The Novel Control Method for Photovoltaic Converter to the National Grid

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Abstract

In this paper, a novel control method for photovoltaic converter connection to the national grid is presented, so in addition to the injection control by solar arrays to the grid, this method can compensate reactive power and harmonics in the load current. The system will be connected in parallel between the grid and load. The proposed system supplies all load power consumption (including active power and reactive power) and if less power is produced by the solar array inverters, the proposed method can be used to compensate the remaining reactive power and harmonics of load. Using this method, power factor of the system will be equal to unity. Finally, to verify the performance of the method, a grid-connected photovoltaic system is simulated.

Keywords: photo voltaic converter, solar array, reactive power and load current harmonic compensation.

1- Introduction

A photovoltaic (PV), or solar electric system, is made up of several photovoltaic solar cells. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. To boost the power output of PV cells, they are connected together to form larger units called modules. Modules, in turn, can be connected to form even larger units called arrays, which can be interconnected to produce more power, and so on. In this way, PV systems can be built to meet almost any electric power need, small or large. By themselves, modules or arrays do not represent an entire PV system. Systems also include structures that point them toward the sun and components that take the direct-current electricity produced by modules and "condition" that electricity, usually by converting it to alternate-current electricity. PV systems may also include batteries. These items are referred to as the balance of system (BOS) components. Combining modules with BOS components creates an entire PV system. This system is usually everything needed to meet a particular energy demand, such as powering a water pump, the appliances and lights in a home, or—if the PV system is large enough—all the electrical requirements of a community. Grid interconnection of PV power generation system has the advantage of more effective utilization of generated power.

However, the technical requirements from both the utility power system grid side and the PV system side need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid.

Clarifying the technical requirements for grid interconnection and solving the problems such as islanding detection, harmonic distortion requirements and electromagnetic interference are therefore very important issues for widespread application of PV systems [1]. Grid interconnection of PV systems is accomplished through the inverter, which converts dc power generated from PV modules to ac power used for ordinary power supply to electric equipment's. Inverter system is therefore very important for grid connected PV systems. Grid connection and extension costs are significant factors for integrating renewable energy sources-electricity (RES-E) generation technologies into an existing electricity network. Prices of both PV and BOS are decreasing, following a trend of increased production and improved technology. This explains the high amount of subsidies for R&D and application of PVs in industrialized countries.

The solar PV electric power generation will play an important role in the future energy supply in China[1].Photovoltaic arrays, convert solar energy directly into electrical energy, and compared to traditional energy systems, these system pollute the environment. For this reason they are also called photovoltaic systems and energy sources or "green" "Clean". With increasing environmental problems, pollution, and declining stocks fossil energy, using photovoltaic systems is increased in recent years [2].Historically, photovoltaic systems due to their high costs were generally used for the power required for electrical satellites.

However, by growing semiconductor industry in recent years and reducing the expenses of production of semiconductor devices, nowadays solar array are used for most practical usages, and one of them is photovoltaic system connected to grid. These systems are used to inject productive power to the grid by solar arrays, and also some other several ways are presented [3], [6].

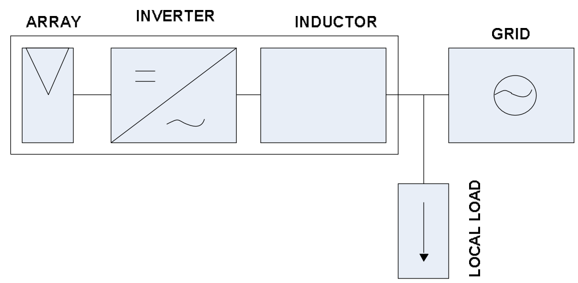

Fig.1. Total structure of photovoltaic systems connected to the grid

In this paper, a new controlling method to connect photovoltaic systems to the grid is presented and figure 1 shows the general structure of such systems. If there is not photovoltaic system here, it is natural that the total active and reactive power consumption will be provided by the grid. If photovoltaic system just injects reactive power into the grid [3], [5], active power from the grid will be decreased by the load, but reactive power drawn from the grid will remain constant. In this way, the grid power factor will be decreased, which is not desirable. To fix this problem, the used controlling method should be capable of producing reactive power of the system [4], [6]. If photovoltaic system produces needed reactivity, in this case, the power factor will be the same grid. It should be noted that usually the array under the terms of most possible solar power produces a DC/DC converter used for connecting solar energy to inverter.

This converter was not the subject of this article, and it is well explained in references section [7], [9]. Using non-linear loads causes harmonic current in the whole grid. Existence of such harmonic current will produce additional losses in transmission lines and will reduce power factor. It is also possible that the parallel capacitors which are connected to the grid cause harmonic resonance .It is mentioned in [10] that the harmonics cause dysfunction in function of sensitive equipment, telecommunication systems, etc.

It was recently shown that we can utilize inverters connected to the grid as active filters [11]-[12]. In this paper, a new controlling method for connecting photovoltaic systems to the grid is presented. In this way, in addition to this fact that solar arrays inject generative power to the grid and also compensate needed load for reactive power, they compensate the load current of harmonics. Harmonic compensation by the controlling method causes the grid current to be entirely sinusoidal, and thus load of harmonics don't enter inside the grid. In this controlling method, if the power produced by the solar arrays is less than inverters' power, we can utilize the remaining capacity to compensate reactive power or filtering of harmonics.

Another feature of the proposed method is that if the grid cuts off entirely, photovoltaic system has this ability to supply power to the load. In this mode, the system will act like an uninterrupted power supply called (U.P.S).

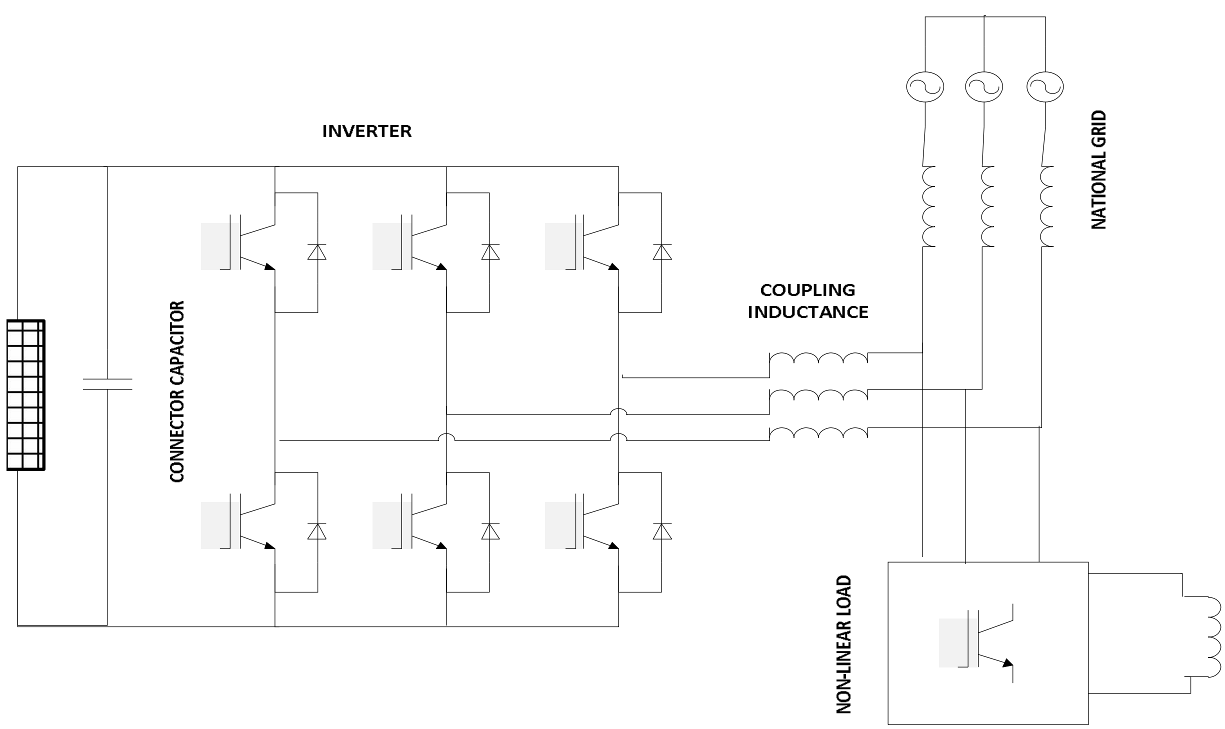

Fig.2. Details of Photovoltaic system connected to grid

2- System Description

In figure2, a photovoltaic system connected to the grid shows more details. In this system, solar arrays are connected to the grid by a voltage source inverter. For connecting VSI to the grid, a series of inductance is used. This series inductance provides the output power of inverter .Considering the matter that total behavior of solar array is a current source [13], in order to utilize them with VSI, a dc capacitor is used in the inverter input.

In grid's perspective and based on the way of controlling method, VSI may act like an ac source, resistor load, inductor and capacitors, all of which can be seen in the same appearance. In normal situation, photovoltaic system, in addition to the power production injected by solar array to the grid, harmonics of load current and also it generates the power of consumed reactive. In this way the drawn current or injected one into the grid is entirely sinusoidal and also it will be in the same phase. (Grid power factor is almost 1).

The topology used in this paper is a voltage source inverter (VSI) because according to the used controller, inverter of input voltage is almost constant. One of the methods of controlling VSI is controlling the output current.

Using method of controlling current to connect photovoltaic systems to grid is more appropriate because:

• Since the grid is almost a constant voltage source, in order to control the power transferred between VSI and grid, we can just control power current through the grid or vice versa.

If we use method of controlling voltage for connecting photovoltaic system to the grid, the smallest error in output inverter voltage phase would pass many currents from the system. Meanwhile, Procedures based on this method of controlling current don't have such problems [14]. In this paper, method of hysteresis for controlling inverter current is used [15].

In the presented method in this paper, the photovoltaic system controller based on power generating of the solar array and also the harmonic currents and reactive power specifies the inverter reference current and it puts that under control of hysteresis controller .Hysteresis controller commands the switching inverter in a way that output current of inverter is equal to reference current.

The performance way of photovoltaic systems connected to grid entirely depend on strategy of control chosen for VSI convertor. In general, the strategy of controlling these systems must have the following abilities:

1. Production of reference current waveform of each of three-phases
2. Stabilized dc input capacitor voltage

3- Control Strategy

In this paper, to specify current of reference inverter, the theory of instantaneous reactive power on controlling active filters presented by Akagi is used [16]. In this system, the reference currents are those currents that if they get generated by inverter, generative power is injected to the grid by the solar array and harmonic currents and reactive power will be compensated by the inverter.

The theory of instantaneous reactive power on the transition of the voltage and current variations is founded in αβ coordinates. The instantaneous values of voltage and current variations in αβ coordination can be calculated by the following equation:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = [A]\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = [A]\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

Where, [A] is matrix of transmission:

$$[A] = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \quad (2)$$

If the above conversion functions are correct $v_a + v_b + v_c = 0$ and voltages v_a, v_b, v_c Sinusoidal and are balanced, instantaneous active and reactive power at the αβ coordinates can be calculated by using the following equations:

$$P(t) = v_\alpha(t) i_\alpha(t) + v_\beta(t) i_\beta(t) \quad (3)$$

$$q(t) = -v_\alpha(t) i_\beta(t) + v_\beta(t) i_\alpha(t) \quad (4)$$

i_α and i_β currents based on the amount of instantaneous powers can be written as follows:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2}\begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix}\begin{bmatrix} p \\ q \end{bmatrix} \quad (5)$$

P and q values which are presented by equations (3) and (4), are sum of the component of the dc and component ac:

$$p = \bar{p} + \tilde{p} \quad (6)$$

$$q = \bar{q} + \tilde{q} \quad (7)$$

In the above equations:

$\bar{p}$: Dc component of the instantaneous power is p and it is related to the main component active current.

$\tilde{p}$: Ac component of the instantaneous power is p and it is related to those groups of harmonic currents that are generated by active component of the instantaneous power.

$\bar{q}$: Dc component of theinstantaneous power is q and to the reactive power which is related to the main components of voltage and current that gets generated.

$\tilde{q}$: Ac component of the instantaneous power is q and it is related to those groups of to those harmonic currents that are generated by reactive component of the instantaneous power. Because of this fact that photovoltaic system can generate harmonic currents produced by nonlinear load, current of its reference must contain $\check{p}$and$\bar{q}$and$\check{q}$.

The advantage of using this theory is that, active and reactive powers correspond to the main component voltage current in dc form, and each one of them can easily be deleted if it was needed to do so. In photovoltaic systems connected to the grid, VSI controlling strategy should not only provide reactive power and current harmonics related to the load, but also it should inject generative active power by solar array to the grid.

If you ignore the inverter losses, the difference between generative powers produced by the solar array and injected power active into the grid is stored in the dc capacitor:

$$\int_{-\infty}^{t} (V_c i_{pv} - P_{active}) d\lambda = \frac{1}{2} C V_c^2 \quad (8)$$

In the above equation, V_c is capacitor instantaneous voltage of inverter input, i_{pv}, is instantaneous current drawn from the solar array and P_{active} is instantaneous power injected into the grid via the inverter. If the power produced by the solar array is not injected into the grid, according to the fact that solar array has current source nature, capacitor voltage will be increased linearly. Controller should control the amount of active power injected into the grid, in that the capacitor voltage ever remains constant.

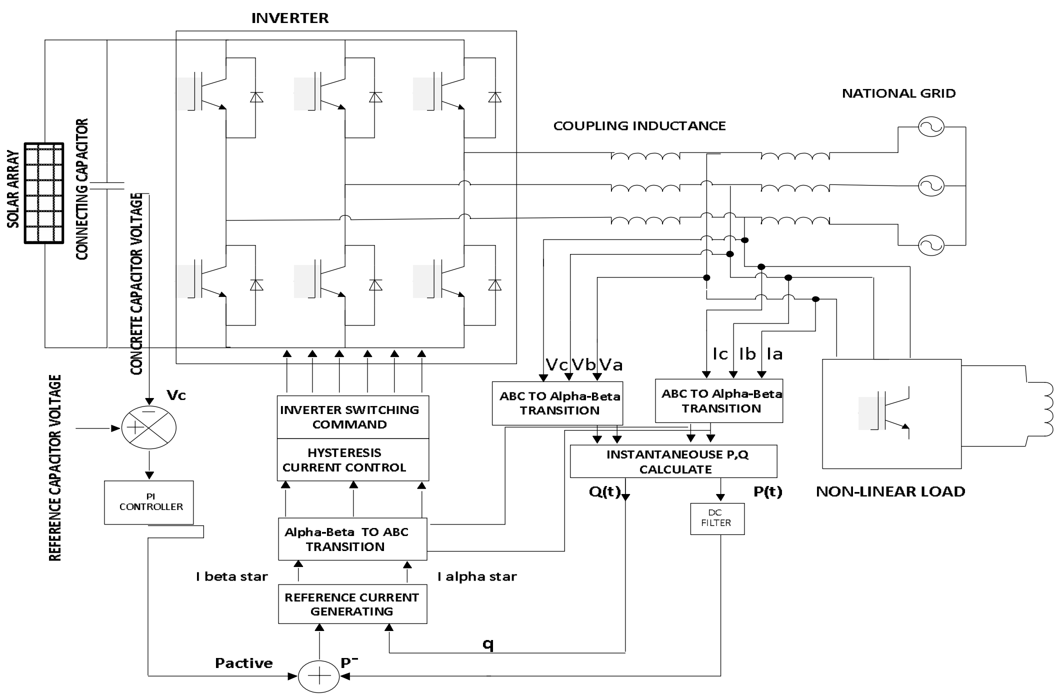

Fig.3. Photovoltaic system connected to grid

Thus, the active power injection of solar cells to the grid can be written as following:

$$P_{active} = K_p(V_c^* - V_c) + K_I \int (V_c^* - V_c)dt \qquad (9)$$

In the above equation, V_c^* is the capacitor reference voltage, V_c capacitors instantaneous voltage, K_p and K_i are proportional and integral factors and they are related to the PI controller. Selection of these coefficients occurs based on a compromise between the steady and dynamic state.

If K_p and K_i be considered large, steady-state error response will be reduced. On the other hand, if K_p and K_i are small, dynamic performance against variations in sun light and environment temperature will be better.

According to equation (5), photovoltaic system reference currents in αβ coordinates, which has the ability to generate reactive power and load harmonic currents and injection of generative power by solar array to the grid. This can be expressed as following:

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p}_L + P_{active} \\ \bar{q}_L + \tilde{q}_L \end{bmatrix} \qquad (10)$$

In the above equation, V_α and V_β are load voltages in the αβ coordinates and i_a^*, i_b^* are photovoltaic system reference currents at αβ coordinates, P_L and q_L are the load instantaneous power at αβ coordinates and P_{active} is the output related to capacitor voltage dc input controller. Reference currents in abc coordinates can be written as following equation:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \qquad (11)$$

If the inverter output current equals i_a^* ‘ i_b^* and i_c^*: The power produced by the solar array to the grid injected implies that the capacitor voltage dc input always remains constant.

1. Harmonic current sand reactive power are provided by the inverter as power factor grid almost equals by one and harmonic currents don’t enter in the grid.

If the power produced by the solar array is low, the controller related to the voltage can attract amount of active power from the grid so voltage of capacitor doesn’t plague in the loss of inverter and photovoltaic system is able to provide reactive power and load harmonic currents.

4- Simulation Results

In this section to verify the correctness of the proposed method, photovoltaic system connected to the grid based on controlling strategy using MATLAB software discussed in chapter 3 is investigated. Figure 3 shows photovoltaic system connected to grid. Parameters used in the simulation are: Phase to neutral grid voltage: 220 V, input dc reference capacitor voltage: 800 V, input capacitor capacity: 1mF and inductance connected to grid: 500 Micro Henry

In controlling current of inverter in hysteresis method, if bandwidth of hysteresis is constant, switching frequency will vary in each cycle. In this article in order to fix this problem, the hysteresis band width is set in the way that the switching frequency ever remains constant about 10 KHz. At first an RL load is used as reactive power consumer. Figure 4A shows results of simulation photovoltaic system in MATLAB. Figure 4B shows inverter current control with hysteresis method in MATLAB. Figure5A shows dc link voltage and Figure 5B shows output of dc link voltage. The results of the simulation based on the presented model are shown in figure 6. Figure 6A assumed that the generative power is less considering the use of solar array, and the system connected to grid can only generate load reactive power. In this way the active power of load consuming is drawn by the grid. In Figure 6B it is assumed that the power produced by the solar array is over required power.

In this case, it is observed that photovoltaic system in addition to feeding active power and required reactive power, injects active power into the grid. To consider way of compensating load harmonics by this system, a full bridge three-phase diode rectifier is used .Results taken from the simulations demonstrate that despite the harmonically load current and also consuming power of reactive by it, current drawn from the grid in figure 7A and current injected to grid in figure 7B are almost sinusoidal and in the same phase with the line's voltage. In figure 7A it is observed that photovoltaic system just compensates the harmonic current and reactive power of load. This system acts like an active filter in this case (Active Filter).One of the benefits of the control mentioned in this article is as if grid voltage cuts off during system operation, the system can be use desperately from the grid and it can provide the required load power. In this way the photovoltaic system functions in U.P.S form.

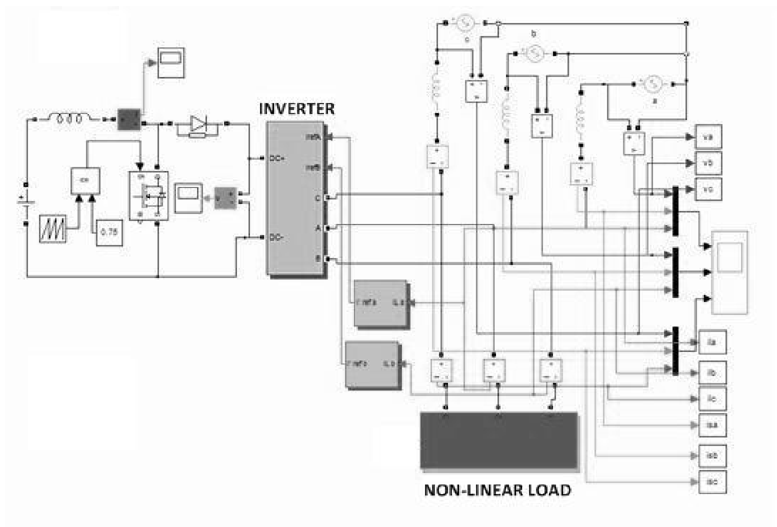

Fig. 4.A. Results of simulation photovoltaic system in Matlab

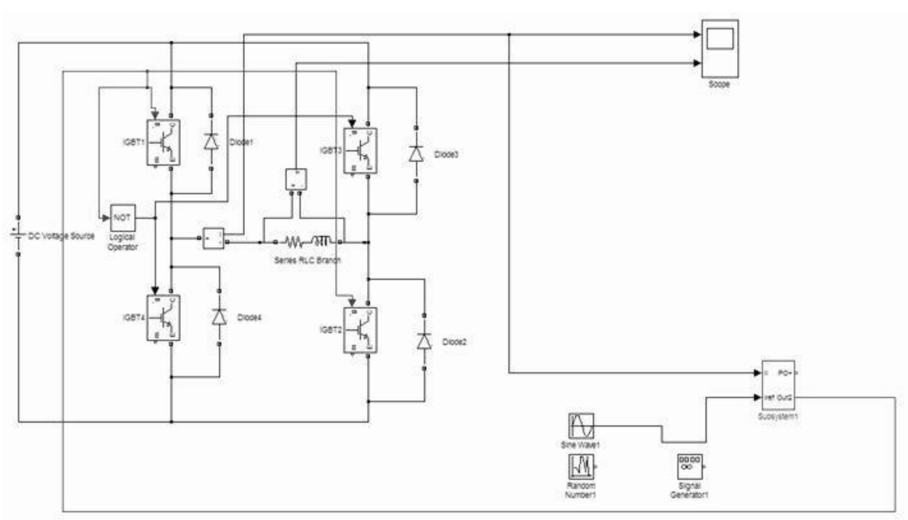

Fig. 4. B. Inverter current control with hysteresis method in MATLAB

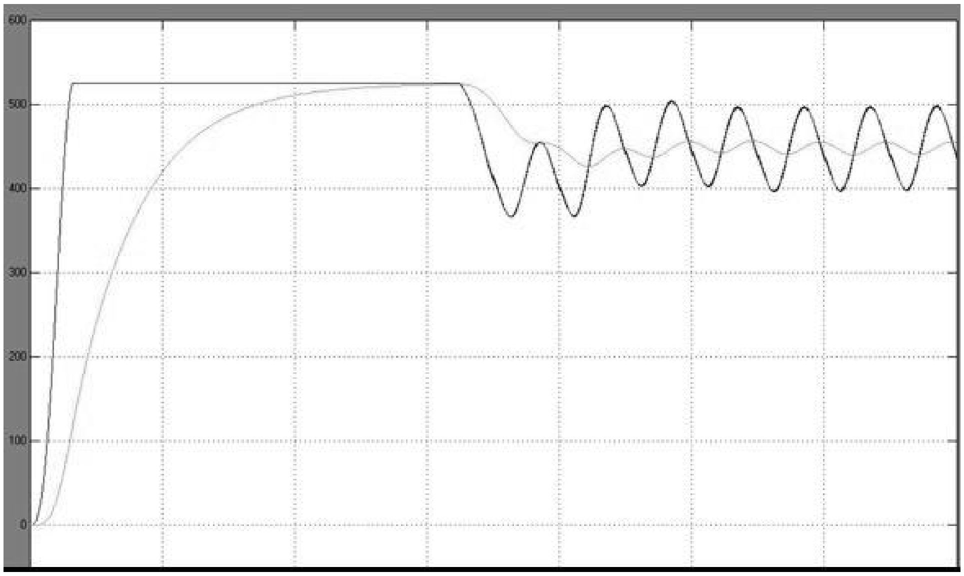

Fig. 5. A.DC link voltage

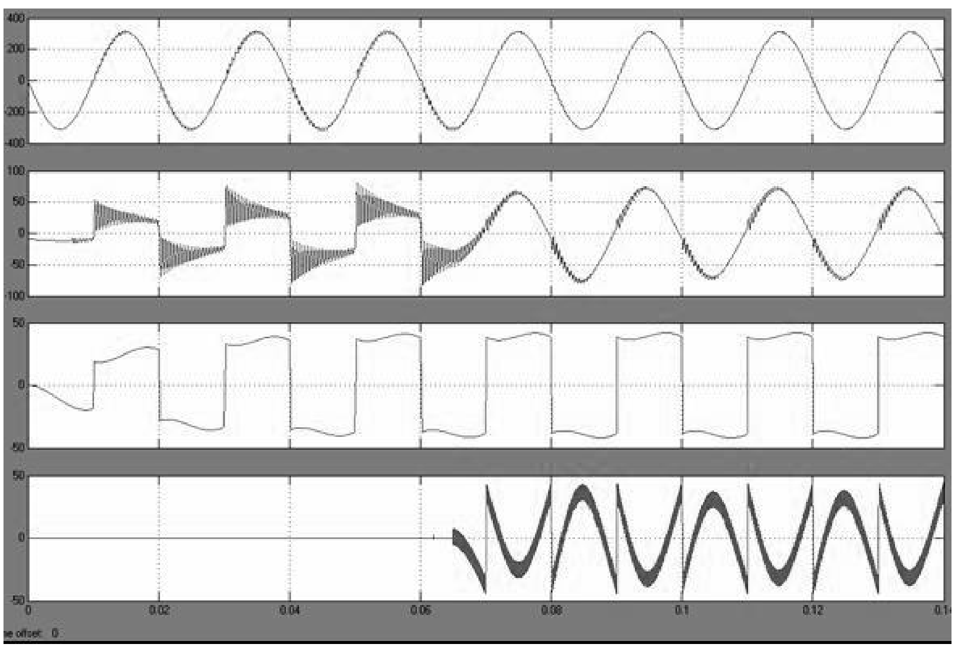

Fig. 5 B. Output of dc link voltage

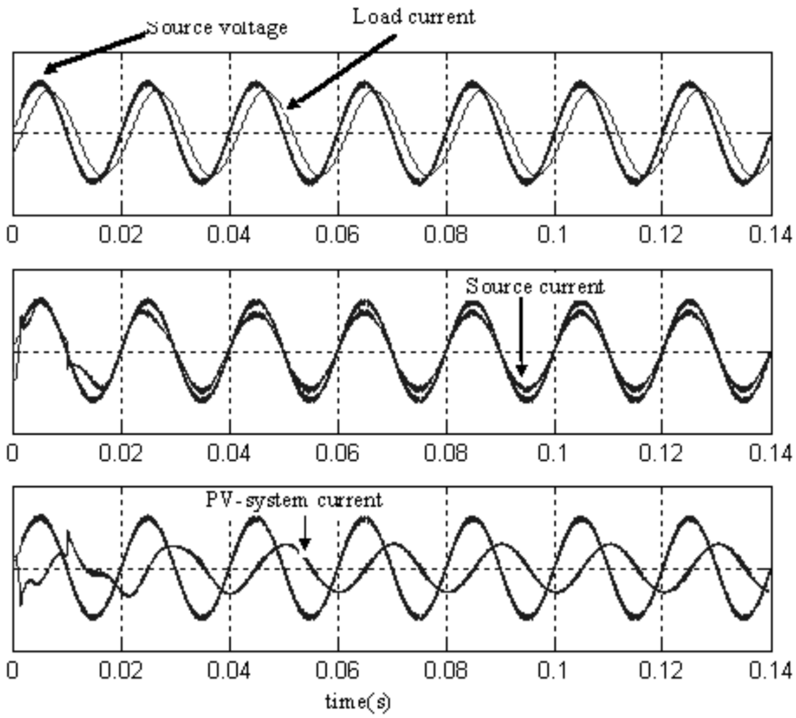

Fig. 6 .A. Photovoltaic system provides load consumption reactive power

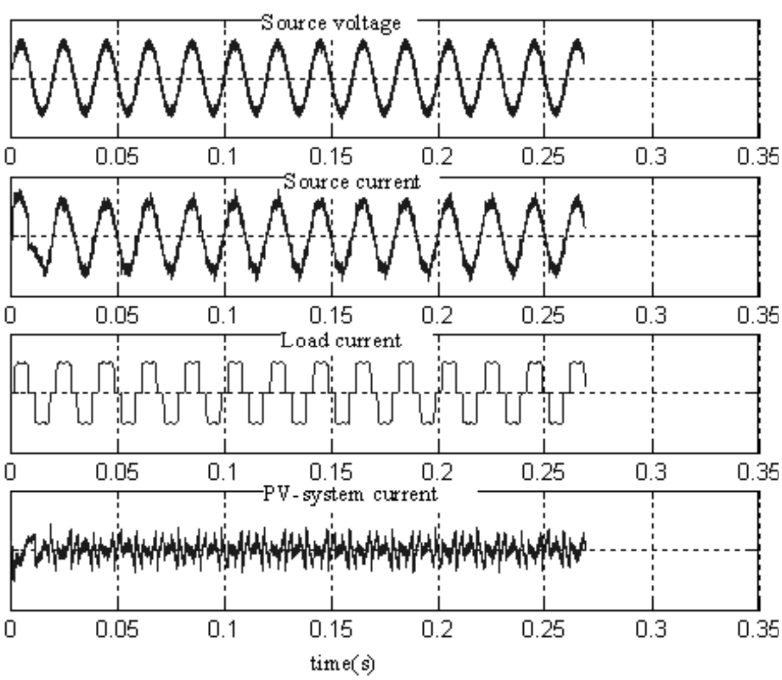

Fig. 6.B. Photovoltaic system in addition to provide load consumption reactive power, it also injects active power to grid

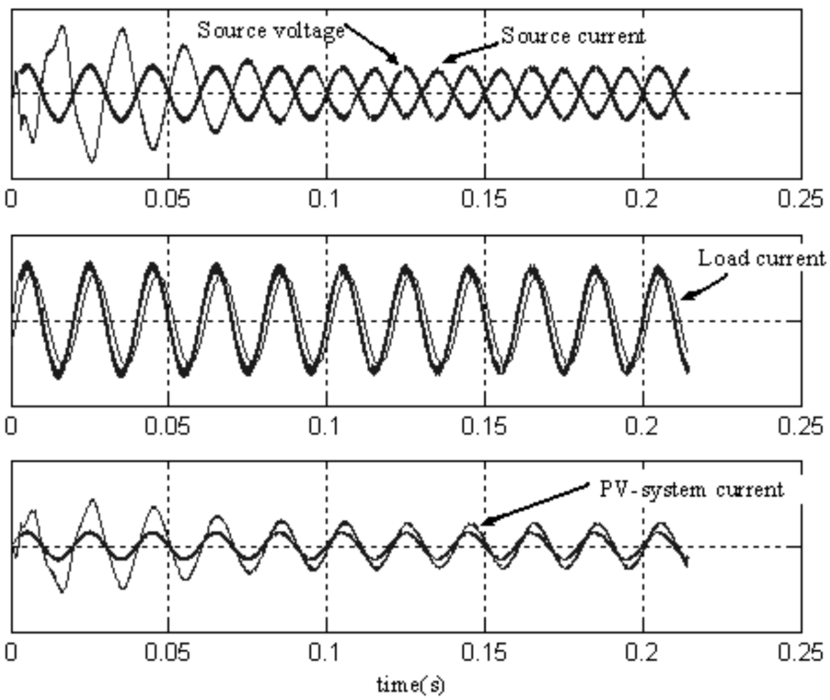

Fig.7.A. Photovoltaic system in addition to provide load consumption reactive power, it generate load harmonic current

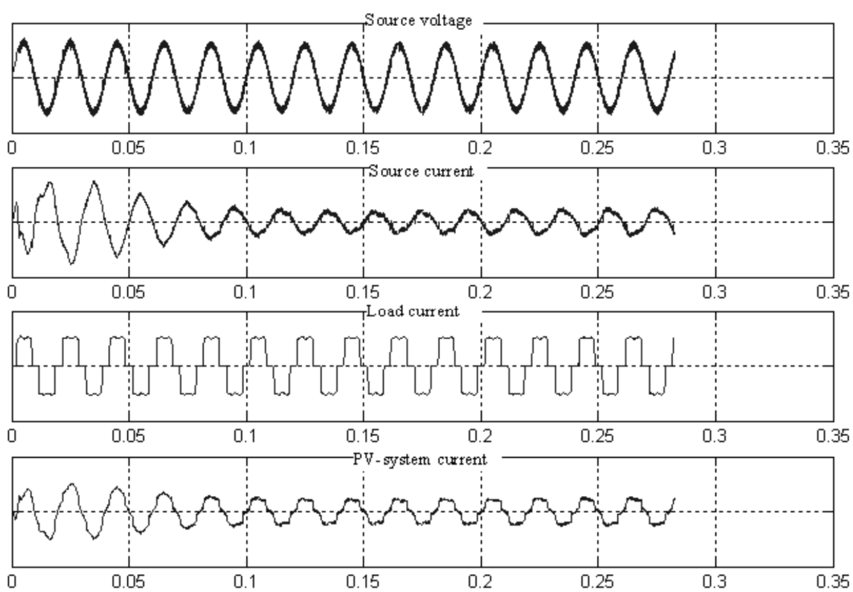

Fig.7.B. photovoltaic system in addition to compensate load, it injects active power to grid

5- Conclusion

In this article, a new controlling strategy for photovoltaic systems connected to grid is presented. The results of the simulation show that regardless of amount of power produced by photovoltaic array, the system can prepare reactive power and load harmonic currents compensate the inverter's power. And also, in the cut-off grid, inverters will feed the load without any interruption

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