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Research paper

Minimizing the loses of PV panel generation by designing an intelligent controller based on FPGA

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Abstract

The increasing of using of an electrical power as a power source in a large number of devices can occur a serious problem in our daily life. One of the useful power sources is PV panel which used to overcome many problems of power generation. In this paper, the PV cells model is proposed to minimize loses of PV panel power generation by designing of an intelligent tracking system based on FPGA. PSO algorithms are used to train the neural networks to control the speeds and the directions of rotations of two DC motors with the help of FPGA cart. The proposed system was implemented in MATLAB; and for the hardware part, FPGA was used for the implementation of neural networks.

Keywords: *PV Panel; Solar Tracking System; Intelligent Controller; Neural Networks; FPGA.*

1. Introduction

In Energy which replenished continuously and produced by natural resources such as sunlight, geothermal and tides, wind etc., can never be fatigued[1]-[4]. Thus, it is considered as unlimited resources. There are many benefits of using it as compared with conventional fossil fuels resources such as the ability of reduction of pollution level as considered a clean power source. Nowadays, most energy resources produced by combustion of fossil fuels such as natural gas, oil, coal etc. [5].Recently, the increasing in demand on the electrical power for daily use leads to many problems. However, the electric energy is not replenished which means the daily used of this energy can leads to terminate it. Therefore, the demand on clean and replenished energy is increased such as renewable energy. Solar energy is considered as a good power source in many practical applications due to its widely existing in the earth and the simplicity of converting it to the electrical power [6].

As knowing, the PV cells are affected by many internal factors such as the type of material which used in the PV panel cell industry and also many external factors such as the intensity of the light and the temperature which falls on the cells and others [7]. Because of the cost of the changing in the internal factors is somewhat expensive, the aim of this research was to control the external factors that affect the productivity of the PV panel for the electrical energy. An intelligent controller was proposed and designed to direct the PV panel towards the sunlight to increasing the production of the solar cell as much as possible. FPGA proved have great efficiency with different research area such as [8]-[10].

2. Mathematical model of PV cell

Image From the physical behavior of a photovoltaic cell and based on the sensitivity of the semiconductor material to the sunlight, ideal solar cell, theoretically, can be modeled as a current source in anti-parallel with a diode Figure (1) shows the equivalent circuit. When the cell is exposed to light the direct current will be generated and varies linearly with solar radiation [11].

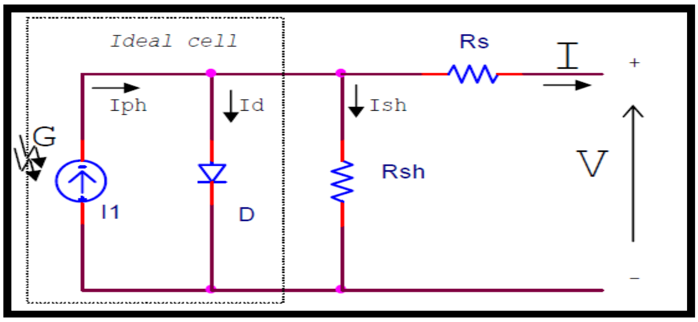

Fig. 1: Photovoltaic Cell Equivalent Circuit.

Solar cell can be modeled in one diode parallel with current source model or can be modeled in two diode parallel with current source model [12].

2.1. Solar model for one diode

Based on the equivalent circuit of photovoltaic panel and for ideal cell its characteristic equation is

$$I = Iph - Id \quad (1)$$

Where
Iis the current out from cell
Iphis a light-generated current or photocurrent,

$$Iph = Isc + KI(TC - TRef) * \frac{G}{Gn} \quad (2)$$

Where

Iscis the cell's short-circuit current at a 25°C and 1kW/m2
KIis the cell's short-circuit current temperature coefficient,
TC =is the cell's working temperature.
TRefis the cell's reference temperature
Gis the surface irradiance of the cell and
Gn Nominal irradiance [W/m^2] at 25oC; Gn = 1000
Idis diode current and it is equals to:

$$Id = Io * \left[e^{\frac{q*(V+IRS)}{K*TC*A}} - 1\right]$$
(3)

Iois the cell saturation of dark current

$$Io = IRs * \left(\frac{TC}{Tref}\right)^3 * \left[e^{\frac{q*EG\,(TC-Tref)}{Tref*TC*K*A}}\right]$$
(4)

Where
IRsis the cell's reverse saturation current at a reference temperature and standard solar radiation.
EGis the bang-gap energy of the semi-conductor used in the cell and.
A is the ideal factor, dependent on PV technology.
$q = (1.6 \times 10^{-19}\ C)$ is an electron charge.
$k= (1.38 \times 10^{-23} J/K)$ is a Boltzmann's constant.
An improved equation which considers temperature variations in order to describe the saturation current is given by [13]

$$Io=\frac{Isc+KI*(TC-TRef)}{\exp\left[\frac{Voc+KV*(TC-TRef)}{A*Vt}\right]-1}$$
(5)

Vocis cell's open circuit voltage

$$Vt = \frac{NS*K*TC*A}{q}$$
(6)

NSis the number of series cells
So,

$$I=\left[Isc + KI(TC - TRef) * \frac{G}{Gn}\right] - \left[\frac{Isc+KI*(TC-TRef)}{\exp\left[\frac{Voc+KV*(TC-TRef)}{A*Vt}\right]-1}\right] * \left[e^{\frac{q*(V+IRS)}{K*TC*A}} - 1\right]$$
(7)

An improvement of the model includes the effects of a shunt resistance (Rsh) and another in series (RS).
The output current will be:

$$I = Iph - Id - Ish$$
(8)

$$I=\left[Isc + KI(TC - TRef) * \frac{G}{Gn}\right] - \left[\frac{Isc+KI*(TC-TRef)}{\exp\left[\frac{Voc+KV*(TC-TRef)}{A*Vt}\right]-1}\right] * \left[e^{\frac{q*(V+IRS)}{K*TC*A}} - 1\right] - \left[\frac{(V+IRs)}{Rsh}\right]$$
(9)

A PV array is a group of many PV cells which are electrically connected in parallel and series circuits in order to generate the required current and voltage. The equivalent circuit for the solar module arranged in Np parallel and Ns series cells is shown in Figure (2).

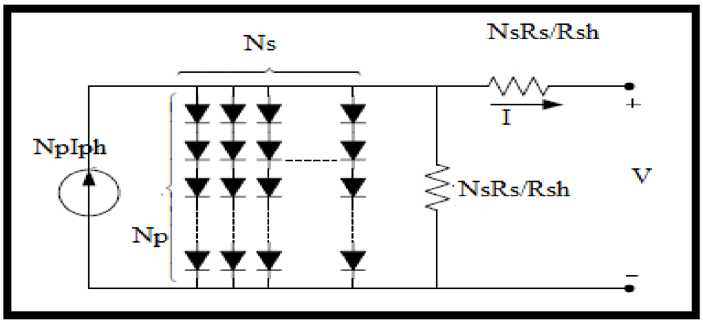

Fig. 2: Equivalent Circuit of Solar Array.

The terminal equation for the current and voltage of the array becomes as follows

$$I= Iph * Np - Np * Io * \left[e^{\frac{q*(\frac{V}{Ns}+\frac{IRS}{Np})}{K*TC*A}} - 1\right] - \left[\frac{(\frac{V*Np}{Ns}+IRs)}{Rsh}\right]$$
(10)

2.2. Two-diode PV model

The two-diode model has one extra diode as shown in Figure (3). In low irradiance level, the two-diode model is more accurate than the single diode model. The voltage – current relation is given in equation (12). Where Io1 and Io2 are diodes reverse saturation current.

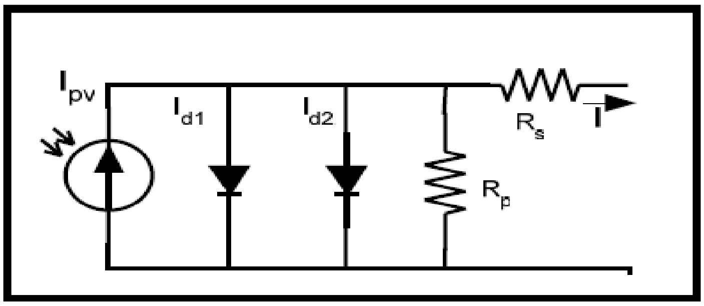

Fig. 3: Two-Diode Model.

$$I = Iph - Id1 - Id2 - Ish$$
(11)

$$I= Iph - Io1 * \left[e^{\frac{q*(V+IRS)}{K*TC*A1}} - 1\right] - Io2 * \left[e^{\frac{q*(V+IRS)}{K*TC*A2}} - 1\right] - \left[\frac{(V+IRs)}{Rsh}\right]$$
b
(12)

3. Proposed method

In this Figure (4) show the proposed system which consists of four LDRs(light dependent sensors), an intelligent controller, ADC0804IC and two DC motors.LDR sensors are used to test the intensity and the direction of the sun which includes (up/ down) and (right/ left) directions.

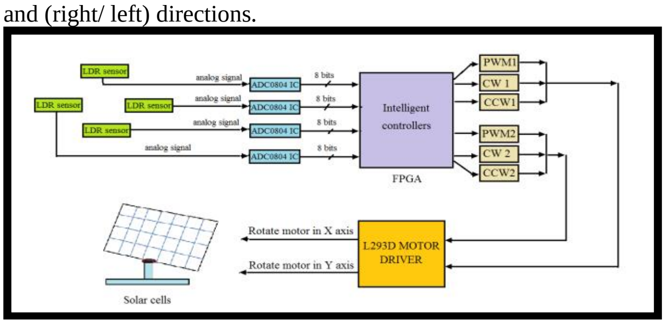

Fig. 4: Block Diagram for Proposed Intelligent Tracking System.

ADC0804IC is used to convert the output signal of the sensors which is analog signal to digital signals as shown in figure (5). The digital signals will be the input to the intelligent controller which in turns sends signals to control the speed and the direction of the two DC motors. One of these motors is used to track the sun in X-axis direction and the other one is used to track the sun in Y-axis direction.

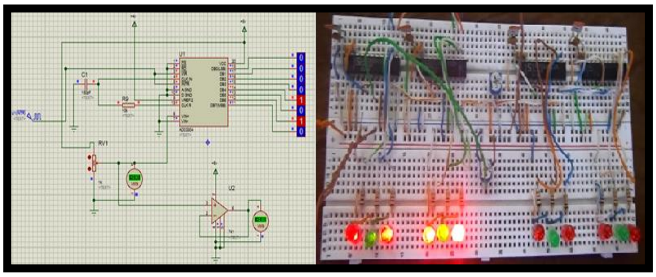

Fig. 5: ADC0804IC Hardware and Simulation Results.

3.1. Simulation results of training ANN with PSO

PSO used in the training of the ANN scheme to obtain best weights for using it in the networks; Figure (6) shows the ANN scheme of the proposed system. There are three output variables in the training data (duty cycle, clockwise rotation, and counter clockwise rotation); in this case, the input processing of the elements includes one neuron, and 8 hidden neurons based on trial and error method.

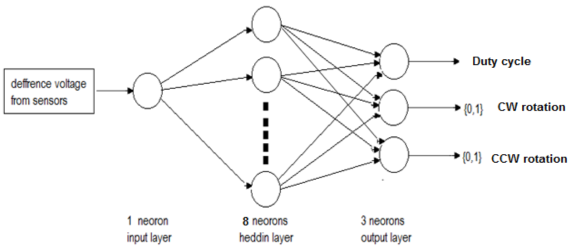

Fig. 6: Training ANN Using PSO and BP.

The performance of the PSO algorithm and the accuracy of this performance shown in Figure (7) and Figure (8).

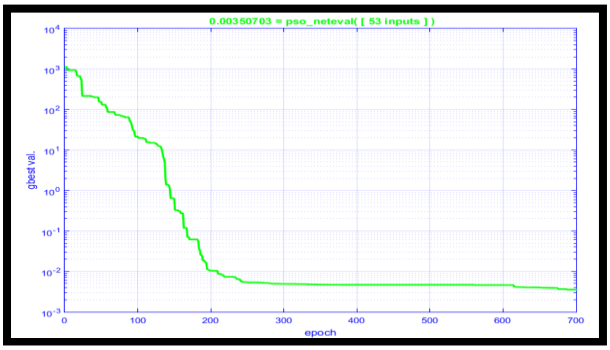

Fig. 7: The Performance of PSO.

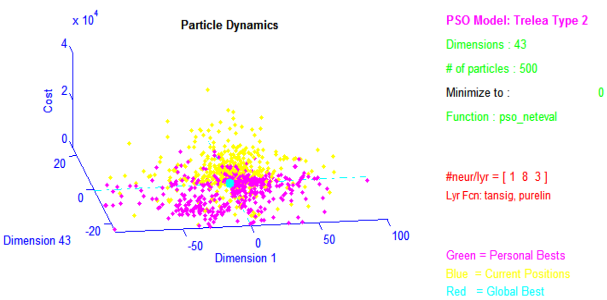

Fig. 8: The Accuracy of Performance.

After obtaining the weights values of the network by using PSO algorithm; the training results are converted to the SIMULINK for testing them with different situations. Figure (9) shows the Simulink of the proposed system.

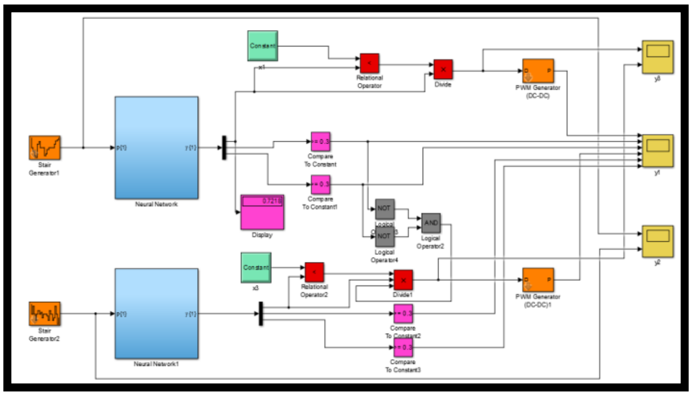

Fig. 9: The Simulink of Proposed Intelligent Controller for Solar Tracking System.

The output results of the proposed system are tested with different situation. When the sun light falls on the right corner of the solar cells, the intensity of the light of the LDRs sensor on the right side is greater than the intensity of the light on the left side; thus, the intelligent controller will send three signals (PWM for controlling the speed of rotation, clockwise and counter clockwise) to the DC motor driver(L293D IC) to rotate it in clockwise direction for tracking the sun in X-axis direction, and send another three signals to the motor driver to stop rotation in Y-axis direction. However, when the sun light falls on the left corner of the solar cells results in increasing the intensity of the light of the LDRs sensor on the left side and became greater than the intensity of the light on the right side. Therefore; the intelligent controller will send three signals (PWM for controlling the speed of rotation, clockwise and counter clockwise) to the L293D motor driver to rotate it in counter clock wise for tracking the sun in X-axis direction, and also will send another three signals to the motor driver to stop it from the rotation in Y-axis direction. Furthermore, when the sun light falls on the middle of the solar cells which means the left and right sensors have the same intensity of the light; the intelligent controller will send signals to stop tracking in X-axis direction and start tracking the sun in Y-axis direction. Therefore, if the upper sensor has intensity of light greater than the lower one, the intelligent controller will send signals to rotate the motor in clockwise direction for tracking the sun in Y-axis and the speed of rotation will be controlled by the PWM. And if the upper sensor has light intensity smaller than the lower one, the intelligent controller will send signals to rotate the motor in counter clockwise direction for tracking the sun in Y-axis direction the speed of rotation will be controlled by the PWM.

Figure (10) shows the different values of the sensors where the x-axis represents the time with different values and the y-axis represents the result of subtraction of the amplitude between the (right/left) and (upper/lower) sensors respectively.

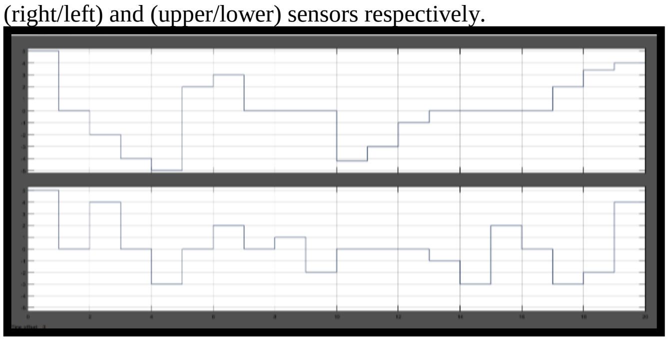

Fig. 10: Different States for Sensor Value.

In more details, the speed of rotation of the two motors is controlled by PWM. Also, the duty cycle will be adjusted by the intelligent controller depending on the difference between sensors which means that if the difference value between sensors is too high, the intelligent controller will send duty cycle to rotate the motor faster, and if difference value between the sensors is too low, it will send duty cycle for rotate the motors slower than previously. Figure (11) shows different situation with different duty cycles.

Fig. 11: The Simulation Results for Different States of Intelligent Controller in Order to Track the Sun with Times.

In order to implement the proposed system on FPGA and simulate the system with ISE 13.3 program, the Simulink of MATLAB converted into VHDL code by HDL coder in MATLAB. Figure (12) shows the RTL of the proposed system in ISE 13.3 after converting it into VHDL code and figure (13) shows the simulation results of the proposed system, FPGA was used to implement the hardware part.

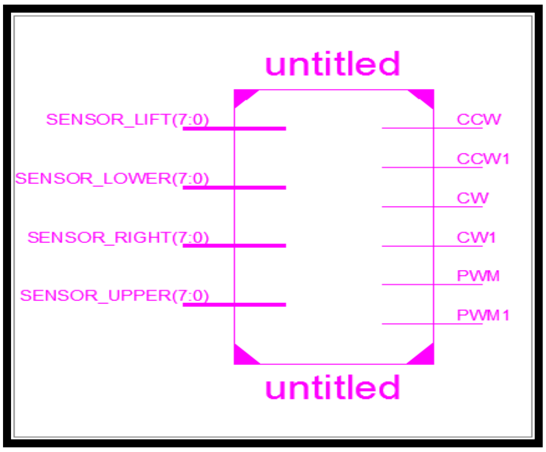

Fig. 12: RTL for Proposed Intelligent System.

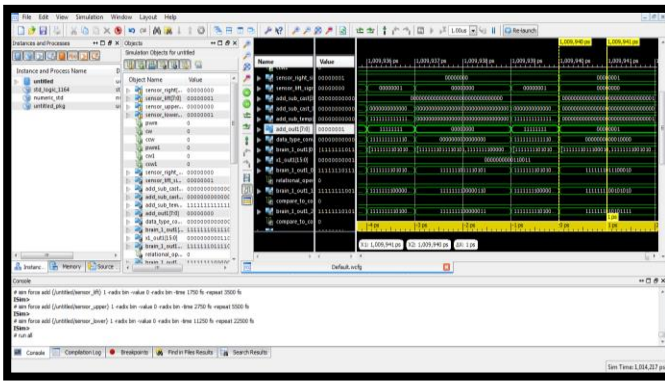

Fig. 13: The Simulation Results of Intelligent System.

4. Conclusion

In this paper, PV panel tracking model was proposed and implemented by using MATLAB.. PSO algorithm used in the neural network, also FPGA card used for the implementation process that controls the speed of motors and the movements of direction to track the sun light all days.

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