Chapter-5

ANALYSIS OF SIMULATION RESULTS

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ANALYSIS OF SIMULATION RESULTS

5.1 WESTERN SYSTEM COORDINATE COUNCIL

The performance of proposed wavelet transform based neuro controller for UPFC is tested on Western System Coordinate Council (WSCC) 9-bus system [67]. Figure 5.1 represents the single line diagram of the 9-bus system.

Fig. 5.1: Single line diagram of WSCC 9-bus system

Fig. 5.2: WSCC 9-bus system without UPFC
The simulation diagram of WSCC 9-bus system without UPFC is represented in figure 5.2. This model is simulated using MATLAB software Simulink environment. The simulation is done in phasor mode.

The UPFC is installed at the midpoint of the transmission line between bus 7 and bus 5. The WSCC 9-bus system with UPFC is shown in figure 5.3. There are six transmission lines present in the system.

![WSCC 9-bus system with UPFC](image)

**Fig. 5.3: WSCC 9-bus system with UPFC**

The installation of UPFC introduces two more new buses viz. bus-10, bus-11 between bus-5 and bus-7 as shown in figure 5.4.
Hence it is required to control the real and reactive flow at bus-11. The bus-10 acts as PCC. Therefore the voltage at bus-10 needs to be maintained constant during the operation of UPFC. The figure 5.5 represents the simulation diagram to calculate the bus-11 real and reactive powers.
5.2 PERFORMANCE DURING REAL POWER CHANGE

To convert the real and reactive powers in MW, MVAr respectively a gain of $10^{-6}$ is used. Initially UPFC is tested for a step change of 8MW in real power with constant reactive power as shown in figures 5.6, 5.7 and 5.8.

**Fig. 5.6:** Variation of $P$ for step increase of 8MW in real power

**Fig. 5.7:** Variation of $Q$ for step increase of 8MW in real power
Fig.5.8: The voltage profile during 8MW increase in real power

Initially real power reference is 82 MW and reactive power reference is 1.8 MVAr. The real power is changed from 82MW to 90MW at 5 second. The power through bus 11 cannot be reaching to the set value if there is no coordination between the shunt and series controllers. With coordination it can be achieved. It is further observed that wavelet based controllers can quickly damped out and the bus voltage is maintained more or less constant.

Fig. 5.9: Variation of P for step decrease of 6MW in real power
The variation in real, reactive powers and voltage changes for a step decrease of 6MW in real power is shown in figures 5.9, 5.10 and 5.11. Without coordination The figure 6.9 shows the variation of bus-10 voltage during this variation. The bus-10 voltage is nearly constant.
5.3 PERFORMANCE DURING REACTIVE POWER CHANGE

Fig. 5.12: Variation of P for step increase of 6MVAR in reactive power

The information about the changes in real and reactive powers of bus-11 during a step increase 6MVAR in reactive power is shown in figures 5.12 and 5.13. The step change in reactive power causes large variation in real and reactive powers if there is no coordination between shunt and series controllers.

Fig. 5.13: Variation of Q for step increase of 6MVAR in reactive power
Fig. 5.14: The voltage profile during 6MVar increase in reactive power

The variation of bus-10 voltage during a step increase reactive power is shown in figure 5.14. From the figure 5.14 it is observed that, the increase in reactive power decreases the bus voltage if the coordination is not present between shunt and series controllers. Once the coordination is present, then the bus voltage is maintained nearer to the prescribed value.

Fig.5.15: Variation of P for step decrease of 6MVar in reactive power
The information about the changes in real and reactive power of bus-11 during a step decrease of 6MVAr in reactive power is given in figures 5.15 and 5.16.

The variation of bus-10 voltage during this change is shown in figure 5.17. The coordination between the controllers keeps the bus voltage near to the prescribed value.
5.4 PERFORMANCE OF UPFC DURING DYNAMIC FAULTS

A fault is created on the line between bus-8 and bus-9 at time 10 second and is cleared by the operation of breaker and auto reclosing after clearing the fault at time 10.08 second. It is required to control the real and reactive powers in the transmission line between bus-5 and bus-7. Hence the UPFC is inserted between bus-5 and bus-7. The generator 1 is considered as slack bus.

5.4.1 Performance of UPFC during LG fault

Fig. 5.18: Line currents during LG fault

Fig. 5.19: Phase voltages during LG fault
The phase voltages and line currents of the faulted line are shown figures 5.18 and 5.19 respectively during single line to ground fault.

**Fig. 5.20:** Relative rotor angle oscillations of Generator 2(G2) with respect to Generator 1(G1) during LG fault.

**Fig. 5.21:** Relative rotor angle variations of Generator 3(G3) with respect to G1 during LG fault

The rotor angle oscillations of generator 2(G2) with respect to generator 1(G1) and generator 3(G3) with respect to generator 1 are shown in figures 5.20 and 5.21 respectively. From the above diagrams
it can be concluded that the DWT based UPFC can quickly damp out the rotor oscillations than the conventional neural network based UPFC.

Fig. 5.22: Active power flow at bus 10 during LG fault

Fig. 5.23: Reactive power flow at bus 10 during LG fault

The active power flow and reactive power flow at bus 10 is shown in figures 5.22 and 5.23 respectively. The DWT based UPFC is injecting less voltage in the line to improve the active power flow through the line to damp out the oscillations quickly.
The profile of the series injected voltage is depicted in figure 5.24. From the above figure it is evident that with coordination control the injected voltage is less which can increase the power flow through the line.

6.4.2 Performance of UPFC during LLG fault

![Fig. 5.25: Line currents during LLG fault](image)
The line currents and phase voltages of the faulted line are shown figures 5.25 and 5.26 respectively during double line to ground fault.

Fig. 5.26: Phase voltages during LLG fault

**Fig.5.27: Relative rotor angle oscillations of G2 with respect to G1 during LLG fault**
The rotor angle oscillations of generator 2 with respect to generator 1 and generator 3 with respect to generator 1 during a double line to ground fault are shown in figures 5.27 and 5.28 respectively. From the above diagrams it can be concluded that the DWT based UPFC can quickly damp out the rotor oscillations than the conventional neural network based UPFC.
The active power flow and reactive power flow at bus 10 is shown in figures 5.29 and 5.30 respectively. The DWT based UPFC is injecting less voltage in the line to improve the active power flow through the line to damp out the oscillations quickly. Figure 5.31 represents the series injected voltage during LLG fault.
6.4.3 Performance of UPFC during LLLG fault

The line currents and phase voltages of the faulted line are shown figures 5.32 and 5.33 respectively during triple line to ground fault.
The rotor angle oscillations of generator 2 with respect to generator 1 and generator 3 with respect to generator 1 are shown in figures 5.34 and 5.35 respectively. From the above diagrams it can be concluded that the DWT based UPFC can quickly control the real and reactive power flows and damp out the rotor oscillations than the conventional neural network based UPFC.
Fig. 5.36: Active power flow at bus 10 during LLLG fault

Fig. 5.37: Reactive power flow at bus 10 during LLLG fault

Fig. 5.38: Series injected voltage during LLLG fault
The active power flow and reactive power flow at bus 10 is shown in figures 5.36 and 5.37 respectively. The magnitude of the series injected voltage is shown in the figure 5.38. The DWT based UPFC is injecting less voltage in the line to improve the active power flow through the line to damp out the oscillations quickly.

5.5 CONCLUSION

By observing the figures from 5.20 to 5.38 it can be concluded that the wavelet based UPFC can dampout the rotor oscillations effectively than conventional neuro controller. The power flow control is one of the solution to improve the power quality[68]. Therefore the wavelet based controller can change the active power reference signal quickly during dynamic fault condition to control the power flows in the lines. Hence the neural network based UPFC with wavelet filter is controlling the power flows effectively in the line with coordination between the neuro and fuzzy controllers controllers than without coordination.