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A DYNAMIC POWER QUALITY ENHANCEMENT MODELING OF HYBRID ACTIVE POWER FILTER USING ARTIFICIAL INTELLIGENCE (ANFIS) CONTROLLER

P. Purnachander Rao, *Research Scholar, Electrical and Electronics Engineering, JNTUH, Hyderabad, India. purnachander216@gmail.com*
K. Prakash, *Professor, Electrical and Electronics Engineering, Vaagdevi College of Engineering, India*
M. Suryakalavathi, *Professor, Electrical and Electronics Engineering, JNTUH, Hyderabad, India*

ABSTRACT
In power systems, the power factor is a major consideration. Damage to electronic and electrical equipment caused by variations in physical parameters, such as voltage, current, and frequency, resulted in a notable loss of power. By implementing filtration techniques in electrical and electronic equipment, the problems with power loss and quality were fixed. The majority of filtering techniques that are currently available make use of appropriate compensation regulating techniques, however they are unable to minimize total harmonic distortion (THD), and harmonic mitigation works best in power systems. This paper presents the creation of an effective hybrid APF that takes a hardware-software approach and uses an artificial-neuro fuzzy interface system (ANFIS). To manage the power losses for H-APF, the suggested method makes use of hybrid controlling techniques, such as PI with artificial intelligence (ANFIS) controller. Moreover, power quality (PQ-theory) and hysteresis-current-controller (HCC) accomplish current compensation. The purpose of ANFIS with HCC's hardware architecture is to enhance the chip-area for real-time power applications. The voltage and current waveforms were simulated in the current work. The suggested H-APF with ANFIS controller—both software and hardware—is contrasted with alternative control strategies, such as H-APF with PI and fuzzy logic controller, in terms of improvements to THD, reactive power, various harmonics, and loads.
Keywords: Active power filter ,ANFIS controller , Harmonic Distortion , Hybrid-APF , Power Quality

1. INTRODUCTION

The need for power requirements in the electricity system is considerable due to current technological advancements, smart grid technology, and industrial reformation. It is challenging to meet the power quality target when power systems use more electrical and electronic components. Because of broken electrical or electronic equipment, power outages have an impact on power systems. PLCs, smart relays, and uninterruptible power supplies (UPS) are important pieces of equipment that consume a lot of power in corporate settings. Smart and small computers are also necessary. Power supplies for residential and commercial use are required and cost more to prevent power outages. Phase deviation, voltage regulation, swell, sag, flickers, harmonics, and frequency mismatch are the causes of the power quality degradation. Improving the PQ requires costly operation study and monitoring of a large power system. With advantages for bigger industrial and control applications, THD reduction with <5% in accordance with IEEE 519 standards, and reactive power compensation for PQ improvements, the harmonics are controlled by filtering techniques, passive, active, and hybrid approaches. These harmonics are reduced by a variety of strategies, including reactor-based, transformer-based, and filtering-based approaches. These techniques are based on avoiding interference and providing the right current and voltages. Numerous researchers have previously completed numerous studies on H-APF. Based on the filter, supply system, and converter, the hybrid APF/PF approach is categorized in series. Signaling conditioning, reference signal generation, firing signal generation, and DC-link control strategy are the foundations upon which the controlling techniques are built. Based on the time and frequency domains, the reference signal generation is categorized. The most often used reference signal production technology is time-domain based, which includes notch filter-based, indirect current control mechanism, DQ, PQ, and iterative approaches. PI, fuzzy logic controllers (FLC), slide mode techniques, adaptive controlling, and neural network approaches are some of the DC-link control mechanisms. A hybrid control strategy technique was used to represent the H-APF in this paper. In shunt-APF, an artificial intelligence technique similar to ANFIC controller with PI controller is introduced. Additionally, the hybrid active power filter is modeled utilizing the reference current compensation with the PQ method and HCC for the creation of the firing signal. The THD and power quality enhancements of the H-APF are modeled using both hardware and software techniques. A power system's various current and voltage control mechanisms are explained in Section 1 along with the history of the H-APF. In Section 2, the comprehensive architecture of the hybrid-APF is explained, incorporating hybrid controlling strategies such as the software and hardware approaches of combining PI with FLC/ANFIS controller. In Section 3, the simulation findings and a comparison study of several design controllers for improvements in reactive power and THD are covered. The work with THD and power enhancements is concluded in Section 4, along with future work.

2. LITERATURE SURVEY

In order to improve power quality, this section explains the current H-APF approaches, which use various regulating strategies and compensating techniques for various loads. In order to compensate for the imbalanced source voltage, Belaidi et al. [1] introduce the 3-phase shunt-APF employing FLC. To regulate the S-APF for source voltage, utilize the phase-locked loop. Gate pulses for the V-I inverter are produced by HCC, and current reference is generated using the PQ-theory-based phase lock loop (PLL) with a fuzzy logic controller (FLC). Using the social spider algorithm (SSA), Thuyen [2] describes a new design for H-APF. Artificial spiders are used to measure the current for an inverter, and PQ-theory and PWM are used to calculate the reference current. In order to lessen the power distribution system's harmonic mitigation, Behera et al. [3] introduce a three-phase hybrid filter that uses a fuzzy-based PI controller. The system's transient performance and robustness are enhanced by the introduction of vector-based PI (VPI) controllers. Likewise, FLC in conjunction with VPI enhances the THD for the power systems' main current. Chau [4] created the H-APF with an adaptive current controller, which better controls harmonic cancellations online and enhances dynamic response. In order to reduce the main H-APF's harmonics, the neural fuzzy-based control system features a prediction and identification mechanism with a cost function. A hybrid filter with a pulse generator for an inverter is presented by Kumar and Bhat [5] utilizing FLC. It has seven fuzzy rules defined for regulating the error inputs to generate the reference current. The settling time of the direct current (DC) voltage has improved compared to the PI controller method. There is a dearth of research on artificial neural network (ANN) based regulating methods for improving power quality for large-scale power systems. A single-phase S-APF with artificial intelligence-based controlling strategy is presented by Choudhary et al. [6]. It consists of ANNs with 25 rule sets that are based on Adaline and predictive and adaptive controllers. Compared to the predictive controller, the ANN-based controller has a better THD. According to Somlal et al. [7], fuzzy based single vector PWM is used to add the indirect current controller method for H-APF. For voltage-source-converters, the SVPWM produces gate pulses that enhance the power quality of distribution networks. Fuzzy logic-based H-APF with a non-linear regulating mechanism is presented by Balasubramanian et al. [8] utilizing DQ theory. The voltage control loop in the FLC-based H-APF employs seven rule sets, whereas the current loop utilizes five. Das et al. [9] compared HCC with THD improvements to the series H-APF with fuzzy sliding mode (FSM) controlling approach. For wind turbine applications, Shahalami and Hosseini [10] present the ANN controller H-APF, which reduces processing time at both steady-state and transient circumstances by canceling reference current. In order to compare with the traditional PI-based controller with THD enhancements, Pedepenki et al. [11], [12] provide a neural fuzzy-based controlling mechanism for H-APF. In their discussion of current trends and many facets of power quality, Sandhya and Nagaraj [13] address the contribution to the field of power quality enhancement research. All-on-chip distribution static synchronous compensator (DSTATCOM) control-based power quality improvement via virtex-5 field-programmable gate array (FPGA) is presented by Sahu and Mahapatra [14]. In addition to low-pass filters, HCC, an instantaneous power calculator, a sequence detector, and a traditional PI controller, the all-on-chip functions as a digital controller. Both reactive power compensation and current harmonic mitigation are accomplished by this digital controller. To be implemented on the chip, the entire model is created using the Xilinx system generation tool and converted to HDL.The shunt hybrid compensator is described by Balasubramanian et al. [15] on the hardware platform utilizing the control approach. The insulated gate bipolar transistor (IGBT) inverter serves as an active filter, passive filters make up the majority of the compensator's components, along with a DC-link capacitor. The shunt hybrid compensator uses a control technique similar to synchronous rotating reference frame (SRRF). The compensator's simulation results are shown as 3-phase VI current/voltage waveforms for both non-linear and rectifier-fed RC load scenarios. With a 26V DC link voltage, a shunt hybrid compensator may achieve a THD of 4.3% for balanced loads and 4.7% for unbalanced loads, respectively. The efficiency parameter can be analyzed by changing the source and load parameters using the shunt-active filter, as presented by Sychev et al. [16]. Five models are proposed for the shunt active filter. The power quality indicator data, which include THD, current and voltage correction degrees, voltage dips and deviations, and current consumption, are measured and examined. Using PQ theory and the space-vector pulse width modulation (SVPWM) technique, Thentral et al. [17] describe the hybrid active power filter. To reduce the THD, the design employs an active filter coupled in series with a passive filter tuned to the seventh harmonic. Without the hybrid active power filter (HAPF), the design achieves THD of 8.32%, 3.35%, and 3.15% utilizing PQ-theory and SVPWM, respectively. The current methods for H-APF are primarily software-based, involving modeling, with minimal emphasis on hardware-based options involving larger chip areas. The typical and insignificant controlling procedures now in use for H-APF are unable to significantly increase power quality or decrease THD. By using hybrid controlling techniques, the suggested system solves these issues.

3. PROPOSED SYSTEM

The purpose of the hybrid-active power filter (H-APF) is to reduce reactive power and mitigate harmonics by utilizing various current management methods. THD and reactive power performance analysis is performed by the H-APF, which is created utilizing several design controllers such as PI, FLC, and ANFIS controller. Figure 1 depicts the thorough design of the H-APF. Comprising of an alternating current (AC) source connected to the mains, RL components linked to a non-linear load, and passive filters connected in series, the H-APF is a combination of these components. The 3-phase AC main linked to a non-linear load, shunt-APF, and passive filter are all part of the technical architecture of the H-APF module. Six diodes connected in parallel and an unbalanced load connection comprise the non-linear's three-phase resistive logic. To cut harmonics, the passive filter is connected in series with a universal bridge-based shunt-APF. The bridge terminates with DC-linked capacitors C1 and C2. To enhance the voltages and currents through the PQ approach, regulating compensation strategies are presented. In the parts that follow, many controllers—including the PI, FLC, and ANFIS controllers—are thoroughly discussed.

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Proposed Model

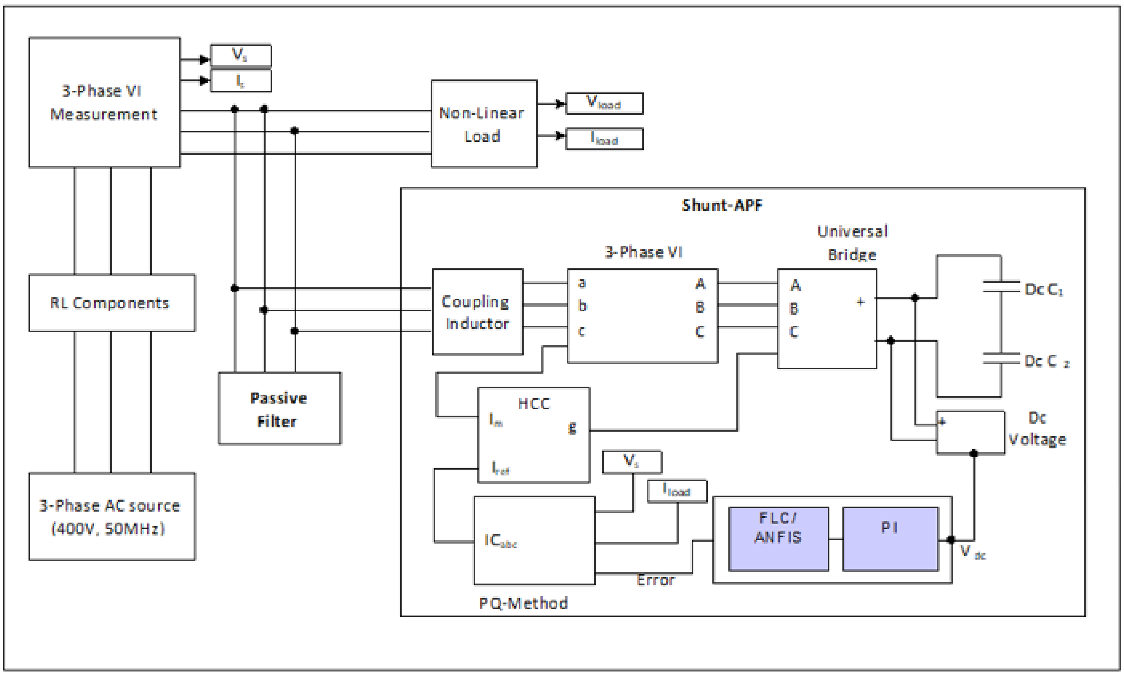

Figure 1. PI and FLC/ANFIS controller-based hybrid-active power filter (H-APF) design in detail

PQ method

The PQ approach is a well-liked and widely applied strategy for increasing power in central power networks. Three-phase instantaneous space vectors (αβ0) represent the waveform values of voltage and current. The values of the three-phase voltage (V) and current (I) are converted to αβ0 values for every 2π/3 phase difference. Clark's transformation is used to convert voltage and current, and the resulting mathematical equations are (1) and (2), respectively.

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{s\beta} \\ V_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} I_{la} \\ I_{l\beta} \\ I_{lc} \end{bmatrix} \quad (2)$$

With a three-phase source voltage and load current, the transformation from ABC to αβ0 is accomplished. The three-phase system does not prolong the zero sequences for additional transformation. Using the voltage and current αβ transformation, the instantaneous p-q power is examined as demonstrated in (3).

$$p = V_\alpha . I_\alpha + V_\beta . I_\beta$$
$$q = V_\alpha . I_\beta + V_\beta . I_\alpha \quad (3)$$

Oscillatory values (pac, qac) and average values (pdc and qdc) are used to correct the p and q. By eliminating the average values, the low pass filter works. The controller sends the compensated values to the Compensating current reference generator (CCRG). Using inverse Clark's transformation, the CCRG of αβ values is converted into ABC values and stated in (4).

$$\begin{bmatrix} I_{ca} \\ I_{cb} \\ I_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix} \quad (4)$$

The converted ABC values are employed in hysteresis current control (HCC) as reference current (Icabc) values. Figure 2 shows the PI, FLC/ANFIS controller, and PQ technique for current correction. The three phases, Vs and Iload, are inputs to the transformation from ABC to ϱβ0 using

(1), (2), and then PQ computation using (3) and (4). Inverse Clark's transformation on (4) is used to generate the final reference current. DC-Link voltage enhances and improves the performance of the shunt-APF.

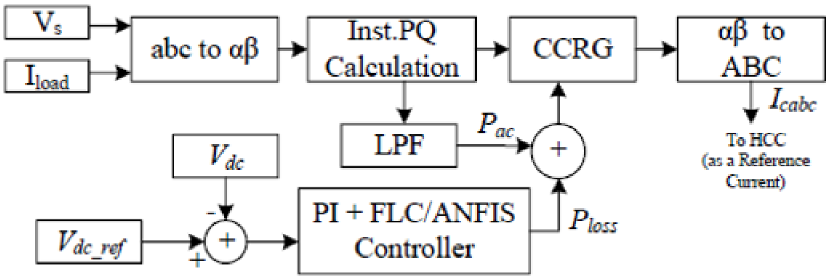

Figure 2. PQ method for current compensation using PI and FLC/ANFIS

Artificial neuro-fuzzy interface system (ANFIS) controller

ANFIS is an extension of PQ method that automatically implements the fuzzy interface system (FIS) using neural networks. It grants access to the combination of language and numerical data. It can translate a language variable into a numerical one. Using a neural network (NN) to optimize the FIS is the main goal of the ANFIS. A powerful learning potential capability is provided by an artificial neural network (ANN), while the FIS can interpret from one variable to another and merges the meaningful data. ANFIS and the FLC's FIS system are comparable. Two inputs, E and CE, and an output (OP) make up the FIS. The PI controller output provides the error input, and the same output provides the capacitor DC voltage and constant DC voltage that make up CE. The dataset is created using DC voltages and stored as a data file. Load the data set from the saved location to train the data after designing the FIS with a new membership function for the ANFIS controller. A hybrid optimization strategy with error tolerance is applied to train the resultant ANFIS system. In order to produce the final neural network output, which is shown in Figure 3, test the FIS system lastly.

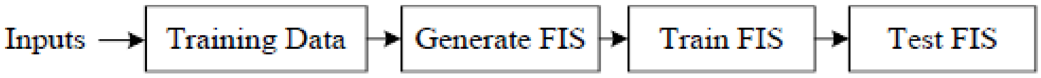

Figure 3. ANFIS controller representation

In the ANFIS designer module, the triangle shape (trimf) is used to set the output membership function, the Sugeno FIS type is selected, and two inputs, such as E and CE, are fuzzified. The weight averaging approach (wtaver) is used to defuzzify. The three membership functions for the error and change in error are negative big (NB), zero (CZ), and positive big (PB), which are represented by (5) and (6), respectively.

$$E = \{ENB, ECZ, EPB\} \quad (5)$$

$$CE = \{CENB, CECZ, CEPB\} \quad (6)$$

Similarly, the output of the ANFIS has three linguistic variables and is represented as shown in (7)

$$OP = \{OPNB, OPCZ, OPPB\} \quad (7)$$

The neural network (NN) is the heart of the ANFIS controller. The ANFIS is trained with the initial dataset produced by the previous FIS. The neural network generates new FIS, and the same ANFIS is placed in an overall system for the next interaction.

4. RESULTS

The MATLAB-Simulink tool is used for software approaches in the design of the hybrid-APF (H-APF) modeling. To set up the tool for simulation, choose the discrete simulation type, Solver-Tustin, and 5µsec sample time. In terms of source voltage and current THD, real power (KW), and reactive power (KVAR), the H-APF is contrasted with various alternative design controller techniques. In order to reduce harmonics and boost reactive power, several design controller techniques are applied to the 400V, 50Hz 3-phase AC supply voltage.

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To produce the THD and reactive power results, the experimental setup is carried out for non-linear load, load with PF, harmonic filter, S-APF, and H-APF, H-APF fuzzy logic controller (FLC), and H-APF artificial neuro-fuzzy interface system (ANFIS) controller using software approach. ANFIS controller with hardware method is also used by the H-APF. The hybrid-APF generates the three-phase Vs, Is, Vload, and Iload waveforms utilizing hardware and software techniques based on ANFIS controllers. Software-based approaches include the HCC compensation methodology and the PQ method. In hardware-based techniques, only the HCC compensation mechanism is employed; both are shown in Figures 4(a) and 4(b).

Figure 8 shows the findings of the FFT analysis of the percentage THD that were obtained after simulating the various controller technique models under load. Figure5(a)-(d) shows the THD values for the Three-T source with the proposed hybrid-APF using PI controller, which is 2.29%, hybrid-APF using FLC, which is 1.85%, hybrid-APF using ANFLC, which is 1.73%, and hybrid-APF using ANFIS controller (hardware approach), which is 1.95 %, for source current. At 0.3 seconds into the simulation, the THD calculation is produced. Artix-7 FPGA is the choice made by Xilinx System Generator (Sysgen) for the hardware-based H-APF with ANFIS controller. Using the Sysgen tool, the HCC and PI with ANFIS controller blocks are designed.

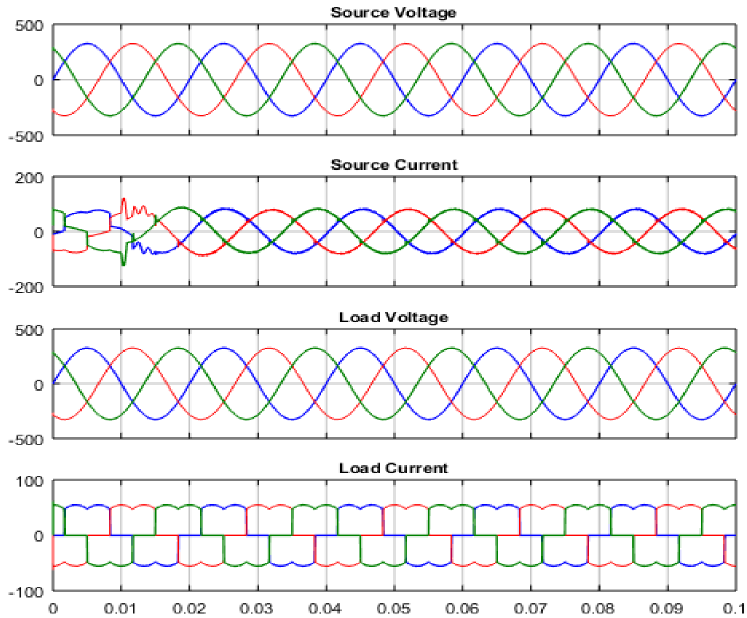

Figure 4. Hybrid -APF using; (a) ANFIS controller source

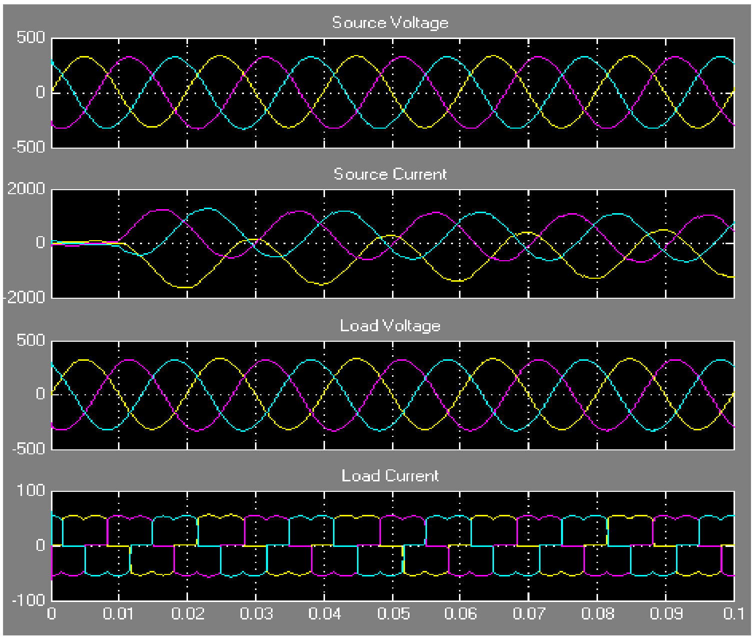

Figure 4.(b) load voltage and current waveforms

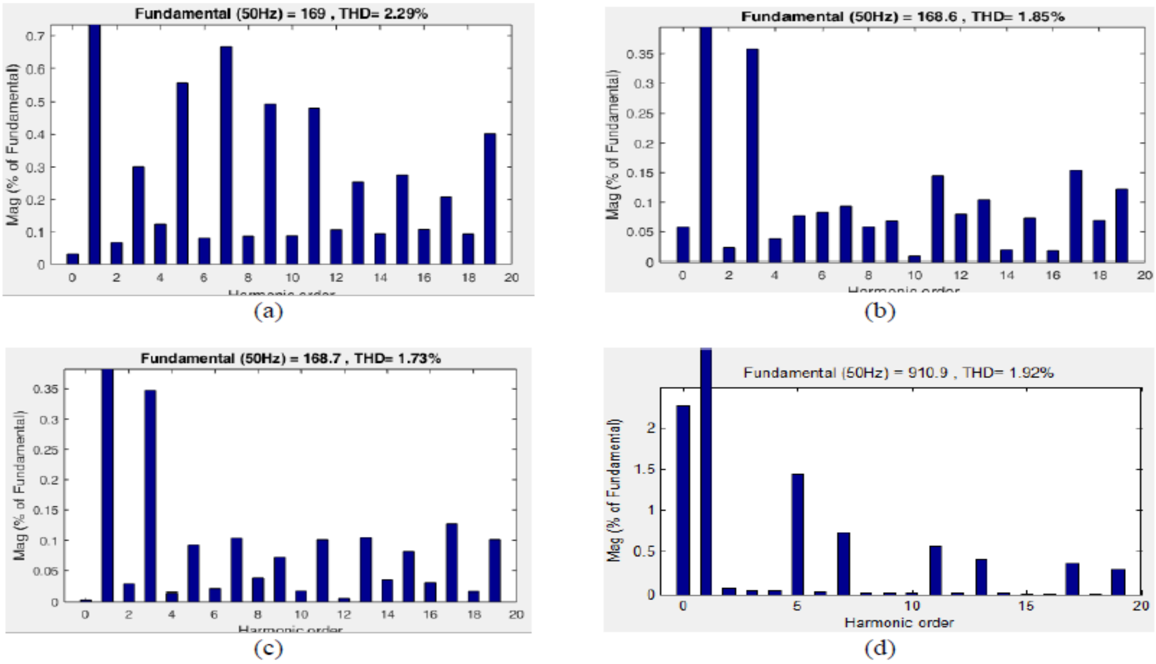

Figure 5. FFT analyses of source current-THD values for different design controller techniques; (a) hybrid-APF using PI controller, (b) hybrid-APF using PI+ FLC, (c) hybrid-APF using PI + ANFIS controller, (d) hybrid-APF using PI + ANFIS controller (hardware)

The THD of source current phase-a ‘Isa,’ and phase-c ‘Isc’ are almost similar after shunt-APF. The THD calculation concerning time for different design controllers is represented in Figure 6 by selecting phase ‘a' source current. The ANFIS controller (hardware) place significant growth from 0.1 sec with a more considerable margin than other techniques.

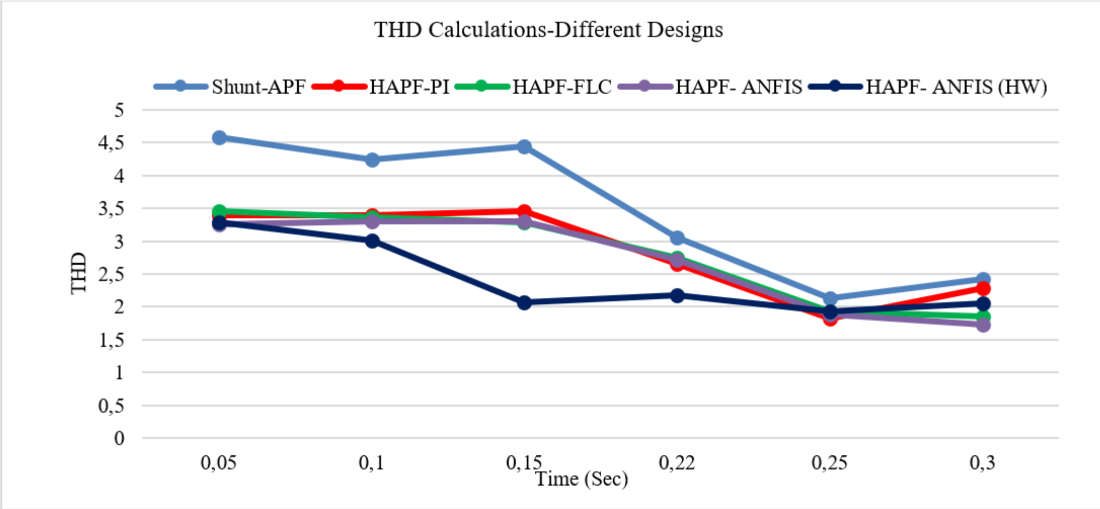

Figure 6.THD calculation v/s time for different design controllers

5. CONCLUSION

In this paper the software modeling of hybrid-APF is presented. The non-linear load is coupled in series with a parallel filter and shunt-APF to form the H-APF. In order to reduce harmonics and adjust voltage and current for a given load using the PQ technique and HCC, the hybrid-APF is developed utilizing a variety of design controllers, including PI, FLC, and ANFIS,. The source current and voltage, load current, and voltage from the H-APF simulation are shown. Different filtering and design controllers, such as passive filters, active harmonic filters, and shunt-APF, are contrasted with the H-APF model with a hybrid control method. Compared to existing control compensating strategies, the suggested H-APF using the ANFIS controller (software) achieves 1.73% THD. which is fairly good compared to other methods (excluding FLC). Reactive power consumption for H-APF using the hardware technique is 15.32% lower than that of H-APF utilizing the software approach and an ANFIS controller. In comparison to previous methods, Future industrial applications for the proposed work include harmonic current compensation and reactive power enhancements in high-speed railway systems, photovoltaic generating systems, and wind farm systems.

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