A Review of harmonic mitigation in power system using hybrid filter

Mayur D.Patel[1], A. L. Vaghamshi[2], A. M. Kubavat[3]
M.E. Student[1], Electrical Engineering Department, Government Engineering College, Bhuj (INDIA),
Assistant Professor[2], Electrical Engineering Department, Government Engineering College, Bhuj (INDIA),
Assistant Professor[3], Electrical Engineering Department, Government Engineering College, Bhuj (INDIA),

Abstract—the power quality problems are common in most of industrial and commercial users. The non linear load can be generates current harmonics and/or voltage harmonics, which makes worse the power quality. Therefore, these harmonics must be mitigation. This review provides a survey of the mitigation of above mention harmonics problems using power electronics based equipments. One traditional solution to mitigate harmonics problems is the use of passive filters. The objective of shunt passive filter is to eliminate harmonics currents generated by nonlinear load. Passive filter has some drawbacks mainly related to the filter frequencies they were previously tuned, fixed compensation, resonance can occur because of the interaction between the passive filter and other load, with undesired results. To avoid the above-mentioned problems regarding the applications of passive filters, recent efforts have been concentrated in the development active filter. Shunt active filter is suitable for the mitigation of harmonics of the loads called harmonics current source. Series active filter is suitable for the compensation of loads called harmonics voltage source. Active filter has some drawback mainly high initial cost, which minimize using hybrid filter or combination of the series active filter and shunt passive filter. In this scheme, a low cost passive high-pass filter (HPF) is used in addition to the conventional APF. The harmonics filtering task is divided between the two filters. The APF cancels the lower order harmonics, and the HPF filters the higher order harmonics. HAPF, the advantages of both passive filter and active filter, provide improved performance and cost-effective solutions.

Index Terms—**power quality, passive filter, active filter, active filter, hybrid filter.**

I. INTRODUCTION

Power electronics has three faces in power distribution: one that introduces valuable industrial and domestic equipment; a second one that creates problems; and third one that helps to solve those problems. Power electronics and microelectronics have become two technologies that have considerably improved the quality of modern life, allowing the introduction of sophisticated energy-efficient controllable equipment to industry and commercial. Those same sensitive technologies are conflicting with each other and increasingly challenging the maintaining of quality of electric energy delivery. It generates serious pollution to the quality of power supply of transmission and distribution network. The presence of harmonics in power lines therefore more power losses in distribution system, interference problems in communication system and in operation failures of sensitive electronics devices. Harmonic may results equipment overheating, capacitor fuse blowing, and inaccurate power metering, etc. And, electrical equipment of modern industry, commerce and resident users is highly sensitive to power quality. The power equipment which includes adjustable-speed motor drives, electronic power supplies, direct current (DC) motor drives, battery chargers, computers, electronic ballasts are responsible for the rise in related PQ problems [2-4]. These nonlinear loads are constructed by nonlinear devices, in which the current is not proportional to the applied voltage.

Ultimately we cannot live without the microelectronics and power electronics based instruments as these are now being very much essential looking at their uses; hence what we can do is that, by using power electronic devices; such as active or passive filter or both we can improve the power quality and compensate the reactive power requirement of the load. Passive filters are widely used in power systems for current harmonic mitigation. They have shunt branches consisting of passive elements; such as inductors and capacitors which are respectively tuned to the predominant harmonics. Design procedure for passive filter is also very simple. Passive filters have the following problems. Source impedance influences the compensation characteristics of passive filters, Frequency variation of the ac source affects the compensation characteristics of the passive filters, Overload occurs when the load harmonics increase, Due to presence of inductors and capacitors, passive filter are generally large and bulky, Because of these problems, electric power engineers are paying more attention to active filters as solutions to power system harmonics.

With remarkable progress in the speed and capacity of semiconductor switching devices, active filters have been studied and put into practical use, because they have the ability to overcome the above-mentioned disadvantages inherent in passive filters. They are more effective in harmonic compensation and improve performance. However, they are high initial costs and running costs and require comparatively high power converter ratings. The term active filter is a generic one and is applied to a group of power-electronic circuits incorporating power switching devices and passive energy-storage-circuit elements, such as inductors and capacitors. The functions of these circuits vary depending on the applications. They are generally used for controlling current harmonics in supply networks at the low-to medium-voltage distribution level or for reactive power and/or voltage control at high-voltage distribution level. Passive filter and active power filter have some drawbacks, those drawback over came by hybrid filter its means combination of passive and active filter. In this scheme, a low cost passive high-pass filter (HPF) is used in addition to the conventional APF. The harmonics filtering task is divided between the two filters. The APF cancels the lower order harmonics, and the HPF filters the higher order harmonics. HAPF, the advantages of both passive filter and active filter, provide improved performance and cost-effective solutions.[4]

The hybrid topologies aim is to enhance the passive filter performance and power-rating reduction of the active filter. Two configurations have been mainly proposed: active filter connected in series with a shunt passive filter and series active filter combined with shunt passive filter. Both topologies are useful to compensate harmonic current source load type. However, when the load also generates voltage harmonics, the second topology is the most appropriate. In this paper, the topology used is series active filter combined with shunt passive filter. For this configuration, different techniques have been applied to obtain the control signal for the APF [5]–[8]. The control target most used is that provides high impedance for the harmonics while providing zero impedance for the fundamental harmonic. This strategy is achieved when the APF generates a voltage proportional to the source current harmonics [12], [9]. Among the hybrid active filter solutions, the hybrid series active filter is attractive and consists of a small rated series active filter and tuned LC passive filters. The active filter has a small rating, typically 5% of the load KVA rating [6], and is controlled to act as a "harmonic isolator" between the supply and load by constraining all the load current harmonics into the passive filters. The harmonic isolation feature reduces the need for precise tuning of the passive filters, allowing their design to be insensitive to the supply impedance.

The series active filter allows the passive filters to be exactly tuned to the dominant load current harmonics, and can also be designed to achieve unity displacement power factor (DPF). This scheme facilitates cost effective harmonic compensation of high peak current harmonic frontends, since the low cost passive filter can be rated to absorb the peak load harmonic current, as opposed to the series active filter. The practical viability and cost-effectiveness of this scheme can be further increased by implementation of low cost power factor correction capacitors as passive filters [10]. For multiple large and diverse types of harmonic producing loads in an industrial plant, a single hybrid series active filter can be installed at the utility-plant point of common coupling (PCC) to meet IEEE-519 harmonic standards, and hence achieve an optimal and cost-effective harmonic-free PCC utility interface solution[11]. Such utility interface applications alleviate concerns of low DPF under light load conditions and allow flexibility in the passive filter design.

This approach can also provide limited line voltage regulation and is easily amenable for retrofit applications -a cost effective solution for ASDs with input power factor correction capacitors that can be utilized as passive filters. The series active filter is coupled to the supply line by a series coupling transformer as shown in Fig.1 However, series active filters require adequate protection in case of malfunction of the active filter because it is in series with the main system. Another important concern is the impact of supply side voltage distortion on the hybrid active filter VA rating, and the ability of the hybrid active filter to provide harmonic damping or harmonic isolation feature under supply voltage distortion conditions. Among the various hybrid active filter schemes, the hybrid series active filter topology has the least impact on its VA rating and is best suited to effectively provide harmonic isolation since it injects a series harmonic voltage source into the supply line. Other hybrid active filter topologies incur significant increase in their VA ratings if they are required to provide damping to supply voltage distortion and may not even be able to provide effective damping under such condition [10]. Further, the effectiveness of damping the supply voltage distortion depends strongly on the filtering algorithm employed for the extraction of the load current harmonics.

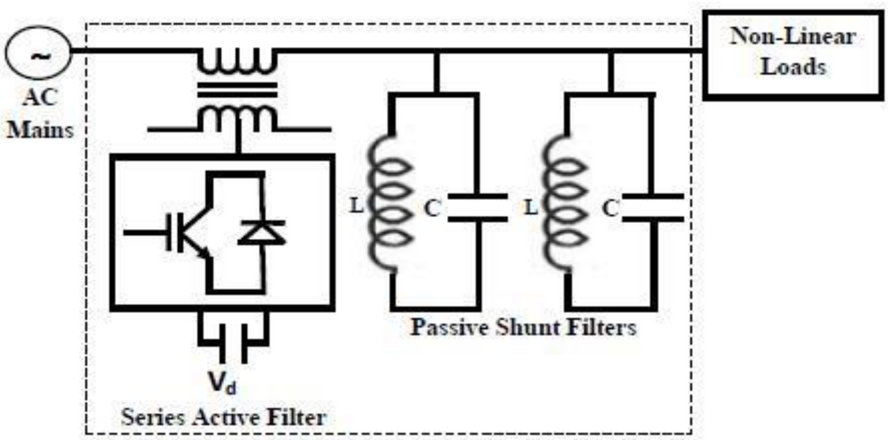


Fig. 1 Hybrid filter

II. SYSTEM CONFIGURATION

Figure 2 shows a system configuration of the hybrid series active filter. A passive filter consisting of a 5th and 7th tuned LC filter is paralleled with a three-phase diode rectifier front end which is considered a typical non-linear load. For simplicity in simulation, the dc capacitor which is the energy storage device of the active filter is replaced with a voltage source. The function of the active filter is not to directly compensate for the harmonics of the load, but to isolate the harmonics between the load and the source. In other words, it is to improve the filtering characteristics of the parallel passive filter and to solve the problems of the parallel passive filter. The series active filter acts not as a harmonic "compensator", but as a harmonic "isolator". Hence, the rating of the series active filter is much smaller than that of a conventional parallel active filter.

A. Compensation principle

The filtering characteristics of a parallel active filter partially depend on the source impedance, which is not accurately known and is predominately inductive. The impedance of the parallel passive filter should be lower than the source impedance at a tuned frequency to provide the attenuation required. Hence the higher source impedance, the better the filtering characteristics. However, the source impedance should exhibit a negligible amount of impedance at the fundamental frequency so that it does not cause an appreciable fundamental voltage drop. These two requirements, which contradict each other, can be satisfied only by inserting active impedance in series with the ac source. Also, series and parallel resonances in the parallel passive filter, which are partially caused by the inductive source impedance, can be eliminated by inserting active impedance. The active impedance can be implemented by a series active filter using voltage-source PWM inverters.

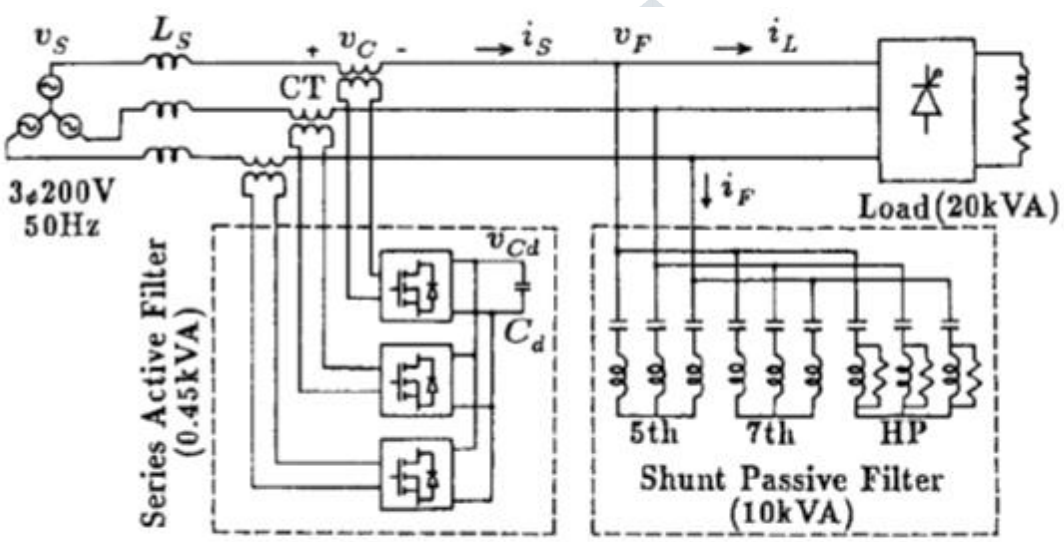
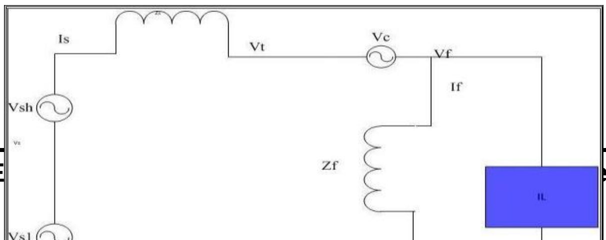


Fig. 2 combination of series active filter and shunt passive filter

For simplicity, assuming that the voltage-source PWM inverter is an ideal controllable voltage source V_c, Figure 3.1 on a per-phase basis. The three-phase diode front-end load is also assumed to be a current source I_L due to the presence of sufficient inductance on the dc side. Z_F is the equivalent impedance of the parallel passive filter, and Zs is the source impedance.

The series active filter is controlled in such a way as to present zero impedance to the external circuit at the fundamental frequency and a high resistance K to source or load harmonics. The control scheme will be discussed later. For the fundamental and harmonics, applying the law of superposition to Figure 3.1 gives two equivalent circuits, as shown in Figures 3.2 and 3.3, respectively. Here V_S1 is the source fundamental voltage and I_Ll is the load fundamental current in Figure 3.2, while V_{Sh} is the source harmonic voltage and k_h is the load harmonic current in Figure 3.3. As is seen in Figure 3.2, the parallel passive filter behaves as a capacitor for power factor improvement, but the series active filter does not play any role. Figure 3.3 shows that the series active filter acts as a harmonic isolator between the source and load.



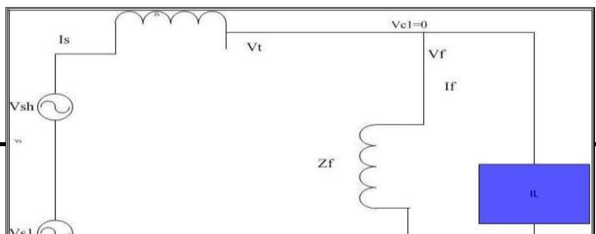


Fig. 3.1 **Fig. 3.2**

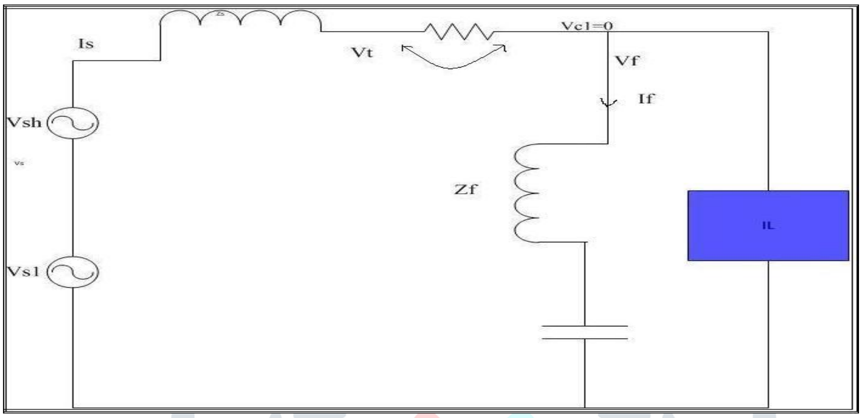


Fig. 3.3

Fig. 3.1 Equivalent circuit for hybrid Series Active Filter on per –phase base,

Fig. 3.2 Equivalent circuit for hybrid series active filter at fundamental frequency on per-phase base

Fig. 3.3 Equivalent circuit for hybrid series active filter at harmonic frequencies on per-phase base

B. Source Harmonic Currents: I_{Sh}

The harmonic current flowing in the source, which is produced by both the load harmonic current ILh and the source harmonic voltage V_{Sh}, is given as follows:

$$I_{sh} = \frac{Z_F}{Z_S+Z_F+K} * I_{Lh} + \frac{V_{sh}}{Z_S+Z_F+K} \qquad (1)$$

Where $$I_{sh} \cong 0 \quad \text{if} \quad K \gg Z_S, Z_F \qquad (2)$$

The first term on the right side of Eq. 1 means that the series active filter acts as a "damping resistance", which can eliminate the parallel resonance between the parallel passive filter and the source impedance. The second term means that the series active filter acts as a "blocking resistance", which can prevent the harmonic current produced by the source harmonic voltage from flowing into the parallel passive filter. If the resistance K is much larger than the source impedance, variations in the source impedance have no effect on the filtering characteristics of the parallel passive filter, thus reducing the source harmonic current to zero, as shown in Eq. 2

C. Output Voltage of Series Active Filter: V_C

The output voltage of the series active filter, which is equal to the harmonic voltage appearing across resistance K in Fig. 3.3, is given by:

$$V_c = Ki_{sh} = K * \frac{Z_K I_{Lh} + V_{sh}}{Z_S + Z_F + K} \quad (3)$$

$$V_C \approx Z_F I_{Lh} + V_{Sh} \text{ if } K \gg Zs, Z_F \quad (4)$$

Eq. 3 implies that the voltage rating of the series active filter is given as a vector sum of the first term on the factor of the parallel passive filter, and the second term, which is equal to the source harmonic voltage.

D. Filter Harmonic Voltage: V_{Fh}

The filter harmonic voltage, which is equal to the harmonic voltage appearing across the parallel passive filter, is given by:

$$V_{Fh} = \frac{Z_S + K}{Z_S + Z_F + K} Z_F I_{Sh} + \frac{Z_F}{Z_S + Z_F + K} V_{Sh} \quad (5)$$

$$V_{Fh} = -Z_F I_{Lh} \text{ if } K \gg Z_S, Z_F \quad (6)$$

Eq. 6 show that the source harmonic voltage does not appear on the load side because it is applies across series active filter.

III. CONTROL SCHEME

The hybrid series active filter is controlled to provide its intended function of harmonic isolation between the supply and load by injection of a controlled harmonic voltage source. It is controlled to offer zero impedance (short circuit) at the fundamental frequency and high impedance (ideally open circuit) at all desired harmonic frequencies. This constrains all load harmonic currents to flow into the passive filter, decoupling the supply and load at all frequencies, except at the fundamental. This results in only fundamental frequency series active filter current and hence supplies current and thereby allows conceptually a simple controller implementation for the series active filter.

A simple controller implementation can be achieved by measurement of the supply current or the series active filter current and involves extraction of the fundamental supply current which forms the current reference for the series active filter inverter. This provides zero impedance (short circuit) at the fundamental frequency. The series active filter inverter is controlled as a current controlled harmonic voltage source. Since all load harmonic currents are constrained to flow into the passive filter, the passive filter terminal voltage will have distortion dependent on the harmonic frequency versus impedance characteristics of the passive filter.

Hence the design of the passive filter is critical for reduction of voltage distortion at the passive filter terminal and rating of the series filter. Note that the series active filter is controlled as an active impedance as opposed to the conventional parallel and series active filters which are controlled as a current source (infinite impedance) and voltage source (zero impedance) respectively. Operation and harmonic isolation feature of the hybrid series active filter system is strongly dependent on the filtering algorithm employed, and the series active filter inverter bandwidth.

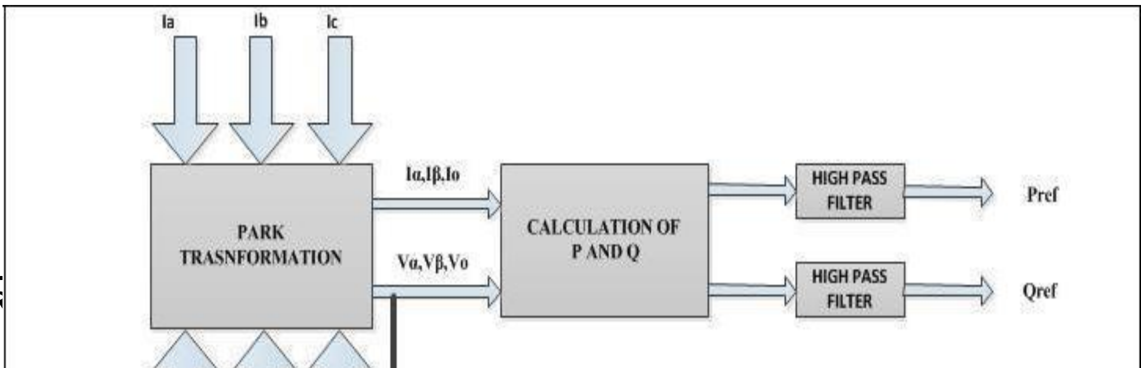


Fig. 4 Control Scheme

The controller is applied as shown in Figure 4. Modified "p-q" theory is applied in extracting harmonic components in the source currents. Fundamental components are transformed into dc quantities and all harmonics are transformed to non-dc quantities and undergo a frequency shift of 50 Hz in the spectrum. The controller extracts the dc quantities by a low pass filter (LPF) and hence it is insensitive to phase errors. The control reference signals are obtained by reverse "p-q" transformation of the non-dc quantities after extracting dc component corresponding to fundamental frequency component. A first-order low pass filter is used to extract dc component. In the controller a negative feedback of a fundamental component corresponding inverter output voltage across the series transformer is added to the reference signal. Again, modified "p-q" theory is used to extract the series transformer fundamental output voltage. A PI regulator is used in the control loop to minimize the control error. The reference output voltage is compared with a triangle carrier, generating PWM switching patterns. Here the frequency of the triangle carrier is 10 kHz. Therefore the series active filter operates as a controllable voltage source, thus a voltage-source PWM inverter is used for the series active filter.

IV. CANCLUSION

The active filter is only controlled to inject harmonic voltages through coupling transformers hence advantage of lower VA ratings of the active filter and one drawback is that the series hybrid active filter needs series coupling transformers, which increase the initial invest cost. On the other hand, a hybrid active filter consists of an active filter and a single-tuned filter that are directly connected in series without transformer. This hybrid filter is exclusively devoted to harmonic “filtering”-phase diode rectifiers of because three it has no capability of reactive-power control from a practical point of view although it has from a theoretical point of view.

Some manufactures have already put active filters for power conditioning on the market. However, they should strive for cost reductions, as well as better filtering performance and higher efficiency, to compete well with traditional passive filters. In addition to the harmonic guidelines or recommendations, sincere efforts by the manufactures would accelerate installation of active filters in the vicinity of nonlinear loads. This in turn would bring greater cost reductions to the active filters due to the economy of large-scale production. Constituting such a positive feedback loop would encourage wide acceptance of the active filters, resulting in solving harmonic pollution and improving power quality.

REFERENCES

[1] Instantaneous power theory and applications to power conditioning (Hirofumi Akagi, Edson Hirokazu Watanabe)

[2] Aredes, M.; Monteiro, L.F.C.; Mourente, J., "Control strategies for series and shunt active filters," Power Tech Conference Proceedings, 2003 IEEE Bologna , vol.2, no., pp.6 pp. Vol.2,, 23-26 June 2003

[3] Morán, Luis A., Juan W. Dixon, José R. Espinoza, and Rogel R. Wallace. "Using active power filters to improve power quality." In 5th Brazilian Power Electronics Conference, pp. 501-511. 1999

[4] Afonso, João L., Carlos Couto, and Júlio S. Martins. "Active filters with control based on the pq theory." IEEE power electronics society newsletter, vol.47, no.3, sept.2000

[5] Patricio Salmer´on and Salvador P. Litr´an "A Control Strategy for Hybrid Power Filter to Compensate Four-Wires Three-Phase Systems," Power Electronics, IEEE Transactions on, vol.25, no.7, pp.1923,1931, July2010

[6] G. Bhuvaneswari and Manjula G.Nair "Three-Phase Hybrid Shunt Filters for Power Quality Improvement" journal power electronics (JPE), vol.7, no.3, july 2007

[7] Litran, S.P.; Salmeron, P.; Herrera, R.S., "Practical design of a control strategy based in current and voltage detection for hybrid power filters," Power Engineering, Energy and Electrical Drives (POWERENG), IEEE 2011 International Conference on , vol., no., pp.1,6, 11-13 May 2011

[8] L. Gyugyi, E.CI Strycula, "Active AC Power Filter", IEEE-IAS Conf. Record, 1976, pp529.

[9] F. Z. Peng, H. Akagi, and A. Nabae, "A novel harmonic power filter," in Proc. IEEE/PESC, Apr. 1988, pp. 1151–1159.

[10] V. F. Corasaniti, M. B. Barbieri, P.L.Arnera, and M. I. Valla, "Hybrid active filter for reactive and harmonics compensation in a distribution network," IEEE Trans. Ind. Electron., vol. 56, no. 3, pp. 670–677, Mar.2009.

[11] F. Zeng , H. Akagi, and A. Nabae, "A new approach to harmonic compensation in power systems-a combined system of shunt passive and series active filters," IEEE Trans. Ind. Appl., vol. 26, no. 6, pp. 983–990,Nov./Dec. 1990.

[12] S. Bhattacharya, D. Divan, "Synchronous Frame Based Controller Implementation for a Hybrid Series Active Filter System", IEEEIIA conf. 1995, pp2531-2540.