POWER QUALITY IMPROVEMENT USING ACTIVE FILTERS: A REVIEW

Annu Govind[1], Omendra Govind[2]

[1] *Research Scholar, Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, (India)*

[2] *Advanced Level Telecom Training Centre (ALTTC), BSNL, Ghaziabad, (India)*

ABSTRACT

This paper covers review of the various configurations and control strategies available for active filters. Various configurations of APFs have been proposed to compensate aforementioned power quality problems. Complexity of the control algorithm can also be reduced with the involvement of artificial intelligence like fuzzy logic, neural network etc. with the conventional approach to resolve the poor power quality problems not only in steady-state but also in dynamic/transients situation.

Keywords: Active Power Filter (APF), Harmonics, Power Quality, Nonlinear, Reactive Power Compensation.

I. INTRODUCTION

The widespread use of non-linear loads in industries and extensive proliferation of energy-efficient power electronic based equipment's have led to many power quality problems in electrical power system and becoming a great concern for utilities and customers. These Non-linear loads draw harmonics and reactive power (VARS) components of current from the utility. In three-phase systems, they could also induce imbalance and draw excessive neutral current. All these issues create serious problems for power quality.

The effective compensation of harmonics, reactive power, neutral current and supply current balancing with other power quality improvement are essential for the utilities as well as the end users. This attracted power electronics and power system engineers to develop dynamic and adjustable solutions to the power quality problems by various custom power devices like active power filter (APF), hybrid filter, unified power quality compensator (UPQC) etc. Many control algorithms with new / improved designs are presented by various researchers in context to this. In this paper a review on the various topologies and control strategies of active filters is presented.

This paper is presented in five sections. First section introduces the power quality issues followed by sections on technologies used in APFs to resolve them, classification of APFs based on converter type, topologies and number of phases and various control strategies. At last, conclusion along with future scope is presented.

II. ACTIVE POWER FILTERS

Many passive and active harmonic filters have been investigated to satisfy the power quality problems. Passive filtering has been preferred for harmonic compensation in the electrical system due to low cost, simplicity, reliability, and control less operation. Active power filters (APF) have many advantages over the passive filters.

They can suppress not only the supply current harmonics, but also the reactive currents and without causing harmful resonances with the power distribution systems like passive filters.

In the beginning, the APFs were used for suppression of harmonics generated by thyristor based converters and inverters used in HVDC transmission system. However, the design could not become technologically and economically practicable until the last two decades when fast and cost effective semiconductor devices such as Insulated Gate Bipolar Transistors (IGBTs) and Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), and high performance and cost effective Digital Signal Processors (DSPs) became available. Modern active filters are superior in filtering performance since they inject voltage / current harmonics produced by nonlinear loads of same magnitude but of opposite sign so they cancel each other and sinusoidal waveforms are obtained at the power line. Depending on the APF type, controllable reactive power compensation for power factor correction, voltage regulation, load balancing, voltage-flicker reduction, harmonic damping, harmonic isolation and / or their combinations could be provided.

Now a day's improved control strategies for AF with design of high efficiency and large capacity converters has been developed for three-phase three- or four- wire power circuit. These wide ranges of objectives are achieved either individually or in combination, depending upon the requirements and control strategy and configuration which have to be selected appropriately.

With the revolution in microelectronics, microprocessors, microcontrollers, DSP technology and with the advent of fast self-commutating solid-state devices like IGBTs and sensor technologies have enhanced performance of active filter. This paper presents various types of active filters and their classification based on topologies, control strategies and number of phases and brief explanation of mainly used techniques.

III. CLASSIFICATION OF ACTIVE POWER FILTERS

Active Filters can be classified based on converter type, topologies and number of phases. On converter based CSI or VSI bridge structure. On topology based shunt, series, hybrid and UPQC. On the bases of no. of phases two-wire (single phase) and three- or four-wire three-phase systems.

3.1 Convertor Based Classification

In general, there are two types of converters used in active filters - CSI or VSI bridge structure. A current source PWM converter (CSI) is equipped with a dc inductor and a voltage source PWM converter (VSI) is equipped with a dc capacitor. Fig.1. shows CSI bridge structure.

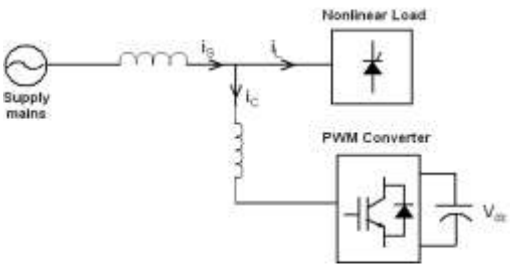


Fig. 1 Voltage Source PWM Converter Based Shunt Active Power Filter

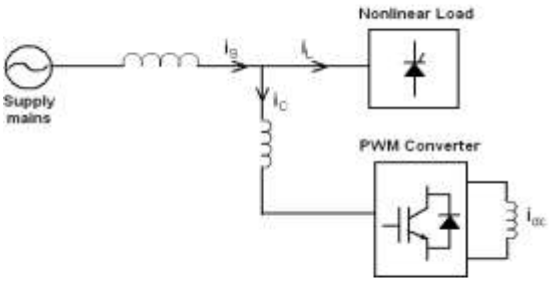


Fig. 2 Current Source PWM Converter Based Shunt Active Power Filter

Fig.2. shows VSI based filter that has a self-supporting dc voltage bus with a DC capacitor. It becomes dominant over CSI because of its high efficiency, lightweight, low cost and expandability to multilevel and multi-step versions.

3.2 Topologies Based Classification

Based on the topology, AF can be classified as series, shunt, hybrid active filters and UPQC. The appropriate topology is used as per the compensation required by the active filter. Parallel or shunt APF is the fundamental system configurations and it has been used in of three-phase three- or four- wire. Fig. 1 and 2 shows shunt APF, which consists of a controllable voltage and current source respectively. It is mainly used to eliminate current harmonics, reactive power compensation and balancing unbalanced input currents. Shunt active filters carries only the compensation current plus a small amount of active fundamental current which is supplied to compensate for system losses. This cancels harmonics and/or reactive components of the nonlinear load current at the point of common coupling (PCC). When it is employed to three-phase four-wire systems, it also compensates the neutral current (zero sequence current) component.

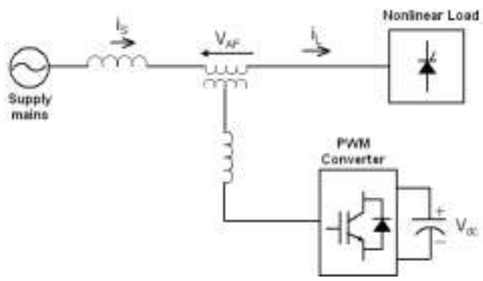
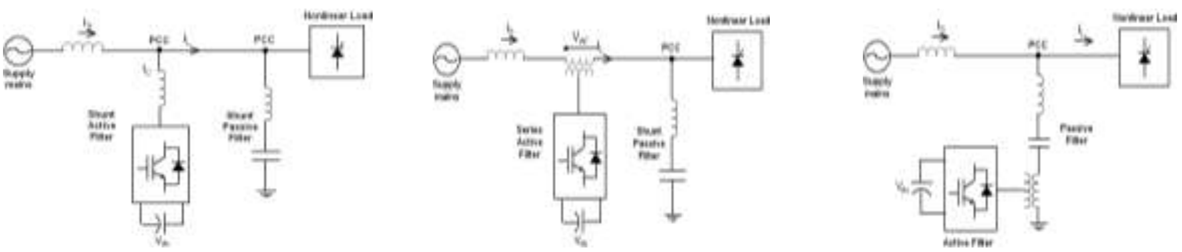


Fig. 3 Principle configuration of a VSI based series active power filter

Series active filter produces a PWM voltage waveform which is subtracted / added, on an instantaneous basis, from / to the supply mains voltage to maintain a pure sinusoidal voltage waveform across the load as shown in Fig. 3. It is similar to shunt APF, except that the interfacing inductor of shunt APF is replaced with the interfacing transformer. Its advantage over shunt active filters is that they are superlative for eliminating voltage-waveform harmonics, and for balancing three-phase voltages



(a) (b) (c)

Fig. 4 Hybrid Active Filter In Combination With
(a) Shunt Active and Shunt Passive Filter, (b) Series Active and Shunt Passive Filter, And
(c) Active Filter Connected In Series With Shunt Passive Filter.

Hybrid active filter configurations are typically the combination of basic active shunt / series and a passive filter. Hybrid APFs inherits the advantages of both active and passive filters. The active filter cancels the lower order harmonics, while the passive filter is responsible for higher order harmonics. Therefore, the main objective of hybrid active filter is to improve the filtering performance of high-order harmonics while providing a cost-effective low order harmonics mitigation. Most prominent hybrid APFs are shown in Fig. 4 (a), (b) and (c).

UPQC, also known as universal AF, is a combination of active series and active shunt filters. Fig. 5 shows basic schematic of UPQC the dc-link storage element (either inductor or dc-bus capacitor) is shared between two current source or voltage-source bridges operating as active series and active shunt compensators.

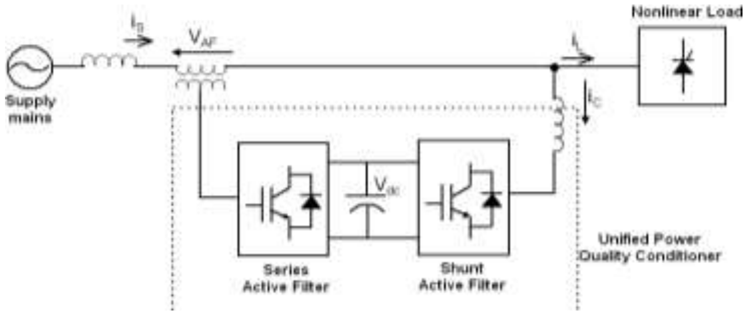


Fig. 5 Schematic diagram of Unified Power Quality Conditioner

Depending upon the nature of supply and/or the load system used, APFs are classified as single phase APFs or three phase APFs (three-phase three-wire and three-phase four-wire).

From various topologies summarized so far, the appropriate type of APFs should be installed at customer premises and utilities points for power quality improvements.

IV. CONTROL STRATEGIES

In APF design and control, calculation of the compensation current and reference signal generation is the main task for achieving the goal of power quality. The accurate estimation of reference signal depends on the control strategies used for the implementation of APF design. Control scheme is implemented in three stages.

- Sensing and conditioning of control signals
- Estimation of compensating signal
- Generation of switching signal for switching devices

The whole control scheme can be realized using analog, digital and advance programmable devices like single-chip microprocessor, digital signal processors (DSPs), field programmable gate array (FPGA), etc.

4.1 Sensing and Conditioning of Control Signals

AC mains voltage, DC link voltage, load currents, supply currents, compensator current, etc. are sensed by using proper voltage and current sensors circuitry. Voltage signals are sensed using either potential transformers (PT) or different Hall-effect voltage sensors or isolation amplifiers. Current signals are sensed using current transformers (CT) and/or Hall-effect current sensors. Sensed signals are also used to monitor, measure, and record various performance indices, such as THD, power factor, active and reactive power, crest factor, etc. Signal conditioning is required to make sensed signal compactable or readable by the platform on which control scheme has to implement. The analog or digital filters with low-pass, high-pass or band-pass characteristics are used for signal conditioning.

4.2 Estimation of Compensating Signals

The important aspect of the compensation process is the designing of the control algorithm for the APFs to generate required reference and later compensating signal. The control algorithm should be simple, robust, and accurate, and it should give its best performance not only in ideal voltage condition but also in distorted and/or distorted and unbalanced voltage condition which are normally present in the electrical distribution system. Proper estimation of compensating signal for achieving particular compensation objectives also affects the steady-state and transient performance of the APFs. Broadly, control strategies for compensating signals generation are based on frequency-domain or time-domain techniques. Fig.6. illustrates the general classification of available techniques.

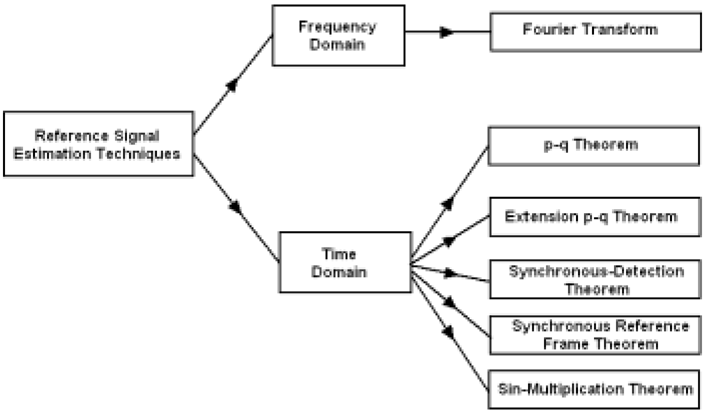


Fig. 6 Classification of Reference Signal Estimation Techniques

Both frequency-domain and time domain techniques have been used with VSI and CSI PWM converters. In recent research new methods based on wavelet transform and Artificial Intelligence (AI) are also reported for extraction of reference signal.

4.2.1 Frequency Domain Approach

In this, reference signal estimation in frequency-domain is suitable for both single and three phase systems. The frequency domain methods are based on Fourier analysis method of discrete signals such as Discrete Fourier Transform (DFT, and Fast Fourier Transform (FFT) and periodicity of distorted voltage and/or current waveforms to be corrected. Its major drawback is the requirement of a window function to analyze the frequency spectrum of the signal; this method also suffers from large memory requirement and large computational power for processor used. To eliminate higher harmonics number of calculations increases, which results in large response time and also not suitable for dynamically varying loads. Although the modified Fourier transform based methods adopting the sliding window show an improved dynamic response. Recent development in the processor technology is helping in reducing the computational time.

4.2.2 Time Domain Approach

This approach is based on instantaneous estimation of reference signal in the form of either voltage or current signal from distorted and harmonic-polluted voltage and current signals. The main advantages of the time domain compensation is its fast response, easy implementation and less computational burden. There is a large number of control methods in the time domain, which are known as instantaneous “p–q” theory, synchronous d–q reference frame method, synchronous detection method, flux-based controller, notch filter method, P–I controller, sliding mode controller, etc.

4.2.3 Control Based on Artificial Intelligence (AI)

AI is a technology to extract information from the process signal by using expert knowledge. Artificial intelligence is popular due to its ability to handle nonlinearity, complex problem without much information about the mathematical model of the system. It can identify the model, if necessary, and give the predicted performance even with a wide range of parameter variation. Different tools of AI such as fuzzy logic, artificial neural network, genetic algorithm, wavelet theory, etc. are used in various applications of power quality and power electronics for improving the robustness and performance of control algorithm

4.3 Generation of Gating Signal to Control Switches

Once the compensation signals are obtained based on the appropriate control scheme, the next stage of APF control is the generation of switching signals for the switching devices of the PWM converter. These switching signals are obtained by comparing the reference compensating current signals with the actual current in a controller. The switching patterns decide the required compensation of current harmonics. There are different control techniques for generation of gating signals. The performance of an APF is significantly affected by the selection of control techniques.

In linear control technique, voltage or current PWM, sinusoidal internal model control, ramp comparison control, etc. are used for obtaining the PWM signals. Nonlinear current control techniques include hysteresis control and SVM. In this section, a brief description of mostly used PWM techniques and their features have been presented.

4.3.1 Voltage or Current PWM Technique

Linear control technique of switching pulse generation for APF semiconductor switches is accomplished by using a negative feedback system as shown in Fig. 8.

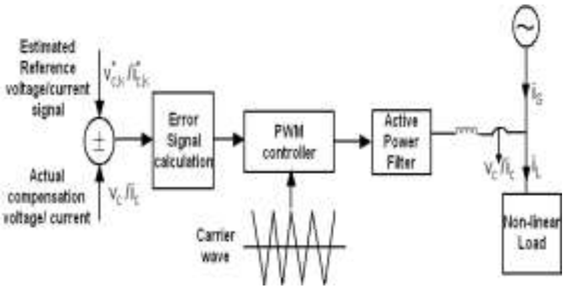


Fig. 8 Block Diagram of Linear Control Technique Linear Control

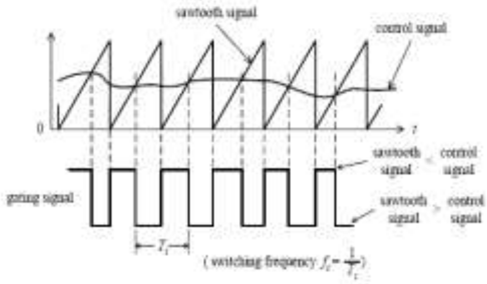


Fig. 9 Generation of Gate Signals Using Technique

voltage v_c signal is compared with its estimated reference signal ($i_{c,ref}$ and $v_{c,ref}$) through the Compensated error amplifier to produce the control signal. The resulting control signal is then compared with a fixed frequency carrier (triangular or ramp) signal. The frequency of the repetitive carrier signal establishes the switching frequency. This frequency is kept constant in linear control technique. As shown in Fig. 9, the gating signal is set high when the control signal has a higher numerical value than the carrier signal and via versa.

4.3.2 Hysteresis Control Technique

This technique forces the compensating current i_c or voltage v_c signal to follow its estimated reference signal ($i_{c,ref}$ or $v_{c,ref}$) within a specified tolerance band, known as hysteresis-band. Switching occurs whenever the error leaves the tolerance band. A basic block diagram of the hysteresis band current control is shown in Fig. 10. H is the hysteresis-band. The APF is switched on in such a way that the peak-to-peak compensation current/voltage signal is limited to a specified band (H) as illustrated in Fig. 11.

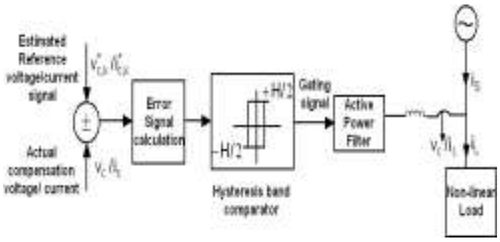


Fig. 10 Block Diagram of Hysteresis Control Technique

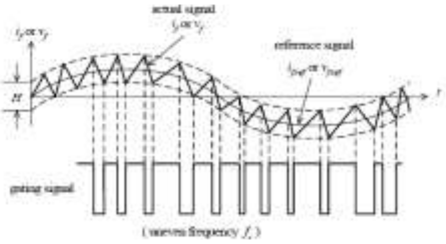


Fig. 11 Gating Signal Generation By Hysteresis Controller

The advantages of using the hysteresis current controller are its excellent dynamic performance and controllability of peak-to-peak current ripple within a specified hysteresis band. The main drawback of this technique is that it produces uneven switching frequency, which affects the APF efficiency and reliability.

4.3.3 Space Vector Modulation (SVM)

This method has several benefits like better voltage utilization, lesser current harmonics, and fixed frequency operation. Although implementation of SVM in digital system is simple, the required calculations and corresponding execution time limits the maximum sampling time and resulting maximum switching frequency and maximum bandwidth. It is reported that hysteresis current control technique is found superior and its performance is almost unaltered by the variation in the firing angle.In direct current control technique APF currents are used as reference compensating current ($i^*_{ca}, i^*_{cb}, i^*_{cc}$) which further compared with actual filter current (i_{ca}, i_{cb}, i_{cc}). Reference compensating current are obtained by subtracting load current from the reference supply current and therefore need more number of current sensors. In indirect current control technique the switching signals are obtained by the comparison of estimated reference source current ($i^*_{sa}, i^*_{sb}, i^*_{sc}$) with actual source current (i_{sa}, i_{sb}, i_{sc}). It is experimentally verified that indirect current control technique is simpler, requires less hardware and offers better performance. It is also capable of eliminating the harmonics and switching ripples, resulting in sinusoidal supply current.

V. CONCLUSION

After reviewing it is found that extensive efforts are being made to improve the performance of the APFs, with the help of new or improved modifications in topology and control methodologies. Various configurations of APFs have been proposed to compensate aforementioned power quality problems. Complexity of the control algorithm can also be greatly reduced with the involvement of artificial intelligence like fuzzy logic, neural network etc. with the conventional approach to resolve the poor power quality problems not only in steady-state but also in dynamic/transients situation.

REFERENCES

[1] Akagi H. Kanazawa Y. and Nabae A. ,"Instantaneous reactive power compensators comprising switching devices without energy storage components", *IEEE Trans. on Industrial Applications*, vol.20 no.3 pp.625-630, 1984.

[2] Akagi H. and Nabae A., "Control strategy of active power filters using multiple voltage source PWM convertors*", IEEE Trans. on Industrial Applications*, vol.IA-22, no.3 pp.460-465,May/June 1986

[3] J. S. Subjak Jr. and J. S. Mcquilkin, "Harmonics-causes, effects, measurements, analysis: An update," *IEEE Trans. Ind. Applicat.*, vol. 26, pp. 1034-1042, Nov./Dec. 1990.

[4] M. E. Amoli and T. Florence, "Voltage, current harmonic control of a utility systemÐA summary of 1120 test measurements," *IEEE Trans. Power Delivery*, vol. 5, pp. 1552-1557, July 1990.

[5] Akagi H. and Fujita H., "A new power line conditioner for harmonic compensation in power systems", *IEEE Trans. on power Delivery*, vol.10 no.3 pp.1570-1575, July 1995.

[6] H. Akagi, "New trends in active filters for power conditioning," IEEE Transactions on Industrial Applications," vol. 32, no. 6, pp. 1312-1322, November/December 1996.

[7] Aredes M., Hafner J. and Heumann K., "Three phase four wire shunt active filter control strategies", *IEEE Trans. on power Electronics*, vol.12, no.2 pp.311-318, 1997.

[8] B. Singh, K. Al-Haddad and A. Chandra, "A New control approach to three-phase active filter for harmonics and reactive power compensation" IEEE Trans. Power Systems, vol. 13, no. 1, February 1998.

[9] B. Singh, A. Chandra, and K. Al-Haddad," Performance comparison of two current control technique applied to an active filter," in Proc. Of 8th international conference on Harmonics and Quality of Power , vol., 1, pp. 133-138,october 1998.

[10]B. Singh, K. Al-Haddad and A. Chandra, "A review of active filters for power quality improvement" IEEE, Trans. Ind. Electron", vol.46, No. 5, pp. 960-971, 1999.

[11]B. Singh, A. Chandra, and K. Al-Haddad," Computer-aided modeling and simulation of active power filters," Taylor & Francis, Inc. Electrical Machine and Power Systems, vol., 27, pp. 1227-1241,1999.

[12]B. Singh, A. Chandra, P.Rastgoufard and K. Al-Haddad," DSP based method of active filter:Elimination of switching ripples," in Proc.of 15th annual IEEE Applied Power Electronics Conference, vol.,1, pp.427-433,2000.

[13]Bansal R.C., Bhatti T.S., and Kothari D.P., "Artificial intelligence techniques for monitoring and control of power systems: an overview", *in Proc. of International conference on Control, Instrumentation and information Communication*, Kolkata, India, pp.91-95, 2001.

[14]D. Rivas, L. Moran, J. Dixon, and J. Espinoza, "A simple control scheme filter for hybrid active power," IEE Proceedings on Generation, Transmission and Distribution, vol. 149, no. 4, pp. 485-490, July 2002.

[15]Jain S.K.,Agarwal P.and Gupta H.O.,"Fuzzy logic controlled shunt active power filter for power quality improvement",in IEE Proc.on Electric Power Applications, vol. 149,no.5, pp.317-328,September 2002.

[16]Aredes M. and Monteiro F.C., "A control strategy for shunt active power filter", *in Proc of IEEE Harmonics and Quality of Power Conference*,vol,2,pp. 472-477,Oct.2002.

[17]Bansal R.C., Bhatti T.S., and Kothari D.P., "Artificial intelligence techniques for reactive power /voltage control in power systems: a review", *in Proc. of Application Evolutionary Strategies to Power, Signal Processing and Control*, Rourkela, India,pp.57-63,2002.

[18]Bansal R.C., "Bibliography on the fuzzy set theory applications in power systems (1994-2001)",*IEEE Trans. on Power Systems*, vol.18,no.4,pp.1291-1299,2003.

[19]Jain S.K.,Agarwal P.and Gupta H.O.,"Design simulation and experimantal investigation on a shunt active power filter for harmonics and reactive power compensation",Electric Power Components and Systems, vol. 31,pp.671-692,2003.

[20]B. Singh, A. Chandra, P.Rastgoufard and K. Al-Haddad," Design simulation and implementation of three pole/four pole toplogies for active filters," IEE Proc. On Electric Power Applications, vol.151,No. 4, pp.467-476,July 2004.

[21]Akagi H. "Active harmonic filters", *in Proc. Of the IEEE,* vol.98 no.12 pp. 2128-2141, December 2005.

[22]Akagi H. "Modern active filters and traditional passive filters", *Bulletin of the Polish Academy of Technical Sciences,* vol549 no.3 pp.255-269,2006.

[23]B. Singh and V. Verma, "An indirect current control of hybrid power filter for varying loads," IEEE Transactions on Power Delivery, vol. 21, no. 1, pp. 178-184, January 2006.

[24]Ali Ajami and Hosseini S.H., "Implementation of a novel control strategy for shunt active filter", *ECI Trans. on Electrical Engineering* , vol.4, no.1 pp.40-46,February 2006.

[25]Akagi H. Watanabe B.H. and Aredes M. "Instantaneous power theory and applications to power conditioning", *IEEE Press Piscataway* NJ 2007.

[26]B. Singh and V. Vermaand J. Solanki, "Neural network based selective compensation of current quality problems in distribution system," IEEE Trans. on Industrial Electronics,vol.54, no. 1, pp.53-60,Feburary 2007.

[27]B. Singh, A. Chandra, P.Rastgoufard and K. Al-Haddad," An improved control algorithm for active filters," IEEE Trans. Power Delivery, vol. 22,No. 2, pp. 1009-1020,2007.

[28]B. Singh and V. Verma, "Selective compensation of power quality problems through active power filter by current decomposition,"IEEE Trans.on Power Delivery,vol.23,no.2, pp.792-799,April 2008.

[29]G. Bhuvaneswari, and M. G. Nair, "Design, simulation, and analog circuit implementation of a three-phase shunt active filter using the I cosΦ algorithm," IEEE Transactions on Power Delivery, vol. 23, no. 2, pp.1222-1235, April 2008.

[30]A. Bhattacharya, C. Chakraborty, and S. Bhattacharya, "Current compensation using shunt type active power filters," IEEE Industrial Electronics Magazine, March 2009.

[31]Patidar R.D.and Singh S.P., " Digital signal processor based shunt active filter controller for customer generated harmonics and reactive power compensation", ",Electric Power Components and Systems, vol. 38,pp.937-959,May 2010.

BIOGRAPHICAL NOTES

	Ms. Annu Govind is presently pursuing Ph.D. in Electrical Engineering Department of Jamia Millia Islamia, New Delhi. She has done her M.Tech. in Power System and B.E. in Electrical Engineering from Malviya National Instititute of Technology (MNIT), Jaipur.
	Mr. Omendra K Govind is presently working at Advanced Level Telecom Training Centre (ALTTC), Apex training centre of BSNL. He has done Master of Design in Industrial Design from IIT Delhi and B.Tech. in Electrical Engineering from Jamia Millia Islamia, New Delhi. He has also done MBA in Operation Management. He has delivered training program for Commonwealth Telecommunication Organization (CTO) at South Africa and also for Asia Pacific Telecommununity (APT) at India.