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Research Article

Comparative Analysis Of Various Topologies For Harmonics Mitigation Techniques For Power Quality Improvement

Mohammad Arsh Khan[1*], Durga Sharma[2]

[1*]PhD Scholar, Electrical Engineering Department, C.V. Raman University, Kota, Bilaspur (C.G.), India
[2]Associate Professor, Electrical Engineering Department, C.V. Raman University, Kota, Bilaspur (C.G.), India

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ARTICLE INFO	ABSTRACT

The increasing use of nonlinear loads in the commercial, residential, and industrial sectors has distorted the power network. The introduction of non-linear loads has a negative impact on system performance and power quality, particularly THD. A FACTS-based device called SAPF is connected between the source and the load employing the STATCOM scheme and hysteresis controlling scheme. The SAF operates as a current source that delivers opposite but equal harmonic components to the PCC. To measure load currents and extract their harmonic components in order to provide a reference current in shunt active power filters (SAPF) and significantly influence the SAPF performance, a variety of techniques have been used. Different control techniques, including Artificial Neural Networks (ANNs), pq-theory, and dq-transformation, are implemented using SAPF using the MATLAB-Simulink toolbox.

Keyword: FACTS, THD, SAPF, STATCOM, PCC

Introduction

The stability of the electricity system is one of its key components. Flickers, voltage dips/sags (31%), unregulated voltages (18%), interruptions or waveform disturbances (power factor, harmonics (18%), others), transient swells (13%), and overvoltages (surges/spikes) (8%) [4] are just a few of the serious power quality issues caused by harmonic currents generated by nonlinear loads. Non-linear loads such as rectifiers, inverters, electronic starters, motor drives with variable frequency, switching power supplies, discharge lights, and others in the power electronics sector produce harmonics. The THD is reduced with FACTS devices. Static Synchronous Compensators (STATCOM) are active devices that regulate voltage and current as well as reduce harmonics [2]. SVC are utilized to compensate for the reactive power.
Harmonics have been successfully eliminated using a variety of techniques. The cost-effectiveness of passive filtering is constrained by its reliance on source impedance, losses, size, and lack of compensating flexibility. To address the drawbacks of passive filters and enhance the effectiveness of the harmonics mitigation method, active filters are provided. In comparison to using passive and active filters alone, hybrid filter topology provides the most cost-effective and effective solution. The issues caused by non-linear loads have been studied, developed, and progressively accepted as an acceptable solution by SAPF. The creation of the reference source current must be done correctly for optimal filter performance. Several techniques, including the Fourier transform, Artificial Neural Networks (ANNs), pq-theory, and dq-transformation, have been introduced in the literature for this purpose. Artificial Neural Networks (ANNs), which have high-speed recognition and learning capabilities but a simple structure, have attracted a lot of attention.

Literature survey

Harmonics are spectral components with frequencies that are integer multiples of the fundamental frequency. Nonlinear loads are the primary cause of harmonic voltage distortion [4]. Passive harmonic filters are simple solutions for systems with poor energy quality [3]. A quality study is the very first step in a filter project to identify the true sources and severity of the problem. The optimal option with the right amount of power for

the system must then be chosen, taking into account both cost and outcome. According to Lv, Qin, Zhao, Guo, and Zong's paper from 2020, there are many different, sophisticated, and variable methods for power system harmonic detection and suppression, and the outcomes vary. The active power filter harmonic suppression method is the most common research strategy in harmonic control currently and in the future [8]. Considering the cost and limitation of these filters a hybrid form was proposed. To achieve the harmonics and reactive power adjustment, a hybrid filter is used. One active filter with a low power rating is used to filter the other high order harmonics while the passive filter with a higher rated power is used to filter the low order harmonic with a big current amplitude [6]. Shunt hybrid active filter robustness will be increased by harmonic extraction techniques such as Adaline and sliding mode controller over conventional extraction techniques [1].
Hoon, Yap (2017) et. al. in their paper states that using a shunt active power filter (SAPF) is the suitable technique to eliminate harmonic contamination, but its effectiveness is totally dependent on how quickly and precisely its control algorithms can function [5]. Harmonics extraction based on a Instantaneous power (PQ) theory algorithm uses a sequence of mathematical calculations of the instantaneous power in a balanced three-phase system used to realize the evaluation, using the Clarke transformation for in α-β-frames computation [5,9,10]. While harmonics extraction based on synchronous reference frame (SRF) uses a sequence of mathematical calculations of three-phase load used to realize the evaluation, using the Park-transform matrix are conducted direct-quadrature-zero frames [5,9]. Using a learning methodology is another way to extract the necessary harmonic components. The properties of the harmonically contaminated distribution system are learned using ANN. The ANN approach is an algorithmic architecture based on the pattern and functioning of biological neural networks. Each harmonic frequency must be represented by a different network, which lengthens the computation process [5], operated alongside extraction methods like PQ and DQ [11]. Krismanto stated in their paper that RBF outperforms multi-layer perceptrons (MLP) in terms of extracting and approximating the harmonic current component from the original distorted current. RBF features a quicker training method, simpler design, and reduced sum of squares error (SSE). Unfortunately, compared to MLP, RBF requires more recursive training because it has more neurons, but overall, RBF outperforms MLP [7].

Problem identified

Typically, both linear and nonlinear loads are present in the system. Nonlinear loads can lead to power quality problems such as harmonic distortion, voltage swings, and noise. Power losses, electric device heating, insulation failures, communication system interference, and, in the worst cases, an electric power system breakdown are all caused by harmonic distortion in low-voltage distribution systems. Therefore, it is essential that problems with power quality are fixed for the good of the service and the consumer. Power filters are efficient and widely used tools that stop harmonic distortion from spreading. Series and shunt passive power filters are commonly attached to the distribution system with the aim of improving power quality.
Shunt Active Power Filters are more prominent among active filters in use nowadays. since it is mainly based on the estimation of reactive power and harmonics, and works on compensating the values to the system. The method for compensation value calculation significantly impacts the performance of the filter. Hence a suitable method depending on the use and working environment needs to sorted and tested accordingly.

Proposed methodology

Series and shunt passive power filters are commonly attached to the distribution system with the aim of improving power quality. acting on the importance of current in a system, we worked on current harmonics using a Shunt Active Power Filter (SAPF). Two terms that are frequently used in relation to harmonics (THD) are Individual Harmonic Distortion (IHD) and Total Harmonic Distortion. THD is the abbreviation for total harmonic distortion (THD), which is the distortion of a voltage or current waveform brought on by the combined effects of all the individual harmonics in the network i.e.

$$Total\ Harmonic\ Distortion\ (\%) = \sqrt{\sum_{n=0}^{\infty} (Individual\ Distortion)^2_{2n+1}}$$

$$THD(\%) = \sqrt{ID_2^2 + ID_3^2 + ID_5^2 + \ldots . ID_n^2}$$

The operation of the SAPF can be noted by its operation before and after the application of the filter. Initially the current in the system flows in the following manner.

$$Source\ current\ (i_S)\ = fundamental\ current\ (i_{fL})\ +\ harmonic\ component\ of\ the\ current\ (i_H)$$

After the application of the filter the system currents given to the components and operation of SAPF can be expressed in the following manner.

Source current (i_S) = [fundamental current (i_{fL}) + harmonic component of the current (i_H)]
+ [DC-link current (i_{dc}) - injected compensation current (i_C)]
Due to the action of the DC-link capacitors (DC cap and DC cap1 in series), the system's current becomes sinusoidal with the fundamental frequency, and the current flowing is as follows:

$$i_S = i_{fL} + i_{dc}$$

In the case of the p-q harmonic extraction method, the shunt active power filter uses the instantaneous active and reactive power control method, or p-q method, to generate compensatory signals by transforming the a-b-c stationary reference into 0-α-β rotational coordinate and back again. And considering the absence of zero sequence current in the system.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

In the α-β coordinate, the complex sum of the active and reactive powers (P and Q) can be represented by

$$S = P + jQ = v_{\alpha\beta} i^*_{\alpha\beta} = (v_\alpha - jv_\beta)(i_\alpha + ji_\beta) = (v_\alpha i_\alpha - i_\beta v_\beta) + j(v_\alpha i_\beta - i_\alpha v_\beta)$$

Harmonic-infused P and Q will manifest as ripples. By employing the retrieved harmonic components $i_{\alpha\beta H}$, the reference current i_{ref} is created via the inverse Clarke transformation. The equation defined below is used to calculate the compensation current while ignoring the zero sequence values. Additionally, these values of - are utilized to compute values of the a-b-c type via an inverse matrix transform.

$$AC\ component\ (\hat{p}) = instantaneous\ real\ power\ (P) - DC\ component\ (\underline{p}) + \underline{p_{loss}}$$

$$\begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \acute{p} \\ Q \end{bmatrix} \qquad \begin{bmatrix} i^*_a \\ i^*_b \\ i^*_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix}$$

The switching signals for the voltage source inverter are produced using the hysteresis band current method. The reference current and actual current are contrasted, and the VSI switches are turned on and off in line with the error, keeping the actual current within the hysteresis band. To maintain a constant DC-link voltage, effectively correct harmonic current, and evaluate compensation current, a proportional-integral controller is used in the DC-link voltage control loop. It uses a reference voltage value, here described as 850V, and compares it with the voltage across DC-link to provide the energy consumed and maintains the value via DC-link loop.
Another well-known methodologies that can be used to drive the VSI is the Synchronous Reference Frame (SRF) method. The Rotating Reference Frame (d-q) case is used instead of the heap flows. Prior to that, the Clark Transformation, which was already carried out during the p-q technique, transforms the a-b-c stationary reference into 0-α-β rotational coordinate. Further the transformation of 0-α-β stationary reference frames coordinate to the d-q synchronous frame is given by equation.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}, \ \theta = \tan^{-1}\left(\frac{v_\alpha}{v_\alpha}\right)$$

Such that the deduced formula is given as:

$$i_d = i_a cos\theta + i_b cos(\theta - \frac{2\pi}{3}) + i_c cos(\theta + \frac{2\pi}{3})$$
$$i_q = i_a sin\theta + i_b sin(\theta - \frac{2\pi}{3}) + i_c sin(\theta + \frac{2\pi}{3})$$

Now this d-q frame id transformed to a-b-c frame by the following:

$$i_a = i_d cos\theta + i_q sin\theta$$
$$i_b = i_d cos(\theta - \frac{2\pi}{3}) + i_q sin(\theta - \frac{2\pi}{3})$$
$$i_c = i_d cos(\theta + \frac{2\pi}{3}) + i_q sin(\theta + \frac{2\pi}{3})$$

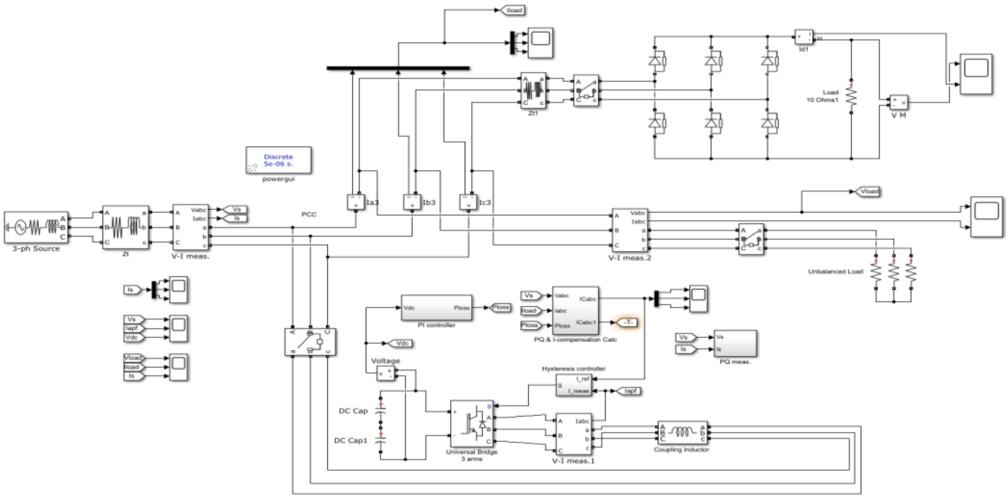

Figure 1: The proposed model of PQ-based Shunt Active Power Filter

The speed of the SRF is constant since it is equal to the speed of the main voltages. Similar to the p-q theory, the derived d-q fundamental current component is regarded as a dc value; the harmonic would resemble a ripple in that situation. And a Butterworth Low Pass Filter (LPF) is employed to eliminate harmonics in the ripple of the modified d-q current in order to eliminate that DC offset.

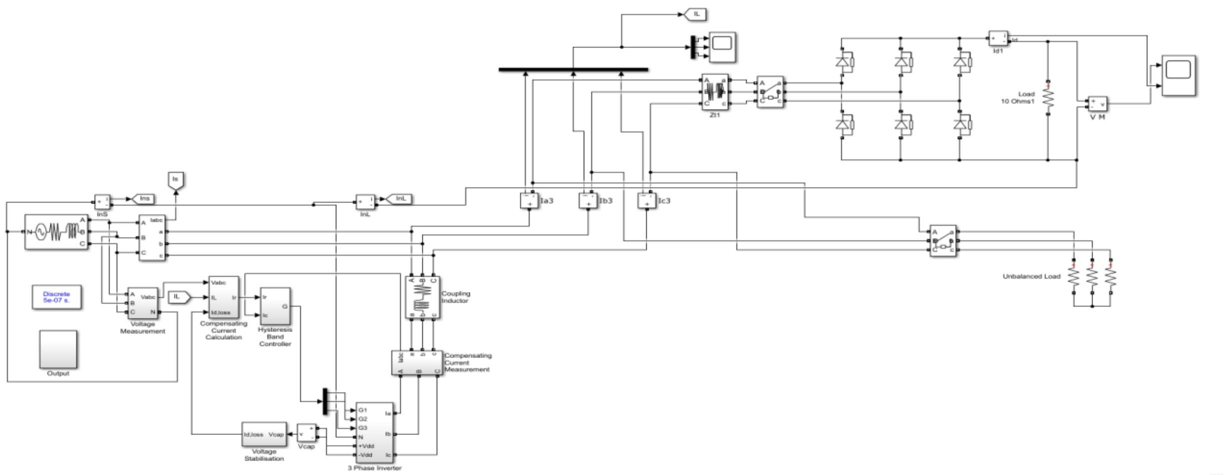

Figure 2: The proposed model of DQ-based Shunt Active Power Filter

During our operation in both p-q and d-q theory a PI controller was used with a reference value of 850 for estimating p_{loss} and further resulted in estimation of compensation current and pulse governing the VSI. Simple PI controllers are used widely due to their efficiency in reducing the steady-state error of a control system as well as its simplicity in implementation has a drawback in that it cannot enhance the transient response of the system. To overcome this an Artificial Neural Network was implied.

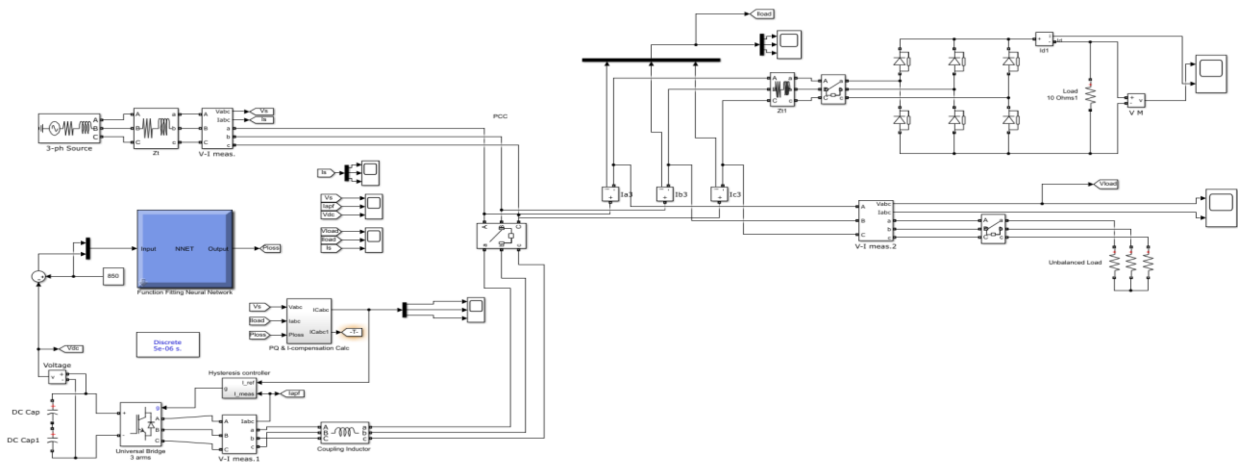

Figure 3: The proposed model of ANN-based Shunt Active Power Filter

The detected current is fed into the ANN. A harmonic current component without a fundamental component is produced by the ANN-based PQ theory. In order to provide a switching signal for a voltage source inverter, the output of the ANN-PQ will be used as a reference signal in comparison to the signal. Finally, the inverter's generated current will be added to the line as a compensation current to reduce harmonics.

Result

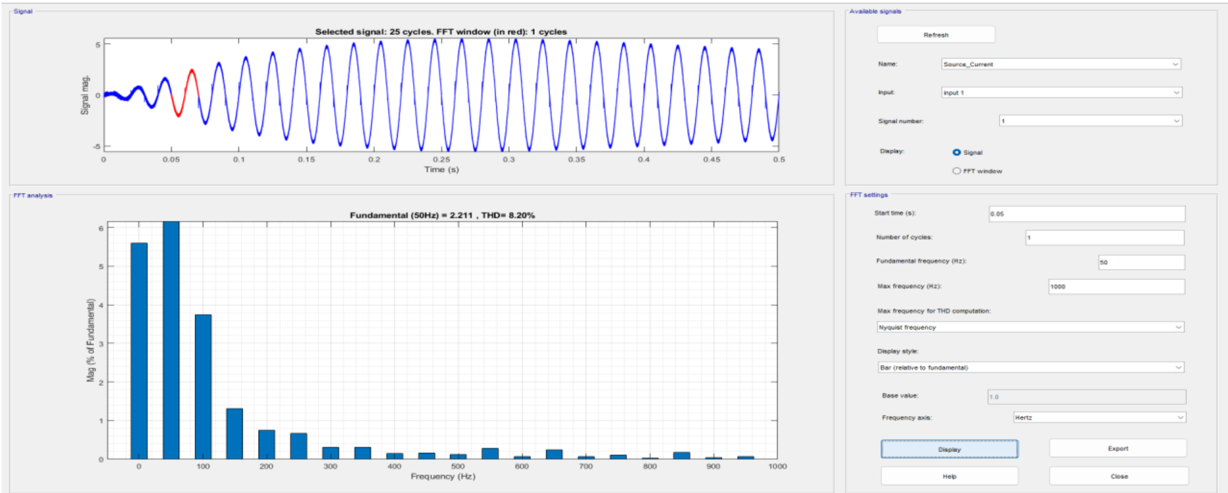

Figure 4: DQ system FFT analysis representing the magnitude of harmonics relative to fundamentals

The DQ control structure provides the adjusted reactive power needed by the loads and is based on currents. This control approach is ineffective when the main voltages are out of balance. The designed system was able to bring down the harmonics in the system to 8.20%.

The PQ control technique is thought to be the most efficient way to manage a conditioner, but it is also the most susceptible to harmonics and an unbalanced main voltage. Four-wire, three-phase power system would work well with this technique. In a three-phase three-wire power system, this would result in a low power factor and ineffective reactive power compensation. Against the previously designed system of DQ method, the PQ method was able to bring down the harmonics to 5.85% which is about 2.35% less, hence 28.6% more effective.

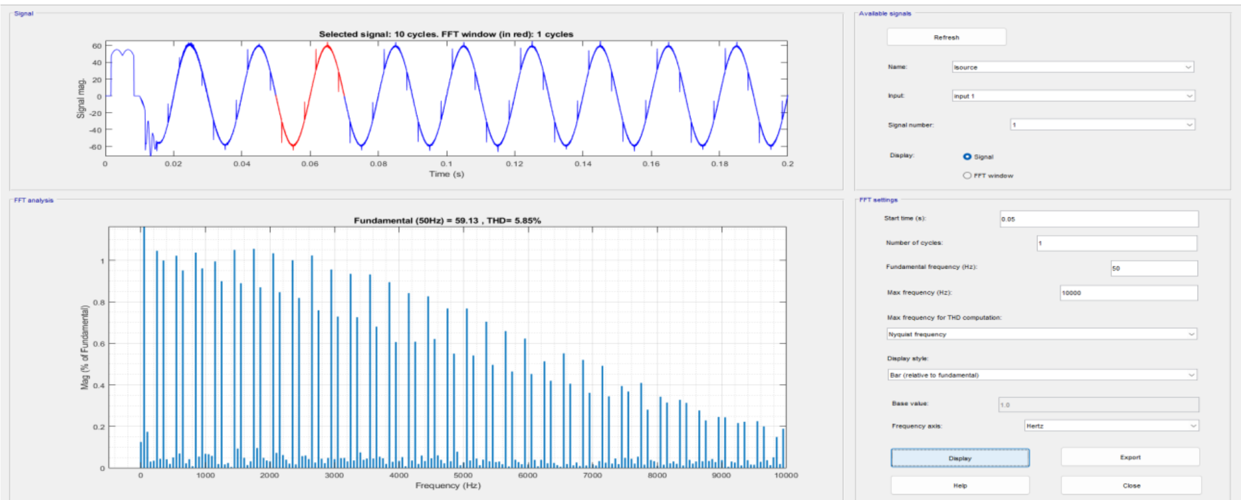

Figure 5: PQ system FFT analysis representing the magnitude of harmonics relative to fundamentals

To compensate for the shortcomings of the above system an ANN based system was designed which was successful in bringing down the harmonics while utilizing the sample from PI controller data from the SAPF designed for the PQ.

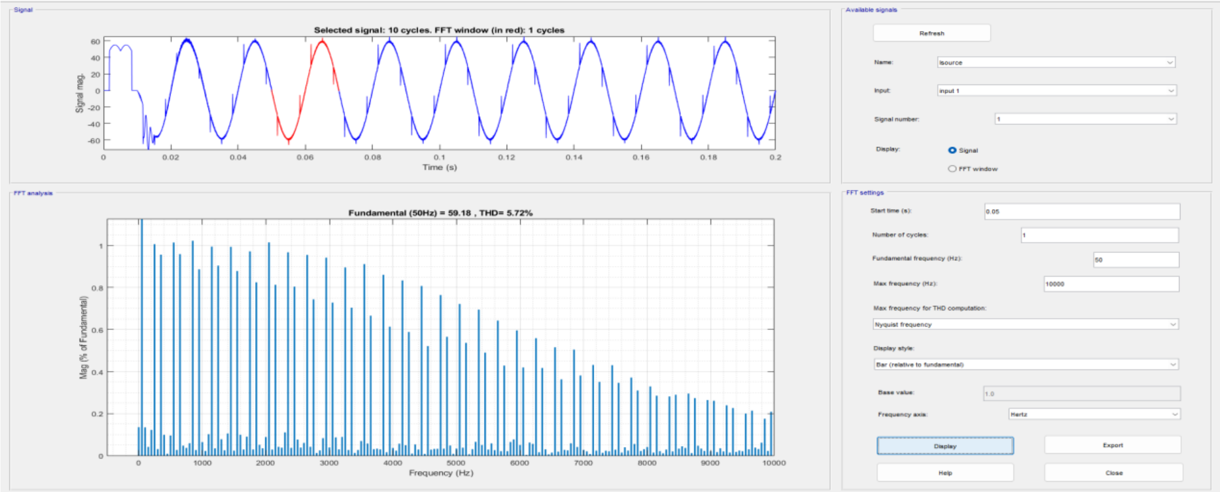

Figure 6: ANN-based PQ system FFT analysis representing the magnitude of harmonics relative to fundamentals

The successfully implemented design was able to bring down the harmonics to 5.72 which shows the effectiveness of the ANN based harmonic mitigation.

Conclusion

The research described in this study significantly focus on improvement of SAPF performance by contributing to identification and control tactics. Different harmonic mitigation strategies have been noted. The effectiveness of the suggested ANN was confirmed through simulated simulations using MATLAB and comparison to the conventional approach. Comparative investigations between the neural approach and two of the most widely used methods for obtaining reference currents from the load current, namely p-q theory and d-q theory, have been accomplished at this level. The designed ANN-based shunt active power filter can significantly lower THD of the source current compared to other. The results obtained show that the artificial neural network-based (ANN) method can successfully recognise harmonic currents across all of their recognition goals.

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