SINGLE-PHASE SHUNT HYBRID ACTIVE POWER FILTER

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Abstract
In recent years, power electronic converters devices are beingwidely used in industrial as well as in domestic applications.These electronic converters suffer from the problem of drawingharmonics and reactive components of current from the source and offer highly nonlinear behavour which results in different undesirable features like, low system efficiency, poorpower factor, disturbance to other consumers and interference in nearby communicationnetworks etc. The current harmonics produced by these nonlinear loads further results in voltage distortion and leads to various power quality issues. This has led to implementationof standards and guidelines such as IEEE 519-1992 for controlling harmonics on the power system.
Classically, passive filters and power capacitors are employed to suppress the harmonicsand to improve power factor respectively but have problem of fixed compensation, large size.Active power filters are viable alternative over the classical methods to compensateharmonics as well as reactive power requirements of the non-linear loads.
Index Terms: total harmonic distortion (THD),total demand distortion (TDD),Point of Common Coupling (PCC),Power Quality (PQ),Discrete Fourier Transform(DFT), Active Power Filter (APF)

I. INTRODUCTION

Nonlinear loads are constructed by nonlinear devices, in whichthe current is not proportional to the applied voltage.They appear to be prime sources of harmonic distortion in a power distributionsystem. Harmonic currents produced by nonlinear loads are injected back into powersystems through the point of common coupling (PCC). These harmonic currentscan interact adversely with power system equipment e.g. capacitors, transformers and motors, causing additional losses, overheating and overloading.
The APF technology is now providing compensation for harmonics, reactive power.It has evolved in the past quarter century ofdevelopment with varying configurations, control strategies and solid-state devices.

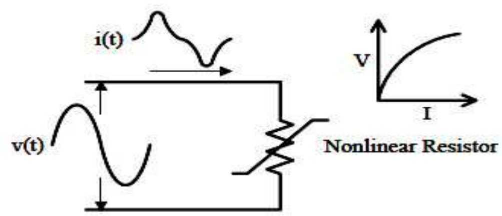


Figure 1. Current distortion caused by nonlinear load

AFs arealso used to eliminate voltage harmonics, to regulate terminal voltage, to suppress voltageflicker and to improve voltage balance in three-phase systems. This wide range of objectivesis achieved either individually or in combination, depending upon the requirements and control
strategy and configuration which have to be selected appropriately.Power systems are designed to operate at frequencies of 50 or 60 Hz. However, certaintypes of loads produce currents and voltages with frequencies that are integer multiples of the fundamental frequency. These frequencies components are a form of electricalpollution known as harmonic distortion. Power quality is defined as a set of electrical boundaries that allows equipment to functionin its intended manner without significant loss of performance or life expectancy.

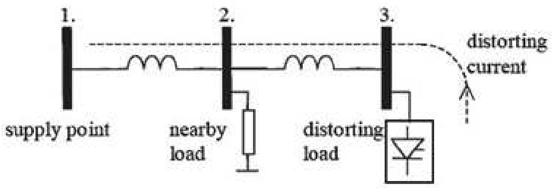


Figure 2. Distorted current causes voltage distortion

These power quality problems led to implementation of standards and guidelines such as IEEE-519 for controlling harmonics on the power system along with the recommended limits.IEEE standard 519 was first issued in 1991. It gave the first guidelines for system harmonic limitations and revised in 1992 [15]. The 5% voltage distortion limit was recommended below 69 kV while the limit on the current distortion is fixed in the range of 2.5% to 20% dependingupon the size of the customer and the system voltage. [8]

Recently, Active Power Filters can be seen as a alternative over traditional passive filters tocompensate harmonics and reactive power requirement of nonlinear loads. The objectives of active filtering are to solve these problems by combining the advantages of APF and passive filter with much reduced rating of the necessary passive components.

Distortion level can be described by the the complete harmonic spectrum with magnitudeand phase angle of each harmonic component.When non-linear load draws such non-linear current that current passes through all of the impedance between the load and system source, asa result of which harmonic voltages are produced by impedance in the system for each of theharmonic. [1]

Mitigation or cancelation of harmonics can be carried out by following ways...

1) Passive filters
2) Active filters
3) Hybrid filters

However it is better to prevent harmonic generation in system.

This paper describes configurations of hybrid filter, control methodology and the selection consideration of APF. The hybrid filter is the combination of active filter and passive filter. It is quite popularbecause the solid state devices used in active filter can be reduced sized and cost Major part is the passive shun LC filter used to eliminate the lower order harmonics. Ithas the capability of reducing voltage and current harmonics at reasonable cost.

II. CIRCUIT DIAGRAM& OPERATIONAL PRINCIPLE

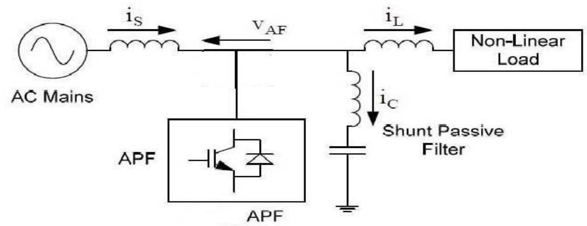


Figure 3.Circuit diagram for hybrib filter

Shunt active power filter compensate current harmonics by injecting equal butoppositeharmonic compensating current. In this case the shunt APF operates as a current source injecting the harmonic components generated by the load butphase shifted by 180^{o}. It is controlled to draw/supply a compensating current $I_c$from/tothe utility, so that it cancels current harmonic on the ac side. This principle is applicableto any type of load considered a harmonic source. Moreover, with an appropriate controlscheme, the active power filter can also compensate the load power factor. In this way,the power distribution system sees the non linear load and the active power filter as anideal resistor. [2] By observing circuit,compensating current is found to be....

$$Ic = Is - IL \qquad (1)$$

Where....

Is - source current

I_L - load current

This compensating current is injected back to system that forces distorted currentto sinusoidal form.The current waveform for canceling harmonics is achieved with thevoltage source inverter and an interfacing filter. The filter consists of a relatively largeisolation inductance to convert the voltage signal created by the inverter to a current signalfor canceling harmonics. [5]

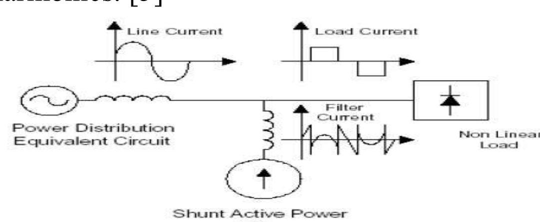


Figure 4.Circuit diagram for APF

A. Interfacing Inductor

The desired compensation current waveform is obtained by controlling the switchingof IGBT in VSI.The switching ripples of compensation of compensating current byavailable driving voltage across interfacing inductor,the size of interfacing inductorand switching frequency.Inproposed scheme,the driving voltage is DC bus voltage.Thebipolar DC bus voltage across the interfacing inductor determines the peak-peakswitching ripple. [4]

The interfacing (L_f) can be calculated as...

$$L_{fmin} = \frac{V_{DC}}{2*\Delta I_L * f_{max}} \quad (2)$$

Where,

f_{max} - switching frequency

I_{sw} - peak-peak switching ripples

B. DC bus capacitor

DC bus capacitor (C_f) is used as a temporarily energy storing element in proposedshunt APF.During steady state condition,the reactive and harmonic current will chargeand discharge DC bus capacitor during source voltage period.The total reactive andharmonic load currents to be compensated are principle factor that causes the DC buscapacitor voltage fluctuations.To get good compensation performance,serious voltagefluctuations must be avoided. That requires proper sizing of Dc capacitor.[4]Thedetermination of value of energy storage capacitor is based on following three situations

(1)Step increase of the real fundamental component of load current: When load current has step increase,the energy stored in capacitor must be released immediately to support the step increase in power consumed by the load i.e. by energy balance concept.

$$\frac{1}{2} * C_c * \{V_{cr}^2 - V_{c\,min}^2\} = \frac{1}{2} * V_{sm} * I_{L1} * T \quad (2)$$

Where,

V_{cmin} - lower limit of capacitor voltage,I

L1- step value of fundamental componentof load current. The value of capacitor is...

$$C_{c1} = \frac{V_{sm} * I_{L1} * T}{\{V_{cr}^2 - V_{c\,min}^2\}} \quad (3)$$

(2)Step reduction of real fundamental component of load current: When load currentis reduced,the utility source current does not change until next cycle.Hence extrautility source current Iwill charge energy storage capacitor i.e. by using energybalance concept.

$$\frac{1}{2} * C_c * \{V_{cr\,max}^2 - V_{cr}^2\} = \frac{1}{2} * V_{sm} * I_{L2} * T \quad (4)$$

Where,

$V_{c\,max}$ - upper limit of capacitor,I

L_2 - step reduction of peak value of fundamentalcomponent of load current. Therefore value of capacitor required is...

$$C_{c1} = \frac{V_{sm} * I_{L2} * T}{\{V_{cr\,max}^2 - V_c^2\}} \quad (5)$$

(3)Harmonic component of load current: During the steady state,harmonic componentof load current will charge and discharge capacitor during the period. So using
energy balance concept.

$$\frac{1}{2} * C_c * \{V_{c\Delta}^2 - V_{cr}^2\} = \frac{1}{2} * V_{sm} * I_{L3} * T/2 \quad (6)$$

Where,

I_{L3}- peak value of component of load current

$V_{c\Delta}$ - max. or min voltage ofcapacitor during one period.So capacitor value comes out to be…

$$C_{c2} = \frac{V_{sm} * I_{L3} * T/2}{\{V_{c\Delta}^2 - V_{cr}^2\}} \quad (7)$$

The size is determination is based on energy balance principle.Using thisconcept,following equation can be written as...

$$\frac{1}{2} * C_{dc} * \left|V_{dc\,ref}^2 - V_{dc}^2\right| = \frac{1}{2} * \sqrt{2} * V_S * I_s * \frac{T}{2} \quad (8)$$

Where V_{dc} - minimum or maximum Dc bus voltage,

V_{cdref} - DC bus voltage reference,

I_L - load current,

T - period of source voltage.

Rearanging the the terms,above equation can be re-written as....

$$C_{dc} \geq \frac{\sqrt{2} * V_S * I_L * \frac{T}{2}}{\left|V_{dc\,ref}^2 - V_{dc}^2\right|} \quad (9)$$

C. CONTROLLER

a. DC capacitor voltage controller

The voltage across the capacitor is sensed and compared with reference voltage.Theerror is given to controller for reducing steady state error.Acordingly P or PI controller is used.ontroller constants are analyzed by trial and error method.This error signal is addedwith compensating current. [3]

b. Direct current control method

APF is standard voltage source inverter having an energy storage capacitor on DCside.SPWM current controller method is employed to generate gating pulses to switches of APF.Diod rectifier with RL load is non-linear load on ac mains.This load draws anon sinusoidal current from source.The proposed APF eliminates harmonics and improvepower factor.In proposed scheme,DC supply voltage of APF and load current is sensed tocontrol APF. Dc capacitor sensor output is compared with reference value in error detector.then it is processed by controller.This is added with harmonic reference current.SPWMis used over this reference current to generate gating signal.The APF,in response to thosegating signals,generates PWM voltage on AC side of APF.This impressed voltage causescurrent to flow through interfacing inductor resulting in sinusoidal current of ac source.

c. Reference current estimation

Bandpass filter is on of the way of finding harmonic reference current.Only signalwith fundamental frequency ia allowed to pass through and then it is subtracted from original load current that gives reference current.It is used as modulating signal for PWMgeneration.

D. Passive filter

it is observed that third harmonic remain persistent. 3rdharmonic current contained in $I_L$flow actively into the system.So to reduce it's content further,a passive filter specially tuned for third harmonicis connected.It contains R,L,C connected in series.It gives least resistive path for thirdharmonic current. The RLC parameters are calculated using the formulae for passivefilters. Components are chosen using following relation between L and C.

$$f = \frac{1}{2\pi\sqrt{L_f * C_f}} \qquad (10)$$

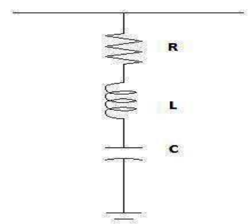


Figure 5. Simple Passive single tuned filter

Effectiveness of designed filter is assessed by plotting is graph of frequency vs impedance.It is shown by..

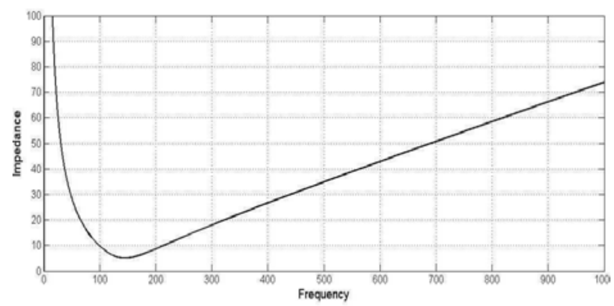


Figure 6. Frequency response of Passive Filter

III. SIMULATION

The single phase system is simulated in MatLab with parameters given in Table.

Supply voltage	*25 V rms*
Frequency	*50 Hzs*
Source impedance	*0.6 Ohm*
Load	*R=50 Ohm L=40mH*

Table 1.Circuit Parameters

The system is simulated in MatLab.Simulink model is as shown…

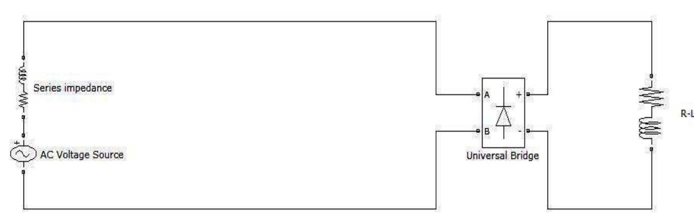


Figure 7. Single phase system

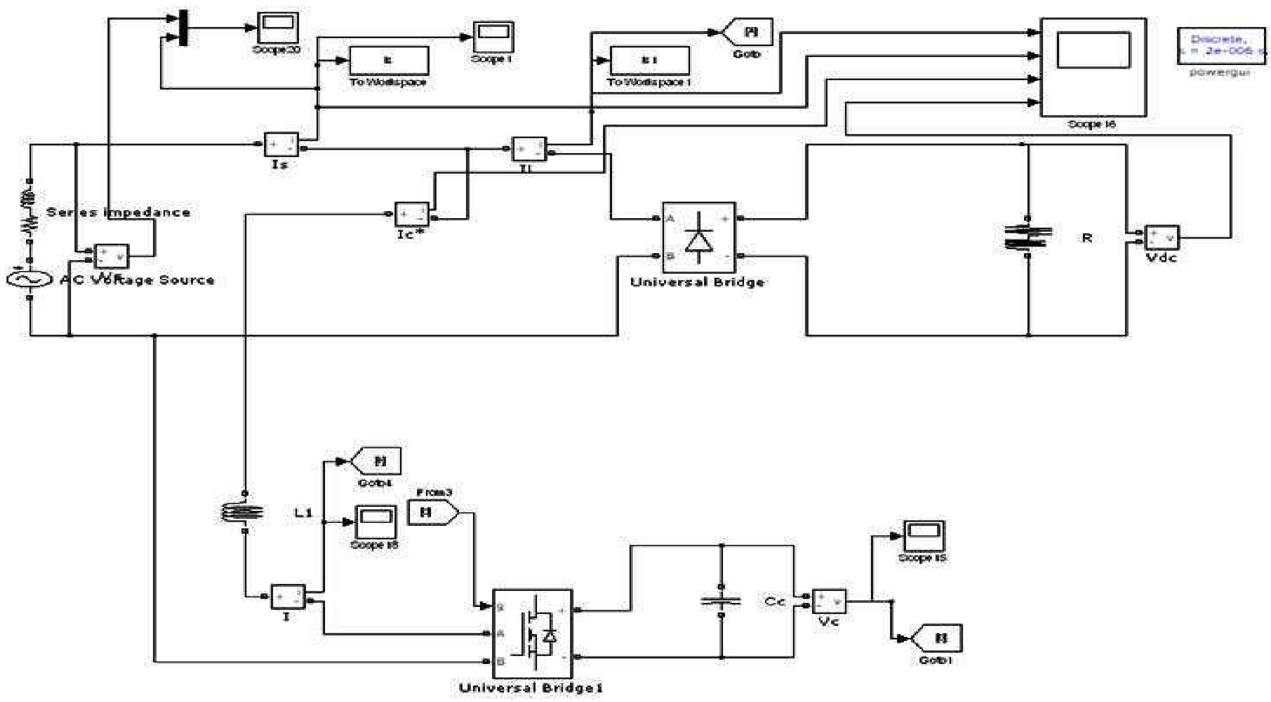


Figure 8. Simulation diagram of shunt APF

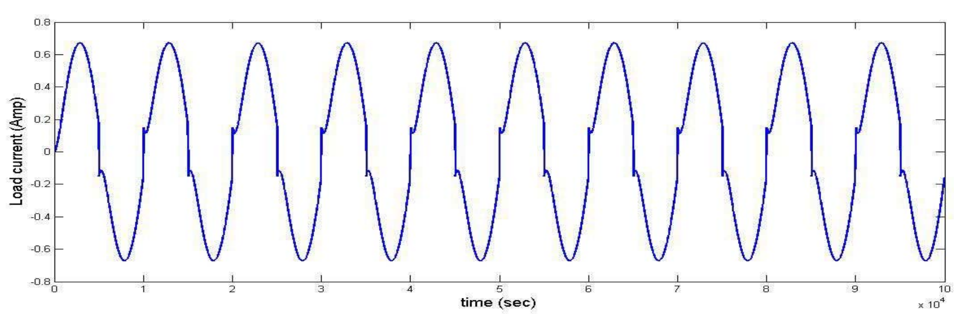
A. SIMULATION RESULTS

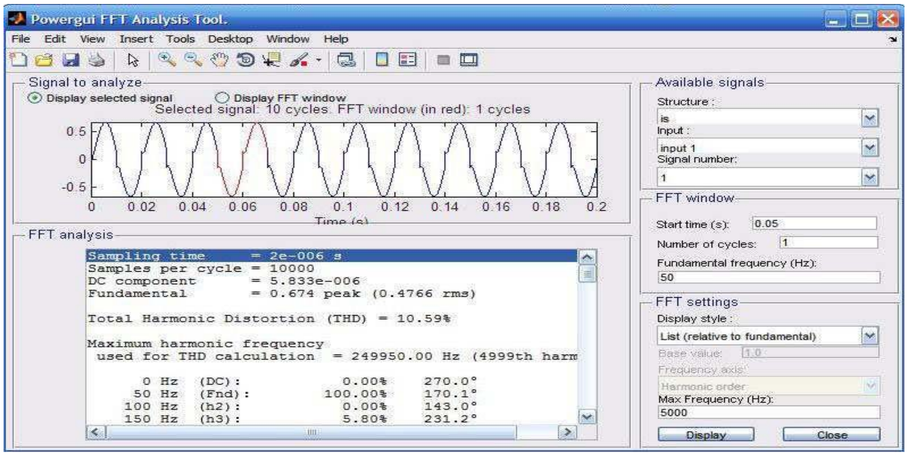
Theobservations are shown in Table.

MatLab result	Harmonic Analyser
THD = 10.59 %	THD = 12.73%

Table 2. THD observations

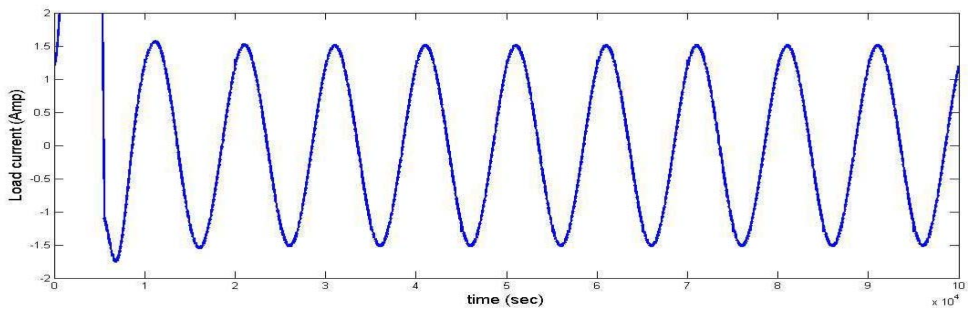
a. Without hybrid Power filter





THD observed

b. With hybrid Power filter



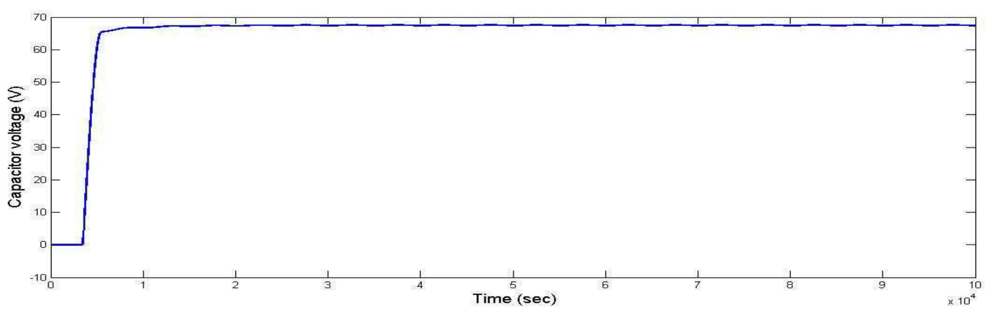


Fig.9.Capacitor voltage

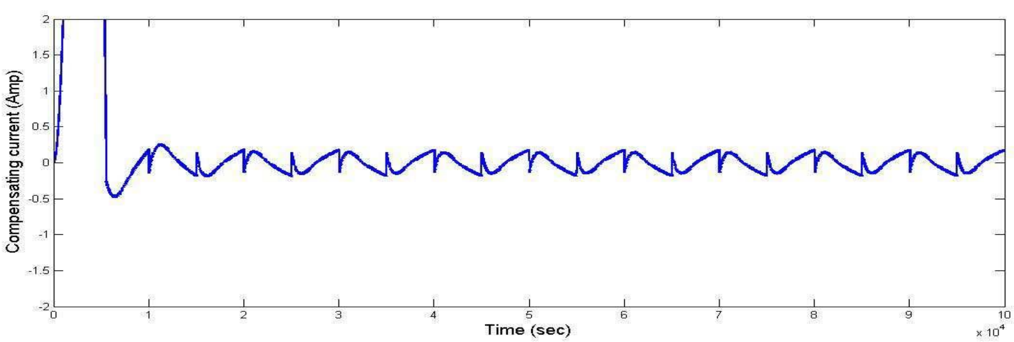
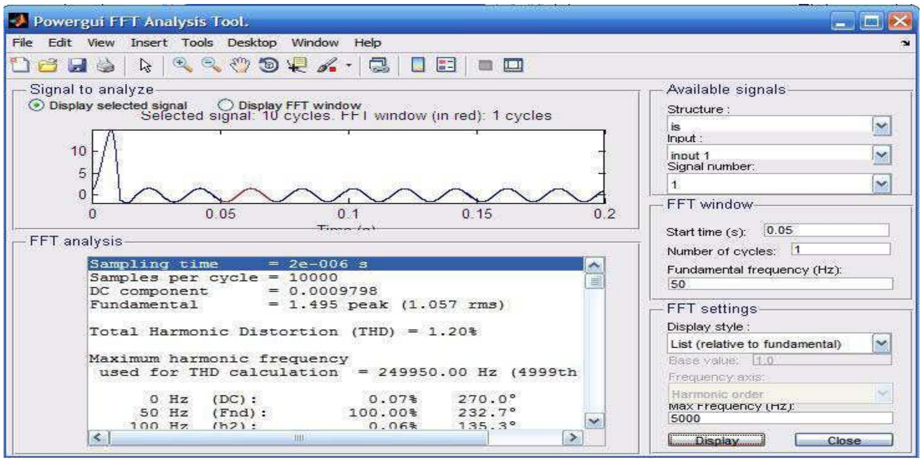


Fig.9.Compensating current



Parameter	Without filter	With APF	With hybrid filter	% reduction
THD	10.59	2.70	1.20	88.67
3^{rd}	5.80	2.23	0.90	84.48
5^{th}	4.53	0.15	0.06	98.67
7^{th}	3.60	0.08	0.06	98.33
9^{th}	2.95	0.05	0.05	98.30

B. VA rating of hybrid filter

The volt-ampere rating required for the active filter in the hybrid filter as follows:

$$P_f = \sqrt{3} * \frac{V_{dc}}{\sqrt{2}} * \frac{I_{APF\,max}}{\sqrt{2}} \qquad (11)$$

Where,

I_{APF} - maximum filter current

IV. CONCLUSION

The harmonic filtering performance of the proposed hybrid filter is validatedby a detailed THD analysis. The analyzed results conclude that the proposed filter improves the harmonic filtering performance of the basic shunt APF.The designed power filter is applied to single phase system with RL as non linear load.The THDobserved is 10.59 %. By using hybrid filter it is reduced to 1.20 %, which is less than the limitgiven by IEEE.

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