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Load Flow Control on Power System Transmission Networks using UPFC

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Abstract: **The paper examines the performance of a unified power flow controller (UPFC) on the electrical power transmission network. The UPFC performance is investigated in controlling load flow over the transmission lines. Voltage source system is utilized to study the behavior of the UPFC in management the active power, reactive power, voltage profile of the system; and the UPFC is used to relief power congestion of the transmission system. The model consist combined equations of UPFC and the balance power equations of the network into one set of non-linear algebraic equations. Case studies were carried out on five standards bus network and the load flow option of the powergui block was used; the model was initialized with plant 1 and 2 generating 500MW and 1000MW respectively, with the simulation is conducted by Matlab/simulink environment. The results of the network with and without UPFC were compared in terms of active and reactive power flows in the line, and the active and reactive power flows at the buses were used to analyze the performance of the UPFC.**

Keywords: **UPFC, Voltage Source Model, Series and Shunt Converter, Active and Reactive Power flow and Power Transmission Network.**

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1. INTRODUCTION

Power System, in general are interconnected and there is a great need of improvement in electric power utilization by maintaining reliability and security. The power demand is growing considerably and the extension in transmission is restricted with the limited availability of recourses. This will cause some of the transmission lines are overloaded and others will loaded well below their normal limits [1]. With the fast growing research on power electronic components, Flexible AC Transmission Systems (FACTS) is used in the present deregulated electric market in order to transmit more power through transmission line. This will help to improve the performance of existing transmission line up to its maximum limit [2]. The FACTS devices will offer rapid response, smoothly adjustable output, responds to frequent variations in output without violating stability and thermal limits [3]. The power flow control in the line is changed by series compensation, shunt compensation and phase angle regulation. All series controllers will inject a voltage in series in the line. If the phase difference between the line voltage and injected voltage is 90˚, series controllers will absorb/consumes reactive power. Shunt controllers can deliver/absorb reactive power demanded by the load [4].Phase shifter is considered to be sinusoidal ac voltage source with the controlled amplitude and phase angle. The phase angle regulator will inject a voltage which will change the effective phase angle at the sending end and thereby changing the power flow in the line. Third generation of FACTS controllers contains the Unified Power Flow Controller (UPFC) and Interline power flow controller (IPFC).They will have two Voltage Source Converters (VSC) connected though a DC link. By using UPFC, many FACTS devices distributed in the line can be avoided, thereby the problem of unwanted interactions between the devices can be eliminated up to a great extent [5]. UPFC proposed by Dr.Gyugyi in 1995[1] is the most versatile and powerful device that can provide effective means of controlling the power flow and improving the stability of a power network. In this paper, UPFC employed as controlling device in transmission line and performances of a five bus system have been analyzed. The control of UPFC is done by decoupled control strategy [8] and is found that this enables the device to follow the changes in reference values of active and reactive power. The power flow control is done by the UPFC by changing the injected voltage magnitude and phase angle.

2. OPERATING PRINCIPLE OF UPFC

In the UPFC configuration shown in Fig. 1 had two voltage source converters, one is shunt converter connected via a shunt transformer and another is series converter connected via a series transformer. The two converters are connected back to back with a common DC link capacitor. This arrangement has three major functions namely series, shunt and phase angle regulation to be unified in the same circuit. The basic function of the shunt converter is to absorb or generate active power from the line similar to that of shunt compensator. The shunt converter can charge the DC link capacitor and satisfy the power demand of series converter through the DC link capacitor. Thus shunt branch is required to compensate for any real power drawn /supplied by the series branch and the losses. If power balance is not maintained, V_{DC} cannot remain at a constant voltage. Series converter can provide series and phase angle compensation by injecting a series voltage of proper phase relationship. The active power can have a closed path through the converter because of the coupled DC link capacitor between the two converters but reactive power does not have a closed path between the converters [6]. Series converter voltage can be represented as $V_{sh} < \sigma$ where V_{sh} is voltage with controllable magnitude V_{sh} $(0 \le V_{sh} \le V_{shMAX})$ and phase angle $(0 \le \theta \le 360)$ with respect to sending end voltage and this voltage will inject in series with the line via a series transformer. The line current flows through this voltage source causing real and reactive power exchange in the line. The real power exchanged at the ac terminal (i.e., at the terminal of insertion transformer) is converted by the inverter into dc power that appears at the dc link as positive or negative real power demanded. The reactive power exchanged at the ac terminal is generated internally by the inverter (provided it is a three-phase balanced system).

In Fig.1, the phasors V_{sh} and V_{se} represent the equivalent, injected shunt voltage and series voltage sources, respectively. Z_{sh} and Z_{se} are the UPFC series and shunt coupling transformer impedances, respectively. V_i and V_j are voltages at buses i, j, respectively while V_k is the voltage of bus k of the receiving-end of the transmission line. I_{sh} is the current through the UPFC shunt converter. The shunt converter branch active and reactive power flows, is P_{sh} and Q_{sh} respectively. Direction of P_{sh} and Q_{sh} power flow is from bus i. The currents through UPFC series converters are I_{ij} and I_{ji} , and the $I_{ij} = -I_{ji}$. P_{ij} and Q_{ij} are the UPFC series active and reactive power flows, respectively, leaving bus i. P_{ji} and Q_{ji} are the UPFC series active and reactive power flows, respectively, leaving bus j. P_{sh} is the active power exchange of the shunt converter with the DC link. P_{se} is the active power exchange of the series converter with the DC link.

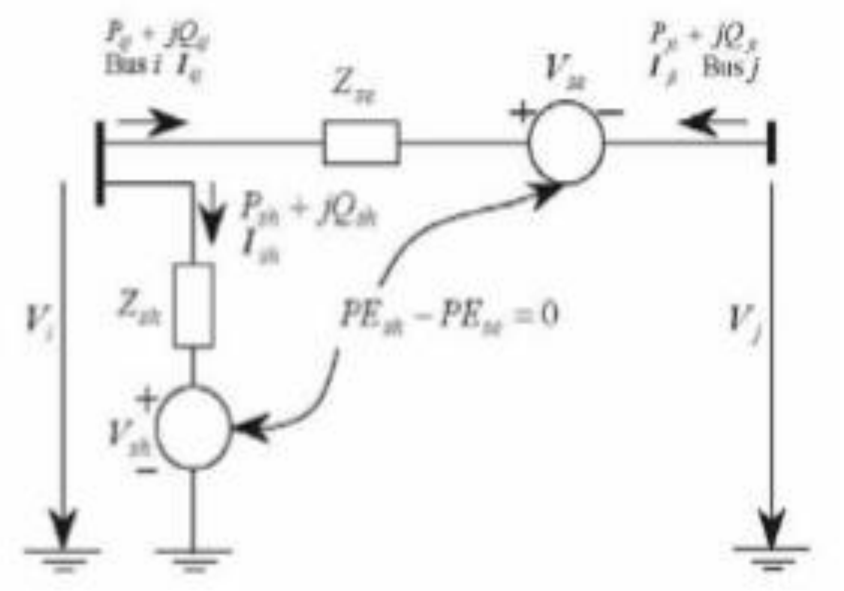

Fig. 1. Equivalent circuit of UPFC

3. POWER FLOW CONSTRAINTS OF UPFC

For equivalent circuit of UPFC presented in Fig. 1, suppose:

$V_{sh} = V_{sh}\angle\theta_{sh}, V_{se} = V_{se}\angle\theta_{se}, V_i = V_i\angle\theta_i, V_j = V_j\angle\theta_j$; then the power flow constraints of the UPFC shunt and series branches are:

$$P_{sh} = V_i^2 g_{sh} - V_i g_{sh}(g_{sh}\cos(\theta_i - \theta_{sh}) + b_{sh}\sin(\theta_i - \theta_{sh}))\text{........}2$$

$$Q_{sh} = V_i^2 b_{sh} - V_i V_{sh}(g_{sh}\sin(\theta_i - \theta_{sh}) - b_{sh}\cos(\theta_i - \theta_{sh}))\text{.........}3$$

$$P_{ij} = V_i^2 g_{ij} - V_i V_j\left(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{\mathrm{ij}}\right) - V_i V_{se}(g_{ij}\cos(\theta_i - \theta_{se}) + b_{ij}\sin(\theta_i - \theta_{se})\text{.......}4$$

$$Q_{ij} = -V_i^2 b_{ij} - V_i V_j\left(g_{ij}\sin\theta_{ij} + b_{ij}\cos\theta_{\mathrm{ij}}\right) - V_i V_{se}(g_{ij}\sin(\theta_i - \theta_{se}) - b_{ij}\cos(\theta_i - \theta_{se})\text{.......}5$$

$$P_{ji} = V_j^2 g_{ij} - V_i V_j\left(g_{ij}\cos\theta_{ji} + b_{ij}\sin\theta_{\mathrm{ji}}\right) - V_j V_{se}(g_{ij}\cos\left(\theta_j - \theta_{se}\right) + b_{ij}\sin\left(\theta_j - \theta_{se}\right)\text{...}6$$

$$Q_{ji} = -V_j^2 b_{ij} - V_i V_j\left(g_{ij}\sin\theta_{ji} - b_{ij}\cos\theta_{\mathrm{ji}}\right) - V_j V_{se}(g_{ij}\sin\left(\theta_j - \theta_{se}\right) - b_{ij}\cos\left(\theta_j - \theta_{se}\right)\text{.......}7$$

Where $g_{sh} + jb_{sh} = 1/Z_{sh},\ \ g_{ij} + jb_{ij} = 1/Z_{se}, \theta_{ij} = \theta_i - \theta_{j,}\theta_{ij} = \theta_j - \theta_i$.

The active power exchange between two inverter via the DC link is:

$$\Delta p_{\Sigma} = PE_{sh} - PE_{se} = 0\text{.........}8$$

Where $PE_{sh} = Re(V_{sh} I_{sh}^{*}) and\ PE_{se} = Re\left(V_{se} I_{ji}^{*}\right)$ are active power exchange of the shunt converter and the series converter with DC link , respectively.

4. TEST SYSTEM FOR IMPLEMENTATION

The single-line diagram of the modeled power system is shown in 500 kV / 230 kV Transmission System.

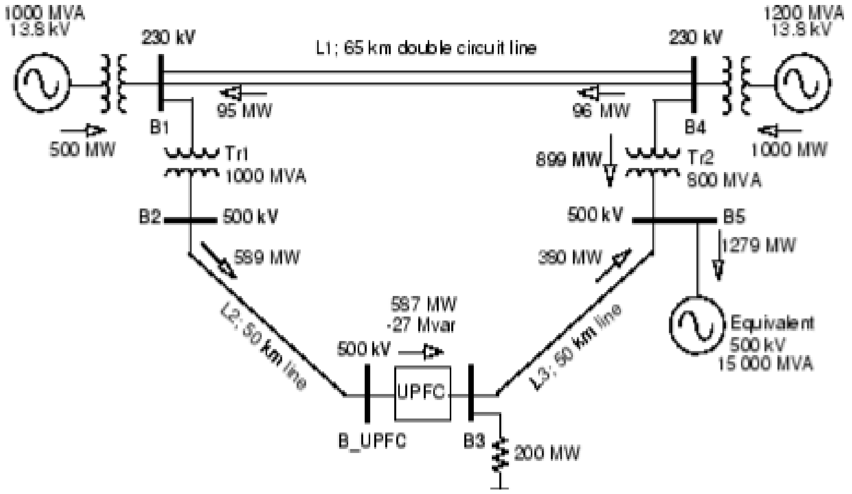

Figure 2: A Single-line diagram of the modeled electric power transmission network

The UPFC is used to control the power flow on a 500 kV /230 kV transmission network or system. The system connected in a loop configuration, consists of essentially five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and two 500 kV/230kV transformer banks T1 and T2. Two power plants located on the 230kV system generate a total of 1500MW which is transmitted to a 500kV, 15000MVA equivalent and to a 200MW load connected at bus B3. The plant models include a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 1200MW generation capacity of power plant 2 is exported to the 500kV equivalent through three 400MVA transformers connected between buses B4 and B5. For this study we are considering a contingency case where only two transformers out of three are available (T2= 2*400MVA = 800 MVA). Figure 3 show the Matlab/simulink model of the test system.

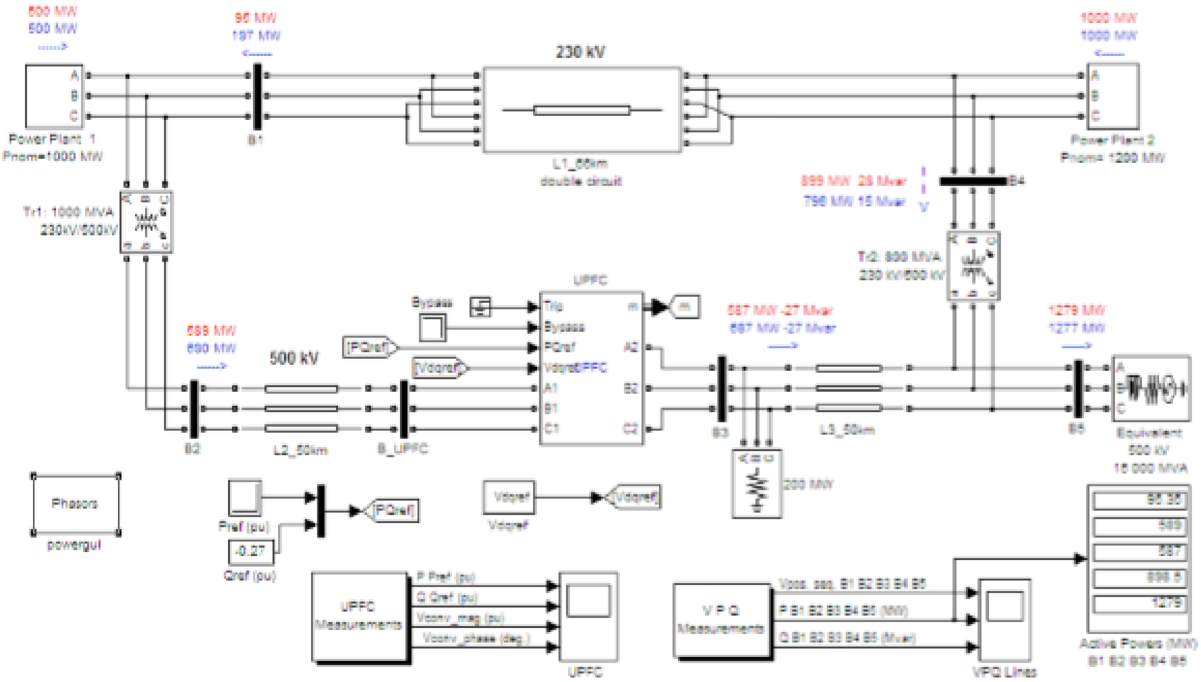

Figure 3: The Matlab/Simulink Model of the Test System

Using the load flow option of the powergui block, the model is initialized with plants 1 and 2 generating 500MW and 1000MW respectively and the UPFC out of service. The resulting power flow obtained at buses B1 to B5 is indicated by red numbers on the circuit diagram in figure 3 below. The load flow shows that most of the power generated by plant 2 is transmitted through the 800MVA transformer bank (899MW out of 1000MW), the rest (101MW), circulating in the loop. Transformer T2 is therefore overloaded by 99 MVA. The study illustrates how the UPFC can relieve this power congestion. The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500kV bus B3, as well as the voltage at bus B_UPFC. It consists of a phasor model of two 100MVA, IGBT-based, converters (one connected in shunt and one connected in series and both interconnected through a DC bus on the DC side and to the AC power system, through coupling reactors and transformers). The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2. The blue numbers on the diagram show the power flow with the UPFC in service and controlling the B3 active and reactive powers respectively at 687MW and -27Mvar.

5. RESULTS ANALYSIS

The UPFC reference active and reactive powers are set in the modeled blocks Pref (pu) and Qref (pu). Initially the Bypass breaker is closed and the resulting natural power flow at bus B3 is 587MW and -27Mvar. The Pref block is programmed with an initial active power of 5.87pu corresponding to the natural flow. Then, at t = 10s, Pref is increased by 1pu (100MW), from 5.87pu to 6.87pu, while Qref is kept constant at -0.27pu as shown in Figure 4 and Figure 5 respectively. The P and Q measured at bus B3 follow the reference values as shown in Figure 9 and Figure 10. At t = 5s, when the Bypass breaker is opened the natural power is diverted from the Bypass breaker to the UPFC series branch without noticeable transient. At t =10s, the power increases at a rate of 1 pu/s. It takes one second for the power to increase to 687MW as seen in Figure 4. The 100MW increase of active power at bus B3 is achieved by injecting a series voltage of 0.089pu with an angle of 94 degrees, this is shown in Figure 6 and Figure 7 respectively. This resulted in an approximate 100MW decrease in the active power flowing through T2 (from 899MW to 796MW), which now carries an acceptable load. See the variations of active powers at buses B1 to B5 on the VPQ Lines scope, Figure 8 show the Bus voltages. The UPFC P and Q signals vary according to the changing phase of the injected voltage. The trajectory of the UPFC reactive power and its active power, measured at bus B3 is shown in Figure 9 and 10. The area located inside represents the UPFC controllable region shown in figure.

TABLE I: Bus Voltages and Power With and Without UPFC

Bus No.	Bus Voltage Without UPFC	Bus Voltage With UPFC	Bus Power Without UPFC		Bus Power With UPFC	
	Voltages (pu)	Voltages (pu)	P(MW)	Q(MVar)	P(MW)	Q(MVar)
1	0.9966	0.9967	95	-16	197	-30
2	0.9993	1.0020	589	-64	690	-94
3	0.9996	1.0010	587	-27	687	-27
4	0.9926	0.9942	899	27	796	16
5	0.9978	0.9978	1279	-106	1277	-89

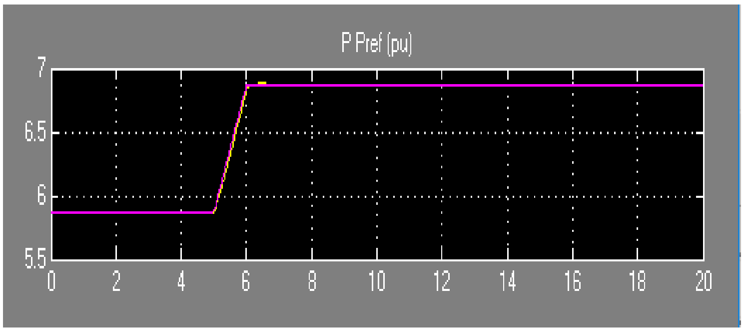

Figure 4: Pref Signal

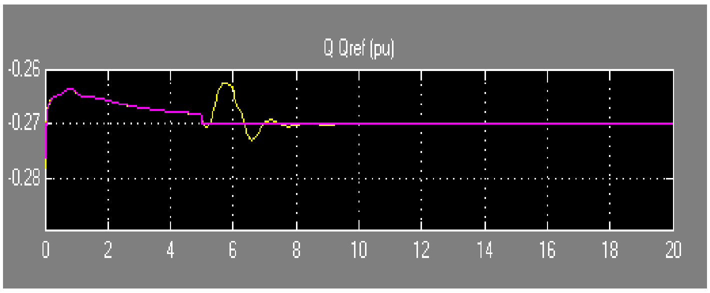

Figure 5: Qref Signal

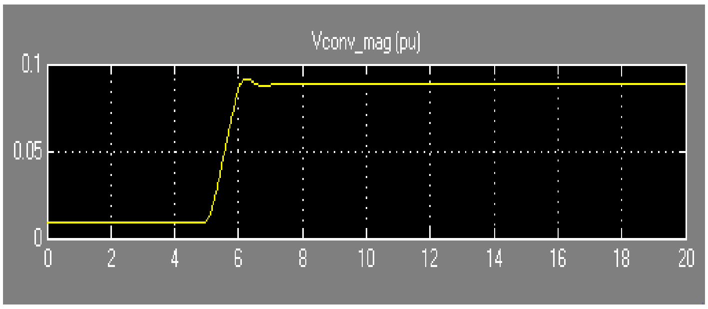

Figure 6: Injected Series Voltage

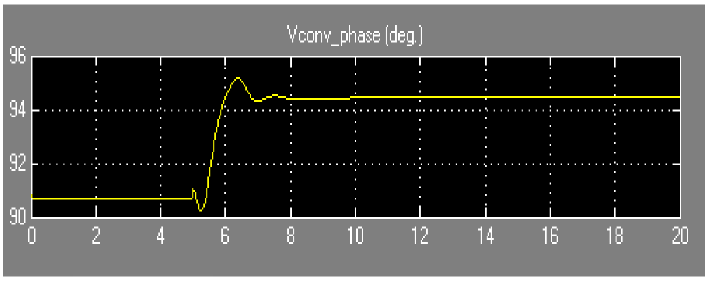

Figure 7: Injected Series Voltage Phase Angle.

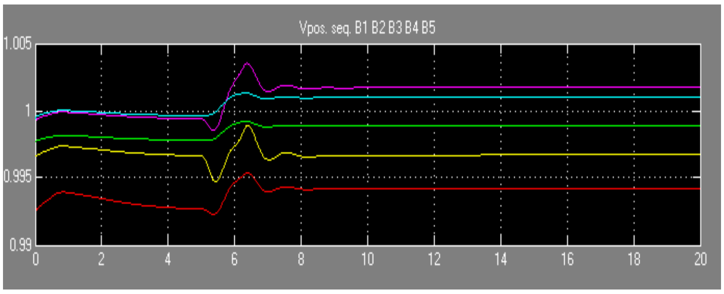

Figure 8: Bus Bar Voltages

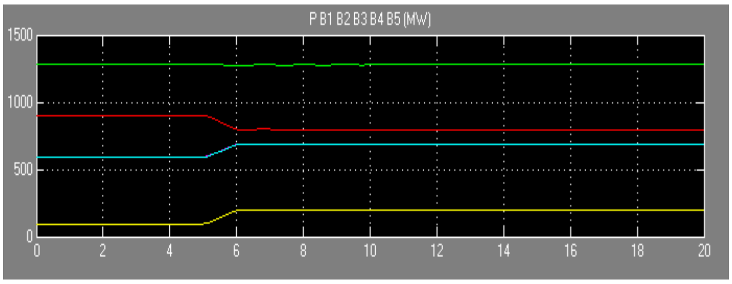

Figure 9: Bus bar Active Power

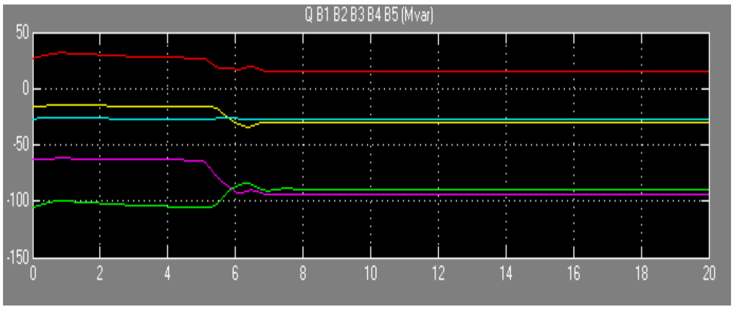

Figure 10:Bus Bar Reactive Power

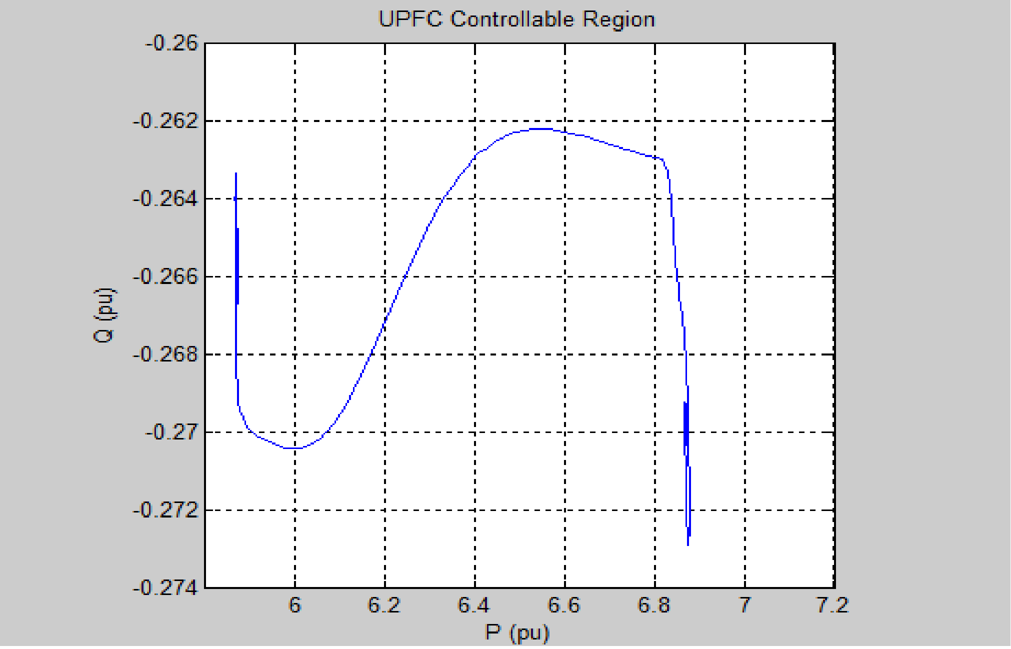

Figure 11: UPFC Controllable Region

6. CONCLUSION

This paper provide the possibility of installed the UPFC, FACTS devices on 500 kV/320kV transmission power system. Application of UPFC for control of the active and reactive power flow has been explored in this study. The Matlab/Simulink environment is used to simulate the model of interconnected transmission lines between three power systems. The control and performance of UPFC intended for installation on a transmission line is presented. Simulation results show the effectiveness of UPFC on controlling the active and reactive power flow through the transmission line with UPFC.

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