

Modelling and Analysis of Single Machine Infinite Bus System with and without UPFC for Different Locations of Unsymmetrical Fault

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Abstract— In this research paper, two simulation models of single machine infinite bus (SMIB) system, with & without UPFC, have been developed. These simulation models have been incorporated into MATLAB based Power System Toolbox (PST) for their transient stability analysis. These models were analyzed for line to line fault at different locations, i.e. at sending end of transmission line, middle of the line and receiving end of transmission line keeping the location of UPFC fixed at the receiving end of the line. Transient stability was studied with the help of curves of fault current, active & reactive power at receiving end, shunt injected voltage & its angle, series injected voltage & its angle, excitation voltage and speed of rotor. With the addition of UPFC, the magnitude of fault current reduces and oscillations of excitation voltage also reduce. It can be concluded that transient stability of SMIB is improved with the addition of Unified Power Flow Controller.

Keywords— SMIB, UPFC, Shunt Injected Voltage, Series Injected Voltage, Transient Stability, STATCOM, SSSC, Unsymmetrical Line to Line Fault

INTRODUCTION

UPFC is a combination of Static Synchronous Compensator (STATCOM) and Static Series Compensator (SSSC). These two are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source [1][3][4][13]. UPFC is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line [2][5][6][9][10]. The schematic of the UPFC is shown in Figure 1.

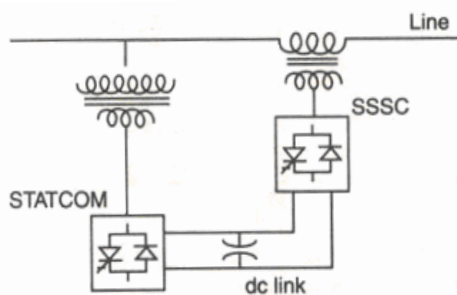


Fig.1 Unified Power Flow Controller

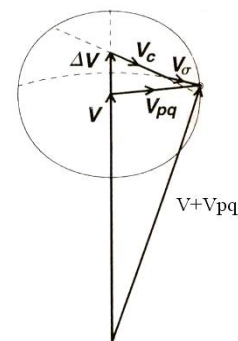


Fig.2 Conventional Transmission Control Capabilities of UPFC (Simultaneous Control of Voltage, Impedance & Angle)

Multifunctional power flow control executed simultaneously with terminal voltage regulation, series capacitive line compensation and phase shifting as shown in Figure 2, where $V_{pq} = \Delta V + V_c + V_\sigma$. This capability is unique to UPFC. No single conventional equipment has the similar multifunctional capability [1][3][4][11].

SIMULATION MODELLING AND TRANSIENT STABILITY ANALYSIS OF SMIB WITH & WITHOUT UPFC

In this research work, simulation models of Single Machine Infinite System (with & without Unified Power Flow Controller) for different type of faults at different locations are developed, keeping UPFC fixed at the receiving end of SMIB. Simulation models have been prepared in MATLAB/ SIMULINK to study the transient stability of SMIB as shown in Figure 3 & 4. [8][12][14].

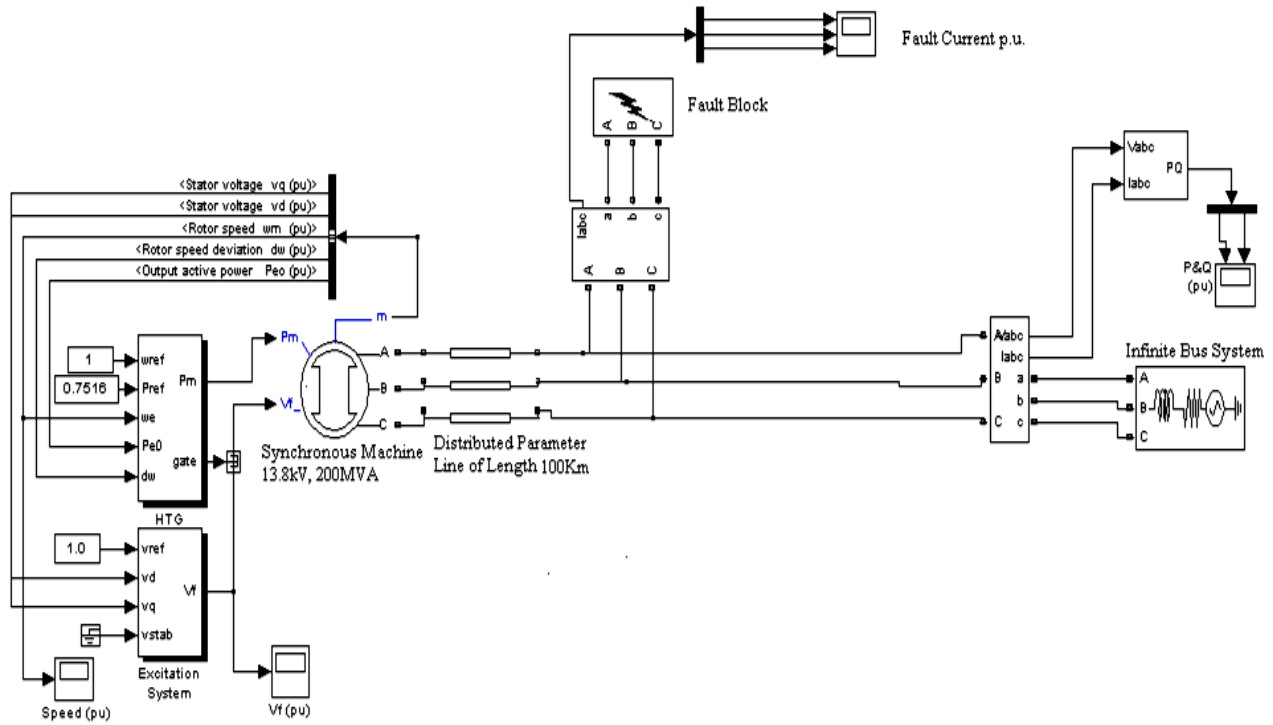


Fig.3 Simulation Diagram of SMIB without UPFC and Fault at Receiving End of Transmission Line

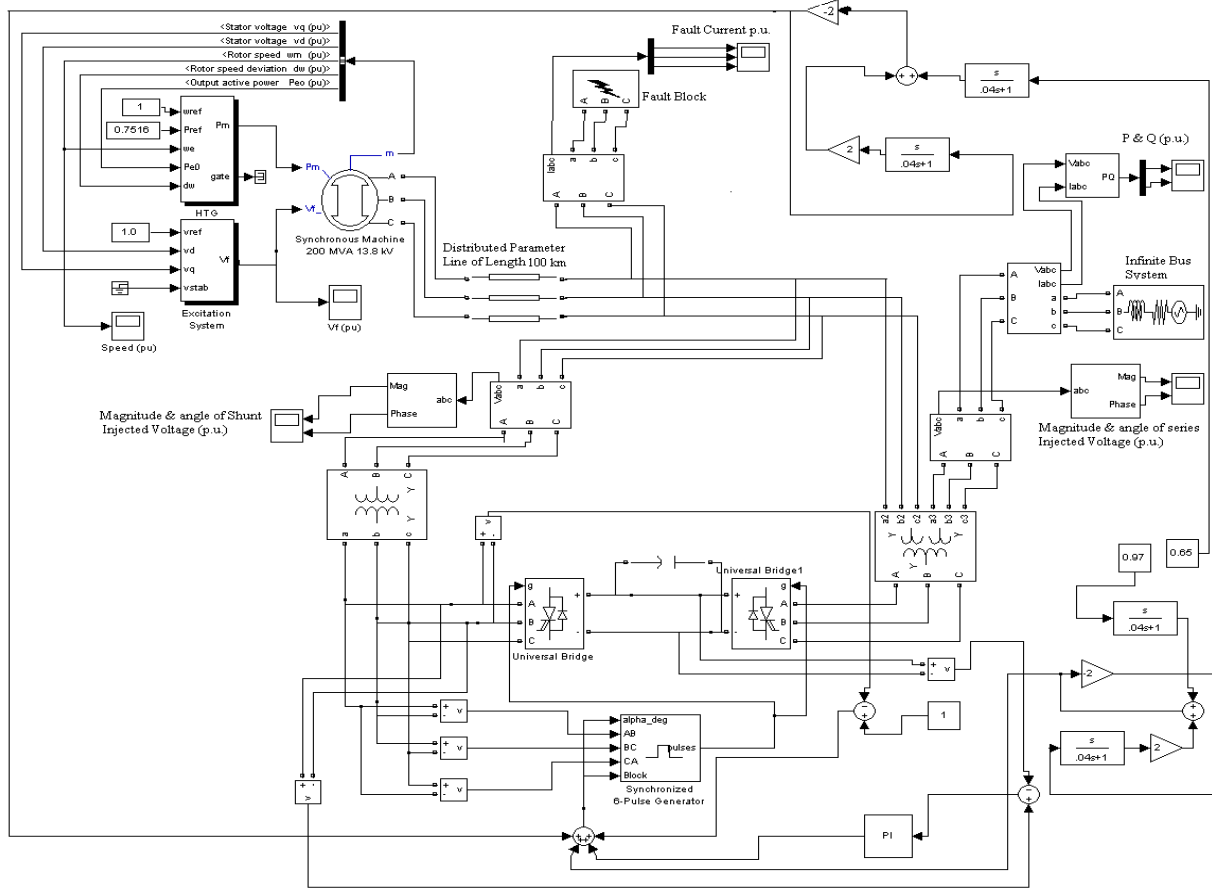


Fig.4 Simulation Diagram of SMIB with UPFC and Fault at Receiving End of Transmission Line

RESULTS OF UNSYMMETRICAL LINE TO LINE FAULT AT DIFFERENT LOCATIONS OF TRANSMISSION LINE WITH AND WITHOUT UPFC

I. Fault at Receiving End of Transmission Line

Single Machine Infinite Bus (SMIB) System without UPFC at Receiving End

Resulting curves of the variation of speed of rotor, excitation voltage, fault current and active & reactive power at receiving end are presented in Figures 5 to 7.

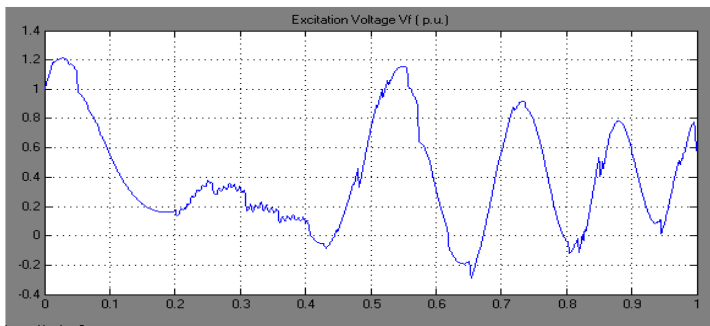


Fig.5 Variation of Excitation Voltage Vs Time

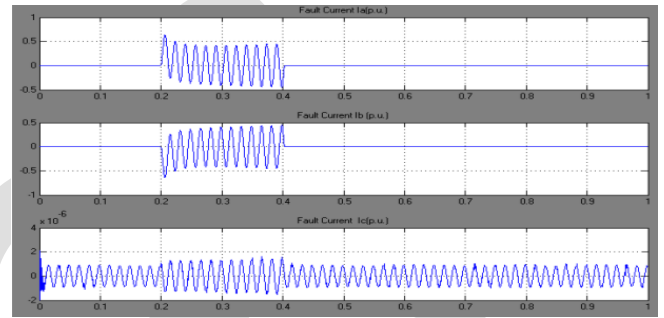


Fig.6 Variation of Fault Current Vs Time

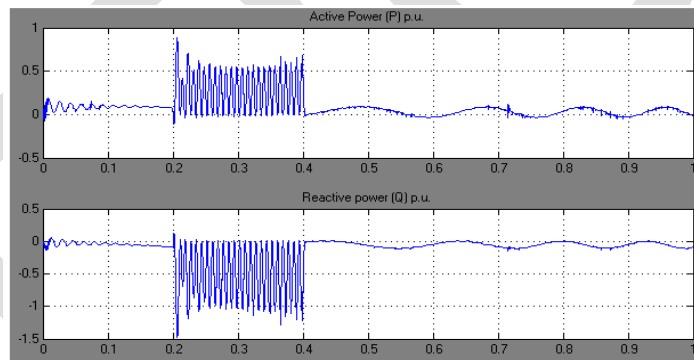


Fig.7 Variation of Active & Reactive Power Vs Time

Single Machine Infinite Bus (SMIB) with UPFC at Receiving End

Resulting curves of the variation of speed of rotor, excitation voltage, fault current, active & reactive power at receiving end, magnitude & angle of series injected voltage and magnitude & angle of shunt injected voltage are shown in Figures 8 to 12.

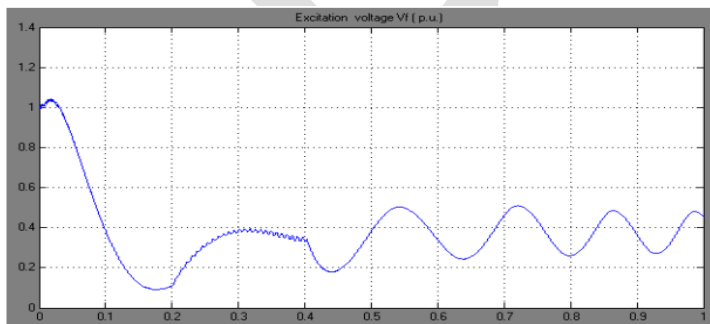


Fig.8 Variation of Excitation Voltage Vs Time

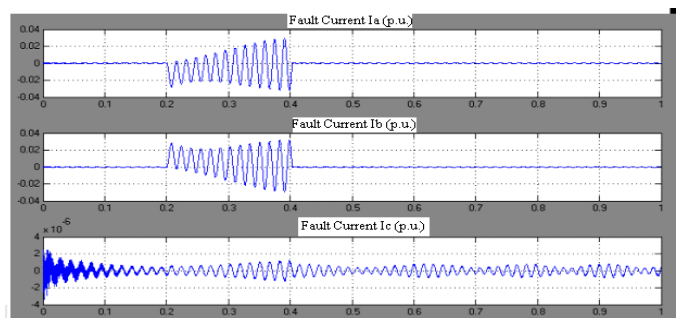


Fig.9 Variation of Fault Current Vs Time

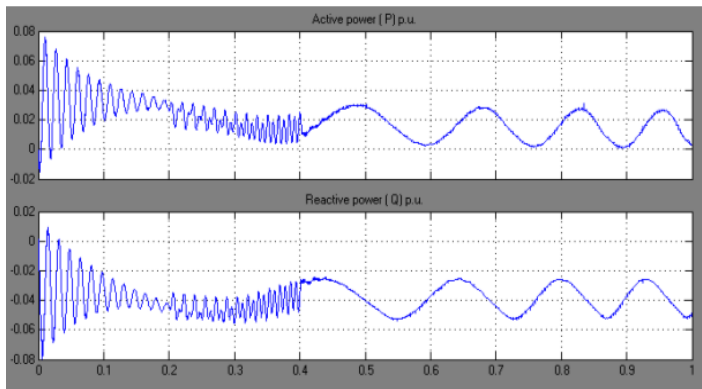


Fig.10 Variation of Active & Reactive Power Vs Time

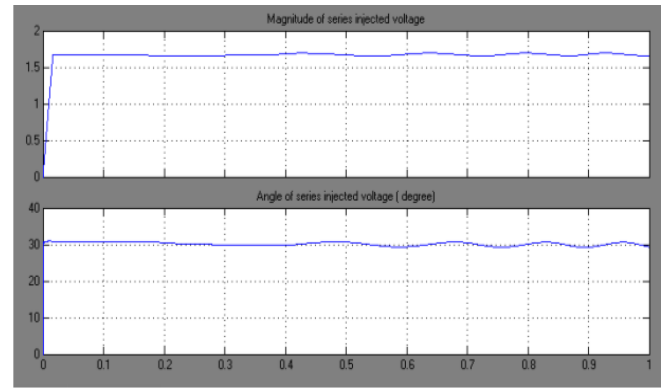


Fig.11 Variation of Series Injected Voltage & its Angle Vs Time

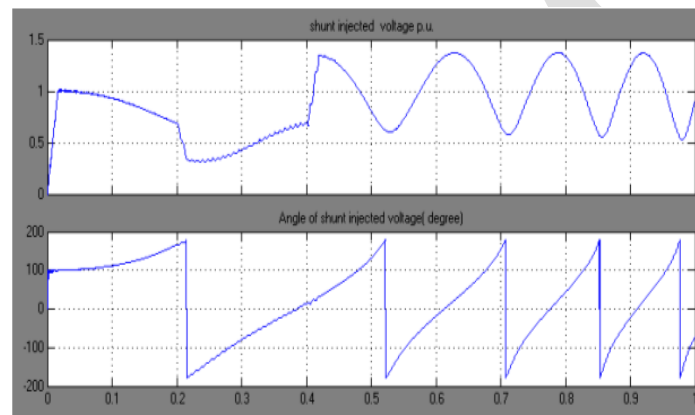


Fig.12 Variation of Shunt Injected Voltage & its Angle Vs Time

Fault Current : Without UPFC, during fault interval, fault current in phases a, b & c lies between 0.60 to -0.50 p.u., -0.60 to 0.50 p.u. & 1.5×10^{-6} respectively (Figure6). With UPFC, fault current in phases a, b & c is reduced to (0.03 to -0.03 p.u., 0.03 to -0.03 p.u. & 0.5×10^{-6} p.u.) respectively (Figure9.). So, using UPFC, the magnitude of fault current has reduced in **a & b** phases.

Excitation Voltage: Without UPFC, before occurrence of fault, excitation voltage lies between 1.2 p.u. to 0.2 p.u., during the fault, it lies between 0.4 p.u. to 0.15 p.u. with large oscillations and it lies between 1.15 p.u. to -0.30p.u. with oscillations after the fault (Figure5). With UPFC, before occurrence of fault, excitation voltage lies between 1.0 p.u. to 0.1 p.u., during the fault, it lies between 0.1 to 0.4 p.u. and it lies between 0.2 to 0.5 p.u. with oscillations dieing out after the fault (Figure 8). So, using UPFC, the number of oscillations of excitation voltage have decreased and die out more smoothly.

Series Injected Voltage: Series part of UPFC injects a voltage of 1.7 p.u. at an angle of 30 degree (Figure11).

Shunt Injected Voltage: Shunt part of UPFC injects a voltage of 1.0 p.u. to 0.7 p.u. with an angle of 100 to 180 degree before the fault, voltage of 0.3 p.u. to 0.7 p.u. with an angle of -180 to 180 degree during the fault and voltage of 1.3 p.u. to 0.6 p.u. with an angle of 180 to -180 degree after the fault (Figure12).

Active and Reactive Power: With addition of UPFC, there is no appreciable change in the values of active and reactive power (Figures 7&10).

II. Fault at Middle of Transmission line

Single Machine Infinite Bus (SMIB) System without UPFC at Middle of Transmission line

Resulting curves of the variation of speed of rotor, excitation voltage, fault current and active & reactive power at receiving end are presented in Figure 13 to 15.

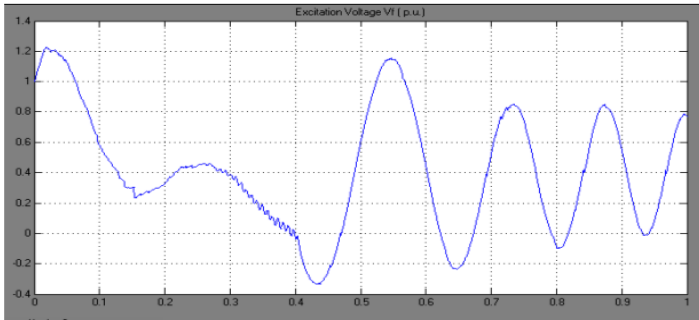


Fig.13 Variation of Excitation Voltage Vs Time

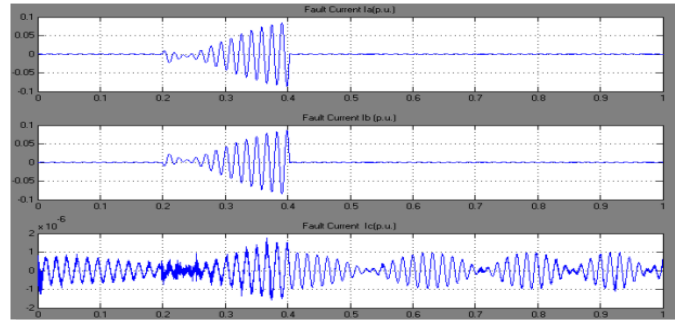


Fig.14 Variation of Fault Current Vs Time

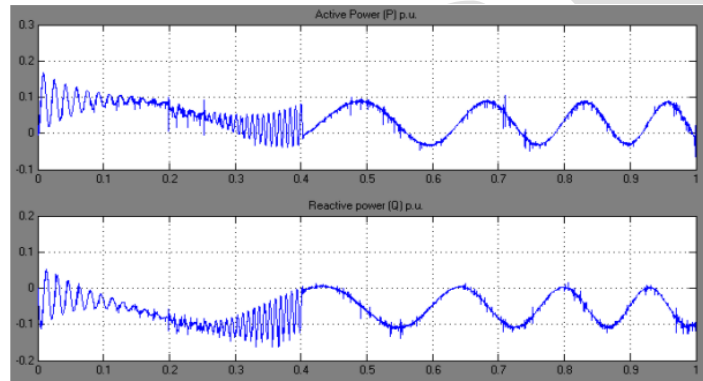


Fig.15 Variation of Active & Reactive Power Vs Time

Single Machine Infinite Bus (SMIB) System with UPFC at Middle of Transmission line

Resulting curves of the variation of speed of rotor, excitation voltage, fault current, active & reactive power at receiving end, magnitude & angle of series injected voltage and magnitude & angle of shunt injected voltage are shown in Figures 16 to 20.

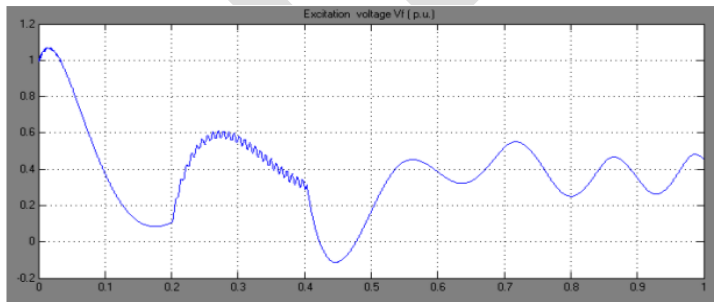


Fig.16 Variation of Excitation Voltage Vs Time

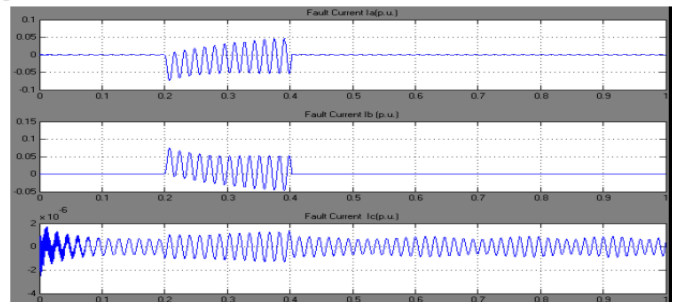


Fig.17 Variation of Fault Current Vs Time

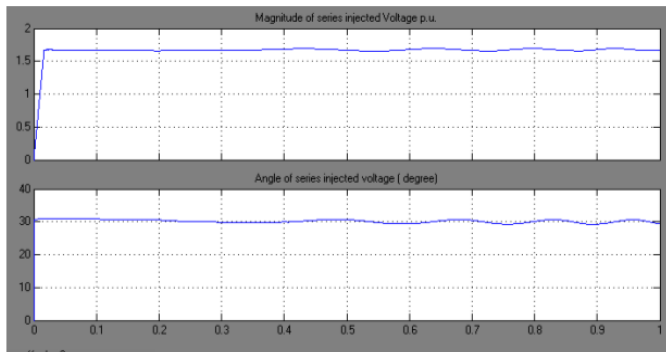


Fig.18 Variation of Active & Reactive Power Vs Time

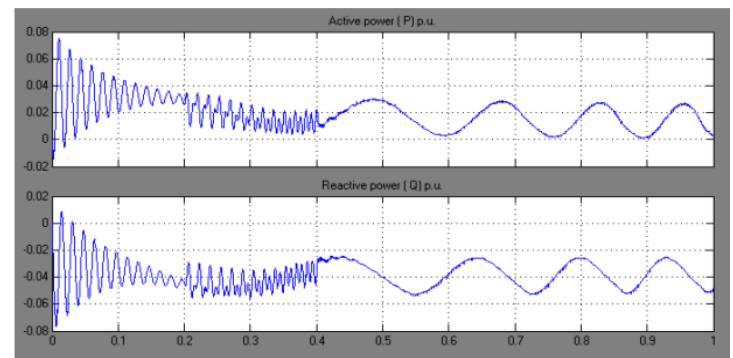


Fig.19 Variation of Series Injected Voltage & its Angle Vs Time

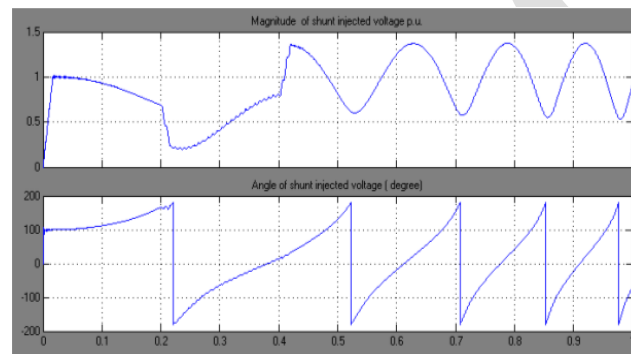


Fig.20 Variation of Shunt Injected Voltage & its Angle Vs Time

Fault Current: Without UPFC, during fault interval, fault current in phases a, b & c lies between 0.10 p.u. to - 0.10 p.u., 0.10 to -0.10 p.u. & 1.5×10^{-6} to 1.5×10^{-6} p.u. respectively (Figure 14). With UPFC, fault current in phases a, b & c is reduced to (0.05 p.u. to -0.07 p.u., 0.07 p.u. to -0.05 p.u. & 1×10^{-6} to -1×10^{-6} p.u.) respectively (Figure 17). So, using UPFC, the magnitude of fault current has reduced in all the three phases.

Excitation Voltage: Without UPFC, before occurrence of fault, excitation voltage lies between 1.2 p.u. to 0.3 p.u., during the fault, it lies between 0.45 p.u. to 0.0 p.u. with oscillations and it lies between -0.3 p.u. to 1.15 p.u. with oscillations after the fault (Figure 13). With UPFC, before occurrence of fault, excitation voltage lies between 1.0 p.u. to 0.1 p.u., during the fault, it lies between 0.1 p.u. to 0.6 p.u. and it lies between -0.1 p.u. to 0.55 p.u. with oscillations dieing out after the fault (Figure 16). So, using UPFC, the number of oscillations of excitation voltage have decreased and die out more smoothly.

Series Injected Voltage: Series part of UPFC injects a voltage of 1.7 p.u. at an angle of 30 degree (Figure 19).

Shunt Injected Voltage: Shunt part of UPFC injects a voltage of 1.0 p.u. to 0.7 p.u. with an angle of 100 to 180 degree before the fault, voltage of 0.25 p.u. to 0.8 p.u. with an angle of 180 to -180 degree during the fault and voltage of 1.3 p.u. to 0.7 p.u. with an angle of 180 to -180 degree after the fault (Figure 20).

Active and Reactive Power: With addition of UPFC, there is no appreciable change in the values of active and reactive power (Figures 15 & 18).

III. Fault at Sending End of Transmission line

SMIB System without UPFC at Sending End of Transmission line

Resulting curves of the variation of speed of rotor, excitation voltage, fault current, active & reactive power at receiving end are presented in Figures 21 to 23.

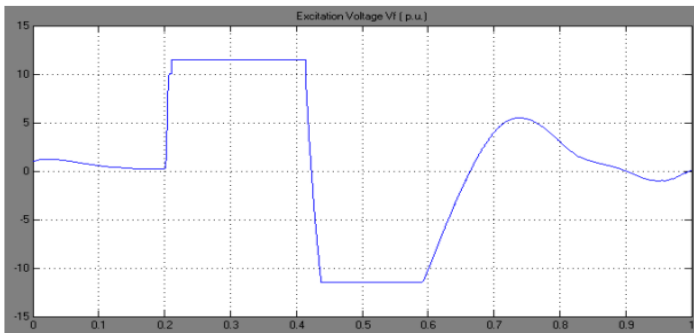


Fig.21 Variation of Excitation Voltage Vs Time

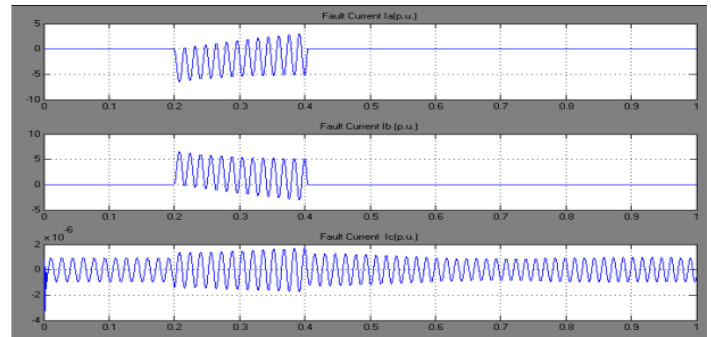


Fig.22 Variation of Fault Current Vs Time

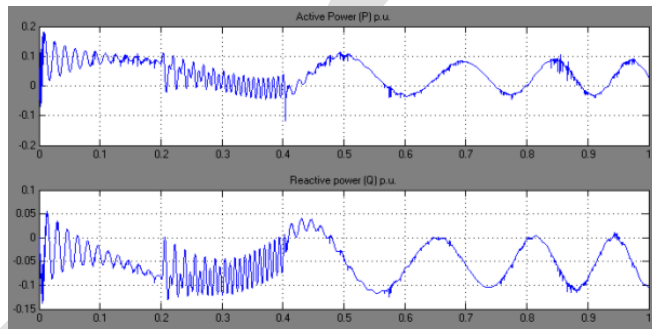


Fig.23 Variation of Active & Reactive Power Vs Time

SMIB System with UPFC at Sending End

Resulting curves of the variation of speed of rotor, excitation voltage, fault current, active & reactive power at receiving end, magnitude & angle of series injected voltage and magnitude & angle of shunt injected voltage are shown in Figures 24 to 28.

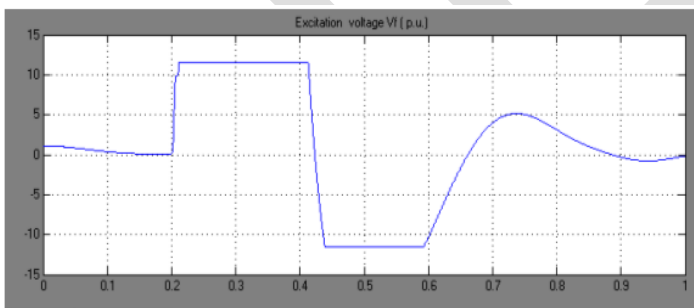


Fig.25 Variation of Fault Current Vs Time

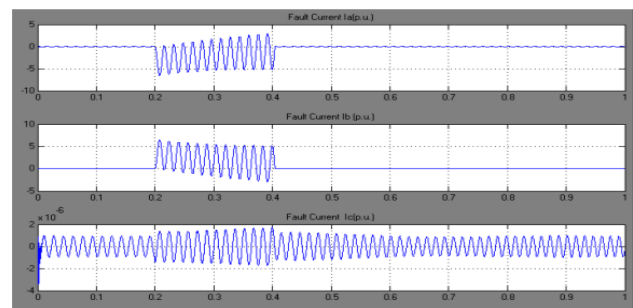


Fig.24 Variation of Excitation Voltage Vs Time

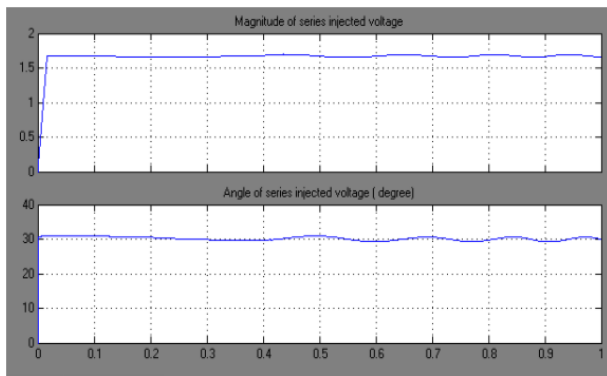


Fig.26 Variation of Active & Reactive Power Vs Time

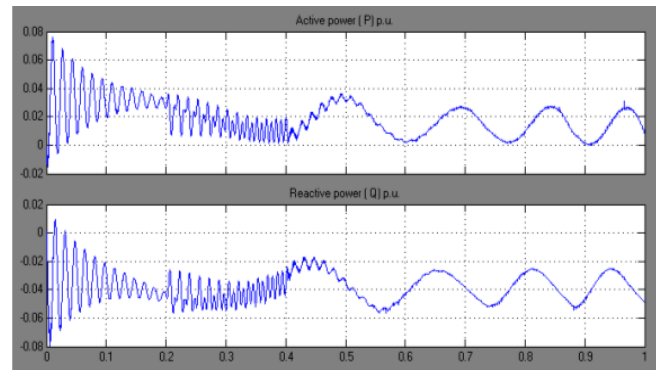


Fig.27 Variation of Series Injected Voltage & its Angle Vs Time

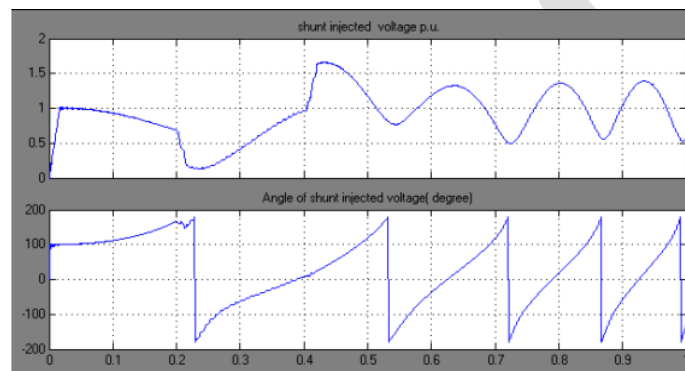


Fig.28 Variation of Shunt Injected Voltage & its Angle Vs Time

Fault Current: With & without UPFC, during fault interval, fault current in phases a, b & c lies between -6.0 to 4.0 p.u., 6.0 p.u. to -4.0 p.u. & 2×10^{-6} p.u. respectively (Figures 22 & 25). So, use of UPFC does not reduce the fault current as UPFC is located at receiving end & fault occurs at sending end of transmission line.

Excitation Voltage: With & without UPFC, before occurrence of fault, excitation voltage has the constant value of 1.0 p.u., during the fault, starting at 1.0 p.u., it has the constant value of 12.0 p.u. and it lies between -12.0 p.u. to 5.0 p.u. after the fault (Figures 21 & 24). So, use of UPFC does not modify the excitation voltage as UPFC is located at receiving end & fault occurs at sending end of transmission line.

Series Injected Voltage: Series part of UPFC injects a voltage of 1.7 p.u. at an angle of 30 degree (Figure 27).

Shunt Injected Voltage: Shunt part of UPFC injects a voltage of 1.0 p.u. to 0.7 p.u. with an angle of 100 to 180 degree before the fault, voltage of 0.2 p.u. to 1.0 p.u. with an angle of -180 to 180 degree during the fault and voltage of 1.7 p.u. to 0.5 p.u. with an angle of 180 to -180 degree after the fault (Figure 28).

Active and Reactive Power: With addition of UPFC, there is no appreciable change in the values of active and reactive power (Figure 23 & 26).

CONCLUSION

Fault current is reduced when fault occurs at middle of the line or receiving end of the line. But there is no change in fault current when fault occurs at sending end of the line as UPFC is kept fixed at receiving end of transmission line.

Excitation voltage is modified with damping out of oscillations when fault occurs at middle of the line or receiving end of the line. But there is no change in excitation voltage when fault occurs at sending end of the line as UPFC is kept fixed at receiving end of transmission line.

On the whole, the transient stability of SMIB is improved at middle of the line & receiving end of the transmission line if UPFC is included at receiving end of the line.

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