DEVELOPMENT OF DUAL AXIS SOLAR TRACKING SYSTEM USING FIELD PROGRAMMABLE GATE ARRAY AND LIGHT DEPENDENT RESISTOR

Jun Hao Soon, Haziq Khairam and Wan Rahiman[1]

School of Electrical and Electronic Engineering
Universiti Sains Malaysia, Engineering Campus
Pulau Pinang, Malaysia.

Corresponding Author's Email: [1]wanrahiman@usm.my

ABSTRACT: The natural resources of the Earth such as oil and ores are being harvested over the decades. Soon, these resources will reach it's limit and fully run out. Thus, an alternative energy must be found to overcome the lack of resources. Solar energy had been used as a renewable energy as it can be obtained easily and brought a lot of benefits. The main purpose of this project is to present the development of an automated solar tracking system whereby the system allows solar panel to keep perpendicular with the sunlight to maximize the harvesting of solar power. The system is fully automated, when the light intensity decreases, the system will turn the solar panel to obtain maximum intensity of sunlight. LDR or light dependent resistor is used as a light sensor, two stepper motors are used to rotate the solar panel in 2 axes while the microcontroller used is *Altera DE2-115 Development and Education Board,* a type of field-programmable gate array (FPGA). This project is designed for residential usage applications.

KEYWORDS: *FGPA, Light Dependent Resistor*

1.0 INTRODUCTION

In the last few years, many of residential around the world used solar energy as a sub power at their house. This is due to solar energy is an unlimited energy resource and it is safe to obtain.

A solar tracking system is an automated solar panel which will rotate and follow the sun to maximize the harvesting of solar energy, thus increase in amount of power generated. The position of sun varies every day since the Earth is orbiting the Sun continuously. Therefore, this system required 2 axes so that the solar panel can always keep perpendicular to the sun. An active solar tracking system use motors to direct the solar panel as commanded by a controller responding to the solar direction. The solar tracking system can be used for several applications such as solar cells, solar day-lighting system and solar thermal arrays. According to Clifford M. J. (2004) many of the solar panels in the market had been positioned on a fixed surface such as roof. Since Sun is a moving object, fixing the solar panels on roof is definitely not a best method. Thus, it needs an active solar tracking system which will always facing the sun to operate at its greatest efficiency.

This project is developed for residential area. It dual axis system is controlled by two stepper motors, one is bottom stepper motor which will hold upper motor, while another one is upper stepper motor which will hold the solar panel. On the panel, there are 4 LDRs or Light Dependent Resistor which connected to 4 independent analog circuits relatively. These circuits are responsible to output signals to microcontroller. The microcontroller used is *Altera DE2-115 Development and Educational Board,* a type of field-programmable gate array (FPGA).

2.0 METHODOLOGY

This project consists of three parts, hardware development, sensor circuit, and microcontroller. The basic operation of the dual axis solar tracking system is shown in Figure 1 *Block Diagram of The System.*

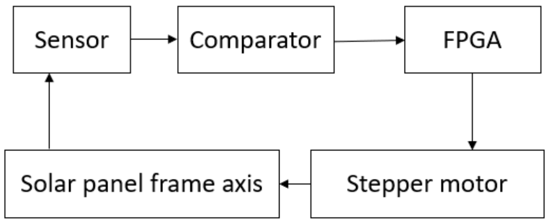

Fig. 1. Block Diagram of Solar Tracking System

The hardware development is very simple one stepper motor is act as base motor which will put at the base of the system. Another stepper motor called upper motor will put directly on top of the base motor. On the top of upper motor, it's the place where the solar panel and LDRs are placed. All LDRs are placed on the solar panel as shown in Figure 2 *Hardware Development.*

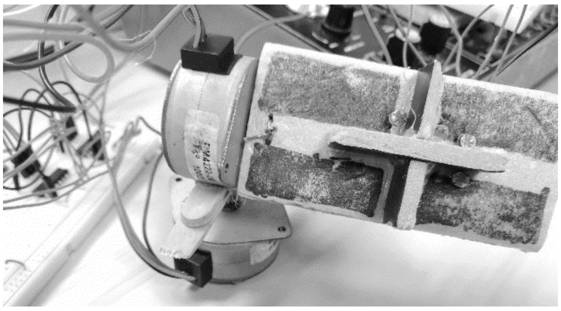

Fig. 2. Prototype Development

The LDRs are separated by divider to let the solar panel face perpendicular to the sun. This is done by shadow is created by the divider when the sun is on one side of the solar panel, thus the solar panel will turn and find the best angle where it will face the sun perpendicularly. There are two pairs of LDRs, first pair is to control the movement of upper motor while the second pair is to control the movement of base motor. Hence, a dual axis movement is created.

Microcontroller, is this case the use of field programmable gate array, FPGA which will process the output signal from sensor circuit and produce outputs to stepper motor driver circuit which will then rotate the stepper motors. The microcontroller will compare the output signal from the sensor circuit and decide whether the base motor to turn in what direction, and to stop both motors when the solar panel in perpendicular to the sun. The details of the microcontroller will be discussed in next section.

3.0 FPGA IMPLEMENTATION

Field Programmable Gate Array is a device that is widely used in electronic circuits. It contains programmable logic blocks and interconnection circuits. It can be programmed or reprogrammed to the required functionality. FPGA is used in this project because it can reduce the number of components or integrated circuit used as all of these are already included in FPGA (Altera (2013)).

The FPGA used in this Dual Axis Solar Tracking System is *Altera DE2-115 Cyclone IV E: EP4CE115F29C7*. Figure 3 shows the schematic diagram of full circuit design using Quartus 10.0.

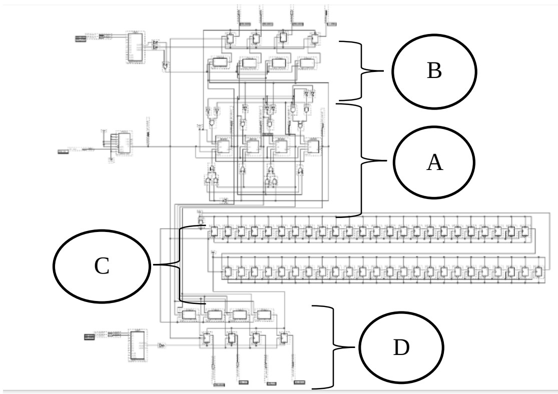

Fig. 3. Schematic Diagram of Full Circuit Design

There are 4 systems in this circuit design which are: (A) Driving system, (B) Base motor direction selection system, (C) Clock pulse generation system and (D) Upper motor limiting system.

A. Driving system

The function of this system is to generate output to drive both base and upper stepper motor. The mode of stepper motor used in this project is half step, thus the outputs required are as shown in Table 1.

Table 1. Output required for Half Step Stepper Motor

Step	**Q0**	**Q1**	**Q2**	**Q3**
1	0	0	0	1
2	0	0	1	1
3	0	0	1	0
4	0	1	1	0
5	0	1	0	0
6	1	1	0	0
7	1	0	0	0
8	1	0	0	1

To obtain the output using JK flip-flops, a truth table (Table 2) and a set of K-maps is drawn to obtain the relative inputs of flip-flops.

Table 2. Truth table of Driving system

Q (current state)				Q+ (next state)				J_3	K_3	J_2	K_2	J_1	K_1	J_0	K_0
0	0	0	0	0	0	0	1	0	X	0	X	0	X	1	X
0	0	0	1	0	0	1	1	0	X	0	X	1	X	X	0
0	0	1	0	0	1	1	0	0	X	1	X	X	0	0	X
0	0	1	1	0	0	1	0	0	X	0	X	X	0	X	1
0	1	0	0	1	1	0	0	1	X	X	0	0	X	0	X
0	1	0	1	0	1	1	0	0	X	X	1	1	X	X	1
0	1	1	0	0	1	0	0	0	X	X	0	X	1	0	X
0	1	1	1	1	0	0	0	1	X	X	1	X	1	X	1
1	0	0	0	1	0	0	1	X	0	0	X	0	X	1	X

1	0	0	1	0	0	0	1	X	1	0	X	0	X	X	X
1	0	1	0	0	0	0	1	X	1	0	X	X	1	1	X
1	0	1	1	0	0	0	1	X	1	0	X	X	1	X	0
1	1	0	0	1	0	0	0	X	0	X	1	0	X	0	X
1	1	0	1	0	0	0	1	X	1	X	1	0	X	X	0
1	1	1	0	0	0	0	1	X	1	X	1	X	1	1	X
1	1	1	1	0	0	0	1	X	1	X	1	X	1	X	0

Figure 4 shows Driving System, there is a Frequency Divider which will divide the default frequency of *Altera DE2-115 Cyclone IV*, 50 MHz into a desired frequency.

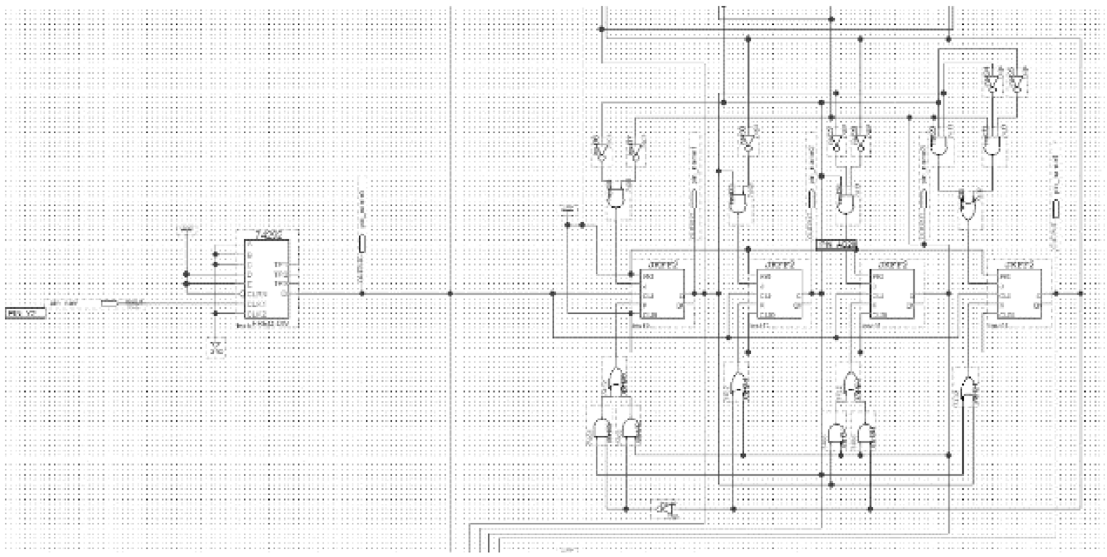

Fig. 4. Driving System

B. Base Motor Direction Selection System

This system consists of three types of digital device, comparator, multiplexer, and D-latch. A comparator is to receive signals from two sensor circuits, and compare those values. There are three conditions that may occur, which are:

(i) LDR1 smaller than LDR2, this output will pass through a NOT gate and produce a LOW signal to multiplexers.
(ii) LDR1 greater than LDR2, this will produce a HIGH signal to multiplexers.
(iii) LDR1 equals LDR2, this output will pass through a NOT gate and send a LOW signal to D-latches.

The outputs from the Driving System will connected to multiplexers. Ascending order of Q_0 to Q_3 will connected to input A of multiplexers while descending order or Qs will connected to input B. This will turn the stepper motor clockwise and anti-clockwise respectively. When the signal received from comparator is LOW, it will choose A as the output and vice versa (Theraja B. L. (2005)).

Before the output send to the stepper motor, it will store at D-latches. If the signal received from comparator is LOW, all of the D-latches will output LOW since they are active low. Thus, the base motor will stop turning.

4.0 RESULTS AND ANALYSIS

A. Sensor Circuit

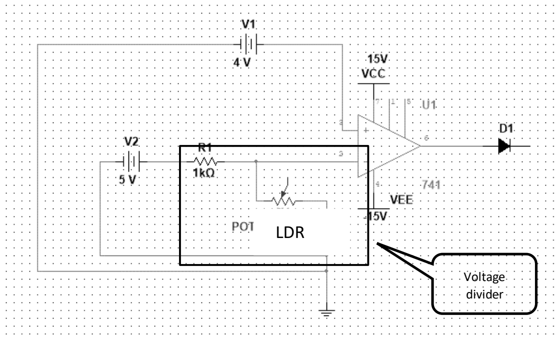

Fig. 5. Sensor Circuit

Figure 5 shows the connection of a sensor circuit with light dependent resistor. Table 3 shows the overall analysis from hardware measurement.

Table 3. Overall Analysis of LDR

Condition	Inverting input, v_{div} (V)	Non-inverting input(V)	Output voltage	Digital representation
Bright	2.5	4	+15	High(1)
Dark	5.5	4	0	Low(0)

When LDR is exposed to sunlight, it's resistance decreases.

v_div=V2/(R1+R_LDR) R_LDR

The formula shows that high intensity of sunlight will cause v_div to be low as R_LDR decreases. The inverting input of the op amp is always higher than the non-inverting input when the LDR not exposed to sunlight. The op amp act as a comparator to compare both voltages. When it is dark, the output voltage of the op amp is -15V. A diode is used to make sure there will be only positive output as the negative value might damage the circuit.

When light hit the LDR, its resistance decreases and cause the v_div to be lower than the non-inverting input. The op amp compares both value and give the output of +15V.

The choice of 1kΩ resistor to connect series with LDR is because the resistance of LDR at normal brightness is between 3kΩ to 4kΩ. By using 1kΩ resistor, the system able to detect a smaller change in voltage across the LDR.

B. Digital circuit analysis

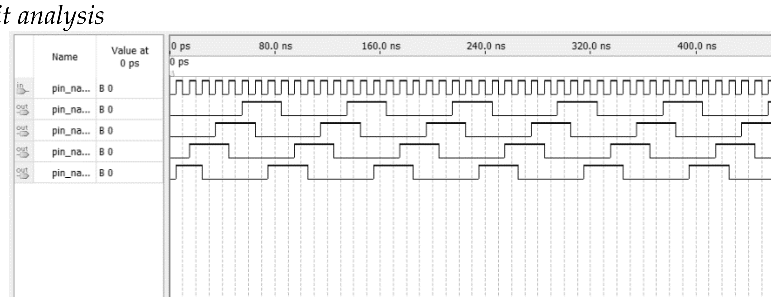

Fig. 6. Simulation of Driving System

Figure 6 shows the simulation of *Driving system.* This figure proves that the signals produced is equivalent to signal required as in Table 1.

To prove the systems work correctly, another simulation had ran by controlling the value of LDR1 and LDR2 which will entering the microcontroller. The Figure 7 shows the simulation result on Base Motor Direction Selection System.

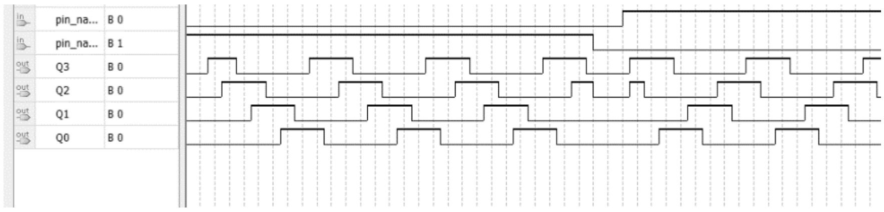

Fig. 7. Simulation result of Base Motor Direction Selection System

The first signal is LDR1 while the second signal is LDR2. The rest are the Qs output. From the simulation result, when LDR1 smaller than LDR2, the Q output is in descending order. When LDR1 and LDR2 both at LOW, all the outputs are cleared. When LDR1 is greater than LDR2, the Q output is in ascending order.

5.0 CONCLUSION

Dual Axis Solar Tracking System prototype model is successfully developed. The designed system is focuses on designing controller part and the main concern is to design appropriate circuits and the circuits supposed to be able to control stepper motor rotation direction without considering. The system able to track and follow sunlight intensity to collect maximum solar power. This finding has shown that the system works successful similarly to project in Sadeque F. (2014). It is shown the FPGA is powerful enough to support any type of works. The constructed system model can be applied in the residential area for alternative electricity generation especially for non-critical and low power appliances.

6.0 ACKNOWLEDGEMENT

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7.0 REFERENCES

Altera (2013). DE2-115. *User Manual. World Leading FPGA Based Product and Design Services.* Terasic Technologies Inc.

Clifford M. J. & Eastwood D. (2004). Design of a novel passive solar tracker, *Solar Energy, vol. 77, page 269 – 280*

Mazidi M. A., Naimi S. & Naimi S. (2009). *The AVR Microcontroller and Embedded Systems, 1st Ed.*, Prentice Hall

Sadeque F. (2014). *Design and Implementation of Automated Solar Tracking System*. Bachelor Dissertation.

Theraja B. L. & Theraja A. K. (2005). *A Text Book of Electrical Technology: AC & DC Machines*, S. Chand & Company