Asian Journal of
Computing and Engineering Technology
(AJCET)

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Asian Journal of Computing and Engineering Technology
ISSN 2520-4674 (Online)
Vol.3, Issue 1 No.1, pp 1 - 13, 2023

An Examination of Modelling, Simulation and Detection of Fault Behaviours in HVDC Monopolar System

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Article History

Received 10th January 2023

Received in Revised Form 25th January 2023

Accepted 10th February 2023

Abstract

Purpose: Some previous researchers work on the HVDC Monopolar systems using Matlab/Simulink environment to carry out their analyses. We continue this discussion of Monopolar HVDC systems.

Methodology: The analyses that are carried out include double phase-to-ground fault, single phase-to-ground fault and three phase-to-ground fault at the AC side of the rectifier and the DC line to ground fault.

Findings: It is discovered, among others, that for three phase-to-ground fault, the voltages at the AC side of the rectifier, the DC line voltage and the voltage at the inverter side of the load are completely zero but that the current in the rectifier will increase from its standard value though will be less harmful and the current of the inverter side will decrease from its original value. It is further discovered that the fastest transient will be the case when fault is applied to the DC transmission system and that transmission network is of critical importance in high voltage transmission lines and engineers can also use this result to identify different faults in the transmission lines and the care of power quality is highly important because of electrical energy demand.

Unique Contribution to Theory, Practice and Policy: The current in the rectifier decreases from its standard value but will be less harmful. The causes of decrease in DC transmission line depend on severity of the fault such as single phase to ground, double line to ground and three phase-to ground at the rectifier side.

Keywords: *Fault Analysis, High Voltage Direct Current (HVDC), Rectifier, Simulation.*

Asian Journal of Computing and Engineering Technology
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INTRODUCTION

Some previous researchers work on the HVDC Monopolar systems. For example, (Kumar M., 2011) work on DC link line to ground fault and line to line fault using Matlab/Simulink environment to carry out their analysis. The result shows that the line to ground fault of DC line decreases during the fault and after fault it is hard to rebalance. (Singaravelu, S., & Seenivasan, S., 2014) Too carry out another broad simulation with a proposed model. They study fault recovery and suppression of temporary overvoltage during the various fault conditions such as the three phase AC fault, two phase AC fault, single phase AC fault and DC fault of both side using Matlab/Simulink environment to carry out their research work. The result shows that firefly algorithm based optimal PI controller is good on transient performances.

Gaur, N. *et al*., 2014 also present critical study of faults on Monopolar HVDC transmission line such as line to ground fault on AC side, synchronized and unsynchronized AC and DC faults on the voltage, current and performance of the converter. The model was simulated in Matlab/Simulink environment. In their result, it shows that during faulty conditions the current waveform decreases from its normal value and slight decrease in voltages. Similarly, (Khairnar, A.K. & Shah, P.J., 2014) present transient characteristics of DC line to line fault (LL) of HVDC system. The PSCAD/MATLAB was used to model the HVDC system. In their results the line to line fault leads to unstable of DC voltage which is hard to balance again.

In HVDC Monopolar system, (Bertinato Alberto *et al*., 2019) simulate a pole to ground fault on a DC link which results to a low steady state DC fault current and further discovers to have a healthy pole it involves large overvoltage. In addition to their work, they also propose a new strategy of fault protection in HVDC grids. Authors such as (Wang Mian *et al*., 2019) focus on pole rebalancing in Monopolar HVDC of DC side. In their paper, they propose post-fault restoration and fault clearing for pole rebalancing in order to deal with DC faults that result to pole-to ground fault. The test is carried out using one of the popular software which is PSCAD/EMTDC. (Shi X. *et al*., 2015) present the analysis and control of multilevel modular converter based HVDC transmission system under the three possible single lines to ground fault conditions, with the special focus on the investigation of their different fault characteristics. In this paper, we want to continue the discussion of Monopolar HVDC system. We present a source and its load of HVDC system using Matlab/Simulink environment to differentiate fault conditions when fault is applied at the AC side of the rectifier and their effect on the DC line and at the inverter side of the load.

Monopolar HVDC System Components

Diode

A diode is one of the semiconductor devices that can be regulated or controlled by its own current and voltage. When the diode occurs in voltage biased across it, it starts to conduct but if the current flow turns off into the device which changes to zero state. In order to accomplish the required output DC voltage, the diode that are six in numbers, are arranged in series. RC snubber circuit is very important in order to protect it from unstable state or transient and high recovery voltage (Mohan N. *et al*., 2003).

Three Phase Converter

The conventional line commutated converter of the diode valves requires a voltage source in order to confirm commutation. Commutation can be defined as the movement of current from one phase to another in connection with the diode valve. The fundamental block for the three phases is the Graetz Bridge (see figure 1.0). When execution occurs the current Id flows through the diode of T1, T3 and T5 (at the up group) and T2 T4 and T6 (at the down group) (Kim, C. K *et al*., 2009).The current will occur naturally from one diode to another.

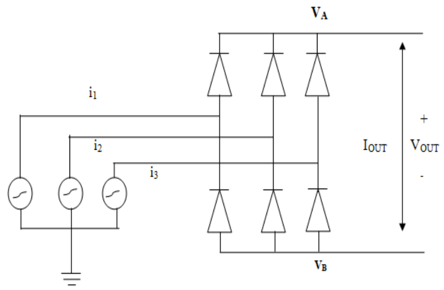

Figure 1: The Diode Arrangement with 6-Pulse Graetz Bridge

Let us consider that the rectifier is provided from a three phase voltage system.

The mathematical formula is expressed as given in equation 1-4

$$V_1 = V_m \cos(w_0 t) \dots \dots \dots \dots Equation(1)$$

$$V_2 = V_m \cos\left(w_0 t - 2 * \frac{pi}{3}\right) \dots \dots \dots \dots Equation(2)$$

$$V_3 = V_m \cos\left(w_0 t - 4 * \frac{pi}{3}\right) \dots \dots \dots \dots Equation(3)$$

The amplitude V_m of the three phase voltage equal

$$V_m = V_{p(rms)}\sqrt{2} \dots \dots \dots \dots \dots Equation\ (4)$$

Where

$V_{p(rms)}$: is the root mean square value

The DC output voltage

$$V_{out} = 3\frac{\sqrt{3}}{pi} V_m$$

For the input current I_{rms} the formula can be expressed as

$$I_{rms} = \frac{\sqrt{6}}{3} I_{out}$$

The power output of the rectifier output,P_{out}

$$P_{out} = V_{out} I_{out} = 3\frac{\sqrt{3}}{pi} V_m I_{out} = P_{in}$$

Converter Transformer

The transformer is placed at the central point to link the AC network of both ends with the universal bridge. The converter transformer is the most significant component. In the three phase arrangement and single phase arrangement, the converter transformer uses either of the two arrangements. However, for the six-pulse converter, the approved model conformation of the converter banks can be three-phase/two winding transformer and one-phase/ two winding transformer (Carlson, Ake & Ludvika Sweden, 1996)

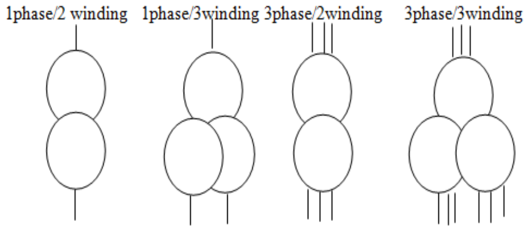

Figure 2: The Transformer Types

Passive AC Filters

In recent times, power Electronic Devices (PED) like Silicon controlled Rectifier (SCR), Insulated Gated Bipolar Transistor (IGBT) and diode are generally used .Nevertheless, the nature of the efficacy causes a non- sinusoidal wave from the supply. The major sources of voltage and current harmonics are from arc furnaces, magnetic core and power electronic device. Harmonic is a big problem in the power system and it wastes valuable energy Passive filter is the most or effective and simplest way to eliminate unwanted signal in the system (Anooja, C. L. & N. Leena, 2013)

The conventional passive filters are:

- tuned filters
- high-pass filters
- multi-tuned high-pass filters

Filter Calculation

To calculate the capacitor in the given filter

Current in the capacitor I_c **;**

$$I_c = \boldsymbol{Q_c}/\boldsymbol{V}$$

Where

$\boldsymbol{Q_c}$ =Reactive power of the capacitor and

Capacitance reactance ($\boldsymbol{X_c}$) is given as

$$X_c = \frac{1}{2*pi*f*C}$$

Required capacity of capacitor in farads/microfarad

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$$C = \frac{K_{var}}{2 * pi * f * V_2}$$

Required capacity of capacitor in K_{var}

$$K_{var} = \frac{C}{2 * pi * f * V_2}$$

To calculate the inductive reactance (X_l) and inductance (L) at the fundamental frequency

$$X_l = \frac{X_c}{N}$$

$$X_n = \sqrt{(X_l * X_c)}$$

To calculate the resistance (R) .the range of the Q is selected by any value. It can be set to either 100, 50 e.t.c

$$R = X_n/Q$$

Where

N= is the harmonic order

R=resistance

X_n= characteristics reactance

Q= quality factor

Band-pass filters or Turned filters are put to use to remove several harmonic frequencies. An inductor, capacitor and a resistor in series are used to construct the filter. The above filters mentioned are used to remove 5th, 7th, 11th and 13th harmonics. The high pass filter can be used to remove 12th and 24th harmonic distortion. The high pass filter is constructed with a resistor paralleled to an inductor.

Model of Monopolar HVDC System in Matlab/Simulink Environment

Table 1: Model Specification of Monopolar HVDC System

Component	Rectifier Side	Inverter Side
Source	Voltage=25KV Frequency=60Hz Power=1000MVA	
Filters	Capacitor Single tuned filter C-type filter	Smoothing reactor L=0.015751 C=0.0000041
Transformer	V_{sec}=25KV Norminal power=50KVA	
Load		Voltage=440V Power=5KW

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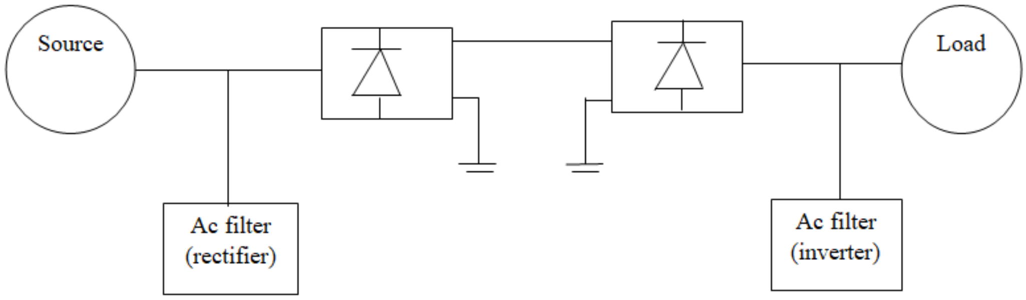

Figure 3: Model of Monopolar HVDC System

Table 3: Fault Conditions Are Carefully Considered

Type of fault	Time (s)
Three phase to ground fault (Rectifier)	0.4 – 0.6
Double phase to ground fault (Rectifier)	0.4 – 0.6
DC link	0.4 – 0.6
Single phase to ground fault (Rectifier)	0.4 – 0.6

Steady State of High Voltage Direct Current (HVDC)

In this behavior, fault was not applied. It is normal when transient occur at the start of the system but balances out. In this our simulation AC source and DC link were simulated. The figures are shown in figure 4a, figure 4b and figure 4c. During the simulation per unit (p.u) was used at both ends excluding the DC transmission line throughout the output result.

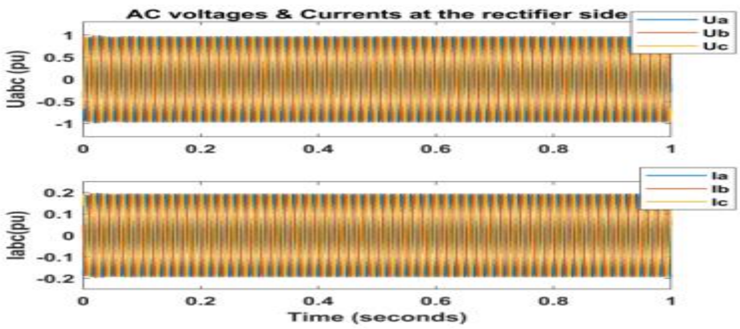

Figure 4(a): Simulation Result for AC Voltages and Currents during Without Fault at the Rectifier Side

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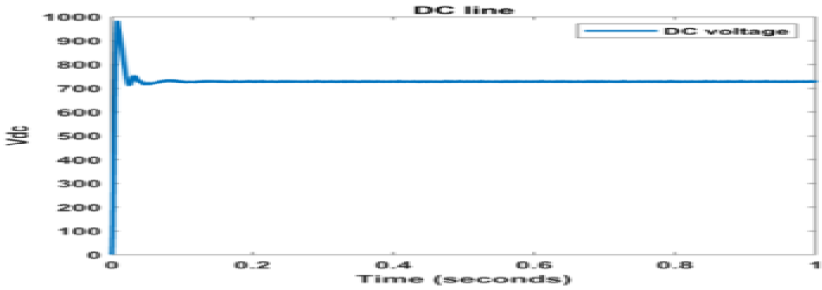

Figure 4(b): Simulation Result For Dc Voltage during Without Fault

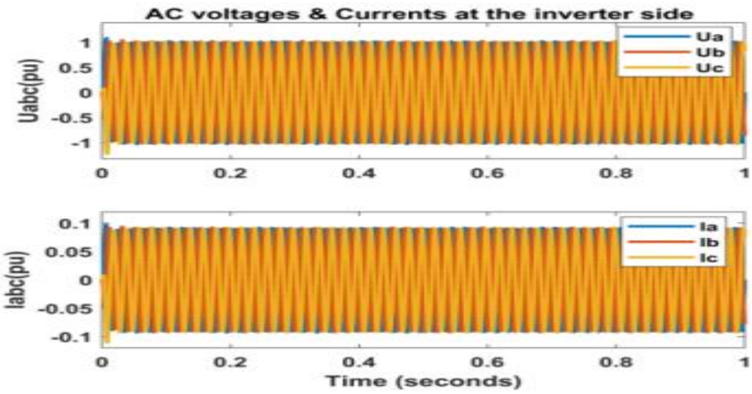

Figure 4(c): Simulation Results for AC Voltages and Currents at the Inverter Side during Without Fault

High Voltage Direct Current Fault Simulation to Predict Actual Behaviour

The leading importance of this paper is to distinguish different fault conditions when it is applied at the AC side of the rectifier and their behavior on DC line and at the inverter side of the load. In this part, it is highly necessary for the engineers to identify the appropriate fault in HVDC power system transmission lines for quick repair so that it can goes back to its continuous steady state.

Three-Phase to Ground Fault (Rectifier)

Three-phase ground (LLLG) fault at the rectifier is simulated during the period of 0.2s. The three-phase to ground fault is a degree or a fault that does not occur often. The LLLG fault is a balanced system that is achieved without few difficulties to explain. When the LLLG take place, the 3-phase voltages go to zero where the fault has occurred and the three-phase AC currents is also affected with the false low waveforms of 0.09742 both are shown in figure 5a. The DC voltage and three phase currents at the inverter side go to zero are shown in figure 5b and 5c.

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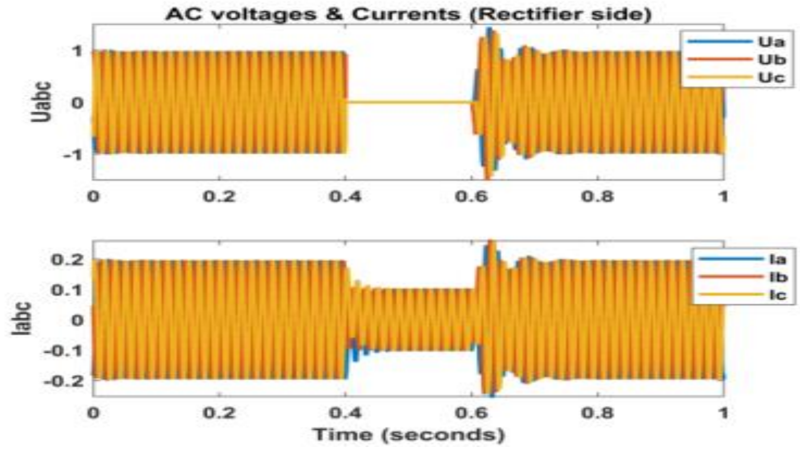

Figure 5(a): Simulation Result for AC Voltages and Currents at Rectifier during LLLG Fault

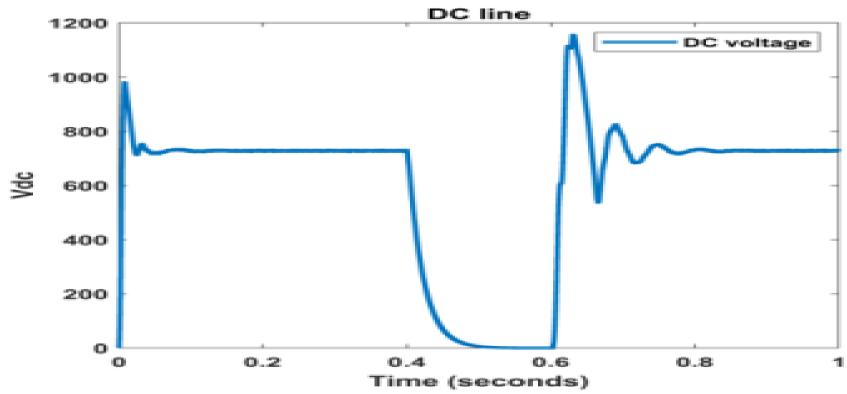

Figure 5(b): DC Voltage during LLLG Fault at the Rectifier

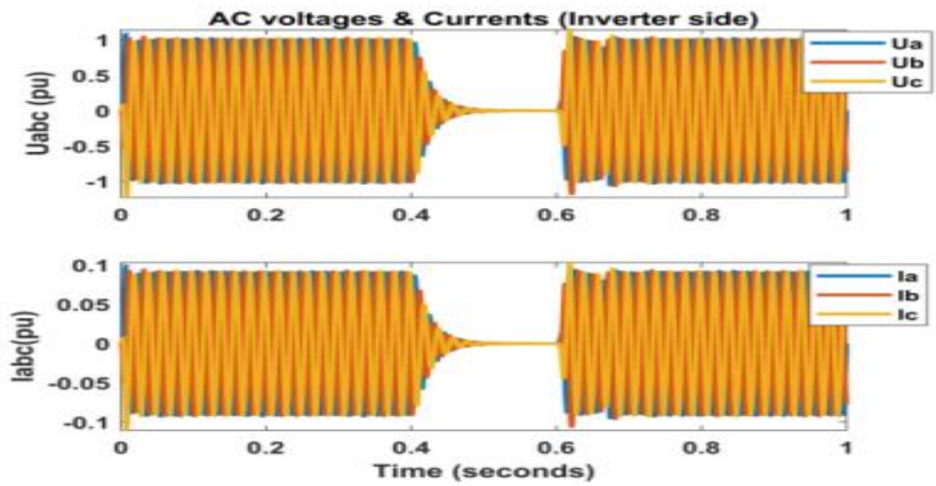

Figure 5(c): Simulation Results for AC Voltages and Currents at Inverter during LLLG Fault at the Rectifier Side

Double Phase to Ground Fault (Rectifier)

During double phase to ground (LLG) fault, two phase voltages are unbalanced. The phase voltage A and phase voltage B will become zero and the currents are affected with decrease in low waveforms of 0.09527 which both are shown in figure 6a. The DC link voltage experience decrease in value of 453.8 as shown in figure 6b. At the inverter side, both the three phase voltages and three phase currents have a decrease in waveform with the value of 0.6739 and 0.06062 are shown in figure 6c.

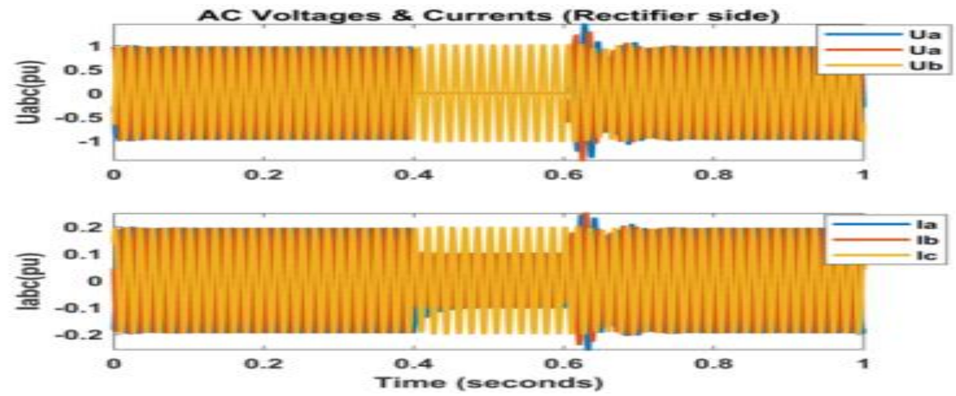

Figure 6(a): AC Voltages and Currents during LLG Fault at the Rectifier

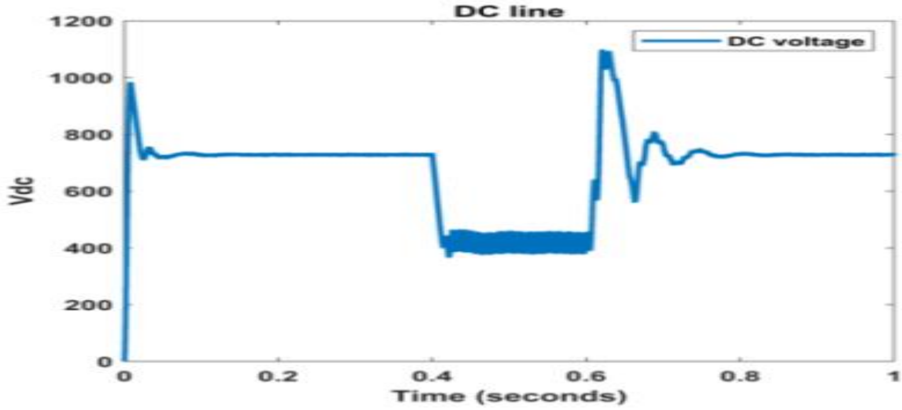

Figure 6(b): DC Voltage during LLG Fault at the Rectifier

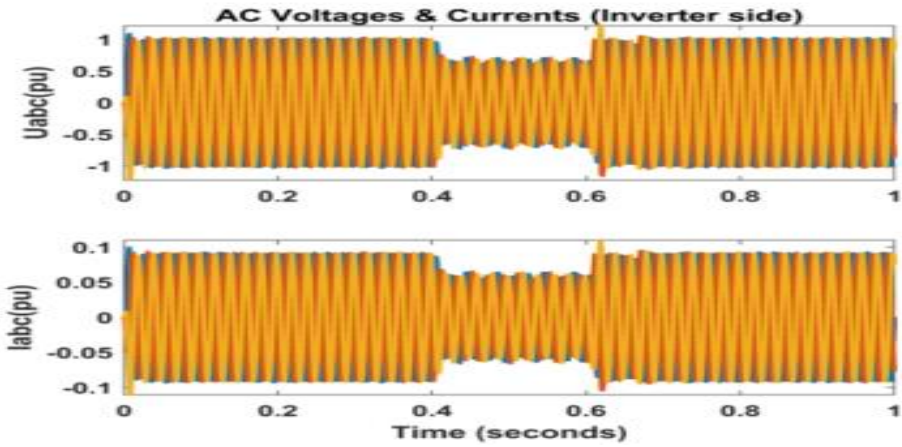

Figure 6(c). AC Voltages and Currents at Inverter during LLG Fault at the Rectifier Side

DC Link Fault

The fault event in the HVDC transmission line and the timing are given in table number (see table 2). The regular faults in the DC link transmission are single line to ground (LG) fault and line to line fault. As the fault in the link is normally brought about by outer mechanical anxiety along these lines, the faults usually last for long repair and repair is considered. For the overhead line, the shortcomings are caused by lightning strikes and pollution. Therefore, during the fault, the DC voltage will decrease which is shown in figure 7a. At the source side, there is slight increase in three phase voltages with the value of 0.9981 and the currents also experience slight increase waveform with the value of 0.197 which are shown in figure 7c. At the load side for both voltages and currents, the shape of the three phase waveforms is like a mouth of a silent pistol with the value of 0.8593 and 0.08188 are shown in figure 7b.

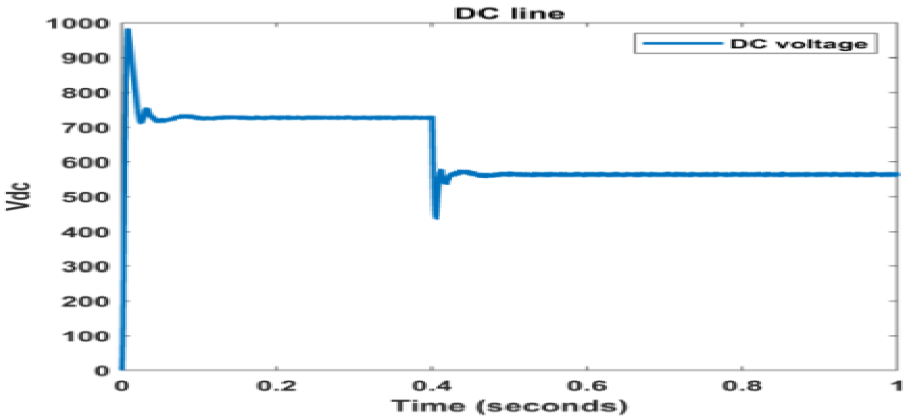

Figure 7(a): DC Voltage during DC Line to Ground Fault at the Rectifier

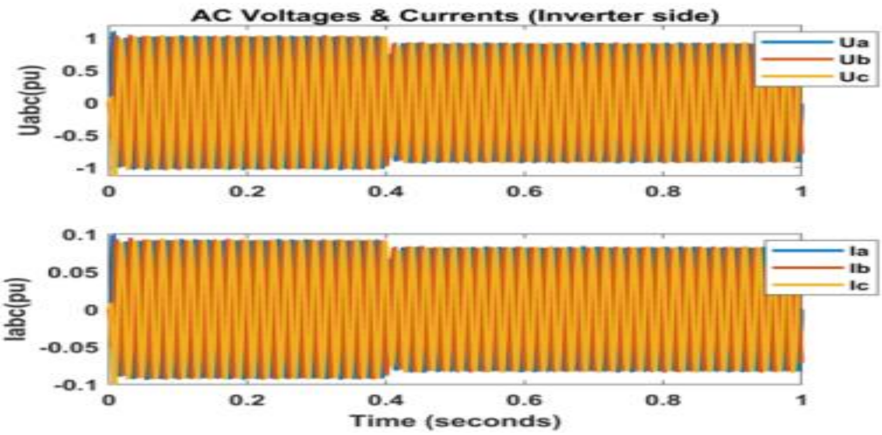

Figure 7(c): AC Voltages and Currents at Inverter during DC Line to Ground Fault

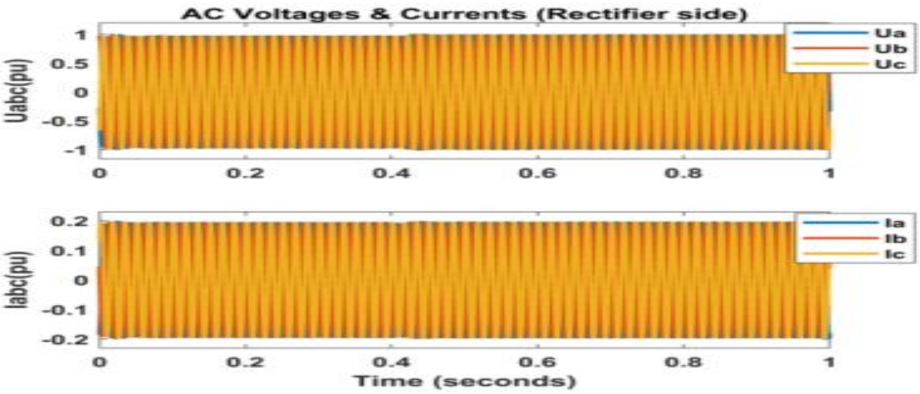

Figure 7(c): AC Voltages and Currents at Rectifier during DC Line to Ground Fault

Single Phase to Ground Fault (Rectifier)

The LG fault at the rectifier is applied in the system. A LG fault is made for 0.2s at the rectifier side. The LG fault is a regular kind of fault in the power system which changes the AC voltage and current. During the fault, the voltage phase A will collapse to zero and the other phases will maintain a standard sinusoidal waveform and the current will have a false waveform with the value of 0.09666 are shown in figure 8a. Meanwhile, the DC line will be affected with decrease in sinusoidal waveform of 564.9 as shown in figure 8b. The receiving end will be affected having decrease waveforms during a short period for both three phase voltages and three phase currents with the value of 0.9274 and 0.08214are shown in figure 8c.

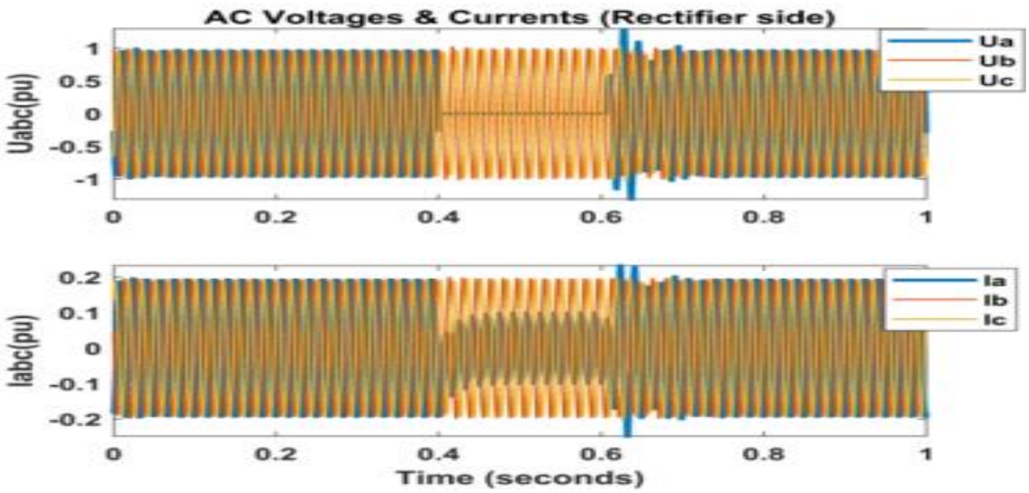

Figure 8(b): AC Voltages and Currents during LG Fault at the Rectifier

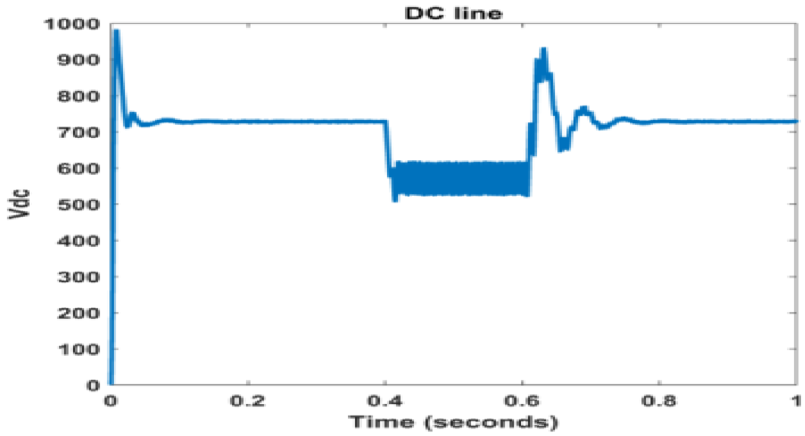

Figure 8(b): DC Voltage during LG Fault at the Rectifier

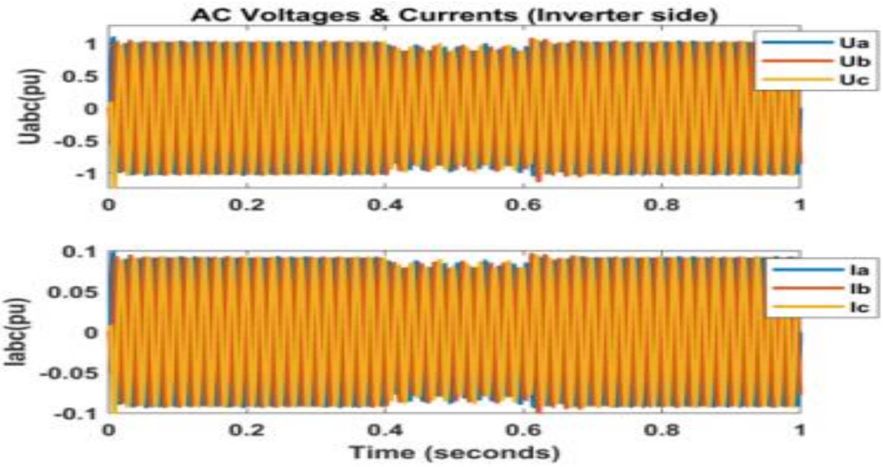

Figure 8(c): AC Voltages and Currents at Inverter during LG Fault at the Rectifier Side

CONCLUSION AND RECOMMENDATIONS

In this paper, we model a source and its load of HVDC Monopolar system using Matlab/Simulink environment. The analyses that are carried out include double phase-to-ground fault, single phase-to-ground fault and three phase-to-ground fault at the AC side of the rectifier and the DC line to ground fault. For three phase-to-ground fault, the voltages at the AC side of the rectifier, the DC line voltage and the voltage at the inverter side of the load are completely zero.

However, the current in the rectifier will decrease from its standard value but will be less harmful. We further argue that the causes of decrease in DC transmission line depend on severity of the fault such as single phase to ground, double line to ground and three phase-to-ground at the rectifier side. Finally, the fastest transient will be the case when fault is applied to the DC transmission system. Therefore, we are of the opinion that transmission network is of critical importance in high voltage transmission lines and engineers can use this result to identify different faults in the transmission lines and the care of power quality is highly important because of electrical energy demand.

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