SIMULATION AND ANALYSIS OF DIRECTIONAL PROTECTION SCHEME FOR FAULT ANALYSIS IN HVDC TRANSMISSION LINES BASED ON REACTIVE ENERGY

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ABSTRACT

As we see modern civilization heavily depends on consumption of electrical energy for commercial, industrial, domestic, agricultural and social purposes. HVDC is most economical way to transmit bulk power over longer distances, complexity in controlling of the power flow, asynchronous power grid interconnections and renewable energy integration due to its flexible power control. Among the numerous techniques concerning HVDC system, DC transmission line protection is one of the important unit thus it provides fast fault clearance and guarantees the operation security of the entire HVDC transmission system. In HVDC transmission lines uses the voltage differential protection in which voltage differential rate to identify the faults takes place on transmission line but this technique not efficient due to not detect high impedance faults and its sensitivity to faults resistance.

In the time difference between the initial wave and reflected wave from the fault point is utilized to calculate the fault distance, but it is difficult to distinguish the reflected wave from the disturbing waves in some cases. This project proposes a novel directional backup protection scheme based on reactive energy for HVDC transmission systems. In this paper reactive energy is defined as the integral of reactive power during a period of time.

INTRODUCTION

As we see modern civilization heavily depends on consumption of electrical energy for commercial, industrial, domestic, agricultural and social purposes. HVDC is most economical way to transmit bulk power over longer distances, complexity in controlling of the power flow, asynchronous power grid interconnections and renewable energy integration due to its flexible power control. Among the numerous techniques concerning HVDC system, DC transmission line protection is one of the important unit thus it provides fast fault clearance and guarantees the operation security of the entire HVDC transmission system. In HVDC transmission lines uses the voltage differential protection in which voltage differential rate to identify the faults takes place on transmission line but this technique not efficient due to not detect high impedance faults and its sensitivity to faults resistance. In high-speed travelling wave based protection to transmission line, but its performance is easily affected by disturbance takes place in system. Distance protection is another method to identify the faults take place on transmission line by fault distance calculation. In the time difference between the initial wave and reflected wave from the fault point is utilized to calculate the fault distance, but it is difficult to distinguish the reflected wave from the disturbing waves in some cases.

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HVDC SYSTEM

Historical Perspective on HVDC Transmission It has been widely documented in the history of the electricity industry, that the first commercial electricity generated (by Thomas Alva Edison) was direct current (DC) electrical power. The first electricity transmission systems were also direct current systems. However, DC power at low voltage could not be transmitted over long distances, thus giving rise to high voltage alternating current (AC) electrical systems. Nevertheless, with the development of high voltage valves, it was possible to once again transmit DC power at high voltages and over long distances, giving rise to HVDC transmission systems.

- **The HVDC technology**

The fundamental process that occurs in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end, and from DC to AC (inverter) at the receiving end. There are three ways of achieving conversion:-

- Natural Commutated Converters. Natural commutated converters are most used in the HVDC systems as of today. The component that enables this conversion process is the thyristor, which is a controllable semiconductor that can carry very high currents (4000 A) and is able to block very high voltages (up to 10 kV). By means of connecting the thyristor in series it is possible to build up a thyristor valve, which is able to operate at very high voltages (several hundred of kV).The thyristor valve is operated at net frequency (50 Hz or 60 Hz) and by means of a control angle it is possible to change the DC voltage level of the bridge. This ability is the way by which the transmitted power is controlled rapidly and efficiently.
- Capacitor Commutated Converters (CCC). An improvement in the thyristor-based commutation, the CCC concept is characterized by the use of commutation capacitors inserted in series between the converter transformers and the thyristor valves. The commutation capacitors improve the commutation failure performance of the converters when connected to weak networks.
- Forced Commutated Converters. This type of converters introduces a spectrum of advantages, e.g. feed of passive networks (without generation), independent control of active and reactive power, power quality. The valves of these converters are built up with semiconductors with the ability not only to turn-on but also to turn-off. They are known as VSC (Voltage Source Converters). Two types of semiconductors are normally used in the voltage source converters: the GTO (Gate Turn-Off Thyristor) or the IGBT (Insulated Gate Bipolar Transistor). Both of them have been in frequent use in industrial applications since early eighties.

The components of an HVDC transmission system To assist the designers of transmission systems, the components that comprise the HVDC system, and the options available in these components, are presented and discussed. The three main elements of an HVDC system are: the converter station at the transmission and receiving ends, the transmission medium, and the electrodes.

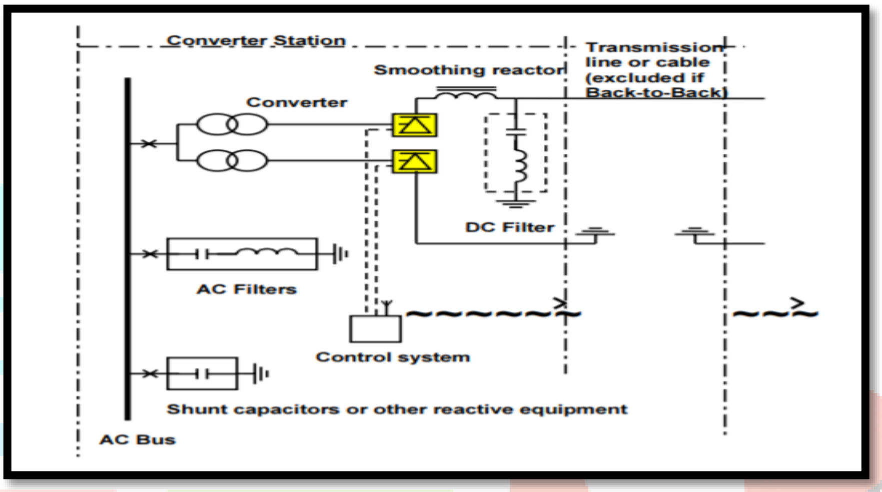

Fig 3.1- Block Diagram of HVDC System

Design, Construction, Operation and Maintenance considerations: -

In general, the basic parameters such as power to be transmitted, distance of transmission, voltage levels, temporary and continuous overload, status of the network on the receiving end, environmental requirements etc. are required to initiate a design of an HVDC system. For tendering purposes a conceptual design is done following a technical specification or in close collaboration between the manufacturer and the customer. The final design and specifications are in fact the result of the tendering and negotiations with the manufactures/suppliers. It is recommended that a turnkey approach be chosen to contract execution, which is the practice even in developed countries.

DIRECTIONAL PROTECTION SYSTEM

PRINCIPLE OF PROTECTION SCHEME

In HVDC systems mostly transmit active power under normal operating condition, but in fault condition the less amount of reactive power flow due to small harmonic components in systems. The harmonic reactive power generated on the DC line depends on components of system like DC filters and the smoothing reactors. The total quantities of the harmonic current and voltage are typically less than10% to 15% of the rated values. When DC line fault occurs, the current and voltage at the terminals of the DC line will contain a transient due to the inductive and capacitive components in the system, thus resulting in significant reactive power flows on the DC line. In traditional HVDC systems, shunt capacitor banks are commonly used for compensating the reactive power which the converters consume due to sudden change in firing angle. Reactive power control is designed to maintain the reactive power balance by switching the capacitor banks.

- ***Reactive Energy Measurement***

In digital signal processing Hilbert transform is useful method for determine instantaneous attributes of time series, especially the amplitude and frequency. It is used to calculate the reactive power, which is defined as follows:-

$$\hat{x}(t) = x(t) * h(t) \quad = x(t) * \frac{1}{\pi t} \quad = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau}\, d\tau \qquad (1)$$

Where

$\hat{x}(t)$ Is the Hilbert transform result of $x(t)$ and '*' isthe operator for time domain convolution.

The frequency characteristic of $h(t)$ is expressed in(eq.2). $h(t)$ induces a -90 degree shift for positive frequency components and a + +90 degree shift for negative frequency components.

$$H(\omega)= -j\ \mathrm{sgn}(\omega) = \begin{cases} -j & for \quad \omega < 0 \\ 0 & for \quad \omega = 0 \\ j & for \quad \omega > 0 \end{cases} \quad \textbf{… (2)}$$

The Hilbert transform can be discretized as,

$$\hat{X}[n]=x[n]*h[n] \qquad \textbf{….. (3)}$$

Where

$$h[n] = \begin{cases} 0 & for\ n\ is\ even \\ \frac{2}{n\pi} & for\ n\ is\ odd \end{cases} \quad \textbf{…. (4)}$$

A Hamming window function is used to truncate $h[n]$for finite calculations in practice.

The instantaneous reactive power is the multiplication of the current signal $i(t)$ and the Hilbert transform of the voltage signal $v(t)$

$$q(t)=\hat{v}(t) * i(t) \quad \textbf{….. (5)}$$

The reactive energy during a period of time t is calculated in

$$W(t)=\int_0^t q(\tau)d\tau = \int_0^t \hat{v}(\tau) * i(\tau)d\tau \qquad \textbf{….. (6)}$$

➢ *Fault Direction Identification*

Directional protection scheme is used for internal and external fault identification. The reference direction of reactive energy is from the rectifier side to the inverter side. If the reactive energies of each side have different directions, an internal fault is identified. Otherwise, an external fault is detected. Thus, the fault direction identification criteria can be expressed as-

$$\text{internal fault } : W_R(t)W_I(t) < 0 \qquad \text{….. (5.1)}$$

$$\text{external fault } : W_R(t)W_I(t) > 0 \qquad \text{…… (5.2)}$$

Where $W_R(t)$and$W_1(t)$are the reactive energies measured at the rectifier side and inverter side, respectively. In a monopolar HVDC system, single pole reactive energy is used for direction identification, whereas in a bipolar system, the sum of the reactive energies at the two poles is used.

➢ *Start-up Component*

A protection starts up component is introduced to ensure the reliability of the protection scheme in case of disturbances. In this study, the DC voltage differential du/dt or current differential di/dt is used as the start-up component. Once the start-up requirement is satisfied, the protection scheme is triggered to start the calculation process.

➢ *Time Delay*

Frequent energy exchange due the inductive and capacitive components at the beginning of the fault so the reactive energy varies between positive and negative values, which results in fluctuate directions during this period. So, time delay is required to prevent this fluctuating nature of reactive energy direction.

➢ *Threshold Setting*

A threshold for the reactive energy is necessary to preventable-operation during disturbances. When the calculated reactive energy is larger than the threshold value, the fault direction identification module is activated.

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- ***Fault Pole identification***

In a bipolar HVDC transmission system, during single pole to ground fault pole selection is required to isolate faulty pole and maintain continues operation of system through another pole.

Due to the mutual coupling effect of the two poles, the healthy pole may also generate reactive energy during a single-pole to ground fault, but this reactive energy is considerably smaller than that in the faulty pole. By which three types of faults can be classified.

MODELLING AND SIMULATION

Matlab Model of HVDC system with internal Fault

The Matlab model of the HVDC proposed system without internal fault is shown in the fig below. The simulation results of Voltage and Current also shows the unbalancing due to internal fault in HVDC system.

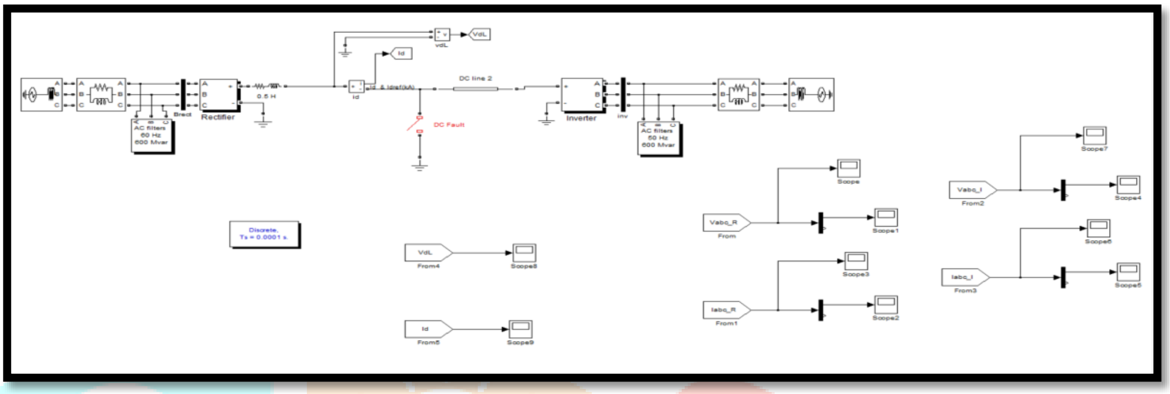

Figure Matlab Model of HVDC System with Fault

Results

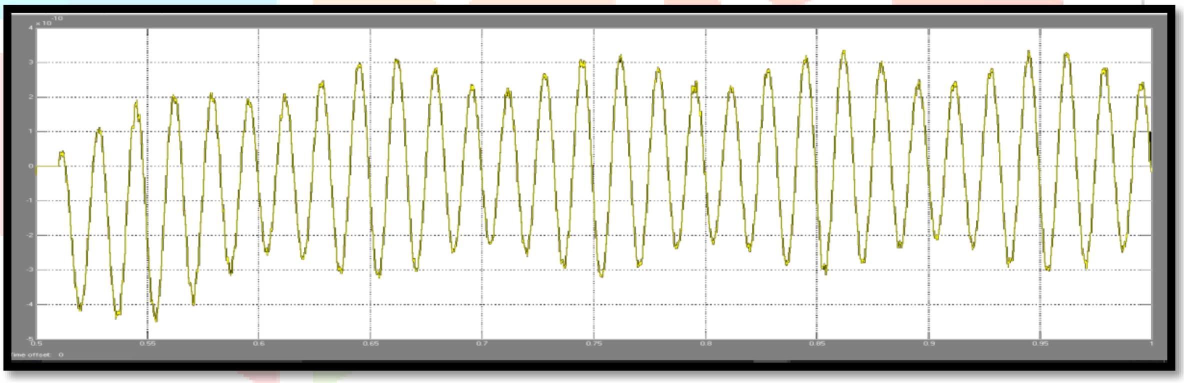

Figure Voltage variation due to fault

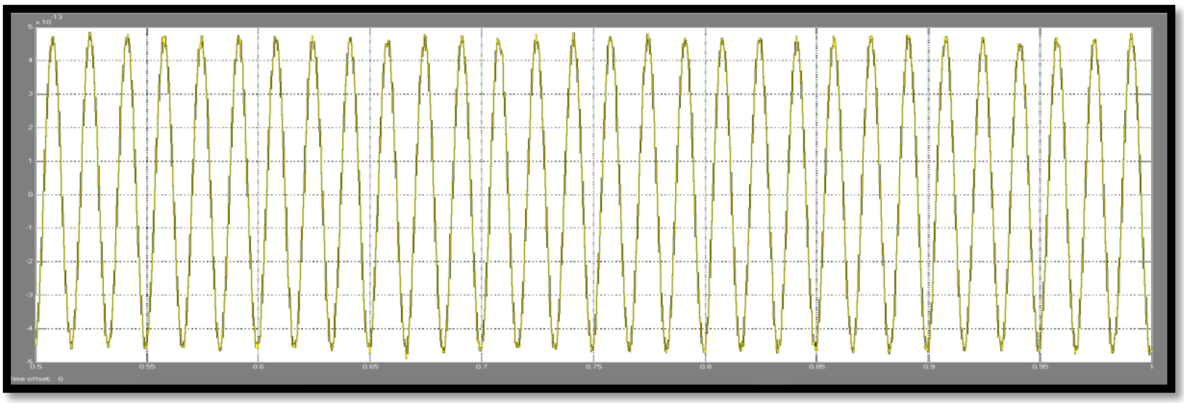

Figure current variation due to fault

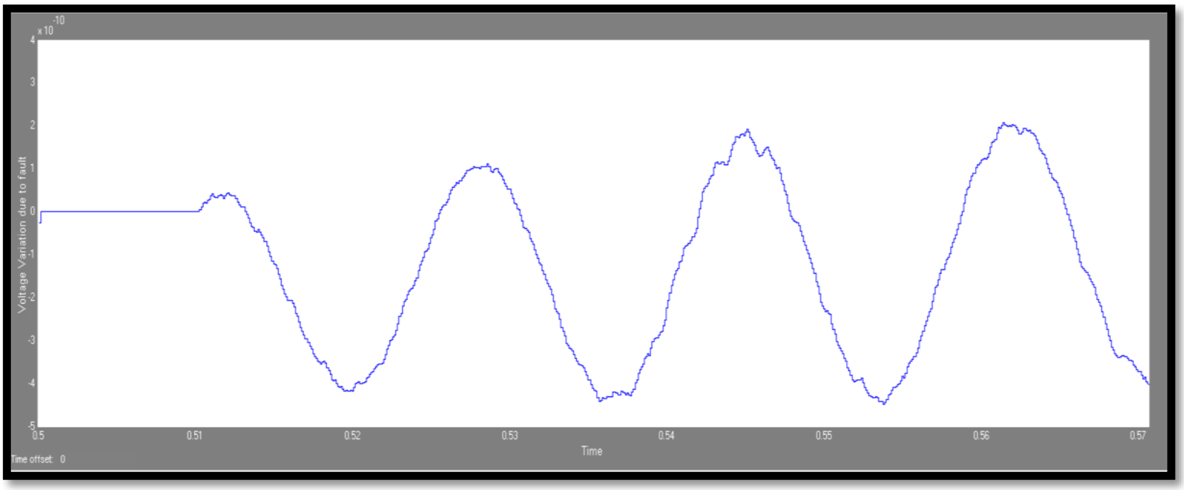

Figure Voltage variation due to fault

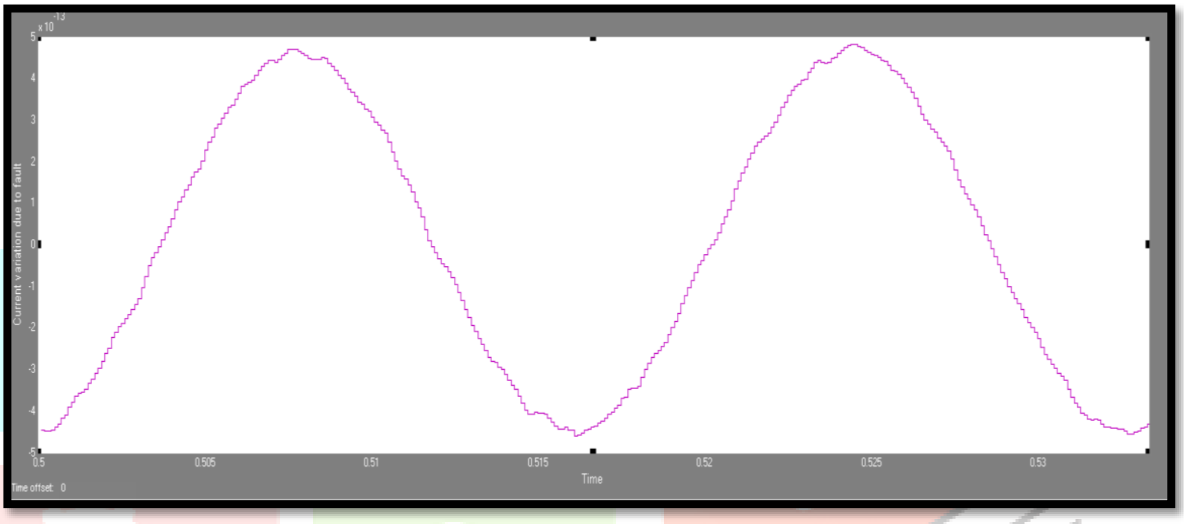

Figure current variation due to fault

Matlab Model of Reactive power control with HVDC system

The Matlab model of Reactive power control with HVDC system for internal Fault is shown in the fig below. In the controlling block the Selective Harmonic Technique used for the angle control using Reactive power control and providing the protection against the internal fault.

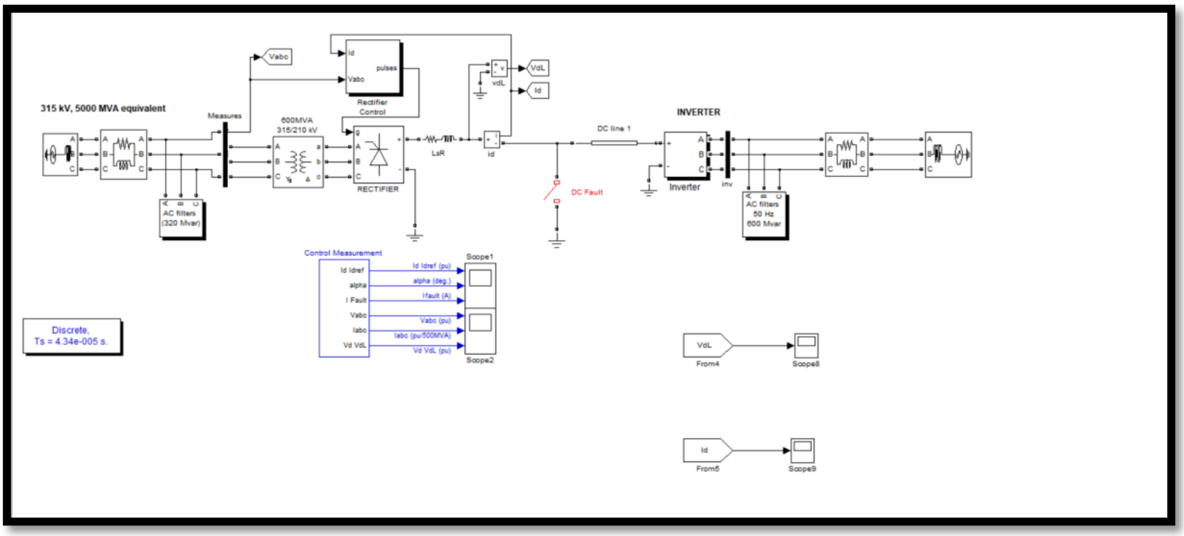

Figure HVDC system with proposed control strategy

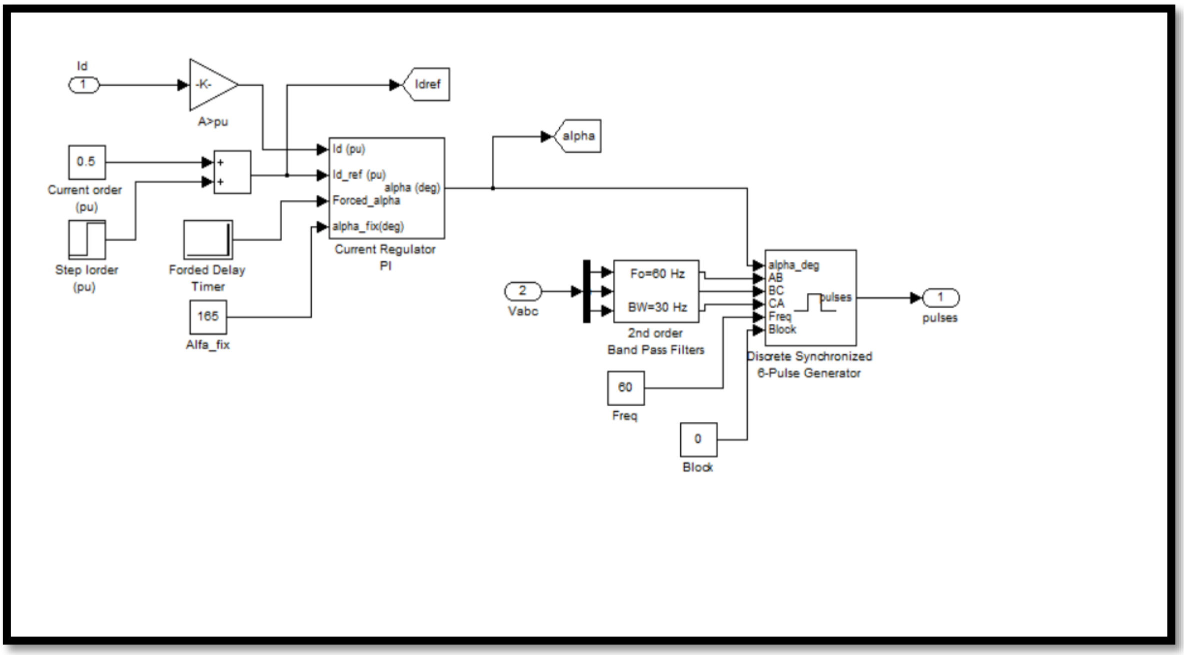

Figure Control block for Reactive power control

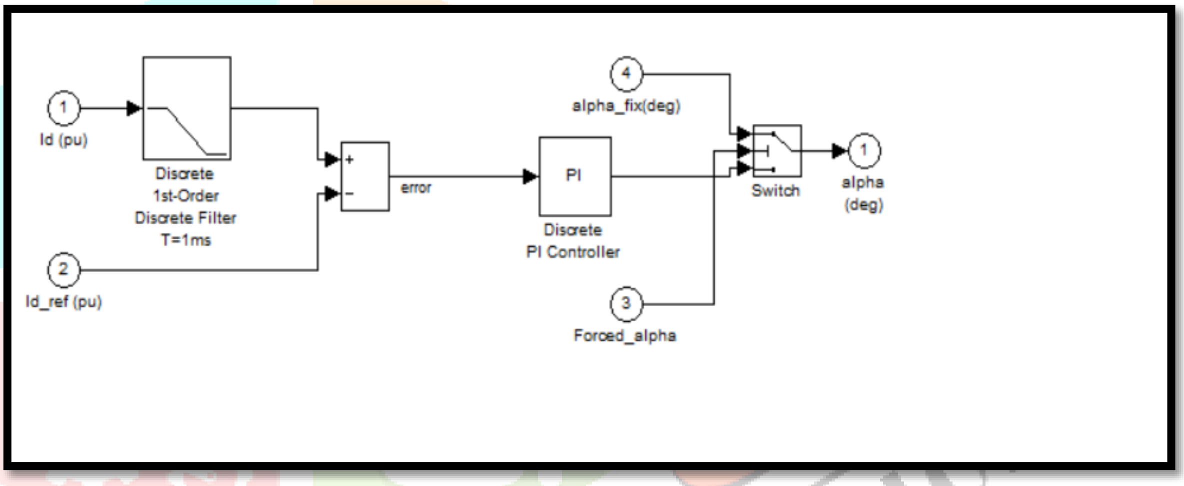

Figure Angle controlling block

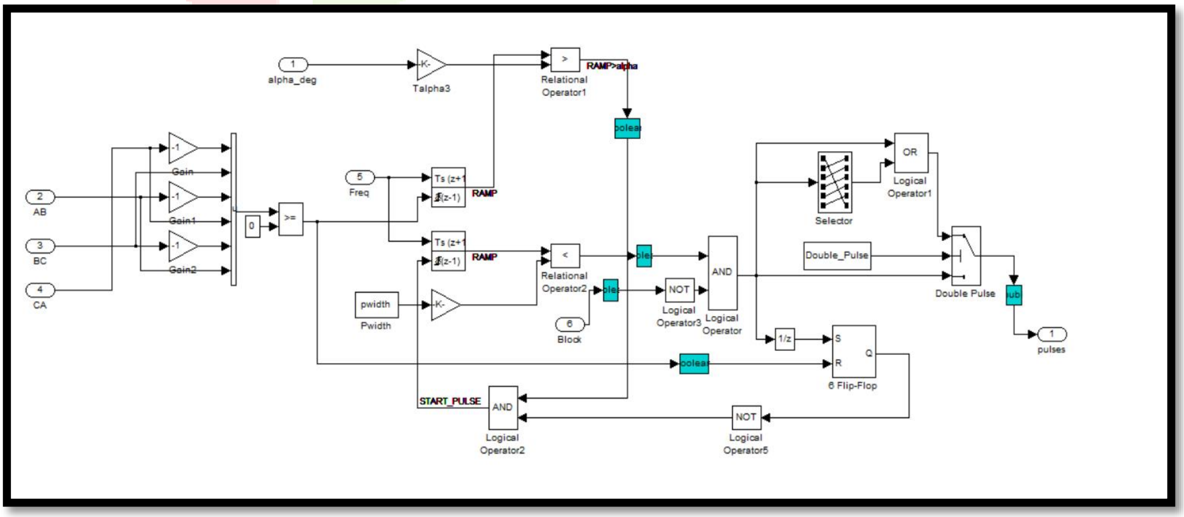

Figure Triggering pulse control system at Rectifier side

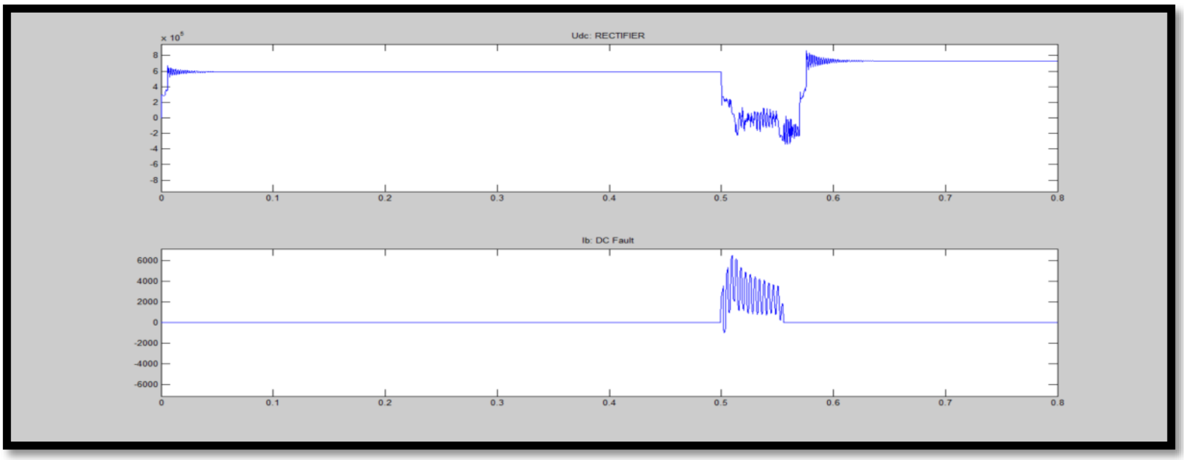

Figure fault clearance and protection system time

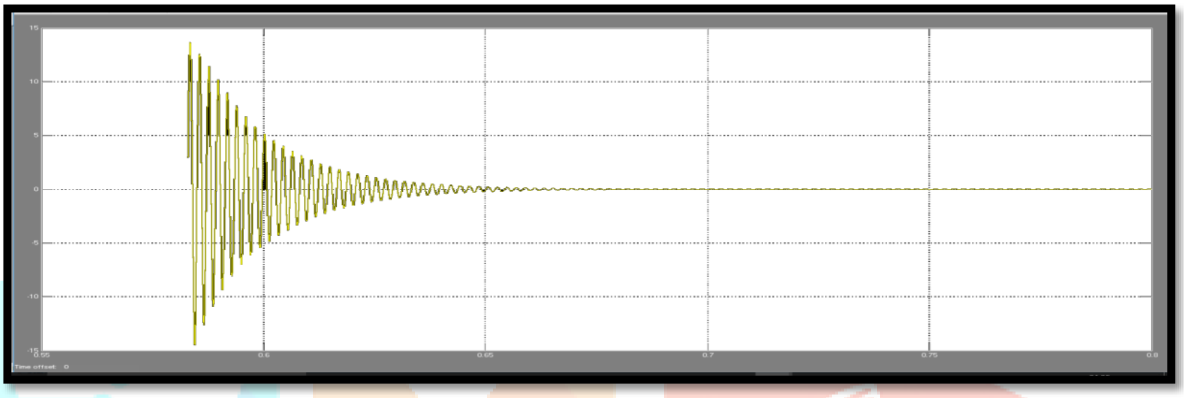

Figure Stable voltage in HVDC after fault controlling

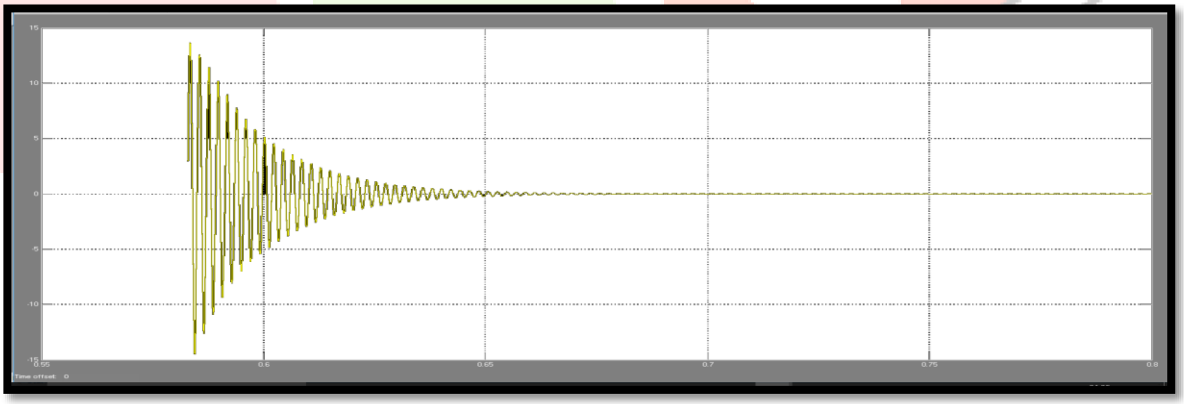

Figure Stable current in HVDC after fault controlling

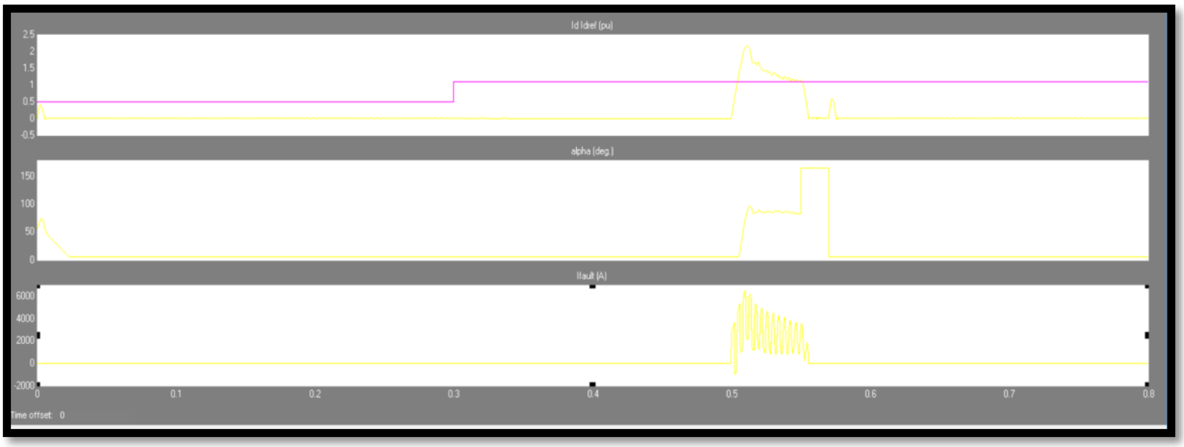

Figure Controlling Parameters

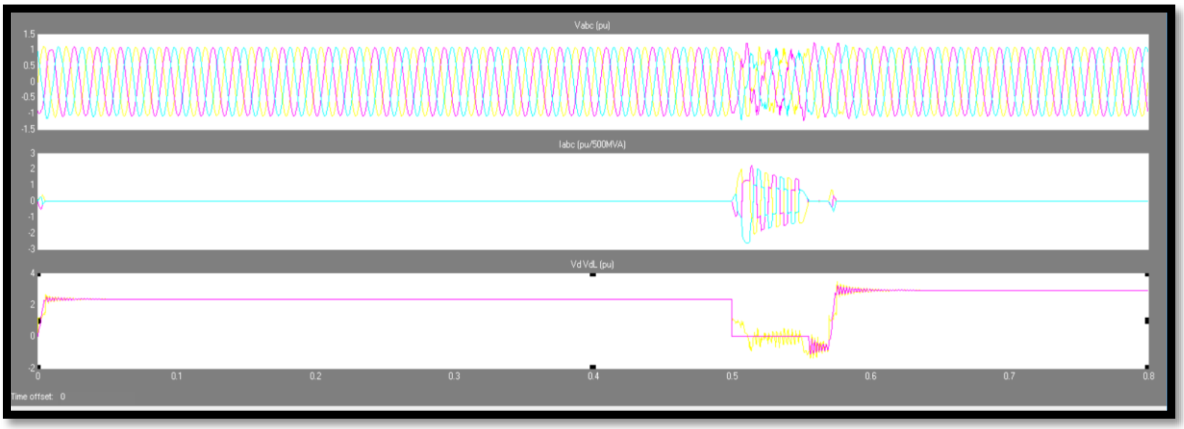

Figure Compensated outputs

Matlab Model of control of HVDC system for External Fault: -

The Matlab model of control with HVDC system for External Fault is shown in the fig below. In the controlling block the HVDC System has been proposed with PLL and hysteresis controller for controlling the converter and inverter side output parameters.

Description

A 200 MVA (+/- 100 kV DC) forced-commutated Voltage-Sourced Converter (VSC) interconnection is used to transmit power from a 230 kV, 2000 MVA, 50 Hz system to another identical AC system. The rectifier and the inverter are three-level Neutral Point Clamped (NPC) VSC converters using close IGBT/Diodes.

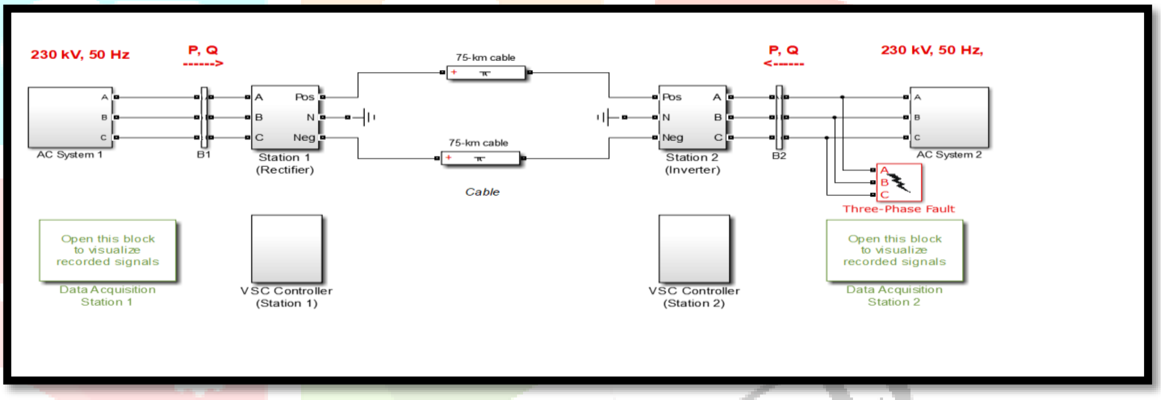

Fig- HVDC system for external fault

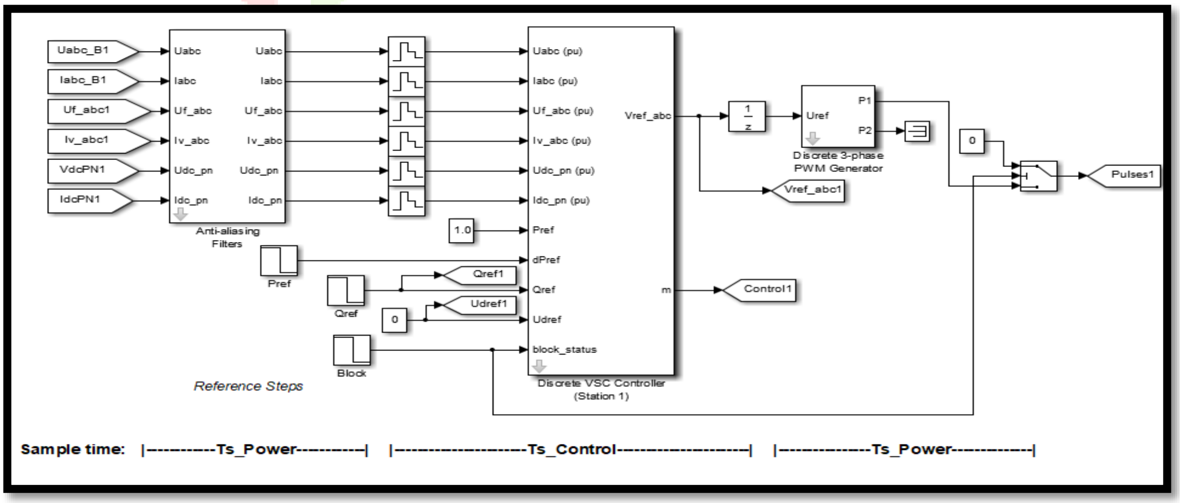

Fig Controlling Subsystem for proposed system

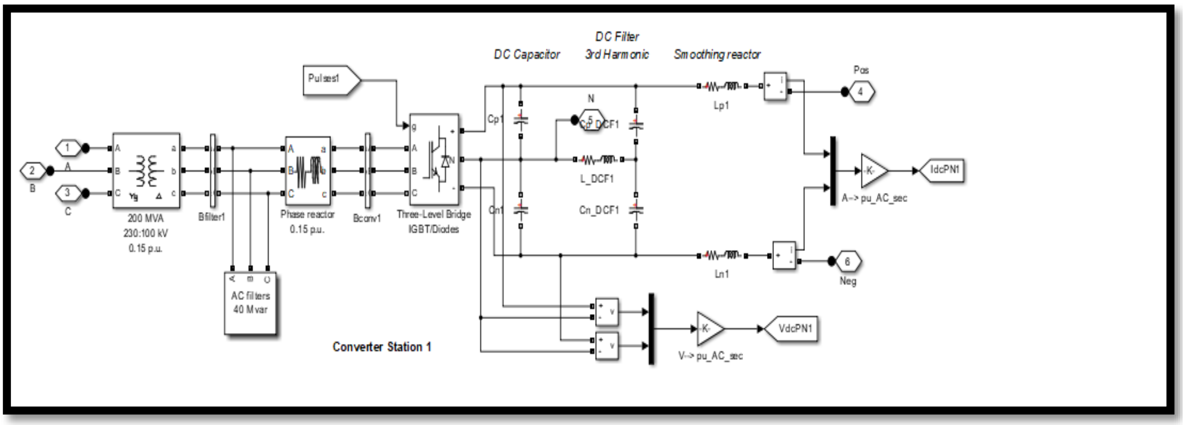

Fig Converter side-1

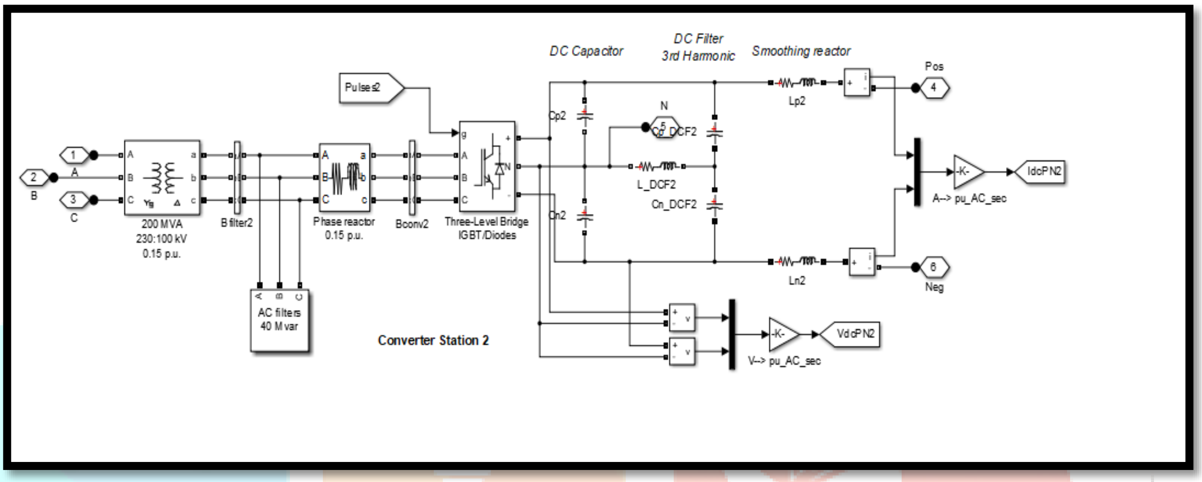

Fig Converter side-2

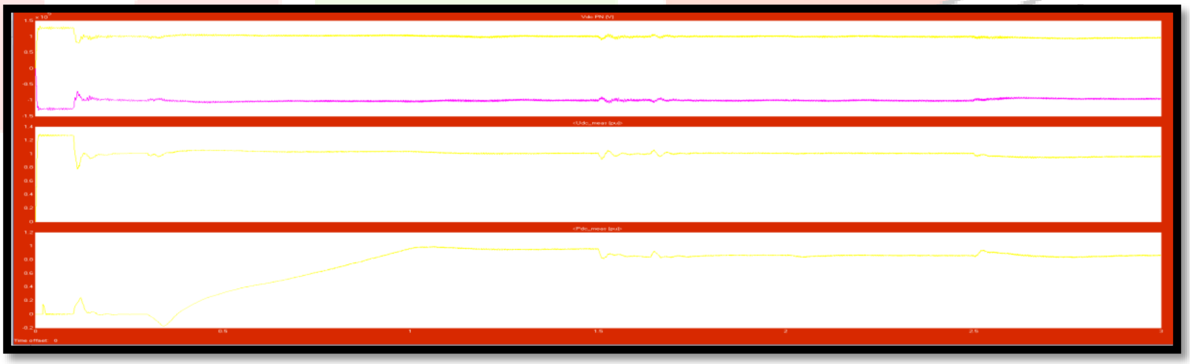

Fig Converter-1 output D.C Parameters

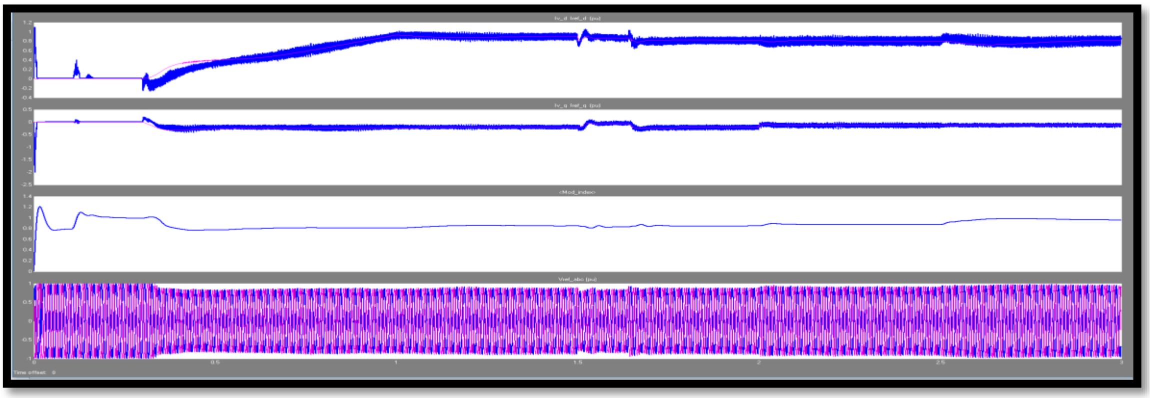

Fig Converter-1 Direct and Quadrature axis output Parameters and output Vabc

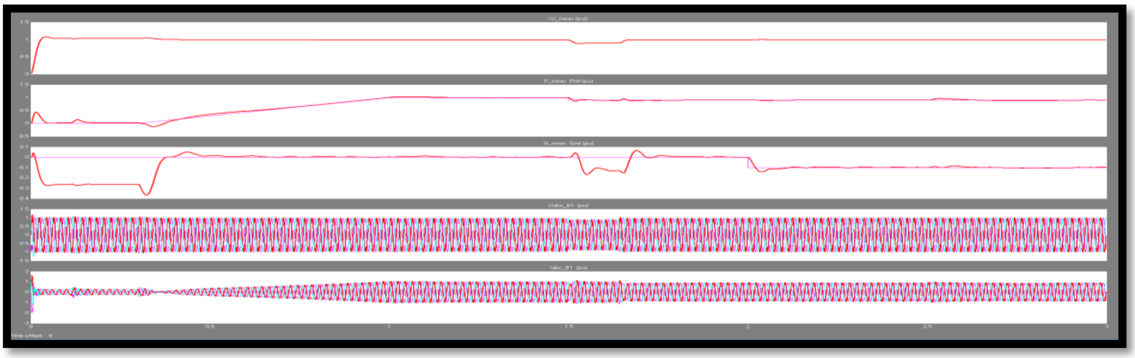

Fig Converter-1 output-controlled parameters

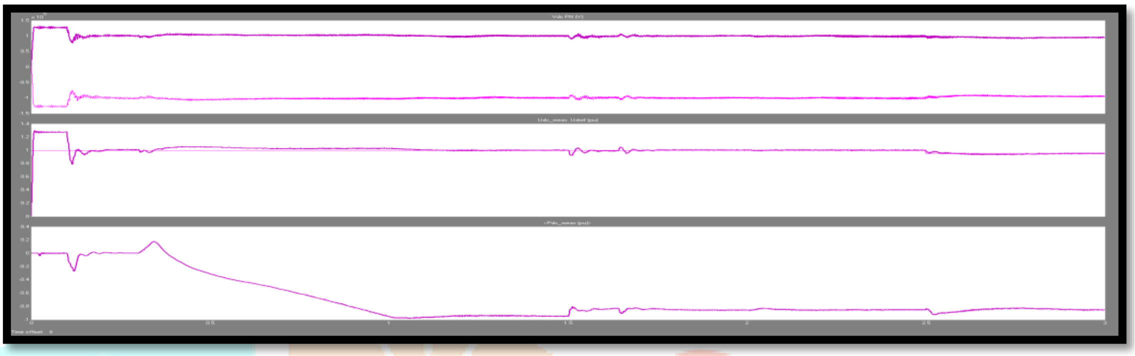

Fig Converter-2 output D.C Parameters

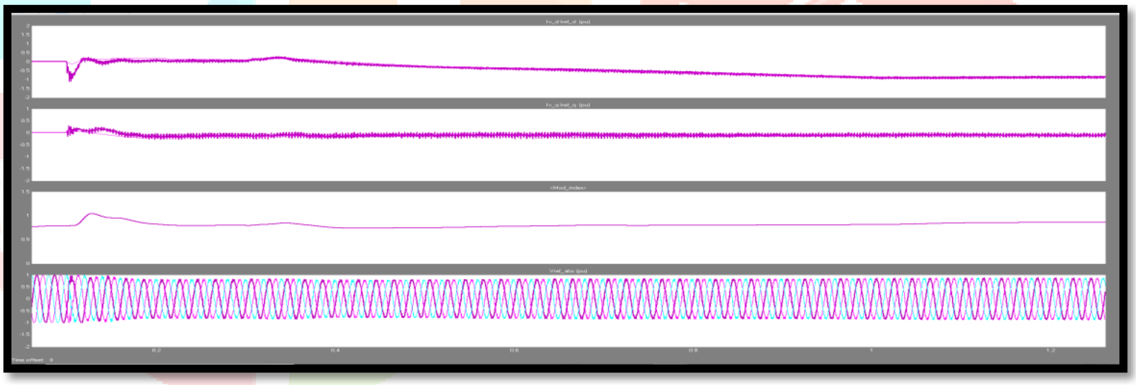

Fig Converter-2 Direct and Quadrature axis output Parameters and output Vabc

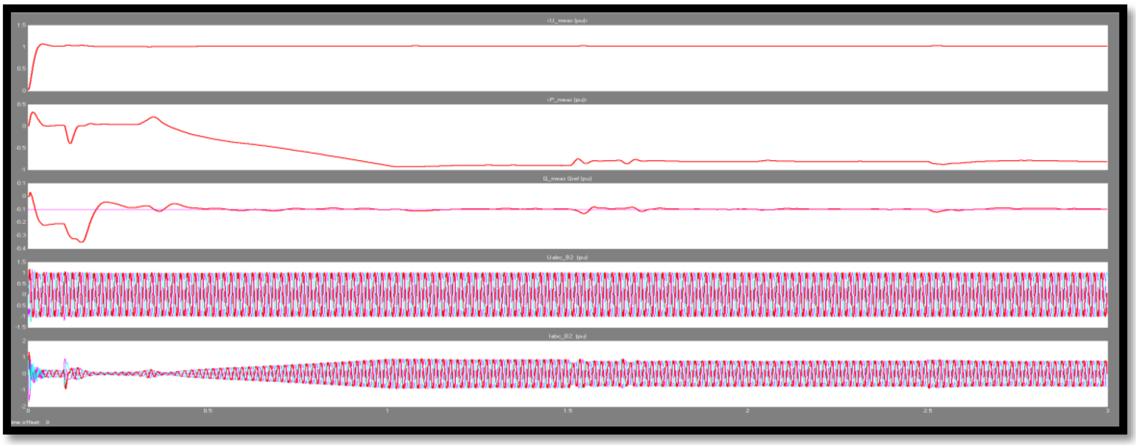

Fig Converter-2 output-controlled parameters

Proposed Control system of Protection using C.B for internal and external fault

In the below section the C.B based protection system has been proposed in the earlier control system for internal and external fault conditions. There are simulation results for both the cases are shown in this section. The simulation results show the comparison for internal and external fault conditions protection using Circuit breaker device.

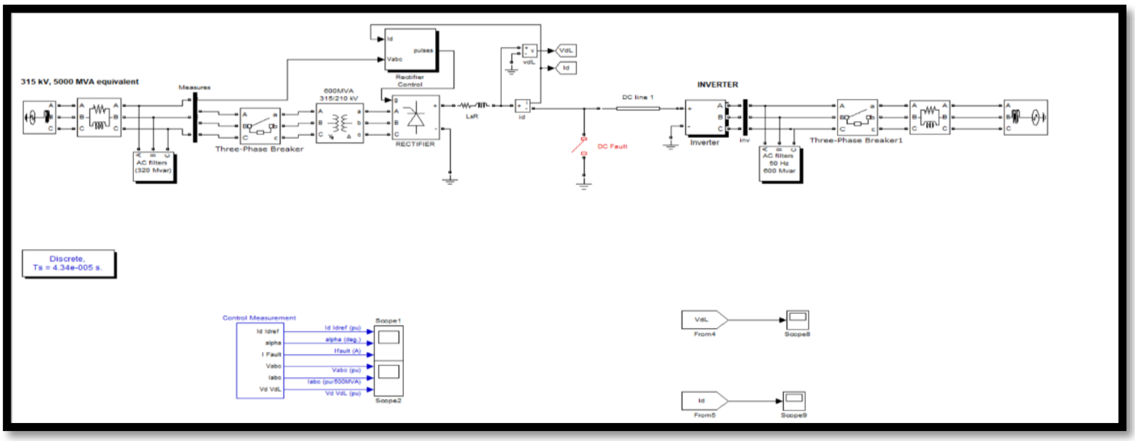

Fig Proposed system for internal fault using C.B

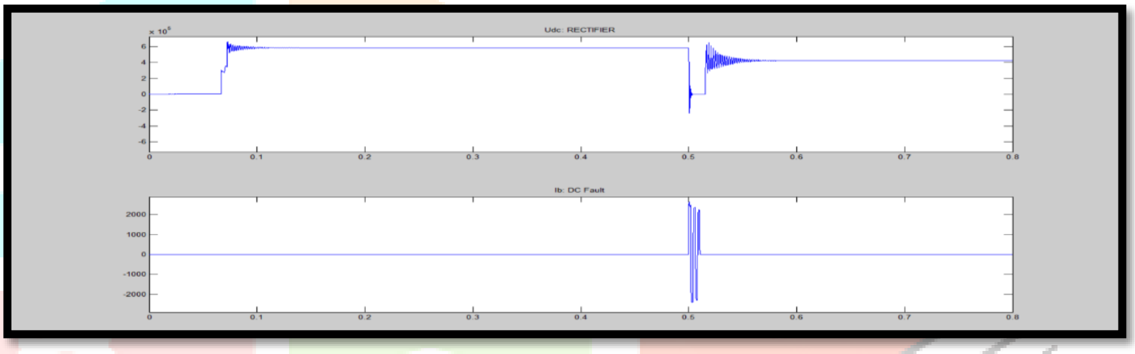

Fig fault condition waveform (fault clearance and protection system time)

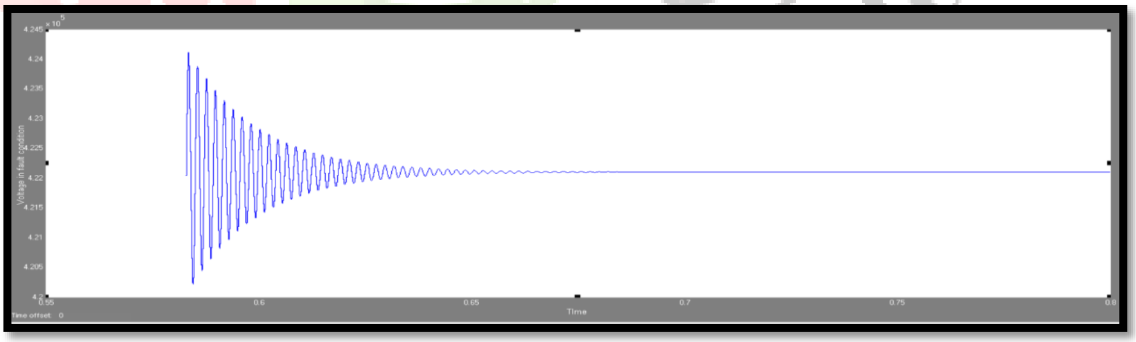

Fig D.C voltage variation during internal fault condition

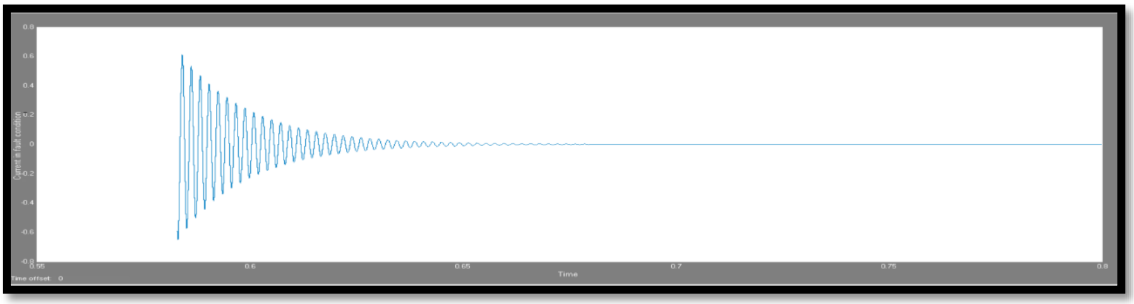

Fig D.C current variation during internal fault condition

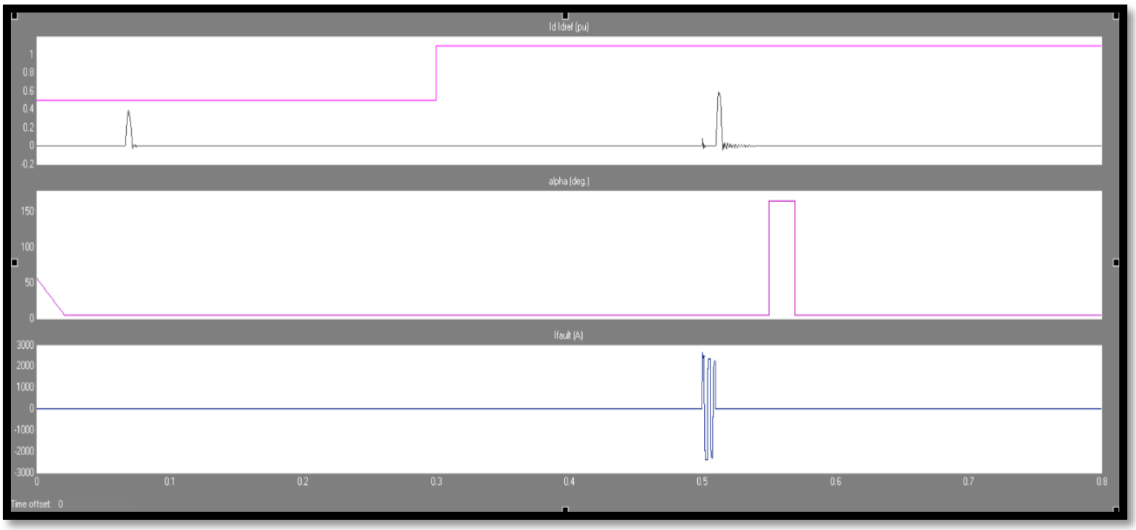

Fig Controlling Parameters

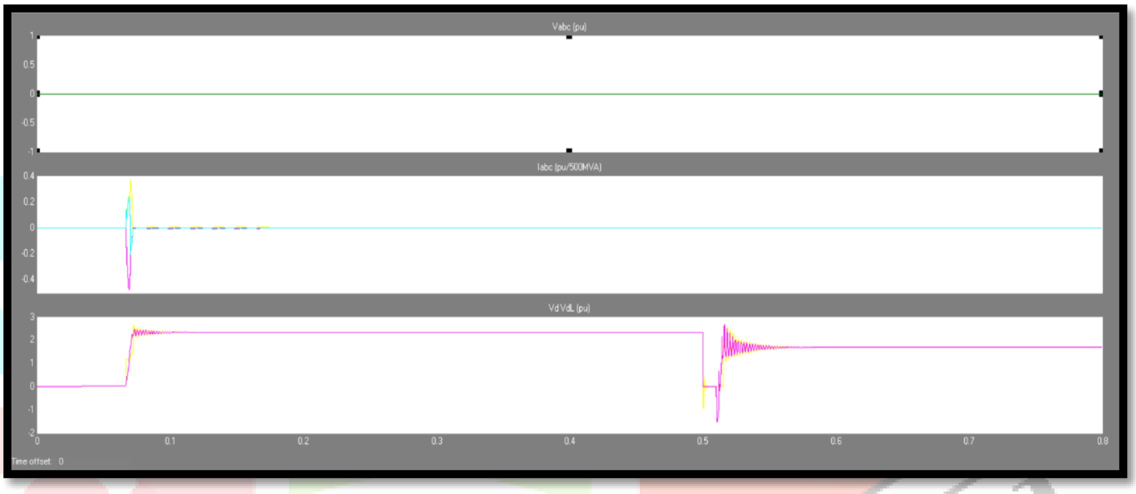

Fig Compensated output

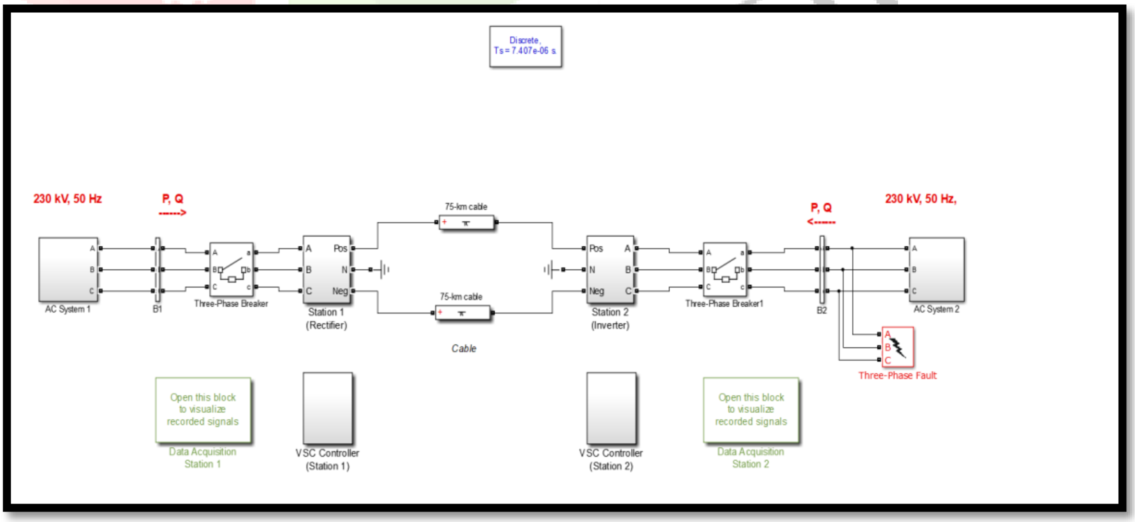

Fig Proposed system for external fault using C.B

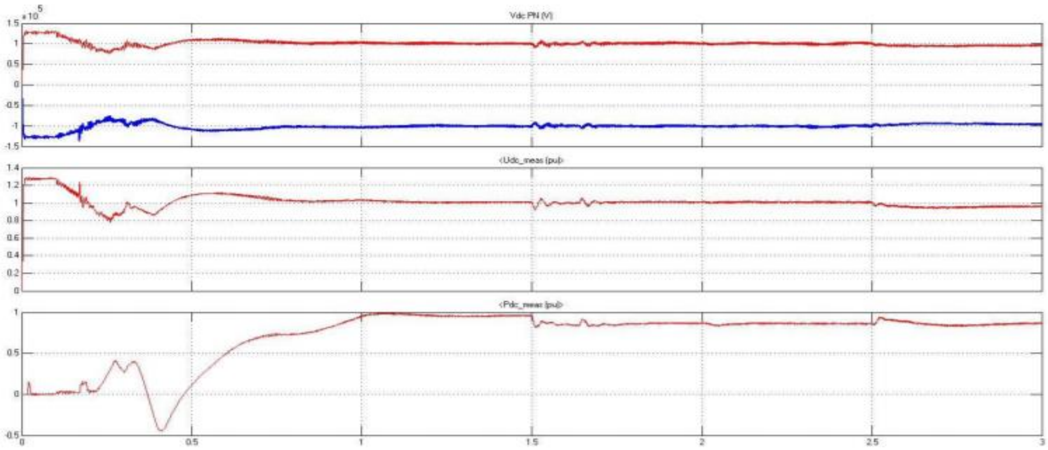

Fig Converter-1 output D.C Parameters using C.B

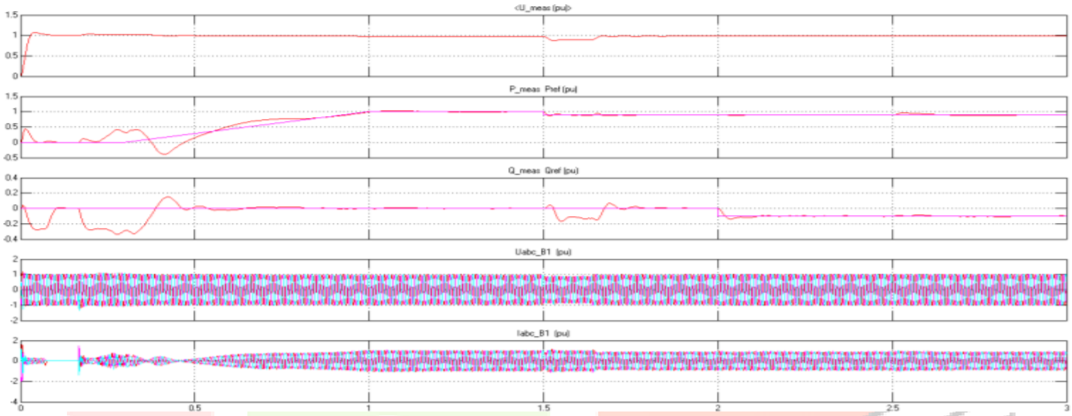

Fig Converter-1 output-controlled parameters using C.B

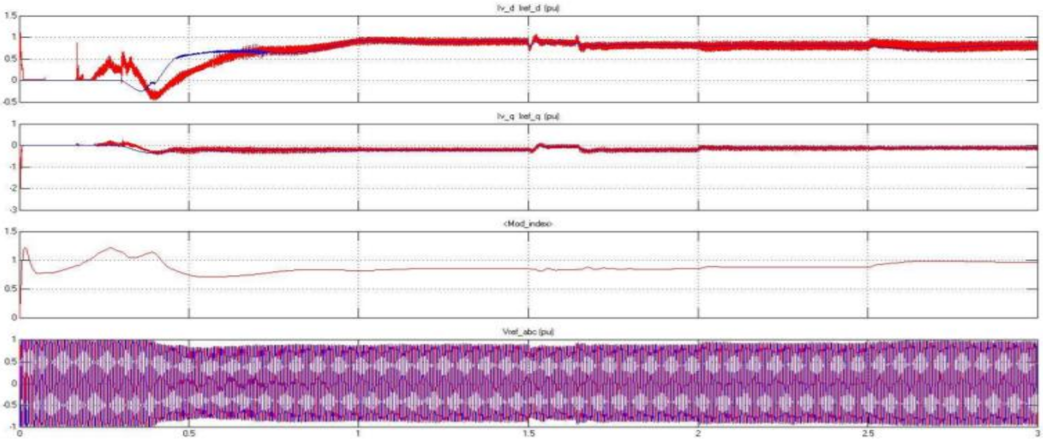

Fig Converter-1 Direct and Quadrature axis output Parameters and output Vabc using

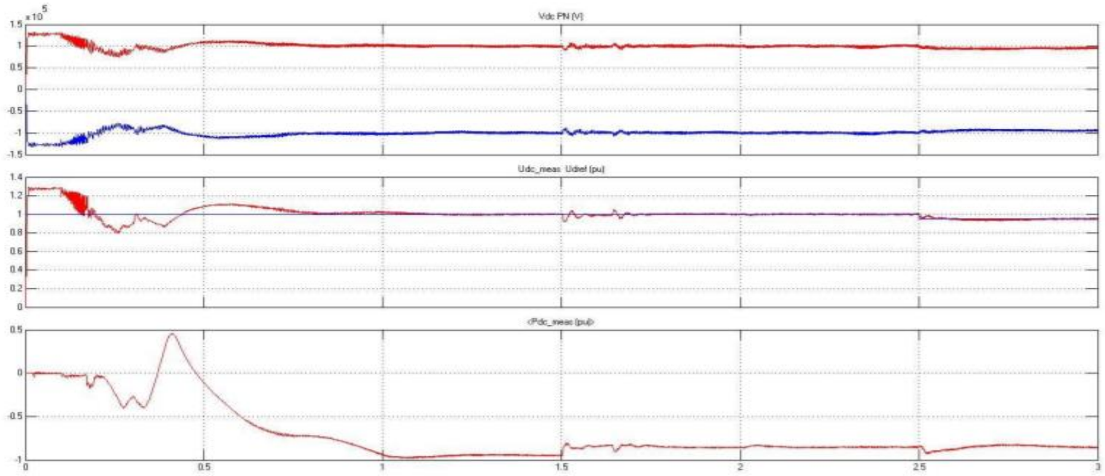

Fig Converter-2 output D.C Parameters using C.B

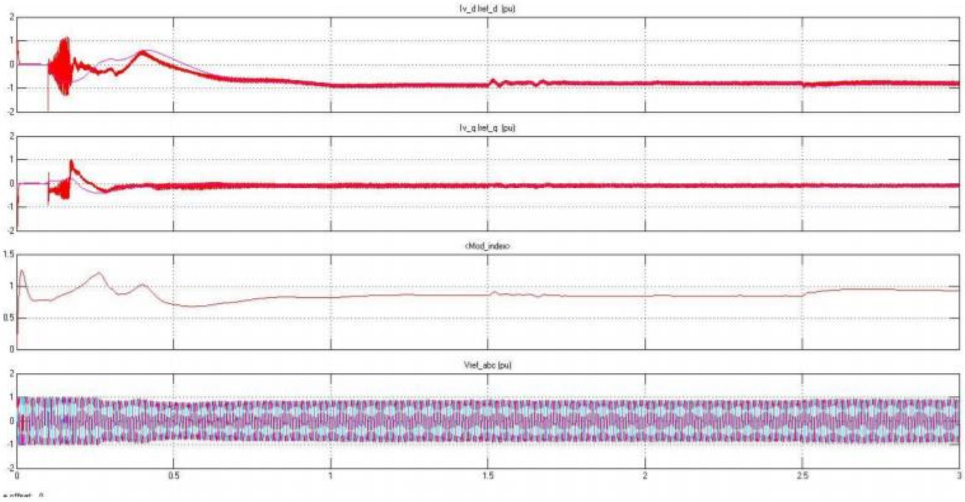

Fig Converter-2 Direct and Quadrature axis output Parameters and output Vabc using C.B

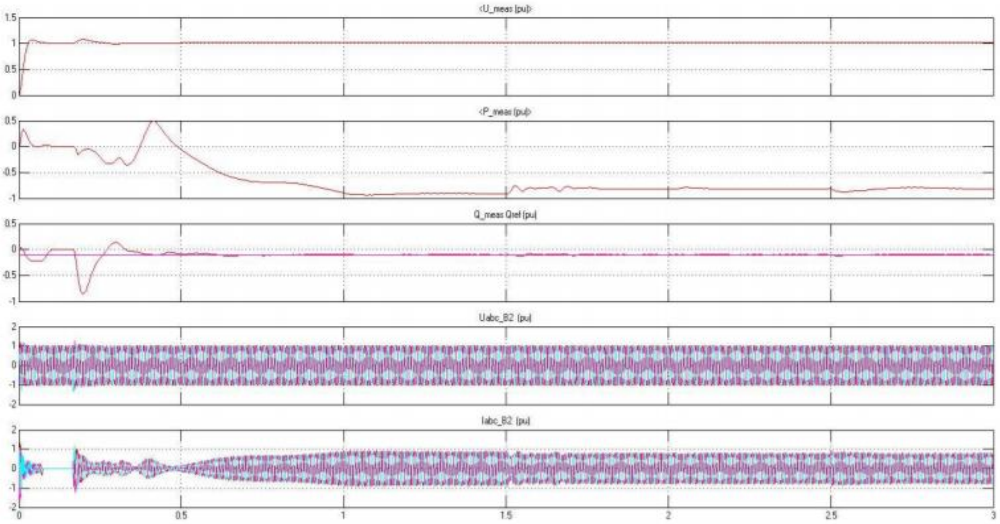

Fig Converter-2 output-controlled parameters using C.B

Conclusion

This paper proposes a novel protection scheme based on reactive energies for HVDC transmission lines. The selective harmonic technique is employed to calculate the reactive energy, which ensures the continuous outcome of the reactive energy and fault direction during the entire time of protection. The characteristics of the reactive energy under various fault conditions are analyzed based on the equivalent circuit of the

HVDC system and applied to construct the direction protection. Matlab simulations are conducted to verify the effectiveness of the protection scheme. The proposed protection scheme correctly effective for internal fault, fault distance variations. Compared to current differential protection, this protection induces a smaller time delay, thus significantly accelerating fault detection. Moreover, the protection is adaptive to fault resistances, which guarantees the protection sensitivity.

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