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Performance of Superconducting Fault Current Limiter and Fault Current Limiter in Power System

G Swetha[1]; R. Sathish Kumar[2]& B. Venkata Prasanth[3]

[1]PG Scholar, Dept of EEE, QIS College of Engineering & Technology, Ongole, AP, India,
E-mail: swethagunapati@gmail.com.
[2]Associate Professor, Dept of EEE, QIS College of Engineering &Technology, Ongole, AP, India,
E-mail: rsksjcetsathish@gmail.com.
[3]Professor & HOD, Dept of EEE, QIS College of Engineering &Technology, Ongole, AP, India,
E-mail: bvprasanth@gmail.com

Abstract- *In recent world the trend of using electrical energy is increased, which results in increased power demand and hence the occurrence of abnormal events. Superconducting fault current limiter is an innovative protection device which is used to reduce the magnitude of fault current in high voltage system. In this paper the application of resistive type superconducting fault current limiter is explained, which is used to reduce the magnitude of fault current. As the electrical power system is very wide, the chance of occurrence of any kind of fault is very common, due to that high magnitude of current flows through the system. This may harm the mechanical equipments of the power system. As the equipment's in power system are expensive, so it is essential to protect from the abnormal events. It is not possible to eliminate these faults completely, but it is possible to lower their harmful effects, by decreasing the level of fault current. The application of the fault current limiter (FCL) would not only decrease the stress on network devices, but also can offer a connection to improve the reliability of power system. There are various types of FCL's, which are made of different superconducting materials and have different designs. They are categorized into three broad types: the resistive type, the inductive type and bridge type SFCL. We discussed the operating characteristics of SFCL introduced into a simplified power transmission model system. It was finally revealed that SFCL could satisfactorily bring about the functions of fault current suppression and power system stability improvement. In order to evaluate the impact of fault current limiter in power system performance, simulation work is performed by using Mat lab/Simulink tool.*

Index Terms— Power Quality (PQ); Superconducting Fault Current Limiter (SFCL); Switch Gear Units.

I.INTRODUCTION

Now-a-days there is drastic change in growth in power system and interconnected networks. This growth is expected to continue in future. When there is occurrence of an accidental events like lightning or downed power lines, a large amount of power flows through the grid which results in a failure of the electric system. Therefore protection of the system is an important consideration to avoid harm to the system parameters and system equipments from large amount of current during fault [1]-[4]. A device which limits the short circuit current during fault in a power transmission network is a Fault Current Limiter (FCL). Use of Fault current limiters (FCL) is an effective way to reduce fault current, which results in saving in the investment of high capacity circuit breakers. A various types of fault current limiters uses variety of new techniques for limiting excess fault current [5]. However focus is on superconducting technologies i.e. Superconducting Fault current Limiters (SFCL). Whereas non-superconducting technologies contain devices like simple inductors or variable resistors are also known as Fault Current Controllers. Due to the rapid growth in the power generation systems there is a growth in fault current level, which may cross the rated capacity of available circuit breaker. Replacement of this existing switchgear due to increased fault level will not be the feasible option by considering cost parameter. By considering all these parameters it is necessary to use some reliable means to minimize fault current level and hence allow the circuit breaker to operate at lower fault currents. Superconducting Fault current Limiters provides an effective way to suppress fault current [6].

Many types of fault current limiter have been developed in the past few years [7]. Superconducting fault current limiter (SFCL) is the most inventive fault current limiting device [8]. It offers many advantages, like having no impact on the system in typical conditions, limiting fault current quickly and response automatically in an abnormal condition. In power system, studies of SFCL are anticipated not only to limit fault current but also to develop stability of the system [9]. Many studies have been carried out for the practical application of SFCL in electric power system in the past few years [10]. It includes current limiting characteristics of SFCL, optimal resistive value of SFCL to improve transient stability, optimal place to install the SFCL etc. But most of the important practical application concern of SFCL in power system to enhance system capacity with existing switchgear has not been studied.

There are several kinds of SFCLs, which can be classified in three types such as the resistive type, the inductive type and bridge type SFCL. Each type of SFCL has its merits and demerits. Many studies have focused on the topology and capability of SFCLs. The inductive type SFCL is able to suppress the voltage drop and limit the fault current. The resistive type SFCL can consume the energy of the fault current and limit it. This capability can improve the power system stability. The bridge type SFCL is a kind of SFCL, which has zero impedance under the normal condition and large impedance under fault condition. Its advantage is the fault current limitation without any delay and smoothing the surge current waveform. But, it cannot limit the steady state fault current [11-13]. Among the parameters of FCL, the magnitude of the limiting impedance and its merits affects the current limiting performance of FCL much more than the other parameters. In other words, depending upon the kind of FCL and its merits, the insertion of FCL into the power system can result in more severe interrupting problems. Therefore, it is important to study the interrupting behaviour of circuit breakers in presence of the kinds of FCL [14].

II.SUPERCONDUCTING FAULT CURRENT LIMITER

Superconducting fault current limiter is a promising technique to limit fault current in power system. Normally non-linear characteristic of superconductor is used in SFCL to limit fault current. In a normal operating condition SFCL has no influence on the system due to the virtually zero resistance below its critical current in superconductors. But when system goes to abnormal condition due to the occurrence of a fault, current exceeds the critical value of superconductors resulting in the SFCL to go resistive state. This capability of SFCL to go off a finite resistive value state from zero resistance can be used to limit fault current. Different types of SFCLs have been developed until now [10-13]. Many models for SFCL have been designed as resistor-type, reactor-type, and transformer-type etc. In this paper a resistive-type SFCL is modelled using Simulink. Quench and recovery characteristics are designed on the basis of [14].

An impedance of SFCL according to time t is expressed by

(1)

$$R_{SFCL} = \begin{cases} 0, & (t_0 > t) \\ R_m\left[1 - \exp(-\frac{t - t_0}{T_{sc}})\right]^{\frac{1}{2}}, & (t_0 \le t < t_1) \\ a_1(t - t_1) + b_1, & (t_1 \le t < t_2) \\ a_2(t - t_2) + b_2, & (t_2 \le t) \end{cases} \quad (1)$$

Where R_m is the maximum resistance of SFCL in the quenching state, T_{sc} is the time constant of SFCL during transition from the superconducting state to the normal state. Furthermore, t_0 is the time to start the quenching. Finally, t_1 and t_2 are the first and second recovery times, respectively. Quenching and recovery characteristics of SFCL are modelled by using MATLAB are shown in Fig. 1. In normal condition, the impedance of SFCL is zero which is shown in Fig. 1. Quenching process of SFCL start at t=1s due to the occurrence of fault causing impedance rises to its maximum value. Impedance again becomes zero after the fault clears.

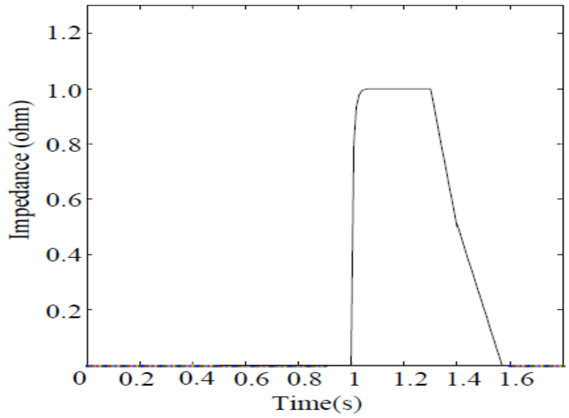

FIG.1. QUENCH AND RECOVERY CHARACTERISTICS OF SUPERCONDUCTING FAULT CURRENT LIMITER

III.DESIGNING OF SFCL

The working principle of SFCL model developed in Simulink/Sim Power system is described below. Firstly, RMS value of incoming current (passing through current measurement block) is measured by RMS block. 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. But if the current is larger than the triggering current, SFCL's impedance rises to 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.

These parameters are used for implementing resistive SFCL characteristic is shown in Fig. 2. Quenching and recovery time of SFCL are specified using step and transport block respectively. A Switch block is used to give minimum or maximum impedance in output which is determined by considering the incoming current. The simulation model of SFCL for a single phase system is shown in Fig. 3.

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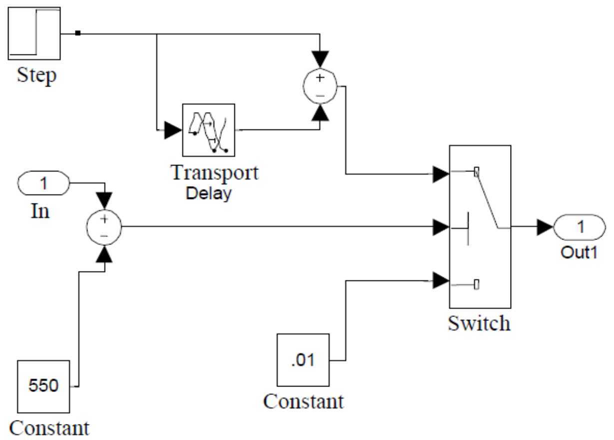

Fig.2 Implementation of Resistive SFCL Characteristics in Simulink

Simulink/Sim Power system is chose to design resistive SFCL. Four fundamental parameters is used for modelling resistive-type SFCL. The parameters and their values are: Transition or response time = 2ms, minimum impedance= 0.01Ω & maximum impedance= 20Ω, triggering current =550A, recovery time =10ms.

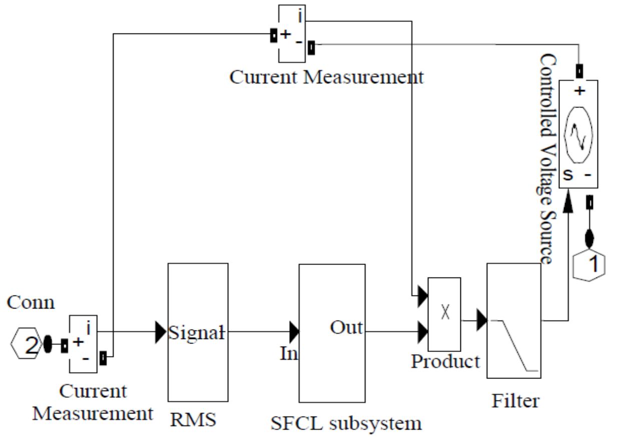

Fig.3 Resistive SFCL model in Simulink

The designed model of SFCL is implemented in single phase system and fault current characteristics are taken with and without SFCL. The simulation model for this purpose are shown in fig.4 and fig.5 respectively. The fault is introduced directly through AC source in order to decrease the difficulty of simulation. An RMS block is used to calculate the RMS value of the incoming current and scope is used to see the output of the system.

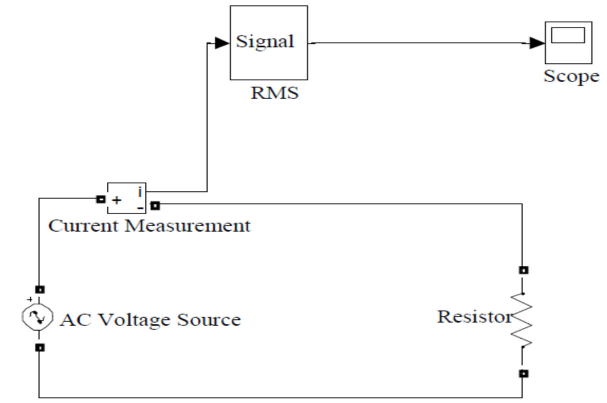

Fig. 4. Simulation model of single phase system without SFCL.

A three phase system with a nominal capacity (110 MW) is designed in Simulink/Sim- Power System shown in Fig.6. Here a 3 phase simplified synchronous machine having 140MVA rating is used as a synchronous machine. The generating capacity of the machine is 20KV. A step up transformer (20/154 KV) is used to step up the generating voltage which is ultimately connected to an industrial load. Now the capacity of the conventional system is increased to 220MW.

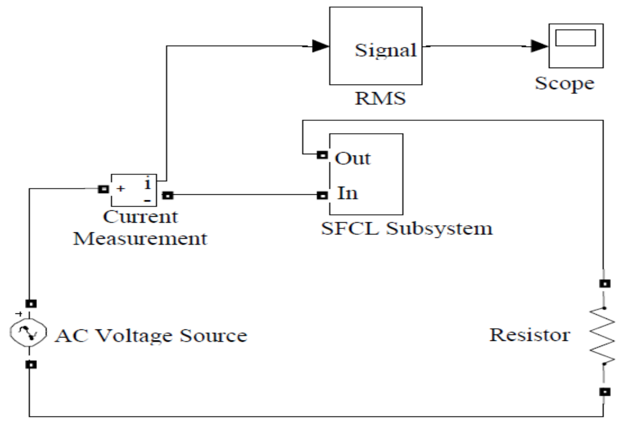

Fig.5 Simulation model of single phase system with SFCL.

Here also a 3- phase Simplified synchronous machine is used as a synchronous machine having rating 275MVA for the purpose of supplying improved capacity 220MW. Here also the generation voltage is 20KV. A SFCL is connected to each phase of the system keeping other equipments unchanged.

IV.FAULT CURRENT LIMITER

Fig. 6 shows the circuit topology of the proposed FCL which is composed of the two following parts:

1) Bridge part that includes a diode rectifier bridge, a small dc limiting reactor. (Note that its resistance is involved too.), a semiconductor switch (IGBT or GTO), and a freewheeling diode.

2) Shunt branch as a compensator that consists of a resistor and an inductor.

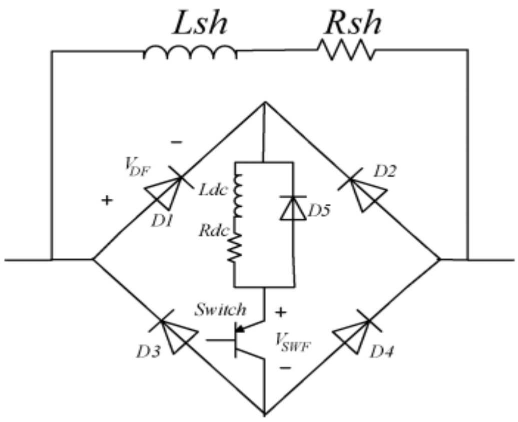

Fig.6. Proposed FCL topology

The total power losses of the proposed structure become a very small percentage of the feeder's transmitted power.

V.MATLAB/SIMULINK RESULTS

The type of the fault introduced in the model is single phase to ground fault is shown in Fig. 7 and Fig. 8 where it is induced through the AC voltage source. The simulated current waveforms of the single phase system model with and without SFCL are shown in Fig. 8 and 10. Due to the absence of SFCL the current value is first 720A shown in Fig.8 and 10.

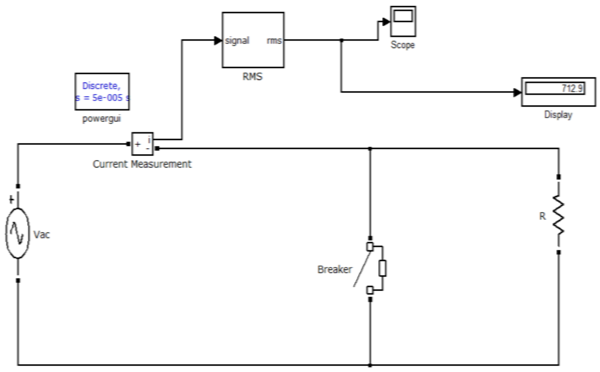

Fig.7 Simulation model of Single phase without SFCL.

Fig. 7 shows the single phase without SFCL model developed in Simulink/Sim Power System.

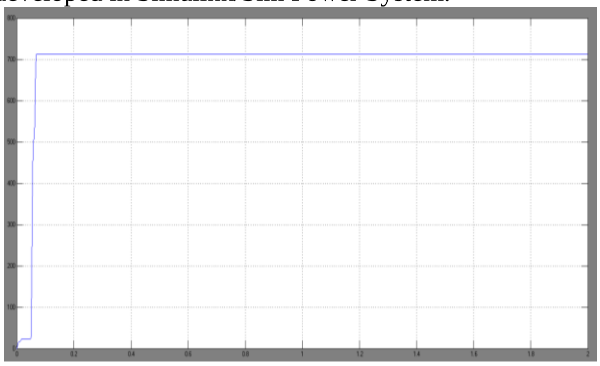
Fig.8 Simulated Output Waveform Single Phase without SFCL.

Above figure shows the single phase without SFCL. Simulation results shows that the proposed model reduces the large fault currents to a lower level.

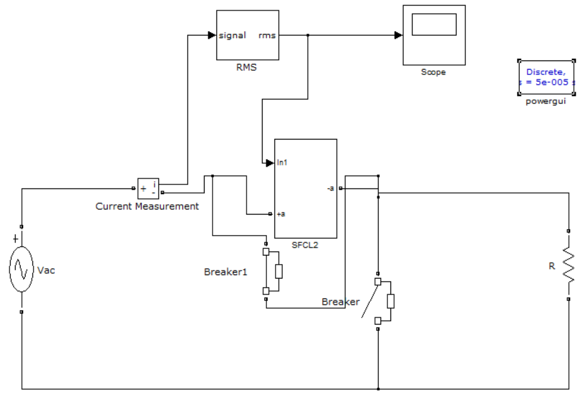

Fig.9 Simulation Model of Single Phase with SFCL.

Fig. 9 shows the single phase with SFCL model developed in Simulink/Sim Power System. The SFCL model working is explained as follows. First, SFCL model calculates the RMS value of the passing current and then compares it with the characteristic. Second, if a passing current is larger than the triggering current, SFCL resistance increases to maximum impedance level in a pre-defined response time.

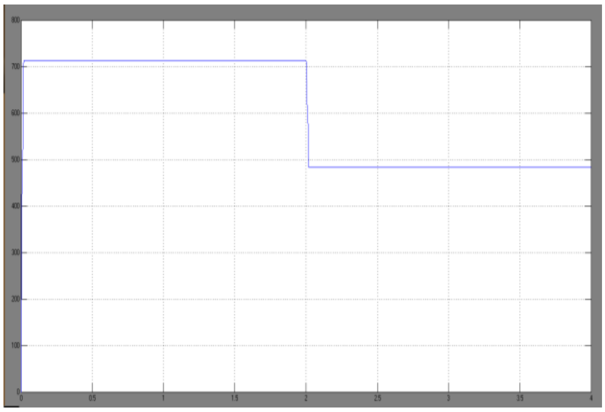
Fig.10. Simulated Output Waveform of Single phase with SFCL.

SFCL has the advantage of fast operation characteristics of within ¼ cycles, whereas conventional circuit Breakers require more than 5-15 cycle. Simulation results shows that the proposed model reduces the large fault currents to a lower level.

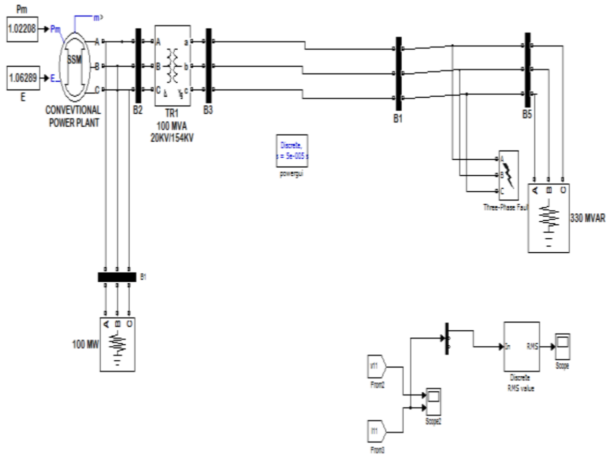

Fig.11.Simulation Model of 110MW System without SFCL.

Fig. 11 shows the three phase 110 MW systems without SFCL model developed in Simulink/Sim Power System.

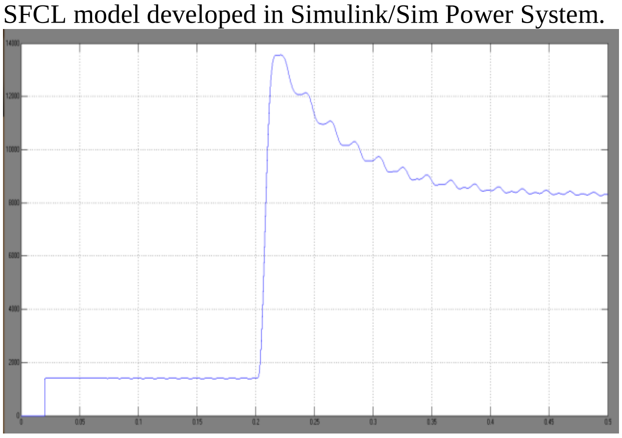

Fig.12.Simulated Fault Current Wave Form without SFCL.

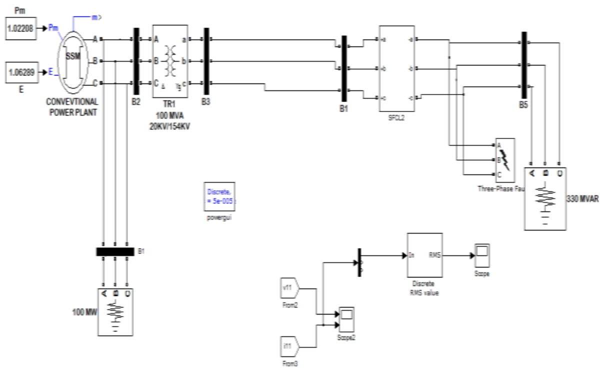

Fig.13.Simulation Model of 110MW System with SFCL.

Fig. 13 shows the three phase with SFCL model developed in Simulink/Sim Power System. The SFCL model working is explained as follows. First, SFCL model calculates the RMS value of the passing current and then compares it with the characteristic. Second, if a passing current is larger than the triggering current, SFCL resistance increases to maximum impedance level in a pre-defined response time.

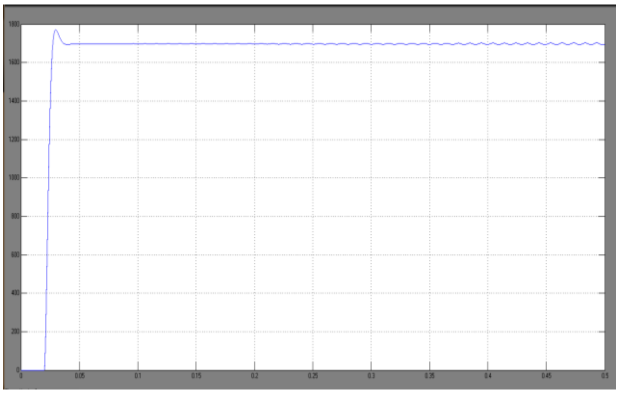

Fig.14.Simulated Fault Current Wave Form with SFCL.

Above Figure shows the simulated fault current with 110MW waveform with SFCL has the advantage of fast operation characteristics of within ¼ cycles, whereas conventional circuit Breakers require more than 5-15 cycle. Simulation results shows that the proposed model reduces the large fault currents to a lower level.

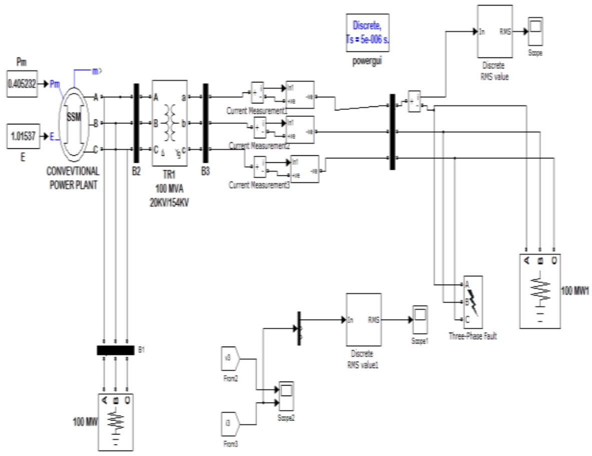

Fig.15.simulation Model of 220MW system with SFCL.

Fig. 15 shows the simulation model of three phase with SFCL model developed in Simulink/Sim Power System. The SFCL model working is explained as follows. First, SFCL model calculates the RMS value of the passing current and then compares it with the characteristic. Second, if a passing current is larger than the triggering current, SFCL resistance increases to maximum impedance level in a pre-defined response time.

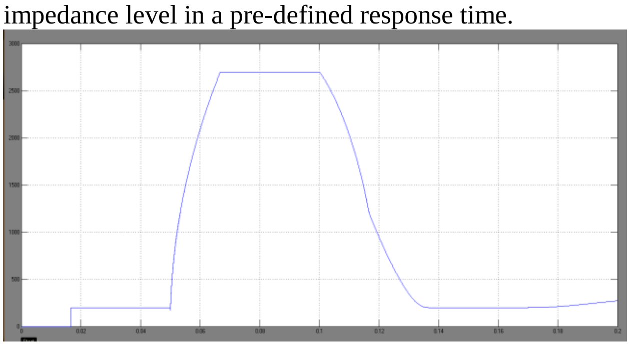

Fig.16.Simulated wave form of fault current with 220MW.

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Above Figure shows the simulated fault current with 220MW waveform with SFCL has the advantage of fast operation characteristics of within ¼ cycles, whereas conventional circuit Breakers require more than 5-15 cycle. Simulation results shows that the proposed model reduces the large fault currents to a lower level.

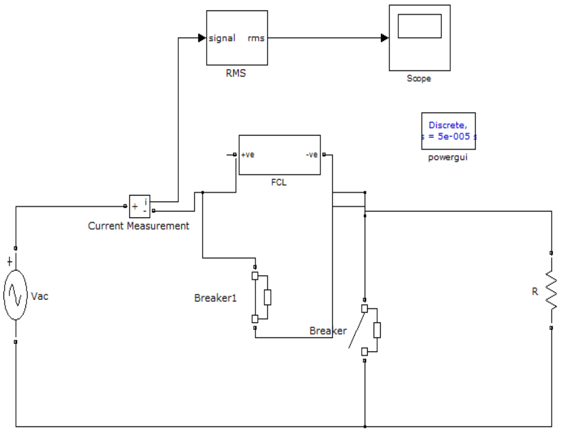

Fig.17.Simulated Single phase with FCL.

Fig. 17 shows the single phase with FCL model developed in Simulink/Sim Power System. The SFCL model working is explained as follows. First, FCL model calculates the RMS value of the passing current and then compares it with the characteristic. Second, if a passing current is larger than the triggering current, FCL resistance increases to maximum impedance level in a pre-defined response time.

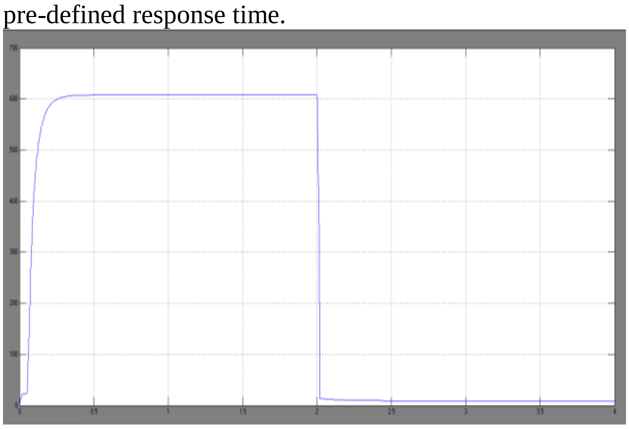

Fig.18.simulated output waveform of Single phase with FCL.

FCL has the advantage of fast operation characteristics of within ¼ cycles, whereas conventional SFCL require more than 5-15 cycle. Simulation results shows that the proposed model reduces the large fault currents to a lower level.

Fig. 19 shows the simulation model of three phase with FCL model developed in Simulink/Sim Power System. The FCL model working is explained as follows. First, FCL model calculates the RMS value of the passing current and then compares it with the characteristic. Second, if a passing current is larger than the triggering current, FCL resistance increases to maximum impedance level in a pre-defined response time.

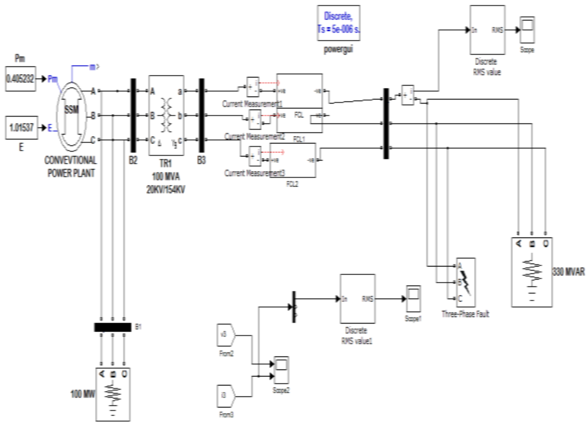

Fig.19. Matlab/Simulink model of three phase 220MW with FCL.

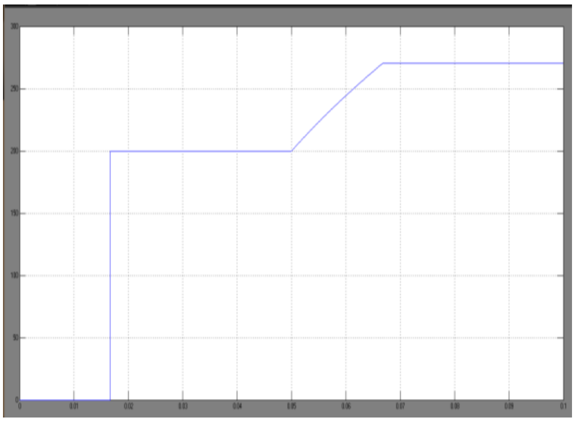

Fig.20.Simulated wave form of fault current with 220MW FCL system.

Above Figure shows the simulated fault current with 220MW waveform with FCL has the advantage of fast operation characteristics of within ¼ cycles, whereas conventional SFCL require more than 5-15 cycle. Simulation results shows that the proposed model reduces the large fault currents to a lower level.

VI.CONCLUSION

Superconducting fault current limiter is an innovative protection device which is used to reduce the magnitude of fault current in high voltage system. This paper explains the need of fault current limiter in present and future, because of increase in distributed generation. The fault current limiter proposed in the paper has the merit to meet the problem of voltage sags in distribution utilities with a solution that does not require control system and power electronic & also power capacity can be increased with out change in existing switchgear The simulation performed proves effectiveness as well as the possibility of building the 'FCL' with commercially available components.

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Author's Profile:

G.Swetha is pursuing M-Tech at QIS college of Engineering & Technology under JNTU, Kakinada. She received her B-Tech degree from Rao & Naidu Engineering College, Ongole. Her current research interests are Research areas, Power systems.

Sri.R.SathishKumar received B.Tech. in Electrical and Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, in 2005 and M.Tech in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, in 2010. Currently, he is working as an Associate Professor in QIS College of Engineering and Technology, Ongole, India. He has published a number of papers in various national & international journals & conferences. His research areas are power system operation & control and economic load dispatch.

Dr. B. Venkata Prasanth received B.Tech. in Electrical & Electronics Engineering from Sri Krishnadevaraya University & M.Tech. Degree in Electrical Power Systems from Jawaharlal Nehru Technological University, Ananthapur, India. He received his Ph.D. in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India. He has got a teaching experience of more than 15 years. Currently, he is working as Professor& Head in QIS College of Engineering and Technology, Angola, India in the Dept. of Electrical & Electronics Engineering. He has published a number of papers in various national & international journals & conferences. His research interests include application of intelligent controllers to power system control design, power system restructuring, power system economics & optimization.