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COMPARATIVE STUDIES OF SUPERCONDUCTING FAULT CURRENT LIMITER FOR TRANSFORMER PROTECTION

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Abstract: The short circuit faults are the most dangerous phenomenon ones among the numerous faults occurring in power distribution systems. The amplitude of current becomes 20times more than the normal rated current. And this causes the thermal and mechanical stress over the conductors. The electrical equipment can interrupt over current up to rated dimensions, so beyond the limits overstress can damage the equipment and lead to the power quality problems. To minimize the worse effects of certain over current fault in equipment and super conducting materials technique introduces to eliminate the risk at power distribution sides. Here superconducting fault limiter or reactor plays utmost important role to limit the fault current. Mainly DC core type superconducting fault limiter is discussed and developed in proposed project. To check the efficacy of this simulation is also done and discussed the results. This is one of the effective technique used for the termination of over current at power distribution side.

Keywords: SFCL, FCL, SC, Transformer, Protectionetc.

I. INTRODUCTION

The short circuit faults are the most destructive ones among the numerous faults occurring in power distribution systems. Sometimes the short-circuit faults generate over current more than 20 times the rated current. The consequences of inevitable fault current in electrical network usually mean thermal or mechanical stress for the affected equipment. The normal power flow is interrupted by the protection relays. The results are voltage interruption and other power quality problems to the end-users. Power equipment is normally dimensioned for the tremendous stress under fault conditions. The maximal short circuit current is one of the most important dimensioning parameter and it is directly linked to the price of the equipment. The downsizing of the existing equipment, such as transformers, lines, bus-bars and circuit-breakers is possible by decreasing the maximal fault current [1].

The traditional devices, used for fault current limitation are:-

- Fuses are simple, reliable and they are usually used in low voltage and in middle voltage distribution grids. The main disadvantages are the single-use and the manually replacement of the fuses;
- Circuit-breakers are commonly used, reliable protective devices. The circuit-breakers for high current interrupting capabilities are expensive and have huge dimensions. They require periodical maintenance and have limited number of operation cycles;
- Air-core reactor and transformers with increased leakage reactance increase the impedance of distribution network and consequently limit the short-circuit currents;
- System reconfiguration and bus-splitting.

There have been an increase in the number of studies on the alternative solution to improve the reliability of electrical systems and one of them is the application of a fault current limiter (FCL). The main purpose of the installation of FCL into the distribution system is to suppress the fault current.
The FCL is series element which has very small impedance during a normal operation. If the fault occurs the FCL increases its impedance and so prevents over current stress which results as damaging, degradation, mechanical forces, extra heating of electrical equipment.

The main requirements to the FCLs are:-

- To be able to withstand distribution and transmission voltage and currents;
- To have low impedance, low voltage drop and low power loss at normal operation;
- To have large impedance in fault conditions;
- To have a very short time recovery and to limit the fault current before the first peak;
- To properly respond to any fault magnitude and/or phase combinations;
- To withstand the fault conditions for a sufficient time;
- To have a high temperature rise endurance;
- To have a high reliability and long life;
- To have fully automated operation and fast recovery to normal state after fault removal;
- To have a low cost and low volume.

II. RESEARCH GAP &OBJECTIVES

The pyrotechnic FCL (so called explosion faults limiting fuses, Is-limiters) takes special place. Is-limiters are consisting of an ultra-fast acting switch for nominal loads connected in parallel to a heavy duty fuse. A small explosive charge is used to open the main current path if the fault occurs. The current is transferred to the fuse and its magnitude is limited. In general case of DC reactor type superconducting fault current limiter (SFCL), a fault current gradually increases during the fault. It takes above 5 cycles to cut off the fault in the existing power system installed the conventional circuit breakers (CBs). Therefore, the fault current increases during the fault even if the SFCL is installed. This paper proposes a technique for decaying the fault current with the function of the fault detection and control of power converter of the SFCL. Using the proposed method, the fault current can decay after 1–2 cycles when the fault occurs. The SFCL has just one DC reactor, an AC to DC power converter which has thyristors as the rectifying device, and a three-phase transformer, which is called magnetic core reactor (MCR). The short-circuit tests of this SFCL were performed successfully. Comparing the result using the proposed technique with the typical result, the fault current is decreased effectively by the proposed technique. This result shows that this SFCL using the fault detection and control of power converter can be applied to the existing power system which has conventional CBs.

Superconducting fault current limiter (SFCL) which plays the role of limiting fault current is one of promising power apparatuses. There are several kinds of SFCLs which have been developed by many research groups. Among them, the experimental result and analysis of DC reactor type SFCL is mainly described in this project. One of advantages of a DC reactor type SFCL is that a waveform of fault current does not have a surge current because DC reactor prevents a sudden increasing of current. Therefore, the fault current gradually increases during the fault. It takes above 5 cycles to cut off the fault in the existing power system installed the conventional circuit breakers (CBs). Therefore, the fault current increases during that time even if the SFCL is installed. This project proposes a technique for decaying the fault current, which are the fault detection and control of power converter of the SFCL. This proposed technique makes the fault current controllable. The fault current can be controlled as well as limited using the technique.Using the proposed method, the fault current can decay after 1–2 cycles when the fault occurs. To analyze this technique, three-phase 6.6 kV/200 A SFCL was fabricated. The SFCL has just one DC reactor, an AC to DC power converter which has thyristors as the rectifying device, and a three-phase transformer, which is called magnetic core reactor (MCR). The short-circuit tests of this SFCL were performed successfully.

Comparing the result using the proposed technique with the typical result, the fault current is decreased effectively by the proposed technique. This result shows that this SFCL using the fault detection and control of power converter can be applied to the existing power system which has conventional CBs.

III. ROLE OF FAULT CURRENT LIMITER

In response to ever growing needs for electricity, power producers have been expanding the power grids continually, particularly with the proliferation of independent power producers (IPP's). Technical advancements and promotions of various types of renewable energy generation have also led to a large number of distributed generators (DG's) connected to the power grids. Figure 3.1 shows a diagram of added electricity generations to a power grid. However, this fast expansion of generation capacity obscures a hidden issue, which must be resolved: the potential fault current levels keep increasing as the source impedances are lowered due to the paralleled connections of the growing number of generators. As a result, the potential short-circuit current levels increase substantially, approaching the limits of the devices in existing power systems, including the cables, switchgears, protection devices, and loads. Specifically, if the fault current levels exceed the interruption ratings of existing protection devices, such as fuses and circuit breakers, the equipment will suffer serious damage. In extreme cases, failure to interrupt fault current may destroy insulation of conductors and oil-filled equipment, causing fire or explosion.

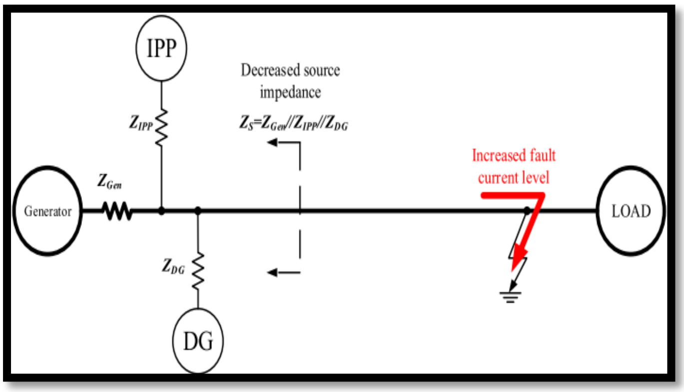

Figure 3.1 Parallel IPP and DG decrease source impedance and increase potential fault current level on the power system

Moreover, many of the existing protective devices need several cycles to interrupt the fault current. Within this period of time, several high peaks of fault current are introduced to the system, posing large thermal and mechanical stresses to the protection devices and other equipment in the system.

Various techniques have been proposed to mitigate the increasing fault current issues. The most straightforward way would be upgrading all the conductors, switchgears, and protection devices in existing power systems to raise their fault current ratings and interrupting speed. However, the process of replacing equipment is expensive, complicated, and time consuming. In many cases, given the scale of the existing power systems, system upgrades remain unviable for the foreseeable future. Unfortunately, faults will not wait, so alternative means should be taken in order to safeguard against the increased fault currents, in order to ensure the robustness and safe operation of the power system.

Bus splitting (or network splitting) is one of the practical strategies being used in the power industry against large fault current. By reconfiguring the network topology, the sources of the fault current are separated into different buses, thereby reducing the available fault current. However, this strategy leads to the permanent increase of system impedance during normal operation, which contradicts the demand for more efficient and stable power grids. Also, bus splitting reduces the number of power sources that can connect to the buses under normal conditions, sacrificing the power system's flexibility in supplying and dispatching power.

Why fault current limiters required?

Because of urgency of the increasing fault current problem and the issues with the other solutions discussed above, Fault

Current Limiters (FCL's) are becoming the preferred option to address the over-rating issue and permit the bypass or postponing of costly system upgrades. The merits of FCL technology are:

- FCLs can be used to mitigate the effect of high fault current levels on a distribution system, permitting the use of lower rated protection devices and avoiding costly device replacements;
- Since many FCLs can limit the fault current within the first quarter-cycle, they can protect existing devices from the first large peak during a fault;
- Short circuit faults are often the origin of voltage sags at a point of common coupling (PCC) in a power network. Since the extent of the voltage sag is proportional to the short circuit current level, reducing the fault current level within the networks can reduce voltage sags during faults and protect sensitive loads that are connected to the same PCC.

Fig 3.2 shows that in fault conditions, an FCL increases the source impedance in the system and limits the fault current. Figure 3.3 demonstrates the typical operation of an FCL and its effect on fault current limiting.

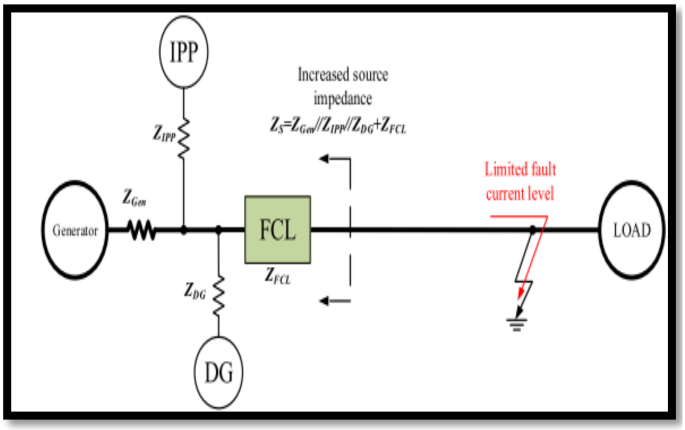

Figure 3.2 FCL increases source impedance and limits fault current during fault condition

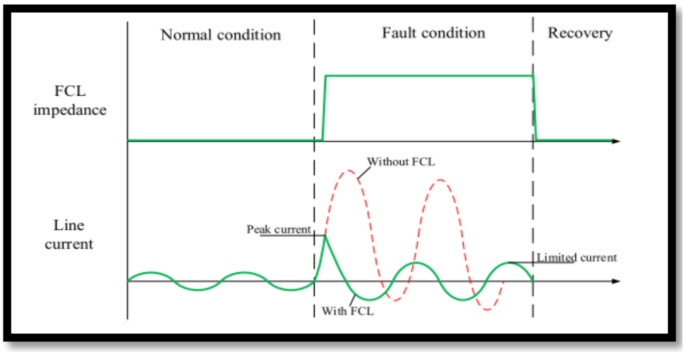

Fig 3.3 Fault current limitation effects on FCL in fault conditions

Fig 3.3 shows the principle of operation shared by most FCL technologies. An FCL maintains low impedance in normal conditions; when a fault occurs, it quickly inserts high impedance to power line quickly, so as to limit the fault current presented on the system. Therefore, an ideal FCL should meet the following requirements:

- Efficient and non-intrusive: During normal operation, the FCL should be as "invisible" as possible to the power line, meaning that the power loss, voltage drop, and harmonic injection to both current and voltage waveforms should be minimized;
- Fast action: Like all protection devices, the FCL's response (pick up and action) speed to a short-circuit fault is vital. For FCL's, action must be taken within the first half cycle upon fault occurrence;
- Fast recovery: Fast recovery capability is favored for FCL's in order to handle sequential fault events or to coordinate with the reclosing actions in many relaying protection applications;
- Low cost: As an intermediate device to be added into systems to prevent expensive system upgrades, an FCL should provide reasonable economic benefits compared to a higher rated protection device.

In summary, an FCL is defined as an intermediate device that presents negligible impedance in normal operation, while inserting high impedance to the faulted lines quickly after short-circuit fault occur.

IV. CONCEPT OF SFCL

The Superconducting Fault Current Limiter (SFCL) presents unique characteristics inherited from the properties of superconductors. This chapter introduces basic elements of superconductivity that are used to present the origin of the electrical resistance occurring in the flux-flow regime in high temperature superconductors. Superconductivity is a state of the matter characterized by a weak attractive interaction between conduction electrons. In this particular state, that occurs for many elements of the periodic system, this weak interaction reduces the system entropy and allows the in phase motion of correlated-electrons over important distances. This long-range phase coherence is thought to be responsible of the perfect conductivity observed in superconductors. In addition to the zero-resistance hallmark, ideal superconductors are characterized by a perfect and reversible diamagnetism. This special behaviour is termed the Meissner effect i.e. the nonexistence of any magnetic flux into the material bulk for any initial conditions. Those unique features of the superconducting state are overcome when an external input of energy (thermal, magnetic or kinetic) is sufficient to break down the fragile phase equilibrium. More specifically, the superconductor becomes a normal metal if the critical surface defined by the critical values (the temperature, magnetic field and current density) is reached as shown in figure-4.1.

Superconductors are classified into two main groups according to their behavior at the state transition. The figure 4.2 presents the typical responses of these groups to an applied magnetic field. As depicted in the figure, the first group, termed type-I, shows a first order transition i.e. an abrupt and complete loss of the Meissner state at H = Hc, the thermodynamic critical field. This value is related to the maximal magnetic pressure the material can stand to hold the field out (condensation energy). For the second group, named type-II, the "pure" Meissner state exist only below a minimum field H = Hc1. Above this value, the magnetic flux starts to penetrate the material. Once the penetration starts to occur the superconductor is said to be in the mixed-state (Shubnikov phase) which is a state characterized by the nucleation, in the superconductor, of normal metal filaments called vortex, each carrying a quantized magnetic flux ϕ_0. For type-II superconductors, the flux penetration allow a second-order phase transition (continuous) that reduces the energy needed to hold the field out. This allows the complete penetration of the magnetic field to occur in a larger field Hc2 than the thermodynamic critical value Hc.

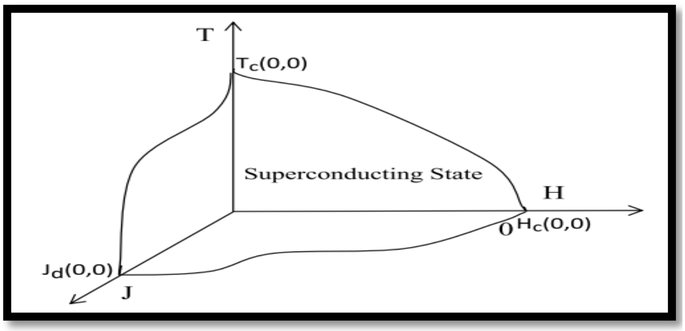

Figure 4.1the critical surface of superconductor

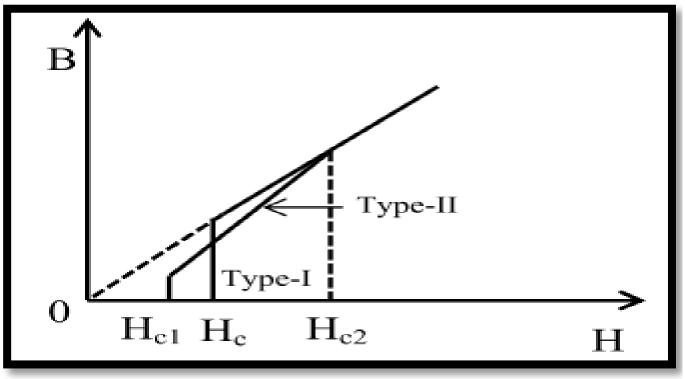

Figure 4.2 B-H phase diagram for type-I and type-II superconductors

Magnesium Diboride (MgB2) has also emerged as a suitable candidate material for FCL devices. The major advantages of this material is its inexpensiveness, hence utilizing MgB2 is expected to reduce the cost for superconducting material used in the SCFCL.Superconducting fault current limiter (SFCL) is an ideal current limiter, but it is still only in the researching stage. The technical performance of superconducting fault current limiters has been demonstrated by numerous successful projects worldwide.

Different types of SFCL

Superconducting fault current limiters are basically of two types:

1) Resistive type SFCL
2) Inductive type SFCL
   a) Shielded iron-core type SFCL
   b) Saturated iron-core type SFCL

Resistive type SFCL

The resistive type is a 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. When the current is normal, the superconductor is in the superconducting state without resistance. If the current increases over the critical current, the superconductor goes into its normal state and it has a high resistance connected in series with the network. This resistance will limit the current. A parallel resistance is required to be connected with the superconducting element.

The parallel resistance or inductive shunt is needed to avoid hot spots during quench, to adjust the limiting current and to avoid over-voltages due to the fast current limitations. The resistive SFCLs are much smaller and lighter than the inductive ones. First commercial resistive FCL has been energized in late 2009 in Europe. Currently, two parallel projects in US aiming to build transmission voltage level resistive FCL are undergoing.

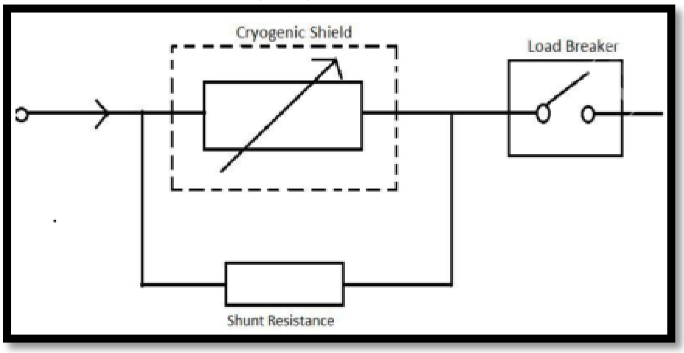

Figure 4.3 Resistive type SFCL

superconducting wires for fault current limiter applications,” In the recent decades the price of the YBCO coated conductor drops significantly and the performance has improved, therefore, it has gained significant attentions as the superconducting material for resistive type FCL and the research on it has been carried out worldwide. In October 2011, a 138 kV, 0.9 kA resistive SFCL was successfully tested in a high-voltage transmission grid. The tested system proved to reduce fault current levels by more than 50 percent.

Inductive type SFCLs

The inductive type is a special transformer connected in series with the network. This transformer has a conventional primary coil, and a rather special secondary “coil”: a superconductor ring. When the current is normal, the superconductor ring gives a de excitation. In normal operation the primary winding resistance and leakage inductance determine the impedance of the limiter. Thus during normal operating condition the FCL exhibits a low impedance (approximately the leakage reactance). When the current increases over the critical current, the superconductor ring goes into normal state. In this case the FCL represents high impedance (approximately the main field reactance).

a) Inductive Shielded Superconducting Fault Current Limiter

This device is based on the principle of perfect diamagnetism of the superconductor that is in super conducting state the magnetic field is expelled from the superconductor. This effect was first discovered by MeiBner and Ochsenfeld. It works like transformer, the superconducting element is a cylinder which forms the single turn short circuited secondary of an iron cored transformer which has part of the power line as its primary. In its superconducting state, this cylinder effectively screens the iron core from the primary, and a low inductance (i.e. impedance) is introduced in the line. However, when the current (and hence the magnetic field) increases above a certain level, the superconductor can no longer shield the iron core), flux enters the iron and a high impedance is inserted in the line which is to be protected.

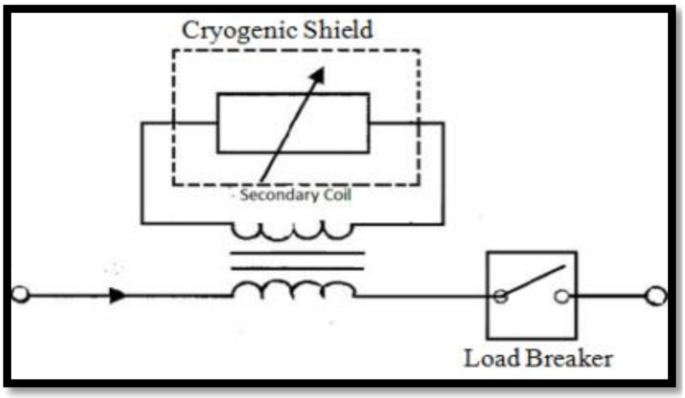

Figure 4.4 Inductive Shielded Superconducting Fault Current Limiter

The primary winding acting as the main current lead of the circuit is built in a way not to be exposed to the cryogenic part but to the temperature level of the environment. In normal operation the magnetic field is expelled from the superconductor. That means that the magnetic flux, generated by the primary winding, is not able to penetrate the iron core. Therefore the iron core doesn't cause any magnetization losses and the limiter inserts very low impedance to the network. Only in the resistive state when the superconductor is no longer able to expel the magnetic field, large impedance is inserted into the network.

b) Saturated iron-core type SFCL

In the saturated-core FCL, two iron cores (one for each half of the cycle) are saturated by the dc magnetic field produced by a superconducting coil wrapped around each core. The main power line is wound around both cores and, when the current becomes high enough (i.e. a fault) the cores are driven out of saturation and the impedance rises - limiting the current.

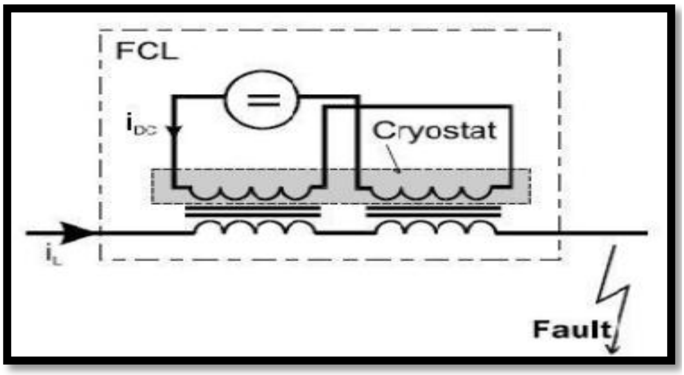

Figure 4.5 Saturated iron-core types SFCL

Figure 4.5, above shows a structure diagram of single-phase magnetic saturated core type SFCL, which is composed by iron cores, AC windings, superconducting DC winding, DC power and the control circuit. Under the normal operating condition, DC superconducting coil generate a lot of magnetic flux which can make the core saturated. Therefore it offers very small impedance to the power system which has no adverse effect on normal transmission.

V. PROPOSED WORK

Resistive type SFCL

Resistive SFCLs utilize the superconducting material as the main current carrying conductor under normal grid operation. The principle of their operation is shown in the one-line diagram at the top of Figure 5.2. As mentioned above, the lower figure is a normalized plot of voltage across RSC as a function of the ratio of current through the device, ILine, to the "critical current", IC, of the superconducting element. At present, for HTS materials, the convention is to define "critical current" as the current at which a voltage drop of 1.0 μV/cm is observed along the conductor. When a fault occurs, the current increases and causes the superconductor to quench thereby increasing its resistance exponentially. The current level at which the quench occurs is determined by the operating temperature, and the amount and type of superconductor. The rapid increase in resistance produces a voltage across the superconductor and causes the current to transfer to a shunt, which is a combined inductor and resistor. The shunt limits the voltage increase across the superconductor during a quench. In essence, the superconductor acts like a switch with millisecond response that initiates the transition of the load current to the shunt impedance. Ideally, the incipient fault current is limited in less than one cycle.

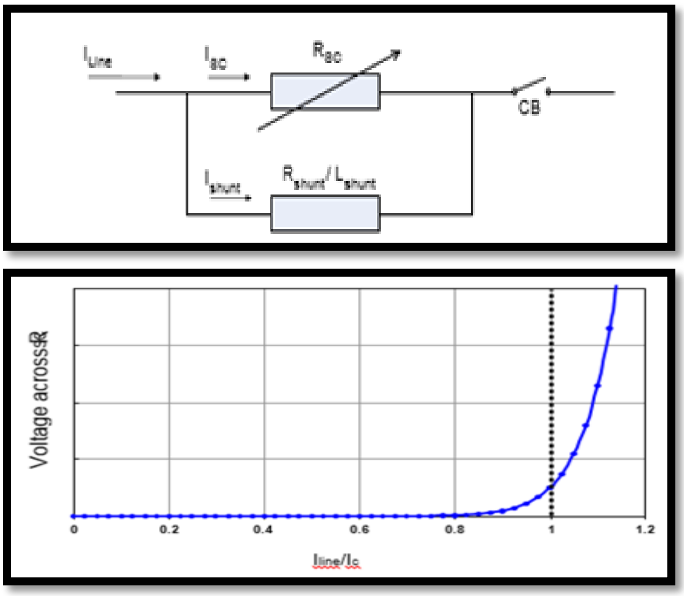

Figure 5.2 Resistive Type SFCL with Shunt Element and a normalized plot of voltage and current in a superconductor at a constant temperature and magnetic field

Early resistive SFCL designs experienced issues with "hot spots", or non-uniform heating of the superconductor during the quench. This is a potential failure mode that occurs when excessive heat damages the HTS material. Recent advances in procedures for manufacturing HTS materials coupled with some creative equipment designs have reduced the hot-spot issue.

The grid characteristic of the resistive SFCL after a quench is determined by the shunt element. Thus, because the shunt is typically quite reactive, a resistive SFCL typically introduces significant inductance into the power system during a fault. During the transition period when current is being transferred from the superconductor to the shunt, the voltage across the combined element shown in Fig 5.2 is typically higher than it is after the current has transitioned into the shunt. The dynamics of this process depend on the two elements and their mutual inductance.

Shielded-Core SFCL

One of the first SFCL designs developed for grid deployment was the shielded-core design, a variation of the resistive type of limiter that allows the HTS cryogenic environment to remain mechanically isolated from the rest of the circuit. An electrical connection is made between the line and the HTS element through mutual coupling of AC coils via a magnetic field. Basically, the device resembles a transformer with the secondary side shunted by an HTS element. During a fault, increased current on the secondary causes the HTS element to quench, resulting in a voltage increase across L1 that opposes the fault current.

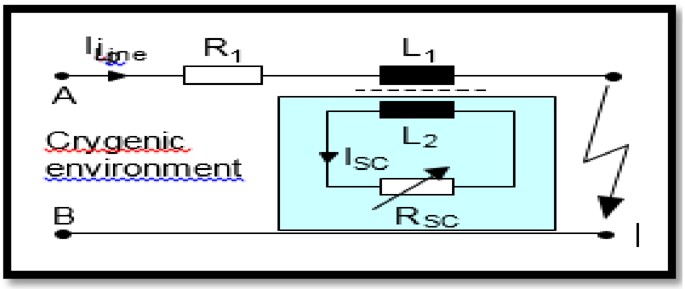

Figure 5.3 Shielded-Core SFCL Concept

Although the superconductor in the shielded-core design has to re-cool after a limiting action just like the resistive type, non-uniform heating of the superconductor (hot spots) is easier to avoid through optimization of the turns ratio. A major drawback of the shielded-core technology is that it is approximately four times the size and weight of purely resistive SFCLs. Although prototypes of shielded-core designs have worked well, their size and weight have limited grid deployment.

Saturable-Core SFCL

Unlike resistive and shielded-core SFCLs, which rely on the quenching of superconductors to achieve increased impedance, saturable-core SFCLs utilize the dynamic behaviour of the magnetic properties of iron to change the inductive reactance on the AC line. The concept (shown in Figure 5.4) utilizes two iron cores and two AC windings for each phase. The AC windings are made of conventional conductors that are wrapped around the core to form an inductance in series with the AC line. The iron core also has a constant-current superconductive winding that provides a magnetic bias.

Under nominal grid conditions (when the AC current does not exceed the maximum rating for the local system), the HTS coil fully saturates the iron so that it has a relative permeability of one. To the AC coils, the iron acts like air, so the AC impedance (inductive reactance) is similar to that of an air-core reactor. Under fault conditions, the negative and positive current peaks force the core out of saturation, resulting in increased line impedance during part of each half cycle.

The result is a considerable reduction in peak fault current. During a limiting action, the dynamic action of the core moving instantaneously in and out of saturation produces harmonics in the current waveform. However, under normal conditions, the voltage and current waveforms are basically unaffected by the saturable-core SFCL.

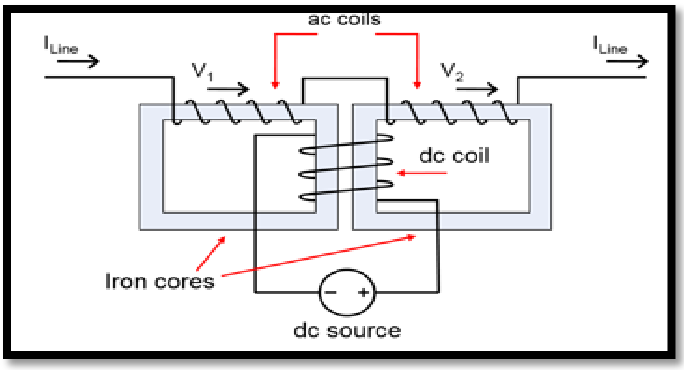

Figure 5.4 Operation of the Saturable-Core SFCL

Essentially, the saturable-core SFCL is a variable-inductance iron-core reactor that has the impedance of an air-core reactor under normal grid conditions and a very high impedance during fault events. Unlike resistive SFCLs, which may require time between limiting actions to cool the superconducting components, the saturable-core approach can manage several actions in succession because the superconductor does not quench. In fact, the saturable-core FCL need not use a superconducting coil; however, the use of an HTS DC field winding reduces operating losses and makes the winding more compact.

VI. SIMULATION & RESULTS

Modelling and Simulation of Proposed system without any Control of SFCL

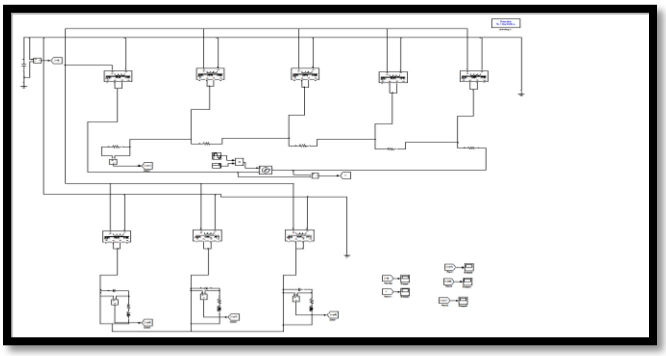

Fig 6.1- Proposed System without SFCL

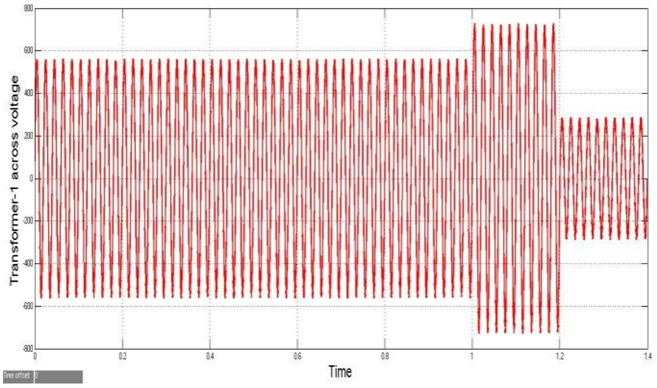

Fig 6.2- Voltage Fluctuation at Transformer-1 without SFCL

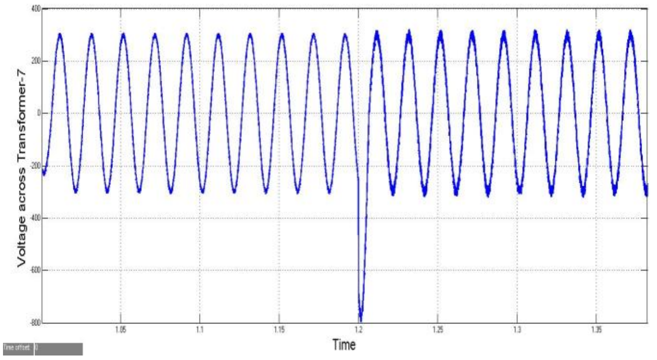

Fig 6.3- Voltage Fluctuation at Transformer-7 without SFCL

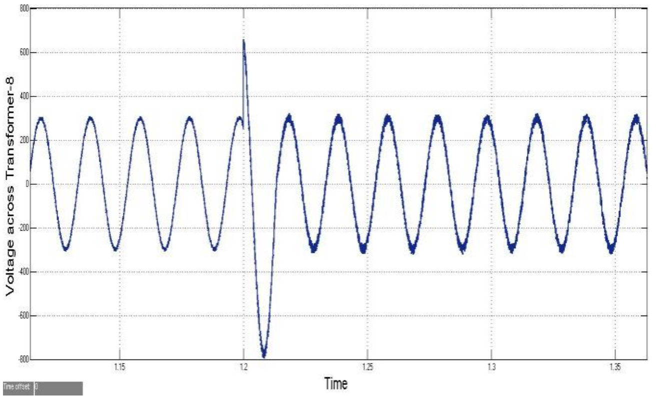

Fig 6.4- Voltage Fluctuation at Transformer-8 without SFCL

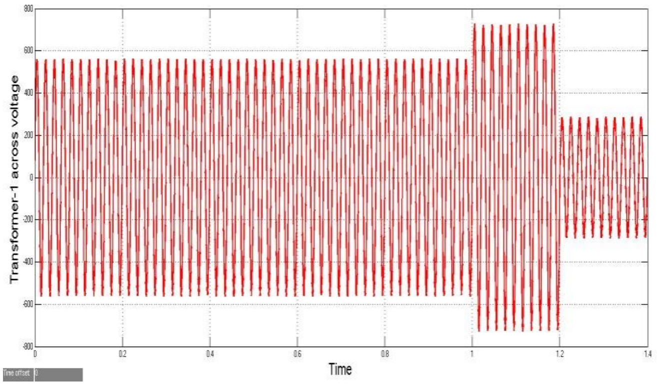

Fig 6.5- Source Voltage Fluctuation without SFCL

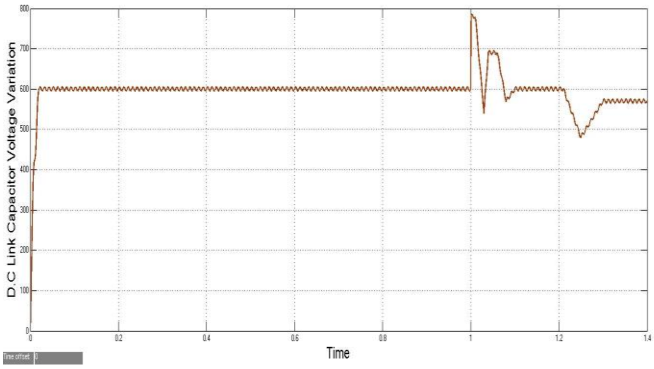

Fig 6.6- Capacitor Voltage Fluctuation without SFCL

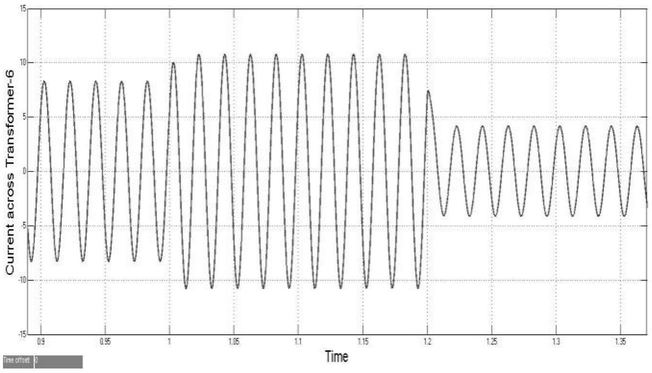

Fig 6.7- Current Fluctuation without SFCL at Transformer-6

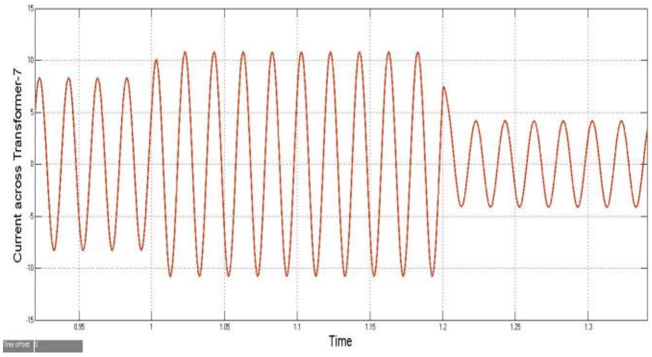

Fig 6.8- Current Fluctuation without SFCL at Transformer-7

Proposed System with SFCL Controlling

As Discussed and shown in the previous sections the proposed system have been affected using fault current which also shown in the simulation results. So we have to use DC reactor type SFCL system in the proposed system to mitigate the fault current in the given system. Now in this section we show the controlling subsystem and operating system of SFCL for the fault current limiter of the proposed system. The Simulation of the proposed system with the SFCL and dc reactor is shown in the fig 6.15 is shown and the improvements in voltage, current waveforms and fault current and fluctuation mitigation also shown in the simulation results.

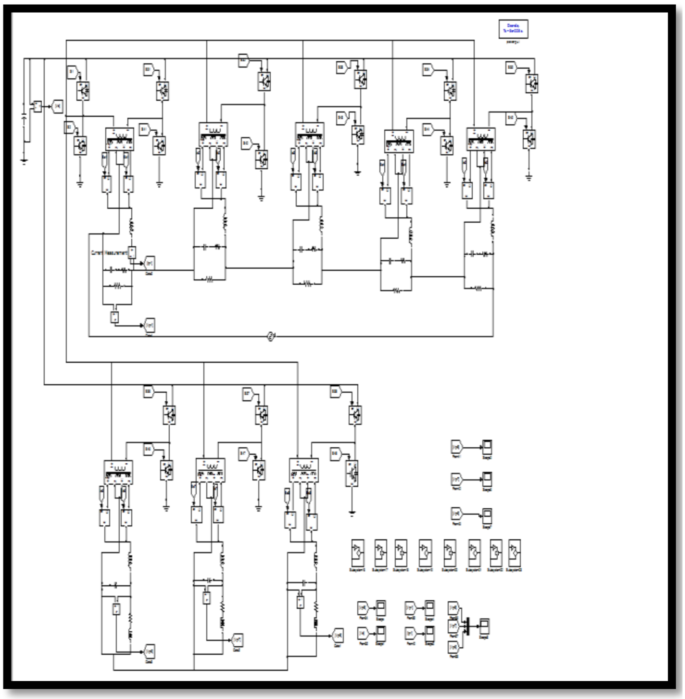

Fig 6.9 proposed system with controlling of SFCL

The Proposed control scheme of SFCL includes Power converters and Digital relay type controlling system for triggering the IGBT devices of the proposed Control scheme of power converter in the system.

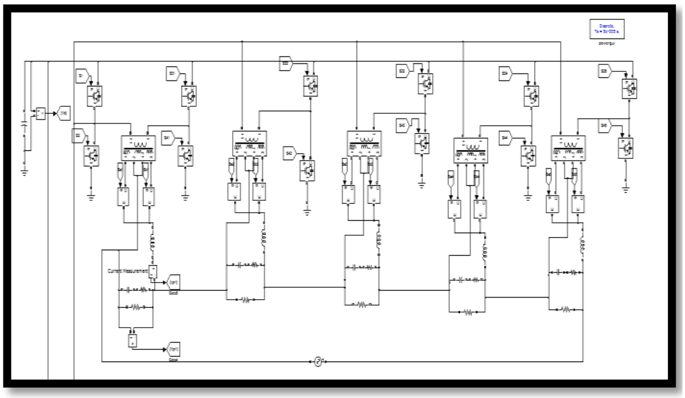

Fig 6.10- Upper Half of the control system

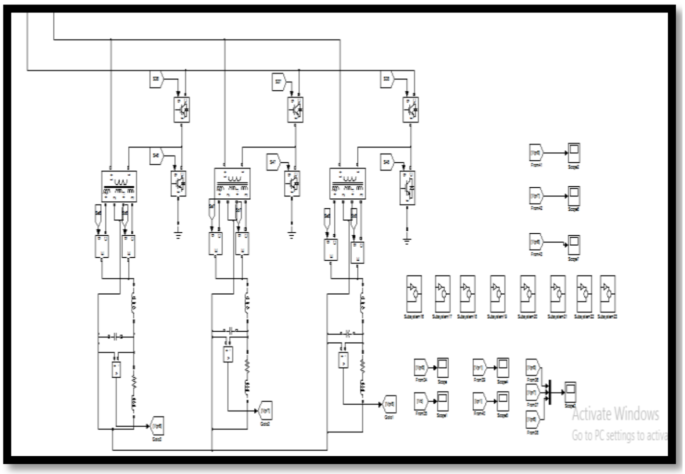

Fig 6.11- Lower Half of the Proposed System

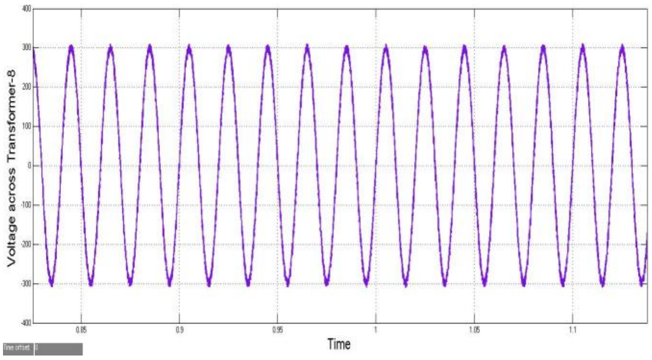

Fig 6.12- Voltage Improvement at Trasformer-8 after SFCL

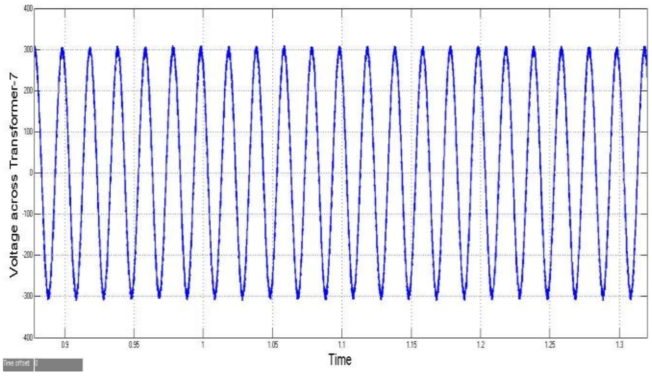

Fig 6.13- Voltage Improvement at Trasformer-7 after SFCL

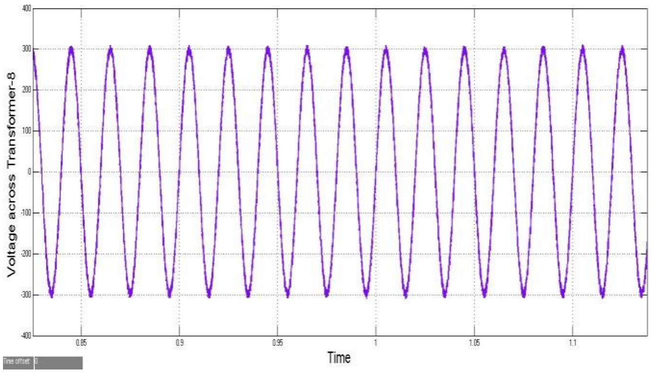

Fig 6.14- Voltage Improvement at Trasformer-8 after SFCL

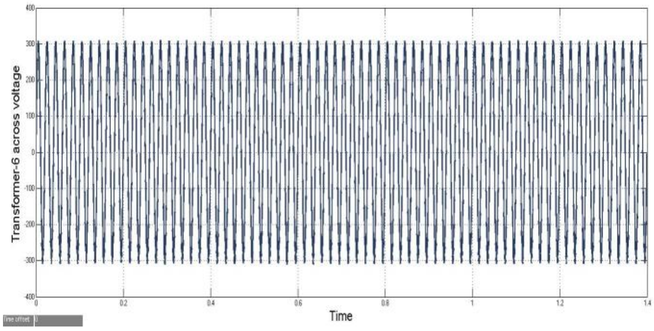

Fig 6.15- Voltage Improvement at Trasformer-6 after SFCL

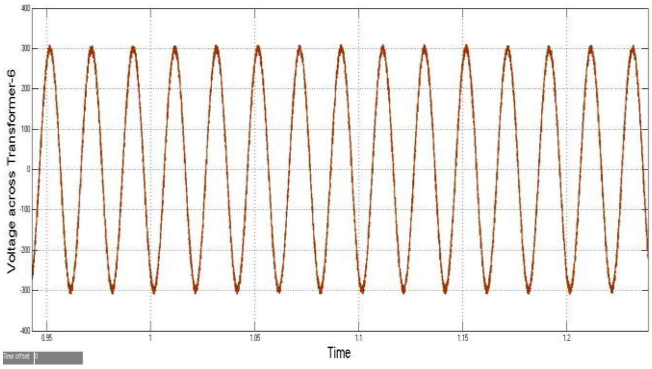

Fig 6.16- Voltage Improvement at Trasformer-6 after SFCL

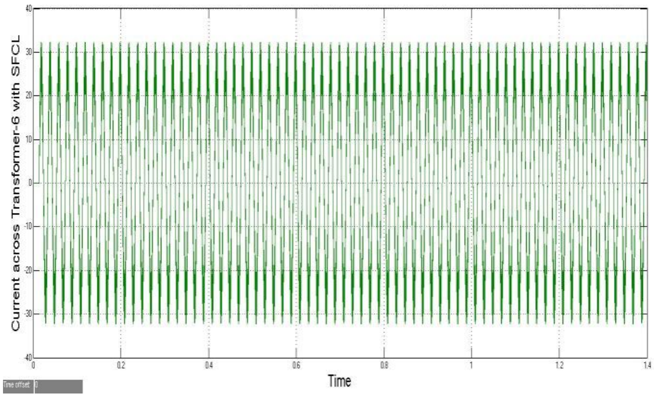

Fig 6.17- Current Improvement after SFCL

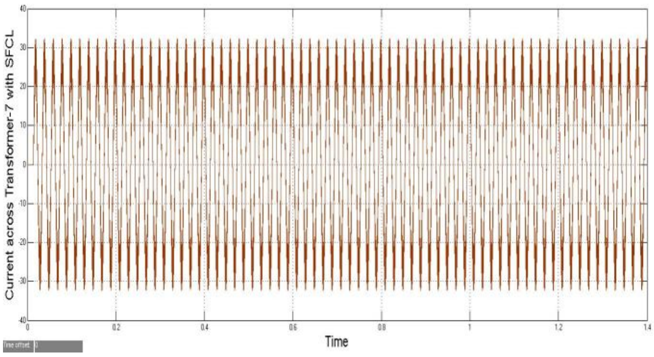

Fig 6.18- Current Improvement after SFCL across Transformer-7

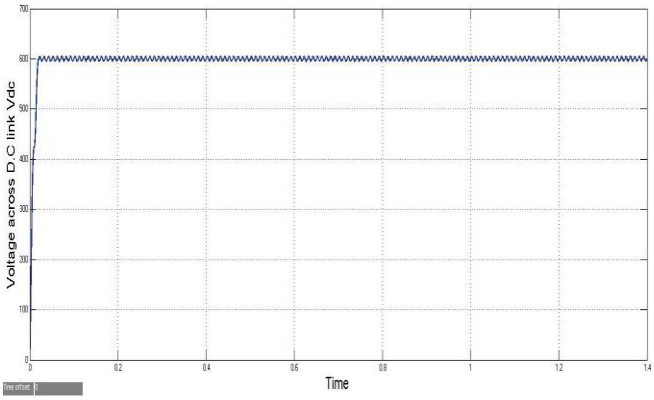

Fig 6.19- Capacitor Voltage after SFCL

Comparative analysis for SFCL

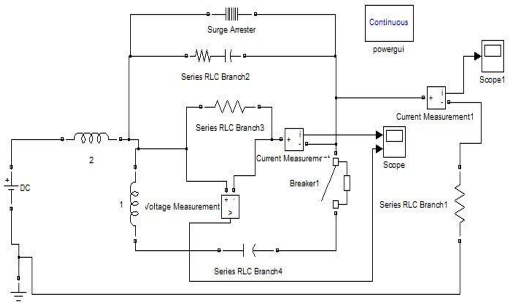

Fig 6.20-Normal System for SFCL Testing

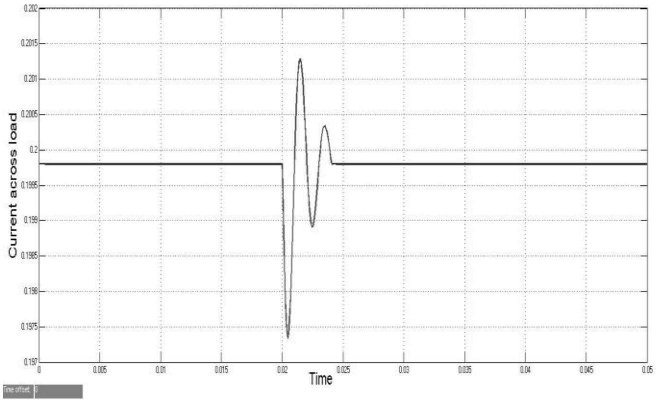

Fig 6.21- Current across load

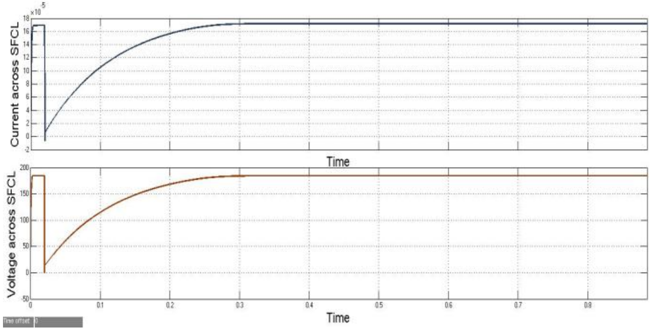

Fig 6.22- voltage and current variation across SFCL

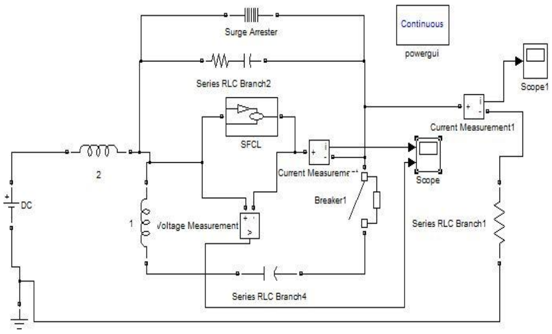

Fig 6.23- Normal System with SFCL controlling

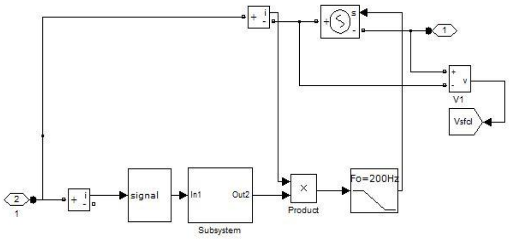

Fig 6.24- SFCL subsystem

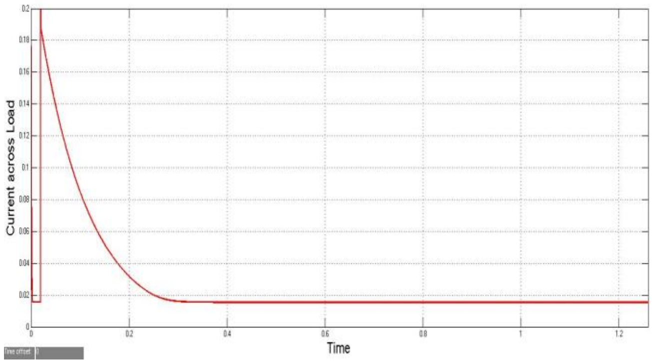

Fig 6.25- Current across load

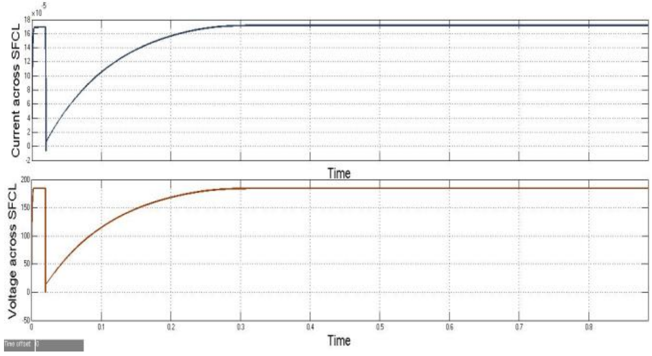

Fig 6.26- voltage and current variation across SFCL

VII. CONCLUSION

In this work I have studied different types of fault current limiter technology. To eliminatethe risk of superconducting fault current DC type reactor is best solution to limit the overcurrent and its effects like thermal and mechanical stress on the equipment. Simulation inMATLAB software is done to support the proposed technique and results showed theefficiency of present technique.Thus, in this paper, the transient characteristics of the transformer type super-conducting fault current limiter are analyzed by the numerical simulation considering the magnetic saturation of the transformer iron core and the time dependent resistance of the current limiting device. The analysis is carried out by using the parameters obtained from the experimental superconducting fault current limiter. From the results of the analyses, the influence of the transformer core is clarified. A method of the transient analysis of the transformer type superconductingfault current limiter is proposed. The proposedmethod considers the magnetic saturation of the series transformercore and the time-dependent resistance of the currentlimiting device.

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