RESEARCH ARTICLE OPEN ACCESS

Three-Phase Grid Connected Solar System With Svm Algorithm

Khac Lai Lai[1], Thi Thanh Thao Tran[2]
[1,2]Thai Nguyen University of Technology, Vietnam
Corresponding author: Khac Lai Lai

ABSTRACT
Solar and wind power are renewable energy sources that are considered as reliable alternatives for the conventional energy sources such as coal, oil, and natural gas. However, improving the efficiency and effectiveness of the renewable energy system is continuously growing up. The power electronic structures and control of them in photovoltaic (PV) grid connected are important parts of energy conversion and transmission. They need to be improved and perfected to satisfy the requirements of grid connection and performance enhancement. This paper presents the modeling of major electronic parts of the three-phase grid connected solar power system using the vector space modulation (SVM) method for inverter and incremental conductance algorithm (INC) to detect and maintain the optimal working point of PV. Controlling the active power and reactive power is implemented by SVM solution. The modeling and simulation results obtained by employing Matlab/Simulink show the effectiveness of proposed control method and satisfy the dynamics of the three-phase grid connected solar power system.
Keywords:photovoltaic,vector space modulation, power electronic transformation, three-phase inverter, three-phase power grid

---

Date Of Submission:16-11-2018 Date Of Acceptance:30-11-2018

I. INTRODUCTION

With the increasing demand of energy in the world, solar power is getting more popular. Compared with traditional energy sources such as coal, oil and gas, the photovoltaic energy is environmentally friendly. However, until now the problem of improving conversion efficiency and the ability to control them are still major constraints. In addition, the management of grid transmission systems are imposing tough standardsfor the PV system is connected to the grid. The requirements of electrical system stability and power quality are the main requirements that generator sources must adhere to when joining the power grid. Most renewable energy technologies in general and PV in particular produce DC power outputs.

A power electronic converter is necessary to convert DC energy from renewable source into AC. The converters either work independentlyor connect to the grid.In case of grid connection, it must ensure that the requirements for grid connection such as amplifier, frequency and phase order of the output voltage of the converter should be matched with the magnitude, frequency and phase order of grid voltage [1], [2], [9]. The converter control system is responsible for meeting grid connection requirements, and it also has to maintain other requirements to ensure power quality, such as harmonics, switching speed of electronic components used in converters and so on.

The control problem of grid connected can be separated into two parts: the controller of input and the controller of grid [3], [5], [8]. The control objectives of the input controller are to convert the DC voltage to the appropriate value, detecting and maintaining the maximum working point of PV. The goals of the grid controller are synchronized to the grid, distributed the power to the grid, and ensuring high quality of power is provided.

In this paper, we describe the operation of a three-phase power grid connected solar system, using the INC method to detect and maintain a maximum power working point of the PV; propose the method of using space vector modulation (SVM) for grid-connected inverters. The entire converter system is modeled and simulated by the Matlab / Simulink software, which includes the non-ideal parts of the electronic components that employed in the converters.

The paper is organized as follows: Structure of PV system connected to three-phase grid and mathematical description of the system are presented in section 2; Section 3 presents the control of a three-phase grid converter, including an incremental inductor algorithm, a SVM space vector modulation method and a grid-connected source-inverter synchronization method; The modeling and simulation results are shown in section 4. Finally, the conclusions and remarks are given.

II. STRUCTURE OF THREE-PHASE GRID CONNECTED PV SYSTEM

Figure 1 shows an electronic circuit structure to connect a photovoltaic to a three-phase grid. The major circuit consists of main blocks such as photovoltaic cells, turbochargers, DC lines, 3-phase inverters, filters and grids. The control circuit includes maximum power point detection, space vector modulation for inverters and grid synchronization.

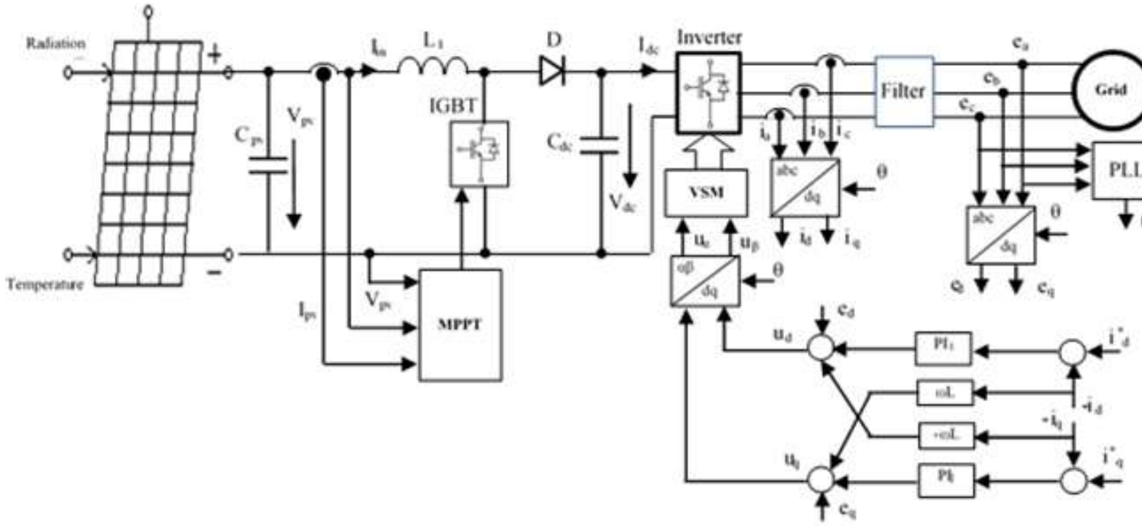

Fig. 1. Structure diagram of 3-phase grid connected PV system

1. Photovoltaic Generator - PVG

Photovoltaic generators are considered as current source with an equivalent electrical diagram as shown in Fig. 2 [2], [3]. The relationship between the current, voltage, and power (I_{pv}, V_{pv} and P_{pv}) parameters of a photovoltaic (PV) depends on the intensity of the solar radiation and its temperature as the following equation (1) [8], [9].

$$I_{pv} = I_g - I_0\left(e^{\frac{V_{pv}-I_{pv}R_S}{AV_t}} - 1\right) - \frac{V_{pv} - I_{pv}R_S}{R_{sh}} \quad (1)$$

where: I_g: photoelectric current (A); I_0 is the saturated reverse current (A); R_s is the serial resistor of cell pin (Ω); R_p is the parallel resistor of the cell (Ω); The N_s: the number of serial photocells; K is the Boltzmann constant ($K=1.338.10^{-23}J/^0K$); T_c is the working temperature of the photovoltaic (^0C); q is the charge of electrons ($1.602.10^{-19}C$)

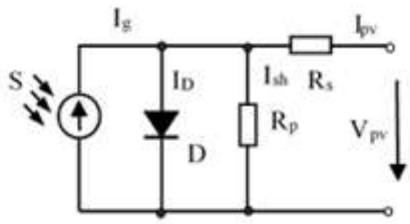

Fig.2. The corresponding circuit of PV module

The I-V relationship of photovoltaic corresponding to the different intensity of solar radiations and working temperatures is shown in Fig. 3 and Fig. 4 [1].

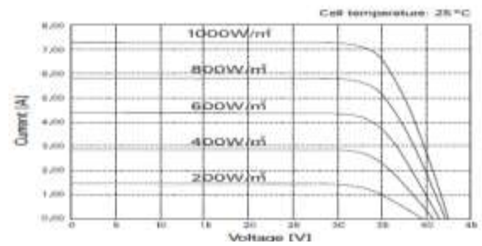

Fig. 3. The I-V relation of PV corresponding to the different light intensity of light

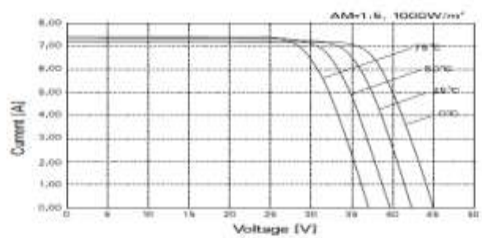

Fig.4. The I-V relation of PV corresponding to different working temperatures

2. DC/DC Converter

The DC/DC converter is a voltage boost that includes L_1 inductance, IGBT transistors and Diode D. They are responsible for increasing the voltage and performing the maximum power point detection algorithm of the photovoltaic (MPPT).DC/DC has 2 energy accumulation factors and therefore, has 2 control variables. They are the photoelectric voltage U_{pv} and the photoelectric current I_{pv}. The input/output voltage of the Boost is:

$$V_{out} = \frac{V_{in}}{1\text{-}D}; \quad D = \frac{T_{on}}{T} \qquad (2)$$

Where T, T_{on} are the switching period and open time of the IGBT.

3. DC Line

In general, the DC line voltage varies depending on the environmental conditions, means that depending on the temperature and the density of solar radiation. It is represented by the following equation:

$$\frac{dV_{dc}}{dt} = \frac{1}{C_{dc}}\left(I_{dc} - I_{in}\right) \qquad (3)$$

where C_{dc} is the capacitance of the capacitor [F], I_{dc} is the output current of the MPPT, I_{in} is the input current of the DC/ C converter.

4. Three-phase grid connected inverter

The three-phase grid connection has 6 IGBT switches connected in form of bridge diagram as shown in Fig.5. The output of the inverter has a filter inductance to filter the harmonics to reduce current distortion. The inverter needs to operate as a power controller between the DC link and the grid. [1]

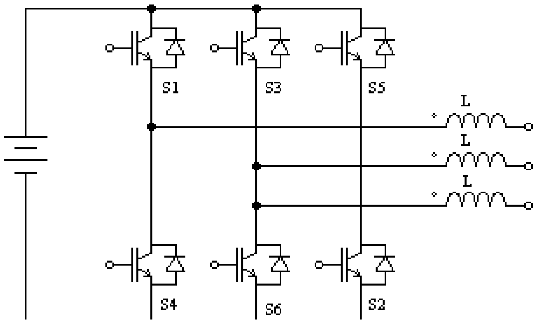

Fig.5. The three-phase inverter

5. Grid

According to Thevenin, it can be represented the three-phase grid by voltage source that has 220V voltage, 50Hz of frequency in series with the Z = R + jx, in which the Z impedance includes the impedance of filter output of the inverter (Fig. 6).

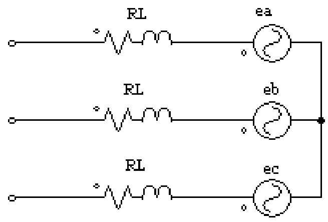

Fig.6.The Thevenin diagram of three-phase grid

III. CONTROL SYSTEM

The control system has the function of controlling the detection and maintenance of maximum power working point; space vector modulation; controlling grid synchronization and types of power for inserting into the grid.

1. Maximum power point tracking control (MPPT)

Due to environmental conditions (solar radiation and temperature) are constantly changing, the maximum power working point of the photovoltaic cells is constantly changing according to environmental conditions (Fig. 2). Therefore, to improve the efficiency of the generator, it is necessary to control the photovoltaic cells to continuously work at the maximum power point. There are many MPPT algorithms, such as constant voltage algorithms, pertubation and observation (P & O) algorithms, incremental conductance algorithm (INC) algorithms, fuzzy control algorithms [4], [7], [8]In this paper, we employ an incremental induction algorithm to determine and maintain the maximum power point of a photovoltaic cell. Incremental flow algorithm is shown in Fig. 7.

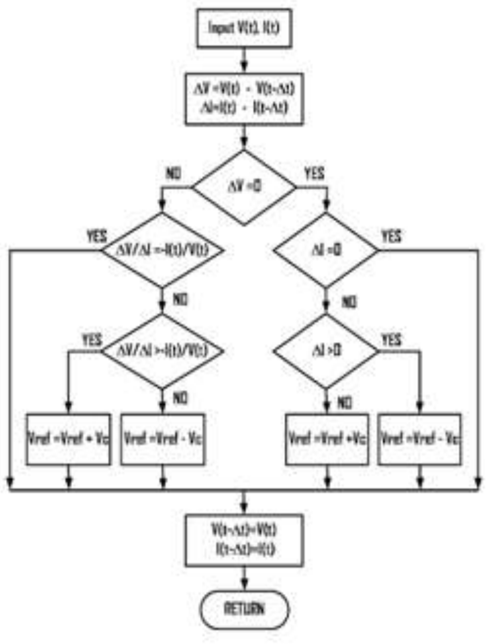

Fig.7. Structure diagram of INC algorithm

2. Grid-Connected Inverter control

The mathematical model of three-phase grid connected insynchronous dq reference frame is described by [3]

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = L\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + R\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega L\begin{bmatrix} i_q \\ i_d \end{bmatrix} + \begin{bmatrix} e_d \\ e_q \end{bmatrix} \quad (4)$$

where e_d and e_q are the grid voltages in the synchronous dq reference frame. v_d and v_q are the components of the inverter output voltage in the synchronous reference frame. ω is the angular frequency of the grid. L, R is the connected inductance and resistor between the inverter and the grid.

It can be seen from Fig. 1 that two controllers PI_1, PI_2 are employed to compensate the current vector components defined in the synchronous reference frame (dq). By coordinate transformations, id and i_q are DC elements, therefore, the compensators PI_j reduce the error between the currents I^*d, I^*q and the currents I_d, I_q to 0. The power output and power factor could be controlled by changing the current I_d and I_q.

3. Vector space modulation

Control of the inverter is done by pulse width modulation (PWM). In this article we propose the method of space vector modulation (SVM), which is a digital modulation method that considered as the best pulse width modulation technique in three-phase inverter. SVM has outstanding advantages such as constant switching frequency, optimizable switching losses or optimization of the harmonics[1].

The SVM for three-phase inveter contains eight states.The individual state is determined by a space voltage vector as seen in Fig.8. Six space voltage vectors (U_1 to U_6) divide the entire space into six sections from 1 to 6 (6 secters), two null vector U_0 and U_7located at the base. The angular between two adjacent sectersis 60.

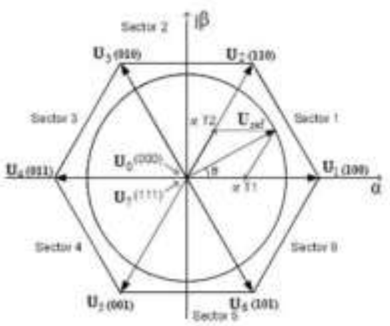

Fig. 8. The space vectors of the SVM

In SVM, the reference voltage on the coordinate system (dq) is moved to the coordinate system (αβ) through the Clark transform.

$$\begin{aligned} V_a &= V_d \cos\theta - V_q \sin\theta \\ V_b &= V_d \sin\theta + V_q \cos\theta \end{aligned} \quad (5)$$

SVM can be done by four following steps:

1) Calculate the voltage and reference phase angle (U_{ref}) according to the expression

$$V_{ref} = \sqrt{V_\alpha^2 + V_\beta^2} \qquad \theta = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right) \quad (6)$$

2) Determining the locations of sectors is done by taking the angular obtained from the last step and then comparing it to the angular range of each sector;

3) Calculate the modulation factor (m) and time interval T_1, T_2, T_0;

$$T_1 = T_s.m.\frac{\sin(\pi/3-\theta)}{\sin(\pi/3)} \qquad T_2 = T_s.m.\frac{\sin(\theta)}{\sin(\pi/3)} \qquad T_0 = T_s - (T_1 + T_2) \quad (7)$$

where: $T_s = \frac{1}{f_s}; m = \frac{V_{ref}}{V_{dc}}$

4) Determine the switching time of the valves (S_1 - S_6). After calculating the T_1, T_2 and T_0, it is possible to determine the time of SVM pulses for switching valves (Table 1).

Table 1. Period of time for on/off valves in each sector

Sector	Upper valve group(S_1,S_3,S_5)	Lower valve group (S_4,S_6,S_2)
1	$S_1 = T_1+T_2+T_0/2$ $S_3 = T_2+T_0/2$ $S_5 = T_0/2$	$S_4= T_0/2$ $S_6 = T_1+T_0/2$ $S_2 = T_1+T_2+T_0/2$
2	$S_1 = T_1+ T_0/2$ $S_3 = T_1+T_2+T_0/2$ $T_0/2$	$S_1 = T_2+T_0/2$ $S_6 = T_0/2$ $S_2 = T_1+T_2+T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1+T_2+T_0/2$ $S_5 = T_2+T_0/2$	$S_1 = T_1+T_2+T_0/2$ $S_6 = T_0/2$ $S_2 = T_1+ T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1+ T_0/2$ $S_5 = T_1+T_2+T_0/2$	$S_1 = T_1+T_2+T_0/2$ $S_6 = T_2+T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2+T_0/2$ $S_3 = T_0/2$ $S_5 = T_1+T_2+T_0/2$	$S_1 = T_1+T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1+T_2+T_0/2$ $S_3 = T_0/2$ $S_5 = T_1+T_0/2$	$S_1 = T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_2+T_0/2$

4. Grid synchronization

To connect the inverter and grid, the output voltage of the inverter must be synchronized with the grid voltage. The objective of the synchronization algorithm is to extract the phase angle of the grid voltage. Therefore, grid phase angular detection has important role in grid connection of solar power sources. Grid synchronization algorithms must respond quickly to changes in the grid, and they must be able to eliminate interferences and high harmonics. Many synchronization algorithms have been proposed to extract the phase angle of the grid voltage as "zero" point detection, and phase lock loop (PLL).

The simplest synchronization algorithm is “zero” point detection. However, this solution has many disadvantages such as low dynamics. In addition, it is affected by interference and high harmonics in the grid. Therefore, this method is not suitable for applications that require consistent phase angle detection.

Nowadays, the most common synchronization algorithm for extracting the phase angle of the grid voltage is the PLL. Figure 9 is a diagram of a phase lock loop implemented in the synchronous reference frame (dq). The obtained voltage from the grid (eabc) is converted into DC elements (ed, eq) according to the Park transformation formula. PLL is locked by setting e * d = 0 and acting as a phase detector. A controller (usually PI) is applied to control this variable which ensures phase error is zero and acts as a loop filter. ω_{ff} represents for the nominal frequency of the additional utility of theregulator output and extracts output as a grid frequency. After the loop filter, its output is the grid frequency, the voltage control oscillator (VCO) is applied. This is usually an integrated set, providing the locking angle of the grid θ as the output.

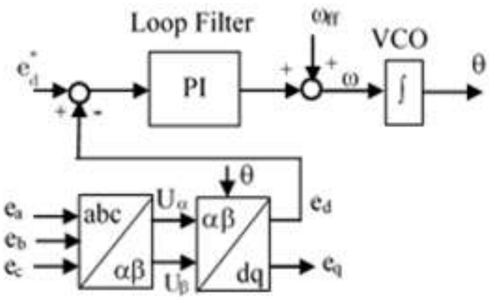

Fig.9. Structure diagram of PLL

This phase lock loop is able to successfully detect the phase angle of the grid voltage even when a high harmonic disturbance and other disturbances appeared in the grid.

IV. SIMULATION RESULTS

This section describes the grid connected solar system on the Matlab-Simulink software as aforementioned theory. The parameters used in the simulation are as follows:

- Solar cell Aavid Solar ASMS-220P consisting of 40 strands of parallel PV, each PV strand has 10 modules in series, the intensity of solar radiation (G) varies from 800W/m^2 to 1000W/m^2, the assumed working temperature T^{0}C of PV was maintained at 45^{0}C during simulation.
- Three-phase power grid has voltage of 380V, frequency of 50Hz, the internal impedance of the source is R_0 = 0.001Ω, L_0 = 0.01mH; The grid is operating with three-phase load of 10^{3}W
- The turbocharger has the following parameters: L_1 = 0,4H, using IGBT valve IRG4BC40FPbF, diode with 1mΩ forward resistance, rated voltage of 0.8V.
-Voltage of DC line varies between 600 - 700V.
- Inverter contains 6 IGBT switches IRG4BC40FPbF, each with 0.5Ω forward resistor, the inverter output filterhas 3 coils with inductance L = 4.6mH, R = 4.3mΩ.

Simulation time was 0.5s, initially the solar system ran idle with G = 800W/m^2 and T0C = 45^{0}C, after 0.1s the system was connected to the grid, at t = 0.3s the solar radiation increased to 1000W/m^2. The simulation results are as follows:

+ The voltage and current curve of the PV is shown in Fig. 10. It can be seen that V_{pv} is almost stable when the solar radiation changes.

+

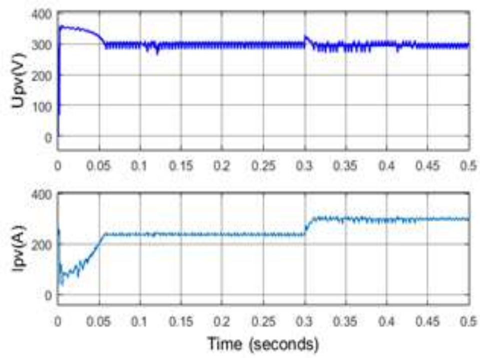

Fig. 10. Voltage and current of PV

DC Line voltage is presented in Fig. 11 informing that Vdc-Line has minor fluctuations when the PV system is connected to the grid. Besides, when G increases the Udc-Line also increases.

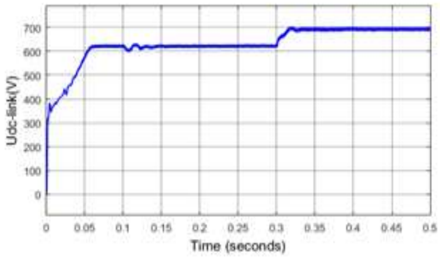

Fig. 11: DC link voltage

The principle of the space vector modulation algorithm is described by a 6-sector graph (from sector 1 to sector 6) when the phase angular varies from π to π (Fig. 12)

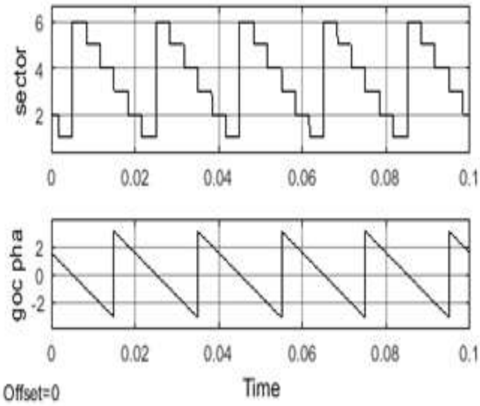

Fig. 12. The modification of sectors along with phase angular

Voltage and phase currents at the output of the inverter are shown in Fig. 13, three-phase voltage and current are illustrated in Fig.14. At first, the inverter's voltage is different from sine signal due to the transient, the current is zero when the inverter is not connected to the grid and the non-zero when the inverter connected to the grid and alsoappeared at the transient.

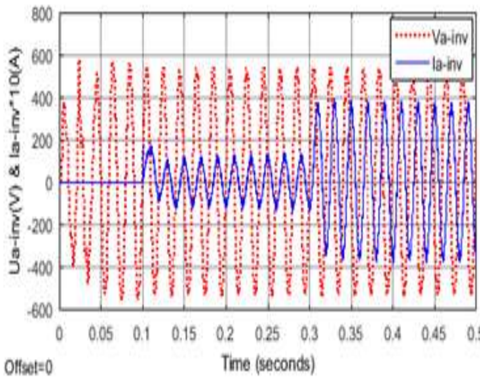

Fig. 13.Voltage and current of phase A at the inverter output

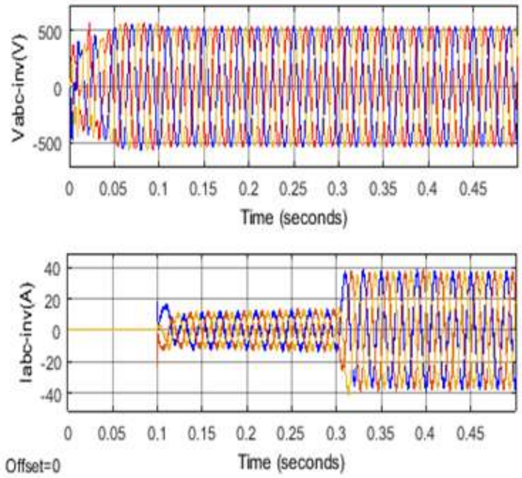

Fig. 14.Voltage and current of inverter output

The photovoltaic power and inverter power inserted into the grid are shown in Fig. 15. It can be seen that the P_{pv} curve is a bold line representing the fluctuation of the MPPT algorithm, which results in the power to insert into the grid is also fluctuating, this is undesirable result need to be resolved.

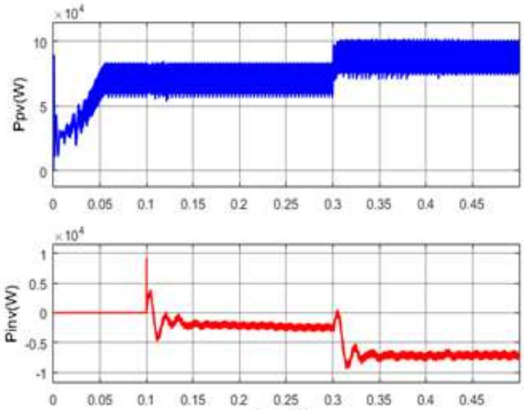

Fig. 15. The power of the photovoltaic battery and the power of the inverter inserted into the grid

The simulation results of the PLL as shown in Fig. 16 show that the PLL can accurately extract the phase angular of the grid voltage which allows for grid synchronization and used to convert the reference systems (abc), (αβ) and (dq).

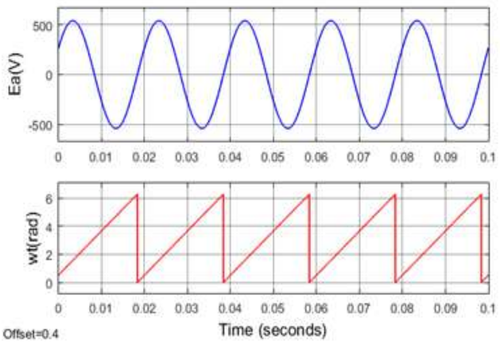

Fig. 16. Phase voltage of the grid and phase angular of the PLL

V. CONCLUSION

The efficiency and productivity of using solar energy can be increased by developing appropriate control structures. In this article, the authors described the operation of a three-phase grid connected PV system using the incremental conductance (INC) method to detect and maintain a maximum power point of PV, apply the vector space modulation (SVM) method for inverter, PLL to synchronize grid. The complete operation of the system is modeled and simulated on Matlab/Simulink, includes the non-ideal elements of electronic components in the converter.

REFERENCES

[1]. Ahmed Abdalrahman, Abdalhalim Zekry, Ahmed Alshazly "Simulation and Implementation of Grid-connected Inverters" International Journal of Computer Applications (0975 – 8887) Volume 60, No.4, December 2012, pp. 41-49.

[2]. Vipul S. Gaigol1, Dhiraj L. Gahukar2,Vaibhav S.Naik3, Abhilash M.Jaisingpure4 “Modeling and Simulation of Solar and Wind Hybrid Power System Using Matlab” International Journal of Research in Advent Technology, E-ISSN: 2321-9637; Vol.4, No.4, April 2016, pp. 339-343.

[3]. N. Hamrouni* and A. Chérif "Modelling and control of a grid connected photovoltaic system" Revue des Energies Renouvelables Vol. 10 N°3 (2007) 335 – 344.

[4]. M.Lokanadham, K.Vijaya Bhaskar "Incremental Conductance Based Maximum Power Point Tracking (MPPT) for Photovoltaic System" International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue 2,Mar-Apr 2012, pp.1420-1424.

[5]. Palak H. Patel1 Mihir Parikh2 "Design and Simulation of Solar Grid Tied Inverter" International Journal for Scientific Research & Development| Vol. 3, Issue 03, 2015 | ISSN (online): 2321-0613.

[6]. ST. Kourtesi, L. Ekenomou, A. Nakulas, G.P. Fotis, E. Zoulias "Modeling and simulation of a singlephase photovoltaic inverterand investigation of switching strategies for harmonic minimization" Proceedings of the 6th WSEAS International Conference on Applications of Electrical Engineering, Istanbul, Turkey, May 27-29, 2007.

[7]. Lai Khac Lai "Fuzzy Logic Controllerfor Grid connected Single Phase Inverter" Journal of Science and Technology - Thai Nguyen UniversityIssue 2, pp. 33-37, 2013.

[8]. Lai Khac Lai, Dang Danh Hoang, T-Thanh Hoa Lai “A new method to determine and maintain the maximum power operating point of grid-connected solar power system” Journal of Science and Technology - Thai Nguyen University;Volume 162, Issue 2, pp. 189-194, 2017.

[9]. KhacLai Lai, DanhHoang Dang, XuanMinh Tran"Modeling and Control the grid-connected Single-phase Photovoltaic System" SSRG International Journal of Electrical and Electronic (SSRG-IJEEE), Volume 4, Issue 5 - May 2017, pp. 545-550.

Khac Lai Lai"Three-Phase Grid Connected Solar System With Svm Algorithm " "International Journal of Engineering Research and Applications (IJERA) , vol. 8, no.11, 2018, pp 42-48