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Application of Superconducting Fault Current Limiter for Protection in Electrical Transmission System

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ABSTRACT

This paper introduced an application of superconducting fault current limiter (SFCL) to limit the fault current value to a lower level in electrical power system. Resistive type SFCL is implemented in MATLAB version 8.1 Unsymmetrical faults are observed at different positions i.e. near the bus 1, bus 2, and bus 5. Simulations are performed to observe mainly three types of faults which are single line to ground fault, line to line fault and double line to ground fault. For simulation purpose IEEE 5 bus transmission systems is considered. The simulations indicate that the SFCL may give better results in feeder position near at bus 5, compared with other positions. Also a fast recovery to the superconducting state has been observed as the fault is reduced within the first cycle of fault. With the help of this a small current rating circuit breaker can be used in the system. It has been observed that after installation of SFCL for a single line to ground fault the fault current reduces almost 92%. Also the level of other two unsymmetrical faults is also decreased to a lower level.

Keywords— *Fault current, Power system, Unsymmetrical fault and Superconducting fault current limiter (SFCL), MATLAB.*

I. INTRODUCTION

With the development of our society and the power grid, the consumption of electricity has continued to increase. As a result, the possibility of abnormal operations in power system also becomes very high. Due to the sudden decreases in the impedance of the power systems network which causes increase in the current value known as fault current [1]. Faults in power system can either be symmetrical faults or unsymmetrical faults. Most power system faults are unsymmetrical [2]. Symmetrical fault is defined as the simultaneous short circuit across all the three phases to ground while unsymmetrical fault consist of single line-to ground, line-to-line and double line-to-ground. Fault current is also known as short -circuiting current (I_{sc}) and have great influence on power system planning [3].

During occurrence of fault in the system, the current rises to very high value which is many times the normal current in the system. Due to flow of very high current in the system during fault, damage can occur to any equipment installed in the system. Large mechanical forces developed due to the generation of large fault current that endanger the mechanical integrity of power system hardware, transformer and other equipment. As

the equipment in power network is expensive, their protection from large fault current is needed. The value of the fault current is required to limit to a lower level to have continuous and reliable operation of the power systems [4]. Electric power systems are so designed that impedances among generation and loads are considerably low. However, the main disadvantage of low interconnection impedance is large fault currents, i.e., 5-20 times of nominal during fault current. In faults SFCL perform two important functions. It limits the fault current and quickly brings back to the normal value after fault is removed. Shunt reactors (inductors) were used previously to limit the current. But they have in several cases to decrease fault current. These devices have fixed impedance, and therefore introduce continuous load. Even the circuit breaker sometimes fails to handle the excessive fault current and fail to trip the system. Most power system faults are unsymmetrical [2].

In this paper the application of resistive SFCL in IEEE 5 bus transmission systems to describe its ability for various unsymmetrical faults. The simulations were performed using MATLAB version 8.1 to shows its capability.

II.OVERVIEW

A.SUPERCONDUCTING FAULT CURRENT LIMITER(SFCL)

According to the principle of superconductivity, any superconducting material is in superconducting stage as long as temperature, current and magnetic field density are below their critical limit[4]. However, if any of the critical values defining the switching between the superconducting state to the normal state, such as critical current density (J_c), critical temperature (T_c), or critical magnetic field (H_c), exceeds, then SFCL resistance adds in the circuit to suppress the magnitude of fault current. SFCL is not completely disconnected during fault, after the faulty branch is disconnected it automatically returns to the normal condition. There are two main types of SFCL, resistive and inductive.[7]

B. Resistive SFCL

In the resistive type, the superconducting element connected in series with the network. It is the simplest type of SFCL. It can be just only a low temperature superconducting wire or a certain length of high temperature superconductors. The superconductor will be in superconducting state without resistance when the current is normal. When the current exceeds over the critical current, the superconductor goes into its normal state .It has a high resistance which is connected in series with the network that will limit the current**.** A parallel resistance is used with the superconducting element. The purpose of using parallel resistance is to avoid hot spots during quench, to adjust the limiting current and to avoid over-voltages due to the fast current limitations. Resistive SFCL's are much smaller and lighter in weight compared to the inductive ones.

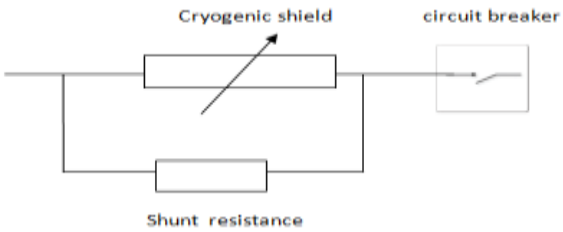


Fig.1 Schematic of Resistive Superconducting Fault Current Limiter

***C.* Modeling of SFCL**

The mathematical model for a resistive SFCL is represented as a equation of non linear resistance showing its non linearity in different temperature zones can be expressed as [7]:

$$\text{I.} \quad R(t) = \begin{cases} 0 \\ [R_n[1 - exp(\\ a_1(t - t_1) + b \\ a_2(t - t_2) + b \\ 0 \end{cases} \tag{1}$$

Where, R_n=impedence being saturated at normal temperature

τ=time constant of transition from the superconducting state to the normal state

t_0, t_1, t_2, t_3=quench-starting time, the first recovery starting time, and the secondary recovery-starting time, respectively

a_1, a_2, b_1, b_2=co-efficient of finite linear function

As shown in Fig.2, it indicates the detailed quenching and recovery characteristics[9].In normal condition impedance of SFCL is zero quenching process of SFCL starts at t=1s due to the occurrence of fault causing impedance rises to its maximum value. Impedance again becomes zero after the fault clear.

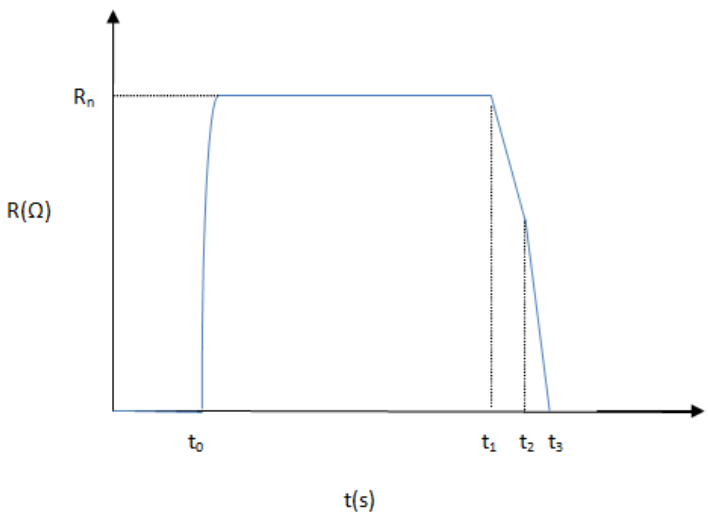


Fig.2 Quenching and recovery characteristics of a resistance type SFCL.

III. METHODOLOGY

Fig. 3 shows the flowchart for analysis of unsymmetrical fault with SFCL

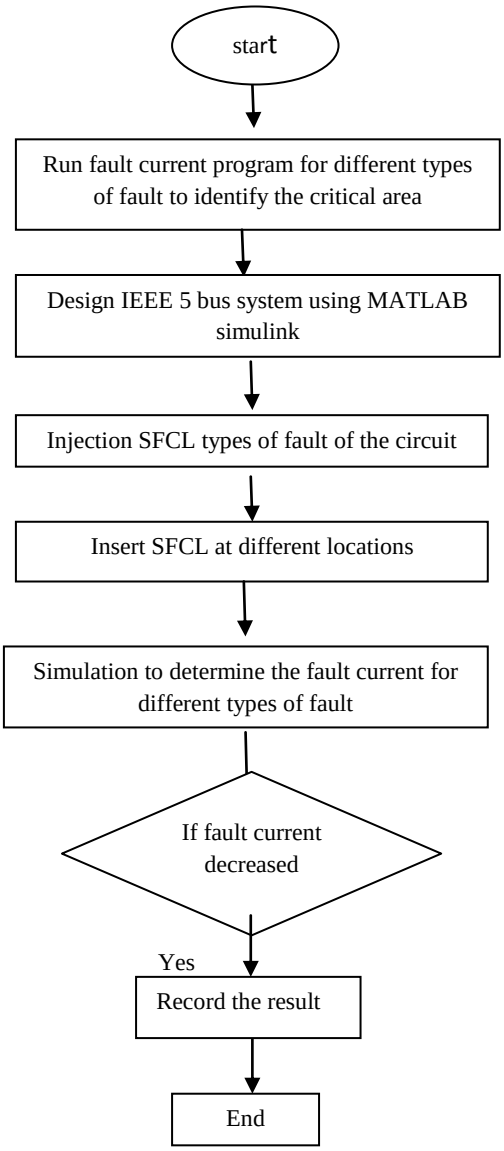


Fig.3 Flowchart for methodology

A. Test System

Fig 4 shows IEEE 5-bus transmission system used for the simulation. It has 2 generators interconnected through four three phase loads at the end of the feeder. To determine the impact of SFCL, the critical bus with the highest fault current was determined using MATLAB simulation. The values for different types of fault were also obtained.

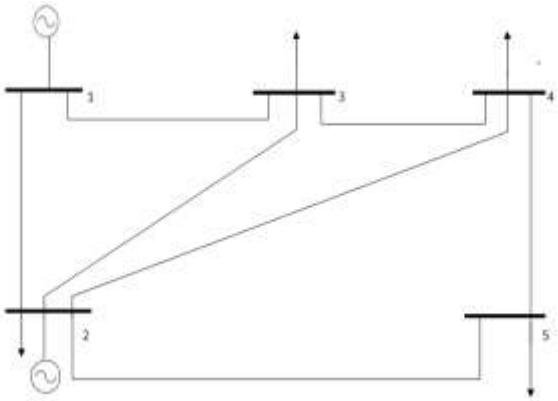


Fig. 4 IEEE 5 bus system

B. IEEE 5-bus System with fault and SFCL

Three buses were chosen for the analysis, namely bus1,bus 2 and bus 5. For these three buses, fault current was determined for different types of unsymmetrical fault. Fig .5 shows the insertion of SFCL at different positions. As the most suitable location for SFCL installation was found near feeder position, so all the studies for fault current were tested near bus 5.

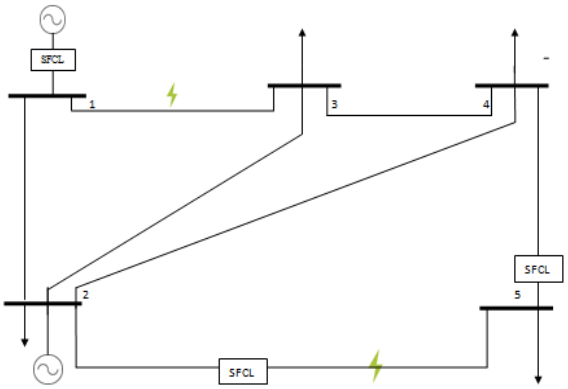


Fig. 5 IEEE 5-bus system with SFCL and fault

C. Resistive SFCL Model

A Switch block is mainly display minimum or maximum impedance in output which is determined on the basis of incoming current. The simulation model of resistive SFCL is shown in the fig.7.The working principle of the SFCL model developed in Simulink is given below. RMS block is used to measure the RMS value of incoming current. Then it compares the current with the specified current in the SFCL subsystem. SFCL gives minimum resistance, if the incoming current is less than the triggering current level. When the value of current is larger than the triggering current, the impedance of SFCL rises to its maximum state. It ultimately raises the total

impedance of the system which results in limiting the fault current. Finally, the SFCL's resistance will be minimum when the limited fault current is below the triggering value [6].

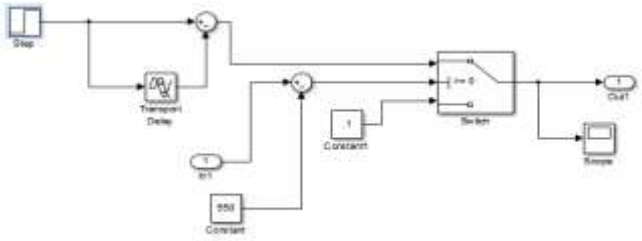


Fig.6 Implementation of resistive SFCL characteristics in simulink

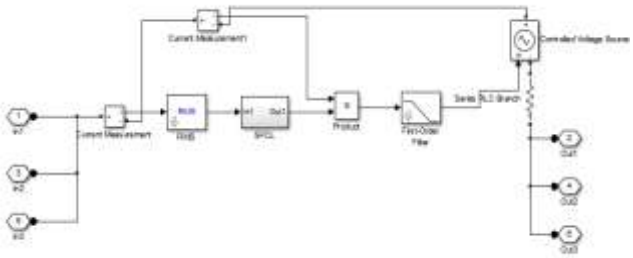
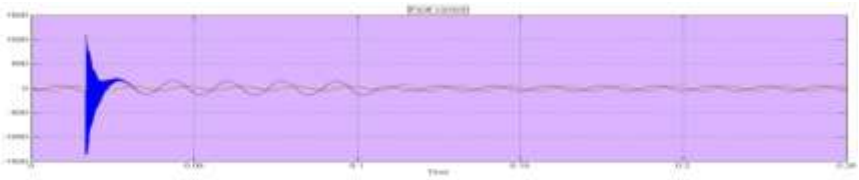


Fig.7 Resistive SFCL model in Simlink

IV. RESULTS AND DISCUSSION



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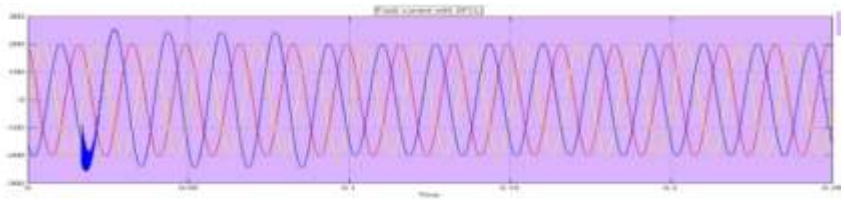
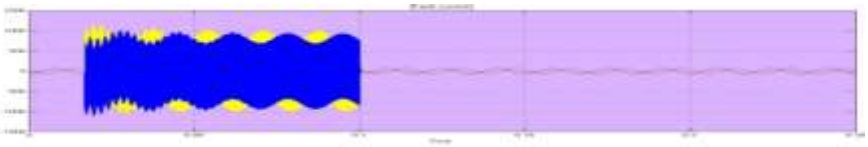


(b)

Fig. 8 Fault current waveform for single line to ground fault (a) without insertion of SFCL (b) with SFCL

The 3-phase unsymmetrical fault occurred between 0.01sec and 0.12sec.Fig 8(a), 8(b) shows the waveforms of fault current obtained for single line to ground fault occurs at line 2 to 5 near. It is observed that the detection of fault time is reduced to 0.9sec after installation of SFCL in case of single line to ground fault as shown in fig.8 (b).



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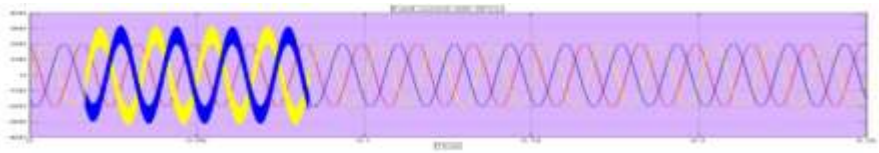
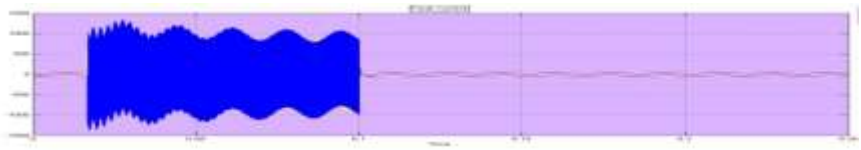


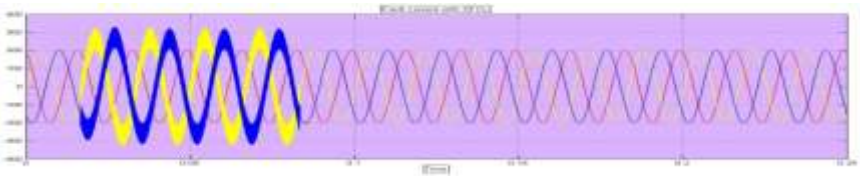
(b)

Fig.9 Fault current waveform for line to line fault (a) without insertion of SFCL (b) with SFCL

The 3-phase unsymmetrical fault occurred between 0.01sec and 0.1sec.Fig 9(a), 9(b) shows the waveforms of fault current obtained for line to line to line fault occurs at line 2 to 5 near bus 5. It is seen that the detection of fault time is reduced to 0.8sec after installation of SFCL in line to line fault as shown in fig.9 (b).



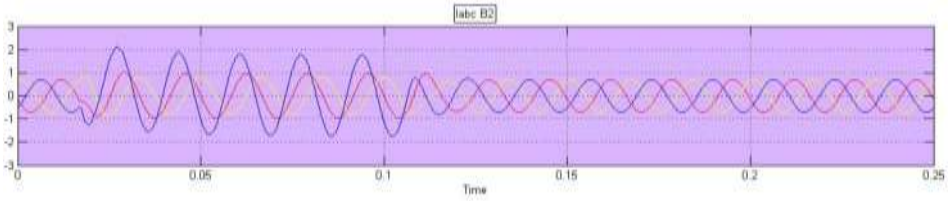
(a)



(b)

Fig.10 Fault current waveform for double line to ground fault (a) without insertion of SFCL (b) with SFCL

The 3-phase unsymmetrical fault occurred between 0.01sec and 0.1sec.Fig 10(a), 10(b) shows the waveforms of fault current obtained for double line to line to ground fault occurs at line 2 to 5 near bus 5. It is seen that the detection of fault time is reduced to 0.8sec after installation of SFCL in case of double line to ground fault as shown in fig.10 (b).



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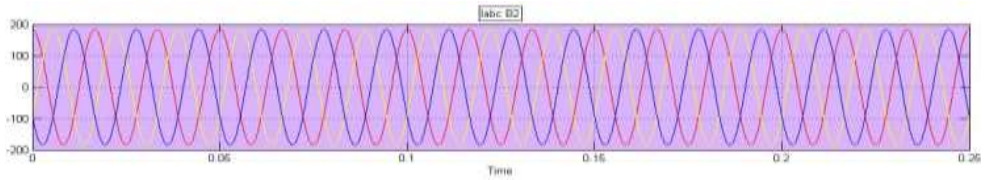
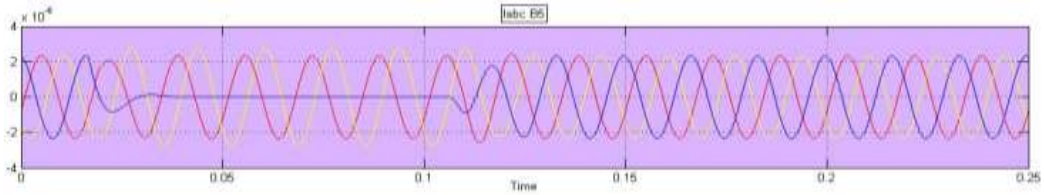


(b)

Fig. 11 Output current waveform for single line to ground fault at bus 2
(a) without insertion of SFCL, (b) With SFCL
(b)

Fig.11 (a), 11(b) shows the output waveform of current for single line to ground fault obtained atbus 2 which is connected to the generator 2.Fig 11(a) shows the output before installation of SFCL. Fault occurred between 0.01sec and 0.102sec. On the other hand the output waveform with SFCL is more like as steady state current with small fault value as shown in fig.11 (b).



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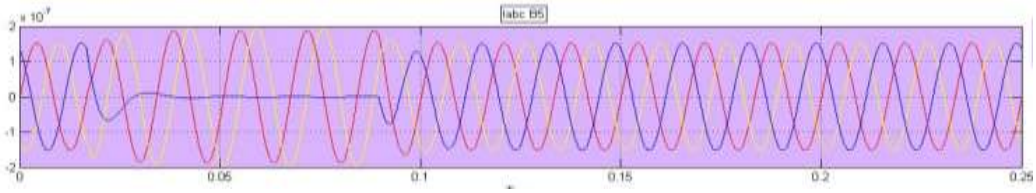
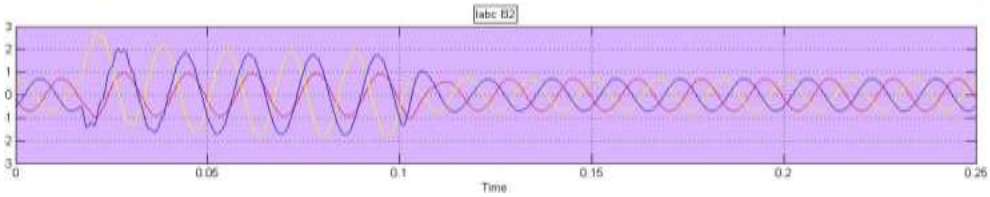


/(b)

Fig. 12 Output current waveform for single line to ground fault at bus 5
(a) without insertion of SFCL, (b) With SFCL

Fig.12 (a), 12(b) shows the output waveform of current for single line to ground fault obtained at bus 5 which is connected to the load 3.Fig.12 (a) shows the output before installation of SFCL. Fault occurred between 0.01sec and 0.12sec. On the other hand the fault current correction occurs between 0.01sec and 0.08sec after installation of SFCL as shown in fig.12 (b).



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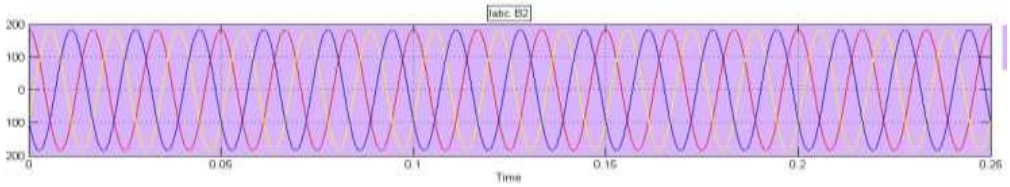
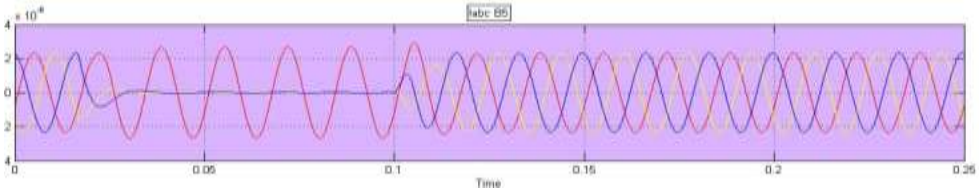


(b)

Fig.13 Output current waveform for line to line fault at bus 2
(a) without insertion of SFCL, (b) with SFCL

Fig.13(a), 13(b) shows the output waveform of current for line to line fault obtained at bus 2 which is connected to the generator 2.Fig 13(a) shows the output before installation of SFCL. Fault occurred between 0.01sec and 0.1sec. On the other hand the output waveform with SFCL is more like as steady state current with small fault value as shown in fig.13 (b).



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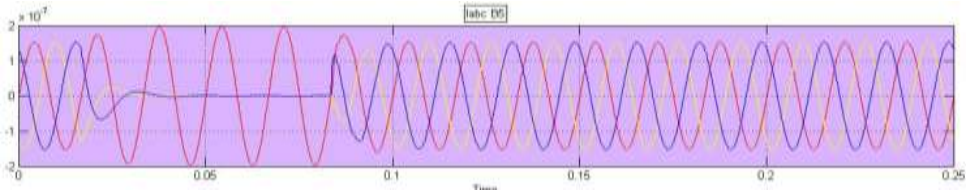
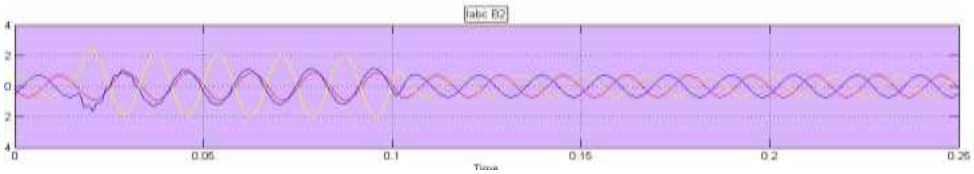


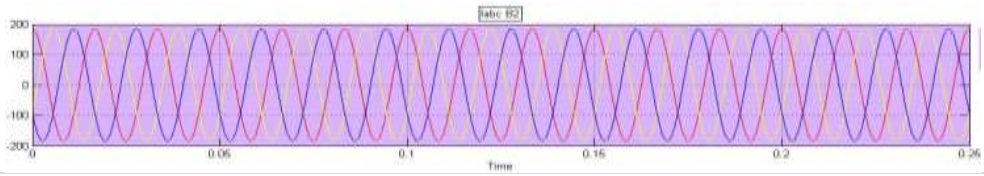
(b)

Fig. 14 Output current waveform for line to line fault at bus 5
(a) without insertion of SFCL, (b) with SFCL

Fig.14 (a), 14(b) shows the output waveform of current for line to line fault obtained at bus 5 which is connected to the load 3.Fig.14(a) shows the output before installation of SFCL. Fault occurred between 0.01sec and 0.12sec. On the other hand the fault current correction occurs between 0.01sec and 0.08sec after installation of SFCL as shown in fig.14 (b).



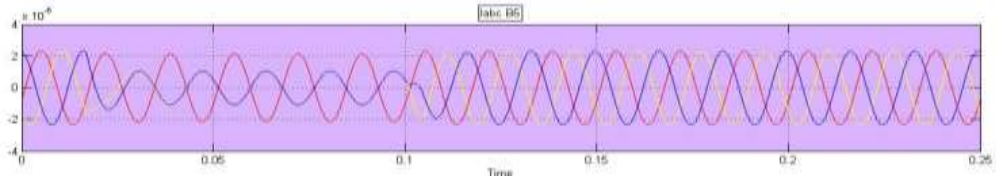
(a)



(b)

Fig.15 Output current waveform for double line to ground fault at bus 2
(a) without insertion of SFCL, (b) with SFCL

Fig.15 (a), 15(b) shows the output waveform of current for double line to ground fault obtained at bus 2 which is connected to the generator 2.Fig 15(a) shows the output before installation of SFCL. Fault occurred between 0.01sec and 0.1sec. On the other hand the output waveform with SFCL is more like as steady state current with small fault value as shown in fig.15 (b)



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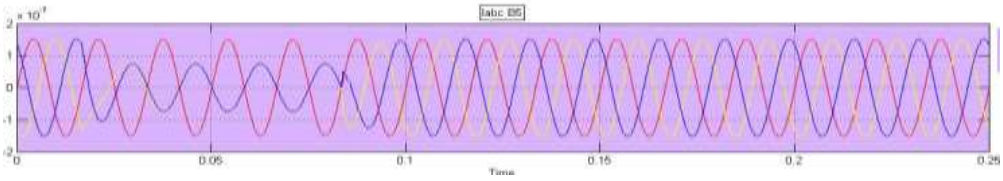

(b)

Fig.16 Output current waveform for double line to ground fault at bus 5
(a) without insertion of SFCL, (b) With SFCL

Fig.16(a), 16(b) shows the output waveform of current for double line to ground fault obtained at bus 5 which is connected to the load 3.Fig.16(a) shows the output before installation of SFCL. Fault occurred between 0.01sec and 0.12sec. On the other hand the fault current correction occurs between 0.01sec and 0.08sec after installation of SFCL as shown in fig.16 (b).

Table 1. Fault current values with and without SFCL for different values

Type of fault	**Magnitude of Fault Current(A)**	
	Without using circuit breaker and SFCL	**With SFCL**
Single Line to Ground Fault	2430	180
Line to Line Fault	2160	310
Double Line to Ground fault	2500	390

V. CONCLUSION

Application of SFCL on 5-bus IEEE transmission system using MATLAB simulink was performed for various unsymmetrical faults. It can be concluded that in transmission system the location of SFCL is very effective in

feeder than any other positions. And the function of SFCL is mainly to reduce fault current to a lower value. Moreover it detects the fault within the first cycle of fault so a small rating circuit breaker can be used in the system. Hence small current rating circuit breaker can be used in the system to detect the fault and the level of fault can be reduced to a lower limit with the insertion of SFCL at different positions of the power system. It has been observed that after installation of SFCL for a single line to ground fault the fault current reduces almost 92%. Also the level of line to line faults is decreased to approx 85%.Again in case of double line to ground fault the value of fault reduction is found as approx 84.44%

SFCL's provide the opportunity to increase distribution and transmission equipment utilization and reduce reinforcement requirements. SFCL technologies continue to make progress day by day as power utilities worldwide deal with the issue of increasing fault current levels.

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