AN EFFICIENT HYBRID ACTIVE POWER FILTER (H-APF) FOR HARMONIC MITIGATION USING COMPENSATION TECHNIQUES

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ABSTRACT

The deviation of physical characteristics like current, voltage, and frequency in power systems affects the damage of electronic equipment with significant power loss. Power quality issues are resolved using filters like passive filters (PF) and active power filters (APF). The drawbacks of the PF and APF are resolved using Hybrid-APF. In this article, the Hybrid-APF (H-APF) is designed for harmonic reduction and power quality improvements using current compensation technique. The proposed H-APF has of 3Φ- AC Source connected in series with Non-linear load, Shunt-PF, and Shunt-APF. The Shunt-PF (S-PF) is connected in Series with Shunt-APF (S-APF) to form a Hybrid-APF. The compensation techniques include PQ-method/DQ Method and Hysteresis-Current- Controller (HCC) are used to reduce the harmonics from the Load. The complete model is designed using MATLAB Simulink and analyze the simulated voltage-current waveforms. The H-APF is compared with different filtering technique concerning THD and reactive power with improvements. The H-APF improves the THD of 5.76% over shunt–APF using PQ-Method. The H-APF using PQ-Method improves the THD over 69.54% than the H-APF using DQ-method.

KEYWORDS

Hybrid -APF, Active Power Filter, Passive Filter, Harmonic Filter, PQ Theory, DQ Theory, HCC, Simulink Modelling.

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1. INTRODUCTION

The growth and economy of the country depend on the power generation and its usage. Due to recent advancement in technology, people demand high-quality power to their daily need. The problem occurred in power system due to voltage, current, frequency variation like swell, transient, harmonics, and spikes in electrical and electronic equipment's. The usage of the new power electronic devices starts from small non-linear load in the home to extensive industrial applications. The power quality problems are resolved in recent years by incorporating new techniques in power systems (Ahsan, Pan, & Li, 2018; Diab *et al.*, 2018). The voltage and current harmonics in power systems are solved by using filtering methods. The harmonics are occurred by electromagnetic interference and voltage/ current distortion. The Reactors, transformations-K-factor, Pulse and Phase shifting solutions, Tuned, low-pass filters, active and hybrid-Harmonic filters are the different harmonics mitigation techniques to compensate the current from the loads (Schwanz, Bollen, & Larsson, 2016).

The Passive Filters (PF's) are used to mitigate the current harmonics, but facing problems with parallel resonance. The APF's are used to reduce the drawbacks of PF's and mitigate the harmonics. The APF mainly performs the harmonics detection, reference current signal calculation and gate pulses generation. In general, APF is classification is processed on Topology, Converter, and Number of phases. The converter base includes voltage and current source inverter. The Topology type includes Unified Power Quality-Conditioner (UPQC), Series, Shunt, and Hybrid APF. The phases include single-phase, 2-Wire and 3-phase, 3 or 4 -wire. The Hybrid-APF are classified based on the topology includes Shunt APF with Series APF, Shunt APF with Shunt PF, APF in Series along with Shunt PF and Series APF with Shunt PF. The control strategies are used to compensate the current in APF, which includes proper signal conditioning, reference signal generation based on time and frequency domain, DC Link controlling using PI Controller, sliding mode, and Fuzzy and finally firing signal generation using HCC, PWM and other Techniques (Demirdelen *et al.*, 2013).

Most of the existing research done is on active filters or passive filters individually. The active filters classify as the shunt filter, which is costly and not convinced for higher energy

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systems and series filters to isolate the harmonics, but not to a great extent. Similarly, passive filters eliminate particular harmonics but cause parallel resonance. The hybrid filter offers efficient and cost-effective solutions with harmonic elimination with better power quality improvements. In the proposed design Hybrid–APF is designed, is the integration of S-PF connected in Series with S–APF. The Hybrid-APF overcomes the drawbacks of the APF. The Hybrid-APF is designed using controlling strategies, which includes reference signal generation with time-domain using PQ –method and DQ-Method, DC-Link controlling using PI Controller, firing signal generation using HCC.

The proposed method has hybrid combination of Passive and Shunt active power filter, using current compensation techniques like PQ-Theory and Hysteresis current controller. The switching losses are controlled by PI controller and improve the APF computations. The proposed approach is improved version of conventional methods in terms of THD and reactive power. The proposed model is easily reconfigurable by replacing PQ-method with DQ-method and vice versa. In future, by replacing the PI controller with artificial neural network (ANN) based controller to improve the THD and power.

Section 1.1 discusses the background of the previous research works of Hybrid-APF and Shunt -APF. Section 2 describes the detailed architecture of Hybrid-APF and elaborates the current compensation techniques which include PQ-Method, DQ-Method and HCC. Section 3 explains the simulation results of the Hybrid-APF. Section 4 discuss the other filtering methods with THD and reactive power comparison with improvements and also concludes the overall work with improvements.

1.1 THE BACKGROUND

This section explains the background of existing APF and Hybrid-APF using different approaches. Chau (2016) present Adaptive current control technique for H-APF, which includes Prediction model, identification, and fuzzy neuro controller with a cost function. The fuzzy neuro controller is working on membership function used in the fuzzy layer and rules layer. Temerbaev and Dovgun (2014) describe the power quality in distributed systems using H-APF, which contains load compensation with Notch IIR Filter for harmonic mitigation. The analysis of Shunt H-APF Controller by Harmonic voltages, Series H-APF controlled by source harmonic current and Combined H-APF controlled

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by Load harmonic current is discussed. A practical design approach for transformer-less Shunt-APF is explained by Unnikrishnan *et al*. (2015) which include design procedures for selecting the components and controlling techniques. The controlling method includes PQ-Theory with Low and high Filter along with PI Controller for current and dc-voltage controlling along with THD findings for different harmonic orders. Das, Ray, and Mohanty (2017) explain the RLS algorithm for harmonic mitigation using Hybrid-power filter with better power quality, which includes shunt PF connected series with series APF. The RLS algorithm is incorporated with DQ-theory in series AF by replacing the PI Controller and HCC. The Shunt-Hybrid-APF is designed by Tahmid and Ahmad (2017) which includes 3Φ-4-wire -non-linear load, along with PF, DQ method, and PLL. The PLL is used to frequency elements of Non-linear loads and generation current by HCC.

Nandankar and More (2017) present transformer-less H-APF using different inverter topologies, which includes Six-switch Two-leg, Nine-Switch and Voltage-Source Inverters. The nine-switch Two-leg inverter-based HPF achieves better THD and reactive power. Babu, Kar, and Halder (2016) and Kar and Halder (2016) analyze the H-APF using HCC for power quality, which includes PQ-Theory, HCC for current compensation, along with Fryze compensation theory. The PQ method is better THD than Fryze compensation method. Balasubramanian and Palani (2016) present Shunt H-APF using PQ Theory with current source and voltage source type non-linear load.

The APF is designed using six Transistors are connected parallel and acts as an inverter with DC voltage capacitance along with HCC and PQ method. Thuyen (2018) presents improved P-Q harmonic detection technique for H-APF using Fuzzy logic controller. The instantaneous P-Q theory is replaced by fuzzy adjustor to decreases the response time and increases overshoot time. The same author, Thuyen (2019), extends the work by introducing a new design based on Social Spider Algorithm (SSA), which supports multi-objective optimization by replacing the Fuzzy adjuster with improved THD and reactive power. Wang, Lam, and Wong (2018) present Shunt–HAPF based on Thyristor Controller LC-coupling (TCLC) to improve the cost, reliability, and power loss of the power system.

Esfahani, Hosseinian and Vahidi (2015) describes the Fuzzy based Particle Swarm Optimization (PSO) for HAPF for better PQ improvements. Damodhar and Kumar

https://doi.org/10.17993/3ctecno.2021.specialissue8.623-643

(2016) explain the hardware based (FPGA) Hybrid power generator for different industrial applications. Dhineshkumar and Subramani (2018) describe the Kalman filter-based H-APF for PQ improvements with good harmonic mitigations.

2. PROPOSED METHOD

In this section, the proposed Hybrid-APF is designed for Power quality improvements and to mitigate the harmonics. The Hybrid-APF is an integration of S-PF connected serially with S-APF. The primary model includes Three-Phase AC Source, RL components followed by Non-linear Load along with S-PF and S-APF.

Hybrid-APF architecture is represented in Figure1. The Three-Phase AC mains is connected with Non-linear Load and also to Shunt Passive filter (S-PF), Shunt-APF, Universal Bridge, PI Controller and HCC

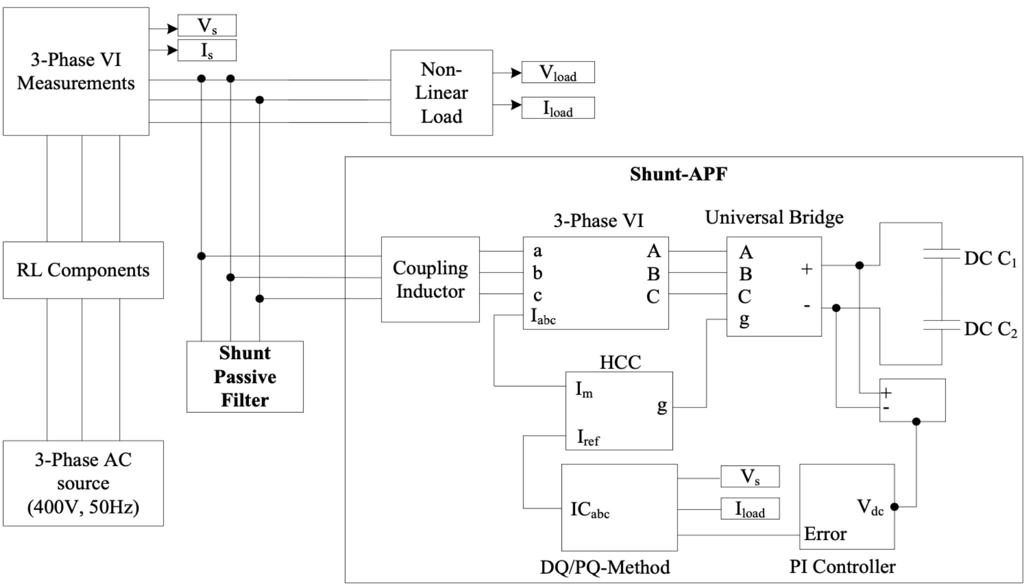

Figure 1. Detailed Architecture of Hybrid-Active Power Filter (H-APF).
Source: own elaboration.

The Non-linear load includes the 3-phase RL load, followed by six-diodes connected in parallel and an unbalanced load. The unbalanced load has three resistors 2Ω,4Ω and 6Ω in parallel. The Shunt PF is wired in series with IGBT (Universal Bridge) based Shunt-

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APF to mitigate the harmonics and ended with DC link capacitors C_1 and C_2. The control strategies are incorporated to compensate the voltages and currents using PQ-Method and HCC are explained in the below section.

2.1. PQ METHOD

There are so many methods that are used to compensate the currents, in that PQ-method is a commonly used method in power system to improve the power quality. The instantaneous I and V waveform values are expressed by three-phase instantaneous space vectors (αβ0). These current and voltage values of the 3-phase system are converted to αβ0 values with the difference of $2\pi/3$ on each phase. The mathematical equations are expressed in a matrix using Clark's Transformation for current and voltage conversion is below.

$$\begin{bmatrix} V_a \\ V_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} I_a \\ I_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix} \tag{2}$$

The three-phase instantaneous space vectors are generated using equations (1) and (2) using *abc* to *aβ0* or (Clark's) transformation. The zero sequence values of equations (1) and (2) are removed from the 3-phase systems, so V_0 and I_0 are not considered for further analysis. The p and q values are generated using below equations (3) and equation (4) are expressed in matrix form.

$$\begin{aligned} p &= V_\alpha . I_\alpha + V_\beta . I_\beta \\ q &= V_\alpha . I_\beta - V_\beta . I_\alpha \end{aligned} \tag{3}$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{4}$$

The p and q values are compensated using average and oscillator values are expressed in the below equation (5).

$$\begin{aligned} p &= p_{ac} + p_{dc} \\ q &= q_{ac} + q_{dc} \end{aligned} \tag{5}$$

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The p_{ac} and q_{ac} are oscillatory values and p_{dc} and q_{dc} are average values. The compensating power of p and q is expressed in equation (6).

$$\begin{aligned} p^* &= -p_{ac} \\ q^* &= -q \end{aligned} \tag{6}$$

The compensating current reference generator (CCRG) of $\alpha\beta$ is expressed in the below equation (7).

$$\begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix} = \frac{1}{V_\alpha^{\ 2} + V_\beta^{\ 2}} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} p^* \\ q^* \end{bmatrix} \tag{7}$$

The CCRG of $\alpha\beta$ values are converted back to abc values using Inverse Clark's transformation and are expressed in equation (8).

$$\begin{bmatrix} I_{ca} \\ I_{cb} \\ I_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix} \tag{8}$$

These abc transformed values are considered as reference current and used in Hysteresis Current Control (HCC).

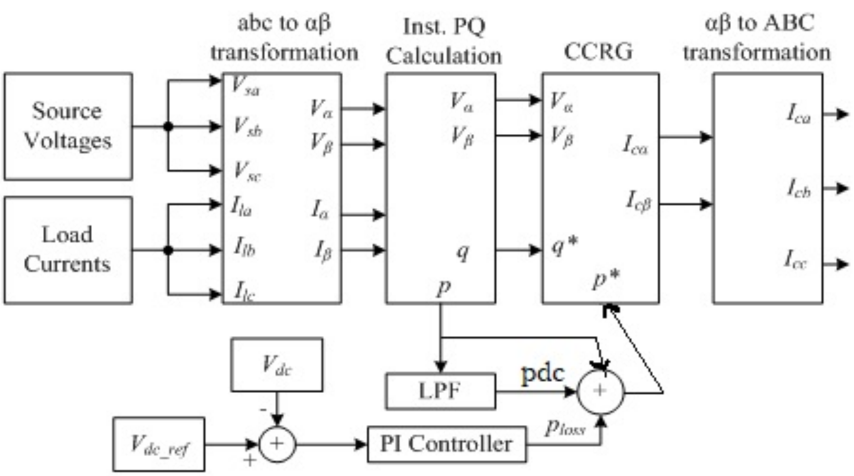

Figure 2. Current Compensation Using PQ Method.
Source: own elaboration.

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The current compensation using PQ-Method is represented in Figure 2. The 3Φ Main's voltage (V_{sabc}) and load current (I_{labc}) from the 3-phase main power supply are given as input to the *abc* to *aβ0* transformation block (eq (1-2)) followed by instantaneous PQ calculation using (eq (3-4)). The reference compensated current is generated by CCRG using equations (5-7). Finally, the conversion of the *aβ* to ABC transformation is achieved by equation (8).

The DC link voltage is used to improve the APF computations. PI Controller achieves the generation of the switching losses of the converters. The Hybrid-APF switching losses are balanced by using the DC link voltage as constant.

2.2 DQ-METHOD

The DQ-Method is similar to PQ-Method and it is represented in Figure 3. The 3-phase source voltage (V_{sabc}) is applied to Phase- Locked Loop (PLL) which is used to synchronize the different frequencies and voltage signals based on gains. The PLL output (k) is used to synchronize the DQ and CCRG. The load current (I_{labc}) is converted to *aβ0* values with the difference of 2π/3 using equation (2). The DQ calculation is achieved using park conversion below equation (9).

$$\begin{bmatrix} d \\ q \end{bmatrix} = \begin{bmatrix} \cos(k) & \sin(k) \\ -\sin(k) & \cos(k) \end{bmatrix} * \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{9}$$

The rotating reference frame (RRF) – *dq* occurred based on DC components and harmonic values are frequency shifted by '*k*'. The DC values are extracted by using LPF with margin at the line frequency.

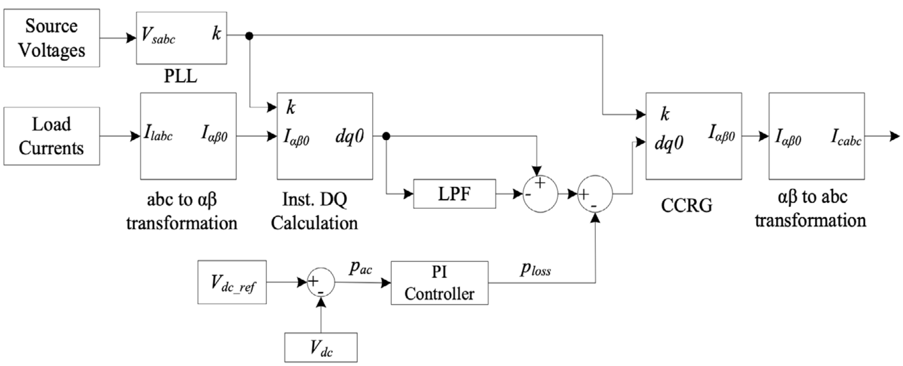

Figure 3. Current Compensation using DQ Method.
Source: own elaboration.

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The CCRG generates the *αβ0* values using inverse park conversion in below equation (10).

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \begin{bmatrix} \cos(k) & -\sin(k) \\ \sin(k) & \cos(k) \end{bmatrix} * \begin{bmatrix} d \\ q \end{bmatrix} \quad (10)$$

Apply the inverse Clarke transformation using equation (8) to generate the final compensated current I_{cabc} values and these values are processed in HCC.

2.3 HYSTERESIS CURRENT CONTROLLER (HCC)

The HCC is used to obtain the pulse width modulation (PWM) signals for Hybrid-APF. The HCC is working based on the feedback mechanism. The switching gate signals are given, when the error limitation crosses the given tolerance value in H-APF. The architecture of the HCC is represented in Figure4.

The PQ/DQ Method generates the compensated reference three-phase current (I_{cabc}) and measured current (I_{mabc}) from the mains are inputs to the HCC model. The relation operator (>=) acts as a switch to compare the three-phase reference and measured current.

If (I_{ca}>= I_{ma}) then g_1 will be activated (Switch ON) otherwise g_4 will be activated. Similarly, if (I_{cb}>= I_{mb}) then g_2 else g_5 gate pulses and If (I_{cc}>= I_{mc}), g_3 else g_6 gate pulse is generated. The switching control of the Hybrid-APF using HCC is achieved to generates the gate pulses and input to the Universal Bridge (IGBT Inverter).

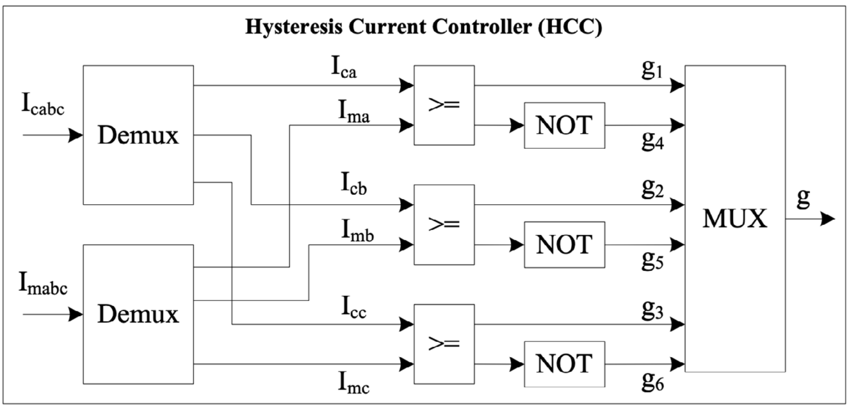

Figure 4. Block diagram of HCC.
Source: own elaboration.

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3. RESULTS

The Modelling of the Hybrid –APF (H-APF) is designed using Matlab-Simulink Tool and by selecting the simulation type-Discrete, Solver-Tustin, and sample period of 5μsec.The H-APF is compared with other different filtering techniques concerning Total Harmonic Distortion (THD), and reactive power (KVAR) of source voltage and current. The Modelling parameters considered as a specification for different filtering techniques are represented in Table 1.

Table 1. Specification for Different Filtering Design.

DESIGN SPECIFICATIONS	VALUES
3-Phase AC Mains Voltage,	400V
Fundamental Frequency	50Hz
Line Impendence	R_s = 0.01Ω, L_s = 1μH
Unbalanced Load	2Ω, 4Ω, 6Ω
Coupling Inductor	1.2mH
DC Capacitance (Cdc)	C_{dc1}= 40 μF, C_{dc2}= 40 μF,
Reference DC Voltage	V_{dc_ref}= 850V

Source: own elaboration.

The Schematic of Hybrid- Active Power Filter (H-APF) using Simulink Tool is represented in Figure 5. The 3Φ- AC source voltage 400V with a frequency of 50Hz is selected for different filtering techniques for harmonics reduction reactive power improvements.

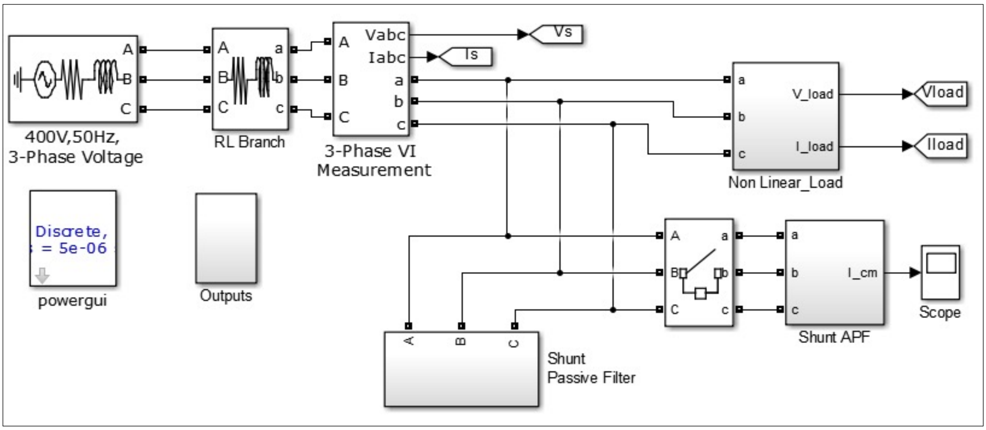

Figure 5. Schematic of Hybrid- Active Power Filter (H-APF) using Simulink Tool.
Source: own elaboration.

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To compare with Hybrid-APF, other filtering techniques are designed and analyzed in this section. The S-PF is wired to 3-phase mains, which includes three-phase RL, which is connected in parallel. Harmonic Filter is designed separately, which includes two 5^{th} & 7^{th} order, 11^{th}& 13^{th} order are connected in parallel. Shunt-APF is connected with 3-phase mains, which includes Universal Bride, PI Controller, followed by HCC and DQ/PQ-Method.

The experimental setup is conducted for non-linear Load, Passive Filter with Load, harmonic filter with Load, Shunt-APF with Load, and proposed Hybrid-APF with load to generate the THD and reactive power results. The Hybrid-APF generates the three-phase V_s, I_s, V_{load} and I_{load} waveforms, after PQ method and HCC compensation technique and it is represented in Figure 6.

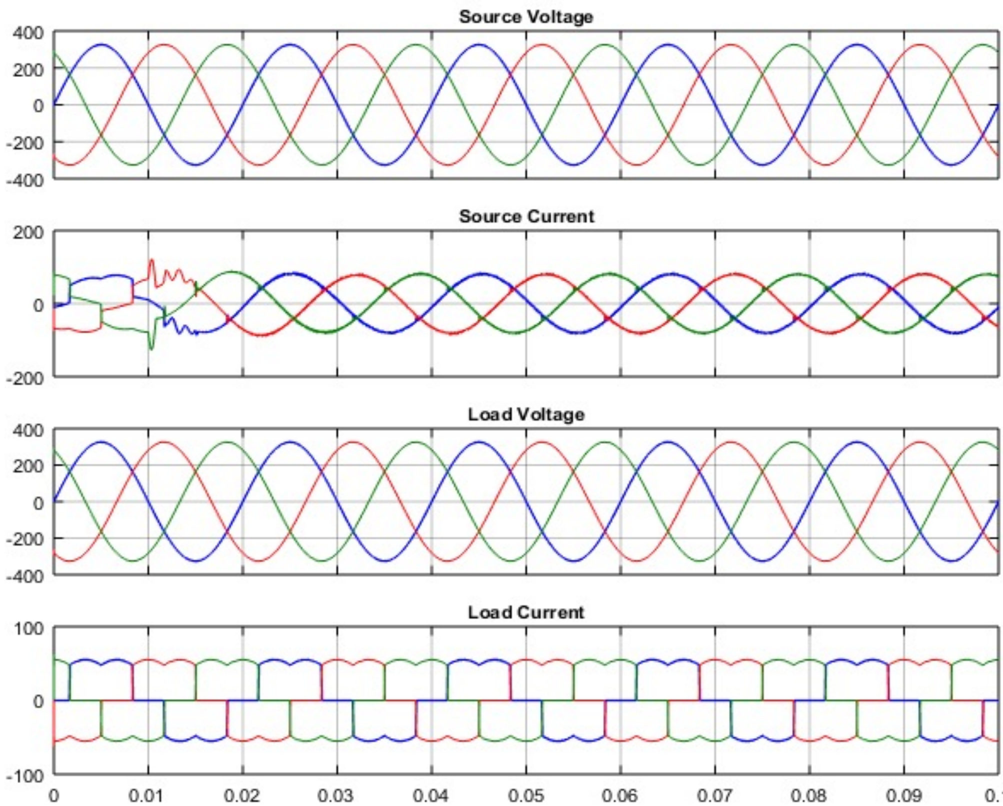

Figure 6. Hybrid –APF source and load Voltage and current waveforms Using PQ Method.
Source: own elaboration.

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The Hybrid-APF has performed the current compensation using PQ method and HCC with the Load. After compensation, the DC Link V and I waveforms are represented in Figure 7 and 8, respectively.

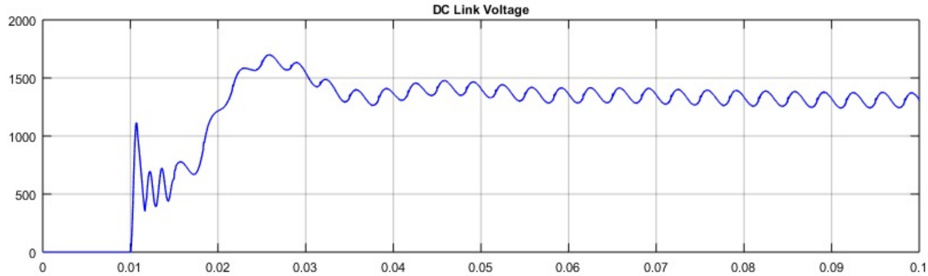


Figure 7. DC-Link Voltage Waveform after compensation.
Source: own elaboration.

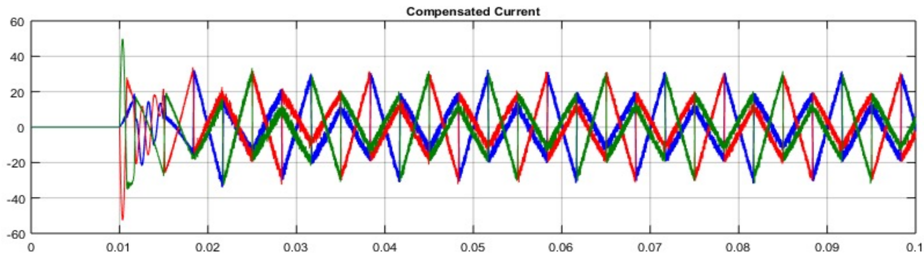
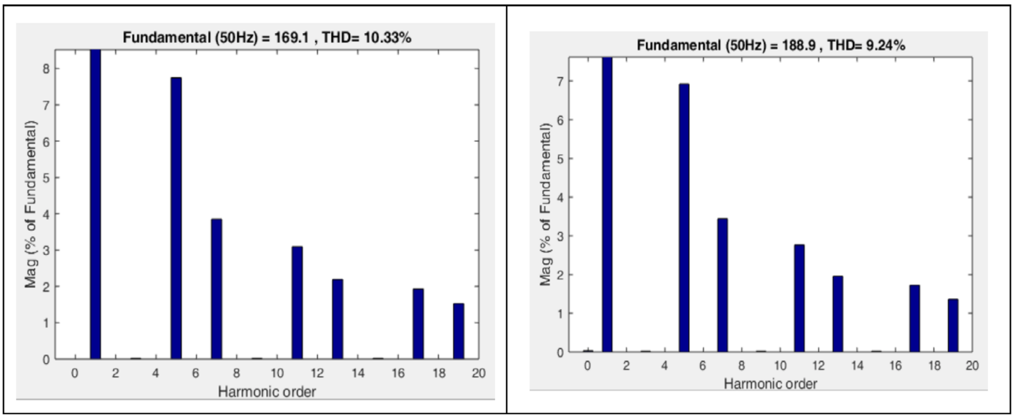


Figure 8. Compensated Current Waveform after Hybrid-APF using HCC.
Source: own elaboration.



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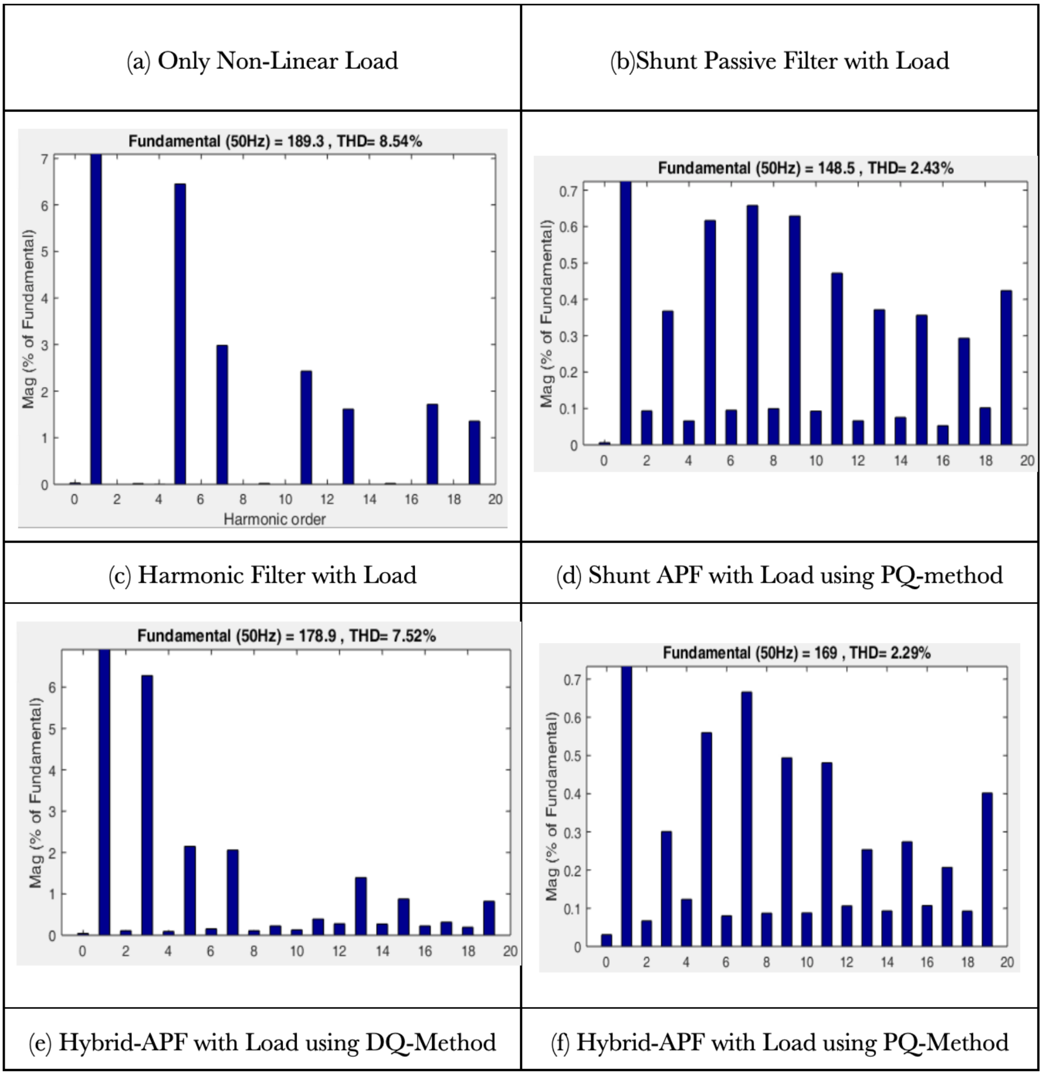

Figure 9. FFT analysis of Source Current-THD Values for Load and different Filtering techniques.
Source: own elaboration.

The FFT analysis of percentage THD results are obtained after simulating the different filtering technique models with Load is represented in Figure 9. The Three-Φ source with only non-linear load results the 10.33 % THD for I_s before filtering technique introduced in Figure 9(a).The Shunt Passive filter with Load obtains 9.24% THD, the Harmonic Filter with Load obtains 8.54% THD, shunt-APF obtains the 2.43% THD, Hybrid–APF using

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DQ-Method achieves 7.52% and proposed Hybrid–APF using PQ-Method obtains 2.29% THD for source current are represented in Figure 9(b-f)respectively.

4. DISCUSSION

The THD is a central part of the electrical modules to eliminate the harmonics in main power systems as per IEEE 519 standards. The THD calculation for H-APF using PQ-Method for different Harmonics and Nonlinear loads are tabulated in Table 2 and Table 3 respectively.

Table 2. THD Calculation (%) using different Harmonics for H-APF -PQ-Method.

HARMONICS	SINGLE TUNED			DOUBLE TUNED		
	5	7	11	5 & 7	7 & 11	5 & 11
THD	2.49	2.47	2.34	2.45	2.56	2.35

Source: own elaboration.

Table 3. THD Calculation (%) using different nonlinear loads for H-APF -PQ-Method.

NONLINEAR LOADS	R =10Ω	R= 1KΩ	RL (10Ω, 1mH)	RL (1KΩ,1μH)	RLC (10Ω,1mh, 10μF)	RLC (1KΩ,10mh, 100μF)
THD	2.29	3.07	2.1	3.05	3.1	3.13

Source: own elaboration.

The THD Calculation (%) of Vs and Is for Load and different Filtering Techniques is tabulated in Table 4. The Non-linear Load achieves 10.33 % THD without filtering techniques. By using Shunt Passive Filter with Load achieves 10.55 % THD reduction over Non-linear load model. The Harmonic Filter with Load achieves 8% THD reduction over only Passive Filter with the Load. The Shunt-APF Filter with Load achieves 45%THD reduction over Harmonic Filter with the Load. The Hybrid Filter with Load achieves 29.78% THD reduction over Shunt-APF Filter with Load for source Current. The PQ-Method achieves better THD 69.54% overhead than DQ-method.

https://doi.org/10.17993/3ctecno.2021.specialissue8.623-643

Table 4. THD Calculation (%) of Vs and Is for Load and different Filtering Techniques.

% THD	Only Load	Passive Filter	Harmonic Filter	Shunt-APF (DQ)	Hybrid-APF (DQ)	Shunt-APF (PQ)	Hybrid-APF (PQ)
Source Voltage (V_s)	0.08385	0.08368	0.0796	0.1298	0.1308	0.2209	0.2094
Source Current (I_s)	10.33	9.24	8.5	8.3	7.52	2.43	2.29

The percentage of reactive power is generated for Load, and different Filtering Techniques is tabulated in Table 5. The reactive power for a non-linear load is 12.06%, for Passive Filter with Load is 13.08%, for Harmonic Filter with Load is 11.6%, Shunt-APF with Load is 1.104% and Hybrid–APF uses 5.05% KVAR. The H-APF using DQ method utilizes 5.033 % reactive power.

Table 5. Reactive Power calculation (%) of Vs and Is for Load and different Filtering Techniques.

Power	Only Load	Passive Filter	Harmonic Filter	Shunt-APF (DQ)	Hybrid-APF (DQ)	Shunt-APF (PQ)	Hybrid-APF (PQ)
Reactive Power (KVAR)	12.06	13.08	11.6	1.699	5.033	1.104	5.05

Source: own elaboration.

The Shunt-APF uses less reactive power than Hybrid–APF, but it utilizes more THD and affects for harmonics mitigation. Hybrid-APF achieves the three-Phase Current compensation for Non-linear loads.

The comparison of proposed model with similar work of Balasubramanian and Palani (2016) of same parameters with THD improvements of 34% are tabulated in Table 6.

https://doi.org/10.17993/3ctecno.2021.specialissue8.623-643

Table 6. Comparison of Proposed H-APF.

PARAMETERS	PROPOSED WORK	PREVIOUSWORK (BALASUBRAMANIAN & PALANI, 2016)
Phase Voltage and Frequency	230V and 50HZ	230V and 50HZ
Load	Full bridge Diode Rectifier	Full bridge Diode Rectifier
Load resistance	26	26
THD (Current)	2.25%	3.42%

Source: (Balasubramanian & Palani, 2016).

5. CONCLUSIONS

This article presents the Hybrid-APF with modeling and simulation. The Hybrid-APF is an integration of Shunt-PF and Shunt–APF along with 3-Phase AC Source, RL Components and Non-linear Load. The S-APF will compensate for the voltage and currents using PQ Method and HCC. The Hybrid-APF simulation results for Source current and voltage, load current and voltage is presented. The Hybrid-APF is compared with other filtering techniques like Passive Filter, Active Harmonic Filter and Shunt-APF. The Proposed Hybrid –APF achieves better THD than other Filtering techniques. The Hybrid-APF achieves 2.29 %THD using PQ-Method which is better than DQ-Method THD-7.52%. The Hybrid-APF using PQ Method THD improvement over Shunt-APF is 5.76%. The Hybrid–APF utilizes less reactive power (KVAR) around 5.05%, which is quite useful for power system networks. In the future, improve the THD and reactive power of Hybrid-APF by using Artificial-Neuro- Fuzzy Logic Controller as a current compensation method.

REFERENECS

Ahsan, M. K., Pan, T., & Li, Z. (2018). A Three Decades of Marvellous Significant Review of Power Quality Events Regarding Detection & Classification. *Journal of Power and Energy Engineering*, *6*(8), 1-37. https://www.scirp.org/journal/paperinformation.aspx?paperid=86408

https://doi.org/10.17993/3ctecno.2021.specialissue8.623-643

Babu, P. N., Kar, B., & Halder, B. (2016). Modelling and analysis of a hybrid active power filter for power quality improvement using hysteresis current control technique. In *2016 7th India International Conference on Power Electronics (IICPE)* (pp. 1-6). IEEE. https://ieeexplore.ieee.org/document/8079381

Balasubramanian, R., & Palani, S. (2016). Simulation and performance evaluation of shunt hybrid power filter for power quality improvement using PQ theory. *International Journal of Electrical and Computer Engineering, 6*(6), 2603. http://ijece.iaescore.com/index.php/IJECE/article/view/5871

Chau, M. T. (2016). Adaptive current control method for hybrid active power filter. *Journal of Electrical Engineering, 67*(5), 343-350. https://www.sciendo.com/article/10.1515/jee-2016-0049

Damodhar, T. B., & Kumar, A. S. (2016). Implementation of FPGA based hybrid power generator for PV and wind grid applications. *Circuits and Systems, 7*(13), 4280-4290. https://www.scirp.org/journal/paperinformation.aspx?paperid=72395

Das, S. R., Ray, P. K., & Mohanty, A. (2017). Improvement in power quality using hybrid power filters based on RLS algorithm. *Energy Procedia, 138,* 723-728. https://doi.org/10.1016/j.egypro.2017.10.207

Demirdelen, T., Inci, M., Bayindir, K. Ç., & Tümay, M. (2013). Review of hybrid active power filter topologies and controllers. In *4th International Conference on Power Engineering, Energy and Electrical Drives* (pp. 587-592). IEEE. https://ieeexplore.ieee.org/document/6635674

Dhineshkumar, K., & Subramani, C. (2018). Kalman filter algorithm for mitigation of power system harmonics. *International Journal of Electrical and Computer Engineering, 8*(2), 771. http://ijece.iaescore.com/index.php/IJECE/article/view/10653

Diab, M., El-Habrouk, M., Abdelhamid, T. H., & Deghedie, S. (2018). Survey of active power filters configurations. In *2018 IEEE International Conference on System, Computation, Automation and Networking (ICSCA)* (pp. 1-14). IEEE. https://www.

semanticscholar.org/paper/Survey-of-Active-Power-Filters-Configurations-Diab-El-Habrouk/3c4052421432706db6368ffd19f3503436b921ff

Esfahani, M. T., Hosseinian, S. H., & Vahidi, B. (2015). A new optimal approach for improvement of active power filter using FPSO for enhancing power quality. *International Journal of Electrical Power & Energy Systems, 69,* 188-199. https://doi.org/10.1016/j.ijepes.2014.12.078

Kar, B., & Halder, B. (2016). Comparative analysis of a Hybrid active power filter for power quality improvement using different compensation techniques. In *2016 International Conference on Recent Advances and Innovations in Engineering (ICRAIE)* (pp. 1-6). IEEE. https://www.semanticscholar.org/paper/Comparative-analysis-of-a-Hybrid-active-power-for-N.-Kar/f8f82e857143 45a4c279384211e4e6da3ff427d0

Kedra, B. (2014). Comparison of an active and hybrid power filter devices. In *2014 16th International Conference on Harmonics and Quality of Power (ICHQP)* (pp. 556-560). IEEE. https://www.semanticscholar.org/paper/Comparison-of-an-active-and-hybrid-power-filter-K%C4%99dra/ba7b6bc0d0c5a58e73696e0e95e8c87a83147b25

Nandankar, M. P., & More, D. S. (2017). Performance analysis of transformer-less hybrid active power filter using different inverter topologies. In *2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT)* (pp. 892-897). IEEE. https://www.semanticscholar.org/paper/Performance-analysis-of-transformer-less-hybrid-Nandankar-More/f1bda36700e093bbc1c9a5e87fa1f615d8ec093f

Rahmani, S., Hamadi, A., Al-Haddad, K., & Dessaint, L. A. (2013). A combination of shunt hybrid power filter and thyristor-controlled reactor for power quality. *IEEE Transactions on Industrial Electronics, 61*(5), 2152-2164. https://ieeexplore.ieee.org/document/6557048

Schwanz, D., Bollen, M., & Larsson, A. (2016). A review of solutions for harmonic mitigation. In *2016 17th International Conference on Harmonics and Quality of Power (ICHQP)* (pp. 30-35). IEEE. http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1047315&dswid=-1367

Tahmid, R., & Ahmad, S. (2017). Power quality improvement by using shunt hybrid active power filter. In *2017 International Conference on Electrical, Computer and Communication Engineering (ECCE)* (pp. 381-386). IEEE. https://www.semanticscholar.org/paper/Power-quality-improvement-by-using-shunt-hybrid-Tahmid-Ahmad/83bb3a469ea95e3bbb12197e34e67c65453f942a

Temerbaev, S. A., & Dovgun, V. P. (2014). Improvement of power quality in distributed generation systems using hybrid power filters. In *2014 16th International Conference on Harmonics and Quality of Power (ICHQP)* (pp. 694-698). IEEE. https://www.energia-europa.com/wp-content/uploads/2020/08/Grasso_Improving_Efficiency_final_05.pdf

Thuyen, C. M. (2018). Improved p-q harmonic detection method for hybrid active power filter. *International Journal of Electrical and Computer Engineering (IJECE), 8*(5), 2910-2919. http://ijece.iaescore.com/index.php/IJECE/article/view/7800

Thuyen, C. M. (2019). A new design algorithm for hybrid active power filter. *International Journal of Electrical & Computer Engineering, 9*(6), 2088-8708. http://ijece.iaescore.com/index.php/IJECE/article/view/18581

Unnikrishnan, A. K., Chandira, E., Subash, T. G., Manju, A. S., & Joseph, A. (2015). Shunt hybrid active power filter for harmonic mitigation: A practical design approach. *Sadhana, 40*(4), 1257-1272. https://www.ias.ac.in/describe/article/sadh/040/04/1257-1272

Wang, L., Lam, C. S., & Wong, M. C. (2018). The Analysis of DC-link Voltage, Compensation Range, Cost, Reliability and Power Loss for Shunt (Hybrid) Active Power Filters. In *2018 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)* (pp. 640-645). IEEE. https://ieeexplore.ieee.org/document/8566367

Wang, Y. W., Wong, M. C., & Lam, C. S. (2015). Historical review of parallel hybrid active power filter for power quality improvement. In *TENCON 2015-2015 IEEE Region 10 Conference* (pp. 1-6). IEEE. https://ieeexplore.ieee.org/document/7373190

https://doi.org/10.17993/3ctecno.2021.specialissue8.623-643

https://doi.org/10.17993/3ctecno.2021.specialissue8.623-643