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A study of electromagnetic induction in HVDC lines from parallel AC lines under short circuit conditions

Sreeram V* and Sudhakara Reddy S**

High Voltage Direct Current (HVDC) lines running parallel to AC transmission lines will encounter electromagnetic induction which will rise to substantial levels during a short circuit. The actual magnitude of induced current depends on several factors like distance between the lines, soil resistivity etc. The unenergised DC line will also have a voltage due to induction and the associated discharging equipment will have to carry the induced current. This paper attempts to study the levels of induction encountered by the HVDC line and associated equipment during a short circuit in the AC line. It was observed that magnitude of induced current during steady state and three phase fault did not exceed 5 A while the magnitude of induced current during single phase to ground fault exceeded 15 A.

Keywords: *Double circuit transmission lines,electromagnetic induction, HVDC, short circuit currents*

1.0 INTRODUCTION

HVDC power transmission has become an important part of modern day transmission systems with significant capacity added each year. In regions of high population density, the HVDC lines will share Right Of Way (ROW) with AC transmission lines running in parallel. This will lead to electromagnetic induction in the DC lines from the parallel AC lines. There will be static induction due to the positive sequence voltages and dynamic induction due to positive sequence and zero sequence currents under normal conditions. The induction would be of negligible magnitude under perfectly balanced load currents in the AC lines with proper transposition. This phenomenon has been subjected to investigation in various previous studies. Stability and control issues under such a scenario has been presented in [1].The steady state induction in an 800 kV HVDC line due to 400 kV and 765 kV AC transmission lines has been presented in [2]. Experimental investigation of the fundamental frequency coupling between HVDC and HVAC lines is presented in [3]. However during a short circuit, the level of induction would become high due to an increase in the current carried by the AC lines. The overvoltages during steady state and under short circuit has been investigated in [4]. Most of the studies have utilised PSCAD/EMTDC™ for studying the phenomenon while modern computational methods have also been attempted [5]. This paper attempts to study the electromagnetic induction under various conditions during short circuit using PSCAD/EMTDC™.

2.0 PSCAD™ MODEL

A hypothetical model was developed in PSCAD™. A 1000 km HVDC transmission line was placed in close proximity to a 400 kV single circuit line with a fault level of 20 kA, carrying a steady state power of 1000 MW. The HVDC line had a

*Engineering Officer-2, High Power Laboratory, Central Power Research Institute, Bangalore - 560080, India.
E-mail : sreeram@cpri.in, Mobile : +91 8861557034
**Joint Director, High Power Laboratory, Central Power Research Institute, Bangalore - 560080, India. E-mail : ssreddy@cpri.in

voltage rating of +/- 500 kV and a power rating of 1000 MW. The lines were placed in parallel for a length of 50 km. The HVDC system was bipolar and dedicated metallic return conductors were not considered in the study. The HVDC controls were adopted from the Cigre benchmark model developed by Szechtmann, Wess and Thio [6]. The main model is given in Figure 1. The single circuit transmission line used stranded quad conductors. The transmission line model is presented in Figure 2.

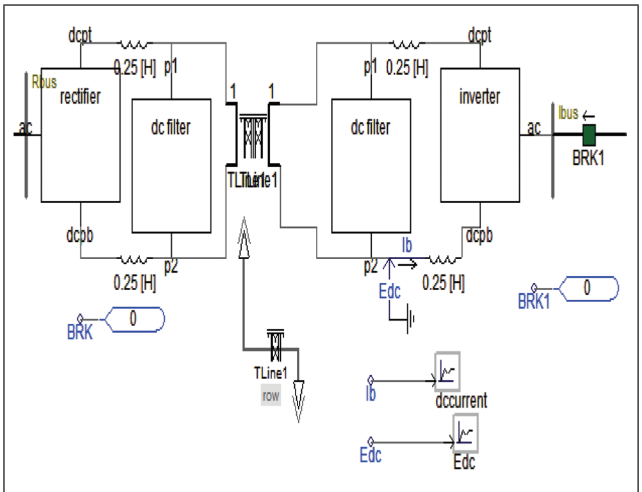

FIG. 1 DC SYSTEM MODELLED IN PSCAD™

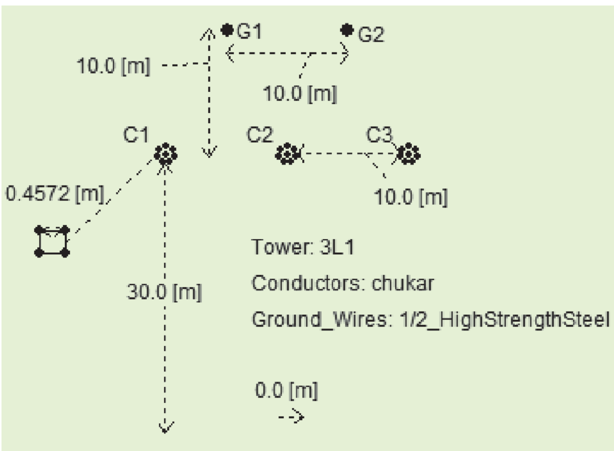

FIG. 2 DOUBLE CIRCUIT TRANSMISSION LINE IN PSCAD™

The induced voltage can be calculated by using basic equations of electromagnetics. The induced electric field is given in equation 1.

$$\vec{E} = -\nabla\emptyset - \frac{\partial \vec{A}}{\partial t} \quad ....(1)$$

Where ϕ is the static potential and A is the magnetic vector potential. The static electric potential due to a line charge is given by

$$\Phi(x,y,z) = \frac{q}{4\pi\varepsilon} ln \frac{l-x+\sqrt{((l-x)^2+y^2+z^2)}}{-x+\sqrt{(x^2+y^2+z^2)}} \quad ....(2)$$

Where q is the charge on the line, l is the length of the line, and (x,y,z) are the cartesian co-ordinates of the point. The magnetic vector potential is given by

$$\vec{A} = \frac{\mu}{4\pi}\int \frac{I\vec{dl}}{r} \quad ....(3)$$

Where I is the current in the incremental conductor and r is the distance from the incremental conductor to the point. The total emf developed on the transmission line is given by

$$V = \int \vec{E}.\vec{dl} \quad ....(4)$$

The PSCAD/EMTDC™ software uses trapezoidal method to solve these integral equations.

3.0 STEADY STATE INDUCTION

As a preliminary study, the system was simulated at steady state with all the transmission lines carrying rated power. The AC lines will induce fundamental frequency currents in the HVDC line and it is the only source of the fundamental frequency component. Hence the fundamental frequency current measured in the HVDC line was taken as the induced current. The three phase AC current waveforms are presented in Figure 3 and the DC current is shown in Figure 4.

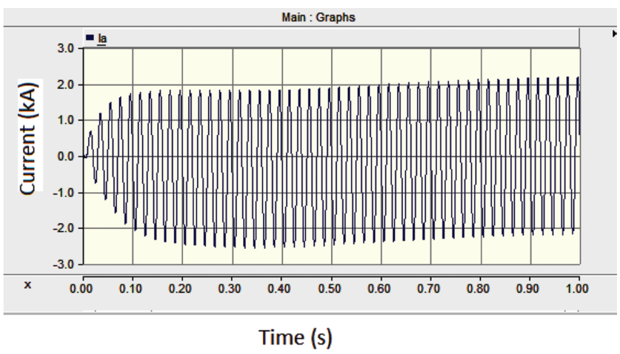

FIG. 3 STEADY STATE PHASE CURRENT (kA) IN AC LINE

The distance between the transmission lines was varied from 50 m to 300 m in steps of 50 m and the magnitude of induced current is plotted against distance in Figure 5. The minimum distance considered was 50 m since the study is limited to transmission lines on different towers and it is practically impossible for transmission towers to come any closer.

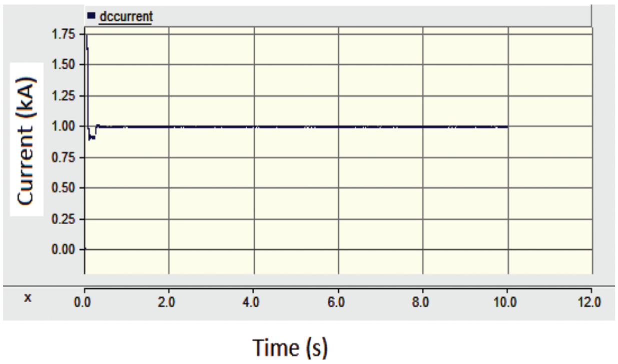

FIG. 4 STEADY STATE DC (kA) CURRENT

The magnitude of induced current decreased from 3.57 A to 0.21 A with increase in distance between the transmission lines from 50 m to 300 m. The positive currents and voltages would drive current in the AC lines but it will be negligible under perfectly balanced conditions even though the coefficients of induction are slightly different for the three lines. The calculated DC current appearing on the AC side flowing into the converter transformer is plotted in Figure 6.

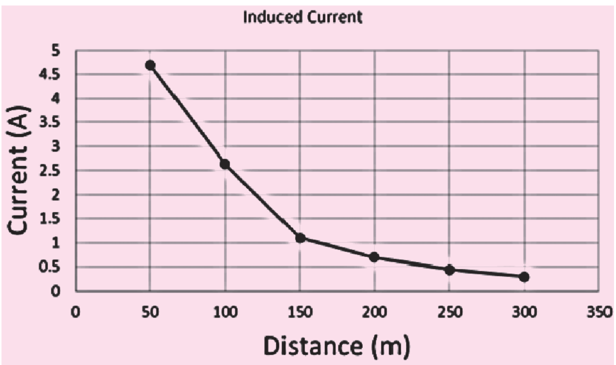

FIG. 5 MAGNITUDE OF INDUCED CURRENT UNDER STEADY STATE

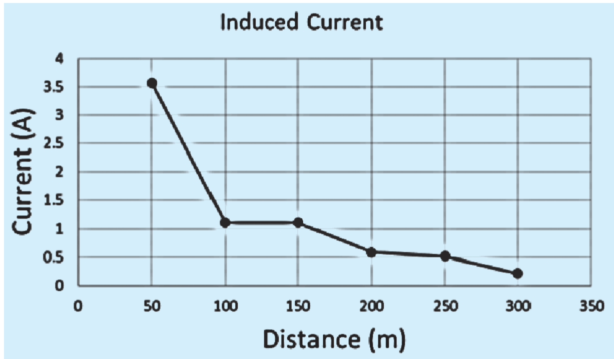

FIG. 6 DC CURRENT (A) FLOWING INTO THE CONVERTER TRANSFORMER AT STEADY STATE

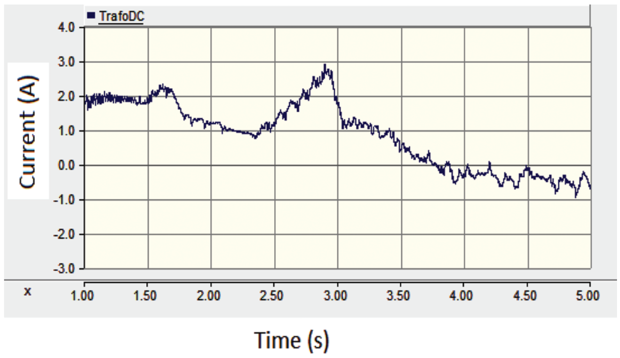

FIG. 7 MAGNITUDE OF INDUCED CURRENT UNDER THREE PHASE FAULT

This current is responsible for saturation of the transformer core injecting multiple harmonics into the power system in addition to causing various other nuisance.

4.0 INDUCTION UNDER SHORT CIRCUIT CONDITIONS

The magnitude of induced current is expected to increase during short circuit as the driving current in the AC lines will increase. Three different types of short circuits are considered – three phase short circuit (LLL fault), phase to phase fault (LL fault) and single phase to ground fault (LG fault) – in the AC line.

4.1 Three phase short circuit

A three phase fault was applied at one end of the AC transmission. The fault current magnitude was 20 kA. The variation of induced current with distance between the AC and DC lines is given in Figure 7. It is found that the induced current decreases from 4.7 A to 0.3 A with increase in distance from 50 m to 300 m. Even though the magnitude of driving current is high, the magnitude of induced current is still low due to the balanced nature of currents.

4.2 Phase to phase fault

In this scenario, a phase to phase fault was applied achieving a fault current of 20 kA. The magnitude of induced current is plotted against distance between the lines in Figure 8. The current decreased from 3.62 A to 0.45 A with increase in distance from 50 m to 300 m. As the short circuit current is flowing back through the transmission line itself, the effects cancel each other and the magnitude of induced current is still low.

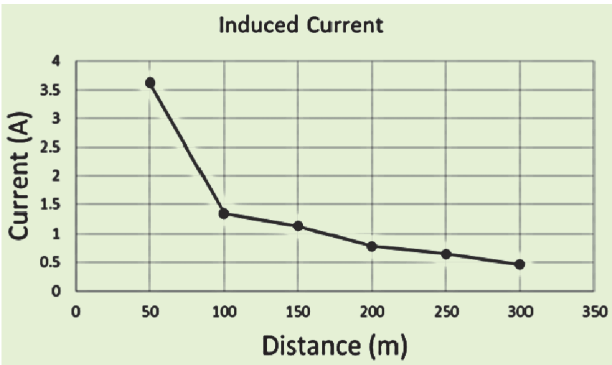

FIG. 8 MAGNITUDE OF INDUCED CURRENT UNDER LINE TO LINE FAULT

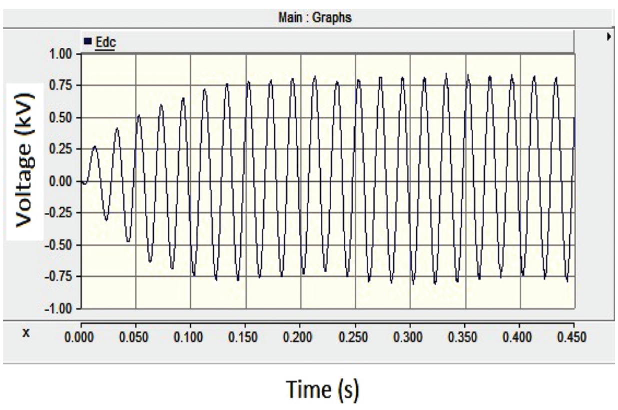

FIG. 9 MAGNITUDE OF INDUCED CURRENT UNDER SINGLE LINE TO GROUND FAULT

4.3 Single phase to ground fault

A single phase to ground fault was applied at one end of the near phase of the AC transmission line. The magnitude of induced current is high during this fault since the nature of current flow is unbalanced. Apart from the positive sequence current, the presence of zero sequence current contributes towards the induction in DC line. The variation in induced current with respect to distance between the transmission lines is presented in Figure 9. The current decreased from 15.85 A to 4.28 A with increase in distance from 50 m to 300 m. This magnitude is the highest among all the scenario considered.

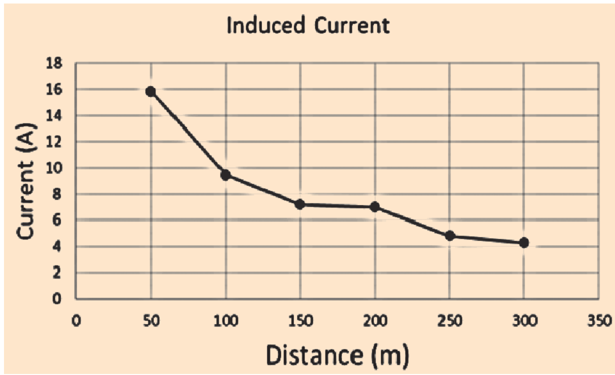

FIG. 10 VOLTAGE (KV) IN THE ISOLATED DC LINE

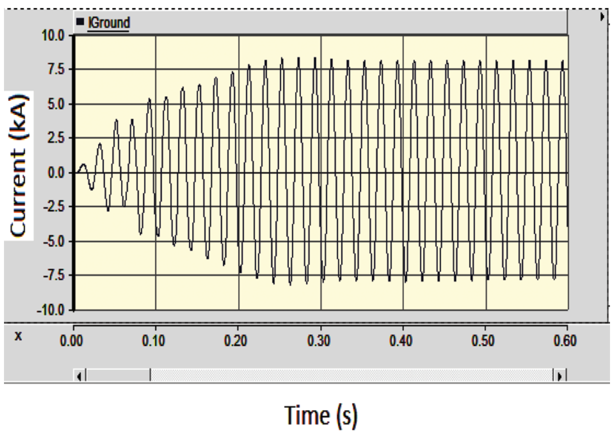

FIG. 11 CURRENT (A) IN THE EARTH SWITCH CONNECTED TO DC LINE

As an extention of the scenario, the voltage on the DC line was measured when it was disconnected on either side. The voltage waveforms are given in Figure 10. The earth switch discharging the DC transmission line will have to carry a continuous current under such a condition. Hence the discharge current through a conductor to ground was measured and is given in Figure 11. The DC current flowing into the converter transformer is presented in Figure 12. It can be seen that there is significant increase compared to the steady state condition.

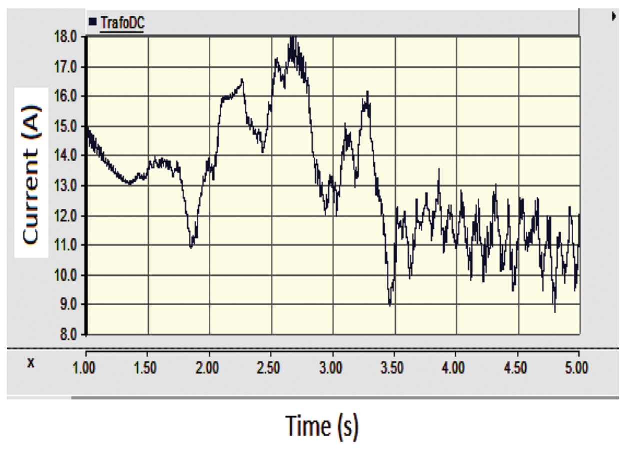

FIG. 12 DC CURRENT FLOWING INTO CONVERTER TRANSFORMER UNDER STEADY STATE

5.0 CONCLUSIONS

The simulation study on 1000 MW HVDC system with parallel 400 kV lines led to the following conclusions.

1. The induced current under steady state conditions did not exceed 3.57 A which is 0.0357% of the total current.
2. The induced current under three phase short circuit and line to line short circuit also did not exceed 4.7 A which is 0.047% of the total current.
3. The induced current under single line to ground fault reached upto 15.85 A which is equal to 0.1585% of the total current.
4. The DC current magnitude flowing into the converter transformer during single line to ground fault reached upto 18 A (0.18%) which can lead to significant saturation of the transformer.

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