# Design of Shunt Hybrid Power Filter for Mitigation of Harmonics Using Hysteresis and PI Controller

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***Abstract—***In the existing distribution system, non-linear loads cause power quality concerns such as harmonics at source (supply) current, voltage sag and voltage swell, and so on. Primary purpose of the project is to reduce source(supply) current harmonics while increasing THD. Passive filters were used to remove the certain harmonics. A SHPF is designed in this study to diminish harmonics at the supply side for nonlinear loads by connecting both passive filters and active filters parallelly. In shunt passive filter (SPF), a tuned RLC circuit functions as a band-pass filter for a certain harmonic. Shunt hybrid power filters are generally voltage source inverters (VSIs) that use Clarke's transformation to create reverse harmonic current. The control strategy is done by building a Shunt Hybrid Power Filter (SHPF) for a nonlinear load using instantaneous reactive power theory. To validate the proposed analysis, thorough simulation and modelling in MATLAB/SIMULINK shall be done. The results demonstrate that, suggested regulator on shunt hybrid power filter (SHPF) decreases total harmonic distortion (THD) of source current from 28.38 % to 0.36 %.

**Keywords—**Power Quality, Inverse Clarke’s transformation, Instantaneous reactive power theory, Shunt Hybrid Power Filter (SHPF), Clarke’s transformation.

## I. INTRODUCTION

Commercial appliances require regular high-quality power supply. Numerous elements, including voltage(v) & frequency(f) changes power outages, faults, harmonics because of non-linear loads, and so on, have an impact on the quality of power provided to the consumer. As a result, the apparatus's life duration is reduced. Thus, issues produced by harmonics should be removed to improve the operation of end-user equipment as well as the overall power system. [1]-[3]. Filters must be constructed to counteract the influence of harmonics created in the system by nonlinear loads. Several filter topologies are widely discussed in the paper. In [4]-[6] filters which are passive were first used in filtering just specified harmonics which are impacted by system impedance and cause resonance. The usage of an APF with numerous control algorithms to improve system reliability is described [7]. The active filter must be constructed with a good control algorithm to improvise the specs of the passive filters as well as the overall system. In [8–11] the active filter is managed by employing instantaneous PQ theory.

Primary purpose of control system is to develop an active power filter (APF) to supply current back into the line while reducing harmonic content [12]-[15].Active filters have certain disadvantages, such as requiring higher rating converter, being highly costly than passive filters, being bigger, and having higher losses. For avoiding this disadvantage, a hybrid power filter is designed that is the combination of both passive filter and active filters are a viable option for improving power quality [16], [17].

Passive components like resistors(R), inductors(L), capacitors(c), and single or multiple voltage source converters (VSC) are used in hybrid power filters. In terms of usability and efficiency, hybrid power filters exceed passive filters in filtering harmonics, particularly for high power purposes [18],[19]. In this approach, a hybrid filter is created that consists of both active and passive filters and are connected in parallel. Distinct control approaches, like machine intelligence and artificial neural networks, are utilized in designing of hybrid filter reduce harmonics in lines caused by nonlinear loads [20-[25].

In this study, an effort is made to establish a control mechanism in the SHPF design based on instantaneous reactive power concept to minimize harmonic currents in the source side. To minimize harmonics in supply current for RL non-linear loads, a shunt hybrid filter is simulated using the MATLAB Simulink software. The simulation results indicate that hybrid filters beat both active filters and passive filters. The harmonics on AC side is diminished to 0.36% from 28.38% by executing instantaneous control procedure in SHPF.

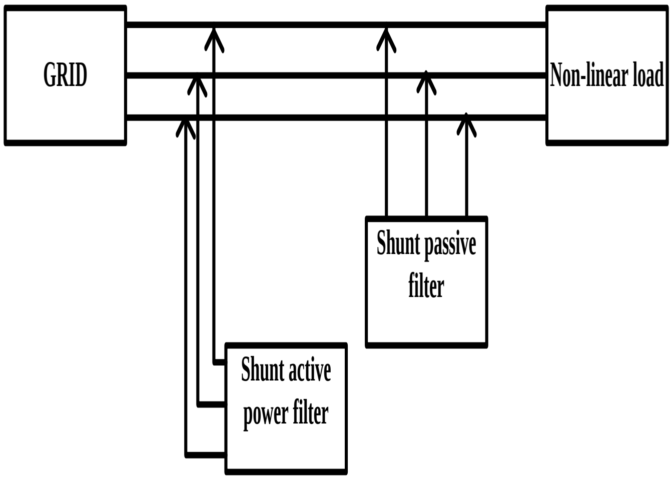


Fig. 1 Block diagram of the proposed system

## II. GRID CONNECTED SHUNT HYBRID POWER FILTER

Figure 1 illustrates the basic diagram of SHPF, which includes shunt active filter (SAF) and a passive filter (PF). The power grading of an APF is determined by the frequency order that must be sorted. As a result, an APF (active power filter) is used to minimise lower harmonics along with a lower power rating, reducing the cost and size of the active filter. This methodology is used in the model of the shunt hybrid power filter.

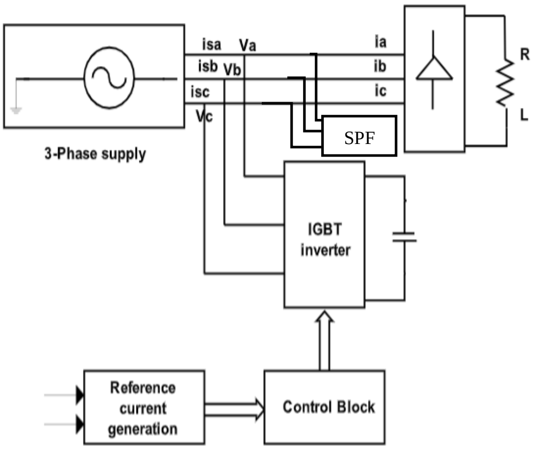


Fig. 2 Block diagram of Grid connected shunt hybrid power filter

Figure 2 depicts a block schematic of a shunt hybrid power filter, in [26] which includes a pulse width modulation converter and a filter regulator. This converter is made up of a three-legged circuit and a modulation controller that generates gate pulses for the inverter. In a hybrid filter, the controller determines the currents to be regulated such that the inverter accurately detects and introduces back into the line at the point of common coupling. The controller receives voltages $v_a$, $v_b$,$v_c$ and currents $i_a$,$i_b$,$i_c$ from the lines as input. To compute the current harmonics exhibited in the lines, a control method based on instantaneous reactive approach is employed in the controller. The harmonic in currents to be regulated from the controller $i_{ca}$*, $i_{cb}$*, $i_{cc}$* are fed into the gate contacts of the voltage source inverter. The inverter's output currents ica, icb, and icc are fed back to the line, which contains harmonic currents that must be regulated according to non-linear loads.

## III. CONTROL METHODOLOGY

A three-phase shunt active power filter with an energy storage capacitor on the DC bus and a voltage source inverter (VSI) with IGBT switches. The PI controller and the Hysteresis current controller make up the control block (HCC). The PI controller's job is to calculate the reference current based on the detected DC bus voltage. HCC is in charge of generating the VSI's switching pulses.

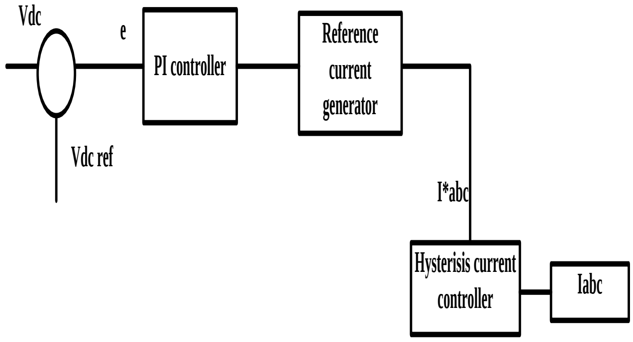


Fig. 3 Block diagram of the control unit

### A. PI Controller

The PI controller's job is to calculate the reference current based on the detected DC bus voltage. In shunt active power filters, the proportional integral (PI) controller has been widely utilised for DC bus voltage adjustment. It's simple to put into practise and yields good results. A shunt active power filter's control system should compute the reference current waveform for each of the inverter's three phases, keep the dc link voltage constant, and create the inverter gating pulses. A proportional term, Kp, and an integral term, Ki, make up a PI controller. The reaction to the current error is determined by the proportional value; similarly, the response based on the sum of recent errors is determined by the integral part.

### B. Reference Current Generator

The performance of an active power filter is determined by a number of parameters, the most important of which is the reference generation scheme. The filter objective is met if the filter current is the same as the reference current. There are a variety of methodologies, however the instantaneous active and reactive power theory (p-q theory) [27] was employed in this study. The reference current is generated in a five-step process. Clarke transformation, instantaneous p-q calculation and compensatory power selection, reference calculation, and ultimately inverse Clarke transformation are the steps. "αβ0-

transformation" is the base to p-q theory, where it includes real matrix & that converts three phase voltage and current into the αβ0 stationary reference frame voltage and current.
The Clarke transformation voltage for a 3-phase, 4-wire system is shown below equation.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

Because our subject is about a three-phase, three-wire system, we may ignore or omit zero sequence voltage and current. As a result, $v_0$ may ignored in the following equation, the similar calculation can also be employed to current for simplicity.
After removing the zero-sequence current and voltage, the following equations are shown.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (3)$$

Using Clarke transformation, we obtained the voltage(V) and current (I) in the frame of αβ from the previous equations (2) and (3).We must now compute the instantaneous active and reactive power using vα and vβ , iα and iβ.
The equation is

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

The real and imaginary powers are p and q. The references Iα* & Iβ* may then be obtained using the below equation.

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2+V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (5)$$

Then determined using the Clarke equation's inverse transformation. The active filter's reference frame current abc determined. the inverse Clarke transformation is shown below

$$\begin{bmatrix} i_\alpha^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (6)$$

### *C. HCC-Hysteresis Current Controller*

The VSI requires a correct gate pulse from the current controller to follow the reference current.

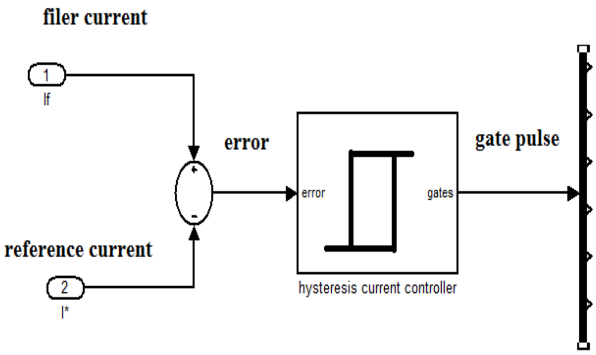


Fig. 4 Hysteresis Current Controller

The current controller is utilized here to regulate the gate pulse of the power converter. The major supply current is examined regularly and contrasted to the reference currents obtained by the suggested technique. To obtain specific control, the IGBT device be supposed to be configured in such a way that error signal considers zero, resulting in a rapid response. The hysteresis current control has a quick reaction time and high reliability. And the reference current is matched to the real current of the system. If it go beyond the top of the H-band, the top switch on the voltage source inverter limb is switched off and the lower switch is switched on. Due to that the current begins to decay. If the current cross over the lower limit of the H-band, the current flows backwards into the H-band. The real current is constrained to trace the reference current inside the H-band during this operation [28].

## IV. MATLAB SIMULATION RESULTS

The suggested shunt hybrid active power filter was tested under nonlinear load simulations utilising modern continuous simulation tools and simulation language.

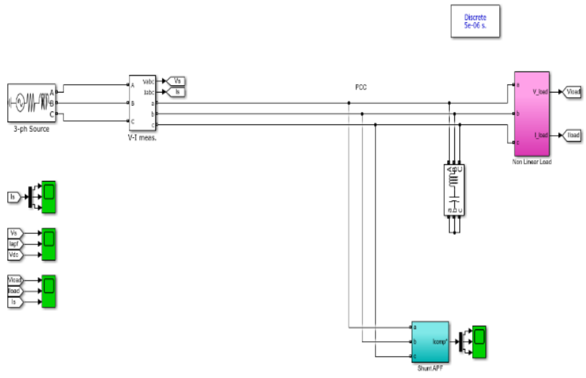


Fig 5 Schematic diagram of proposed system

TABLE 1 Demonstrates system parameters under Non-linear load

| ***S. NO*** | ***Parameters*** | ***Values*** |
|---|---|---|
| 1. | Line-to-line grid RMS voltage | 156V |
| 2. | Frequency | 50HZ |
| 3. | 3-phase Nonlinear load | R=60Ω |
| 4. | Shunt Passive Filter | L=100e$^3$H,C=100e$^6$ F |
| 5. | Shunt Active Filter | 3-Phase VSI inverter with 6- IGBT's |

When a linear load is associated to the grid, the supply side voltage(V) and current(I) are pure sinusoidal, hence no adjustment is required. However, if a nonlinear load is associated to the grid, the supply current varies, indicating that it is not sinusoidal, thus we needed some compensation techniques to make the supply current sinusoidal.

Deliberate the non-linear load situation without any control at the moment, and the succeeding result will be attained: non sinusoidal load current and supply current are illustrated in figures 6 and 7.

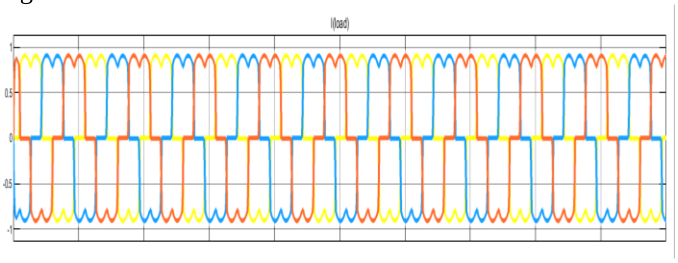

Fig. 6 Load current ($I_{Load}$) without Compensation

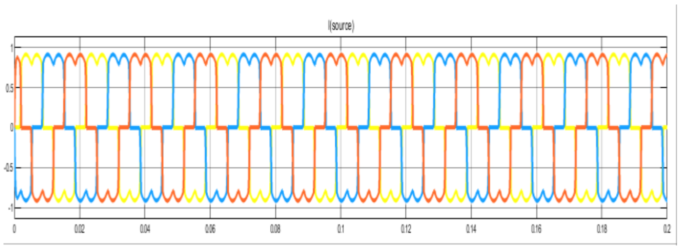

Fig. 7 Source current ($I_{Source}$) without Compensation

Consider using a non-linear load with a SHPF to decrease source (Supply) current harmonics. Figures 8 and 9 shows the MATLAB simulation results that we obtained.

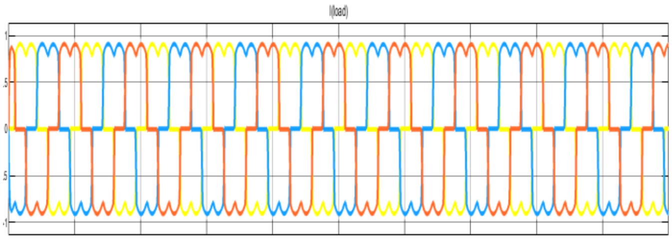

Fig. 8 Load current ($I_{Load}$) with Compensation

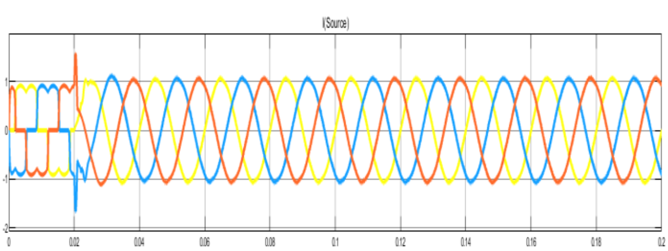

Fig.9 Source current ($I_{Source}$) with Compensation

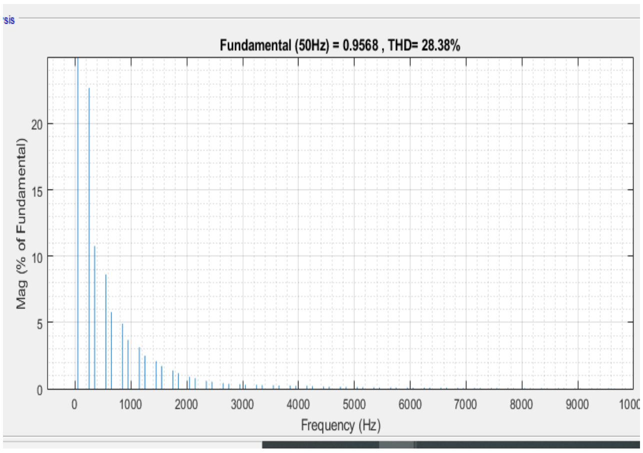


Fig 10. % THD of source currents without filter

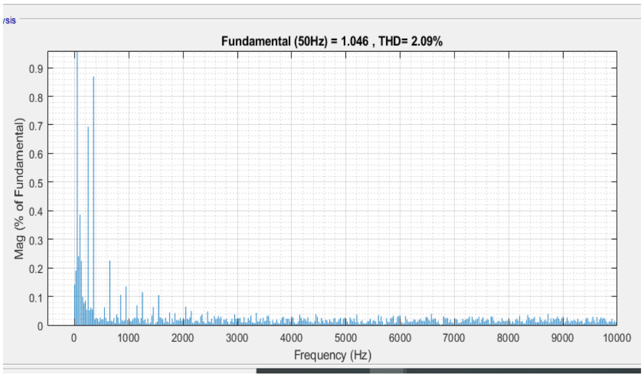


Fig 11. % THD of source currents with shunt active power filter

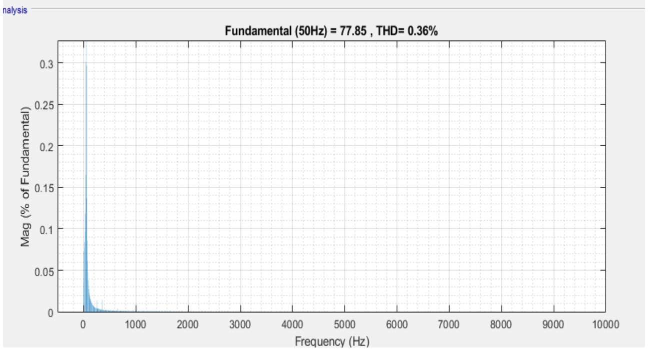


Fig 12. % THD of source currents with shunt hybrid active power filter

Figure 11 illustrates that by utilising shunt active power filter, the supply current harmonics are minimised with a less harmonic distortion of 2.09%. Figure 12 indicates that for nonlinear load conditions, shunt hybrid power filter decreases harmonics in source(Supply) current and the THD value of source current from 28.38 % to 0.36 %.

## VII. Conclusions and Future work

The proposed work uses the MATLAB Simulink platform to create a control algorithm based on instantaneous reactive power theory to regulate HPF (hybrid power filter). Through feedback compensations, the proposed algorithm on shunt hybrid power filter (SHPF) increases the performance of both passive and active filters. The shunt hybrid power filter improves power system power quality even with fluctuating nonlinear loads. The simulation results show that by applying the control algorithm on shunt hybrid power filter, overall THD percentage on the AC side has been decreased from 28.38 % to 0.36 %.

Authors are now investigating various switching approaches for the inverter of a SHPF (shunt hybrid power filter) in order to increases power efficiency by minimizing noise injected into the grid.

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