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A Modelling of 500 Kv Long Transmission Line and Fault Detection Using Inverse Definite Minimum Time Over Current (IDMT O/C) relay

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ABSTRACT

As electricity demand increases day by day due to economic growth, the process of transmitting efficient electrical power is vital. Thus, a power simulation study is required to determine the mechanism of the transmission line, and possible faults that occurred in the transmission line system. On a daily basis, single line to ground fault (L-G), double line to ground fault (2L-G), and triple line to ground fault (3L-G) are the faults that normally occur in the long transmission line system. In this project, a model of a 300km/500 kV EHV transmission line consisting of a three-phase source, distribution line, and load is simulated using MATLAB software. When the L – G fault is applied, the voltage is diminished to zero and upon fault clearance, the R – G line produced overvoltage and overcurrent by 518.9 kV and 1889 A, which increased about 46.83% and 15.67% compared to normal lines of Y – G and B – G at 353. kV and 1633 A. Then, for the 2L – G fault, again the voltage is reduced to zero and when fault clearance occurred, the R – G and Y – G lines experienced overvoltage and overcurrent at 570.4 kV and 708.5kV, which showed more than 60% transient compared to normal line B-G at 353.4 kV. In Contrast, the 3L – G fault causes all transmission lines to experience overvoltage and overcurrent at different times and can damage the whole transmission system. Thus, to reduce the severe impact of fault, the Inverse Definite Minimum Time Over Current (IDMT O/C) relay protection is installed in the line model.

Keywords: Faults in transmission line; Extra High Voltage (EHV); Simulink/MATLAB; IDMT O/C.

INTRODUCTION

Faults are common incidents in transmission lines, and it normally occurs when one or more transmission line conductors contact either each other or with the ground. The line-to-line fault (L-L), the line-to-ground fault (L-G), double line to ground fault (2L-G), triple line to ground fault (3L-G) are the different fault locations and may occur on the long transmission line (Afrasiabi, S et al. 2022; Chavez, J et al. 2021 & Shakiba, F et al. 2023). Some other common faults are caused by lightning strikes on towers or conductors, which cause voltage build-up and may result in a voltage flash-over (Heidler, F. H. et al. 2022). These incidents will cause a reduction in the percentage efficiency of the transmission line system. At the same time, the voltage regulation of the system may be affected. Therefore, it is very important to have a reliable protection system to detect any faults in the power system. Computational technology and software advancement have brought benefits to power system studies. Operational architecture, detection, and analysis of power transmission lines and distribution systems can be done by simulating the design using available electrical software such as PSCAD and MATLAB (Mohseni-Bonab, S. M. et al 2020). The used of MATLAB in this research are due to real-time identification and localization of line faults for power networks to detect line fault along the transmission line such a determination of line current, bus voltage, and reactive powers to develop a better protection system.

Faults can cause immense transient currents, which are capable of damaging transformers, generators, and other equipment along with the transmission line systems. If not cleared within a specific time interval, fault may lead to power system instability (Alimi, O. A. et al 2020 & Hernández-Mayoral et al. 2023). Study on detection of different faults on the long transmission line of 300km/500 kV is possible to find the properties of traveling waves on EHV during the transient. The line-to-line fault (L-L), single line to ground fault (L-G), double line to ground fault (2L-G), and triple line to ground fault (3L-G) are the four types of faults that may occur in EHV transmission line (Velpula, R., Reddy, et al. 2023). Previous researchers have studied line faults in a different location, however, there is a lack of study in the determination of the effect of fault to voltage and current waveform on the long 500 kV EHV transmission line. The findings in this work can help the researcher to select a suitable protection device such as a circuit breaker to minimize the losses by the fault.

Based on the previous study, the analysis of the EHV transmission line was done by using Simulink software to observe fault location, detection, and classification (Raval, P. D. et al 2020 & Shingare, S. S., et al. 2022). The paper focuses on the different types and locations of the faults, where the researchers studied fault location at the middle of the EHV transmission line and include study of using overcurrent relay (Ji, L., et al. 2020, Rojnić, M. et al. 2022 & Atsever, M. B 2021)

This project is focusing on modelling the 500 kV EHV long transmission line system and determines the receiving-end voltage (VR), receiving-end current (IR), real power (P), reactive power (Q), apparent power (S) at the receiving-end bus by using Simulink. The effect of different fault lines along 500 kV/300 km EHV long transmission lines also will be observed in this project based on the voltage and current waveform. This project proposed suitable protection devices and optimal placement to protect from damage (Ghotbi Maleki, et al. 2020)

METHODOLOGY

This project has three parts. First is modelling the 500 kV/300 km EHV Long Transmission Line in Simulink. Next, this project will be continued with the involvement of the fault at successful model of the EHV long transmission line. The study of fault location and classification. Lastly, this simulation will include overcurrent relay protection at the EHV long transmission line after a fault occurs.

MODELLING OF 500 KV EHV TRANSMISSION LINE IN SIMULINK

This project begins with the modelling of a 500 kV EHV long transmission line with 300 km in distance in Simulink as shown in Figure 1. The overall parameters used for modelling the 500 kV/300 km EHV long transmission line with 300 km in distance were recorded in Table 1.

TABLE 1. Network of 500 kV/300 km EHV long transmission line parameters.

Parameters	Value
Source VLL (V)	617,530
Load VLL (V)	500,000
Load Active Power, P (W)	800,000,000
Load Reactive Power, Q (var)	600,000,000
Line Length (km)	300,000

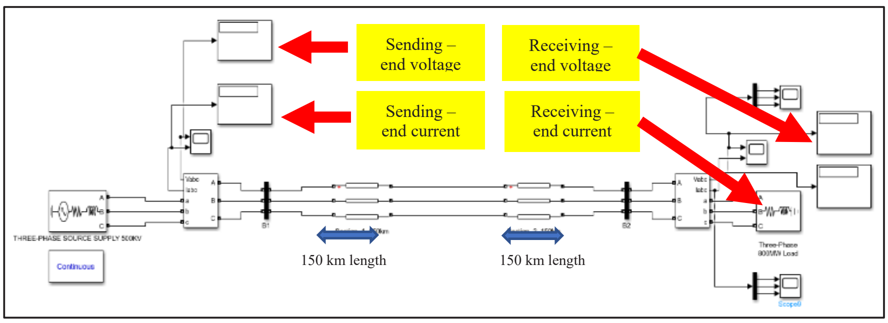

FIGURE 1. Model 500 kV/300 km EHV Long Distance Transmission Line in SIMULINK.

After the model of 500 kV/300 km EHV long transmission line was built, the voltage (V), current (I), real power (P), and reactive power (Q) of the system will be generated using Simulink. At this stage, the power at sending – end bus and receiving–end bus without disturbance was recorded.

TRANSMISSION LINE FAULT IDENTIFIED AND ANALYSIS

The fault will be located at the mid-point EHV transmission line as shown in Figure 2. Three types of faults will be studying in this project namely single line to ground fault (L – G), double line to ground fault (LL – G), and three-phase to ground fault (3L – G). Then, the observation of voltage and current waveform at receiving bus will be recorded. The analysis of voltage and current waveforms was done to detect the overcurrent or overvoltage that occurred in the transmission line model. The procedure will start with the analysis of the L – G fault. The analysis of voltage and the current waveform is done after the L – G fault is applied. The maximum voltage and current after fault incident are recorded to detect the location of the fault in EHV long transmission line. After the analysis and observation of single line to ground fault L – G fault is done, the procedure is continued LL – G Fault and 3L -G. The same analysis was done as in L – G fault observation.

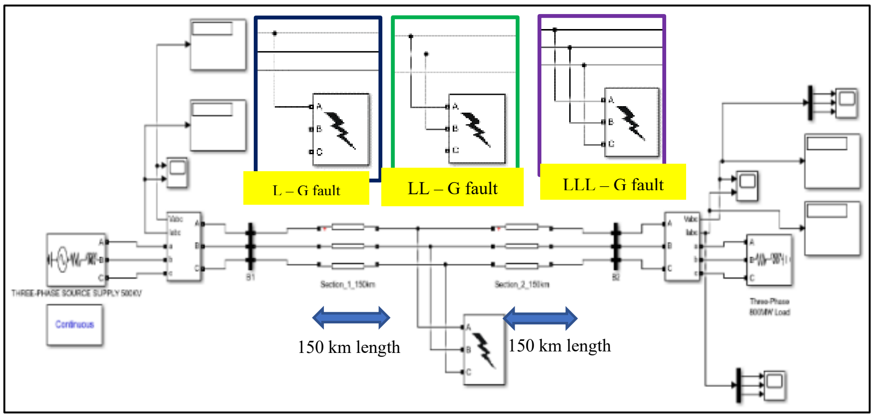

FIGURE 2. Model 500 kV/300 km EHV Long Distance Transmission Line with Fault Application in Simulink.

PROTECTION DEVICE

To protect the transmission line from damage, the device protection relay will be placed on the transmission line. The design is based on selectivity, reliability, speed, and sensitivity to reduce the fault impact along the transmission line. At this stage, an IDMT O/C relay will be used and connected to the circuit breaker. Figure 3 shows a successful connection between IDMT overcurrent relay protection on the transmission line together with the fault, where IDMT O/C works as a protection relay for the lines.

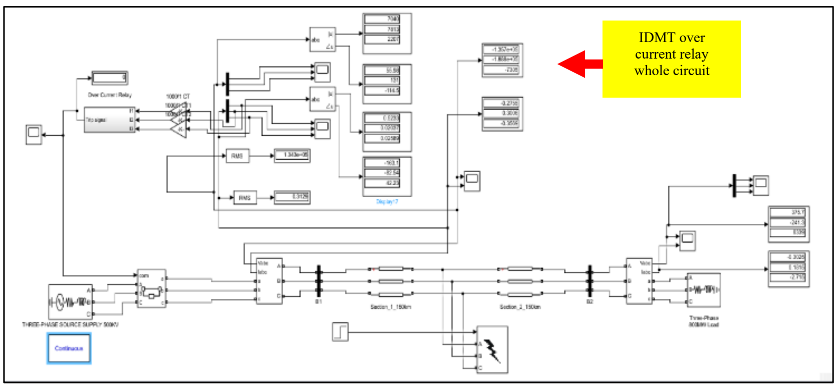

FIGURE 3. Model 500 kV/300 km EHV Long Distance Transmission Line with the application of Fault and IDMT Overcurrent Relay Protection

The IDMT O/C relay will send the signal to the circuit breaker to trip the system if the system is experiencing an overcurrent. The transmission line protection will close, and it will show "1" to notify the overcurrent relay protection is not active since there is no overcurrent triggered the relay protection. The fault applied at 0.1 s causes the circuit breaker to open, then the IDMT will detect the current when it exceeds the current limit in the relay subsystem (Saldarriaga-Zuluaga et al. 2021).

RESULTS AND DISCUSSION

The analysis of L – G, LL – G, and LLL – G faults was described in this section. The waveform of voltage and current are studied to detect the fault occur at each location. Then the output voltage and current waveform were studied to see the function of IDMT O/C relay protection to the 500 kV/300 km EHV long transmission line.

500 KV/300 KM EHV LONG TRANSMISSION LINE

The model of a 500 kV/300 km EHV long transmission line is built successfully in Simulink. The value of parameters, voltage (V), current (I), real power (P), and reactive power (Q) was measured at the sending – end and receiving end – end of the transmission line. All parameters were recorded in Table 2.

TABLE 2. Parameters of model 500 kV/300 km EHV long transmission line.

PARAMETERS	Sending- end Bus	Receiving – end Bus
Voltage (V)	356,500	500,000
Voltage phase angle (°)	16.1	30.0
Current (I)	902.6	1155
Current phase angle (°)	17.91	36.88
Real Power, P (W)	445,900,000	800,000,000
Reactive Power, Q (var)	334,400,000	600,000,000

Table 2 shows the sending–end bus parameters such as voltage, current, phase angle, P, and Q are smaller compared to receiving–end bus. The voltage and current at receiving end are higher at 40.44% and 27.96%, respectively compared to sending end. This happened due to the injection of reactive current by capacitors into the transmission line. As a result, the phasor of currents from the sending–end bus and the reactive current would make the receiving–end current higher than sending ending. This phenomenon is known as the Ferranti effect (Azeredo, L. F. et al.2023 & Kashef, H. H. et al. 2023), since the model is built using the inductance and capacitance, there is an interaction between the inductance and capacitance along the transmission line. This phenomenon is assumed as a reasonable incident, and it only happened in long-distance transmission lines.

VOLTAGE AND CURRENT WAVEFORM WITHOUT FAULT (HEALTHY CONDITION)

At first, the model of a 500 kV/300 km EHV long transmission line was simulated without fault and operated with balanced input. Figures 4 and 5 (a) and (b) shown the output voltage and current flown at the receiving end of the 500 kV/300 km EHV long transmission line were normal and balanced. In addition, there was no overcurrent or overvoltage generated in both waveforms as there is no fault along the EHV long transmission line that can rise either the voltage or current.

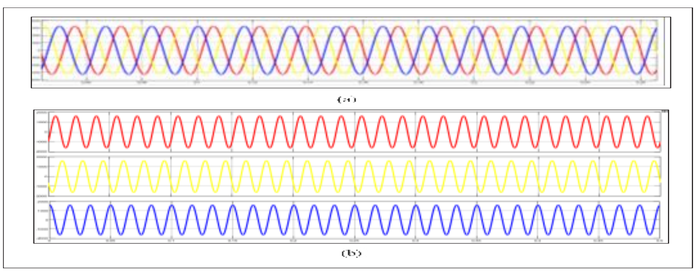

FIGURE 4. (a) Output voltage waveform (b) R – Y – B output voltage waveform without fault

The waveform of Figure 4 and Figure 5 were analyzed at the receiving end of the EHV long transmission line. The output shows the normal and balanced value of the voltage and current as the fault does not occur along the transmission line. Thus, there is no overcurrent or overvoltage shown in both waveforms.

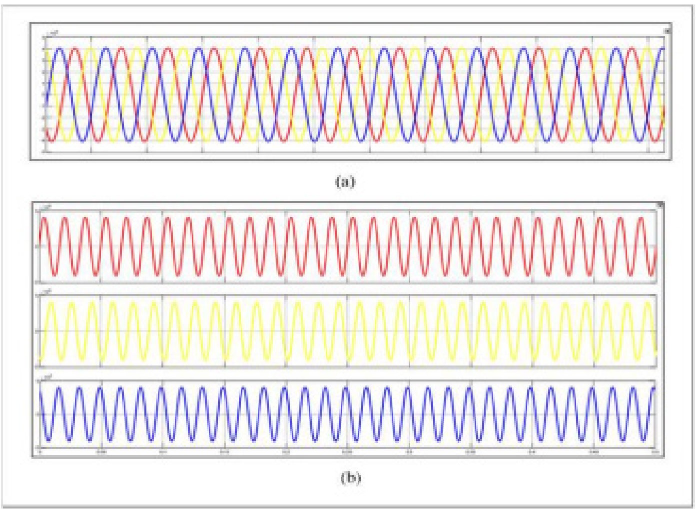

FIGURE 5. (a) Output current (b) R – Y – B output current without fault

SINGLE LINE TO GROUND FAULT (L – G FAULT)

Voltage on faulty stage of R-G lines is diminished and decreased to zero as shown in Figure 6. The voltage of defective stage moreover shoots at the time of clearance of fault at 518.9 kV (t = 0.089 s) compared to Y – G and B – G at 353.4 kV where both lines were operated at normal condition as presented in Table 3. Due to fault, an overcurrent had occurred at R – G lines at 15.67% compared to Y – G and B – G lines at the time of clearance of the fault as shown in Table 4 and Figure 7. The waveform shows in Figure 7 shows an abnormal transient has occurred at the Red -phase while Yellow – phase and Blue - phase shows the normal wave.

TABLE 3. Maximum peak value of voltage (kV).

Phase	Value (kV)	Time (s)
R - G	518.9	0.089
	504.1	0.086
	494.6	0.086
Y - G	353.4	Normal
B - G	353.4	Normal

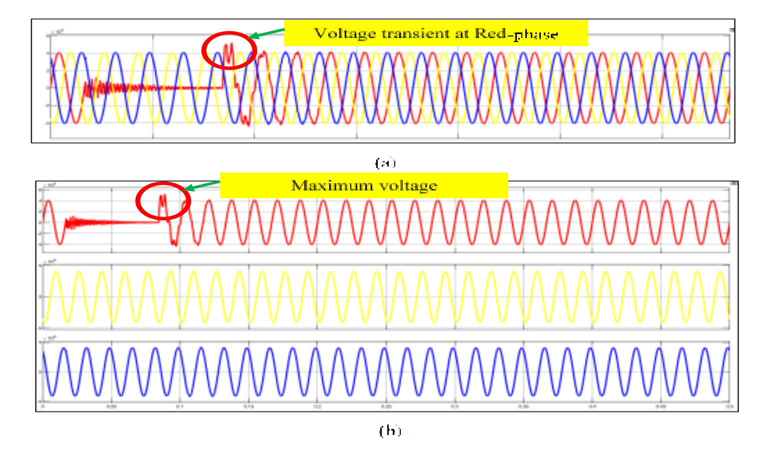

FIGURE 6. (a) Output voltage (b) R – Y – B output

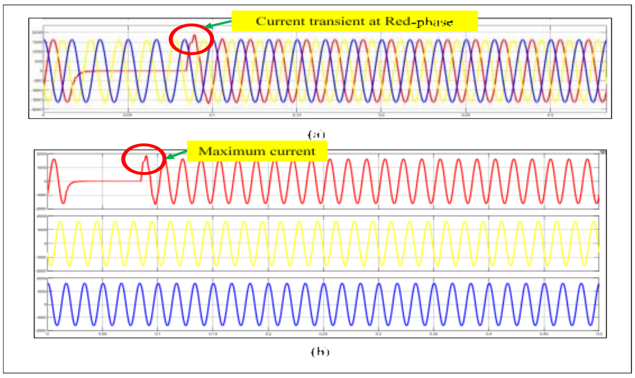

FIGURE 7. (a) Output current (b) R – Y – B output current voltage L-G fault L - G fault

TABLE 4. Maximum peak value of current (A).

Phase	Value (A)	Time (s)
R - G	1889.0	0.090
	1680.0	0.106
	1644.0	0.123
Y - G	1633.0	Normal
B - G	1633.0	Normal

DOUBLE LINE TO GROUND FAULT (2L -G FAULT)

Figure 8 shows the voltage in both stages diminished during fault to zero voltage. However, at the time of clearance fault, the voltage at the R-G and Y-G lines experienced maximum peak voltage at 570.4 kV and 708.5 kV respectively as presented in Table 5. The current within the faulty lines also diminished to zero value and the difference between the faults and healthy lines indicated a slight deviation as presented in Table 6.

TABLE 5. Maximum peak value of voltage (kV).

Phase	Value (kV)	Time (s)
R - G	570.4	0.086
	560.6	0.089
	529.7	0.086
Y - G	708.5	0.019
	684.0	0.021
	624.8	0.095
B - G	353.4	Normal

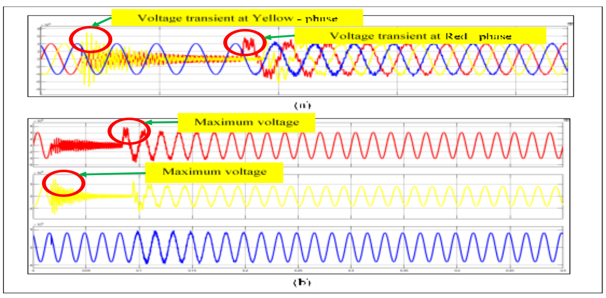

FIGURE 8. (a) Output voltage (b) R – Y – B output

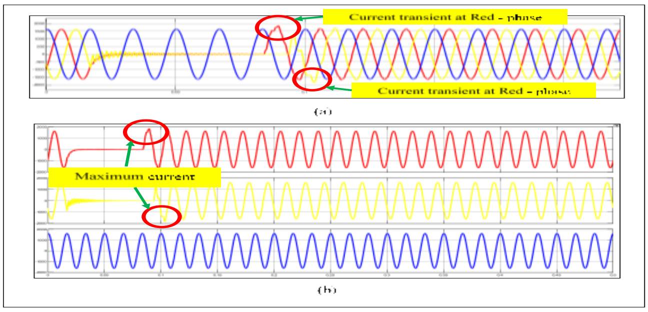

FIGURE 9. (a) Output current (b) R – Y – B output voltage LL - G fault current LL - G fault.

TABLE 6. Maximum peak value of current (A).

Phase	Value (A)	Time (s)
R - G	1853.0	0.090
	1765.0	0.089
	1675.0	0.122
Y - G	1722.0	0.112
	1671.0	0.128
	1658.0	0.145
B - G	1633.0	Normal

TRIPLE LINE TO GROUND FAULT (3L -G FAULT)

Then, the EHV long-distance transmission line system model has been tested with the triple line to ground fault (LLL -G). The analysis of voltage and current waveforms was continued in this section. A maximum peak value of voltage was recorded in Table 7 while maximum peak value of current has been recorded in Table 8. The waveform of voltage and current of the EHV long transmission line after applied triple line to ground fault at the middle of the model has been analyzed. Based on Figure 10 and Figure 11, the waveforms have been analyzed at the receiving – end of the 500 kV/300 km EHV long-distance transmission line model.

TABLE 7. Maximum peak value of voltage (kV).

Phase	Value (kV)	Time (s)
R - G	529.0	0.105
	512.7	0.086
	509.0	0.086
Y - G	774.9	0.021
	745.8	0.019
	640.5	0.094
B - G	701.4	0.020
	675.2	0.098
	674.8	0.098

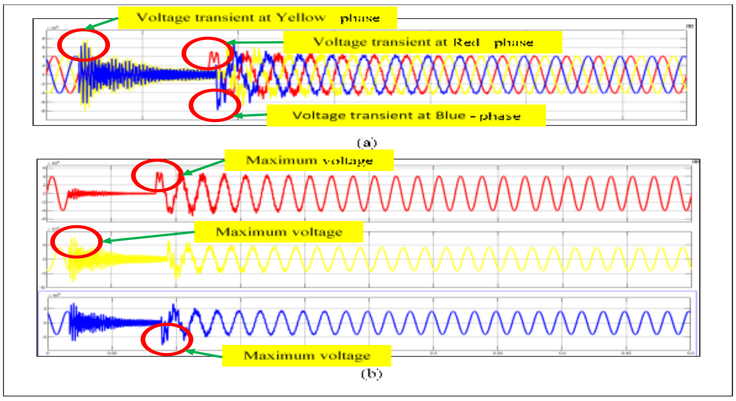

FIGURE 10. (a) Output voltage (b) R – Y – B output

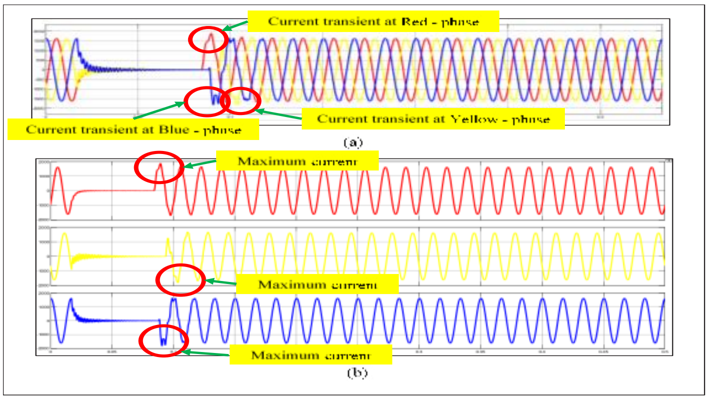

FIGURE 11. (a) Output current (b) R – Y – B output current 3L - G fault.current 3L - G fault.

Figure 10 shows the voltages in all lines are diminished to zero. Then, at the time of fault clearance, the voltage is increased tremendously for Yellow – phase line with a value of 774.9 kV with increment exceed at 100% as shown in Table 7. This can cause damage to transmission lines. In addition, Red – phase also produced the maximum peak value of voltage at the fault clearance with a value of 529.0 kV at 0.105 with increment exceed 49.69 % while the Blue – phase signal generated a maximum peak value of voltage with a value of 701.4 kV at 0.020 s with increment 98.47% as shown in Table 7.

TABLE 8. Maximum peak value of current (A)

Phase	Value (A)	Time (s)
R - G	1895.0	0.090
	1702.0	0.106
	1684.0	0.106
Y - G	1703.0	0.111
	1695.0	0.128
	1680.0	0.145
B - G	1657.0	0.099
	1648.0	0.102
	1645.0	0.200

Figure 11 shows the output waveform of the current at the receiving – end of the EHV long-distance transmission line model. The current in all the three lines is reduced to zero after the fault occurred and increased the values after clearance of the fault (Chukwuekwe, D. O.et al. 2023). The Red – phase signals have the maximum peak value of current 1895.0 A at 0.090 s with increment 16.04 % as in Table 8. Table 8 presented a Yellow – phase signal and the Blue – phase signal produced a maximum peak value of current with a value 1703.0 A at time 0.111 s with increment 4.29 % and 1645.0 A at 0.200 s with increment 0.74 %, respectively. Meanwhile, for the Red – phase signals the maximum value of current was 1853.0 A for Red – phase signals.

ENHANCEMENT OF VOLTAGE AND CURRENT WAVEFORM AFTER OVERCURRENT RELAY PROTECTION APPLIED

In this section, Inverse Definite Minimum Time overcurrent (IDMT O/C) relay protection is installed at the 500 kV/300 km EHV long transmission line to reduce the fault impact by analyzing the output voltage and current of the transmission line model. The waveforms were analyses based on voltage and current flows along with the 500 kV/300 km EHV long transmission line model.

VOLTAGE AND CURRENT WAVEFORM WITHOUT FAULT

Firstly, the model of a 500 kV/300 km EHV long transmission line was simulated without fault and operated with balanced input. The result of the current waveforms is presented in Figures 12 for transmission line is normal and balanced.

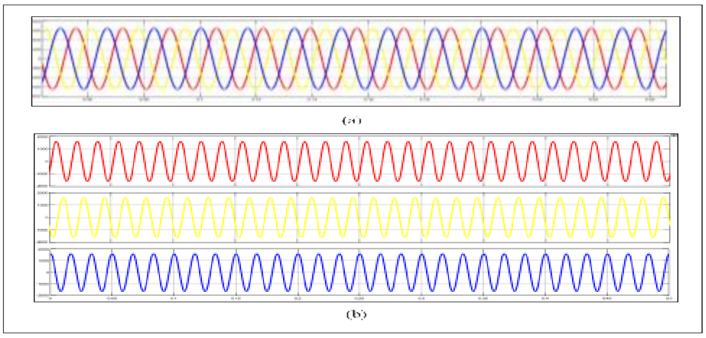

FIGURE 12. (a) Output current (b) R – Y – B output current without fault.

The IDMT O/C relay protection is closed as it maintains the value at "1". There is no fault that happened in transmission line voltage, it will not be triggered the IDMT O/C relay protection to open (N. H. Hussin et al. 2016)

SINGLE LINE TO GROUND FAULT (L – G FAULT)

The IDMT O/C relay protection when the L -G fault occurred with the trip signal. The trip started at 0.107 s. The IDMT O/C relay is activated when it detects the overcurrent flow in the transmission line model.

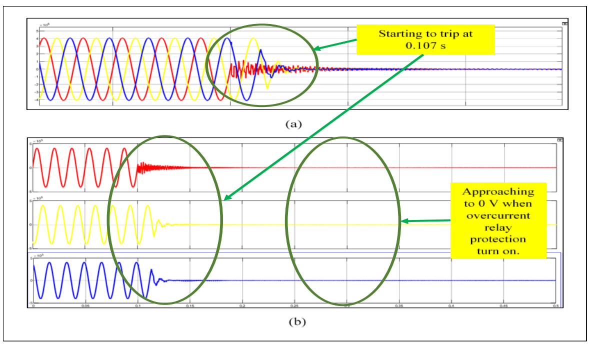

FIGURE 13. (a) Output voltage (b) R – Y – B output voltage L - G fault.

Figure 13 shows the voltage waveform after IDMT O/C relay protection is applied when L – G fault occurred. The waveform for the R – G will be tripped at 0.107 s and approaching zero. The Y – G and B – G lines also started approaching zero as it reaches 0.107 s as the system will trip as there is over-voltage occur in the system.

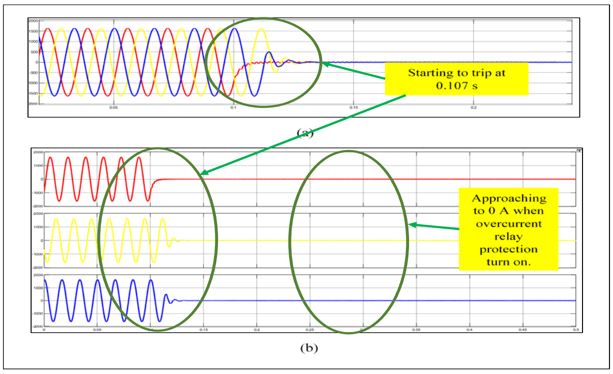

FIGURE 14. (a) Output current (b) R – Y – B output current L - G fault.

Figure 14 shows the current waveform after IDMT O/C relay protection was applied. The waveform for the R – G will be tripped at 0.107 s as the overcurrent occurs at R – G and then continue approaching zero. The Y – G and B – G lines also started approaching zero as it reaches 0.107 s as the system will trip when the overcurrent occurred in the system.

DOUBLE LINE TO GROUND FAULT (2L – G FAULT)

The analysis of output voltage and current waveforms continued with 2L -G fault occurred. The voltage and current waveforms are analyzed at the receiving – end of the EHV long-distance transmission line as in Figure 15 and Figure 16. The trip started at 0.101 s. The IDMT O/C relay is active when it detects the overcurrent on the transmission line model.

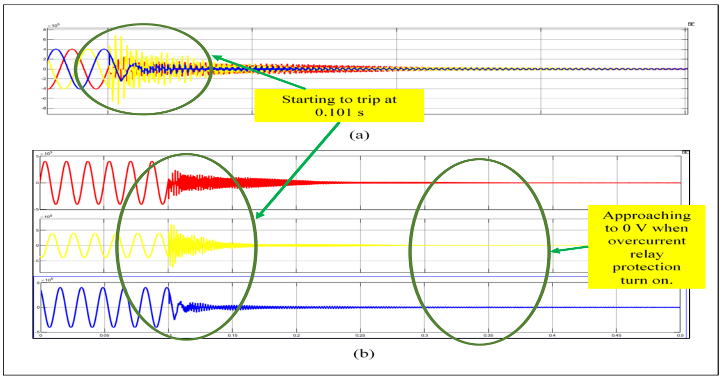

FIGURE 15. (a) Output voltage (b) R – Y – B output voltage LL - G fault

Figure 15 shows the output voltage waveform after IDMT O/C relay protection tripped at 0.107 s as the overvoltage occurs at R – G and Y – G lines when it reaches 0.101 s. The B – G line also started approaching zero as it reaches 0.101 s but slight delay as at B – G line is not experienced voltage.

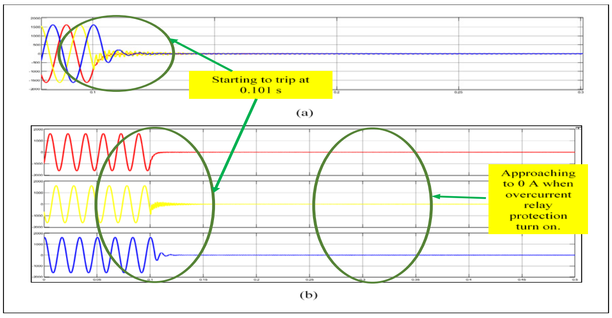

FIGURE 16. (a) Output current waveform (b) R – Y – B output current waveform LL - G fault

Figure 16 shows the current waveform of the EHV long transmission line after IDMT O/C relay protection is applied. The waveform for the R – G and Y – G line will be tripped at 0.101 s as the overcurrent occurs at the R – G and Y – G line when it reaches 0.101 s. The B – G line also approached zero current as it reaches 0.101 s due to overcurrent occurred in the system.

TRIPLE LINE TO GROUND FAULT (LLL – G FAULT)

At this stage, the 500 kV/300 km EHV long-distance transmission line system model is tested with a 3L -G fault. Figure 17 and Figure 18 show the waveforms at the receiving – end of the 500 kV/300 km EHV long-distance transmission line model after the 3L – G fault was experienced a fault. The IDMT O/C relay protection detects an abnormal value of current in the EHV transmission line after fault locates at the 2L – G fault happened. The trip starts at 0.100 s. The IDMT O/C relay is activated when it detects the overcurrent that flows in the transmission line model (M. A. Ibrahim et al. 2022)

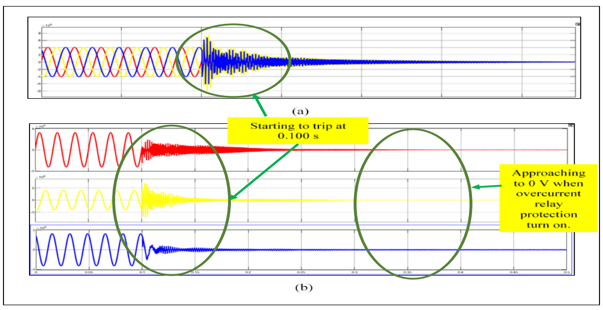

FIGURE 17. (a) Output voltage waveform (b) R – Y – B output voltage waveform 3L - G fault

Figure 17 shows the voltage waveform generated by the EHV long transmission line after IDMT O/C relay protection tripped at 0.107 s as the overvoltage occurred at all lines when it reached 0.100 s. All lines approach zero voltage after 0.100 s as the relay detected an abnormal voltage occur.

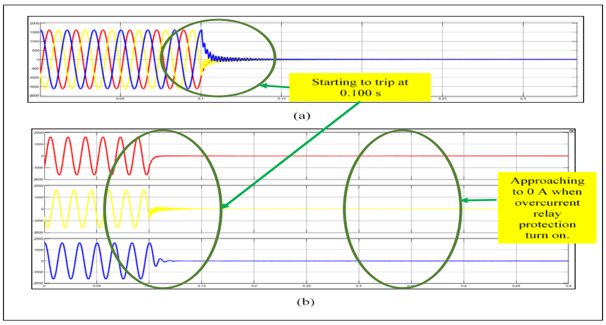

FIGURE 18. (a) Output current waveform (b) R – Y – B output current waveform 3L - G fault

Figure 18 shows the current waveform generated at the receiving end of the EHV long transmission line after IDMT O/C relay protection tripped at 0.100 s as the overcurrent occurs at all line when it reaches 0.100 s. The current flows at the R – G, Y – G, and B – G lines are reduced to zero as the IDMT O/C relay trip the system when the abnormal current flow in the transmission line model.

CONCLUSION

The 500 kV/300 km EHV long transmission line in healthy and fault conditions were successfully simulated using Simulink. The properties of voltage and current waves were discussed in this project to detect transient phenomenon after L – G fault, LL – G faults and LLL – G faults were applied in the system, the current will be increased, and voltage will be reduced to zero and diminished. This study proven the application of IDMT O/C relay protection to the EHV transmission line is required to reduce the impact of faults.

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DECLARATION OF COMPETING INTEREST

None.

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