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Fault Current Limitation and Voltage Dip Mitigation in a Radial Distribution System with the Use of Active Type Superconducting Fault Current Limiter

Supriya Saddi[(1)] and K. Muthukumar[(2)]

PG scholar [(1)], Assistant Professor - III [(2)] EEE / SEEE SASTRA UNIVERSITY

Abstract

Electrical energy usage is increasing day by day and to meet out the increased load demands, the installation of distributed resources has increased in distribution networks considerably. As a consequence, there is a possibility of rise in fault current level which impose more stress on the power system components and a possibility of abnormal operation of the power system network during fault instants. To solve such problems the safety measures such as replacing the existing Circuit breakers, changing the operating mode of the systems has been proposed. To cope with the increased fault current level limitation, introduction of a promising power apparatus namely active type super conducting fault current limiters (ASFCL) is one of the viable solution from both technical and economical point of view. In this paper active type SFCL has been modeled and its fault current-limiting and voltage dip mitigation characteristics are simulated in MATlab-SIMULINK. The simulation results reveals that the active type-SFCL can mitigate the voltage dip and fault current effectively, thus preventing the equipment's from fault currents and improving the system safety and reliability.

Keywords— Active type Superconducting fault current limiter, distribution system, Pulse width modulation technique

I- INTRODUCTION

With the rapid increase in technology the grid system has become very complex. By the increase in the consumption of electric power, the existing system has become complicated and the equipment's like circuit breakers have the probability that the fault current can be exceeded of its cut-off limit. The severity of current having fault has created a stress on the equipment's connected in the grid along with the disturbanceinpower system stability. An inductive type SFCL is a promising power apparatus which changes its behavioral characteristics of high temperature superconductor to suppress the prospective fault current during faults in power system networks [1].

The applications of different types of SFCLs in a distribution system are analyzed and their research focuses on the current limitation and improvement of the devices connected in grid. [2] - [4]. An active SFCL of voltage compensation type has been proposed in earlier studies [5]. The superconducting fault current limiters are good conductors of electricity, which has zero resistance when they are cooled below critical temperature. SFCLs provide a better solution to minimize the levels of fault current in an electric power system. At the time of fault, the SFCLs will insert impedances when it loses superconductivity and place them into the circuit [6].Laboratory prototype of 800V/30A was made, and its working performances were studied well [7]. The location of SFCL in a distribution system can be determined by using the distribution reliability technique, considering the minimization of fault current [8].

The SFCL is placed on the primary winding side of the transformer, to reduce the level of fault current magnitude, since fault current is inserted from the transformer primary side to the fault point. The active type SFCL consists of an air core superconducting transformer and IGBTs. Air-core consists of magnetic field, whichcan be controlled by the adjusting the PWM converters outputcurrent and thereby equivalentimpedance of the active SFCL can be regulated for current limitation and voltage dip mitigation. The effect of the ASFCL on the radial distribution system has been analyzed by creating an artificial three phase fault to ground fault. In this proposed work, inductive type SFCL has been modeled for current-limitation and voltage dip mitigation during a three phase fault which is simulated in MATlab-SIMULINK.

II- THEORETICAL ASPECTS OF ACTIVE TYPE- SFCL

A. Structure of ASFCL

An active type superconducting fault current limiter consists of, generally an air-core transformer, a PWM converter for controlling the pulses of an IGBT. In an air-core superconducting transformer, the primary winding is connected to the IGBTs which are controlled by PWM techniques. The air-core has many benefits like the non-appearance of iron losses, magnetic saturation, and reduction in size, harmonics and weight [9]. The saturation of core is negligible in the air-core transformer there by the linearity in the impedance of ASFCL is ensured.

B. Circuit diagram

The circuit diagram of ASFCL is depicted in Fig. 1 [10].

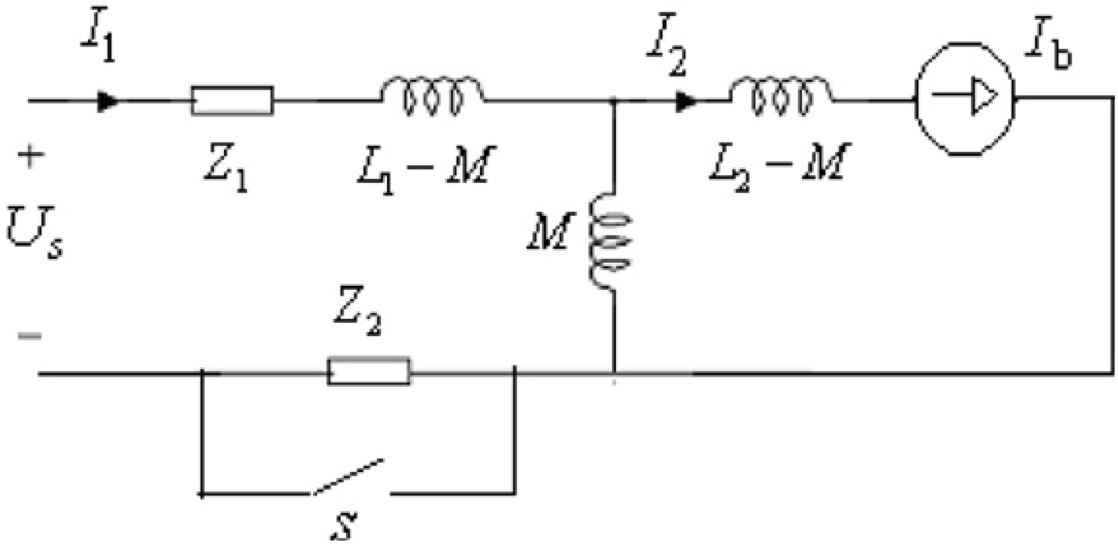

Fig. 1. Circuit diagram of ASFCL.

Where Us represent the AC voltage source, L_1, $L_2$and M are the self and the mutual inductance of superconducting transformer. Z_1, Z_2 are the circuit impedance and the load impedance with I_b as the AC current source and I_1 and I_2 are the primary and the secondary winding current. The injected current I_2 flowing in the secondary winding is controlled during fault conditions, by adjusting in terms of amplitude (or) phase angle and thus the level of current having higher fault magnitude can be limited during first few cycles from the instant of fault.

C. Application of Active Type-SFCL

The single line diagram representation of radial distribution system is shown in Fig. 2 consisting of an AC source Us, with the SFCL, three phase auto transformer are connected to a common bus bar and two feeder lines are emanating radially with circuit breakers with resistive loads. It is assumed that a balanced three phase fault is simulated to evaluate the impact of ASFCL against fault current and voltage dip mitigation characteristics on the radial distribution system.

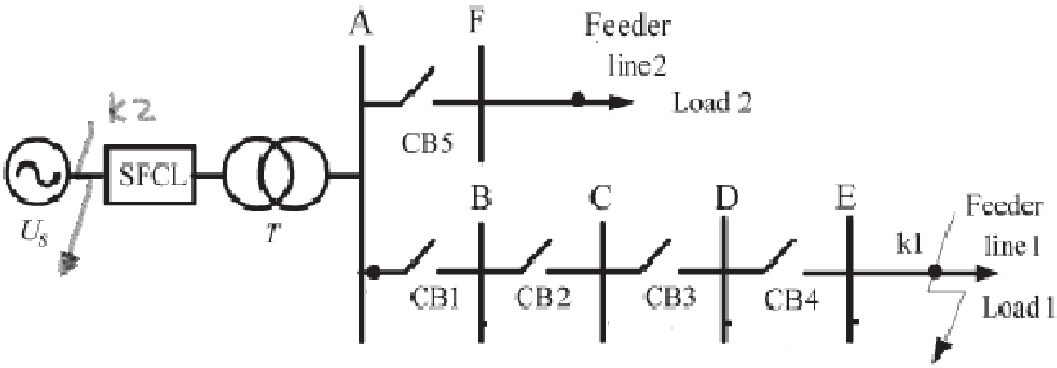

Fig. 2. ASFCL in a typical radial distribution system.

III- SIMULATION RESULTS AND DISCUSSION

The proposed model of active type SFCL has been simulated as shown in Fig. 3. The simulation model consists of an AC voltage source in series with the circuit impedance and the load impedance. The ideal switch is connected in parallel with the load impedance. To simulate the single phase to ground fault, sine wave is given as a pulse to the switch, which closes at t = 0.1 sec. Once the fault is simulated, the fault current magnitude in the secondary side of superconducting transformer is limited by changing amplitude and phase angle of secondary current.

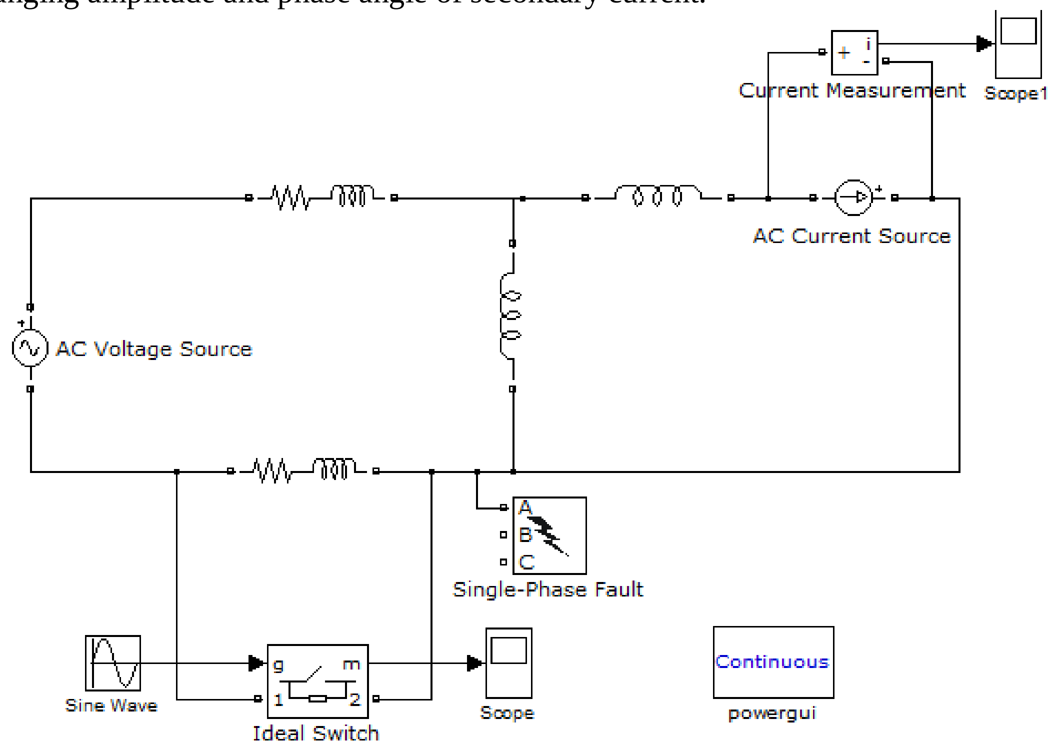

Fig. 3. Single phase representation of ASFCL model.

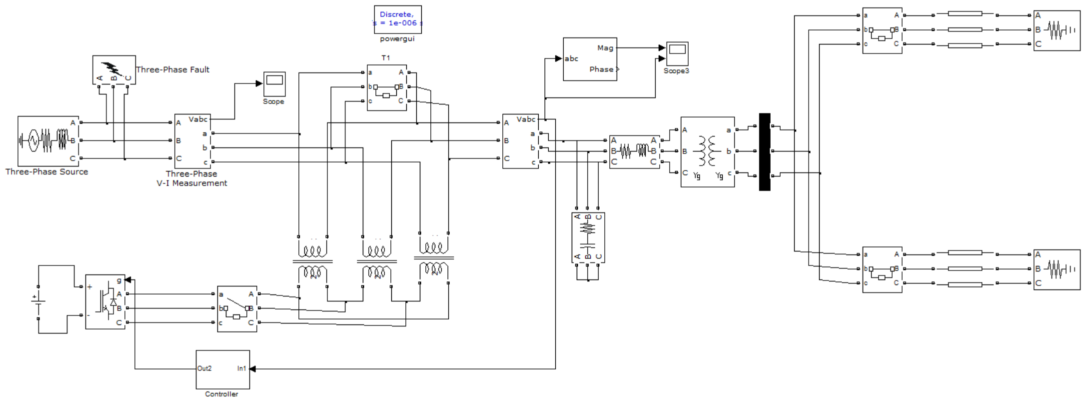

Fig. 4. Implementation of ASFCL in a radial distribution system.

Fig. 4 represents the application ofASFCL in radial distribution system. During normal operating condition, the three-phase source supplies the power to resistive load. The circuit breaker connected in series with the source and load is closed, hence the power supply is continuous and the ASFCL has no role. At t=0.2 sec, a three phase to ground fault is simulated near the source side in the transmission lines which creates a dip in the voltage. This voltage dip is sensed by the voltage measurement block and given as an input to the control unit. The pulses are generated in the control unit for triggering the IGBT. The battery source serves as a backup source for continuous supply, by closing of circuit breaker 2.

The control unit of the circuit consists of the voltage dip as the input along with an unit delay, it is given to the PI controller then the signal is phase modulated and pulses are generated. These pulses are used as the triggering pulse for the IGBT. The control unit is shown in the Fig. 5.Table 1 represents the values of the block sets which are used in Fig. 4.

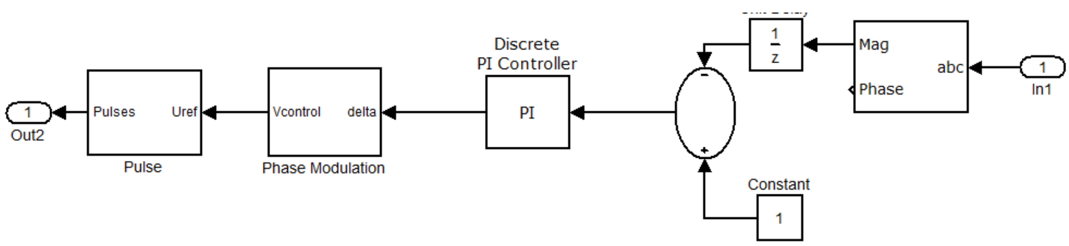

Fig. 5. Control unit for triggering the pulses for IGBT.

Table 1. Simulation Parameters of the System.

Active type SFCL	
Primary inductance	50mH
Secondary inductance	30mH
Mutual inductance	32.9mH
Distribution Transformer	
Rated capacity	5000kVA
Transformation ratio	35 kV/10.5kV
Feeder line	
Line length	35km
Power load	
Load 1, Load 2	50km

A. Voltage dip mitigation characteristics

In Fig. 6 due to the occurrence of three phase fault at t=0.2 sec, the voltage near the source side is dropped from 1 p.u to 0.2 p.u. In Fig. 7 the voltage drop occurs at t=0.2 sec due to the three phase ground fault but with the use of ASFCL, immediately the voltage is maintained back to normal value of 1p.u.

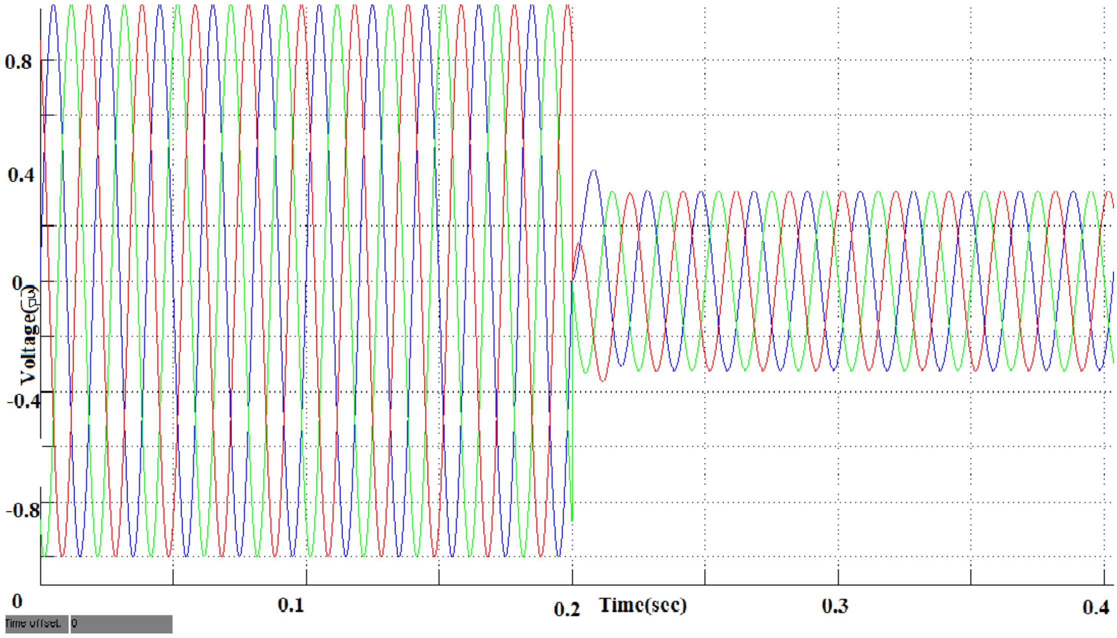

Fig. 6. Voltage drop due to three phase fault near the source side at t=0.2 sec.

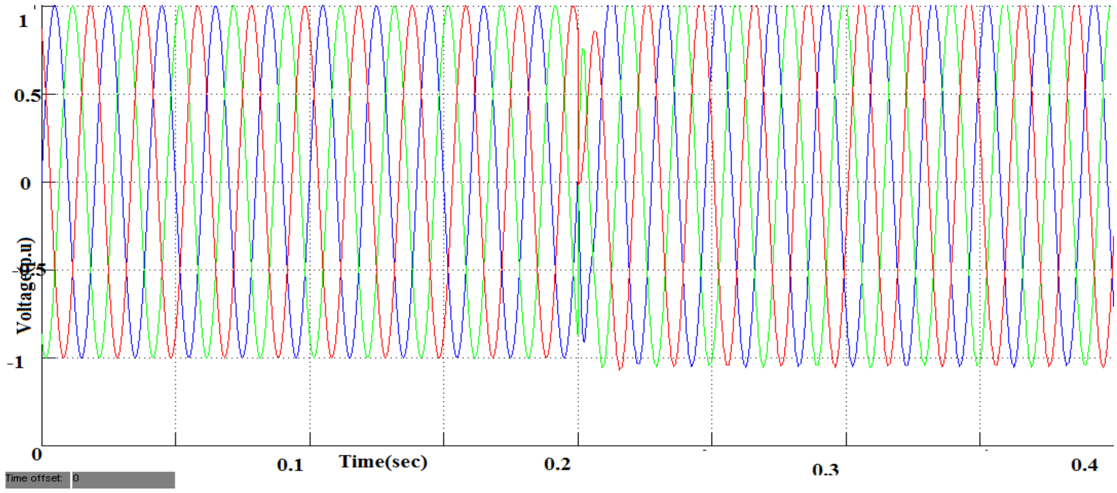

Fig. 7. Normal voltage restored after t=0.2 sec when a three phase to ground fault occurs in a distribution system with ASFCL.

B. Fault current limiting characteristics

The three phase to ground fault is simulated near the source side, at t=0.2 sec in a radial distribution system with ASFCL, to study the fault current limiting characteristics of ASFCL. The change in fault current is sensed and ASFCL is utilized to limit the fault current to normal value.

In Fig. 8 the normal load current flowing is 20A,after simulating the three phase to ground fault at t=0.2 sec, the current rises to 100A. In Fig. 9 with the use of ASFCL at t=0.25 sec to t= 0.4 sec, the fault current magnitude is reduced to 20A.

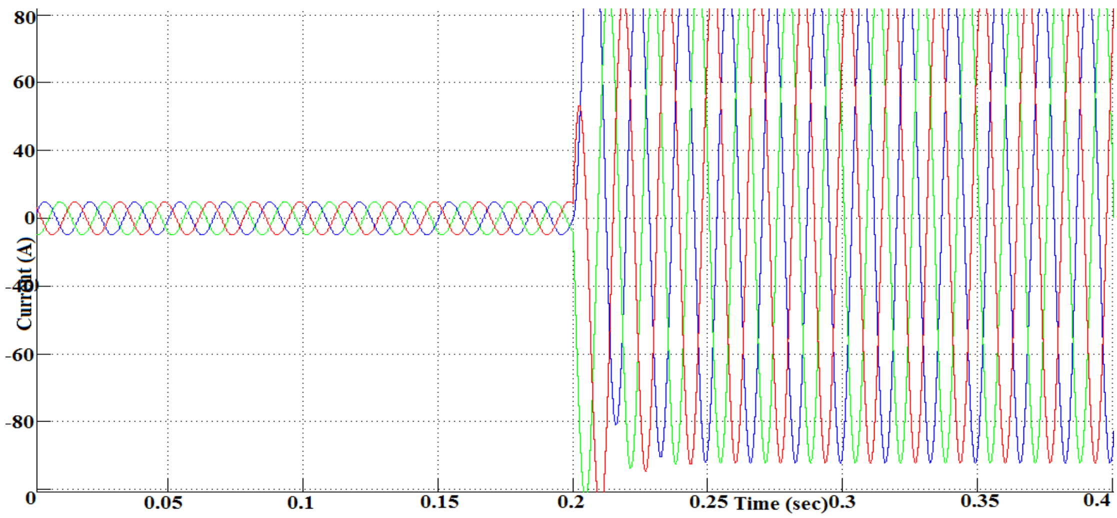

Fig. 8. Load current rises from 20A to 100A from t=0.2 sec to t= 0.4 sec due to three phase to ground fault.

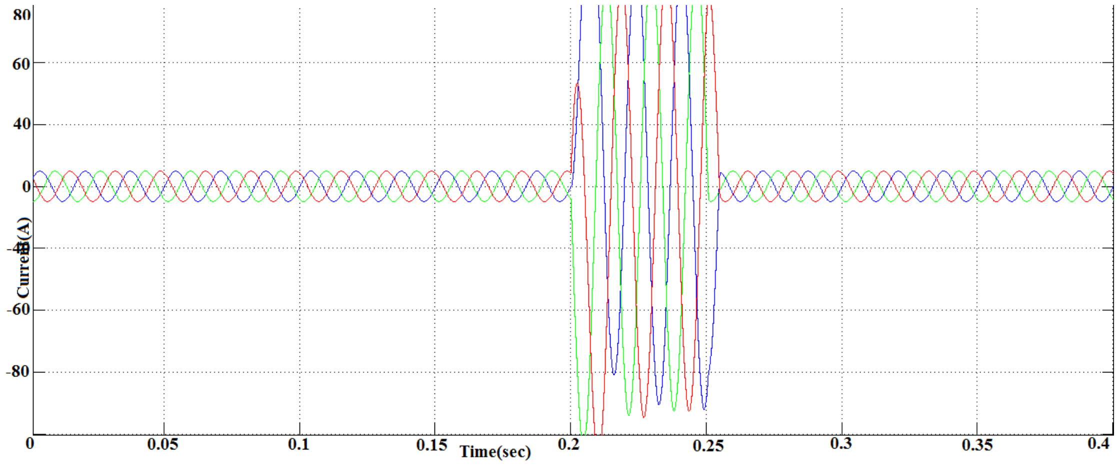

Fig. 9. Load current reduced from 100A to 20A from t=0.2 sec to t=0.4 sec by the use of ASFCL.

C. Control strategy

Active type superconducting fault current limiter can be implemented with different types of control strategies in control unit for the generation of pulses for IGBT. The ASFCL model with these control strategies is implemented in a distribution system as shown in Fig. 10. The ASFCL is connected in series with the switch which in turn is connected in parallel to the transmission line. From t=0.1 sec to t= 0.26 sec, a three phase fault is simulated. The switch is initially in open condition, but after fault detection from t=0.1 sec to t=0.26 sec, the current rises in the system. The switch is closed immediately after detecting the increase in fault current and the ASFCL placed in the distribution system limits the current again to normal value.

The open loop control strategy and closed loop control strategy for ASFCL, has been analyzed [11]. In open loop control strategy the input used is three phase sine wave, which is fed to the PWM generator which generates six pulses for the IGBT. These gate pulses are input for the IGBT, which provides compensation needed by the system at the time of fault condition. Fig. 11 shows the open loop control strategy developed in the control unit of ASFCL.

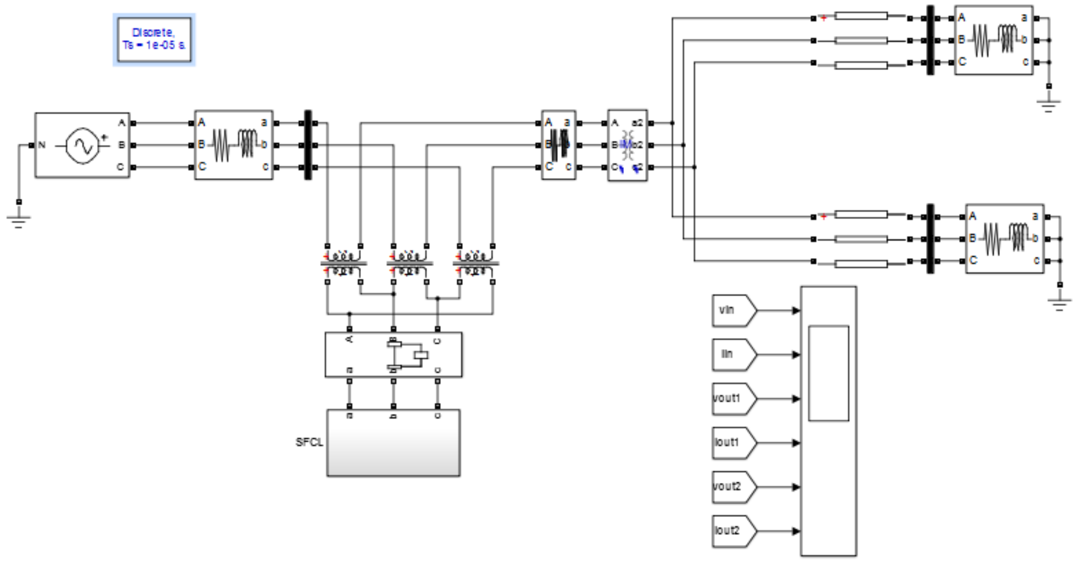

Fig. 10. Model of ASFCL in distribution system for open loop strategy.

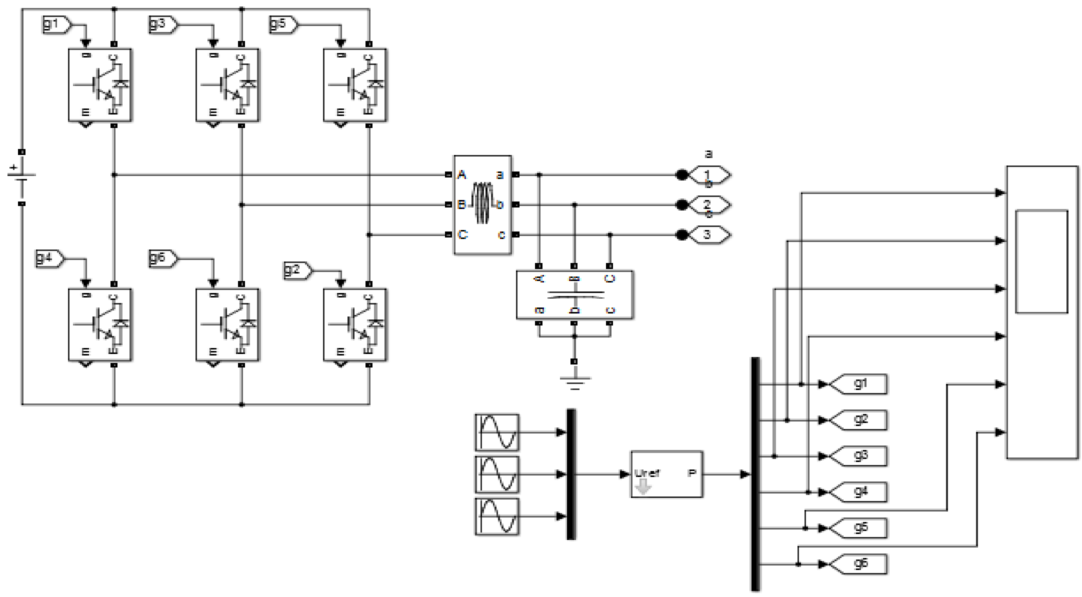

Fig. 11. The open loop control strategy.

The closed loop control strategy used is shown in Fig. 12. The output voltage and output current are used for reference measurement during the time of three phase fault. PID controllers are used for minimization of error in the control signals. The voltage obtained is in the dq0 frame and given as an input to the SPWM. The pulses generated are used for triggering of IGBTS.

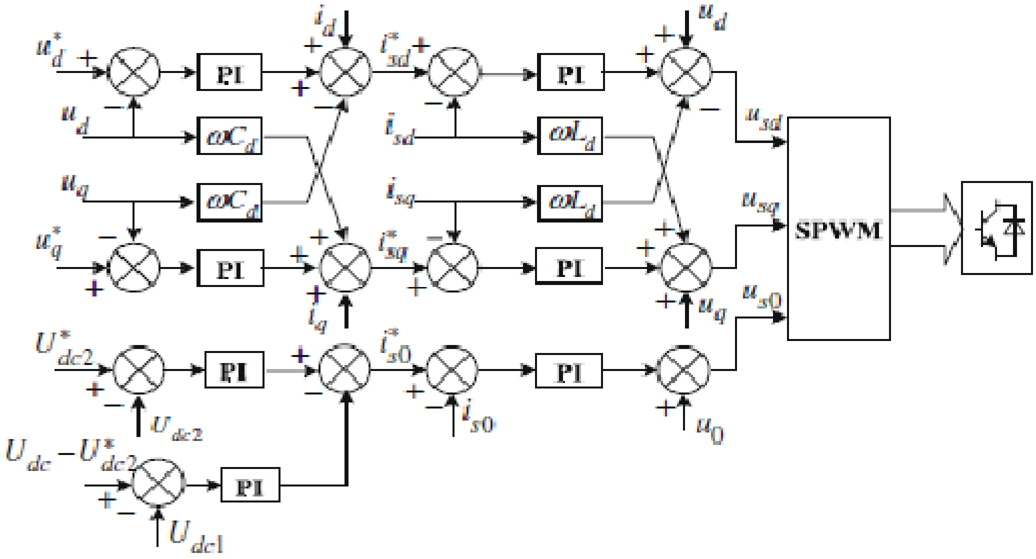

Fig. 12. The closed loop control strategy for ASFCL.

Fig. 13 shows the input voltage of 50kV, load current of 15A during normal condition. From t=0.1 sec to t=0.26 sec the output current rises to 100A due to three phase fault. Fig. 14 depicts the ASFCL activated at the time of three phase fault from t=0.1 sec to t=0.26 sec, where fault current is reduced from 100A to 15A in the radial distribution system by the use of ASFCL.

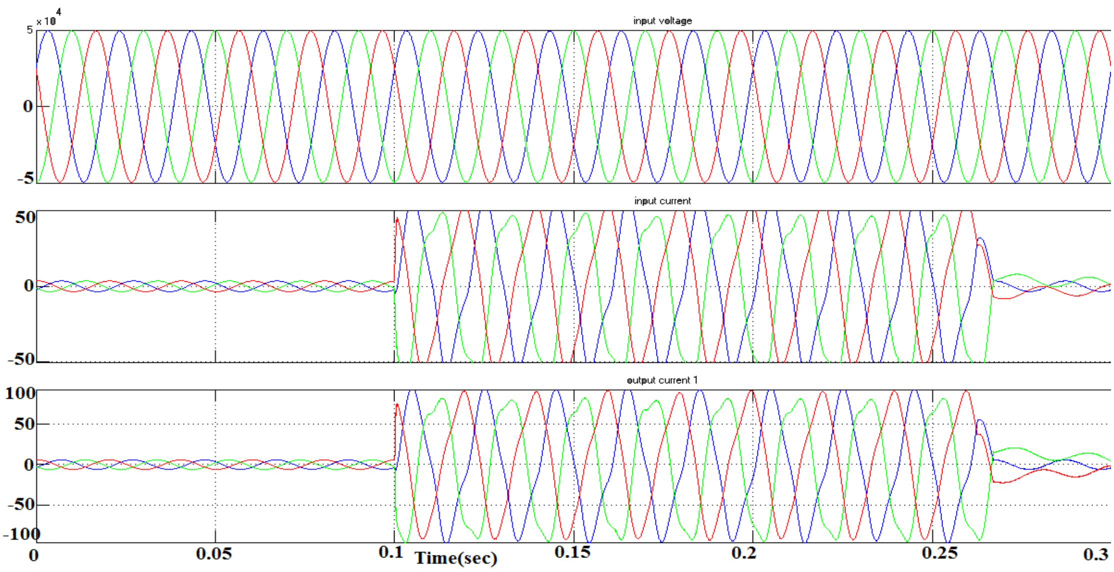

Fig. 13. The load current increases in t=0.1 sec to t=0.26 sec during the time of three phase fault.

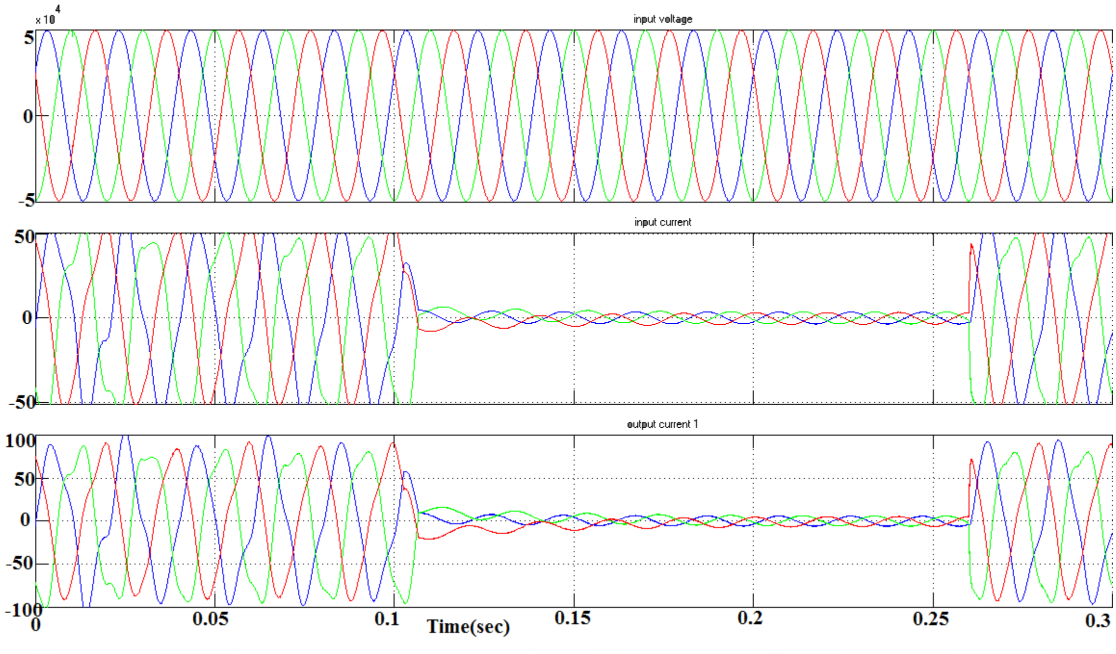

Fig. 14. Load current restored to normal value after three phase fault removal by ASFCL from t=0.1 sec to t=0.26 sec.

IV- CONCLUSION

This paper describes the effect of ASFCL during the time of three phase fault in a radial distribution system. From the analysis it is evident that the closed loop strategy was more advantageous than the open loop control strategy. The feedback mechanism in the closed loop control strategy was implemented using the SPWM technique. The fault current level is reduced to a desired level by using ASFCL with closed loop control strategy.With theintegration of dispersed energy sources such as wind, photovoltaic energy sources installed in the distribution system will increase fault current level. In suchcondition the utilization of ASFCL is one of the efficient method to limit the fault current and safeguard the distribution system equipments during fault condition.

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