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Implementation of UPFC for Improvement of Power Stability

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Abstract: The FACTS device which is usually called Unified Power Flow Controller (UPFC) can give synchronous control of basic power system parameters like voltage, flow of active power, flow of the reactive power, the impedance and the phase angle. In this research work, simulation models for various multi machine systems are carried out, e.g. a hybrid power system, a power system with two synchronized hydro power stations etc., without UPFC &with UPFC presented at the load end of the power system, has been developed. Simulation models have been intergrated into MATLAB based Power System Toolbox (PST) for analysis of their voltage stability. The study of these models were for voltage, active power flow, and reactive power flow and phase angle, with and without UPFC. The results of the power system with UPFC and without UPFC are compared.
Key Words: UPFC, active, reactive, phase.

I. INTRODUCTION

Now a day power system is becoming more complex and interconnected for improving power utility so it is necessary to maintain reliability and security. Series compensation is a direct method to increase transmission capability by reducing effective reactance of line. However, a power transfer capability of long transmission line is limited by stability consideration [1-5]. Oscillation of generator angle or line angle are generally linked with the transmission system disturbances and they occur due to step changes in load, immediate change of generator output, transmission line switching and short circuit [6]. Various modes of rotor oscillation are local mode, intra-area mode and inter-area mode. The rotor swings oscillation frequency varies from 0.2 to 4 Hz [7]. The problem of Instability in power systems may cause partial or full blackout which can be divided into three main categories, i.e. voltage, phase angle and problem related to frequency. [8]. In early age this signal instability problem was solved by amortisseurs implemented in generator rotors, later with the application of fast excitation system this was solved by development & utilization of Power System Stabilizer (PSS) and however in modern power system due to the connection of power grids in vast area, for inter area oscillation damping due to the ability of controlling line impedence, power flow and bus voltage, Flexible AC transmission Systems (FACTS) devices implementation offers an alternative solution [9-13].

II. UPFC PRINCIPLE AND MODES OF OPERATION

The Unified Power Flow Controller is a sort of multi-function controller which can play an important role in solving various transmission system problems. UPFC can control, continously or selectively, all the parameter that effect power flow in the transmission line i.e. voltage, impedance and phase angle. An alternate name is given to it i.e. "UNIFIED" it can independently control the real and reactive power flow in the line. The main aim of this chapter is to give details of the construction, principles and different modes of operation of the UPFC. For simplicity a simple single-phase circuit is considered in this chapter to describe the different modes of the UPFC operation.

The UPFC concept was proposed by Gyugyi [5] in 1992 within the concept of using converter based FACTS technology. In this circuit two voltage source inverters are connected back-to-back through a common d.c. link, as shown in Figure 1.

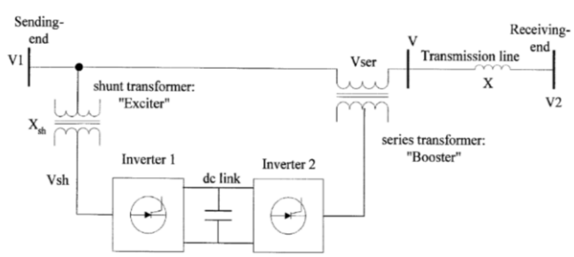

Fig.1 Schematic diagram of a UPFC system.

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The UPFC injection model is derived enabling three parameters to be simultaneously controlled. They are namely the shunt reactive power, Qcon v*i*, and the magnitude, r, and the angle, 7, of injected series voltage *Vse*.

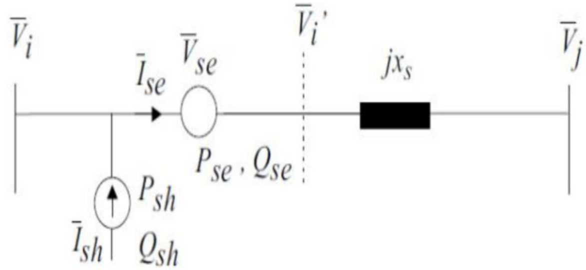

Fig.2 The UPFC electric circuit arrangement

III. SIMULATION & MODELLING

The advantages of the UPFC and its injection model with different types of control methods contributing to changes of the voltage stability & power transfer capability are explored by analyzing a hybrid system consisting of a combination of a thermal power generating station, a hydro power generating station and a wind farm. 5 buses system is shown in Fig.1 and the voltage, active and reactive power flow is checked on all the five buses. The system model is observed with two hydro power generating stations and Power system consisting of a combination of a hydro power generating station & a thermal power generating station is designed for performance analysis of UPFC. Now the work is extended with the addition of wind power generating farm, with and without UPFC. A basic model is shown below.

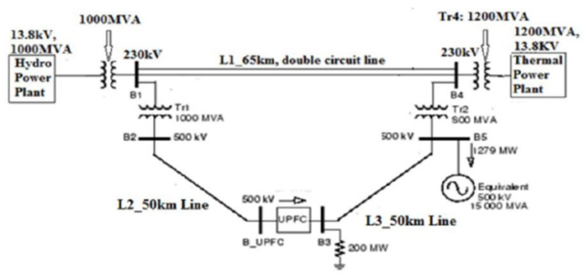

Fig 3 Single Line Diagram of a Hybrid Multi Machine Power System with UPFC

Cases have been studied With Two Hydro Generating Stations, with a hydro power station and a thermal power station, hybrid power systems are Under Normal Condition, Under 3-Phase to Ground Fault Condition, Using UPFC under Normal Condition, Using UPFC under 3-Phase to Ground Fault Condition

IV. METHODOLOGY AND DIFFERENT BLOCKS USED IN CREATING SIMULINK MODEL

A. *Methodology*

The methodology used for designing the UPFC based Simulink model is obtained from Power System Simulink Tool (PSST). Recently PSST may be used in the analysis and research for calculation of power flow, small signal stability analysis, time-domain simulation. PSST is easy to use and has good extensibility and easy to use, and it is alternative to the defect of conventional large-scale commercial software, that it is difficult to add new components to them, therefore PSST can add user defined new modules seamlessly in the form of Simulink module. As per requirement of actual simulation accuracy PSST can select appropriate Simulink solver flexibly for the simulation while the simulation model does not need to be modified. To verify the effectiveness and accuracy of simulation results by PSST, taking New England system under a certain fault condition for example, the time-domain simulation results by PSST are analyzed and compared with time-domain simulation results of the same example by powersystem toolbox (PST).

B. *Basic Building Blocks*

The Unified Power Flow Controller (UPFC) is the most versatile member of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids [1]. The UPFC consists of combination of a shunt controller

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(STATCOM) and a series controller (SSSC) which are interconnected through a common DC bus as illustrated in the figure below.

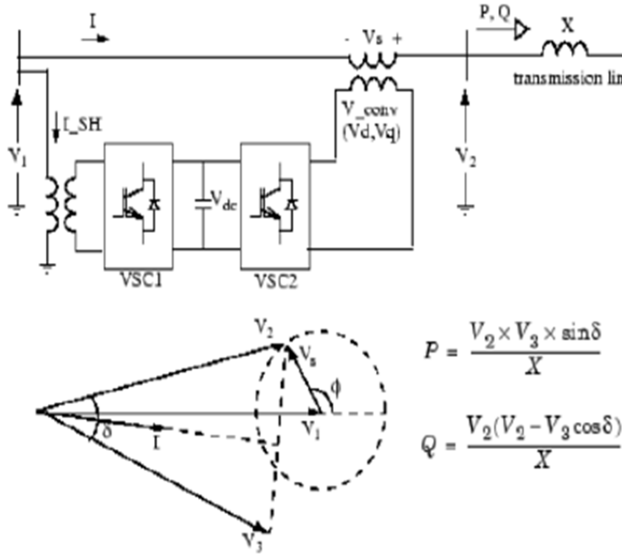

Fig 4 Unified power flow control

The UPFC provides more flexibility than the SSSC for control of the active and reactive power of line because the active power can be transferred from the shunt converter to the series converter, through the DC bus. Contrary to the SSSC where the injected voltage Vs is constrained to stay in quadrature with line current I, the injected voltage Vs can now have any angle with respect to line current. If injected voltage Vs is kept constant and its phase angle [[PHI]] with respect to V1 is changed from 0 to 360 degrees, the locus described by the end of vector V2 (V2=V1+Vs) is a circle as shown on the phasor diagram. As [[PHI]] is varying, the phase shift d between voltages V2 and V3 at the two line ends also varies. It shows that the active power P and the reactive power Q are transmitted at one line end can be controlled. The UPFC controllable region in the P-Q plane is the area enclosed by an ellipse as shown on the figure below.

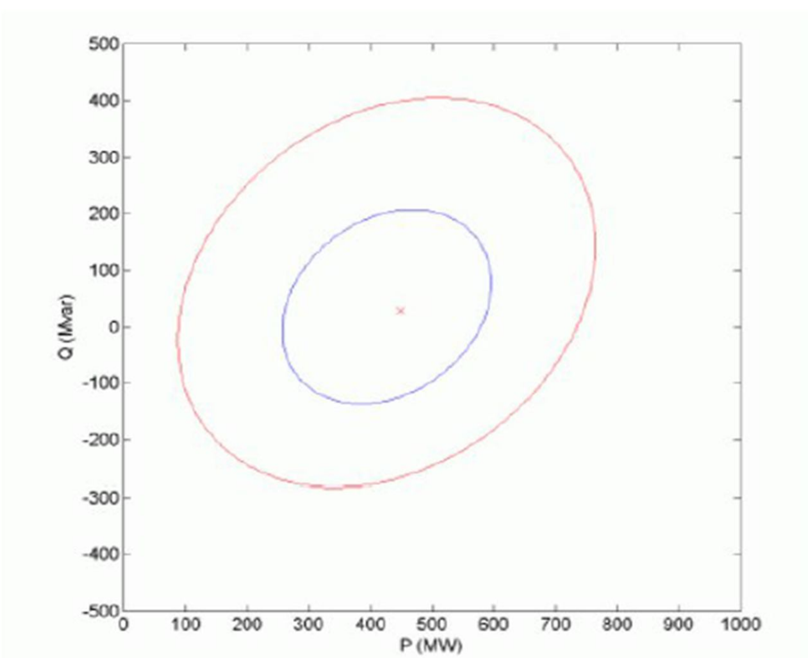

Fig 5 UPFC controllable region in P-Q plane

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This figure was obtained with a 100 MVA UPFC controlling active and reactive power at one end of a 500 kV, 200 km transmission line. The parameters used in it are as follows: length of line = 200km; reactance of line = 0.35 O /km
System voltage: 500 kV infinite sources V1 and V3; V1=1.0 pu, 0 degree; V3= 1.0 pu, - 7.22 degrees
Series and shunt converter rating: 100 MVA
In case of Series converter: nominal injected voltage = 10% of nominal line-to-ground voltage (28.9 kV); impedance (transformer leakage reactance and filters) = 0.15 pu
With voltage V3 lagging V1 by 7.22 degrees, the natural power flow without compensation is 450 MW or 50% of the line surge impedance loading (SIL=900 MW). With an injected voltage Vs = 0.1 pu any operating point inside the larger ellipse can be obtained and active power can be varied by approximately +/- 300 MW. To allow control of the active and reactive power of line, the UPFC provides an additional degree of freedom.The voltage V1 is controlled by shunt converter which is operating as STATCOM by absorbing or generating reactive power. Both the series and shunt converters use a Voltage-Sourced Converter (VSC) is connected on the secondary side of a coupling transformer. The VSCs use forced-commutated devices such as (GTOs, IGBTs or IGCTs) to synthesize a voltage from a DC voltage source. The common capacitor connected on the DC side of the VSCs acts as a DC voltage source. Two VSC technologies can be used for the VSCs: VSC using GTO-based square-wave inverters and other is special interconnection transformers. Here four three-level inverters are used to make a 48-step voltage waveform. For neutralizing harmonics contained in the square waves generated by individual inverters some special interconnection T/F are used. In this form of VSC, the fundamental component of voltage is proportional to the voltage Vdc. So Vdc has to changed for controlling the injected voltage.

V. FINAL RESULTS AND DISCUSSION

A. *Case 1:Considering Two Hydro Generating Stations*

1) *In Case of Normal Condition:* SIMULINK model for two hydro power plants of rating 1000MVA & 1200MVA respectively connected to a 200MW load via transmission lines. Appendix-A provide rating of various components used in it. The active power, reactive power, voltage and phase angle curves with respect to time at all five buses (B1 B2 B3 B4 B5) are shown in fig.6-9.

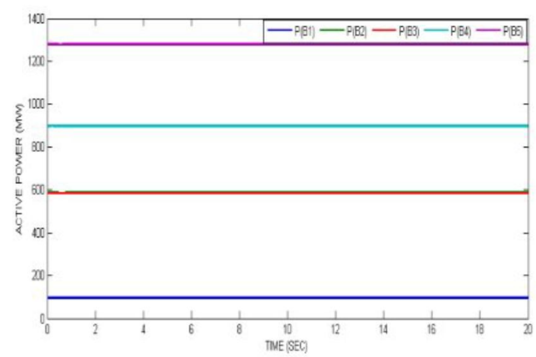

Fig. 6 Active Power at Different Bus

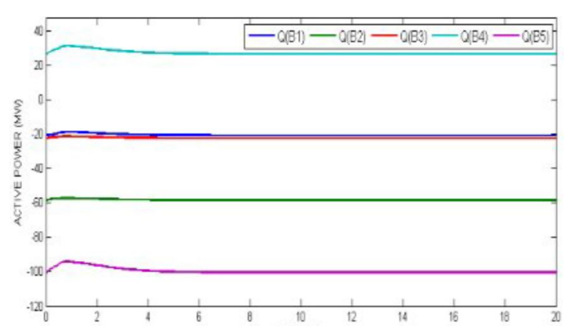

Fig. 7 Reactive Power of Different Bus

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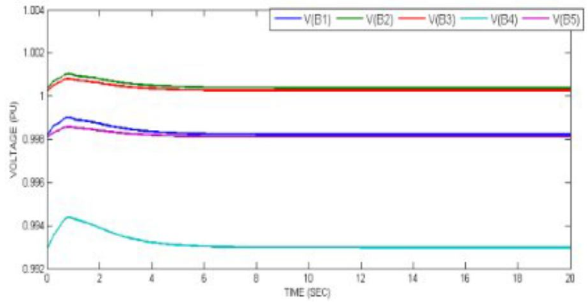

Fig. 8 Different Buses voltage

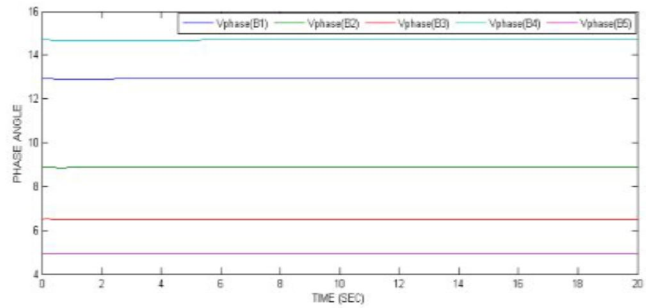

Fig. 9 Phase Angle at Different Buses

2) *Under 3-Phase to Ground Fault Condition:* A three phase to ground fault is created at t=10 sec for 0.08 sec at bus 2. The active and reactive power, voltage and phase angle curves with respect to time at different buses (B1 B2 B3 B4 B5) are illustrated in following fig. 10-13

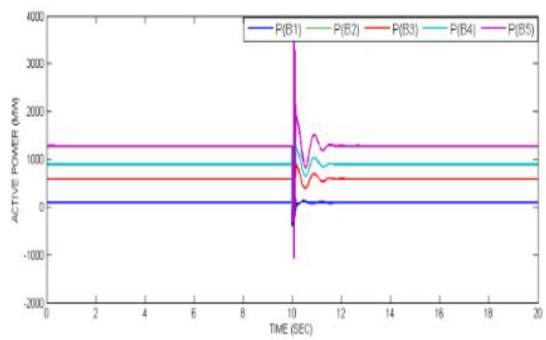

Fig. 10 Active Power At Different Bus

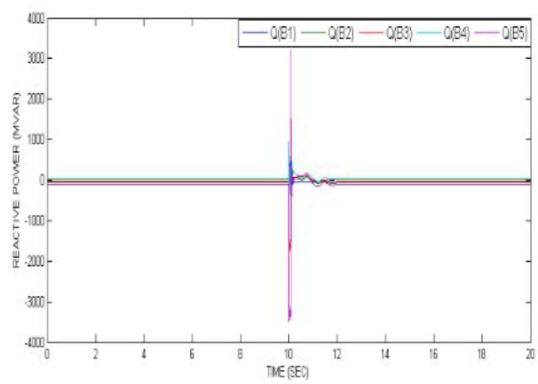

Fig.11 Reactive Power At Different Bus

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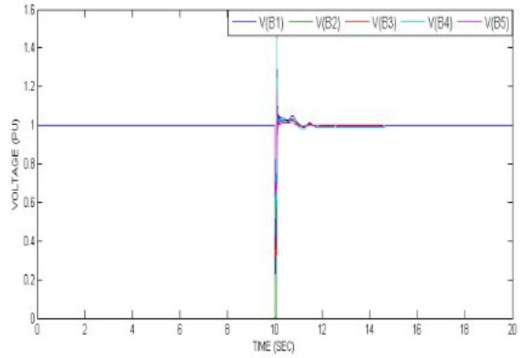

Fig. 12 Voltage At Different Bus

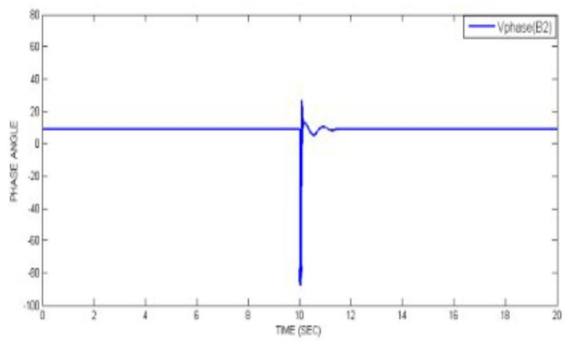

Fig. 13 Phase Angle At Different Buses

3) *Using UPFC under Normal Condition:* The UPFC SIMULINK model has been connected to bus B5. UPFC is turn on at t=8sec. and the power flow is increased from 5.87 pu to 6.87 pu. Appendix-B will provide rating of various components. The active and reactive power, voltage and phase angle at different buses (B1 B2 B3 B4 B5) with respect to time are illustrated in fig.14-17. It is observed that UPFC has increases the level of power flow in all the buses under normal conditions (without faults) which is shown in observations tables:

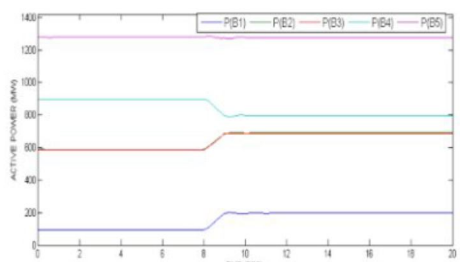

Fig. 14 Active Power at Different Bus

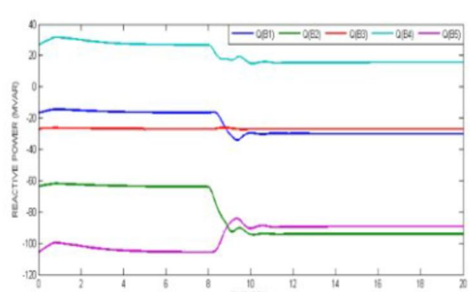

Fig. 15 Reactive Power at Different Bus

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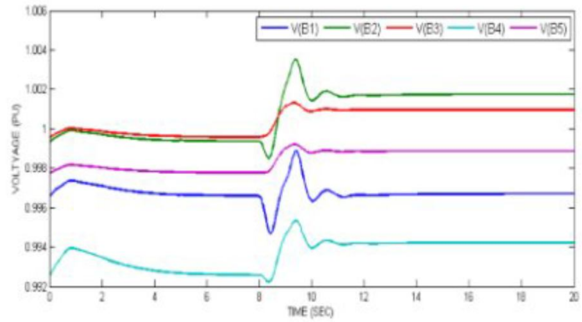

Fig.16 Voltage at Different Bus

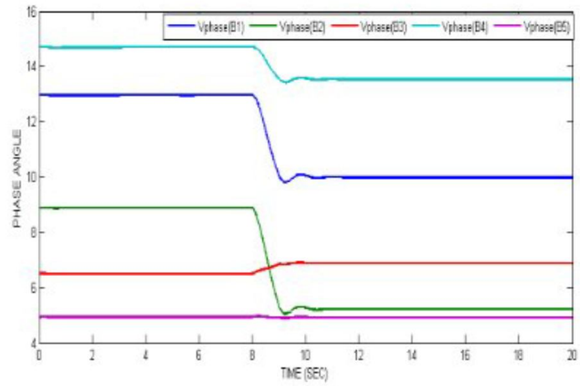

Fig. 17 Phase Angle at Different Buses

4) *Using UPFC under 3-Phase to Ground Fault Condition:* A three phase to ground fault is created at t=10 sec for 0.08 sec at bus 2. Appendix-B will provide rating of various components. The UPFC is turn on at t=8sec and the power flow in the system goes from 5.87pu to 6.87pu. The active power, reactive power, voltage and phase angle curves, voltage at UPFC with respect to time at all five buses (B1 B2 B3 B4 B5) are illustrated in fig. 18-21.

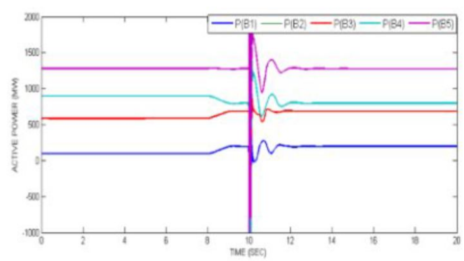

Fig. 18 Active Power at Different Bus

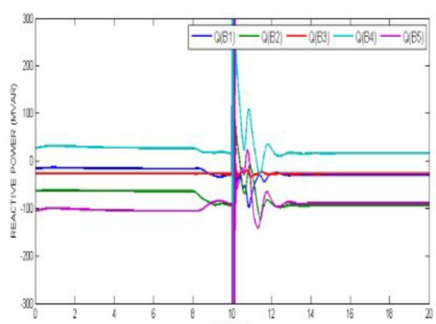

Fig. 19 Reactive Power at Different Bus

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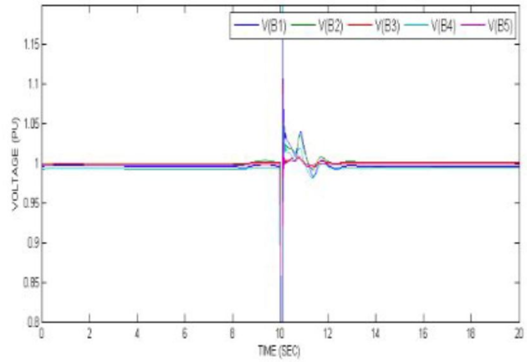

Fig. 20 Voltage at Different Bus

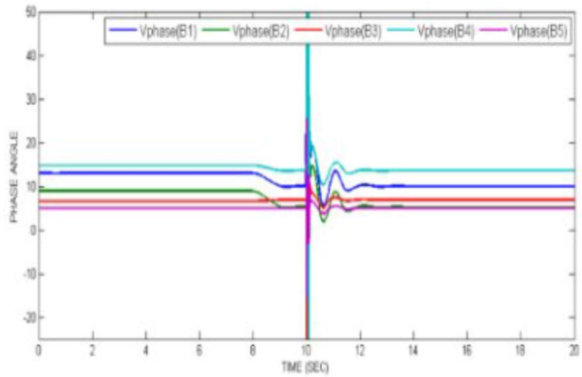

Fig. 21 Phase Angle at Different Buses

B. *Cases-2 with a Hydro Power Station and a Thermal Power Station*

1) *Under Normal Condition:* SIMULINK model for a power system with a hydro power station (1000MVA) & a thermal power station (1200MVA), connected to a 200MW load via transmission lines. The ratings of the various components used are given in appendix-C. The phase angle curves with respect to time at different buses (B1 B2 B3 B4 B5) are shown in fig. 22.

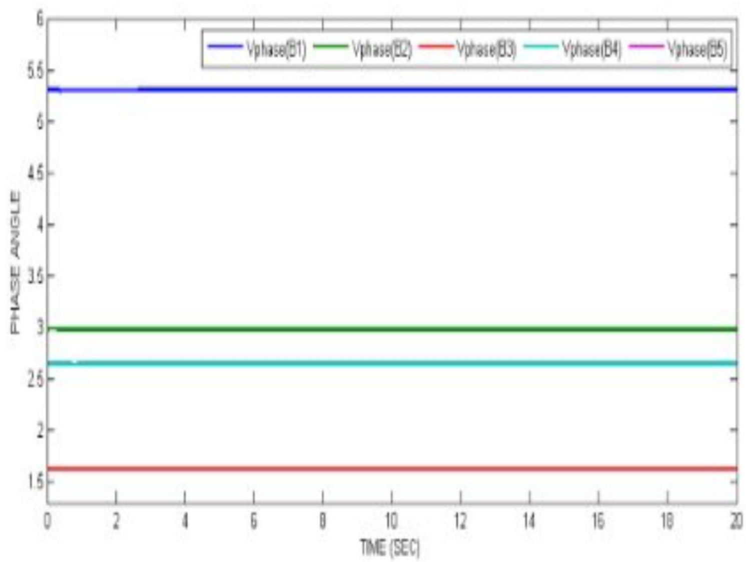

Fig. 22 Phase Angle at Different Bus

2) *Under 3-Phase to Ground Fault Working Condition:* A three phase to ground fault is created at t=10 sec for 0.08 sec at bus 2. The phase angle curves with respect to time at different buses (B1 B2 B3 B4 B5) are shown in fig.23

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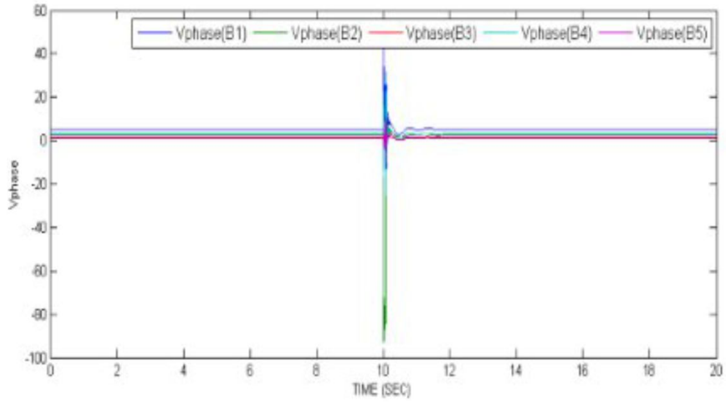

Fig. 23 Phase Angle at Different Buses

3) *Using UPFC under Normal Working Condition:* The UPFC SIMULINK model has been connected to bus B5 as shown in fig. 6.6.8. UPFC is turn on at t=8sec. and the flow of power is increased from 5.87 pu to 6.87 pu. Appendix-D can be used for the rating of various components used.The phase angle at different buses (B1 B2 B3 B4 B5) with respect to time are illustrated in fig. 24. It is observed that UPFC has increases the level of flow of power in all the buses under normal conditions (without faults) as shown in observations table.

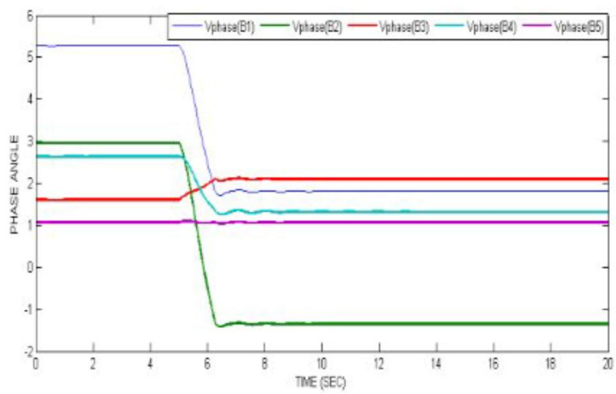

Fig. 24 Different buses Phase Angle

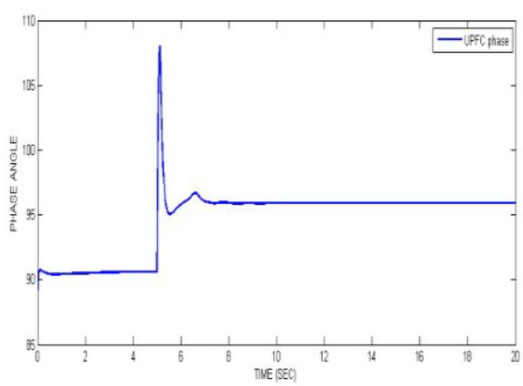

Fig. 25 Phase Angle of UPFC

4) *Use of UPFC under 3-Phase to Ground Fault Working Condition:* A three phase to ground fault is created at t=10 sec for 0.08 sec at bus 2 as shown in fig. 6.6.9. The ratings of the various components used are given in appendix-D. The UPFC is made on at t=8sec and the power flow in the system goes from 5.87pu to 6.87pu. The phase angle curves, voltage at UPFC with respect to time at all five buses (B1 B2 B3 B4 B5) are provided in fig. 26.

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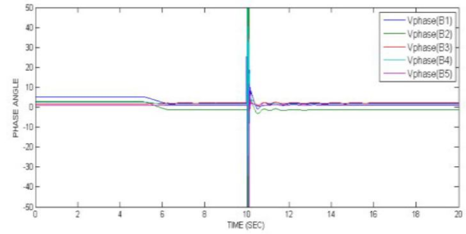

Fig. 26 Phase Angle at Different Buses

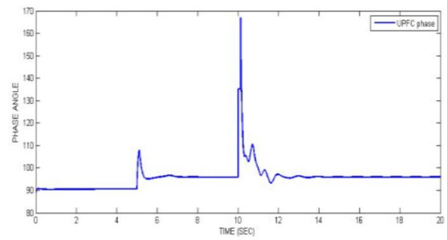

Fig. 27 Phase Angle at UPFC

C. Case-3 Hybrid Power Systems

1) *Under Normal Condition:* SIMULINK model for a hybrid power system, which is connected to a load of 200MW via transmission line. The ratings of the various components used are given in appendix-E. The phase angle curves at different buses (B1 B2 B3 B4 B5) are shown in the fig.28

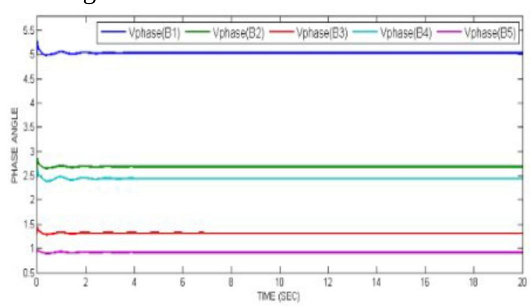

Fig. 28 Phase Angle at Different Buses

2) *Under 3-Phase to Ground Fault Condition:* A three phase to ground fault is made at t=10 sec for 0.08 sec at bus 2. The phase angle curves with respect to time at all five buses (B1 B2 B3 B4 B5) is shown in fig. 29.

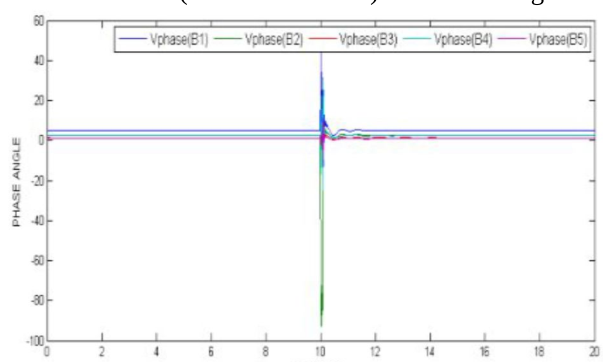

Fig. 29 Phase Angle at Different Buses

3) *Use of UPFC under Normal Condition:* The UPFC SIMULINK model is connected to bus B5. UPFC is turn on at t=8sec. and the flow of power is increased from 5.87 pu to 6.87 pu. Appendix-F is used for rating of various components. The phase angle at different buses (B1 B2 B3 B4 B5) with respect to time are shown. It is observed that UPFC increases the flow of power level in all the buses under normal conditions (without faults) as illustrated in observations.

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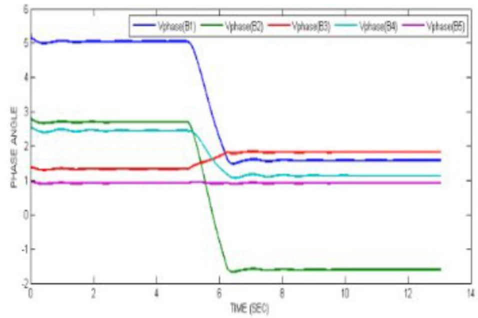

Fig. 30 Phase Angle of Different Buses

4) *Use of UPFC under 3-Phase to Ground Fault Condition:* A three phase to ground fault is made at t=10 sec for 0.08 sec at bus 2. Appendix-F is used for rating of various components. The UPFC is turn on at t=8sec and the power flow in the system goes from 5.87pu to 6.87pu. The phase angle curves at all five buses (B1 B2 B3 B4 B5) is shown in fig.31.

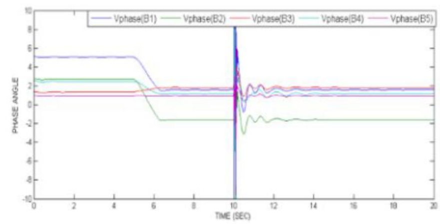

Fig. 6.12.8 Phase Angle of Different Buses

VI. CONCLUSION & FUTURE SCOPE

A. Conclusion

It is observed that with the help of the unified power flow controller, the active power flow in all the buses are improved although UPFC has significant effect on reactive power flow, voltage and phase angle of the system. UPFC plays an important role even when the fault occurred at the other bus. It is also observed that the fault clearing timing and also the magnitude of oscillations is less when the system is connected with UPFC. The research work shows that UPFC has no worse or ill effect on any of the line connected to the hybrid power system. The unified power flow controller (UPFC) is a versatile controller that helps to control all the parameters (voltage, impedance, and phase angle) in a transmission line which ultimately decides the power flow through the line. The UPFC plays an important role in voltage regulation, phase angle regulation and thus in the power flow regulation in the system. In this research work, simulation models for performance analysis in a 5 bus system with and without UPFC have been made. The system models are observed with two hydro power generating stations and Power system consisting of a combination of a hydro power generating station & a thermal power generating station is designed for performance analysis of UPFC. The work is extended with the addition of wind power generating farm, with and without UPFC. The analysis is done on the basis of active power flow, reactive power flow, voltage, and phase angle of the system. From the results and observations shown in the previous chapter, following conclusions are obtained.

B. Future Scopes

UPFC controls over-voltage condition in the distribution line. However, it is important to control distribution line voltage optimally when the flow of power reverse. Also, it needs to research why line voltage angle leads source voltage angle when the reactive power flows. The work can be extended

1) To develop a better control technique for the UPFC.
2) To a multi machine system for congestion management problems.
3) To a system with more no of buses.
4) To be used with artificial neural network and the combination of fuzzy-neural to improve the dynamic performance of UPFC.

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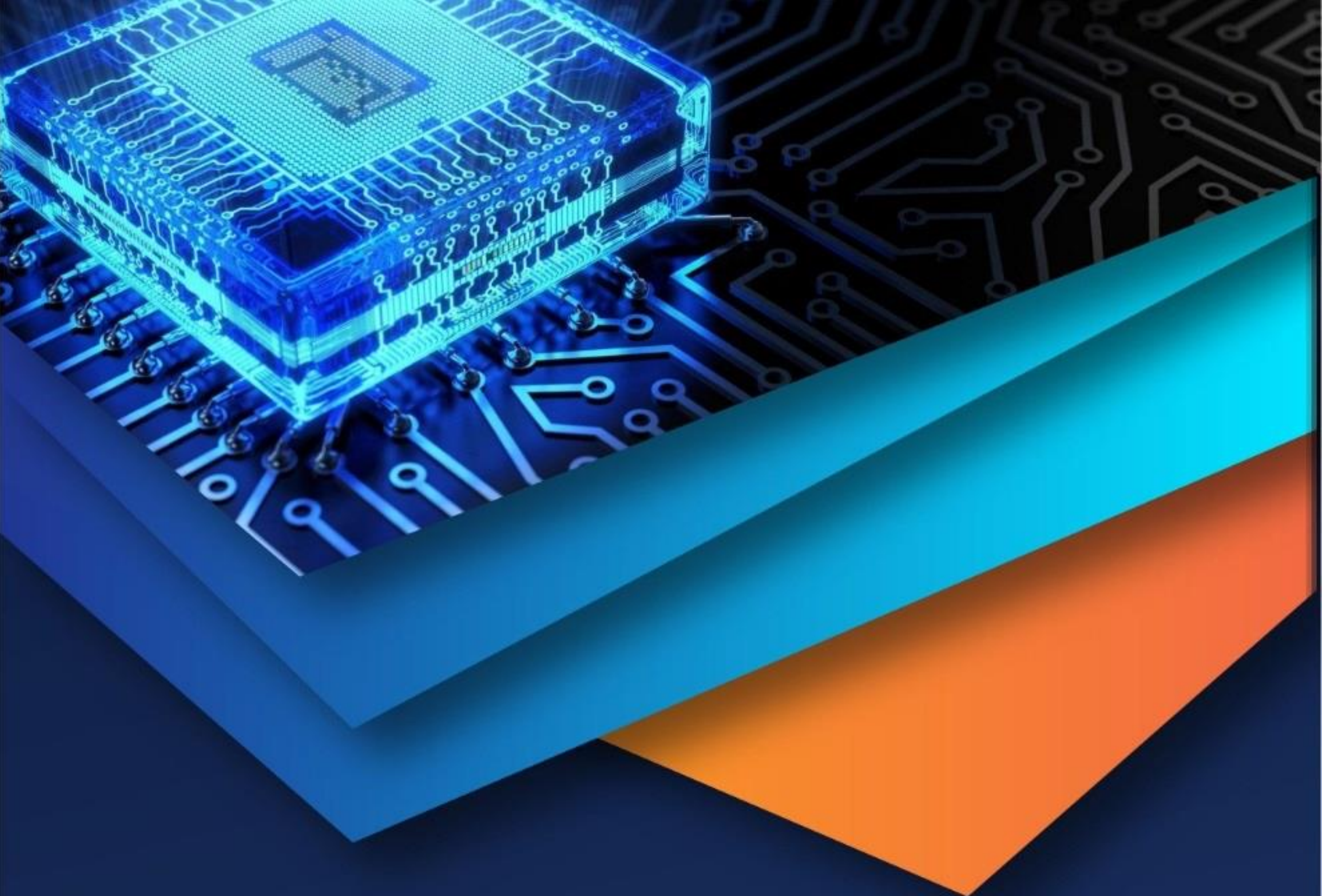

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