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TRANSIENT STABILITY CONTROL IN TRANSMISSION LINE WITH UPFC

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Abstract

A versatile model of a unified power flow controller (UPFC) in a single machine six bus system is proposed. Increase in load demand on power system is a threat to transient stability limit so we need some methods to improve the transient stability limit. Control by changing the network parameters is an effective method of improving transient stability. The solution is the use of FACTS (Flexible AC Transmission Systems) devices especially the use of UPFC. (Unified Power Flow Controller) and draw model with the help of modeling of a power system in MATLAB, The model consists of a simple voltage source whose magnitude and angle depends on the UPFC control parameter. These simulation models have been incorporated into MATLAB based Power System Toolbox (PST) for their transient stability analysis. In this paper the study of UPFC with its various modes of operation. Finally by help of modeling of a power system in MATLAB, and by installing UPFC in transmission link, its use as power flow controller and voltage injection. Conclusion is made on different results to see the benefit of UPFC in power system.

Key-Words: UPFC, Voltage source Model, Simulation Model, Transient analysis.

Introduction

It is becoming increasingly important to fully utilize the existing transmission facilities to satisfy the constraints of environmental legislation, right-of-way issues, cost of construction of new lines and deregulation policies that have recently introduced in the power market .But this increasing load on the power system can be a threat to transient stability limit so we need some methods to improve the transient stability limit. Control by changing the network parameters is an effective method of improving transient stability. Flexible AC Transmission Sys-tem (FACTS) controller due to their rapid response are suitable for transient stability control since they can bring about quick changes in the network parameters. Transient stability control involves changing the control variables such that the system state enters the stability region after a large disturbance. Static Compensator (STATCOM), Static Series Synchronous Compensator (SSSC) and UPFC are the voltage source converter based controller. UPFC consist of a shunt and series converter which have a common dc capacitor. UPFC injects a series voltage and a shunt current. The series and shunt branches of UPFC can gener-ate/absorb reactive power independently and the two branches can exchange real power; therefore UPFC has three degree of freedom. The application of UPFC to control the steady state power flow is described in [1,10] UPFC is very fast acting FACTS device and thus can also help to improve the stability and damping of a power system by properly regulating the dynamic period [2,7]

Most of the previous studies on stability improvement by UPFC were carried out at component level using some standard software, such as EMTP[8,11] and PSCAD/EMTDC[3,5] ,In these studies all UPFC components are represents in detail and thus no mathematical model of the overall UPFC is required. The system voltages and currents represent by sine functions and that requires a considerable amount of computational time because of the smaller step .However, almost the same stability result with significantly less computational burden can be found when the system voltages and current are represented

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by their effective or RMS values [6] this requires an appropriate mathematical model to represent the UPFC.

Unified power flow controller

The Unified Power Flow Controller (UPFC) concept was proposed by Gyugi in 1991. UPFC is an electrical device for providing fast-acting reactive power compensation on high-voltage electricity transmission networks. The UPFC is a combination of a Static Synchronous Compensator (STATCOM) and a Static Synchronous Series Compensator (SSSC) coupled via a common DC voltage link.

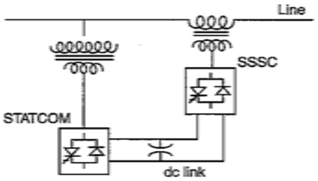


Fig.2.1 Unified Power Flow Control

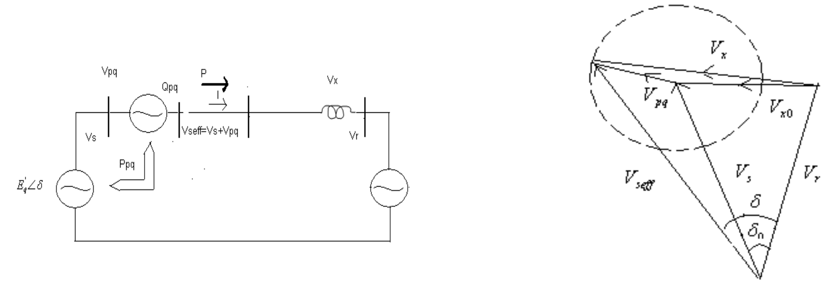


Fig .2.2 Conceptual Representation of UPFC Inherent a two Machine Power System

The UPFC is generalized synchronous voltage source (SVS) represented at the fundamental (power system) frequency voltage phasor and angle in series with transmission line, for the elementary two machine system as shown in Fig 2.2 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 power exchanged, the real power must be supplied to it, or absorbed from it, by a suitable power supply or sink. In the UPFC arrangement the real power exchanged is provide by one of the end buses as indicated in Fig. 2.

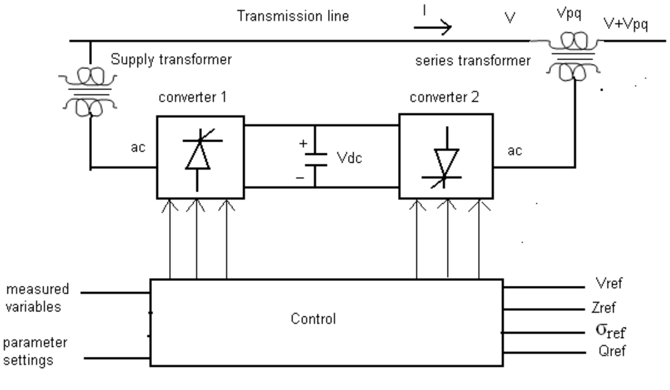


Fig.2.3 Implementation of the UPFC by two Back –to- Back Voltage Sourced Converters

In the presently used practical implementation, the UPFC consists of two voltage-sourced converters as il-lustrated in Fig .2.3 these back to back converters, labeled “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 con-verter in which real power can freely flow in either direction between the AC terminal of the two converter, and each converter can independently generate(or absorb) reactive power at its own AC output terminal Converters 2 provides the main function of UPFC by injecting a voltage with controllable magnitude and phase angle ρ in series with line via an insertion transformer. This injected voltage acts essentially as a synchronous AC voltage source. The transmission line current flows through the this voltage source resulting in reactive and real power exchange between it and the AC system. The reactive power exchanged at the AC terminal (i.e. at the terminal of the series insertion transformer) is generated internally by the converter .The real power exchanged at the AC terminal is converted into DC power which appears at the DC link as a positive or negative real power demand. 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 ex-changed 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 addi-tion 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 operate 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

Operating modes of UPFC: The UPFC has many possible operating modes.

The shunt inverter can be controlled in two different modes:

(a) VAR Control Mode: The reference input is an inductive or capacitive VAR request. The shunt inverter control translates the Var reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current. For this mode of control a feedback signal representing the dc bus voltage, Vdc, is also required

(b) Automatic Voltage Control Mode: The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer.

The series inverter can be controlled in four different modes:

(a) Direct Voltage Injection Mode: The reference inputs are directly the magnitude and phase angle of the series voltage.

(b) Phase Angle Shifter Emulation mode: The reference input is phase displacement between the sending ends voltage and the receiving end voltage.

(c) Line Impedance Emulation mode: The reference input is an impedance value to insert in series with the line impedance

(d) Automatic Power Flow Control Mode: The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

CONTROL SYSTEM: In order to understand the UPFC Control System the phasor diagram in the Fig.2.4 and Fig.2.5 given below is system

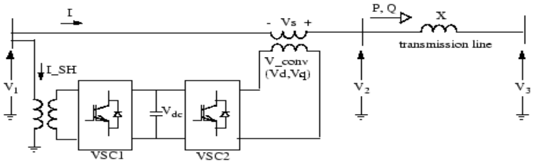
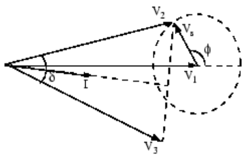


Fig. 2.4: Single-Line Diagram of a UPFC



$$P = \frac{V_2 \times V_3 \times \sin\delta}{X}$$

$$Q = \frac{V_2(V_2 - V_3 \cos\delta)}{X}$$

Fig. 2.5 Phasor Diagram of Voltages and Currents

power because active power can now 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 quadraure with line current I, the injected voltage Vs can now have any angle with respect to line current. If the magnitude of injected voltage Vs is kept constant and if its phase angle with respect to V1 is varied 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 is varying, the phase shift δ between voltages V2 and V3 at the two line ends also varies. It follows that both the active power P and the reactive power Q transmitted at one line end can be controlled.

The shunt converter operates as a STATCOM. In summary, the shunt converter controls the AC voltage at its terminals and the voltage of the DC bus. It uses a dual voltage regulation loop: an inner current control loop and an outer loop regulating AC and DC voltages. Control of the series branch is different from the SSSC. In a SSSC the two degrees of freedom of the series converter are used to control the DC voltage and the reactive power. In case of a UPFC the two degrees of freedom are used to control the active power and the reactive power. A simplified block diagram of the series converter is shown below Fig.2.6

The series converter can operate either in power flow control (automatic mode) or in manual voltage injection mode. In power control mode, the measured active power and reactive power are compared with reference val-ues to produce P and Q errors. The P error and the Q error are used by two PI regulators to compute respectively the Vq and Vd components of voltage to be synthesized by the VSC.

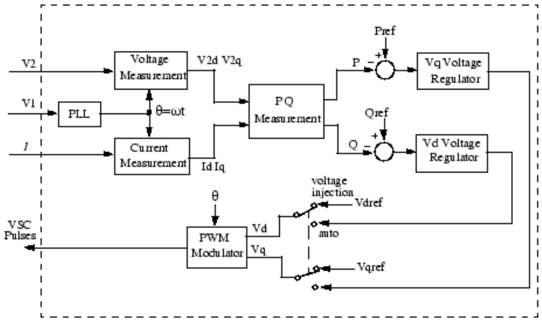


Fig.2.6 Functional Block Diagram of the Series Converter Control

In manual voltage injection mode, regulators are not used. The reference values of injected voltage Vdref and Vqref are used to synthesize the converter voltage

Simulation model

This model consists of six buses, three transmission lines, two transformer banks Tr1 and Tr2 and two power plants. In this paper a new simulation model for transient stability analysis of UPFC is developed and increase power flow and voltage profile improvement of the test system, UPFC have been connected in transmission line. The performance of system studied has been simulated through MATLAB SIMULINK v7.9 with and without connecting UPFC for two operating modes i.e. power flow control and voltage injection mode. In present work a simulation model as shown in Fig.3.1 to determine the transient stability of test system for various type of faults i.e. L-G,L-L,L-L-G,L-L-L and L-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.

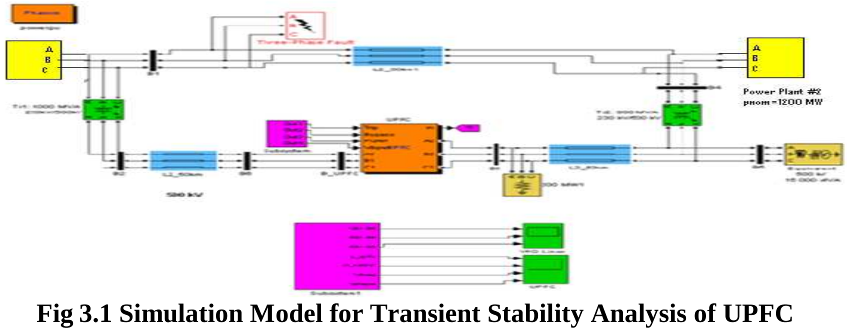


Fig 3.1 Simulation Model for Transient Stability Analysis of UPFC

Result

The simulation model shown in Fig.3.1 has been simulated to determine the steady-state and transient stability of the test system under various faults condition. Results obtained for two operating modes i.e. power flow control mode and voltage injection mode with and without UPFC are given below.

1. Power Flow Control Mode: - The UPFC reference active and reactive powers are set in the reference blocks labeled as Pref (pu) and Qref (pu) in simulation model as shown in Fig.5.2. Initially the bypass breaker is closed and resulting natural power flow at bus B3 is 584 MW and -27 Mvar. The Pref parameter set is with an initial active power of 5.87 pu corresponding to the natural power flow. Then at t=10s, Pref is increased by 1 pu (100 MW), from 5.87 pu to 6.87 pu, while Qref is kept constant at -0.27 pu .The control strategies have been tested for different type of disturbances i.e. Line to Line (LL), Line to Ground (LG), Line to Line to Ground (LLG), 3 phase (LLL) and 3 phase ground (LLLG) fault. Duration of fault for all type of faults are considered between t=3.00s to t=4.99s in all simulation.

Performance of the system has been analyzed for different types of faults further results obtained for with and without UPFC are compared.

. (I) L-G Fault

(a) Power Flow Control without the UPFC

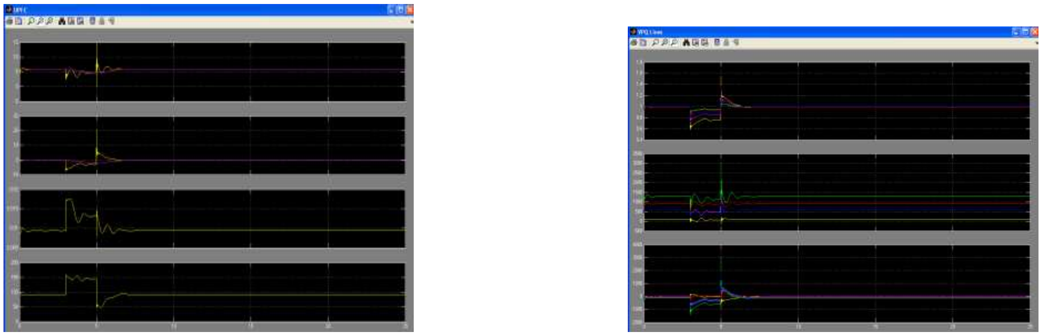

(a) (b)

Fig.4.1 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses without UPFC.

(b)Power flow control with UPFC

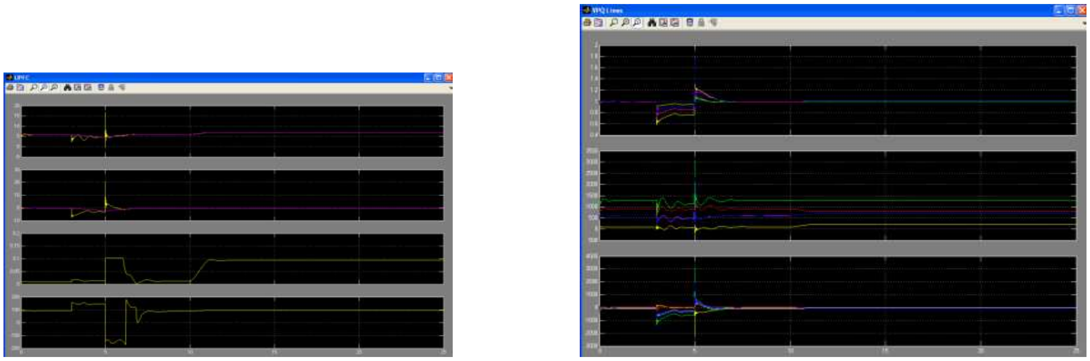
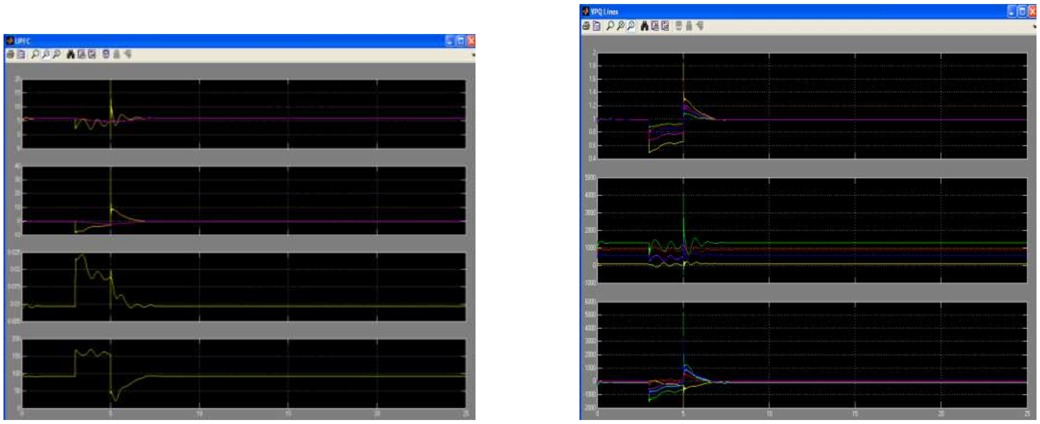

(a) (b)

Fig.4.2 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses with UPFC.

(II) L-L Fault without UPFC

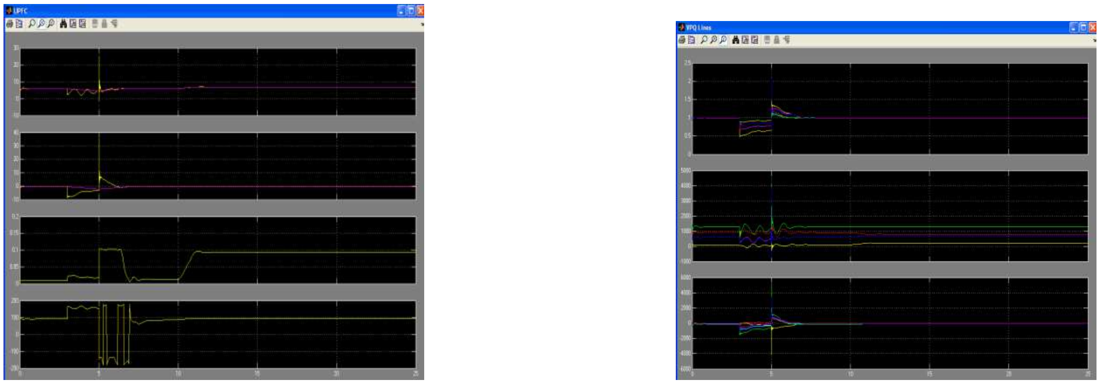
(a) Power Flow Control without the UPFC



(a) (b)

Fig.4.3 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses without UPFC.

(b)Power flow control with UPFC

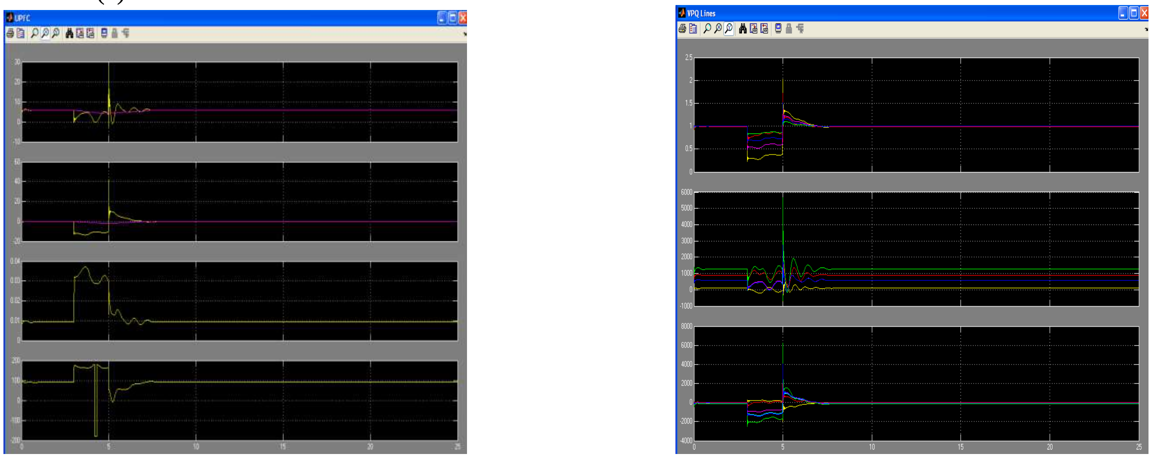


(a) (b)

Fig.4.4 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses with UPFC.

(III) L-L-G Fault

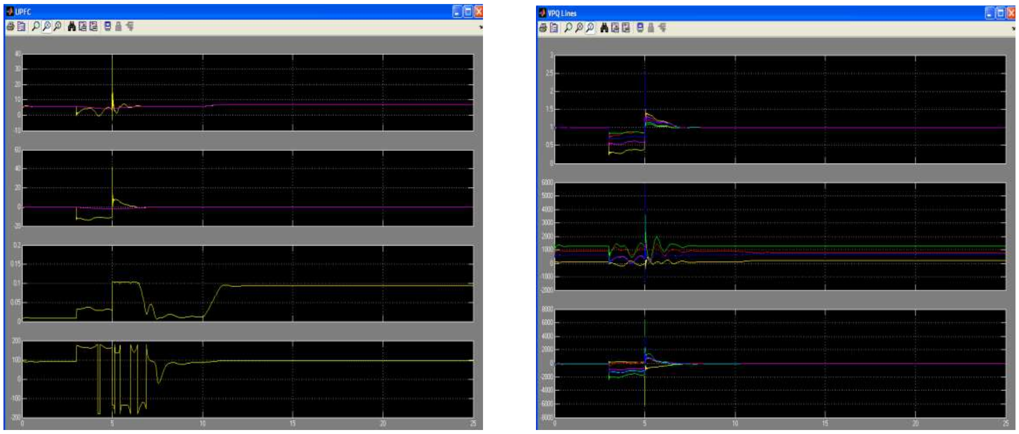
(a) Power Flow Control without the UPFC



(a) (b)

Fig.4.5 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses without UPFC.

(b)Power flow control with UPFC

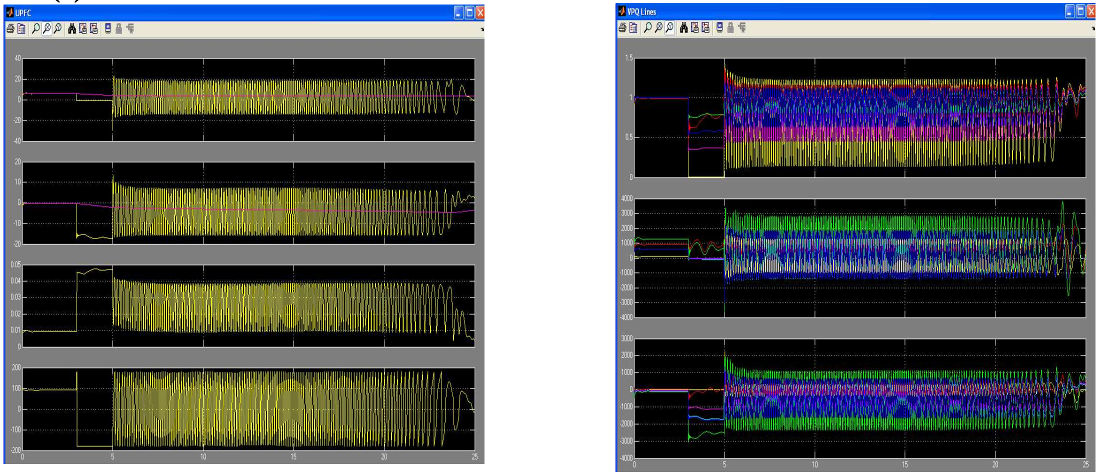


(a) **(b)**

Fig.4.6 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses with

(IV) L-L-L Fault

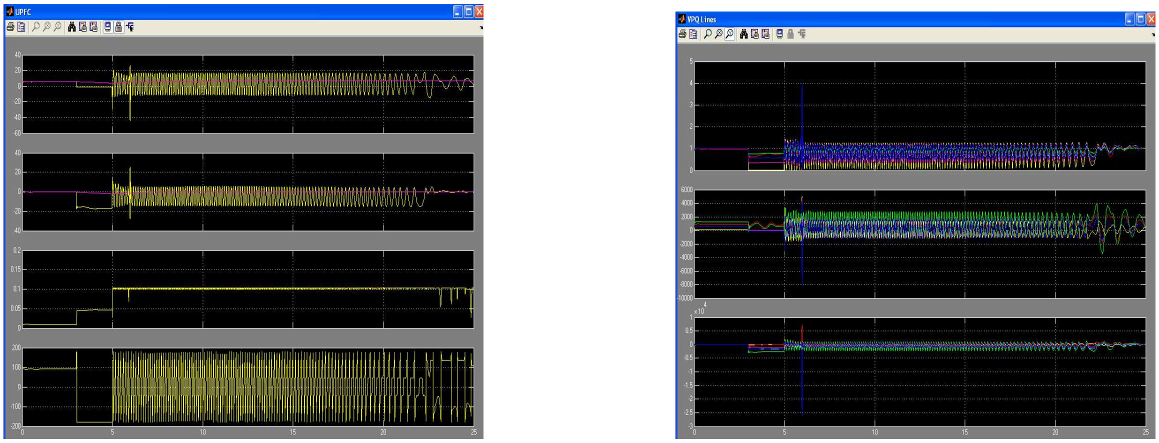
(a) Power Flow Control without the UPFC



(a) **(b)**

Fig.4.7 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses without UPFC.

(B) Power flow control with UPFC

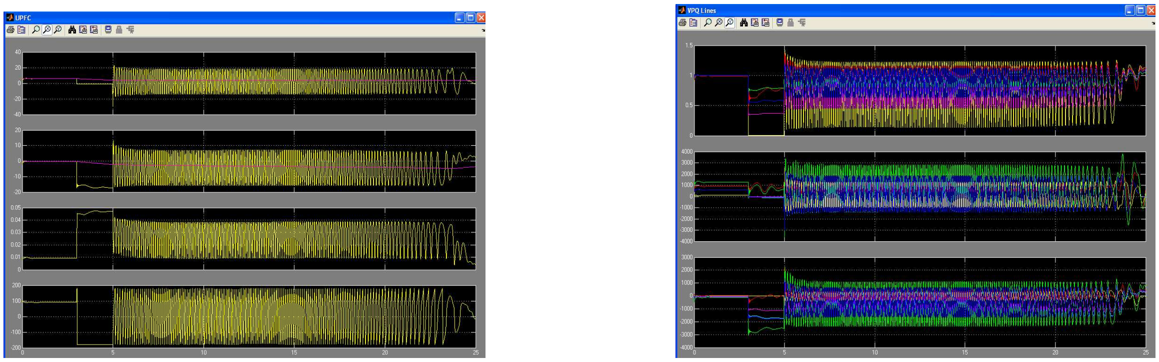


(a) (b)

Fig.4.8 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses with UPFC.

(V) L-L-L-G Fault

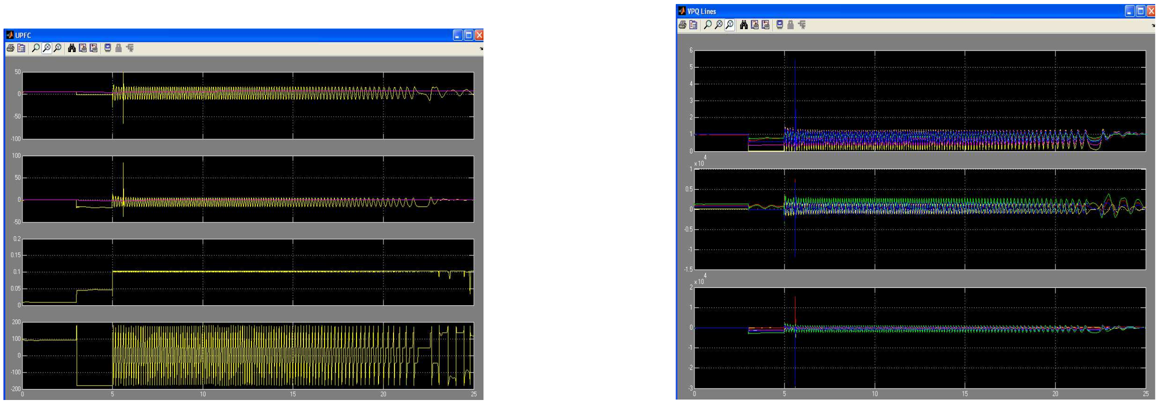
(a) Power Flow Control without the UPFC



(a) (b)

Fig.4.9 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses without UPFC

(b)Power flow control with UPFC



(a) (b)

Fig.4.10 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses with UPFC

Table 4.1-Result for Comparison

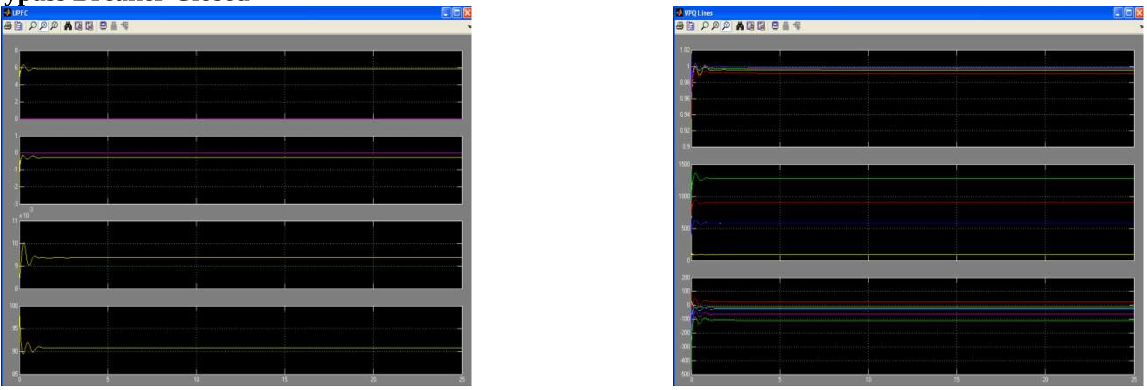
Faults	**Without UPFC**		**With UPFC**	
	P	**Q**	**P**	**Q**
L-G	**584.3**	**-27.87**	**687**	**-27**
L-L	**584.3**	**-27.88**	**687**	**-27**
L-L-G	**584.3**	**-27.87**	**687**	**-27**
L-L-L	-41.67	254.7	152.1	-33.15
L-L-L-G	-4118	253.5	-91.79	-16.61

In view of above mentioned results as obtained at various faults condition it has been found that for first three faults i.e. LG,LL and LLG are same results with and without UPFC .In remaining two faults i.e. LLL and LLLG P_{Ref},Q_{Ref} is changing and better than without UPFC is shown following table 4.1

2. Voltage Injection Mode:-In the UPFC dialog box Control parameters (series converter) are seen. The mode of operation is now Manual Voltage injection. In this control mode the voltage generated by the series inverter is controlled by two external signals Vd, Vq multiplexed at the Vdq$_{ref}$ input and generated in the Vdq$_{ref}$ magenta block.

Simulink Result

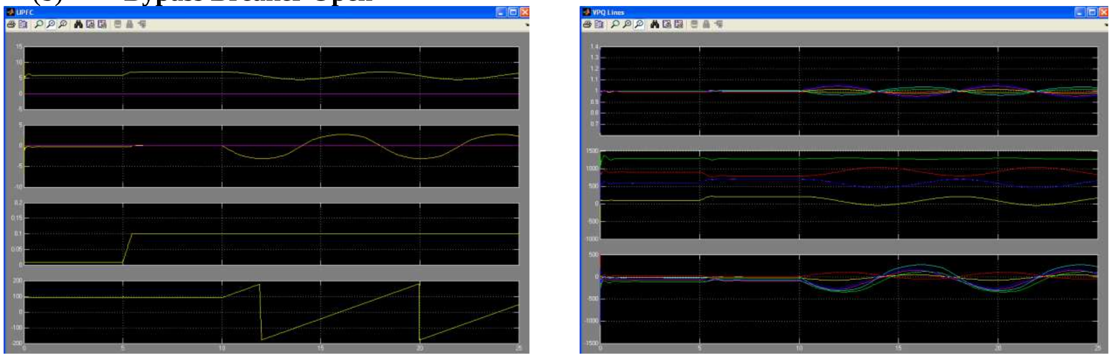
(a) Bypass Breaker Closed



(a) (b)

Fig.4.11 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses without UPFC.

(b) **Bypass Breaker Open**



(a) (b)

Fig.4.12 (a) Variation of P_{Ref},Q_{Ref},$V_{Mag(pu)}$ and $V_{Phase(deg)}$ (b) Variation of P,Q, and V at all Buses with UPFC.

The voltage is injected by the series controller by the series transformer. This shows above graph 4.11 and 4.12 the voltage profile of the system has improved which increase the net power flow between transmission lines.

From above graphs and tables used in both modes transient stability is improved by using UPFC Controllers.

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 below and can be concluded as follows.

1. For first mode consider various faults:
    - i.LG fault(without UPFC):P= 584.3,Q=-27.87,V=0.9991
    - ii.LG fault(with UPFC):P= 687,Q=-27,V=1.00
    - iii.LL fault(without UPFC):P= 584.3,Q=-27.88,V=0.9991
    - iv.LL fault(with UPFC):P= 687,Q=-27,V=1.00
    - v.LLG fault(without UPFC):P= 584.3,Q=-27.87,V=0.9912
    - vi.LLG fault(with UPFC):P= 687,Q=-27,V=1.00
    - vii.LLL fault (without UPFC):P=-41.67,Q=254.7,V=1.063
    - viii.LLL fault(with UPFC):P=152.1,Q=-33.15,V=1.00
    - ix.LLLG fault(without UPFC):P=-41.18,Q=253.5,V=1.083
    - x.LLLG fault(with UPFC):P=--91.79,Q=-16.61,V=1.00

As it can observed from above that in case of power flow control mode for first three faults i.e. LG,LL,LLG active power is increased with same reactive power with the use of UPFC.

2.For voltage injection mode:
    - i. Bypass breaker closed P=584.2MW,Q=-27Mvar
    - ii.Bypass breaker open, the magnitude of the injected series voltage is increase.

Above simulation result shows the effectiveness of UPFC to control the real and reactive power. Modeling of the system and studying the results have given an 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.

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