Modeling Of Unified Power Flow Controller (UPFC) For The Control Of Real And Reactive Power Flow On 500 kV Interconnected Power System

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Abstract—**Continuous demand in electric power system network has caused system to be heavily loaded leading to voltage instability. The control of power and the usable capacity enhancement of existing as well as new and upgraded line can be effectively done by Flexible Alternating Current Transmission System (FACTS) technology. FACTS technology opens up new opportunities for controlling power flow and enhancing the usable capacity of present, as well as new lines. The Unified Power Flow Controller (UPFC) is the most promising FACTS device for power flow control. This paper describe the performance of UPFC for effective control of active and reactive power flow on a 500 kV interconnected lines for the purpose of compensation as well as enhancement of power transmission capability of transmission line. To evaluate the performance of UPFC, simulation was carried out in MATLAB/SIMULINK environment. The simulation results reveal that UPFC device has an excellent capability to enhance real and reactive power flow.**

Keywords—Flexible AC Transmission System (FACTS); Unified Power Flow Controller (UPFC); Real and Reactive Power, Bus Voltage

I. INTRODUCTION

A power system is a complex arrangement comprising of numerous generators, transmission lines, variety of loads, switches, compensators and transformers. Such a network is non-linear and non-stationary, and in practice it is prone to several faults and disturbances. As a consequence of increasing power demand, some transmission lines are more loaded than was planned when they were built. At the same time, the construction of new generating units and transmission circuits becomes more difficult because of economic reasons and growing environmental concerns [1]. Making existing line as well as new ones more efficient and economical becomes a compelling alternative. Optimum power transmission and distribution also entails the reduction of transfer losses and provision of adequate power quality and availability at the receiving end. The purpose of the interconnected transmission network is to pool power plants and load centers in order to minimize the total power generation capacity, fuel cost and at the same time to meet the load demand [2, 3]. In general, if a power delivery system was made up of radial lines from individual local generators without being part of a grid system, more generation sources would be needed to serve the load with same reliability and the cost of electricity would be much higher [1]. In this point of view, grid system is an alternative to a new generation resources. As power transfer grows, the power system becomes increasingly more complex to operate and the system becomes less secure. It may lead to a large power flow with inadequate control, excessive reactive power in various parts of the system and large dynamic swings between different parts of the system, thus the full potential of transmission interconnections cannot be utilized. Restructuring has greatly reduced the degree to which grid operators can manage the generation side of the relationship, so the emphasis here is upon enhanced system performance through improvements in transmission capabilities alone [4]. Reinforcing a power system can be done by increasing the voltage level or adding transmission lines. However, these solutions require considerable investment which is difficult to recover. Power system can be effectively improved by the use of FACTS devices. Flexible AC transmission system (FACTS) devices can be a solution to these problems. FACTS devices have shown very promising steady-state performances because of the extremely fast control action associated with FACTS-device operations, they have been very promising candidates for utilization in power system damping enhancement [4, 5, 6]. A Unified Power Flow Controller (UPFC) is the most promising device among the FACTS family. It has the ability to adjust the three control parameters, i.e. the bus voltage, transmission line reactance, and phase angle between two bus voltages, either simultaneously or independently. A UPFC performs this through the control of the in-phase voltage, quadrature voltage and shunt compensation [4, 5]. UPFC can also be used not only for power flow

control, but also for power system stabilizing control [7]. Several trials have been reported in the literature to model a, UPFC for steady – state and transient studies [8, 9].

UNIFIED POWER FLOW CONTROLLER

The UPFC, which was first proposed by [10, 11, 12] consists of shunt (exciting) and series (boosting) transformers as shown in Figure 1.
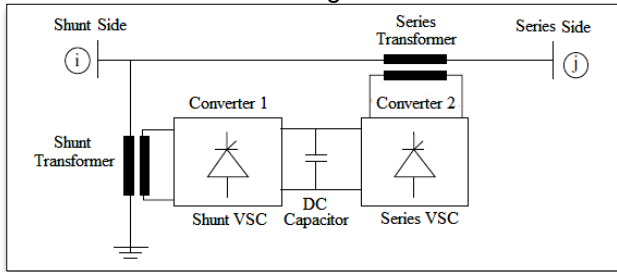

Figure 1: UPFC Basic Configuration Arrangement

The UPFC consists of two switching converters based on VSC valves. The two converters are connected by a common DC link. Series inverter is coupled to a transmission line via a series transformer. The shunt inverter is coupled to a bus i via a shunt connected transformer. The shunt inverter can generate or absorb controllable reactive power, and it can provide active power exchange to the series inverter to satisfy operating requirements.

II. METHODOLOGY

In order to investigate the impact of UPFC on power systems effectiveness, it is essential to formulate their correct model. Based on the circuit arrangement, the equivalent circuit of UPFC established [4] in figure 2 below.
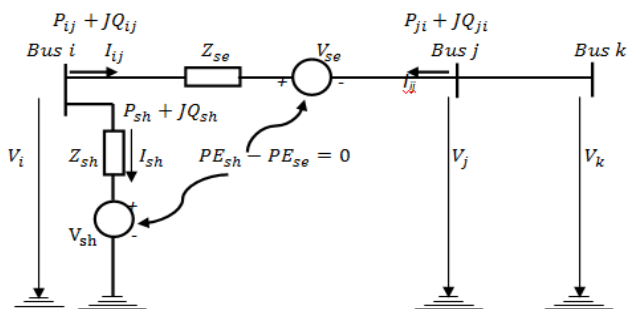

Figure 2: Equivalent Circuit of UPFC

In figure 2, the phasor vector 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 the voltage at bus i and j respectively.

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

P_{sh} and Q_{sh} Is the shunt converter active and reactive power flows

I_{ij} and I_{ji} are the current through the UPFC series Converter $I_{ij} = -I_{ji}$

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} and P_{se} is the active power exchange of the shunt and series converters with the DC link.

A. Power Flow Constraints of UPFC

For equivalent circuit of UPFC presented in figure 2, Suppose

$$V_{sh} = V_{sh} \angle \theta_{sh}, \quad V_{se} = V_{se} \angle \theta_{se}, \quad V_i = V_i \angle \theta_i, \quad V_j = V_j \angle \theta_j$$

Then the power flow constraint of the UPFC shunt and series branches are:

$$P_{sh} = Vi^2 g_{sh} - V_i V_{sh} \ (g_{sh} \cos(\theta_i - \theta_{sh}) + b_{sh} \sin \ (\theta_i - \theta_{sh})) \quad (1)$$

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

$$P_{ij} = Vi^2 g_{ij} - V_i V_j \ (g_{ij} \cos \theta_{ij} + b_{ij} \sin \theta_{ij}) - V_i V_{se}(g_{ij} \cos \ (\theta_i - \theta_{se}) + b_{ij} \sin(\theta_i - \theta_{se})) \quad (3)$$

$$Q_{ij} = -Vi^2 b_{ij} - V_i V_j \ (g_{ij} \sin \theta_{ij} - b_{ij} \cos \theta_{ij}) - V_i V_{se}(g_{ij} \sin \ (\theta_i - \theta_{se}) - b_{ij} \cos(\theta_i - \theta_{se})) \quad (4)$$

$$P_{ji} = V_j^2 g_{ij} - V_i V_j \ (g_{ij} \cos \theta_{ji} + b_{ij} \sin \theta_{ji}) + V_j V_{se}(g_{ij} \cos \ (\theta_j - \theta_{se}) + b_{ij} \sin(\theta_j - \theta_{se})) \quad (5)$$

$$Q_{ji} = -V_j^2 b_{ij} - V_i V_j \ (g_{ij} \sin \theta_{ji} - b_{ij} \cos \theta_{ji}) + V_i V_{se}(g_{ij} \sin \ (\theta_j - \theta_{se}) - b_{ij} \cos(\theta_j - \theta_{se})) \quad (6)$$

Where $\quad g_{sh} + jb_{sh} = 1/Z_{sh}, \quad g_{ij} + jb_{ij} = 1/Z_{se},$

$\theta_{ij} = \theta_i - \theta_j, \quad \theta_{ji} = \theta_j - \theta_i$

The active power exchange between two inverters via a DC link should be balanced at any instant which described by equation (7):

$$\text{where } \Delta PE_{sh} = PE_{sh} - PE_{se} = 0 \quad (7)$$

$$\text{Where } PE_{sh} = \Re_e(V_{sh}I^*_{sh}) \text{ and } PE_{se} = \Re_e(V_{se}I^*_{ji})$$

is the active power exchange of the shunt converter and the series converter with the DC link, respectively.

B. Description of Power System Case Study

The single line diagram of the model of interconnected 500 kV transmission lines between three power systems is shown in figure 3 below. The UPFC is installed between bus B1 and bus B2 to analyse the impact of UPFC for the control of power flow and better usage of line capacity.
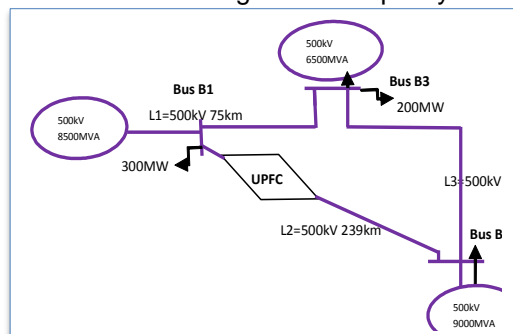

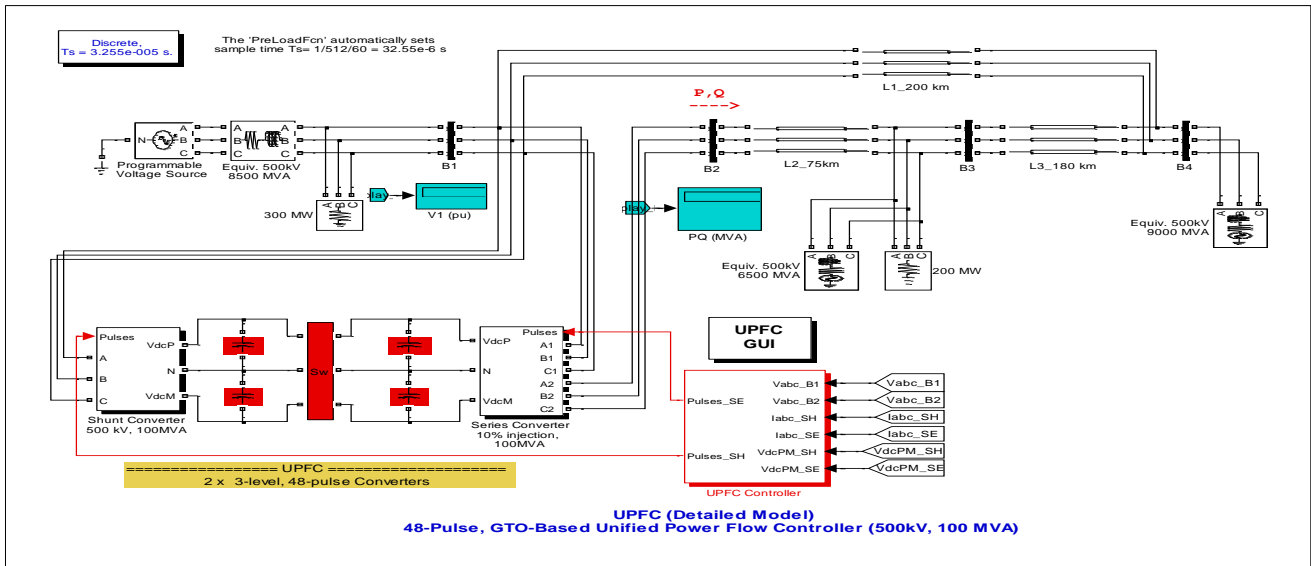Figure 3: Single Line Diagram of System Study Case Model.

Figure 4: Study System Model in MATLAB / SIMULINK with UPFC

The Typical Overhead Transmission Line parameters of the 500 kV Transmission line system was taken from[1]..

 a) Harmonics generated by the UPFC is neglected
 b) The system as well as the UPFC is three phase balanced.
    Rated frequency =   50Hz

DISTANCES
Line L1 =   500 kV 90 KM
Line L2 =   500 kV 239 KM
Line L3 =   500 kV 180 KM

UPFC Rating
Shunt transformer rating = 500kV/20kV, and Rated power 100MVA
Series Transformer Rating = 20kV/500kV, and Rated power 100MVA

Vdc =   20 kV

Capacitor rating = 2500µF

III. SIMULATION RESULT AND DISCUSSION

The procedure for real and reactive power control based on UPFC described in figure 3 above was implemented using MATLAB/SIMULINK 2009 (7.8) for windows and couple on a 500 kV grid system. The feasibility and effectiveness of the new approach is demonstrated.

The device consists of two (2) 100MVA GTO based converters, one connected in shunt at bus B1 and another one connected in series between bus B1 and B2. The shunt and the series converters can inject a maximum of 10% of normal line to ground voltage(28.8kV) in series with L2. To test the effectiveness of the new approach, the UPFC device is used to control the power flow in a 500 kV transmission system. The UPFC is located at the left end of the 239KM line L2, between 500kV buses B1 and B2. The device is used to control real and

reactive power flow on the transmission. The reference values of the UPFC are set below.

The   Active   power   reference   value,
$P_{ref} = +8.7 Pu / 100 MVA (870 MW)$.

The   reactive   power   reference   value,
$Q_{ref} = -0.6 Pu / 100 MVA (-60 MVAr)$.

Also the reference voltage to the shunt converter is kept constant at Vref=1.02pu during the whole simulation and simulation stop time (0.8 seconds).

The impact of the UPFC installed at the sending end of the transmission line, is shown in figure 5 and 6 respectively. The simulated results show an increase of power flow through monitored line using UPFC control. The simulation was run for 0.8 seconds.
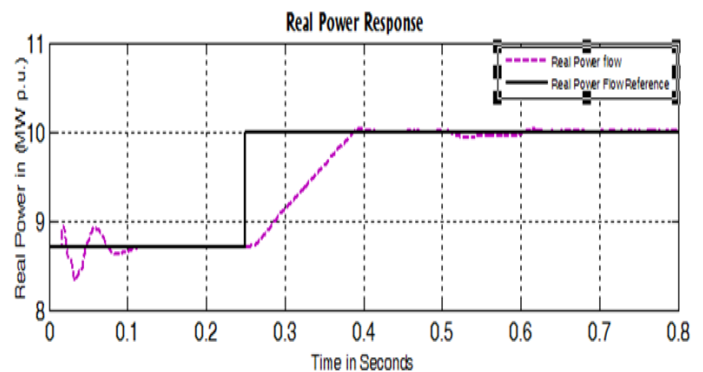

Figure 5: Active power response after UPFC action installed in sending end of the transmission line.

Figure 5 shows the impact of UPFC on active power flow which is transmitted through the line. After a transient period lasting approximately 0.15sec, the steady state is reach. At time t=0.25sec, UPFC is activated and P_{ref} has started to grow from P=+8.7p.u (870MW) to 10p.u (1000MW).
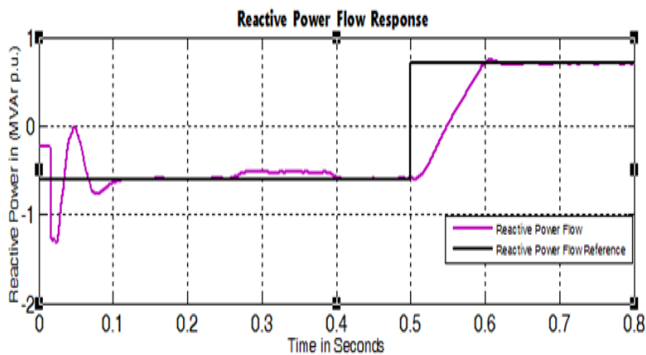
Figure 6: Reactive power response after UPFC action installed in sending end of the transmission line.

The figure 6 above displays the impact of the UPFC for reactive power flow which is transmitted through the line. The response of the UPFC was noticed after 0.5 seconds and the reactive power has started to grow from -0.6p.u (-60MVAr) and after 0.1 seconds it has rapidly increased to 0.7 p.u (70MVAr). So, the reactive power has a small change around its steady state value due to the changes in the active power at 0.25seconds and there is small changes in the reactive power.
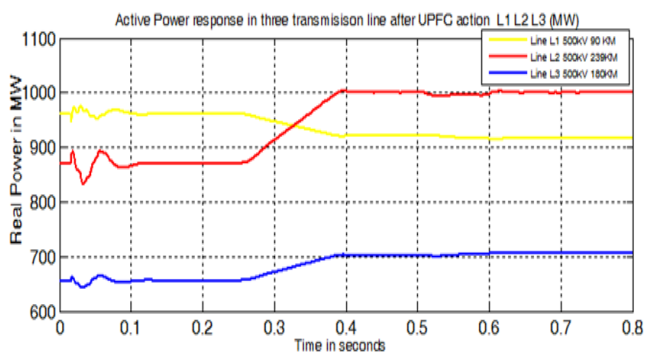

Figure 7: Active power response in three (3) transmission line of study model after UPFC action.

In figure 7 one can observe the resulting changes in active power flow on the three (3) transmission lines interconnected in our study model. After activation of UPFC, active power flow in transmission line L1 increased to 1000MW, while the active power flow in transmission line L2 was reduced from 980MW to 920MW and that of L3 was also improved from *650MW* to 700MW. The increase in real power tends to decrease the congestion on the line and makes it more flexible. This can be seen from the above figure.
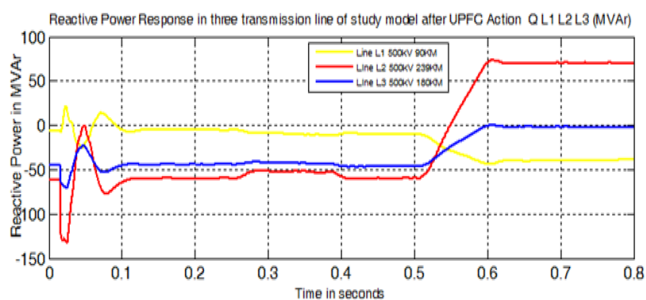

Figure 8 Reactive power response in three transmission lines of study model after UPFC action

In figure 8, the resulting changes in reactive power flow on the three (3) transmission line interconnected in our study model has been observed. After activation of UPFC, reactive power flow in transmission line L1 increases to +70MVAr, while the reactive power flow in transmission line L2 reduces further from 0MVAr to -40MVAr and that of L3 was also augmented from -50MVAr to 0MVAr.

IV. CONCLUSION

The paper provides the possibility of installing UPFC FACTS device on a 500KV transmission system. Application of UPFC for control of active and reactive power flow has been explored in this study. The MATLAB/SIMULINK environment was used to simulate the model of interconnected line between three (3) power systems. The control and performance of UPFC intended for installation on a transmission line is presented. Simulation results show the effectiveness of the UPFC in controlling the active and reactive power flow through the transmission line. The computer simulation results also indicate that the attainable response of the control is very fast, almost instantaneous, and thus the UPFC is effective in handling dynamic system response.

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