Load Flow Analysis with UPFC under Unsymmetrical Fault Condition

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Abstract

This paper addresses the comparative load flow analysis with and without Unified Power Flow Controller (UPFC) for six buses, three phase transmission line under unsymmetrical faults (L-G, L-L and L-L-G) in simulation model. Unified Power Flow Controller (UPFC) is a typical Flexible AC Transmission System (FACTS) device playing a vital role as a stability aid for large transient disturbances in an interconnected power system. The main objective of this paper is to improve transient stability of the six bus system. Here active and reactive power on load bus of the system considered has been determined under different fault conditions. UPFC has been connected to the system and its effects on power flow and voltage profile of test system has been determined with various line data and bus data for six buses, three lines power system and simulation model by using simulation toolbox has been developed. In this work a versatile model is presented for UPFC inherent order to improve the transient stability and damp oscillation.

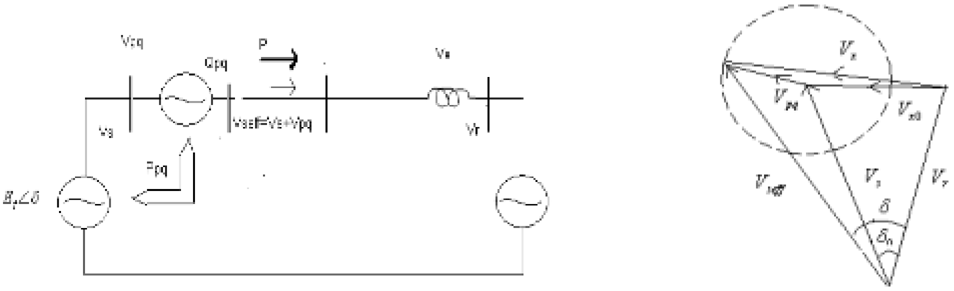
Index Terms – Unified Power Flow Controller (UPFC), Control, simulation, transients, line to ground fault (L-G), double line to ground fault (L-L-G), double line fault (L-L)

I. INTRODUCTION

The Unified Power Flow Controller (UPFC) concept was proposed by Gyugi in 1991. The UPFC was devised for the real-time control and dynamic compensation of AC transmission system, providing multifunctional flexibility required to solve many of the problems facing the power delivery industry within the framework of traditional power transmission concepts.UPFC is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line (i.e. voltage impedance and phase angle). Unified Power Flow Controller (UPFC) is a typical Flexible AC Transmission System (FACTS) device playing a vital role as a stability aid for large transient disturbances in an interconnected power system, UPFC for improving the performance of the power system. Two objective functions are simultaneously considered as the indexes of the system performance, maximization of system load ability in system stability margins (voltage stability index and line stability factor) and minimization of active power losses in transmission line by considering installation cost of UPFC controller [1-2]. The transient experiments proved that UPFC can improve the stability of power grid. The MATLAB simulation results are taken to prove the capability of UPFC on power flow control and the effectiveness of controllers on the performance of UPFC in the different operating modes [3-4]. A unified power controller offers substantial advantages for static and dynamic operation of power system. But it also brings with its major challenges in power electronic and power system design [5-6]. A transient stability and power flow model of a UPFC and a different control strategy proposing novel, efficient and simple controls for this controller. Proposed model accurately represents the behaviour of the controller in quasi-steady state operating conditionally and it is adequate for transient as well as steady state stability analysis of power systems validated with the help of EMTP (Electromagnetic Transient Programme) [7]. The UPFC control can also improve the system performance under faulty conditions [8] in power system control; there is the practical concern of optimal location of UPFC to be selected. Latest computing tools like Genetic algorithm could be used for this purpose [9]. The risk of angle instability is evident due to the sizable length of the 500kV transmission lines, the fast increase of load demands the resulting considerable amount of power transmitted through these lines. The angle stability must be studied in detail in order to ensure a security and safety in the operation and to find the solutions to improve the stability of the system [10]. The Lyapunov stability theory and the injection model of UPFC have been used to make a supplementary control loop in order to improve first swing transient stability [11]. A control strategy is developed to achieve maximal improvement in transient stability, and damp the rotor oscillation using UPFC, which involves maximization and minimization of power flow in a line. In general, this involves the solution of a constrained optimization problem at each step to determine the voltage and current injected by the UPFC [12]. Current injection model of UPFC is used to investigate its effect on load flow and loss reduction in power system and Newton-Raphson algorithm is modified to consider the benefits of having UPFC in the power system. This method suggests the optimum place for installing UPFC in order to have minimum loss in the system [13]. To avoid instability and loss of DC link capacitor voltage during transient conditions, a new real power coordination controller has been designed. The need for reactive power coordination controller for UPFC arises from the fact that excessive bus voltage excursions occur during reactive power transfers [14-15].

II. OPERATING PRINCIPLE

The UPFC is generalized Synchronous Voltage Source (SVS) represented at the fundamental (power system) frequency voltage phasor Vpq $(0 \leq V_{PQ} \leq V_{pq\ max})$ and angle ρ $(0 \leq \rho \leq 2\pi)$ in series with transmission line, for the elementary two machine system as shown in Fig.1.In this functionally unrestricted operation, which clearly includes voltage and angle regulation, the SVS generally exchanges both reactive and real power with the transmission system, an SVS is able to generate only the reactive



(a) Two machines system transmission line (b) Phasor diagram

Fig.1 Conceptual representation of UPFC inherent a two machine power system and phasor diagram.

In the presently used practical implementation, the UPFC consists of two voltage-sourced converters as illustrated in Fig.2, these back to back converters, labelled “converter 1” and “converter 2” in the figure are operated from a common DC link provided by DC storage capacitor. UPFC is an ideal AC to AC power converter in which real power can freely flow in either direction between the AC terminals of the two converter, and each converter can independently generate (or absorb) reactive power at its own AC output terminal. The basic function of the converter 1 is to supply or absorb the real power demanded by converter 2 at the common DC link to support the real power exchanged resulting from the series voltage injection. This DC link power demand of converter 2 is converted back to AC by converter 1 and coupled to the transmission line via a shunt connected transformer. In addition to the real power need of converter 2, converter 1 can also generate or absorbed controllable reactive power, if it is desired and thereby provide shunt independent shunt reactive compensation for the line. The important thing is that whereas there is a closed direct path for the real power negotiated by the action of series voltage injection through converter 1 and back to the line, the corresponding reactive power exchanged is supplied or exchanged is supplied or absorbed locally by the converter 2 and therefore does not have to be transmitted by the line. Thus converter can be operating at a unity power factor or be controlled to have a reactive power exchanger with line independent of the reactive power exchanged by converter 2. Obviously, there can be no reactive power flow through the UPFC DC link.

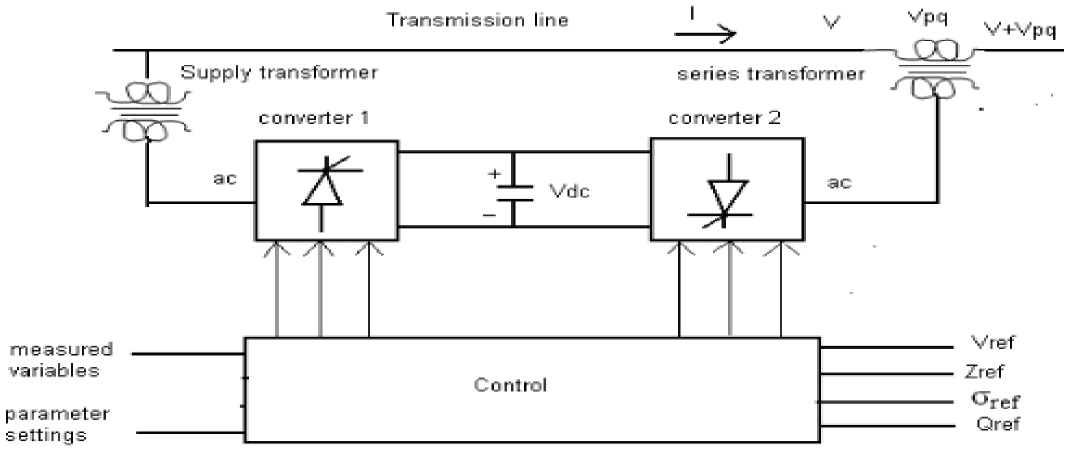


Fig.2 Implementation of the UPFC by two back –to- back voltage sourced converters.

III. CONTROL SCHEME

The UPFC control system may be divided functionally into inverter (or converter) control and functional operational control. The internal controls operate the two converters so as to produce the commanded series injected voltage and, simultaneously, the desired shunt reactive current. The internal controls provide gating signal to the converter valves so that the converter voltages will properly respond to the internal reference variables i_{pRef}, i_{qRef} and $\bar{v}_{pqRef}$ inherent accordance with the basic control structure shown inherent Fig.3. As can be observed, the series converter responds directly and independently to the demand for series voltage vector injection. Change I series voltage vector v_{pq} can therefore be affected virtually instantaneously. In contrast the shunt converter operates under a closed loop current control structure whereby the shunt real and reactive power components are independently controlled .The shunt reactive power respond directly to input power demand. However, the shunt real power is dictated by another control loop that acts to maintain a preset voltage level on the DC link, thereby to providing the real power supply or sink needed for the support of the series voltage injection. In other words, the control loop for the shunt real power ensures the required real power balance between the two converters.

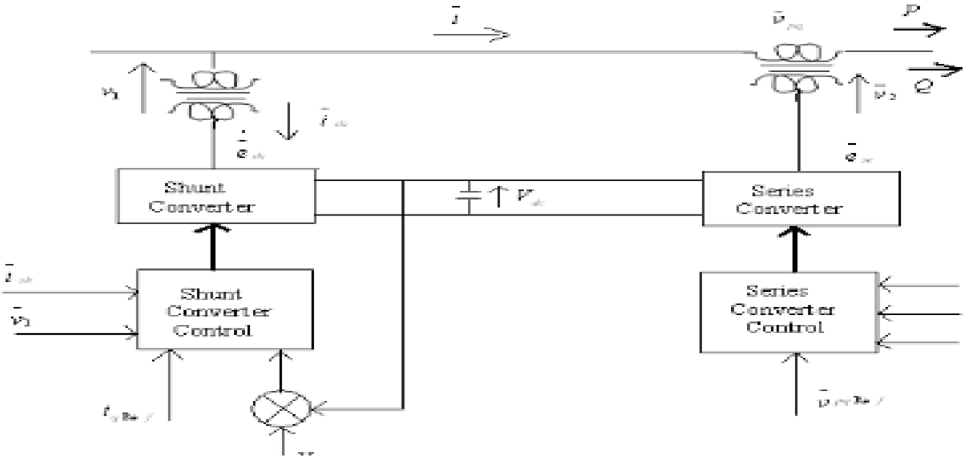


Fig 3. Basic UPFC control scheme.

The functional operational control defines the functional operating mode of the UPFC and is responsible for generating the internal references $\bar{v}_{pqRef}$ and i_{qRef} for the series and shunt compensation to meet the prevailing demands of the transmission system. The functional operating modes and compensating modes, represented by external (or system) reference inputs, can be set manually by the operator or dictated by the an automatic system optimization control to meet specific operating the contingency requirements. An overall control structure showing the internal, the functional operation, and system optimization controls with the internal and external references is presented inherent Fig 3.

IV. SIMULATION

The load flow analysis and simulation of test system as shown in Fig.4.1. is done using power flow simulator available in MATLAB SIMULINK. This power flow simulator helps to calculate the power flow, the voltage at each bus and the cost effectiveness of the system. A UPFC is used to control the power flow in a 500 kV /230 kV transmission systems. The system connected in a loop configuration, consists of six buses(B1 to B6) interconnected through three transmission lines (L1, L2, L3) and two 500 kV/230 Kv transformer banks Tr1 and Tr2 shown Fig.5.1. Two power plants located on the 230 kV system generate a total of 1500 MW which is transmitted to a 500 kV, 15000 MVA equivalent and to a 200 MW load connected at bus B3. All the test system data are given in Appendix I and II. The UPFC located at the right end of line L2 is used to control the active and reactive powers at bus B3, as well as the voltage at bus B_UPFC. The UPFC consists of two 100 MVA, IGBT-based converters. The series converter can inject a maximum of 10% of nominal line-to-ground voltage in series with line L2.

V. SIMULATION MODEL

In present work a simulation model as shown in Fig.5.1 to determine the transient stability of test system for unsymmetrical faults i.e. L-G,L-L and L-L--G with & without UPFC is developed and performance have been analyzed for two operating modes i.e. power control mode and voltage injection mode. This model consists of six buses, three transmission lines, two transformer banks Tr1 and Tr2 and two power plants. Details of main blocks used in present simulation model are given in subsequently.

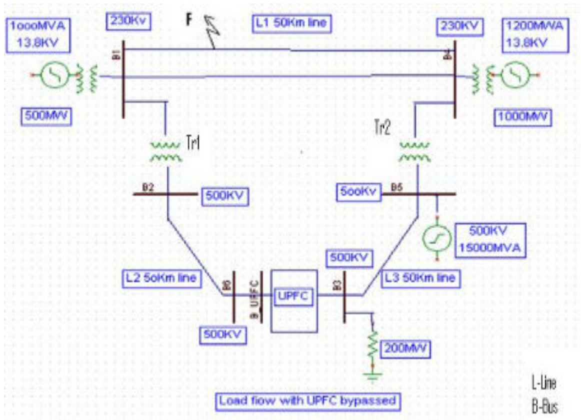


Fig.4.1 Single line diagram of 3-line, 6-bus transmission test system.

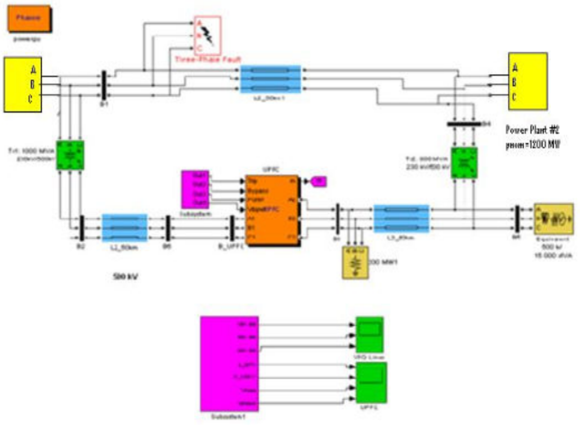


Fig.4.2 MATLAB SIMULINK model with UPFC.

VI. RESULT AND ANALYSIS

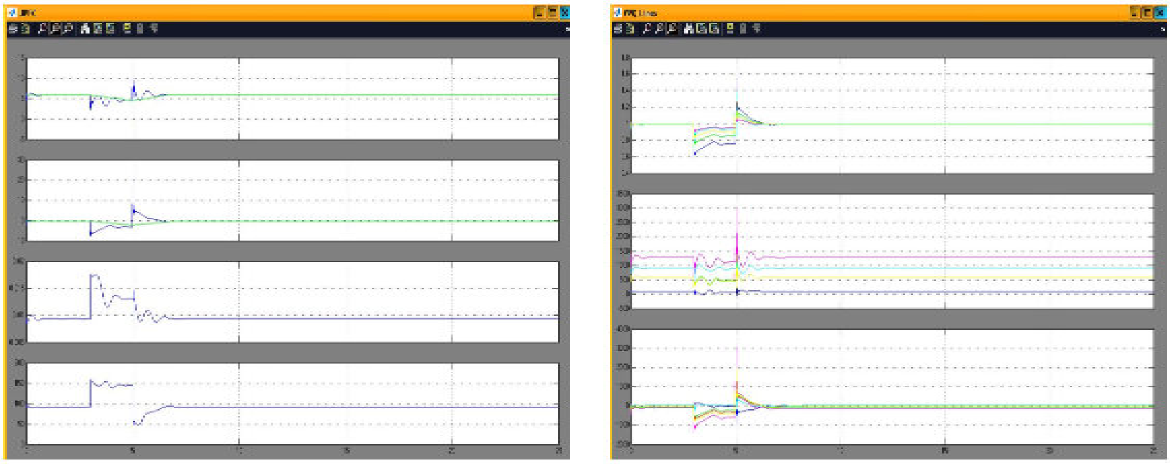
Simulation results for power flow control mode with and without UPFC are taken for different fault conditions which are given below.

A. L-G fault: Fig.6.1 and Fig.6.2 shown the simulation results under L-G fault in case of obtained without and with UPFC. Whereas table 6.1 and 6.2 mention voltage, active power and reactive power at different buses of test system.

(i) Power flow control without UPFC

Table 6.1. - Bus voltages, active power and reactive power without UPFC for L-G fault

S.No.	V	P	Q
B1	0.995	92.28	-14.68
B2	0.998	586.2	-66.00
B3	0.999	584.3	-27.39
B4	0.991	901.6	22.39
B5	0.997	128.0	-112.3
B6	0.999	584.5	-31.47



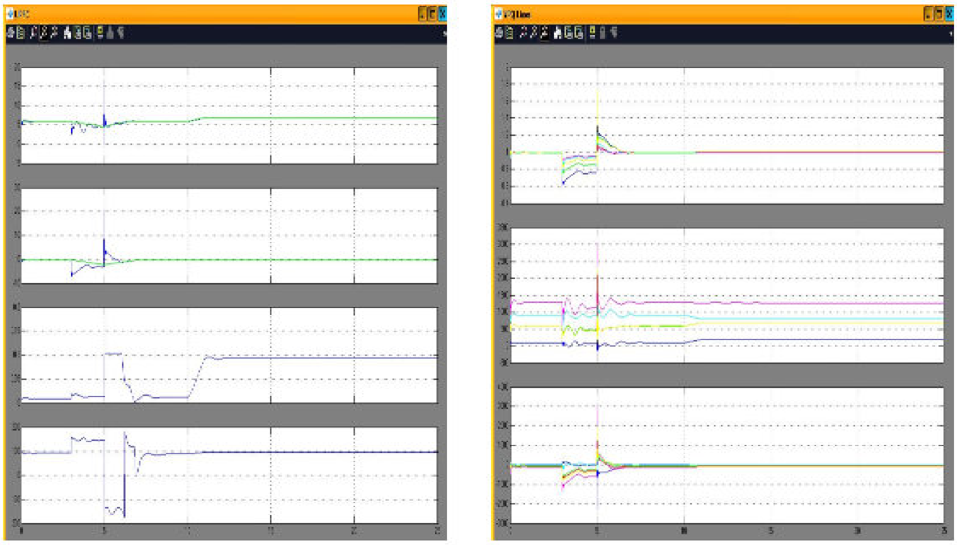
(a) Reference value of P, Q, $V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Active power, reactive power and voltage

Fig.6.1 Variation of reference values, active power, reactive power and voltage at all buses without UPFC for LG fault.

(ii) Power flow control with UPFC

Table 6.2. - Bus voltages, active power and reactive power with UPFC for L-G fault

S.No.	V	P	Q
B1	0.995	196.4	-24.74
B2	1.000	689.7	-93.62
B3	1.000	687	-27
B4	0.992	796.9	9.486
B5	0.998	1277	--96.68
B6	1.000	687.3	-70.05



(a) Reference value of P, Q, $V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Active power, reactive power and voltage

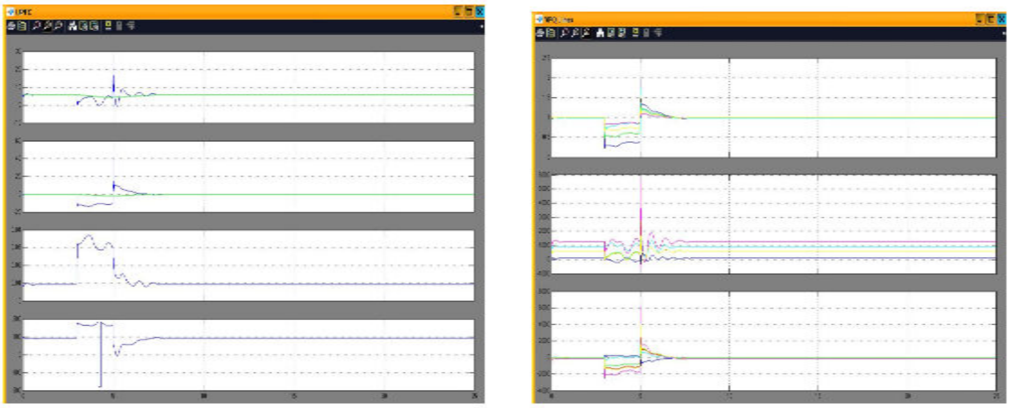
Fig.6.2. Variation of reference values, active power, reactive power and voltage at all buses with UPFC for L-G fault.

B. L-L-G fault: Fig.6.3 and Fig.6.4 shown the simulation results under LLG fault in case of obtained without and with UPFC. Whereas table 6.3. and 6.4. mention voltage, active power and reactive power at different buses of test system.

(i) Power flow control without UPFC

Table 6.3- Bus voltages, active power and reactive power without UPFC for LLG fault

S.No.	V	P	Q
B1	0.995	92.32	-14.68
B2	0.998	586.4	-66.61
B3	0.999	584.4	-27.89
B4	0.991	901.7	22.41
B5	0.997	1280	-112.4
B6	0.999	584.6	-31.05



(a) Reference value of P, Q, VMag(pu) and VPhase(deg)   (b) Active power, reactive power and voltage

Fig.6.3 Variation of reference values, active power, reactive power and voltage at all buses without UPFC for LLG fault.

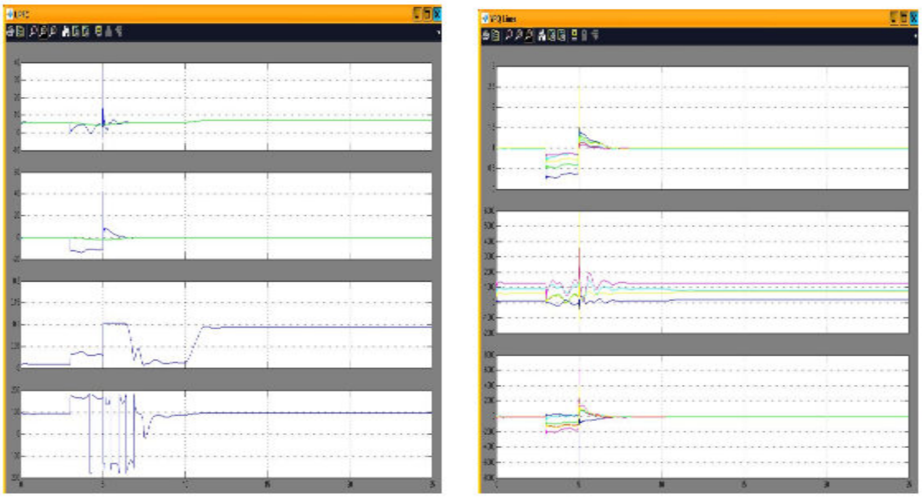
(b) Power flow control with UPFC

Table 6.4- Bus voltages, active power and reactive power with UPFC for LLG fault

S.No.	V	P	Q
B1	0.996	196.2	-24.88
B2	1.000	689.7	-97.33
B3	1.000	687	-27
B4	0.992	797.1	9.51
B5	0.998	1278	-96.18
B6	1.000	687.3	-70.64

Table.6.5-Comparison of power flow control mode results at different fault with and without UPFC.

Faults	Without UPFC		With UPFC	
	P	Q	P	Q
L-G	584.3	-27.87	687	-27
L-L	584.3	-27.88	687	-27
L-L-G	584.3	-27.87	687	-27



(a) Reference value of P, Q, VMag(pu) and VPhase(deg) (b) Active power, reactive power and voltage

Fig.6.4 Variation of reference values, active power, reactive power and voltage at all buses with UPFC for LLG fault.

In view of above mentioned results as obtained at unsymmetrical faults condition it has been found that LG,LL and LLG faults results are obtained better with UPFC . By voltage injection mode, voltage profile of the system has improved which increase the net power flow between transmission lines.

C. Voltage Injection Mode

In the UPFC dialog box setting, with the help of bypass,control parameters are seen. The mode of operation is now manual voltage injection. In this control mode voltage generated by series inverter is controlled by two external signals V_d, Vq multiplexed at the V_{dqref} input and generated in the V_{dqref} reference block in simulation model. For the first five seconds the bypass breaker stays closed, so that the PQ stays at the (584.2MW -27Mvar) point. Further when breaker opens, the magnitude of the injected series voltage is increase.

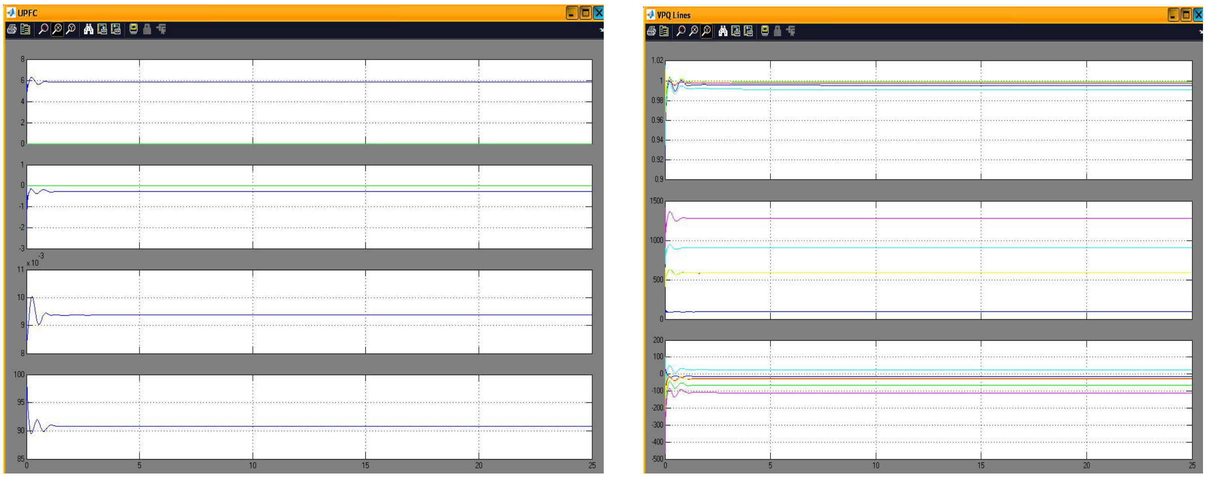
(i)Simulink results: Simulation results for voltage injection mode with and without UPFC using bypass breaker.

(a) Bypass breaker closed: Fig.6.5 and Fig. 6.6 shown the simulation results obtained without and with UPFC. Whereas table 6.6 and 6.7 mention voltage, active power and reactive power at different buses of test system.

(ii) Bypass breaker open: In voltage injection mode with UPFC result are given in Fig.6.6 and table 6.7. By voltage injection mode, voltage profile of the system has improved which increase the net power flow between transmission lines. These results are shown in table 6.6 and 6.7 across all the buses. Simulation results obtained for various faults in both the modes shows that transient stability is improved by using UPFC controllers.

Table 6.6- Bus voltages, active power and reactive power without UPFC

S.No.	V	P	Q
B1	0.995	92.4	-14.69
B2	0.998	586.2	-66.6
B3	0.999	584.2	-27.87
B4	0.991	901.6	22.39
B5	0.997	1280	-112.3
B6	0.999	584.4	-31.02

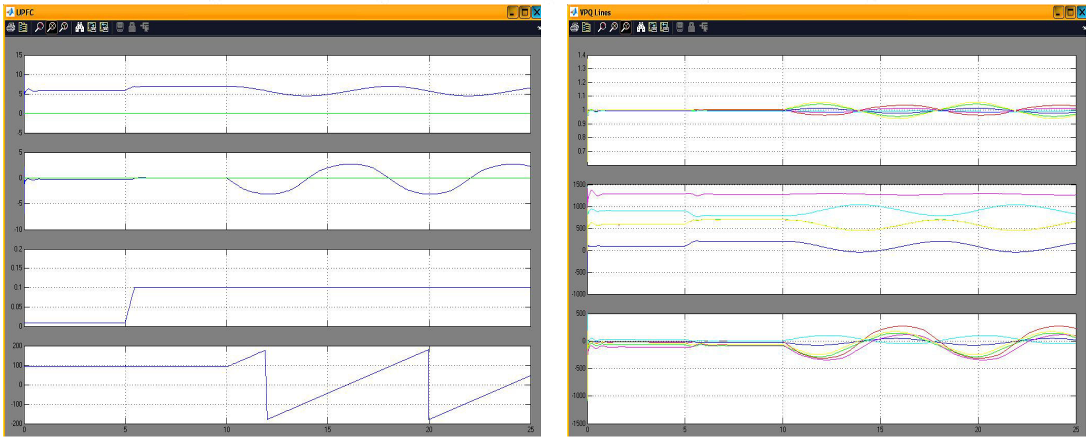


(a) Reference value of P, Q, VMag(pu) and VPhase(de (b) Active power, reactive power and voltage

Fig.6.5 Variation of reference values, active power, reactive power and voltage at all buses without UPFC.

Table 6.7- Bus voltages, active power and reactive power with UPFC

S.No,	V	P	Q
B1	0.996	196.4	-24.9
B2	1.001	689.1	-97.36
B3	1.001	687	-27
B4	0.992	796.9	9.484
B5	0.998	1278	-96.14
B6	1.000	687.3	-70.67



(a) Reference value of P, Q, VMag(pu) and VPhase(deg) (b) Active power, reactive power and voltage

Fig.6.6 Variation of reference values, active power, reactive power and voltage at all buses with UPFC.

VII. CONCLUSIONS

In power system transmission, it is desirable to maintain the voltage magnitude, phase angle and line impedance. Therefore, to control the power from one end to another end, this concept of power flow control and voltage injection is applied. The results obtained by these modes are explained in this paper. As it can observed from above that in case of power flow control mode for the L-G and L-L-G fault, active power is increased with same reactive power with the use of UPFC. Also the simulation result shows the effectiveness of UPFC to control the real and reactive power. Modelling of the system and its result analysis has given clear indication that UPFC is very useful for organize and maintaining power system. The voltage profile of the system has improved which increase the net power flow between transmission lines. Transient stability is also improved by UPFC and faster steady state stability is achieved. This work can be further enhance in terms of finding optimal placement of UPFC in power system and other FACTS controller such as Interphase Power Controller (IPC) can be used in place of UPFC.

VIII. Future Scope

This work can be further enhance in terms of finding optimal placement of UPFC in power system and other FACTS controller such as Interphase Power Controller (IPC) can be used in place of UPFC.

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