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A Review of Active Power Filters and Their Control Strategies

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ABSTRACT

Active power filters are the emerging devices, which can perform the job of harmonic elimination more effectively. The active power filters are used to filter out higher as well as lower order harmonics in the power system. The report deals with the basic working and classifications of active power filters, its reference signal generation techniques and some of the controlling schemes of APF. One of the key points for a proper implementation of an active filter is to use a good method for current/voltage reference generation. There exist many implementations supported by different theories proposing ever better solutions. This paper introduces some of the commonly used theories. Also for efficient working of active power filter better controlling techniques have to be implemented. The paper presents a brief study of active power filter (APF) control strategies put forward recently. It is aimed at providing a broad perspective on the status of APF control methods for better operation of the system.

KEYWORDS: Reference signal estimation techniques, Gating signal generation methods, Active power filter, Harmonics mitigation, Power quality, control strategy, Power system harmonics.

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INTRODUCTION

Power electronic appliances are used widely in industrial, commercial and consumer environment. These appliances generate harmonics and reactive power in the utility system. The improvement of power quality by reducing harmonics has become an important issue nowadays [1,2,3,4]. Conventionally, passive LC filters have been used to eliminate line current harmonics and to improve the power factor. But the passive filters have many disadvantages, such as fixed compensation, large size and resonance problems. To solve above mentioned problems, active power filters were introduced.

Power quality can be defined as the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged or stressed, we would say that the electrical power is of good quality. On the other hand, if the electrical equipment malfunctions, is unreliable, or is damaged during normal usage, we would suspect that the power quality is poor. Power quality determines the fitness of electrical power to consumer devices. The presence of harmonic wave forms in power system is the main cause of power quality problems. Harmonics have a number of undesirable effects on the distribution system. It causes excessive voltage distortion, increased resistive losses or voltage stresses, reductions in ac motor efficiency and product quality etc in the power system. With the widespread use of harmonic generating devices, the control of harmonic currents to maintain a high level of power quality is becoming increasingly important. An effective way for harmonic suppression is the harmonic compensation by using active power filter. Active power filters are considered as a feasible solution for reducing current harmonics and reactive power due to the it's small size, no requirement for tuning and stable operation.

The basic compensation principles of active filters were proposed around 1970. They act as harmonic current source to provide an effective result to eliminate the harmonic currents and also to compensate the reactive power.

POWERSYSTEMHARMONICS

Power system harmonics are integer multiples of the fundamental power system frequency. Power system harmonics are created by non-linear devices connected to the power system. Harmonics are voltage and current frequencies riding on top of the normal sinusoidal voltage and current waveforms. The presence of harmonics (both current and voltage) is viewed as `pollution' affecting the operation of power systems.

The most common source of harmonic distortion is electronic equipment using switch-mode power supplies, such as computers, adjustable-speed drives, and high-efficiency electronic light ballasts. Harmonic waveforms are characterized by their amplitude and harmonic number. When a sinusoidal voltage is applied to a certain type of load, in which the load cause the current to vary disproportionately with the voltage during each cyclic period. These are classified as nonlinear loads, and the current taken by them will be a non sinusoidal waveform. When there is significant impedance in the path from the power source to a nonlinear load, these current distortions will also produce distortions in the voltage waveform at the load. Waveform distortion can be mathematically analyzed to show that it is equivalent to super imposing additional frequency components on to a pure sine wave(figure.1).These frequencies are harmonics (integer multiples) of the fundamental frequency, and can sometimes propagate outwards from nonlinear loads, causing problems elsewhere on the power system.

The harmonics generated by the most common non-linear loads have the following properties:

- Lower order harmonics tend to dominate in amplitude
- If the waveform has half-wave symmetry there are no even harmonics
- Harmonic emissions from a large number of non-linear loads of the same type will be added.

The figure.1 shows the effect of harmonics on normal voltage or current waveform[5]. Odd harmonics waveforms contribute more to power system instability. In the figure the combined waveform shows the result of adding the harmonics on to the fundamental.

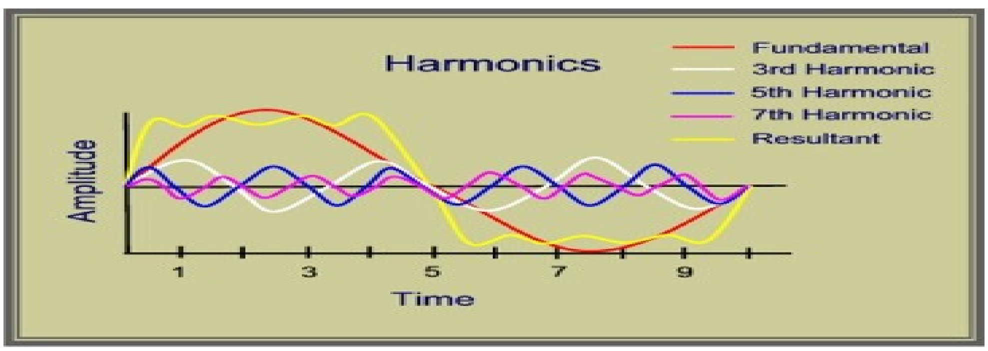

Figure.1 Effect of harmonics on normal voltage or current wave form

Harmonics in power systems can become the source of a variety of unwelcome effects. For example, harmonics can cause signal interference, over voltages, data loss, and circuit breaker failure, as well as equipment heating, malfunction, and damage. Any distribution circuit serving modern electronic devices will contain some degree of harmonic frequencies. The greater the power drawn by nonlinear loads, cause greater the level of voltage distortion. Potential problems (or symptoms of problems) attributed to harmonics include:

- Malfunction of sensitive equipment
- Random tripping of circuit breakers
- Flickering lights

- Very high neutral currents
- Overheated phase conductors, panels, and transformers
- Premature failure of transformers and uninterruptible power supplies(UPSs)
- Reduced power factor
- Reduced system capacity (because harmonics create additional heat, transformers and other distribution equipment cannot carry full rated load)

In addition, the harmonic currents produced by nonlinear loads can interact adversely with a wide range of power system equipment, most notably capacitors, transformers, and motors, causing additional losses, overheating, and overloading. These harmonic currents can also cause interferences with telecommunication lines and errors in metering devices. Because of the adverse effects that harmonics have on power quality, Standard has been developed to define a reasonable frame work for harmonic control. Harmonic distortion in power distribution systems can be suppressed using different approaches. One among them is the use of active power filters.

ACTIVE POWER FILTERS

3.1 The working of APF

Harmonic distortion in power distribution systems can be suppressed mainly by, passive and active filtering. The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. The uses of passive elements do not always respond correctly to the dynamics of the power distribution systems. Passive filters are known to cause resonance, thus affecting the stability of the power distribution systems. Frequency variation of the power distribution system and tolerances in components values affect the passive filtering characteristics. As the regulatory requirements become more stringent, the passive filters might not be able to meet future revisions of a particular Standard. This may required a retrofit of new filters.

Remarkable progress in power electronics had spurred interest in Active Power Filters (APF) for harmonic distortion mitigation. Active filtering is a relatively new technology, practically less than four decades old. The basic principle of APF is to utilize power electronics technologies to produce specific current components that cancel the harmonic current components caused by the nonlinear load.

APFs have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also their active currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. Consequently, the APFs performances are independent on the power distribution system properties. Active filtering is a relatively new technology, practically less than four decades old. There is still a need for further research and development to make this technology well established.

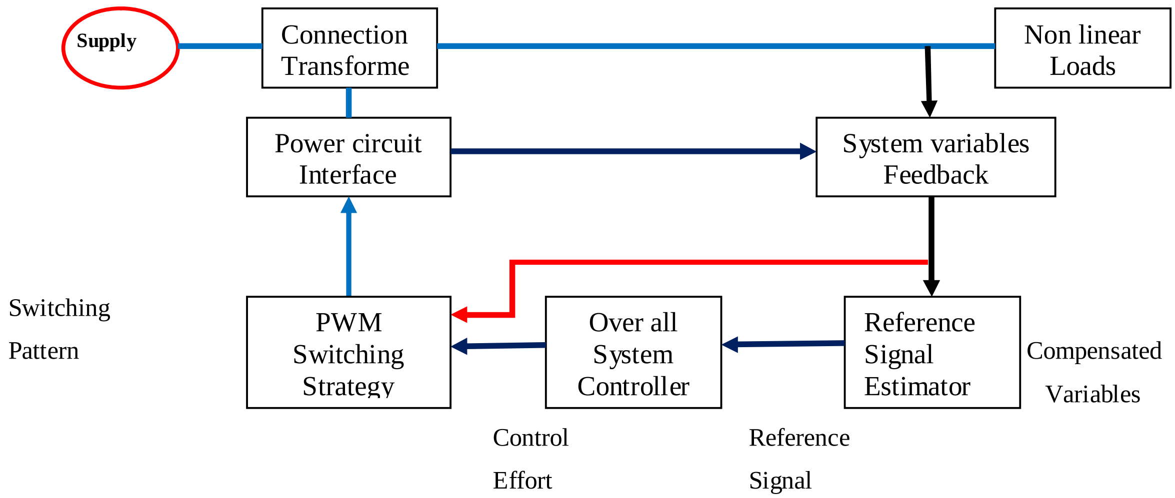

Figure.2 Basic block diagram of active power filter

The Figure.2 shows the components of a typical APF system and their connections. The compensation reference signal from the estimator drives the overall system controller. This in turn provides the control for the gating signal generator. The output of the gating signal generator controls the power circuit via a suitable interface[6].

Finally, the power circuit in the generalized block diagram can be connected in parallel, series or parallel/series configurations depending on the interfacing inductor/transformer used. An unfavorable but inseparable feature of APF is the necessity of fast switching of high currents in the power circuit of the APF.

An active power filter can be considered as a compensator for power system harmonics. The working of active power filter consists of mainly three stages[7]. They are:

1. Signal conditioning
2. Derivation of compensating signal.
3. Generation of gating signal.

Signal conditioning refers to the detection or sensing of harmonics in the power distribution line. As shown in Figure.2, the reference signal to be processed by the controller is the key component that ensures the correct operation of APF.

The reference signal estimation is initiated through the detection of essential voltage/current signals to gather accurate system variables information. The voltage and current variables in power system is sensed by using potential transformers, current transformers, isolation amplifiers etc. The voltage variables to be sensed are AC source voltage, DC-bus voltage of the APF, and voltage across interfacing transformer. Typical current variables are load current, AC source current, compensation current and DC-link current of the APF. Based on these system variables feedbacks, reference signals estimation in terms of voltage/current levels are estimated in frequency-domain or time-domain.

The next stage is the derivation of compensating signal from the disrupted wave consists of both fundamental wave and the harmonic content. It can be done by two different methods- frequency domain approach and time domain approach. Frequency domain approach use Fourier transformation method for this purpose. While Time domain approach uses different methods like Instantaneous Reactive-Power Theorem, Synchronous-Reference-Frame Theorem, Synchronous Detection Theorem, Sine-Multiplication Theorem, notch filter method etc.

The third stage is the generation of gating signal for harmonic suppression. So many control techniques like space Vector PWM, repetitive control, hysteresis current control, one-cycle control, dead-beat control, sliding mode control, fuzzy control and the artificial neural network method have been introduced and applied to various configurations of active power filters. Gating signal generator in the general block diagram of APF is used for this purpose.

3.2 Classifications of APF

APF can be connected in several power circuit configurations as illustrated in the block diagram shown in Figure.3. In general, they are divided into three main categories, namely shunt APF, series APF and hybrid APF[8].

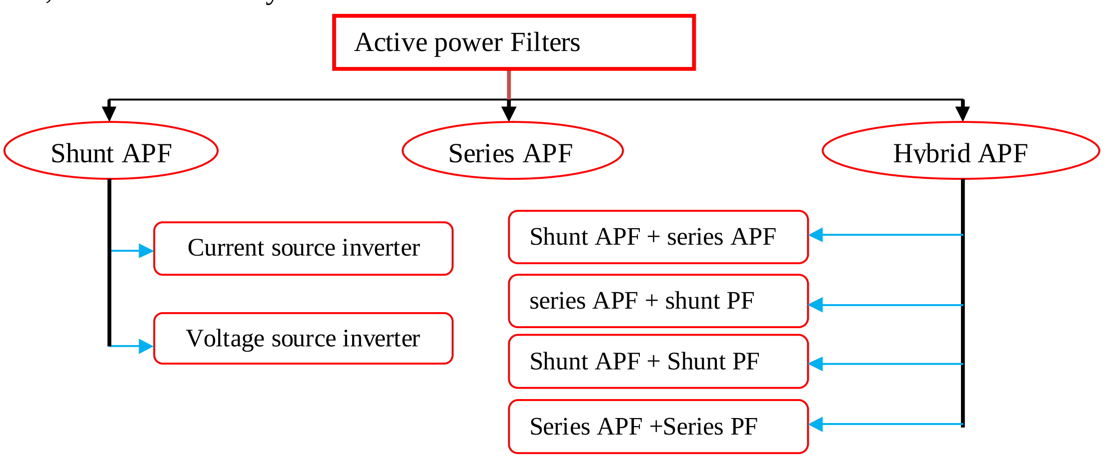

Figure.3 classification of Active Power Filters

3.2.1 Shunt Active Power Filter

This class of filter configurations is the most important and most widely used type in active filtering applications. It is connected to the main power circuit, as shown in the single-line diagram of Figure.4. The purpose is to cancel the load current harmonics fed to the supply. It can also contribute to reactive-power compensation and balancing of three-phase currents, as mentioned above. Parallel filters have the advantage of carrying only the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. It is also possible to connect several filters in parallel for higher currents, which makes this type of circuit suitable for a wide range of power ratings.

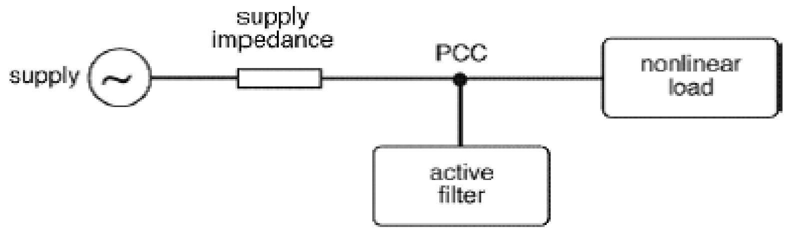

Figure.4 Shunt Active Power Filter

3.2.2 Series Active Power Filter

The active filter in this configuration produces a PWM voltage waveform which is added or subtracted, on an instantaneous basis, to/from the supply voltage to maintain a pure sinusoidal voltage waveform across the load. The main power-circuit configuration is shown in Figure.5.

The inverter configuration accompanying such a system is a voltage-fed inverter without any current-control loops. Series active filters are less common industrially, than parallel active filters. This is because of the main drawback of series circuits, namely that they have to handle high load currents, which increases their current rating considerably compared with parallel filters, especially in the secondary side of the coupling transformer.

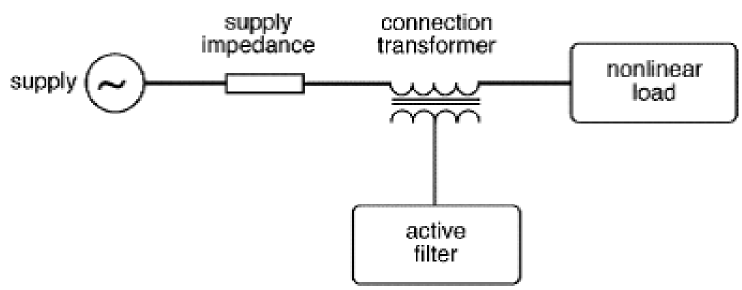

Figure.5 Series Active Power Filter

3.2.3 Hybrid Active PowerFilters

Technical limitations of conventional APFs can be overcome with hybrid APF configurations. They are typically the combination of basic APFs and passive filters. Hybrid APFs, inheriting the advantages of both passive filters and APFs provide improved performance and cost-effective solutions. The idea behind this scheme is to simultaneously reduce the switching noise and electromagnetic interference.

The idea of hybrid APF has been proposed by several researchers. 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, while the HPF filters the higher order harmonics. The main objective of hybrid APF is to improve the filtering performance of high-order harmonics while providing a cost-effective low order harmonics mitigation.

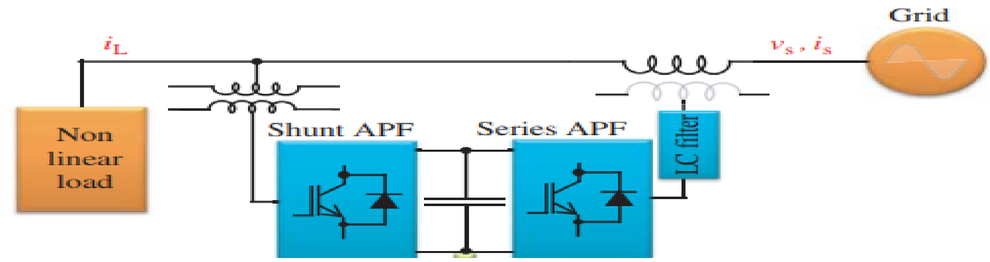

Figure.6 Hybrid Active Power Filter

Nowadays various hybrid APFs using in electronic industry, but the most prominent one is shown in Figure.6. It is the system configuration of the hybrid shunt APF and series APF are connected in parallel with the nonlinear load. The function of the hybrid APF can thus be divided into two parts: the low-order harmonics are cancelled by the shunt APF, while the higher frequency harmonics are filtered by series APF. This topology lends itself to retrofit applications with the existing shunt APF.

REFERENCE SIGNAL ESTIMATIONTECHNIQUES

One of the most discussed software part (in the case of a DSP implementation) of an active filter is the harmonic detection method. In brief, it represents the part that has the capability of determining specific signal attributes from an input signal (that can be voltage, current or both) by using a special mathematical algorithm. Different algorithms emerged for the harmonic detection, which led to a large scientific debate on which part the focus should be put on, the detection accuracy, the speed, the filter stability, easy and inexpensive implementation, etc. The classification of these methods can be done relative to the domain where the mathematical model is developed. Thus, two major directions are described here, the time domain and the frequency-domain methods.

Figure.7 illustrates the considered reference signal estimation techniques. They cannot be considered to belong to the control loop since they perform an independent task by providing the controller with the required reference for further processing. This section presents the considered reference signal estimation techniques, providing for each of them a short description of their basic features.

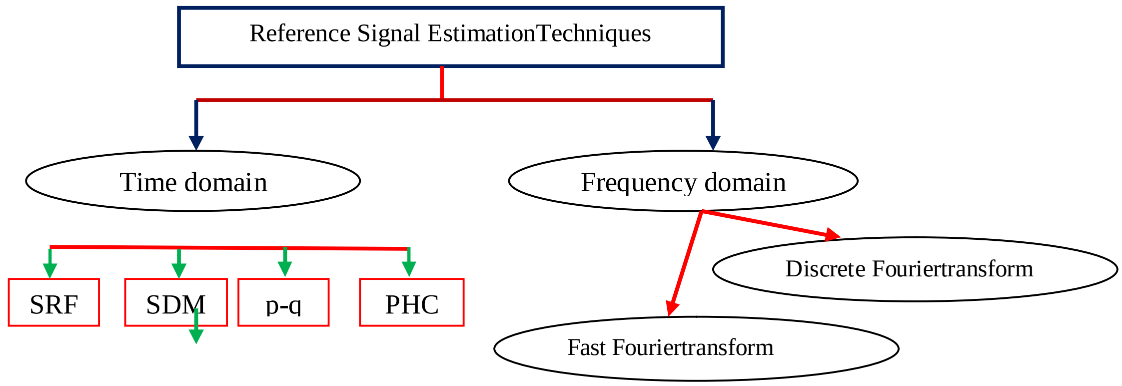

Figure.7 Reference signal estimation techniques

4.1 Frequency domain Approaches

Reference signal estimation in frequency-domain is suitable for both single- and three-phase systems. They mainly derived from the principle of Fourier analysis as follows.

In principle, Fourier Transform (conventional or Fast Fourier Transform (FFT)) is applied to the captured voltage/current signal. The harmonic components of the captured voltage/current signal are first separated by eliminating the fundamental component. Inverse Fourier Transform is then applied to estimate the compensation reference signal in time domain.

The main drawback of this technique is the accompanying time delay in system variables sampling and computation of Fourier coefficients. This makes it impractical for real-time application with dynamically varying loads. Therefore, this technique is only suitable for slowly varying load conditions. In order to make computation much faster, some modifications was proposed and practiced later. In this modified Fourier-series scheme, only the fundamental component of current is calculated and this is used to separate the total harmonic signal from the sampled load-current waveform.

4.2 Time Domain Approaches

Time-domain approaches are 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. These approaches are applicable for both single-phase and three-phase systems except for the synchronous-detection theorem and synchronous-reference-frame theorem which can only be adopted for three-phase systems[9].

4.2.1Instantaneous power theory OR p-q Theory

Instantaneous power theory based in instantaneous values in three-phase power systems, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms, allowing the control of the active filters in real-time. Another advantage of this theory is the simplicity of its calculations, since only algebraic operations are required. The only exception is in the separation of some power components in their mean and alternating values. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the a-b-c coordinates to the α-β coordinates, followed by the calculation of the p-q theory instantaneous active and reactive powers components[10,11]. This scheme is most widely used because of its fast dynamic response but gives inaccurate results under distorted and asymmetrical source conditions. p-q theory compensates the harmonic currents, corrects the power factor, compensates dynamically, and instantaneously, the zero-sequence current[12]. Also balances and reduces the values of the currents supplied by the source to the load. Since p-q method is frequency variant, on providing additional PLL circuit it becomes frequency independent.

4.2.2 Synchronous Reference Frame (SRF) Theory

The synchronous reference frame theory also known as dq theory is based on time-domain reference signal estimation techniques. In this theory, the compensation signals are calculated based on a synchronously rotating reference frame. The synchronous reference frame theory or d-q theory performs the operation in steady-state or transient state as well as for generic voltage and current waveforms. .The active power filters controlling is done in real-time system using d-q theory. SRF theory is used to extract the three-phase reference currents (i_{ca}*, i_{cb}*,i_{cc}*) used by the active power filters [2]. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation. Large numbers of synchronization problems with unbalanced and non sinusoidal voltages are also avoided because it is observed that instantaneous active and reactive current id-iq method always give better result under un-balanced and non-sinusoidal voltage conditions over the instantaneous active and reactive power p-q method. It is found from study of various present techniques for reduction of current harmonic, SRF Theory is the best for both near load and non linear load and also for non-regular source[13].

4.2.3 Synchronous Detection Method (SDM)

In SDM [8], it is assumed the source currents (i_{sa}, i_{sb}, i_{sc}) are balanced after compensation. Then the three-phase reactive powers are calculated from the source voltages. Then the three-phase source currents are calculated. Finally the reference currents are calculated for the active power filters Using SDM. But the performance p-q theory is much faster than compensation using SDM. It is proved that p-q theory compensates the undesirable current components within 1st cycle whereas SDM takes about 14 cycles (approximately 0:23 seconds for 50 Hz source). So for faster power quality improvement SDM is not preferable.

4.2.4 Perfect Harmonic Cancellation (PHC)

PHC strategy is capable of simultaneous mitigation of harmonics distortion, compensation of fundamental reactive power, and elimination of imbalance in source current. Therefore, the source current will be in phase with the fundamental positive sequence component of the voltage at PCC[14,15].

GATING SIGNAL GENERATION METHOD

In active filter applications, the inverter delivers a current which compensates for harmonics and distortions absorbed by the load. The mostly used techniques for the generation of gating pulses are Pulse Width Modulation (PWM) and Hysteresis Current Control (HCC). The switching signals thus generated are fed to VSI with a DC link capacitor across it. Based on these switching signals the inverter generates compensating current in phase opposition to the line current.

Output Voltage of the Inverter can be modified or controlled by controlling or modifying switching current, or in case of Power Switches, by controlling or modifying Gate current. The compensating current is injected back into the power line at the PCC and thus suppressing the current harmonics present in the line[16].

5.1 PWM Techniques

These techniques are most efficient and they control the drives of the switching devices. We get a controlled or modified AC output voltage by varying the ON and OFF time of power switches of the inverter. This method is popularly called as Pulse Width Modulation (PWM) method. A fixed DC voltage is given to the inverter and power switches are controlled by this PWM control signal to modulate input DC voltage to required AC voltage. The power switch is usually of MOSFET or IGBT. Since frequency of operation is inversely dependent upon Inverter size so to reduce the Inverter size we have to increase the switching frequency.

5.2 Hysteresis Current Controller

The hysteresis band current control for active power filter is used to generate the switching pattern of the inverter. There are various current control methods proposed for active power filter configurations; but the hysteresis current control method is proven to be the best among other current control methods, because of quick current controllability, easy implementation unconditioned stability, fastest control with minimum hardware. The method minimizes mutual interference among the controls of the various phases, while requiring only an approximate knowledge of passive load parameters. Moreover, PLL synchronization ensures constant frequency operation of inverter switches [17].

5.3 Sliding Mode Controller

The sliding mode control has characteristics such as fastness, robustness and stability for large load variations. The references for the sliding mode control system are obtained by using the instantaneous reactive power theory [18]. In sliding-mode controllers, either dc-bus voltage (in a VSI) or dc-bus current (in a CSI) is maintained to the desired value and reference values for the magnitudes of the supply currents are obtained. Subtracting load currents from reference supply currents, compensating commands are derived. Sliding-mode control technique uses the nonlinear control law shown in Table -1.

Table - 1: Sliding-mode control technique uses the nonlinear control law

Switch	is < k v_s	is ≥ k v_s
i	0	1
ii	1	0
switch	$v_s \leq 0$	$v_s > 0$
iii	1	0
iv	0	1

Here, is source current, v_s source voltage, k scaling factor and 0 – Low Level, 1 –High Level

CONCLUSION

In this paper, a comprehensive study on APF and their control strategies has been presented, which covers a deep understanding on various types of APFs and their configuration and also understanding the reference signal estimation techniques, voltage and current control approaches for maintaining effective operation of APFs. In present scenario current harmonics and reactive power are the major problems related to power quality. Active power filer is a best solution to reduce the harmonics and enhance the power quality of power system.

REFERENCES

1. S. L. Clark, P. Famouri, W. L. Cooley. Elimination of supply harmonics. IEEE Industry Applications Magazine B: March/April I997.
2. Luis A. Morán, Juan W. Dixon, José R. Espinoza, Rogel R. Wallace. Using active power filters to improve power Quality. IEEE Transactions on2004; 40: 232-241.
3. J.L. Hernandez, M.A. Castro, J. Carpio and A. Colmenar. Harmonics in Power Systems. International Conference on Renewable Energies and Power Quality (ICREPQ'09) Valencia (Spain);15th to 17th April, 2009.
4. BudwalAmrinder Singh, Chinmaya R. Chute, Shiva Gourishetti. Harmonics Effect on Power Quality and its Mitigation Techniques using Active Power Filter. Proceedings of Third Biennial National Conference: NCNTE- 2012, Feb 24-25.
5. Institute of Electrical and Electronics Engineers (IEEE), Standard 519-1992: IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power

Systems.

6. Zainal Salam, Tan Perng Cheng and AwangJusoh. Harmonics Mitigation Using Active Power Filter: A Technological Revie., ELEKTRIKA 2006; 8(2)
7. Park ki-won. A Review of active power filters. R&D Center: POSCON. M.E-Habrouk, M.K.Darwish and P.Mehta. Active power filters: A review. IEEE Proc.-Elertr. Power Appl September 2000; 147(50
8. Md. Ashfanoor Kabir and Upal Mahbub. Synchronous Detection and Digital control of Shunt Active Power Filter in Power Quality Improvement. IEEE; 2000.
9. María Isabel Milanés Montero, Enrique Romero Cadaval, and FermínBarrero González. Comparison of Control Strategies for Shunt Active Power Filters in Three-Phase Four-Wire Systems. IEEE transactions on Power Electronics; January 2007; 22(1)
10. L. Afonso, Member, IEEE, M. J. SepúlvedaFreitas, and Júlio S. Martins,Member,IEEE.p-q Theory Power Components Calculations. ISIE'2003;IEEE International Symposium on Industrial ElectronicsRio de Janeiro, Brasil, 9-11 Junho de 2003;ISBN: 0-7803-7912-8.
11. Bhattacharya S. and Divan D. Synchronous frame based controller implementation for a hybrid series active filter system. IEEE Conf. On Industry applications; 1995; 4: 2531–2540.
12. M. Suresh , S.S.Patnaik, Y. Suresh, Prof. A.K. Panda. Comparison of Two Compensation Control Strategies for Shunt Active Power Filter in Three-Phase Four-Wire System. 2011; IEEE.
13. Mahmoud Ranjbar, and AlirezaJaliliany. Compensation Strategies for Shunt Active Power Filter in Single- and Three-Phase Systems: Different Formulation, Comparison and Evaluation. journal of electric power and energy conversion systems (jepecs): jepecs spring 2016; 1(1):37-45, issn: 2345-4830 print/2345-4733.
14. Mahmoud Ranjbar, Student Member, IEEE, AlirezaJalilian, Abbas Shoulaie. DSP-Based Digital Control of a Single-Phase Shunt Active Power Filter under Distorted Voltage Source.
15. Arindamghosh, Gerard Ledwich. Power Quality Enhancement Using Custom Power Devices.
16. Luigi Malesani, Paolo Tenti. A Novel Hysteresis Control Method for Current-Controlled Voltage-Source PWM Inverters with Constant Modulation Frequency. IEEE Transactions On Industry Applications: Januaryi/february 1990; 26(I).
17. N. Mendalek. Sliding Mode Control of Three-Phase Four-Wire Shunt Active Power Filter. CCECE/CCGEI May 5-7 2008: Niagara Falls. Canada.