

A Controller for PV System Using Artificial Neural Network

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Abstract.

In this research, study theory of system includes the use of important source of renewable energy sources (solar source) and linking this system with an electrical load typical (home) using artificial intelligence. The world is witnessing significant rise in fossil fuel prices since the end of the last century until now, this rise in price increases with the decrease in inventory day after day. Therefore, turned the attention of researchers in the field of power generation to expand in non-conventional energy sources (new and renewable energy sources). New and renewable energy is inexhaustible energy in use because they rely on renewable natural resources. So in this study find detailed explanation about the system of photovoltaic cells system with solar cell types. The mathematical model is an important part of the detailed study for PV systems. As well as study models for photovoltaic systems via the MATLAB/Simulink, is a programming environment contains many models for renewable systems intended to perform simulation and analysis. Solar cells system needs to apply the (MPPT) algorithm due to the instability of external circumstances such as solar radiation and temperature. Therefore, a neural network technology applied to train solar cell data is intended to perform the optimization process and get the greatest value for electric power. At the end of this research, study conducted the operation of PV system for processing load appropriate electricity around the clock. Where the system simulation with the analysis of the results within 24 hours. Simulation results showed that the response of the Neural MPPT algorithm was faster than the classical P&O algorithm. Moreover, the average tracking efficiency of the neural network algorithm was higher than the classical P&O algorithm.

KEYWORDS: Maximum Power Point Tracking Algorithms (MPPT), PV _array, Photovoltaic (PV) Modelling, Neural Network Simulink modeling.

الخلاصة

في هذا البحث أجريت دراسة نظرية لنظام شمسي يتضمن استخدام مصدر مهم من مصادر الطاقة المتجددة (مصدر الشمس) وربط هذا النظام مع حمل نموذجي (منزل) باستخدام الذكاء الاصطناعي. يشهد العالم ارتفاعا ملحوظا في أسعار الوقود الاحفوري منذ نهاية القرن الماضي وحتى الان، حيث يزداد هذا الارتفاع والتناقص في المخزون يوما بعد يوم. ولهذا فقد اتجهت انظار الباحثين في مجال توليد القدرة الكهربائية الى التوسع في استغلال مصادر الطاقة الغير تقليدية بصورة خاصة مصادر الطاقة الجديدة والمتجددة. تعتبر الطاقة الجديدة والمتجددة من أنواع الطاقة التي لا تنضب بالاستخدام لأنها تعتمد على مصادر طبيعية متجددة. حيث تناولت الدراسة في هذا البحث شرح مفصل عن طاقة الشمس مع التطرق الى أنواع الخلايا الشمسية. النموذج الرياضي يعتبر جزءا مهما من الدراسة التفصيلية الخاصة بالأنظمة الشمسية. كذلك دراسة النماذج الخاصة بنظام الخلايا الضوئية (الشمسية) عن طريق بيئة (الماتلاب/سميولنك) التي هي عبارة عن بيئة برمجية إلكترونية تحتوي على العديد من النماذج الخاصة بالأنظمة المتجددة الغرض منها هو اجراء المحاكاة والتحليل للنتائج. نظام الخلايا الشمسية يحتاج الى تطبيق خوارزميات ذكية وذلك نتيجة لعدم استقرار الظروف الخارجية مثل مستوى الاشعاع الشمسي ودرجة الحرارة. لذلك تم تطبيق تقنية الشبكات العصبية التي تعتمد على اجراء التدريب للبيانات الخاصة بنظام الخلايا الشمسية (الفولتية-التيار) الغرض منها هو اجراء عملية التحسين. والحصول على أعظم قيمة للقدرة الكهربائية. في نهاية الدراسة يتم تشغيل نظام الخلايا الشمسية مع اجراء عملية السيطرة على النظام الشمسي من اجل تجهيز الحمل بالطاقة الكهربائية المناسبة على مدار الساعة. حيث تجرى محاكاة للنظام مع تحليل النتائج خلال 24 ساعة. بالمقارنة مع نتائج الابحاث الأخرى تم التحقق من صحة النتائج وأثبتت بانها نتائج دقيقة .

Nomenclature

I, V	Cell output current, Cell output voltage, A, V.
I_{ph}, I_d,	The Photocurrent, The diode current,
I_o	The saturated reverse current or leakage current , A.
T_c, T_a	Cell operating temperature, ambient air temperature, K
T_r	Reference cell operating temperature= 25C = 298.13 K.
N_s, N_p	Number of series cells, Number of parallel cells.

Rsh	Shunt resistance	Ω .
Rs	Series resistance	Ω .
I_{ph}	The photovoltaic current at T _c & G,	A.
I_o	Reverse saturation current at T _c ,	A.
G	The intensity of solar irradiance,	W/m ² .
G_r	The reference intensity of solar irradiance = 1000	W/m ² .
K_i	Temperature coefficient of the short-circuit current.	
K_o	Temperature coefficient of the open circuit voltage.	
Q	Electron charge (1.602×10^{-19}	C.
K	Boltzmann constant (1.38×10^{-23}	J/k.
A	The diode ideality factor.	
V_T	thermal voltage.	
I_p	Current leak in parallel resistor.	A.
E_g	Band-gap of the semiconductor material.	

1- Introduction:

Every country in the world needs to develop its resources and policies, as this development related to energy, keeping in mind the environmental pollutants. The purpose is to better plan for the future [1]. If using traditional energy sources such as fossil fuels, there is, an important fact is the growing energy consumption significantly related to carbon dioxide emissions. The increase in the rate of emissions as well as the global warming has a close relationship with developments on energy sources. Energy sources especially electric energy sources in many countries is the main motivation for agriculture and industry. Energy development is the main measure of power as well as the level of development in the future. The use of new and renewable sources of energy in the countries of the world whose purpose is to avoid problems caused by dependence on fossil fuels because they are exhaustible sources as they are considered non-environmentally friendly.[2]

However, non-renewable sources are always non-sustainable sources. An example of this is the energy crisis that occurred in 1973 in parts of the world due to lack of fuel, where people are faced with many problems. The oil embargo was found in March 1974. Despite the oil embargo found that, oil prices remain high and this increase was the impact on the continuing energy crisis throughout this century. In the period 1974-1975, there were some laws imposed to rationalize energy consumption, including: price controls, rationing of gasoline, reduce speed, and extinguish the lights during the day. All these laws were imposed because of the crisis-taking place in the energy.

There are many reasons that led to the rapid spread of technologies of new and renewable energy across the countries of the most important of these reasons are:[3].

1-climate changes.

2-rising fossil fuel prices.

2-increased air pollution as a result of traditional energy sources.

4-lack of processing power.

An important example of the use of renewable energy technology is certified for emissions of carbon dioxide gas in the following countries: Iran, Iraq, and Saudi Arabia from 2000 to 2010, respectively, where the percentage of increase in emissions as follows: 35.7%, 21.75% and 15.6%. Although these countries have been able to use renewable energy. Where there are recognized scheme through which the rates of increase and decrease emissions of carbon dioxide gas in the Middle East and North Africa regions from 2003 to 2010. [4].

1.1-Photovoltaic (PV) Energy.

Photovoltaic energy is energy obtained from sunlight. Through the system of photovoltaic cells that directly convert solar radiation into electricity. Photovoltaic cell has the primary role in this conversion process. Set of photovoltaic cells connected together called Panel. In General, Panels are a number of solar cells linked to form a series cells for getting high voltage. Either for the purpose getting high currents, this is done by increasing the surface area of cells or by connecting cells in parallel. Photovoltaic system consists of one or more Panel; they are connecting to either parallel or a series. Photovoltaic system consists of five major components:

1- PV array. 2- Dc-Dc converter. 3- inverter. 4- digital controller. 5- AC filter. [5]

1.2-Intelligent MPPT techniques:

Recently appeared a group of smart techniques. These techniques are described as smart, because it is a simulation of the human mind. Several researchers have clarified these techniques, where they use computational techniques in control units to reach the maximum power point (MPP), quick response, reduce Oscillations occurring in the power curve in PV system.

1.2.1- Neural network technique:

Neural network technology has become commonly used in non-linear systems. The Difficult problems in modelling systems was solved by neural networks using parameters approximations. Neural network consists of three layers: input layer, hidden layer, and output layer. Input layer consists of 36 neurons; Feed this layer by two-variable voltages and current. Which they obtained from the photovoltaic system. The Output of the neural network is a duty cycle, which is used to drive the converters operated at or near the MPP. Hidden layer used to distribute signals input to output layer; this is based on the transfer function. There is no accurate calculation to determine how many neurons in the Hidden layer. Select number of neurons through a trial and error. There are also multiple formulas for transfer function. They are tangent sigmoidal function used in hidden layer and pure linear function used at output layer. The advantages of neural networks in creating the mpp is that train these networks equipped high and accurate electrical point without the need of great knowledge about the determinants of photovoltaic system. [6] [7] [8].

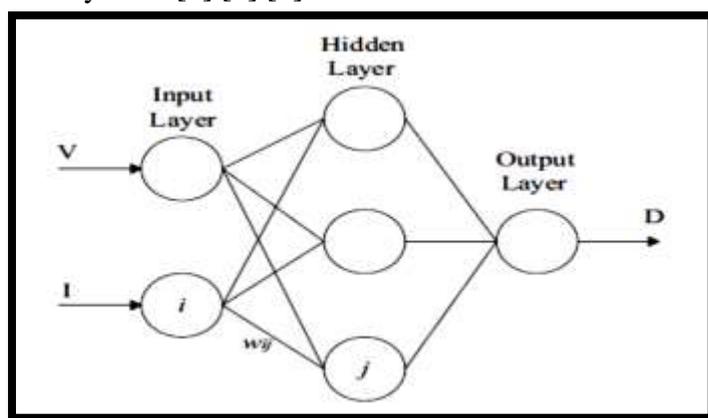


Figure1: Neural network technique based on MPPT. [9]

2-Mathematical modeling of Photovoltaic System.

Study of solar photovoltaic cells model using electric circuit equations for solar cell. Take into consideration the effect of solar radiation and temperature changes. Solar cell's circuit consists of a photoelectric current source connected in parallel with a diode, Series Electrical resistance (R_s) and Electrical resistance in parallel (R_p).

Photocurrent source generates a constant value for the current proportion, with the intensity of solar radiation that falls directly on the surface of the solar cell. The external conditions of the weather, have a significant impact on photovoltaic systems, among these conditions is the

level of solar radiation and temperature. The amount of electric power produced, price, location and design of those systems all rely on external work conditions.

Therefore, must focus on precision and performance study for those systems, because they operate under variable conditions. The relationship between voltages and current (I-V) is the basis for the study and analysis of solar photovoltaic cell system. Then put the appropriate control method, which adapt these systems with changing conditions.

Diode equivalent circuit of a solar cell is necessary to determine the characteristics of the current-voltage curve. According to the Shockley equation, the voltages increase logarithmically, In the case of an open circuit. Diode current is directly proportional to the saturation current [10] [11] [12] [13] [14] [15].

$$I_d = I_{o, cell} * \exp \left[\left(\frac{qV}{AKTc} \right) - 1 \right] \dots \dots \dots (1)$$

$$V_T = \frac{K * T_c}{q} * N_s \dots \dots \dots (2)$$

$$I = I_{ph, cell} - I_d - I_p \dots \dots \dots (3)$$

$$I = I_{ph, cell} - I_{o, cell} * e^{\left[\left(\frac{q(V+I R_s)}{AKTc} \right) - 1 \right]} - \left[\frac{V + I R_s}{R_{sh}} \right] \dots \dots \dots (4)$$

$$V = \frac{AKTc}{q} \ln \left[\frac{I_{ph, cell} + I_{o, cell} - I}{I_{o, cell}} \right] - I R_s \dots \dots \dots (5)$$

$$I_{ph, cell} = \frac{G}{G_r} [I_{phr} + k_i * (T_c - T_r)] \dots \dots \dots (6)$$

$$I_{o, cell} = \left[I_{or} * \left(\frac{T_c}{T_r} \right)^3 \right] * e^{\left[\frac{q E_g}{AK} * \left(\frac{1}{T_r} - \frac{1}{T_c} \right) \right]} \dots \dots \dots (7)$$

Main parameters of solar cells can be enumerated as follows: [15]

- 1-short circuit current (Isc).
- 2- Open circuit voltage (Voc).
- 3-maximum power point (MPP).
- 4-efficiency of solar cell and fill factor.

$$P_{max} = V_{max} * I_{max} \dots \dots \dots (8)$$

$$\eta = \frac{P_{max}}{P_{in}} * 100 \dots \dots \dots (9)$$

$$P_{in} = G * A_{sur} \dots \dots \dots (10)$$

$$FF = \frac{P_{max}}{V_{oc} * I_{sc}} \dots \dots \dots (11)$$

3. Simulink modeling of Photovoltaic (PV) system.

A 100-kW PV array is connected to a 25-kV grid via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC). Maximum Power Point Tracking (MPPT) is implemented in the boost converter by means of a Simulink model using the 'neural network' technique.

The average model contains:

- 1-PV array delivering a maximum power of (100 kW) at (1000 W/m²) sun irradiance.
- 2- Average model of boost converter increasing voltage to 500 V DC.
- 3- MPPT controller use the “neural network” technique.it connect with Average model of boost converter.

4-Average model of VSC. The VSC converts the 500 V DC to 260 V AC and keeps unity power factor.

5-10-kvar capacitor bank filtering harmonics produced by VSC.

6-100-kVA 260V/25kV three-phase coupling transformer.

7-Utility grid model (25-kV distribution feeder + 120 kV equivalent transmission system).[16]

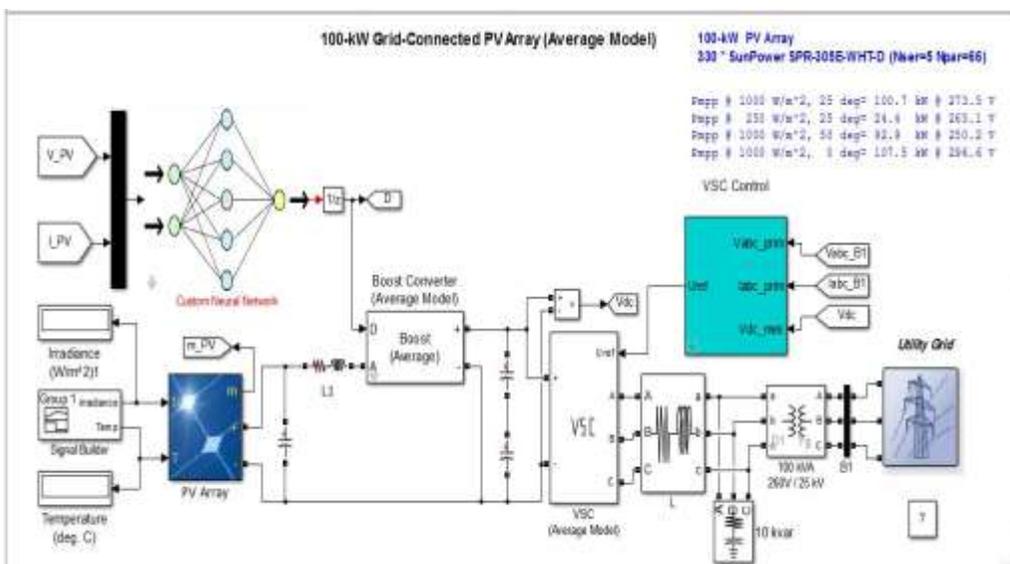


Figure 2: Photovoltaic system Simulink modeling (PV Array (Average Model)).

3.1 - Neural Network Simulink modeling.

The function `gensim` generates block descriptions of networks so you can simulate them using Simulink[®] software.

`gensim(net,st)`

The second argument to `gensim` determines the sample time, which is normally chosen to be some positive real value.

If a network has no delays associated with its input weights or layer weights, this value can be set to -1. A value of -1 causes `gensim` to generate a network with continuous sampling. The input blocks are actually a standard Constants blocks.

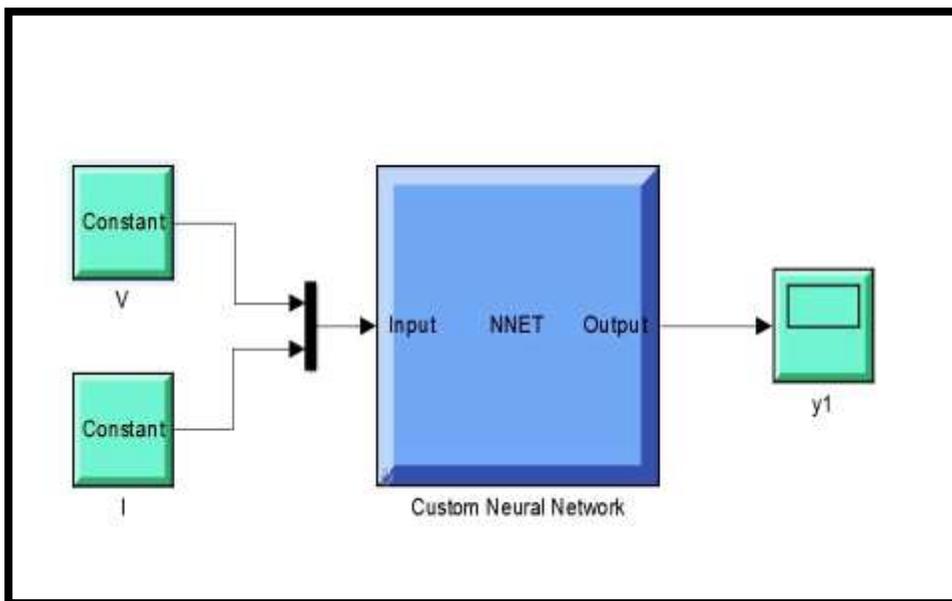


Figure 3: Deploy Neural Network Simulink Diagrams. [The Math Works, Inc., MATLAB R2015b].

4. Results:

By using Simulink models of PV array and neural network and implemented this models the result display as shown in figure [4, 5, 6, 7, 8, 9,10,11,12, and 13] below:

The 100-kW PV array of the detailed model uses 330 SunPower modules (SPR-305). The array consists of 66 strings of 5 series-connected modules connected in parallel ($66 \cdot 5 \cdot 305.2 \text{ W} = 100.7 \text{ kW}$).

Open the PV-array block menu and look at model parameters.

Manufacturer specifications for one module are:

- Number of series-connected cells: 96
- Open-circuit voltage: $V_{oc} = 64.2 \text{ V}$
- Short-circuit current: $I_{sc} = 5.96 \text{ A}$
- Voltage and current at maximum power: $V_{mp} = 54.7 \text{ V}$, $I_{mp} = 5.58 \text{ A}$

The PV array block menu allows you to plot the I-V and P-V characteristics for one module and for the whole array. The characteristics of

the SunPower-SPR305 array are reproduced below [16].

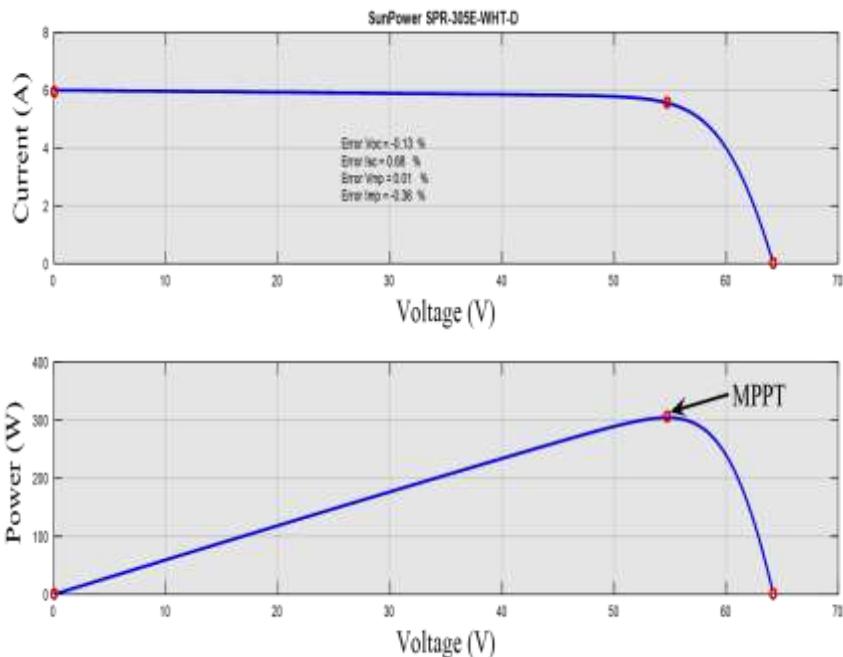


Figure 4 : I-V and P-V characteristics of the PV array modules show I_{sh} , V_{oc} , I_{mp} , V_{mp} , and MPPT.

To validate the results of the solar cell model, the results are compared with the results obtained from ref. [17]. These comparisons are shown in figures 5, 6, 7, and 8.

Figure (5) Showing the relationship between I-V under the influence of different radiation values (200, 500, 800, 1000 W/M^2) for one module only. So this figure (5) compares with the figure (6) for one module too under same conditions.

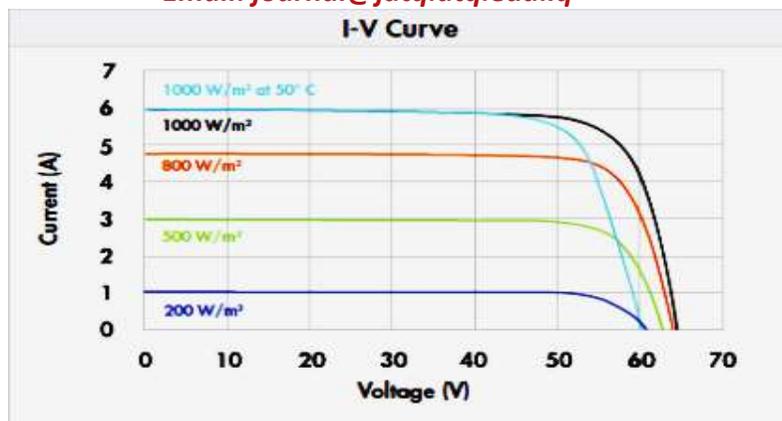


Figure 5: I-V characteristics of PV array with Varying Solar Irradiance Level Of one module [Antonio Faggio 2015] [17].

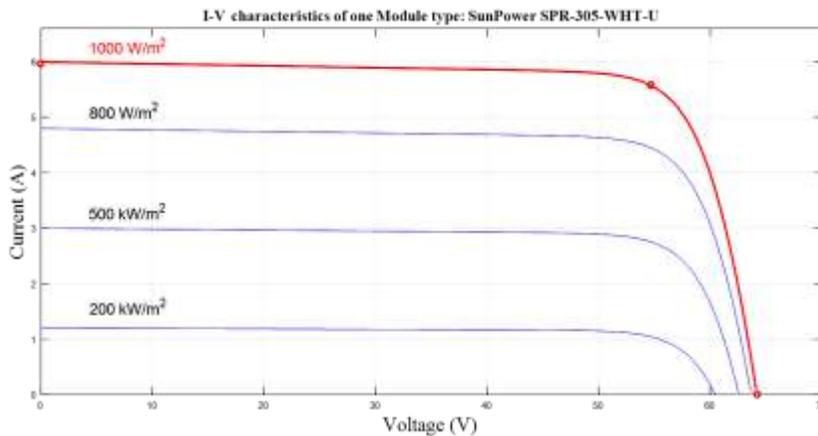


Figure 6: I-V characteristics of PV array with Varying Solar Irradiance Level of one module.

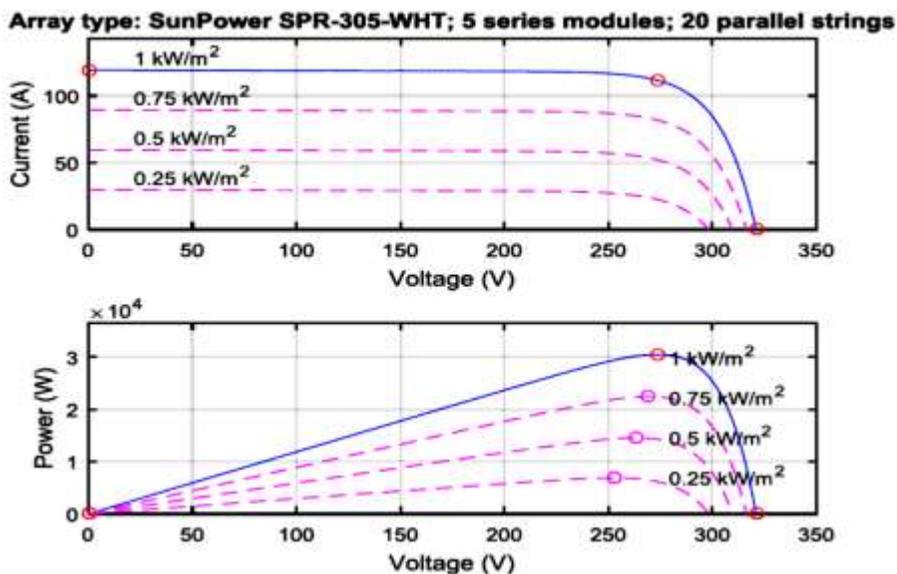


Figure 7: I-V and P-V characteristics of PV array with Varying Solar Irradiance Level of 5 series modules; 20 parallel strings [Antonio Faggio 2015] [17].

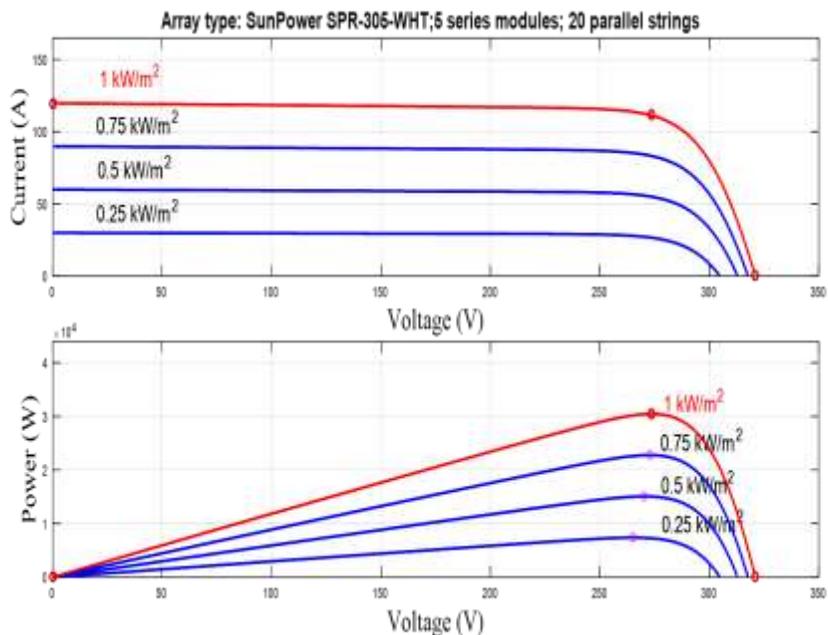


Figure 8: I-V and P-V characteristics of PV array with Varying Solar Irradiance Level.

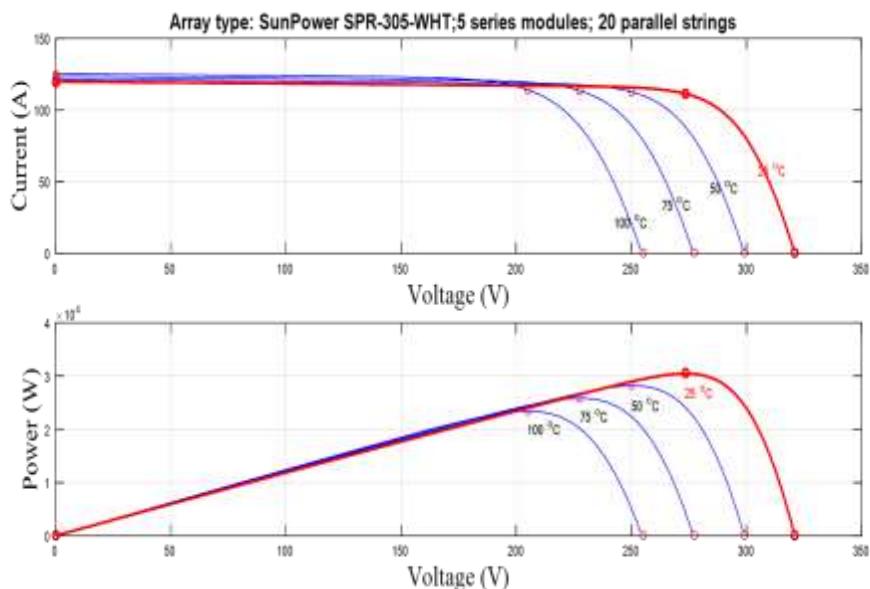


Figure 9: I - V and P - V Characteristics with Varying Operating Temperature.

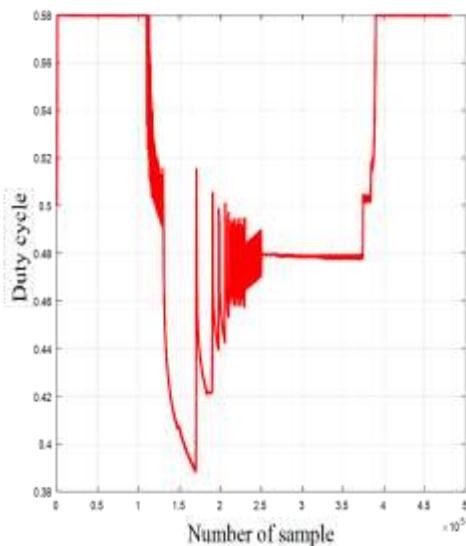


Figure 10a: Duty cycle of MPPT Controller using perturb & Observe technique.

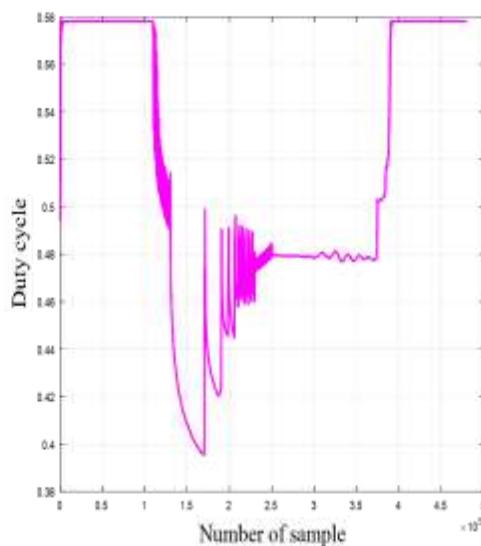


Figure 10b: Duty cycle of Controller using neural network.

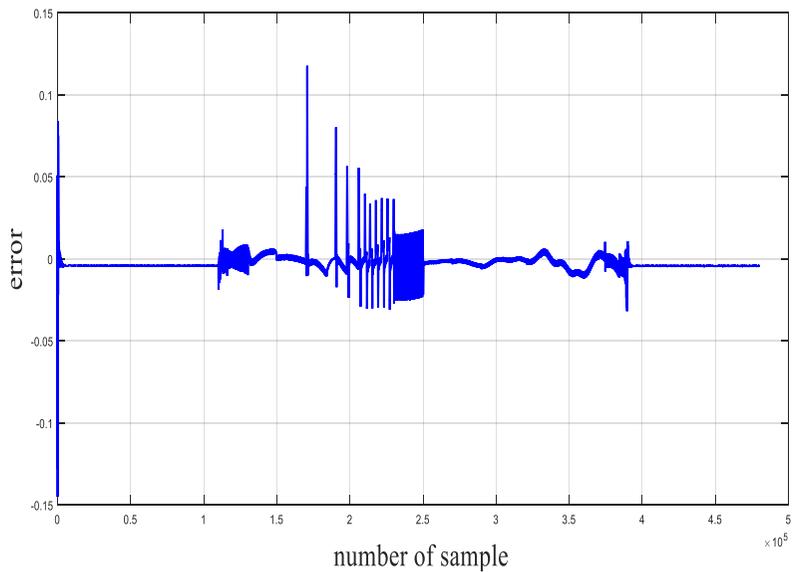
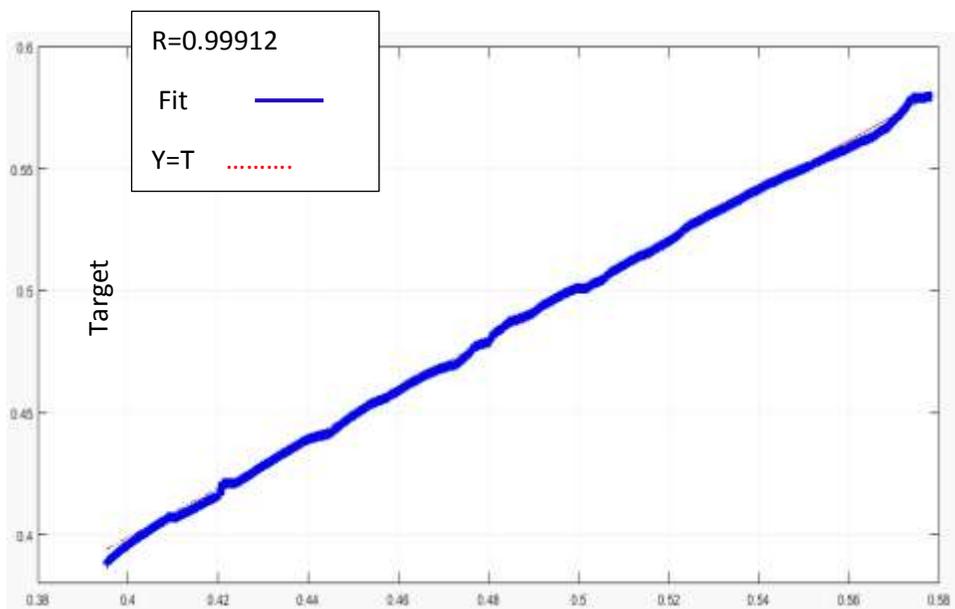


Figure 11: errors values of neural network.



Y1

Figure 12: the regression of neural network.

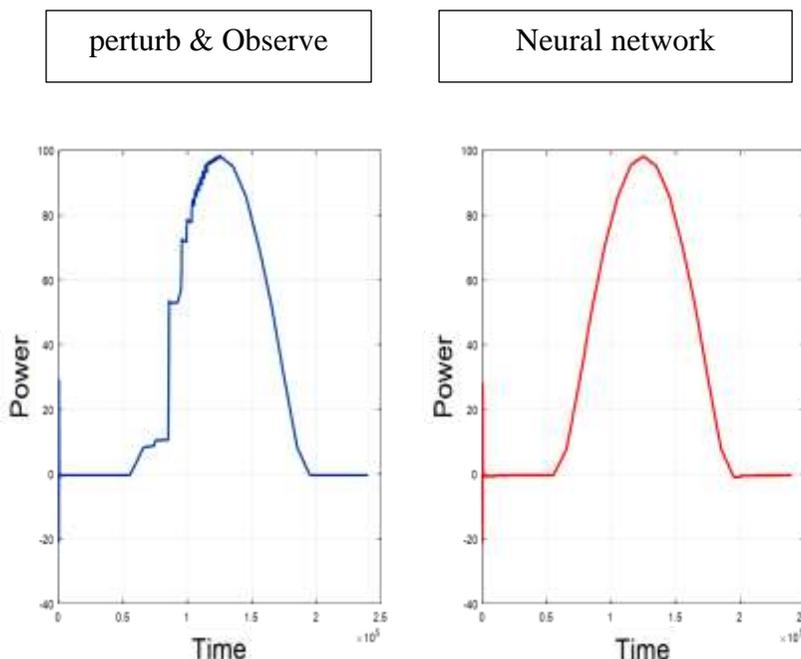


Figure 13: Power curve simulation result within 24 hours.

5-Discussions.

Using the MATLAB program, specifically the Simulink model was implemented the PV array that is addressed in the section Simulink modeling. There are several types of models the PV array. In this research was selected one of these models is SunPower SPR-305E-WHT-D. Parameters for this model are shown in the Dialog Box and Parameters of PV array. When an implementation of the model via MATLAB/Simulink, there are three important variables represent the output of the model for PV array, Voltages, current and power. Where the focus is on the non-linear relationship between (current-voltage) and (power- voltages) (the I-V and P-V characteristics). Study of the solar model results are first and second case, the first case is to be constant temperature (25c) with solar radiation level changes. The second case is the temperature change with a constant level of solar radiation (1000 w/m²). The I-V and P-V characteristics are shown in figures (4, 6, 8, and 9). Curves of the solar model featuring non-linear nature. The output current and power of PV cell depend on the cell's terminal operating voltage and temperature, and solar radiation.

❖ ***I-V and P-V Characteristics with Varying Solar Radiation Level***

Fig.6, 8, it is observed that with the increase of the solar radiation, the short-circuit current of the PV module increases and the maximum power output increase.

❖ ***I-V and P-V Characteristics with Varying Operating Temperature***

Fig. 10, it is observed that with the increase of the operating temperature, the short-circuit current of the PV module increases. However, the maximum power output decrease.

- ✓ The reason is the open-circuit voltage is logarithmically dependent on the solar irradiance, yet the short-circuit current is directly proportional to the radiant intensity.

Neural network architecture is very important to find the right solution for complex systems with non-linear relations or which owns random variable. The training process is the basis for the neural network. There are multiple algorithms to perform the training process but the famous type of the back propagation (or feed-forward), it is widely used. The simplest form of neural network is using architecture consists of three layers. Input layer receives external data, hidden layer receive data from input layer and sent to the output layer. Training through the back propagation based on two main points: learning and knowledge. This research was applied by the use of tan-sigmoid function as an activation function in order to calculate the hidden layer output and a linear function to calculate the output.

Figure (13) shows the curve for electric power data produced from solar cells but different control methods. The curve on the right represents the power curve using a smart algorithm neural network technology; the purpose is to reach and stability at maximum power, either the curve on the left is the power curve using the classic algorithm Perturb & Observe (P & O). Instability in power value led to use maximum power point tracking (MPPT). The other target of Figure (13) is validated using neural network technique through comparison with classical algorithm (P &O) adopted in most published research. Simulation results showed that the response of the Neural MPPT algorithm was faster than the classical P&O algorithm. Moreover, the average tracking efficiency of the neural network algorithm was higher than the classical P&O algorithm.

6. Conclusions:

The detailed study of the PV system led to access a number of necessary conclusions:

1- Relying on new and renewable sources of energy as successful alternative sources. Renewable energy sources (SOLAR SOURCE) provide sufficient electrical energy without causing environmental pollution with the possibility of not being depleted as they emanate from sources of nature.

2- Modern techniques like neural network used in control of new and renewable energy systems has led to excellent results, like getting the maximum value for the electrical power.

3- Easily handle with the results of implementation of PV system model, as a result of the use of the environment (matlab/Simulink) that contain many systems and electronic means which help to deal with the smooth systems.

4- Dealing with the modern electronic control led to convenience in operation of the PV systems, which reduced operational cost.

5- Neural networks are characterized by fast tracking for maximum power value with neglecting oscillations.

6- Neural network performance is not affected by variation load, noticing a slight variation, and during a few time reach to MPP point.

7- High smoothness is a salient feature of neural network simulation on during execution in the electric power curve, as opposed to using the classic technique (P @ O) known as frequent oscillation and slow in response.

References:

[1]- Payam Nejat , Abdul Kasir Morsoni , Fatemeh Jomehzadeh , Hamid Behzad , Mohamad Saeed Vesali , M.Z.Abd.Majid. Iran's Achievements In Renewable Energy During Fourth Development Program In Comparison With Global Trend, Renewable And Sustainable Energy Reviews , (2013);Vol 22: 561–570.

- [2]-Omid Nematollahi, Hadi Hoghooghi, Mehdi Rasti , Ahmad Sedaghat, "Energy Demands And Renewable Energy Resources In The Middle East", Renewable And Sustainable Energy Reviews, (2016); Vol 54:1172–1181.
- [3]- Bob Vander Zwaan, Lachlan Cameron, Tom Kober, Potential For Renewable Energy Jobs In The Middle East, Energy Policy (2013);Vol 60:296–304.
- [4]- The World Bank. Available From: (<[Http://Data.Worldbank.Org/Indicator/En.Atm.Co2e.Pc](http://Data.Worldbank.Org/Indicator/En.Atm.Co2e.Pc)>).
- [5]-Cemal Zeray. Renewable Energy Sources. Institute Of Natural And Applied Sciences. Department Of Electrical Electronic Engineering. January 2010, Pages 112.
- [6]-S. Saravanan, Ramesh Babu N. Maximum Power Point Tracking Algorithms for Photovoltaic System – A Review. Renewable And Sustainable Energy Reviews (2016).Vol 57 .192–204.
- [7]- F. Chekired , A. Mellit , S.A. Kalogirou , C. Larbes , Intelligent Maximum Power Point Trackers For Photovoltaic Applications Using Fpga Chip: A Comparative Study, Solar Energy (2014); Vol 101: 83–99.
- [8]- Bidyadhar Subudhi, Raseswari Pradhan, A Comparative Study On Maximum Power Point Tracking Techniques For Photovoltaic Power Systems, Ieee Transactions On Sustainable Energy, January (2013);Vol. 4: No. 1.
- [9]- Trishan Eswam, Comparison of Photovoltaic Array Maximum Power
- [10]- M.B. Eteiba, E.T. El Shenawy, J.H. Shazly, A.Z. Hafez. A Photovoltaic (Cell, Module, Array) Simulation And Monitoring Model Using Matlab®/Gui Interface. International Journal of Computer Applications. – No.6, (May 2013); Volume 69: (0975 – 8887).
- [11]- Şaban Yılmaz, Hasan Rıza Özçalık, Mahit Güneş, Osman Doğmuş. Mathematical Model Derivation Of Solar Cell By Using Onedioder Equivalent Circuit Via Simulink. International Journal of Education and Research. (December 2013); Vol. 1:No. 12.
- [12]- G.Joga Rao, Dr. D.K.Mangal, Dr.S.K. Shrivastava, Md.Gouse Baig. Modeling And Simulation Of Incremental Conductance Maximum Power Point Tracking (Mpppt) Algorithm For Solar Pv Array Using Boost Converter. Engineering and Technology. (2016); Volume 2: Issue 4 | Print ISSN: 2395-1990 | Online ISSN: 2394-4099.

- [13]- S. Sheik Mohammed. Modeling And Simulation Of Photovoltaic Module Using Matlab/Simulink. International Journal Of Chemical And Environmental Engineering. (October 2011); Volume 2: No.5.
- [14]- Habbati Bellia, Ramdani Youcef, Moulay Fatima. A Detailed Modeling Of Photovoltaic Module Using Matlab. Nriag Journal Of Astronomy And Geophysics.(June 2014) ;Volume 3:Pages 53–61.
- [15]-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); Isbn: 978-988-98671-0-2.
- [16]- Pierre Giroux, Gilbert Sybille, Hydro-Quebec Research Institute (Ireq) Carlos Osorio, Shripad Chandrachood, The Mathworks (2015).
- [17]- Antonio Faggio, Hierarchical Control of a DC Low Voltage Microgrid Supplied by Distributed Energy Resources, Thesis submitted for examination for the degree of Master of, Politecnico Di Milano, School of industrial engineering and information Master of Science in electrical engineering, Academic year 2014-2015, page 276.