HVDC Line Protection Using Modal Transformations

Rajaram Verma[1], Prof. A,K, Jhala, Prof. Manish Prajapati
[1] *M.Tech Scholar HOD,Co-Guide Deptt. of Electrical & Electronic Engineering,*
RKDF College of Engineering, Bhopal, MP,India

Abstract – In this paper HVDC (High Voltage DC) transmission line protection is presented. Growing concern about the generation of the power and distribution it to the far ended consumer became very important issue. To prevent the system from power loss, and power theft HVDC is employed over a range of long distance. HVDC units are comprised with rectification, inverters and protection unit. Minimizing the complexities with modeling and performance of the system one need to comprise a signal variations as internal or external fault.

Key Words: HVDC, 12 Pulse transformers, Protection, Modeling, Modal Transformation.

I. INTRODUCTION

The HVDC systems are becoming more and more popular in the present power network. One can estimate the future for long distance transmission of power from one end of generation to another end of consumer. In this paper fundamental concept of HVDC line is discussed along with the power capability and design of components. HVDC system consists of rectification unit, cable or transmission line and the inverter unit. Such a system is more popular when the transmission is done for the long distance as the transmission loss is very great area of concern. For the shorter or medium line distance this becomes costlier than the conventional ac transmission. Since the HVDC unit requires at sending end a well developed and controlled rectification, and an inverter at receiving end. Number of rectification unit may be one or greater than one, but the inversion unit count depends on the supply point, *i.e.* how many number of supply point is connected to the system. Although, the shorter range of transmission, this may increase the cost of installation, operation and maintenance of the system. Comparatively with the conventional AC network, HVDC has advantages such as high transmission capability, transmission of power over long distance and low line loss.

HVDC system came to existence as fully developed and controlled system in late 1970s due to great research on the Thyristors as high frequency and power switching element.

From past few decades protection of HVDC line using travelling wave and other method was great area of research. Up till now, many researchers have reported their contribution in the field of HVDC line protection and classification of faults. But, the accuracy of protection depends on the how accurate the system is modeled. However, accuracy of modeling of converter and HVDC line is also a great area of concern to be followed.

In [1]–[6], author had discussed about the various protection scheme for the high voltage DC system and the protection of rectification and inverter unit also. Since the rectification and the inverter unit comes with the controlled scheme and their controller behaves as the protection unit for the system integration.

In literature [7]-[9] author had discussed the advantages of the HVDC over the conventional AC transmission system. The modeling and the converter analysis is not has been discussed.

As travelling wave protection and the line regulated protection has several disadvantages. In the [10-12] author described the method of differential backup protection and that is much slower and requires the synchronization of data.

However, in this paper the line protection scheme is not discussed. But the modeling aspect of the HVDC for the protection is discussed which will help to improve the protection strategy for the sake of continuity of the supply.

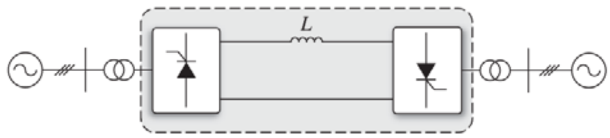

Figure 1 Back to Back Connection of the HVDC link

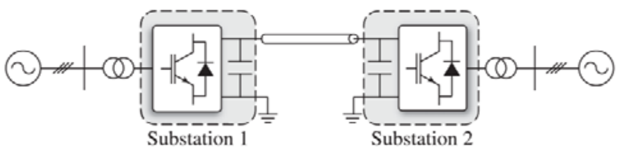

Figure 2 Monopolar Link arrangement of the system

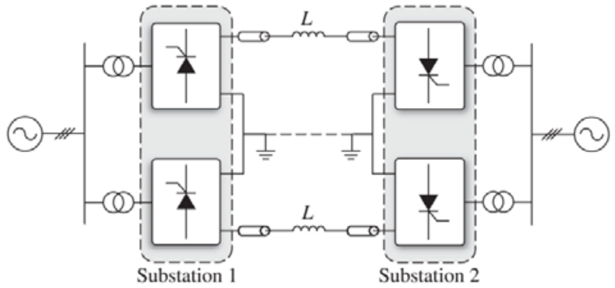

Figure 3 Bipolar Arrangement of the system.

II. HVDC LINE TWO POLE SYSTEM

A typical arrangement of HVDC system with the all unit named is shown in figure 4. While figure1, 2 and 3 shows the different arrangement of the HVDC system. It depicts the double pole arrangement of the power network with the possible fault location named in figure itself. Small unit of capacitor and the inductor elaborates the function of filter. In the arrangement, filters are designed to remove the harmonics and higher frequency components. For a 12 pulse rectification system generally h=12n, harmonic are removed. Where n = 1,2,3,4,. . . while the filters are designed to operate at the 12/24 or 12/24/36 level of frequency for dc filter.

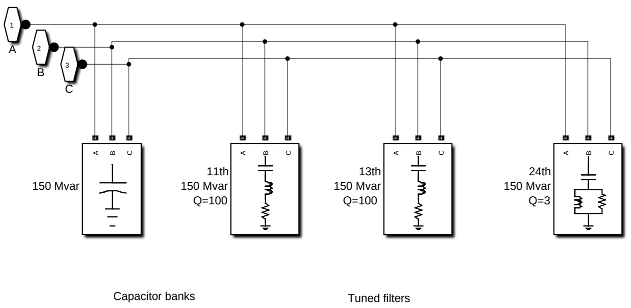

Figure 4 Filter at 60Hz supply End.

In a two pole arrangement the first pole represents the positive DC line while the second pole represents the negative DC line. The scheme is also known as bipolar HVDC line. However, the single pole arrangement is known as the uni-polar HVDC link.

2.1 Rectifier Operation of HVDC Line

In this section rectification operation of HVDC unit is discussed. In rectification process, 12 pulse, 24 pulse and 48 pulse system becoming so modern using Graetz Bridge is shown in fig.2. For 24 and 48 pulse operation the rectification transformer are installed.

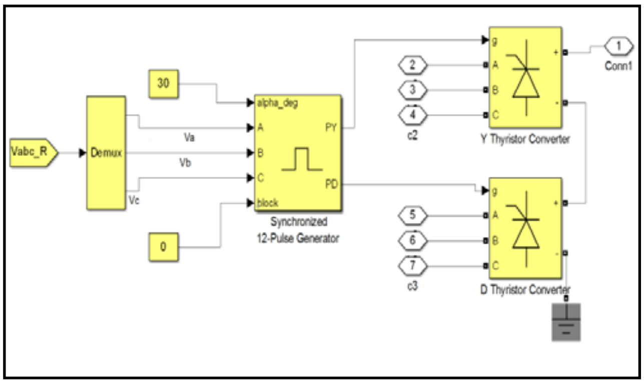

Figure 5 Connection of 12-Pulse Transformer Rectification

Figure 4 represents the converter circuit with the three phase source for rectification.

$$e_a = E_m \sin(\omega t)$$
$$e_b = E_m \sin(\omega t - 120°) \qquad (1)$$
$$e_c = E_m \sin(\omega t - 240°)$$

Equation (1) represents the source with peak magnitude of E_m and phase voltages are placed in space with 120° to each other. In order to rectify the three phase AC two types of rectification comes with the process viz. controlled and un-controlled system. In this paper controlled rectification is used. There are two types of converter for the application as VSC and CSC, generally CSC is used as it has constant current through the line which reduces the line loss, eddy current loss and other components.

For a Valve,

$$V_{do} = \frac{3\sqrt{3}}{\pi} E_m \cos\alpha \qquad (2)$$

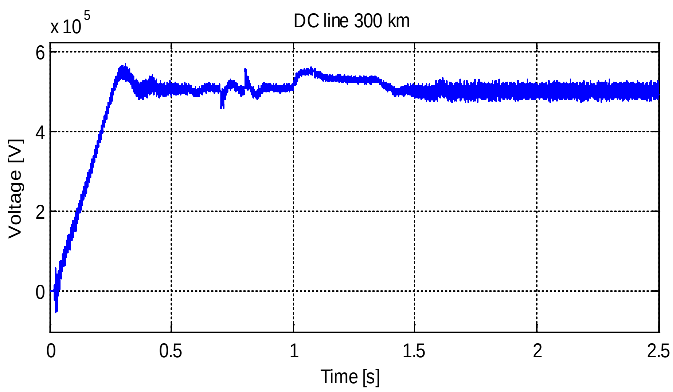

Figure 6 Monopolar HVDC Voltage Level

Where, equation (2) shows the output voltage at the dc terminal. In equation (2) α is firing angle for the valve operation for a three phase system it varies from 0 to 120 degrees.

2.2 Modal Based Transformation

Modal based protection scheme is well developed scheme in the protection of HVVAC system as it has sequence component of the system. In this proposed method local protection of system is not disturbed and does not require any special modification in data acquisition and the system parameter. Using this method a simple directional based protection is employed in the line to obey the system fault and analysis of the current phenomena.

This phenomenon of protection is achieved taking modal transformation of the system.

$$\begin{bmatrix} i_- \\ i_+ \end{bmatrix} = \mathrm{T} \begin{bmatrix} i_{m0} \\ i_{m1} \end{bmatrix}$$
$$T = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (3)$$
$$\begin{bmatrix} i_- \\ i_+ \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} i_{m0} \\ i_{m1} \end{bmatrix}$$

In equation (3) Modal transformation is given for the HVDC system line current.

$$\begin{bmatrix} v_- \\ v_+ \end{bmatrix} = \mathrm{T} \begin{bmatrix} v_{m0} \\ v_{m1} \end{bmatrix}$$
$$T = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (4)$$
$$\begin{bmatrix} v_- \\ v_+ \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} v_{m0} \\ v_{m1} \end{bmatrix}$$

In the equation (4) voltage is given with modal based transformation for the detection of fault in the system.

$$\begin{cases} v_{m0} = \frac{1}{\sqrt{2}}\left(v_+ + v_-\right) \\ v_{m1} = \frac{1}{\sqrt{2}}\left(-v_+ + v_-\right) \end{cases} \quad (5)$$

In equation (5) modal voltage equations are presented in which the bipolar is presented as modal positive and zero sequence components. In subsequent set of equations (6) and (7) in

$$\begin{cases} i_{m0} = \frac{1}{\sqrt{2}}\left(i_+ + i_-\right) \\ i_{m1} = \frac{1}{\sqrt{2}}\left(-i_+ + i_-\right) \end{cases} \quad (6)$$

$$\begin{cases} v_{m0} = \frac{1}{\sqrt{2}}\left(v_+\right) \\ v_{m1} = \frac{1}{\sqrt{2}}\left(-v_+\right) \end{cases} \quad (7)$$

$$\begin{cases} i_{m0} = \frac{1}{\sqrt{2}}\left(i_+\right) \\ i_{m1} = \frac{1}{\sqrt{2}}\left(-i_+\right) \end{cases} \quad (8)$$

2.3 AC Side Protection

For AC side protection a various series of fault can be sensed and a detection signal can be sent to the protection zone.

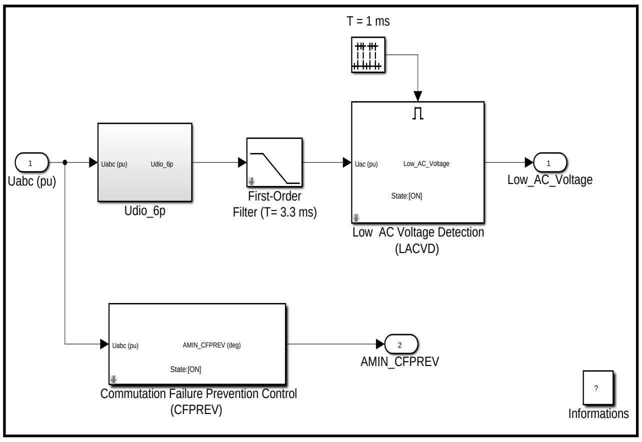

Figure 7 AC Side Protection Technique

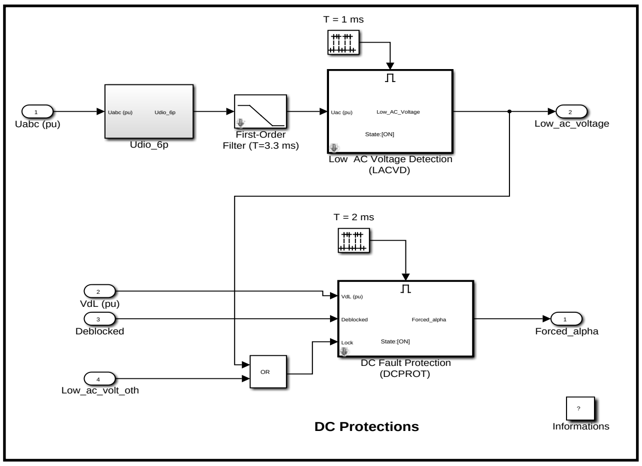

Figure 8 DC side Protection Technique

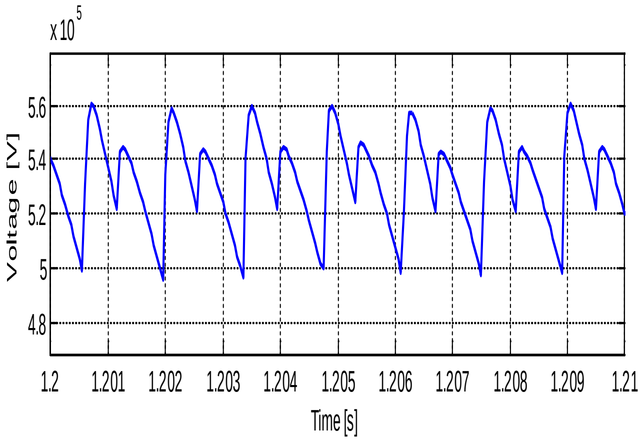

Figure 9 Rectified Voltage at DC rectification End With Ripple

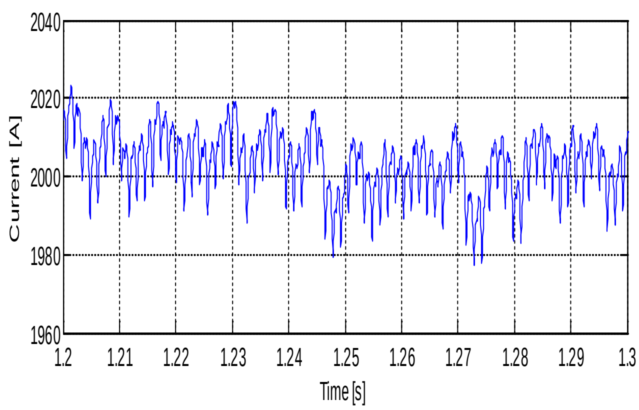

Figure 10 DC Current ripple Current at DC end

2.4 DC Side Protection

For DC side protection various faults as low dc voltage, converter leg fault etc. can occur which need to be removed locally to avoid the measure system breakdown.

In Figure (9) and Figure (10) a waveforms of ripple voltage and currents are shown which are generated at the very end of DC converter to be fed to the link. In the system these ripples are very small and removed by the DC link capacitor at very moment.

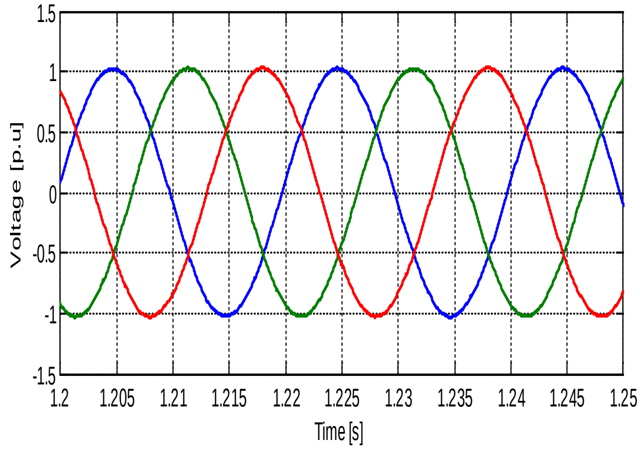

Figure 11 Inverter Output Voltage at Grid End

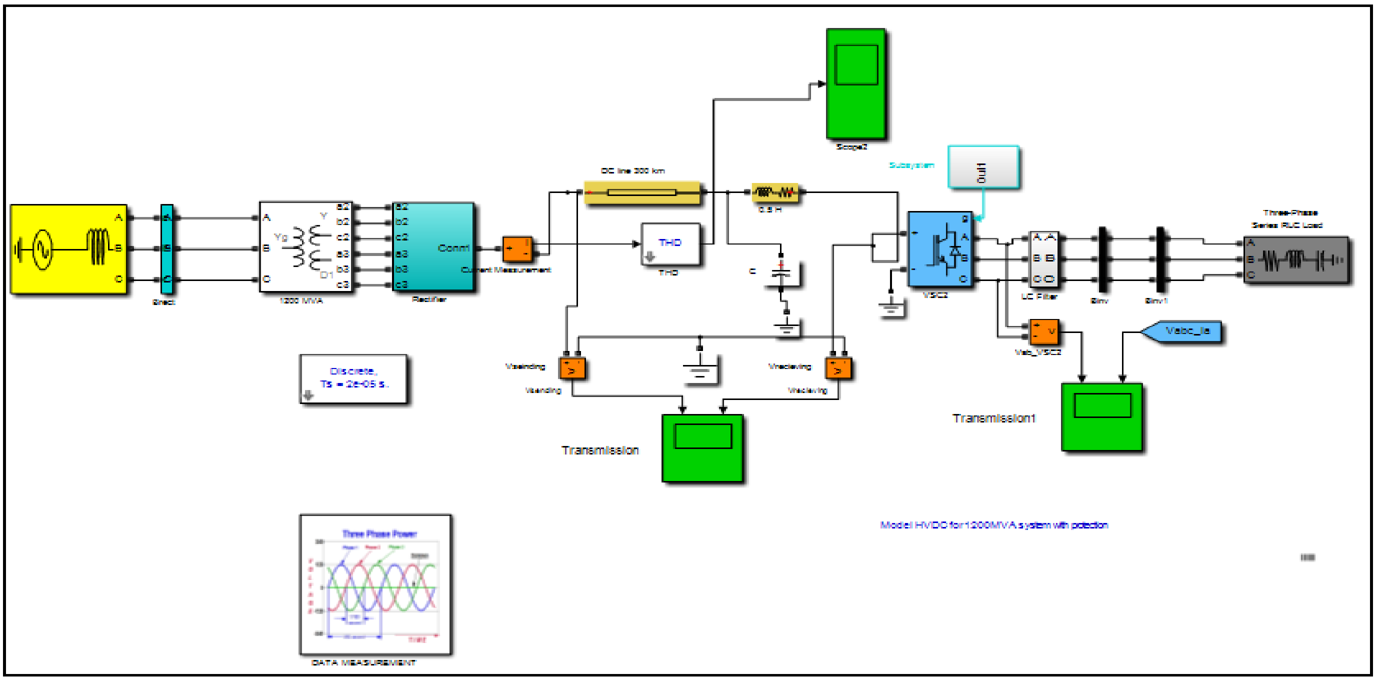

Figure 12 Simulation of Proposed System

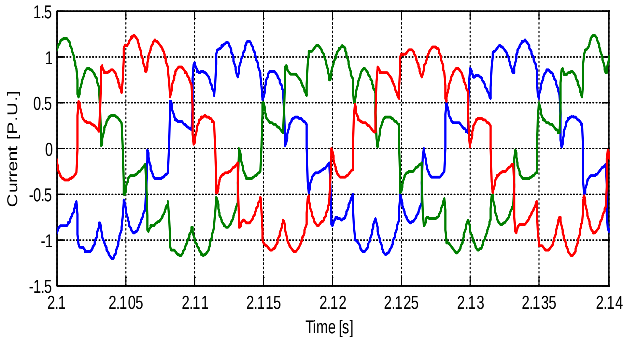

Figure 13 Unfiltered Waveform of Three phase current

Pole to ground fault is simulated using MATLAB as stated earlier. This response is very much transitive and current during the fault draws a large amount of current during the fault.

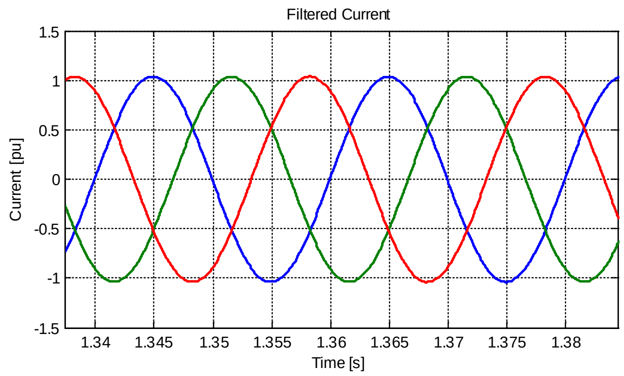

Figure 14 Filtered Current at AC-Grid End.

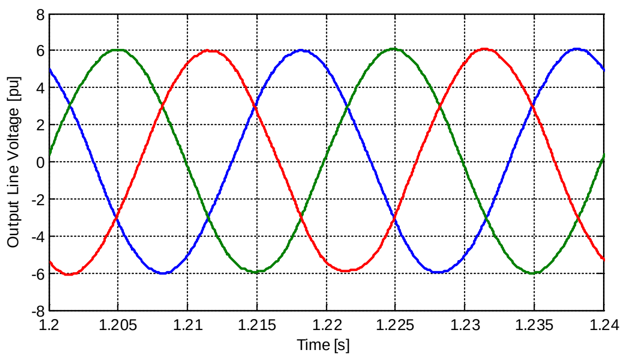

Figure 15 Filtered Voltage Waveform

2.4 PROTECTION STRATEGY

The protection of transmission line is done by the modal transformation and the trip signal for the isolation is generated by the system algorithm. In this work generation of trip signal by using modal transmission is performed successfully in order to protect the system with transients and other conditions.

An extensive study of HVDC system with protection strategies against different type of fault is mentioned. One of the common faults in the system is pole to ground fault. For this type of fault many systems cannot sustained in stability. However, detection of such fault is primary issue for the system operation and to maintain stability.

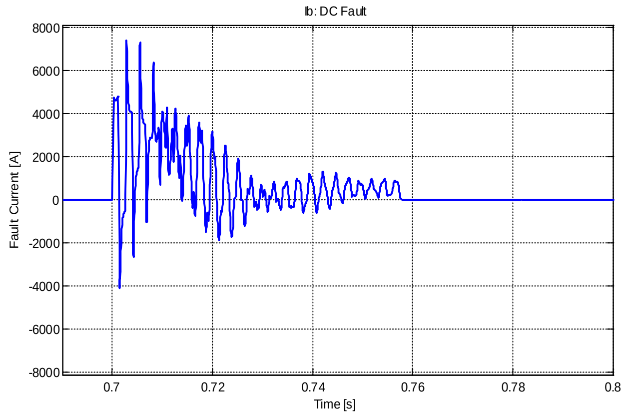

Figure 16 Waveform of fault in the DC Line

Fault is created at pole-to-ground fault and detected as per proposed algorithm. The fault signal is given in figure 16 and it is evident that the value of this fault current increased rapidly in magnitude. While in figure in 17 is provided for the trip signal generated by the system at analysis level. This trip signal is sent to the relay end for the analysis and required action.

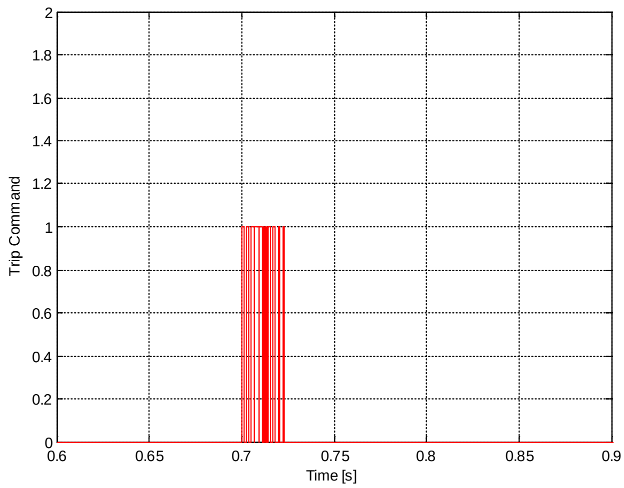

Figure 17 Trip Command for detection of fault.

III. CONCLUSIONS

Based on the present analysis and theories till date and best of our knowledge, a protection scheme is proposed in this work to avoid dc fault level. However, many works has been done and performed to achieve the protection scheme of the HVDC monopolar line with the different operating condition. Although, literature survey have been made to point out their work in field of protection and detection of faults. Proposed method is very simple and requires no additional signal processing term for the same. In this work, method to generate fault at any location is done by the simple simulation of shorting the line with the ground at extreme condition it means for solid grounded fault. In this condition high amount of current is drawn by the sources.

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