A Novel And Smart Design of Solid State Fault Current Limiter

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Abstract*-The continues growth of electrical energy demand is resulting in a corresponding increase in the short circuit in power system. Several solutions have been implemented, including the use of Fault Current Limiter (FCL), in order to reduce circuit breakers rated capacity and to limit the electromagnetic stress in associated equipment. This project presents a comprehensive study of the impact of fault current limiter in power system performance. The FCL use for this study is solid-state type because it has advantages in term of flexibility and control over superconducting type. In order to evaluate the impact of fault current limiter in power system performance, simulation model of power system performance with solid-state FCL are used.*

I. INTRODUCTION

In today circumstances, rapid development of power network cause the fault current of the system increased greatly. The levels of fault current in many places have often exceeded the withstand capacity of existing power system equipment. As implication to this matter; security, stability and reliability of power system will be negatively affected. Thus, limiting the fault current of the power system to a safe level can greatly reduce the risk of failure to the power system equipment due to high fault current flowing through the system. Because of that, there is no surprise to fault current limiting technology has become a hotspot of fault protection research since this technology can limit the fault current to a low level. In power system design view, limiting the fault current to a low level can reduce the design capacity of some electrical equipment in the power system. This will lead to the reduction to the investment cost for high capacity circuit breakers and construction of new transmission line. Consequently, from both technical and economical points of view, fault current limiting technology for reducing short circuit current is needed. A short circuit cannot be neglected in the power system due to numerous causes. When short circuit occurs in power system, large current will flow in the system which can cause damage to the equipment due to heating effects and electromagnetic forces. Furthermore, during fault, some point in the power system network (depending on the distance of the fault point) will experience voltage sag. This problem may cause to a complete shutdown of healthy plants connected to the network. Power utilities associate that 80-90% of their customers complaining about voltage sags.

One of the main concerns related with the continuous growth of electricity demand is the corresponding increase in short circuit currents. This matters has been discussed since early 1960s, replacing existing switchgear with others of higher rating is certainly a solution this problem. This solution probably is the best to solve this matter which, solving the increment of the switchgear rating problem as well as providing for future growth. However, this is the most expensive of all the other solution and also consumes a lot of time to replace all existing switchgear which leads to reduction of power system reliability for that period of time. A questionnaire was sent out in 2003 from CIGRE WG A3.16 asking about the typical structures of distribution systems, type of protection used in the networks and the need of limitation of short circuit currents in MV and HV networks. Based on 53 responds from 14 different countries, 74% shows the needs for short circuit current limitation and only 26% state otherwise. Figure 1.1 shows the pie chart that represented responses from this survey.

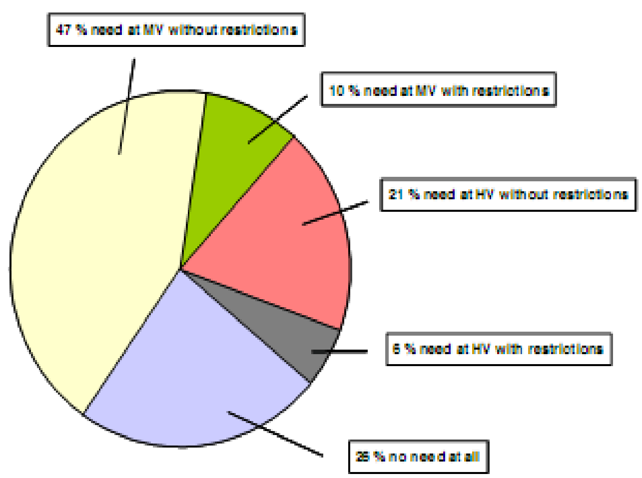

Fig 1.1 – Responses from CIGRE WG A3.16 questionnaire survey

Over the last four decades, different types of FCLs have been under the spotlight in power protection research. In recent years, various types of FCL have been proposed and developed in many countries. Mainly two types of them are discussed most. One is superconductor fault current limiter (SFCL), the other one is solid state fault current limiter (SSFCL). This interest comes not just due to their excellent current limiting characteristics but also due to their positive contribution to the quality of supply. FCLs can be effective in reducing supply outage and mitigate voltage sag on power network.

1.1 Problem Statement

Recent researches show that the implementation of FCL can be used to control the short circuit capacity of power system. Thus, a study needs to be carried out to investigate the performance of power system when using FCL in various conditions;

i. Normal condition
ii. Balanced fault condition
iii. Unbalanced fault condition

1.2 Project Scope

The scope of this project is limited to the following works;

i) There are two different types of FCL discussed most; Superconductor FCL and Solid-state FCL. In this project, only Solid State FCL will be discussed.
ii) A distribution system fed from a single source radial system is used in this project.

II. FAULT CURRENT LIMITER

2.1 Fault Current Limiter

FCLs is a device that has potential to reduce fault level on the electricity power networks and may ultimately lead to lower rated components being used or to increased capacity on existing systems. Electricity industry is very attracted in such devices, providing that FCL offer them satisfaction in economics aspect as well as technical constraints.

2.2 The Role Of A Fault Current Limiter

Consider the simple power network, shown in Figure 2.1, consisting of a supply (voltage, V_S and impedance, Z_S) and a load (Z_{LOAD}).

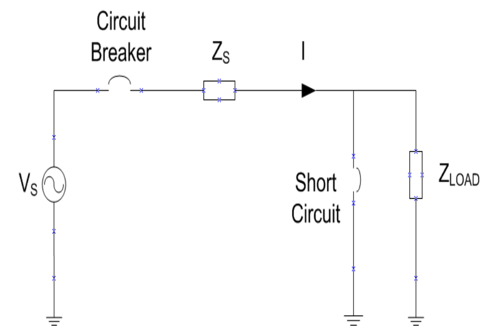

Fig 2.1–SimplePower Network

Since the supply impedance, Z_S is much lower than the load impedance, the current during fault are significantly large compared to normal current. Although circuit breaker will eventually stop this fault current, it does do it immediately, taking about 2-3 cycles to act. Within this period of time, damage can occur to components between the supply and load. The role of a fault current limiter is to prevent damage faster than 2-3 cycles of a fault current rising.

Figure 2.2 shows the similar power circuit with additional of fault current limiting element with impedance Z_{FCL}. To work as a fault current limiter, Z_{FCL} should automatically increase on the occurrence of the fault. Ideally, $Z_{FCL\ would}$ equal zero in the normal (non-fault) state and equal to $Z_{LOAD.}$ When a fault occurs. Even if the $Z_{FCL}=Z_{S\ during}$ the presence of fault, the fault current will be half that without the FCL in the circuit.

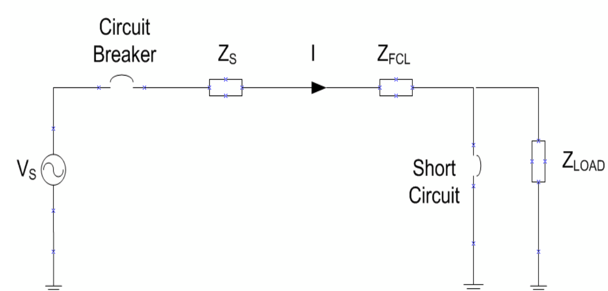

Fig 2.2 – Simple power network with FCL

2.3 Types Of Fault Current Limiter

Main types of FCLs may be divided into three main groups which are Fast Interrupting Devices, Fault Current Limiting Devices and finally, the group that performs both functions which is Fault Current Limiting and Interrupting Devices (FCLID). Fast interrupting devices can interrupt fault current instantly while fault current limiting devices can limit the fault current to a save value and leaves the function of current interruption to other downstream protection devices. As for fault current limiting and interrupting devices, this group of FCLs can limit the fault current and also interrupt it after a preset time.

A Fault Current Limiter (FCL) is a device which limits the prospective fault current when a fault occurs (e.g. in a power transmission network). The term includes superconducting devices and non-superconducting devices, however some of the more simple non-superconducting devices (such as simple inductors or variable resistors) are typically termed[neutrality is disputed] Fault Current Controllers.

2.4 Fast Interrupting Devices

Fast interrupting devices can be separated into two types, fault current limiting fuses and solid-state circuit breaker (SSCB). Fault current limiting fuses consist of a thin wire that simply melts when the current is too high. While fuses are very reliable, they have practical drawbacks. First, it takes a certain minimum amount of time before the wire heats up enough to melt. Once installed, it is not possible to change the sensitivity of a fuse, or how much current it will take to melt it. Then, once the wire melted, it has to be physically replaced before the connection can be re-established. This usually means a time delay for restoring the connection. Fuses are used for radial feeders in distribution systems, the desired sensitivity of fuse is fixed and the time delay for restoring service is considered acceptable because only a small number of consumers are affected.

To overcome that matter, the SSCB was introduced. This circuit breaker employs a high speed switch and a surge arrester, as shown in Figure 2.3. There are various combinations of solid state switches but generally, all share the same concept. During normal operation, the semiconductor switch is continuously on. However, during fault occurrence, the switch is turn off and the fault current is turn is completely interrupted within few milliseconds.

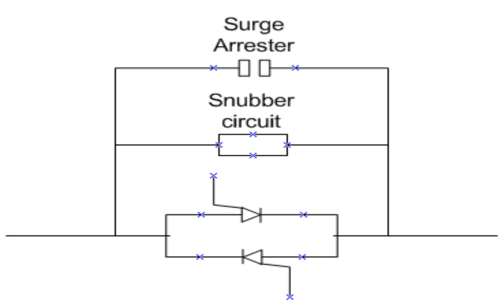

Fig 2.3–Solid-state Circuit Breaker

2.5 Fault Current Limiting Devices

Fault current limiting devices can be segregated into three types; the tuned circuit impedance current limiter, the superconducting fault current limiter and the solid state fault current limiter. The tuned circuit impedance current limiters normally exploit tuned circuit or non-linear elements that produce an increase of impedance at the sensing of fault current. Figure 2.4 shows the basic arrangement of tuned circuit impedance current limiter. The net impedance of the resonance circuit can rapidly increase when the switch is triggered. The nuisance of this FCLs is that it is bulky, expensive tuning is very critical.

Superconducting FCL can be classified into two types; resistive and inductive. Resistive SFCL is simplest the type of SFCL to visualize its concepts. A superconducting section of the power lined switches from zero resistance to a significant resistance when either the critical current, I_C, or the critical magnetic field, HC, is exceeded within the material

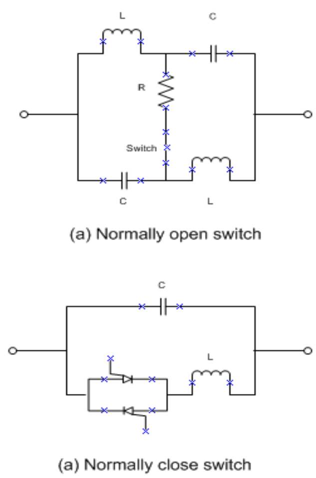

Fig 2.4 – Basic arrangement for tuned circuit impedance current limiters.

Saturated cored FCL, which fall into second category, consist of two iron cores 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 (during fault), the cores are driven out of saturation and the impedance rises and current will be limited to a smaller value. The advantage of this concept is it does not require the superconductor to become normal to operate. However, it require larger iron core (approximately twice compared to the previous type). Figure 2.5 shows the typical superconducting fault current limiter.

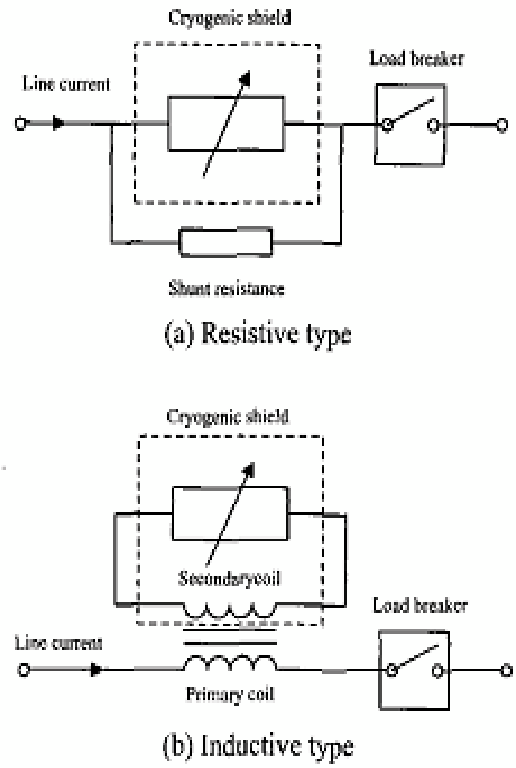

Fig 2.5 - Typical superconducting fault current limiter

Solid state FCL (SSFCL), generally, a semiconductor A.C switch (connected in inverse parallel) is placed in series with each phase of the power line. In parallel with each switch is current limiting impedance.

When a fault is detected, the normally conducted switch is turned off and the current is diverted to parallel impedance which limits the current. In parallel with the switch is a voltage arrester and a snubber circuit to limit the level and the initial rate of rise of the transient voltage across the thyristor. The solid-state FCLs have the additional advantages of flexible and fully controllable operation. Figure 2.6 represents the solid state fault current limiter.

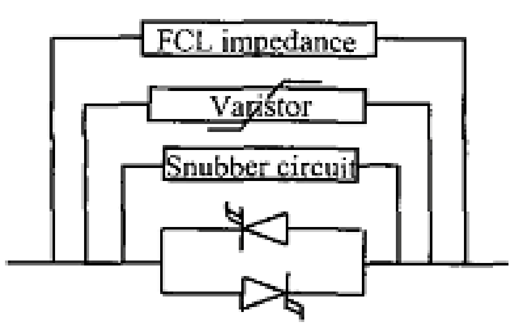

Fig 2.6 - The solid-state fault current limiter

III.SOLID STATE FAULT

Current Limiter Modeling

This study will be based on simulation of SSFCL in the power system. In order to congregate data to be analyzed, simulation model of SSFCL need to be modeled. SSFCL modeling is the vital part throughout this project and need to be model appropriately.

Figure 3.1 shows the basic configuration of the SSFCL consisting of two parallel connected solid state switches. The first branch (Thyristor Branch 1) comprising of thyristors switches and the other branch (Thyristor Branch 2) consist of thyristor and current limiting reactor. Switches are connected in inversely parallel manner for both branches. Surge arrester used to protect the system from voltage surge during switching.

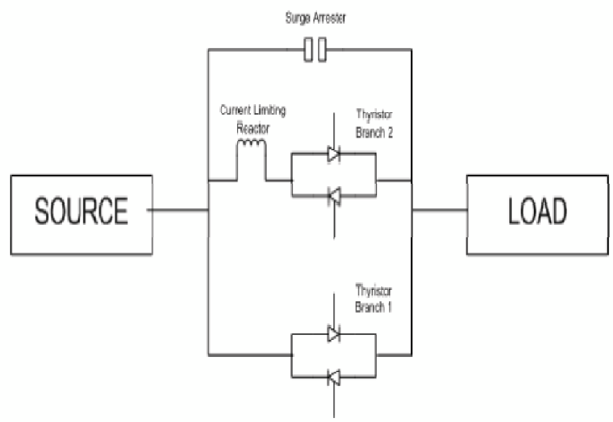

Fig 3.1 – Basic arrangement of solid-state FCL

During normal condition, the Thyristor Branch 1 is gated continuously and allow current to flow to the load. When a fault occurs on the load side and if the load current exceeded a certain pre-set level, control circuit is activated and rapidly turns off thyristor switches at Thyristor Branch 1. Immediately after the thyristors are turned off, the current will be diverted into Thyristor Branch 2 through the current limiting reactor.

The surge current level that thyristor need to withstand during fault can be limited by a proper design of a limiting reactor. When the fault is cleared and the line current drops back to its normal value, the thyristor switches from Thyristor Branch 1 will turn back on at an instant.

Simulation model of SFCL shown in Figures 3.6 – 3.8 is developed using simulation tools in MATLAB, SIMULINK. The interface of the simulation software can be referred in Appendix A. The SSFCL consist of two parallel connected solid state switches in each phase, one is formed by thyristors and the other one is formed by thyristor with current limiting reactor in series. Each switch connected in inversely parallel. An arrester is connected in parallel to protect the system from overvoltage during switching operation.

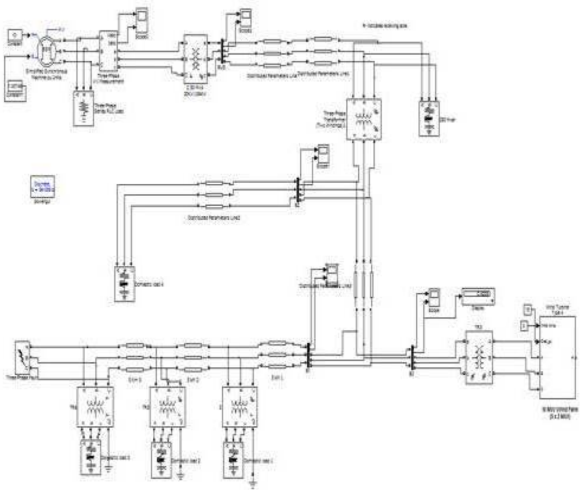

Figure 4.2 – Simple Power System Model Without Protective Devices.

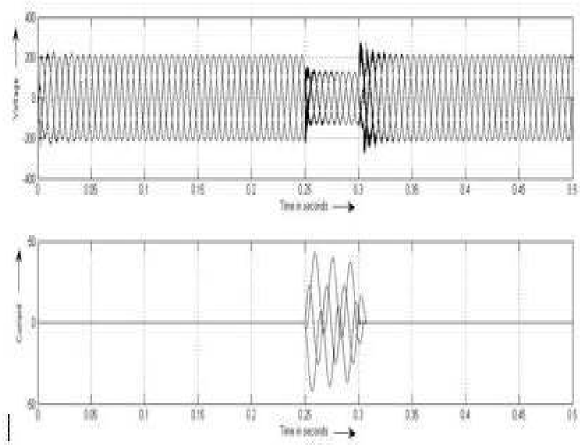

Figure 4.3 – Voltage and Current Waveforms During Fault Condition Without Protective Devices.

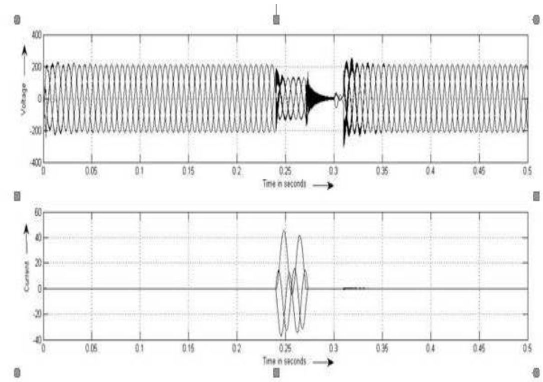

Figure 4.5 – Voltage and Current Waveforms During Fault Condition With Circuit Breaker.

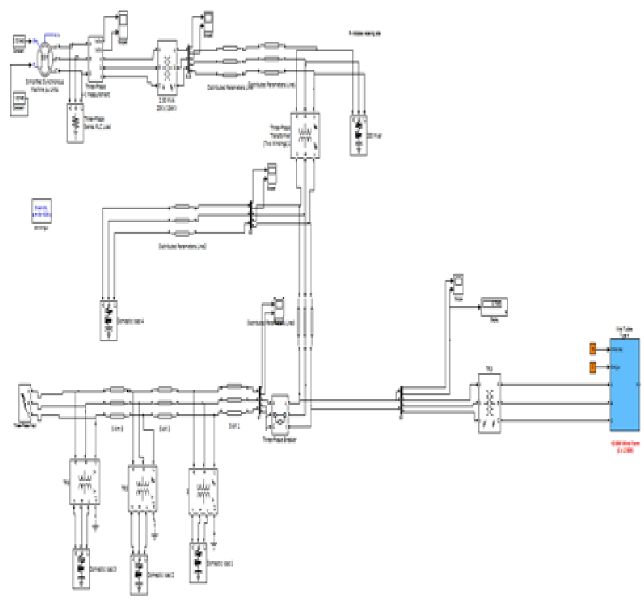

Figure 4.4 – A Simple Power System Model With Circuit Breaker.

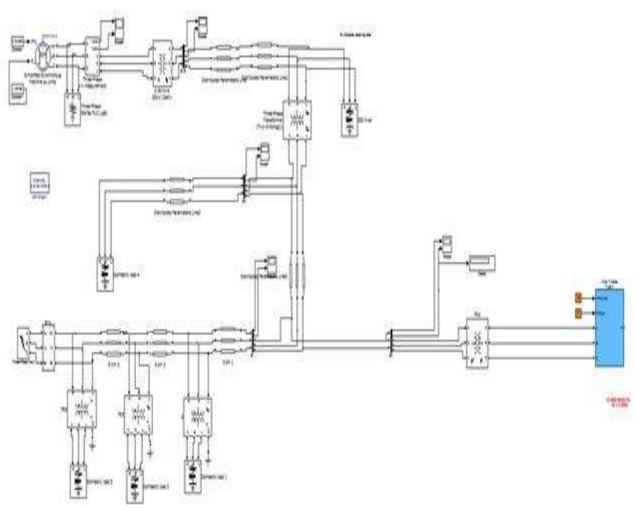

Figure 4.6 – A simple Power System Model With SFCL

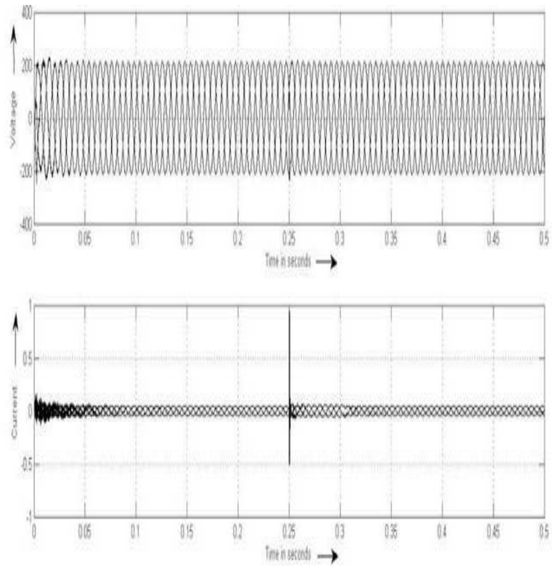

Figure 4.7 – Voltage and Current Waveforms During Fault Condition With SFCL.

IV. SFCL MODE OF OPERATION

The period of 0-0.25s represents the PRE-FAULT normal period, the 0.25-0.3s represents the FAULT period, and the period of 0.3-0.5s represents POST-FAULT period. During PRE- FAULT period, thyristor 2, 3, 6, 7, 10 and 11 are gated ON and as result; current will flow to the load. In the event of fault, thyristor 2, 3, 6, 7, 10 and 11 are gated OFF and instantaneously, thyristor 0, 1, 4, 5, 8 and 9 are gated ON.

4.1. SFCL Control Strategies

The control system of the SSFCL is shown in term of block diagram in Figure 3.5. In the operation of SSFCL, fault current need to be detected promptly before it becomes harmful to other equipment. The fault current detection is done by comparing RMS current level with a predetermined reference value. The output from the comparator used to generate switching signals for the thyristors.

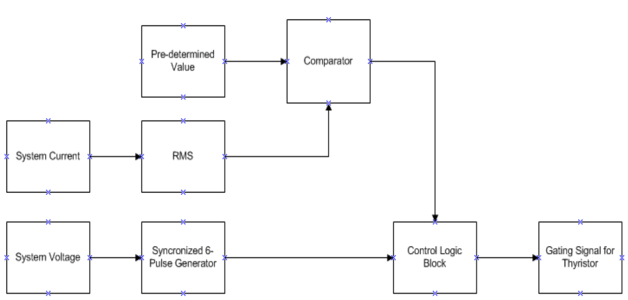

Figure 4.5–Block Diagram of SSFCL Control System

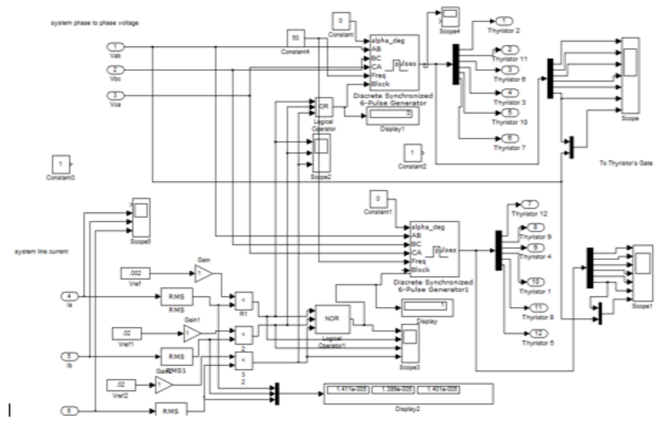

Figure 4.6 – Control Strategy for SFCL in Simulink

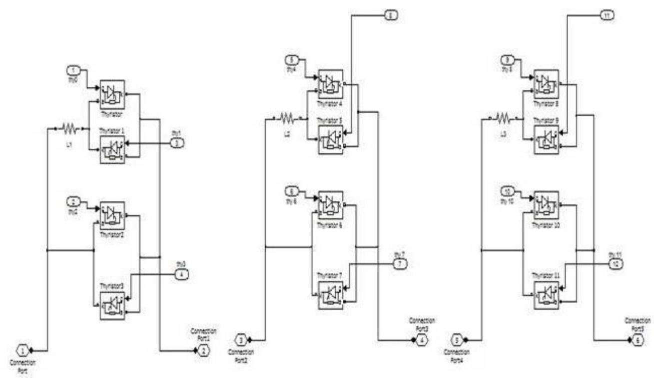

Figure 4.7 – Arrangement of Thyristor Pair in Simulink

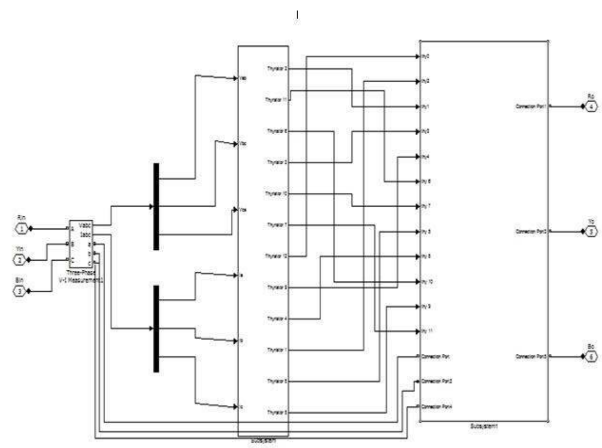

Figure 4.8 – Connection Pattern of SFCL

The Synchronized 6-Pulse Generator block used to fire the six thyristors for each state of operation. For each state of operation, 6 thyristors need to be gated continuously. Thus, for 2 states of operation, 12 thyristors need to be controlled and 2 Synchronized 6-Pulse Generators is needed for the whole operation. The output of the block is a vector of six pulses individually synchronized on the six thyristor voltages. The pulses are generated alpha degrees after the increasing zero crossings of the thyristor commutation voltages. Figure 3.9 envisaged the synchronization of the six pulses for an alpha angle of 0 degrees. The pulses are generated exactly at the zero crossings of the three line-to-line synchronization voltages.

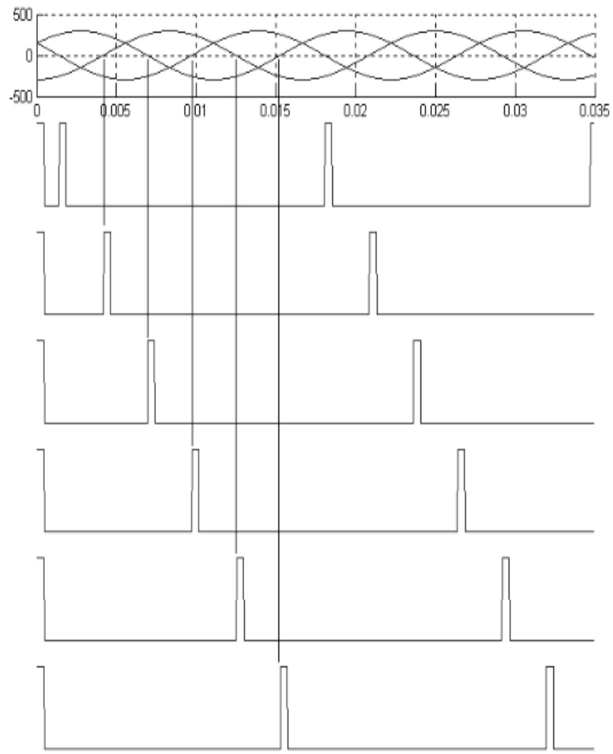

Figure 4.9 – Synchronization of six pulses

4.2 Analysis Of The Proposed System Performance

To analyze the performance of power system during insertion of SSFCL, simulations were carried out using the MATLAB Simulation Tool: SIMULINK. Simulations were performed by considering a test system show in Figure 3.2. To simulate a fault condition, three phase fault was applied one at a time to the terminal of a load and line currents were monitored. For voltage sag mitigation analysis purposes, fault is applied to terminal of Load and RMS voltage was monitored at terminal of Load.

4.2.1 Voltage Sag Mitigation

Voltage sag is defined by a decrease in RMS voltage at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage. SSFCL can be used to mitigate the voltage sag caused by the different types of fault in the distribution system. Voltage sags need to be mitigated since it can cause improper working of the load.

Results show that without SSFCL, the load voltage rapidly drops to almost zero and voltage sag created. By inserting the SSFCL, the voltage sags during fault incidence mitigated. The voltage is restored to the rated voltage after fault detection. For that reason, SSFCL can help mitigate the voltage sags at the load bus bar when the fault occurred in the system.

V. CONCLUSION

This project presents the impact of SSFCL to power system performance. The purposes of SSFCL in power system are it works as circuit breaking element as well as limiting fault current. SSFCL is considered as the solution to the increment of short circuit level in power system. It is cheapest option compared to any others conventional solution to overcome this matter. Despite can limit the fault current, SSFCL offer advantages to the electricity supply industry, technically and economically. Performance evaluation of the power system is carried out by the simulations using MATLAB Simulation Tool: Simulink. A simulation model of SSFCL as well as its control system for the device has been developed and verified. On the other hand, the simulation model of distribution system has been developed to test its performance when inserting SSFCL during fault conditions. Simulation results show that the SSFCL detects the fault current and activating the control circuit. After that, control circuit sends the firing signal thyristors switches to divert the fault current to limiting reactor. Comparison of current has been made between the system without SSFCL and the system with SSFCL for fault condition.

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