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Maximum Power Point Tracking Simulation for Photovoltaic Systems Using Perturb and Observe Algorithm

Samer Alsadi, Basim Alsayid
Electrical Engineering Department, Palestine Technical University-Kadoorie (PTU), Palestine-Tulkarm

Abstract*— This paper is a simulation study of maximum power point tracking (MPPT) for photovoltaic systems using perturb and observe algorithm. Maximum power point tracking (MPPT) plays an important role in photovoltaic systems because it maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency and minimize the overall system cost. Since the maximum power point (MPP) varies, based on the irradiation and cell temperature, appropriate algorithems must be utilized to track the (MPP) and maintain the operation of the system in it. Matlab/Simulink is used to establish a model of photovoltaic system with (MPPT) function. This system is developed by combining the models established of solar PV module and DC-DC Boost converter. The system is simulated under different climate conditions. Simulation results show that the photovoltaic simulation system can track the maximum power point accurately. A particular typical 50W solar panel was used for model evaluation, and results of simulation were compared with points taken directly from the data sheet and curves published by the manufacturers.

Index Terms—**Modeling, Photovoltaic Cell, MPPT, DC-DC Converters, Simulation, MATLAB/Simulink**.

I. INTRODUCTION

The field of photovoltaic (PV) solar energy has experienced a remarkable growth for past two decades in its widespread use from stand alone to utility interactive (PV) systems. A photovoltaic (PV) system directly converts sunlight into electricity. The obtained energy depends on solar radiation, temperature and the voltage produced in the photovoltaic module. The voltage and current available at the terminals of a PV device may directly feed small loads. More sophisticated applications require electronic converters to process the electricity from the PV device [1], [2], [3], [4], [5], [14]. Unfortunately PV systems have two major problems: the conversion efficiency of electric power generation is very low (9—17%), especially under low irradiation conditions, and the amount of electric power generated by solar arrays changes continuously with weather conditions. Moreover, the solar cell V-I characteristic is non linear and varies with irradiation and temperature. In general, there is a unique point on the I-V or P-V characteristic, called maximum power point (MPP), at which the entire PV system (array, converter, etc…) operates with maximum efficiency and produces its maximum output power. Therefore maximum power point tracking (MPPT) techniques are needed to maintain the PV array's operating point at its MPP. Many MPPT techniques have been proposed in literature, these techniques vary between them in many aspects, including simplicity, convergence speed, hardware implementation, sensors required, cost range of effectiveness and need for parameterization. Perturb and observe is the technique to be used in this paper, [10], [11].

II. SOLAR CELL MODELING

Solar cells consist of a p-n junction fabricated in thin wafer or layer of semiconductors, whose electrical characteristics differ very little from a diode represented by the equation of Shockly [1], [2] ,[3], [4]. Thus the simplest equivalent circuit of a solar cell is a current source in parallel with a diode as shown in fig. 1. The output of the current source is directly proportional to the light falling on the cell (photocurrent **Ipv, cell**) .So the process of modeling this solar cell can be developed based on equation (1) :

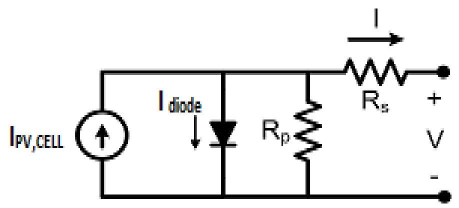

Fig.1. Equivalent Model of a Photovoltaic Cell.

$$I = I_{PV,CELL} - I_{diode} = I_{PV,CELL} - I_{0,CELL}\left[\exp\left(\frac{q*V}{\alpha*k*T}\right)-1\right] \quad (1)$$

Where:

- ❖ $I_{PV},cell$ is the current generated by the incident light .
- ❖ I_{diode} is the Shockley diode equation.
- ❖ $I_{0,cell}$ [A] is the reverse saturation or leakage current of the diode [A].
- ❖ q is the electron charge [1.60217646 · 10^{-19}C].
- ❖ k is the Boltzmann constant [1.3806503 · 10^{-23}J/K].
- ❖ T [K] is the temperature of the p-n junction.
- ❖ α is the diode ideality constant which lies between 1 and 2 for monocrystalline silicon.

The basic equation (1) of the elementary PV does not represent the I-V characteristic of practical PV arrays. Practical modules are composed of several connected PV cells requires the inclusion of additional parameters Rs and Rp, with these parameters (1) becomes (2)

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$$I = I_{PV} - I_0\left[EXP\left(\frac{V + R_S * I}{Vt * \alpha}\right) - 1\right] - \frac{V + R_S * I}{R_P} \qquad (2)$$

The light-generated current of the module depends linearly on solar irradiation and is also influenced by temperature according to (3).

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \qquad (3)$$

Where K_I is the Temperature coefficient of I_{SC} , G is the irradiance (W/m²) and G_n is the irradiance at standard operating conditions.

The diode saturation current I_0 dependence on temperature can be expressed as shown in (4).

$$I_0 = I_{0,n}\left(\frac{T_n}{T}\right)^3 EXP\left[\frac{q * E_g}{\alpha * k}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \qquad (4)$$

E_g is the band gap energy of the semiconductor and $I_{0,n}$ is the nominal saturation current expressed by (5)

$$I_{0,n} = \frac{I_{SC,n}}{\left[EXP\left(\frac{V_{OC,n}}{V_{t,n} * \alpha}\right) - 1\right]} \qquad (5)$$

From (4) and (5) I_0 can be expressed as shown in (6).

$$I_0 = \frac{I_{SC,n} + K_I \Delta T}{EXP\left(\frac{V_{OC,n} + K_V \Delta T}{V_t * \alpha}\right) - 1} \qquad (6)$$

Where $V_{OC,n}$ is open circuit voltage ,$I_{SC,n}$ is the short circuit current , $V_{t,n}$ is the thermal voltage , T_n is the temperature at standard operating conditions. V_t = Ns*kT/q is the thermal voltage of the module with Ns cells connected in series. Equation (2) originates the I-V curve seen in fig. 2, where three remarkable points are highlighted:

a) open- circuit (*Voc*, 0),
b) Short circuit (0, *Isc*),
c) Maximum power point (V_{MP}, I_{MP}).

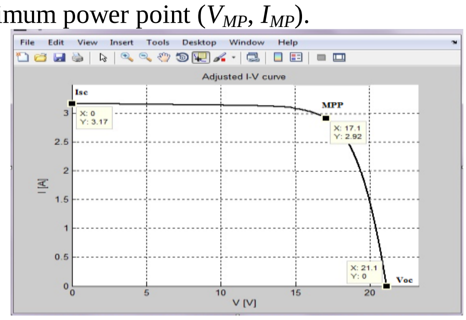

Fig. 2. Characteristic I-V, P-V Curve of a Practical Photovoltaic Device

The best conditions are the "standard operating conditions" happen at Irradiance equal to 1000W/m², cells temperature equals to 25°C, and spectral distribution (Air Mass) AM is equal to 1.5.

III. PHOTOVOLTAIC MODULE

A. Photovoltaic Module Characteristics

MSX-50 solar array PV module is chosen for a MATLAB simulation model. The module is made of 36 multi-crystalline silicon solar cells in series and provides 50W of nominal maximum power. Table 1 shows its electrical specification from data sheet.

Table 1. Electrical characteristics data of the MSX-50 solar at 25 °C, 1.5AM, 1000W/m². Taken from the datasheet

Electrical Characteristics	
Maximum Power (Pmax)	50W
Voltage at Pmax (Vmp)	17.1V
Current at Pmax (Imp)	2.92A
Open-circuit voltage (Voc)	21.1V
Short-circuit current (Isc)	3.17A
(K_I)Temperature coefficient of Isc	(0.0032±0.015)%/°C
(K_V) Temperature coefficient of Voc	– (80±10)mV/°C
NOCT	47±2°C

B. Photovoltaic Module Simulation

Fig.3 shows the modeling circuit of the PV module by Matlab/simulink. The modeling of the PV is done applying the equations seen before, (1),(2),(3),(4),(5) and (6) . Irradiance and temperature are the inputs of the system. In fig. 4 the three remarkable points *Voc=21.1V, Isc=3.17A* and maximum power point (Pmax=50W,V_{MP} =17.1V, I_{MP} =2.92A) are shown and are identical to the values given by the datasheet. Fig. 5 and fig. 6 shows the effect of irradiance variation (1000, 800, 600,400) w/m² at constant temperature (T=25° C) on V-I and P-I characteristics respectively where results are much closed to the real data. In fig. 7 the simulation results are shown for different values of temperature (T=25° C, T=50 ° C, T=75° C).

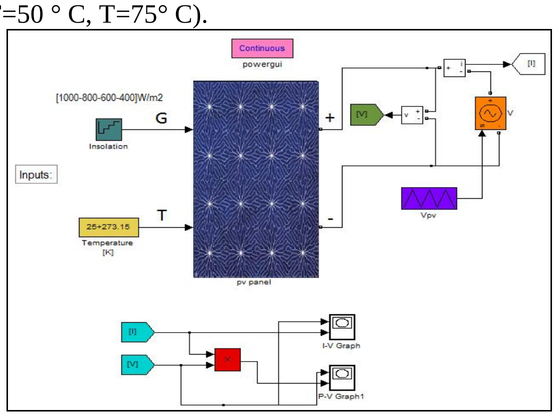

Fig. 3. PV Module Model in Simulink

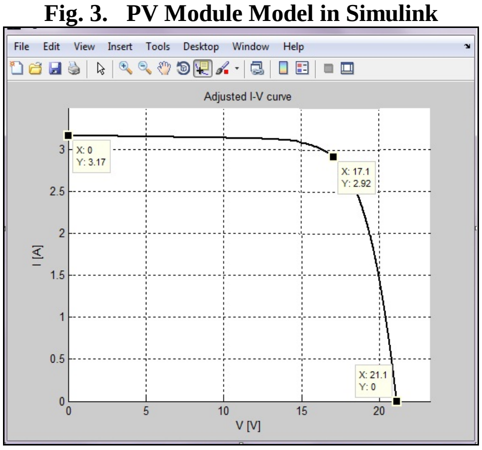

Fig. 4. I-V Characteristics at T=25° C, Irradiance 1000W/M2 By Simulink.

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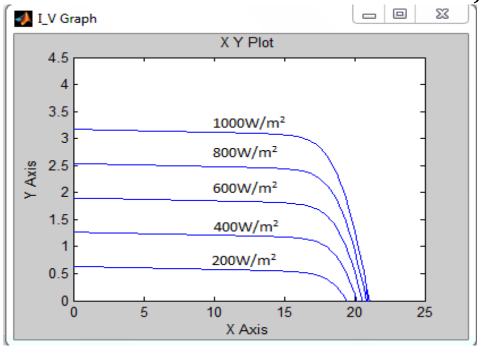

Fig. 5. I-V characteristics at T=25° C, by Simulink With different Irradiances.

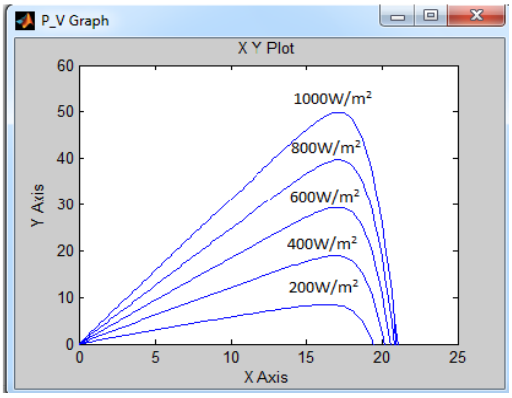

Fig. 6: P-V Curve at T=25° with Different Irradiances

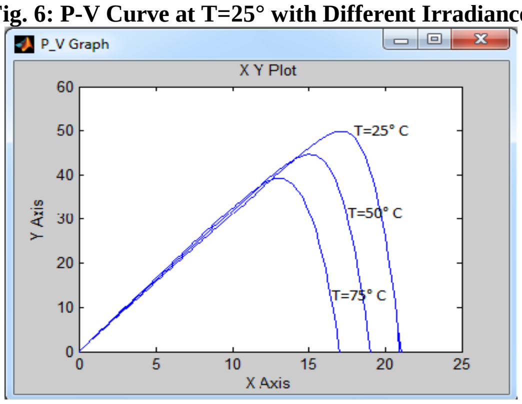

Fig. 7. PV Model for Different Values of Temperature.

IV. MAXIMUM POWER POINT TRACKING

When a PV module is directly connected to a load, see fig. 8, the PV module's operating point will be at the intersection of its I-V characteristic and the load line which is I-V relationship of the load [11]. In general this operating point is not at the PV array's MPP, which can be clearly seen in fig. 9.

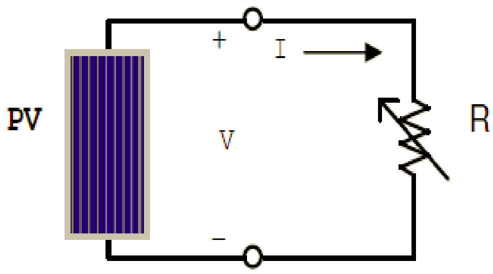

Fig. 8. Direct Coupled Resistive Load.

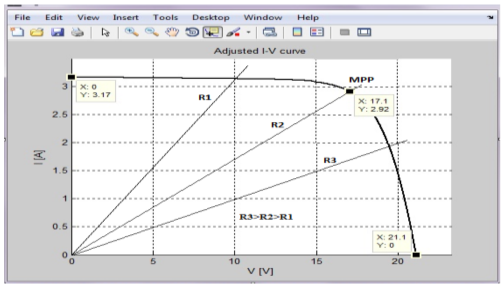

Fig. 9. I-V Curves with Various Resistive Loads.

Thus in a direct-coupled system, the PV array must usually be oversized to ensure that the load's power requirements can be supplied. This lead to an overly expensive system. To overcome this problem, a switch-mode power converter, as shown in fig. 10, can be used to maintain the PV's operating point at the MPP. The MPPT does this by controlling the PV array's voltage or current independently of those of the load. However, the location of the MPP in the I-V characteristic is not known a priori. It must be located, either through model calculation or by search algorithm. The situation is further complicated by the fact that the MPP depends in a nonlinear way of irradiance and temperature [12].

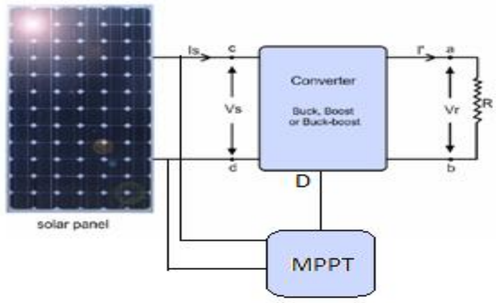

Fig. 10. Standalone PV System with Power Converter and MPPT Control.

V. BOOST CONVERTER

A. *Boost Converter Design*

A simple boost converter consists of an inductor, a switch, a diode, and a capacitor as shown in Fig. 11. Boost converter circuit can be divided into two modes [13]. Mode 1 begins when the switch SW is turned on at t = Ton as shown in Fig. 12. The input current which rises flows through inductor L and switch SW. During this mode, energy is stored in the inductor. Mode 2 begins when the switch is turned off at t = Toff. The current that was flowing through the switch would now flow through inductor L, diode D, capacitor C, and load R as shown in Fig. 13. The inductor current falls until the switch is turned on again in the next cycle. Energy stored in the inductor is then transferred to the load. Therefore, the output voltage is greater than the input voltage and is expressed as in equation 7:

$$V_{out} = \frac{1}{(1-D)} * V_{in} \qquad (7)$$

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Where *Vout* is the output voltage, *D* is duty cycle, and *Vin* is input voltage which in this case will be the solar panel voltage.

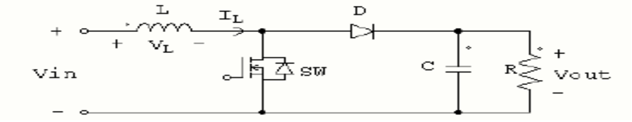

FIG. 11. BOOST CONVERTER.

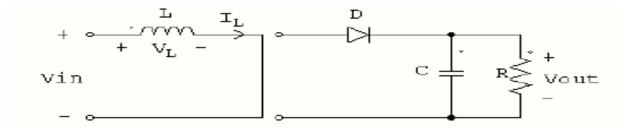

fig. 12. Mode one of the boost converter.

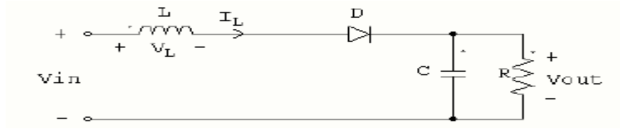

FIG. 13. MODE TWO OF THE BOOST CONVERTER.

In order to operate the converter in continuous conduction mode (CCM), the inductance is calculated such that the inductor current IL flows continuously and never falls to zero as shown in Fig. 14. Thus, L is given by equation 8

$$L_{\min} = \frac{(1-D)^2 * D * R}{2 * f} \qquad (8)$$

Where $L_{\min}$ is the minimum inductance, *D* is duty cycle, *R* is output resistance, and *f* is the switching frequency of switch SW. The output capacitance to give the desired output voltage ripple is given by equation 9:

$$C_{\min} = \frac{D}{R * f * V_r} \qquad (9)$$

Where $C_{\min}$ is the minimum capacitance, *D* is duty cycle, *R* is output resistance, *f* is switching frequency of switch SW, and *Vr* is output voltage ripple factor. *Vr* can be expressed as equation 10:

$$V_r = \frac{\Delta V_{out}}{V_{out}} \qquad (10)$$

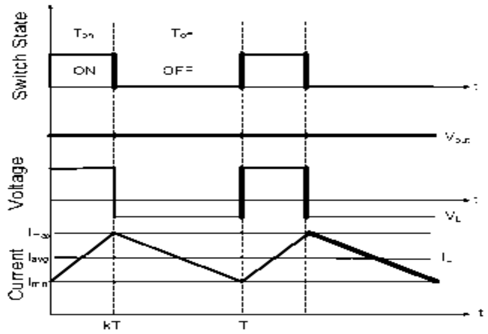

Fig. 14. Switch State, Vout, VL and IL.

B. Boost Converter Simulation

The detailed Simulink model is shown in fig. 15. Fig. 16 shows the simulation results for PWM frequency of 100 KHz, duty cycle D=0.5 , L=63μH, C1=C=5μF and R=50Ω.

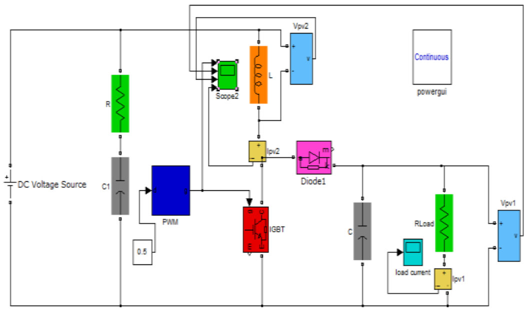

Fig. 15. Boost Converter Simulation.

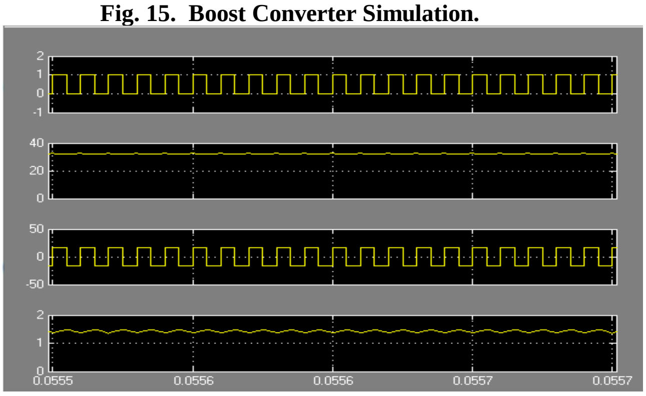

Fig. 16. Simulation Results for PWM, Vout, VL and IL.

VI. PERTURB AND OBSERVE ALGORITHM AND SIMULATION

In this algorithm a slight perturbation is introduced to the system. Due to this perturbation the power of the module changes. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached the power at the next instant decreases and hence after that the perturbation reverses. When the steady state is reached the algorithm oscillates around the peak point. In order to keep the power variation small the perturbation size is kept very small as shown in fig. 17 [13].

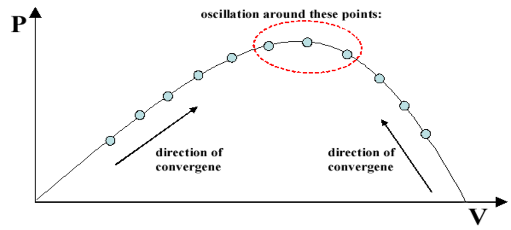

Fig. 17. Perturb and Observe Algorithm

The flow chart of the algorithm is shown in the fig. 18. The algorithm reads the value of current and voltage from the solar PV module. Power is calculated from the measured voltage and current. The value of voltage and power at kth instant are stored. Then next values at (k+1)th instant are measured again and power is calculated from the measured values. The power and voltage at (k+1)th instant are subtracted with the values from kth instant. If we observe the power voltage curve of the solar pv module we see that in the right hand side curve where the voltage is almost constant the slope of power voltage is negative (dP/dV<0) where as in the left hand side the slope is positive.(dP/dV>0). The right side curve is for the lower duty

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cycle (nearer to zero) where as the left side curve is for the higher duty cycle (nearer to unity). Depending on the sign of dP (P(k+1) - P(k)) and dV (V(k+1) -V(k)) after subtraction the algorithm decides whether to increase the duty cycle or to reduce it [13].

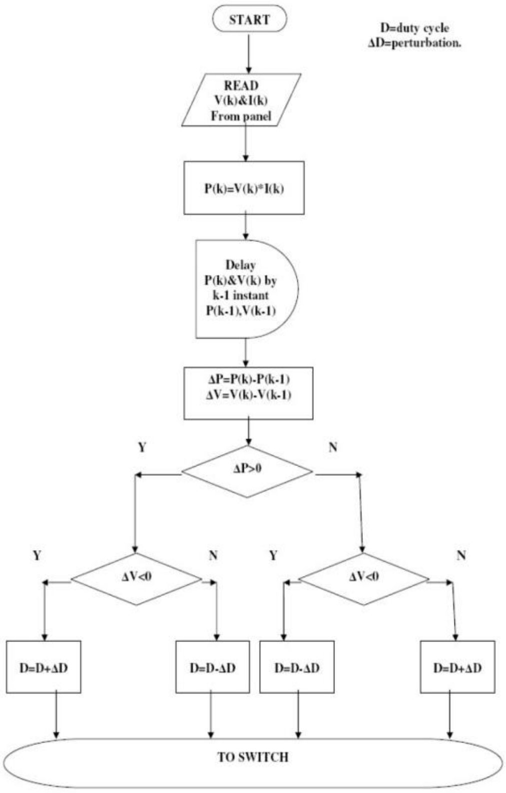

Fig. 18. Perturb and Observe Flow Chart.

The detailed Simulink model is shown in fig. 19. The V_{pv} and I_{pv} are taken as the inputs to MPPT unit, duty cycle D is obtained as output.

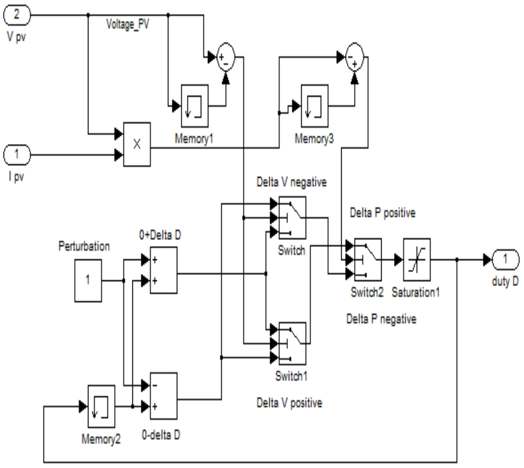

Fig. 19. Perturb and Observe Algorithm simulation

VI. SYSTEM SIMULATION

The whole system simulation is shown in fig. 20. It includes all the components seen before, the PV, the boost converter, the MPP tracker using perturb and observe algorithm and the resistive load. The simulation has been done for a gradual change of solar radiation from 300 to 1000W/m^2 as shown in fig. 21.

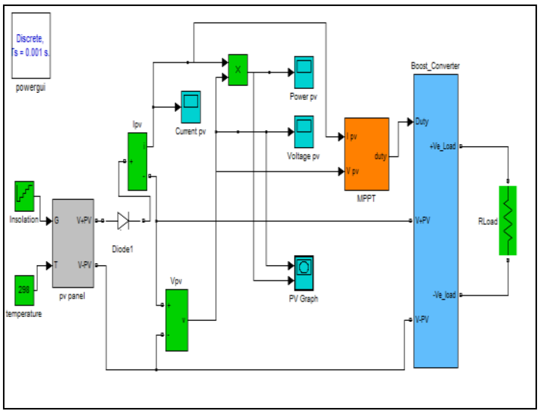

Fig. 20 The Whole System

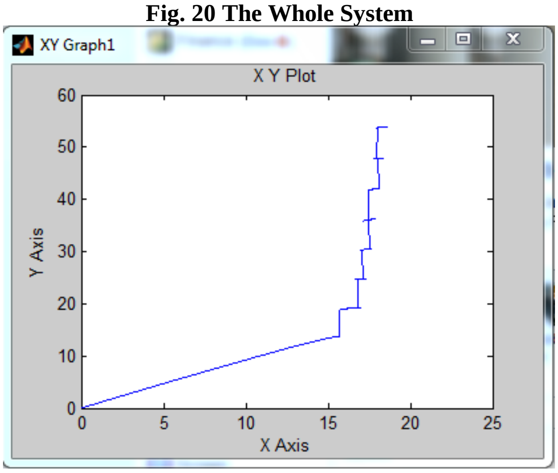

FIG. 21. MAXIMUM POWER POINT TRACKING BY PERTURB AND OBSERVE ALGORITHM FOR 300,400,500,600,700,800,900,1000W/M2 IRRADIANCES.

VII. CONCLUSION

In this paper a standalone PV system has been simulated by Matlab/Simulink. Perturb and observe algorithm has been used for maximum power point tracking. Simulation results show that the system operates in the maximum power point for the different irradiances values.

REFERENCES

[1] Ramos Hernanz, JA. Campayo Martin,JJ. Zamora Belver,I., Larranga Lesaka,J. , Zulueta Guerrero,E. p "Modeling of photovoltaic module", International Conference on Renewable Energies and Power Quality (ICREPQ'10) Granada (Spain), 23th to 25th March, 2010.

[2] Francisco M. González-Longatt, "Model of photovoltaic Module in Matlab™", (II CIBELEC 2005).

[3] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, Member, IAENG, "Development of generalized photovoltaic model using MATLAB /SIMULINK", Proceedings of the World Congress on Engineering and Computer Science 2008,WCECS 2008, October 22 - 24, 2008, San Francisco, USA .

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 6, December 2012

[4] M.G. Villalva, J.R. Gazoli and E.R. Filho, "Comprehensive approach to modeling and simulation of photovoltaic array", IEEE Trans on Power Electronics, Vol. 24, n°5, pp. 1198-1208,May 2009 .

[5] Savita Nema, R.K.Nema, Gayatri Agnihotri, "Matlab / simulink based study of photovoltaic cells / modules / array and their experimental verification", International Journal of Energy and Environment, Volume 1, Issue 3, 2010 pp.487-500.

[6] S. Rustemli, F. Dincer, "Modeling of photovoltaic panel and examining effects of temperature in Matlab/Simulink" Electronics and Electrical Engineering, ISSN 1392 – 1215, 2011. No. 3(109).

[7] 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.

[8] Syafrudin Masri, Pui-Weng Chan, "Development of a microcontroller-based boost converter for photovoltaic system", European Journal of Scientific Research ISSN 1450-216X Vol.41 No.1 (2010), pp.38-47 ©

[9] Matlab and Simulink, The Math works, Inc. as of September 2010, http://www.mathworks.com.

[10] D.P Hohm and M.E. Ropp, "Comparative study of maximum power point tracking algorithms", Progress in Photovoltaic: Research and Applications, 2003, 11:47-62.

[11] Manoj Kumar, F. Ansari, A.K. Jha "Maximum power point tracking using perturbation and observation as well as incremental conductance algorithm",IJREAS , ISSN 2294-3905, Vol.1,Issue 4 (2011), pp.19-31.

[12] Pandiarajan N., Ramaprabha R., Ranganath Muthu, "Application of circuit model for photovoltaic energy conversion systems", research article.

[13] Vikrant A. Chaudhari, "Automatic peak power tracker for solar pv modules using dspace software", Master thesis.,Maulana Azad National Institute of Technology, Deemed University,2005

AUTHOR'S PROFILE

Samer Alsadi Received his diploma in electrical Engineering in 1996 from D. Mendeleyev University of Chemical Technology, Moscow, Russian Federation, June 1996, Moscow, Russia and received his PhD from Moscow Power Engineering, Moscow, Russia in 2000. He is working now as an Assistance Professor in the electrical Engineering Department in Palestine Technical University-Kadoorie, Member in IEEE; Published in several national and international Journals, His area of interest includes Renewable Energy, Power Systems.

Dr. Basim Alsayid received B.Sc. in Electrical Engineering from Studies University of Bologna, Bologna, Italy in 1991. He received his PhD Degree in Electrical Drives Engineering from University of Bologna, Bologna in 2002. From 2002 to 2007 he worked as Assistant professor in the Department of Electrical Engineering, Palestine Technical University (Kadoorie) ,Tul Karm – Palestine. From 2007 to 2009 he worked as the head of the electrical engineering department and from 2009 till now he is the dean of the college of engineering and technology at the same university. He is a member of IEEE, Palestinian Engineers Association. His research areas are in electrical drives and renewable energy, in fact he is now also involved in a 2 years research program about design and control of photovoltaic systems with a French research group. He published in international journals and presented in various conferences throughout the world.