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A Comparative Analysis of Three Single-Phase GCPV-Based DSTATCOM System Using Conjugate Gradient Backpropagation and Frequency Domain Control Algorithms

Aini Syahida Mohd Shaizad [1,*], Nor Hanisah Baharudin[1,2*], Tunku Muhammad Nizar Tunku Mansur[1,2], Rosnazri Ali[1,2], Mohd Syahril Noor Shah[1,2], Norjasmi Abdul Rahman[1,2]

1 Department of Electrical Engineering, Faculty of Electrical Engineering & Technology, University of Malaysia Perlis, 02600 Arau, Perlis, Malaysia
2 Centre of Excellence for Renewable Energy (CERE), Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia

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ABSTRACT

Power quality is important for distribution system as it may impact both the provider and consumer of the electricity negatively if it has an issue such as harmonic current. This issue may result in a breakdown of equipment of both the consumer and the provider hence why it important to solve the power quality issue. Therefore, this research is conducted to overcome the power quality issues that is faced by the distribution system by adding DSTATCOM to the system as it can compensate harmonic current. Fast Fourier Transform (FFT) is chosen as DSTATCOM controller for this research. The outcome for this project is that the THD value of the source current need to be below 8% as stated in IEEE standard 519-2014. All the simulations are performed by using MATLAB/Simulink where it has been proved that the THD of source current has been greatly reduced after adding DSTATCOM compensation to it.

1. Introduction

Power quality problems result from the growing use of non-linear loads like power electronics devices. [1][2]. It non-linearity traits cause abnormalities in voltage waveform which the produce harmonics. [3]. Overvoltage, undervoltage, voltage sags, voltage swells (surges), harmonics distortion, noise, and voltage flicker Voltage sags, and voltage swells are the most prevalent types of power quality problems. [4]–[7]. Others than the non-linear loads, photovoltaic penetration level of GCPV[8] also effect the waveform of the source current and produce harmonic.

Integrating PV systems into the grid raises also concerns about maintaining power quality. Managing load harmonics and reactive power in the distribution system is a significant challenge [9]. Load harmonics involve non-standard currents or voltages, often caused by various electrical loads.

* *Corresponding author.*
E-mail address: norhanisah@unimap.edu.my

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They can lead to problems like increased power losses, equipment overheating, and interference with other devices. It is crucial to mitigate these harmonics to uphold overall grid power quality.

Reactive power is another critical consideration. It depicts power that flits back and forth between the source and the load without accomplishing any useful work. High reactive power levels can affect grid capacity and efficiency, which can affect voltage stability. Properly balancing and regulating reactive power is essential for a stable and reliable distribution system [10] .

Grid-connected PV systems (GCPV) can benefit from custom power devices (CPDs) like distribution static compensators (DSTATCOM), which function as filters to reduce harmonic voltage and help with all the power quality issues listed[11]–[13]. The DSTATCOM will inject a current of desired amplitude, frequency, and phase into the grid [14]. As DSTATCOM performance relied on its controller, Fast Fourier Transform (FFT) is chosen as DSTATCOM controller for this research.

2. Methodology

2.1 DSTATCOM System Configuration

In order to design DSTATCOM, there are a few values need to be calculated, which is DC bus voltage, DC bus capacitor and AC inductors [15].

- DC Bus Voltage

Effective PWM control of the DSTATCOM VSC will depend on how the PCC voltage affects the dc bus voltage (Vdc). The value needs to exceed the amplitude of the AC mains voltage. A single-phase VSC's DC bus voltage is defined as

$$V_{dc} = \frac{2\sqrt{2}\ V_{LL}}{\sqrt{3}(m)} \tag{1}$$

where V is the DSTATCOM AC line output voltage, which is 230V, and m is the modulation index, which is regarded as 1. Eq. (1). yields a value of 339V for Vdc, which is selected as 360V..

- *DC bus capacitor*

DSTATCOM's immediate energy availability and the DC bus voltage's second harmonic or ripple voltage determine the value of the DC bus capacitor. The definition of the DC bus capacitor for a single-phase VSC is given by Eq. (2).

$$C_{dc} = \frac{I_o}{2\omega \Delta V dc_{rip}} \tag{2}$$

Where I_o is the capacitor current, ω is the angular frequency and V_{dcrip} is the ripple in capacitor voltage. Considering I_o is 138.88A, ω is 100π and V_{dcrip} is 18V, using Eq. (2), the value obtained for C_{dc} is 12279µF. Hence, the chosen capacitor value is 13000 µF.

- AC Inductors

The AC inductance is determined by the ripple current, I_{crpp} and switching frequency, f_s. AC inductor will be used to reduce the current ripple that was produced. Eq. (3). defines L_f in terms of the value of an AC inductor.

$$L_f = \frac{mV_{dc}}{4 \times a \times f_s \times I_{crpp}} \quad (3)$$

Where m is the modulation index and is considered as 1, switching frequency, f_s is 1.8kHz, DC bus voltage, V_{dc} is 700V, over load factor, a is equal to 1.2 and I_{crpp} is 20.83A. Using Eq. (3), the value obtained for AC inductor, L_f is 4mH.

2.2 Design of GCPV

To construct a solar PV panel, we must use Equations (4) and (5) to determine the panel's series and parallel arrays. Table 1 lists the parameters of the PV module's values. After the computations are completed, a PV array consisting of 13 series and 2 parallel panels with a combined rated power of 10784.83W is used.

$$N_{s\_oc\_max} = round\ down \left[\frac{V_{max\_inv\_abs} \times k_3}{V_{oc\_max}}\right] \quad (4)$$

$$N_{p\_max} = round\ down \left[\frac{I_{\mathrm{dc\_max\_inv}} \times k_7}{I_{\mathrm{sc\_string\_stc}}}\right] \quad (5)$$

Table 1
The value of the parameter of PV module type Q.Peak Duo-G5 315-335

Parameter	Value
I_{MPP}	5.69A
V_{MPP}	72.9V
V_{OC}	85.3V
I_{SC}	6.09A
Max.Power	414.801W

2.3 Fast Fourier transform (FFT)

The Fast Fourier Transform (FFT) is a computational algorithm developed to compute the Discrete Fourier Transform (DFT), which is a critical tool for evaluating frequency-domain signals [15]. The FFT translates signals from their time (or space) domain representation to the frequency domain via Fourier analysis, and vice versa. This efficiency is obtained by converting the DFT matrix into a product of sparse elements containing many zeros.

This method provides considerable computational benefits, especially in applications such as DSTATCOM control, allowing for more simplified processing when compared to traditional DFT. As a result, the FFT is now widely used in many domains, including engineering, science, and mathematics [16]. The FFT algorithm is used in the context of DSTATCOM control to assess waveforms and make required modifications.

The control system can effectively isolate frequency components from measured signals and generate appropriate compensation signals by utilizing the FFT method. This simplifies the control method by removing the requirement for complex calculations other than waveform adjustments [17].Figure 1 depicts the basic circuit diagram of the DSTATCOM system with the FFT control algorithm [18].

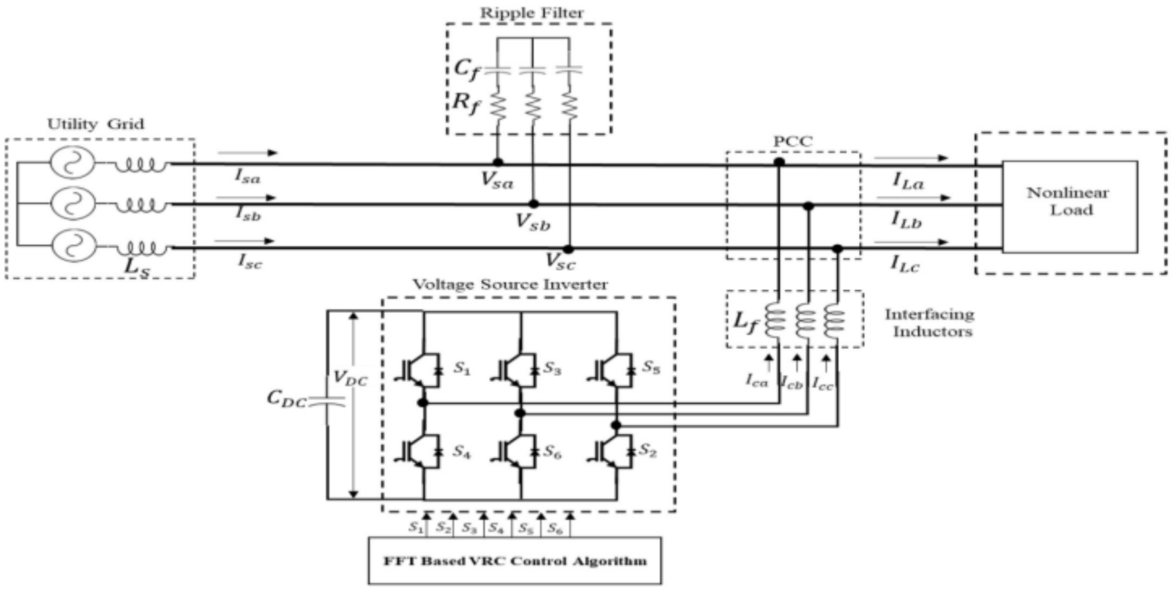


Fig .1. Basic circuit diagram of a DSTATCOM system with Fast Fourier transform theory (FFT) control algorithm

2.4 Conjugate Gradient Back-Propagation Neural Network

Conjugate gradient outperforms the other two back-propagation optimisation techniques, Levenberg-Marquardt and robust back-propagation, because it has a faster training time and needs less memory [19]. When generalization no longer improves, as indicated by an increase in the validation samples' mean square error, training will automatically end. With this approach, the training process is stopped when additional iterations are no longer beneficial to enhancing the model's capacity for generalization and accurate prediction-making. [20].

Mean squared error is the average squared difference between outputs and objectives. There is no error if the value is 0. If the network does not perform effectively after training, the number of neurons can be increased. Gradient conjugation Back-propagation can reduce system training time and is capable of dealing with complex nonlinear situations [19]. It can have as many inputs as you like, but it only has one output.

2.5 Circuit Design

Circuit was designed in 3 topologies, which are three single-phase system without DSTATCOM, three single-phase with GCPV-based DSTATCOM and three single-phase with GCPV-based DSTATCOM system and CGBP.

2.4.1 Three single-phase system without DSTATCOM compensation

The fundamental block diagram of the three-phase system with a non-linear load and no DSTATCOM compensation is displayed in Figure 2. The rectifier with RL load constitutes the non-linear load.

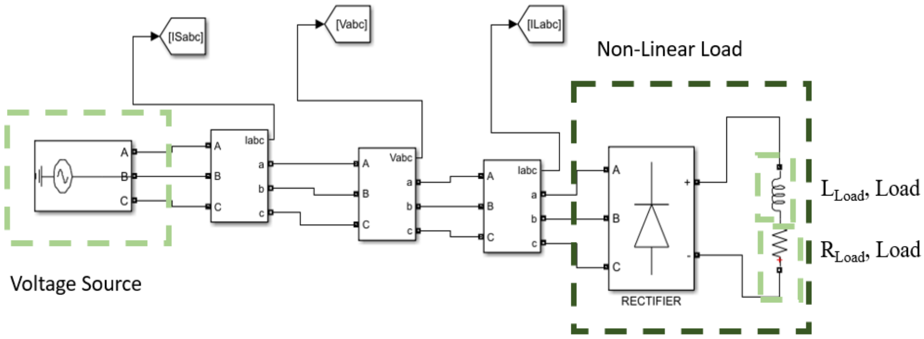


Fig.2. Basic block diagram of the single-phase system under non-linear load without DSTATCOM compensation

2.4.2 Three single-phase system with GCPV-based DSTATCOM system

Figure 3 displays the basic block diagram of the three single-phase GCPV-based DSTATCOM system under non-linear load. To compensate for the harmonic current, DSTATCOM is added at the PCC. The inverter diagram is shown in Figure 4. A DSTATCOM's inverter is often made up of power electrical devices such as insulated gate bipolar transistors (IGBTs). It creates compensating currents or voltages to help the distribution system mitigate power quality concerns and offer reactive power support. The FFT controller is depicted in Figure 5. The FFT algorithm will analyses the current signal and assist PWM in generating appropriate compensation signals based on the findings of the study.

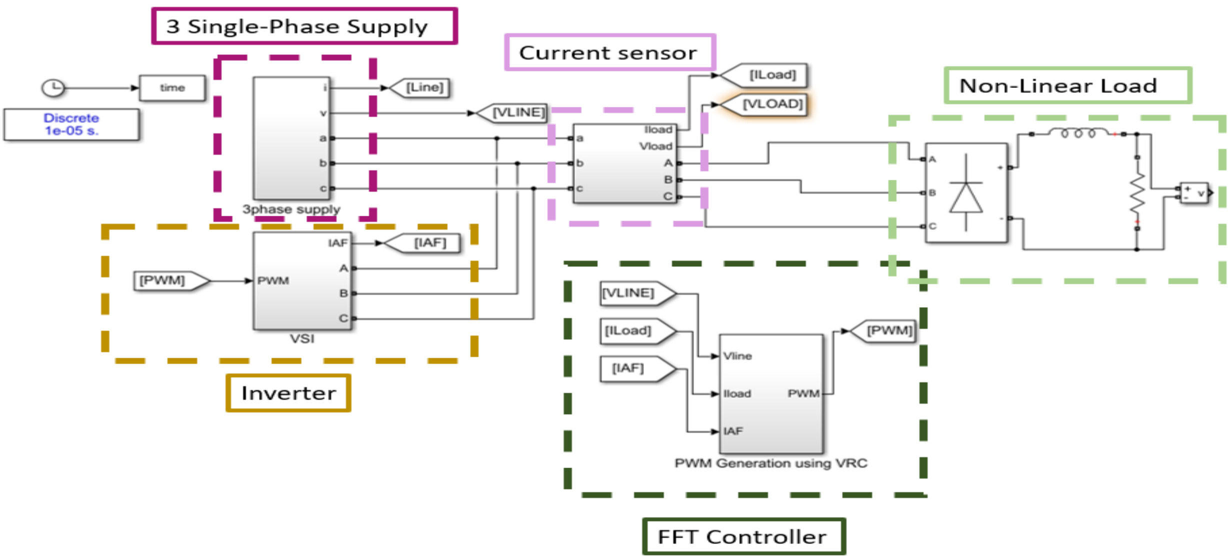


Fig.3. Block diagram of the three single-phase GCPV-based DSTATCOM system under non- linear load

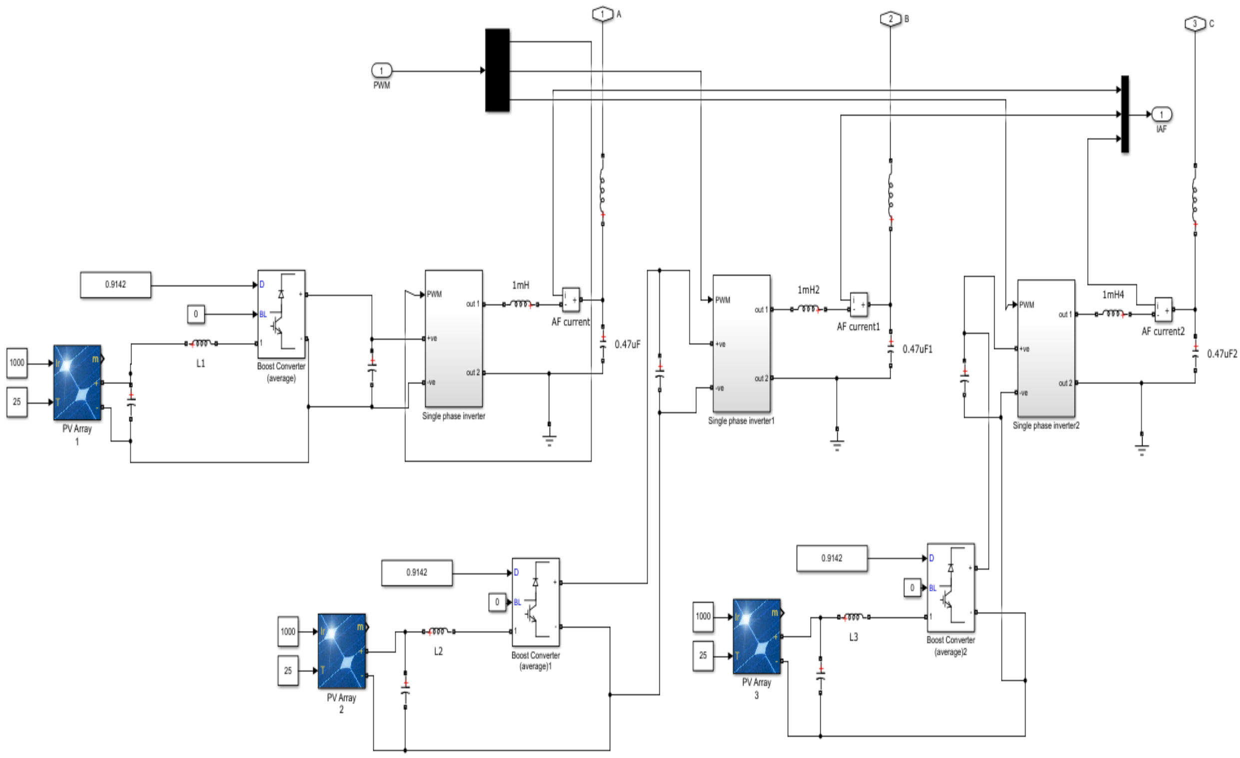


Fig.4. Basic Block Diagram of The Inverter

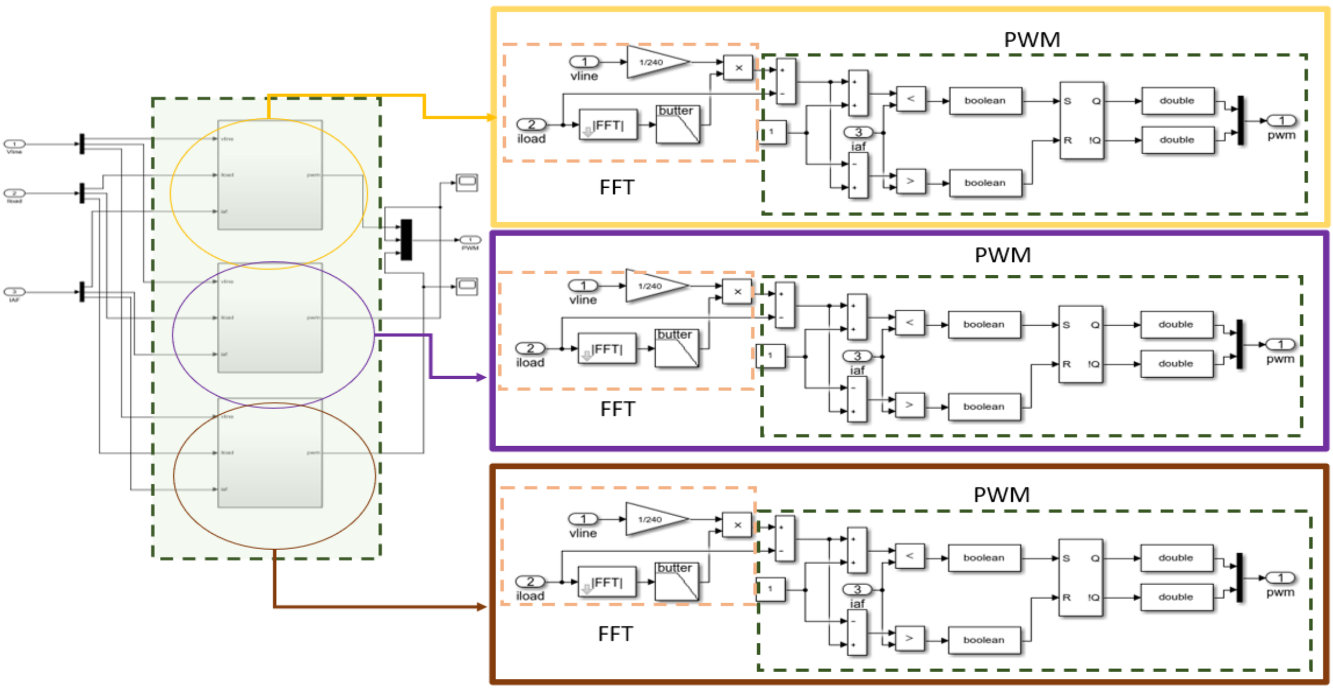


Fig.5. Basic Block Diagram of The FFT Controller

2.4.3 Three single-phase system with GCPV-based DSTATCOM system and CGBP

Figure 3 depicts the fundamental block design of the three single-phase GCPV-based DSTATCOM and CGBP system. The only difference is in the FFT block diagram. The neural network is only added at the FFT controller block diagram, which drastically reduces the time required to assess and generate the reference current. Figure 6 depicts the FFT controller block diagram following the addition of CGBP.

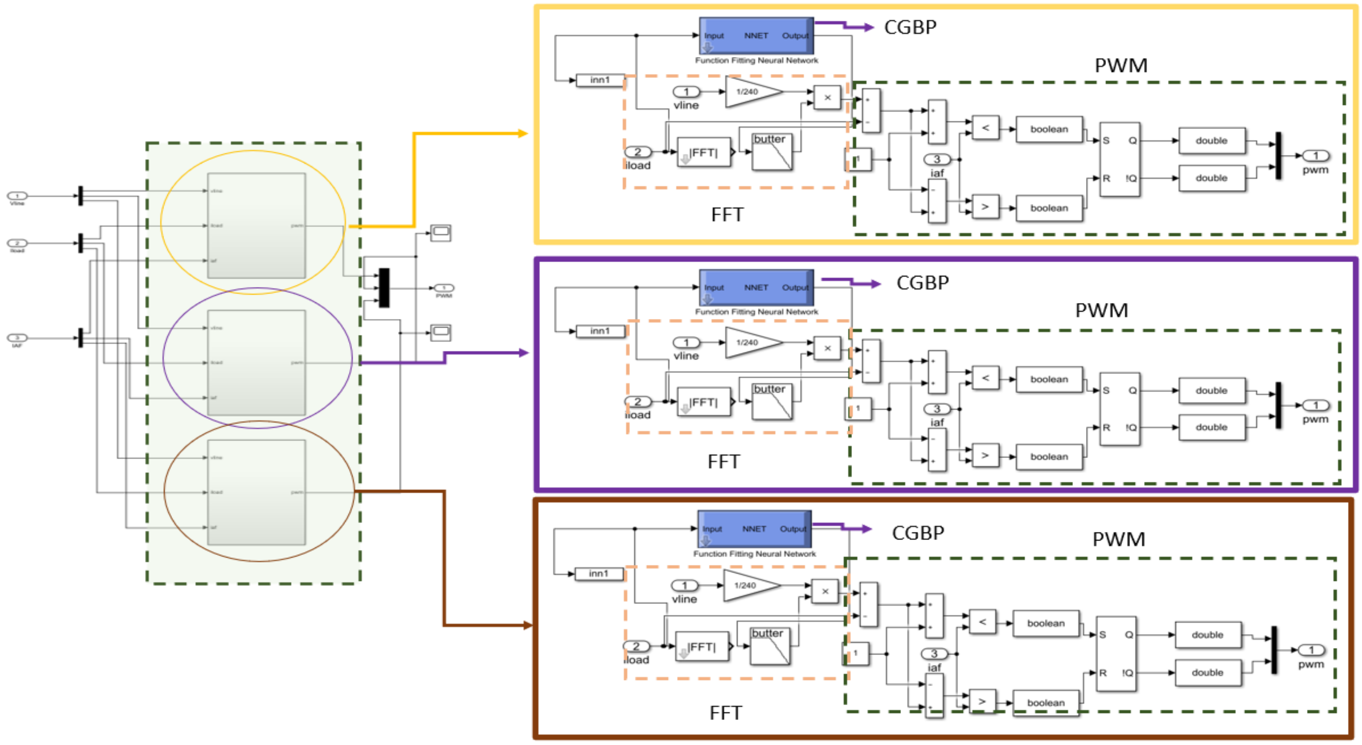
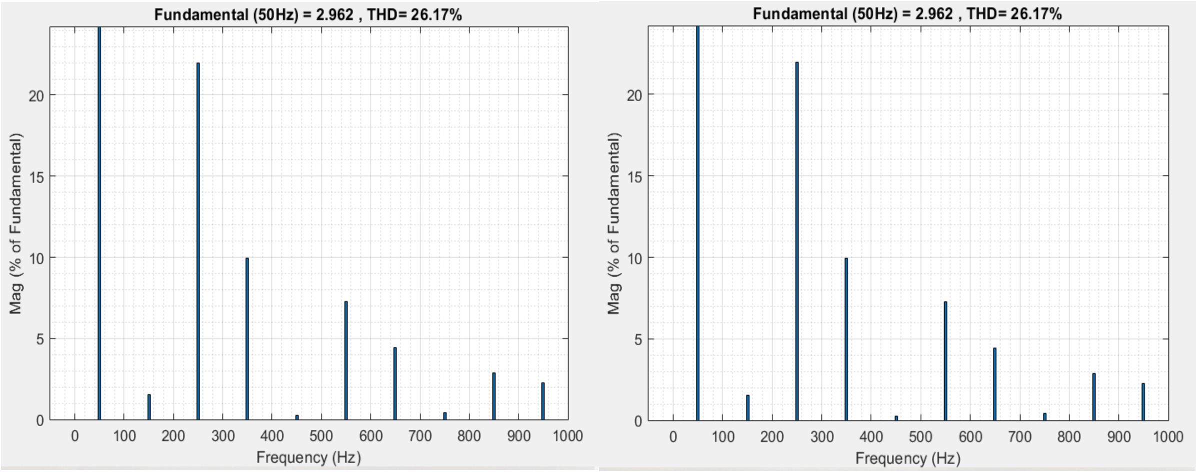


Fig.6. Basic Block Diagram of The FFT Controller with CGBP

3. Results

3.1 Performance of Three Single-Phase System without DSTATCOM Compensation

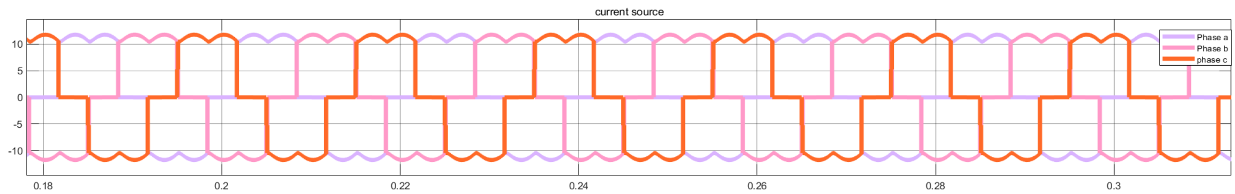
Based on its load voltage, load current, and source current, the single-phase system's performance under non-linear load in the absence of DSTATCOM is assessed. To determine the effect of non-linear load on it, their waveform and THD value will be examined. The total harmonic distortion of the source current, load current, and voltage source is displayed in Figure 7, accordingly. Pulsed current is drawn by electrical devices during the AC to DC conversion. Many harmonics are produced in the distorted current waveforms by these pulses. The total harmonic distortion also surpasses IEEE STD 519-2014's suggested current harmonic distortion value of 8%.



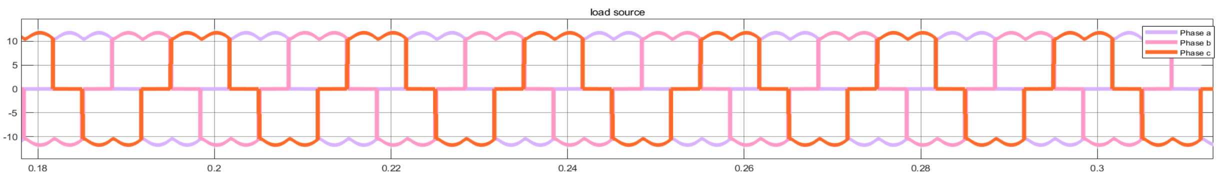
(a) (b)

Fig.7. (a)Total Harmonic Distortion of Load Current under Non-Linear Load without DSTATCOM Compensation (b) Total Harmonic Distortion of Source Current under Non-Linear Load without DSTATCOM Compensation

The non-linear load's distorted load current waveform is displayed in Figure 8. The source current will be impacted by the load current's distorted waveform. This waveform is warped because of the circuit's high total harmonic load from the user's load.



(a)

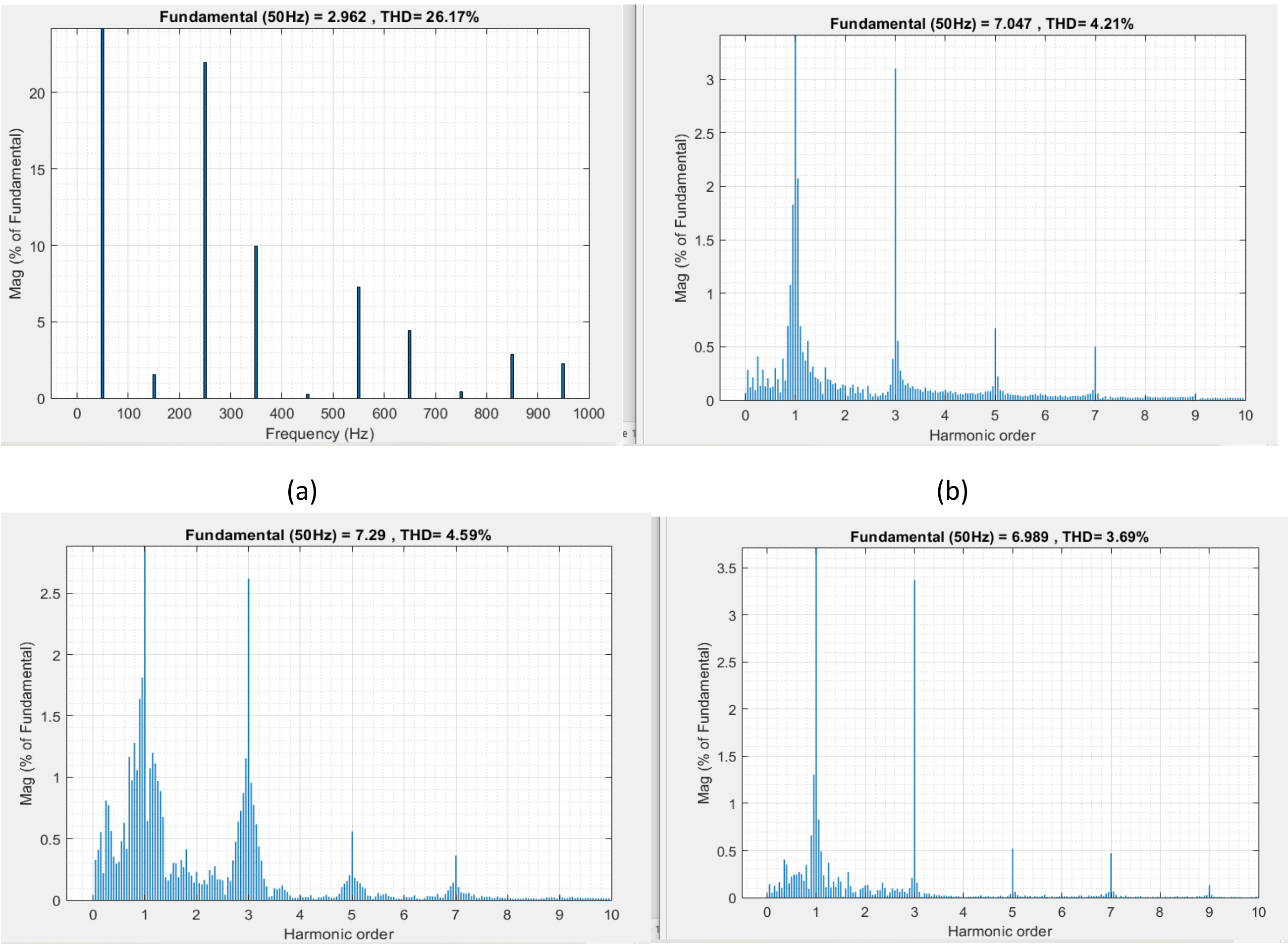


(b)

Fig.8. (a) Waveform of Load Current under Non-Linear Load without DSTATCOM Compensation (b) Waveform of Source Current under Non-Linear Load without DSTATCOM Compensation

3.2. Performance of Three single-phase system with GCPV-based DSTATCOM system

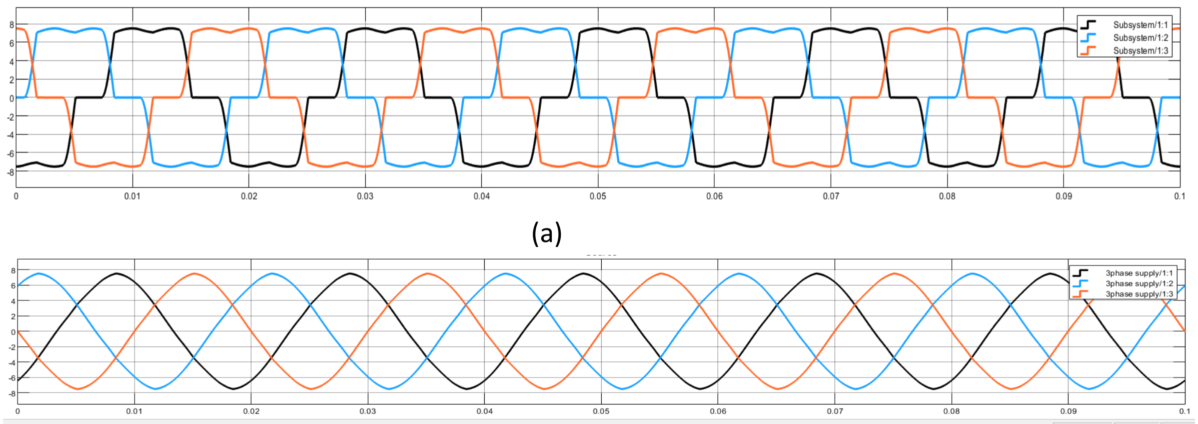
Since harmonic distortion is related to current, DSTATCOM is employed to alleviate it. THD for source current significantly decreased after adding DSTATCOM to the system, as all three-phase current achieved THD below 8%. This is because the DSTATCOM injected at the PCC aids in the generation or absorption of current harmonics produced by nonlinear loads. The load current and source current's THD value is shown in Figure 9, and their waveform is shown in Figure 1.



(a) (b)

(c) (d)

Fig.9. (a)THD of source Current, Isa under Non-Linear Load with DSTATCOM Compensation (c) THD of Source Current, Isb under Non-Linear Load with DSTATCOM Compensation (d) THD of Source Current, Isc under Non-Linear Load with DSTATCOM Compensation



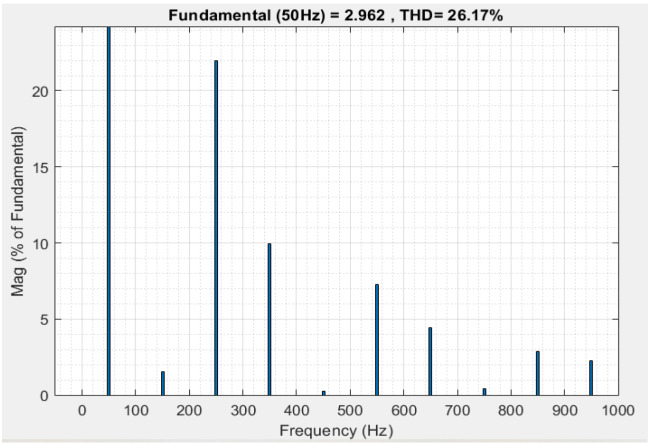
(a)

(b)

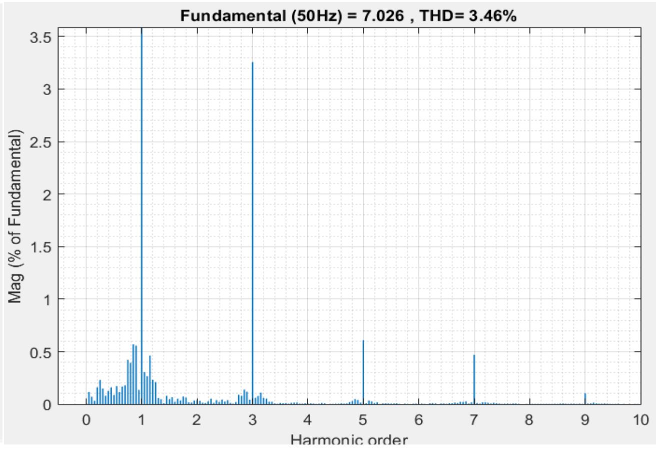
Fig.10. (a) Waveform of Load Current under Non-Linear Load with DSTATCOM Compensation (b) Waveform of Source Current, Isa, Isb and Isc under Non-Linear Load with DSTATCOM Compensation

3.2. Performance of Three single-phase system with GCPV-based DSTATCOM system

To help reduce the time required by FFT to assess and create reference current, CGBP is introduced to the three single-phase with GCPV-based DSTATCOM system. The THD for source current using GCPV-based DSTATCOM has been lowered again after adding CGBP for phase A and phase C current, while for phase B, the THD is somewhat higher than before adding CGBP, but it is still acceptable because it is less than 8%.



(a)



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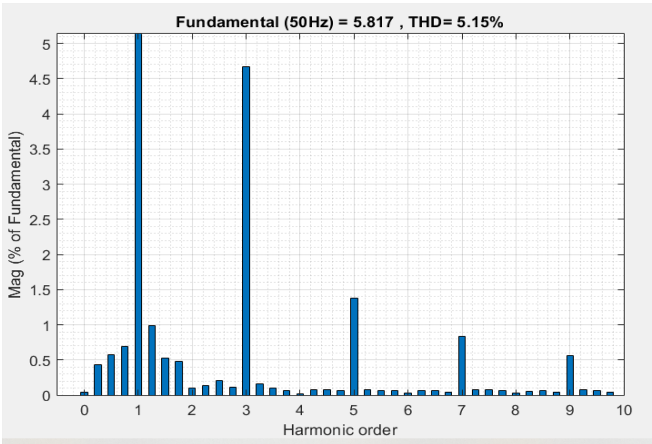

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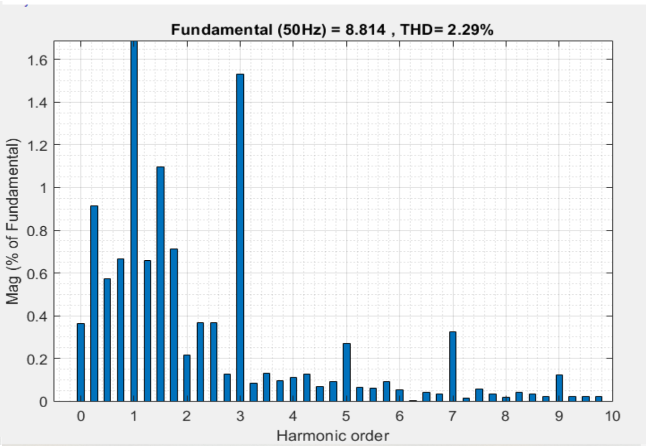
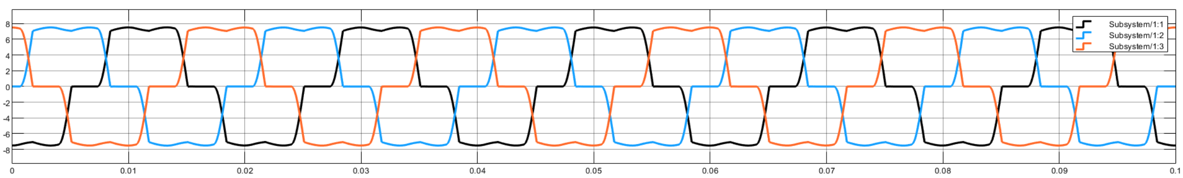
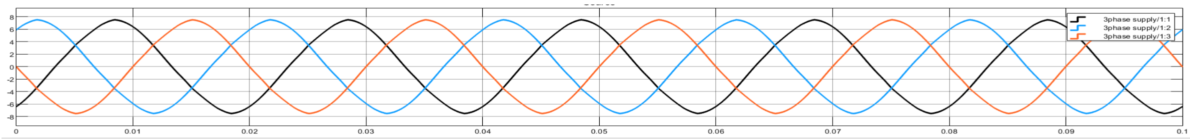


(d)

Fig.11. (a)Total Harmonic Distortion of Load Current under Non-Linear Load with DSTATCOM Compensation and CGBP (b) Total Harmonic Distortion of Source Current, Isa under Non-Linear Load with DSTATCOM Compensation and CGBP (c) Total Harmonic Distortion of Source Current, Isb under Non-Linear Load with DSTATCOM Compensation and CGBP (d) Total Harmonic Distortion of Source Current, Isc under Non-Linear Load with DSTATCOM Compensation and CGBP



(a)



(b)

Fig.12. (a) Waveform of Load Current under Non-Linear Load with DSTATCOM Compensation and CGBP (b) Waveform of Source Current, Isa, Isb and Isc under Non-Linear Load with DSTATCOM Compensation and CGBP

4. Conclusions

As a conclusion, power quality issues are a serious problem that cannot be ignored as it brings harm to both utility and user if it is ignored. Power quality problems must be traced back to their source in order to be appropriately addressed. For example, DSTATCOM is used to mitigate power quality issues because they are related to current, and DSTATCOM is a great device that mitigates all current-related problems. Proper control algorithm of DSTATCOM also need to choose wisely, as performance of DSTATCOM is depend on its control algorithm. THD of source current is greatly improve after adding DSTATCOM as it able to mitigate the harmonic that occurs. THD for phase current A and C was reduce again after adding CGBP while for phase B, it become slightly higher but is still acceptable. This may due to various reason such as imbalance load or specific harmonics sources.

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