International Journal of Scientific Research & Engineering Trends
Volume 11, Issue 1, Jan-Feb-2025, ISSN (Online): 2395-566X

Review on Improvement of Shunt Active Filter Performance Using Artificial Intelligence Methods

Manish Tomar, Raghunandan Singh Baghel
Department of Electrical Engineering
School of Engineering and Technology, Ujjain (M.P.)

Abstract- In this review study, we looked at a variety of power filter approaches for high-power applications that frequently involve complicated digital control circuits and expensive batteries. An analog-based hysteresis current controller and capacitive energy storage are used to create a simple and low-cost active power filter circuit in this study. The filter is designed to be a low-power add-on item that reduces AC harmonic currents generated by existing electronic equipment (such as personal computers), which cause nonlinear loads on the AC mains. The suggested filter is addressed in terms of its operating concept, design requirements, and control method.

Index Terms- Power Active Filter, Shunt filters, Simulink.

I. INTRODUCTION

Harmonics is defined as "a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency". Harmonic is mix of several of frequency current or voltage multiply by fundamental voltage or current in the provided system. Previous technique used to compensate load current harmonics is L-C passive filter; as a result the filter cannot adapt to the various range of load current and sometimes produce undesired resonance. The presence of harmonics, when power lines are considered leads to even greater power losses in distributing, causing noise troubles in the communication systems and, every so often, causing breakdown of functioning of electronic apparatus, which have superior sensitivity for the reason that the addition of microelectronic control systems plus these systems lead to devices with low power and therefore a minute noise can be noteworthy. These become the reasons that put together the power quality issue as one of the most apprehensive issues as far as the final user is concerned. International standards concerning electrical energy consumption impose that electrical equipment should not produce harmonic contents greater than specified values. Meanwhile it is a must to solve the harmonic problems caused by those devices which have already been installed. Use of the passive filters is one of the classic solutions to solve harmonic current problems, but they present several disadvantages, namely: they only filter the frequencies they were previously tuned for; their operation cannot be limited to a certain load; resonances can occur because of the interaction between the passive filter and other loads, with unpredictable results. As a result, conventional solutions that rely on passive filters to perform a harmonic reduction are ineffective. Under these conditions it has been proved that the most effective solutions are active filters which are able to compensate not only harmonics but also asymmetric currents caused by nonlinear and unbalanced loads. Due to the remarkable progress in the last two decades in the field of power electronics devices with forced commutation, active filters have been extensively studied and a large number of works have been published.

II. SHUNT ACTIVE POWER FILTER

Due to its efficiency and ease of installation, the shunt topology is more prevalent than the others. In order to counteract the influence of harmonics in the system, the shunt APF injects harmonic current in opposite to the load harmonics, as illustrated in fig. 1. For current reference generation, simulink employs the instantaneous power (p-q) theory. In the literature, hybrid active filters have been proposed as a less expensive harmonic compensation alternative to solely active filters. Hybrid filters combine passive components to lower the active element's necessary ratings [1-4]. The evolution of hybrid filter topologies has been a logical progression from long-used fully passive tuned filters to simpler passive structures with a single active element. The original tuned structures served as a foundation for these passive buildings. This study examines the various hybrid active filter topologies available and identifies those that are most suited for harmonic reduction while maintaining low active component ratings. The following is the procedure that was followed:

- Select suitable models for the load
- Determine the desirable attributes of a filter
- Generate possible topologies and identify useful filters This approach uncovers existing and new topologies and

establishes a systematic framework for describing active filters.

Effect of Harmonics

Harmonics may cause interference and disturbance in power systems network. Some of the major problems include:

- Harmonic currents present in the power system causes heating of equipment, such as transformers and generators and give huge copper loss.
- In generators owing to multiple zero crossings of distorted current waveform causes voltage instability and voltage fluctuation.
- Since frequency of harmonic current is different from that of fundamental may cause improper breaker and switch operation which is undesirable.

Harmonic Mitigation Techniques

Harmonic elimination techniques are used to improve the power system performance with some objectives

To improve the system power factor and to compensate the reactive power. To maintain a particular THD limit in current harmonic distribution. Hence various devices and equipment serves the purpose of harmonic elimination from power system. Some of widely used equipment is:

- Line reactors (Inductive reactor)
- Isolation transformers (provide isolation of high power circuit from low power circuit)
- K-Factor or harmonic mitigating transformers
- Phase shifting transformer
- Harmonic filters But mostly current harmonic filters are used to reduce current harmonics in power system. There are generally two types of harmonic filters are present:
- Passive filter and
- Active filters.

III. LITERATURE REVIEW

Pavankumar Daramukkala et al.[1] This research article details the design and implementation of a nonlinear adaptive filtering (NAF) technique using an exponential functional link network (EFLN) for a shunt hybrid active power filter (SHAPF) control to solve the current-associated power quality issues on the utility side at the distribution level of electrical power systems. Separation of the fundamental component from the harmonics, achieving unity power factor operation, reducing the reactive power drawn from the source, balancing the currents during transients, and reduction of total harmonic distortion (THD) of the source current are the issues considered to resolve. The proposed technique solves these issues by generating the sinusoidal reference current and separating the fundamental current from the harmonics. When compared to conventional and existing adaptive filtering techniques such as least mean square (LMS), least mean fourth (LMF), and variable step size LMS (VSS-LMS), the proposed EFLN-NAF method excels in terms of speedy convergence, adaptability in noise-specific environments and reduced steady-state coefficient error. MATLAB/Simulink software is utilized to perform the simulations to examine the suggested strategy for the chosen SHAPF topology both in static and dynamic scenarios. For a 15 kW and 3kVAr requirement of the nonlinear load, simulation results proved that the designed PPF for 2kVAr is able to share the reactive power with the APF, thereby reducing its rating and cost. The proposed method of filtering has been proven to be fast converging with 0.049 s, and the THD in steady state is brought to 1.32 % in steady-state and to 3.77 % during transient conditions, which are under standard limits. A hardware prototype of the experimental setup is constructed at the laboratory scale with OPAL-RT (OP4510) as the controller. With an active and reactive power demand of 1.1 kW and 210VAr, the designed PPF supplies 110 VAr, whereas the rest is supplied by the APF. The practical THD in source current is observed to be 2.081 %, which meets the standards. The results from both simulations and experiments are validated, and the efficacy of the proposed technique in mitigating the aforementioned power quality issues is proved.

Behnam Amini et al.[2] Current harmonics produced by nonlinear loads have destructive effects that affect the power quality of the power system and cause serious problems throughout the network. Active Power Filter (APF) is one of the best and most common solutions to reduce or eliminate harmonic disturbances; But due to the complexity and sensitivity of these filters, the accurate and fast performance of the control technologies used in it is the important and basic requirement. Therefore, by performing accurate and optimal adjustments for APF control, system performance and power quality level can be improved significantly. In this article, the design principles of Shunt Active Power Filter (SAPF) are introduced and the optimal control method of this system is explained by providing appropriate modeling. Also, as a suitable structure for the current control of the SAPF system, a Proportional-Resonant (PR) controller optimized by Genetic Algorithm (GA) is proposed. The PR controller with the capability of accurate tracking of harmonic currents and fast dynamic response is highly compatible with the SAPF system. In general, the goal is to achieve better and more appropriate performance to reduce harmonic disturbances and create a robust, faster, more accurate, flexible, stable, and optimal performance of these systems in detecting and generating compensation signals. The simulations have been done in MATLAB/SIMULINK, and also the experimental tests of this device have been done and validated in a real DSP-based SAPF. Finally, according to the results obtained under steady-state conditions with a favorable dynamic response, the Total Harmonic Distortion (THD) of the grid current has been significantly reduced from 20.2 % to 4.2 % for the R-L load and from 56.1 % to 4.5 % for the R-C load with a power factor of almost unity. These results confirm the optimal and standard performance of the proposed method.

Asmae Azzam Ja et al.[3] This study develops three new machine learning-based algorithms using the SVR prediction approach. The overall objective is to enhance the performance of the PV shunt active power filter (PV-SAPF) in order to successfully fulfil its multi-functionality in terms of PV power generation along with power quality upgrades. The first technique, named "SVR-INC MPPT", incorporates an ML-based duty cycle prediction function, which is intended to speed up the MPP finding process. The algorithm then switches to the INC approach, guaranteeing an accurate steady-state response. The second and third techniques are the ML-based Adaline for DC voltage regulation, and the ML-based Adaline SRF strategy for reference currents generation. The adopted approaches are based on the prediction of two weights performing the actions of the proportional and integral of DC voltage controller, and nine weights for the fundamental currant extraction. The advantage lies in overcoming the Adaline-based algorithm's limitations, requiring an on-line large number of iterations. Three simulation scenarios along with six controllers based on classical and intelligent techniques, are adopted to prove the effectiveness of the proposed ML-controllers. The results display (i) an accurate and immediate ML-based harmonics identification (minimizing the extraction error by up to 99% compared to the Adaline approach). (ii) a response time reduction range from 65% to 100%, of the ML-based DC voltage output controller compared to the PI-based one. (iii) a THD range from 2.41% to 4.45%. (iv) 20 ms and 0% of PV power response time and overshoot, respectively (v) DC voltage overshoot range from 0.04% to 1.1%. Consequently, these three ML-based controllers offer the best options for a powerful PV-SAPF system in terms of performance tracking and harmonic attenuation. Moreover, the obtained metrics comply with IEEE-519 standard.

Zineb Hekss et al.[4] This paper investigates the problem of controlling a single phase shunt active power filter (SAPF) connected to two photovoltaic arrays through a half bridge inverter involving two DC link capacitors. The control aims are threefold: ensuring a satisfactory power factor correction (PFC) at the grid-power filter connection point by compensating the harmonic and reactive currents produced by the nonlinear loads; extracting a maximum active power in the output photovoltaic arrays by applying the maximum power point tracking (MPPT) block and balancing the power exchange between the photovoltaic source and the AC power grid by regulating the DC link capacitors voltages. The problem is dealt with using a cascade nonlinear adaptive controller. The inner loop is designed using sliding mode and Lyapunov stability techniques so that to ensure a unity power factor. It also includes an adaptive observer that performs online estimation of the grid state variables which are not accessible to measurements. The outer loop is mainly constituted of filtered proportional-integral (PI) regulator, that ensures a tight regulation of the photovoltaic voltage, and the incremental conductance (IC) algorithm to meet MPPT. The resulting controller performances are formally analyzed making use of averaging theory. The theoritical analysis results are confirmed by numerical simulation within MATLAB/SimPowerSystems environment.

Soufiane Khettab et al.[5] Model Predictive Control (MPC) is widely used in control systems for its ability to handle constraints and optimize performance. However, conventional MPC methods often employ Euler integration for trajectory computation, which introduces computational errors that escalate with the sampling time, leading to diminished tracking performance and higher switching frequencies, particularly at larger intervals. To address these challenges, we propose a novel approach that integrates the 4th-order Runge-Kutta (4oRK) method into MPC. The 4oRK method offers improved accuracy over Euler integration by significantly reducing computational errors through its higher-order approximation. A comparative analysis of the two methods, conducted under varying load profiles and voltage sag conditions, revealed that while the Euler-based approach produces grid currents with a Total Harmonic Distortion (THD) exceeding 5 %, the 4oRK-based method consistently achieves a THD below 5 %, ensuring superior harmonic suppression. Moreover, the 4oRK method effectively reduces power losses without increasing computational complexity, as demonstrated by comparable task execution times. This improvement is achieved through a two-stage computation process prediction and correction that enhances MPC's performance at larger sampling intervals while reducing control adjustment frequency. Extensive MATLAB/Simulink simulations and physical prototype experiments validate the proposed 4oRK-based MPC, showing its ability to minimize THD, achieve unity power factor, and maintain robust control performance at lower switching frequencies. This advancement in MPC integration contributes to more efficient, accurate, and reliable control system design.

N.F. Guerrero-Rodríguez et al.[6] This work shows the design and validation of a Shunt Active Power Filters (SAPF) using Controller Hardware-In-the-Loop (CHIL) Simulations by using a OP5707XG Real-Time Simulator module provided by OPAL-RT, an external OP8666 controller, a host PC and an oscilloscope for visualization. A novel methodology for the modelling of real non-linear electrical loads by making use of MATLAB/SIMULINK is presented. This allows, in conditions like real physical systems, an evaluation of the behavior of active filters before their prototyping, allowing improvements to be made in their design. For the compensation strategy, the calculation of a compensation current from the estimation of the ideal current is used. This strategy is implemented in a microcontroller system for validation with a CHIL configuration simulation. The results have demonstrated significant progress in harmonic mitigation, with the effectiveness of the SAPF in reducing the current Total

Harmonic Distortion (THD) across various load types firmly established. As demonstrated in the test cases, the SAPFs significantly reduced THD from significant double-digit percentages to values well below 3 %. This confirms their significant impact on maintaining the integrity and quality of the power system.

Ahmed M.M. Nour et al.[7] Shunt active power filters (SAPFs) are effective in addressing power quality issues such as harmonics and voltage unbalance. During abnormal grid conditions, there will be a substantial variation in both the actual and reactive power of the system. Various SAPF control approaches were employed to address these issues. This paper presents an improved bandpass filter technique that serves multiple purposes: extracting the reference current harmonic for SAPF, providing reactive current for power factor correction, and functioning as a backup synchronization method in the event of a loss of bus voltage measurement. Furthermore, it should be minimally affected by the unbalance in supply voltage. The case study model and the proposed reference technique have been executed and validated using the MATLAB software environment.

N. Madhuri et al.[8] This research proposes a novel method that combines Proportional-Integral (PI) control, Artificial Neural Networks (ANNs), and Synchronous Reference Frame (SRF) theory to improve the performance of a three-phase shunt Active Power Filter (APF) under fault situations. The main goal is to reduce power quality problems in electrical grids that are having problems, such harmonics and voltage sags. To precisely manage the APF, the reference frame in which the grid voltages and currents are synchronized is identified using the SRF theory. In order to provide quick and precise correction of voltage and current distortions, the PI controller is integrated to control the APF's compensatory action. The PI controller offers trustworthy control while running normally, but during errors or disruptions, its functionality may suffer. In order to overcome this difficulty, a self-tuning filter in the form of an Artificial Neural Network (ANN) is presented, which may adaptively modify the PI controller's settings under fault situations. To maintain ideal filter performance, the ANN constantly learns from the system's reaction and modifies in real-time. This self-adjusting feature makes sure that even in the event of grid failures, the APF maintains its ability to mitigate problems with power quality. The suggested method effectively reduces harmonics, voltage sags, and other power quality disturbances under both normal and fault circumstances, as shown by the simulation results. In complicated electrical grid systems, the combination of SRF theory, PI control, and ANN-based self-tuning provides a strong way to improve the dependability and effectiveness of three-phase shunt Active Power Filters.

Abdallah El Ghaly et al.[9] Active filters are commonly employed to mitigate voltage and current distortions by rapidly responding to harmonic disturbances originating from the load side. However, the effectiveness of these filters depends on the accuracy of reference signal extraction, which is susceptible to measurement noise and source voltage distortion.

This paper proposes an extraction method consisting of decomposing the distorted signal into its constituent harmonic components by the matrix pencil method, reconstructing the fundamental component from the estimated fundamental frequency and amplitude, and subtracting the fundamental component from the distorted signal to obtain the reference signal. The robustness of the proposed method to noise and source voltage distortion stems from the over-modeling technique of the matrix pencil method and its ability to extract the reference signal without a low-pass filter, which often introduces errors in phase shift and magnitude. Simulation scenarios developed in MATLAB/Simulink involving measurement noise, source disturbance, and asymmetrical loads are used to compare the performance of the proposed method with the instantaneous reactive power theory and synchronous reference frame methods. Additionally, an experimental prototype is developed to validate the effectiveness of the proposed method on real data. Analysis of simulation and experimental results shows that the proposed method outperforms the conventional methods in robustness to source distortions and measurement noise, as demonstrated by the total harmonic distortion, which is around 0.77 % for simulated data and 1.68 % for experimental data. These findings underscore the significant enhancement in the overall power filter performance facilitated by the proposed extraction method.

O. Khentaoui et al.[10] The present paper concentrates on the improvement of power quality using a single-phase active power filter (APF) connected to the photovoltaic (PV) array operating in the presence of a non-linear load. A novel controller design, based on the energy stored in the half-bridge shunt APF is proposed to ensure two main objectives at the same time: (i) the transfer of active power to the electrical network by extracting the maximum of active power from the PV panels and regulating the PV voltage to a reference value provided by the MPPT; (ii) the improvement of power factor correction (PFC) by compensating for the harmonic current and reactive power produced by the non-linear load using the backstepping technique and Lyapunov tools.

The nonlinear controller is developed in two loops. An inner loop is constituted of a PFC regulator based on the energy stored in the APF to minimize the total harmonic distortion (THD). An outer loop uses a linear PI regulator to regulate PV array voltage. The controller also comprised an observer to estimate the voltage network, which is not accessible to measurements. The performance of the proposed controller is validated by simulation using MATLAB/Simulink.

IV. CONCLUSION

The filter presents good dynamic and steady-state response and it can be a much better solution for power factor and current harmonics compensation than the conventional approach (capacitors to correct the power factor and passive filters to compensate for current harmonics). Besides, the shunt active filter can also compensate for load current unbalances, eliminating the neutral wire current in the power lines. Therefore, this active filter allows the power source to see an unbalanced reactive non-linear load, as a symmetrical resistive load.

REFERENCES

1. Daramukkala, P., Mohanty, K. B., & Behera, B. P. (2024). Improved performance of a shunt hybrid active power filter by a robust exponential functional link network-based nonlinear adaptive filter control to enhance power quality. ISA transactions.
2. Amini, B., Rastegar, H., & Pichan, M. (2024). An optimized proportional resonant current controller based genetic algorithm for enhancing shunt active power filter performance. International Journal of Electrical Power & Energy Systems, 156, 109738.
3. Jai, A. A., & Ouassaid, M. (2024). Three novel machine learning-based adaptive controllers for a photovoltaic shunt active power filter performance enhancement. Scientific African, 24, e02171.
4. Hekss, Z., Abouloifa, A., Lachkar, I., Giri, F., Echalih, S., & Guerrero, J. M. (2021). Nonlinear adaptive control design with average performance analysis for photovoltaic system based on half bridge shunt active power filter. International Journal of Electrical Power & Energy Systems, 125, 106478.
5. Khettab, S., Kheldoun, A., & Bradai, R. (2025). A novel Runge-Kutta-based model predictive controller for PUC7-based single-phase shunt active power filter. Computers and Electrical Engineering, 123, 110051.
6. Guerrero-Rodríguez, N. F., Nuñez-Ramírez, V., Batista-Jorge, R. O., Mercado-Ravelo, R., Ramírez-Rivera, F. A., Ferreira, J. A., & Reyes-Archundia, E. (2024). Modelling real non-linear loads for a Controller Hardware-in-the-Loop configuration to evaluate a Shunt Active Power Filter. Energy Reports, 12, 1947-1976.
7. Nour, A. M., & Helal, A. A. (2025). A voltage sensorless technique for a shunt active power filter adopting band pass filter under abnormal supply conditions. Electric Power Systems Research, 238, 111133.
8. Madhuri, N., & Kalavathi, M. S. (2024). Fault-tolerant shunt active power filter with synchronous reference frame control and self-tuning filter. Measurement: Sensors, 33, 101156.
9. El Ghaly, A., Tarnini, M., & Chahine, K. (2025). A robust reference extraction method for shunt active power filters in the presence of noise and source voltage distortion. Measurement, 242, 116243.
10. Khentaoui, O., Mchaouar, Y., Abouelmahjoub, Y., Abouobaida, H., Giri, F., & Chakiri, S. (2024). Observation and Backstepping Control of Single-Phase Shunt Active Power Filter Connected to photovoltaic System. IFAC-PapersOnLine, 58(13), 92-97.