Design of Intelligent Controller for Solar Tracking System Based on FPGA

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ABSTRACT

The needs for increasing the power generation make the use of solar cells plays an important role in the daily life. For this reason, it is important to use solar tracking system to increase or getting almost optimum amount from solar cells. In this paper, proposed intelligent controllers were designed and used to make solar cells facing the sun over the year. The proposed controller was trained by two ways; the first was trained by supervised feed forward neural network and the second by Particle Swarm Optimization (PSO) the results obtained for both designs are then compared. The controller was trained using MATLAB and then converted to SIMULINK model in order to test it, and convert it to a Very high speed integrated circuit Hardware Description Language (VHDL) language using MATLAB tool box in order to download it on Spartan 3A Field Programmable Gate Arrays (FPGAs) card. This makes the implementation of the intelligent controller more efficient and easy to use because of its reprogram-ability and the high speed performance. The controller was designed to a fully controlled DC motor driver which is used to rotate two DC motors in X-axis and Y-axis directions respectively.

The experimental results show that tracking sun increases the efficiency of the system to produce energy from solar cell about 44.3778 % more energy than the solar cell without tracking system.

Index Terms— Sun Tracker, Back propagation, PSO, ADC, Field Programmable Gate Array (FPGA), DC motor drive.>

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تصميم متحكم ذكي لنظام تعقب شمسي بالاعتماد على مصفوفة البوابات الرقمية القابلة للبرمجة (FPGA)

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INTRODUCTION:

Renewable energy plays an important role in our daily life. There are multiple types of renewable energy sources such as solar energy, wind energy, geothermal etc. Solar heavily used because it is pollution-free since it converts the incident light from the sun directly into electrical energy by using solar cell.

Increasing the applications that use solar cells as an energy source has increases the need to generate more electrical energy. Solar cell is dependent on many factors including internal factors such as the type of metal used in fabrications, or manufacturing methods, and external factors such as ambient temperature, intensity of light falling on the cell and the intensity of the wind. Because the development of the internal factors be expensive so the best solution and easier to increase the power generated by the solar cell is to increase the intensity of light falling on the solar cell. There are multiple ways to increase the intensity of the incident light, including sun tracking, Maximum Power Point tracking (MPPT) or both. There are multiple ways to control MPPT have been proposed such as: perturb and observe[1], incremental conductance[2], parasitic capacitance[3], constant voltage[4], fuzzy logic[5] and neural networks[6]. These methods differ in difficulty, complexity, price and stability .There are multiple ways to control the sun tracking the control may be conventional like PID controller or intelligent controller such as fuzzy [7], genetic or neural.

Artificial Neural Networks (ANN) are widely accepted as a technology offering an alternative way to solve complex problems and have been successfully applied in many areas. In addition, ANN simplifies dealing with nonlinearities in systems.

One of most conventional way used to implement ANN is by using general-purpose microprocessor or microcontroller. Which are economic ways but it's difficult to handle systems need very high speed processing. Field Programmable Gate Array (FPGA) is good choice for implementation of ANN in very high speed processing systems. The aim of this paper is to build intelligent system using FPGA to maximize the power output of the solar arrays and the specific objectives including designing intelligent system controllers, realizing controllers on FPGA, building a DC motor driver and tracking the sun all the day

1- Sun Tracker

Solar tracking system uses two DC motors to rotate the solar panel in two axes. The position of the sun is tracked by using four LDR as a tracking sensor, the out from sensors are converted from analog form to digital form by using four ADC0804 ICs. The digital output from sensors will be applied to the intelligent controller that implemented on FPGA card and the output from the controller will be the inputs for L293D that used as DC motor driver IC. Figure (1) shows the proposed solar tracking system.

One of the most important methods used for obtaining the solution to analysis and design the controller for sun tracking system is the computer simulation. All simulations are implemented using MATLAB R2013a, Proteus 7 Professional and Xilinx_ISE 13.3.

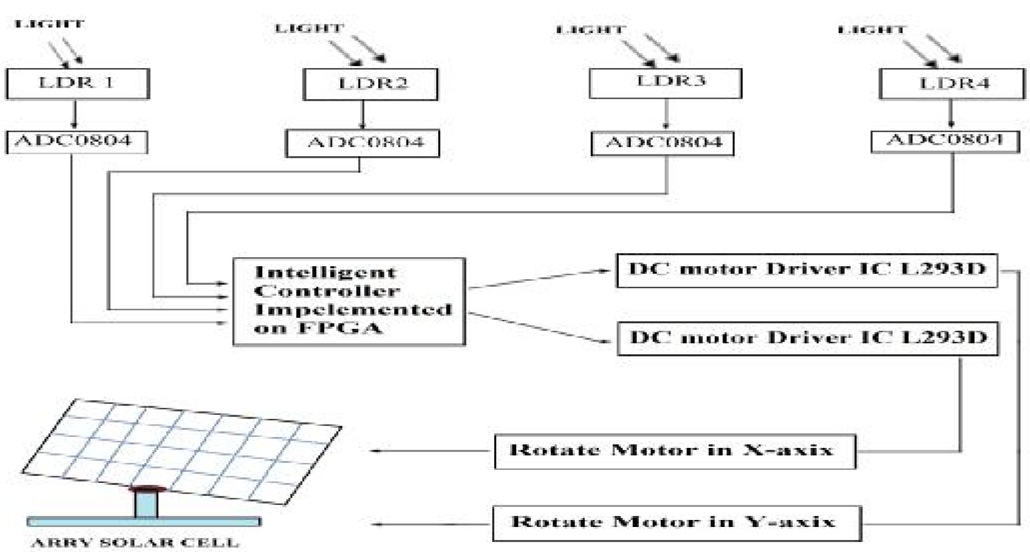


Figure (1) The proposed solar tracking system.

In this work, a design of intelligent controller is proposed and then downloaded on FPGA card by using HDL code based on MATLAB package.

Light Dependent Sensor (LDR)

The LDR sensor is changeable resistance value when it is exposed to light intensity therefore it can be connected in series with a constant resistor in order to achieve voltage deviation. Figure (2) show the LDR sensor connected with constant resistor.

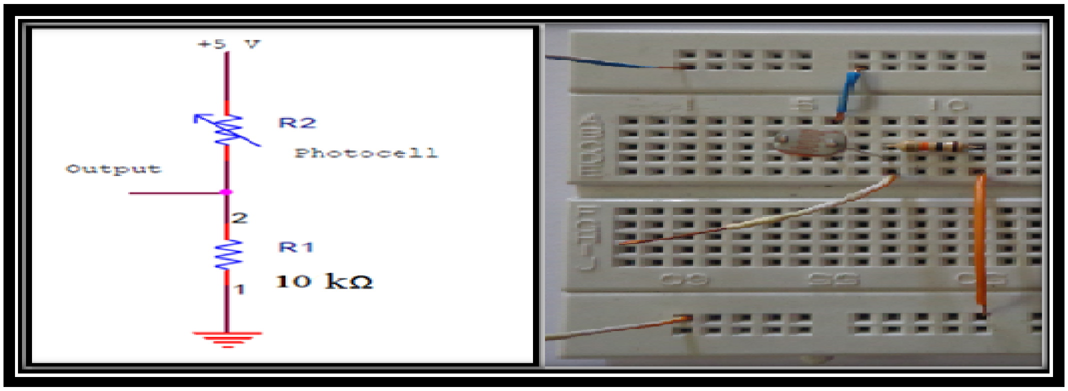


Figure (2) LDR sensor connected with constant resistor

The LDR sensors used for sensing the position of the sun intensity in two axes right/left and up/down, four LDR sensors are mounted on the solar panel and placed in an enclosure as shown in Figure (3). It has a response which is similar to the human eye. The right and left LDR sensors compare the intensity of received light in the right and left directions. The up and down LDR sensors compare the intensity of received light in the up and down directions. The light source intensity received by the sensors are different, The system obtains signals from the sensor output voltage in the four orientations. The sensor output voltage values will be input to the ADC.

Figure (3) Four LDR sensors used to detect the sun light

Analog to Digital Converter

ADC0804 are CMOS 8-Bit, successive approximation A/D converter. Figure (4) show pins diagram for ADC0804.

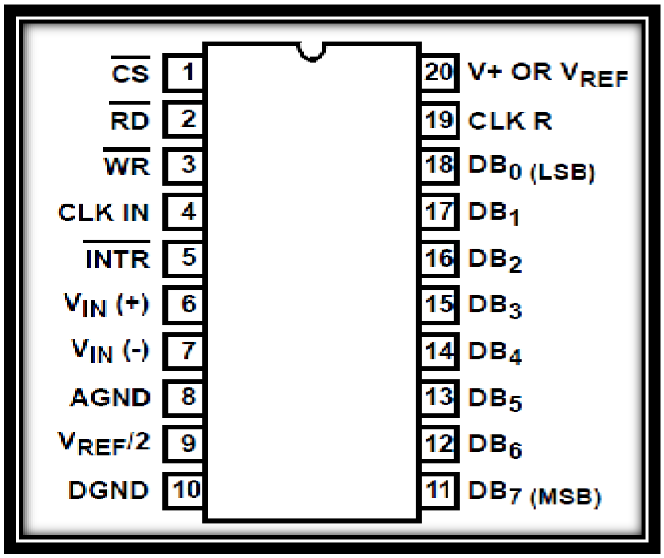
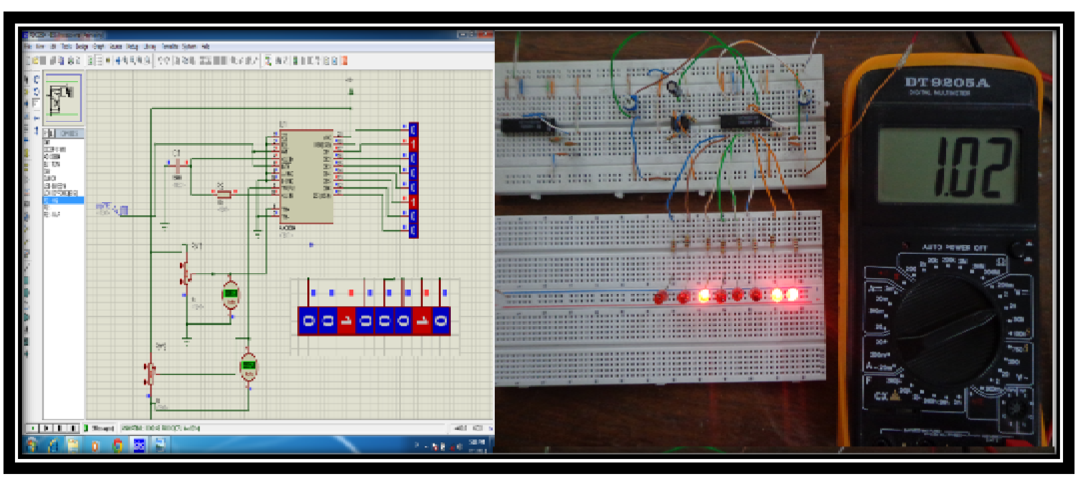


Figure (4) ADC0804 pins diagram.

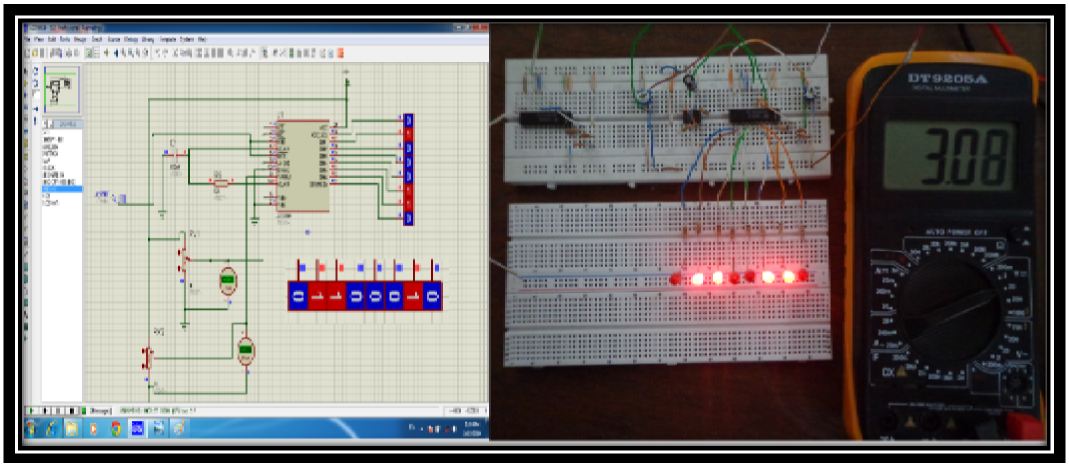
The voltage reference input can be adjusted to allow encoding any smaller analog voltage span to the full 8 bits of resolution. In this work the reference input to pin (9) was taken 4V as a constant voltage input.

Based on data sheet and Proteus 7 Professional program the simulation and experimental results are obtained. Figure (5) and Figure (6) shows the results for different inputs.



(A) Simulation result **(B) Experimental result**

Figure (5) Simulation and experimental results for 1.02 volt.



(A) Simulation result (B) Experimental result

Figure (6) Simulation and experimental results for 3.08 volt

The 8 bits presented from ADC will be input to the FPGA card where the intelligent controller implemented there.

Simulation Results for Intelligent Controller

The controller trained by two ways first by supervised feed forward neural network (Back Propagation) and second by PSO. The numbers of neurons in input, hidden and output layers are chosen by trial and error. Figure (7) show the neural network with one input neuron, ten hidden neurons and three output neurons and. Figure (8) (A&B) shows the training results of BP and PSO respectively.

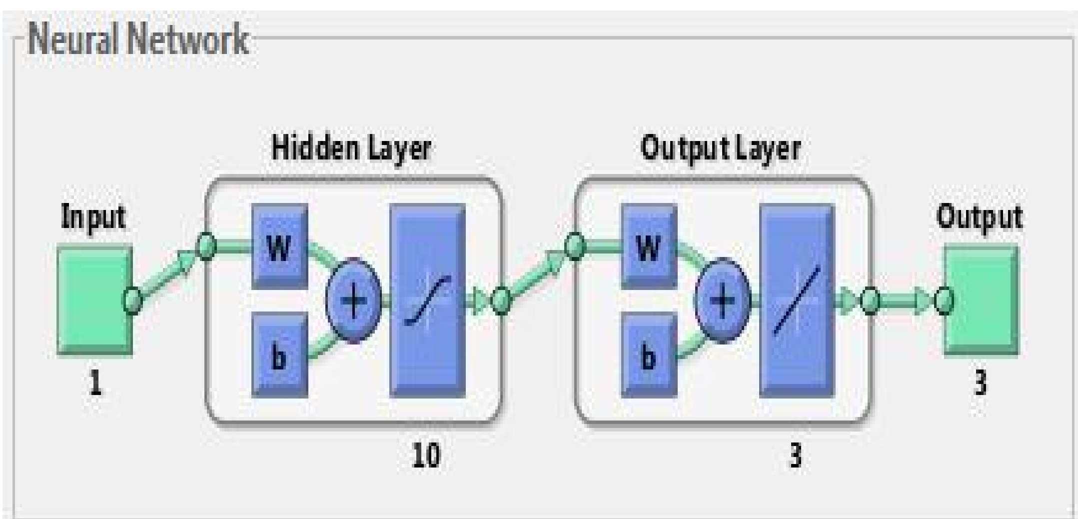
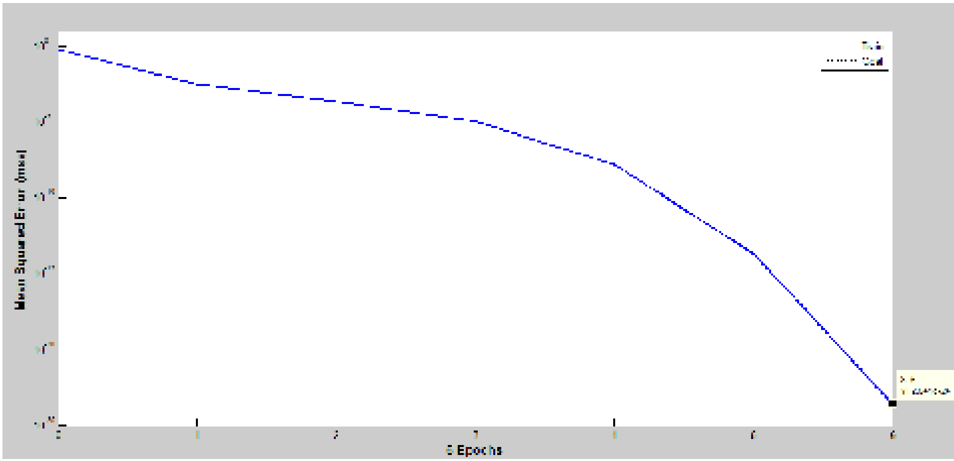
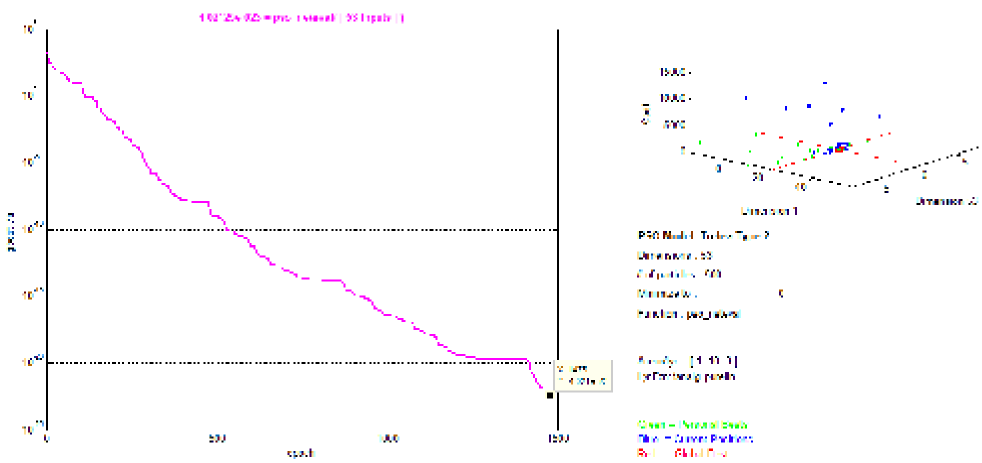


Figure (7) The neural network with one input neuron, ten hidden neurons and three output neurons



A



B

Figure (8) A: simulation result for BP, B: simulation result for PSO.

The simulation results of PSO and BP for solar tracker controller training with 10 hidden neurons are shown in Table (1).

Table (1) Results of PSO and BP of case two.

Parameters	PSO	BP
Learning Iterations	1478	6
Error Convergence	4.02125e-23	2.641e-24
No. of Initial Weights	500 set	1 set

After training the purpose intelligent controller for solar tracker the simulation shows that BP is better than PSO in this work so that it can be converted to SIMULINK model such that shown in figure (9). In this model which is depend on the voltage produced from four sensors there are two ANN controllers (Neural Network1 and Neural Network2). Neural Network1 used to fully controlling motor 1 that can be rotate in X–axis direction and Neural Network2 used to fully controlling motor 2 that rotate in Y-axis direction.

The controller have several states used for rotate motor 1 and motor2 in clock wise , counter clock wise or stop them such as show below.

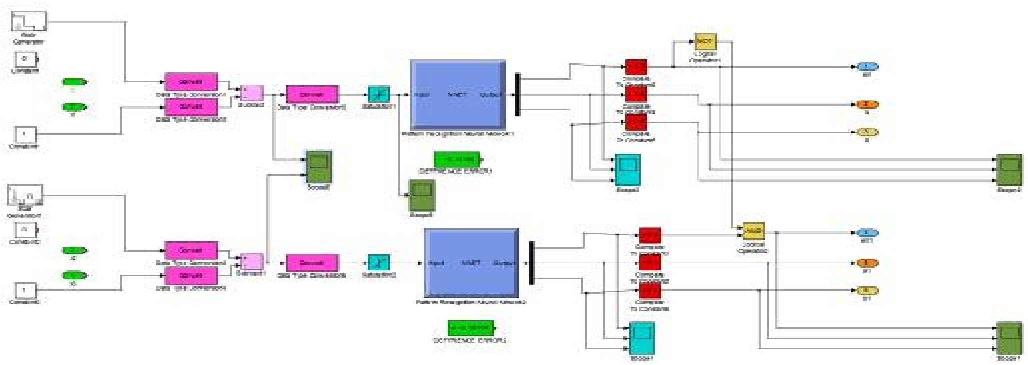


Figure (9) SIMULINK model for complete solar tracker intelligent controller

To show the simulation results there are five global states for solar tracker controller.

State One: Sensor right is given too high value as camper with the value of left sensor at any values of upper and lower sensors, at this state the controller will send three signals to rotate motor1 in clock wise direction in X-axes in order to tracking the sun and then send three signals to stop motor2 from rotation at Y-axes.

State Two: Sensor left is given too high value as camper with the value of right sensor at any values of upper and lower sensors, at this state the controller will send three signals to rotate motor1 in counter clock wise direction in X-axes in order to tracking the sun and then send three signals to stop motor2 from rotation at Y-axes.

State Three: Sensor right and left sensor are equally or have too small difference values, with upper sensor have too high value as camper with the value of lower sensor, at this state the controller will send three signals to stop motor1 from rotation in X-axes and sends three signals to rotate motor2 in clock wise direction in Y-axes in order to fully track the sun.

State Four: Sensor right and left sensor are equally or have too small difference values, with lower sensor have too high value as camper with the value of upper sensor, at this state the controller will send three signals to stop motor1 from rotation in X-axes and sends three signals to rotate motor2 in counter clock wise direction in Y-axes in order to fully track the sun.

State Five: Sensor right and sensor left are equally or having too small difference value between them, sensor upper and lower also are equally or having too small difference value at this state the controller will send three signal to motor1 and three signal to motor2 in order to stop rotation of motor1 and motor2 respectively .

Figure (10) shows the signals that send to motor driver for rotation mechanism.

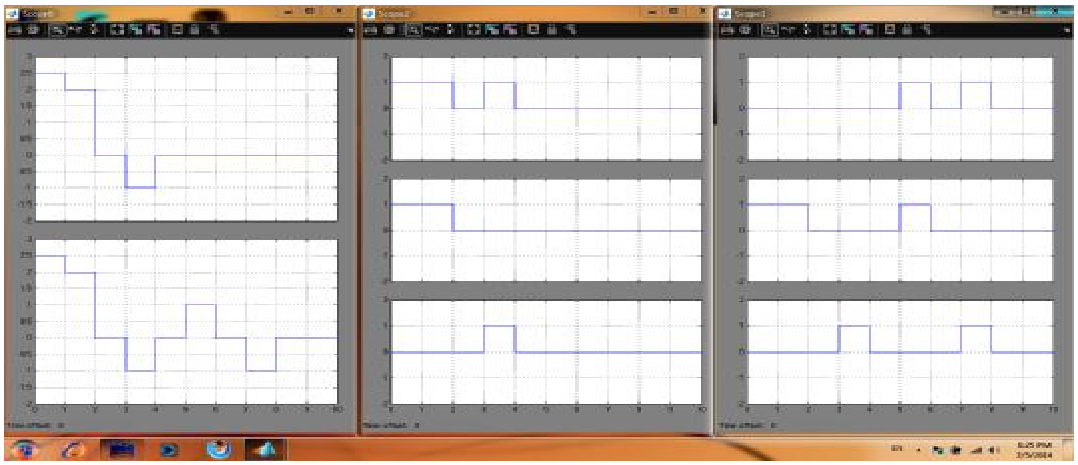


Figure (10) The simulation results and the signals that send to motor driver for rotation mechanism.

In this work a proposed controller was used for controlling sun tracking system. This controller can implement on FPGA card by using HDL code in MATLAB package. The decision will be taken for each clock of the FPGA talking about 50MHZ for Spartan 3A to state which motor will rotate and which one will stop.

Implementation of Controller on FPGA

Xilinx Foundation ISE Design Suite 13.3is a software tool used to perform ANN for solar tracking controller on FPGA

Figure (11) shows the RTL schematic diagram in Xilinx software RTL Viewer to view a schematic representation for the intelligent controller and other components after implementing it on Xilinx_ISE 13.3 software.

Figure (11): RTL schematic diagram.

After the solar tracking controller signal generation, it's time to observe the output and see if the experimental result goes the same way as the simulation result and this achieved in Figure (12) and Figure (13) for simulation and experimental results respectively.

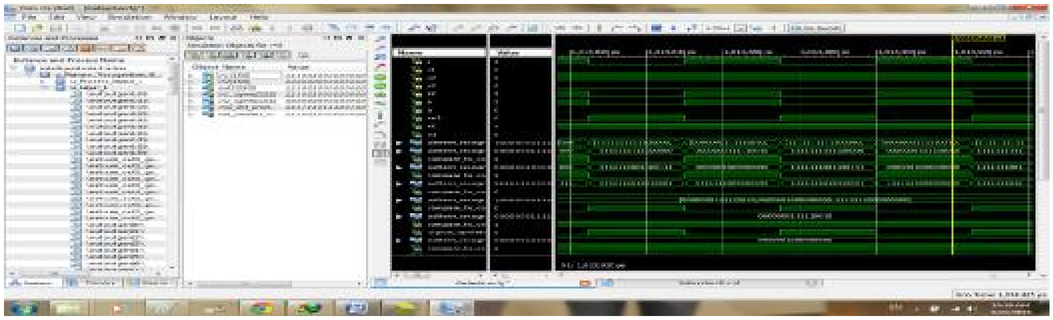


Figure (12) Simulation results for implementation intelligent controller on FPGA.

Figure (13) shows the experimental results by using oscilloscopes

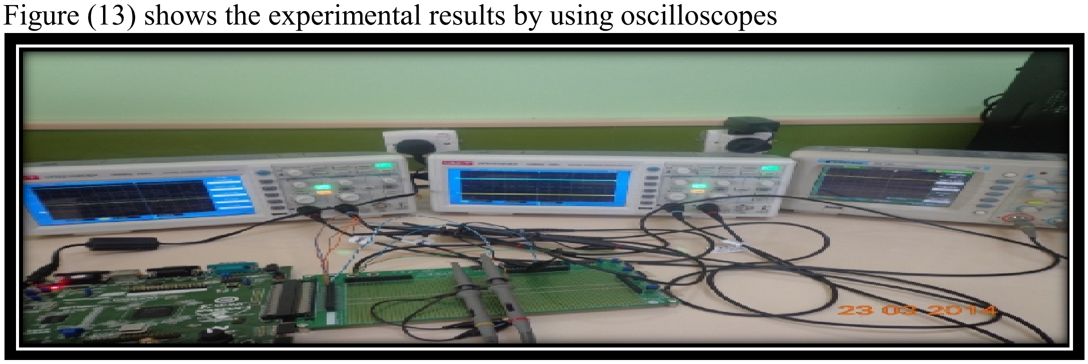


Figure (13) experimental results for intelligent controller by using oscilloscopes.

DC Motor Driver L293D:

The L293 and L293D are quadruple high-current half-H drivers. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. This device designed to drive inductive loads such as relays, solenoids, DC and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications. Figure (14) shows Pins diagram for L293D DC motor driver.

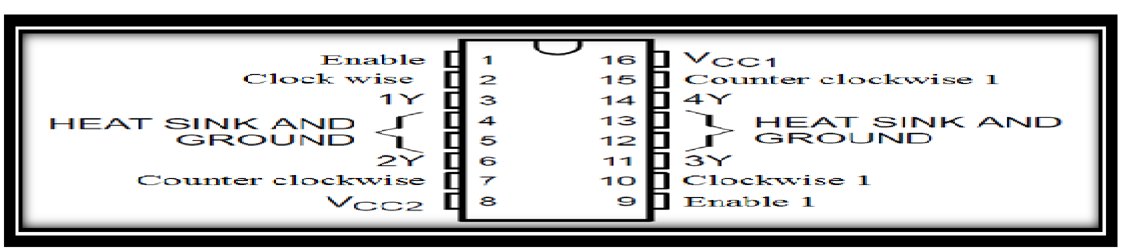


Figure (14) Pins diagram for L293D DC motor driver.

There are many states for rotate two motors can be illustrate in Table (2)

Table (2) State for motors

Enable (1,9)	Clock wise (2,10)	Counter clockwise (7,15)	FUNCTION
H	L	H	Turn right
H	H	L	Turn left
H	L	L	Fast motor stop
H	H	H	Fast motor stop
L	X	X	Fast motor stop

L=low, H=high, X=don't care

The simulation results of L293D DC motor driver by using Proteus 7 Professional is shown in Figure (15)

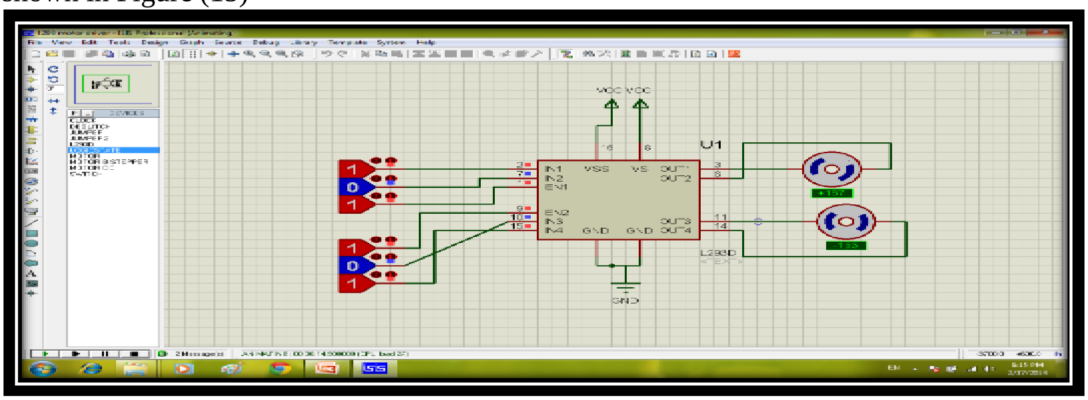


Figure (15) The simulation result for L293D DC motor driver.

The real measurement Data Response Results

The experimental data results for solar cell power generation are measured in 6-5-2014 and by taken the result of voltage and current for same load in each half hour for fixed solar cell and solar cell with tracking system and then calculating the efficiency increase with tracking system all day. Table 2 shows these values.

Figure (16) show the mechanical system design for dual sun tracker system.

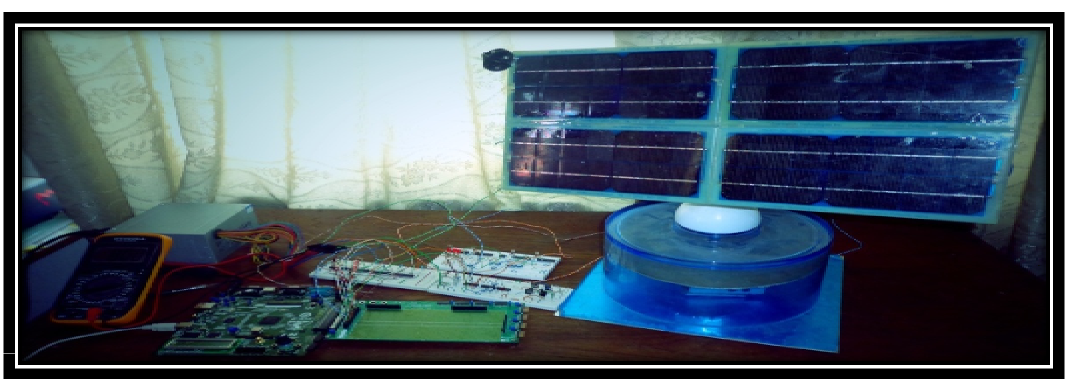


Figure (16) The mechanical system design for dual sun tracker system.

Table (2) Real measurement for fixed solar cell and solar cell with tracking system.

	Without tracking			With tracking		
TIME	VOLTAGE	CURRENT	POWER	VOLTAGE	CURRENT	POWER
5:30 AM	5.52	0.44	2.4288	6.06	0.48	2.9088
6:00 AM	6.42	0.72	4.6224	6.6	0.8	5.28
6:30 AM	6.6	0.87	5.742	7.94	6.6	52.404
7:00 AM	6.44	0.9	5.796	7.76	6.3	48.888
7:30 AM	6.9	0.92	6.348	8.1	6.34	51.354
8:00 AM	7.22	1.33	9.6026	7.97	6.23	49.6531
8:30 AM	7.3	4.2	30.66	7.8	6.52	50.856
9:00 AM	7.4	5.98	44.252	7.6	6.06	46.056
9:30 AM	7.26	5.74	41.6724	7.2	5.8	41.76
10:00 AM	7.28	5.81	42.2968	7.5	6	45
10:30 AM	7.3	5.82	42.486	7.51	6.06	45.5106
11:00 AM	7.3	5.6	40.88	7.3	5.6	40.88
11:30 AM	7.6	5.8	44.08	7.57	5.82	44.0574
12:00 AM	7.1	5.03	35.713	7.19	5.06	36.3814
12:30 AM	7.22	5.52	39.8544	7.27	5.72	41.5844
1:00 PM	7.25	5.62	40.745	7.42	5.63	41.7746
1:30 PM	7.35	4.97	36.5295	7.43	5.3	39.379
2:00 PM	7.19	5.67	40.7673	7.2	5.78	41.616
2:30 PM	7.38	5.7	42.066	7.55	5.91	44.6205
3:00 PM	7.12	4.8	34.176	7.68	5.93	45.5424
3:30 PM	7.09	1.56	11.0604	7.51	5.33	40.0283
4:00 PM	6.96	0.88	6.1248	7	1.56	10.92
4:30 PM	6.9	1.32	9.108	7	1.34	9.38
5:00 PM	6.97	0.87	6.0639	7.25	3.52	25.52
5:30 PM	6.6	0.76	5.016	6.78	1.03	6.9834
6:00 PM	6.36	0.56	3.5616	6.41	0.61	3.9101
6:30 PM	5.22	0.19	0.9918	5.23	0.22	1.1506
SUM	187.25	87.58	632.6447	195.83	121.55	913.3986

Figure (17) represents the voltage data in the Table (2) as a graphical curve using MS_EXEL program.

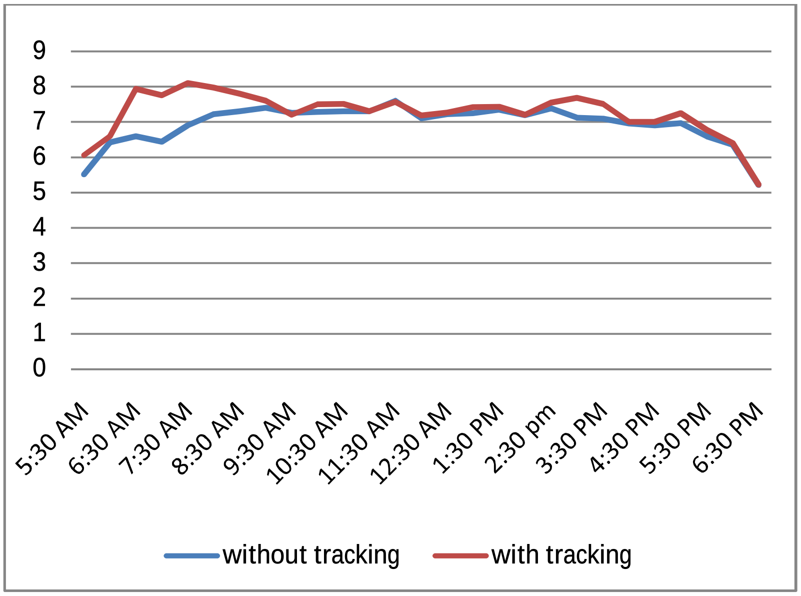


Figure (17) The voltage comparison of solar cell with and without tracking system.

Figure (18) represents the current data in the Table (2) as a graphical curve using MS_EXEL program.

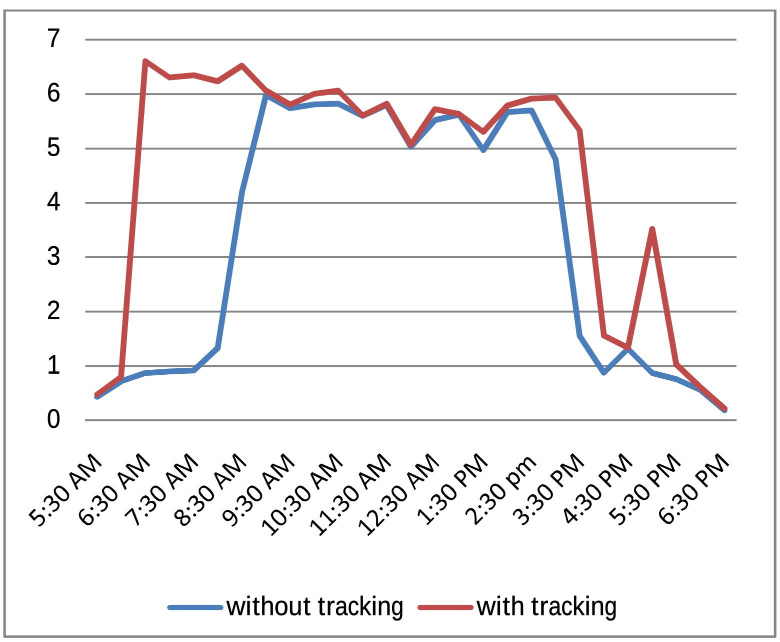


Figure (18) The current comparison of solar cell with and without tracking system.

Figure (19) represents the power data in the Table (2) as a graphical curve using MS_EXEL program.

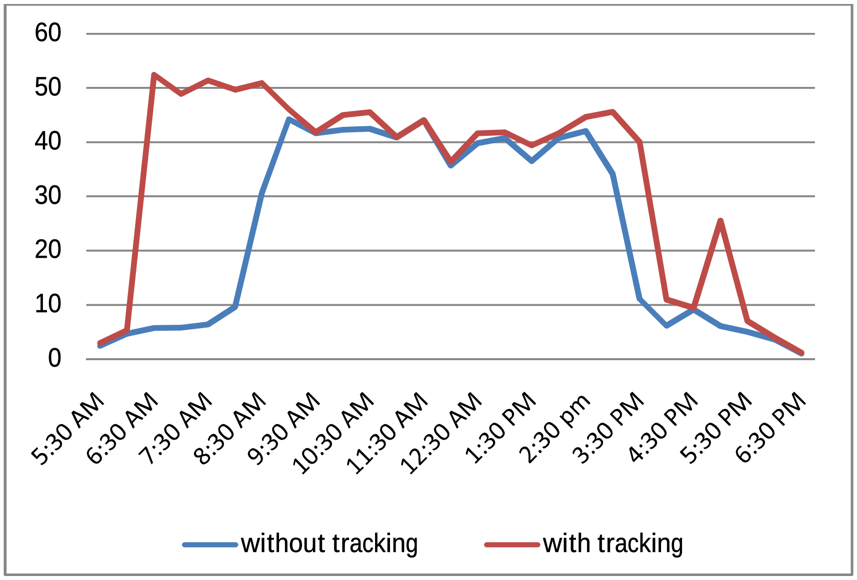


Figure (19) The power comparison of solar cell with and without tracking system. Based on table (2) the efficiency can be calculated.

$$efficiency = \frac{913.3986 - 632.6447}{632.6447} * 100\% = 44.3778\%$$

In 2014 Dr. Hanan A. R. Akkar and Nawras M. Akesh produce a proposed solar tracker and the system increase the power produced form tracker system to be 40% higher than the solar cell without tracker system [7].

In this paper the proposed system used with experimental results shows that the power generation from solar cell can be increased to 44.3778% when use the tracking system.

CONCLUSIONS:

In Iraq and because of the sources that provided energy don't cover all people requirements, the renewable energy sources such as solar energy play an important role in electric power generation, it is unlimited and clean.

In this paper, intelligent controller was designed to maximizing the energy received from solar cells and this controller was trained by PSO and Back Propagation.

The proposed controller was implementing on Spartan 3A FPGA card and used to keep the solar panel facing the sun all day with the help of using two DC motors provided with gearbox. The use of DC motor enables accurate tracking of the sun depending on the speed of the FPGA card can performed. Four LDR resistors are oriented to determine the solar light intensity in four directions. This controller has been tested for different data by using Matlab/Simulink program. The proposed solar tracking system increase solar energy about 44.3778% more energy than a solar cell without tracking system.

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