Interval Type - 2 Fuzzy Logic Controller Based Shunt Active Power Filter for Power Quality Enhencement

Hamisu Usman, Nuraddeen Magaji

***Abstract:** Frequent wide spread of power electronics equipment to consumers have led to power quality problem in power system network, as a result to their nonlinear in nature. Due to this problem, current and voltage wave forms are no longer sinusoidal, which resulted in harmonics on them. Various methods have been deployed in order to mitigate the harmonic issues, like passive power filters and shunt active power filters. Presently, passive power filters are limited in used, because of its demerits as it produced parallel resonances, heavy in size and mitigate few harmonics. With the advancement in technology, shunt active power filters have become superior to passive power filters due to its limitations. Shunt active power filters was tested for suppressing harmonics produced by nonlinear loads. This article, used synchronous reference frame (SRF) in generating harmonic produced by nonlinear loads. However, T2FLC is utilized in controlling the DC bus voltage of the filter constant. Hysteresis current controller was introduced for firing the gating signal of the IGBT inverter circuit. MATLAB software was deployed in the simulation work. Results obtained have satisfied the tolerable 2014 revised harmonics limit.*

***Keywords**: SRF, Harmonic Issues, T2FLC*

I. INTRODUCTION

Due to high increase in population in the entire universe, the demand for energy and electricity sources are highly very imperative to the teeming population. With these, more generations, transmissions and distributions networks are needed in order to meet up with the demand. However, the wide spread and used of modern electronics devices to consumers, has led to the problem of harmonics distortion and power quality issues[1][2][21]. The solutions to the harmonics distortion are the filters, which will greatly reduce the issues of unbalance on the power systems [3]. Classical passive power filters were in used to mitigate current harmonic distortions caused by nonlinear loads, but passive filters have disadvantages of heavy and bulky in size, series and parallel resonances, that is why they are not much in service nowadays. Now, shunt active power filters are superior to traditional power filters, which proven and tested to be the viable solution to mitigate current harmonic distortion so as to overcome the problem of passive power filters[4]. The reason why shunt active power filters are used rather than passive power filters is because of their superior characteristics like complete mitigation of harmonics and reactive power compensation [5]. Various methods are used for controlling gating signals of the IGBT/MOSFET inverter circuit such as Pulse Width Modulation, Hysteresis current controllers, sliding mode controller etc.

It is well known that Fuzzy Logic system was adopted by Zadeh Lofty in 1965[6]. With the introduction of Fuzzy, a lot of researchers have developed interest in designing the Fuzzy Logic Controllers for various engineering researches. However, with development in research, a lot of researchers have put more interest in (T2FLC) which was initiated by L. Zadeh due to uncertainties and nonlinearities with type-1 Fuzzy Logic controller (T1FLC). (T1FLC) and (T2FLC) are almost the same in design with only different in type reduction block in (T2FLC). The Foot print of uncertainty (FOU) is the main future of (T2FLC) which shows the level of uncertainty and nonlinearity of the system. (T2FLC) is more robust in dealing with uncertainty when correlate with (T1FLC)[7][20][8] Frequent used of the (PI) and (PID) controllers are used to maintain the DC bus voltage regulation of the SAPF [9]

For this article, (T2FLC) is proposed to maintain the DC bus voltage constant for the (SAPF). Section 2 deal with the concept of extraction of current harmonic distortion using synchronous reference frame (SRF) d-q theory, while in section 3 described hysteresis current controller (HCC), while section 4 explored the design of the (T2FLC). While Section 5 discussed simulation results/analysis, as well as the conclusion and references are presented at the tail end of the paper.

II. REFERENCE CURRENT EXTRACTION TECHNIQUES

Time –domain is deployed for extraction the harmonic current in a simple mathematical computation, and the technique basically gives a precise different and duplicate harmonic load current detection. However, the advantage of this approach has a quick result as against other technique. This method is a time domain-based algorithm, that aimed to generate harmonic current which can perform in a dynamic –state conditions in order to control the filter perfectly when developed as real-time application.

Manuscript received on 07 September 2023 | Revised Manuscript received on 07 October 2023 | Manuscript Accepted on 15 October 2023 | Manuscript published on 30 October 2023.
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However, SRF theory has another feature of simplicity of mathematical computation which only involved in algebraic calculation [10].
Figure 1 depicts the classical SRF block diagram. The basic structure of the algorithm use Phase-lock-loop (PLL) circuit purposely for synchronization.

In this algorithm, the load currents of the line currents i_{La}, i_{L_b} and i_{Lc} are in stationary axis coordinates which converted into two phase, the direct axis (d) and quadrature axis (q) rotating coordinates currents $i_d - i_q$ as given in matrix notation as:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

The generated reference frame is rotating synchronously with the fundamental currents. Moreover, the time variant currents together with the fundamental frequencies are kept nearly steady after conversion. The d-axis current parts are there purposely for removing of harmonics and the reactive components of the power. But the d-q transformation output signals rely on the load current and the action of the phase locked loop[11]

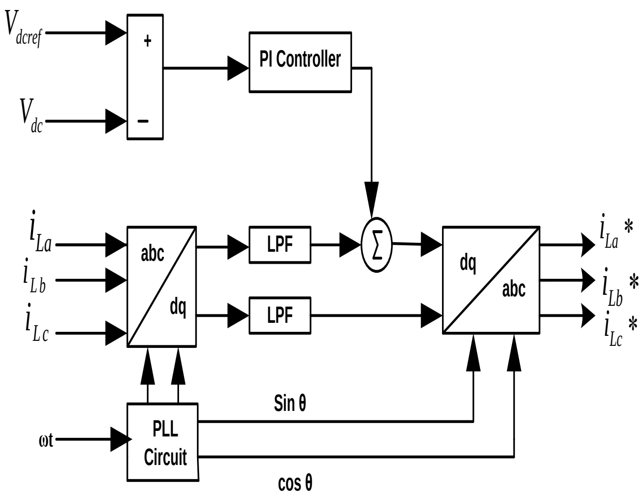

Figure 1. Synchronous Reference Frame

The components of the $i_d - i_q$ currents went through a filter in order to remove the superior order harmonics components and allow the main frequency components to stay. PI controller is purposely there to eliminate the steady state error of the dc –component. The positive sequence fundamental frequency of the active components of the $d-q$ currents are added so as to reduce the losses in the inverter by keeping the d. c. voltage constant or within a limit. However, the resultant current $(a-b-c)$ of the stationary frame, is also determine from $i_d - i_q$ rotating frame using the second transformation.

$$\begin{bmatrix} i_{sa}* \\ i_{sb}* \\ i_{sc}* \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ \sin\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta-\frac{2\pi}{3}\right) \\ \sin\left(\theta+\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (2)$$

The generated current from the SRF algorithm is correlated with the main currents and also produced the targeted switching pulses for the inverter using hysteresis current controller. Similarly, PLL-circuit is reference to the source voltage for vector orientation.

III. HYSTERESIS CURRENT CONTROLLER

This type of controller is also referred as fixed (HCC), which employed in switching the gating signals of the inverter.
The classical hysteresis current controller work with inverter by differentiating the current error e(t) with fixed-hysteresis limit. Figure 2 (a) depicts the block diagram of (HCC). The difference between the ref current and main current gives current error. If the error current supersede the upper limit of the hysteresis limit, the upper switch of the inverter arm is OFF and the bottom switch is ON, due to that, the current start to reduced [12]. However, Figure 2 (b) depicts the switching pattern to drive the inverter in an ON and OFF modes. But, if the error current passes the bottom limit of the band, the bottom switch is at OFF position and the upper switch is ON. Due to that, the current returned into the hysteresis band position. Also, the main current is now pushed to search the reference current within the hysteresis limit. In this work, (HCC) is proposed due to its simplicity in implementation.

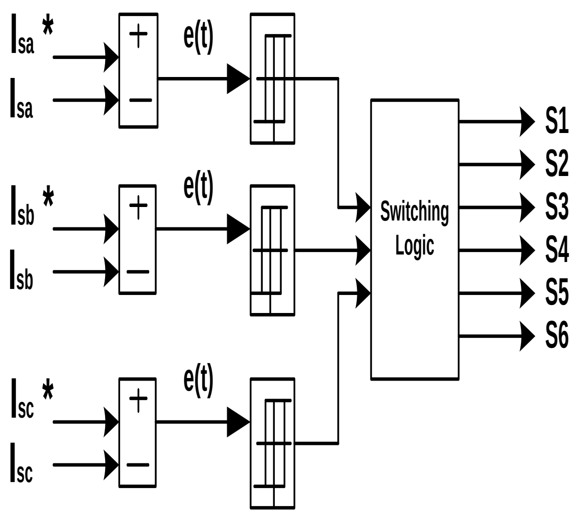

Figure 2(a). Hysteresis Current Controller switching Pattern

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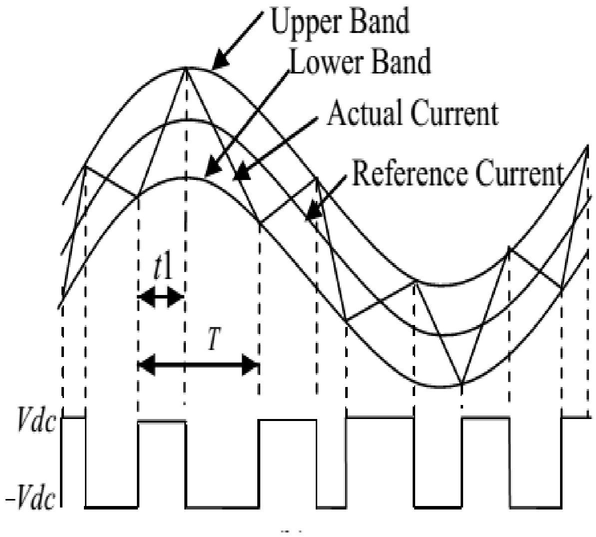

Figure 2(b). Hysteresis Current Controller [13][19]

A typical example of phase-A switching performance is given by the expression:

S=OFF if $i_{sa}(t) > i_{sa}{\times}(t) + hb$ (3)
S=ON if $i_{sa}(t) < i_{sa}{\times}(t) - hb$

Two-level hysteresis current controller is employed in shunt filter due to its simplicity in implementation. This controller only employed the use in dc supply voltage to produce the pulses of the inverter [14].

IV. T2FLC

Type-2 Fuzzy Logic controller was first developed by L. Zadeh in order to solve the uncertainties with the traditional type-1 fuzzy logic controller [15]. The design structure of T2FLC is similar to typeT1FLC with only different in type reduce block in T2FLC. However, a type-2 fuzzy set is represented by Ā, which also described as:

Ă = ((y, u), μ_A(y, u))I Ʉ$_x$€X (4)

Where X is input variable domain and y is the range of the input variable, u is the primary grade of the type-2 fuzzy logic set and J_x is the membership of T2F set, and $\mu_A(x,u)$ is the secondary membership of the fuzzy set. So, T2F which denoted as a continuous universe of discourse as described in equation 5 below.

$$A^2 = \int_{x\in X} \int_{u\in Jx} uA(x,u)/(x,u) \quad (5)$$

Here, $J_x \subseteq [0,1]$ and $\iint$ represent the union on all the values of x and u. However, A can be written as:

$$A = \left(x, \mu_A(x)\right) / \forall \in X \quad (6)$$

$$A = \int_{x\in X} \left[\int_{u\in J_X} f_x(u)/u \right] / xJ_X \subseteq [0,1] \quad (7)$$

$$A = \sum_{i=1}^{N} \left[\sum_{u\in J_{xj}} f_{xj}(u)/u \right] / x_i \quad (8)$$

All membership union is referred to Footprint of uncertainty (FOU). Also, (FOU) is denoted mathematically as:

$$\text{FOU}(A) = \bigcup_{x\in X} J_x \quad (9)$$

The basic structure of T2FLC is similar to the classical T1FL structure with only different in type reduction block in type-2 fuzzy logic controller. Figure 3. Depicts the structure of T2FLstructure.

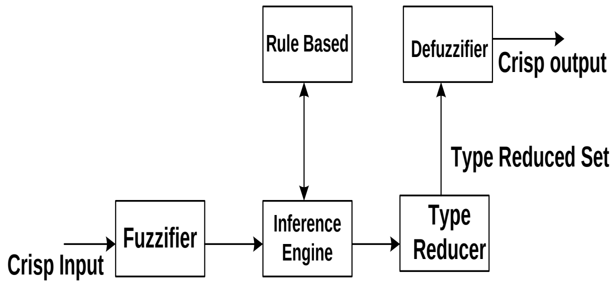

Figure 3. T2FLC Block Representation

However T2F, each membership grade is fuzzy itself range between (0, 1) unlike in type-1 fuzzy system where the memberships are only crisp number (0, 1) [16][17][18].

- Fuzzification process: The fuzzification is the input blocks that received and processes the crips values and processes it in to the inference engine for onward processing.
- Knowledge Base: The block is aimed to define the linguistics terms for the two inputs and single output for the error and change of error respectively.
- Inference Mechanism: This block accept the fuzzified crisp values and rule base which further the result into the type reduction block for defuzzification process.
- Type reduce block: The type reduction block is aimed at converting the crisp value into type-1 fuzzy set before the fuzzification process.
- Defuzzification process that is responsible for the conversion of the fuzzified output data by the output membership's functions to the process system which is to be controlled.

Table 1 Rule Table

E	N	Z	P
N	N	LN	Z
Z	LN	Z	LP
P	Z	LP	P

Table 1. Shows the rule table of the T2FLC which defined the linguistic rules as: Error (E), Change of error (CE), Negative (N), positive (P), Zero (Z), Large Negative (LN), and Large Positive (LP).

Retrieval Number:100.1/ijeat.A42991013123
DOI: 10.35940/ijeat.A4299.1013123
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A.Simulation Studies

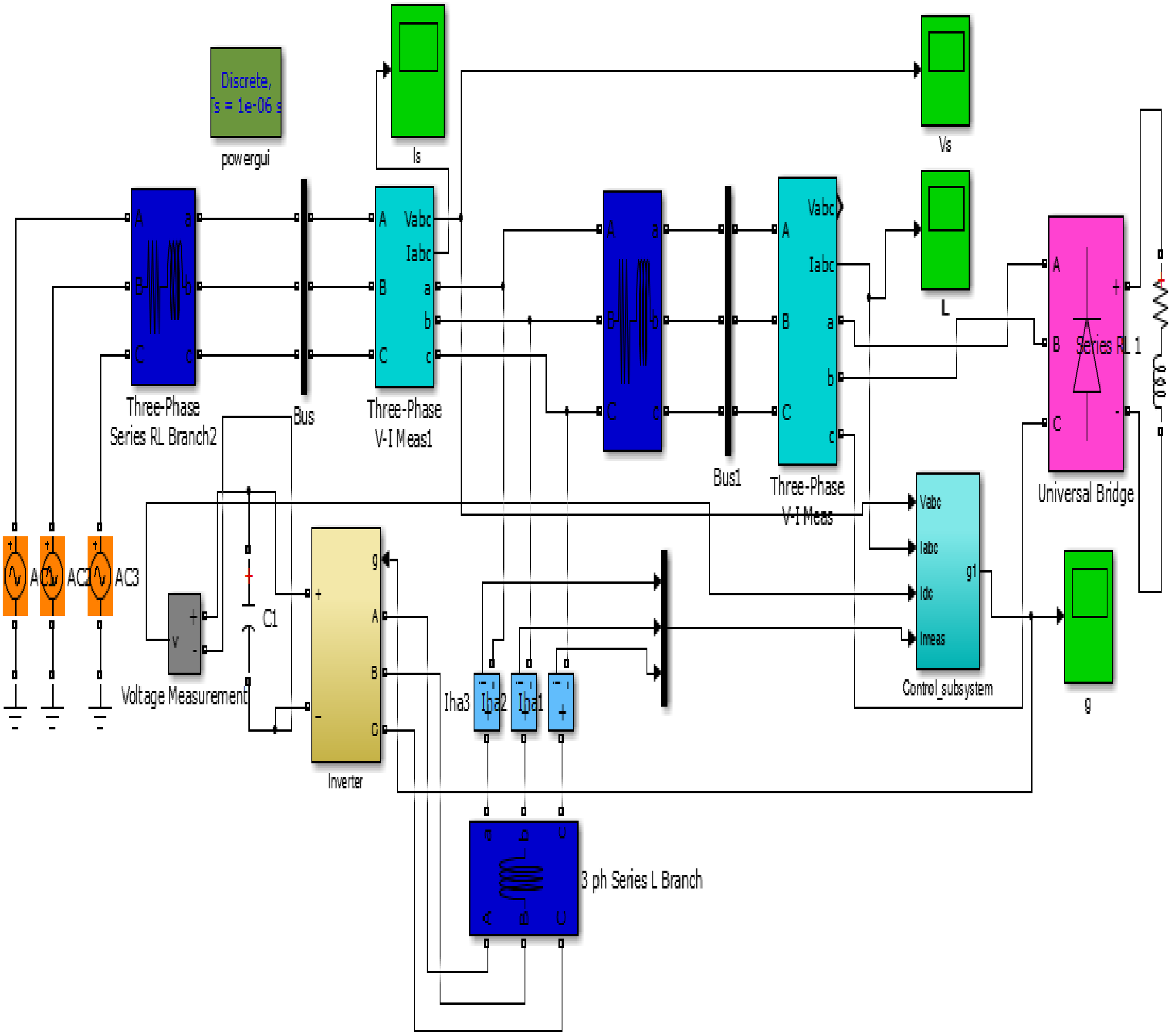

Figure 4. Complete SIMULINK of Shunt Active Power Filter

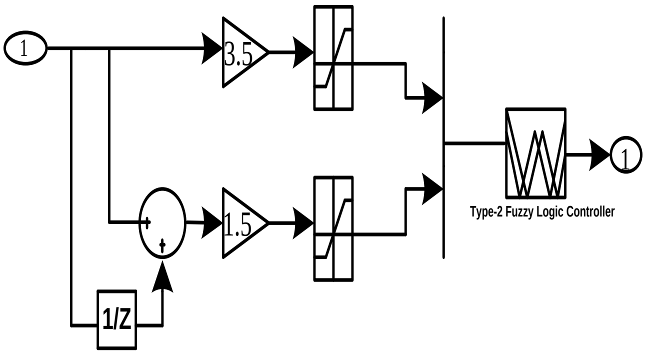

Figure 5. Sub System of the Simulink Model of T2FLC

[Figure 4.](#) Shows the complete simulation work using MATLAB/SIMULINK. The extraction technique using synchronous reference frame, the T2FLC.

Moreover, [Figure 5](#) depicts the sub system of the T2FLC which has two inputs error (E) and its derivative (ΔE) with a single output.

B. Simulation Results and Analysis

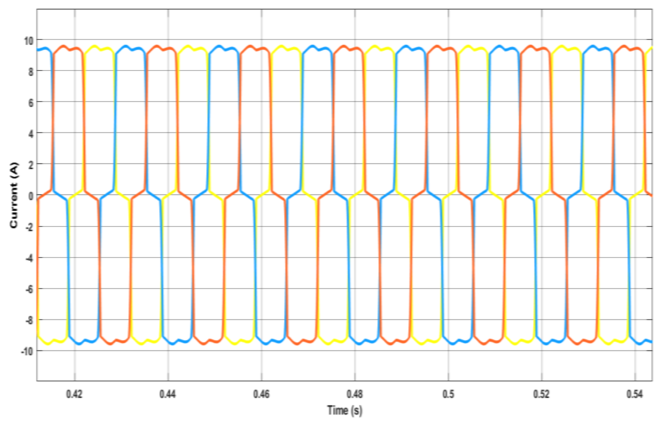

Figure 6. Load Current Before Compensation with Filter

Retrieval Number:100.1/ijeat.A42991013123
DOI: [10.35940/ijeat.A4299.1013123](https://doi.org/10.35940/ijeat.A4299.1013123)
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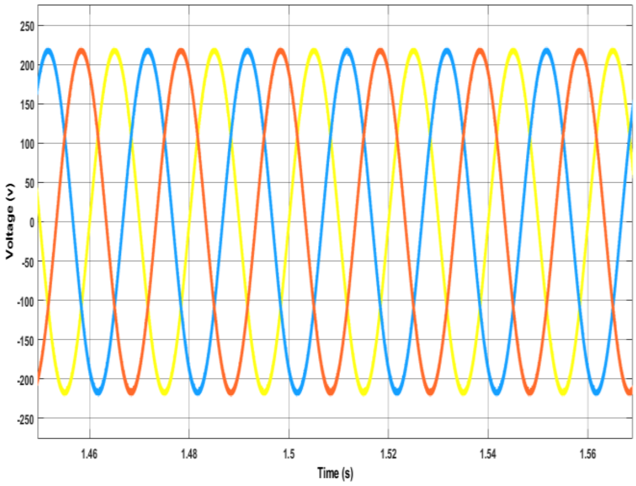

Figure 7. Source Voltage

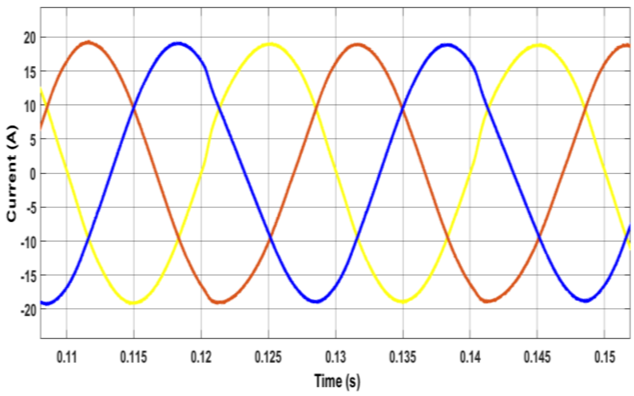

Figure 8. Source Current After Compensation Filter

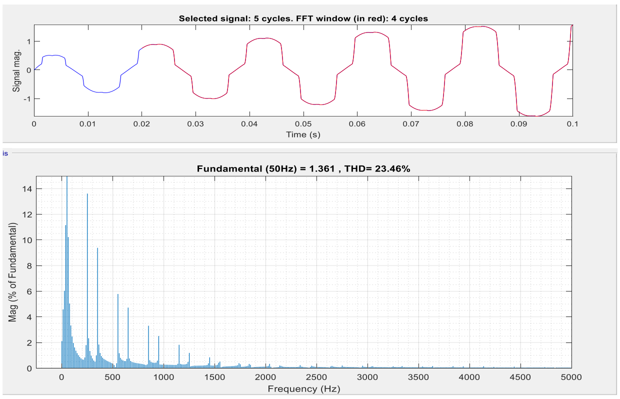

Figure 9. Total Harmonic Distortion (THD%) before applying filter.

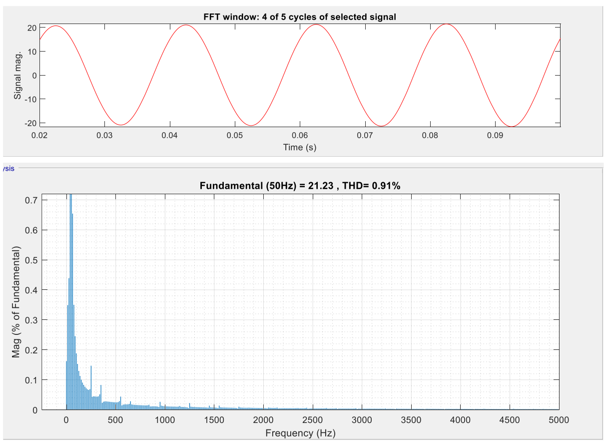

Figure 10. Source Current after applying filter.

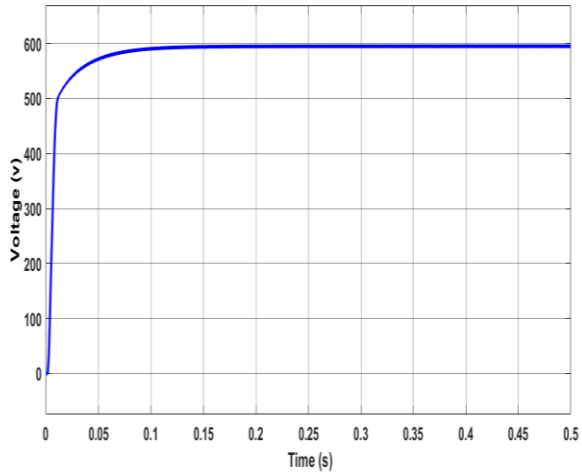

Figure 11. D.C Bus Voltage of the Filter

Figure 6. Shows the load current due to nonlinear load without using the SAPF. While Figure 7. Is the supply voltage which supposed to be purely sinusoidal in nature even with or without applying the filter. Figure 8. Depicts the supply current after applying the filter and is in the same polarity with the supply source voltage. Moreover, Figure 9. Shows the level of harmonic distortion using Fast Fourier Transform and the THD% found to be 23.46% which did not satisfy the imposed IEEE 519-2014 norms. Figure 10 shows the compensated current after applying SAPF and the THD% found as 0.91% and have satisfied the recommended imposed harmonic norms. Meanwhile Figure 11. Indicate the stability of the direct current bus voltage which stabilized at 600V.

V. CONCLUSION

Design simulation of SAPF with T2FLC for the improvement of power quality was achieved in the article. Results found for the THD% of the load current and supply current were obtained to be 23.46% and 0.91% without and with shunt active power filter respectively. These results show the capability of the filter to mitigate the harmonics produced by nonlinear load and the results obtained satisfied the required IEEE harmonic norms. However, the controller has shown its effectiveness in reducing the harmonic to it minimum level

DECLARATION STATEMENT

Funding/ Grants/ Financial Support	No, I did not receive any financial support for this article.
Conflicts of interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, this article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors having equal contribution for this article.

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