A Review of Hybrid filter topologies for power quality compensation

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Abstract - *Large industrial loads have significant capacity to perturb the supply grid in terms harmonic power and also in terms of fundamental reactive power. A hybrid filter which is the combination of active and passive filter can be used to compensating harmonics and reactive power also for balancing unbalanced non linear loads under non ideal mains voltage condition. For providing a cost effective three phase shunt current quality compensator different hybrid filter topologies were discussed. From these different topologies one of **them '(**APF in series with shunt PPF)is chosen for depth study because it can offer lower cost , size and weight and has potential to provide dynamic reactive power compensation.*

Key Words,Hybrid active power filter , APF in series with shunt PPF , High Voltage Direct current(HVDC).

1. Introduction

Electric power quality has become as an important part of power systems and electric machines. It is normally used synonymously with "supply reliability," "service quality," "voltage quality," "current quality," "quality of supply," and also for quality of consumption . Non linear loads such as switch mode power converters , arc furnaces, adjustable speed drives, welding equipment, fluorescent lamps, TV sets etc., cause a challenging problem to the power system network [1] . These loads are injecting current harmonics which degrades the utility voltage . Mainly harmonics in the system results in several adverse effects such as increased heating losses in lines, motors and transformers, rotary machine vibration, voltage quality degradation, low power factor, Another main function of electric power system is to minimize reactive power flow in supply and distribution systems, thus minimizing the charge for reactive power active energy this will result in reducing fare for electrical energy .

There were a few solutions, that deals with the problem of reactive power compensation and harmonic mitigation . Passive filters , active filters and hybrid filters can be used for this . The first installations of passive power filters are in mid 1940's,[2], [3] and it have been used to compensate current quality problems in distribution power systems due to its low cost, simplicity and high efficiency [2]. But they have some disadvantages such as low dynamic performance, resonance problems etc . After this the concept of "Active Power Filter" was first developed by L. Gyugyi in 1976. [2],[3] These are solid state power electronic converters whose switching can be controlled according to the system harmonics or reactive power requirement. APFs overcome some of the disadvantages in PPFs, but the initial costs are relatively high because the dc-link operating voltage should be higher than the system voltage. In order to lower the cost of APFs, different hybrid active power filter topologies have been proposed. Different hybrid active power filter topologies composed of active and passive components in series and/or parallel have been proposed in order to improve the compensation characteristics of PPFs and reduce the voltage and/or current ratings (costs) of the APFs .This leading to improvements in cost and performance . There were different hybrid active power filters are available. Three general configurations available are series active filter & shunt passive filter, shunt active filter & shunt passive filter and active power filter is in series with shunt passive filter [4]. The third topology aims to reduce the voltage rating of the APF. Several topologies of hybrid filter with different control techniques are available for power quality improvement. Different control techniques in time domain and frequency domain can be used . Frequency domain control methods are mainly based on the fast Fourier transformation (FFT) [5],[6] . Time domain control methods are mainly based on the instantaneous derivation of compensating signals. Instantaneous reactive power theory [7], [8] synchronous reference frame method [9], [10] sliding mode control[11],[12] are the common time domain control techniques . When comparing time domain and frequency domain controls , time domain method has For the switching signal generation we have several methods such as P/PI/PID ,hysteresis pwm [2] , sinusoidal pwm ,space vector pwm[13], soft computing techniques such as fuzzy logic control, artificial neural network control etc.. [16], [14] .

2. POWERQUALITY IMPROVEMENT USING HYBRID ACTIVE FILTER

Hybrid filter provide cost effective harmonic compensation particularly for high power non linear load. A parallel hybrid power filter system consists of a small rating active filter in series with a passive filter. The active filter is controlled to act as a harmonic compensator for the load by confining all the harmonic currents to passive filter. This eliminates the possibility of series and parallel resonance.

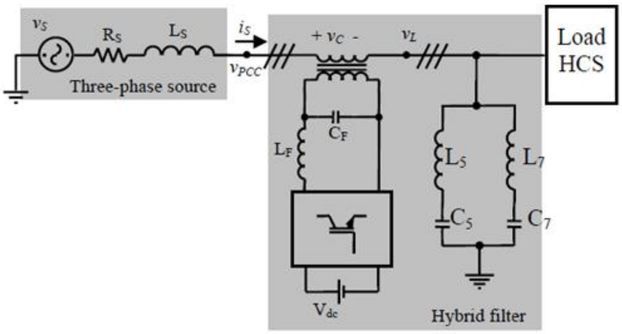

Fig-1:Series active filter and parallel passive filter with HCS type non linear load

Fig: shows a three-phase circuit with a voltage source that feeds a HCS type nonlinear load and a SAPPF hybrid filter. The active power filter is connected in series with the source through a coupling transformer. The passive filter is connected in parallel with the load. It consists of two LC branches tuned to 5thand 7th current harmonics [15]

2.1 COMPENSATION PRINCIPLE

A general goal of hybrid combinations is to reduce the rating requirements of the active component. Lower ratings are achieved by reducing the fundamental components of voltage and or current in the active element [18] .

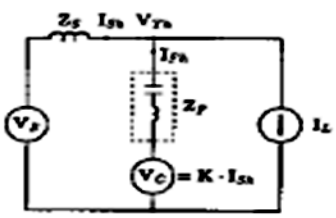

Fig -2: Single phase equivalent circuit of Series active and shunt passive filter

Active filter is the controllable voltage source Vc and load is a current source IL .When there is no active filter in the system load harmonic current is compensated by passive filter . [17] Filtering characteristic depends on ratio of Zs and Zf If source impedance is small , or unless the passive filter is tuned to harmonic frequencies generated by the load then the desired filter characteristics will not occurs . Parallel resonance between Zs and Zf will also occurs at specific frequencies causes harmonic amplification . More amount of harmonic current will flows through source than load . If we are introducing active filer in to the system as a controllable voltage source , active filter forces all the harmonics contained in the source through passive filter so no harmonic current will not flow through the source. And no fundamental voltage is applied to active filter . This results in the reduction of voltage rating of active filter .

2.2 HYBRID FILTER TOPOLOGIES

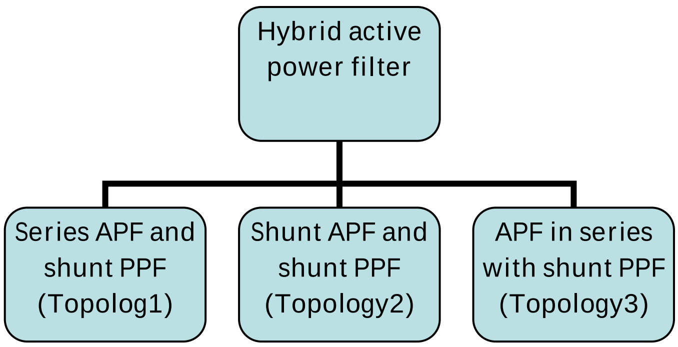

Fig-3: General classification of hybrid active power filter

Hybrid filter topologies are generally classified as series active filter & shunt passive filter, shunt active filter & shunt passive filter and active power filter is in series with shunt passive filter [4] .

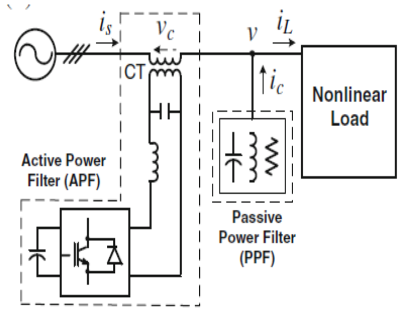

Fig -4: Series active and shunt passive filter

In HAPF topology 1 active power filter is connected in series with distribution power system through filtering inductor & capacitor . In this APF acts as a harmonic isolator and forces all the harmonic current to flow through PPF [4] .

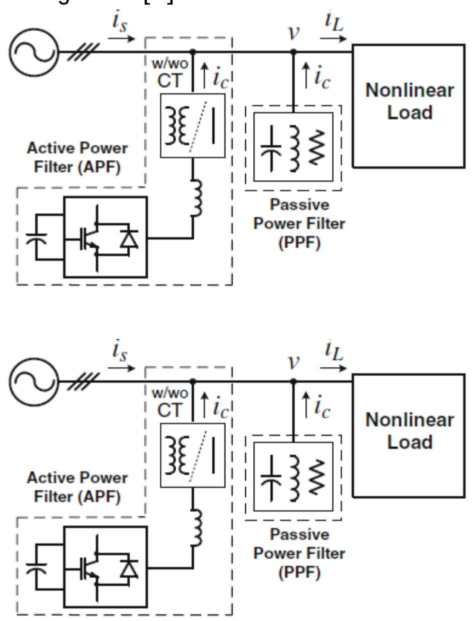

Fig-5: Shunt active and shunt passive filter

In topology 2 [4] PPF acts as main harmonic compensator and active power filter is used for compensating the remaining harmonic currents. Another advantage of this system is shunt active filter is applicable if shunt passive filter is existing and reactive power is controllable.

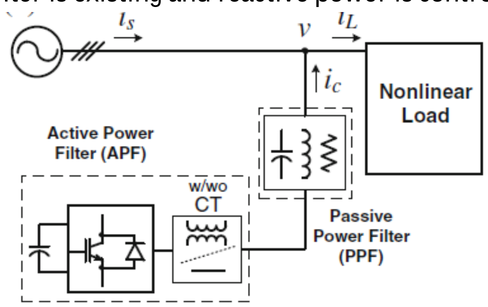

Fig-6: Active power filter is in series with shunt passive filter

In the third topology [4] APF and PPF connected in series then shunted to distribution power system . When APF and PPF connected in series the fundamental system voltage dropped across the capacitor of PPF . So this topology aims to reduce the voltage rating of APF. The table (2.3) shows the comparison between the above mentioned three topologies.

Sl .no:	Characteristics	Topology 1	Topology2	Topology 3
1	Function of APF	Harmonic isolator	Harmonic compensator	To improve the filtering characteristics of PPF
2	Series and parallel resonance prevention capability	Effective on both cases	Effective on parallel resonance	Effective on both cases
3	Advantages	Current capacity reduction of APF	Current capacity reduction of APF	Voltage capacity reduction of APF
4	Dynamic reactive power compensation	Possible to support	Possible to support	Possible to support
5	Harmonic current compensation	Mainly support	Mainly support	Mainly support
6	Size and weight	Bulky due to CT	Bulky due to CT	Bulky due to CT

Based on the advantage mentioned above further investigation is mainly focused on the third topology. This third topology differ in different cases based on either the circuit configuration or control technique incorporated .

2.3 BASED ON CIRCUIT CONFIGURATION

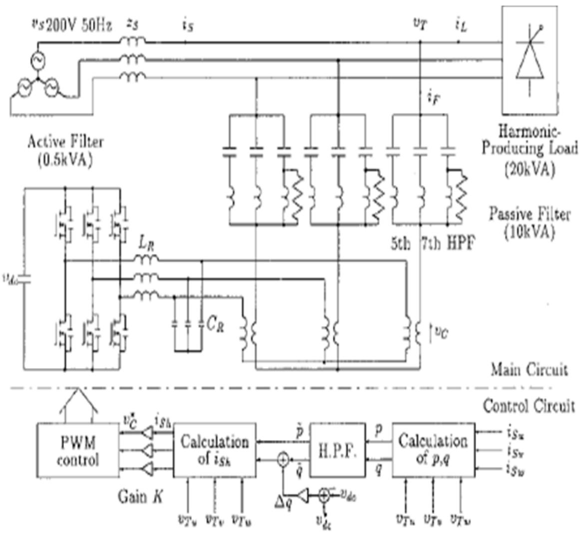

Fig-:6 Topology1

In this case active &passive filters are connected in series with each other . If the active filter outputs a fundamental voltage that is in phase with the fundamental current of the passive filter active power formed is supplied to the dc capacitor . Active filter forces all the harmonic current to flow to the passive filter[17]

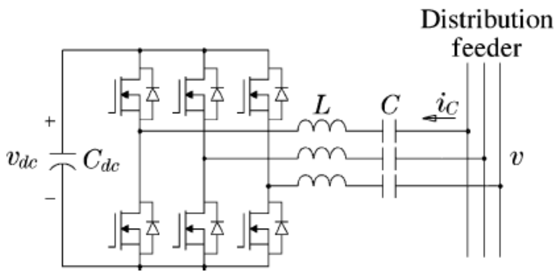

Fig-:7 Topology2

In this filter topology transformer in the ordinary filter is replaced by capacitor . Weight of the 6.6 KV capacitor is Ranges from one tenth to one twentieth as light as a 6.6-kV/400-V step-down transformer with the same kVA rating as the capacitor and the LC is tuned for seventh harmonic frequency[19] . The same topology is found in [20]

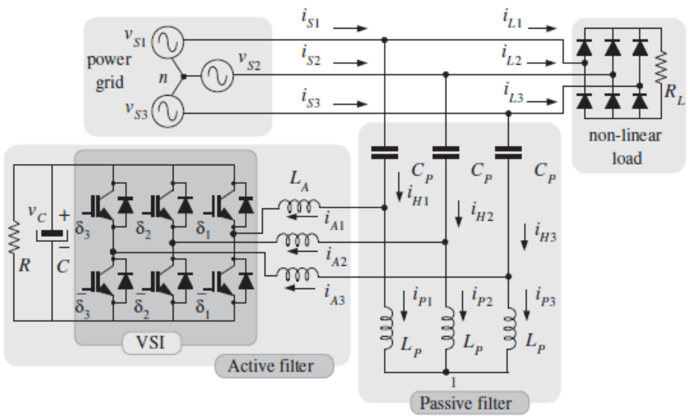

Fig-:8 Topology3

APF is connected to the midpoint of L&C components .Here controller design is divided in to two stages one is Regulation stage and harmonic compensation stage . In the first regulation stage it is aimed to maintain the dc-link capacitor in a reference voltage level . Second stage deals with the compensation of harmonic distortion in the line current[21] .

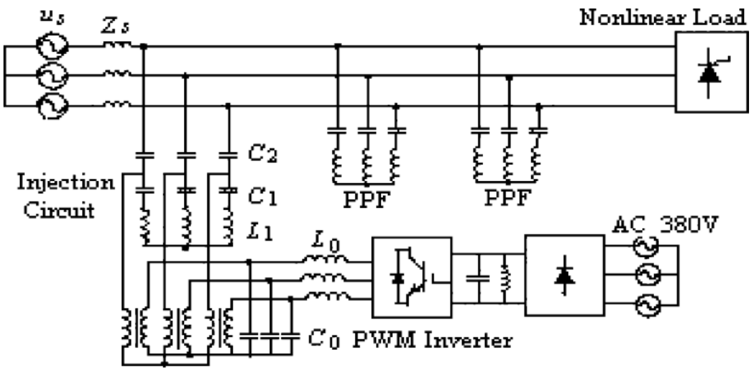

Fig-:9 Topology4

This shunt hybrid active filter with injection circuit is used for active power filter rating . In this case it describes about two methods for dc – side voltage stabilization. One is hysteresis control and energy releasing circuit and the second method is the controllable pulse width modulation rectifier on dc side . The active part of this system will not have any fundamental voltage drop . Because it has small fundamental impedance . This reduces APF ‘ power requirement and which minimizes the voltage rating of semiconductor switches . For maintaining dc bus voltage as constant uncontrolled rectifier is usually used[22] .

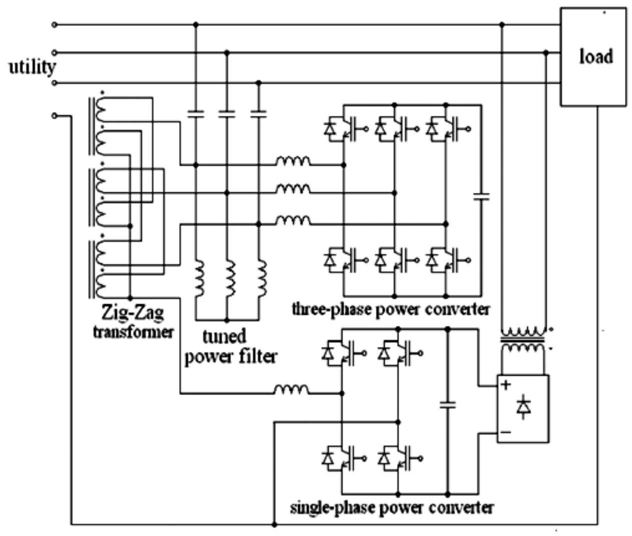

Fig-:10 Topology5

It consists of neutral line current attenuator , for suppressing the neutral line current . Single phase diode bridge rectifier is used for supplying power to the dc bus of single phase power converter . Generally the neutral line current attenuator is connected between three phase lines and neutral line of three phase four wire utility . this will increases the size and volume of zig-zag transformer . So in this case neutral line current attenuator is connected between capacitors of tuned power filters in series . Single phase diode bridge rectifier is used for supplying power to the dc bus of single phase power converter[23] .

2.4 BASED ON CONTROL

Control can be broadly divided in to two categories switching signal generation and reference current generation. The performance of hybrid filter depends on the switching signal generation and reference current generation. Different control techniques in time domain and frequency domain can be used . Frequency domain analysis is based on Fourier analysis ,wavelet analysis methods. The main limitation of frequency domain analysis is their long response time .The different control methods in time domain are instantaneous reactive power theory , synchronous reference frame theory , sliding mode method . The main advantage of time domain control methods when compared with the frequency domain methods is the fast response .

a)Fourier transform based extraction method

In method it uses Fourier transform to extract the harmonic components [1] which is the reference for the hybrid filter to generate compensating current or voltage . The basic principle of this method is to separate the fundamental and harmonic components from the load or source current voltages. After this inverse Fourier transform is used for generating the compensating reference signals in time domain. It is suitable for cases where the loads whose harmonic content has varying nature . The main drawback of this method is time delay for sampling and computation of Fourier coefficients. The block diagram of this method is given in the figure11

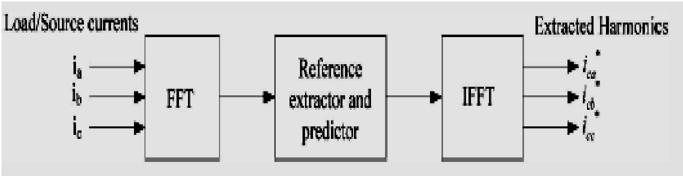

Fig-:11 Block diagram of fourier transform based extraction method

b)Synchronous reference frame method

Synchronous reference method is one among the common method [24] . In this basic principle is that the current or voltage signals are transformed using Park' transformation [1] in to the rotating reference frame . Fundamental components are transformed into DC components of currents or voltages and which can be filtered by using a low-pass filter. Then this signal is transformed to the stationary abc reference frame by applying the inverse Park's transformation technique. All this is based on the assumption that the voltage waveform is sinusoidal. One of the specialities of this method is that it is applicable only to three-phase system. Fig-: 12 shows the Synchronous reference frame extraction method with direct current control technique

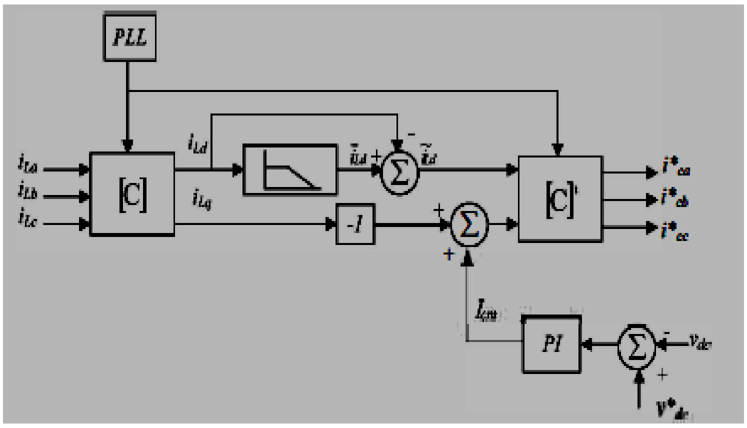

Fig-: 12 Synchronous reference frame extraction method with direct current control technique

c)Instantaneous reactive power theory(p-q method)

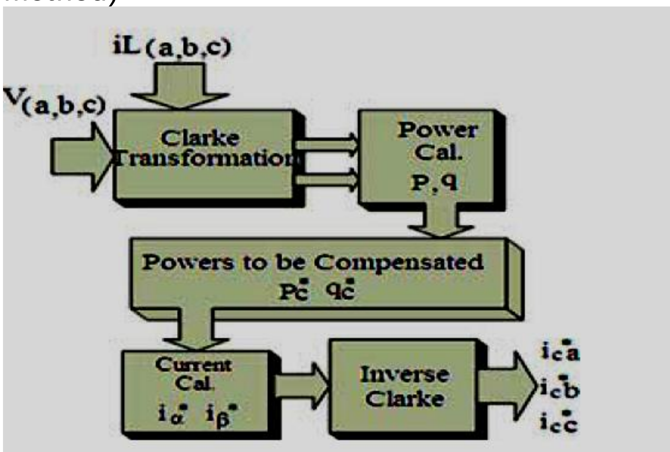

Fig-: 13 Instantaneous reactive power theory

In 1983 Akagi et al . [25], [26] proposed a new theory for the control of active power filters [24] in three phase power system known as Generalized theory instantaneous reactive power in three phase circuits . p-q theory is used in time domain so that it is valid for both steady state as well as transient operations . It uses a transformation, from a stationary reference a-b-c to α-β-0 co-ordinates [24] . This method is applicable to three phase three wire system as well as three phase four wire system under balanced conditions [1]. Table 2 shows the comparison between p-q & SRF method [29] .

	p-q method	SRF method
Harmonic distortion effects of source voltage	Yes	NO
Unbalanced load effect	Yes	No
Calculation complexity	Complicated	Middle
With reactive power compensation	No	Yes

Table-2: Comparison between p-q & SRF method .

The third stage of control of the compensating devices is the generation of gating signals for the solid-state devices of the compensating device based on the derived compensating commands, in terms of voltages or currents. For switching signal generation we have several methods such as

- P/PI/PID
- Hysteresis PWM
- Sinusoidal PWM
- Space vector PWM
- Soft computing techniques

a)Hysteresis PWM

Hysteresis band current controller has properties which are sturdiness, fastest control, and tremendous dynamics with minimum hardware requirement . In this method reference supply current (isa*, isb*,isc*) and sensed supply currents (isa, isb, isc) [27] .The actual compensation current is subtracted from its estimated reference. The resulting error is sent through a hysteresis controller to determine the appropriate gating signals [28] . The controlled compensation current is injected such that the supply current follows the reference current. Final reference and actual compensating currentis given to the PWM control part thus the PWM trigger signals for switching devices can be generated . In this method if (Iact greater than Iref+Hb) upper switch of leg is ON and lower switch is OFF . if (Iact less than Iref-Hb) upper switch of leg is OFF and lower switch is ON . Where, hb is the hysteresis band around the reference current Iref .

b) Sinusoidal pwm

Sinusoidal PWM technique produces a sinusoidal waveform by filtering output waveform with varying width . Desired output voltage is obtained by varying the frequency or amplitude of the reference or modulating signal . Variations in the amplitude and frequency of the reference voltage changes the pulse width patterns of the output voltage , but kepts sinusoidal pattern .

c) Space vector modulation

In space vector PWM technique duty cycles are computed rather than derived through comparison as in case of sine PWM .

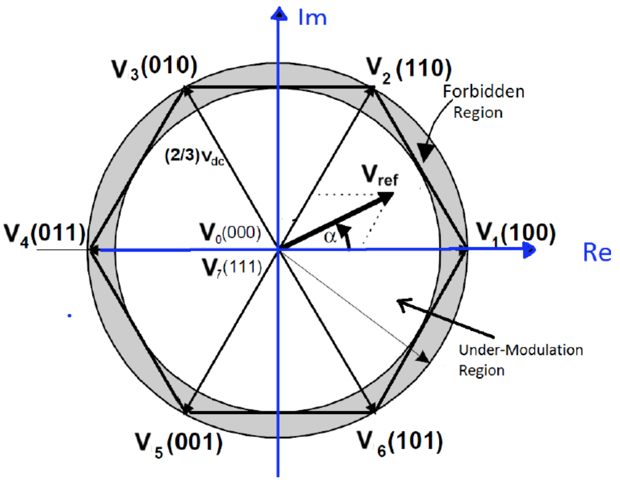

Fig-:14 Under modulation and over modulation regions in space vector modulation scheme .

Space vector modulation is carried out by rotating a reference vector around the state diagram. It composed of

Six non zero vectors forms a hexagon. A circle can be inscribed inside the state map and corresponds to the sinusoidal operation. Area inside the inscribed circle is called under modulation region and area between inside circle and outside circle is known as over modulation region. The details in the operation in the over modulation and under modulation region depends on the modulation index , which indirectly affects the inverter utilization capability .

In [13] Space vector PWM is used to suppresses the residual harmonic current to the recommended limits by injecting a compensating current. Space vector modulation is different from other technique since there is no need of using separate modulators for each of the three phase converters. Instead a global reference vector is computed to control the three phase inverter legs simultaneously. Space vector PWM is superior to other PWM schemes in the aspects of dc bus voltage utilization and minimization of current harmonics. In [15] for minimizing the capacity of hybrid active power filter adaptive fuzzy dividing frequency control is used . Instead if we adopt PI controller and state feedback controller there will be considerable steady state error in harmonic reference signal . In case of adaptive fuzzy dividing frequency control it consists of two control parts such as a generalized integrator control unit and fuzzy adjustor unit . Fuzzy adjustor is used for the timely adjustment of the PI coefficients. In [14] Neural network based controller has been used to facilitate the calculation of reference currents. This controller has self learning with high accuracy and simple architecture.

3. CONCLUSIONS

The best measure of power quality is the ability of electrical equipment to operate in a satisfactory manner, given proper care and maintenance and without adversely affecting the operation of other electrical equipment connected to the system. To overcome the problem of higher rating and higher cost of active filter and resonance problems of passive filter , many topologies of hybrid filter have been evolved. Hybrid active power filters are provided to be better choice for compensation of nonlinear load and therefore to provide a clean power supply to all types of load . Firstly a comprehensive review of hybrid active power filters for power quality improvement has been presented here . Different harmonic extraction methods have been also analyzed . Hybrid filters damps resonance occurs between system impedance and passive filters and also provide cost effective compensation. APF in series with shunt PPF aims to reduce the voltage rating of the APF.

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