Performance Study of Unified Power Quality Conditioner Using Matlab Simulink

Kuldeep Kumar Singh, J. K Dwivedi

Abstract:- Modern power system comprises of complex networks, where many generating stations and load centres are interconnected through long power transmission and distribution networks. Utility distribution networks, critical commercial operations and sensitive industrial loads all suffer from various types of outages and interruptions which can lead to significant financial loss, loss of production, idle work forces etc. Today due the changing trends and restructuring of power systems, the consumers are looking forward to the quality and reliability of power supply at the load centres. A power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end use equipments. With shifting trend towards distributed and dispersed generation, the issue of power quality is taking new dimensions. The present investigates PID controller and fuzzy logic controller as concerned to UPQC application for power quality improvement. The UPQC is studied and its advantages over conventional APFs and UPQC are discussed in detail. The relevant mathematical models and equations to explain the working of UPQC are derived for both the cases (PID controller and fuzzy logic controller).The relevant simulations are carried out using MATLAB Simulink**.**

Index Terms:- Matlab (2007)Shunt Controller, Series Controller, PWM inverter, PID, Fuzzy logic controller and PLL.

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1 INTRODUCTION

To provide quality power has become today‟ s most concerned area for both power suppliers and customers due to the deregulation of the electric power energy market. Efforts have been made to improve the power quality. Aspects on power quality can be classified into three categories that is, voltage stability, continuity of supplying power, and voltage waveform. The concept of custom power was introduced by Yashpal [7]. The term custom power means the use of power electronics controllers for distribution systems. The custom power increases the quality and reliability of the power that is delivered to the customers. Customers are increasingly demanding quality in the power supplied by the electric company. One of the many solutions is the use of a combined system of shunt and series active filters like Unified Power Quality Conditioner which aims at achieving low cost and highly effective control. The UPQC is the most versatile and complex of the FACTS devices, combining the features of the STATCOM and the SSSC. The Unified Power Quality Conditioner is a custom power device that is employed in the distribution system to mitigate the disturbances that affect the performance of sensitive and/or critical load [2]. It is a type of hybrid APF [10] and is the only versatile device which can mitigate several power quality problems related with voltage and current simultaneously therefore is multi functioning devices that compensate various voltage disturbances of the power supply, to correct voltage fluctuations and to prevent harmonic load current from entering the power system. Fig.1 shows the system configuration of a single-phase UPQC.

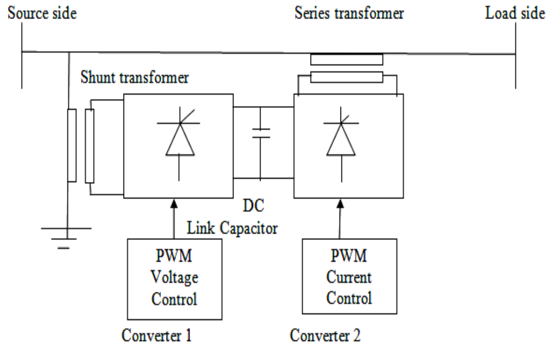

Figure 1: Unified Power Quality Conditioner

Unified Power Quality Conditioner consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. The shunt converter is connected in parallel to the load. It provides VAR support to the load and supply harmonic currents. Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply [2]. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor. The UPQC can provide simultaneous control of all basic power system parameters, transmission voltage harmonic compensation, impedance and phase angle.

2 CONTROL STRATAGEY FOR UNIFIED POWER QUALITY CONDITIONER

2.1 dq transformation

It is established that the active filter flows from leading voltage to lagging voltage and reactive power flows from higher voltage to lower voltage. Therefore both active and reactive power can be controlled by controlling the phase and the magnitude of the fundamental component of the converter voltage with respect to line voltage. dq theory provides an independent control of active reactive power by controlling phase and the magnitude of the fundamental component with respect to converter voltage [9].According to the dq control theory three-phase line voltages and line currents are converted in to its equivalent two-phase system called stationary reference

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frame. These quantities further transformed into reference frame called synchronous reference frame. In synchronous reference frame, the components of current corresponding to active and reactive power are controlled in an independent manner. This three-phase dq transformation and dq to three-phase transformation are discussed in detail in this chapter. The outer loop controls the dc bus voltage and the inner loop controls the line currents. The instantaneous real power at any point on line can be defined by:

$$p = v_R I_R + v_B I_b + v_C I_c \qquad (1)$$

And we can define instantaneous reactive voltage conceptually as a part of three phase voltage set that could be eliminated at any instant without altering *p*. Reference frame theory based d-q model of shunt active filter is presented in this section. While dealing with instantaneous voltages and currents in three phase circuits mathematically, it is adequate to express their quantities as the instantaneous space vectors [10]. Vector representation of instantaneous three phase quantities R, Y and B which are displaced by an angle 2π/3 from each other is shown in Fig.2

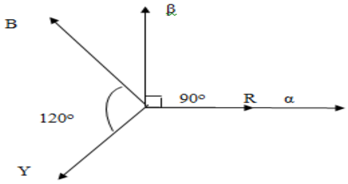


Figure 2 : Frame Transformation (abc to αβ)

The instantaneous current and voltage space vectors are expressed in terms of instantaneous voltages and currents as:

$$v = [v_R\ v_Y\ v_B] \quad I = [I_R\ I_Y\ I_B] \qquad (2)$$

Instantaneous voltages and currents on the RYB coordinates can be transformed into the quadrature α, β coordinates by Clarke Transformation as follows:

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} = T \begin{bmatrix} v_R \\ v_Y \\ v_B \end{bmatrix} \qquad (3)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} = T \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} \qquad (4)$$

Where Transformation matrix

$$T = \sqrt{2}/3 \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \qquad (5)$$

Since in a balanced three-phase three-wire system neutral current is zero, the zero sequence current does not exist and zero sequence current can also be eliminated using star delta transformer. These voltages in α-β reference frame can further be transformed into rotating d- q reference frame as Fig.3

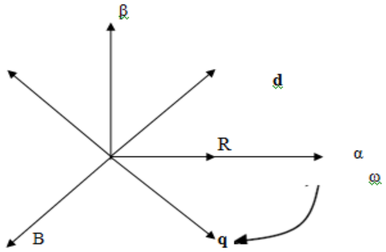


Figure 3 : αβ to dq Transformation

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = T \begin{bmatrix} v_d \\ v_q \end{bmatrix} \qquad (6)$$

$$T = \begin{bmatrix} \cos\omega_r & -\sin\omega_r \\ \sin\omega_r & \cos\omega_r \end{bmatrix} \qquad (7)$$

Where ω_r is the angular velocity of the d- q reference frame as shown in Fig. 3 The current components in the d- q reference frame can be similarly obtained using the α-β to d-q transformation matrix T_1. The unit vector required for this Transformation is generated using the grid voltage.

2.2 Basic Control Function

It is evident from above discussion that UPQC should separate out the fundamental frequency positive sequence components first from the other components. Then it is required to control both series and shunt active filter to give output.The control strategy uses a PLL based unit vector template for extraction of reference signal from the distorted input supply. The block diagram of extraction of unit vector template is as given in Fig.4.

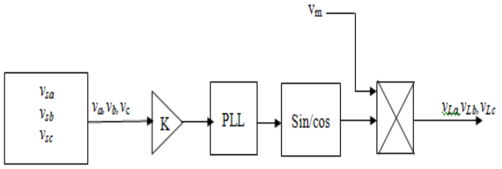


Figure 1: Extraction of Unit Vector Template

The input source voltage at point of common coupling contains fundamental and distorted component. To get unit vector templates of voltage, the input voltage is sensed and multiplied by gain equal to *1/vm*, where *vm* is peak amplitude of fundamental input voltage. These unit vector templates are then passed through a PLL for synchronization of signals. The unit vector templates for different phases are obtained as follows:

$$v_a = \sin \omega t$$
$$v_b = \sin(\omega t - 120^0)$$
$$v_c = \sin(\omega t + 120^0) \qquad (8)$$

3 MODELING OF UPQC IN MATLAB

The three-phase system shown in Fig.5 is considered for verifying the performance of UPQC. [9] Three-phase source feeding this system at one end. For the best performance, UPQC is placed at the midpoint of the system as shown in Fig.5 UPQC is placed between two sections source and nonlinear load of the transmission line.

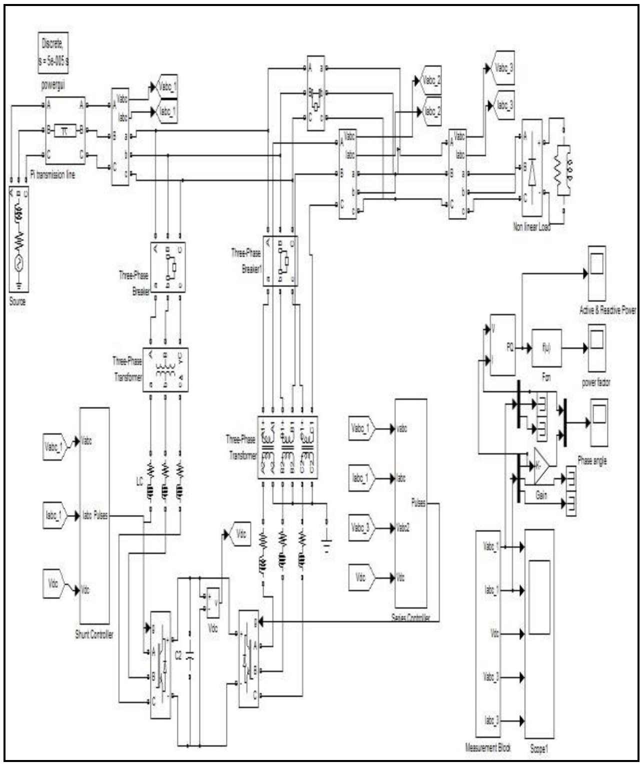


Figure 5: Simulink Model Of UPQC

3.1 Shunt Controller/STATCOM Model in MATLAB

The STATCOM controller has the capability of independently controlling the shunt real and reactive power components. In the automatic voltage control mode, the shunt converter reactive current is automatically regulated to maintain the transmission line voltage to a reference value at the point of connection. However, the shunt real power control is dictated by the dc voltage controller as shown in Fig 6. which acts to maintain a preset voltage level on the dc link, thereby providing the real power supply or sink needed for the support of the series voltage injection. As shown in Fig.7, inner current controller is considered particularly suitable for current source rectifier due to its safety, stability performance and fast response. Typically the inner current control loop is at least ten times faster than the outer loop controlling the dc voltage. The *Idref* obtained from the voltage controller is compared with the actual *d*-axis current and stabilized through PID controller to get the equivalent *d*-axis reference voltage v_d. Similarly the actual *q*-axis current is compared with *Iqref* and the error so obtained is stabilized through PID controller to get the equivalent *q*-axis reference voltage v_q. The parameters of these PID controllers are tuned and fine adjustment is carried out by trial and error procedure to minimize the performance indices, namely the integral square error and integral time absolute error so as to give the best response. The reference voltages v_d and v_q are compared with actual v_d and v_q to obtain the equivalent v_{dav}, and v_{qav}. Then these two-phase quantities are converted into three-phase quantities using dq–abc transformation. These three-phase voltages are fed as control signals to the PWM modulator for developing the switching pulses to the current source rectifier switches.

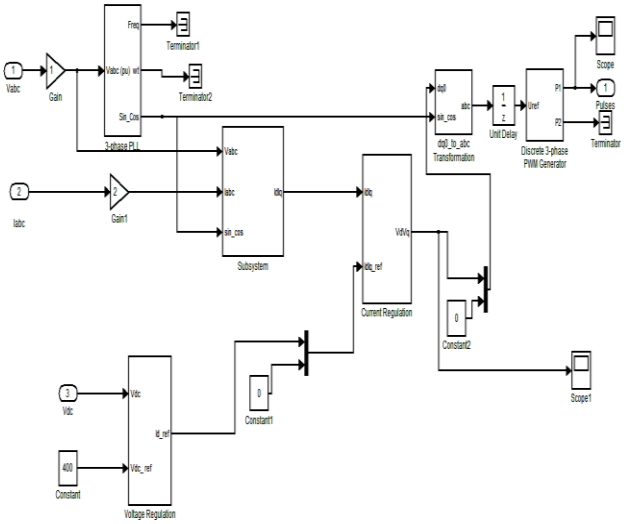


Figure 6.: Simulink Model of Shunt Controller

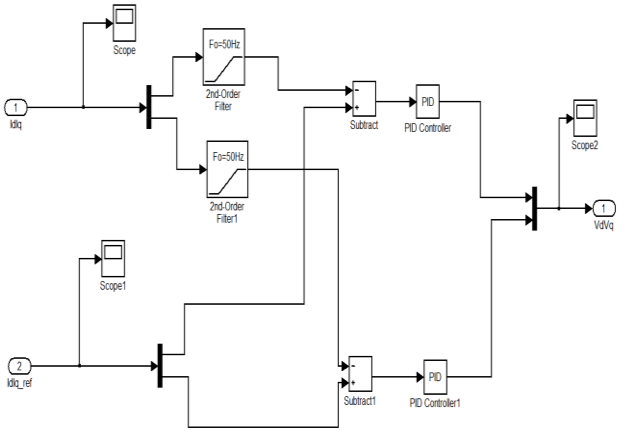


Figure 7: Current controller using PID controller

3.2 Series Converter/SSSC Model in MATLAB

A SSSC is a solid-state voltage source inverter, which generates a controllable AC voltage source, and connected in series to power transmission lines in a power system. The injected voltage (v_q) is in quadrature with the line current *I*, and emulates an inductive or a capacitive reactance so as to influence the power flow in the transmission lines. The compensation level can be controlled dynamically by changing the magnitude and polarity of v_q and the device can be operated both in capacitive and inductive mode. The MATLAB modeling of control system of SSSC is shown in Fig.8. The control system consists of:

- A phase-locked loop (PLL) which synchronizes measured positive-sequence component of the current with self generated current. The output of the PLL ($\theta = \omega t$) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents.
- Sequence of voltages v_1 and v_2 (V_{1q} and v_{2q}) as well as the dc voltage v_{dc}.
- AC and DC voltage regulators which compute the two components of the converter voltage (v_{dcnv} and v_{qcnv}) required obtaining the desired dc voltage (v_{dcref}) and the injected voltage (v_{qref}).

The variation of injected voltage is performed by means of a Voltage-sourced converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (e.g. GTOs, IGBTs or IGCTs) to synthesize a voltage v_{cnv} from a dc voltage source. A capacitor connected on the dc side of the VSC acts as a dc voltage source. In the control system block diagram $v_{dcn}v$ and v_{qcnv} designate the components of converter voltage v_{cnv} which are respectively in phase and in quadrature with line current *I*. VSC using IGBT-based PWM inverters is used in the present study. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed dc voltage v_{dc}. The converter voltage v_{cnv} is varied by changing the modulation index of the PWM modulator.

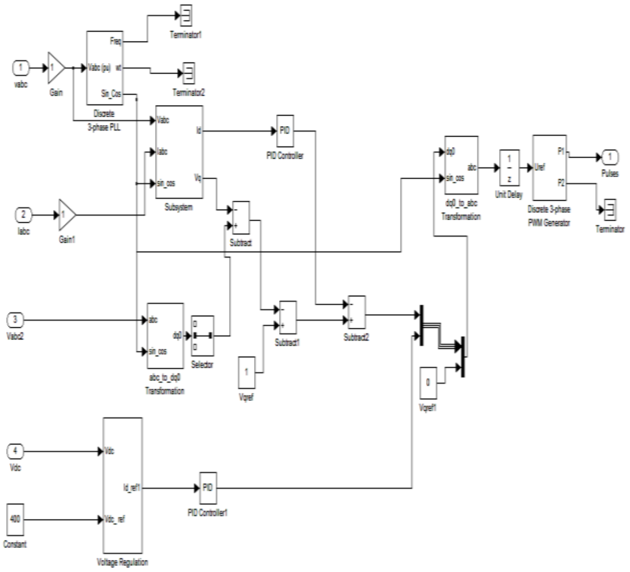
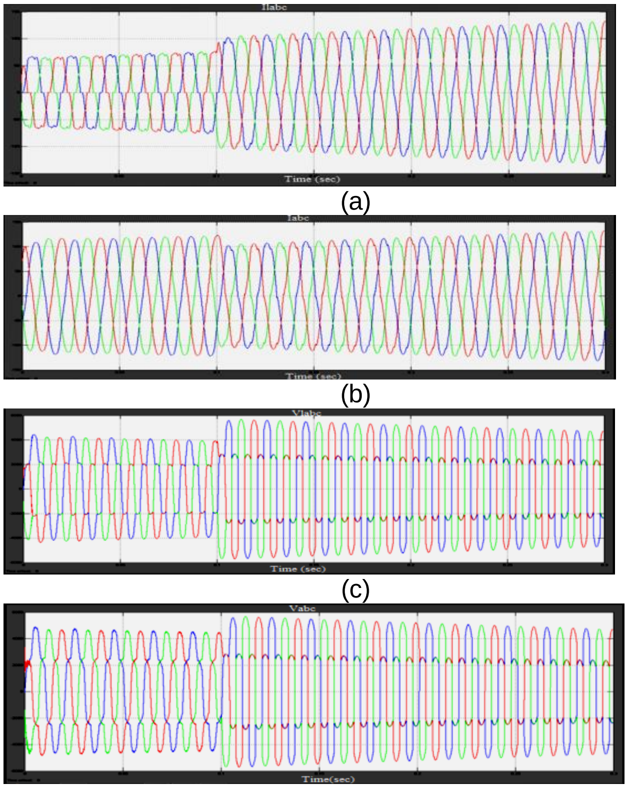


Figure 8 : Series controller Model using PID controller

4. SIMULATION RESULTS OF UPQC USING PID CONTROLLER

An ideal three-phase sinusoidal supply voltage of 11kV, 50Hz is applied to the non-linear load (diode rectifier feeding an *RL* load) injecting current harmonics into the system. Fig. 9 (b) shows supply current in three phase before compensation from 0s to 0.1s, and after compensation from 0.1s to 0.4s. Shunt inverter is able to reduce the harmonics from entering into the system. The Total Harmonic Distortion (THD), which was 10.64% Fig.10(a) before compensation was effectively reduced to 8.53 % Fig. 10 (b) after compensation using PID controller. The compensating shunt currents generated contain harmonic content of the load current Fig. 9 (a) but with opposite polarity such that when they are injected at the point of common coupling the harmonic content of supply current is effectively reduced. Reduced value is held constant using PID controller. Fig.9 (c) and Fig. 9 (a) shows the load voltage and load currents respectively. The distortion due to non linear *RL* load. THD response of the line current and line voltage in the STATCOM side are found to be very low. Fig. 9 (c) shows load voltage.



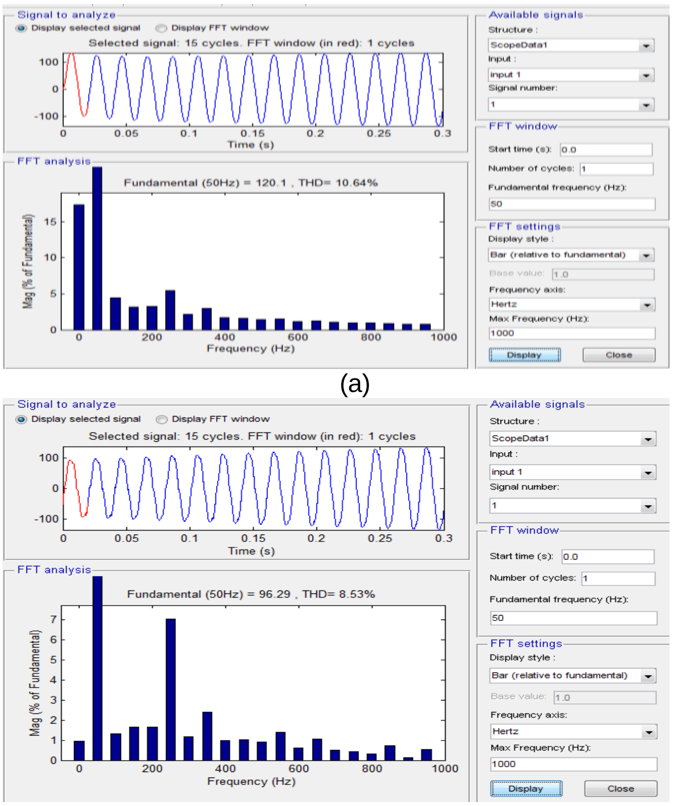
(a)

(b)

(c)

(d)

Figure 9: Simulated results of UPQC (a) load current (b) source current (c) load voltage (d) source voltage



● Display selected signal ○ Display FFT window

Selected signal: 15 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 120.1 , THD= 10.64%

Structure : ScopeData1

Input : input 1

Signal number: 1

Start time (s): 0.0

Number of cycles: 1

Fundamental frequency (Hz): 50

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

(a)

● Display selected signal ○ Display FFT window

Selected signal: 15 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 96.29 , THD= 8.53%

Structure : ScopeData1

Input : input 1

Signal number: 1

Start time (s): 0.0

Number of cycles: 1

Fundamental frequency (Hz): 50

Display style : Bar (relative to fundamental)

Base value: 1.0

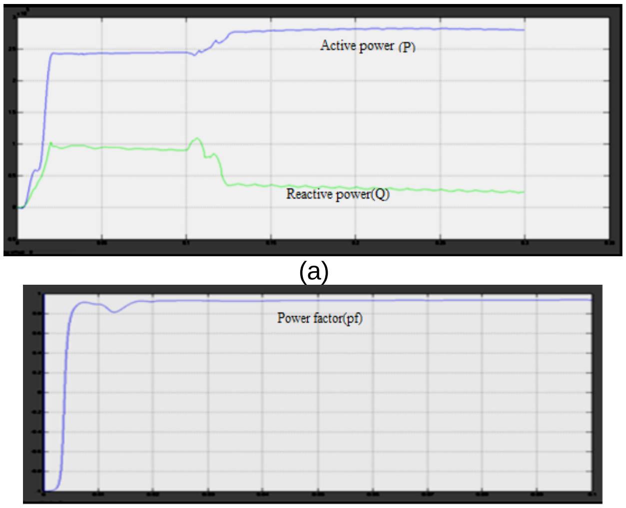
Frequency axis: Hertz

Max Frequency (Hz): 1000

(b)

Figure 10 : Total Harmonic Distortion (THD) (a) Distorted Source Current THD (b) Compensated Source Current THD

When the transmission line is without UPQC, the real and reactive power flow cannot be controlled. Fig. 11 (a) shows the active power and reactive power through the line without UPQC from 0s to 0.1s after that with UPQC connected. The active power flow through line which is controlled by UPQC. Transmission capability of the existing transmission line is highly improved with the presence of UPQC. The difference between the sending-end real power and receiving end real power is high in the transmission line without UPQC. This is due to the increase in transmission losses, which are minimized with the help of UPQC. It also helps in improving power factor of the transmission line. As shown in Fig. 11 (b), without UPQC, power factor of the transmission line is 0.91 but as UPQC switched, the power factor increases to 0.99. The reactive Power flow through the transmission line with and without UPQC is shown in Fig.11(a) the raise in the transmission capability is noticed from the simulation results. The power transfer capability of long transmission lines is usually limited by their thermal capability. Utilizing the existing transmission line at its maximum thermal capability is possible with UPQC. The series inverter injects voltage of variable magnitude and phase into the transmission line at the point of its connection, there by controlling real and reactive power flow through the line. The active power through the line is supplied by SSSC active power. This real power obtained from the dc source connected to its dc terminals. The shunt inverter provides the required power to the series inverter through the dc link. UPQC performs active, reactive compensation,[2] phase angle regulation and harmonic filtering. Hence UPQC performance tasted under normal as well as unbalanced condition.



(a)

Figure 1: Simulated Results of UPQC (a) Active Power & Reactive Power (b) Power Factor

5. CONCLUSION

This paper presents control and performance of UPQC intended for installation on a transmission line with the help of PID controller. A control system is simulated in switching and unbalanced condition with shunt inverter and series inverter in open loop phase angle control mode. Simulation results show the effectiveness of UPQC in active filtering and controlling real and reactive power through the line.AC voltage regulation and power factor of the transmission line also improved. This chapter presents an improvement in the real and reactive power flow through the transmission line with UPQC using PID controller when compared to the system without UPQC.

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