

A Survey On Control Strategies For Shunt Active Power Filter For Reactive Power Compensation

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Abstract

This paper bestows a survey on different control strategies for Shunt active filters employed for reactive power compensation. An assortment of power quality tribulations are instigated in the power system due to frequent use of non-linear and inductive loads. In practical scenario, the load and source condition may not be predicted. For effective harmonic control and reactive power compensation, the control strategy employed in SAPF should be enough to handle distorted, unbalanced source and load conditions. Further the elected control strategy must handle steady state and dynamic conditions. The cram also guides the researchers to pick the finest control strategies for SAPF based on commitment.

Key words: Shunt Active Power Filter, Instantaneous Power Theory, Control Strategies, Harmonics, Non Linear Load.

I. Introduction

Augmented use of Non linear loads introduced solemn trouble in electric power distribution system. Customary raise in the harmonic origin and imbalance of current with the addition of high utilization reactive power can be pragmatic. Currents with harmonic in electric grids can introduce harmonics and disorder in voltage. Polluted currents can interact harmfully with an ample collection of power system components, control systems, protection circuits and non-linear loads. This review paper significantly classifies the available control strategies for Shunt active power conditioning system, from the view of power system conditions.

This escorts eventually to the stipulation of the key procedure for picking the appropriate control strategy for power system applications. The power quality disquiet can be easily solved with the application of appropriate control strategy, relevant to source and load conditions.

II. Control Strategies for active power filters

The desired compensation properties can be arrived by an appropriate control strategy with Shunt active power filter. There are numerous control strategies in which some are pertinent only for normal source conditions and few are much appropriate even for distorted and unbalanced source conditions. An instantaneous reactive power compensator without capacitor is elaborated [1]. A control strategy based on only real power is employed in shunt active power conditioners [2].

The various line conditioning methodologies were discussed for active power conditioners [5]. The p-q theory and properties of three phase system are revealed [7]. An instantaneous active and reactive current based compensator is employed and performance is appraised for normal source conditions [9]. An unbalanced current compensator was employed in three phase system for reactive power compensation [10].

The performance analysis of a shunt active power filter based on new control algorithm for compensation of harmonic and reactive power of a 3-phase system under non-ideal source voltage scenarios was carried out [13]. An improved instantaneous active and reactive current component method is employed for power factor correction and harmonic reduction [16].

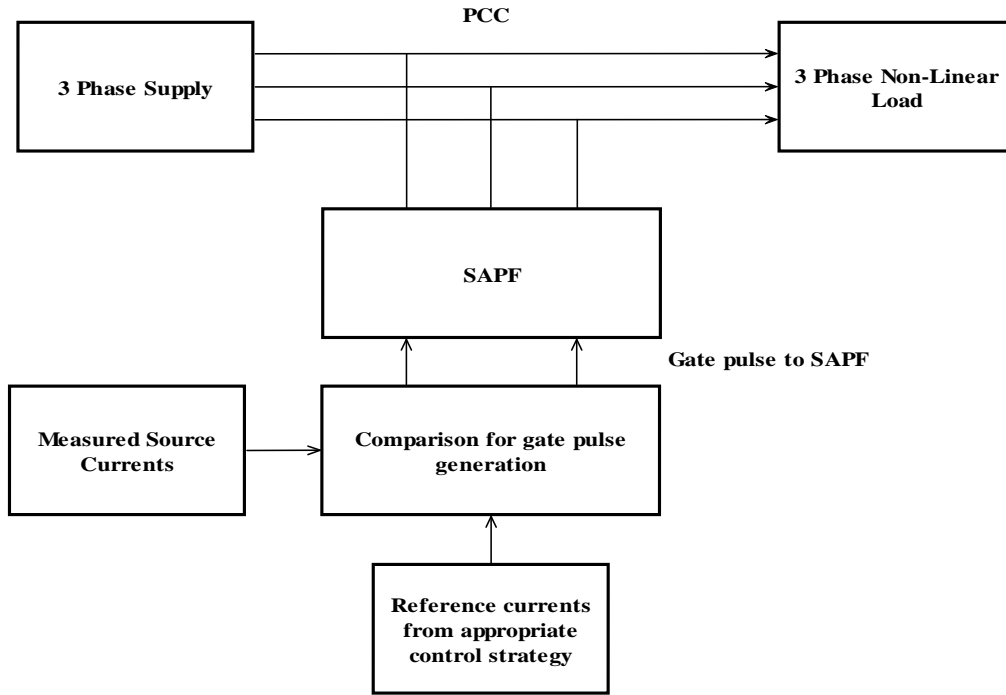


Fig 1. Structure of SAPF with Control Strategy

III. Instantaneous active and reactive power (PQ) method.

Shunt active power filter compensation currents are derived from measured instantaneous active and reactive powers of load. This is realized by computation of supply voltages and non-linear load currents in α - β frame as given below.

$$\begin{pmatrix} u_{\alpha} \\ u_{\beta} \end{pmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{pmatrix} 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 0 & \sqrt{3} & -\sqrt{3} \end{pmatrix} \begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} \quad (1)$$

u_a, u_b and u_c are the measured voltages from the source.

$$\begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \end{pmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{pmatrix} 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 0 & \sqrt{3} & -\sqrt{3} \end{pmatrix} \begin{pmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{pmatrix} \quad (2)$$

i_{la}, i_{lb} and i_{lc} are the measured currents from the load. Instantaneous active and reactive load powers P_l and Q_l are computed as

$$\begin{pmatrix} p_l \\ q_l \end{pmatrix} = \begin{pmatrix} u_{\alpha} & u_{\beta} \\ -u_{\beta} & u_{\alpha} \end{pmatrix} \begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \end{pmatrix} \quad (3)$$

Which can be perished into oscillatory and average terms as $p_l = \tilde{p}_l + p_l$. The active filter should compensate oscillatory power components to ease the power rating of the filter. To compensate for $p_c = -\tilde{p}_l$ and $q_c = -\tilde{q}_l$, a filter of second order

is used to extract the oscillatory component from real and reactive powers. The compensation current is obtained by taking inverse of matrix (3) and resulting as (4) & (5).

$$\begin{pmatrix} ic_{\alpha} \\ ic_{\beta} \end{pmatrix} = \frac{1}{u_{\alpha}^2 + u_{\beta}^2} \begin{pmatrix} u_{\alpha} & -u_{\beta} \\ u_{\beta} & u_{\alpha} \end{pmatrix} \begin{pmatrix} pc \\ qc \end{pmatrix} \quad (4)$$

$$\begin{pmatrix} ic_1 \\ ic_2 \\ ic_3 \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} ic_{\alpha} \\ ic_{\beta} \end{pmatrix} \quad (5)$$

Compensation currents from (5) are compared with measured grid currents for switching signals in the active filter.

IV. Instantaneous Real Power Theory

Foundation of this theory is from the universal P-Q theory. The active filter need to compensate the oscillating part of the instant active current of load and thereby produces sinusoidal source current. For computation of compensation current, the oscillating component of load real power alone is considered in this method. The real power of the load is calculated from (1), (2), (3) as above and a filter is used to separate oscillating component. The power loss due to DC-link capacitor also taken in to account for computation of compensation current.

$$P_{DC(loss)} = \begin{pmatrix} v_{DC,ref} & -v_{DC} \end{pmatrix} \begin{bmatrix} KI \\ kP + \frac{KI}{s} \end{bmatrix} \quad (6)$$

Now the real power need to compensate is given as,

$$p = \tilde{P}_{ac} + P_{dc(loss)} \quad (7)$$

The compensation current is given by (8).

$$\begin{pmatrix} ic_{\alpha} \\ ic_{\beta} \end{pmatrix} = \frac{1}{u_{\alpha}^2 + u_{\beta}^2} \begin{pmatrix} u_{\alpha} & -u_{\beta} \\ u_{\beta} & u_{\alpha} \end{pmatrix} \begin{pmatrix} p \\ 0 \end{pmatrix} \quad (8)$$

Compensation currents are calculated by substituting (8) in (5) and are compared with measured grid currents for gate pulse generation to switches in the active filter.

V. Reactive Power Theory

This method is also derived from universal PQ theory like instantaneous real power theory. For computing the compensation currents, only oscillating component of load reactive power is considered. The reactive power of the load is deliberated from (1),(2),(3) as above and a filter is used to separate oscillating component.

The compensation current is given by (8).

$$\begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} = \frac{1}{u_{\alpha}^2 + u_{\beta}^2} \begin{pmatrix} u_{\alpha} & -u_{\beta} \\ u_{\beta} & u_{\alpha} \end{pmatrix} \begin{pmatrix} 0 \\ \tilde{q} \end{pmatrix} \quad (9)$$

The Compensating currents are premeditated by substituting (9) in (5) and compared with measured grid currents for generation of switching pulses in active filters.

VI. Instantaneous Active and Reactive current component i_d - i_q method

The exploitation of control strategy is based on instantaneous active and reactive current components to obtain compensation current [4]. From synchronous reference frame theory the load current components are derived in d-q frame as in (6).

$$\begin{pmatrix} i_{ld} \\ i_{lq} \end{pmatrix} = \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \end{pmatrix}, \quad \theta = \tan^{-1} \left(\frac{u_{\beta}}{u_{\alpha}} \right) \quad (10)$$

By geometric relations (10) can be written as,

$$\begin{pmatrix} i_{ld} \\ i_{lq} \end{pmatrix} = \frac{1}{\sqrt{(u_{\alpha}^2 + u_{\beta}^2)}} \cdot \begin{pmatrix} u_{\alpha} & u_{\beta} \\ -u_{\beta} & u_{\alpha} \end{pmatrix} \cdot \begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \end{pmatrix} \quad (11)$$

i_{ld} and i_{lq} are passed through second order high pass filter to eliminate dc value. As a result of above, compensation currents become

$$i_{cd} = -i_{ld} \quad \text{and} \quad i_{cq} = -i_{lq}$$

By transforming (11) from dq to $\alpha\beta$ frame,

$$\begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} = \frac{1}{\sqrt{(u_{\alpha}^2 + u_{\beta}^2)}} \begin{pmatrix} u_{\alpha} & -u_{\beta} \\ u_{\beta} & u_{\alpha} \end{pmatrix} \begin{pmatrix} i_{cd} \\ i_{cq} \end{pmatrix} \quad (12)$$

Substitute (12) in (5) with this above values of i_{cd} and i_{cq} we get the reference currents as below.

$$\begin{pmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} \quad (13)$$

VII. Improved instantaneous Active and Reactive current component method

The compensation currents for SAPF are derived from measured instantaneous active and reactive current components of load. This is realized by computation of supply voltages and non-linear load currents in α - β frame. Computation of load currents in rotating (dq) reference frame is attained by Park's transformation (10).

The voltage components (direct and the quadrature) are given by,

$$u_d = \left| \overline{u_{dq}} \right| = \left| \overline{u_{\alpha\beta}} \right| = \sqrt{u_{\alpha F}^2 + u_{\beta F}^2}$$

and

$$u_q = 0$$

By substituting,

$$\cos \theta = \frac{u_{\alpha F}}{\sqrt{u_{\alpha F}^2 + u_{\beta F}^2}} \quad \text{and} \quad \sin \theta = \frac{u_{\beta F}}{\sqrt{u_{\alpha F}^2 + u_{\beta F}^2}}$$

$$\begin{pmatrix} i_{ld} \\ i_{lq} \end{pmatrix} = \frac{1}{\sqrt{u_{\alpha F}^2 + u_{\beta F}^2}} \begin{pmatrix} u_{\alpha F} & u_{\beta F} \\ -u_{\beta F} & u_{\alpha F} \end{pmatrix} \begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \end{pmatrix} \quad (14)$$

Active and reactive currents of load in rotating reference frame, i_{ld} and i_{lq} can be divided into oscillatory and average terms as,

$$\dot{i}_{ld} = \overline{\dot{i}_{ld}} + \tilde{\dot{i}}_{ld} \quad \text{and} \quad \dot{i}_{lq} = \overline{\dot{i}_{lq}} + \tilde{\dot{i}}_{lq}$$

The harmonic segregation of d-q transformed signal is derived by eliminating the dc component and the reference compensator currents are achieved as.

$$\dot{i}_{cd}^* = -\tilde{\dot{i}}_{ld} \quad \text{and} \quad \dot{i}_{cq}^* = -\tilde{\dot{i}}_{lq}$$

The reference currents for Shunt active power filter in the $\alpha\beta$ coordinates are computed by Inverse Park transformation as,

$$\begin{pmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{pmatrix} = \frac{1}{\sqrt{u_{\alpha F}^2 + u_{\beta F}^2}} \begin{pmatrix} u_{\alpha F} & -u_{\beta F} \\ u_{\beta F} & u_{\alpha F} \end{pmatrix} \begin{pmatrix} i_{cd}^* \\ i_{cq}^* \end{pmatrix} \quad (15)$$

The reference currents for Shunt active power filter in the abc coordinates are computed by Inverse Clark transformation as,

$$\begin{pmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{pmatrix} \quad (16)$$

Compensation currents are computed by (16) are compared with measured grid currents for generating switching pulses.

VIII. Improved instantaneous PQ theory

The universal instantaneous reactive power (p-q) theory is reprehensible under non-ideal voltage conditions. In order to improve the performance, the new algorithm is proposed in [5]. The d-q reference transformation is applied for reducing number of filters used.

From (3),

$$\begin{pmatrix} i\alpha \\ i\beta \end{pmatrix} = \frac{1}{u\alpha^2 + u\beta^2} \begin{pmatrix} u\alpha & -u\beta \\ u\beta & u\alpha \end{pmatrix} \begin{pmatrix} p \\ q \end{pmatrix} \quad (17)$$

Measured voltages are converted to $\alpha\beta$ frame and filtered as shown in the block diagram below.

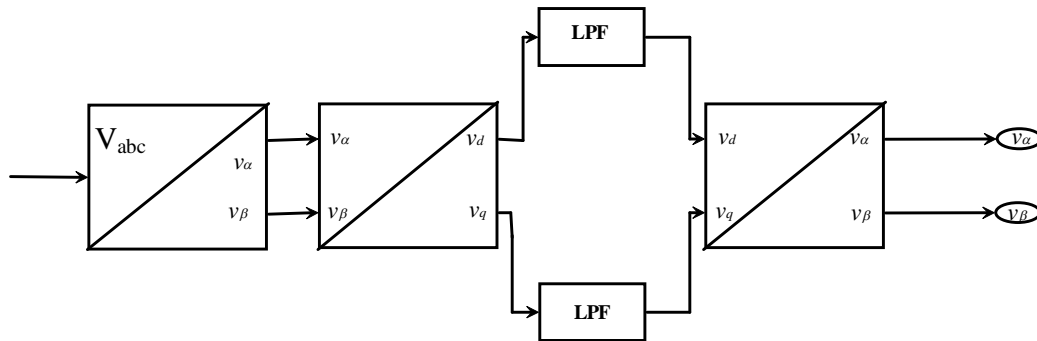


Fig 2. Block diagram for filtering voltages.

$$\begin{pmatrix} u\alpha \\ u\beta \end{pmatrix} = \begin{pmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{pmatrix} \begin{pmatrix} udF \\ uqF \end{pmatrix} \quad (18)$$

$$\begin{pmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{pmatrix} = \frac{1}{u\alpha^2 + u\beta^2} \begin{pmatrix} u\alpha & -u\beta \\ u\beta & u\alpha \end{pmatrix} \begin{pmatrix} -\tilde{p} \\ -q \end{pmatrix} \quad (19)$$

Compensation currents are calculated by substituting (22) in (13) and are compared with measured grid currents for generation of pulses in the active filter.

IX. Average Power method

To obtain fundamental component of mains voltage a PLL is preferred. The mains voltage possess fundamental and distorted component. Unit vector templates of voltage is obtained by sensing the input voltage and multiplied by $1/v_{pk}$, where v_{pk} is maximum value of fundamental voltage. By passing the Unit vectors via PLL, synchronization of signals is achieved. The fundamental frequency components from PLL are multiplied by v_{pk} to get fundamental mains voltage.

The reference for load current component I_{smp}^* is computed with the help of sensed average load power P_{avg} . The sensed load currents (I_{La}, I_{Lb}, I_{Lc}) and bus voltages (V_a, V_b, V_c) through PLL are used to obtain the instantaneous power P_L ,

$$P_L = u_a.iLa + u_b.iLb + u_c.iLc \quad (20)$$

The average power P_{ave} is computed by taking the average of instantaneous power for $1/6^{\text{th}}$ of supply frequency. The peak current component of load I_{smp}^* ,

$$P_{avg} = 1.5 V_{pk} . I_{smp}^* \quad (21)$$

The reference peak current required to compensate the losses in APF is I_{smd}^* and computed by comparing the reference voltage and actual capacitor voltage. Average voltage of capacitors used in each phase is taken as the actual capacitor voltage. The peak reference source current I_{sm}^* is calculated as in(16).

$$I_{sm}^* = I_{smp}^* + I_{smd}^* \quad (22)$$

The reference source currents ($i_{sa}^*, i_{sb}^*, i_{sc}^*$) are calculated by the product of peak value I_{sm}^* with unit current templates (u_{sa}, u_{sb}, u_{sc}) obtained from bus voltages (v_a, v_b, v_c) through PLL. The APF desired references currents ($i_{ca}^*, i_{cb}^*, i_{cc}^*$) are as follows,

$$i_{ca}^* = i_{sa}^* - i_{sa} \quad (23)$$

$$i_{cb}^* = i_{sb}^* - i_{sb} \quad (24)$$

$$i_{cc}^* = i_{sc}^* - i_{sc} \quad (25)$$

The equations (23),(24),(25) are compared with measured grid currents for gate pulse generation to switches in the active filter.

From various control methodologies, the comparison has been established in table 1

Table 1 Comparison of control strategies

S.No	control strategy	Normal& Balanced Source Voltage Condition	Normal& Unbalanced Source Voltage Condition	Balanced Distorted Source Voltage Condition	Unbalanced Distorted Source Voltage Condition
1	PQ theory	Excellent Compensation	Incompatible	Incompatible	Incompatible
2	P theory	Excellent Compensation	Incompatible	Incompatible	Incompatible
3	Q theory	Excellent Compensation	Incompatible	Incompatible	Incompatible
4	id-iq method	Excellent Compensation	Incompatible	Incompatible	Incompatible
5	Improved id-iq method	Excellent Compensation	Excellent Compensation	Excellent Compensation	Excellent Compensation
6	Improved PQ theory	Excellent Compensation	Excellent Compensation	Excellent Compensation	Excellent Compensation
7	Average power method	Excellent Compensation	Excellent Compensation	Excellent Compensation	Excellent Compensation

X. Conclusion

This literature assessment has given prominence to describe the effectiveness of suitable control strategy for SAPF to augment power quality under various source voltage conditions in three phase system supplying non-linear load. Seven different control strategies for SAPF are discussed and their suitability for different source voltage scenarios have been elaborated. From the table1, the effectiveness of control strategy for various source voltage conditions is determined.

XI. References

- [1] H. Akagi, Y. Kanazawa, A. Nabae, (1984) "Instantaneous reactive power compensators comprising switching devices without energy storage components", *IEEE Trans. Ind. Appl.* Vol.20. 625–630.
- [2] Karuppanan P, KamalaKanta Mahapatra Jan(2011) "Cascaded Multilevel Inverter based Active Filter for power line conditioners using instantaneous real- power theory" IEEE International conference on Power Electronics,NSIT.
- [3] Bhim Singh, Kamal Al-Haddad and A. Chandra, (1998) "A new control approach to three phase Harmonics and reactive power compensation", *IEEE Trans. On power systems* Vol. 13, No 1 pp. 133-138.
- [4] H. Akagi, "New trends in active filters for power conditioning", (1996) *IEEE Trans. Ind. Appl.* vol.32. 1312–1322.
- [5] W.M.Grady, M.J.Samotyj, A.H.Noyola July (1990) "Survey of active power line conditioning methodologies" *IEEE Trans. Power delivery* vol.5.no.3 1536–1542.
- [6] L.Gyugyi, E.C.Strycula,(1976) "Active AC Power Filters" in Proc. IEEE/IAS Annu. Meeting, vol.19-c, 529-535.

- [7] Leszek S. Czarnecki (2006) "Instantaneous Reactive Power p-q theory and Power properties of Three –Phase Systems " *IEEE Trans on Power* vol.21.no.1 362–367.
- [8] Arindam Ghosh, Gerard Ledwich "Power Quality Enhancement Using Custom Power Devices" Kluwer Academic Publishers USA.
- [9] Vasco Soares, Pedro Verdelho, Gil D. Marques "An Instantaneous Active and Reactive Current Component Method for Active Filters" *IEEE TRANSACTIONS ON POWER ELECTRONICS*, VOL. 15, NO. 4, JULY 2000.
- [10] P. Verdelho and G. D. Marques, "An active power filter and unbalanced current compensator," *IEEE Trans. Ind. Electron.*, vol. 44, pp. 321–328, June 1997.
- [11] V. Soares and P. Verdelho, "Instantaneous active and reactive current $i_d - i_q$ calculator suitable to active power filters," in *Proc. PEMC'98 Conf.*, vol. 7, 1998, pp. 111–114.
- [12] L. A. Pittorino, J. A. du Toit, and J. H. R. Enslin, "Evaluation of converter topologies and controllers for power quality compensators under unbalanced conditions," in *Proc. PESC'97 Conf.*, vol. 2, 1997, pp. 1127–1133.
- [13] Murat Kale, Engin Ozdemir, (2005) "Harmonic and reactive power compensation with shunt active power filter under no-ideal mains voltage" *Electric Power System research* vol. 74, pp 363-370.
- [14] S.J. Huang, et al., A study of three-phase active power filters under non-ideal mains voltages, *Electric Power Syst. Res.* 49 (1999) 125–137.
- [15] C.C. Chen, Y.Y. Hsu, A novel approach to the design of a shunt active filter for an unbalanced three-phase four-wire system under nonsinusoidal conditions, *IEEE Trans. Power Deliv.* 15 (4) (2000) 1258–1264.
- [16] Naimish Zaveri Ajitsinh chudasama, (2012) "Control strategies for harmonic mitigation and power factor correction using shunt active filter under various source voltage conditions" *Electrical Power and Energy Systems* vol. 42, pp 661-671.
- [17] Jain S, Agarwal P, Gupta H. Control algorithm for customer-generated harmonics and reactive power. *IEEE Trans Power Delivery* 2004;19(1):357–66.
- [18] Ghosh A, Joshi A. A new approach to load balancing and power factor correction in power distribution system. *IEEE Trans Power Delivery* 2000;15(1):417–22.
- [19] Chandra A, Singh B, Singh BN, Al-Haddad K. "An improved control algorithm of shunt active filter for voltage regulation, harmonic elimination, power factor correction and balancing of non-linear loads". *IEEE Trans Power Electron* 2000 May;15(3):495–507.
- [20] Waware Madhukar, Pramod Agarwal (2010) "Comparison of Control Strategies for Multilevel Inverter based Active Power Filter used in High Voltage Systems" *IEEE conference* 2010.