Active and Reactive Current Control Strategy Based on Active Power Filter for Power Balance Application using PV Arrays

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Abstract— In this paper, the merged performance of the active power filter on the photovoltaic generation system has been analysed. The suggested scheme comprises of a PV power plant, a Quasi-z-source DC-DC converter, and a shunt active power filter. A new contained scheme for the DC–DC converter has evolved in order to distil the utmost quantity of power by means of PV arrays. As well as a new contained scheme, which are based on instantaneous active and reactive current control strategy (id-iq) has been suggested for the active power filter. The simulation results are done on MATLAB, show that the advised scheme could supply for the power balancing, harmonic elimination, injecting active current and Interpose the maximal power available from the PV array into the power grid.

Key words: Photovoltaic Arrays, Active Power Filter, Id-Iq Control Strategy, Quasi-Z-Source Converter

I. INTRODUCTION

Solar energy bears avid potential to provide energy on lowest affect on the environment, as solar energy is clear, pollution-Absolve and unlimited. On the decrement in the cost of photovoltaic (PV) modules and the growth in the cost from conventional petrochemical fuels, the application of the PV generation system gets more practical, executable and achievable[1,2]. PV cells are generally associated conjointly to catch up modules, which Could be merged into PV arrays as expected. Hence, power electronic converters are an sanctioning technology that is essential to Change over PV array DC power into available AC power for grid abide or adding special loads .

Grid-connected PV generation are among the leading growing Drifts of solar energy diligences. Furthermore, PV grid-connected generation functions on the daytime and stops at night time. This Impacts the stabilization of power system and the usage of equipment. Therefore to increment the usage, the PV system could be configured as well as to allow the procedure of power quality managements. Also, grid-connected PV system can be used to cut back the peak demand that the utility must fulfil [3].

In this application, the PV arrangement doesn't need a battery bank just the power stage stays idle on the night time. One disadvantage of solar energy sources are the demand for battery bank as the system to be utilized. Elimination of Adding up a battery bank to a PV generation system effects in a intent, which needs the combining process with Active Power Filter (APF)to as well allow the power factor correction, load balancing, harmonic Evacuation, reactive power compensation [5]and simultaneously inject the maximum power available from the PV array into the grid. When the solar irradiation is inaccessible, and then the active power filter could even be applied to amend the power quality .As the solar irradiation are accessible, the suggested system can Issue the load and at the same time resolve arising troubles of harmonics, unbalanced loads and reactive consumption in distribution y system.

The PV array is interfaced with the utility network through Quasi-z source DC to DC converters and a three phase Pulse Width Modulation (PWM) DC–AC converter; The DC voltage generated from a PV array Changes widely. So, a DC–DC quasi z source converter is essential to generate a determined higher DC voltage for desired converter input voltage. Commonly, the grid connected PV systems extract maximum power from the PV arrays. The Maximum Power Point Tracking (MPPT) technique is generally associated with a DC–DC converter.

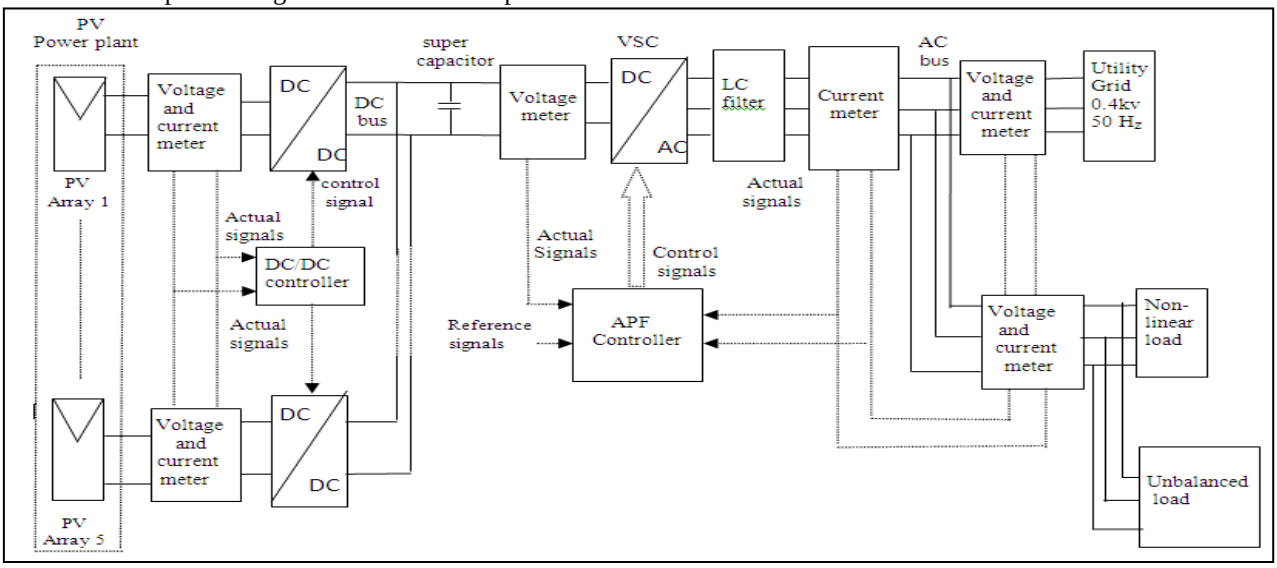

Fig. 1: Proposed System Based On APF and Grid Connected PV

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The shunt APF, which contains a DC–AC Voltage Source Converter (VSC) can allow the harmonic elimination, load balancing and power factor correction. Furthermore [16], VSC is engaged to interface PV array with utility grid under both on-grid and off-grid operation modes. The DC–AC converter injects sinusoidal current into the grid, and can control the power factor. Hence, DC–AC converter in grid-connected PV system can have the function of shunt APF [4].It shows the merged operation of shunt active power filter and photo voltaic grid connected generated system.

The proposed system has been used as shunt APF, when solar irradiation is not available .Also; it can produce the power by PV array and function as APF, when solar radiation is available. The new control strategy of the active power filter should be able to give a more amount of active and reactive power to the grid and to provide the load balancing, harmonic elimination or reactive power compensation [6]. In this technique, a new control strategy of the DC–DC converter has been obtained, in order to obtain the maximal quantity of power from the PV array. Also, an (id-iq) control strategy has been introduced for the active power filter. The active and reactive control approach which means the (id-iq) control strategy, which is used for the separation of the active and reactive current [14] . The advantage of the (id-iq) control strategy over the (pq) control strategy is that controllers are minimized and capability of the proposed system is to compensate the unbalanced load current, the harmonics and the reduction of the total harmonic distortion.

II. PROPOSED SYSTEM

The projected technique of Active Power Filter and grid-connected PV generation system is shown fig.1.A verified model of a 200W Photovoltaic module which is used for the PV power plan. The PV power plant has five PV arrays connected in parallel. Quasi-z source DC–DC converters drain the energy from PV arrays and give it to the DC bus capacitor based on Maximum power point tracking control method. In these the DC bus voltage is Vdc=600V The DC bus is coupled with a bi-directional six-switch current controlled VSC, with neutral clamped DC capacitors. Through this converter, the energy generated by the PV arrays is transferred to the three phase utility grid or the non linear loads. An LC filter is used after the voltage source converter to filter the switching frequency harmonics.

In this paper, the AC loads are nonlinear and unbalanced. The calculation to obtain these components is followed from the method instantaneous active and reactive power (p-q) theory. The main advantage of this method is that angle 'θ' can be directly calculated from the mains voltages and thus make this frequency independent by avoiding the phase locked loop (PLL) in the control circuit. Furthermore, under unbalance and non-sinusoidal mains voltage situations, a bulk number of synchronization problems can be avoided [1, 7]. In these the active current which is injected to the non linear load and the excess power will be send to the grid. Thus id-iq achieves large frequency operating limit essentially by the cut-off frequency of voltage source inverter.

III. POWER MANAGEMENT OF PROPOSED SYSTEM

Power management strategy of AC–DC converter gives suitable power transfer and regulation between AC source and active power filter.fig.2 shows the ideal active and reactive power flow of PV power plant. The reference active power of a PV unit is specified by its power management system which should consider various technical and economical constraints and environmental conditions.

The operation of the proposed system can be divided into daytime and night time operation modes. the AC loads are absorbing the active power (pLs) and reactive power (qLs). In the daytime mode, if the APF starts to inject active power (pf), clearly the active power supplied by the AC source, ps will decrease. When the PV power is larger than the load demand throughout the system, the excessive power of PV will be injected to the AC source. If the available power is insufficient for loads, the AC source will supply the loads. In the night time mode, pf is equal to zero and the AC source will supply AC loads. In both modes, the reactive power of AC loads must be compensated by APF. If qf is equal to qLs, then the source power factor can be kept equal to unity under different load conditions [1, 10].

IV. QUASI-Z-SOURCE CONVERTER

The quasi-Z-source network consists of two capacitors , two inductors and a diode . The high-frequency isolation transformer provides the required voltage gain, as well as the galvanic isolation of the input and output sides of the converter, compared with the conventional DC-DC converters, quasi-z-source DC-DC converters have low inrush current, the harmonic injection will be lower and the range of the output DC voltage will be larger. It can capable of operating in either voltage or current fed mode [13]. The PWM ratio can be controlled as just like in conventional DC_DC converters to control a quasi-z-source DC-DC converter.

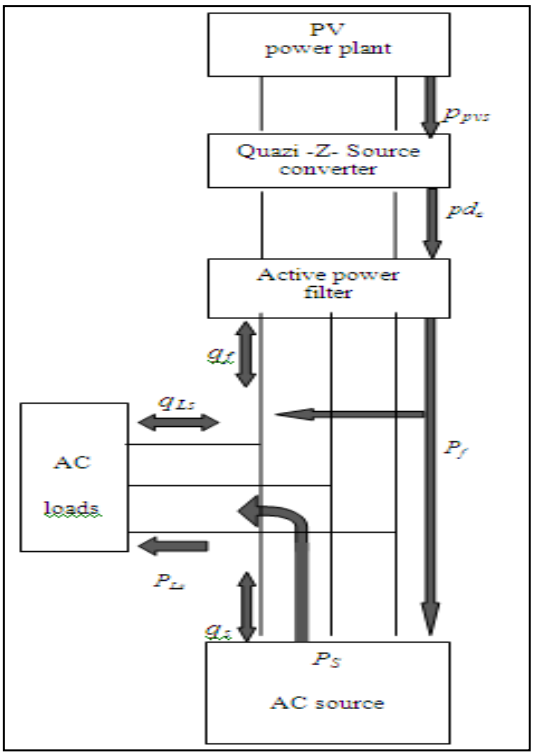

Fig. 2: Active and Reactive Power Flow of System

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V. DYNAMIC MODELS OF PV MODULE

In an array, many PV modules have been connected in series and parallel to obtain a suitable power rating. Also, the PV cells are connected in series and parallel in a module. The most commonly used model of a PV cell is DC current source (IL) with an anti-parallel diode. The DC source current depends on ambient temperature (Ta) and solar irradiation (Ga). Rs represent the losses in the circuit. In this paper, PV dynamic model has been used to model the PV arrays. The PV array can be modelled by temperature and irradiation dependent V–I characteristic. It is important to use the PV system near maximum power point to increase the efficiency of photovoltaic array. This can be realized by using a MPPT algorithm[11].In this study, a suitable voltage-based MPPT controller for the optimum operation of PV modules has been used. The parameters of a 200-W PV have been used for PV array simulations.

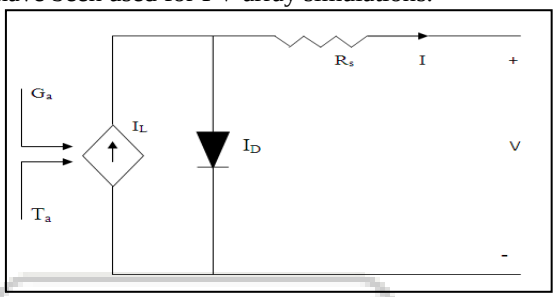

Fig. 3: Model of a Single PV Cell

VI. CONTROL OF POWER CONVERTERS

The current controller of power converters can be a closed loop PWM scheme, such as Hysteresis Current Control (HCC), linear PWM, predictive controllers, optimized controller. In comparison to open loop PWM techniques, closed loop PWM schemes have several considerable advantages, such as extremely good dynamics, instantaneous peak current control and prevention of overload and pulse dropping problems. But merit of HCC is its good stability, which is provided by maintaining current errors within the hysteresis band. Thus, HCC has been selected in this paper. The controller provides the reference current for the HCC.

The instantaneous power regulation has much faster response in comparison with the average power regulation. Therefore, instantaneous power regulation has been used for the converter in this paper[13,15]. As a result, reference currents for the closed loop PWM scheme of the converter are calculated by using instantaneous active and reactive current concept. The instantaneous powers can be expressed in either synchronous or stationary reference frame. In this paper, the active and reactive current method is used for the converter reference current generation.

VII. CONTROL SYSTEM OF APF

The APF controller must provide the power factor improvement, load balancing, harmonic reduction, reactive power suppression, improve the dynamic behaviour of grid-connected PV system and simultaneously inject the maximum power available from the PV array into the grid. The grid-connected operation allows the converter to operate parallel with the grid, providing grid support. The average large signal model of the APF is shown in Fig. 4.

The DC–AC converter has been modelled by three current sources, i.e.i_{fa}^{ref}; i_{fb}^{ref} and i_{fc}^{ref}. The converter manages the current injected to the utility.

Since the current generated from the converter can be controlled independently the active and reactive power controls are decoupled as shown in the fig.4, the input signals of the active power controller are source phase voltages, (v_{sa}, v_{sb} and v_{sc}), AC loads phase currents, (i_{La}, i_{Lb} and i_{Lc}), three phase output currents of this converter (i_{fa}, i_{fb} and i_{fc}), the DC bus voltage (v_{dc}),the reference of DC bus voltage v_{dc}^{ref}[14] . Lf is the inductance of the converter filter. i_{sa}, i_{sb} and i_{sc} are the phase currents of the AC source. This controller uses the HCC switching technique. Thus, with this control strategy shunt active filter gains additional capability to reduce neutral currents and there-by supply necessary compensation when it is most required in the system. A low-pass filter with cut-off frequency 20 Hz is used to render it insensitive to the fundamental frequency (50 Hz) voltage variations. The operation of the active and reactive current control strategy is done in the APF control system and from these the reactive currentis suppressed and the active current alone is injected.

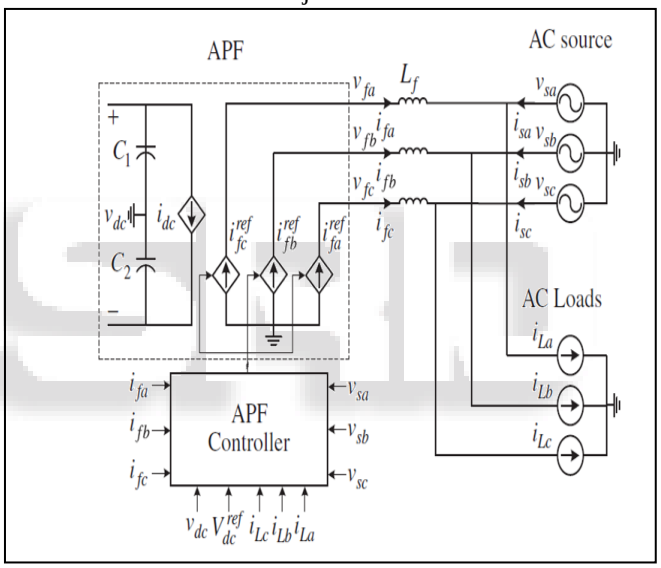

Fig. 4: Large Signal Model of Active Power Filter

VIII. REAL AND REACTIVE POWER METHOD (p - q)

The active filter currents are achieved from the instantaneous active and reactive powers p and q of the non-linear load. In these the phase voltages v_a, v_b, and v_c and the load currents i_{La}, i_{Lb}, and i_{Lc} which are transformed into the α - β orthogonal coordinates as given in Equation (1-2) .The compensation objectives of active power filters [14] are the harmonics present in the input currents. Thus, with this control strategy shunt active filter gains additional capability to reduce neutral currents and there-by supply necessary compensation when it is most required in the system

$$\begin{bmatrix} vo \\ v\alpha \\ v\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \qquad (1)$$

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$$\begin{bmatrix} io \\ i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ila \\ ilb \\ ilc \end{bmatrix} \quad (2)$$

In these the V_a,V_b,V_c which denotes the grid voltages and also the i_{La},i_{Lb},i_{Lc} which denotes the load current by means of the known values we can able to determine the values for the V_o,V_α,V_β and from the known load current values we can determine the values for the i_0,i_α,i_β and the respective terms which are given as the following equations

$$v_0 = \sqrt{\frac{2}{3}} \left[\frac{1}{\sqrt{2}} va + \frac{1}{\sqrt{2}} vb + \frac{1}{\sqrt{2}} vc \right] \quad (3)$$

$$v_\alpha = \sqrt{\frac{2}{3}} \left[va - \frac{vb}{2} - \frac{vc}{2} \right] \quad (4)$$

$$v_\beta = \sqrt{\frac{2}{3}} \left[0 - \frac{\sqrt{3}}{2} vb - \frac{\sqrt{3}}{2} vc \right] \quad (5)$$

$$i_0 = \sqrt{\frac{2}{3}} \left[\frac{iLa}{\sqrt{2}} \quad \frac{iLb}{\sqrt{2}} \quad \frac{iLc}{\sqrt{2}} \right] \quad (6)$$

$$i_\alpha = \sqrt{\frac{2}{3}} \left[iLa \quad \frac{-iLb}{2} \quad \frac{-iLc}{2} \right] \quad (7)$$

$$i_\beta = \sqrt{\frac{2}{3}} \left[0 \quad \frac{\sqrt{3}}{2} iLb \quad -\frac{\sqrt{3}}{2} ilc \right] \quad (8)$$

IX. ACTIVE AND REACTIVE CURRENT METHOD (i_d - i_q)

The id-iq method is derived from the mains voltages without the use of a phase-locked loop (PLL). In this theory, active filter currents are obtained from the instantaneous active and reactive current components (id and iq) of the nonlinear load In the first step, the a-b-c reference frame is transformed to d-q-o by means of the parks transformation. The dqo _to_ abc transformation block performs the reverse of the so called parks transformation.

In this method reference currents are obtained through instantaneous active and reactive currents id-iq of the non-linear load. The calculations follows from the active and reactive power method, however dq load currents can be obtained from Equation (9). However, the dq load current components are derived from a synchronous reference frame based on the Park's transformation in these the following transformation is used:

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \frac{1}{\sqrt{v^2\alpha + v^2\beta}} \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (9)$$

$$id = \frac{1}{\sqrt{v^2\alpha + v^2\beta}} [v\alpha i\alpha \quad v\beta i\beta] \quad (10)$$

$$iq = \frac{1}{\sqrt{v^2\alpha + v^2\beta}} [-v\beta i\beta \quad v\alpha i\beta] \quad (11)$$

From these i_d,i_q we can able to separate the active current and the reactive current by means of substituting the equations from (3-8) in the i_d and i_q expression. And in these the reactive current is suppressed and the active current alone is injected to the load and if there is excess current it will be injected to the grid else it will be supplied from grid to the non-linear load.

X. REFERENCE CURRENT EXTRACTION WITH (ID-IQ) METHOD

The fig shows the control diagram for shunt active filter and harmonic injection circuit. On owing load currents id and iq are obtained from park transformation then they are allowed to pass through the high pass filter to eliminate dc components in the nonlinear load currents. Filters used in the circuit are Butterworth filter. It can be obtained through the low pass filter (LPF) of same order and cut-off frequency simply difference between the input signal and the filtered one, which is clearly shown in Figure.5. Butterworth filters used in harmonic injecting circuit have cut-off frequency equal to one half of the main frequency (fc = f/2), with this a small phase shift in harmonics and sufficiently high transient response can be obtained.

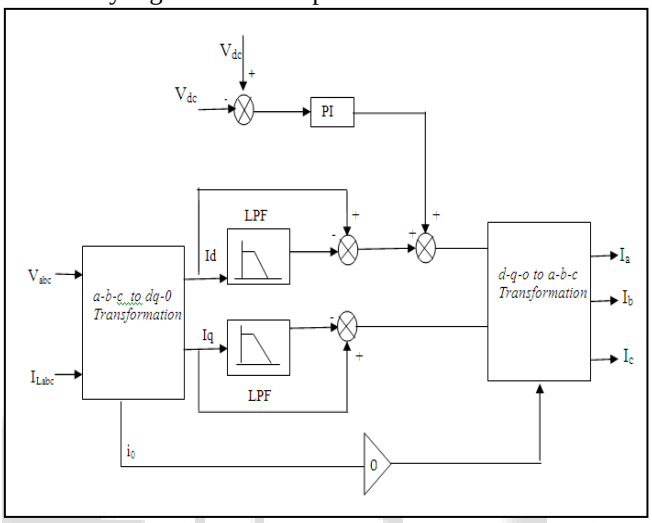

Fig. 5: Reference Current Extraction with Id-Iq Method with PI Controller

XI. SIMULATION RESULTS

To evaluate the performance of the combined operation of APF with PV generation system, the proposed control system and the on-grid operation mode have been modelled and simulated by MATLAB. The Id-Iq current control strategy of APF with neutral clamped DC capacitors has been studied for on-grid operation mode. In the simulations, the rated power of each PV unit is 25 kW.

The below wave forms indicates the power which is obtained from the generated, load and grid, the non linear load current and the grid voltages are shown in the upcoming waveforms

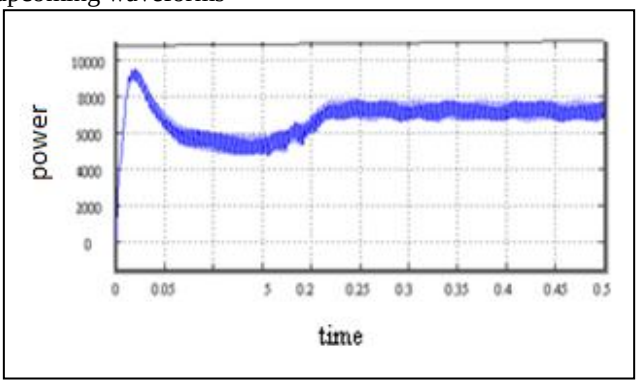

Fig. 6: Generated Power

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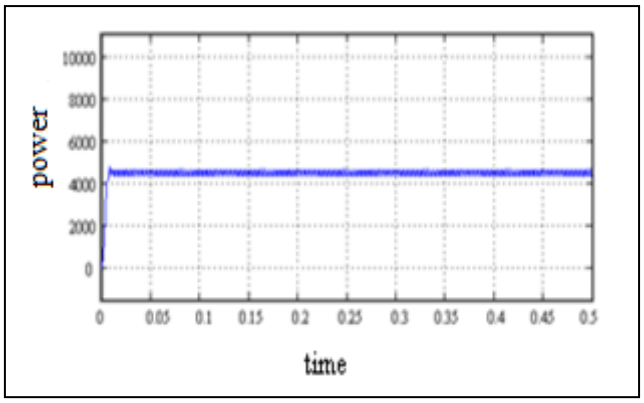

Fig. 7: Load Power

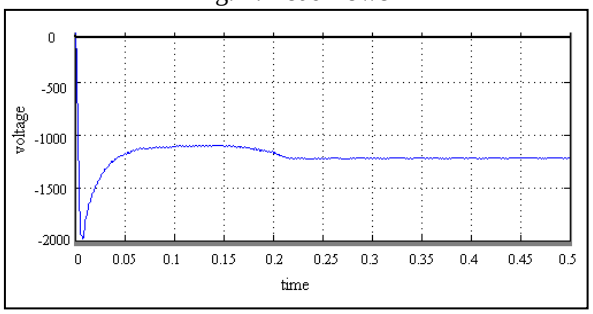

Fig. 8: Grid Power

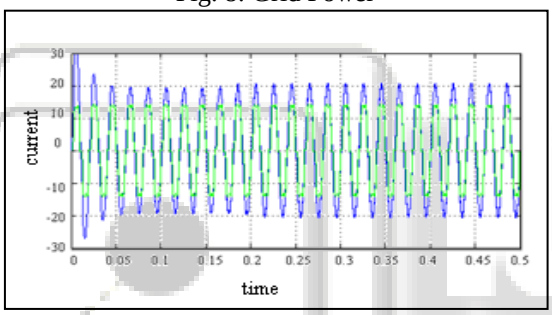

Fig. 9: Non-Linear Current Vs Source Current

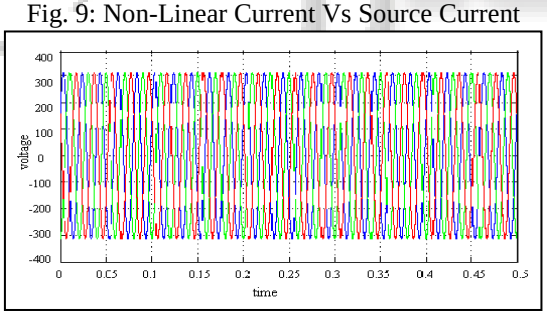

Fig. 10: Grid Voltage

XII. CONCLUSION

In this paper, a proposed control system for combined operation of active power filter with PV generation system in on-grid operation mode has been presented. A validated 200W PV dynamic model has been used to model PV arrays. The dynamic model of PV modules and its power electronic interfaces have been modelled, too. Also, an id-iq control strategy for active power filter has been suggested, which is based on instantaneous active and reactive current method which helps in injecting the active current. The current and DC voltage controllers have been used to transfer the PV power and synchronize the output converters with the grid. The controller designs for different operation modes of active power filter have been studied. It is observed that the instantaneous active and reactive current id-iq method with PI controller leads away better results under unbalanced and non-sinusoidal conditions over the generalized instantaneous reactive power method. The simulation results, carried out by MATLAB software, show the effectiveness of the suggested control systems in grid-connected mode. Also, the simulations show that the proposed control system results in power factor correction, harmonics suppression, and load balancing and non-sinusoidal voltages will be suppressed.

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