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Efficiency Improvement of Sun Tracking Systems Controlled by FPGA

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Abstract— This paper presents an implementation of a solar tracking system to achieve power enhancement based on FPGAs .The proposed system tracks altitude angle and azimuth angle separately as a single-axis system, then tracks altitude-azimuth angles with each other as dual-axis system. The proposed single-axis tracking system increases the efficiency by 23.93% compared with the fixed system, while the dual-axis tracking system increases the efficiency by 33.23% compared with fixed system. The system consumes low power and takes into consideration weather changes such as clouds, dust and other conditions that may lead to undesirable results. This paper also presents a comparative study between Azimuth-tracking and Altitude-tracking systems. Results showed an increase in efficiency in case of Azimuth-Tracking system up to 11.39% more than Altitude-Tracking system, and dual-axis tracking up to 9.3% more than Azimuth-tracking system..

Index Terms— Solar tracking systems, Renewable energy, FPGA ,dual-axis sun tracking.

1 INTRODUCTION

Renewable energy sources are energy sources that are continually replenished. These include energy from water, wind, geothermal sources, biomass sources and the sun .The solar energy is the most important resource of renewable energy which can be turned into electrical energy which is known as the theory of Photovoltaic (PV) and can be tuned into thermal energy [1].

Solar cells consist of a p-n junction made of a thin layer of semiconductors, which turn light energy into electricity without any moving parts, noise, pollution or radiation. Photovoltaic (PV) cells are the basic building blocks of PV modules. The single cell produces one-half volt. Therefore, cells are connected together in series to increase the voltage and connected together in parallel to increase the current [2]

To increase the energy production from solar cell, this requires: Improving materials which the solar cell is made from, improving tracking system to collect a large amount of falling radiation, and also improve methods used to store power [3]. There are three major approaches in solar tracking systems. First, Mechanical tracking system, Second, Maximum Power Point Tracking, frequently referred to as MPPT which deal with electronic system that operates the Photovoltaic (PV) modules. Third, combining the two systems [4]. Sun-tracking system plays an important role in increasing the energy production from a solar cell, especially systems that directly convert the solar energy into thermal or electrical energy. In order to get a higher degree of power, we must track the path of the sun from sunrise to sunset.

Time spent in tracking is a key factor in increasing the efficiency of tracking systems, in other words, efficiency increase for any tracking system whether single-axis or dual-axis depends on the time spent in tracking process. So the system that moves continuously throughout the day consumes a great amount of energy at the expense of increased efficiency, and need to complex systems. Therefore, in this paper the proposed system moves a few seconds during the day so consumes a small amount of energy with simplicity of design. Increasing the efficiency of PV in energy production between 10 –50% depends on the season [5]. Bin-Juine Huang, presented a study about increasing efficiency throughout the year, He explained that the efficiency increase varies according to the season [6].

Designers of solar tracking systems must take into consideration: weather changes such as clouds, dust and other conditions which may lead to undesirable results. So we avoided that in our design by using FPGAs in controlling the system and programmed by Very High Speed Integrated circuits (VHSIC) Hardware Description Language (VHDL) code using finite state machine (FSM) which is appropriate to handle during the change of weather, as well as appropriate to any tracking system either single-axis or dual-axis and also any types of motors.

We can track the position of the sun by three angles: Altitude angle, Azimuth angle and Slope angle to achieve a maximum amount of falling radiation on the panel. Many studies showed that, including a study on a single-axis tracking system in October that reached 19.2 % increase in efficiency more than the fixed system [6]. Shyngys Almakhanovich presented a dual-axis tracking system in October 2013 that reached 31.3% more than the fixed system [7]. Altitude angle and Azimuth angle changing at a large scale throughout the day but the azimuth angle variation is wider compared with the altitude angle variations. Slope angle changing with small rate throughout the day and at a large rate with changing seasons related to latitude, as shown in fig.(1, 2) [8].

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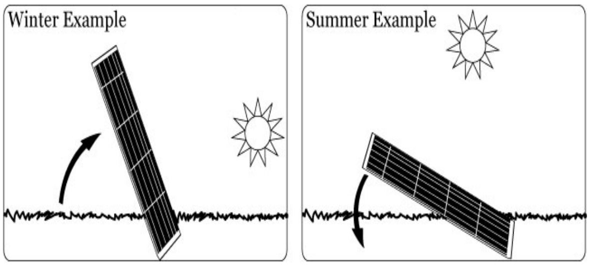

Figure (1) :Tilt angle in winter and summer.

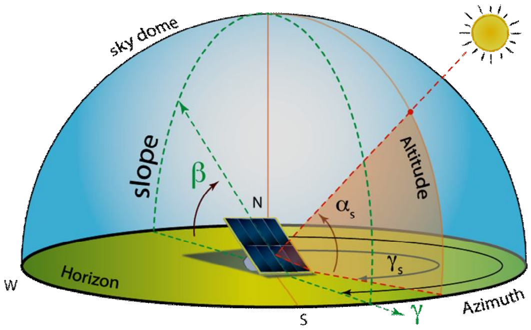

Figure (2): Azimuth, altitude and slope angles

Many solar tracking systems are controlled by Microcontroller, Microprocessor, Programmable Logic Controller (PLC), Lab VIEW, Video Processing Sensor and other methods. Iulia Stamatescu presented Solar PV System using single-Axis controlled by using Lab VIEW [9]. Adolfo Ruelas, presented dual-axis tracking system Based on a Video Processing Sensor [10]. These methods are slower than FPGA, consume more power, complex design and can't execute complex calculations than FPGA.

FPGA has the ability to operate faster than a microprocessor chip. Because of its flexibility. It can be programmed in microseconds. This short time means that the system will not even sense that the chip was re-programmed. FPGA is suitable for fast implementation controller and can be programmed to do any digital functions [2].

In this research, we designed and implemented a mechanical tracking system that tracks altitude and azimuth angle separately as a single-axis system, then tracks altitude-azimuth angle with each other as dual-axis system, by using two dc motors controlled by FPGAs Spartan 3E 1600K card. Measurements were taken in October from 5 to 10, and then we compared results with previous studies for Bin-Juine Huang and Shyngys Almakhanovich [6],[7]. The results of solar tracking system are simulated using OriginPro8, 2007 program, and VHDL written by using Xilinx ISE 12.1, 2009.

2 SUN-EARTH ASTRONOMICAL RELETIONS

The amount of solar energy on the solar panel depends on the daily motion of the earth around a fixed axis and also on the seasonal variation around the sun. So we can collect a large amount of solar energy by tracking three angles: Azimuth angle, Altitude angle and Slope angle. Equations (1, 2) determine azimuth angle and altitude angle [11].

$$\alpha = \sin^{-1}\left[\sin\delta\sin(\phi - B) + \cos\delta\cos(\phi - B)\cos\omega\right] \quad (1)$$

$$\psi = \cos^{-1}\left[(\sin\alpha\sin(\phi - B) - \sin\delta)/(\cos\alpha\cos(\phi - B))\right] \quad (2)$$

Where α is altitude angle, δ solar declination depends on day number, B slope angle depends on latitude, ψ is azimuth angle and ϕ is the latitude.

The optimum slope angle can be calculated from equations (3, 4, and 5).

For summer:	B = 0.92ϕ - 24.3	(3)
For spring and autumn:	B = 0.98 ϕ - 2.3	(4)
For winter:	B = 0.89ϕ + 24	(5)

3 PROPOSED SOLAR-TRACKING SYSTEM

The designed system consists of three stages: Sensor, FPGA card and dc motor driver. Four signals output from sensor to FPGA card as inputs signals (Ls, S1, S2 and S3), VHDL code download into permanent memory (The Platform Flash PROM) in FPGA card in order to deal with these signals daily non-stop over the year, by using a mathematical abstractions like FSMs that used to solve a large variety of problems. Then, four signals output from FPGA card (de, dw, en1 and en2) to driver circuit for controlling two dc motors (motor1used for tracking azimuth angle and motor2 used for tracking altitude angle) as follows: en1 is a timer to enable motor1, en2 is a timer to enable motor2, de enable motor for rotating towards East and dw enable motor for rotating towards West. So you can operate the system as a single-axis solar tracking or a dual-axis solar tracking. The complete tracking system is as shown fig.(3).

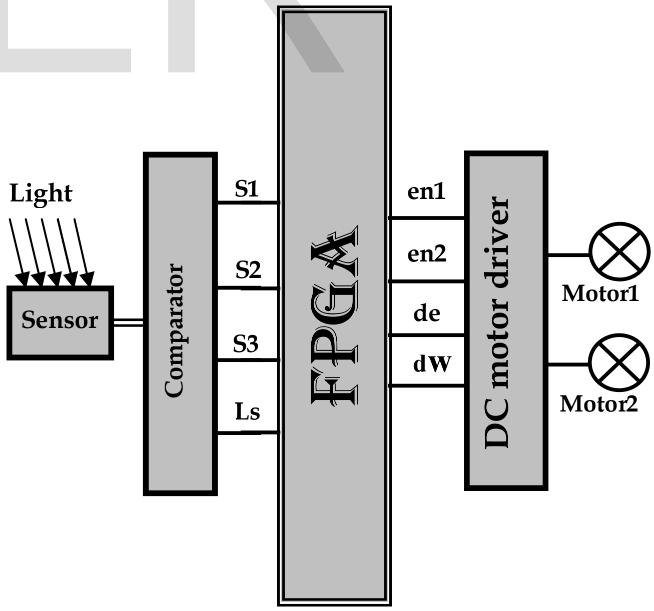

Figure (3): The block diagram for complete design

3.1 SENSOR

The sensor consists of four phototransistors (Q1, Q2, Q3 and Q4), one of them (Q4) for daytime and night, and the others (Q1, Q2 and Q3) to determine the position of sun. The design shown in fig(4-a) consists of three regions (A,B and C)

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separated by slides each 60° to track the sun in three stages daily to achieve the maximum power as shown in fig(4-b) .The output signals connected with voltage comparator circuit as shown in fig.(5). During the day, the output signals (S1, S2, S3, and Ls) from voltage comparator circuit divided into four states called ST0, ST1, ST2 and ST3 as shown in table (1)

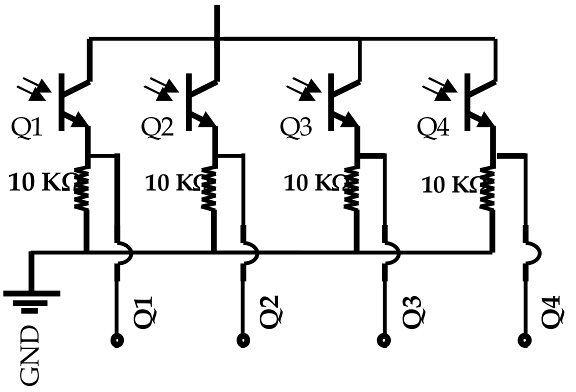

Figure (4-a) : The Sensor circuit

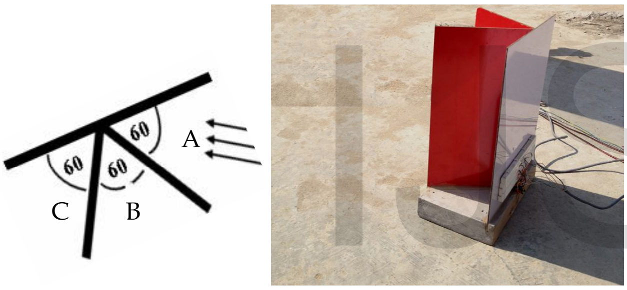

Figure (4-b): Sensor

Table (1) shows tracking states during day

States	Intensity of light				Signals			
N	Q4	Q3	Q2	Q1	S3	S2	S1	Ls
ST0	L	L	L	L	0	0	0	0
ST1	H	L	M	H	0	0	1	1
ST2	H	M	H	M	0	1	0	1
ST3	H	H	M	L	1	0	0	1

When the sun rises, the region A is more luminous than regions B and C, so the voltage comparator circuit gives ST1 (i.e S1 = '1', S2 = '0', S3 = '0' and Ls = '1'). At Noon, region B is more luminous than regions A and C, so the voltage comparator circuit gives ST2 (i.e S1 = '0', S2 = '1', S3 = '0' and Ls = '1'). At Evening before sunset, region C is more luminous than regions A and C, so the voltage comparator circuit gives ST3 (i.e S1 = '0', S2 = '0', S3 = '1' and Ls = '1'). At night ST0 (i.e S1 = '0' , S2 = '0' , S3 = '0' and Ls = '0') and so on daily.

3.2 VOLTAGE COMPARATOR CIRCUIT

The output signals from sensor circuit are connected with voltage comparator circuit which consists of four op-amp 741, and we use four diode (D1, D2, D3 and D4) at the output of the comparators to give the signals outputs (S1, S2, S3 and Ls) . as shown in fig (5).

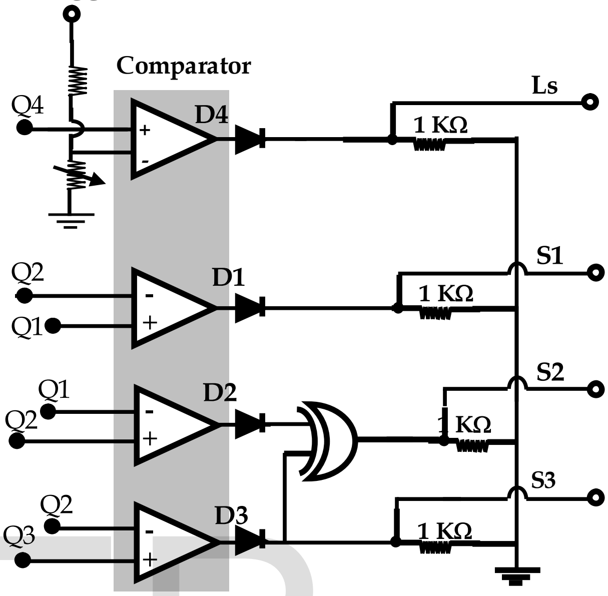

Figure (5): Voltage comparator circuit

3.3 DC MOTOR DRIVER

To drive dc motors directly from the FPGAs pin require two stages : The first stage consists of four NPN transistors can be just about any general purpose NPN (2N2222) , four diodes can be most general purpose diodes (1N4001 or similar) , four resistances 10 KΩ and four relays contact 5v. The second stage called directions control connected directly with two dc motors as shown in fig.(6). Driver circuit drives any type of dc motors whether low power (watts) or high power (kilowatts).So, we can use this design for controlling a large tracking system without any change in design and without any additional costs.

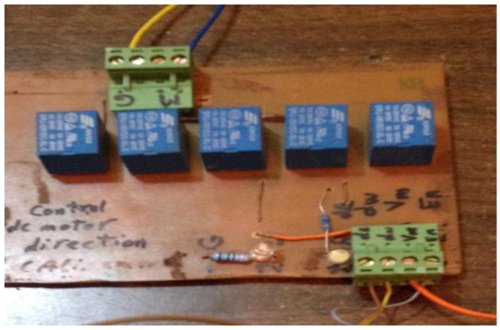

Figure (6): The second stage of dc motor driver

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4 EXPERIMENTAL RESULTS AND SIMULATION

The experimental data of the solar power generating system were measured outdoors in Mansoura city from 5 to 10 October 2014, by measuring the voltage and current for the same load 10Ω every half an hour, Slope angle panel equals 28° and latitude is 31°. The experimental data are divided into three groups: The first group is the Altitude-Tracking system (as a single-axis) measured in 5, 6 October 2014, and the average values are represented in table (2). The second group is the Azimuth-Tracking system (as a single-axis) measured in 7, 8 October 2014, and the average values are represented in table (2). The third group is the Altitude–Azimuth Tracking system (as a dual-axis) measured in 9, 10 October 2014, and the corrsseponding average values are shown in table (2) while data for dual-axis tracking measured in 9 October,2014 are shown in table (3).

Table (3) : The experimental data in 9 October, 2014 in case of dual-axis tracking system

Time	Altitude -Azimuth tracking (dual-axis)			Fixed system		
	I(A)	V(v)	P(w)	I(A)	V(v)	P(w)
6:30 am	0.24	2.4	0.58	0.09	1	0.09
7:00 am	0.86	8.8	7.568	0.22	2.3	0.51
7.30 am	0.98	10	9.8	0.44	4.5	1.98
8 :00 am	1.05	10.8	11.34	0.65	6.7	4.36
8:30 am	1.04	10.6	11.02	0.84	8.6	7.22
9:00 am	1.02	10.5	10.71	0.94	9.4	8.83
9:30 am	1.03	10.5	10.82	0.97	9.7	9.40
10:00 am	0.99	10	9.9	0.97	9.9	9.6
10:30 am	0.98	10	9.8	0.98	10	9.8
11:00 am	0.98	9.9	9.7	0.98	9.9	9.7
11:30 am	0.98	9.9	9.7	0.98	9.8	9.6
12:00 pm	1	10.1	10.1	1	10.1	10.1
12:30 pm	0.97	9.8	9.5	0.97	9.8	9.5
1:00 pm	0.96	9.7	9.31	0.96	9.7	9.31
1:30 pm	0.97	9.7	9.41	0.97	10	9.7
2 :00 pm	0.98	9.7	9.51	0.97	9.7	9.41
2.30 pm	1.02	10	10.2	0.94	9.4	8.83
3:00 pm	1	9.8	9.8	0.81	9.1	6.561
3:30 pm	0.95	9.6	9.12	0.58	5.8	3.36
4:00 pm	0.74	7.4	5.48	0.48	4.8	2.3
4:30 pm	0.69	7	4.83	0.3	3	0.9
5:00 pm	0.16	1.5	0.24	0.09	0.9	0.081
5:30 pm	0.02	0.2	0.004	0.02	0.2	0.004

Figure (7) represents the output voltage data of the PV module in 6 October in case of single-axis tracking system and fixed system. Figure (8) represents the output voltage data of the PV module in 9 October in case of dual-axis tracking system and fixed system by using OriginPro8, 2007 program.

Table (2): The efficiency increase for three tracking system with respect to the fixed system.

Kind of System	Day	Efficiency increase	Average Efficiency increase
Azimuth-Tracking Single-axis system	5/10/2014	23.75%	23.93%
	6/10/2014	24.11%	
Altitude-Tracking Single-axis system	7/10/2014	13.53%	12.54%
	8/10/2014	11.55%	
Altitude-Azimuth Tracking dual-axis system	9/10/2014	33.51%	33.23%
	10/10/2014	32.96%	

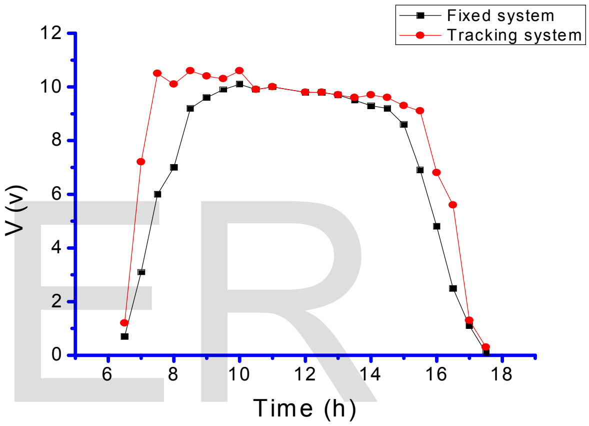

Figure (7): The voltage comparison of fixed PV and tracking PV system in case of single-axis

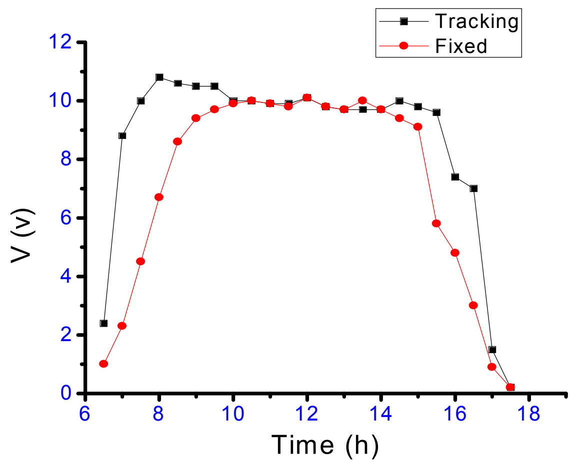

Figure (8): The voltage comparison of fixed PV and tracking PV system in case of dual-axis

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Figure (9): Tracking system and fixed system

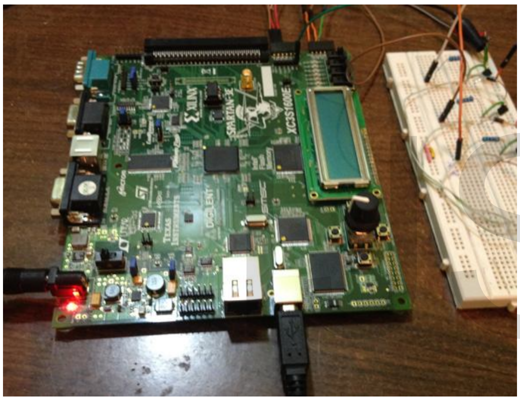

Figure (10): Xilinx Spartan 3E 1600K

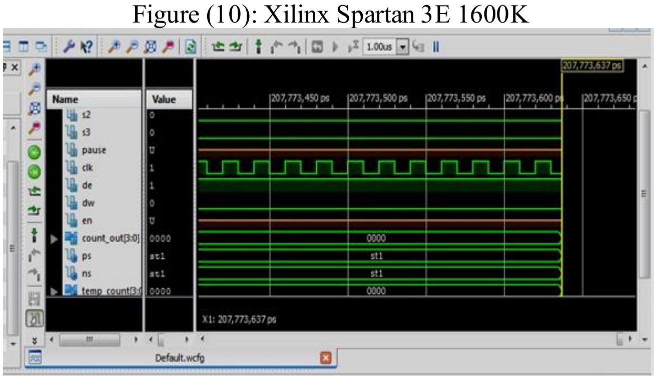

Figure (11): Simulation to VHDL code by using Xilinx ISE12.1, 2009.

5 CONCLUSION

The proposed sun tracking system based on FPGA have design flexibility, low power consumption and takes into consideration weather changes. The system attains an efficiency increase of 23.93% in case of single-axis tracking and 33.23% in case of dual axis tracking compared with fixed system.

7 ACKNOWLEDGMENT

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