

Implementation of Unified Power Flow Controller for Wheeling charges Reduction in a Deregulated Power System

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Abstract

We deal with the effect of unified power flow controller installation on the objective function of an electricity market. Also this paper proposes a novel UPFC modeling The OPF which facilitates the consideration of the impact of four factors on the power market. Transmission pricing is an important issue in view of increased deregulation. Purpose of pricing is to recover cost of transmission encourage efficient use and investment. The unified power flow controller (UPFC) integrates properties of both shunt and series compensations, and can effectively alter power system parameters in a way that increases power transfer capability and stabilizes system.

Keywords: FACTS, UPFC, Wheeling charges, Pricing, MW-Mile method.

Introduction

Transmission pricing has been an important issue on the ongoing debate about power system restructuring and deregulation.[1] The rapidly increasing cost of electricity in recent years has brought about awareness to the importance of pricing policies in maximizing the social welfare. Electric energy must be treated commodity which can be bought, sold and transmitted taking into account its time varying values and costs, known as “spot pricing”. Some efforts have been made to study the impact of FACTS devices on transmission charges. Oliveira have shown the ability of FACTS devices to change the production cost and their impact on transmission charges [2] . They made clear in [3] that effect of FACTS devices on transmission charge varies according to the pricing methodology adopted. They considered production cost minimization as the objective function. [4] was provided the index which reflects the FACTS device operation, wheeling transactions and network congestion. [5] has described a new approach of transmission pricing calculation taking social welfare maximization as the objective and has studied the impact of FACTS devices on it The motivation to use FACTS devices has been their potential to control the flow of power. They control the power flow in the transmission lines by handling one or more of these parameters: nodal voltage, nodal angular difference, and line series impedance. Optimal power flow is one of the most important operational functions of the modern day energy management system. The purpose of the optimal power flow is to find the optimum generation among the existing units, such that the total generation cost is minimized while simultaneously satisfying the power balance equations and various other constraints in the system. In [6] OPF has been solved by dynamic programming, considering the uncertainty in the loads demand and generation using fuzzy logic and possibility of using TCSCs to satisfy the transmission capacity constraint in the OPF has been explored . [7] presented a theory and simulation results of real-time pricing of real and reactive powers that maximize social benefits. Optimal location of FACTS devices is also an important issue in a restructured power system. A method [8] for the suitable locations of unified power flow controller, with a static point of view, has been used in this paper for different objectives, based on the real power flow performance index sensitivity with respect to control

parameters of the unified power flow controller (UPFC). A sensitivity-based approach has been developed in [9] for determining the optimal placement of FACTS devices in an electricity market having pool and contractual dispatches.

Structure and Operation of UPFC

FACTS devices have been newly developed and applied in some well-developed countries. Their operations are realized using advance power electronics components which make them respond quickly to control inputs. Their instant response grants a high ability for power system stability enhancement in addition to control of steady state power flow. The UPFC is the fastest, most flexible, and the best-featured FACTS device. It can be seen as a combination of the STATCOM and SSSC.[10][11] It has the power full advantage of providing, simultaneously and independent, real time control of voltage, impedance and phase angle, which are the basic power system parameter on which system performance depends. Therefore, UPFC can be used efficiently and flexibly to optimize line utilization and increase system reliability, to enhance system stability, and to dampen system oscillations. The schematic diagram shown in figure 1 represents the basic structure of UPFC. A UPFC consists of two linked self-commutating converters share a common dc capacitor, which is connected to the ac systems through series and shunt coupling transformers. The ac/dc converters are switching voltage –sourced converters with semiconductor device having turn-off capability. The dc side of both converters is connected to a common dc capacitor, which provides a dc voltage support for the converter operation and functions as energy storage element. Real power flows between the shunt and series ac terminals of UPFC through the common dc link, UPFC generates or absorbs the needed reactive power locally by the switching operations of its converters. Each converter generates or absorbs the reactive power independently, i.e. reactive power does not flow through the dc link.

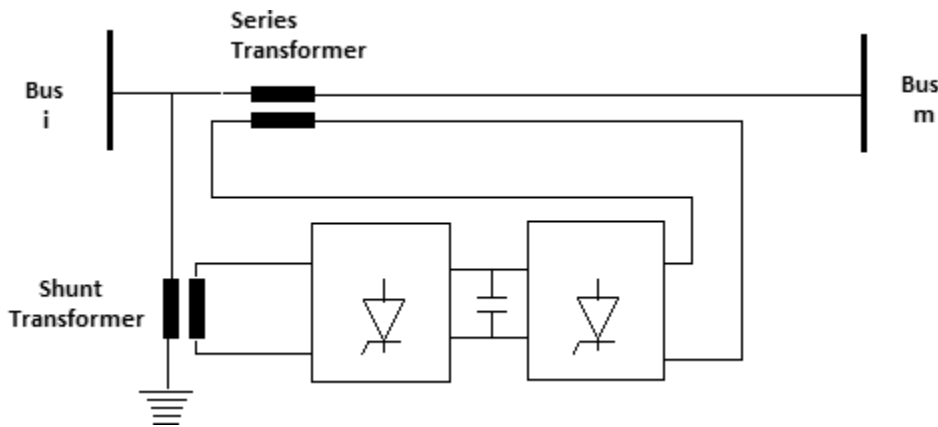


Figure 1: Basic circuit arrangement of UPFC

The power transfer between the shunt converters and series convert sets the UPFC rating. This rating should be at least as least as large as the real power exchanged between the two converters. The series converter performs the main function of the UPFC, where it produces an ac voltage of the UPFC, where it produces an ac voltage of controllable magnitude and phase angle, and injects this voltage at this fundamental frequency in series with the transmission line through a booster transformer. It also exchanges real and reactive power at its ac terminals through the series connected transformer. The active power needed by this converter is provided from the ac power system by the shunt converter through the dc link. The line thermal limit (current) sets the maximum limit through the series converter. The series converter can be used to

increase the transmission capability. The ac side of the shunt converter is connected in parallel with the transmission line through a transformer where a current of controllable magnitude and a power factor angle is injected to or absorbed from the power system. The basic function of this converter is to supply or absorb the active power demanded by the series converter at the dc terminals. It also can generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line. The shunt controller can be used for local voltage control, which in turn improves system voltage stability. The shunt voltage and its current are limited by the rating of shunt converter. [1]

Transmission Pricing

Many pricing schemes have been proposed and implemented in different markets. The postage stamp method is based on the average system costs, which include separate charges for peak and off-peak periods. According to this method the users are not differentiated by the extent of use of transmission facilities but charged based on an average embedded cost and the magnitude of transacted power. The other method is the contract path method, which assumes that the transacted power is confined to flow along an artificially specified path through the involved transmission systems and does not reflect the flows through the grid that include the loop and parallel path flows. An improvement to the above methods is the MW-mile method in which, power flow and the distance between the injection and withdrawal locations reflect the transmission charges. However all these methods do not consider the aspect of transmission congestion. The MW- Mile method is one of the first pricing methods proposed for the full recovery of the fixed transmission costs based on the actual use of the transmission network[13] [14]. The “transmission network capacity use” defines the extent of use of transmission network facilities by the users of transmission service including wheeling transactions [15] and the “wheeling transactions” define the transmission of electric power for other entity (ies) by a utility that neither generates nor intends to use the power as system resources. It is also called the line-by-line method as it considers changes in MW transmission flows and transmission line lengths in miles and the charges are calculated based on the transmission capacity usage as a function of magnitude of transacted power, the path followed by the transacted power as well as the distance travelled by the transacted power. Thus it is also useful for identifying transmission paths for a power transaction. In this method the nodal power injections involved in transaction t , are used to calculate the transaction related flows on all the network lines using an approximate dc model, which are multiplied by its line length and the cost per MW per unit length of the line and summed over all the lines. The net power flow impact is determined using an incremental absolute approach which considers the difference in magnitude irrespective of the flow direction.

$$\Delta P_i = |\pm P_{t,i}| - |\pm P_{b,i}|$$

Here ΔP_i is the power flow impact in line i , $P_{t,i}$ is the power flow in line i during transaction in MW and $P_{b,i}$ is the power flow in line i for base case in MW. ΔP is the negative power flow impact if $|\pm P_{t,i}| < |\pm P_{b,i}|$ i.e. flow in a particular line decreases after the transaction. The contribution of each transaction t to the total transmission capacity cost can be summarized as follows:

$$TC_t = TC * \frac{\sum_{k \in K} c_k L_k MW_{t,k}}{\sum_{t \in T} \sum_{k \in K} c_k L_k MW_{t,k}}$$

Where,

TC_t = price charged for transaction t in \$/MW

TC = total cost of all lines in \$ L_k = length of line k in mile

C_k = cost per MW per unit length of line k $MW_{t,k}$ = flow in line k due to transaction t

T = set of transactions

K = set of lines

An analysis of the contribution of each transaction is done before and after the placement of the FACTS devices to show how the share of each transaction changes with the inclusion of the FACTS devices. The pricing methodology is given below:

Step-A: Find the total cost of the line by multiplying the unit cost of the line with line length.

Step-B: Find the base case power flow on all lines. (This is obtained here using MATLAB/Simulink model)

Step-C: find the new power flow solution with the transaction T1, and hence the power flow on each line. (A negative sign indicates a reversal of flow direction with respect to the base case power flow. Here negative sign is dropped because of absolute approach)

Step-D: Find the new power flow solution with the transaction T2, and hence the power flows on each line.

Step-E: Calculate the incremental power flow on each line caused by the transaction T1.

Step-F: Calculate the incremental power flow on each line caused by the transaction T2.

Step-G: Calculate each line usage due to transaction T1 and hence find the total transmission system usage by T1.

Step-H: Calculate each line usage due to transaction T2 and hence find the total transmission system usage by T2.

Step-I: Calculate the total transmission system usage by T1 and T2 for proportional allocation of the cost.

Step-J: Calculate the proportional allocation of costs to transaction T1.

Step-K: Calculate the proportional allocation of costs to transaction T2.

The primary objective of this paper is to calculate wheeling charge for each participant according to their contribution in MW power flow for each line. Here it is assumed that the generators pay 100% of the transmission cost of services to the transmission utility.

Test System For Pricing Analysis

The system having seven transmission lines with three generators supplying an industrial load is chosen for analysis purpose. The load is supplied by the three generators with G1 supplying 500 MW, G2 supplying 1000 MW and G3 supplying 1000 MW. Table 1 shows the line lengths and the cost per MW per unit length of the line. This data is used for calculating the contributions of each generator transaction towards the total transmission capacity cost using the MW-mile methodology. The main aim of the analysis is to look at the impact of the FACTS devices on the system pricing and how the contributions of each transaction change with the inclusion of FACTS devices.

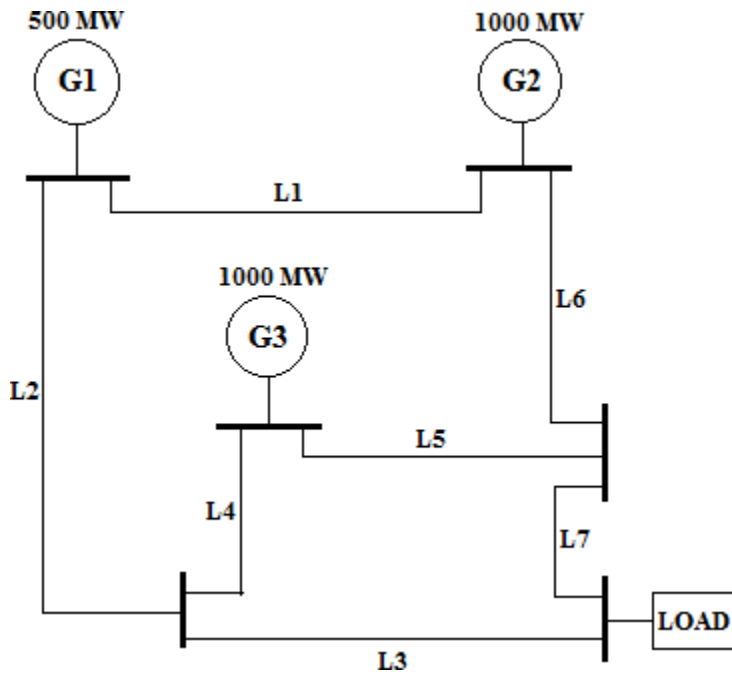


Figure 2: Test System

Table 1: Line Flows With and Without UPFC

Line	P(MW) without UPFC	P(MW) with UPFC
1	182	89
2	675	582
4	672	580
5	1649	1558
6	810	904
7	2450	2451

Transmission Pricing For The Test System

The MW-mile method described in section 3 is used to find the contribution of each generator towards the total transmission cost. Table II and Table III show the individual contribution of all the three generators toward the network. $MW_{t,k}$ due to T1 in the table represents the flow of generator G1's (500 MW) power in all the lines similarly transactions T2 and T3 are for generators G2(1000MW) and G3(1000MW) respectively.

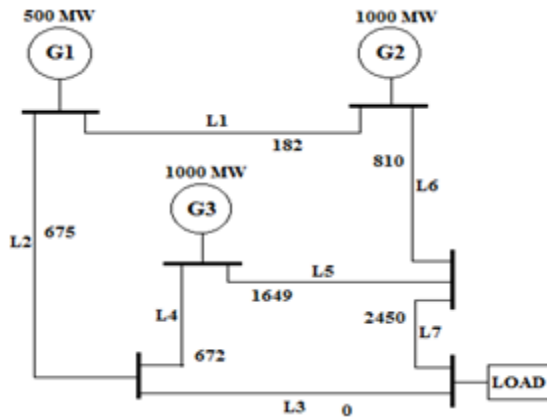


Figure 3: Flow in lines without UPFC

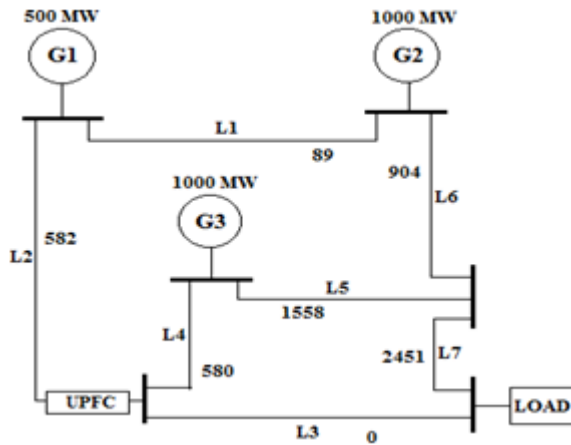


Figure 4: Flow in lines with UPFC

Simulink Model of Test Network

A UPFC is used to control the power flow in a 500 Kv /230 kV transmission system. The system, connected in a loop configuration, consists essentially of seven transmission lines (L1 to L7) two 500 kV/230 kV transformer banks Tr1 and Tr2. Three power plants located on the 230-kV system generate a total of 2500 MW which is transmitted to a 500-kV 15000-MVA equivalent . The plant models include a speed regulator, an excitation system as well as a power system stabilizer (PSS). Using the load flow option of the powergui block, the model has been initialized with plants G1,G2 and G3 generating respectively 500 MW,1000 MW and 1000 MW and the UPFC out of service (Bypass breaker closed). The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500-kV bus B3, as well as the voltage at bus B_UPFC. It consists of a phasor model of two 100-MVA, 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

Table 2: Calculation of Cost Allocation Based on The Mw-Mile Method Without UPFC In The System

Steps	L1	L2	L4	L5	L6	L7
Cost(\$)	364000	202500	134400	197880	48600	245000
Base power flow (MW)	182	675	672	1649	810	2450
Power flow due to T1	80	1068	1061	2030	913	2931
Power flow due to T2	530	1021	1041	1982	1444	3393
Power flow due to T3	142	635	632	257	850	3412
due to T1	102	392	388	380	103	481
due to T2	347	345	368	332	634	943
due to T3	39.9	39.9	45	923	40	962
(Incremental power flow)						

Table 3: Calculation Of Cost Allocation Based On The Mw-Mile Method With Upfc In The System

Steps	L1	L2	L4	L5	L6	L7
Cost (\$)	178000	174600	116000	186960	54240	245100
Base power flow (MW)	89	582	580	1558	904	2451
Power flow due to T1	18	970	963	1935	1013	2933
Power flow due to T2	450	941	935	1903	1526	3391
Power flow due to T3	71	565	563	2504	922	3412
due to T1	71	386	382	375	109	482
due to T2	360	358	354	343	622	940
due to T3	18	17	16	944	18	961
(Incremental power flow)						

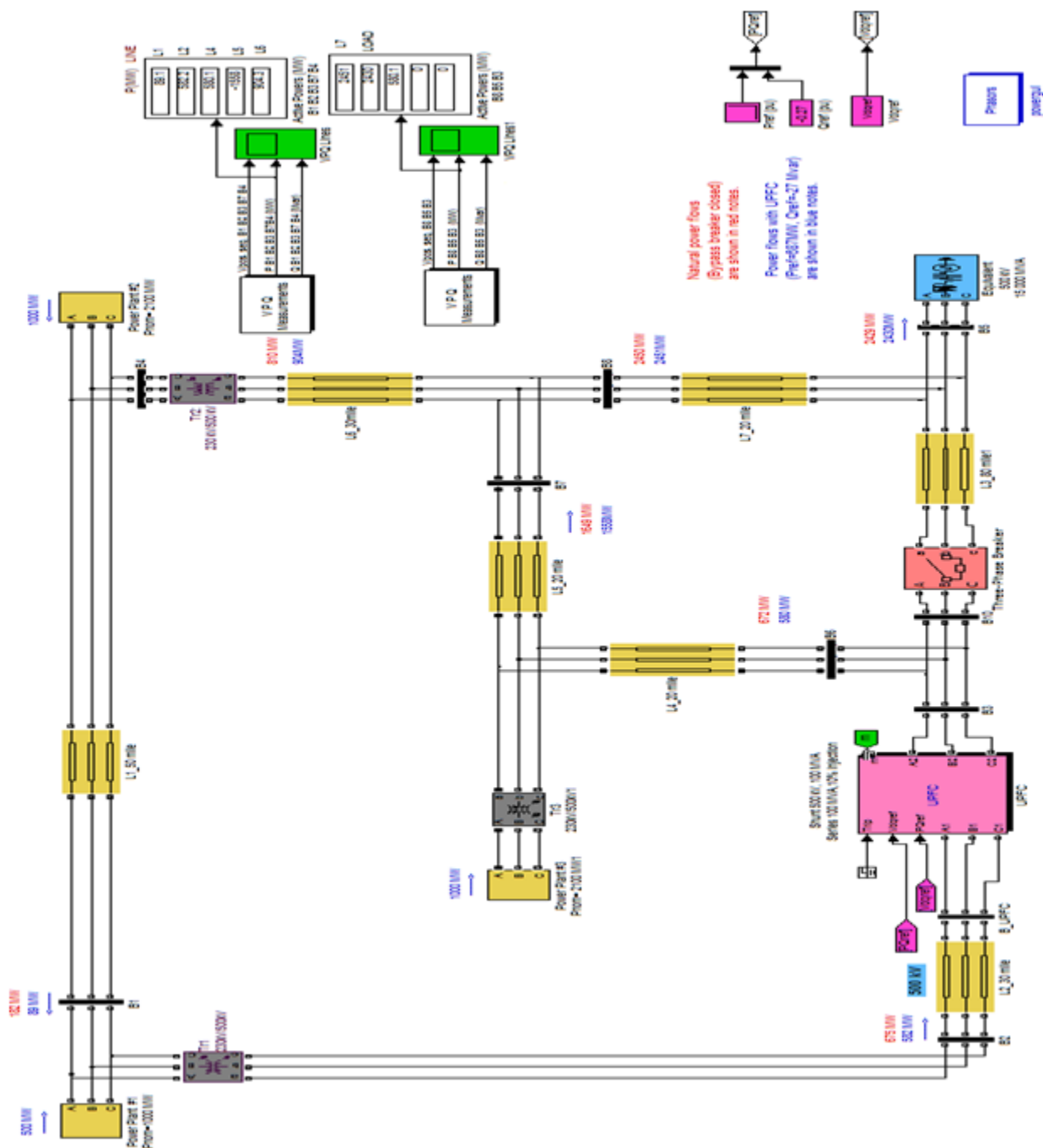
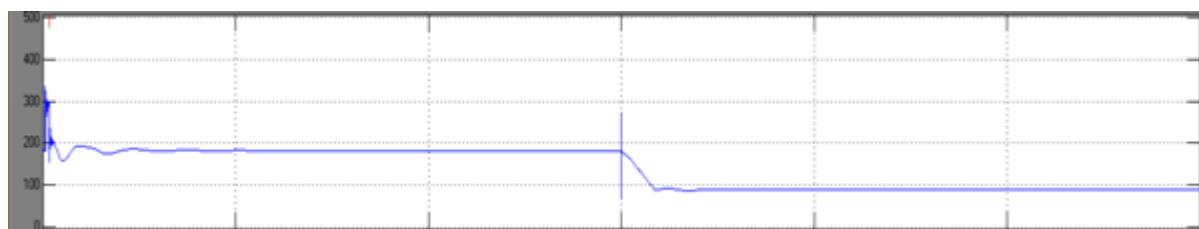
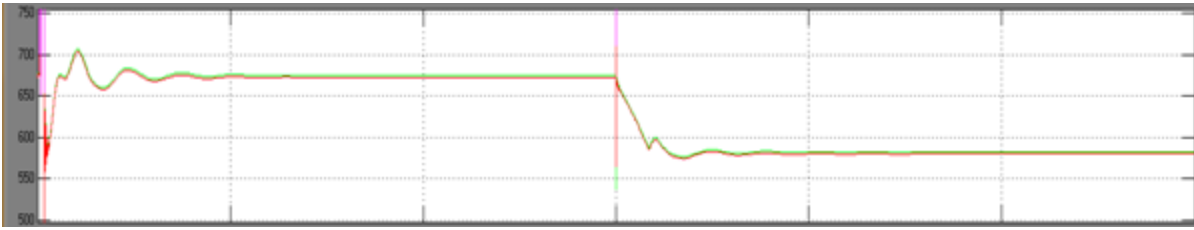


Figure 5: Simulink model of test system with UPFC

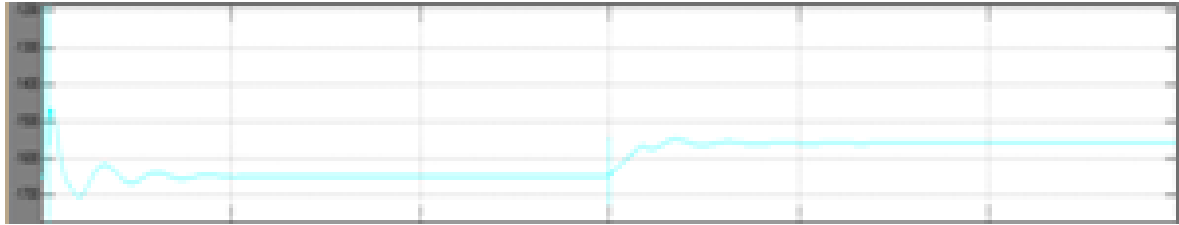
Power Measurement at Various Lines



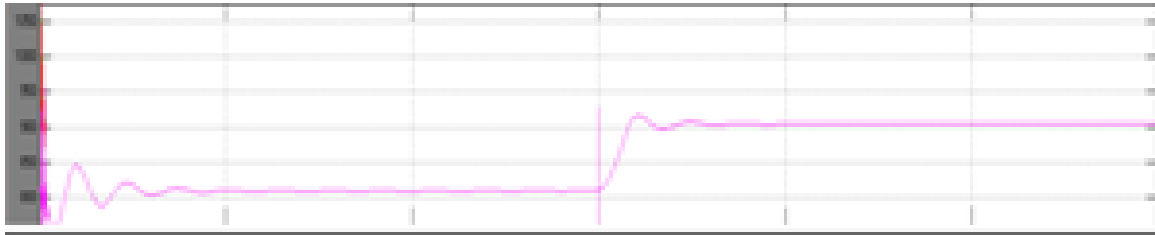
a. Effect of UPFC on Power flow injection at line L1



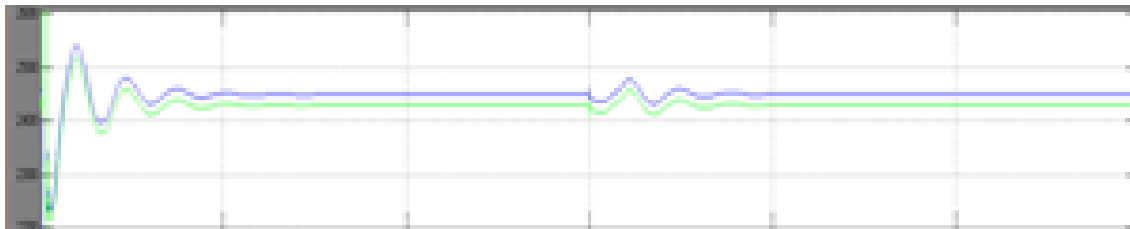
b. Effect of UPFC on Power flow injection at line L2&L4



c. Effect of UPFC on Power flow injection at line L5



d. Effect of UPFC on Power flow injection at line L6



e. Effect of UPFC on Power flow injection at line L7 and load Figure 6. Dynamic performances of UPFC

Table 4: Pricing With and Without FACTS

Pricing Generator	Without FACTS (\$)	With FACTS (\$)
G1	322777	234007
G2	671083	583978
G3	198567	136923

Conclusion

The deregulated power system possesses many advantages over the vertically integrated power systems; however, a deregulated power system faces various technical and non-technical problems like pricing issues, available transfer capability, congestion management and market power. FACTS devices can be an alternative to reduce the flow in heavily loaded lines, resulting in an increased loadability of network, reduced cost of production and fulfilled

contractual requirement by controlling the power flows in the network. 6-bus test system simulated in Simulink shows numerical results and demonstrates the saving in transmission cost to generation companies in delivering the power to loads. Results also present the dynamic performance of UPFC on the system.

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