Performance Evaluation of Hybrid Power Filters under Unbalanced and Distorted Voltage Conditions

Dheeraj Sharma[1], Bhuvnesh Nagar[2], Prajapati Shantilal[3], Vivek Mina[4]

[1]Guest Faculty, Dept. of EE, Government Engineering College, Baran, Rajasthan, India

[2]Guest Faculty, Dept. of EE, Government Engineering College, Baran, Rajasthan, India

[3]Guest Faculty, Dept. of ECE, Government Engineering College, Baran, Rajasthan, India

[4]UG Scholar, Dept. of EE, Government Engineering College, Baran, Rajasthan, India

Emails: dheeraj.eee31@gmail.com[1], bhuvnesh.engineer@gmail.com[2], prajapati.shantilal.5@gmail.com[3], vivekmina71@gmail.com[4]

Abstract

The proliferation of non-linear loads in modern power systems has escalated power quality concerns, primarily due to harmonic currents and reactive power demands. While **Hybrid Power Filters (HPF)**—combining the cost-effectiveness of passive filters with the precision of active filters—offer a promising solution, their performance often degrades under non-ideal grid conditions. This paper presents a comprehensive **performance evaluation** of a shunt hybrid power filter specifically designed to operate under **unbalanced and distorted supply voltage conditions**. A robust control strategy, based on Clark Transformation **[p-q Theory]**, is employed to ensure accurate harmonic extraction despite the presence of negative-sequence components and background harmonics in the grid. The study utilizes **MATLAB/Simulink** simulations and experimental validation to analyze Total Harmonic Distortion (THD) and power factor correction across varying load levels.

Keywords: Harmonic Compensation; Hybrid Power Filter (HPF); Power Quality; Total Harmonic Distortion (THD); Unbalanced Voltage.

1. Introduction

The rapid evolution of industrial automation and the integration of renewable energy sources have led to a significant increase in the use of power electronic-based non-linear loads. Devices such as variable frequency drives (VFDs), switched-mode power supplies, and electric vehicle chargers draw non-sinusoidal currents from the grid. These currents interact with the system impedance, leading to **Total Harmonic Distortion (THD)** that can cause overheating in transformers, sensitive equipment malfunctions, and increased transmission losses. Traditionally, **Passive Power Filters (PPF)** have been the preferred solution due to their simplicity and low cost. However, PPFs suffer from inherent drawbacks, including fixed compensation characteristics, susceptibility to resonance with grid impedance, and bulky physical dimensions. To overcome these limitations, **Active Power Filters (APF)** were introduced. While APFs offer superior flexibility and dynamic compensation, their high initial cost and significant power rating requirements for high-power applications often limit their widespread adoption. The **Hybrid Power Filter (HPF)** emerges as a technically and economically viable compromise. By combining a small-rated APF with a PPF, the HPF configuration mitigates the drawbacks of both individual systems.[1-15]

The passive part is designed to handle the bulk of the lower-order harmonics and reactive power, while the active part improves the overall filtering performance and prevents resonance.

2. System Configuration

In present scenario, electrical distribution systems as a sudden increment of harmonics in view of single and three phase non-linear loads. Non-linear loads are reason for harmonics. A passive and active filter has been utilized to overcome these issues. In this paper both filters are utilized for mitigation of total harmonic distortion. MATLAB simulation is utilized for modelling and analysis.

The proposed system configuration block diagram is shown in Fig. 1, consists of passive filter (LC configuration) and active filter (six pulse IGBT diode configuration). A passive filter is connected in series with line whereas active filter is connected in across source and load side. The pulse is feed in active filter through PID controller, pulse is generated through source current is compared with reference current thus pulse is generated which is feed in converter circuit.
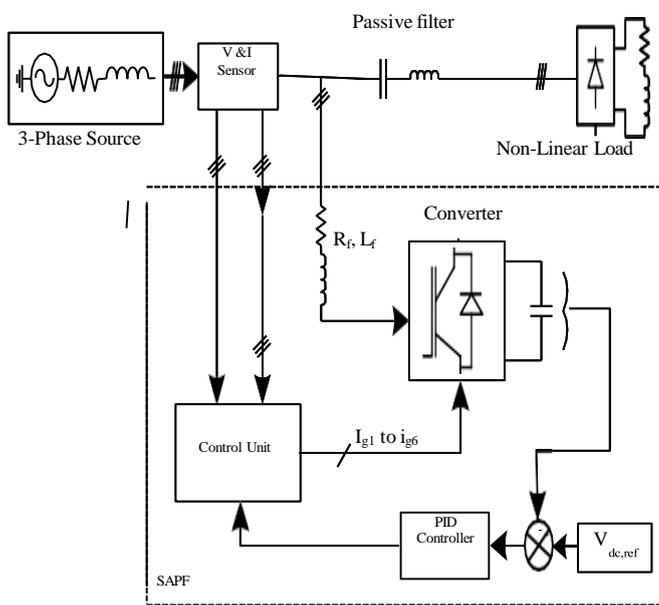

Figure 1 Proposed System Configuration Block with Hybrid Filter

3. Mathematical Modelling

Three phase instantaneous source voltage and current signal are transformed into two phases using Clark's transformation [13].

$$\begin{bmatrix} V_{S\alpha} \\ V_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (2)$$

Using (1,2) instantaneous active reactive power in 3 phase system are define as following

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_{S\alpha} & V_{S\beta} \\ -V_{\beta\alpha} & V_{S\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (3)$$

Load currents in orthogonal coordinate system can be calculated in (4).

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \frac{1}{V_{S\alpha}^2 + V_{S\beta}^2} \begin{bmatrix} V_{S\alpha} & V_{S\beta} \\ -V_{\beta\alpha} & V_{S\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (4)$$

The reference compensated current can be define as-

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

Using inverse Clark's transformation, we convert orthogonal current component can be transform to 3 phase currents as.

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

4. Simulations and Results

The MATLAB/Simulink has been used to test compatibility of proposed system. Proposed with hybrid filter configuration has been shown on Fig.1. The system is investigated with non-linear load. The simulation results are shown below for without and with filtering mode of system. This section studied that source voltage and source current became distorted due to presence of nonlinear load thus hybrid filter to filter-out harmonics of source. The simulation time is T=0s to T=0.5s. PID controller generates pulse after 0.1s. The distorted source voltage waveforms are shown in Fig. 2. The source currents due to non-linear load have been represented in Fig.3. The compensated waveforms of source voltage occur after 0.1s that are shown in Fig.4. The compensated source current is indicated in Fig.5.

Table 1 System Data Specification for Simulink Modeling

Source	Fundamental supply voltage: 415 (rms line voltage) Source frequency = 50 Hz
APF	DC link capacitor, Cdc = 1200μF Reference Dc Link Voltage: Vdc=600 Filter inductor, Lf = 4 mH, Rf = 7 Ω Dc link PID controller gain, Kp = 0.3, Ki = 0.15 & K_D=0.45
Loads	Three phase diode rectifiers with L_l = 50 mH, and R_l = 40 Ω load

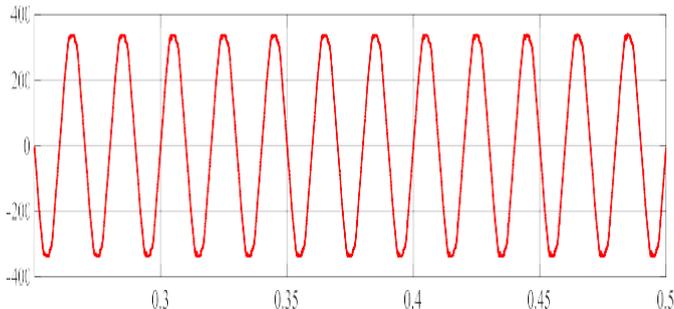| Passive power factor (PPF)	Filter inductor, L= 1.25mH Filter capacitor, C= 10 µF

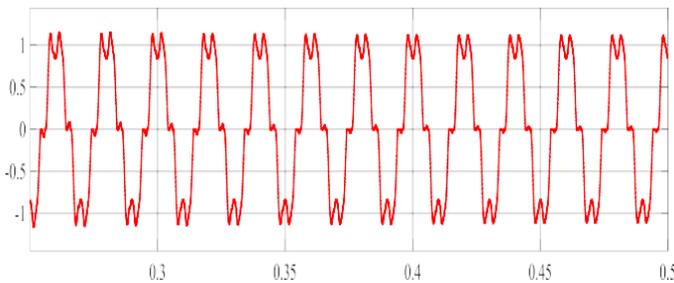**Figure 2** Distorted Source Voltage

Figure 3 Uncompensated Source Current.

The Hybrid filter with PID controller based SAPF system reduces voltage harmonics from 3.97% to 3.05% (Fig.6 & Fig.8) and current harmonics from 28.25% to 2.28% (Fig.7 & Fig.9).
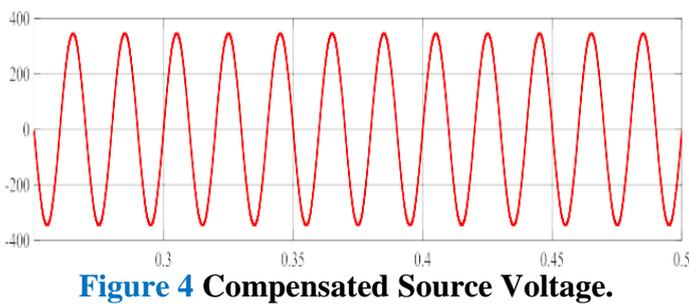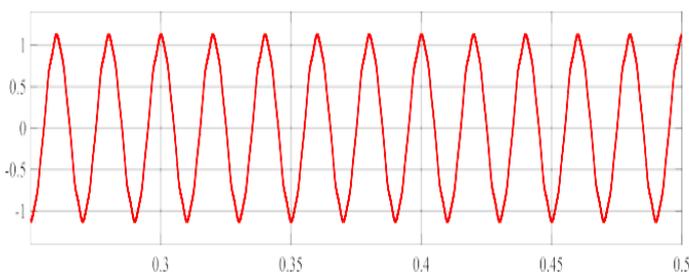

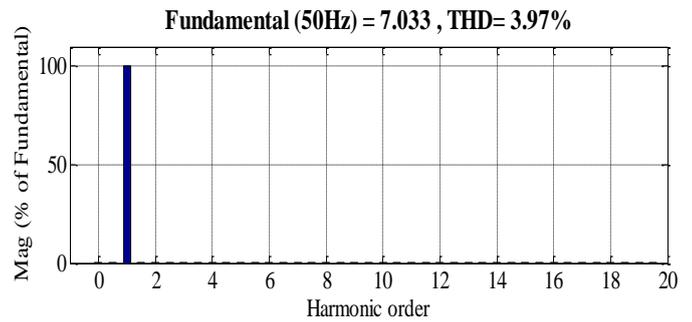**Figure 4** Compensated Source Voltage.

Figure 5 Compensated Source Current.

Fundamental (50Hz) = 7.033 , THD= 3.97%

Figure 6 Harmonic Spectrum of Source Voltage Before Compensation

Fundamental (50Hz) = 6.864 , THD= 28.25%
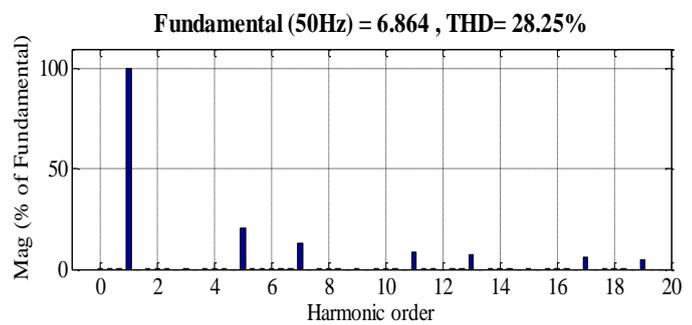
Figure 7 Harmonic Spectrum of Current Before Compensation

Fundamental (50Hz) = 1.09 , THD= 3.05%
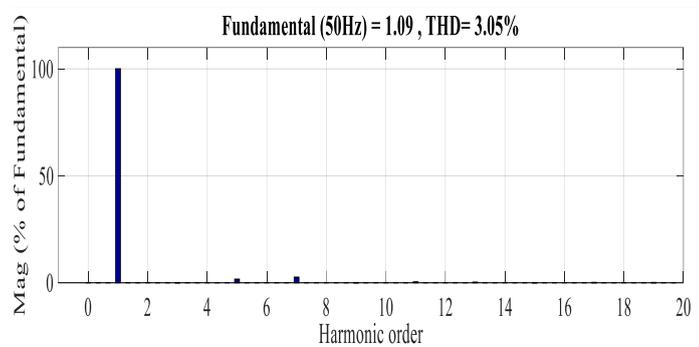
Figure 8 Harmonic Spectrum of Source Voltage After Compensation

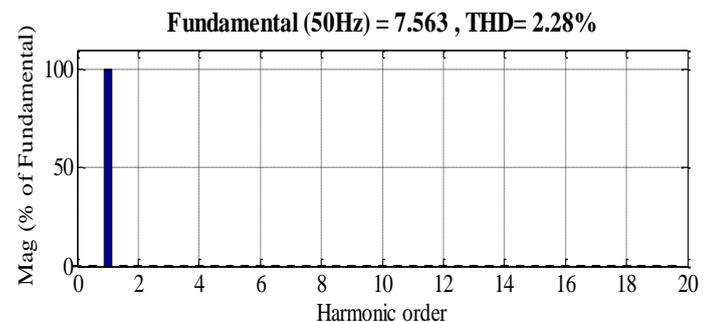Fundamental (50Hz) = 7.563 , THD= 2.28%

Figure 9 Harmonic Spectrum of Source Current After Compensation

Conclusions

Hybrid filter-based system has used to mitigate harmonics which are introduced in source voltage and current through nonlinear load. The source current and voltage harmonics are 28.25% and 3.97% respectively without filtering stage, and source current harmonics level goes to 2.28% as well as source voltage harmonic becomes 3.05%. The overall function of hybrid filter to filter-out supply source voltage and current harmonics component.

References

[1]. Su, Wei-Fu, Chin E. Lin, and Ching-Lien Huang. "Hybrid filter application for power quality improvement." Electric power systems research 47.3 (1998): 165-171.

[2]. Detjen, Dirk, et al. "A new hybrid filter to dampen resonances and compensate harmonic currents in industrial power systems with power factor correction equipment." IEEE Transactions on Power Electronics 16.6 (2001): 821-827.

[3]. Chen, Lijun, and Annette von Jouanne. "A comparison and assessment of hybrid filter topologies and control algorithms." 2001 IEEE 32nd Annual Power Electronics Specialists Conference (IEEE Cat. No. 01CH37230). Vol. 2. IEEE, 2001.

[4]. Lin, Bor-Ren, Bor-Ren Yang, and Hui-Ru Tsai. "Analysis and operation of hybrid active filter for harmonic elimination." Electric Power Systems Research 62.3 (2002): 191-200.

[5]. T.M.X. Ji, "Variable Structure Control for a Hybrid Power Filter", Trans. of China Electrotechnical Soc., vol. 1, pp. 1-11, 2002.

[6]. Koutsoukos, Xenofon, James Kurien, and Feng Zhao. "Monitoring and diagnosis of hybrid systems using particle filtering methods." International Symposium on Mathematical Theory of Networks and Systems. 2002.

[7]. Choi, Sewan, and Minsoo Jang. "A reduced-rating hybrid filter to suppress neutral current harmonics in three-phase four-wire systems." IEEE transactions on industrial electronics 51.4 (2004): 927-930.

[8]. Inzunza, Rubén, and Hirofumi Akagi. "A 6.6-kV transformerless shunt hybrid active filter for installation on a power distribution system." IEEE Transactions on Power Electronics 20.4 (2005): 893-900.

[9]. Singh, Bhim, et al. "Hybrid filters for power quality improvement." IEE Proceedings-Generation, Transmission and Distribution 152.3 (2005): 365-378.

[10]. Ahrabian, Ghasem, Farhad Shahnia, and Mehrdad Tarafdar Haque. "Hybrid filter applications for power quality improvement of power distribution networks utilizing renewable energies." 2006 IEEE International Symposium on Industrial Electronics. Vol. 2. IEEE, 2006.

[11]. Luo, An, et al. "Development of hybrid active power filter based on the adaptive fuzzy dividing frequency-control method." IEEE transactions on power delivery 24.1 (2008): 424-432.

[12]. Khanna, Ravish, Saji T. Chacko, and Naveen Goel. "Performance and investigation of hybrid filters for Power Quality Improvement." 2011 5th International Power Engineering and Optimization Conference. IEEE, 2011.

[13]. Vijayakumar, M., and S. Vijayan. "Design and implementation of PV-based three-phase four-wire series hybrid active power filter for power quality improvement." Sadhana 39.4 (2014): 859-877.

[14]. Badgujar, Mr Dipak Suresh, K. P. Varade, and C. Veeresh. "Shunt active filter for power quality improvement." International Journal of Engineering Research and General Science 3.4 (2015): 137-148.

[15]. Sharma, Dheeraj, et al. "Performance analysis of hybrid filter to mitigate harmonics." Int. J. Electron. Electr. Comput. Syst 6.3 (2017): 235-238.