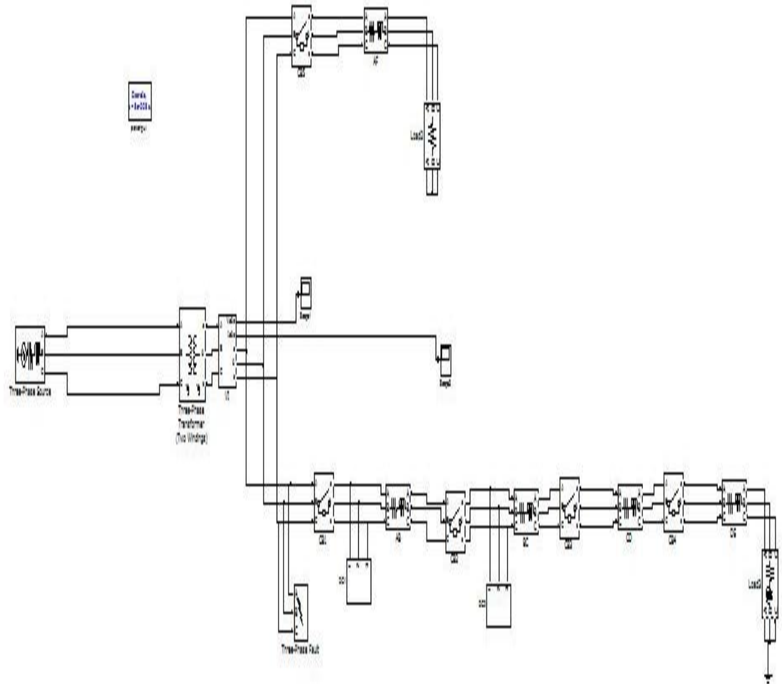

Fig.9.Simulink model of Proposed Distribution System without Active SFCL

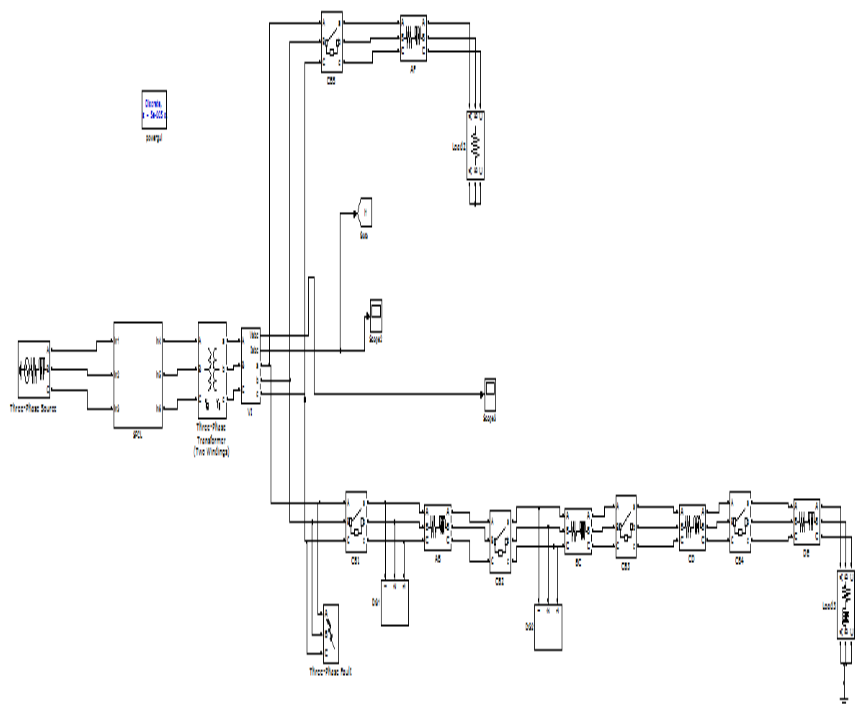

Fig.10.Matlab/Simulink model of Proposed Distribution System with Active SFCL

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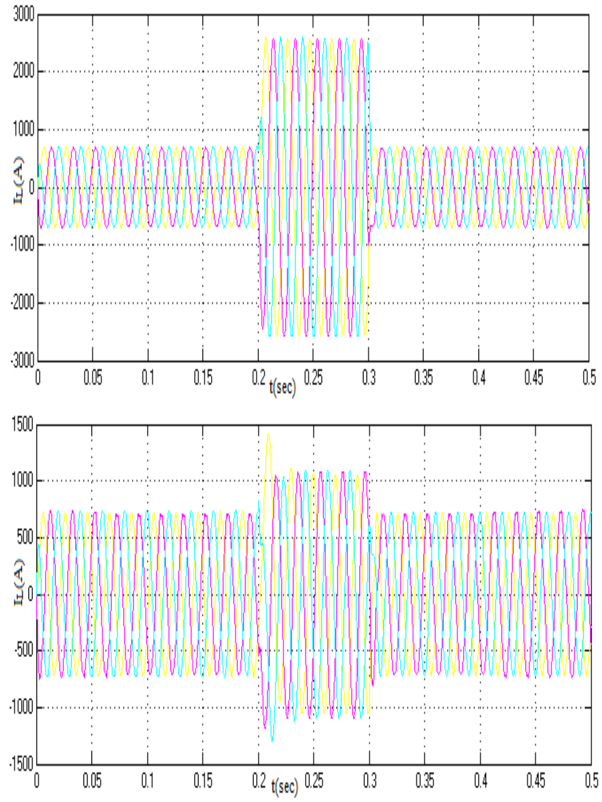

(a)

(b)

Fig.11.Line current waveforms when the three-phase short-circuit occurs at k3 point.(a)Without SFCL and (b) with the active type SFCL

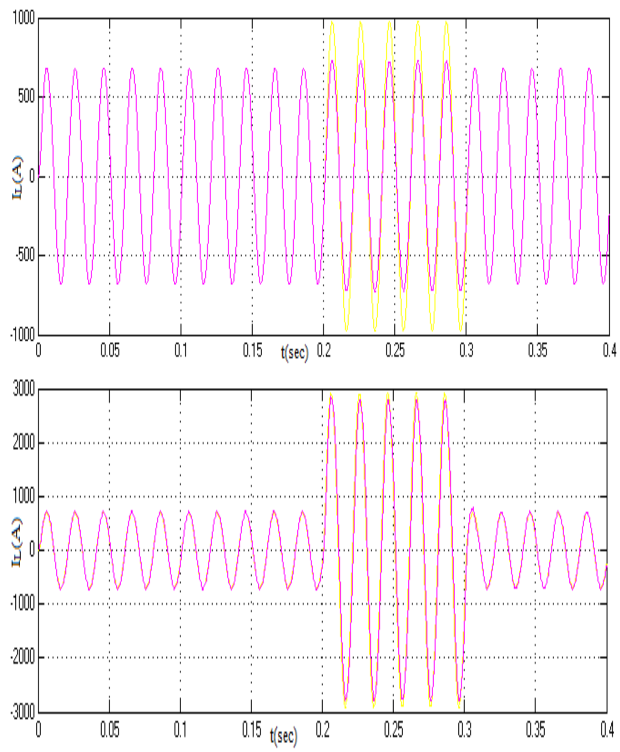

Fig.12.Active SFCL current limiting performances at fault Locations of (a) k_1 point and (b) k_2 point

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CONCLUSION

In this paper analyze the fault current and over voltages in distribution system. The new device of active SFCL can reduce over voltage and fault current under abnormal conditions such as single phase to ground faults and three phase ground fault .The use of active SFCL into a distribution network in the presence of DG units improved the system safety, reliability and also stability. It is observed that the performance of active SFCL is better if the distance between installation of SFCL and the location of fault reduced. The reduction in fault level is verified by MATLAB / SIMULINK software.

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BIOGRAPHIES

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