International Journal of Electrical and Power Engineering 6 (2): 77-81, 2012
ISSN: 1990-7958

Unified Power Quality Conditioner for Voltage and Current Compensation

[1]P. Annapandi and [2]M. Rajaram
[1]Department of Electrical and Electronics Engineering,
Dr. Sivanthi Aditanar College of Engineering, Tiruchendur, Tamil Nadu, India
[2]Anna University of Technology, Tirunelveli, Tamil Nadu, India

Abstract: This study deals with a Unified Power Quality Conditioner (UPQC) for load balancing, power factor-correction, voltage regulation, voltage and current harmonics mitigation, mitigation of voltage sag, swell and voltage dip in a three-phase three-wire distribution system for different combinations of linear and non-linear loads. The Unified Power Quality Conditioner (UPQC) is a combination of back to back connected shunt and series Active Power Filters (APFs) to a common DC link voltage which compensates voltage and current based distortions, independently. Using instantaneous active and reactive power theory, harmonic detection, reactive power compensation, voltage sag and swell have been simulated and the results are analyzed. The operation and capability of the proposed system was analyzed through simulations with Matlab/Simulink.

Key words: Harmonics, power factor correction, voltage sag, voltage swell, instantaneous power theory, power quality, Unified Power Quality Conditioner (UPQC)

INTRODUCTION

Today, industry automation utilizes power electronic based power processing devices for getting higher efficiency, accurate controllability, faster response and compact size. But on the other side, due to the switching actions of these power electronics devices (SCR, MOSFET, BJT and IGBT) behave as non-linear loads. And they draw non-sinusoidal and or lagging/leading current from the supply resulting to poor displacement and distortion factors. Hence, these power converters draw considerable reactive volt-amperes from the utility and inject harmonics in distribution networks. The harmonic current from these power converters flows through the line and source impedance of the power system can cause voltage distortion and excessive voltage drop and line losses (Singh *et al.*, 1999; Fujita and Akagi, 1998). The distorted supply voltage results in malfunction of control, protection and metering equipment used in other sensitive loads and industrial automation monitoring devices. Harmonic currents can also cause unwanted system resonance with passive filters, overloading of power factor correcting capacitors, a decrease of overall system efficiency due to increased line and machine losses, interference with communication and control signals and saturation and overheating of distribution transformers and lines (Fujita and Akagi, 1998). At the same time, an increase of sensitive loads involving digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper control and load operation. This forces the industries to filter the harmonics and compensate reactive power. The immediate and cheap solution is passive filters. But it has its own limitations such as harmonic resonance and harmonic amplification due to varying line impedance. In addition to this, the effectiveness of the passive filters is purely based on line and source impedance and load parameters which is highly unpredictable.

The advancement in power electronic devices combined with the active filter technology resulting into matured source for providing compensation for harmonics, reactive power, unbalance and/or neutral current in ac networks (Fujita and Akagi, 1998). Active filters can be classified based on converter type, topology and the number of phases. The converter type can be either Current Source Inverter (CSI) or Voltage Source Inverter (VSI) bridge structure. The topology is the way in which the CSI/VSI is connected to load or source can be shunt connected (Akagi *et al.*, 1984), series connected or a combination of both (Singh *et al.*, 1999). The third classification is based on the number of phases such as

Corresponding Author: P. Annapandi, Department of Electrical and Electronics Engineering,
Dr. Sivanthi Aditanar College of Engineering, Tiruchendur, Tamil Nadu, India

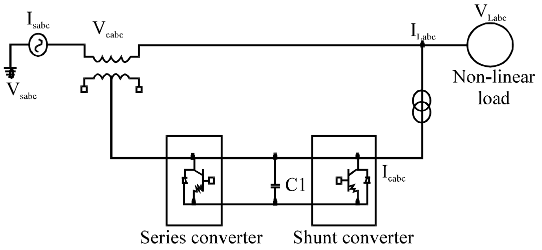

Fig. 1: Configuration of UPQC

2-wire (single phase) and 3 or 4-wire 3-phase systems. Active filtering and the application of FACTS concepts in electric power transmission system then in to distribution systems has resulted in all the functionalities in single compensating device such as UPQC (Fujita and Akagi, 1998). A UPQC is the extension of the Unified Power-Flow Controller (UPFC) concept at the distribution system. It consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a Point of Common Connection (PCC) in the distribution side (Fujita and Akagi, 1998). The series and shunt converters connected back-to-back via a common DC link capacitor. Unlike the UPFC, here the series converter is connected to a supply side and shunt converter is connected load side. This configuration has proved performance with both supply voltage distortions such as sag, swell, harmonics and unbalanced line to line voltages as well as load disturbances such as harmonic current, unbalanced load and reactive power requirement by the load (Ghosh and Ledwich, 2001; Woo and Lee, 2010). This configuration also provides optimum rating for a specific amount of sag/swell and reactive power compensation is shown in Fig. 1. The UPQC controller was designed using the instantaneous power method based on αβ0 transform and fundamental positive sequence detection (Han *et al*., 2006).

CONFIGURATION OF UPQC

The UPQC is aimed for simultaneous compensation of the load current distortion and the supply voltage disturbance. UPQC has 2 voltage-source inverters of 3-phase three wire configuration connected back to back through same DC link capacitor (Fujita and Akagi, 1998). Source side inverter, called the series inverter is connected through coupling transformers between the point of common connection and load. The load side inverter called the shunt inverter is connected in parallel through the transformers or directly connected. The series inverter operates as a controlled voltage source while the shunt inverter operates as a controlled current source (Ghosh and Ledwich, 2001). So, the UPQC has compensation capabilities for the load harmonic current, the reactive power compensation, the source voltage disturbances (including sag/swell) and the unbalance (load and source) compensation (Singh *et al*., 1999).

UPQC CONTROL STRATEGY

The control system has three major elements which are a positive sequence detector, a shunt inverter control and a series inverter control (Han *et al*., 2006; Aredes *et al*., 1998). The positive-sequence detector extracts the positive sequence of component from the disturbed and unbalanced 3-phase source voltage with series of steps as shown in Fig. 2 sub block. The transformed positive sequence reference voltage Vsα, Vsβ based on the αβ0 transform are found out. The measured source voltage passes through the -phase PLL (Phase-Locked Loop) and the sine wave generator to calculate the fundamental component of the α-β transformed current (i_α' = sinω1t) and (i_β' = cosω1t) (Aredes *et al*., 1998). And in Fig. 2, the V_{sabc} divided by k = (V_{rms}/sqrt (3))*sqrt (2)) for getting unit magnitude voltage signals. The powers corresponds to positive sequence fundamental component are calculated as active power p_s' and reactive power q_s' from the of the source voltage V_S and fundamental current components i_α and i_β (Han *et al*., 2006; Aredes *et al*., 1998):

$$\begin{bmatrix} V_\alpha \\ V_\rho \end{bmatrix} = \sqrt{\frac{2}{3}} \times \begin{bmatrix} 1 - 1/2 \ -1/2 \\ 0 \sqrt{3}/2 - \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} p_s' \\ q_s' \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha' \\ i_\beta' \end{bmatrix} \tag{2}$$

So, the instantaneous value of the positive-sequence component voltage is calculated using Eq. 3:

$$\begin{bmatrix} V_{s\alpha}' \\ V_{s\beta}' \end{bmatrix} = \frac{1}{i_\alpha'^2 + i_\beta'^2} \begin{bmatrix} i_\alpha' & i_\beta' \\ i_\beta' & -i_\alpha' \end{bmatrix} \begin{bmatrix} p_s' \\ q_s' \end{bmatrix} \tag{3}$$

Shunt inverter control: The functions of the shunt inverter are to compensate the current harmonics, the reactive power and to regulate the DC link capacitor voltage. Figure 2 shows the configuration of shunt inverter control which includes the current control for

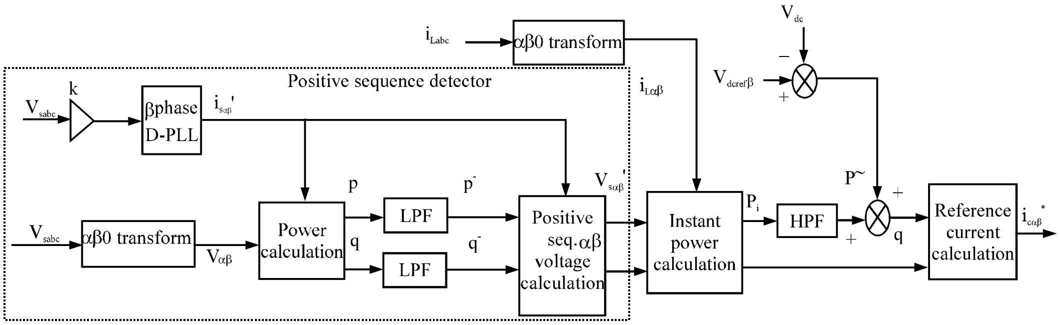

Fig. 2: Shunt inverter control

harmonic compensation and the DC voltage control. Shunt control calculates the reference value of the compensating current for the harmonic current, the load reactive power, real power demand of series inverter to compensate sag/swell in terms of DC link voltage regulation and considering the power loss p_{loss} due to the inverter operation (Mahesh and Karthikeyan, 2009). This loss should be compensated to maintain the dc link voltage constant. The instantaneous power is calculated using α-β components of positive sequence voltage and load current i_L:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V'_{s\alpha} & V'_{s\beta} \\ V'_{s\beta} & -V'_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{U} \begin{bmatrix} V'_{s\alpha} & -V'_{s\beta} \\ V'_{s\beta} & V'_{s\alpha} \end{bmatrix} \begin{bmatrix} -p\sim+p_{loss} \\ -q \end{bmatrix} \tag{5}$$

$$U = V'^2_{s\alpha} + V'^2_{s\beta}$$

Power corresponds to harmonic content is calculated by separating oscillating power and fundamental power by passing throw 5th order butter-worth high pass filter (Han *et al*., 2006). Using these active powers (oscillating power and system power loss) and reactive power the reference value of the compensating current is derived as Eq. 5.

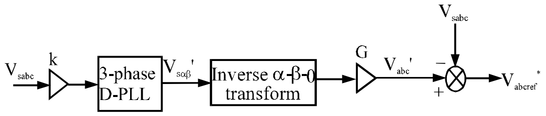

Fig. 3: Control circuit for series converter

Series inverter control: Figure 3 shows the control circuit of series converter. The function of the series inverter is to compensate the voltage disturbance such as voltage harmonics, sag/swell on the source side which is due to the fault and/or line drop because of over load in the distribution line. The function of the series inverter is to compensate the voltage disturbance such as voltage harmonics, sag/swell on the source side which is due to the fault and/or line drop because of over load in the distribution line. The series inverter control calculates the reference voltage to be injected by the series inverter, comparing the positive-sequence component (V_{abc}') with the disturbed source voltage (V_{sabc}) (Han *et al*., 2006). The sag/swell compensation may involves supplying/ absorbing real power from the supply line so there must be real power balance between series and shunt inverters. The instantaneous real power absorbed/ delivered by the series inverter must be equal to the real power delivered/absorbed by the shunt inverter so as to maintain DC link capacitor voltage constant (Khadkikar and Chandra, 2008, 2009). In Fig. 3, k = (V_{rms}/sqrt(3))*sqrt(2) and G = Desired maximum phase voltage value.

SIMULATION RESULTS

Computer simulations with Matlab/Simulink software were performed for the purpose of analyzing the operation of the UPQC. The power circuit is modeled as a 3-phase three wire system with a non-linear load that is composed of a 3-phase diode-bridge rectifier with RL load. The sag/swell can be realized with the programmable source at desired instant and desired magnitude. The circuit parameters used in the simulation is shown in Table 1.

Figure 4 shows the shunt inverter operation, the 1st-4th graph shows, respectively the current waveform of the load, source, shunt inverter reference current and the DC shunt converters started its operation the load harmonics and reactive power required by the load is compensated by injecting equal magnitude of harmonics but opposite polarity. The hysteresis current controller is used for synthesizing the compensating current with the current track band width of 0.02 amp. The reference

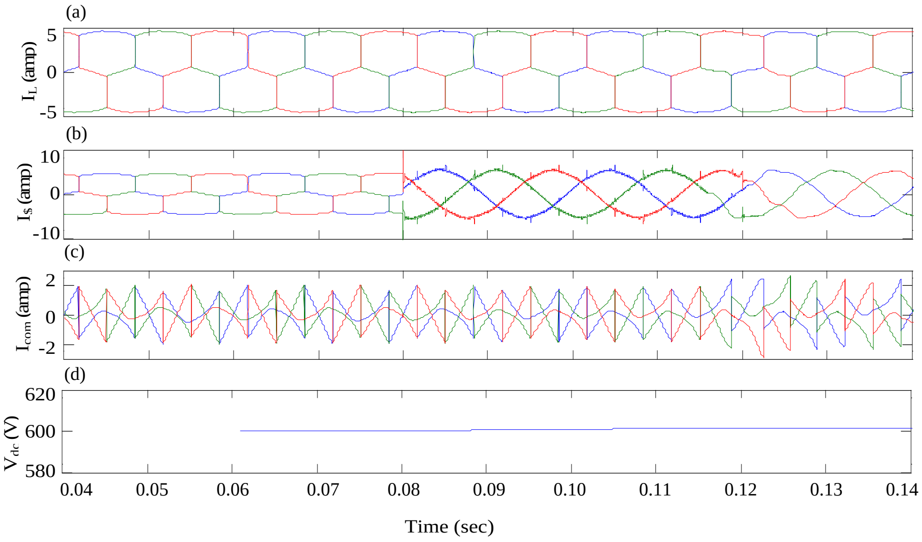

Fig. 4: Shunt inverter operation under non-linear load; a) Load current; b) Source current; c) Compensating current; d) DC link voltage

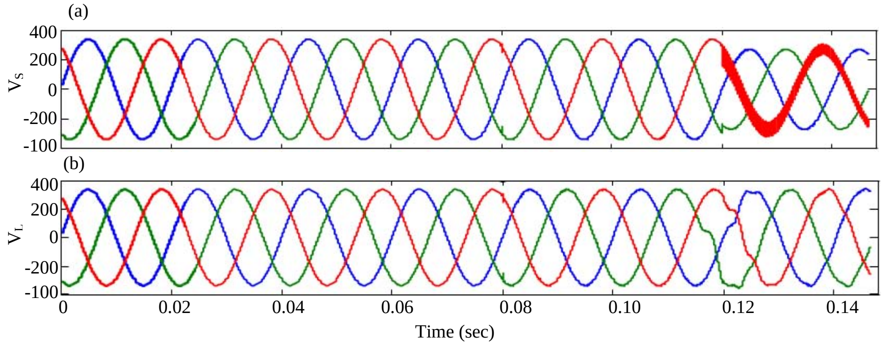

Fig. 5: Source voltage with sag and compensated voltage: a) Source voltage with sag; b) Load voltage

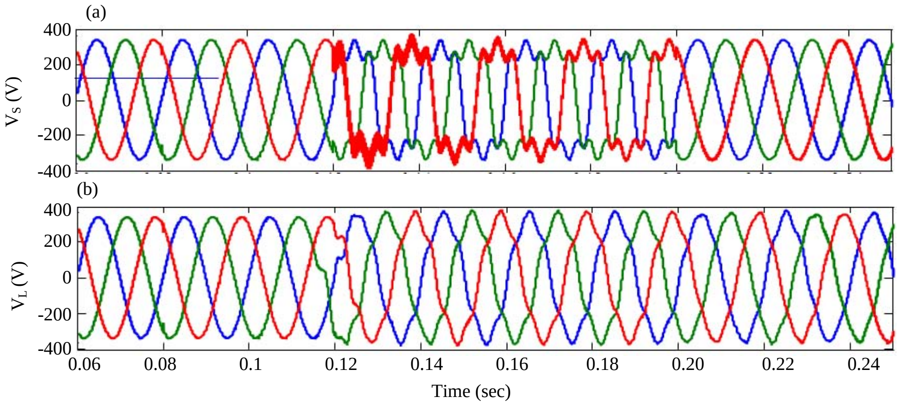

Fig. 6: Source voltage with harmonics and compensated voltage: a) Source voltage with harmonics (3 and 5); b) Load voltage

current of shunt inverter consists of harmonic components of non linear load, reactive current corresponding to load reactive power, power losses due to inverters and DC voltage regulation current. The THD of the load current in graph 1 is 29.6% is reduced to 3.7% in the source side with unity source power factor. It is

Table 1: Simulation parameters

Source	DC link	Shunt inverter	Series inverter	Load
Voltage	Reference voltage	Filter	Filter parameters	Non linear load
(V = 415, 50 Hz)	(600 V)	(L = 1.5 mH, C = 10 μF)	(L = 1.5 mH, C = 10 μF)	(P = 5 kW, Q = 5 kW)
Impedance	Capacitor		Switching frequency	Linear load
(R = 0.01 Ω, L = 0.1 mH)	(C1 = 5000 μF, C2 = 5000 μF)		(10 kHz)	(P = 2 kW)

clear from that graph; the response time is less than quarter cycle (5 msec). Figure 5 shows the compensated result when the voltage sag occurs on the source side at 120 msec. All the three phases have 20% of sag voltage as shown in the 1st graph. The 2nd graph indicates the load voltage after compensation by the UPQC. The compensation reference voltage is generated by the series inverter with the help of PWM pulse generation with the frequency of 10 kHz. The real power injected by the series inverter during sag is compensated by shunt converter current on instantaneous basis. Figure 6 shows the compensated result when the voltage distortion occurs. It is assumed that 3rd and 5th order harmonics of 0.2 pu are added from 120-200 m sec as shown in the 1st graph. The 2nd graph indicates the output voltage across the load after compensation by the UPQC.

CONCLUSION

A novel control strategy to generate the reference source current and reference load voltage under distorted and unbalanced load and source condition is presented in this study. The UPQC can compensate the reactive power, harmonic current, voltage sag and swell and voltage imbalance. The Matlab/Simulink-based simulation results show that the distorted and unbalanced load currents seen from the utility side act as perfectly balanced source currents and are free from distortion.

REFERENCES

Akagi, H., Y. Kanazawa and A. Nabae, 1984. Instantaneous reactive power compensator comprising switching devices without energy storage components. IEEE Trans. Ind. Appli., 20: 625-630.

Aredes, M., K. Heumann and E.H. Watanabe, 1998. An universal active power line conditioner. Inst. Electr. Electron. Eng. Trans. Power Delivery, 13: 545-551.

Fujita, H. and H. Akagi, 1998. The unified power quality conditioner: The integration of series and shunt-active filters. IEEE Trans. Power Elect., 13: 315-322.

Ghosh, A. and G. Ledwich, 2001. A Unified Power Quality Conditioner (UPQC) for simultaneous voltage and current compensation. Electt. Power Syst. Res., 59: 55-63.

Han, B., B. Bae, S. Baek and G. Jang, 2006. New configuration of UPQC for medium voltage application. IEEE Trans. Power Delivery, 21: 1438-1444.

Khadkikar, V. and A. Chandra, 2008. A new control philosophy for a Unified Power Quality Conditioner (UPQC) to coordinate load-reactive power demand between shunt and series inverters. IEEE Trans. Power Del., 23: 2522-2534.

Khadkikar, V. and A. Chandra, 2009. A novel structure for three- phase four-wire distribution system utilizing unified power quality conditioner. IEEE Trans. Ind. Applied, 45: 1897-1902.

Mahesh, M.K. and K. Karthikeyan, 2009. A fast-acting DC-link voltage controller for three-phase DSTATCOM to compensate AC and DC loads. IEEE Trans. Power Del., 24: 2291-2299.

Singh, B., K. Al-Haddad and A. Chandra, 1999. A review of active filters for power quality improvement. IEEE Trans. Ind. Electr., 46: 960-971.

Woo, C.L. and T.K. Lee, 2010. New control scheme for a unified power-quality compensator-q with minimum active power injection. IEEE Trans. Power Del., 25: 1068-1076.