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Grid Interconnected Photo Voltaic System Using Shunt Active Filter for Power Quality Improvement

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ABSTRACT

Now-a-days, power generation and utilization became more complicated which further affects the economy of a country. The available non-renewable energy sources that supply the demanded power do not consider environmental challenges like global warming and pollution. This leads to the development of power generation based on Renewable Energy Resources (RES). These RES are connected to the grid through power electronic converters which offer countless power quality issues that must be rectified to deliver a quality power to the end users. The proposed work uses a three phase Voltage Source Inverter (VSI) based Shunt Active Power Filter (SAPF) fed by solar Photo Voltaic (PV) system to eliminate current harmonics at the source side of the grid. The output of the PV system is given to a boost converter along with self–lift single-ended primary-inductor converter (SEPIC) for supplying high voltage gain which is accompanied by a Perturb & Observe Maximum Power Point Tracking (MPPT).The main objective of this paper is to eliminate the current harmonics at the grid side using SAPF. Also, the proposed SAPF is used for exporting the power generated from PV to the grid. The overall system performance is validated with a help of MATLAB/SIMULINK.

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1. INTRODUCTION

Solar energy is a cost effective alternate resource for power generation. Even though it renders some demerits like maintenance, it offers less complicated structure with no moving parts and easy installation. These features contribute for the consideration of solar energy as the worldwide accepted green resources of energy [1,2]. The efficiency of PV materials enhances rapidly and also the power attained from the panel increases with an increase in its surface area. Hence researchers concentrated towards the emerging technologies for the optimal utilization of power obtained from solar panel and also work on the new circuit topologies and control strategies to make it to be effective [3-5]. The advent of renewable energy resources as an alternative source for power production leads to major issue that involves the grid integration using power electronic devices and the related power quality issues [6]. The power electronic converters are non-linear devices that inject harmonics in the grid. There are various non-linear loads feasible like Adjustable Speed Drives (ASD), Uninterruptible Power Supply (UPS), Switched Mode Power Supply (SMPS) etc. connected to the grid [7].These non-linear devices are the main cause for the production of harmonics, sub harmonics and inter harmonics in current and voltage spectrum. To reduce such harmonics the power systems are generally engaged with two types of filters like active and passive filters. The passive filters comprises of only the passive elements like inductor, capacitor, resistor. Passive filters are affordable but it renders some disadvantages like inability to adapt to the network characteristic variations that leads to the usage of active filters [8]. The active filters are further classified into series, shunt and hybrid active filters. Hybrid active filter is the combination of both passive and active filter [9]. Chiefly shunt active filters are employed to address the current harmonic issues, while the series active filters are used for voltage harmonics. Recently Voltage Source Inverter (VSI) or Current Source Inverter (CSI) based active filters are designed to meet the requirement effectively. It provides some benefits like compactness, economical, low power losses, fast dynamic response to the load changes and reduction of resonance. The compensation performance of SAPF mainly depends on the reference current detection algorithm .There are vast control schemes feasible to inject compensating currents into the electrical network. They are instantaneous PQ theory [10], Synchronous Reference Frame theory [11], Synchronous Current Detection method etc. Of which Synchronous Current Detection method is focused here for the compensating current generation due to its simple calculation and effectiveness. The simulation and hardware implementation of three level VSI based SAPF using Synchronous Reference Frame theory was done in [12]. An improved control algorithm for SAPF was proposed in [13].An indirect current control algorithm has been proposed and its performance was experimentally validated in [14]. As the shunt active power filters and the grid interactive inverters were similar some of the previously reported works combined PV fed grid interactive inverter and active filter [15-18]. This eliminates the additional power circuit cost. This method involves the injection of real power from PV to grid and also eliminates the grid current harmonics at the Point of Common Coupling (PCC).Due to the low voltage characteristics of the PV system the proposed work uses a conventional boost converter with self-lift SEPIC converter whose gain is very high[19]. The Perturb & Observe MPPT method is used for tracking the maximum power output of the solar panel [20]. The gating signals for the active filter are generated using hysteresis current controller which is easy to implement.

2. BLOCK DIAGRAM OF PROPOSED SYSTEM

Figure 1 shows the block diagram of the proposed system. It comprises of PV module, high gain self-lift SEPIC boost converter, MPPT controller, three phase voltage source inverter based Shunt Active Power Filter and non-linear load. The PV module voltage and current depends on solar insolation. Compensating currents are extracted using synchronous current detection method to eliminate current harmonics drawn by non-linear load in the source side.

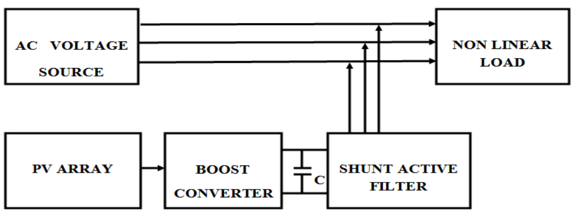

Figure 1. Block diagram of the proposed system

3. SOLAR CELL MODELLING

From the evaluation of the common behavior of solar cell and its mechanism an equivalent electrical circuit model was developed. There are two equivalent circuit models viable and are acknowledged worldwide.One is a simplified model and it renders approximate attributes of solar celland another one encompasses withconsolidation of two diodes one for reflecting diffusion and the other for carrier.The equivalent circuit for one diode model is given in figure 2.

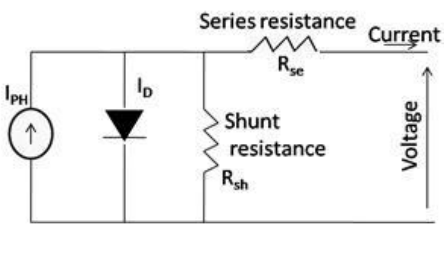

Figure 2. Equivalent circuit of solar model

From that Equivalent circuit, the PV equations are given below.

$$I_{ph} = \left[I_{sc} + K_i\left(T - T_{ref}\right)\right] \times \frac{I_r}{1000} \tag{1}$$

$$I_D = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q \times E_g}{n \times k}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{2}$$

$$I_{rs} = \frac{I_{sc}}{\left[e^{\left(\frac{qV_{oc}}{n_s * k * n * T}\right)} - 1\right]} \tag{3}$$

$$I = I_{ph} - I_D - I_{sh} \tag{4}$$

where, Iph- Photo voltaic current, Isc- Short circuit current, Ki-Temperature coefficient of Isc, T-Temperature, Tref-Reference temperature, Ns- Number of cells in series, Irs- Reverse saturation current, K- Boltzmann constant,Q- Charge of an electron

3.1 Effect Of Solar Irradiation And Teperature On I-V Characteristics Of Solar Panel

The elevated solar insolation on ground level is almost 1000W/m2 .The irradiance level shrinks due to numerous circumstances like rain,humidity,movement of clouds etc. This willreduce the output current of the solar panel because the photo voltaic currentIph is proportional to solar irradiance. Figure 3 shows the I-V characteristics of solar panel for different irradiance.Solar cells are constructed with silicon materials and therefore the effect of temperature on opencircuit voltage is comparatively high while the short circuit current increases with temperature.The reason for such increase in current is due to the nature of the silicon materials which possess negative temperature coefficient (i.e. if the temperature increases then the resistance decreases). Figure 4 shows the I-V characteristics of solar panel for different temperature.

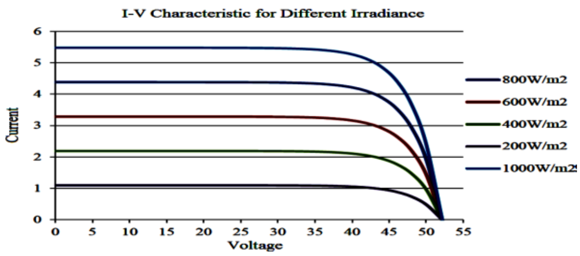

Figure 3 .Effect of solar irradiation

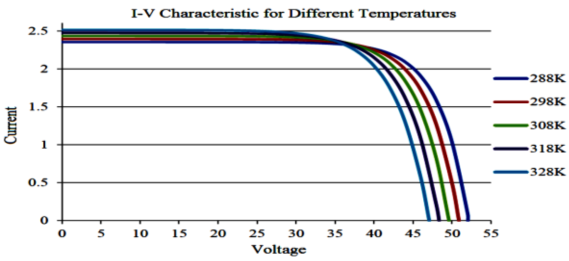

Figure 4. Solar I-V Curve for Different Temperatures

4. HIGH GAIN SELF LIFT SEPIC BOOST CONVERTER

DC-DC converter is an electronic circuit that converts a DC source of a certain voltage level to another voltage level. In modern electronic systems, DC-DC converters are needed to convert the voltage supply from the power source to the voltage level required by the target function block. As the output voltage of the PV arrays is relatively low, boost converters are required to step up the voltage. In the conventional boost converter with high voltage gain the conduction and switching losses are more. In order to avoid that, a self–lift SEPIC boost converter is used here for supplying high voltage gain. Figure 5 shows the circuit diagram of self – lift SEPIC high gain boost converter.

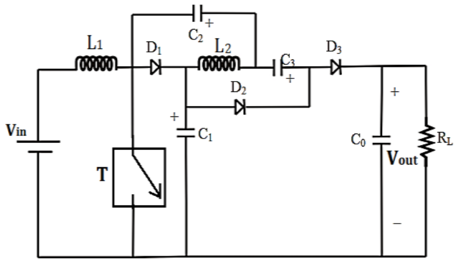

Figure 5. Self-lift SEPIC boost converter

Figure 6 and 7 shows the Continuous Conduction Mode (CCM) operation of the boost converter. When the converter operates in CCM, the current ripples through the input inductor L1 can be assumed negligible.There are 2 stages in this mode.

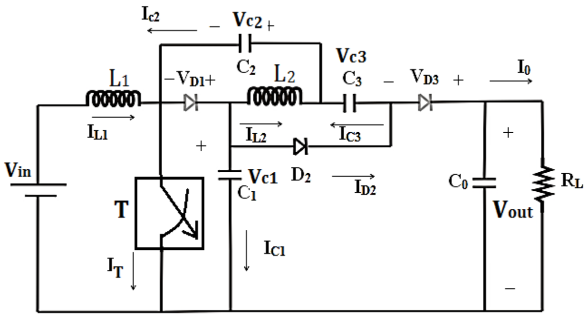

Figure 6. Continuous conduction mode of the converter under switch ON topology

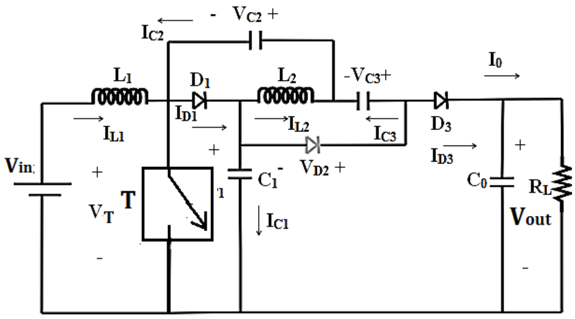

Figure 7. Continuous conductionmode of the converter under switch OFF topology

Stage 1: When the power switch T is turned on, simultaneously diode D2 is turned on. Diodes D1 and D3 are turned off by the negative voltage VC1 and (VC1 - Vo) across them. In this interval, current through the two inductors increase linearly. Capacitor C1 charges capacitor C2 and capacitor C3 is being charged by diode D2 current.

Stage 2: At the end of stage 1, switch T is turned off and simultaneously diodes D1 and D3 are turned on. These diodes set a path for the input and output inductor currents. Diode D2 is reverse biased by the voltage (VC1 - Vo). In this stage, the inductors currents iL1 and iL2 decreases linearly.

The peak-to-peak voltage ripple across the various capacitors in the self – lift SEPIC high gain boost converter can be determined asginen in equation (5)

$$\Delta v_{cn} = \frac{V_0}{R_L C_n f_s} \quad \text{where n=1,2,3} \tag{5}$$

Selection of capacitors C1, C2 and C3 must ensure that the converter does not operate in Discontinuous Capacitor Voltage Mode (DCVM).The design values of various components used in the boost converter are given in table 1.

Table 1. Design Values of Converter

L_1=L_2	180μH
C_1	96μF
C_2	120μF
C_3	480μF
C_0	27.8μF

5. MAXIMUM POWER POINT TRACKING

The operation of the PV module greatly depends on the load characteristics, to which it is connected. For a load with its internal impedance the optimal adaptation appears at the specific operating point, known as MPP. The operating range for MPPT is generally in the order of 20-80 kHz.

5.1. Perturb And Observe Mppt Method

The P&O algorithm operate by regularly perturbing (i.e., incrementing or decrementing) the PV terminal voltage or current and by observing the corresponding PV output power. If the operating voltage of the PV array changes and power increases (dP/dV>0), then the control system changes the operating point of the PV array direction, or else the operating point is altered in the opposite direction. In this algorithm, only voltage is considered and hence it is easy to implement.

5.2. Flowchart For P&O Algorithm

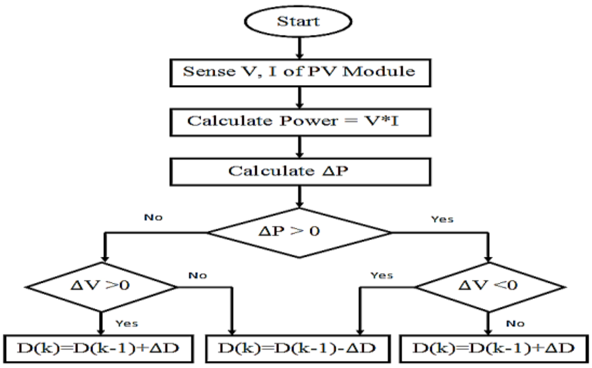

Figure 8. Flowchart for P&O Algorithm

Figure 8 shows the flow chart for P&O algorithm. The output voltage and output current from the module is measured and PV output power is calculated. Then the change in PV output power is calculated by subtracting the PV output power in one period with the PV output power in the previous period. If change in power is positive and change in voltage is negative, then duty cycle is decreased otherwise the duty cycle isincreased.The PV module has been modeled along with P&O algorithm. Here the voltage and current are given as inputs to the embedded MATLAB function and the output is the gate pulse. The output pulse is then compared with the reference triangular signal in order to generate the PWM signal and is given as an input to the converter.

6. OPERATION PRINCIPLE OF SHUNT ACTIVE POWER LINE CONDITIONER.

The non-linear loads like UPS, variable speed drives, and all sorts of rectifiers drawa non-sinusoidal current from the source therefore it isrefered as harmonic current source. Shunt active power filter chiefly acts as a current source that must be designed and controlled to generate compensating currents whose magnitude is same as the harmonic currents created by the non-linear loads but phase shifted by 180º.Figure 9 shows the operation principle of SAPF. Generally, shunt active power filters are connected in parallel with non-linear loads and its harmonic currents are compensated to attain pure sinusoidal source current.

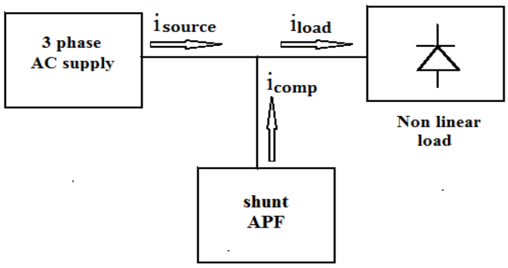

Figure 9. Schematic of Shunt Active Power Filter

6.1 Reference Current Generation Method

Figure 10 shows the schematic of Synchronous Current Detection Method. The control circuitry encompasses with the inner current control loop and one outer voltage control loop. The main function of the outer loop is to manage the capacitor voltage to be at a consistent level and also to predict the amplitude of the ac mains currents in the system. The Synchronous Current Detection Method is more predominantly used to find the amplitude of the source current.This algorithm assumes that it has balanced three phase currents after compensation. The real power p(t) absorbed by the load is derived from the instantaneous voltages and load currents and is given in equation (6)

$$P(t)=v_{sa}(t)v_{sb}(t)v_{sc}(t)\times i_{sa}(t)i_{sb}(t)i_{sc}(t) \tag{6}$$

WhereVsa (t), Vsb (t), Vsc (t) are the instantaneous values of supply voltages andila (t), ilb (t), ilc (t) are the instantaneous values of load currents. The powerp(t) is sent to a low-pass filter to attain its average dc value Pdc. The real power is then split into the three phases as given by theequation(7),(8) and(9).

$$P_a=\frac{P_{dc}\times v_{sma}}{v_{sma}+v_{smb}+v_{smc}} \tag{7}$$

$$P_b=\frac{P_{dc}\times v_{smb}}{v_{sma}+v_{smb}+v_{smc}} \tag{8}$$

$$P_c=\frac{P_{dc}\times v_{smc}}{v_{sma}+v_{smb}+v_{smc}} \tag{9}$$

Thus for purely sinusoidal balanced supply voltages, $P_a=P_b=P_c$ given by equation (10),

$$P_a=P_b=P_c=\frac{P_{dc}}{3} \tag{10}$$

where, $$P_a=V_{sa}\times I_{sa}=\frac{V_{sma}\times I_{sma}}{2} \tag{11}$$

and $$I_{sma}=\frac{2\times P_a}{V_{sma}} \tag{12}$$

Thus the reference source currents for all the phase are given by equation equation (13),(14) and (15)

$$i_{sa}(t)=\frac{2\times V_{sa}(t)\times P_a}{V^2_{sma}} \tag{13}$$

$$i_{sb}(t)=\frac{2\times V_{sb}(t)\times P_b}{V^2_{smb}} \tag{14}$$

$$i_{sc}(t)=\frac{2\times V_{sc}(t)\times P_c}{V^2_{smc}} \tag{15}$$

WhereVsma, Vsmb, Vsmcand are the amplitudes of the supply voltages. The compensation currents are then calculated using equation (16),(17) and (18).

$$i_{ca}(t)=i_{sa}(t)-i_{la}(t) \tag{16}$$

$$i_{cb}(t)=i_{sb}(t)-i_{lb}(t) \tag{17}$$

$$i_{cc}(t)=i_{sc}(t)-i_{lc}(t) \tag{18}$$

This method is concluded as less complicated because of its least computation. Nevertheless this method presents a drawback from an individual harmonic identification.

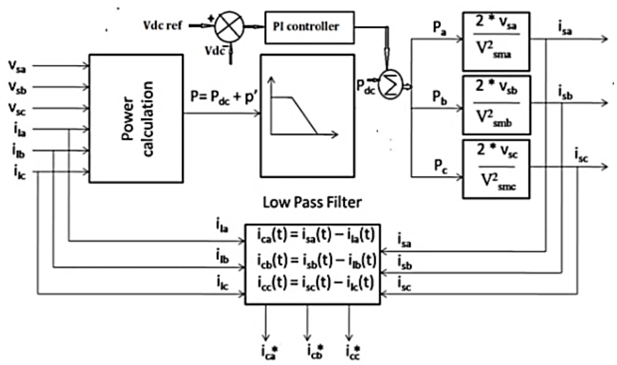

Figure 10. Schematic of Synchronous Current Detection Method

6.2 DC Link Voltage Regulation

For the regulation of DC link voltage in SAPF system, PI controller is used. The comparator block compares the actual DC link voltage and reference voltage and its output is given to the PI controller. The transfer function of PI controller is given by equation (19)

$$H(s) = K_p + {}^{K_i}\!/_{s} \tag{19}$$

The PI controller process the error voltage er given by equation (20)

$$e_r = V_{dc} - V_{dcref} \tag{20}$$

The output of the PI controller is added to the output Pdcof low pass filter shown in synchronous detection block and is used for calculating the reference currents.

6.3 Hysteresis Current Controller

The hysteresis block used for generating gating pulses is shown in figure11.It makes the actual compensating current of SAPF to follow the reference compensating current within a fixed hysteresis band. It provides excellent dynamic performance and simple to implement.

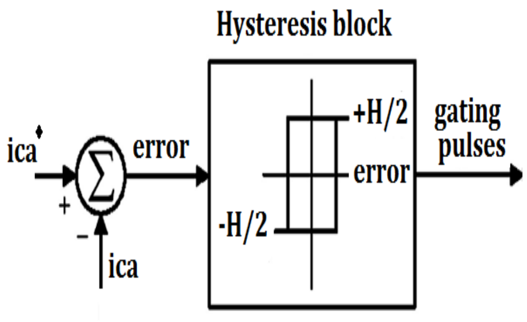

Figure 11. Hysteresis current controller.

7. SIMULATION RESULTS AND DISCUSSIONS

To confirm the effectiveness of the proposed APF fed by PV system controlled by Synchronous Current Detection algorithm, simulations were performedusing the MATLAB/Simulink software. The three phase diode bridge rectifier is used as a non-linear load. The parameters which have been used in the simulations are summarized in Table I, Table IIand Table III. Figure 12 shows the simulation model of the grid interconnected solar PV system with shunt APF. The simulink model of MPPT algorithm with boost converter is shown in figure 13.The I-V and P-V characteristics of the solar panel used in the proposed systemare shown in figure 14 and 15 respectively. Figure 16 shows the load voltage waveform and Figure 17shows the source current waveform before compensation.Figure18 shows the harmonic spectrum of source current before compensation. The Total Harmonic Distortion (THD) of the source current was found to be 45.24% before the implementation of APF. Figure 19 shows the injected current waveform and it is injected at 0.2sec. The SAPF injects the reference current which is determined by the synchronous current detection algorithm. After the implementation of the proposed inverter, the source current waveform becomes nearly sinusoidal as shown in Figure20.The Fast Fourier Transform (FFT) analysis shows that the THD valueis reduced to 0.86% as shown in figure 21.Figure 22 shows the output of self-lift SEPIC converter which is the DC link voltage.

Table 2. Design Values of SAPF

Source voltage	380V
Source Current	5A
Non Linear load R,L	60Ω,10mH
DC Link Voltage	800V
Frequency	50Hz

Table 3.Design Values of PV Array

Power	435W
V_{max}	72.9V
I_{max}	5.97A
V_{oc}	85.6V
I_{sc}	6.43A
No. of cells	128
Irradiation	1000W/m^2
Temperature	25°c

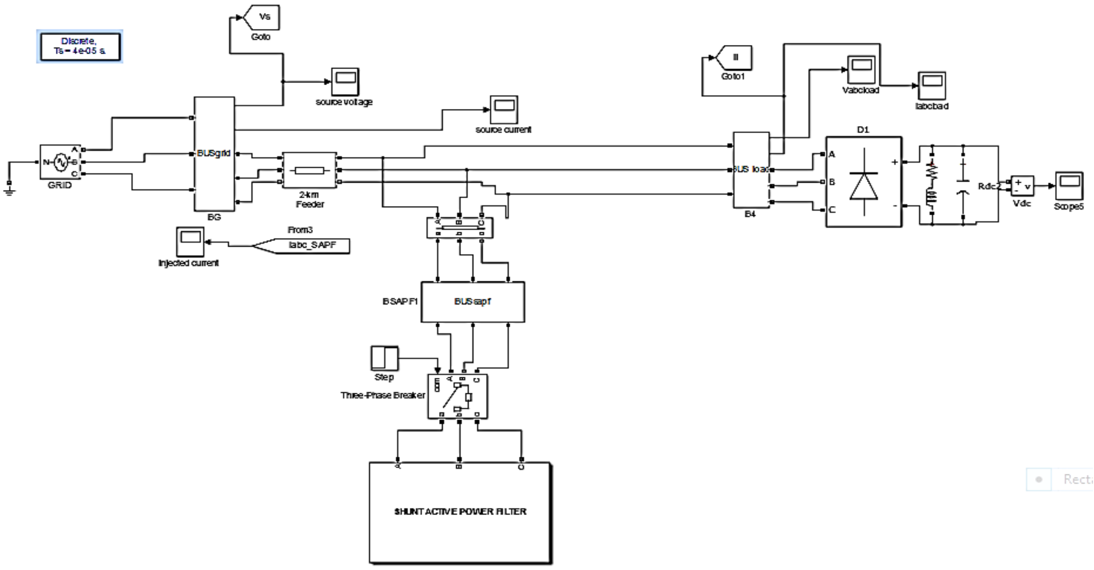

Figure 12.Matlab-Simulink model of the proposed system.

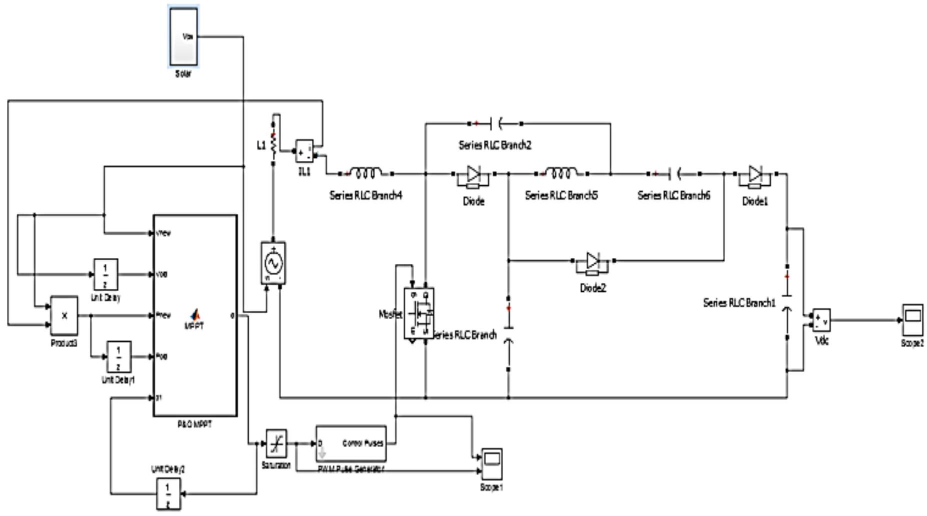

Figure13.Matlab-Simulink model of MPPT algorithm with boost converter

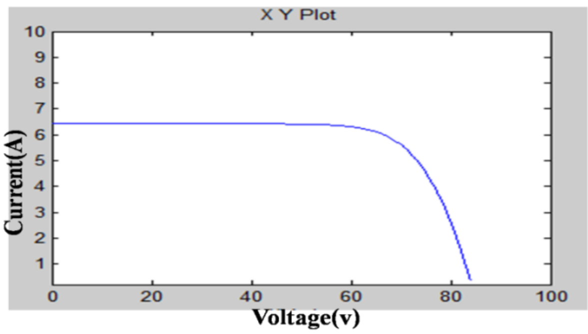

Figure14.Waveform for solar I-V characteristics

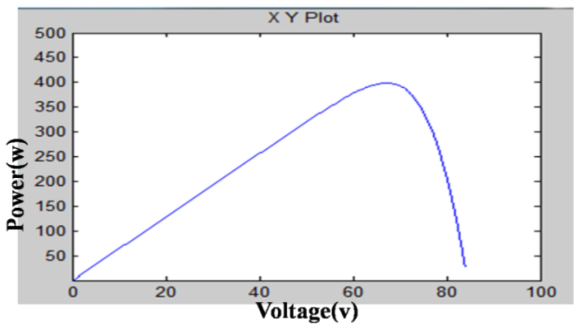

Figure15.Waveform for solar P-V Characteristics

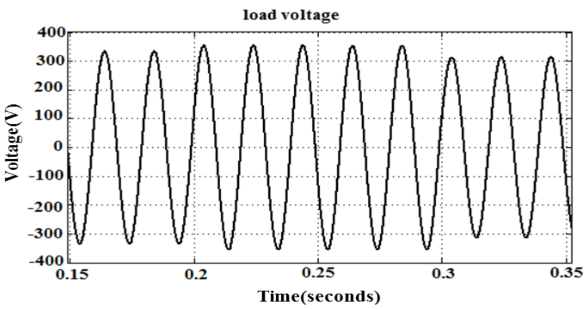

Figure16.Load Voltage WaveformFigure

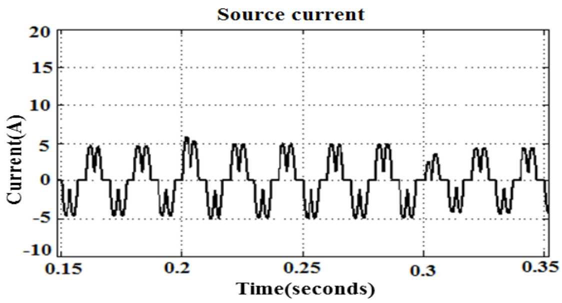

Figure17.Source current waveformbefore compensation

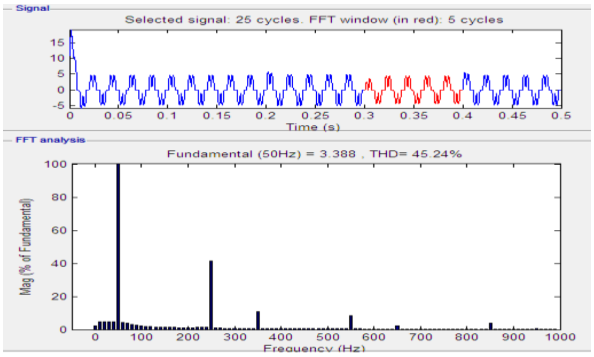

Figure.18.FFT Analysis of Source Current

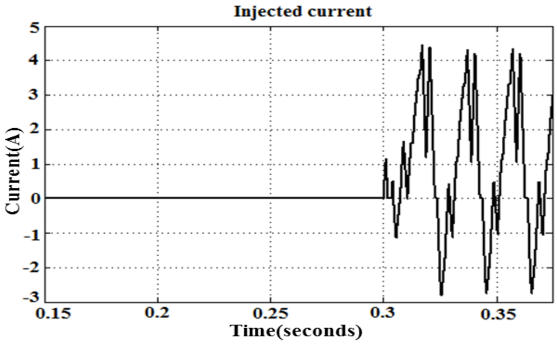

Figure19.Injected Current Waveform before compensation

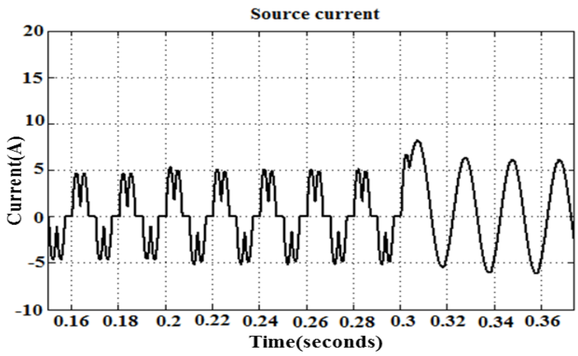

Figure 20.Source current waveform after Compensation at t=0.2 sec

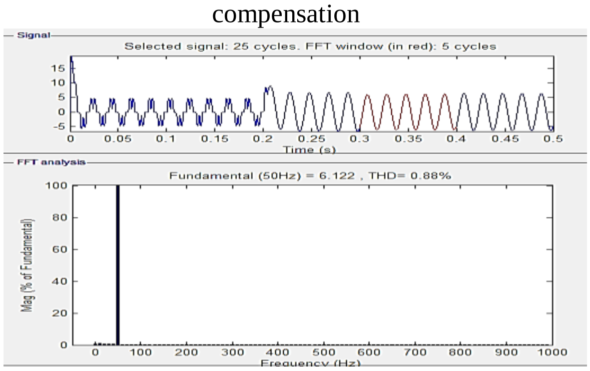

Figure 21.FFT analysis of Source current waveformafter compensation at t=0.2 sec

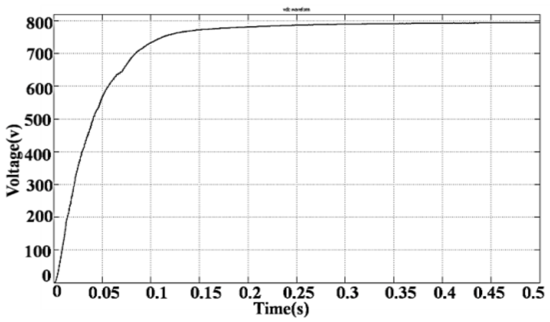

Figure 22.DC link voltage

8. CONCLUSION

In this paper, the design and simulation of a new SAPF system which was fed by a renewable energy source is proposed. The proposed system also includes a conventional boost converter along with self-lift SEPIC converter which is used to step up the voltage to the desired level. The PV system includes an MPPT algorithm in order to extract the maximum available active power generated by the PV system to the grid. The APF system was controlled by synchronous current detection algorithm in order to demolish the current harmonics in the grid include nonlinear load. The simulation work carried out under MATLAB/Simulink proves that the system effectively compensates the harmonic disturbance in the source side. Among the other reference current methods, synchronous current detection possesses simple calculation. From the simulation results it can be seen that the THD of the source current is reduced from 45.24% to 0.86% with the help of the proposed Shunt Active Power Filter. The preliminary simulation results will be compared with the experimental results in future works.

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