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# Elimination of Harmonics Using Hybrid Active Power Filter in 3-Phase System Using PQ Theory

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**Abstract**

In the recent past it is seen that due to the Non linear load on the utility side such as the arc furnace , personal computers , variable frequency drive (VFD), fluorescent lamps produces current harmonics to minimize these effect different types of compensators are used for reducing the harmonics in the current and voltage and for the compensation of the reactive power, these devices are Shunt Active Power Filter(SAPF) and the Tuned Passive Harmonic Filter(TPHF) are used for the mitigation of harmonic ,this paper deals with the design, configuration, control and algorithm of these filters SAPF consist of mainly three parts i.e. Pulse width modulation(PWM),Voltage source inverter and Ripple filter and the Tuned Passive Harmonic Filter(TPHF) consist of single tuned filter used in eliminating 5,7,11,13$^{TH}$ order harmonics, second order damped filter(24$^{th}$ HP 150Mvar), third order damped filter(3C 150Mvar), C-type damped filter are used for producing reactive power, various techniques for controlling the current is done by using hysteresis current controller is used for the production of reference current in SAPF the PQ theory and d q theory is used and it also gives the description of the topology which consist of Clarke transformation and Inverse Clarke transformation and PID controller. In this report both the filters i.e. Shunt active power filter and tuned passive harmonic filter are being used simultaneously in the three phase system which is used in the elimination of the voltage and the current harmonics, reactive power compensation, regulating terminal voltage and voltage flickering it also gives the comparative analysis of with and without any filters which is based on the Total harmonics distortion (THD) and it is carried out by using the MATLAB semolina.

***Keywords:*** *Non linear load Shunt; Active Power Filter(SAPF); Pulse width modulation(PWM); Voltage source inverter; Ripple filter; Tuned Passive Harmonic Filter(TPHF); single tuned filter; second order damped filter; C-type damped filter; P-Q theory; d-q theory Clarke transformation; Inverse Clarke transformation; PID controller; Total harmonics distortion (THD)* .

## 1. Introduction

Due to the globalization and industrialization the power demand is increasing day by day and in this various non-linear load are used such as the compact florescent lamp(CFL), television, personal computer, inverter and various electronic devices are used and also such devices are being used which have variable frequency drive converter etc.

And hence due to the presence of such non-linear loads it may results in the load current distortion as well as it will affect the power quality and due to the switching action of the switching action of the equipment it will result in the power quality due to the switching action the delay is being introduced in the system and which results in the generation of the harmonics distortion and the power factor reduction in the system ,for the harmonic reduction on the load various compensating techniques are being used such as the passive filter and the active filter for the power quality improvement and in the reduction of the selective harmonics and the THD. It is seen that the harmonic frequencies are the root cause of the power quality problem and it is defined as the sinusoidal part of the quantity having the frequency that is the integral multiple of the fundamental frequencies these harmonics are generated by the several non-linear loads and will travel back to the source up to the point of common coupling and will also adversely affect the other equipments hence the Shunt active power filter (SAPF) that generates the harmonic current which has the magnitude equal to the load harmonic current but having 180 degree phase shift in order to cancel out the load current harmonics and the obtained source current will be sinusoidal, in the earlier times the passive filters are being used as an harmonics

removal technique such as detuning large size, series/parallel resonance etc, and to eliminate such drawbacks a the two main devices are being used these are names as Shunt active power filter and the Tuned passive harmonic filter both these two devices are shunted with the three phase transmission line and their main purposes are to eliminate the
harmonics current and to posses the reactive power compensation.

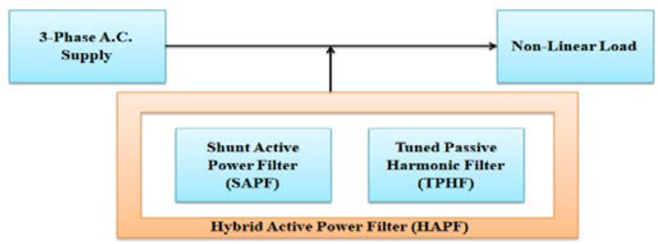


**Figure 1 Block diagram of the proposed method.**

Tuned Passive Harmonic Filter(TPHF) consist of single tuned filter in eliminating 5,7,11,13$^{TH}$ order harmonics, second order damped filter, third order damped filter, C-type damped filter and SAPF consist of mainly three parts i.e. Pulse width modulation(PWM),Voltage source inverter and Ripple filter both these filters are very affluent and it also occupies many parts of the control theories, harmonic extraction method and reference current generation methods of filters of the active power. Adage introduced the instantaneous active and reactive power (PQ) theories according to this theory the three phase quantity is converted to the two phase quantity of the active and the reactive component the study of the shunt active filter(SAPF) and Tuned passive harmonic filter of the PQ theory, where as the d-q theory is used in the extraction of the voltage and the current harmonics and the PID controller is used in controlling the reference current and based on the dq theory the Shunt active power filter was introduced in this context the PID and hysteresis controller are used, and for the correction of the power factor in the three phase circuit the fundamental result of the generalized instantaneous reactive power (PQ) theory is being applied.
The elimination of the harmonics in the voltage and the current using the d-q theory was proposed examination of a shunt voltage unbalanced compensator is based on the the three phase Voltage Source Inverter(VSI) operation which has unbalanced switching function of shunt power filter is proposed. The shunt active power filter and the tuned passive harmonic filter is also being used in the compensation of the reactive power. In this system the invert topology is being used is used in the voltage source inverter (VSI), the main advantage of this type of inverter is in generating the good quality of voltage.

In this research paper the comparative analysis is done which is based on Total Harmonic Distortion (THD) for the system with Shunt Active Power Filter (SAPF) and Tuned Passive Harmonic Filter (TPHF) and without any filter by using the MATLAB simulink.

## 2. Shunt Active Power Filter (SAPF)

Shunt Active Power Filter for the purpose of the harmonics compensation and the compensation of the reactive power.
When a non linear load is connected to the system it results in the generation of the harmonic current its detection is divided into the two main categories of the frequency and the time domain, in which the frequency domain methods has Fast Fourier Transform (FFT) method, time domain methods has wavelet transform methods is based on the time domain and instantaneous reactive theory method has Adaptive Interference Cancellation (ANC). These methods are used in the sum of the reactive current for the generation of the reference signal to control the compensation current of the SAPF.
The SAPF is divided into three major parts parts:

- Pulse With Modulation (PWM)
- Voltage source inverter (VSI)
- Ripple filter
- Hysteresis current control

The compensation is based on the reference signal.

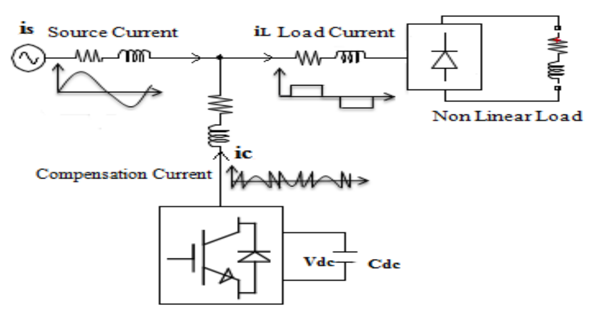


**Figure 2 Proposed Shunt Active Power Filter**

Figure 2 shows the block diagram of Shunt Active Power Filter(SAPF) for harmonic compensation which is connected in parallel with the 3 phase line feeding the Non linear load
Here Is is source current, Il is Load current and Ic is Compensating current that generates the harmonic current which has the magnitude equal to the load harmonic current but having 180 degree phase shift in order to cancel out the load current harmonics and the obtained source current will be sinusoidal.

## 3. Topology

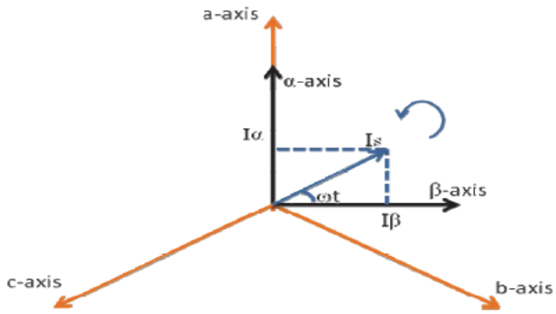


**Figure 4 Vector representation of abc & alpha beta axis**

In the above figure4 the is showing the graphical representation of abc to alpha-beta axis this conversion is known as Clarke Transformation whereas the inverse of Clarke Transformation is known Inverse Clarke Transformation in which alpha-beta is converted into abc.
In the figure abc are the instantaneous values of voltage and current which is getting transformed into alpha-beta stationary axis and vice-versa. Here a,b and c axis are spatially shifted by 120 degree from one another and on the other side alpha and beta axis are perpendicular to each other, here alpha axis is in parallel with 'a' axis while the direction of beta is selected in such a manner that if the voltage and the current vector rotates in abc sequence on the abc coordinate then they would rotate in the alpha-beta sequence which are present on the alpha-beta coordinates.

1. P-Q Theory

P-Q theory is a powerful in defining the instantaneous real and imaginary power, it is used in the elimination of harmonics and in reactive power compensation moreover it helps in controlling the power flow in a transmission line.
The P-Q theory is mainly used in the conversion of 3-phase voltage and current to alpha beta and zero reference frame and its main advantage is in the separation of the zero sequence component, since no contribution is made by alpa and beta axis on the zero sequence components hence it is being possible to eliminate 'Io' from the system.
The Clarke transformation equation for the 3-phase voltages and current is given in the equation 1 and 2 given below.

$$\begin{bmatrix} Vo \\ V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Io \\ I\alpha \\ I\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad (2)$$

On the alpha beta 0 axis the phase voltage and current is responsible in determining the active 'p' and the reactive power 'q' as shown in the equation 3.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad (3)$$

When the above equation is inverted we will get the reference compensating current on alpha beta and zero axis respectively.

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} -P_{ac} + P_{loss} \\ q \end{bmatrix} \quad (4)$$

After that the reference current is converted from alpha beta 0 frame reference to 3-phae abc frame this is done by using Clarke transformation as shown in the equation 5 given below

$$\begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Io \\ I\alpha \\ I\beta \end{bmatrix} \quad (5)$$

From the above equation the reference compensating current is obtained which is then compared with an actual compensating current and at the inverter output the compensating current is generated for 3-phase inverter(VSI).
All these equations are used in the simulation block of Shunt Active Power Filter by using functional blocks in MATLAB.

## 4. PID Controller

A proportional, Integral and derivative (PID) controller is used in the calculation of the error signal values which can be defined as the difference between desired set point 'SP' and that of the measured process variable 'PV' and it applies the correction which is based on the proportional, integral and the derivative term which is being denoted by the P,I and D .

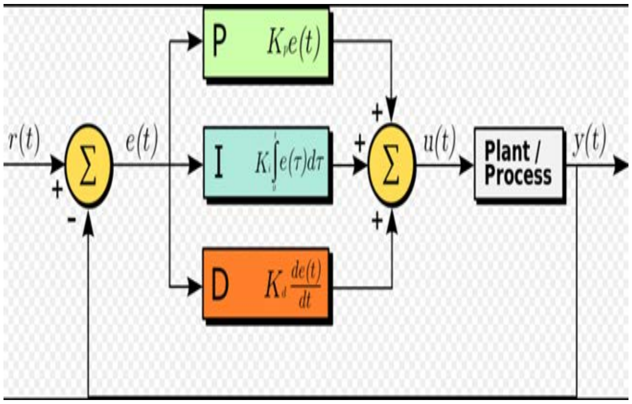


**Figure 5 Block diagram of a PID controller in a feedback loop.**

In the above block diagram Set point 'SP' is represented by r(t) and the Processed value (PV) is represented by y(t), the PID controller has the ability in using the three controlling terms of the proportional, integral and derivative on the influence of the output of the controller in order to apply the optimal and accurate control.
The block diagram shows that how the terms are generated and applied. It shows that a PID controller continuously calculates the error value which is the difference between the Set point 'SP' and the Processed value 'PV' and hence the correction is based on the proportional, integral and derivative term and the controller helps in minimising the error over time.

## 5. Hysteresis Controller

Different controlling techniques are being used for controlling the current in which hysteresis current control method is one of them.
This method is used for the control of voltage source inverter(VSI) in order to generate the output current which is then used by the reference current, with the help of this method we can control the switches(IGBT) used in the inverter asynchronously the current through an inductor in order the current to ramp up and down the in order to track the reference signal.
The major disadvantage of using the hysteresis is that there is no limit to the switching frequency.
In order to control the inverter switching the error signal is used which is given by e(t), the error signal is divided into two components such as the desired current ref(t) i and the current to an inverter is represented by actual(t) i.
There are two limits in hysteresis control method which are the upper limit and the lower limit.
Case 1 If the error in the switch exceeds the margin of transient, then the current is forced to decrease.
Case 2 If the error is under the margin of transient, then the current is forced to increase.

## 6. Total Harmonic Distortion (THD)

Due to the Non linear load harmonics causes the problems in the transformers, motors, transmission lines and various parts o the power system therefore it is made important to measure to measure the total effect of the harmonics. The summation of all the harmonics in the system is known as Total harmonics distortion (THD).
The frequencies in the harmonics are the integral multiple of the waveform fundamental frequency. For example, in a 60Hz fundamental waveform, the $2^{ND}$ ,$3^{RD}$ ,$4^{TH}$ and the $5^{TH}$ harmonics will be at a frequency of 120Hz,180Hz,240Hz and 300Hz respectively.
Total harmonic distortion 'THD', represents the summation of all the components of the harmonics of different voltage and current waveform which is being compared against the fundamental component of the voltage and current wave.
The end result will be the percentage comparing the harmonic component to that of the fundamental component of the signal, higher is the percentage (%THD) greater will be the distortion in the system.
There are zero harmonic component in an idle sine wave.

## 7. MATLAB Simulation

Figure given below shows the MATLAB simulation of a 3-phase rectifier load without any filter hence the load is considered to be the RL type.

### A. Simulation Circuit without any Filter

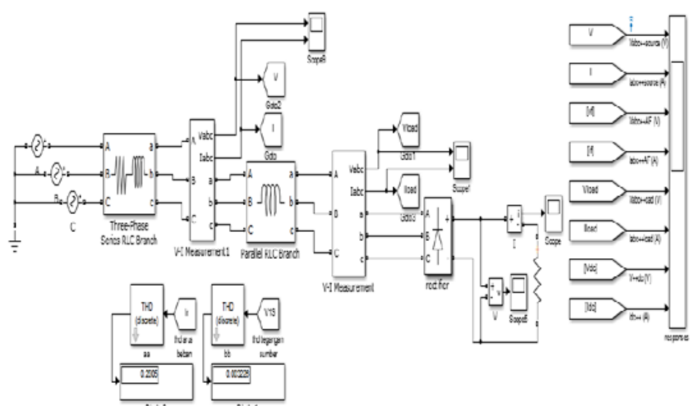

**Figure 6 phase rectifier load without any filter**

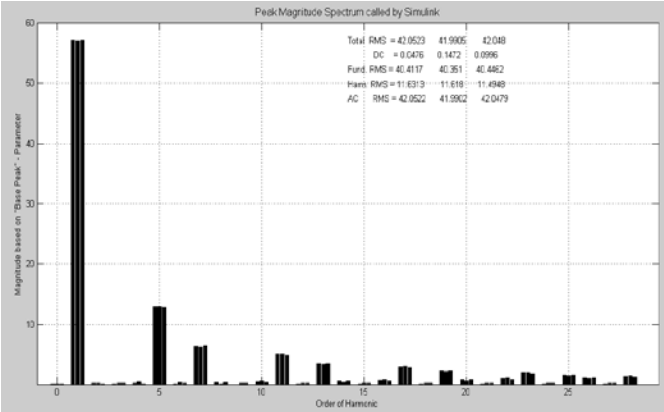


**Figure7 THD (Total Harmonic Distortion) without any filter**

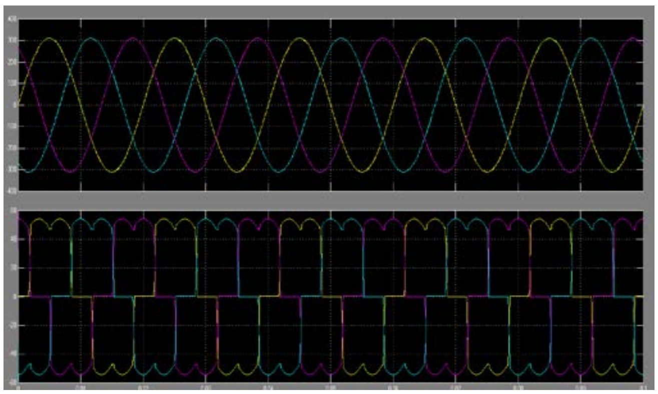

**Figure 8 Source Current(I) and source Voltage(V) without any filter**

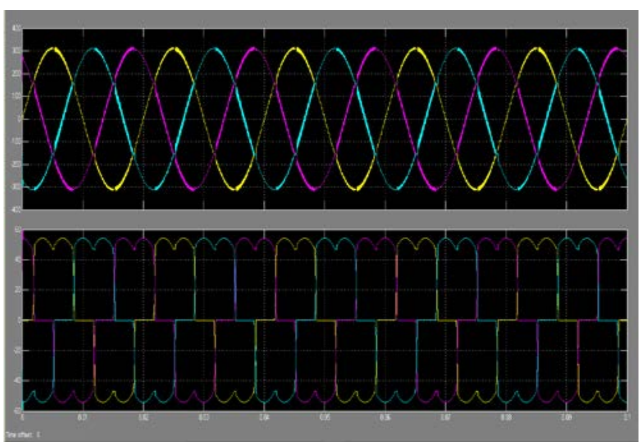

**Figure 9 Load Voltage(V) and Load current(I) without any filter**

### B. Simulation Circuit with tuned passive harmonic filter

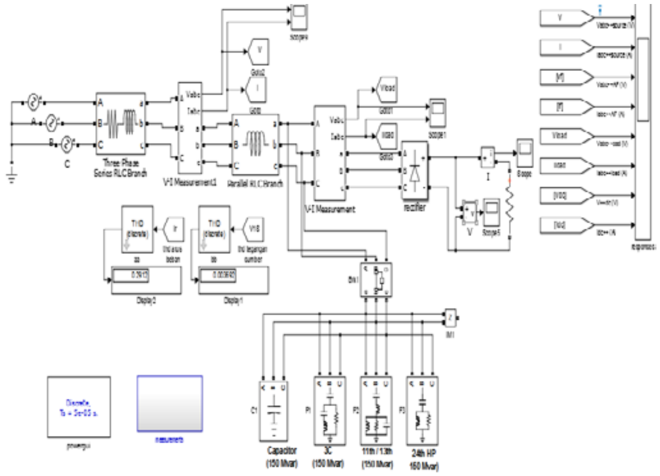


**Figure 10 Model with tuned passive harmonic filter**

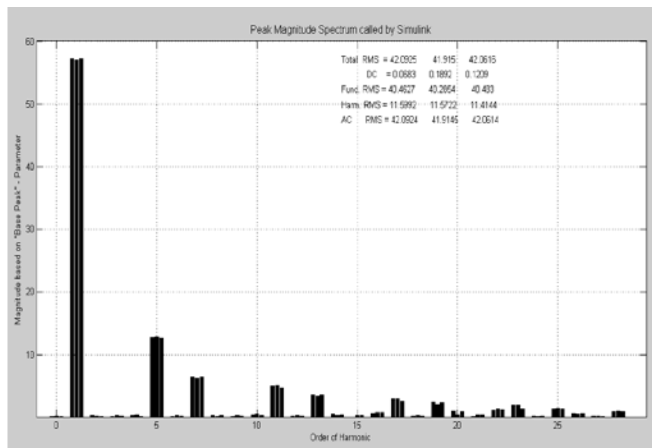


**Figure 11 THD (Total Harmonic Distortion) with tuned passive harmonic filter**

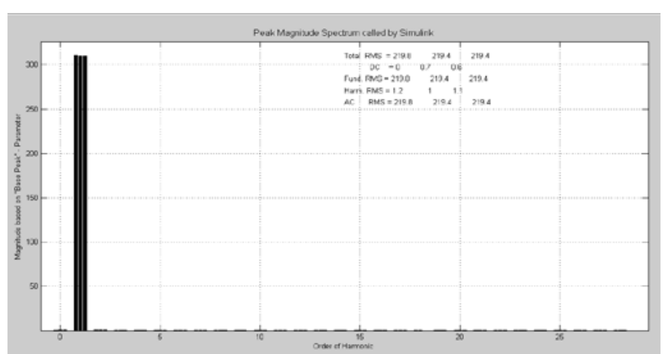


**Figure 12 THD (Total Harmonic Distortion) with tuned passive harmonic filter**

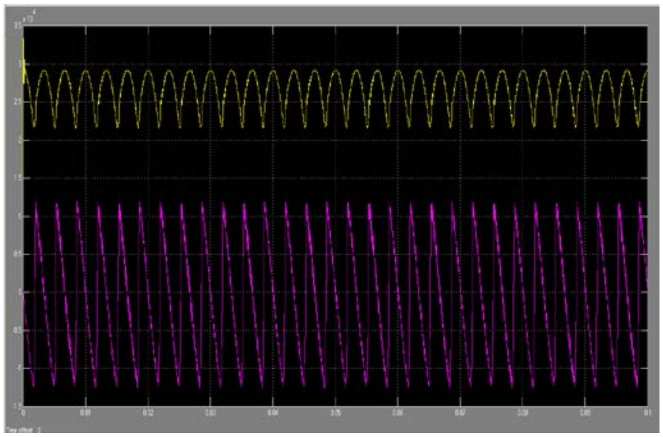

**Figure 13 Active and Reactive Power**

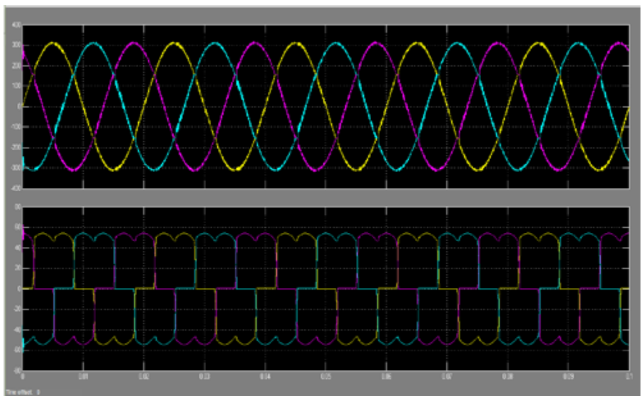

**Figure 14 Load Voltage(V) and Load current(I) with tuned passive harmonic filter**

## C. Simulation Circuit with Shunt active power filter(SAPF)

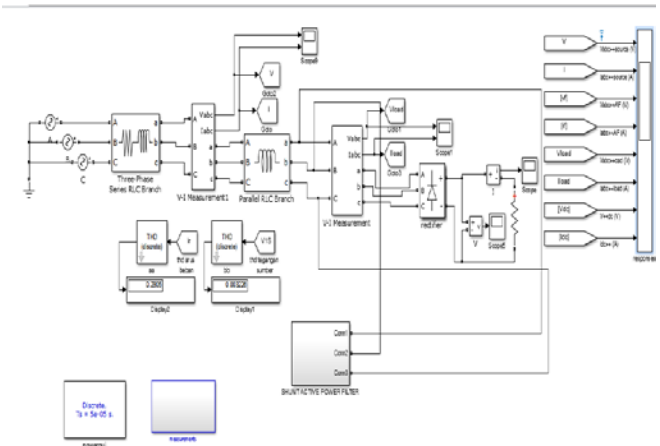

**Figure 15 Model with Shunt active power filter(SAPF)**

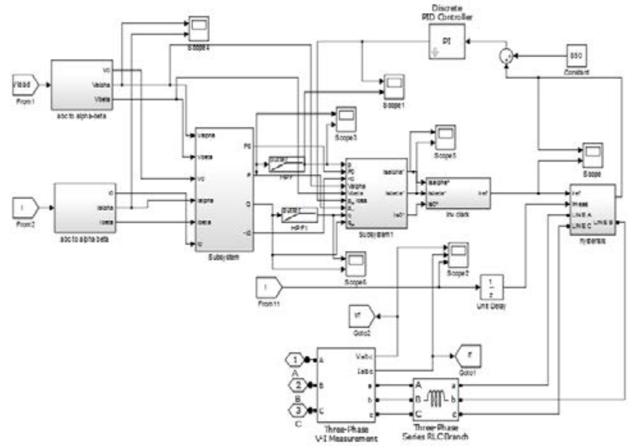

**Figure 16 Shunt active power filter(SAPF)**

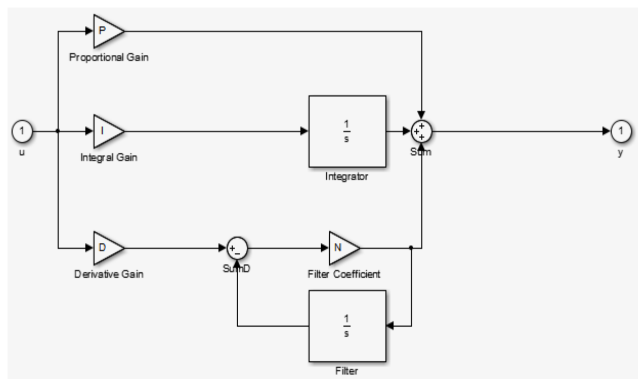


**Figure 17 Sub system of Discrete PID Controller block**

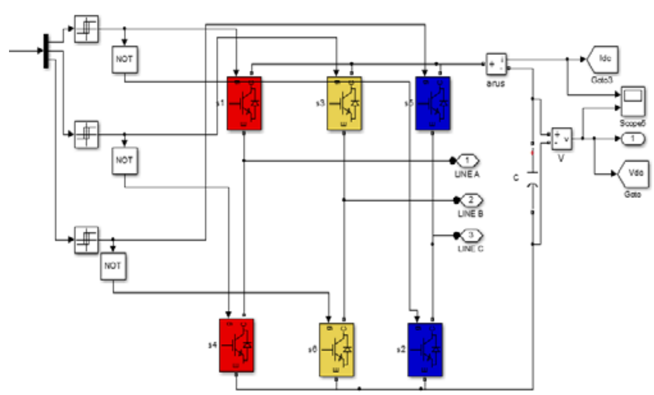

**Figure 18 Sub system of Hysteresis current controller block**

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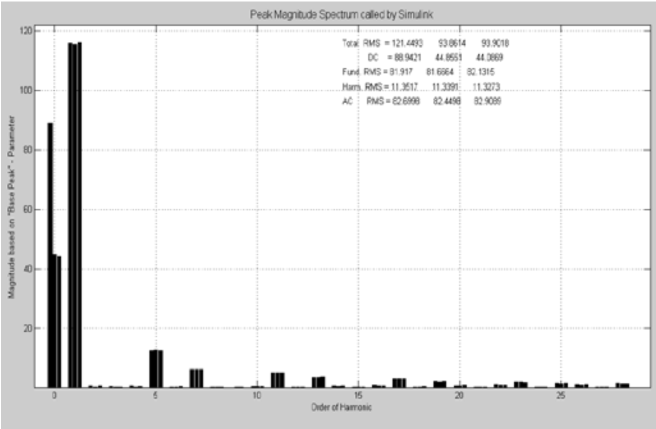


**Figure 19 THD with shunt active power filter**

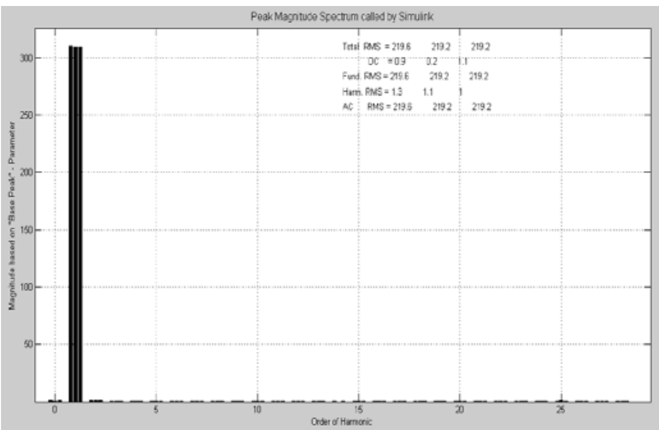


**Figure 20 THD with shunt active power filter**

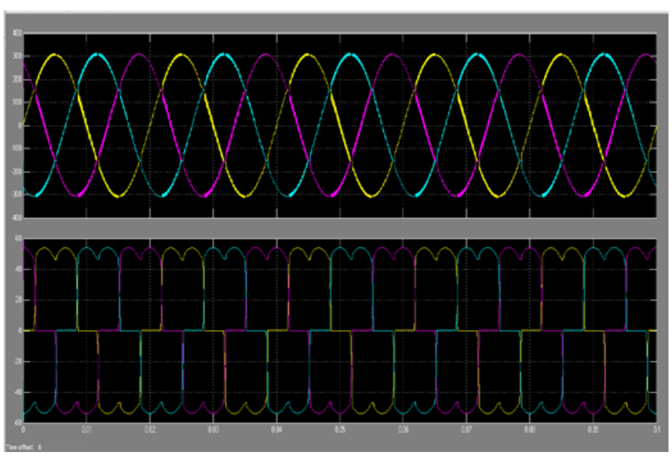

**Figure 21 Load Current(I) and Voltage(V) with shunt active power filter**

### D. Simulation Circuit with Hybrid active power filter (or) Shunt active power filter(SAPF) and tuned passive harmonic filter

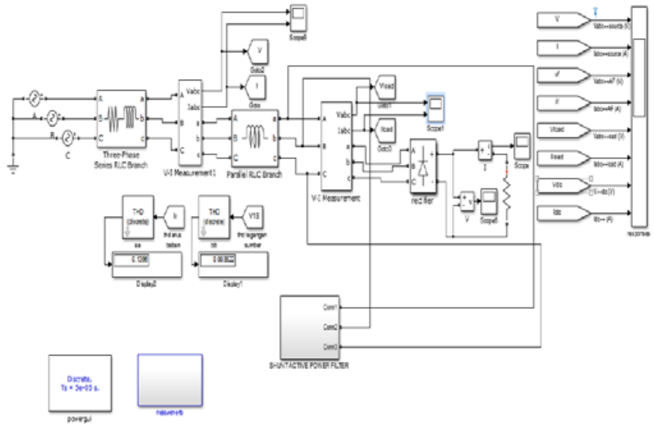

**Figure 22 Model of Hybrid active power filter or Shunt Active Power Filter with tuned passive harmonic filter**

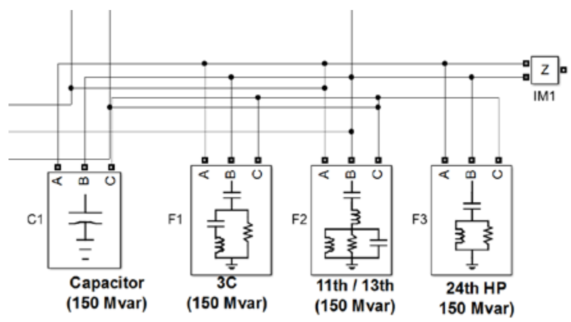


**Figure 23 Subsystem block of Tuned Passive harmonic filter**

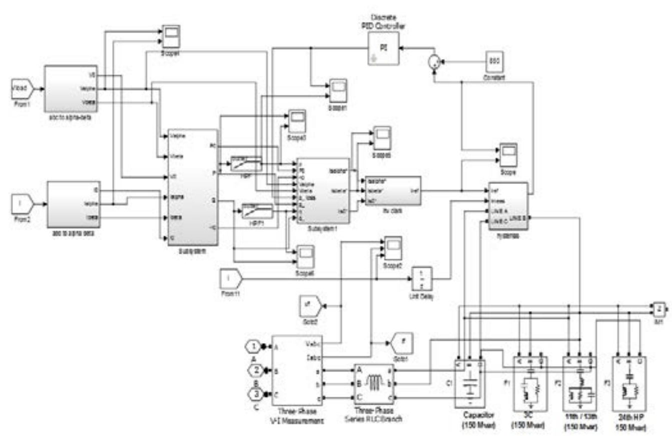

**Figure 24 Shunt Active Power Filter with tuned passive harmonic filter**

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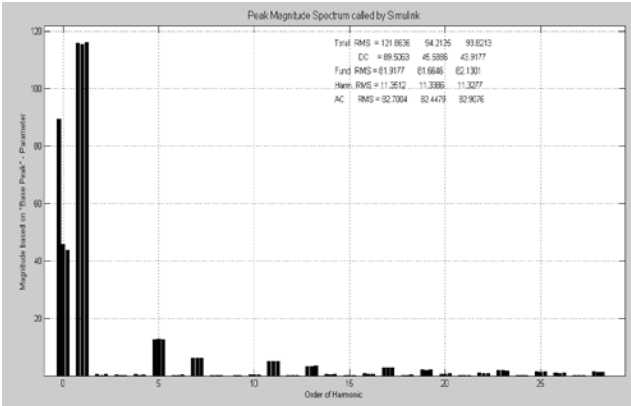


**Figure 25 THD with shunt active power filter and tuned passive harmonic filter**

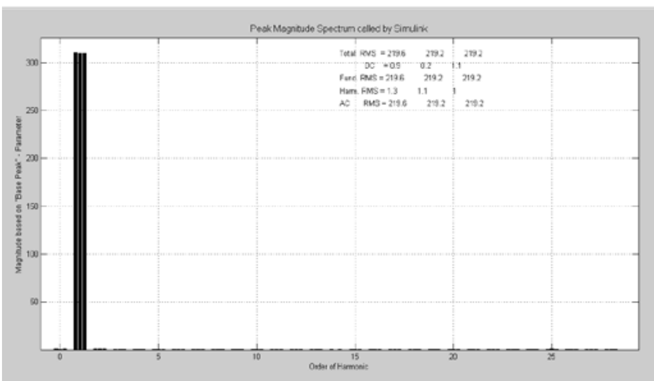


**Figure 26 THD with shunt active power filter and tuned passive harmonic filter**

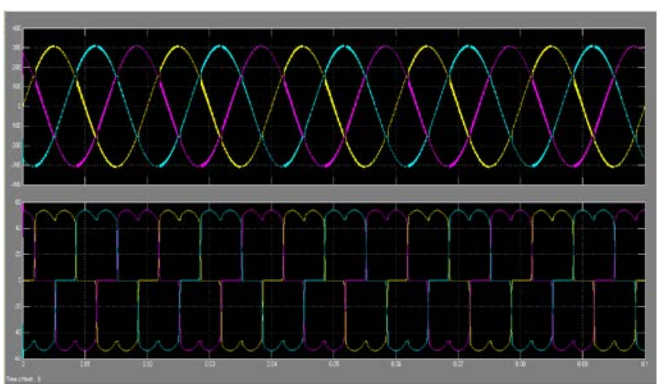

**Figure 27 Load current(I) and Voltage(V) with Hybrid active power filter or shunt active power filter and tuned passive harmonic filter.**

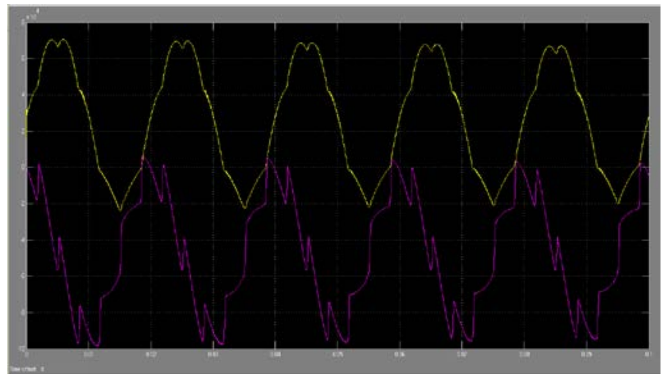

**Figure 28 Active and Reactive Power**

## 8. Result

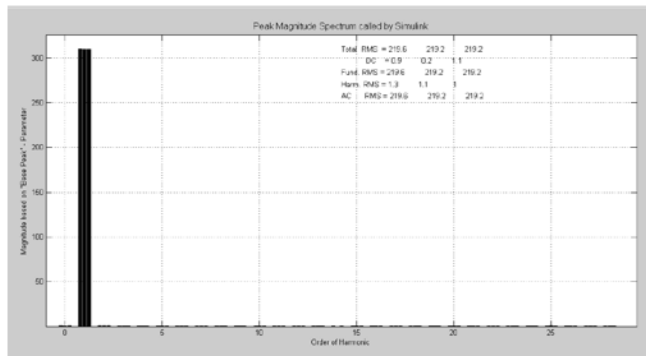


**Figure 29 THD with Hybrid active power filter or shunt active power filter and tuned passive harmonic filter**

In the figure shows the source current, load current and the compensating current and voltages for the system containing the hybrid active power filter. The filter is connected with the 3-phase circuit breaker, breaker will start at 0.15 second and will be remain in the 'ON' position till 0.15 second.

While at the same time it is seen that the supply current sinusoidal then the THD will reduced to 0.1396 from 0.295 while on the other side the voltage for THD will reduce from 0.003822 from 0.003226 with the application of the combination of Shunt Active power filter(SAPF) and Tuned passive harmonic filter (TPHM) or Hybrid active power filter.

SAPF also compensate the reactive power of the given supply it is seen that when the breaker is in the OFF position the demand of the reactive power is supplied to the load by the source but when the breaker is in the ON position i.e from 0.05sec – 0.15 sec, the reactive power is then supplied by the HAPF and source supplies only the active power to the system.

## 9. Comparison

**Table 1**

| Quantity | Without any Filter | With Tuned Passive harmonic Filter (TPHF) | With Shunt Active Power Filter (SAPF) | With (SAPF) and (TPHF) |
|---|---|---|---|---|
| Current (THD) | 0.2905 | 0.2912 | 0.2905 | 0.1396 |
| Voltage (THD) | 0.003226 | 0.003692 | 0.003226 | 0.003822 |

**Figure 30 Comparison table of THD**

Above table 1 is shows the improvement of the harmonics in the voltage and current in a 3-phase supply by comparing the result we get to the conclusion that when there is not any filter and when there are both the Shunt Active Power Filter(SAPF) and Tuned Passive Harmonic Filter(TPHF) or the Hybrid active power filter is present ,it should be noted that power quality is greatly be improved when the value of the total harmonic distortion (THD) is less than unity.

## 10. Conclusion

In this paper, it is described about the use of Hybrid active power filter(HAPF) which is being designed to reduce the harmonics in the 3-phase system with the help of P-Q theory by applying the THD and also for the injection of reactive power in the system.
Hybrid active power filter(HAPF) is basically the combination of Shunt active power filter and the Tuned passive harmonic filter(TPHF) and it is also considered as a reliable technique for the elimination of harmonics because of its fast response and the high quality of filtering.
The control system is also being proposed in this for the removal of current harmonics which is being proposed by the non linear load, P-Q theory is used for generating the reactive current and for the representation of the instantaneous power theory and for its controlling the reference current hysteresis current controller is used which is being implemented by simulink. In this research paper the comparative analysis is done which is based on Total Harmonic Distortion (%THD) and Reactive power of the system, without any filter, With Tuned Passive Harmonic Filter (TPHF), with Shunt Active Power Filter(SAPF) and with Hybrid active power filter (HAPF) or Shunt Active Power Filter (SAPF) and Tuned Passive Harmonic Filter (TPHF) which is being done by using MATLAB simulation.

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