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Designing of Single Phase Shunt Active Filter Using Instantaneous Power Theory

Jeevananthan.K.S

PG Scholar
Alagappa Chettiar College of Engineering and Technology,Karaikudi,India

Abstract: **The active power filter implemented with a voltage source inverter is connected with the load, and the combined filter and load then draws a sinusoidal current from the ac source. The shunt active power filter is considered as a controllable current source to supply the equal but opposite harmonic current and reactive current drawn from the non-linear loads such that the ac source only supplies the fundamental active current to the loads. There are many control techniques available for shunt active power filter. The solar array is used as the source of the filter and the reason for choosing solar source because it is easy to harvest, pollution free and vast energy present around the world. So the solar energy is connected with filter and inject the power to the grid. In this project, shunt active power filter based on PQ theory is implemented. The principle of filter is that the combination of non linear load and the filter is made to be PQ theory by means of controlling the duty ratio of the filter. The simulation results of this filter are carried with well known PQ theory for unbalanced load, where the single phase load is treated as an unbalanced load. Finally, conclusions are duly drawn.**

Keywords**: Instantaneous Power Theory, Maximum Power Point Tracking, Shunt Active Power Filter, Solar PV Array.**

I. INTRODUCTION

Active filters, different from the passive ones, have the capability of dynamically adjusting to the conditions of the system in terms of harmonics and reactive power compensation. The Shunt Active Filter drains from the grid the distorted components of the load currents in a way that the system currents become with small harmonic distortion and in phase with the system voltages. Problems like the ones described above have a greater impact in the industrial environment, but in domestic and commercial use most loads are non linear as well, causing disturbances to the electrical system and to more sensitive loads. In case of unbalanced and distorted load condition, reduced current control method can be identified the problem of 3-phase 4-wire shunt active filter. This control scheme according to PQ theory in which the current sensor used to measure source current and it can be determines the all system parameters. Hence this active power filter is best choice to compensate reactive power. The methods of harmonic current detection play a crucial part in the performance of active power filter [1-4].

The active power generation in static var compensator and active power filter and has been implemented in 27 multi level inverter. In each phase of the multi level inverter composed of three "H" bridges and connect with the same DC link and scaled for 3 phase power. The filter compensate harmonic in load currents and getting sinusoidal source current. A new method for DC link voltage control and harmonic suppression using ant colony optimization based PI controller (ACOPI) and particle swarm optimization based PI controller (PSOPI) to estimate an efficient Photovoltaic interfaced shunt active filter (PV-SAF) has been proposed [5-6].

The series control strategy provides compensated voltages in such a way that the voltage delivered to the critical load is sinusoidal and balanced. a three-phase current-controlled voltage source inverter (CC-VSI) with a filter inductance at the ac output and a DC capacitor. The current-controlled voltage source inverter is worked direct control of the ac grid current to be sinusoidal and in phase with the grid voltage. The switching is controlled using time current control, it is based on the concept of zero average current error. Different power quality problems in distribution systems and their solutions with power electronics based equipment. Shunt, hybrid and series active power filters are described showing their compensation characteristics and principles of operation. Different power circuits topologies and control scheme for each type of active power filter are analyzed [7-9].

Many maximum power point tracking techniques for photovoltaic systems have been developed to maximize the produced energy and a lot of these are well established. MATLAB models for neural networks and PV model are developed to implement classical P&O algorithm for MPPT controller. This algorithm uses ANN to obtain the optimum voltage at which the power is maximum [10-15].

In this paper, Single-Phase Shunt Active Filter Interfacing Solar PV Array with the Power Grid is discussed. The shunt active power filter is considered as a controllable current source to supply the equal but opposite harmonic current and reactive current drawn from the non-linear loads such that the ac source only supplies the fundamental active current to the loads. The filter is made to be PQ theory by means of controlling the duty ratio of the filter.
The paper has been organized as follows: Chapter II gives an overview of PV array. Chapter III describes the proposed method of application of Shunt active filter. Chapter IV explains the MATLAB simulation and its results. Finally, summarization of this work is presented in Chapter VI.

II. PV ARRAY

Photovoltaic power control is one of the burning research fields these days. Researchers are round the clock to develop better solar cell materials and efficient control mechanisms. The challenge of the project and the new area of study were the motivations behind the paper.
The basic objective would be to study MPPT and successfully implement the MPPT algorithms either in code form using the simulink models. Modeling the converter and the solar cell in simulink and interfacing both with the MPPT algorithm to obtain the maximum power point operation would be of prime importance.

A. PV Cell

Solar power is the power obtained from the sun radiation and can be done directly using photovoltaic (PV) systems. Photovoltaic power technology uses semiconductor cells (wafers), generally several square centi meters in size. The cell is basically a large area p-n diode with the junction positioned close to the top surface. Numerous cells are assembled in a module to generate required power.
In comparing alternative cell technologies, the most important measure is the energy cost per kWh delivered. In PV technology, this is primarily based on 2 parameters:

(i) PV energy conversion efficiency and
(ii) The capital cost per watt capacity

B. PV Cell Parameters

For open circuit voltage and short circuit current, power generated is zero in current voltage characteristics. The short circuit current I_{SC} is the current at $V = 0$ and is approximately equal to the light generated current I_L as shown in equation.

$$V_{oc} \approx \frac{AkT}{q} ln\left(\frac{I_l}{I_o}+1\right) \quad (1)$$

$$I_{SC} \approx I_l \quad (2)$$

The maximum point in IV characteristics is maximum is called maximum power point.

C. Simulation diagram of solar array

The Fig. 1 shows the simulation diagram of solar array and the Fig. 2 shows the solar cells in an array.

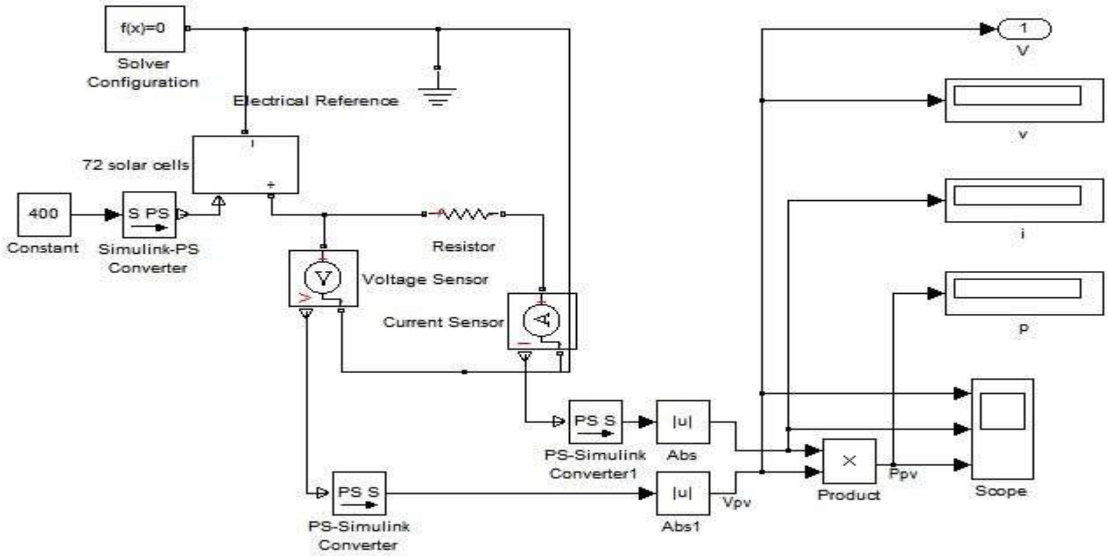

Fig. 1 Simulation diagram of Solar array

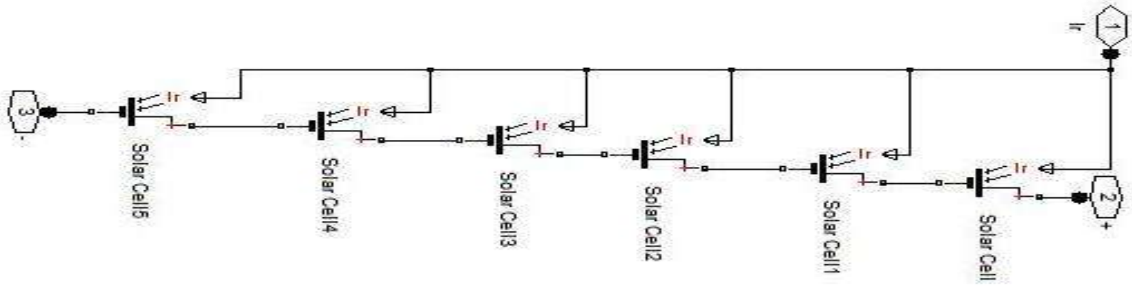

Fig. 2 Solar cells connected to form an array

D. Maximum Power Point Tracking Algorithms

When the output power is maximum, thevenin impedance (source impedance) equal with load impedance according to maximum power transfer theorem. Hence our main problem for tracking the maximum power point decreses an impedance matching problem.

We can use boost converter fed solar panel to improve the output voltage and matching the source and load impedance for changing duty cycle.

Many techniques for track the maximum power point and the most popular methods are: Perturb and Observe, Incremental Conductance method, Constant voltage method,Fractional short circuit current,Constant current method, Fractional open circuit voltage, Neural networks, Fuzzy logic. We can choose perturb and observe algorithm.

P&O method is simple and only one sensor is used i.e voltage sensors to sense solar PV array voltage. The implementation cost is less and easy to make. When PV operating voltage is perturbed by a small increment and the changes make the power P is positive, if the P is negative the direction of MPP is going away and the sign of perturbation is changed. The solar panel characteristic shows MPP in fig.3.

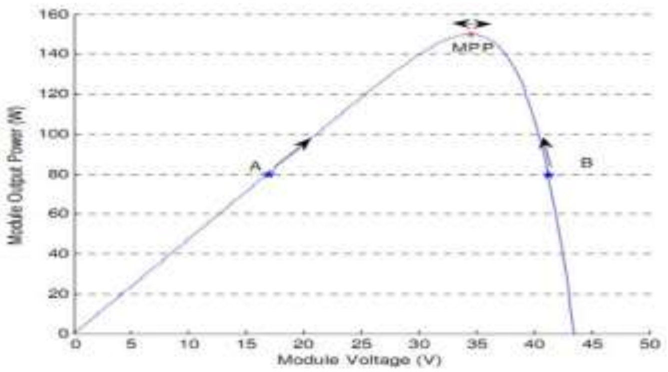

Fig. 3 Solar panel characteristics

For observe A and B as two operating points. From figure left hand side of point A therefore move towards the MPP for obtain positive perturbation and right hand side of point B so essential changes is done for getting MPP. The P&O algorithm flow chart is shown in fig.4.

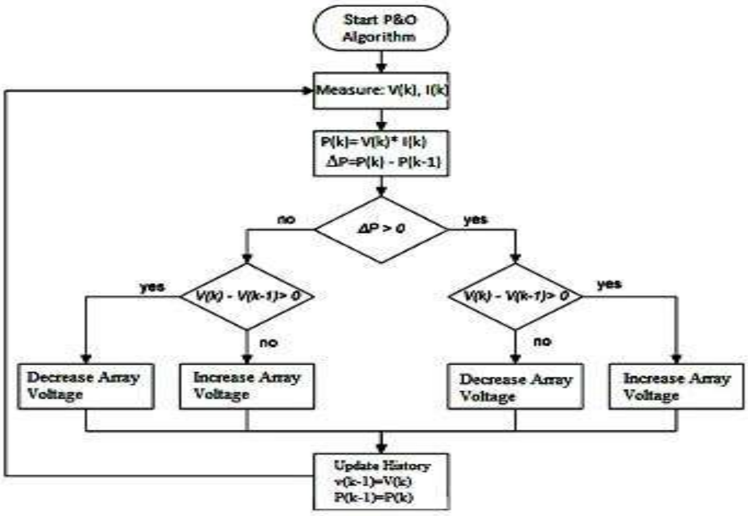

Fig. 4 Flow chart for Perturb and Observe algorithm

III. SHUNT ACTIVE POWER FILTER

Fig.5 shows the shunt active filter, which is used to compensate reactive power, eliminate harmonics and balance the unbalanced currents. The current harmonics are injected by non linear loads so it is mainly used at load side and injects equal magnitude but opposite in phase to compensate reactive power and harmonics. Hence it is used in STATCOM for improving voltage profile and stabilizing in power system network.

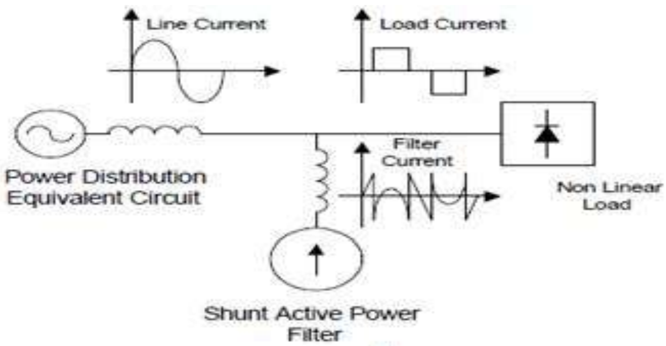

Fig. 5 Basic configuration of shunt active filter

A. Principle

Principle of shunt connected active power filter can be explained by Fig. 5.

$$I_s = I_l - I_f \qquad (3)$$

Where,

I_s – source current,

I_l – load current,

I_f – filter current.

The nonlinear load connected to the ac supply cause harmonics in the source current. But the source should supply only the fundamental component, so the filter injects the harmonic current present in source in opposite phase at the point of common coupling to cancel out the harmonics in the source current.

Fig 5.shows that the shunt connected APF used as the principal example and illustrates the five basic elements in an APF distortion identifier Shunt Active Filter Controller is a signal processing function block in which harmonic current are

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calculated by sensing the various parameters such as source voltage, source current, load current, dc bus voltage depending on the control method Inverter is a current controlled PWM inverter that able to reproduce the reference waveform at suitable amplitude. Inverter Controller is a pulse width modulator and in the case of a voltage source inverter used to inject current, a local current control loop that ensures the tracking of reference current.

Dc Bus is energy store that supplies the fluctuating instantaneous power demand of the inverter. Errors and losses that cause the energy store to engage in long term real power flows must be compensated for by additional action of the inverter controller. Dc Link Inductor is used to filter out the harmonics present in the filter current, due to the switching of the PWM inverter (APF).The Fig. 6 shows the simulation diagram of shunt active power filter.

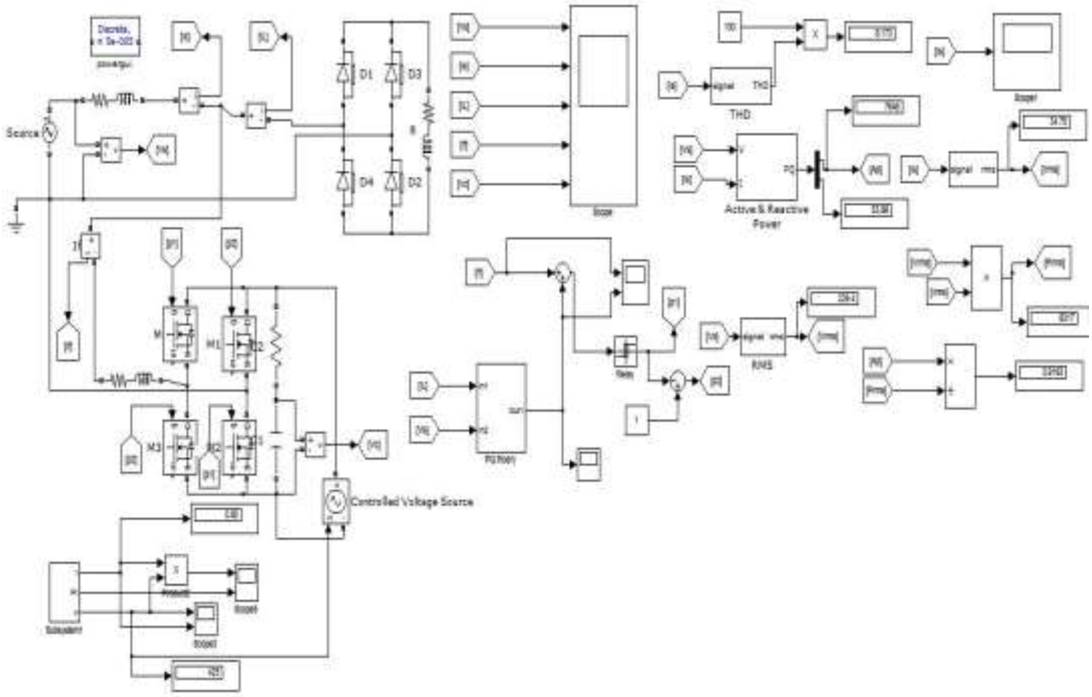

Fig. 6 Simulation diagram of Shunt active power filter

B. Controlling Techniques

(i) Direct method:

In the direct method of reference current generation the reference current is generated by directly calculating the harmonic and reactive current present in the source current by means of sensing the various parameters such as source voltage, load current and capacitor dc link voltage. After the calculated harmonic current generation, it is injected by 180 phase shift through filter at point of common coupling (PCC) to cancel out the harmonics in the source current. The various direct methods are depicted in fig. 7

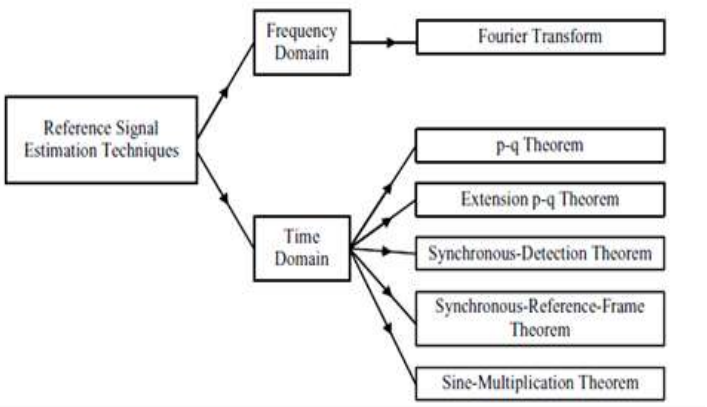

Fig. 7 Direct methods of reference current generation

(ii) Indirect method:

In the indirect method of reference current generation, the reference current is not harmonic and reactive current present in the source current as in the case of direct method. These methods generally involve balancing any one of the system parameters such as capacitor voltage or filter current using controllers like proportional, proportional integral or proportional derivative controllers. There are various methods available for obtaining reference current using indirect method.

- PI CONTROLLER.
- PLL.

IV. THREE PHASE PQ THEORY

The p-q theory, or "Instantaneous Power Theory", was developed by ***Akagi** et al* in 1983, with the objective of applying it to the control of active power filters. Initially, it was developed only for three-phase systems without neutral wire, being later worked by ***Watanabe*** and ***Aredes*** for three-phase four wires power systems. It is based on instantaneous values in the three phase power system and is valid for steady state or transient operations, as well as for generic voltage and current waveforms. The p-q theory consists of an algebraic transformation (known as "Clarke Transformation") of the three phase voltages and currents in a-b-c coordinates to α-β-0coordinates, followed by calculations of instantaneous power components. The block diagram of three phase PQ theory is shown in Fig. 8.

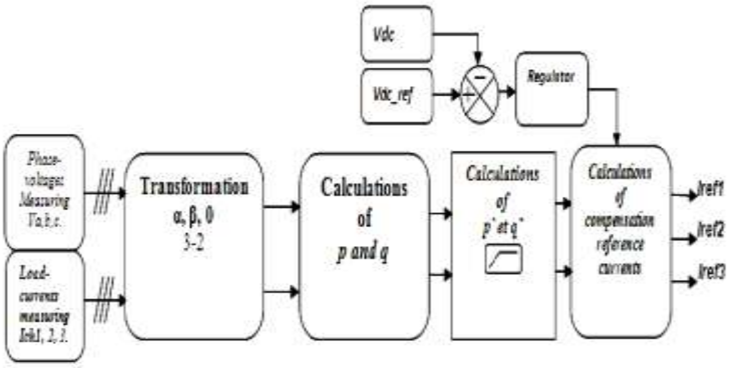

Fig. 8 Block diagram of PQ theory

The PQ theory transforms the three phase source voltage and load current from a-b-c frame to α-β- 0 frame and vice versa using Clarke transform.

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = 0.816 \begin{bmatrix} 1 & -.5 & -.5 \\ 0 & .86 & -.86 \end{bmatrix} \begin{bmatrix} V\alpha \\ Vb \\ Vc \end{bmatrix} \tag{4a}$$

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = 0.816 \begin{bmatrix} 1 & -.5 & -.5 \\ 0 & .86 & -.86 \end{bmatrix} \begin{bmatrix} I\alpha \\ Ib \\ Ic \end{bmatrix} \tag{4b}$$

The three phase instantaneous power is,

$$\begin{bmatrix} P \\ q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ -V\beta & V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \tag{5}$$

p- Instantaneous real power

q- Instantaneous reactive power

$$P = \bar{P} + \tilde{P} \tag{6a}$$

$$q = \bar{q} + \tilde{q} \tag{6b}$$

$\bar{P}$ - DC component related to fundamental active current conventional,

$\tilde{P}$ - AC component of *p*, devoid of mean value and associated with harmonic caused by the AC Component of instantaneous real power.

$\bar{q}$ - DC component related to the reactive power generated by the components fundamental currents and Voltages

$\tilde{q}$ - AC component of *q* and related to harmonic currents caused by the components of AC instantaneous reactive power.

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{1}{\Delta}\left(\underbrace{\begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix}\begin{bmatrix} \bar{P} \\ 0 \end{bmatrix}}_{\text{Active current}} + \underbrace{\begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix}\begin{bmatrix} 0 \\ \bar{q} \end{bmatrix}}_{\text{Reactive current}} + \underbrace{\begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix}\begin{bmatrix} \tilde{P} \\ \tilde{q} \end{bmatrix}}_{\text{Harmonic current}} \right) \quad (7)$$

The harmonic current includes, harmonic current in the real power and reactive power so the reference current is calculated as,

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{1}{\Delta}\left(\underbrace{\begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix}\begin{bmatrix} 0 \\ \bar{q} \end{bmatrix}}_{\text{Reactive current}} + \underbrace{\begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix}\begin{bmatrix} \tilde{P} \\ \tilde{q} \end{bmatrix}}_{\text{Harmonic current}} \right) \quad (8)$$

Where,

$$\Delta = V\alpha\hat{}2 + V\beta\hat{}2 \quad (9)$$

Reference current calculation in α, β ref frame

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix}\begin{bmatrix} \tilde{P} \\ -q \end{bmatrix} \quad (10)$$

Reference compensation current calculation

$$\begin{bmatrix} Ica \\ Icb \\ Icc \end{bmatrix} = \begin{bmatrix} 0.707 & 1 & 0 \\ 0.707 & -.5 & 0.86 \\ 0.707 & -.5 & -0.86 \end{bmatrix}\begin{bmatrix} Io \\ I\alpha \\ I\beta \end{bmatrix} \quad (11)$$

Ica ,Icb, Icc –Reference compensation current

Io - neutral current which is $Io = (Ia + Ib + Ic)\ /\sqrt{3}$

Fig. 8 shows the simulation diagram of PQ theory.

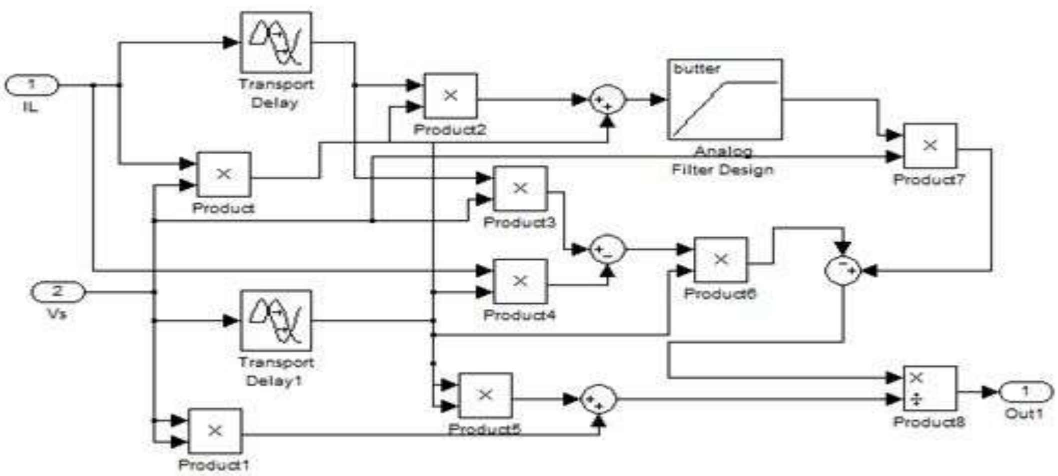

Fig. 8 Simulation diagram of PQ theory

V. RESULTS AND DISCUSSION

The output voltage, current, power of a solar is shown in Fig.9

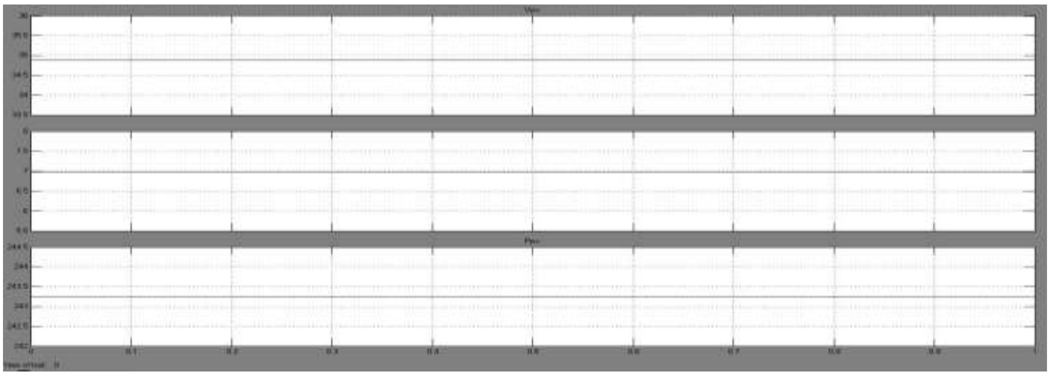

Fig. 9 Output voltage, current, power of solar array

(a) voltage is 34.87V,
(b) current is 6.975A and
(c) power is 243.2W at 1000 in solution and 25^0 C.

The output of the system solar connected filter and corresponding FFT analysis are shown from Fig. 10 & 11.

Fig. 10 Output of Shunt Active Power Filter Fed Solar

(a) Source voltage is 240V,
(b) Source current is 34.75A,
(c) Load current is 26A,
(d) Filter current is -27A,
(e) Capacitor voltage is 425V.

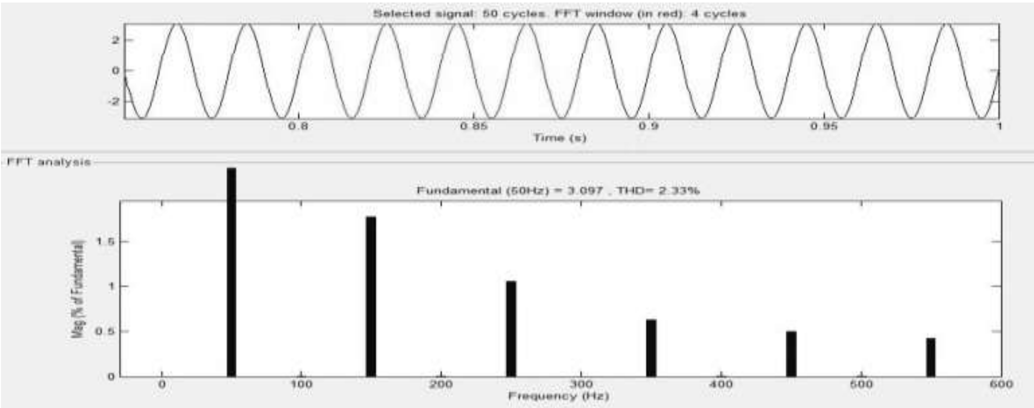

Fig. 11 FFT Analysis of Shunt Active Filter Fed Solar

(a)THD is reduced from 29.34% to 2.33%
(b)RMS value of source current is 34.75A.

Table I Comparitive Results

SYSTEM	THD
without filter	29.34%
with filter	5.67%
solar connected with filter	2.33%

Table II System Parameters

S.No	Components	Value
1	Source resistance	100 ohms
2	Source inductance	1μHenry
3	Filter resistance	0.01 ohm
4	Filter inductance	35mHenry

VI. CONCLUSION

This paper presented experimental results of a single-phase Shunt Active Filter, injecting energy in the electric grid produced by a solar panel array. The results show the performance of the Shunt Active Filter operating alone, and also the complete system behavior in compensation and energy injection tasks simultaneously. The presented configuration shows some advantages over the traditional ones since it gathers functionalities of different equipments using the same hardware to accomplish the different tasks. The only drawback of the presented configuration is that the power inverter has to be increased because the injected current is composed by two components a component that represents the renewable energy to inject in the electric grid and a component to compensate harmonics and power factor of the facility.

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