International Journal of Engineering Processing & Safety Research
Published by Cambridge Research and Publications
Vol. 28 No.5
June, 2023.

SHUNT ACTIVE POWER FILTER USING ROBUST PID-CONTROLLER FOR POWER QUALITY IMPROVEMENT

ISMAILA YUSUF ADUBAZI, HAMISU USMAN AND NURADDEEN MAGAJI
Department of Electrical engineering, Bayero University Kano Nigeria.

ABSTRACT:

The proliferation of power electronics equipment for both industrial and consumers used have led to degradation of power system network at the point of common coupling (PCC). This problem has resulted in poor power quality within the entire power system, which causes harmonics to developed. In order to remedy these lingering issues, traditional passive power filter was the earliest technology to mitigate the harmonics problems, but passive filters inherit draws back such as heavy in size, produced series and parallel resonances and can only mitigate few selected harmonics. However, a superior filter known as shunt active power filter is now the viable and tested solution to mitigate current harmonics produced by nonlinear loads. In this paper, instantaneous real and reactive power (P-Q) theory is proposed to extract the current harmonics as well as robust PID-controller to control the DC side voltage of the shunt active power filter. Hysteresis current controller is used to generate the switching signals of the voltage source inverter (VSI). MATLAB/SIMULINK environment is used for the simulation work. Simulation was done with different nonlinear loads in order to show the robustness of the proposed controller. Results of the total harmonics distortion was found to be within the stipulated imposed IEEE 519-2014 harmonic limit.

Keywords: shunt active power filter, power quality, harmonics, robust PI controller and IEEE-harmonics standard limit.

INTRODUCTION

For every electrical power system network, current and voltage wave forms are supposed to be purely sinusoidal, but due to frequent increased and spread of power electronics equipment for utilizations in industries and local consumers applications, power quality has become deteriorated due to their nonlinear in nature. The nonlinear loads, causes poor power quality within the system network. As a result, harmonics are created that led to the degradation of both current and voltage waveforms. The effects of this harmonics resulted in over heating of supply cables, frequent tripping of sensitive devices such as circuit breakers and fuses, interference within the neighboring communication facilities, reduction in life expectancy of equipment, low power factor, over heating in transformer windings and motors and problem of unit generation while synchronizing generators (Bhatti et al. 2015) (Singh and Agnihotri 2018).

In an attempt to mitigate current harmonics, passive power filters were in used, but due to its demerits such as bulky in size, produced series and parallel resonances, problem of fixed compensation and mitigation of selected harmonics that is why it is not popularly employed. In addition, before the invention of passive and shunt active power filters, line reactors, isolation and phase-shifting transformers were in used for mitigating current harmonics in power system networks (Bitoleanu and Popescu 2013). In this regards, poor power quality parameters in power system networks are not acceptable since are not within the imposed IEEE limits of international power quality standard(Electronics 2012),(Committee, Power, and Society 2014), (Code and Prix 2013).

With advancement in technology, superior filter known as shunt active power filter have been proven to be a viable and dynamic solution to mitigate current harmonic distortion due to nonlinear loads. A lot of DC voltage control for shunt active power filter have been proposed with classical PI controllers as in (Naidu and Kumar 2019), (Qashou 2021), (Imam, Kumar, and Al-turki 2020), (Thajeel 2020).

In this paper, simulation of three phase three wire shunt active power filter with p-q theory for current harmonic extraction as well as the hysteresis current controller for switching the gating signal of the IGBT inverter circuit is proposed. In addition, a robust PI controller is deployed for effective maintaining the DC voltage for the shunt active power filter as compared with the classical PI controller.

DESIGN A PQ CURRENT EXTRACTION

In 1983, Akagi et al. (Ronbunshi 1984) have proposed the "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as instantaneous power theory, or p-q theory. It is based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components:

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1.0}$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{1.1}$$

The instantaneous zero sequence power is given as

$$P_0 = V_0 I_0 \tag{1.2}$$

The instantaneous real power is given as

$$P = V_\alpha I_\alpha + V_\beta I_\beta \tag{1.3}$$

The instantaneous imaginary or reactive power is given as

$$Q = V_\alpha I_\beta - V_\beta I_\alpha \tag{1.4}$$

The active power and reactive power can be written in matrix form as

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{1.5}$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \begin{bmatrix} P \\ Q \end{bmatrix} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \tag{1.6}$$

Reference signal of compensation current in the d-q axes using the inverse park transformation we get the reference currents back to three phase system which is shown in Figure 1.

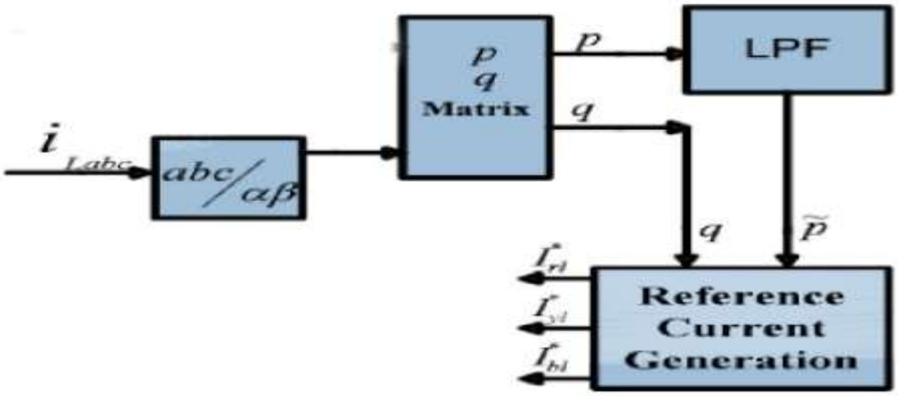

Figure 1. p-q control theory

HYSTERESIS CURRENT CONTROL:

Hysteresis current control is one of PWM methods used for generating pulses to order the power switches of inverter. Among the various current control techniques, HCC is widely used due to the fast response, simple implementation, negligible tracking error, inherent robustness to load parameters variations and proper stability. HCC has high accuracy and fast response as well as provides better low-order harmonic suppression than PWM control which is the main target of the active power filter.

As shown in Figure 2. the difference between reference current and actual current is called error signal (e). the error signal is sent into the hysteresis bands, if it touches the upper or lower band, the hysteresis controller block decides to generate associated switching pulses to keep the error signal in desired area. The outputs of the hysteresis blocks are directly fed as the firing pulse of voltage source inverter (VSI) switches.

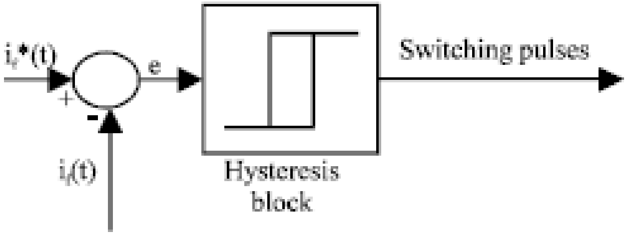

Figure 2. Fixed-band hysteresis current control loop

The variable Hysteresis Band (HB) formula can be calculated based on Figure 2. which is showing one phase of the system illustrated in Figure 2. The following KVL equation can be easily achieved from this figure:

$$\frac{d\mathrm{i}_f(t)}{dt} = \frac{1}{L_f}\left(V_f - V_s(t)\right) \tag{2.1}$$

where, V_f is the inverter-side voltage and can be elaborated as below:

$$V_f = \begin{cases} \frac{V_{dc}}{2} & \text{The upper swich is on} \\ -\frac{V_{dc}}{2} & \text{The lower swich is on} \end{cases} \tag{2.2}$$

Having paid attention to Figure 2.8, the below relations can be obtained:

$$\frac{d\mathrm{i}_f^+(t)}{dt} = \frac{1}{L_f}\left(V_f - V_s(t)\right) \tag{2.3}$$

$$\frac{d\mathrm{i}_f^-(t)}{dt} = \frac{-1}{L_f}\left(V_f - V_s(t)\right) \tag{2.4}$$

where, $t^+{}_f(t)$ and $t^-{}_f(t)$ are the rising current and the falling current, respectively.

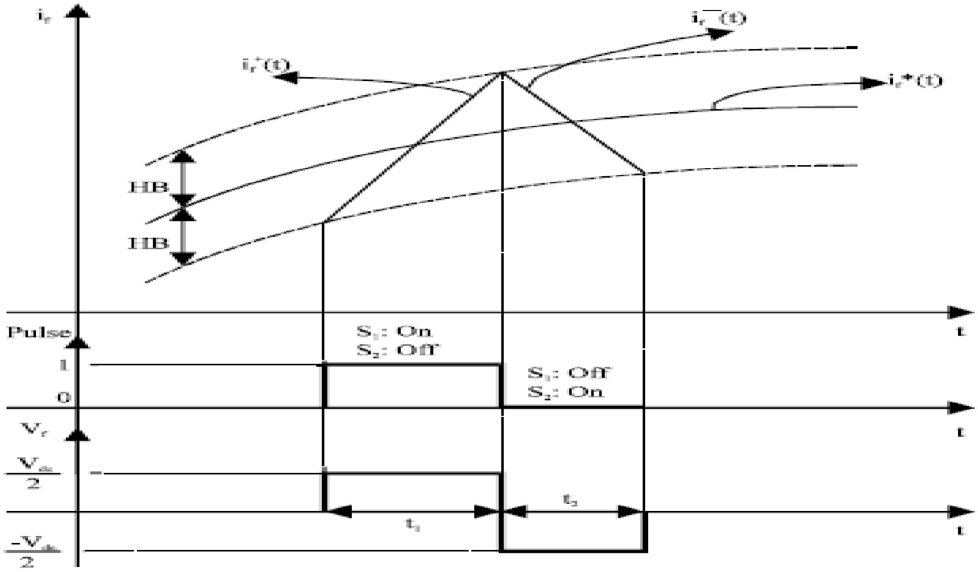

Figure 3. Hysteresis Band (HB)

STRUCTURE OF ROBUST PID CONTROLLER

Consider a control system with $n_{i\ inputs}$ and n_o outputs as shown in Figure 4. where $P(s)$ is the Plant transfer function $P(s)$ is the change in plant, $G_c\ (s)$ is the controller transfer function, $r(t)$ is the reference input signal, $u(t)$ is the control input, $e(t)$ is the error signal, $d\ (t)$ is the external disturbance and $y(t)$ is the output of the system [17].

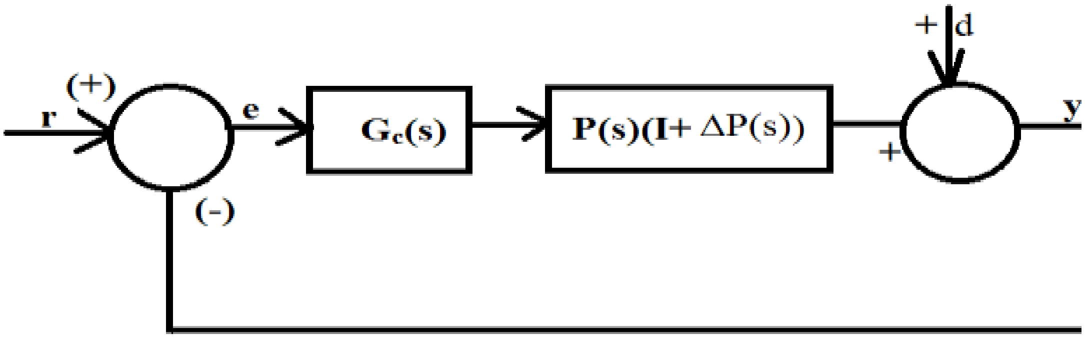

Figure 4. PID Control system with plant perturbation and external disturbance(Shri Bhagwan, 2016)

The change in plant or plant perturbation is bounded by a known stable function matrix $W_i(s)$

$$\bar{\sigma}(\Delta P(j\omega) \leq \bar{\sigma}(\Delta W(j\omega) \qquad (2.5)$$

where $\bar{\sigma}(A)$ denotes the maximum singular value of a matrix A.

The controller Gc(s) is designed by considering an asymptotically stable nominal feedback control system (ΔP(S) = 0 and d(t) = 0) is, the robust stability performance satisfies the following inequality.

$$|W_1(s)S(s)|_\infty < 1 \qquad (2.6)$$

$$|W_2(s)T(s)|_\infty < 1 \qquad (2.7)$$

where the closed loop system is also asymptotically stable with $\Delta P(s)$ and d(t) where $W_1(s)$ *is* a stable weighting function matrix specified by the designers. S(s) and T(s)=1-S(s) the sensitivity and complementary sensitivity functions of the system respectively.

$$S(s) = (1 + P(s)Gc(s))^{-1} \qquad (2.8)$$

$$T(s) = P(s)G_c(s)\left(1 + P(s)Gc(s)\right)^{-1} \tag{2.9}$$

H_∞ norm as,

$$\left|A(s)\right|_{\infty} = aX_{\omega}\bar{\sigma}(A(j\omega)) \tag{2.10}$$

SIMULATION PARAMETERS:

Table 1. Shows the simulation parameters without shunt active power filter.

System Parameters	Values
Source voltage (V_s)	100V(peak)
System frequency (f)	50Hz
Source impedance (R_s,L_s)	0.1Ω;0.15mH
Filter impedance (R_c,L_c)	0.4Ω;3.35mH
Load impedance (R_l,L_l)	6.7Ω;20mH
DC link capacitance	2000µF
Reference DC link voltage (V_{dcref})	220V

Figure 5. below depicts the simulation model of the non-linear load with different parameters values with RL load.

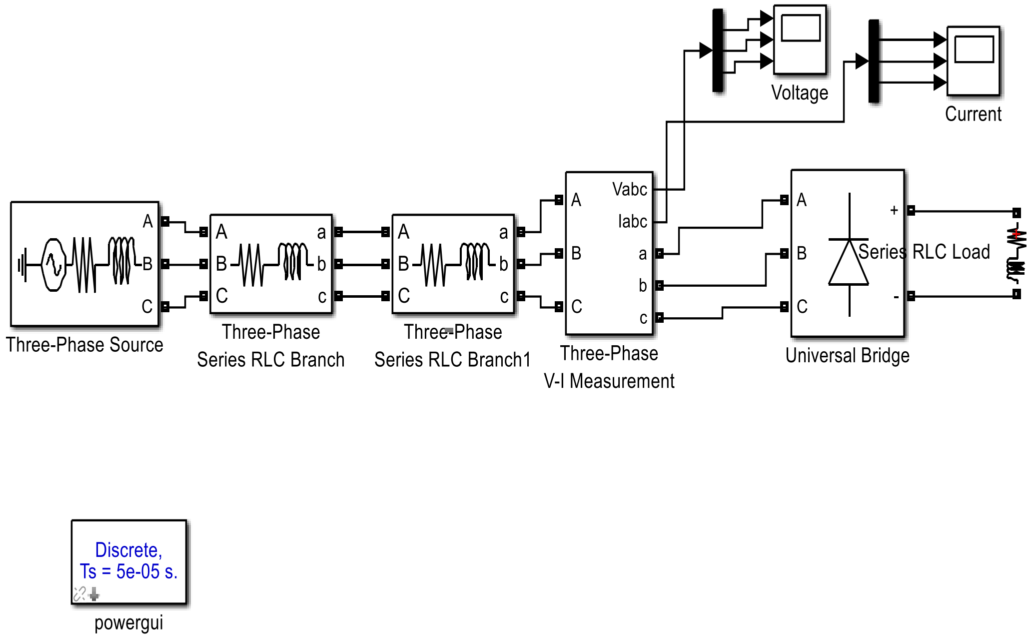

Figure 5. Complete simulation model of the nonlinear load with RL load.

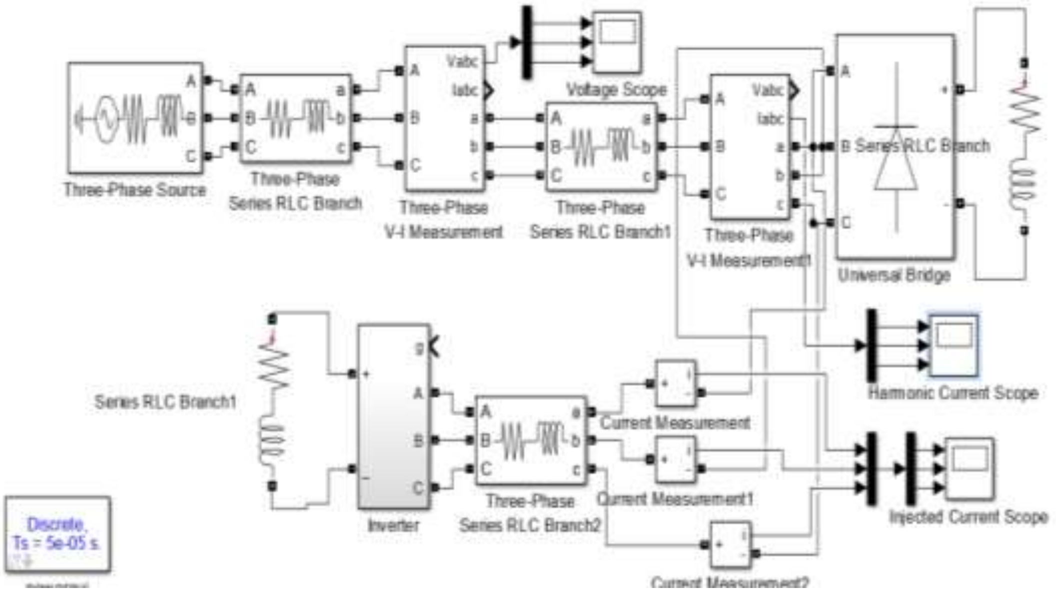

Figure 6. Complete simulation model with Current Controller

RESULTS AND DISCUSSION

The proposed system is simulated in MATLAB/SIMULINK along with the control technique proposed in figure 5 and 6. This load draws a highly nonlinear current rich in harmonics with a substantial reactive power requirement. A three phase, VSI-based shunt AF is connected to the filter system for reactive power compensation and harmonics elimination.

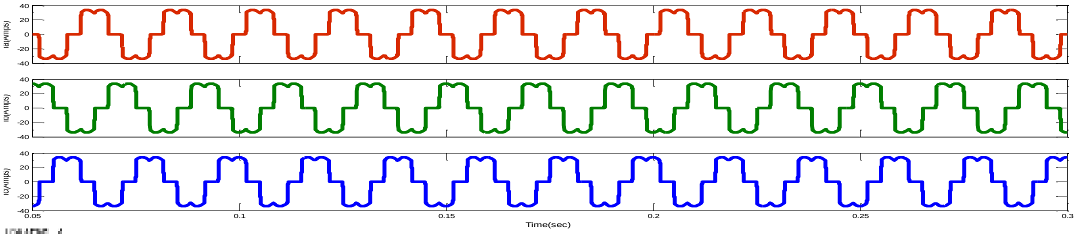

Figure 7. Load Current before applying Shunt Active Power Filter

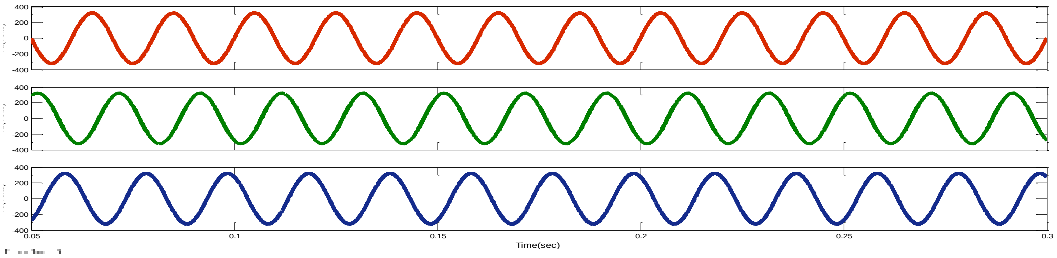

Figure 8. Source Current after applying Shunt Active Power Filter

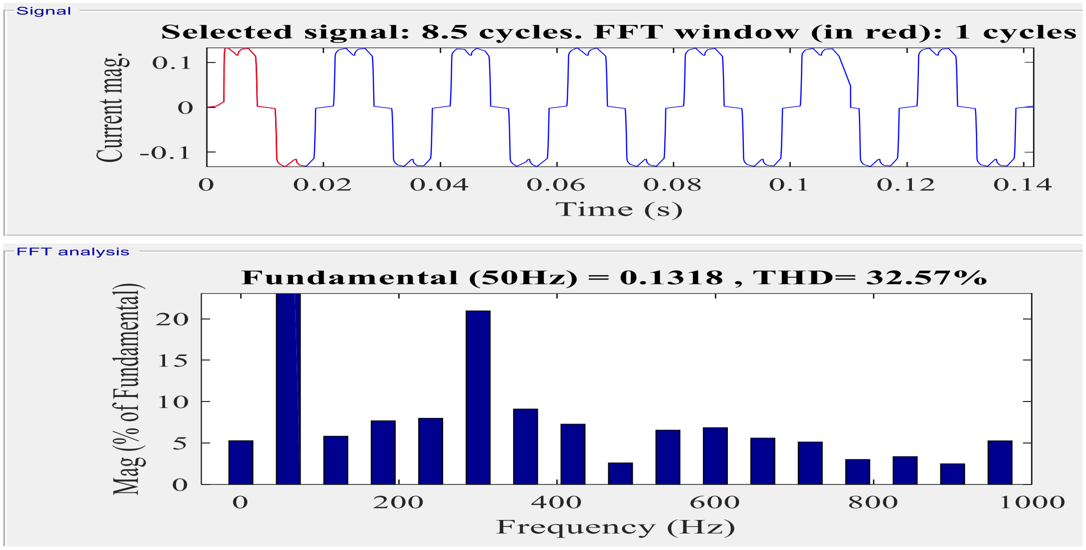

Figure 9. Fast Fourier Transform (FFT) Analysis of the Load current before compensation with Filter

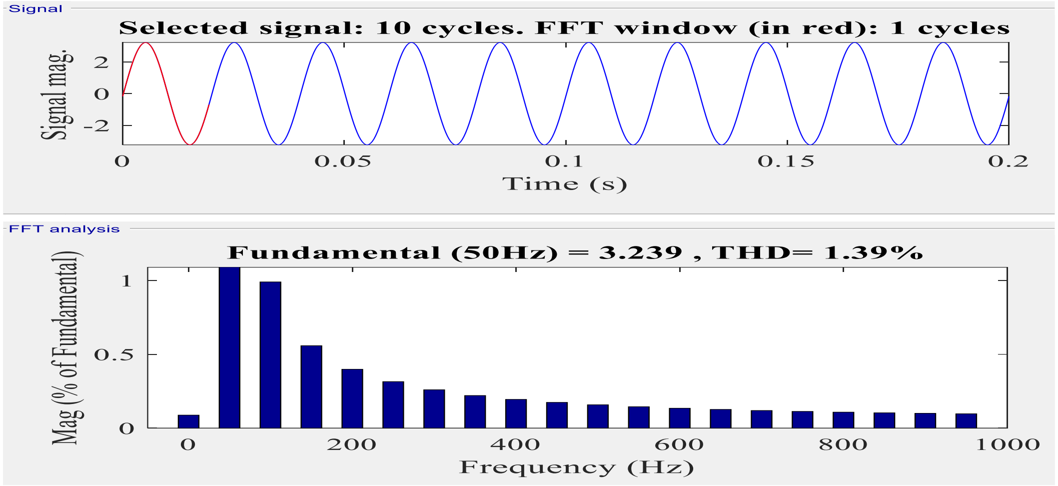

Figure 10. Fast Fourier Transform (FFT) Analysis of the Source Current after compensation with filter.

As shown in figure 7, the resultant load current is non sinusoidal in nature due to the nonlinear loads, while Figure 8, shows that the source current which is sinusoidal as compared to figure 7. However, Figure 9 depicts the frequency analysis of the total harmonic distortion (THD) with THD% of 32.57%, while Figure 10. Is the compensated current of the FFT analysis with THD% of 1.39%.

CONCLUSION

In this paper, modeling and simulation of three phase three wire system in MATLAB/SIMULINK environment was presented. Simulation results revealed that a total harmonic distortion of 32.57% was obtained without shunt active power filter. However, using the filter, a total harmonic distortion of 1.39% was found, this shows that the filter was able to compensate the current harmonics produced by nonlinear load and is within the imposed IEEE 519-2014 harmonic standard limit. The control algorithm have demonstrated a good performance in mitigating the current harmonic distortion.

RECOMMENDATIONS

The paper recommends that further research be carry out with other control algorithms in order to obtained an optimum result. It is also clear that the based paper be implemented using hardware set up in laboratory in order to show an effective, dynamic and robustness of the proposed current controller.

REFERENCES

Bhatti, Shahzad Sarwar, Engr M Umair, Umer Lodhi, and Shan Haq. 2015. "Electric-Power-Transmission-and-Distribution-Losses-Overview-and-Minimization-in-Pakistan.Docx." 6(4): 1108–12.

Bitoleanu, Alexandru, and Mihaela Popescu. 2013. "The P-q Theory and Compensating Current Calculation for Shunt Active Power Filters : Theoretical Aspects and Practical Implementation." (6): 11–16.

Code, Price, and Code Prix. 2013. "INTERNATIONAL STANDARD."

Committee, Distribution, Ieee Power, and Energy Society. 2014. "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems IEEE Power and Energy Society." 2014.

Electronics, M Tech Power. 2012. "Performance Investigation of Shunt Active Power Filter Using Hysteresis Current Control Method Electrical Engineering Department." 1(4): 1–8.

Imam, Amir A, R Sreerama Kumar, and Yusuf A Al-turki. 2020. "Modeling and Simulation of a PI Controlled Shunt Active Power Filter for Power Quality Enhancement Based on P-Q Theory."

Naidu, M Dhanunjaya, and Ch Ravi Kumar. 2019. "Analysis and Control of Shunt Active Power Filter by Use of P-Q and D-Q Theories." 6(4): 100–104.

Qashou, Akram. 2021. "Distribution System Power Quality Compensation Using a HSeAPF Based on SRF and SMC Features." *International Journal of System Assurance Engineering and Management* 12(5): 976–89. https://doi.org/10.1007/s13198-021-01185-w.

Ronbunshi, Cakkai. 1984. "Generalized Theory of Instantaneous Reactive Power And." 103(4): 483–90.

Singh, Naveen, and Piyush Agnihotri. 2018. "Power System Stability Improvement Using FACTS Devices." (September).

Thajeel, Ekhlas M. 2020. "Fuzzy Logic Controller Based Shunt Active Power Filter for Current Harmonic Compensation." : 94–99.