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ANALYSIS OF PV SYSTEM EMBEDED TO DISTRIBUTION GRID FOR ACTIVE & REACTIVE POWER SUPPLY TO GRID

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***Abstract* — In this paper presents a grid connected photovoltaic (PV) system with maximum power point tracking (MPPT). The Voltage Source Inverter (VSI) has been connected between the dc output of PV system and the ac grid. The control strategy applied is based on instantaneous reactive power theory (p-q theory). According to this theory during the sunlight system send active power to grid and same time compensate the reactive power of load and compensate the harmonics. During no sunlight available system only compensate reactive power of load and harmonics. The applicability of the p-q theory control method has been verified on the test system using simulation in Matlab/Simulink.*

***Keywords*- Grid-connected PV system, Instantaneous reactive power theory, MPPT, Reactive power compensation, Power quality.*

I. INTRODUCTION

In recent decades the development of the electricity market has accelerated the use of higher power quality and improved stability. One of the major utilities concerns of is maintain network reliability. Rising energy transfers raise concerns about overloading steady state increasing the risk of voltage collapse and potential stability problems. Therefore, the growing demand for electricity and the increasing use of nonlinear loads have created new challenges for the power quality and stability that lead to the need for security, the network of efficient and clean AC. Energy reserves, such as coal, is likely to be extinct in the near future oil. In addition to the average environmental pollution has led to problems such as emissions of greenhouse gases, acid rain and global warming.

So renewable energy has become increasingly attractive due to the rules of environmental protection and the severe shortage of conventional energy sources. Photovoltaic (PV) generation is the technique that uses photovoltaic cells to convert solar energy into electrical energy. Photovoltaic is assuming increasingly important as a source of renewable energy in place due to its clear advantages, such as simple architecture, easy allocation, pollution-free, low maintenance cost, and etc.

In this paper, the design of photovoltaic system using simple circuit model with detailed modelling of photovoltaic modules circuit is presented. [1] The physical equations governing the (also applicable to PV cells) PV module presents. The operation of the circuit model developed with DC to DC boost converter was verified with simulations. [2] This paper proposes the use of the theory of the instantaneous reactive power (PQ theory). [9] Which controls the active and reactive power at the inverter output. Here presents the experimental verification of simulation results. This paper also proposes to develop a photovoltaic simulation system with maximum power point tracking (MPPT) function using Matlab/Simulink software in order to simulate, evaluate and predict the behaviors of the real photovoltaic system [8]. A model of the most important component in the photovoltaic system, the solar module, is the first to have been established. The characteristics of the established solar module model were simulated and compared with those of the original field test data under different temperature and irradiance conditions. After that, a model of a photovoltaic system with maximum power point tracker (MPPT), which was developed using DC-DC boost converter with the perturbation and observation method, was then established and simulated.

II. PROPOSED SYSTEM

The proposed system is shown in Fig. 1, for analysis of the system's knowledge of the mathematical models that reflect the electrical quantities at the output of the Photovoltaic panel and solar cell is required.

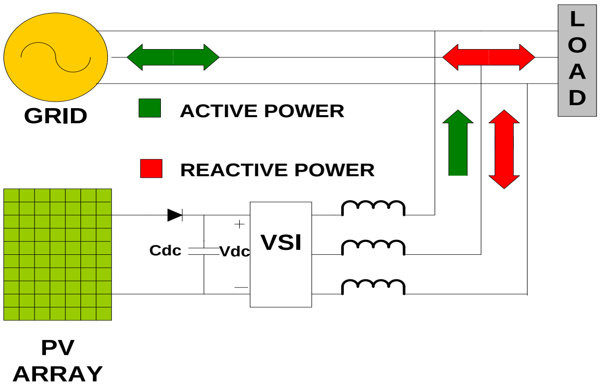

Figure 1. Proposed Grid Connected PV System

2.1. Equivalent Circuit of PV Modelling

A PV array consists of several PV cells connected in series and in parallel. Serial connections are responsible for the higher voltage of the module, while the parallel connection is responsible to increase the flow in the matrix. Typically, a solar cell can be modelled by a current source and a diode connected in reverse parallel. It has its own series and parallel resistance. Series resistance is due to the impediment to the flow path of electrons output P and N parallel resistance is due to the leakage current.

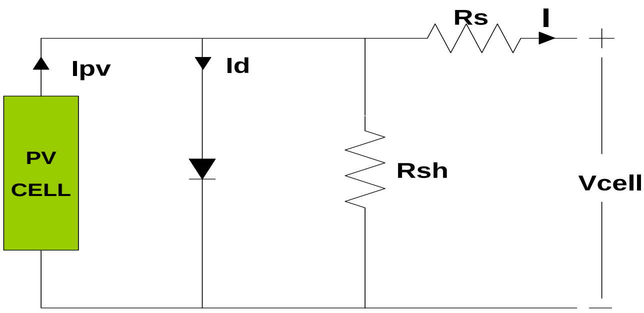

Figure 2. Mathematical Model of PV

The current-voltage relation of the PV cell using PV model is represented by following equations.

$$I = Ipv - Id \tag{1}$$

$$Id = Io\,(e\wedge(\frac{q(V + IRs\,)}{nkT}) - 1) \tag{2}$$

$$Ipv = Ipvn\,(1 + Ki\,(T - T_1\,))\frac{G}{Gn} \tag{3}$$

$$Io\ = \frac{(Iscn + (Ki(T - T_1\,))}{e^{\frac{(Vocn + Kv(T - T_1\,))}{(aVt\,)}} - 1} \tag{4}$$

Where Ipv is the current generation by the incident light (it is directly proportional to the sun irradiation), Id is the Shockley diode equation and Io is the reverse saturation or leakage current of diode. Io is the reverse saturation or leakage current of diode.

2.2 MPPT Algorithm

MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. In this work, Perturbation and Observation (P&O) is used.

It is most commonly used algorithm. In this method, the MPP is tracked by perturbing the duty ratio of boost converter at a regular interval based on the slop of power-voltage (P-V) curve. If the perturbation in duty ratio increased the power than the next perturbation sign is same otherwise perturbation sign is changed. This process is repeated until MPP is reached. Shows in the Fig. 3, the flow chart of P & O MPPT method.

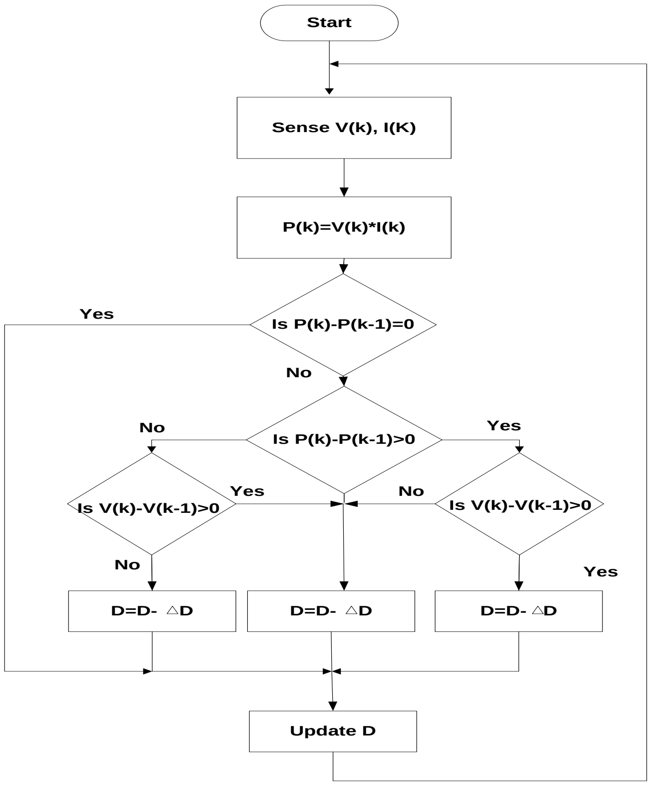

Figure 3. P&O MPPT Flow Chart

III. CONTROL STRATEGY OF GRID CONNECTED PV SYSTEM

For the control strategy of the grid-connected PV system "instantaneous reactive power theory" (P-Q theory) is applied and for control inverter output current the hysteresis bandcontrol technique is used. Block diagram of control strategy for proposed grid connected PV system show in the fig.4.

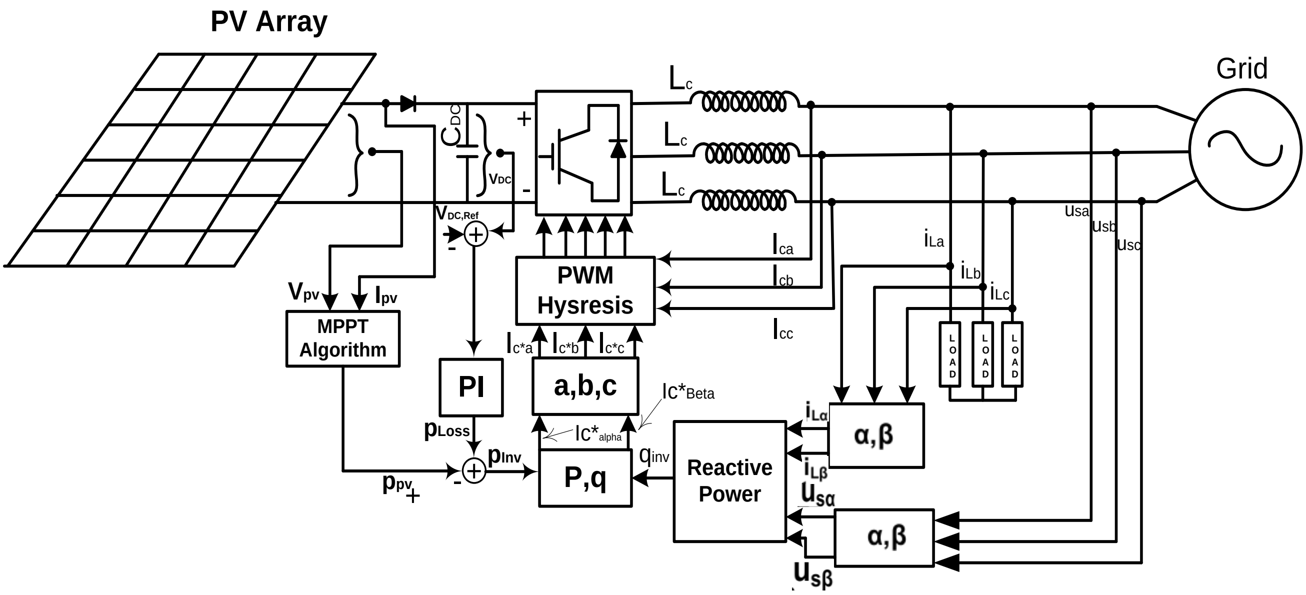

Figure 4. Block Diagram of Control Strategy of Grid Connected PV System

The PV inverter injects the active power and reactive power in controlled manner. The PV inverter is also used utilized as an active power filter to compensate the load harmonics and reactive power.

According to voltages "instantaneous reactive power theorem" and load currents are transformed from abc coordinate reference system α-β coordinate reference system (Clark transformation) this transformation is shown in Fig.5.

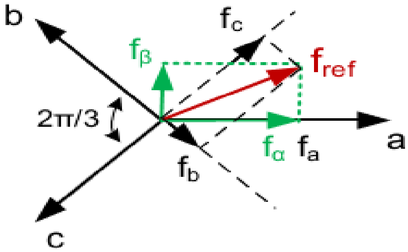

Figure 5. Transformation from a-b-c into α-β coordinates system

The mathematical relationships of the load current and voltages in the two different coordinate systems are given by equations (5) and (6) respectively

$$I_{L,\alpha\beta} = MI_{Labc} \quad (5)$$

$$V_{L,\alpha\beta} = MV_{Labc} \quad (6)$$

Where,

$$I_{L,\alpha\beta} = \left[I_{L\alpha}\, I_{L\beta}\right]^T \quad (7)$$

$$V_{L,\alpha\beta} = \left[V_{L\alpha}\, V_{L\beta}\right]^T \quad (8)$$

M is the matrix of Clark transformation and equals to:

$$M = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \quad \text{And} \quad M^{-1} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \quad (9)$$

3.1 Active Power Control

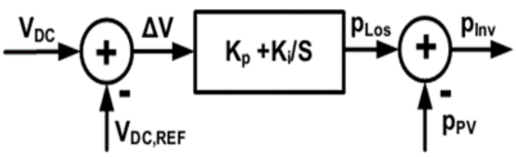

Figure 6. Block Diagram of Inverter's Active Power Control

In voltage source inverter due to switching operation some losses are caused in the above circuit. According to the block diagram of Fig. 6, the losses are covered by the solar system when the PV operates and supplies the active Power grid with. During the period when the PV system produces active power, then the losses are covered by the investor network.

3.2 Reactive Power Control

p-q theory introduces a new variable, which is the instantaneous imaginary power q corresponds to the instantaneous reactive power. Instantaneous reactive power with the inverter feeds the load is given according to the theory by the following equation p-q:

$$q = V_{s\alpha} I_{L\beta} - V_{s\beta} I_{L\alpha} \tag{10}$$

3.3 Reference Current Generation

The p-q theory based on the instantaneous active and reactive power, calculates reference currents in the α-β system according to the equation 11.

$$\begin{bmatrix} I^*_{c\alpha} \\ I^*_{c\beta} \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ V_{s\beta} & -V_{s\alpha} \end{bmatrix} \begin{bmatrix} P_{pv} - P_{loss} \\ -q \end{bmatrix} \tag{11}$$

Using the reverse transformation of the equation .We can calculate the reference currents in the ABC system of coordinates according to the following equation.

$$\begin{bmatrix} I_{ca} \\ I_{cb} \\ I_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I^*_{c\alpha} \\ I^*_{c\beta} \end{bmatrix} \tag{12}$$

3.4 Current Control

To control the inverter output current control technique apply current hysteresis band, shown in Fig. 7, With this method a region around the reference current trying to keep the output current of the inverter within this zone is created. The advantages of the technique of controlling the hysteresis band are its simple application. It's very good dynamic behavior and rapid response.

The hysteresis band current control sets the time and duration of each pulse. The logic of the witches for phase "a" is summarized as follows:

- If the inverter output current reaches the upper limit of the zone, then the upper switch is off and the bottom switch is ON.
- If the inverter output current reaches the lower limit of the zone, then the upper switch is ON and lower switch is off.
- The switching phase "b" and "c" are determined similarly.

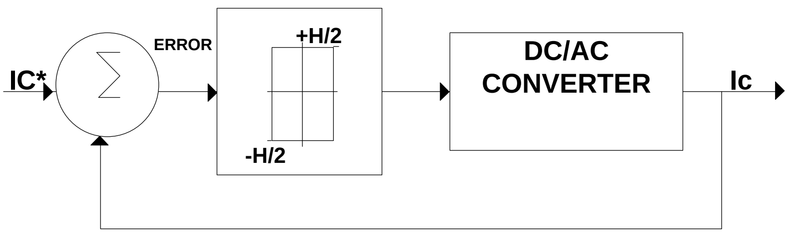

Figure 7. Block diagram of hysteresis band current control technique

IV. SIMULATION RESULTS AND DISCUSSION

The proposed Photovoltaic cells are not only capable of supplying extracted solar power to the power system, but it also can significantly compensate the reactive power and mitigate harmonic currents which are drawn by non-linear loads.

In order to demonstrate the validity of the concepts discussed previously a simulation using MATLAB/SIMULINK environment is done as it is shown in Fig. 4, the parameters of the system are shown in Table I and II.

TABLE.1 PARAMETERS OF POWER SYSTEM

Description	Parameters
Capacitor (DC bus side)	2000µf
Grid Voltage (Per Phase)	230 V
Frequency	50 Hz
Inductance of grid	1.2 mh
Load	20.14 kw

Table.2 Parameters of PV system

Description (20.14 kw)	Parameters
Number of PV cell in per module	96
Open circuit voltage Voc	64.2 V
Short circuit current Isc	5.96 A
Maximum output voltage Vmax (in Volt)	54.7 V
Maximum output current Imax (in Ampere)	5.58 A
No. of series connected module per string	6
No. of Parallel connected module per string	11

Show in fig.8, the changes in solar radiation at specific times. Based on the fig. 9, show the corresponding change in active power of PV system and grid to meet the demand of active power of load.

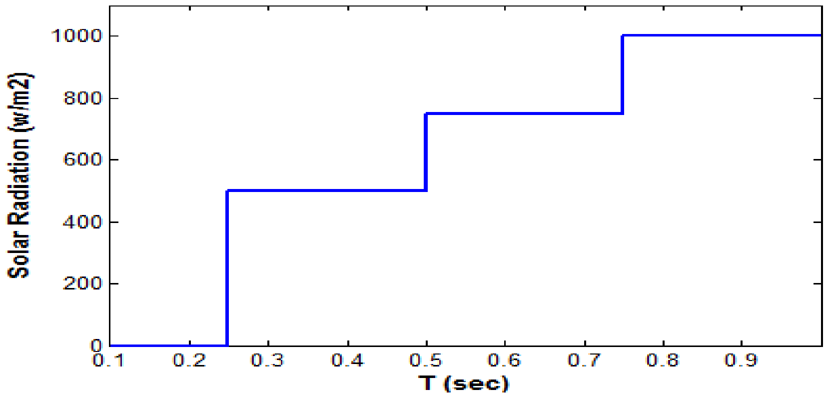

Figure 8. Solar Radiation

Under varying insolation condition load active power demand (20.14 Kw) and reactive power demand (7.4 Kvar) remains constant. For 0 sec. < t < 0.25 sec., insolation is 0w/m2, the active power generated by PV system is zero. Therefore load required active power is fulfilled by grid. At the time 0.25sec.and 0.5sec, there is sudden increase the insolation to 500 w/m2and 700w/m2respectively, the load required active power demand is greater than the generation of PV system, at that time PV system supplies all generated active power to the load and remaining active power is drawn from the grid. At the time 0.75 sec, the insolation increase to full, the active power generated is as same as load required demand active power. Therefore active power drawn from grid is zero. It can be observable that at any time $P_{LOAD} = P_{PVSYSTEM} + P_{GRID}$.

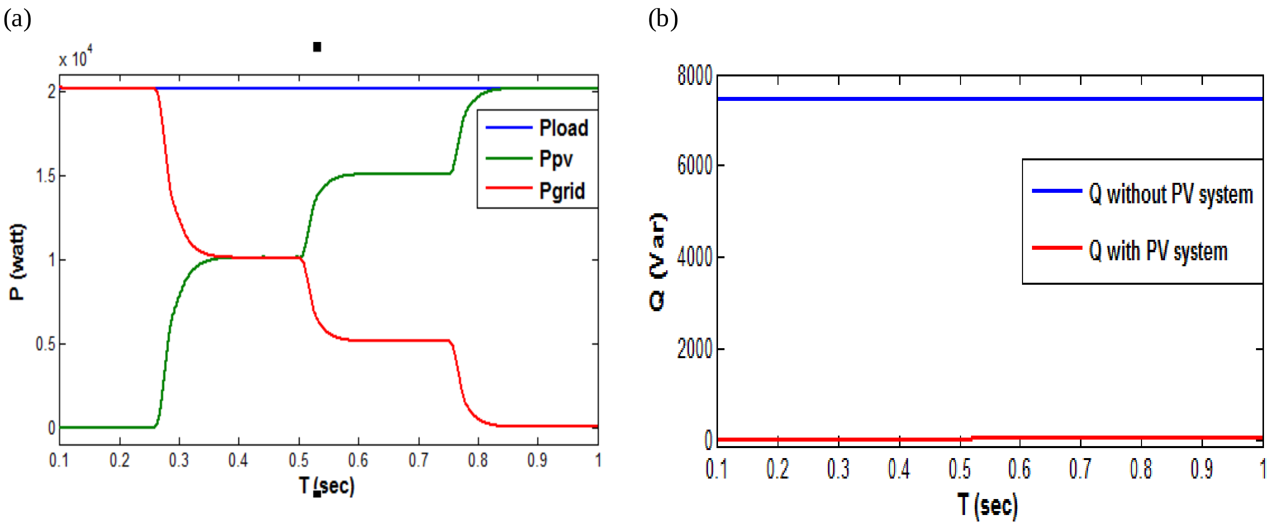

Figure 9. (a) Active Power of load, PV system and grid (b) Reactive power with and without PV system

Fig. 9 (b), show the result for reactive power of the load, PV system, and grid. In any insolation condition the inverter of PV system compensates 100% of load reactive power demand thus, reactive power drawn from grid is zero. Q_{LOAD} = Q_{INV}, Q_{GRID} = 0.

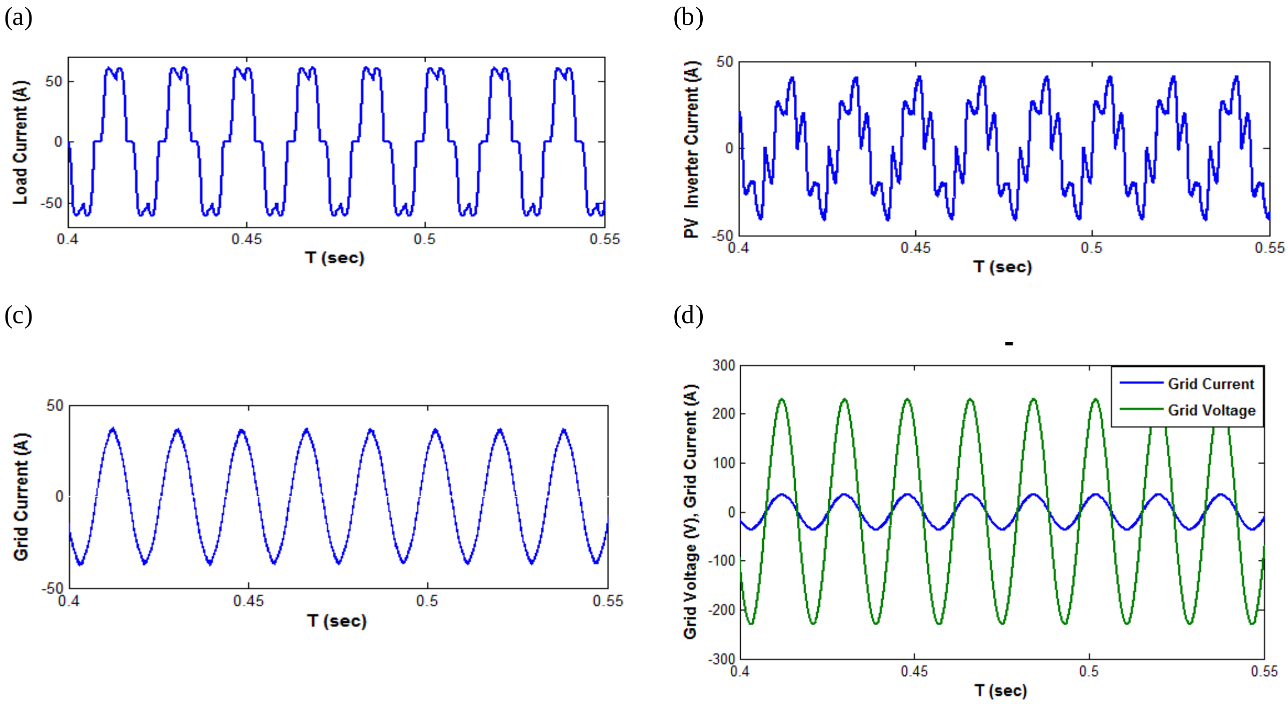

Figure 11. (a) Load Current (b) PV Inverter Current (c) Grid Current (d) Grid Voltage and Current

Fig. 11 (a),(b),(c), shows the phase current waveforms of the grid, PV system and nonlinear load respectively. The current of load is sum of PV system and current of the grid. It can observable that at any time I_{LOAD} = I_{INV} + I_{GRID}. Fig.11(d), shows that the grid phase a voltage and current waveform. We observe that the current is in phase with voltage because of all reactive power is compensated by PV inverter.

Also show in Fig. 12, (a) & (b) harmonic content list relative to fundamental is analysed of the source current with /without PV system. The source current total harmonic distortion (THD) before PV system which is 21.87 % and it reduced to 1.37%.

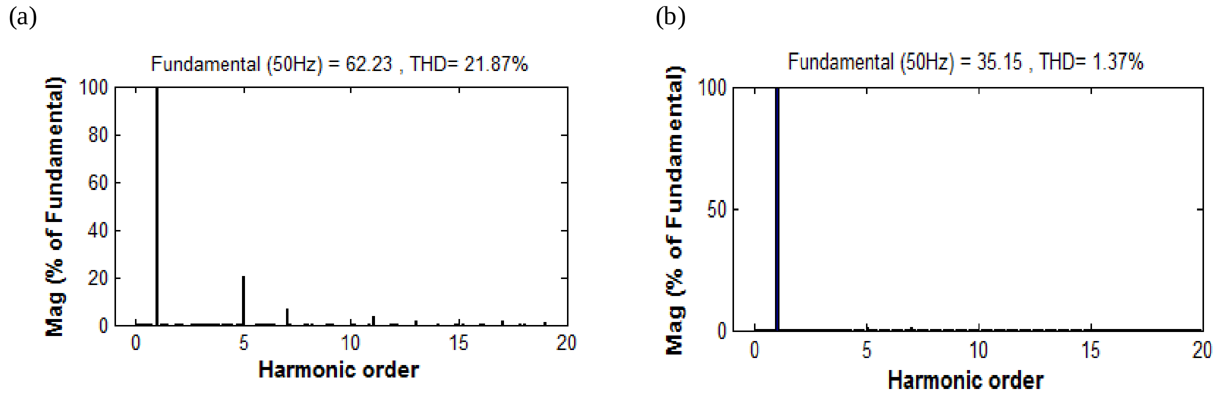

Figure 12. Harmonic analysis (a) with and (b) without PV system

Finally, it is clear that the PV system injects appropriate amount of current to mitigate harmonics generated by the nonlinear load and reactive power compensate at the same time deliver the excess active power to the grid.

CONCLUSIONS

Photovoltaic power seems to be the favourable clean energy source of the future. So, to optimize its use we have proposed a direct coupling of PV system to the grid. From the results obtained, it is proven that by using the proposed system, Photovoltaic power can be efficiently extracted by solar cells and injected into the grid and compensating reactive power of the load all 24 h of the day. The proposed system also compensate the harmonics content of nonlinear load. Finally and according to the obtained results we can consider the proposed system to be efficient solution to the growing demand of power and power quality problem at the present and in the future.

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