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# Power Quality Improvement in Grid from Wind Turbine by Using Shunt Hybrid Active Filter

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## ABSTRACT

This paper presents a shunt hybrid active power filter for power quality improvement. The SHAPF improves the source power factor to unity, provides reactive power compensation and reduces the source harmonics. Therefore the power quality can be enhanced efficiently by using this hybrid active power filter. Finally, representative simulation results of a three phase shunt hybrid active power filter are presented to verify the effectiveness of SHAPF in power quality enhancement.

**Keywords:** Active power filters (APFs), hybrid active power filters (HAPFs), passive power filters (PPFs), power quality enhancement.

## I. INTRODUCTION

In today‘s environment, electronic loads are very sensitive to harmonics, sags, swells and other disturbances. Among these parameters, current harmonics have become a growing power quality concern. One more power quality issue is reactive power compensation. Reactive power is required to maintain the voltage to deliver active power. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines. Though reactive power is needed to run many electrical devices, it can cause harmful effects on electrical appliances. So the reactive power compensation is very important in electrical power system. So, power quality become important in the power system.

In the mid-1940s, passive power filters (PPFs) have been widely used to suppress current harmonics and compensate reactive power in distribution power systems [1] due to their low cost, simplicity, and high-efficiency characteristics. But, PPFs have many disadvantages such as low dynamic performance, resonance problems, and filtering characteristics that are easily affected by small variations of the system parameters [2]–[7]. Since the concept of an ―active ac power filter‖ was first developed in 1976 [1], [5], research studies on active power filters (APFs) for current quality compensation are getting more and more attention. APFs can overcome the disadvantages in PPFs, but their initial and operational costs are relatively high [2]–[6] because the dc- link operating voltage should be higher than the system voltage. This slows down their large scale application in distribution networks.

In addition, different hybrid active power filter (HAPF) topologies composed of active and passive components in series and/or parallel have been proposed, aiming to improve the compensation characteristics of PPFs and reduce the voltage and/or current ratings (costs) of the APFs, thus leading to improvements in cost and performance [2]–[13]. The

HAPF topologies in [2]–[8] consist of many passive components, such as transformers, capacitors, reactors, and resistors, thus increasing the size and cost of the whole system.

A transformer less shunt hybrid active power filter(SHAPF) has been recently proposed and applied for current quality compensation and damping of harmonic propagation in distribution power systems [12]–[13], in which it has only a few passive components. In this paper, an instantaneous power control scheme for the three-phase SHAPF is proposed and studied. In the following, a transformer less three-phase and its single-phase fundamental equivalent circuit model are illustrated in Section II. Then, the instantaneous power theory for hybrid active filter control is deduced in Section III. The simulation verification of the proposed HAPF is presented in Section IV.

## II. TRANSFORMERLESS THREE PHASE HYBRID ACTIVE FILTER

The schematic diagram of the shunt hybrid Active power filter (SHAPF) is presented in Fig 1. This configuration of hybrid filter ensures the compensation of the source current harmonics by enhancing the compensation characteristics of the passive filter besides eliminating the risk of resonance. It provides effective compensation of current harmonics and limited supply voltage distortion. The hybrid filter is controlled such that the harmonic currents of the nonlinear loads flow through the passive filter and that only the fundamental frequency component of the load current is to be supplied by the ac mains.

The HAPF topologies in [2]–[9] consists many passive components which increases the size and cost of the whole system which makes the topology non preferable. As a result, a shunt hybrid power filter topology named transformer less hybrid filter was proposed. The series connection between the passive filter and the voltage source converter is completed without using any matching transformer.

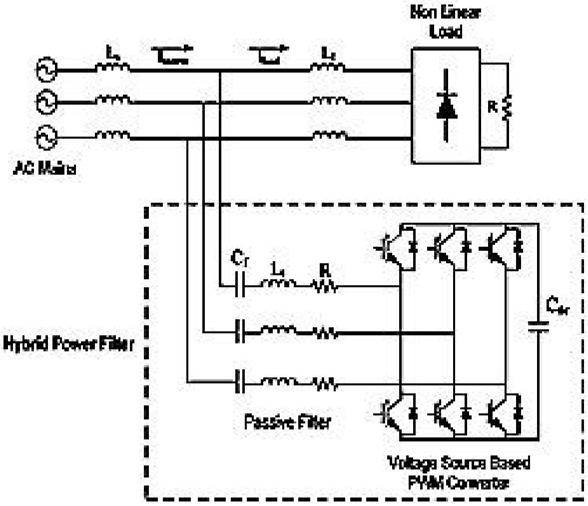

**Figure 1.** Transformerless Shunt Hybrid Power Filter

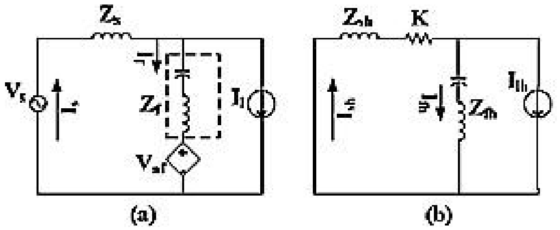

**Figure 2.** (a) Single Phase Equivalent Circuit (b) Harmonic Equivalent Circuit

In order to clarify the compensation characteristic of the shunt Hybrid Power Filter, the system can be simplified by obtaining its single phase equivalent circuit as indicated in (Fig 2) where $Z_s$ represents the source impedance and $Z_f$ represents the passive filter impedance. The non linear load is shown as an ideal current source ($I_l$), and the APF is considered as a voltage source.

If the active power filter terminal voltage is assumed to have no fundamental component, voltage across the PWM inverter can be represented as K x $I_{sh}$ at harmonic frequencies where ‗h‘ stands for the harmonic components and K represents the feedback gain.

Hence, assuming the source voltage to be pure 50Hz and considering the current directions as in Fig 2, the following equations can be obtained by applying Kirchhoff's voltage law.

$$V_{sh} - I_{sh}Z_{sh} - I_{fh}Z_{fh} - V_{af} = 0 \qquad (1)$$

Where,

$$V_{sh} = 0 \text{ and } V_{af} = K.I_{sh}$$

$$I_{lh} = I_{sh} + I_{fh} \qquad (2)$$

Combine (1) and (2),

$$I_{sh} = Z_{sh}/(Z_{fh} + Z_{sh} + K) \qquad (3)$$

Equation (3) indicates that as the active power filter is connected to the system, feedback gain K acts as a damping resistor which suppresses the resonance between the supply and the passive filter. Theoretically, as K approaches to infinity, the harmonic content of the source current goes towards zero. However due to stability problems in the control loop, the gain K should be limited to certain values.

## III. INSTANTANEOUS POWER CONTROL TECHNIQUE

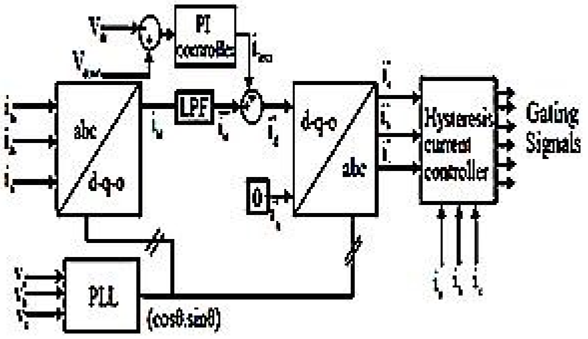

**Figure 3.** Instantaneous power control technique

Figure 3 shows the instantaneous power control block diagram for the three phase shunt hybrid active power filter, which consists of three parts: instantaneous power theory, calculation of current reference and regulation of DC voltage.

### A. *Instantaneous power theory*

The control strategy of the active filter is based on the generation of reference source currents. These reference source currents are generated using synchronous frame reference theory (SRF). The load currents ($i_{la}$, $i_{lb}$, $i_{lc}$), PCC voltages ($V_a$, $V_b$, $V_c$) and dc link voltage ($V_{dc}$) are sensed and used as feedback signals. The load currents in a-b-c coordinates are transformed in to d-q coordinates using Park's transformation. The d-q components of the load currents are calculated as,

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta - a) & \cos(\theta + a) \\ \sin\theta & \sin(\theta - a) & \sin(\theta + a) \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Where cosθ and sinθ are obtained from three phase PLL. These d-axis and q-axis currents can be separated into two parts namely average and oscillatory parts as,

$$I_d = \bar{I}_d + \tilde{I}_d$$

$$I_q = \bar{I}_q + \tilde{I}_q$$

The reference source currents in d-q coordinates are transformed into a-b-c coordinates using inverse Parks transformation and it is expressed as,

$$\begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix} = \left(\frac{2}{3}\right) \begin{bmatrix} \cos\theta & \sin\theta \\ \cos(\theta - a) & \sin(\theta - a) \\ \cos(\theta + a) & \sin(\theta + a) \end{bmatrix} \begin{bmatrix} I_a^* \\ I^* \end{bmatrix}$$

*where,*

$$a = \frac{2}{3}\pi$$

### *B. Calculation of current reference.*

The reference source currents ($i_a^*$, $i_b^*$ and $i_c^*$) are compared with the sensed source currents ($i_a$, $i_b$ and $i_c$). The switching sequence of the IGBTs is generated from the PWM current controller. The current errors are calculated as,

$$I_{a\_err} = i_a^* - i_a$$
$$I_{b\_err} = i_b^* - i_b$$
$$I_{c\_err} = i_c^* - i_c$$

This error signals are fed to the current controller for switching of the IGBTs of the active filter.

### *C. Regulation of dc voltage*

DC link voltage control is maintained by a proportional plus integral (PI) regulator. DC link capacitor voltage is build up and regulated without any external power supply. In order to meet the loss inside the active power filter, an amount of active power is required and generated by producing a fundamental ac voltage controlled by the active filter. Since fundamental leading current flows through the passive filter, the active filter should generate a fundamental voltage that is in phase with this leading current. As a result, the current reference obtained in this control loop is added to the reactive current component.

## IV. SIMULATION RESULTS

### *A. No Load Change Condition*

### *1) Before Compensation*

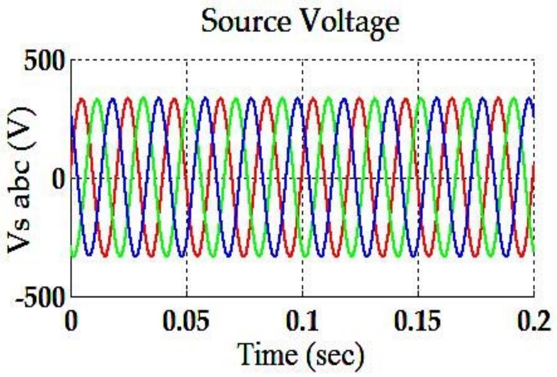

**Figure 4.** (a)

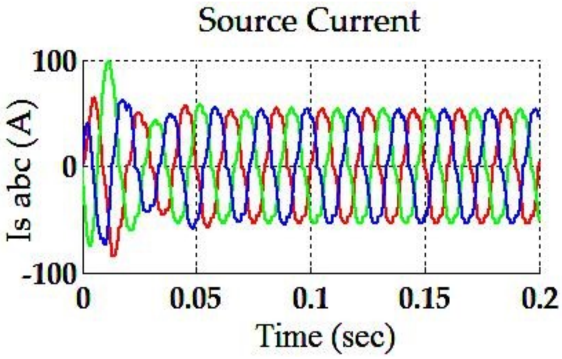

**Figure 4.** (b)

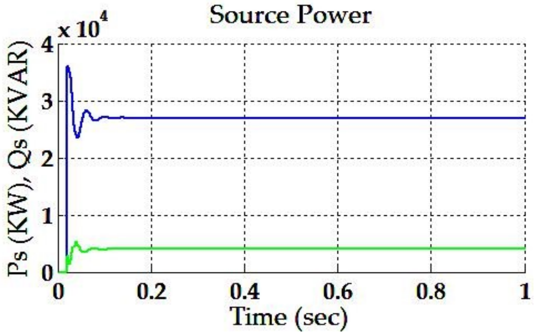

**Figure 4.** (c)

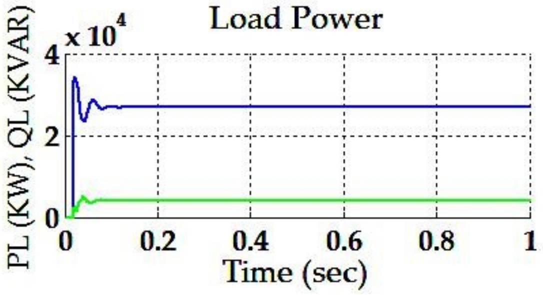

**Figure 4.** (d)

**Figure 4.** (a),(b),(c) and (d) shows the system response without HAPF

### *2) After Compensation*

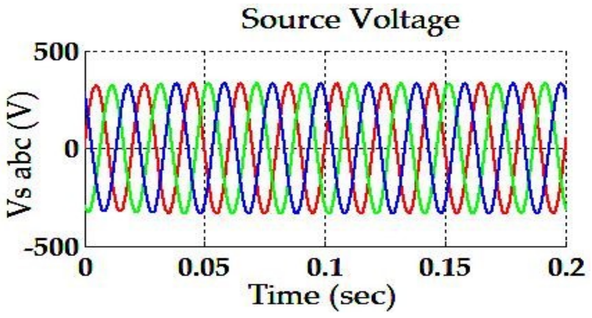

**Figure 5.** (a)

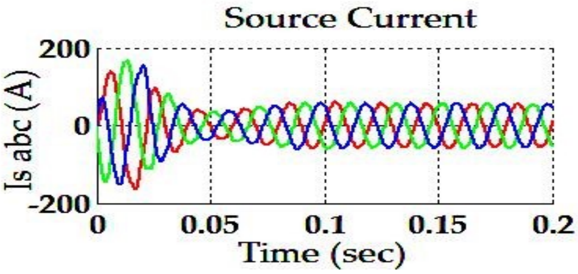

Figure 5. (b)

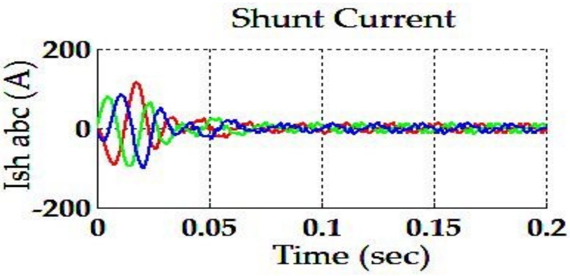

Figure 5. (c)

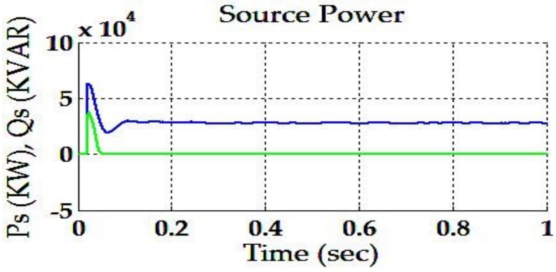

Figure 5. (d)

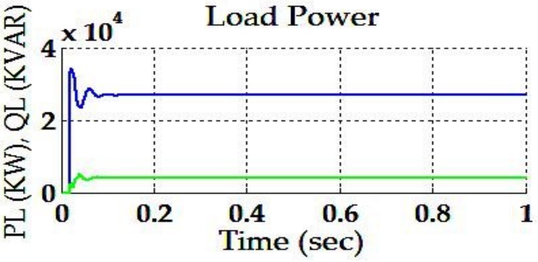

Figure 5. (e)

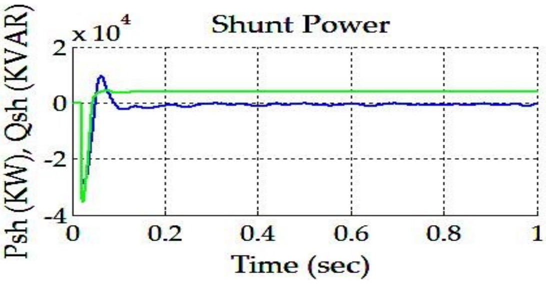

Figure 5. (f)

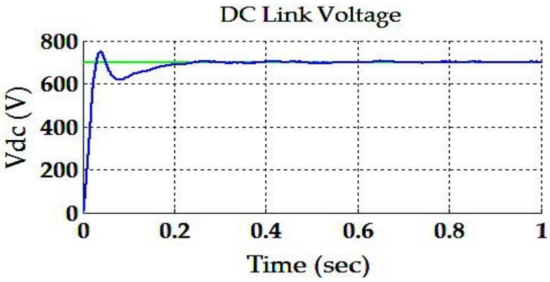

Figure 5. (g)

**Figure 5.** (a) to (g) shows the performance of HAPF.

### B. Load Change Condition

#### 1) Before Compensationg

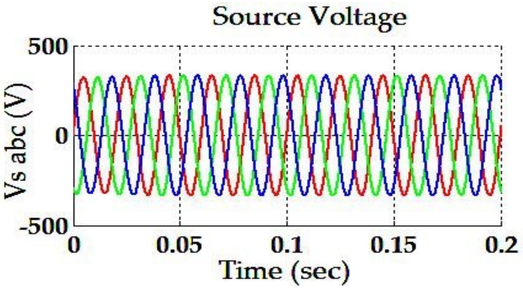

Figure 6. (a)

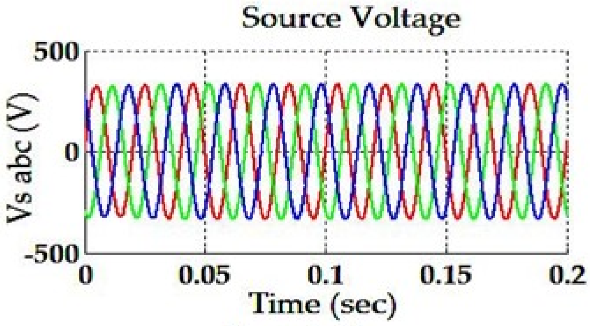

Figure 6. (a)

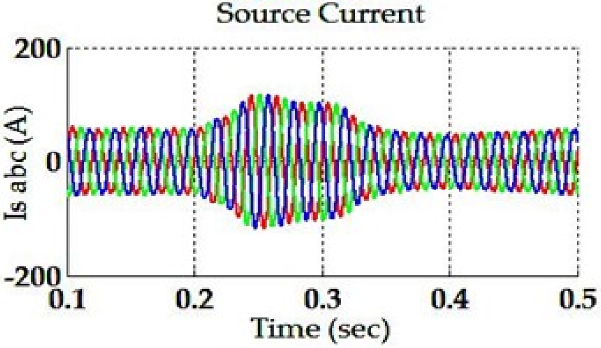

Figure 6. (b)

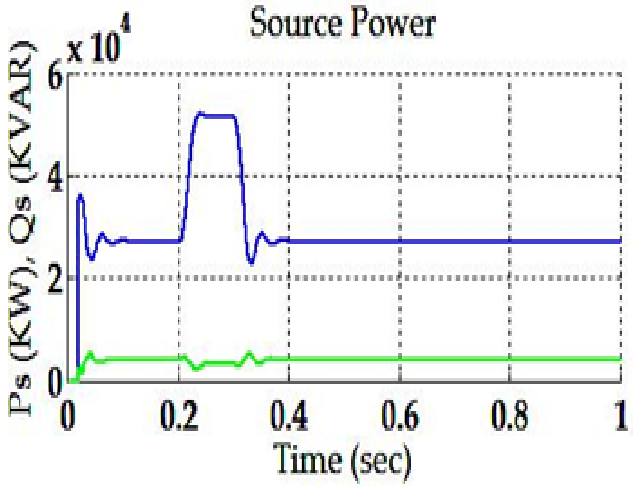

Figure 6. (c)

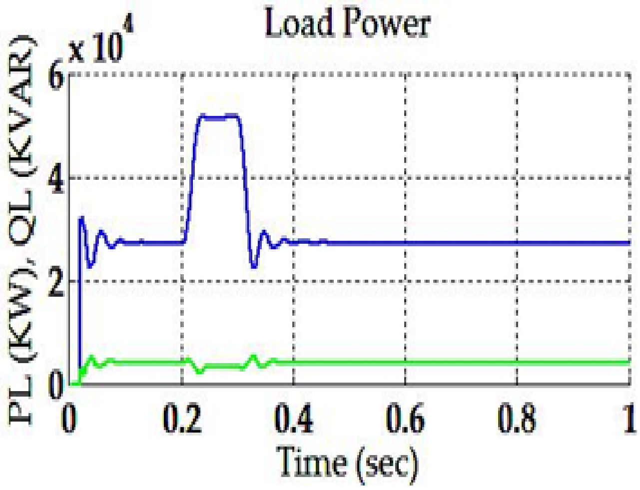

Figure 6. (d)

**Figure 6.**(a) to (d) shows the system response without HAPF. At 0.2 sec. second load is connected with the first load.

At 0.3 sec, second load is disconnected. The above figure shows the simulation response during the load variation.

*2) After Compensation*

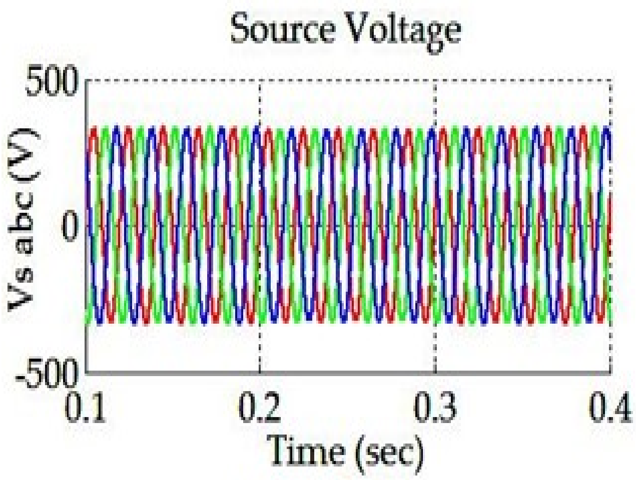

Figure 7. (a)

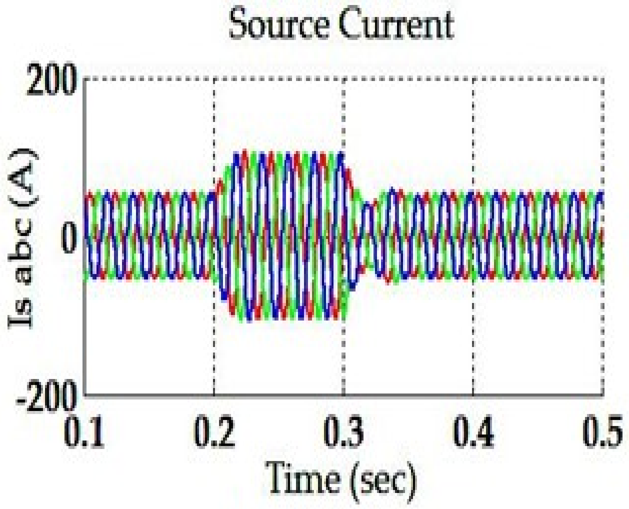

Figure 7. (b)

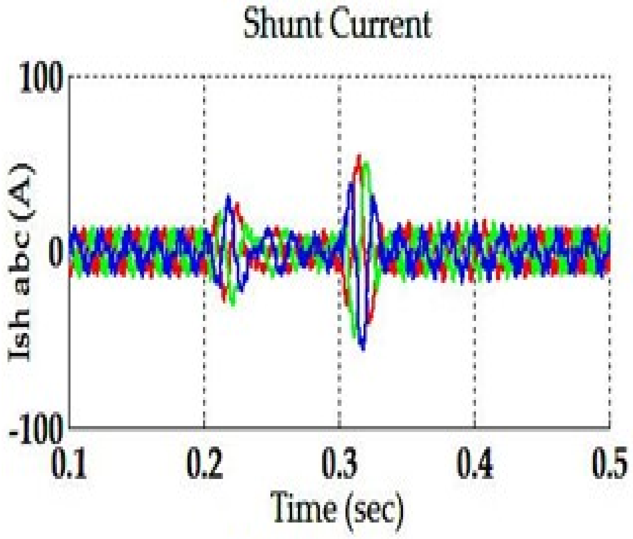

Figure 7. (c)

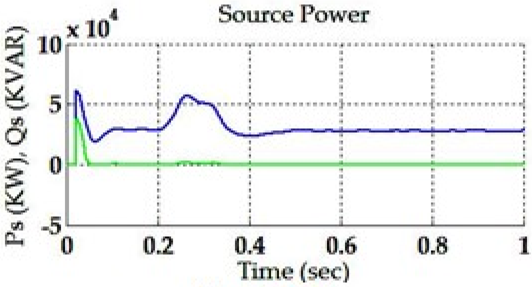

**Figure 7.(d)**

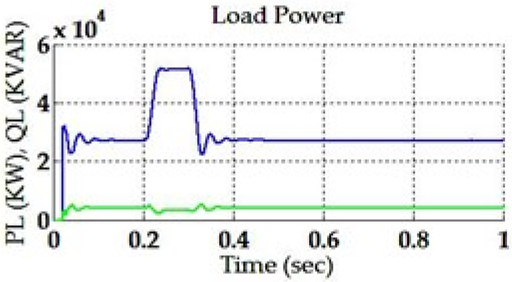

**Figure 7. (e)**

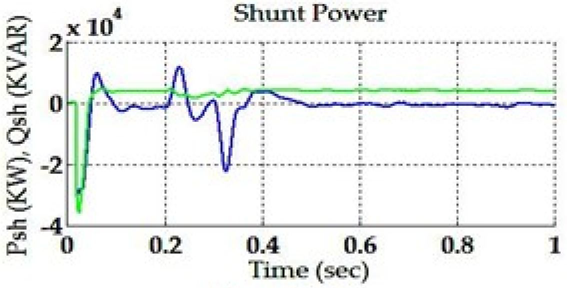

**Figure 7. (f)**

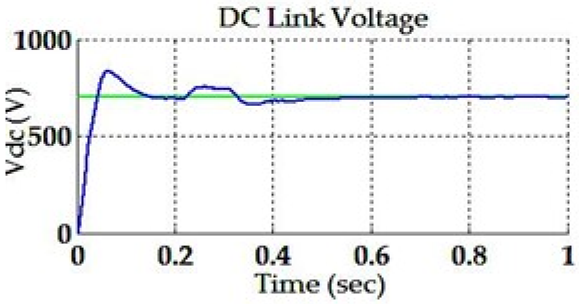

**Figure 7. (g)**

**Figure 7.** (a) to (g) shows the performance of HAPF.

**Table 1.** Load Specification

| | |
|---|---|
| Nominal Line-to-Line rms Voltage | 415 V |
| Line Frequency | 50 Hz |
| Diode Rectifier Rating | 30 KW |
| Rs | 0.1 Ω |
| Ls | 0.1 mH |
| DC Link Capacitor | 3000 µF |
| Filter Capacitor | 3000 µF |
| Filter Inductor | 15 mH |
| DC Link Voltage | 700 V |
| AC Line inductor | 10 mH |

**Table 2.** Dc Link Voltage Regulation

| | Before Compensation | | After Compensation | | | |
|---|---|---|---|---|---|---|
| | $P_S$ (KW) | $P_L$ (KW) | $P_S$ (KW) | $P_L$ (KW) | $P_{sh}$ (KW) | $V_{dc}$ (KW) |
| NoLoad variation | 27.1 | 27.1 | 27.6 | 27.1 | -0.5 | 701 |
| Load variation | 27.09 | 27.09 | 27.91 | 27.1 | -0.81 | 699 |

**Table 3.** Reactive Power Compensation

| | Before Compensation | | After Compensation | | |
|---|---|---|---|---|---|
| | $Q_S$ (KVAR) | $Q_L$ (KVAR) | $Q_S$ (KVAR) | $Q_L$ (KVAR) | $Q_{sh}$ (KVAR) |
| No Load variation | 3.99 | 3.99 | 0.039 | 4.03 | 3.99 |
| Load variation | 3.99 | 9.99 | 0.055 | 4.03 | 3.97 |

**Table 4.** Power Quality Improvement

| | Before Compensation | | | | After Compensation | | | |
|---|---|---|---|---|---|---|---|---|
| | $Q_s$ (KVAR) | $I_s$ (A) | $DPF_s$ | $I_s$THD (%) | $Q_s$ (KVAR) | $I_s$ (A) | $DPF_s$ | $I_s$THD (%) |
| No Load Variation | 3.99 | 54.2 | 0.8 | 9.02 | 0.039 | 56 | 1 | 3.08 |
| Load variation | 3.99 | 54.2 | 0.8 | 9.02 | -0.81 | 55 | 1 | 3.78 |

The simulation responses for Rectifier RL load for both operating conditions are obtained. In no load and load change condition, the THD is compensated from 9.02% to 3.08% and 3.38% respectively by using instantaneous power technique which is represented in Table 3. Hence after compensation, in both the case the supply current THD is reduced to less than 5%, the harmonic limit imposed by the IEEE-519 & IEC-6000-3 standard. The main objective of the shunt hybrid active power filter is unity source power factor. It is achieved in both operating conditions which are shown in Table 3. And also Reactive power is compensated for both operating conditions with hybrid active power filter.

## SIMULATION OUTPUT

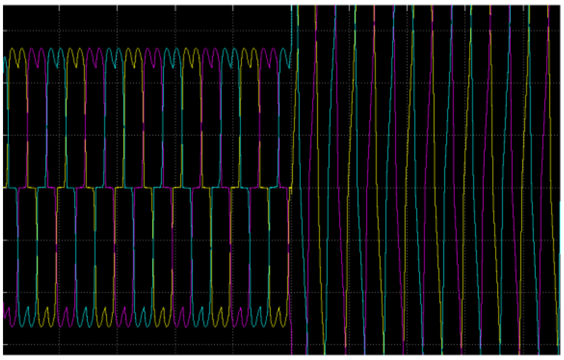

**Figure 8**

## HARDWARE

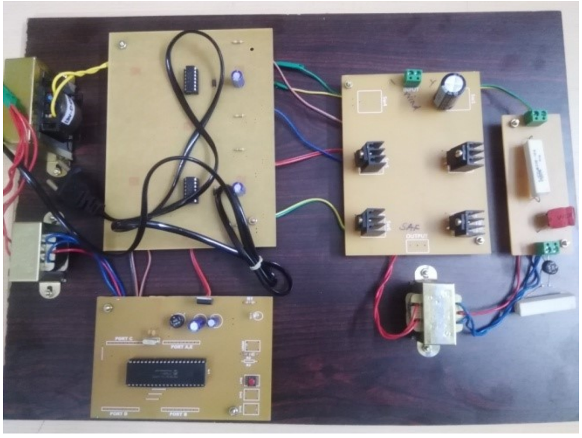

**Figure 9**

## V. CONCLUSION

This paper work presents design of transformer less hybrid active power filter (HAPF) for a distribution system. The above results show the comparative simulation results for both operating conditions. The hybrid filter reduces the harmonics as compare to open loop response. This hybrid filter is tested and verified using MATLAB simulation. A PI controller is implemented for three phase shunt hybrid power filter. The PI controller extracts the reference current from the distorted line current and hence improves the power quality parameters such as harmonic current and reactive power due to nonlinear load. Here the two operating conditions i.e. before and after compensation and the load change condition is analyzed. The harmonic current control and DC capacitor voltage can be regulated under these two conditions.

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