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Photovoltaic System Connected to Three Phase Grid Connected System Incorporating With Active Power Filter

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Abstract: In this paper, a photovoltaic (PV) system at maximum power point tracking is connected to a three phase grid incorporating with shunt active power filter is presented. The connection of the photovoltaic system on the grid takes place in one stage using voltage source inverter (VSI). Meanwhile, the shunt active filter is used to improve power quality of the photovoltaic generation based on d-q theory. The simulations has been carry-out and demonstrate using MATLAB/Simulink (MLS) environment shows that the proposed system offers improvement on power quality and power factor correction.

Key words: photovoltaic, shunt active filter, grid connected system.

INTRODUCTION

With the proliferation of power electronics in energy conversions, power quality is fast becoming an issue of an increasingly important aspect of electrical consumers at all levels of usage. Sensitive equipment and non-linear loads are now a commonplace in both industrial/commercial sector and domestic environment. These nonlinear loads absorb non-sinusoidal current and generally consume reactive power. Harmonics current produce by a nonlinear loads are injected back into power distribution system through the point of common coupling (PCC) (Hasim, A.S.A. and M.K. Hamzah, 2007).

Harmonics voltages appear when the harmonics current passed through the line impedance, causing distortion at PCC. In most cases the direct effect of harmonics includes; communication interference, heating, solid-state devices malfunction, resonance and others (Subjak, J.S. Jr. and J.S. McQuilkin, 1990; Czarnecki, L.S., 1993). In additional, with the push of world economy modernization, the cost price of the traditional energy keeps rising. Therefore, the need to generate pollution-free energy has triggered considerable effort toward renewable energy system. Renewable energy source such as solar photovoltaic (PV), wind, hydroelectricity and biomass offers clean abundant energy. Among the renewable energy, PV have been extensively studies because it closely related with power electronics.

There have been many research efforts to improve the efficiency of the PV system. It aimed at the supplying grid with active and reactive power to reduce the harmonics in the system (Hyo-Ryong, S., 2011; Albuquerque, F.L., 2011; Dasgupta, S., 2011; Indu Rani, B., 2011; Kelesidis, K., 2011; Belaidi, R., 2011). The PV system supply real power from the PV arrays to load and support reactive and harmonics power simultaneously. This technique has good feature such as; easy to expand and applicable to almost everywhere (Belaidi, R., 2011).

This paper present an analysis and simulation of a PV system connected to grid incorporating with active power filter (APF) feeding the nonlinear load (Islam, F.R. and H.R. Pota, 2012). Two inverters namely; PV inverter and APF inverter are used in the system. The PV inverter used to convert dc power to ac power whilst the APF inverter used as the harmonics compensation hence reduce low-frequency ripple problem in the system (Rong-Jong, W. and L. Chun-Yu, 2011). The control algorithm for harmonics detection is based on synchronous rotating frame (SRF) to adjustment of the active and reactive power. The control of active and reactive power is based on the current control in d-q rotating reference system.

Description of the Proposed System:

The overall proposed system is shown in Fig 1. The mathematical model reflecting the electrical quantities in the output of the PV cell and panel is provided (Skocil, P.M.D.T., 2008; Tsengenes, G. and G. Adamidis, 2010. These models are used to calculate the maximum power point tracker (MPPT).

A. *Mathematical Modelling of PVcell and Panel:*

The equivalent circuit of the PV cell are shown in Fig. 2 which includes power supply and a diode.

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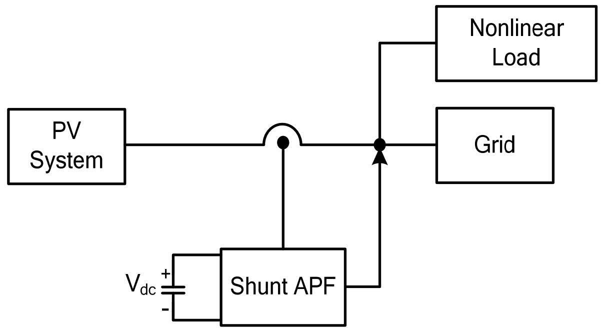


Fig. 1: Overall proposed system.

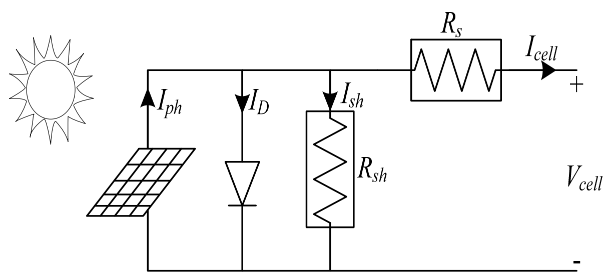


Fig. 2: Equivalent circuit of a PV cell.

The photo current, *Iph* depends on the solar radiation, *G* and the temperature, *T* of the environment. This situation explains in Eq. (1) (Tsengenes, G. and G. Adamidis, 2010). $I_{ph}(T_{ref})$ is the photo current at the nominal temperature T_{ref}. On the other hands, Eq. (2) gives the formula of the photo current at the nominal temperature. K_0 is a constant given in Eq. (3). G_{ref} and I_{sc} are the nominal radiation given by the constructor and short circuit current respectively. These equations are referring to Fig.2 for single PV cell.

$$I_{ph} = I_{ph}(T_{ref})\ x\ \left(1 + K_0(T - T_{ref})\right) \quad (1)$$

$$I_{ph}(T_{ref}) = \frac{G}{G_{ref}}\ x\ I_{sc}(T_{ref}) \quad (2)$$

$$K_0 = \frac{I_{sc}(T) - I_{sc}T_{ref}}{T - T_{ref}} \quad (3)$$

Taking the consideration that the environment temperature is set at nominal one, therefore the PV current only depends on solar radiation which represented in Eq. (4).

$$I_{ph} = I_{ph}(T_{ref}) = \frac{G}{G_{ref}} I_{sc}(T_{ref}) \quad (4)$$

Diode current I_D characteristic is given in Eq. (5) where the I_O is the diode saturation current, while V_T represents the thermal voltage.

$$I_D = I_o\left(e^{V_D/V_T} - 1\right) \quad (5)$$

where; $V_D = V_{cell}\ (I_{cell}\ x\ R$

Therefore, by using Ohm's law, the shunt current I_{sh} can be defined as;

$$I_{sh} = \frac{V_D}{R_{sh}} \tag{6}$$

Taking to account Eq. (1) and (5) and applying Kirchhoff's current law, I-V characteristic for PV are shown in Eq. (7)

$$I_{cell} = I_{ph} - I_D - I_{sh}$$
$$= I_{ph} - I_o\left(e^{V_D/V_T} - 1\right) - \left(\frac{V_D}{R_{sh}}\right) \tag{7}$$

B. ***Maximum Power Point Tracker (MPPT):***

The maximum power point tracker (MPPT) produces maximum power under variable condition of solar radiation and environmental temperature. One of the most used methods of MPPT are the perturb and observe (P&O). The main advantage of this technique is that the search of the MPPT is done independently on the environment condition, however it required current and voltage sensor. On the other hands, constant voltage methods is used to keeping the voltage in the PV terminal constant and closed to the MPPT line (Schonardie, M.F. and D.C. Martins, 2008). Therefore in this work, the PV terminal voltage is set constant and at maximum value.

Shunt Active Power Filter Model and Controller:

The shunt active power filter (APF) were constructed with four essential elements in the namely; (i) signal conditioning, (ii) reference current generation, (iii) signal generation and (iv) three-phase inverter. The signal conditioning circuit used to provide accurate system information from the voltage and current from the grid. The reference current generator is used to generate the required harmonics current to be amplified and injected into the lines, at the point of common coupling (pcc). The switching generation for the inverter is generated at the controller circuit by comparing the reference current (i_a*, i_b*, i_c*) with the injected currents (i_a, i_b, i_c). Figure 3 shows the block diagram of shunt APF.

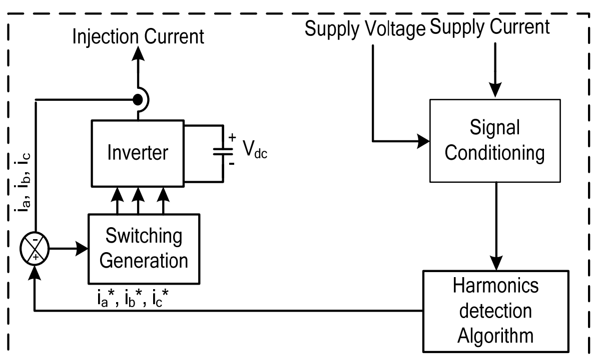


Fig. 3: Block Diagram of Shunt APF.

C. ***Controller Design:***

The synchronous rotating frame or d-q theory is used as the main controller design without considering neutral wire. This method transforms three-phase into *d-q* coordinates (rotating reference frame with fundamental frequency) using Park transformations. This theory is extensively used in active filter because of the simplicity of the control design (Asiminoaei, L., 2007). The equations to transform *a-b-c* coordinate into *α-β-0* coordinate is presented in Eq. (8).

$$\begin{bmatrix} i_o \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{8}$$

By employing Park transformation, the *α-β-0* coordinate is transform into d-q coordinate as shown in Eq. (9)

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (9)$$

where; $\theta = tan^{-1}\left(\frac{v}{v}\right.$

The angular speed in *d-q* frame is same with fundamental frequency which makes the DC fundamental current component $\left(i_{\bar{d}}, i\right.$ and harmonics AC component $\left(i_{\tilde{p}}, i\right.$ arise due to harmonics at the load [15]. By using low-pass filter (LPF) the DC component can be obtained. Subtracting the DC component with the previous component can determine the harmonics component for the system. Fig.4 shows the techniques to determine the harmonics component in the system.

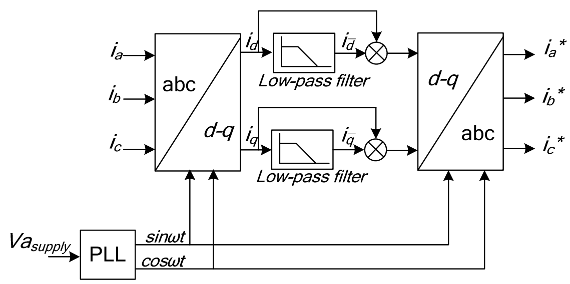


Fig. 4: The detecting principle of harmonics current using d-q theory.

Modelling of the Proposed System:

To carry out the analysis of the proposed system, a simulation platform has been design. Fig. 5 shows the simulation scheme of the PV system connected to the three-phase grid system incorporating with the shunt APF with non-linear load. The non-linear load was constructed using full bridge rectifier connected in parallel with a resistor and a capacitor as the load. AC link inductors use at the APF used to attenuate the switching ripple hence prevent high harmonics switching frequency. The phase- lock-loop use to synchronize the harmonics phases with the grid phases.

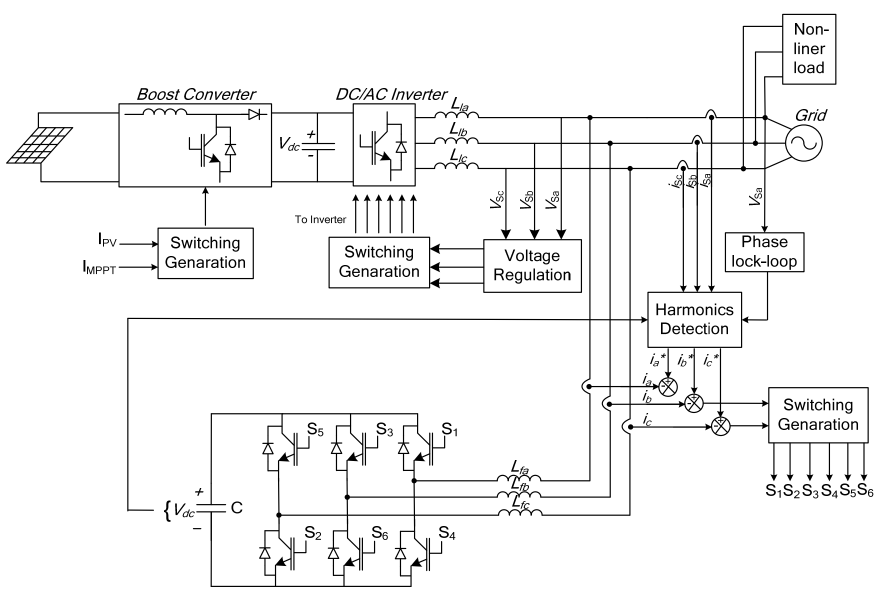


Fig. 5: System Configuration.

Simulation Results:

This section presents the general simulation block diagram of the PV system connected to grid incorporating with active power filter (APF) feeding the nonlinear load in MLS environment. Fig. 6 shows the six module PV arrays that used in this system, while the overall simulation block diagram shown in Fig. 7. The simulation parameters of the PV module and the overall parameters using in this simulation are tabulated in Table I and Table II respectively.

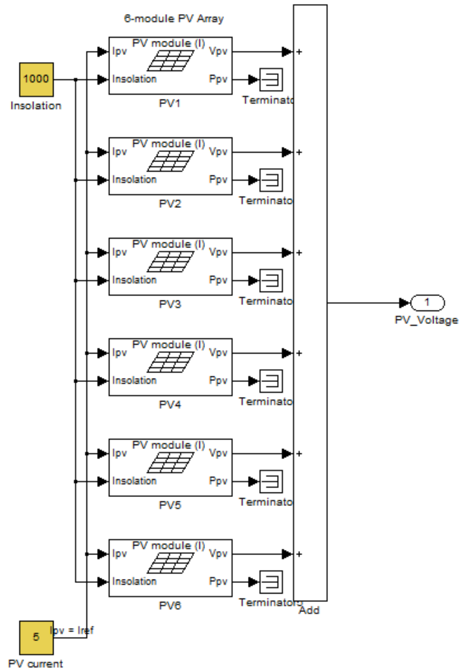


Fig. 6: Six module of PV array.

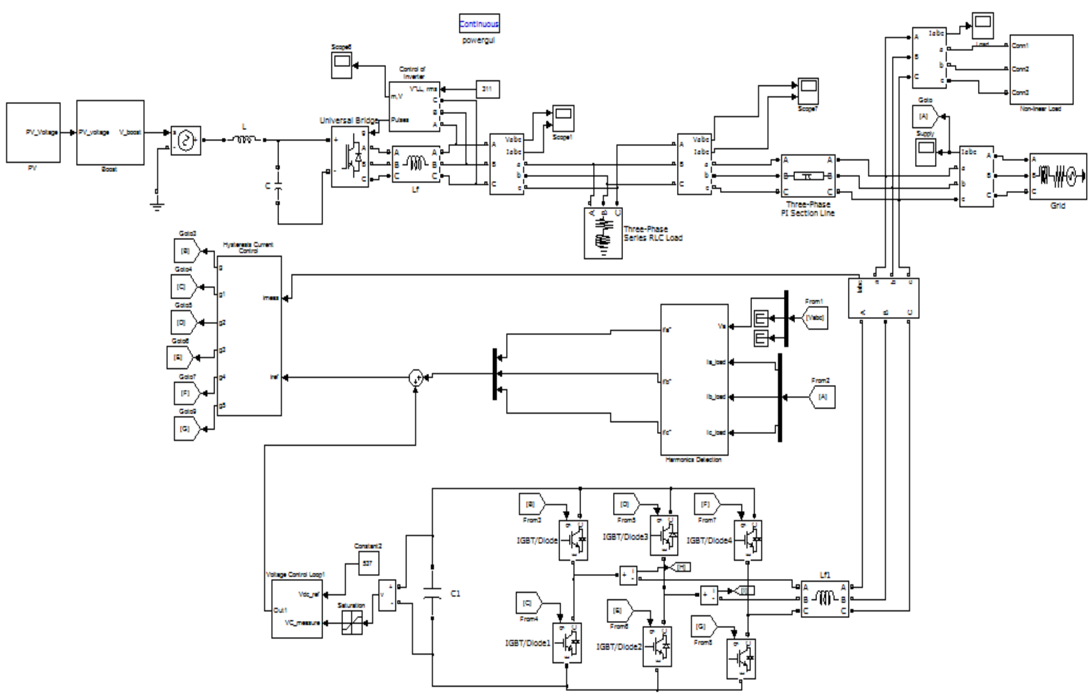


Fig. 7: Simulation diagram of the PV grid connected incorporating with shunt APF.

Table I: Parameters of PV model without at static condition.

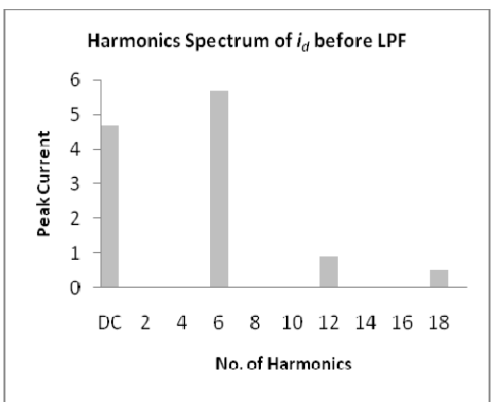
Parameters	Value
Short circuit current	*5.45A*
Open circuit voltage	*22.2V*
Current at Pmax	*4.95A*
Voltage at Pmax	*17.2V*

Table II: Simulation parameters for the overall system.

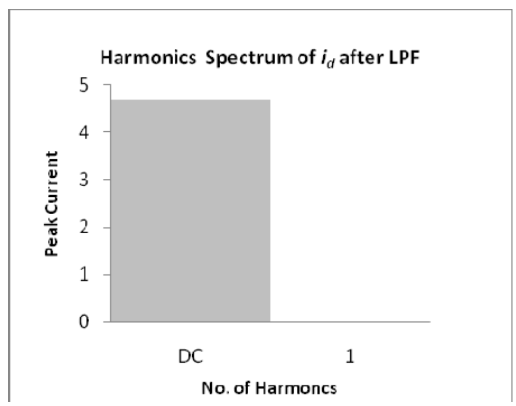
Parameters	Value
Voltage Source	*311 Vrms*
DC link Voltage (V_{dc})	*537V*
DC link capacitor	*C1=2000µF*
Non-linear Load	*R = 100Ω, C = 2000µF*
DC Filter	*L=1mH, C= 2300 µF*
Filter Inductor (L_F)	*5mH*
Low-pass filter	*20Hz*

In the simulation studies, each six PV model have the same parameters values stated in Table I. The pulse width modulation (PWM) was generated using hysteresis current control which is set 10% of the maximum current injected. Fig. 8 shows the harmonics spectrum of i_d before and after low-pass filter. Both result is subtract with each other to eliminate the DC component in the system hence the resultant is used to determine the harmonics component in the system.

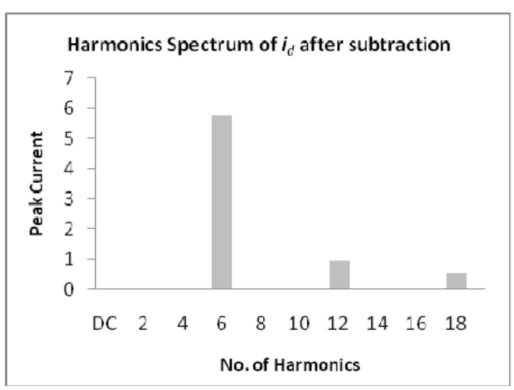
On the other hands, the harmonics spectrum of the load, compensating and supply current are shown in Fig. 9 until 11 respectively. In additional, the waveforms currents are shown in Fig 12. The power factor also improvement when apply shunt APF as shown in Fig. 13 and 14 respectively. Hence, the THD of the system gather from the simulation before and after compensation are 90.27% and 2.58%.



(a)



(b)



(c)

Fig. 8: Harmonics spectrum of i_d. (a) before low-pass filter; (b) after low-pass filter and (c) after subtraction.

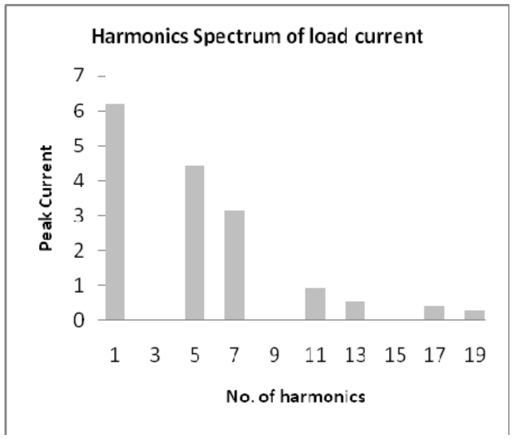


Fig. 9: Harmonics spectrum of load current.

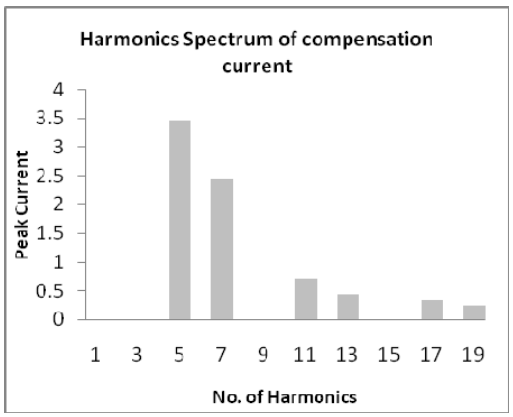


Fig. 10: Harmonics spectrum of the compensating current.

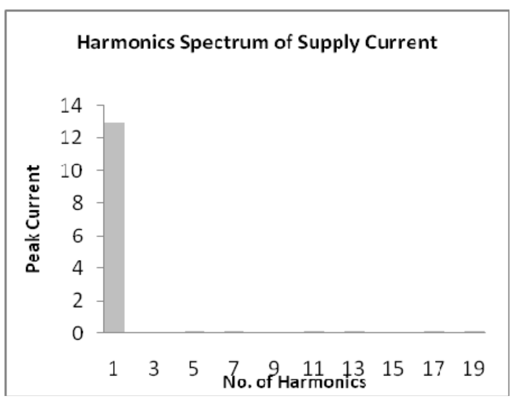


Fig. 11: Harmonics spectrum of supply current.

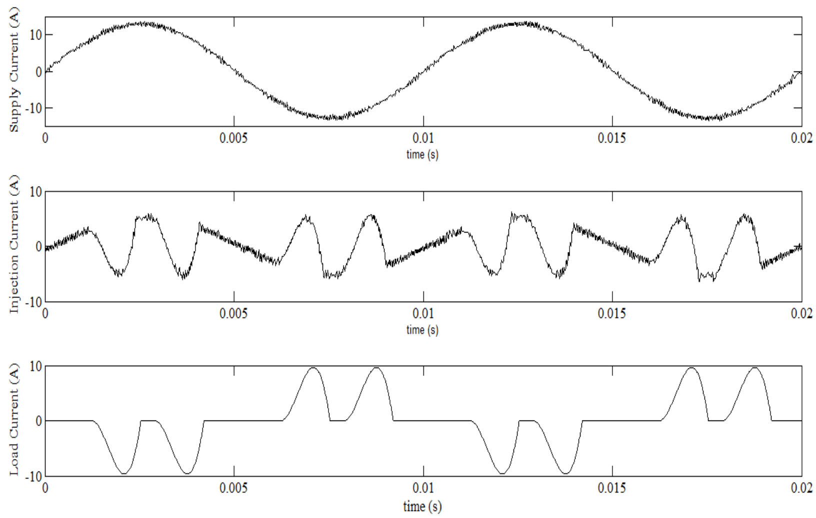


Fig. 12: Supply, injecting and load current after compensation.

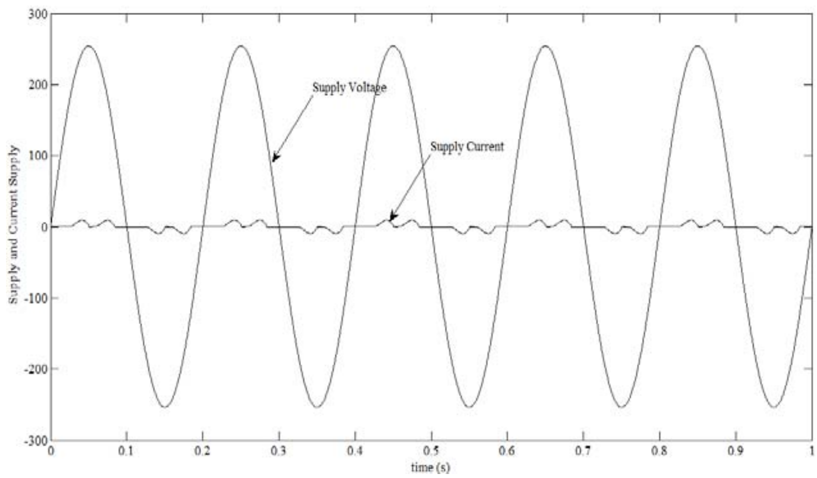


Fig. 13: Voltage and current supply before compensation.

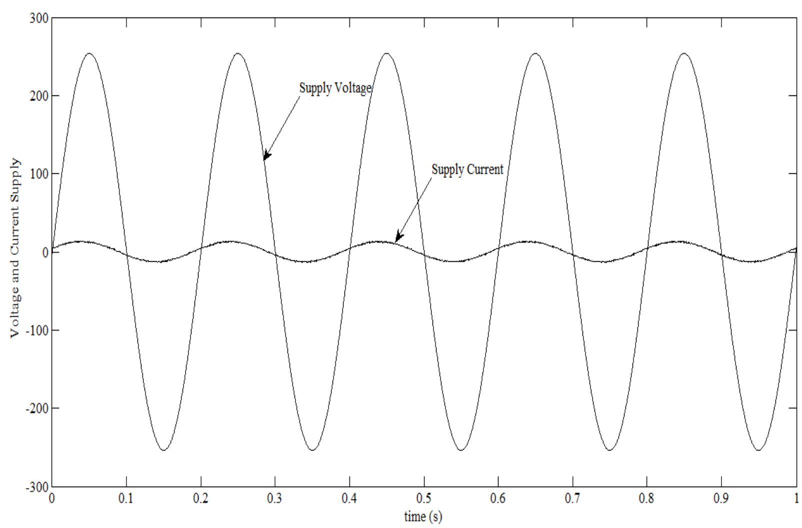


Fig. 14: Voltage and current supply after compensation.

Conclusion:

In this paper a photovoltaic (PV) system connected to a three phase grid incorporating with shunt active power filter is succesfully done. The shunt APF modelling employs d-q transformation as the harmonics control strategy to eliminated the harmonics in the system. PV system is operate at the maximum power point to supply maximum voltage to the grid. The result obtained from the simulation shows that the power quality improved about 88% of THD reduction hence almost unity power factor achived. On a practical level, such a system is extremly useful because it improves the power factor of the power system.

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