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Fuzzy Controller with Shunt Active Power Filter in Reducing THD for Three Phase System

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Abstract: In recent years, power electronics devices have advanced and are now employed in a variety of applications. Furthermore, this gadget produced an issue with power quality in the electrical system. Furnaces, VFDs i.e variable frequency drives, computers and Tube lamps are examples of non-linear loads that create current harmonics. Power quality is a critical problem on both the consumer and distribution sides. The active power filter improves quality of power and compensates for reactive nature of power. From this paper, nonlinear loads causing harmonic effects are addressed. To eliminate harmonics from non-linear loads, a shunt active filter is employed, and in the retrieval procedure, a hysteresis current based controller is utilized. In this study, instantaneous reactive power (PQ) theory is employed to calculate the reference current. The Matlab-Simulink toolbox was used to simulate the results of a shunt active filter utilizing PQ theory.

Keywords: Elimination of harmonics, Shunt Active Power Filters, Hysteresis current baes controller.

1. Introduction

Globalization and industrialization have driven up electricity consumption in recent years. Domestic loads include compact fluorescent lamps (CFLs), televisions, personal computers, inverters, and various electronic gadgets. Different non-linear loads are employed in industries, such as variable frequency drives and convertors [1-2]. The occurrence of such non-linear load creates load current distortion and has an impact on power quality. The delay effect is introduced into power electronics equipment as a result of switching action [3]. This leads to harmonic distortion and a drop in power factor. To reduce harmonics on the load, several compensation techniques are utilized, such as passive or active filters, to improve line side power quality and hence reduce selected harmonics.

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Passive filters are employed to solve power quality problems, but their disadvantages include high cost, dependence on source impedance, and parallel or series resonance. Active power filters are widely used in control theories, harmonic extraction methods, and reference current generating methods. Akagi established the notion of time varying active cum reactive power (PQ). Based on this theory, we may turn 3 phase quantities to 2 phase quantities in a system with active cum reactive components [4]. The equivalent of SAPF and SAF using PQ and dq concept for current cum voltage harmonics extraction also managing the source current PI-controller been discussed [5]. The writer presents fuzzy logic cum hysteresis control using synchronous indicating frame (dq) theory [6]. The authors of study address the PI cum hysteresis controllers and their usage of Power Quality, SRF, and sine multiple theories [7]. A three-phase active filter was devised using dq theory with SVPWM control [8]. A key conclusion of generalized instantaneous reactive power (PQ) theory is used to rectify the power factor in a three-phase circuit. The subject of SAPF cum SA filters using PQ and dq concept for current also voltage harmonics withdrawal also managing the source current PI controller was discussed [9]. The writer presents fuzzy logic cum hysteresis controller using synchronous indicating frame (dq) concept [10].

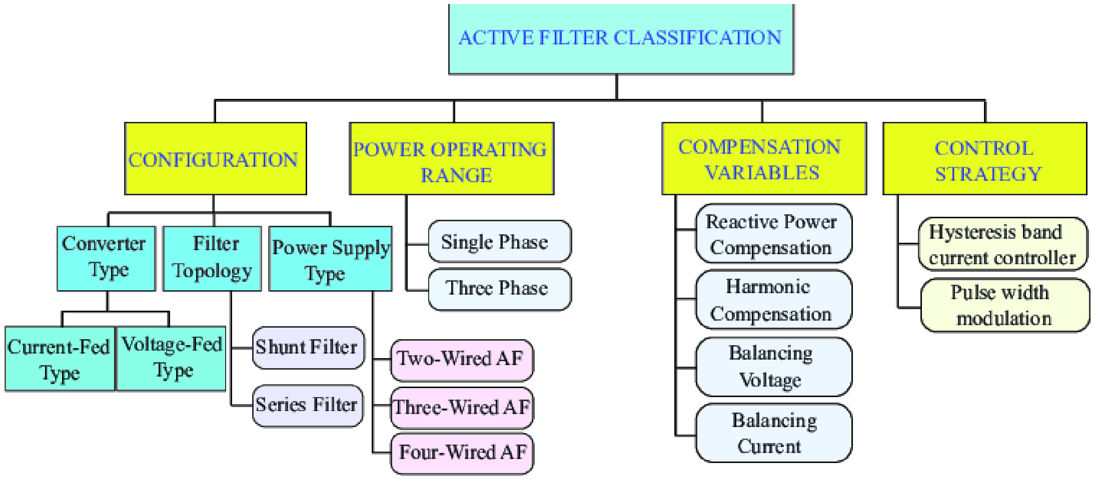


Fig. 1: Classification of filters

Various classification of filters used in the grid connected systems are depicted in Fig. 1. The authors of the study address the PI cum hysteresis controllers also their usage of Power Quality, SRF cum sine multiple concepts [11]. A three-phase active filter was devised using dq theory with SVPWM control [12]. A key conclusion of generalized instantaneous reactive power theory is used to rectify the power factor in a three-phase circuit. Here is a discussion on this document. System conformation for simulation study is the second step. The step three is a proposed strategy control that's broken down into three components: reference signal generation, voltage vector decay, and generalized instantaneous reactive power (PQ) theory. The hysteresis current control stage is the fourth. The fifth stage presents the results of the simulation and the shunt active power filter (SAPF), and the sixth stage presents the conclusion.

The other paper is organized as follows. Section 2, describes the test system, section 3 about proposed controller, section 4 about results and discussion and lastly in section 5 the conclusions are derived.

2. System Configuration

Fig. 2 illustrates the configuration circuit for an SAP Filters. The SAP filter, which couples shunt to the load, is shown in the diagram. Devices like personal computers and inverters have non-linear loads. As a result, the system is producing current harmonics. For the utility side, the SAF setup consists that injecting harmonic current of same magnitude but with opposite sequence of phase. This voltage source inverter (VSI), ripple filter, and pulse width modulation for three phase system comprise the shunt active filter. The test systems parameters are presented in Table. 1.

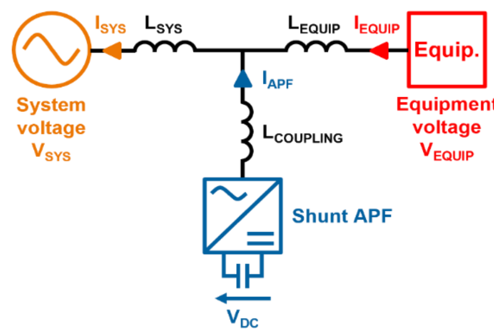


Fig. 2: Basic structure of the shunt active power filter

Table. 1: System parameters

Sl. No	System Parameter	Parameter values
1	Supply voltage	575 v (peak)
2	Line impedance	R=0.1 1Ω, L=2.81mH
3	Ripple filter	R=0.09Ω, L=3.5mH
4	DC link capacitor	C=500 μF
5	Load-1	R=25Ω, C=200μF
6	Load-2	R=50Ω
7	Load-3	R=50Ω, C=1000μF

3. Proposed controlling method

This provides the discussion of proposed controller and its functions. The spontaneous Reactive Power (IRP) concept, HCC, way of pulse generation with PI, PID and fuzzy controllers. The detailed descriptions are given below.

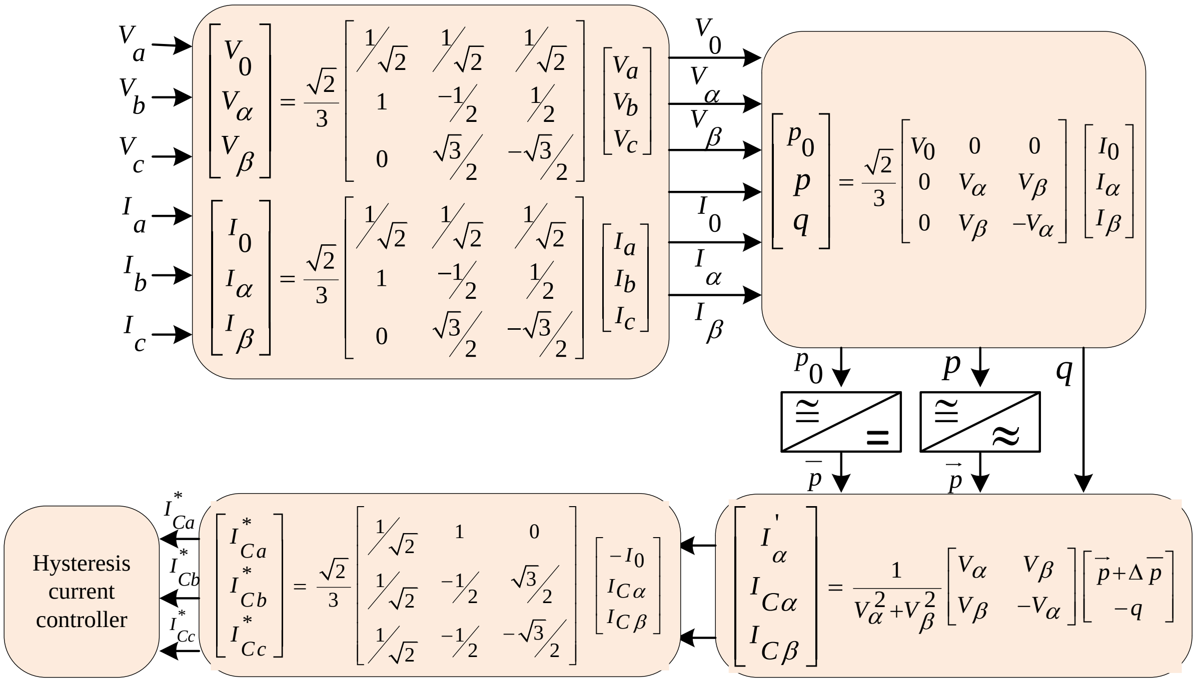


Fig. 3: IPR concept for three phase system

3.1 Spontaneous reactive power concept

The IRP *p-q* concept is related on the Clarke Transform, which converts the voltages cum currents seen in 3-phase model into α cum β coordinates. IRP *p-q* concept makes use of 2 orthogonal cum coordinates to characterize the power attributes in charge of p cum q instantaneous powers [13] as shown in Fig. 3. The immediate real powers and the reactive powers are the names given to these types of effects. The IRP *p-q* theory expresses the attributes of three-phase systems in terms of just two powers active and reactive [14]. However, the power properties of this kind of system, even in the absence of harmonic distortion, depend on three distinct phenomena like energy transmission, phase shifting of voltage, current and asymmetry of line current caused by imbalance in load. The $\alpha\beta0$ transformation cum power calculation is achieved with the following equations (1), (2) and (3)

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

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

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \frac{\sqrt{2}}{3} \approx \begin{bmatrix} V_0 & 0 & 0 \\ 0 & V_\alpha & V_\beta \\ 0 & V_\beta & -V_\alpha \end{bmatrix}\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} \quad (3)$$

The high pass filter with 50Hz cutoff frequency separates the $\vec{p}$ from p and the low pass filter separates $\bar{p}$ from p_0. The $\alpha\beta$ current references can be found from the following equation (4).

$$\begin{bmatrix} I'_\alpha \\ I_{C\alpha} \\ I_{C\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2}\begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix}\begin{bmatrix} \vec{p} + \Delta \bar{p} \\ -q \end{bmatrix} \quad (4)$$

The $\alpha\beta0$ inverse transform gives the instantaneous currents for HCC of VSI s in equation (5).

$$\begin{bmatrix} I_{Ca}^{*} \\ I_{Cb}^{*} \\ I_{Cc}^{*} \end{bmatrix} = \frac{\sqrt{2}}{3}\begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} -I_0 \\ I_{C\alpha} \\ I_{C\beta} \end{bmatrix} \quad (5)$$

The layout of HCC complete layout is presented in the Fig. 4. The compensating currents are compared with the reference currents and then the resultant signals are given to the HCC for generating the switching pulses.

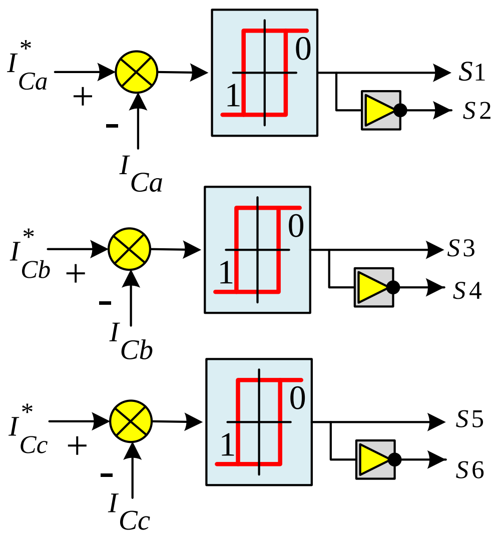


Fig. 4: Hysteresis current controller (HCC) for signal generation

3.2 Conventional PI and PID controllers

The reference current generating portion and the PWM current controller section are the two components that make up SAPF and are responsible for its operation. The PWM current controller's job to give a gate pulse to the active power filter in order to fulfill its duty. The signal processing methods of soft computing make advantage of the expertise and experience of experts. Either it aims to do a control job in place of a person or it takes concepts from the way biological systems handle issues and applies them to control operations. The most important subfields of soft computing include genetic algorithms, neural networks, fuzzy logic, rough sets, and many more. Error is produced as a result of the PI/PID controller providing them with a V_{dc} real signal as well as a V_{dc} indicating signal as source to the comparator. The controller output is given as reference current for the SAPF. The input of the PI-PID controllers is the dissimilarity among the reference and actual voltage. The DC link error can be found from the equation (6)

$$e = V_{dc,ref} - V_{DC} \quad (6)$$

In order to maintain the integrity of the basic mechanisms, this signal is first routed via an LPF, and then, after that, this PI controller determines amount peak indicating current and regulates the dc concerned capacitor. The voltage on DC bus is under the control of the PI controller. The subsequent expression represents its transfer function ae given below (7)

$$H(s) = K_p + \frac{K_i}{s} \quad (7)$$

A PID controller works on the same basic principle as a PI controller, which means there is a lot of overlap between the two. The gain control is determined by linear combination to the error in and of itself as in (8).

$$H(s) = K_p + \frac{K_i}{s} + K_D(s) \quad (8)$$

Where K_p represents the DC side dynamic response, K_i represents settling time cum K_D represents error derivatives.

3.3 Proposed fuzzy controller

One of the early forms of the soft computing method known as fuzzy logic control was developed in 1965 [3]. It is possible to use FLC for SAPF in order to achieve the value specified by IEEE-519 for the THD factor. The FLC is characterized by its great resilience as well as its high tracking accuracy and its rapid reaction [4]. The SAPF Mamdani type and the Takagi-Sugeno-Kang (TS) type are both examples of common control structures that benefit from the use of fuzzy controllers. In the mamdani kind of game, many rules are utilized, however in the TS model, just four rules are utilized. For the purpose of confirming these conclusions, a TS-model FLC been constructed through MATLAB. The consequent of the result is the primary point on which TS FLC differs from Mamdani type in order to be distinct. The linguistic rule consequent is formed by varying the parameters in the model. Because of the consequential factors caused by linguistics rules, an infinite number of different gain characteristics may be obtained.

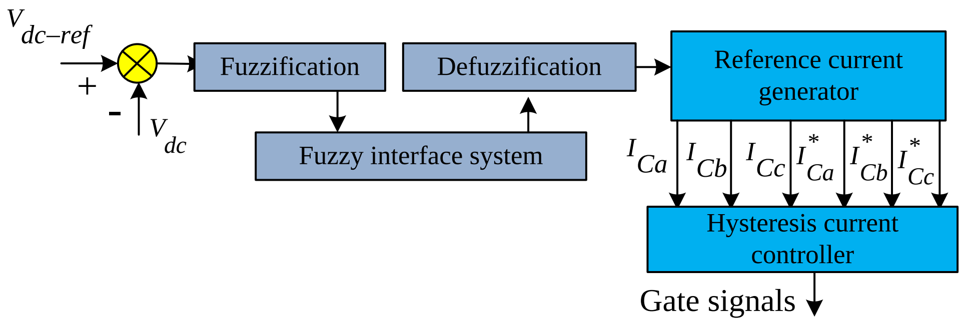


Fig. 5: Fuzzy controller

Therefore, in a constantly changing load environment or with a variety of nonlinear load types, current may be adjusted in a manner that is both more comfortable and more efficient. Therefore, putting in place the TS FLC results in an improvement in the overall performance of SAPF when it is coupled to a nonlinear load. The proposed fuzzy controller is shown in Fig. 5.

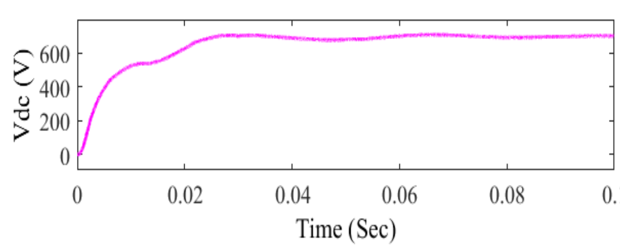
The most essential characteristics of soft computing approaches are the computational time, performance efficiency, the amount of memory that is used, and the computational time. When compared to a Mamdani type fuzzy logic controller, a TS type fuzzy controller, which has a variety of industrial applications, employs a smaller number of rules, which results in a shorter amount of processing time [5]. The quantity and kind of membership functions (MF) may have a significant impact on performance efficiency. In the case of the non-linear function, triangular membership functions are used, since these are the kinds of functions that occur most often overall [6]. The conversion of a rule-based control strategy into an automated control is accomplished via the use of a fuzzy controller, and fuzzy rules are crafted through the utilization of a knowledge database. Which may be found in Table. 2 below. First, the input voltage V_{dc} and the input reference voltage V_{dcref} have been set up as the input variables of the FLC. Next, the angular velocity has been set as the output variable. Following are the seven fuzzy levels that are used in the process of converting the numerical value of the dc link capacitor voltage and reference value into its linguistic equivalent. NM (negative medium), NS (negative small), NB (negative big), ZE (zero), PB (positive big), PS (positive small), PM (positive medium) and as shown in Table. 2.

Table-2: FLC rule set

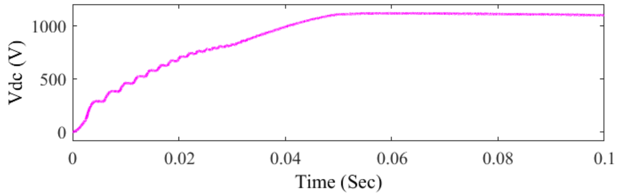
V_{dcref}/V_{dc}	NB	NM	NS	ZE	PS	PM	PM
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

4. Results and Discussion

The MATLAB/Simulink platform is used in order to carry out the simulations of the proposed system. The PV output provides electricity to the SAHF, which generates the resulting current by separating it from the base current provided by the utility. For the PV show machine to function at its highest possible efficiency, this component utilizes a regulator that is based on a P&O MPPT. Based on the characteristics, it is possible to draw the conclusion that an increase in temperature will result in an increase in the short-circuit current, despite the fact that the open-circuit voltage will decrease. The DC link voltage is presented via the use of PI controller, as shown in Fig. 6 (a), and the voltage profile is improved through the utilization of PID controller, as shown in Fig. 6 (b), more so than through the utilization of PI controller.



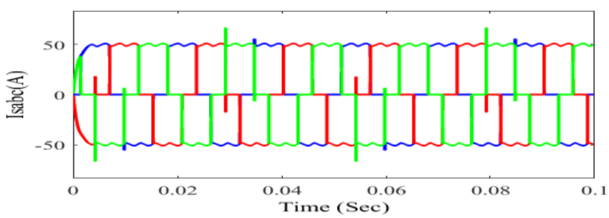
(a)



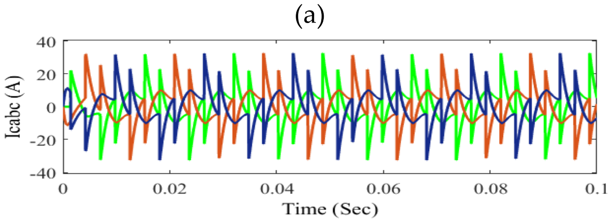
(b)

Fig. 6: DC link voltage (a) With PI controller, (b) With PID controller.

The source current without SAHF is shown in Fig. 7 (a), whereas the compensatory current and the load currents with SAHF are shown in Fig. 7 (b) and Fig. 7 (c). The results show that the harmonics may be eliminated entirely by using the SAHF, as is seen in figure 7 (c). It is possible to see that the source current becomes sinusoidal as a consequence, so being unaffected by harmonics which is seen in Fig. 7 (d).



(a)



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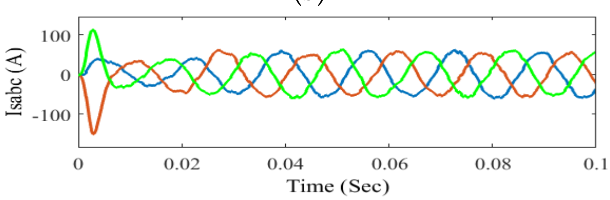
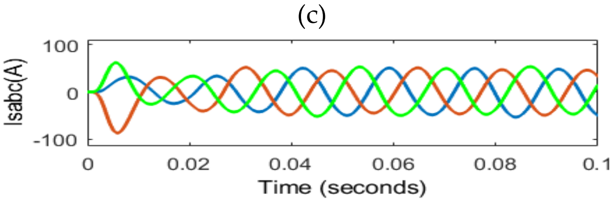
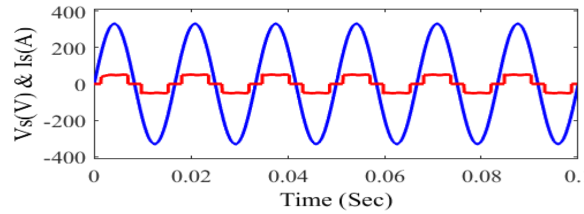


(c)

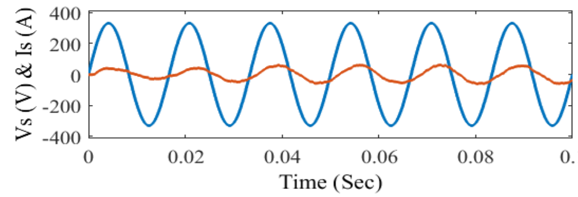


(d)

Fig. 7: (a) Source current without SAHF, (b) Injected current, (c) Load current after compensation with SAHF and PI controller, (d) Load current with fuzzy controller



(a)



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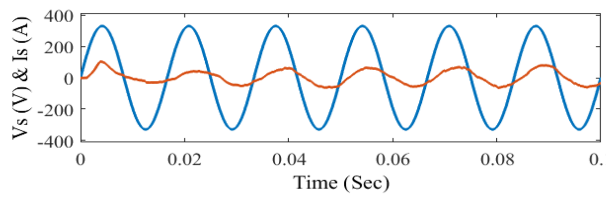
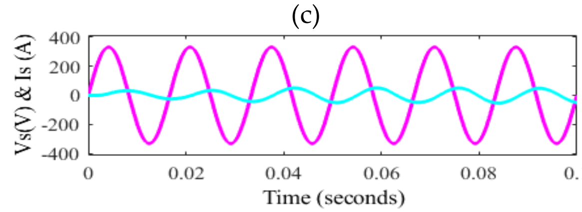


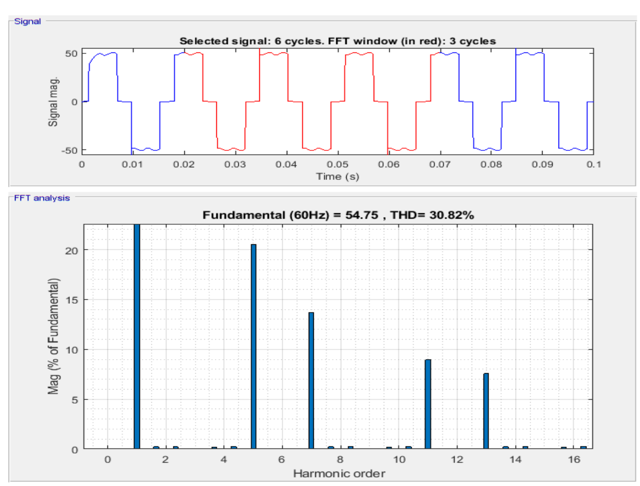
(c)



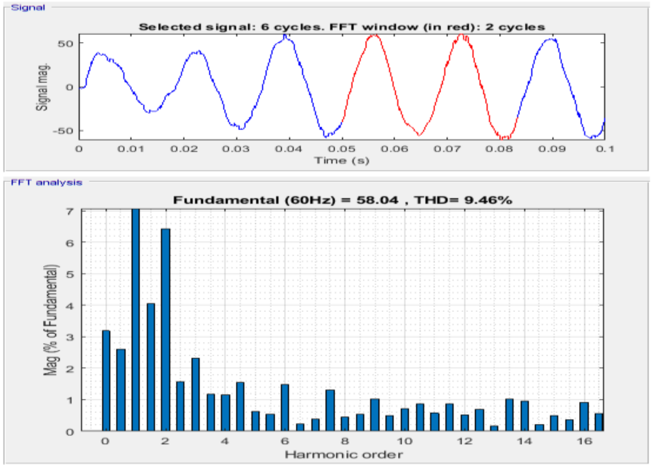
(d)

Fig. 8: Power factor (a) Without SAHF, (b) With SAHF (c) with PID controller (d) With fuzzy controller

The improvement in the power factor both without and with SAHF is shown in Fig. 8 (a) to Fig. 8 (d). Harmonic interference is reduced by the shunt SAHF structure, which also contributes to increased power factor.



(a)



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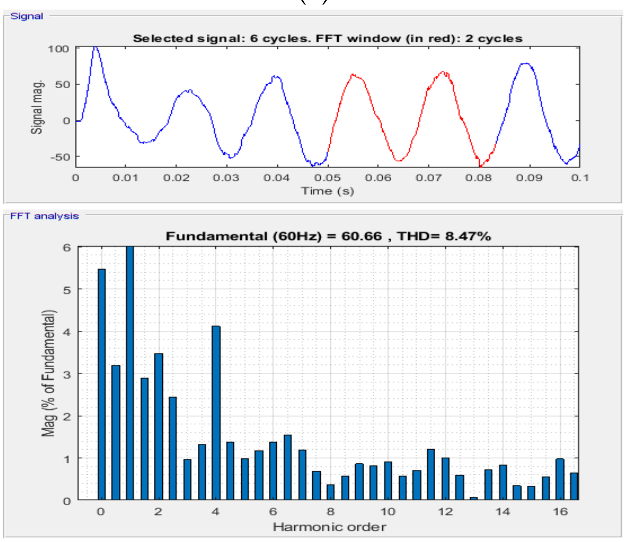

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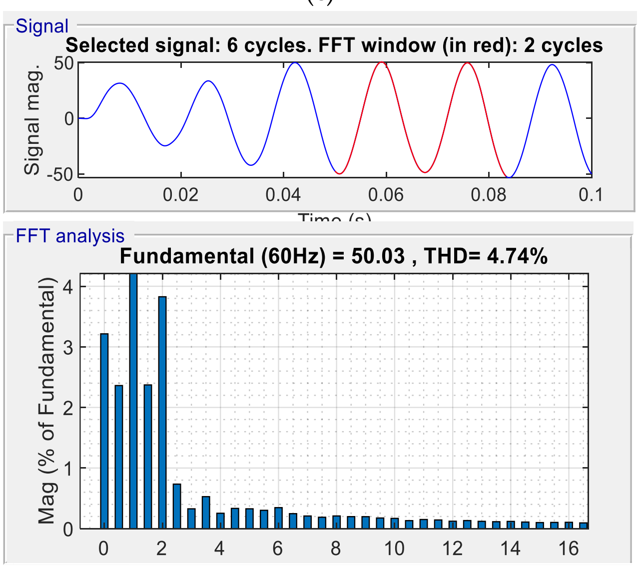

(d)

Fig. 9: THD of load (a) Without SAHF, (b) PI controller (c) PID controller (d) Fuzzy controller

The THD of an NLL without SAHF is shown in Fig. 9 (a), and it has a value of 30.82%. This figure also depicts the magnitude of the consonant current that is present in the source current when the SAHF is associated with the level of the primary portion. Fig. 9 (b) shows that the THD with PI controller and SAHF is 9.46%; after interfacing the SAHF, the odd harmonics were reduced to a level that was more tolerable; and Fig. 9 (c) shows that the THD with SAHF and PID controller is 8.47%. This demonstrates that the THD achieved by the PID controller has decreased from 9.46% to 8.47%. In Fig. 9 (d) the THD was brought down to 4.74% with the use of fuzzy controller.

5. Conclusion

The purpose of this article is to describe a TS-type fuzzy logic-based SAPF designed to enhance power quality for loads that are not balanced. This method has helped reduce the number of regulations, which has resulted in time savings during operations. As an output, the general power system stability has been significantly improved as a result. The control approach that was presented was evaluated and shown to be effective in mitigating harmonics and reactive power with a reduced amount of computing effort, all while keeping the THD to 4.74% of the source current within the parameters set by the IEEE-519 standard. According to the findings of the simulation, it is abundantly obvious that the dc voltage excursion of the TS fuzzy controller is superior to that of the standard PI and PID controller for a wide variety of load situations as well as changes in filter parameter settings.

Conflict of Interest

The authors declared "No conflict of interest".

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