



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

Power Quality Enhancement Using Hybrid Active Filter

D.Jasmine Susila, R.Rajathy

Department of Electrical and electronics Engineering, Pondicherry Engineering College, Pondicherry

Abstract— This paper presents a transformerless 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.

Index Terms— 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.

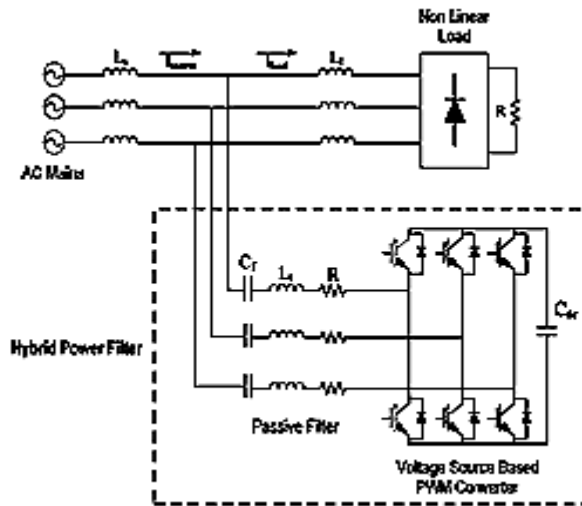


Fig 1 Transformerless Shunt Hybrid Power Filter

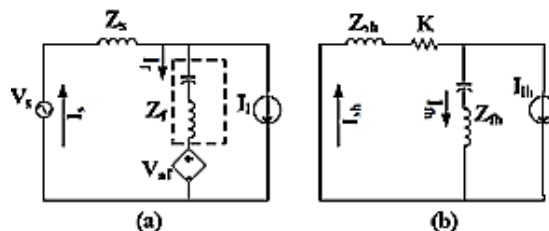


Fig 2 (a) Single Phase Equivalent Circuit (b) Harmonic Equivalent Circuit

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_1), 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 $K \times I_{sh}$ 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.

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

Where,

$$\begin{aligned} V_{sh} &= 0 \text{ and } V_{af} = K \cdot I_{sh} \\ I_{sh} &= I_{1h} + I_{fh} \end{aligned} \quad (2)$$

Combine (1) and (2),

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

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

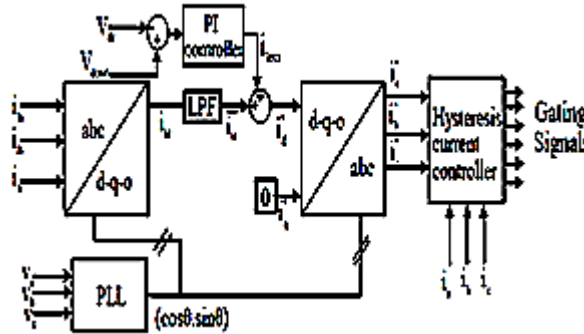


Fig 3 Instantaneous power control technique

Fig. 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 $\cos\theta$ and $\sin\theta$ 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,

$$\begin{aligned} I_d &= \tilde{I}_d + \bar{I}_d \\ I_q &= \tilde{I}_q + \bar{I}_q \end{aligned}$$

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

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

where,

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

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,

$$I_{a_err} = i_a^* - i_a$$



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

$$I_{b_err} = i_b^* - i_b$$

$$I_{c_err} = i_c^* - i_c$$

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

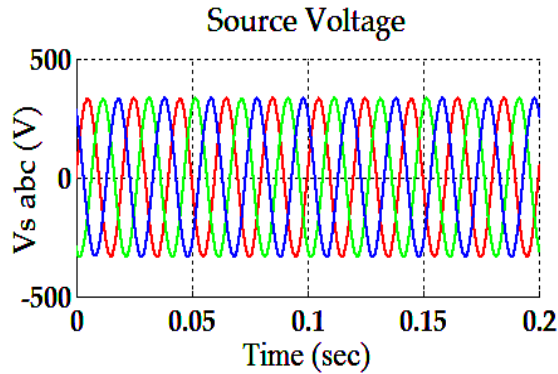


Fig 4. (a)

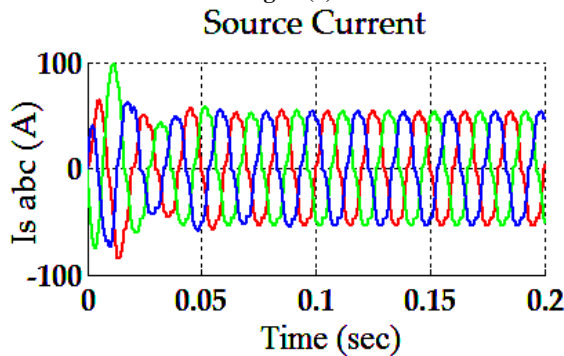


Fig 4. (b)

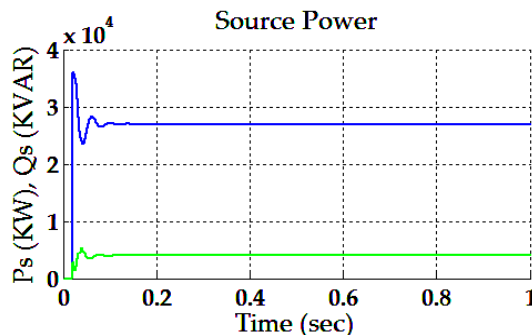


Fig 4. (c)



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

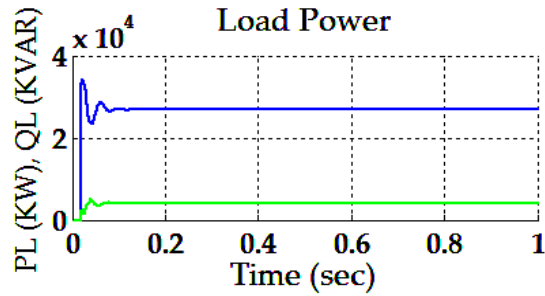


Fig 4. (d)

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

2) After Compensation

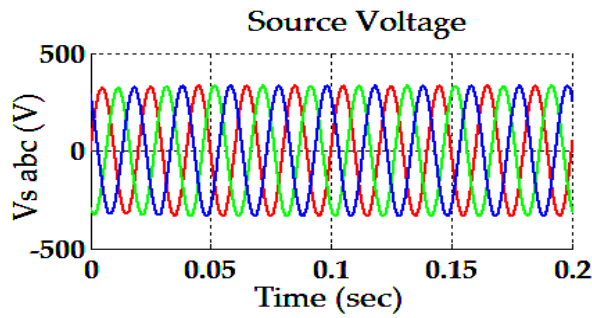


Fig 5. (a)

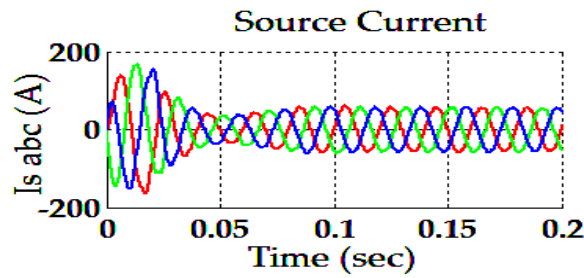


Fig 5. (b)

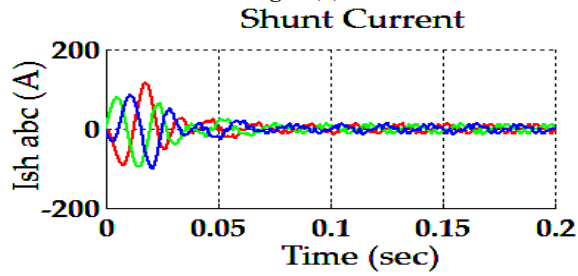


Fig 5. (c)

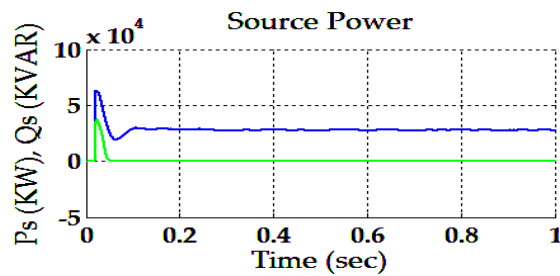


Fig 5. (d)



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

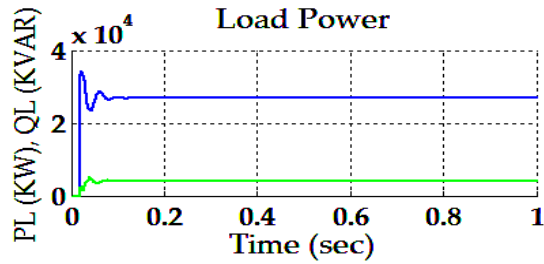


Fig 5. (e)

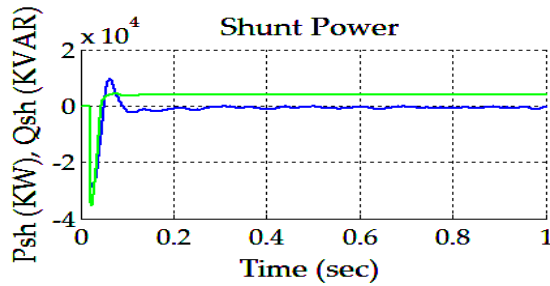


Fig 5. (f)

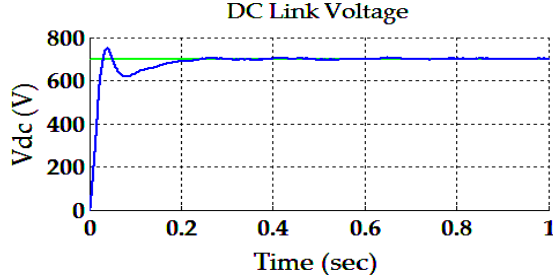


Fig 5. (g)

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

B. Load Change Condition

1) Before Compensating

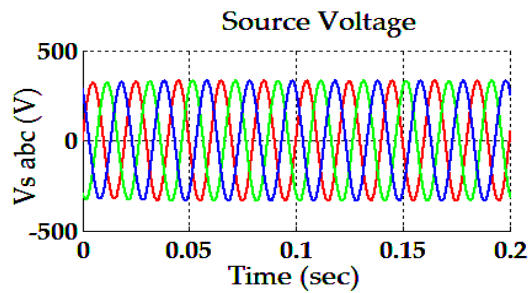


Fig 6. (a)

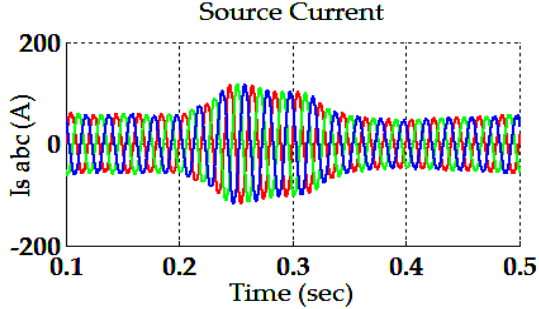


Fig 6. (b)



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

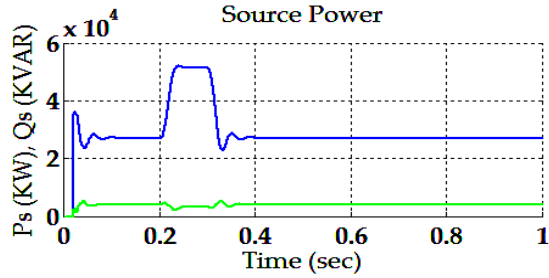


Fig 6. (c)

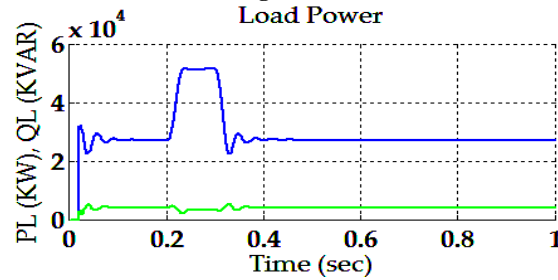


Fig 6. (d)

Fig 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

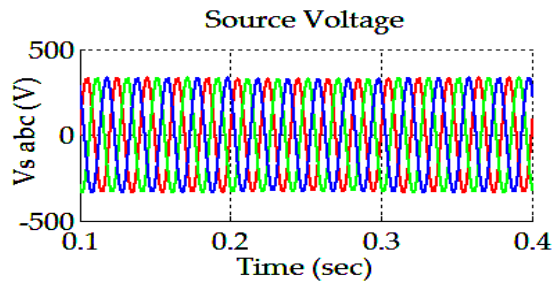


Fig 7. (a)

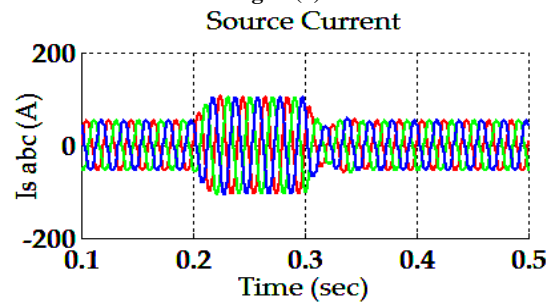


Fig 7. (b)

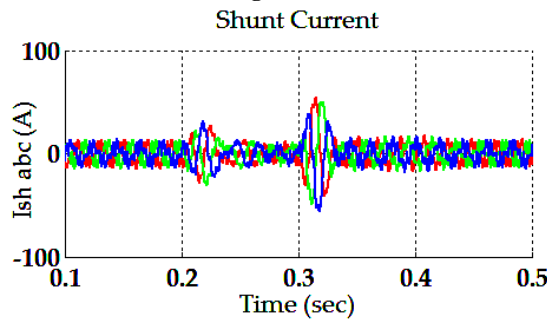


Fig 7. (c)



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

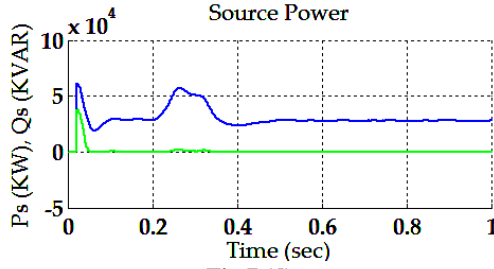


Fig 7.(d)

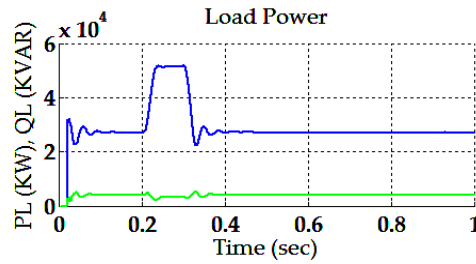


Fig 7. (e)

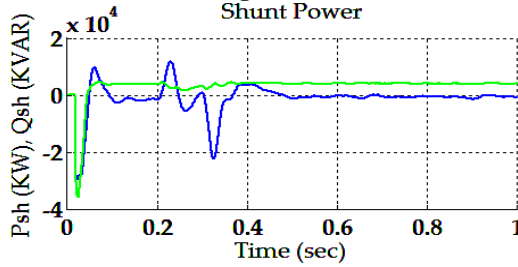


Fig 7. (f)

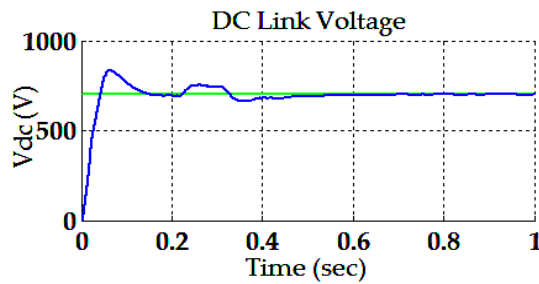


Fig 7. (g)

Fig 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
R_s	0.1 Ω
L_s	0.1 mH
DC Link Capacitor	3000 μ F
Filter Capacitor	3000 μ F
Filter Inductor	15 mH
DC Link Voltage	700 V
AC Line inductor	10 mH



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

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)
No Load 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.

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.

REFERENCES

- [1] S. T. Senini and P. J. Wolfs, "Systematic identification and review of hybrid active filter topologies," in Proc. IEEE 33rd Annu. Power Electron. Spec. Conf., 2002, vol. 1, pp. 394–399.
- [2] P. Salmeron and S. P. Litran, "A control strategy for hybrid power filter to compensate four-wires three-phase systems," IEEE Trans. Power Electron., vol. 25, no. 7, pp. 1923–1931, Jul. 2010.



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 2, Issue 3, May 2013

- [3] Luo, Z. K. Shuai, Z. J. Shen, W. J. Zhu, and X. Y. Xu, "Design considerations for maintaining dc-side voltage of hybrid active power filter with injection circuit," *IEEE Trans. Power Electron.*, vol. 24, no. 1, pp. 75–84, Jan. 2009.
- [4] H. Fujita and H. Akagi, "A practical approach to harmonic compensation in power systems: Series connection of passive and active filters," *IEEE Trans. Ind. Appl.*, vol. 27, no. 6, pp. 1020–1025, Nov./Dec. 1991.
- [5] Z. Peng, H. Akagi, and A. Nabae, "A new approach to harmonic compensation in power systems: A combined system of shunt passive and series active filters," *IEEE Trans. Ind. Appl.*, vol. 26, no. 6, pp. 983–990, Nov./Dec. 1990.
- [6] S. Park, J.-H. Sung, and K. Nam, "A new parallel hybrid filter configuration minimizing active filter size," in *Proc. IEEE 30th Annu. Power Electron. Spec. Conf.*, 1999, vol. 1, pp. 400–405.
- [7] D. Rivas, L. Moran, J. W. Dixon, and J. R. Espinoza, "Improving passive filter compensation performance with active techniques," *IEEE Trans. Ind. Electron.*, vol. 50, no. 1, pp. 161–170, Feb. 2003.
- [8] H. Akagi, "New trends in active filters for power conditioning," *IEEE Trans. Ind. Appl.*, vol. 32, no. 6, pp. 1312–1322, Nov./Dec. 1996.
- [9] W. Tangtheerajaronwong, T. Hatada, K. Wada, and H. Akagi, "Design and performance of a transformerless shunt hybrid filter integrated into a three-phase diode rectifier," *IEEE Trans. Power Electron.*, vol. 22, no. 5, pp. 1882–1889, Sep. 2007.
- [10] R. Inzunza and H. Akagi, "A 6.6-kV transformerless shunt hybrid active filter for installation on a power distribution system," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 893–900, Jul. 2005.
- [11] S. Srianthumrong and H. Akagi, "A medium-voltage transformerless ac/dc Power conversion system consisting of a diode rectifier and a shunt hybrid filter," *IEEE Trans. Ind. Appl.*, vol. 39, no. 3, pp. 874–882, May/Jun. 2003.
- [12] H. -L. Jou, K. -D. Wu, J.- C. Wu, C. -H. Li, and M. -S. Huang, "Novel power converter topology for three phase four-wire hybrid power filter," *IET Power Electron.*, vol. 1, pp. 164–173, 2008.
- [13] S. Rahmani, A. Hamadi, N. Mendalek, and K. Al-Haddad, "A new control technique for three-phase shunt hybrid power filter," *IEEE Trans. Ind. Electron.*, vol. 56, no. 8, pp. 2904–2915, Aug. 2009.
- [14] H. Akagi, S. Ogasawara, and K. Hyosung, "The theory of instantaneous power in three-phase four-wire systems: A comprehensive approach," in *Conf. Rec. IEEE 34th IAS Annu. Meeting*, 1999, vol. 1, pp. 431–439.
- [15] Khadkikar, A. Chandra, and B.N. Singh, "Generalized single-phase p-q theory for active power filtering: Simulation and DSP-based experimental investigation," *IET Power Electron.*, vol. 2, no. 1, pp. 67–78, Jan. 2009.
- [16] L. H. Wu, F. Zhuo, P. B. Zhang, H. Y. Li, and Z. A. Wang, "Study on the influence of supply-voltage fluctuation on shunt active power filter," *IEEE Trans. Power Del.*, vol. 22, no. 3, pp. 1743–1749, Jul. 2007.
- [17] M. Aredes, J. Hafner, and K. Heumann, "Three-phase four-wire shunt active filter control strategies," *IEEE Trans. Power Electron.*, vol. 12, no. 2, pp. 311–318, Mar. 1997.