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Performance Analysis of SSFCL Device for Different Types of Fault Scenarios in Three Phase A.C Grid Network

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Abstract: Recently, the development of solid state fault current limiters (SSFCL) offers one of the most attractive alternatives to solve the fault current problems. The operation of an SSFCL is based on the natural transition of the superconducting state to normal state by exceeding the critical current of the material. In modern power system, an increase in the growth of electrical energy demand is inevitable resulting in a corresponding increase in the short circuit in the power system. For this, Fault Current Limiter (FCL) became best option to reduce circuit breakers rated capacity and may limit the electromagnetic stress in associated equipment's. In this paper modelling of solid state fault current limiter (SSFCL) under various fault conditions are carried out. The function of SSFCL in power system is to work as circuit breaking element as well as limiting the fault current to a safe level. SSFCL is considered as the solution to the increment of short circuit level in power system. It is the most economical option compared with any other conventional solution to overcome this matter. Despite, it may limit the fault current, SSFCL offer advantages to the electricity supply industry, technically and economically. The proposed SSFCL is implemented on 11 KV feeders. This paper presents the modelling of solid state fault current limiter (SSFCL) using Matlab Simulink.

Keywords-SFCL, FCL, Fault, Feeder, etc.

I. INTRODUCTION

The ever-increasing demand for electrical energy had resulted in increased size of generating stations and interconnected distribution network called power grids which leads to the risk of increasing abnormal operation. The conventional Circuit Breakers can't be used in the network as the rising fault current levels may soon cross its rated fault current breaking capacity. This increasing level of fault current will result in replacing a large number of devices in power systems, like transformers and circuit breakers. Solid State Fault Current Limiter (SSFCL) is one of the most novel alternate solutions to avoid the problem of increasing fault current. It improves power system reliability and stability by reducing the fault current instantaneously. SSFCLs have large impedance in fault conditions and have very low impedance in normal conditions and also instantaneous recovery to zero impedance post fault clearance. Superconducting materials have a highly non-linear behavior which is ideal for the application as FCLs. The high temperature superconductors, called Second-Generation superconductors with critical temperature around the boiling point of nitrogen (77K) have been studied here.

Conventional Protection Functionality

The role of power system protection is to detect and isolate faults. Clearly, this must be done for safety reasons, but protection is also needed to minimize the damage to power system equipment, and therefore to minimize the cost and duration of repairs.

Protection systems should ensure that the minimal number of power consumers are affected by faults and, in the most extreme cases, protection aims to prevent wide-scale disruption or even blackouts in the power system. A protection system conventionally consists of current and voltage measurements, a protection relay, and one or more circuit breakers, as shown in Figure-1. There are several types of well-established protection functions, including: phase overcurrent, earth fault overcurrent, distance, differential, and loss of mains (which includes a variety of methods, such as under- or over-voltage, and under- or over-frequency.

With the increasing of system capacity, fault occurrence probability becomes higher, that can induce severe damages in electrical power system. For example, the high value of the short-circuit current can damage the insulation strength of electrical devices, synchronous generators, protective relays, lines transmission, and loads. The continuous increase in the demand of active and reactive power in the power system network has limits as scope for network expansion many a times poses serious problem.

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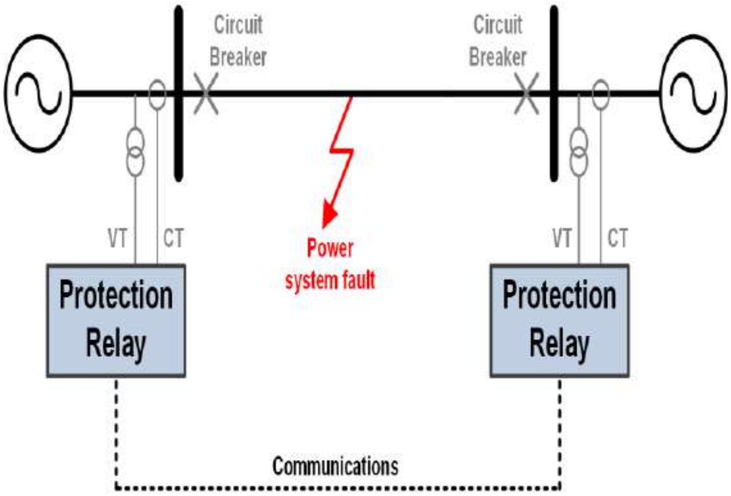

Figure 1: Typical two-terminal differential protection arrangement

The power system must be able to maintain acceptable voltage at all nodes in the system at a normal operating condition as well as post disturbance periods. Among all stability issues, voltage instability due to the inability of the transmission or generation system to deliver the power requested by loads is one of major concerns in today's power system operations. Usually, voltage instability initiates from a local bus but may develop to wide-area or even system-wide instability. In addition, the electrical power needed by the system when a fault occurs is modified and induced instable state of the power generators. Voltage instability is mainly associated with the inability of the power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subject to disturbances such as gradual load increases or outages of critical lines or generating units. The general characteristic of voltage instability is that the voltage level at different locations slightly changes after the disturbance but abruptly declines near to the collapse point. The system operator needs performance indices either in online or offline modes to determine how close the system is to the collapse and what the control actions should be carried out in that event.

Recently, the development of solid state fault current limiters (SSFCL) offers one of the most attractive alternatives to solve the fault current problems. The operation of an SSFCL is based on the natural transition of the superconducting state to normal state by exceeding the critical current of the material. This transition from the superconducting to the normal state must be done in a very short time, generally, to limit the first current peak to a threshold value not exceeding three to five times the rated current, below the short-circuit current without limitation. Thanks to their fast transition from a low to a high impedance, superconducting devices can limit, in a very short time, the value of any fault current. This paper presents concept to determine the optimal location of a resistive superconducting fault current limiter (SFCL) for enhancing the transient stability of an electric power grid (EPG). To select the optimal location of the SFCL, the sensitivity analysis of the angular separation of the rotors of synchronous machines present in the power system is introduced. The optimal location of the SFCL in EPG is coordinated with the corresponding optimal resistive value to improve transient stability and low-frequency oscillation damping performance of the system. It is shown that the SFCL can have different impacts (positive and negative) in function of its location in the EPG when a fault occurs.

The operation of an SSFCL is based on the natural transition of the superconducting state to normal state by exceeding the critical current I of the material. This transition from the super conducting to the normal state must be done in a very short time, generally, to limit the first current peak to a threshold value not exceeding three to five times the rated current, below the short-circuit current without limitation. The SSFCL is placed in series with a circuit breaker. During the fault, the current increases up to reach the threshold of transition from superconducting wire. This transition from the super conducting element to normal state causes the development of resistance that limits or triggers the current limit. The time between threshold crossing and the limitation is small (a few microseconds). The circuit breaker isolates the line as soon as possible after the beginning of the limitation.

These super conducting fault current limiters use one of the fundamental properties of superconductors.

The qualifications of SSFCL are:

1. Very low impedance during normal operation.

The current limiter must be “invisible” in this mode. Some transients such as those caused during the switching of a transformer should not inadvertently cause a transition of the limiter.

2. High impedance system during short circuit.
The limiter must perform its function in the case of massive short circuit but also in the case of low short circuit fault.

3. Very good dynamic.
The system must transit in very quickly (with in millisecond) to effectively limit the value of the short circuit.

Research Objectives

- The Working of SSFCL and role of SSFCL for Power system Stability enhancement
- Use of resistive superconducting fault current limiter (SFCL) for an electric power grid
- Implementation of SFCL in optimal location of IEEE bus system for power system stability improvement
- Matlab Simulink of SSFCL for proposed system with analysis of different fault conditions

II. NEEDS OF FAULT CURRENT LIMITER

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-2 shows that in fault conditions, an FCL increases the source impedance in the system and limits the fault current. Figure 3 demonstrates the typical operation of an FCL and its effect on fault current limiting.

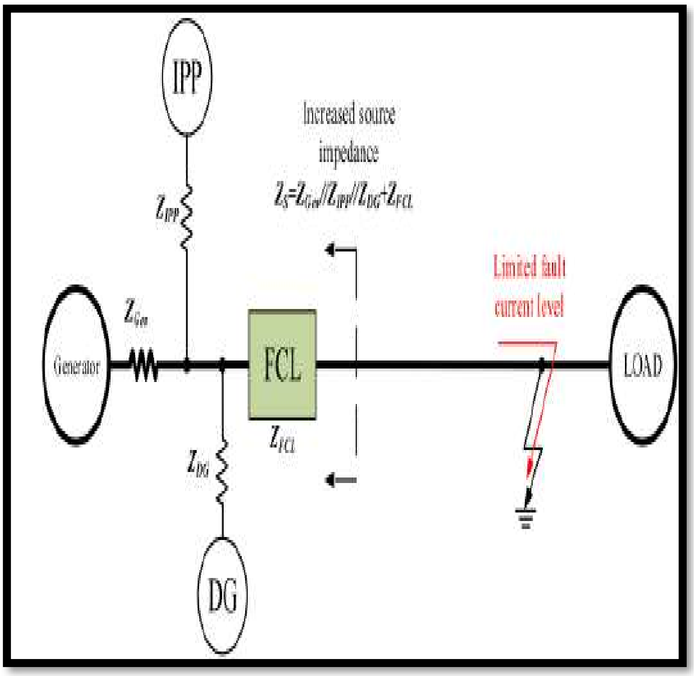

Figure-2 FCL increases source impedance and limits fault current during fault condition

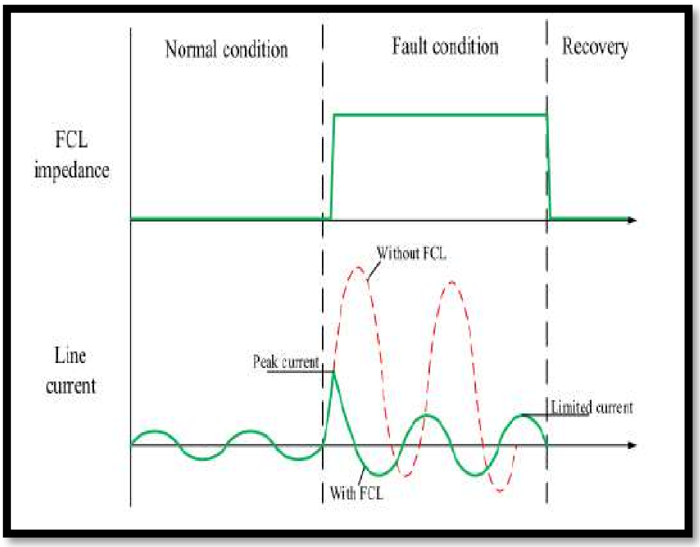

Fig 3 Fault current limitation effects on FCL in fault conditions

Fig 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.

III. PROPOSED WORK

There are several types of SFCL; the main ones include:

1. The resistive limiter.

This is a coil of superconductive material, non-inductive by construction, mounted in series on the line. In case of fault, the winding initially at the superconducting state changes to the normal state. Its impedance appears in the line, which limits the fault current. This limiter can be applied in AC or DC systems.

2. The inductive limiter.

It consists in its simplest form, two windings connected in parallel. This association is made so that the impedance of all is the lowest possible. In case of fault, one of the coils (made of superconducting material) returns to its normal state. The other winding made either copper or superconducting material limit the current through the inductance.

3. The limiting transformer.

It consists of a superconducting secondary short-circuit and primary winding of a conventional copper. In normal Operation, the impedance of this transformer is mainly due to the coupling between the windings and may be very low. Under fault, the secondary winding quenches under the effect of fault current and acts as a switch that opens the secondary of the transformer. Therefore, we obtain the no load impedance of a transformer which is very important.

As we said, the first function of an SSFCL is to limit the fault current induced in the faulty line. In this case, the passage to its superconducting state to its normal state can only be achieved if the fault appears in the line where the limiter is placed. The probability that a fault appears at a specific location in the power system is very low. Consequently, if the fault appears at a different location in the power system, the SSFCL cannot be used for its first function because the current value through the SSFCL will be not sufficient to ensure a transition of this last. The originality of the presented work is that the SFCL is used if the fault appears anywhere in the system. In this case, the SSFCL can be seen as a rapid switch that introduces a resistance in the power system.

The presence of this additional resistance improves the power system stability in case of short-circuit and this, regardless of the position of the fault. The SSFCL is not used to limit the Fault current but to improve the stability of the power system. If the fault appears in the line where the limiter is placed, the two functions of the SSFCL are used (limitation of the fault current in the line and improvement of the power system stability). By cons, if a fault appears at a different location, the SSFCL introduce its resistance in the power system to improve the transient stability of generators. In this case, the passage to its superconducting state to its normal state will be accomplished by applying a magnetic field superior to its critical magnetic field after the detection of the fault in the EPG. For an EPG with more than one generator, a necessary condition for satisfactory system operation is that all synchronous machines remain in synchronism when a severe transient disturbance appears (loss of transmission line, important increase of load, three-phase short circuit). This aspect of stability is influenced by the dynamics of generators rotor angle and power-angle relationships. SFCL and SMES have been used to control the flow of excessive fault current and to stabilize the voltage level during fault condition respectively. Though these system perform to improve the stability of the overall system during fault conditions, their operation in a simultaneous coordinated manner theoretically proves to improve the performance of the system to a greater extent compared to the individual operation. This brings the need of an optimization algorithm to simultaneously co-ordinate the working of SFCL and SMES in the system.

Switch on all SCRs at the start of current limiter operation, and part of the current will run through primary winding of series coupled transformer. This current is coupled with the second winding, then run through the bridge to charge for DC reactor, on which an increasingly large current is formed. Meanwhile, the current through bypass reactor which paralleled on the primary winding of transformer and is gradually reduced. After several cycles, this charging stage ends and the limiter enters the steady stage.

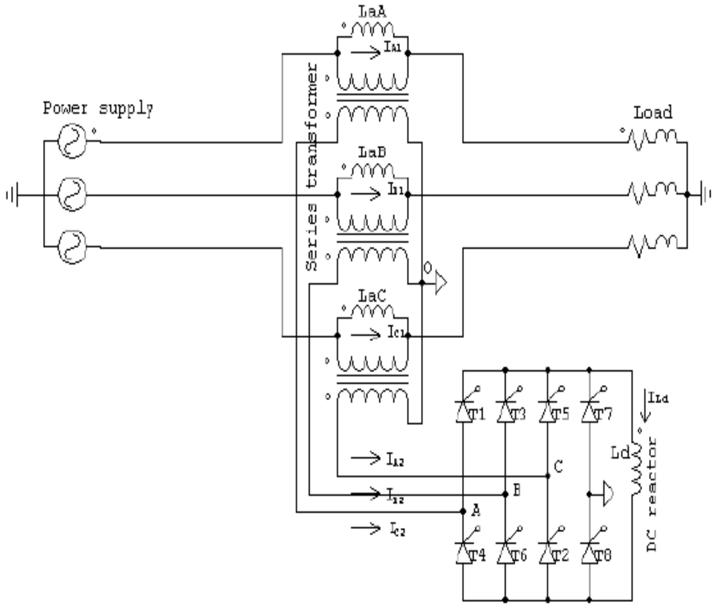

Fig. 4 Proposal FCL for three-phase grounded power system

IV. SIMULATION AND RESULTS

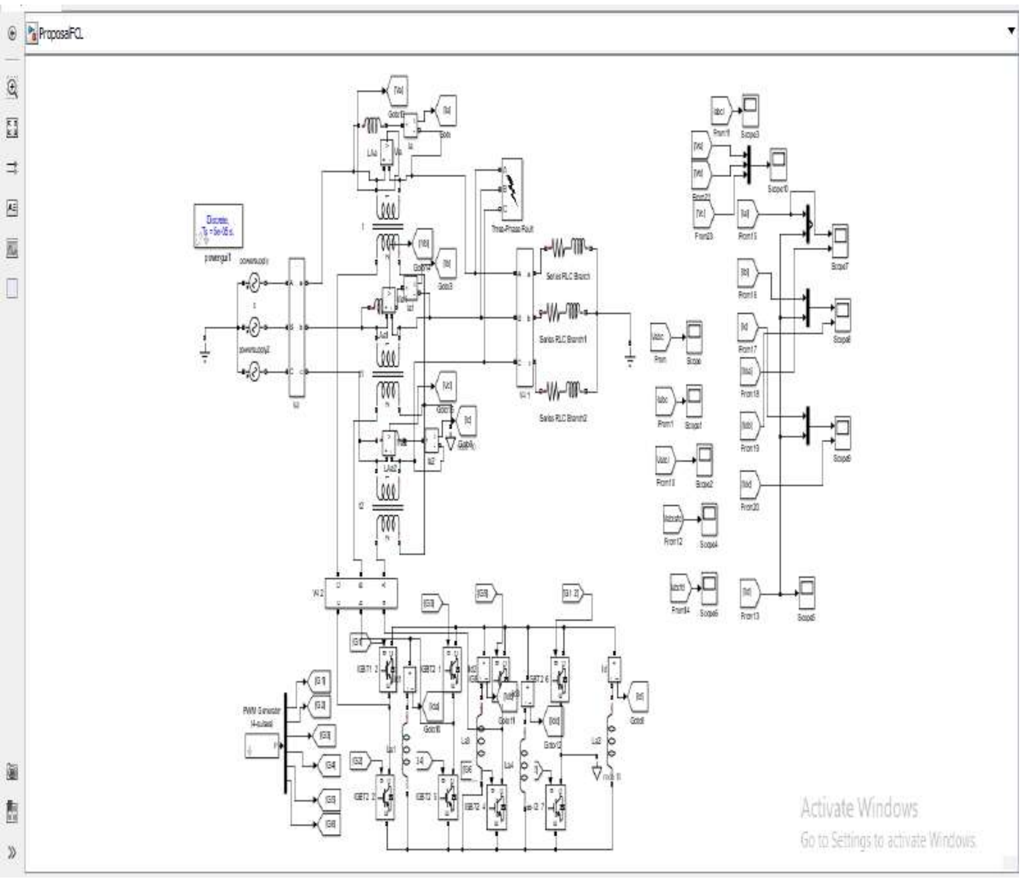

Fig 5- Matlab Simulation of Proposed System

Sr. No.	Parameter Name	Value
1	Power supply	10 kV
2	Load current rating	500A
3	Load Resistance	9.24Ω
4	Load Inductance	0.02207H
5	Turn ratio of transformer	2
6	DC Reactor inductance	18.39mH
7	AC Reactor inductance	7.35 mH

Table-System Parameter of Proposed System

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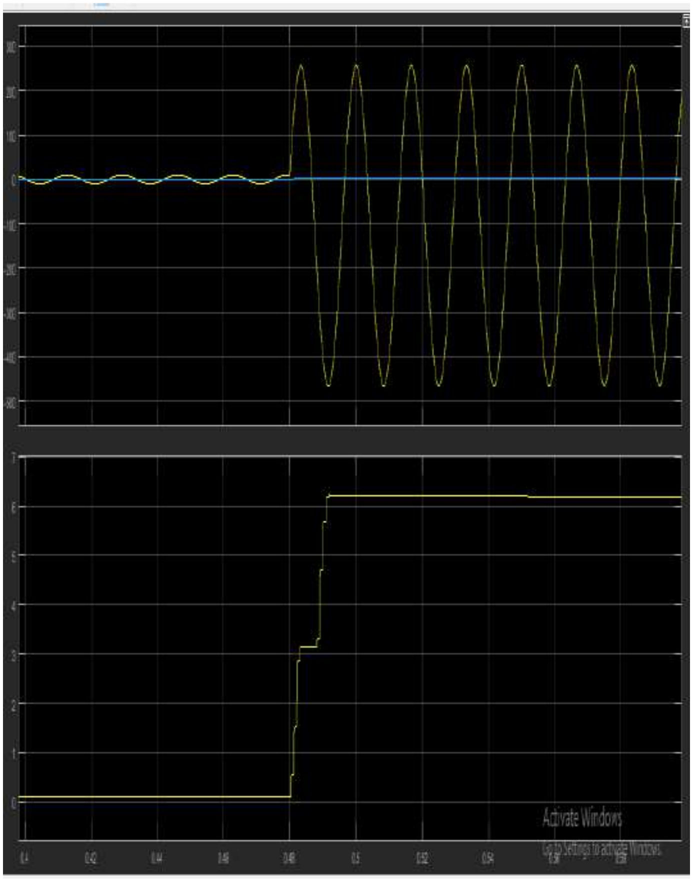

Fig. 6 Waveforms of DC reactors and AC reactors current at single-phase (phase a) to ground accident.

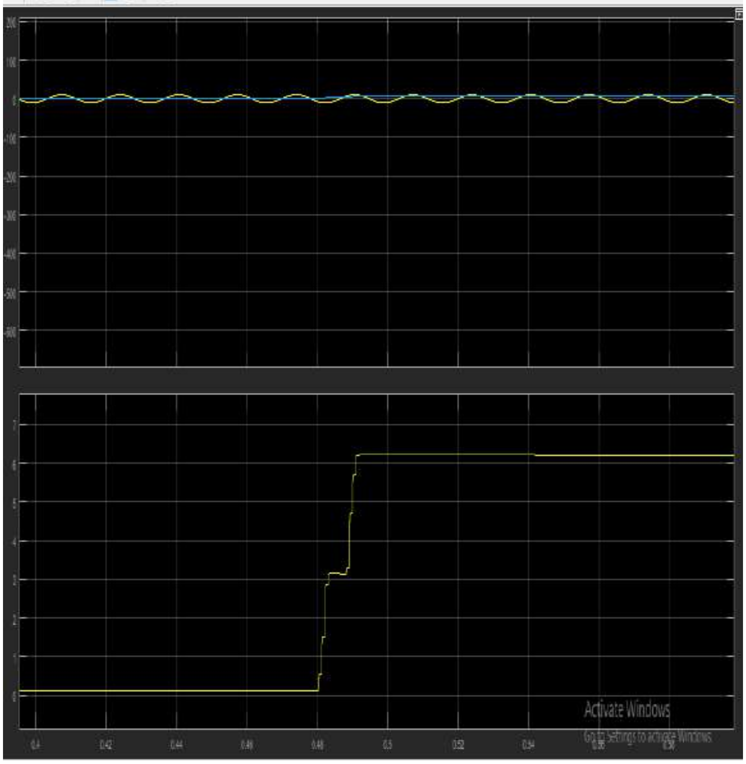

Fig. 7 Waveforms of DC reactors and AC reactors current at single-phase (phase a) to ground accident.

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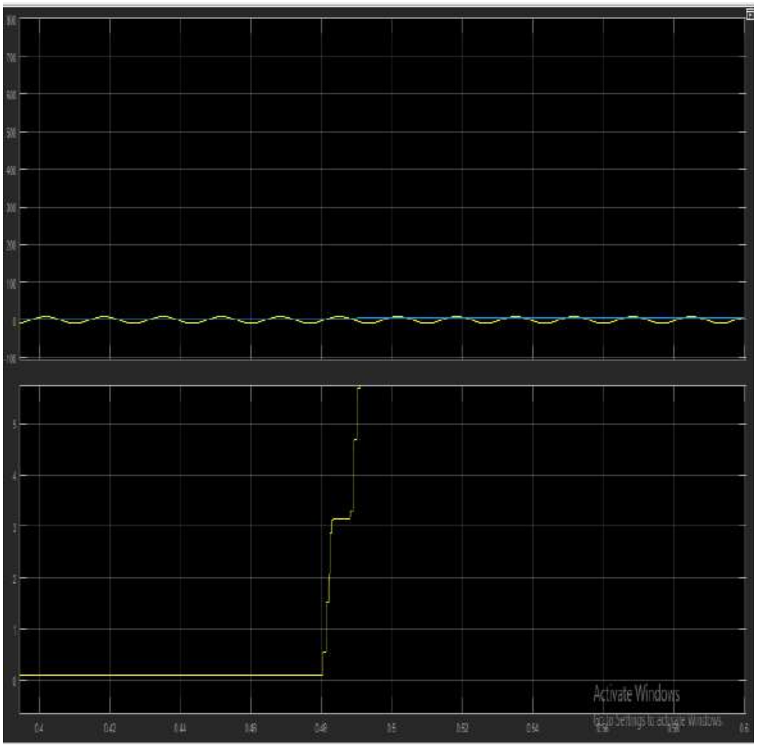

Fig. 8 Waveforms of DC reactors and AC reactors current at single-phase (phase a) to ground accident.

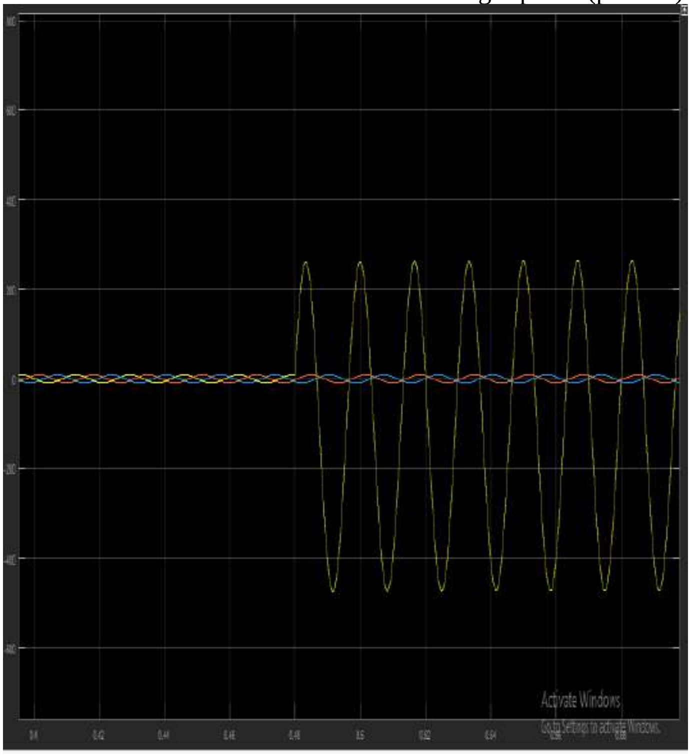

Fig. 9 Waveforms of load current and voltage drop upon transformer primary windings at single-phase (phase a) to ground accident.

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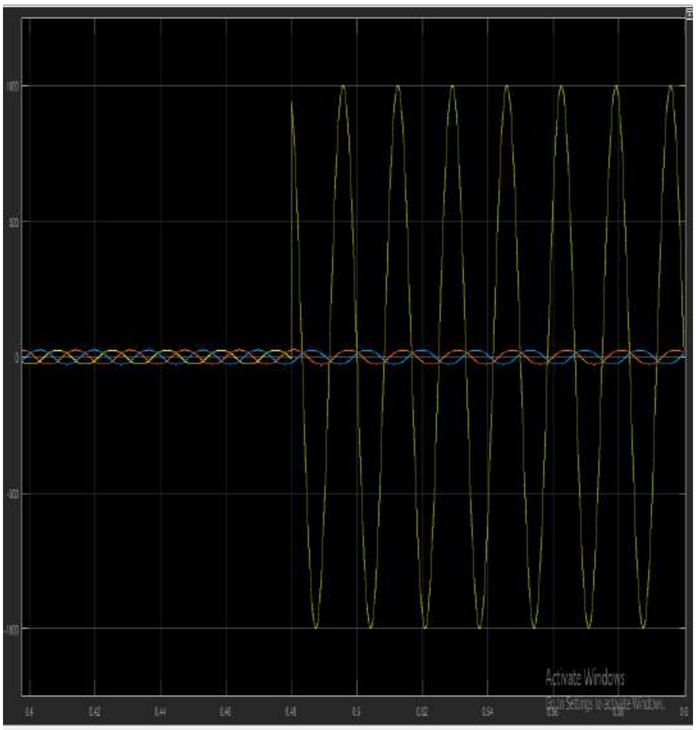

Fig.10 Waveforms of load current and voltage drop upon transformer primary windings at single-phase (phase a) to ground accident.

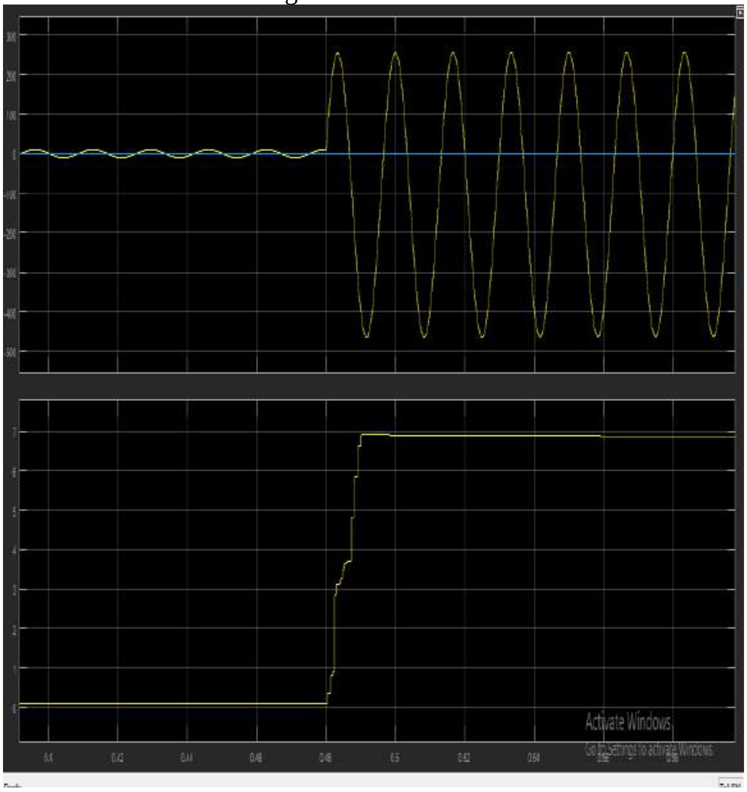

Fig. 11 Waveforms of DC reactors and AC reactors current at two-phase (phase b and c) to ground accident.

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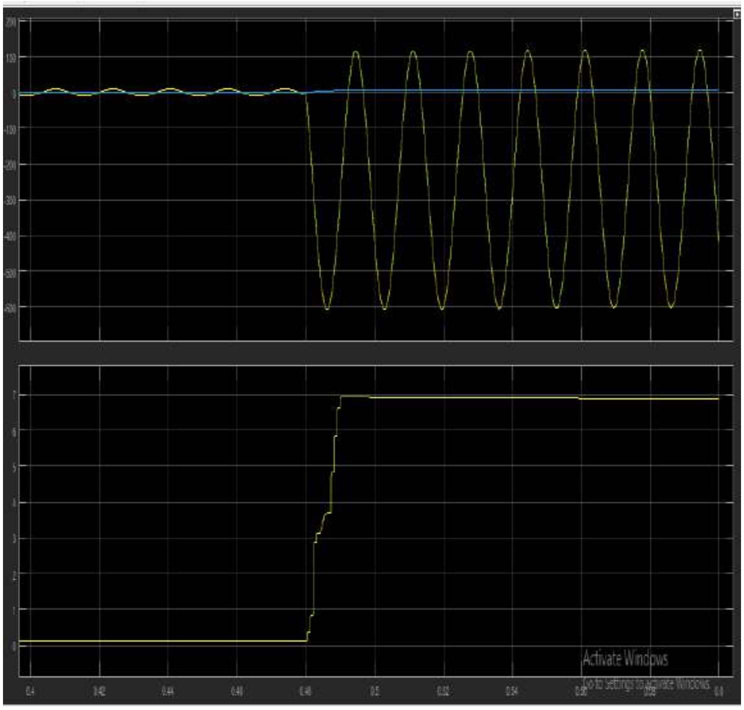

Fig. 12 Waveforms of DC reactors and AC reactors current at two-phase (phase b and c) to ground accident.

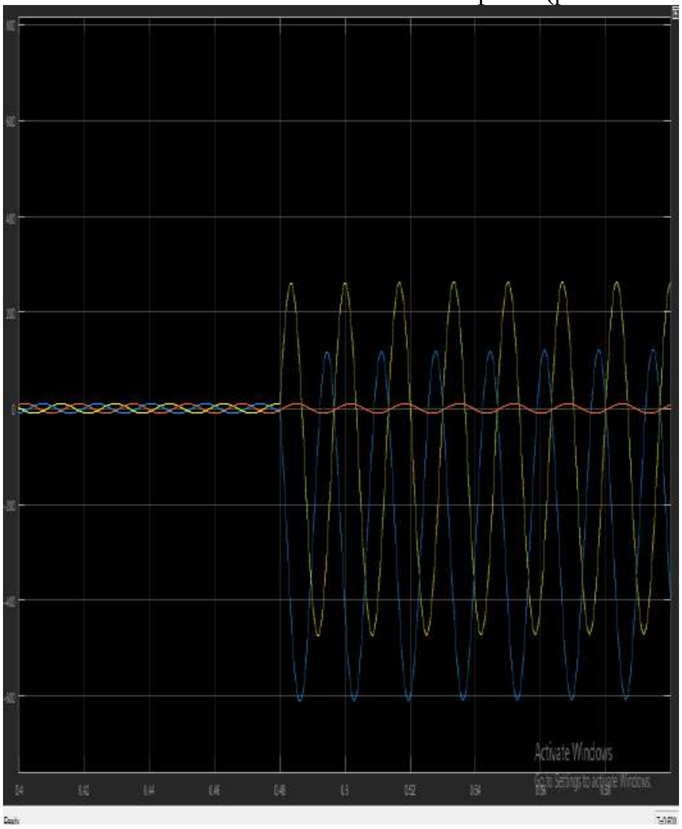

Fig. 13 Waveforms of load current and voltage drop upon transformer primary windings at two-phase (phase b and c) to ground accident.

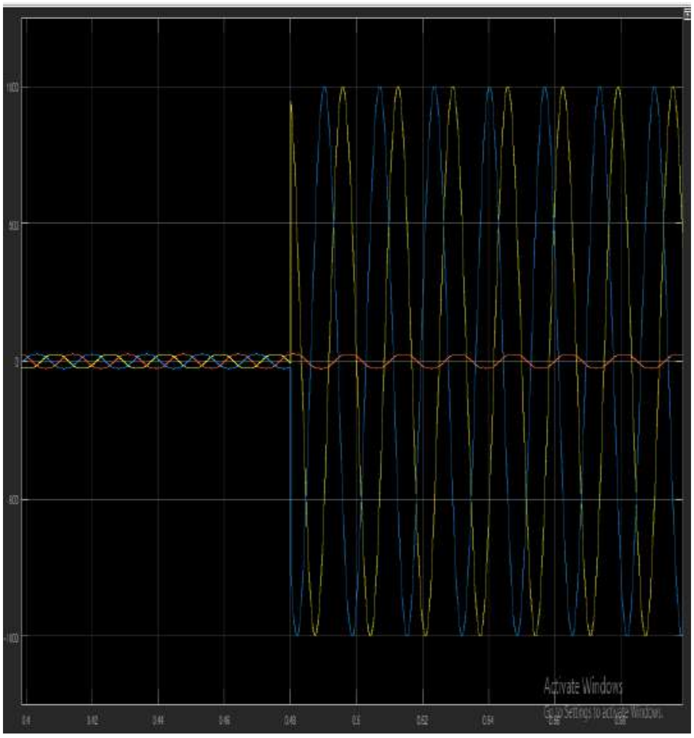

Fig. 14 Waveforms of load current and voltage drop upon transformer primary windings at two-phase (phase b and c) to ground accident.

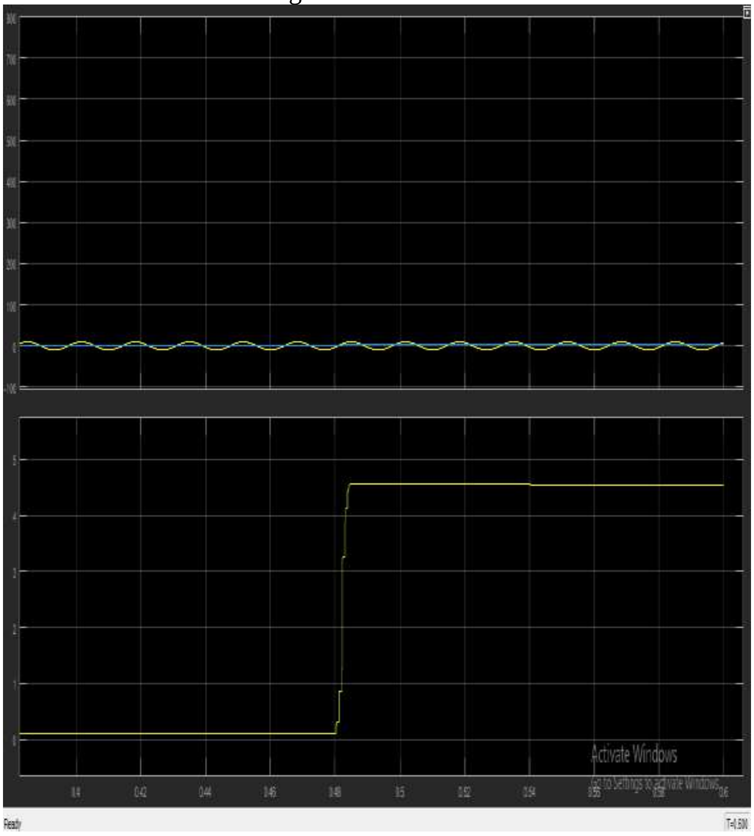

Fig. 15- DC reactors and AC reactors current at two-phase (between phase b and c) accident.

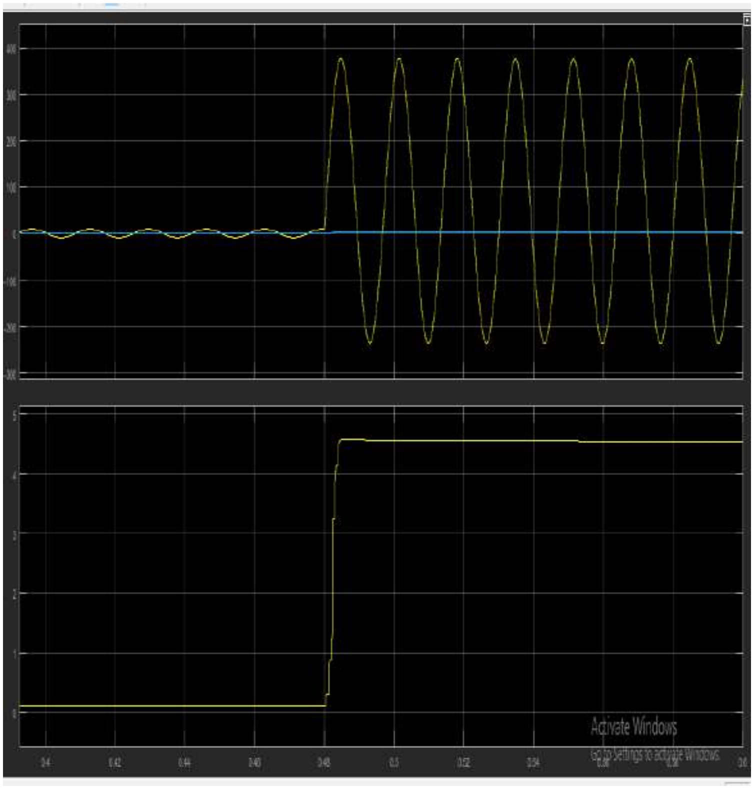

Fig. 16 DC reactors and AC reactors current at two-phase (between phase b and c) accident.

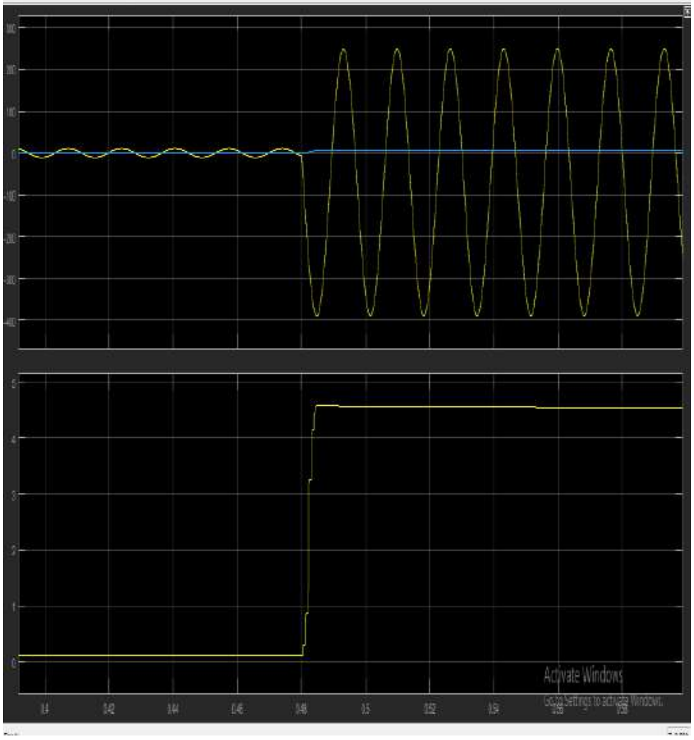

Fig. 17 DC reactors and AC reactors current at two-phase (between phase b and c) accident.

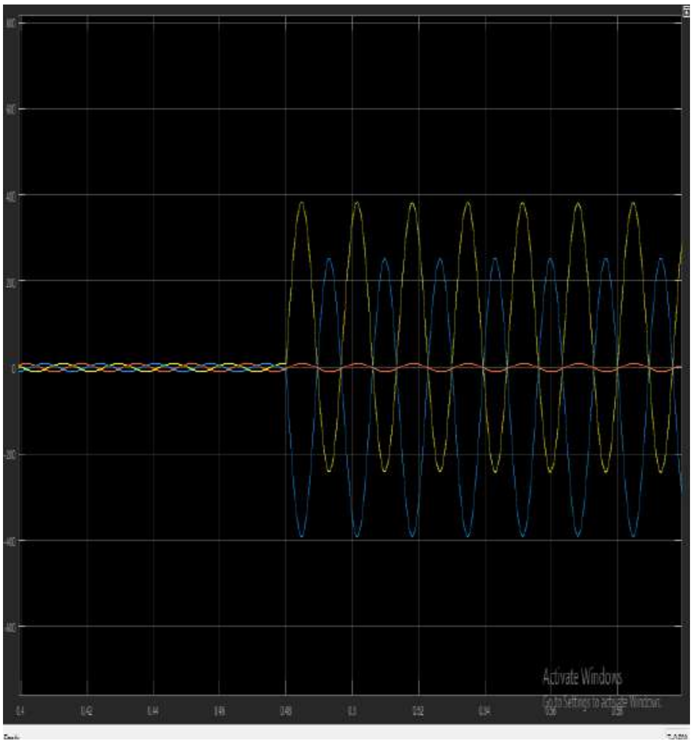

Fig. 18 Waveforms of load current and voltage drop upon transformer primary windings at two-phase (between phase b and c) accident.

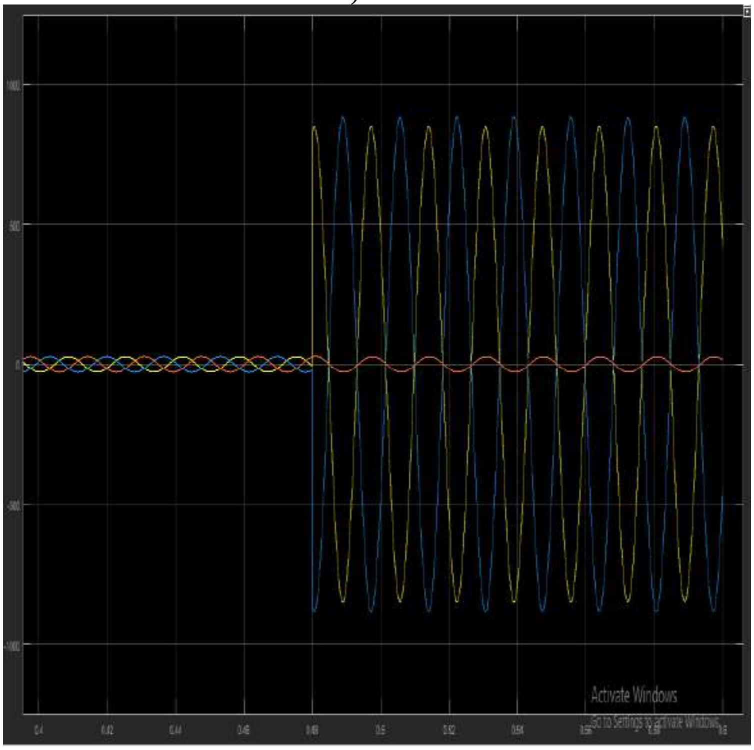

Fig. 19 Waveforms of load current and voltage drop upon transformer primary windings at two-phase (between phase b and c) accident.

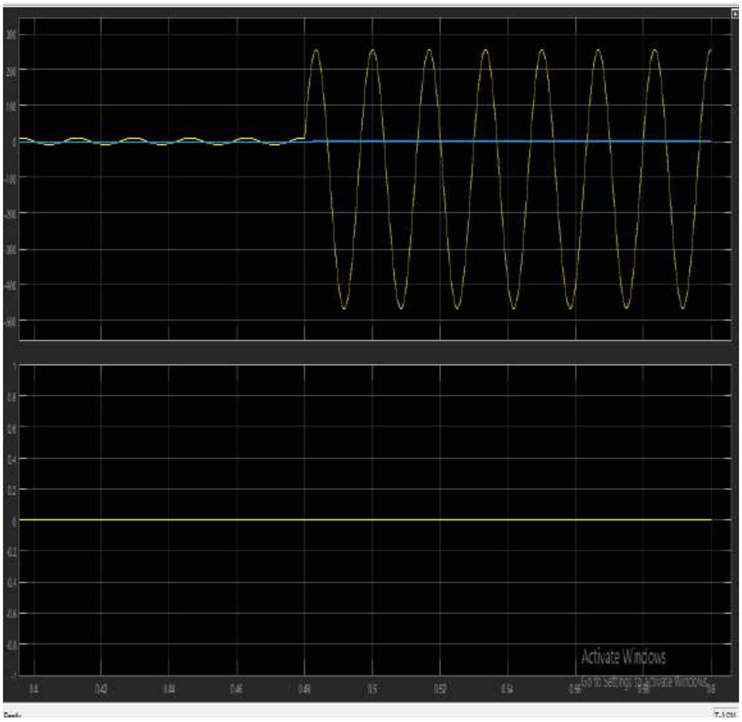

Fig. 20 Waveforms of DC reactors and AC reactors current at three-phase to ground accident

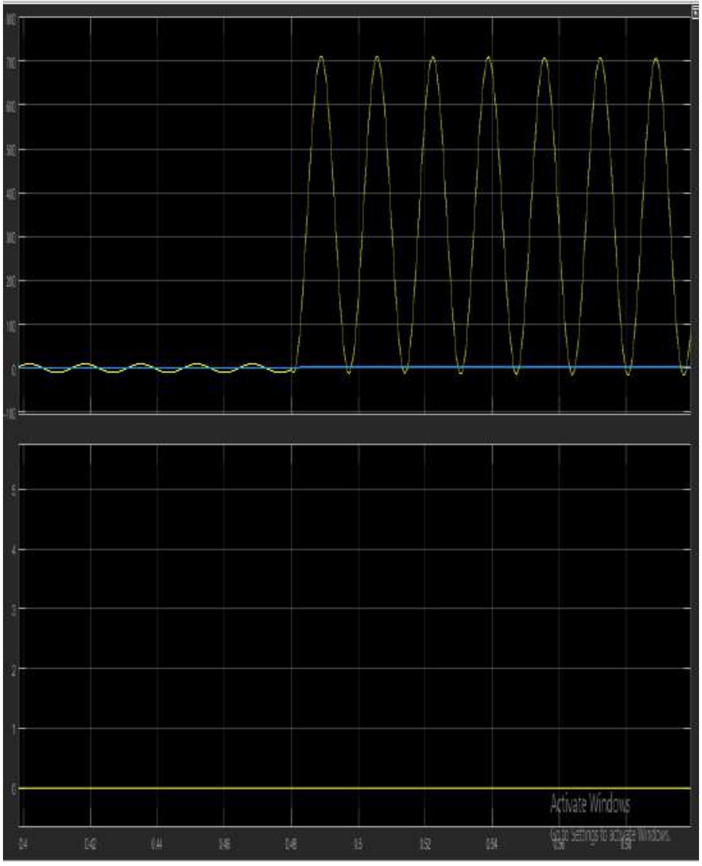

Fig. 21 Waveforms of DC reactors and AC reactors current at three-phase to ground accident

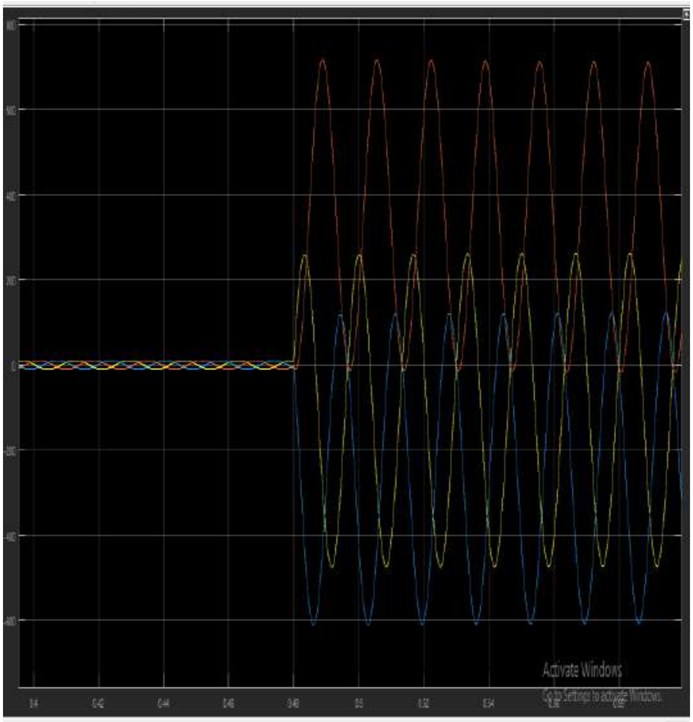

Fig. 22 Waveforms of load current and voltage drop upon transformer primary windings at three-phase to ground accident.

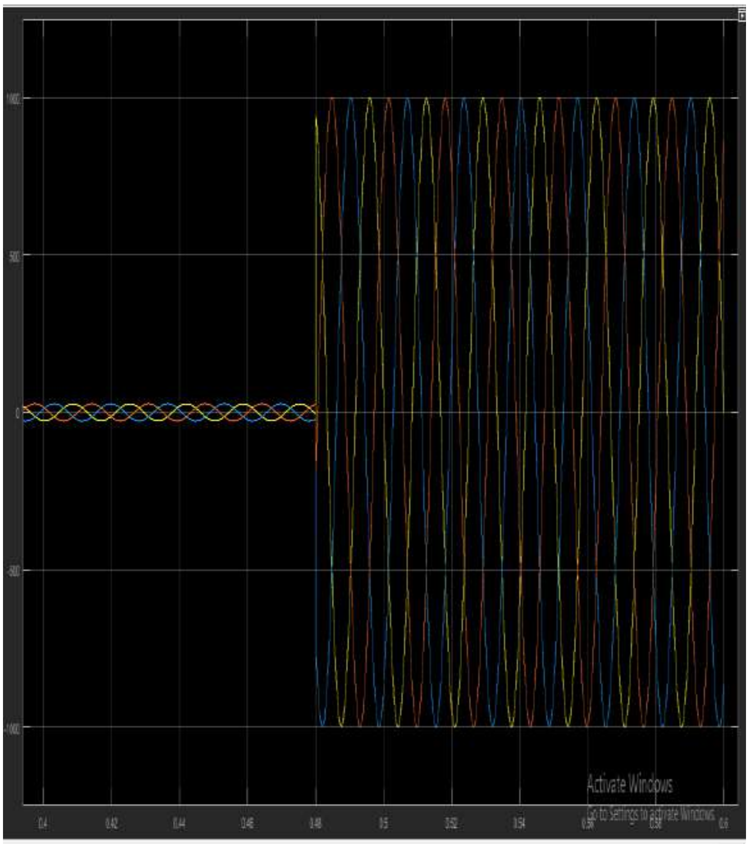

Fig. 23 Waveforms of load current and voltage drop upon transformer primary windings at three-phase to ground accident.

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V. CONCLUSION

This paper presents concept to determine the optimal location of a resistive superconducting fault current limiter (SFCL) for enhancing the transient stability of an electric power grid (EPG). To select the optimal location of the SFCL, the sensitivity analysis of the angular separation of the rotors of synchronous machines present in the power system is introduced. The SSFCL presented in this paper can be used in high-voltage power network in normal operation with low voltage drop and little effect on circuit. When fault arises, bypass reactor is immediately inserted in faulty circuit to limit short-circuit current and invert bridge circuit of faulty phase. Then the energy stored in DC reactor is fed back to power network and the bridge circuit retreat from faulty circuit as soon as possible. The faulty current is limited by bypass AC reactor alone. Parameters of solid device of the SSFCL and DC reactor are not restricted by permitted short-circuit current level. They can be flexibly optimized in designing. While in work, SSFCL produces no oscillation, thus protecting the security of distribution system.

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