CHAPTER 4

SIMULATION AND IMPLEMENTATION OF UPQC SYSTEM

4.1 Introduction

The objective of this chapter deals with modeling, simulation and implementation of UPQC system. The Two Bus System with UPQC is modeled and simulated using the blocks of Simulink. Sending end acts as one Bus and receiving end acts as another Bus. The function of UPQC is to compensate the sag and supply the harmonics using UPQC.

In a transmission system, the independent control of real power and reactive power is essential to maintain the desired voltage level in a transmission system. In this chapter two bus system is considered and it is modeled by using the blocks of simulink. The UPQC is connected in this system to achieve the independent control of real and reactive power. The real power is independently controlled by varying the angle of voltage injection of the UPQC. The reactive power is controlled by varying the magnitude of shunt voltage injected by the UPQC.

Harmonic distortion originates in the nonlinear characteristics of devices and loads on the power system. The harmonic distortion is measured in single quantity as Total Harmonic Distortion (THD). Voltages and currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate are called interharmonics. It can be found
in networks of all voltage levels. The main sources of interharmonics waveform distortion are power electronic circuits such as static frequency converters, cycloconverters, induction furnaces and arcing devices. Power line carrier signals are also coming in this category. These harmonics result in failure or misoperation of consumer equipments.

The output of inverter contains odd harmonics. PWM is considered such that lower order harmonics are eliminated. Higher order harmonics are harmless since their magnitude is negligible. The output does not contain even harmonics since the output has odd symmetry. THD is the ratio of harmonic voltage to the fundamental voltage.

4.2 Circuit model of single phase Two Bus System with UPQC

The circuit model of Two Bus System with UPQC is shown in figure 4.1. Shunt converter at the sending end is represented as a voltage source ($V_{shunt}$). The series converter is represented by another source ($V_{series}$).

Fig. 4.1 Circuit model of the UPQC System
Design is done using the equations given in the previous section. L & C are designed by assuming ΔI = 0.4A, f = 3 kHz & R = 1K Ω.

L & C for boost converter work out to be 7.5 mH & 12 µF; T_{ON} : 0.25ms; T_{OFF} : 0.08 ms.

Power measurement block is connected in parallel with the load to measure real and reactive powers. Scopes are connected to measure receiving end voltage, receiving end current, real power and reactive power. The generator is represented as series combination of R, L&E. Each line is represented by series impedance. The load at the receiving end is series combination of resistance 200Ω and inductance of 100 mH. The parameters of the additional load are 50Ω and 50mH. DC required by UPQC is applied from a photo cell. The output of UPQC is injected using a series transformer. The circuit inside the UPQC block is shown in Fig 4.2.

Fig. 4.2. Inverters used in the UPQC System
The inverter of DVR used in the UPQC is triggered at 50 Hz. All the switches are operated with pulses of width 10ms. The pulses given to the other two switches are displaced by 10ms. The output of inverter is filtered by using LC filter. This will reduce heating since harmonics are reduced. The inverter switches of active filter are triggered at 250Hz. In Fig.4.3 the circuit consists of two inverters.

Fig. 4.3. Boost converter circuit

The DC required by the DC link is supplied using solar cell and boost converter. This circuit is shown in Fig 4.3. The output of solar cell is not sufficient to drive the load at the output of the inverter. Therefore the output of solar cell is boosted by using a boost converter. The boost converter uses boost inductor, capacitor and blocking diode.

The output voltage is controlled by using a MOSFET. Fig.4.4 shows the variation of output voltage with time.
The voltage across loads 1 and 2 are shown in Fig 4.4. An additional load is applied at t=0.2 seconds. The total load current increases and the drop in the line impedance increases. The receiving end voltage is reduced. At t =0.3 seconds, the voltage is injected by the UPQC to bring the receiving end voltage to the normal value. From the waveform of $V_{L1}$, it can be seen that the sag is compensated by using the DVR part of UPQC.

The voltage $V_{L2}$ is zero up to 0.2 seconds, since the breaker is open. The waveforms of real and reactive powers are shown in Figures 4.5 and 4.6 respectively. The real and reactive powers increase at t = 0.2 seconds due to the increase in the load. This increases further at t = 0.3 seconds, due to the injection of the voltage by UPQC.
In Fig. 4.5 the real power increase at t=0.2 sec and it remains at the same value upto t=0.3sec due to increase in load and again it increases due to the injection of the voltage by UPQC.

In Fig.4.6 the reactive power increases at t=0.2sec and suddenly decreases and maintain the constant upto t=0.3sec due to the increase in the load. At t=0.3sec reactive power gets increases and maintain a constant value due to the injection of the voltage by UPQC. The circuit diagram without enabling the active filter is shown in Fig. 4.7.

Harmonic distortion originates in the nonlinear characteristics of devices and loads on the power system. The harmonic distortion is measured in single quantity as Total Harmonic Distortion (THD). Voltages and currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate are called interharmonics. It can be found in networks of all voltage levels. The main sources of interharmonics waveform distortion are power electronic circuits such as static frequency converters, cycloconverters, induction furnaces and arcing devices. Power line carrier signals are also coming in this category. These harmonics result in failure or misoperation of consumer equipments.
The output of inverter contains odd harmonics. PWM is considered such that lower order harmonics are eliminated. Higher order harmonics are harmless since their magnitude is negligible. The output does not contain even harmonics since the output has odd symmetry. THD is the ratio of harmonic voltage to the fundamental voltage. A nonlinear rectifier system with inductive load is connected in parallel with the linear load. This non-linear load draws alternating square current which contains 5th harmonic.

Fig. 4.7. Circuit diagram without the Active Filter
The spectrum for current is shown in Fig. 4.8. The frequency system is drawn with frequency on x-axis and magnitude of voltage on y-axis. The magnitude of higher order harmonics are negligible. The height decreases with the increase in the order of harmonics. This is due to the increased impedance at high frequency. The THD is 8.6%.

The circuit diagram with active filter is shown in Fig. 4.9(a). The output of active filter is connected to the load. The inverter in the active filter is triggered at 250 Hz. FFT analysis is done for the receiving end current and the frequency spectrum is obtained as shown in Fig.4.9(b).
Fig. 4.9.(a). Circuit diagram with the Active Filter

Fig. 4.9.(b). Spectrum for the current
The frequency spectrum is drawn with frequency on x-axis and magnitude of voltage on y-axis. The magnitude of higher order harmonics are negligible. The height decreases with the increase in the order of harmonics. This is due to the increased impedance at high frequency. The THD is 1.6%. Thus the THD is reduced to a minimum value by using active filter. Thus the quality of sending end current is improved by using UPQC.

### 4.3 Circuit model of Three phase Two Bus System with UPQC

The three phase circuit model of two bus system is shown in Fig. 4.10.

![Circuit Model of Three Phase System with the additional load](image)

Fig. 4.10. Circuit Model of Three Phase System with the additional load.

The scope S2 shown in above figure gives Three phase voltages in single figure. The scope S3 gives three voltages separately. An additional heavy load is connected in parallel with the existing load to create sag in the voltage. The line is represented by a series impedance. The voltages of all the three phases are shown in Fig. 4.11.
The additional load is applied at $t = 0.3$ seconds. Therefore the voltage decreases beyond 0.3 seconds. Voltage across load 2 is shown in Fig. 4.12.

The RMS value of voltage across load 2 reduced due to the voltage drop in the line impedance. The voltage exists beyond 0.3 seconds since the switch
was closed at 0.3 seconds. The FFT analysis is done for load voltage and the spectrum is shown in Fig. 4.13.

![FFT analysis](image)

**Fig. 4.13 Frequency Spectrum**

In the above figure, The frequency spectrum is drawn with frequency on x-axis and magnitude of voltage on y-axis. The magnitude of higher order harmonics are negligible. The height decreases with the increase in the order of harmonics. This is due to the increased impedance at high frequency. The THD is 14.9%. The three phase circuit model with UPQC is shown in Fig. 4.14. Three phase Two Bus System with UPQC is shown here. The voltage drop in the line is compensated by using the injected voltage of UPQC. The injected voltage is approximately equal to the line drop.
The sub system of UPQC in each phase is shown in Fig. 4.15. Each UPQC consists of two inverters. The first inverter compensates the drop in line 1.
The second inverter compensates the voltage in the second line using PV system. The output voltage with compensation is shown in Fig. 4.16.

![Fig. 4.16 Three Phase Voltage with Compensation](image)

In the above figure all the voltages are shown in single figure. The sag appears from 0.3 to 0.4 seconds. At t = 0.4 seconds, the UPQC injects voltage and the load voltage is brought to the rated value as shown in Fig. 4.17.

![Fig. 4.17. Voltage of each Phase with Compensation](image)

In the above figure, individual phase voltages are shown. The voltage drop and recovery are also shown in figure. The FFT analysis is done for the output voltage and the spectrum is shown in Fig. 4.18.
In the above figure, the frequency system is drawn with frequency on x-axis and magnitude of voltage on y-axis. The magnitude of higher order harmonics are negligible. The height decreases with the increase in the order of harmonics. This is due to the increased impedance at high frequency. The THD value is 6.4 percent.

4.4 Experimental Verification

UPQC system is fabricated and tested in the laboratory. The Layout of the hardware implemented is shown in Fig. 4.19(a).
DC input is applied from a solar cell. The hardware consists of power supply board, control board and two inverters boards. The micro controller PIC 16F84 is used for generating the pulses. These pulses are amplified by using the driver IR2110. The device IRF840 is used as the switch in the inverters.

The output of solar cell is shown in Fig. 4.19(b).

![Image of output of the solar cell](image)

**Fig. 4.19 (b) Output of the Solar Cell**

Scale:
- X axis : 1 unit = 1 ms
- Y axis : 1 unit = 10 V

In the above Fig, wave forms drawn between time on x-axis and output voltage in y-axis. Scales measured as for time 1 unit as 1 milliseconds and for voltage 1 unit as 10 volts for output voltage. Output voltage is maintained as constant value throughout the system.

The switching pulses for $M_1$ and $M_2$ are shown in Fig. 4.19(c) and 4.19(d) respectively. From fig.4.19c the graph drawn between time on x-axis and voltage as y-axis. Scale measured 1 unit as 20 micro seconds per division for x-axis and 1 unit as 5 volts per division for y-axis. Due to ON and OFF process it draws like square wave.
Fig. 4.19 (c) Switching Pulses for $M_1$

Scale:
X axis : 1 unit = 20 $\mu$s / div
Y axis : 1 unit = 5 V / div

Fig. 4.19 (d) Switching Pulses for $M_2$

Scale:
X axis : 1 unit = 20 $\mu$s / div
Y axis : 1 unit = 5 V / div
From fig.4.19(d) the graph drawn between time on x-axis and voltage as y-axis. Scale measured 1 unit as 20 micro seconds per division for x-axis and 1 unit as 5volts per division for y-axis. Due to ON and OFF process it draws like square wave.

The output of inverter 1 is shown in Fig. 4.19(e)

![Output Voltage of the Inverter 1](image)

Scale:
X axis : 1 unit = 5 ms / div
Y axis : 1 unit = 20 V / div

From the above wave form, the graph drawn between time on x-axis and voltage as y-axis. Scale measured 1 unit as 5milli seconds per division for x-axis and 1 unit as 20volts per division for y-axis. Due to ON and OFF process it draws like square wave.

The output of inverter 2 is shown in Fig. 4.19(f). The graph drawn between time on x-axis and voltage on y-axis. Scale measured 1 unit as 5milli seconds per division for x-axis and 1 unit as 20volts per division for y-axis. This is nearly a sine wave due to the presence of LC filter in the output side.
4.5 Results and Discussions

4.5.1 Results of single phase Two Bus System with UPQC

From wave form 4.4, at t=0.3 sec, the voltage is injected by the UPQC to bring the receiving end voltage to the normal value. From the wave form of voltage across load 1, it is shown that the sag is compensated by using the DVR part of UPQC. From wave form 4.5 and 4.6, the real and reactive power increase at t=0.2sec due to the increase in the load. This increase further at t=0.3sec, due to the injection of voltage by UPQC. Total harmonic distortion is improved from 8.6% to 1.6%. Thus the THD is reduced to a minimum value by using UPQC.

4.5.2 Results of Three phase Two Bus System with UPQC

From wave form 4.16, at t=0.4sec the UPQC injects voltage and the load voltage is brought to the rated value as shown in figure 4.17. Total harmonic distortion is improved from 14.9% to 6.4%.
4.5.3 Results of experimental verification

From wave form 4.19(e) and 4.19(f), output of inverters nearly a sine wave due to presence of LC filter in the output side. The experimental results are similar to the simulation results.

4.6 Conclusion

Single phase and three phase UPQC systems are modeled and simulated successfully. Basic UPQC system is fabricated, tested and the experimental results are presented. The experimental results are similar to the simulation results.