

## POWER QUALITY IMPROVEMENT IN FOURTEEN BUS SYSTEM USING UNIFIED POWER FLOW CONTROLLER

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**Abstract:** This work deals with Modeling and Simulation of 14 bus system employing Unified Power Flow Controller (UPFC). The UPFC is a Flexible AC Transmission Systems (FACTS) device used for improving the power quality in power systems. Simulink model is developed for 14 bus systems with and without UPFC. Digital simulation is done with this model and results are presented. The effect of UPFC on the nearby buses in a multibus system is also presented.

**Keywords:** FACTS, UPFC, Power Quality, MATLAB, SIMULINK.

### INTRODUCTION

UPFC is the most comprehensive multivariable Flexible AC Transmission systems (FACTS) Controller. Simultaneous control of multiple power system variables with UPFC poses enormous difficulties. In addition, the complexity of the UPFC control increases due to the fact that the controlled and the control variables interact with each other.

UPFC which consists of a series and shunt converter connected by a common DC link capacitor can simultaneously perform the function of transmission line real and reactive power flow control in addition to UPFC bus voltage shunt reactive power control [1]. The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. The series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle. The interaction between the series injected voltage and the transmission line current leads to real and reactive power exchange between the series converter and power system. Under steady state conditions, the real power demand of the series converter is supplied by the shunt converter. But

during transient conditions, the series converter real power demand is supplied by the DC link capacitor. If the information regarding the series converter real demand is not conveyed to the shunt converter control system, it could lead to collapse of the dc link capacitor voltage and subsequent removal of the UPFC from operation.

Very little or no attention has been given to the important aspect of co ordination control between the series and the shunt converter control systems [2]-[7]. The real power coordination discussed in [4] is based on the known fact that the shunt converter should provide the real power demand of the series converter. In this case, the series converter provides the shunt converter control system an equivalent shunt converter real power reference that includes the error due to change in DC link capacitor voltage and the series converter real power demand. The control system designed for the shunt converter in [4] causes excessive delay in relaying the series converter real power demand information to the shunt converter. This could lead to improper coordination of the overall UPFC control system and subsequent collapse of DC link capacitor voltage under transient conditions.

In contrast to real power coordination between the series and shunt converter control system, the control of transmission line reactive power flow leads to excessive voltage excursions of the UPFC bus voltage during reactive power transfers. This is due to the fact that any change in transmission line reactive power flow achieved by adjusting the magnitude/phase angle of the series injected voltage of the UPFC is actually supplied by the shunt converter. The excessive voltage excursion of the UPFC bus voltage is due to absence of reactive power coordination between the series and the shunt converter control system. This aspect of UPFC control has also not been investigated [2]-[7].

The above literature does not deal with the simulink modeling of fourteen bus system using UPFC. This work presents modeling and simulation of fourteen bus system using Matlab Simulink.

## 2. CONTROL STRATEGY FOR UPFC

### 2.1. Shunt Converter Control Strategy

UPFC is a FACTS device used for improving power quality in power systems is shown in fig.1. The UPFC consists of combination of series converter and shunt converter. The DC terminals of shunt device are connected to a common link DC capacitor. The series device acts as a controllable voltage source. Shunt device acts as a controllable current source. Shunt device has the capability of controlling reactive power.

The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. In this case, the shunt converter voltage is decomposed into two components. One component is in phase with the UPFC bus voltage. Decoupled control system has been employed to achieve simultaneous control of the UPFC bus voltage and the DC link capacitor voltage.

The real and reactive power equations are as follows:

$$(1) P = \frac{V^2}{X} \sin \delta$$

$$(2) Q = \frac{V^2}{X} (1 - \cos \delta)$$

Where  $V$  is the line voltage,  $\delta$  is the transmission angle and  $X$  is line impedance.

### 2.2. Series Converter Control Strategy

The series converter of the UPFC provides simultaneous control of real and reactive power flow in the transmission line. To do so, the series converter injected voltage is decomposed into two

components. One component of the series injected voltage is in quadrature and the other in phase with the UPFC bus voltage. The quadrature injected component controls the transmission line real power flow. This strategy is similar to that of a phase shifter. The in phase component controls the transmission line reactive power flow. This strategy is similar to that of a tap changer.

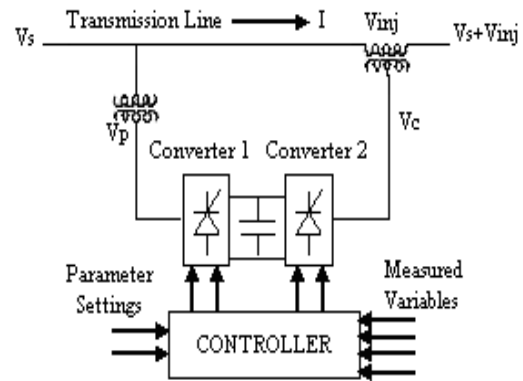


Fig.1 Basic power system with UPFC

## 3. SIMULATION RESULTS

The goal of the simulation study is to prove that the UPFC is capable of improving the voltage stability.

Circuit model of two bus system with UPFC is shown in Fig. 2. Shunt converter is represented as a voltage source ( $V_{shunt}$ ). The series converter is represented by another source ( $V_{series}$ ). Power measurement block is connected in parallel with the load to measure real and reactive powers. The load voltage and current waveforms at  $\alpha=0^\circ$  are shown in Fig. 3. The corresponding real and reactive powers are shown in Fig. 4. Load voltage and current waveforms at  $\alpha=36^\circ$  are shown in Fig. 5. The real and reactive powers with  $\alpha=36^\circ$  are shown in Fig. 6. Load voltage and current waveforms at  $\alpha=72^\circ$  are shown in Fig. 7. The real and reactive powers with  $\alpha=72^\circ$  are shown in Fig. 8.

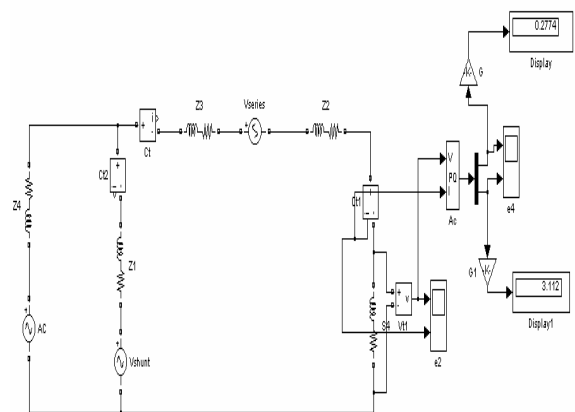


Fig. 2. Circuit Model of 2 Bus System with UPFC

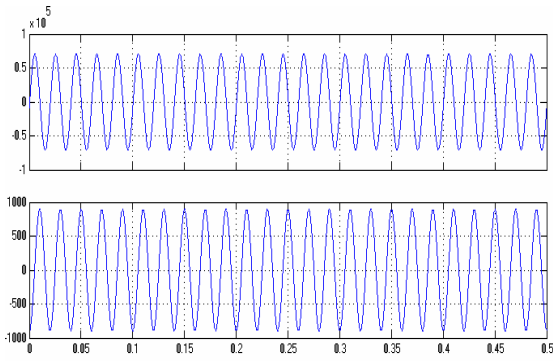


Fig.3. Load Voltage and Current waveform at  $\alpha=0^\circ$

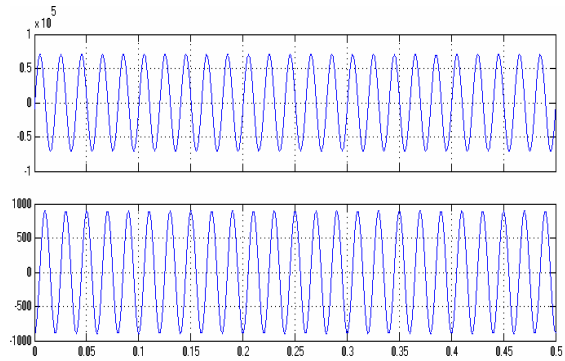


Fig. 7. Load Voltage and Current waveform at  $\alpha=72^\circ$

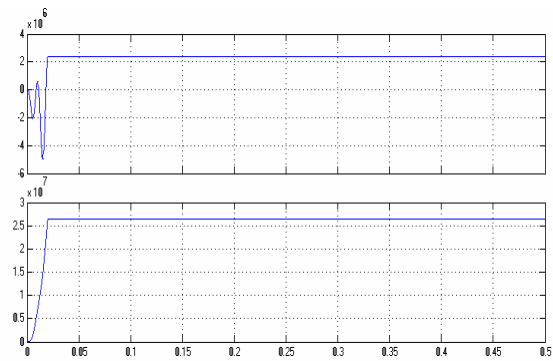


Fig. 4. Real and Reative Power at  $\alpha=0^\circ$

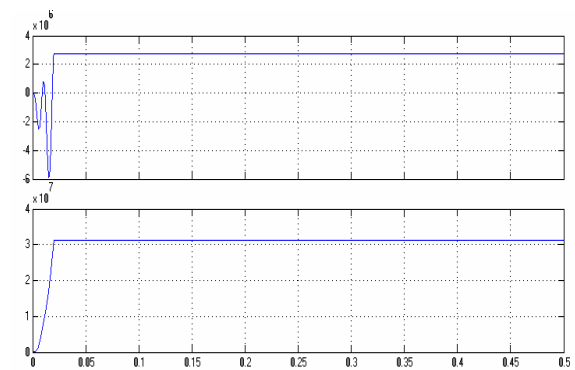


Fig.8. Real and Reative Power at  $\alpha=72^\circ$

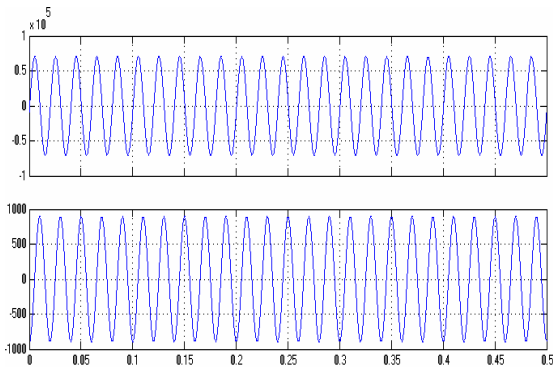


Fig.5. Load Voltage and Current waveform at  $\alpha=36^\circ$

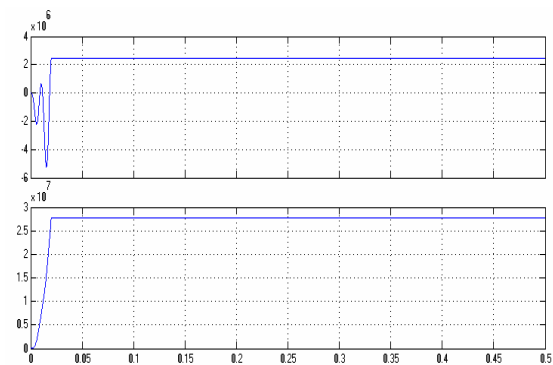


Fig. 6. Real and Reative Power at  $\alpha=36^\circ$

The variation of real power with the variation in the angle of injected voltage is given in Table1. The real power increases with the increase in the angle of injection. The corresponding graph is shown in Fig. 9. The variation of reactive power with variation in the magnitude of shunt voltage is given in Table 2. The bus voltage increases with the increase in the injected voltage. The corresponding graph is shown in Fig. 10. The reactive power increases with increase in the shunt voltage.

Table.1. Variation of Real Power

S. NO.	Angle of Injected Voltage $V_{Series}$ (Deg.)	Real Power (KW)
1	0	236.3
2	18	239.3
3	36	247.7
4	54	260.8
5	72	277.4
6	90	295.7
7	108	314.0

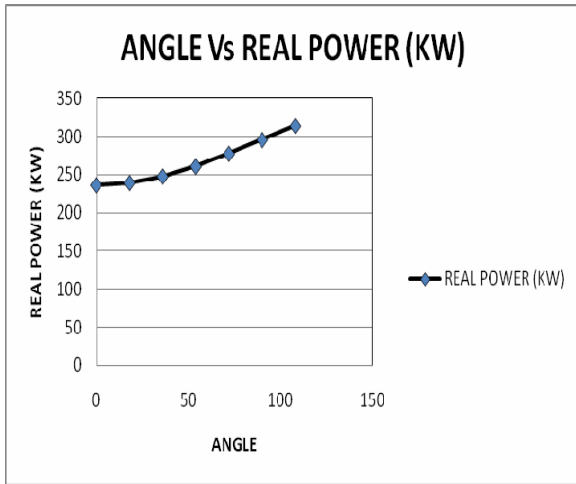


Fig. 9. Real Power Vs Angle

Table.2 Variation of Reactive Power

S.No.	Injected Voltage $V_{Shunt}$ (KV)	Reactive Power (KVAR)
1	4	2770
2	6	2772
3	8	2774
4	10	2776
5	12	2777
6	14	2779

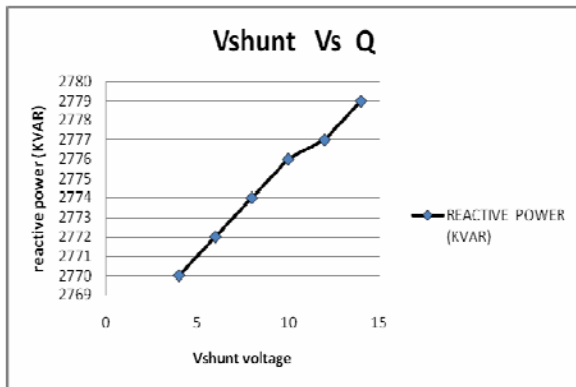


Fig.10. Reactive Power Vs Shunt Voltage

Simulink model of 14 bus system is shown in Fig. 11. Lines are represented by series impedances. The circuit model of 14 bus system is presented without UPFC. The load voltage waveform of bus 2 is shown in Fig. 12. The real and reactive power at bus 2 are shown in Fig. 13.

The circuit model of 14 bus system with UPFC is shown in Fig. 14. The UPFC is connected between the buses 6 and 12. Load voltage at bus 2 is shown in Fig. 15. The real and reactive powers in bus 2 are shown in Fig. 16. The summary of real and reactive power at various buses are given in Table 3. The real and reactive powers at buses 11,12,13 and 14 increase due to the presence of UPFC near bus 11. The summary of reactive power with different values of injected voltage is given in Table 4. The reactive power can be further increased by increasing the magnitude of injected voltage. The corresponding graph is shown in Fig. 17. It can be seen that the reactive power increases with the increase in the injected voltage.

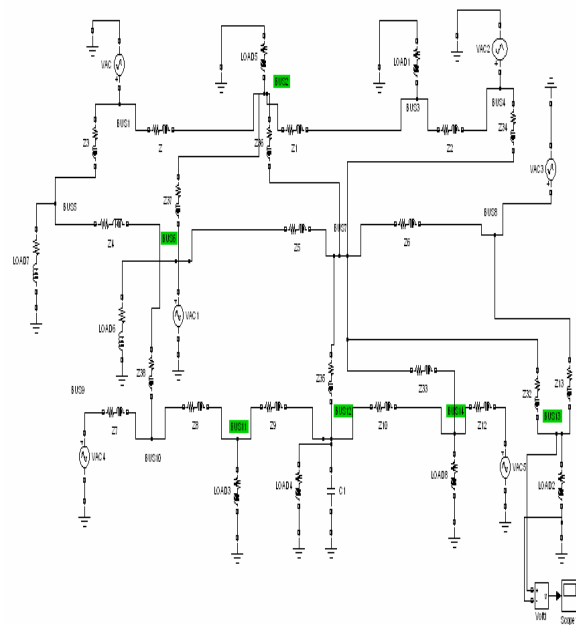


Fig.11. 14 Bus system model without UPFC

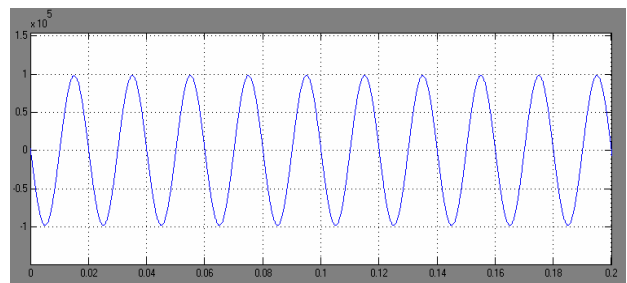


Fig.12. Load voltage in bus 2

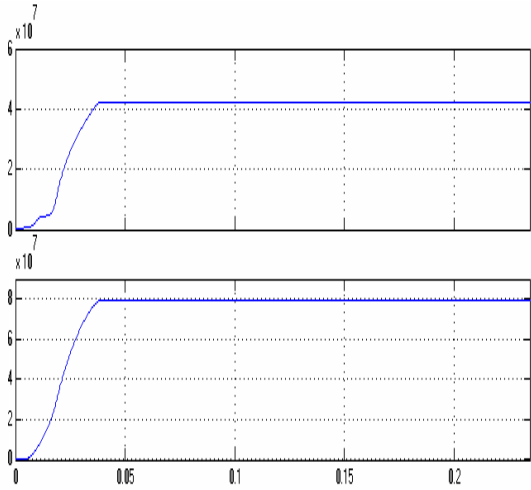


Fig.13. Real and Reactive power in bus 2

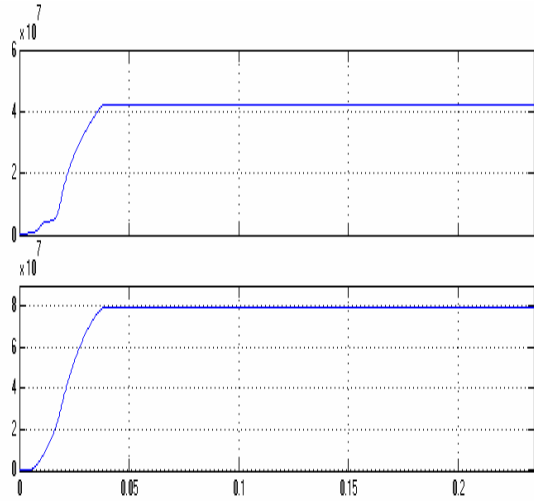


Fig.16. Real and Reactive power in bus 2

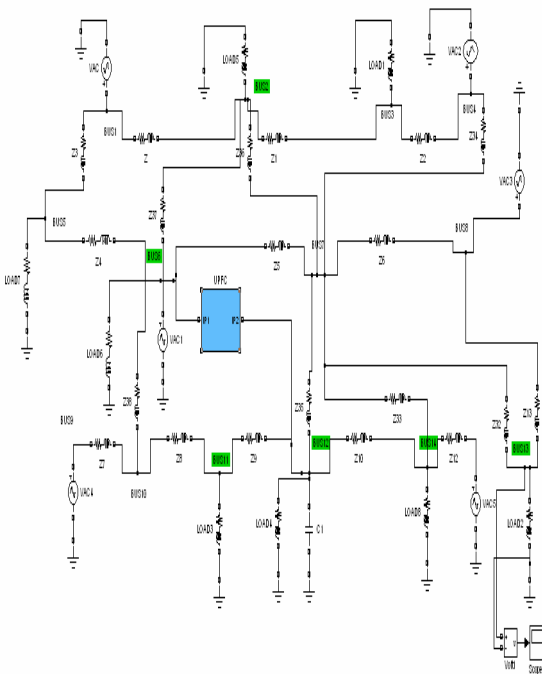


Fig. 14. 14 Bus system model with UPFC

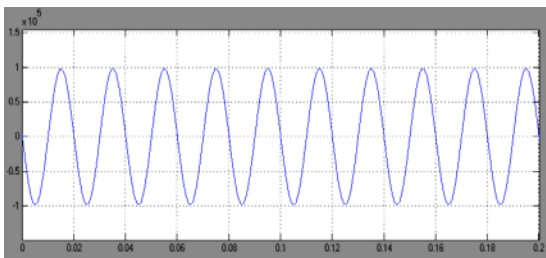


Fig.15. Load voltage in bus 2

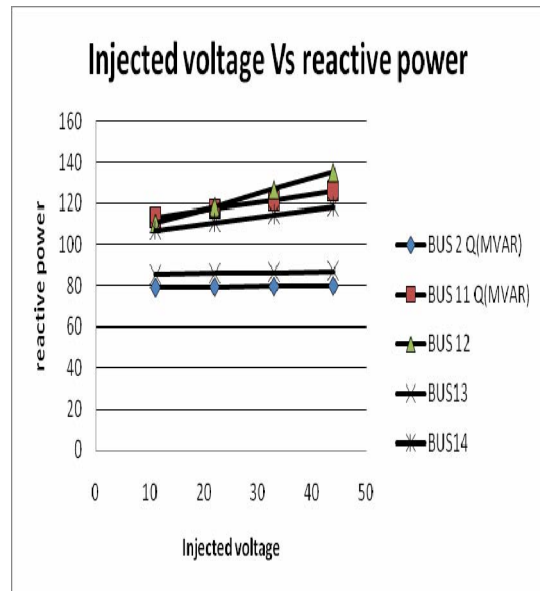


Fig. 17. Reactive Power Curves

Table.3 Summary of P and Q

Bus no	P (MW) without UPFC	P (MW) with UPFC	Q (MVAR) without UPFC	Q (MVAR) with UPFC	Voltage (KV) without UPFC	Voltage (KV) with UPFC
2	41.97	42.29	79.12	79.72	69.12	69.39
11	120.4	129.1	113.4	121.7	47.67	49.37
12	31.04	35.28	111.5	126.7	54.94	58.57
13	67.94	68.87	85.38	86.54	66.19	66.64
14	29.4	31.90	105.9	114.5	53.56	55.69

Table 4 Variation of Q with injected voltage

Injected Voltage (KV)	Bus 2 Q (MV AR)	Bus 11 Q (MV AR)	Bus 12 Q (MV AR)	Bus 13 Q (MV AR)	Bus 14 Q (MV AR)
11	79.16	113.2	110.3	85.46	107
22	79.44	117.4	118.3	86.1	110.8
33	79.72	121.7	126.7	86.54	114.5
44	80	126	135.3	87.08	118.4

#### 4. CONCLUSION

The circuit model is developed for 14 bus system with and without UPFC. Voltage quality is improved by using voltage source injection. The simulation is done successfully with the models developed. It is observed that the real power increases with the increase in the angle of injection and the reactive power increases with the increase in the magnitude of shunt voltage. The simulation results are in line with the predictions.

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