Performance Analysis of Hybrid Filter with HUA Optimization based PI-SRF Control Technique for Power Quality and Reactive Power Management

Palarapu Sravan Kumar [1]* B. Mangu [2]
[1,2]Department of Electrical Engineering, University College of Engineering,
Osmania University, Hyderabad, India

Abstract: This paper proposes a new Human urbanization algorithm (HUA) tuned Proportional-Integral (PI)-Synchronous reference frame (SRF) method for the control of hybrid filter. Hybrid filter is a custom power device that takes care of harmonic and unbalancing related power quality issues along with reactive power compensation, without burdening the design rating of active filter components like inverter and its switches. The performance of hybrid filter heavily depends on its control design, which in turn, relies on the controller design parameters, such as the PI controller. The performance of SRF method relies heavily on PI controller. The proposed HUA based optimization for PI offers better control and response, when compared with other popular methods. Moreover, the SRF method for controlling the active filter component of hybrid filter offers flexibility to support a controlled amount of reactive power depending on its rating. The hybrid filter system comprises of a four-leg shunt active filter and a shunt passive filter, to provide harmonic, neutral current and reactive power compensation. A complete simulation performance analysis is presented for the proposed HUA tuned PI-SRF based hybrid filter using MATLAB/SIMULINK. Also, a comparative analysis is performed for different tuning methods of PI controller.

Keywords: Hybrid filter, Human urbanization algorithm (HUA), Synchronous reference frame (SRF), Proportional-integral (PI), Current harmonics, Current unbalancing, Reactive power compensation.

1. Introduction

Custom power devices have emerged as a ground-breaking innovation that has the potential to completely alter how we manage power quality problems [1]-[6]. From past two decades, a lot of research work has been carried out on different devices, falling under the umbrella of custom power devices. These devices mostly includes passive filter, shunt active filter, series active filter, hybrid filter, UPQC and their different variants [7]-[9]

A state-of-the-art development in power electronics and control systems is the Shunt Active Power Filter (SAPF) [10]-[13]. It actively corrects for harmonic current, reactive power and other disturbances in real-time by using sophisticated control algorithms and high-speed semiconductor devices. However, when it comes to reactive power compensation the SAPF has a design rating constraint, which limits its capacity to provide required compensation [14]. Henceforth, a hybrid filter, which is a combination of active and passive filter, is a convenient option, where the passive filter not only supports the active filter in reactive power compensation but also in harmonic compensation [15], [16].

Different control mechanisms have been developed for the same over the years [17]-[19], but can be categorized basically in three categories [20]. One is the PQ theory which was devised very early, since its inception. Second is the Id-Iq method which is also termed as SRF (synchronous reference frame) method. And third is the UVT (Unit Vector Template) method. Various other extended and different versions of the same methods have been investigated upon by the researchers [21], [22]. Among the three, SRF method is found to be better in performance and control as compared to other two [20].

The control structure, such as the SRF method, of any custom power devices depends on the proper tuning and functioning of its error processing controller, in order to control the converter [23]-[25]. It is clearly validated over the years that Proportional-Integral (PI) controller is found to be the most robust and practically feasible controller for applications, such as active filter or hybrid filter control design [26], [27]. Thus, when one of the main design constraints of the system is to make the control structure more flexible and dynamic, precise tuning of these PI controller parameters, with fast response, is of utmost importance.

Metaheuristic optimization is vital for the PI-SRF control technique in power quality and reactive power management due to its ability to handle complex, high-dimensional, and non-convex optimization problems. In this paper, HUA tuned PI-SRF based control scheme is proposed for hybrid filter. The proposed hybrid filter is investigated for its performance and also a comparative analysis is carried out with other conventional methods. Hybrid filter consists of a parallel combination of a four-leg shunt active filter and three-phase tuned passive filter. Both in combination are used to mitigate load reactive power demand, current harmonics and neutral current due to unbalanced load. The control scheme for hybrid filter is based on SRF method. The SRF control scheme implemented for the hybrid filter includes an error processing PI controller, which is tuned using HUA based algorithm. The objective of implementing the proposed control scheme for hybrid filter is to reduce the design rating requirement of active filter components by specifically controlling the sharing of reactive power compensation Also, to improve its dynamic performance, i.e. during initial condition and during load change.

2. Hybrid filter configuration for three-phase four-wire system

This research paper considers a three-phase four-wire distribution system, depicted in Fig. 1. This system is connected to an unbalanced load, comprising a three-phase non-linear load represented as an uncontrolled rectifier connected to an RL load. Additionally, a three-phase linear load is included to account for reactive power demand. Furthermore, two single-phase non-linear loads are connected to phase-A and phase-B, signifying the presence of unbalancing in the system. The proposed work aims to study the effects and challenges posed by this configuration on the distribution system. Hybrid filter system comprises of a three-phase four-leg, shunt APF system connected via coupling inductors and three-phase passive filter, which in each phase consist of series combination of filter inductor and filter capacitor. The APF is controlled by the proposed HUA tuned PI-SRF method.

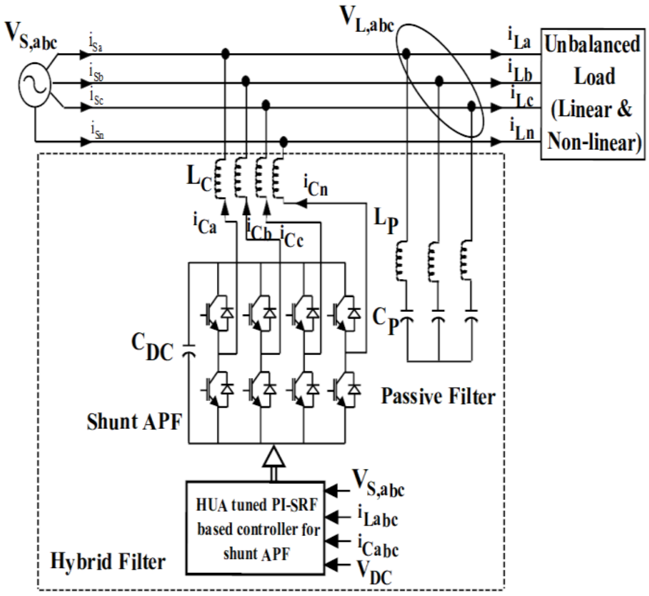

Figure 1. Hybrid filter configuration for 3-phase 4-wire system

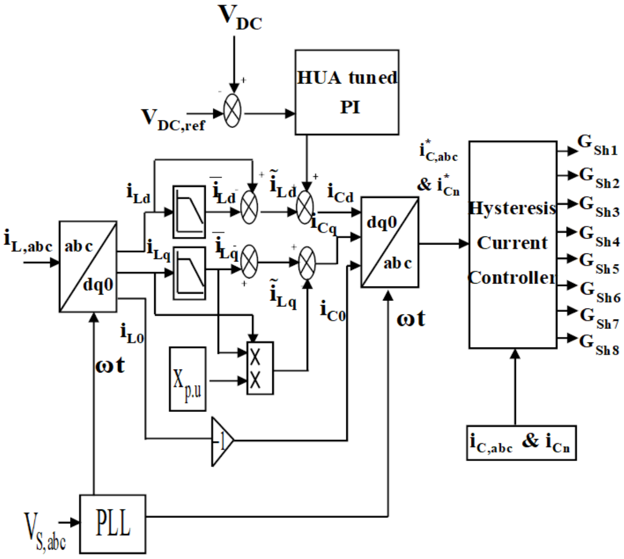

Figure 2. Control block diagram for shunt APF of hybrid filter with HUA tuned PI

2.1 HUA tuned PI-SRF control for Hybrid Filter

Fig. 2 depicts the control block diagram for the HUA tuned PI-SRF based APF portion of the hybrid filter. It participates in handling current harmonics due to non-linear load, neutral current due to unbalanced load, and major load reactive power compensation due to reactive linear load.

In this research paper, we investigate the use of a reference source current signal and a reference compensating current signal as the reference signal for a shunt active filter with an SRF-based controller. Specifically, we focus on comparatively more manageable compensating current reference signals and compare them with actual compensating current signals. Additionally, shunt APF handles a sizable percentage of the fundamental reactive current demand from the load side.

Three phase load current signal are converted to active current (d) and reactive current (q) components using abc-dq0 transformations

$$\begin{bmatrix} i_{l0} \\ i_{ld} \\ i_{lq} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin \omega t & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos \omega t & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix}$$

(1)

The average components of the active current, which is represented by the d axis component and includes both oscillating and average components, are filtered using a tailored low pass filter. The loss component of the filter, derived from the processed error of the DC-link capacitor voltage using a HUA tuned PI controller, is effectively integrated with the oscillating active current. To extract oscillating reactive current component, a low pass filter is also applied to the q axis component that represents reactive current. In order to govern the amount of reactive power being supplied by active filter part of hybrid filter, a value of $x_{p.u}$ is given as input to control the fundamental reactive current component from the active filter. This value is estimated on the basis of passive filter rating (i.e how much load reactive power passive filter can handle) and total load reactive power demand.

With dq0-abc transformation dq0 compensating current components are again converted back to abc three-phase compensating currents:

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \begin{bmatrix} \cos \omega t & -\sin \omega t & 1 \\ \cos\left(\omega t - \frac{2\pi}{3}\right) & -\sin\left(\omega t - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\omega t + \frac{2\pi}{3}\right) & -\sin\left(\omega t + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_{ld} \\ i_{lq} \\ i_{l0} \end{bmatrix}$$

(2)

Moreover, in order to control the forth leg of the active filter inverter, the reference three-phase compensating currents (denoted as $i_{ca}^*, i_{cb}^*, i_{cc}^*$) are used to obtain the neutral compensating reference current, as depicted by the following equation:

$$\mathrm{i}_{\mathrm{n}}^{*} = \mathrm{i}_{\mathrm{ca}}^{*} + \mathrm{i}_{\mathrm{cb}}^{*} + \mathrm{i}_{\mathrm{cc}}^{*} \quad (3)$$

Henceforth, a hysteresis current controller is utilized where these compensating reference currents are equated with compensating actual currents to produce switching pulses for the active filter ($\mathrm{G}_{\mathrm{sh1}}$ to $\mathrm{G}_{\mathrm{sh8}}$).

The proposed optimization method of PI controller, i.e HUA is discussed in the following section.

3. Human urbanization algorithm (HUA)

3.1 HUA basics

One of the metaheuristic algorithms is Human urbanization algorithm that is inspired by the qualities of human urbanization for maximize the life positions. Because of circumstances and growth of cities, many people are moving their [28]. HUA approach is based on the better surroundings of the cities. Journey, immigrate; depopulation and exposure are some of the urbanisms affecting factors. Adventuring is defined as motion for exploring new areas depend on the preceding experiences and random motions Migrations are alterations of livelihood change from a town to other town by calculating the luxuries. Populations were known by various routes that are open to towns. In the lookup every output is assumed as possible result.

3.2 HUA implementation

In the manuscript, this algorithm can be applied to solve the optimal tuning of Kp and Ki values for the Proportional-Integral (PI) controller used in a Shunt Active Power Filter (SAPF), with the objective function being the Integral of Time multiplied by Absolute Error (ITAE). The following steps outline the implementation of the HUA for this purpose:

Step 1: Initialization

In this process, input parameters are known by load current, dc link voltage, source voltage, proportional and integral gain constants in the PI controller are used.

Step 2: Random Generation

In this stage, the initialized parameters are randomly generated.

$$D = \begin{bmatrix} {K_{pt}}^{11}{K_{it}}^{11} & {K_{pt}}^{12}{K_{it}}^{12} & \cdots & {K_{pt}}^{1n}{K_{it}}^{1n} \\ {K_{pt}}^{21}{K_{it}}^{21} & {K_{pt}}^{22}{K_{it}}^{22} & \cdots & {K_{pt}}^{2n}{K_{it}}^{2n} \\ \vdots & \vdots & \vdots & \vdots \\ {K_{pt}}^{m1}{K_{it}}^{m1} & {K_{pt}}^{m2}{K_{it}}^{m2} & \cdots & {K_{pt}}^{mn}{K_{it}}^{mn} \end{bmatrix} (4)$$

Step 3: Fitness Evaluation

The fitness function of the proposed approach has been aimed at reducing the cost by optimally tuning the Kp and Ki values of the PI controller employed in SAPF, and it is defined in (5).

$$OF = f(k_p, k_i) \quad (5)$$

where OF represents the cost. The cost function chosen for our design are integral absolute error (ITAE).

Step 4: Position Updation using HUA

Using the following equation the city population like HUA method was reorganized as fitness

$$P_i(t+1) = P_i(t) + Index_j \quad (6)$$

Where, index of city specifies $Index_j$

Step 5: Determine the Radius of the City

The city radius is established in below equation,

$$R_i = \frac{k*D*R}{P_i} \quad (7)$$

Where, the radius of the city$i$ specifiesR_i, Population of city i specifies P_i , and the iteration specifies k. The variable Dmeasured and it depends upon the quality of city center compared to the city capital. Variable $D$is measured as,

$$D = arc\ tan\left(\left|\frac{(F(capi) - F(discent))}{F(capi)}\right|\right) + 0.5 \quad (8)$$

Where, the distance from the city centre specifies $F(discent)$

Step 6: Determine the Optimal Location

Step 6 shows, the parameters, that are already defined from the city center and the value is stored and are fragmented. By using these values the best active power are identified and the parameter is set to capital. Hence, step three and four is continued for each iteration.

Step 7: Termination Criteria

Series are checked to attain the highest level, if not reached its optimal solution, repeat the process again until the desired solution is found.

4. Outcomes and discussions

The hybrid filter with proposed HUA based PI-SRF method is analyzed for different load conditions for the configuration shown in Fig. 1. Also, a comparative analysis is carried out to showcase its effectiveness with other optimization methods. This analysis is performed by implementing the stated system in MATLAB/SIMULINK. Load section consists of three different load types, i.e. three-phase non-linear load, three-phase linear load and single-phase non-linear loads. Non-linear load introduces harmonic content in the system. Linear load poses heavy active and reactive power demand. Single-phase non-linear load introduces unbalancing in the system. The objective of simulation analysis is two-fold here, one is to validate the efficacy of SRF based APF system in terms of its multiple support for power quality improvement and other is to establish a comparative investigation for different tuning methods under similar load conditions. Simulation parameters are as given in Table I.

Table 1. Simulation System Parameters

Source	Per phase steady state voltage	230 V (RMS)
	Frequency	50 Hz
Shunt APF	Coupling Inductor	3.35mH
Passive filter	Filter Inductor	8.3 mH
	Filter Capacitor	25 µF
DC Link	Capacitor	3000 µF
	Reference Voltage	725 V
Load	3 Ø Linear Load	2 kW, 5 kVAR
	3 Ø Non-Linear Load (Rectifier with RL load)	R = 26 Ω, L = 10 mH
	1Ø Non-Linear Load (Rectifier with RL load) - Phase A	R = 15 Ω, L = 12 mH
	1Ø Non-Linear Load (Rectifier with RL load) - Phase B	R = 35 Ω, L = 10 mH

4.1 Three-phase non-linear load

In this case, the electrical load system consist of only non-linear load, which can be a representation of heavy rectifier or other converter based loads. This type of load creates a lot of harmonic distortion in the source current, thus polluting the electric supply system to a great extent. Under this case, hybrid filter with the proposed HUA based PI-SRF method is analysed for its accuracy, supported by a comparative performance analysis, with proposed and other conventional methods. Also, simulation analysis of the Hybrid Filter with proposed method is presented to highlight its harmonic mitigation capabilities.

Simulation analysis of the system shown in Fig. 3 is carried out with only three-phase non-linear load to understand the harmonic mitigation capacity of the hybrid filter. This is because, only non-linear load presents higher harmonic content in the source current as compared to both linear and non-linear. Fig. 3(a) shows the three-phase source voltage available from the grid source and is assumed to be balanced and ideal. Fig. 3(b) illustrates the three-phase source current without any harmonic compensation. Also, its harmonic content is shown in Fig. 3(c), in terms of its THD (Total harmonic Distortion). THD is found to be around 28.73 %. Fig. 3(d) illustrates the three-phase source current after compensation from the hybrid filter. Thus, it is observed that the source current is almost sinusoidal in contrast to the source current before compensation. Also, its THD content is shown in Fig. 3(e), found to be 2.27 %, which is less than the IEEE standards of 5 % limit. Fig. 3(f) and Fig. 3(g) shows the APF current and PF current, which both combined contributes in compensation of source current. Also, Fig. 3(h) shows the FFT analysis of PF current in order to understand that the passive filter is tuned to compensate the 7th order harmonic component present in the source current. Here, the role of passive filter is analyzed for the part of only harmonic compensation. However, the passive filter not only contributes for harmonic compensation, but also, it comes into play majorly in reactive power compensation, as explained in the next analysis section.

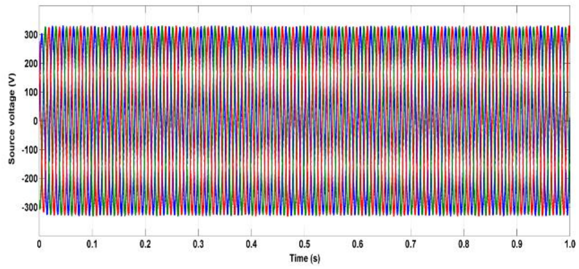

Figure 3(a) Source voltage

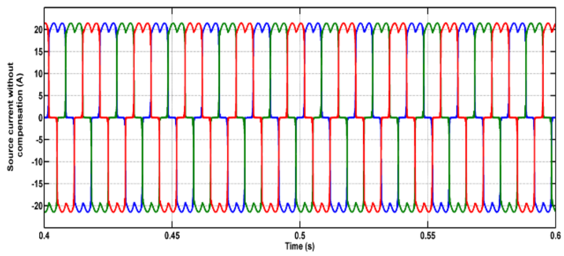

Figure. 3(b) Source current without compensation

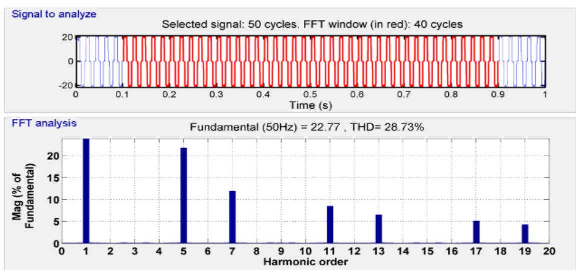

Figure 3(c) FFT analysis for source current without compensation

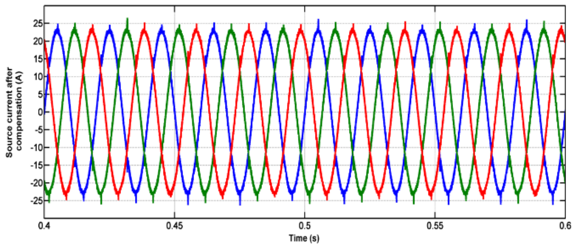

Figure. 3(d) Source current after compensation

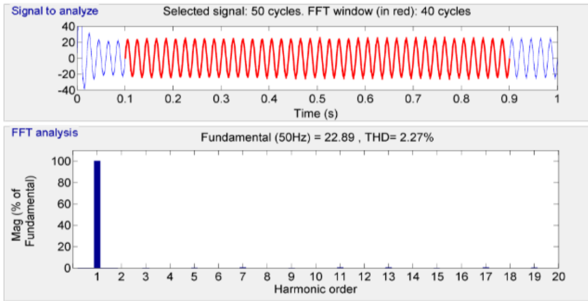

Figure. 3(e) FFT analysis for source current after compensation

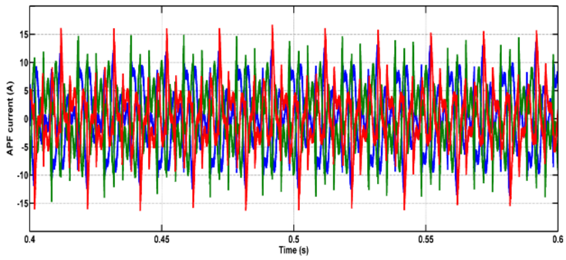

Figure. 3(f) Compensating current from APF

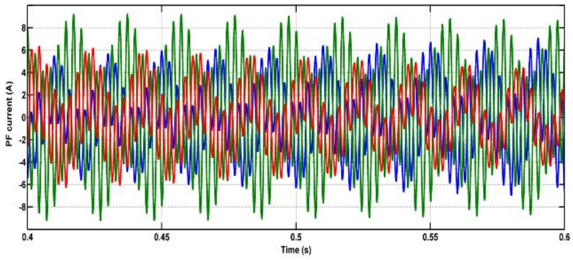

Figure. 3(g) Compensating current from passive filter

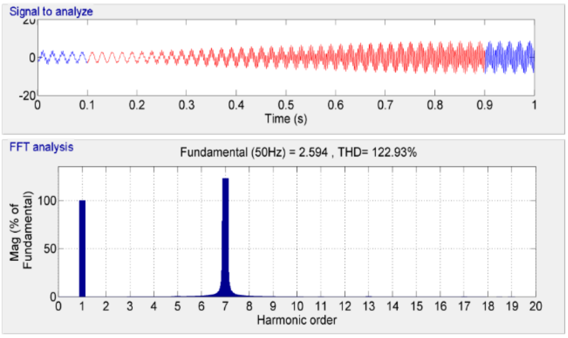

Figure. 3(h) FFT analysis for compensating current from passive filter

4.2 Linear and Non-linear load

The introduction of linear load along with non-linear load poses a demand of reactive power along with the requirement of harmonic compensation. However, harmonic compensation requirement is less as compared to only non-linear load scenario. In this section, at first simulation analysis of the system shown in Fig. 1 is presented, with load as a combination of linear and non-linear load. Also, a comparative analysis is presented for the same, understanding the efficacy of hybrid filter over only passive and active filter. Source voltage is same as shown in Fig. 3(a).

Fig. 4(a) illustrates the source current without compensation, which clearly indicates the non-sinusoidal nature of the same. Also, its THD content is shown in Fig. 4(b), which is observed to be 21.14 %. After compensation from the hybrid filter, source current becomes sinusoidal, as shown in Fig. 4(c), with its THD getting reduced to 1.87 %, shown in Fig. 4(d). The linear load poses a reactive load of 5 kVAR. This reactive load is compensated by the hybrid filter, where both active as well as passive contribute. Fig. 4(e) depicts the reactive power demand, compensation and sharing quite affectively. Active filter shares around 3.7 kVAR and passive filter contributes around 1.3 kVAR of the total demand. Henceforth, this sharing of VAR demand makes a significant impact on the rating reduction of APF. TABLE 2 indicates a comparative analysis on the impact of using hybrid filter, over active and passive alone. It clearly shows 16 % reduction in active filter rating by including single passive filter tuned to compensate 7th harmonic.

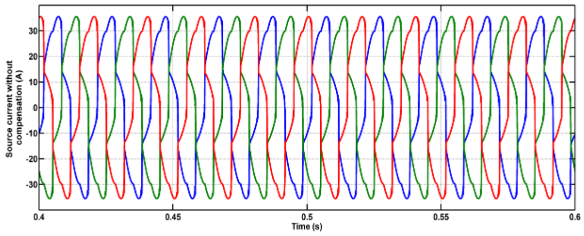

Figure. 4(a) Source current without compensation

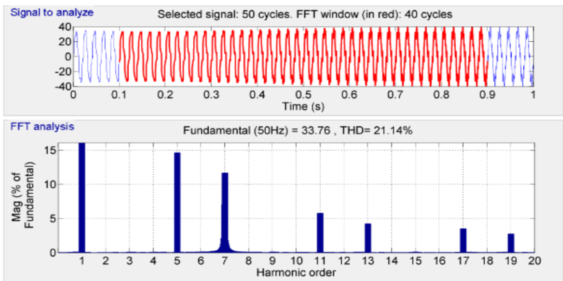

Figure. 4(b) FFT analysis for source current after compensation

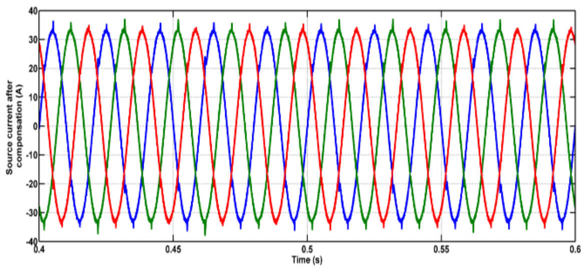

Figure. 4(c) Source current after compensation

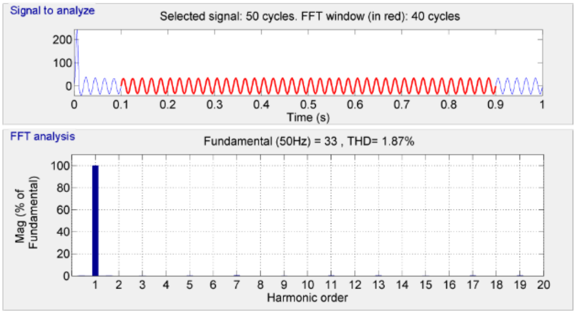

Figure. 4(d) FFT analysis for source current without compensation

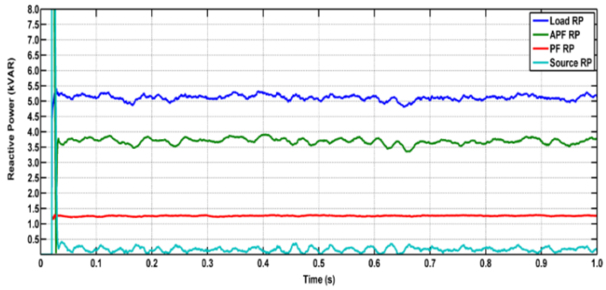

Figure. 4(e) Reactive power of load, APF, PF and source

Table 2. Performance parameter comparison

Conditions	Source			Reactive power (kVAR)		
	THD (%)	Current (A)	AP (kW)	Source	APF	PF
No Filter	28.73	20.7	11	5	---	----
Only Passive Filter	21.6	19.6	10.9	4.25	----	0.75
Only Active Filter	2.63	16.4	11.3	0.15	4.85	---
Hybrid Filter	2.27	16.3	11.2	0.1	3.7	1.3

*AP: active power, RP: reactive power. APF: active power filter, PF: passive filter

4.3 Comparative performance analysis of various PI tuning methods

For any hybrid or active filter based power conditioning system, the performance and response to transient conditions like initial condition or load change, are directly connected with the DC-link capacitor voltage profile. Here also, in order to understand the efficacy of proposed HUA tuned PI-SRF method over few other optimizations, DC-link voltage profile is considered as the analytic result. The other optimization methods used for tuning PI controller are grey wolf optimization (GWO), chimp optimization algorithm (ChOA), whale optimization algorithm (WOA), genetic algorithm (GA).

Fig. 5 illustrates the DC-link voltage pattern for different methods, for a duration of 5 s, and voltage range of 800 V. In order to analyze, the transient response, linear load is connected with the non-linear load at 1.0 s. There are three conditions to be analyzed here, first is the initial response time, second is transient response time and third is fluctuation observed during transient instant. The comparative parameters from the result are presented in Table 3. It is quite evident from the result and data presented that the proposed method offers better control and response than other methods. The DC-link voltage profile pattern, in turn, decides the performance parameter of the hybrid filter. HUA results in almost 82 % and 92 % lesser response time during initial (at the start) and transient condition (during load change) respectively, as compared to GWO optimization and even better than others. Also, the compensation performance improves with source current THD at 1.87 % as compared to others, which are further higher, for the same load condition. Thereafter, the efficacy of the proposed method is affectively visualized in the data presented, in terms of harmonic mitigation and response time

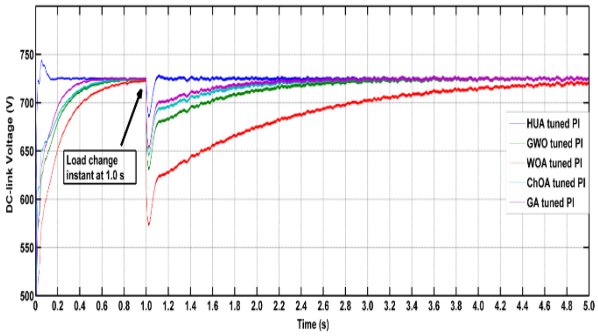

Figure. 5 Comparison of dc-link voltage using different metaheuristic algorithms

Table 3. PI optimization comparative analysis

PI tuning method	kp, ki values	Initial settling time (s)	Voltage undershoot (%)	Transient settling-time (s)	THD_Is (%)
HUA	0.2, 7	0.1	4.8	0.1	1.87
GWO	1.4, 10.3	0.55	9.6	1.2	3.82
WOA	3.4, 13.3	0.75	10.1	1.6	4.21
ChOA	4.1, 16.7	0.85	13.1	1.8	4.45
GA	6, 14.8	0.95	21.3	4.9	4.74

4.4 Unbalanced load condition

In order to analyze the proposed HUA tuned PI-SRF method under unbalanced load condition, along with the linear load stated in the above section, two different types of non-linear loads are considered here, one is a three-phase rectifier based load and the other is a set of two single-phase rectifier based load (unequal) for phase A and phase B. Single-phase load creates unbalancing in the system, and creates the origination of neutral current and thus has to be dealt with.

Fig. 6(a) indicates the unbalanced three-phase source current without compensation, thus along with its non-sinusoidal nature of wave shape, the three phases are unequal in magnitude. Also, the unbalancing is observed with the presence of source neutral current as shown in Fig. 6(b). Fig. 6(c) depicts the same three-phase source current after compensation from hybrid filter, which clearly shows that the three phases are completely balanced in magnitude and sinusoidal in nature. Thus, the source neutral current also diminishes to negligible value after compensation, as shown in Fig. 6(d).

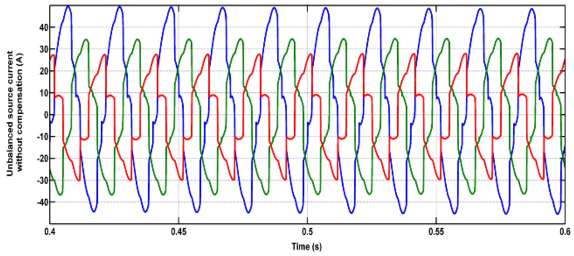

Figure 6(a) Unbalanced source current without compensation

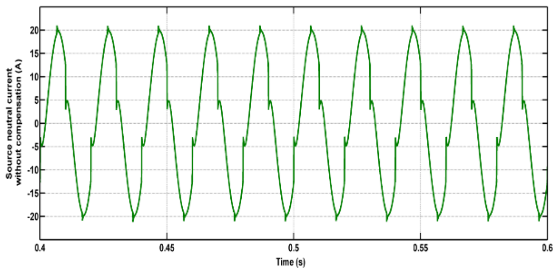

Figure 6(b) Source neutral current without compensation

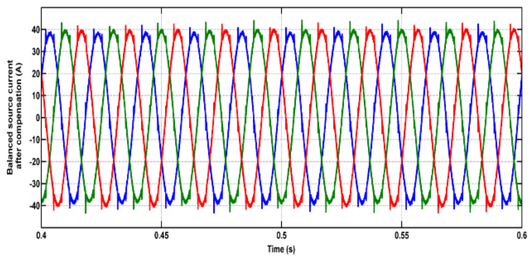

Figure 6(c) Balanced source current after compensation

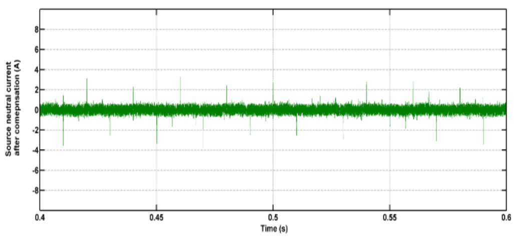

Figure 6(d) Source neutral current after compensation

5. Conclusion

A detailed simulation analysis is carried out to analyze the operation and performance of hybrid filter using HUA tuned PI-SRF method. The analysis comprised of different conditions and scenarios such as with non-linear load only, where harmonic contamination is very high, with both non-linear and linear load, to observe its reactive power compensation ability and unbalanced load condition to analyze its neutral current compensation ability. The SRF control method exhibited simpler control on reactive power compensation by active filter, thus keeping its burden below the design rating. Also, HUA optimization method is compared with other optimization methods, in order to showcase its superior performance over others. The proposed optimization results in almost 82 % and 92 % lesser response time during initial (at the start) and transient condition (during load change) respectively, as compared to GWO optimization and even better than others. Also, the compensation performance improves with source current THD at 1.87 % as compared to others, which are further higher, for the same load condition.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, xxx; methodology, xxxx; software, xxxx; validation, xxxx; formal analysis, xxxx; investigation, xxxx; resources, Raghuram; data curation, yyyyy; writing—original draft preparation, xxxx; writing—review and editing, yyyyy; visualization, yyyy; supervision, yyyy.

References

[1] Soomro, D.M., Chong, S.C., Memon, Z.A., Uqaili, M.A. and Abbasi, F., 2017. Performance of shunt active power filter based on instantaneous reactive power control theory for single-phase system. *International Journal of Renewable Energy Research (IJRER), 7(4), pp.1741-1751.*

[2] *Goud, B.S. and Rao, B.L., 2020. An intelligent technique for optimal power quality enhancement (OPQE) in a HRES grid connected system: ESA technique. International Journal of Renewable Energy Research (IJRER), 10(1), pp.317-328.*

[3] S. R. Das *et al.*, "A Comprehensive Survey on Different Control Strategies and Applications of Active Power Filters for Power Quality Improvement," *Energies*, vol. 14, no. 15, p. 4589, 2021

[4] S. Praveena and B. S. Kumar, "Performance of custom power devices for power quality improvement," *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*, Chennai, India, pp. 912-917, 2017

[5] M. Sharanya, B. Basavaraja and M. Sasikala, "Voltage quality improvement and harmonic mitigation using custom power devices: DVR and hybrid filters," *2013 IEEE Asia Pacific Conference on Postgraduate Research in Microelectronics and Electronics (PrimeAsia)*, Visakhapatnam, India, pp. 213-218, 2013.

[6] *Thirupathaiah, M., Prasad, P.V. and Ganesh, V., 2018. Enhancement of power quality in wind power distribution system by using hybrid PSO-firefly based DSTATCOM. International Journal of Renewable Energy Research, 8(2), pp.1138-1154.*

[7] A. V. Barva and S. Joshi, "A Comprehensive Survey on Hybrid Active Power Filter Topologies & Controller and Application in Microgrid," *2022 IEEE Region 10 Symposium (TENSYMP)*, Mumbai, India, pp. 1-6, 2022.

[8] T. Demirdelen, M. İnci, K. Ç. Bayindir and M. Tümay, "Review of hybrid active power filter topologies and controllers," *4th International Conference on Power Engineering, Energy and Electrical Drives*, Istanbul, Turkey, pp. 587-592, 2013.

[9] M. Diab, M. El-Habrouk, T. H. Abdelhamid and S. Deghedie, "Survey of Active Power Filters Configurations," *2018 IEEE International Conference on System, Computation, Automation and Networking (ICSCA)*, Pondicherry, India, pp. 1-14, 2018

[10] V. Khadkikar, "Enhancing Electric Power Quality Using UPQC: A Comprehensive Overview," in *IEEE Transactions on Power Electronics*, vol. 27, no. 5, pp. 2284-2297, May 2012.

[11] B. Singh and V. Verma, "Selective Compensation of Power-Quality Problems Through Active

Power Filter by Current Decomposition," in *IEEE Transactions on Power Delivery*, vol. 23, no. 2, pp. 792-799, April 2008.

[12] R. Zahira, A. Peer Fathima, “A Technical Survey on Control Strategies of Active Filter for Harmonic Suppression,” in Procedia Engineering, vol. 30, pp. 686-693, 2012.

[13] B. Singh, S. R. Arya, C. Jain, S. Goel, A. Chandra and K. Al-Haddad, "Four leg VSI based active filter in distribution system," *2014 Eighteenth National Power Systems Conference (NPSC)*, Guwahati, India, pp. 1-6, 2014

[14] V. Khadkikar, A. Chandra, B. Singh, “Digital signal processor implementation and performance evaluation of split capacitor, four-leg and three H-bridge-based three-phase four-wire shunt active filters,” IET Power Electronics, 2011, 4, (4), p. 463-470.

[15] Mohammad A.S. Masoum, Ewald F. Fuchs,” Chapter 9 - The Roles of Filters in Power Systems and Unified Power Quality Conditioners, Power Quality in Power Systems and Electrical Machines (Second Edition),” Academic Press, Pages 779-886, 2015

[16] B. Singh, I. Hussain, A. Chandra and K. Al-Haddad, "Power quality enhancement of the distribution system using hybrid filter," *2015 Annual IEEE India Conference (INDICON)*, New Delhi, India, 2015, pp. 1-6.

[17] D. Daftary and M. T. Shah, "Design and Analysis of Hybrid Active Power Filter for Current Harmonics Mitigation," *2019 IEEE 16th India Council International Conference (INDICON)*, Rajkot, India, 2019, pp. 1-4.

[18] T. K. Panigrahi, S. R. Das and R. Tripathy, "Power Quality Improvement Using Different Control Techniques in Hybrid Filters," *2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP)*, Hyderabad, India, 2022, pp. 1-5.

[19] S. Rahmani, A. Hamadi and K. Al-Haddad, "A new combination of Shunt Hybrid Power Filter and Thyristor Controlled Reactor for harmonics and reactive power compensation," *2009 IEEE Electrical Power & Energy Conference (EPEC)*, Montreal, QC, Canada, 2009, pp. 1-6.

[20] S. Rahmani, A. Hamadi, K. Al-Haddad and L. A. Dessaint, "A Combination of Shunt Hybrid Power Filter and Thyristor-Controlled Reactor for Power Quality," in *IEEE Transactions on Industrial Electronics*, vol. 61, no. 5, pp. 2152-2164, May 2014.

[21] N. Patnaik and A. K. Panda, "Comparative analysis on a shunt active power filter with different control strategies for composite loads," *TENCON 2014 - 2014 IEEE Region 10 Conference*, Bangkok, Thailand, pp.1-6, 2014

[22] B. Gutierrez and S. . -S. Kwak, "Finite set model predictive control method of shunt hybrid power filter," *2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia)*, Seoul, Korea (South), pp. 2849-2852, 2015

[23] K. Naftahi, A. Abouloifa, Z. Hekss, S. Echalih, F. Ait bellah, I. Lachkar, “Three-Phase Four-Wire Shunt Active Power Filter Based on the Hybrid Automaton Control with Instantaneous Reactive Power Theory,” IFAC-PapersOnLine, Vol. 55, Issue 12, Pages 532-537, 2022

[24] K. S. DedY, A. Mochamad Ashari, S. Heri, “Transient Operation of a Four-Leg Inverter in Rooftop Solar Connected to a Grid Using Optimized Constructive Neural Network,” International journal of intelligent engineering and systems, Vol.14, No.6, pp.258-273, 2021

[25] R. R. Chegudi, B. Ramadoss, A. RamaKoteswaraRao, “Artificial Rabbits Optimization Based Optimal Allocation of Solar Photovoltaic Systems and Passive Power Filters in Radial Distribution Network for Power Quality Improvement,” *International journal of intelligent engineering and systems*, Vol.16, No.1, pp.100-109, 2023

[26] A. A. Imam, R. Sreerama Kumar, and Y. A. Al-Turki, “Modeling and Simulation of a PI Controlled Shunt Active Power Filter for Power Quality Enhancement Based on P-Q Theory,” *Electronics*, vol. 9, no. 4, p. 637, Apr. 2020

[27] Mishra, A.K., Ray, P.K., Patra, A.K., Mallick, R.K., Das, S.R. (2020). Self-tuned PI Controller Based Hybrid Shunt Active Power Filter for Power Quality Enhancement. In: Pradhan, G., Morris, S., Nayak, N. (eds) Advances in Electrical Control and Signal Systems. Lecture Notes in Electrical Engineering, vol 665. Springer

[28] Ghasemian, H., Ghasemian, F. and Vahdat-Nejad, H., 2020. Human urbanization algorithm:

A novel metaheuristic approach. *Mathematics and Computers in Simulation*, *178*, pp.1-15.