International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 09, September-2019

Modeling And Simulation of a Photovoltaic System using Different MPPT Techniques under Irradiation and Load Variations

Sonali Asutakar
PG Scholar,
Department of Electrical Engineering
Ballarpur Institute of Technology
Balharshah, Maharashtra, India.

Nilesh Chamat
Assistant Professor,
Department of Electrical Engineering
Ballarpur Institute of Technology
Balharshah, Maharashtra, India.

***Abstract*— This paper presents modeling and simulation of a stand-alone solar PV system in order to analyze its performance under load and irradiation variations. Indeed, to supply an alternative load with a sinusoidal line without harmonic distortion under weather conditions, most widely used three basic MPPT (Maximum Power Point Tracking) algorithm like perturbation and observation, Incremental conductance and Fractional open circuit voltage has used to control a DC-DC buck converter to generate the MPP (Maximum Power Point) of the photovoltaic generator to load via three phase inverter.**

Keywords*— Photo-voltaic (PV), Maximum power point tracking (MPPT), Perturb and observe (P&O), Incremental conductance (INC), Fractional open circuit voltage (FVOC).

I. INTRODUCTION

The solar photovoltaic system is one of the important renewable energy sources. It offers many advantages such as the energy produced is not polluting, requiring little maintenance, most promising and inexhaustible [20][21]. However, the PV system still has comparatively low conversion efficiency. Indeed, the power produced by the photovoltaic generator relates to the irradiance, temperature, and electrical loads, and it has a MPP at a certain working point [22]. At the MPP (Maximum Power Point), the PV operates at its highest efficiency.

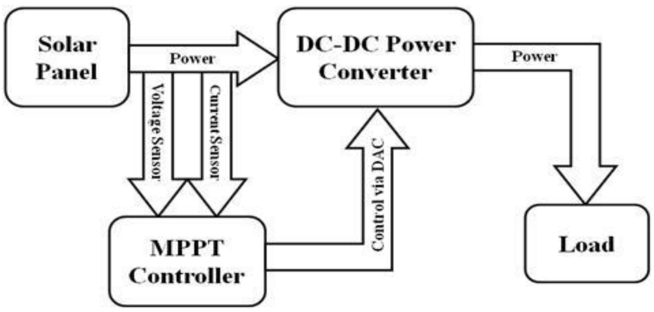

Fig. 1. Block diagram of a MPPT controlled PV system.

Therefore, to extract the maximum power under the different conditions stated earlier, a maximum power point tracking (MPPT) technique is used via a DC-DC converter to get stable and reliable power from PV system for loads, and thus improve both steady and dynamic behaviors of the whole generation system [18] [19].

The Fig.1 shows the basic block diagram of the PV system. It contains a photovoltaic generator, power electronic components (DC-DC converter), MPPT system, Inverter circuit and finally local loads.

The paper treats the deepened modeling of the whole system. DC/DC converter with an MPPT (Maximum Power Point Tracker) connected to the solar array to optimize the PV output; the voltage received from the photovoltaic generator to the voltage level required by the voltage source inverter (VSI) and finally is given to the load.

This work is organized as follows: solar cell modeling and the simulation behavior of PV module will be presented and discussed in section 2, at different operating conditions. In section 3, the DC voltage control is presented. Whereas in section 4, a voltage source inverter model is discussed. Of course, the simulation results in Matlab/Simulink environment of the full PV power system are presented and talked over in section 5, so as to evaluate its performance. Eventually, conclusion is presented in section 6.

II. MODELING AND SIMULATION OF PV ARRAY

A. Modeling of the solar cell

Solar cells are composed of a p-n junction fabricated by differently doped semiconductor materials. Thereby the solar cell can be presented by a simple circuit consisting of a current source in parallel with a diode. The output of the current source is directly proportional to the light incident on the cell. The model of the solar cell used in this research work is shown in Fig.2.

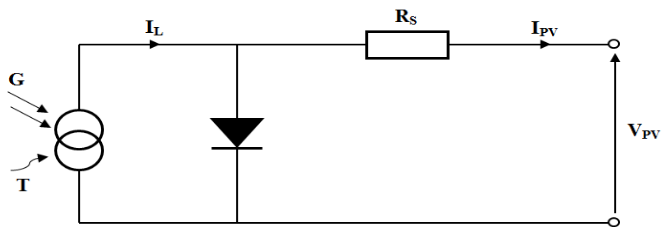

Fig. 2. Equivalent circuit model of PV cell.

The equations which illustrate the I-V characteristics of the cell are:

$$I = I_{sc} - I_d \qquad (1)$$

$$I_d = I_0(e^{q\frac{V_d}{KT}} - 1) \quad (2)$$

$$I = I_{sc} - I_0(e^{q\frac{V_d}{KT}} - 1) \quad (3)$$

$$I = I_{sc} - I_0(e^{q\frac{V+IRs}{nKT}} - 1) \quad (4)$$

B. Effect of Variation of Solar Irradiation

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. As a result of the environmental changes, the solar irradiation keeps on fluctuating, but control mechanisms are available which tracks this change and alter the working of the solar cell to meet the desired load demands. Higher the solar irradiation; higher the solar input to the solar cell and hence the power magnitude increases for the same value of voltage. The open circuit voltage increases with increase in the solar irradiation. The electrons are supplied with higher excitation energy, when more sunlight incidents on to the solar cell, thereby increasing the electron mobility and thus generated more power [7 and 10].

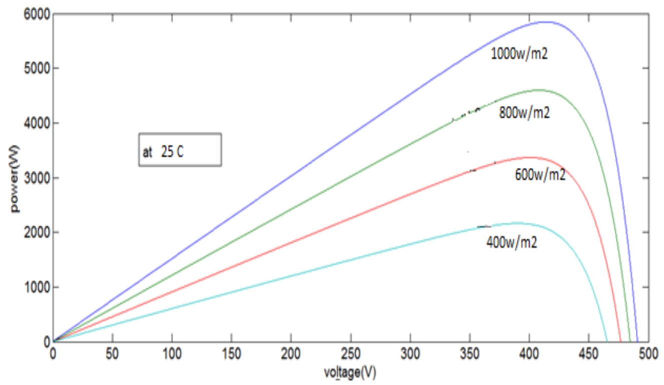

Fig. 3. Variation of P-V curve with solar irradiation.

C. Effect of Variation of Temperature

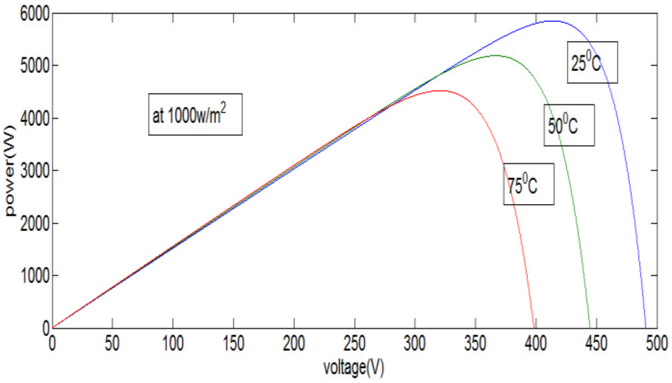

Fig. 4. Variation of P-V curve with temperature.

On the other hand, the increase in temperature around the solar cell has a negative impact on the power generation capability. Temperature Increase is accompanied by a decrease in the value of open circuit voltage. Increase in the band gap of the material occurs due to increase in temperature and thus to cross this barrier more energy is required. Thus the solar cell efficiency gets reduced [7 and 10].

As shown in Fig.3 and Fig.4, the characteristic P-V. PV has only one maximum power point called MPP that makes the PV generator generating its maximum power under different environmental conditions. Therefore to exploit the maximum power of the module and optimize the efficiency of PV cells, a MPPT technique is required.

III. DC VOLTAGE CONTROL

The continuous part of the PV system is presented in Fig.5. The first DC/DC converter is a buck converter circuit controlled by an MPPT algorithm for rise the low PV power to an optimal level under different weather conditions. [10] The DC/DC converter is maintain the input voltage to the voltage level demanded by the VSI and works with a variable duty cycle. [1]

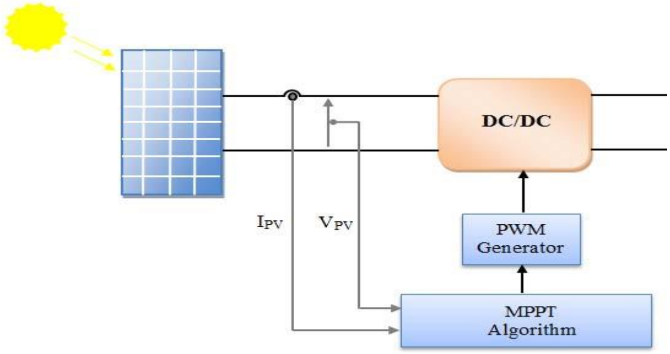

Fig. 5. DC Voltage Control.

The main aim in MPPT system is to control the duty cycle (D) of the converter used source side. In the source side we use a convertor that is connected to a solar panel in order to enhance the output voltage and by changing the duty cycle of the converter appropriately the source impedance can be matched with the load impedance.

Among all MPPT techniques, the MPPT techniques which are to be discussed in this paper are:

A. Perturbation and observation (P&O) MPPT algorithm

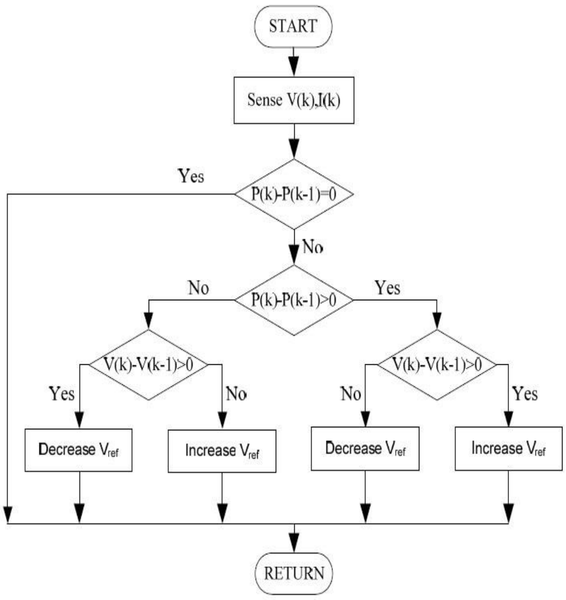

Fig. 6. Flowchart of P&O method.

In Perturb-and-observe algorithm method, we only use one sensor and hence it is very easy to implement. Voltage sensor used, senses the PV array voltage and so the cost of implementation is less among all other MPPT algorithm.

The Perturb-and-observe algorithm for maximum power point tracking is simplest techniques among all the MPPT techniques in literatures. It is based on the simple mathematical condition, i.e. dP/dV = 0, where P and V are power and voltage at output of PV module respectively.

From figure 1, it can be seen that increase in voltage increases power when the PV array operates in the left of MPP and power decreases on increasing voltage when the same is operates in the right of MPP. Hence if dP/dV > 0, the perturbation should be same and if dP/dV < 0, the perturbation should be reversed. The process should be repeated periodically until dP/dV = 0 reached (maximum power point) [1], [3], [4], [9].

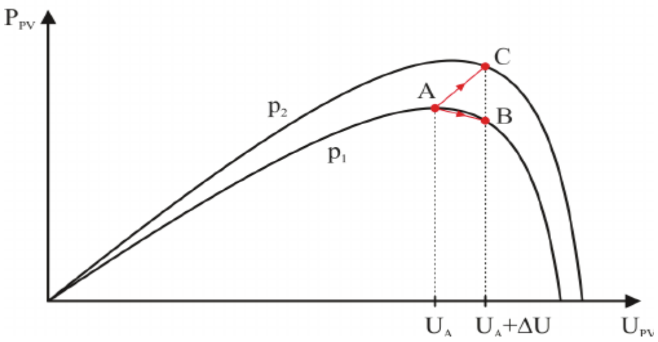

Fig. 7. Divergence of P&O from MPP.

Under sudden changing atmospheric conditions P&O method does not respond well as illustrated in figure 6. Due to small perturbation of ΔV in the PV voltage V under constant atmospheric conditions the operating point moves from A to B. Since power decreases to B so according to P&O algorithm the perturbation should be reversed. And when the power curve shifts from P_1 to P_2 due to increase in irradiance the operating point will change from A to C. Now there is increase in power so again according to P&O algorithm the perturbation should be kept same which results in the divergence of operating point from Maximum Power Point [3], [4] and hence calculates the wrong MPP. To avoid this problem we can use incremental conductance method to track MPP correctly even under rapid change in irradiance.

B. Incremental Conductance (INC)s

INC is commonly used for solar PV MPPT. The incremental conductance method is based on the fact that the slope of the P vs. V (I) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right of MPP. This technique deals with the sign of dP/dV without a perturbation which overcome the limitations of P&O technique [5].

dP/dV > 0 left side of the curve

dP/dV < 0 right side of the curve

dP/dV =0 peak of the curve

The above expressions can be expressed as (shown in fig. 8):

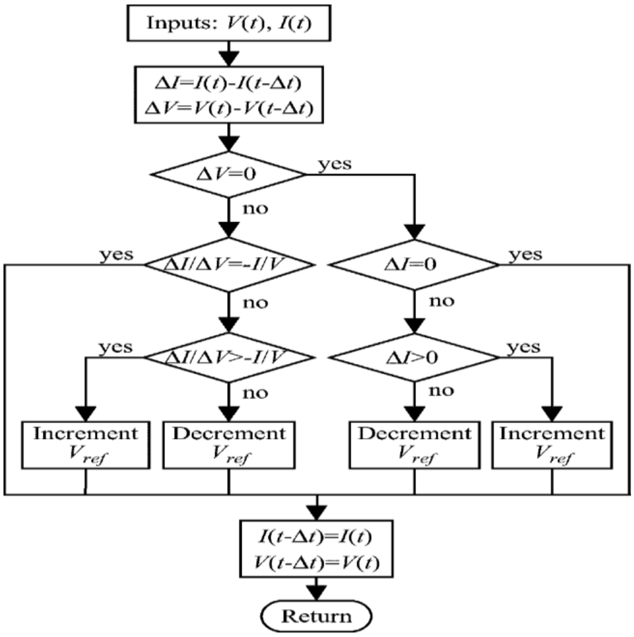

Fig. 8. Flow chart of Incremental Conductance method.

$$\frac{dP}{dV} = \frac{d\,(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \qquad (5)$$

For MPP by putting $\frac{dP}{dV} = 0$, we get,

$$I + V\frac{\Delta I}{\Delta V} = 0$$

Hence,

ΔI/ΔV= -I/V , At MPP
ΔI/ΔV > - I/V, Left of MPP
ΔI/ΔV < - I/V, Right of MPP

Where,

I/V is instantaneous conductance,

ΔI/ΔV is incremental conductance,

VREF is reference voltage at which PV array is to be operated.

According to above equations the maximum power point of PV array can be tracked by comparing the I/V to ΔI/ΔV as shown in the flow chart (fig. 8).

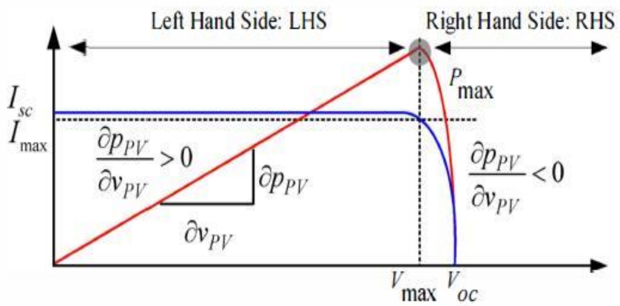

Fig. 9. I-V and P-V curve and maximum power point of PV module.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 09, September-2019

C. Fractional open circuit voltage (FVOC) MPPT algorithm

The Fractional open circuit voltage (FVOC) method of maximum power point tracking based on the near linear relationship between the maximum power point voltage (VMPP) and open circuit voltage (VOC) PV array [4].

$$V_{MPP} \approx K_1 V_{OC} \qquad (6)$$

Where, k1 is proportionality constant and the value of k1 is dependent on the characteristics of the solar cell being used. Its value is usually between 0.71 and 0.78 i.e. the ratio VMPP/VOC will be up to 78% [5].

VMPP can be calculated easily using the known value of k1 with the help of (2) with measured value of VOC periodically by shutting down the converters for a very short time which results the temporary loss of power.

The problem of power loss can be overcome by using pilot cells from which VOC can be taken. The major problem with FVOC algorithm is the wastage of available energy when the power converter is getting disconnected from load. And another problem is value of k1 is not constant, it varies according to the PV parameters [4], [5].

IV. VSI Model

The VSI used in this work converts DC voltage to three-phase AC voltages. Fig.6 shows the detail circuit of the inverter. The power part of the inverter is composed of three arms consisting each one two switches. Each switch is composed of transistor (IGBT, MOSFET…) and of a diode coupled in parallel. The LC filter is connected to the inverter output, it's designed to reduce high order harmonics produced by the pulse-width modulation (PWM) inverters. [1][16][10]

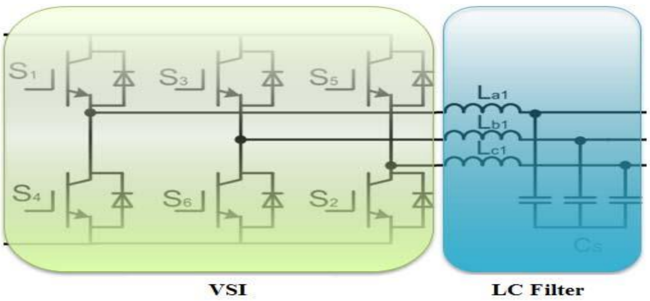

Fig. 10. Three-phase VSI

A. PWM Control

To generate an analog signal using a digital source a pulse width modulation signal is mostly used. Two main components define the behavior of PWM signal which are duty cycle and a frequency. The interest of the PWM is to provide a variable DC voltage from a fixed DC voltage source. PWM decreases the Total Harmonic Distortion (THD) of load current. The THD requirement can be met when the output of a PWM inverter is filtered since the unfiltered output of a PWM based inverted will have a relatively high distortion.

There are different types of PWM schemes, the most used ones being sinusoidal PWM (SPWM), hysteresis PWM (HPWM), space vector modulation (SVM) and optimal PWM [13]. The inverter switching, used in this studied system, is controlled by the SPWM. The high-frequency triangular carrier wave VCR is compared with a sinusoidal reference Vm of the desired frequency (shown in Fig.7) to realize SPWM and generate the gating signal for the transistors (shown in Fig.11).

B. LC Filter

The filter is an essential element after semiconductor converter. The effect caused by switching semiconductor devices on other devices is reduces by filter. It delivers a sinusoidal output current with THD less than 5 % [11]. Consequently, the low-pass LC filter is designed so that the cut-off frequency, fC is higher than the load current and voltage frequency and lower than the inverter switching frequency.

V. Simulation Result

The power system is simulated in Matlab/Simulink power system toolbox software. In this work, the simulation model for the full PV power system components is designed (shown in Fig.11).

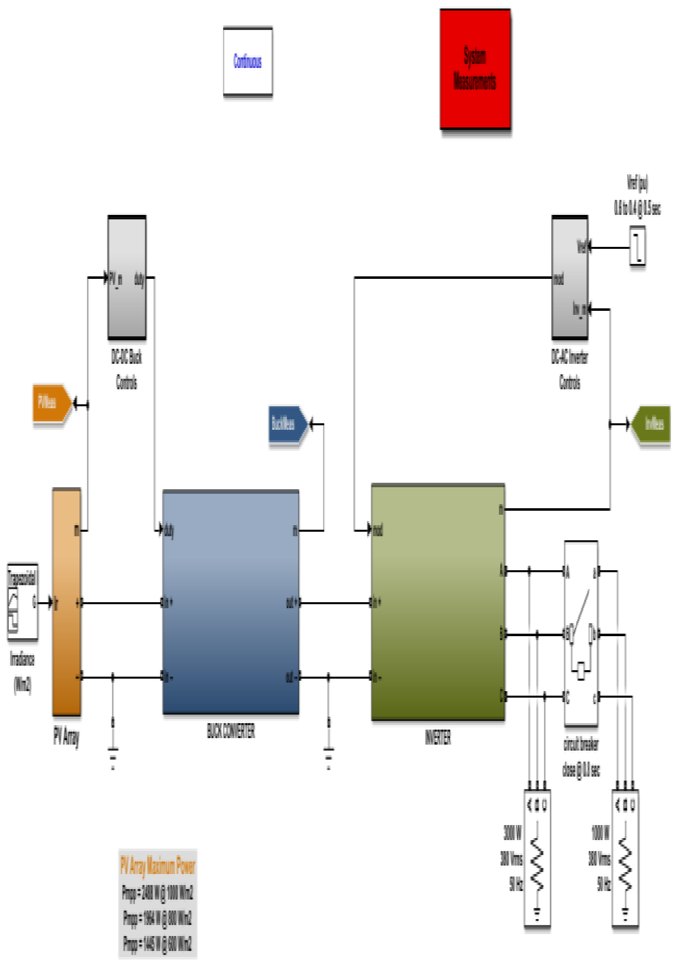

Fig. 11. Simulink model of the PV with buck converter and inverter.

The simulation is run at t=0s to 1s. At the beginning, the irradiation is set at G=800[W/m2], at t=0.2s a step change of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 09, September-2019

irradiation to 600 [W/m2], at t=0.7s a step change of irradiation to 1000 [W/m2] and again at t=1s a step change of irradiation to again 800 [W/m2], is performed. The output of PV array, buck converter and three-phase inverter using Pno, INC and FoC are shown in Figure 7.4.

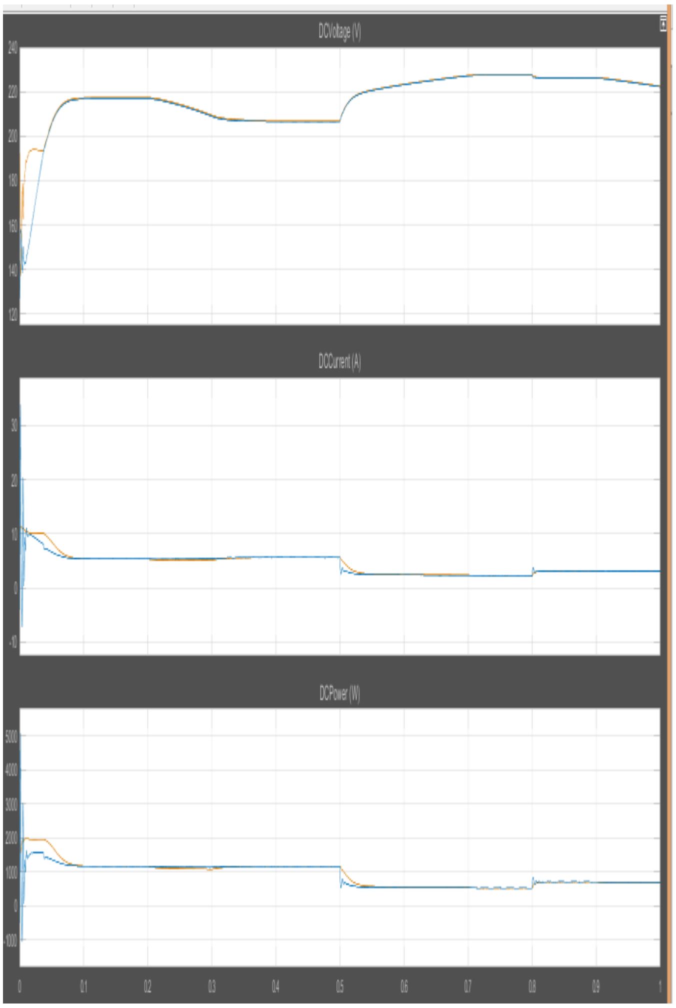

Fig. 12. DC measurement using FoC MPPT.

Fig. 13. AC measurement using FoC MPPT.

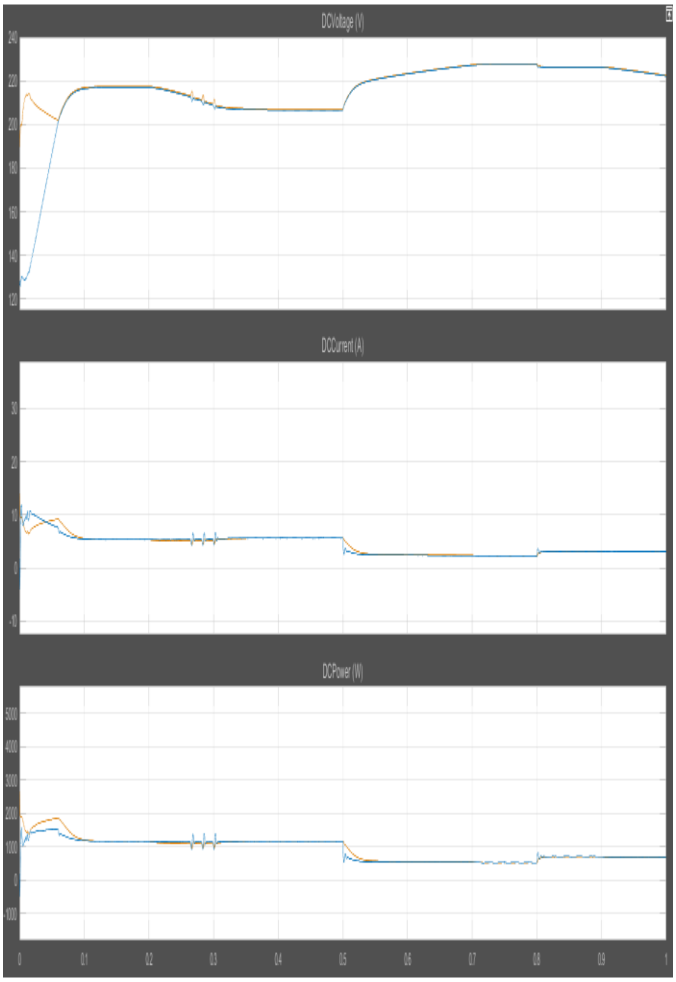

Fig. 14. DC measurement using INC MPPT.

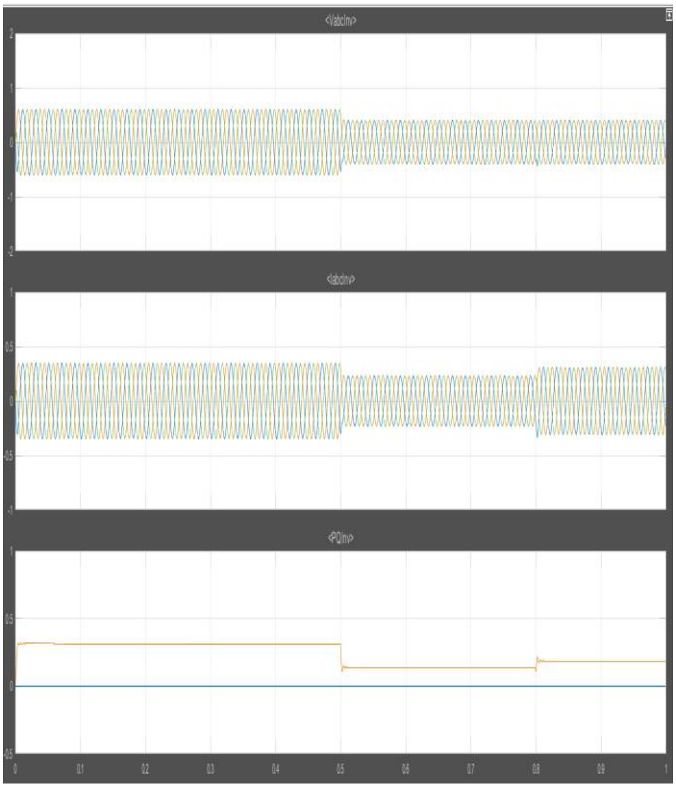

Fig. 15. AC measurement using INC MPPT.

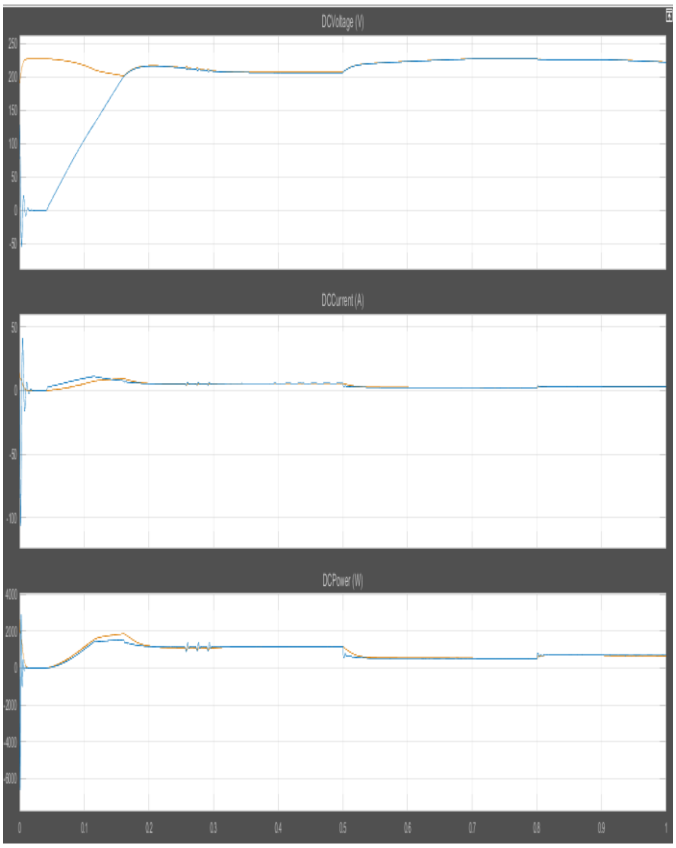

Fig. 16. AC measurement using PnO MPPT.

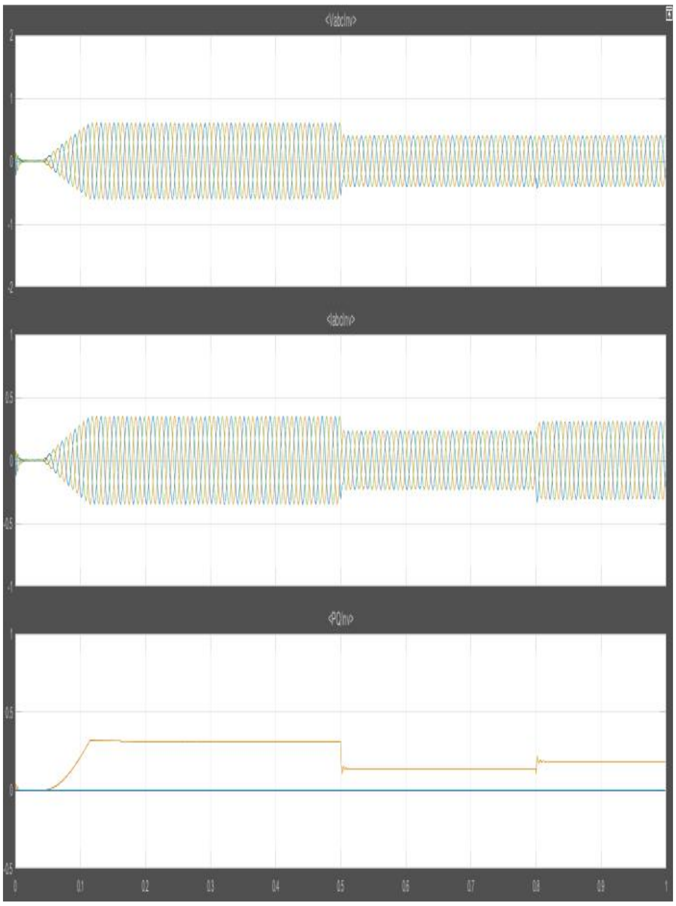

Fig. 17. AC measurement using PnO MPPT.

VI. CONCLUSION

In this paper, the study of the photovoltaic system with maximum power point controller has been developed. From the theory of the photovoltaic, a mathematic model of the PV has been presented. Then, the photovoltaic system with DC-DC buck converter; maximum power point controller and resistive load have been designed. Finally, the system has been simulated with Simulink MATLAB.

First, the simulations of the PV panels showed that the simulated models were accurate to determine the characteristics voltage current because the current voltage characteristics are the same as the characteristics given from the data sheet. The PV models output voltage current change, when the irradiance or temperature varies. Then, the simulation showed that Perturb and observe algorithm can track the maximum power point of the PV, it always runs at maximum power no matter what the operation condition is. The results showed that the Perturb and observe algorithm delivered an efficiency close to 100% in steady state.

The simulations of the PV with maximum power point, boost converter and resistive load were performed by varying the load, the irradiance and the temperature.

Finally, the PV performance and the maximum power point were analyzed, and the three phase half bridge DC-AC inverter was simulated on a resistive load. The results showed that the DC voltage generated by the PV array could produce an AC current sinusoidal at the output of the inverter. The amplitude of the current depends on the PV power.

REFERENCES

[1] Jiyong Li and Honghua Wang, "A Novel Stand-alone PV generation System based on Variable Step Size INC MPPT and SVPWM control," Power Electronics and Motion Control Conference, 2009. IPEMC '09. IEEE 6th International, July 2009, pp. 2155 - 2160.

[2] Zeng, Q., Chang L. and Song, P., "SVPWM-based Current controller with Grid Harmonic Compensation for three-phase grid connected VSI," Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual, vol. 4, April 2005 pp. 2494 - 2500.

[3] Villalva, M.G., Gazoli, J.R. and Filho, E.R.; "Modeling and circuit-based simulation of photovoltaic arrays," Power Electronics Conference, IEEE 2009. COBEP '09. Brazilian, December 2009, pp. 1244 - 1254.

[4] Zhou Dejia, Zhao Zhengming, Eltawil, M. and Yuan Liqiang; "Design and control of a Three-phase Grid connected Photovoltaic system with developed Maximum power point tracking,"Applied Power Electronics Conference and Exposition, 2008. APEC 2008. Twenty-Third Annual IEEE, May 2008, pp. 973 - 979.

[5] Zhou Xuesong,Song Daichun, Ma Youjie and Cheng Deshu, "Grid-connected control and simulation of single-phase two-level photovoltaic power generation system based on repetitive control," Measuring Technology and Mechatronics Automation (ICMTMA), 2010 International Conference, vol. 2, May 2010, pp. 366 - 369.

[6] Liang Ma, Wang Ran and Zheng, T.Q., "Modeling and Control of 100 kW Three-phase grid-connected Photovoltaic inverter," Industrial Electronics and Applications (ICIEA), 2010 the 5th IEEE Conference, July 2010, pp. 825 - 830.

[7] Rujia Men and Xiaoqing Han, "Optimum control and simulation for a grid-connected photovoltaic system," Probabilistic Methods Applied to Power Systems (PMAPS), 2010 IEEE 11th International Conference, July 2010, pp. 431 - 435.

[8] Azevedo, G.M.S., Cavalcanti, M.C., Oliveira, K.C., Neves, F.A.S. and Lins, Z.D., "Evaluation of maximum power point tracking methods for grid connected photovoltaic systems," Conference on Power

Electronics Specialists, 2008. PESC 2008. IEEE , August 2008, pp. 1456 - 1462.

[9] Kjaer, S.B., Pedersen, J.K. and Blaabjerg, F., "A Review of single-phase grid connected inverters for photovoltaic modules," Industry Applications, IEEE Transactions, vol. 41, September 2005, pp.1292-1306.

[10] Jain, S. and Agarwal, V., "A single-stage grid connected inverter topology for solar PV systems with maximum power point tracking," IEEE Transactions on Power Electronics, vol. 22, September 2007, pp. 1928-1940.

[11] Weiping Luo and Gujing Han, "Tracking and controlling of maximum power point application in grid-connected photovoltaic generation system," Second International Symposium on Knowledge Acquisition and Modeling 2009, KAM '09, vol. 3, December 2009, pp. 237 - 240.

[12] Hui Zhang, Hongwei Zhou, Jing Ren, Weizeng Liu, Shaohua Ruan and Yongjun Gao, "Three-phase grid-connected photovoltaic system with SVPWM current controller,"Power Electronics and Motion Control Conference, 2009.IPEMC '09. IEEE 6th International, July 2009, pp. 2161 - 2164.

[13] Meza, C., Negroni, J.J., Guinjoan, F. and Biel, D., "Inverter Configuration Comparative for Residential PV-grid connected systems,"32nd Annual Conference on IEEE Industrial Electronics, IECON 2006 , April 2007, pp. 4361 - 4366.

[14] Calais, M., Myrzik, J., Spooner, T. and Agelidis, V.G., "Inverters for single-phase grid connected photovoltaic systems – an overview," Power Electronics Specialists Conference, 2002. pesc 02. 2002 IEEE 33rd Annual, vol. 4, November 2002,pp. 1995 - 2000.

[15] Sera, Dezso, Teodorescu, Remus and Rodriguez, Pedro, "PV panel model based on datasheet values," International Symposium on Industrial Electronics, 2007. ISIE 2007. IEEE, November 2007, pp. 2393 - 2396.

[16] Altas, I.H. and Sharaf, A.M., "A photovoltaic array simulation model for matlab Simulink GUI environment," International Conference on Clean Electrical Power, 2007. ICCEP '07, July 2007, pp. 341 - 345.

[17] Dhople, S.V., Davoudi, A. and Chapman, P.L., "Dual stage Converter to improve transfer efficiency and maximum power point tracking feasibility in photovoltaic energy-conversion systems," Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE, March 2010, pp. 2138 - 2142.

[18] Hasaneen, B.M. and Elbaset Mohammed, A.A., "Design and simulation of DC/DC converter," Power System Conference, 2008. MEPCON 2008. 12th International Middle-East, July 2008, pp. 335 - 340.

[19] Koutroulis, E., Kalaitzakis, K., Voulgaris, N.C., "Development of a microcontroller-based photovoltaic maximum power point tracking control system," Transactions on Power Electronics, IEEE, vol. 16, August 2002, pp. 46 - 54.

[20] Calais, M. and Agelidis, V.G., "Multilevel Converters to Single-phase grid connected photovoltaic Systems – An overview," IEEE International Symposium on Industrial Electronics, 1998. Proceedings. ISIE '98, vol. 1, August 2002, pp. 224 -229.

[21] Gonzalez, R. Lopez, J. Sanchis, P. Marroyo, L, "Transformerless Inverter for Single-Phase Photovoltaic Systems", ,IEEE Transaction in Power electronics 2007 volume 22 issue 2, page 693-697.

[22] Svein Erik Evju, "Fundamentals of Grid Connected Photo-Voltaic Power Electronic Converter Design", Norwegian University of Science and Technology. june 2007, avalaible at NTNU Innovation and creativity.

[23] Ali Keyhani, "Department electrical engineering, OSU class notes Electromechanical devices", lecture 25, 2009

[24] H.W. van der Broeck, H.-C. Skudelny, and G.V. Stanke, "Analysis and realization of a pulse width modulator based on voltage space vectors," IEEE Transactions on Industry Applications, vol.24, pp. 142-150, 1988

[25] Luis Castaner, Santiago Silvestre, "Modeling Photovoltaic Systems Using PSpice", Wiley, 2002

[26] Timothy L. Skvarenina, "The Power Electronics Handbook, Industrial electronics series", CRC Press, 2002.

[27] Ali Keyhani, Mohammad N. Marwalli, Min Dai, "Integration of Green and Renewable Energy in Electric Power Systems", Wiley, 2010

[28] IEEE Std 1547-2003. "IEEE Standard for Interconnecting Distributed Resources with Electric Power systems", 2003

[29] IEEE Std. 929-2000, "IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems", 2000

[30] IEC 61727 second edition 2004, "International standard, Photovoltaic (PV) systems- Characteristics of the utility interface", 2004

[31] Chan, D.S.H. and Phang, J.C.H., "Analytical methods for the extraction of solar –cell single and double diode parameters from I-V characteristics," IEEE Transactions on Electron Devices, vol. 34, August 2005, pp. 286 - 293.

[32] Hui Zhang; Hong Ji; Jing Ren; Lin Shan and Yongjun Gao, "Research on MPPT control and Implementation method for Photovoltaic generation system and its simulation," Power Electronics and Motion Control Conference, 2009. IPEMC '09. IEEE 6th International, July 2009, pp. 2108 - 2112.

[33] Ortiz-Rivera, E.I., "Maximum power point tracking using the optimal duty ratio for DC-DC converters and Load matching in photovoltaic application," Applied Power Electronics Conference and Exposition, 2008. APEC 2008. Twenty-Third Annual IEEE , May 2008, pp. 987 - 991.

[34] Sachin Puranik, "Control of fuel cell based green energy systems for distributed generation applications", Avalaible from Ohio State University library, The Ohio state University 2009