International Journal of Advanced Technology & Engineering Research (IJATER)
www.ijater.com

DESIGN OF FPGA BASED SOLAR TRACKING SYSTEM USING VERILOG

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Abstract

This paper illustrates design of solar tracking system using FPGA(Field Programmable Gate Array).Use of Astronomical equation in this design. Astronomical equation gives altitude and azimuth angle using this position of the sun can be determined. Main idea of this design is to develop an solar panel which uses sun rays as energy and generate maximum power effectively.This design contain clock module, sunrise module and PWM generator module. The design of verilog code has been successfully implemented on SPARTEN 3E FPGA kit. For design entry Xilinx ISE 14.2 software is used, synthesis and dump the bit file onto FPGA kit has been done, Xilinx simulator used for functionality check. FPGA having advantages of massively parallel data processing, field reprogram ability, Performance gain for software applications and real time application performance, which allowed fast processing and lower development cost.

Keywords-FPGA, Verilog, Azimuth, Altitude

I. Introduction

The use of the energy is more demanding as the world population increases day by day. In present time oil and coal which is main source of energy is about to end up. we require reliable source of energy. Solar energy is one of the non-pollutant, reliable and cost-effective source of energy[Garg 2000].There are variety of applications of solar energy such as producing electricity, transportation, cooking and many more.

Solar cell become extremely popular for utilizing solar energy. we use solar energy through SPV(Solar Photovoltaic Cell) or solar cell to meet our electricity requirements. Solar cell is a electrical device that convert solar radiation directly into electricity by photovoltaic effect. The solar radiations are gathered by solar collector. In photovoltaic effect light form the sun is collected by the P-N type junction and causes movement of electrons to p-side and holes to n-side of junction. As the result number of electron-hole pairs are generated which create the flow of electric current[G.D.Sharma May 2006].

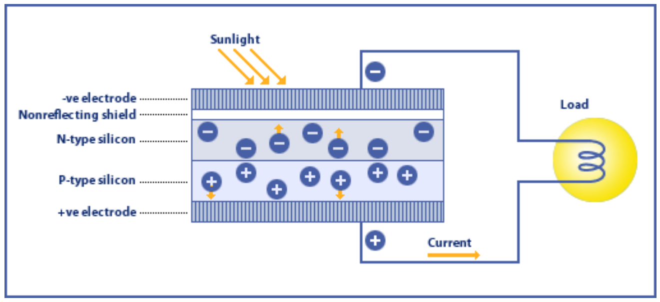

Figure 1. Working of PV cell

II. Evaluation of solar tracker

As the sun moves across the sky, for receiving the best angle of the sun radiation for collection of energy. Most photovoltaic (PV) solar panels are fitted fixed. Though the sun moves across the sky during the day, this is not an ideal solution. Solar panels are installed in the direction of maximum of radiation of sunlight. Now the problem arises that the sun is moving so we can't get maximum radiation all time.

To solve this problem a tracking mechanism is often implemented into the solar panel to keep the panel's face in the direction of the sun. A sun tracker is device over it the solar panels are fitted which tracks the sun movement across the sky make sure that the maximum amount of sunlight strikes on the panels throughout the day. Most of solar radiation is absorb when it strikes perpendicular to the PV panel. By accurately tracking the sun, efficiency of the power generation can be increased. There are basically two types of tracker one is passive tracker and the another is active tracker[Vaibhaa Sharma 2013].

The passive trackers use a low boiling point gas fluid which is driven and cause to move the tacking system. The liquid is then vaporized by the added heat of the sun and the center of the mass is shifted leading to that system finds the new position.

Active tracking mechanism directed the solar panel towards the sun with the help of light dependent resister(LDR). Motors are employed to direct the tracker towards the sun's direction[Balfour 2013].

III. Types Of Tracker

The sun position in the sky changes with seasons and during the day. There are two types of trackers are being described.

Mechanism rotates the single axis tracker in one direction only. Single axis tracking system increase power production by 20% to 25% compared to fixed PV cell panel[Dhanabal, R.et al 2013]. Advantages of single axis trackers are less complicated and cheaper.

Dual axis tracks the sun entirely. Track the sun both in azimuth and altitude angles, Capture full path of the sun. Dual axis tracking system increase power production by 34% to 37% compared to fixed PV cell panel[Dhanabal, R.et al 2013]. But dual axis trackers are slightly more complex, little expensive.

IV. Sun Path

In earth's southern hemisphere, the sun rises in the east, sets in the west and move across the northern sky. The location of the sun can by described by two angle, the altitude and the azimuth angle[Sanjay K. Jain 2012].

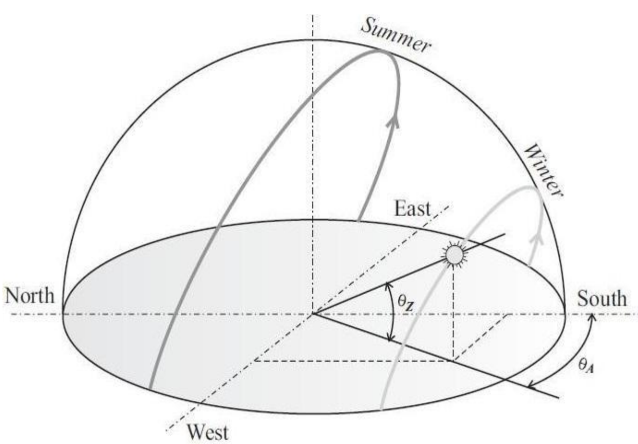

Figure 2. Solar altitudes and azimuth's typical behavior of sun path.

Azimuth angle (Θ_A) is measured clockwise around person's horizon from north. So an object due north has azimuth of 0^0 ,east 90^0,south 180^0 and west 270^0.The vector from position of person to the sun position is projected perpendicularly onto a plane means the angle between a reference plane and projected vector. The sun Altitude angle (Θ_z) is the angle between the line connecting to the sun and the horizontal plane. The altitude angle depend on latitude of the earth, the declination angle and the hour angle[Fawzi et al 2011].

$$Azimuth\ Angle = \frac{\cos^{-1}[\sin \delta \cos \Theta - \cos\delta \sin \Theta \cos(HA)]}{\cos \alpha} \quad (1)$$

$$Altitude\ Angle = \sin^{-1}[\sin \delta \cos \Theta + \cos \delta \cos \Theta \cos(HA)] \quad (2)$$

Where, HA is Hour Angle and α is the elevation angle, declination angle is б, latitude is denoted by ∅.

Declination Angle(б) of the sun is the angle between a line drawn from the centre of the Earth to the sun and equator. The declination is maximum (23.45^0) in the summer/winter (India 21 June and 22 December)
Declination angle is given as

$$Declinaton\ Angle = 23.45^0 \sin[\frac{360}{365}(D - 81)] \quad (3)$$

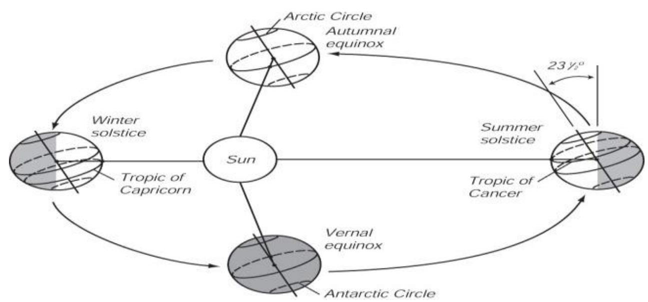

Figure 3. The Declination Angles

Where, the number of the day is denoted by D.
Hour angle which convert local solar time(T) into degree. It is given as

$$HRA = 15^0 (T - 12) \quad (4)$$

V. Design Methodology Of Tracking System

Figure 4 shows the block diagram of solar tracking system. This diagram contain FPGA, two stepper motor driver IC, stepper motor to rotate panel both in horizontally as well as in vertical direction.

This design contain four modules are clock module, sunrise module and two PWM generator module. These have been implemented on FPGA kit. This design is cost effective. Figure 5 shows Design of Tracking System.

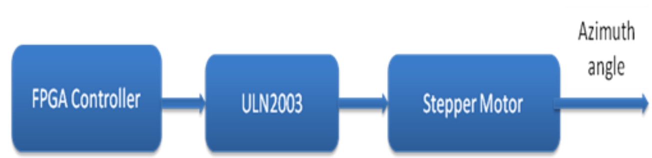

Figure 4. Block Diagram of Solar Tracking System

A. Digital Clock Module

When I turn on the tracking circuit clock starts. Clock module used in the tracker provides outputs in second, minute ,hour ,day and day5.day5 is the output which contains 5 days. To make my calculation easier I divide 365days in 73group.For this counter is used like second counter when it reaches 59 then minute output increase by 1.If second and minute counter exceed 59 then hour has increased by 1 and hour counter reaches 24 then day increased by 1 and so on.

B. Sun Rise Time Module

This module gives rise time for each group. When it goes high then stepper motor set for azimuth angle start rotating from east to west and when it goes low then west to east.

C. PWM generator modules

There are basically Pulse generator module is design to send the pulses to stepper motor, for rotation of motor in both direction.

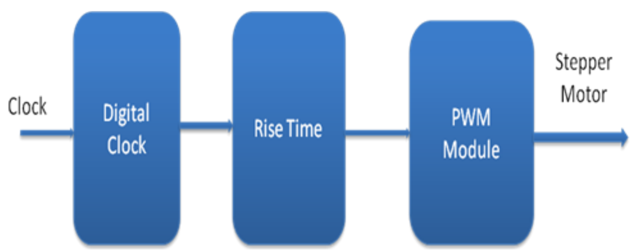

Figure 5. Design of Tracking System

VI. Working Principle of Solar Tracking System

There are various ways from which we can find the position of the sun. Implementation of astronomical equations for calculating azimuth angle is quiet difficult and takes more time. To tackle this problem, I have used online sun position calculator to calculate the azimuth angle value of sun for the year of 2014. I gathered the data containing values of azimuth angle for location Ahmedabad city in India for 2014.

Table 1. Angles of sun rotation with delay

Time	Azimuth
7 to 8	6^0
8 to 9	7^0
9to 10	11^0
10 to 11	13^0
11 to 12	16^0
12 to 13	19^0
13 to 14	18^0
14 to 15	15^0
15 to 16	12^0
16 to 17	8^0
17 to 18	7^0

The whole problem is divided into three parts.

a. There is almost negligible variations in degree of azimuth for 5 days, so to make calculations easier take 5 days as one group thus there are total 73 groups means 1^{st} to 5^{th} day be the 1^{st} group and 360^{th} to 365^{th} become the 73^{rd} group
b. The data is taken online contains values for azimuth angle for every group with delay of 60 minute.
c. Calculate angle changes after every 60 minute of delay from sunrise time to sunset time for every group of the year

Table 1 lists the change in azimuth angle for the 1^{st} group after a delay of one hour. For instance time from 7 to 8 the value of azimuth angle varies by 6°.

Table 2. values of azimuth angle for 1^{st} Group

Time	Day 1	Day 2	Day 3	Day 4	Day 5
7	113^0	113^0	113^0	112^0	112^0
8	119^0	119^0	119^0	118^0	118^0
9	126^0	126^0	126^0	126^0	126^0
10	137^0	136^0	136^0	136^0	136^0
11	150^0	150^0	149^0	149^0	149^0
12	167^0	166^0	166^0	166^0	166^0
13	185^0	185^0	185^0	185^0	185^0
14	204^0	203^0	203^0	203^0	203^0
15	218^0	218^0	218^0	218^0	218^0
16	230^0	230^0	230^0	230^0	230^0
17	238^0	238^0	238^0	238^0	238^0
18	245^0	245^0	245^0	245^0	245^0

The grouping of the days makes task easier. The changes in azimuth angle from the previous day value are negligible as shown in Table 2.This table represent azimuth angle for Ahmedabad city in India.

➢ Method of tracking

The motion of the tracking system 0^0 at sunset and sunrise time and 90^0 for tilt angle.

The tracker system starts from 1st group .The tracker reaches the 365th day of the year up to this the tracker system is doing its operation continuously.

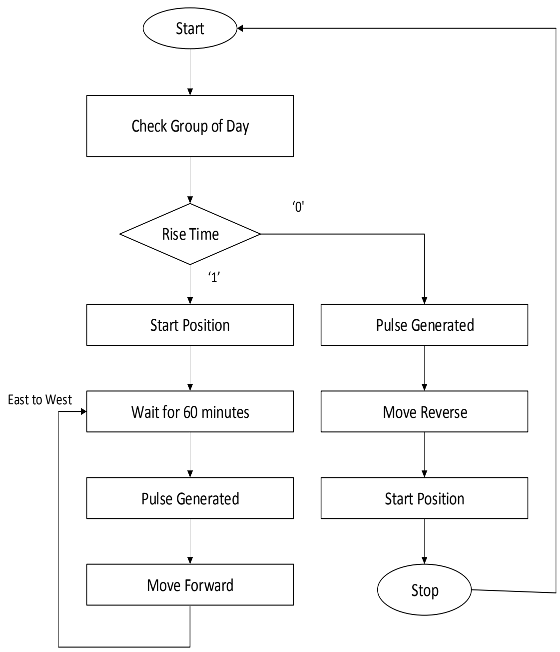

Figure 6. azimuth angle movement flow chart

The flow charts for azimuth angle movement is shown in Figure 6.As given in the flow chart, angle have to wait for rise time.PWM generation depends on the rise time value. After initializing, the tracker will first check group of the day it belongs to. If the rise time is 'HIGH' then start the position of the tracker.

VII. Stepper Motor & Driver Theory

The tracking system consists of two motors, which control the solar panel position and a control circuit to direct these motors.

A stepper motor is controlled by the series of electromagnetic coils. Series of magnet mounted on the center shaft, the coils surrounding the shaft are given current alternately and generate fields which attract or repulse the magnet, causing motor to rotate[9].

The motors are classified into two types unipolar stepper motor and bipolar stepper motor.

A. Unipolar Stepper Motor

The unipolar stepper motor has five wires or it may be six also. Power always comes in on this pole so they are called unipolar stepper motor[10].

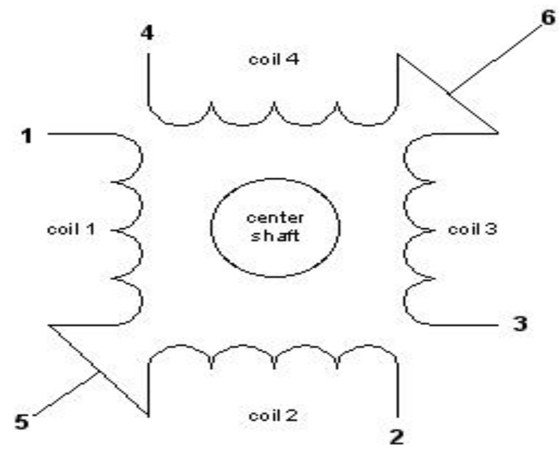

Figure 7. Stepper Interior

B. Bipolar Stepper Motor

The bipolar stepper motor has four wires. Unlike unipoar, bipolar stepper motor has no common connection. They have two separate sets of coils[10]. The sequence are given in table 3.

Table 3. steps of the stepper motor

Step	Wire1	Wire2	Wire3	Wire4
1	high	low	high	low
2	low	high	high	low
3	low	high	low	high
4	high	low	low	high

Stepper motor are mostly used in the position control application and robotics application. Stepper motor moves when the pulses are provided by PWM generator and given to a driver IC for current amplification. The driver circuitry is the main heart of stepper motor. The stepper motor strongly depends on driver circuitry[Urmila Meshram et al 2009].

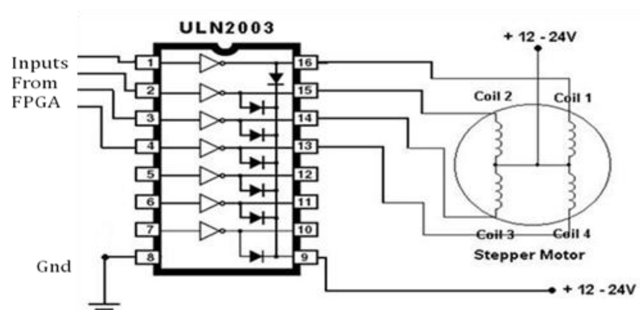

Figure 8. Stepper motor with driver circuit.

VIII. Simulation And Results

The control logic of solar tracking system contains the digital clock module, the sunrise time module and pulse generator modules(PWM module). Three modules are designed, synthesized and dump on FPGA. The output from FPGA is given to stepper motor driver IC(ULN2003) which drive the stepper motor in azimuth direction. Each module explain one by one. Solar tracking system simulated using Xilinx ISE 14.2.

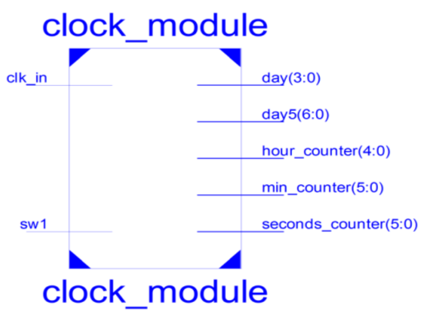

Figure 9. RTL view of clock module

Figure 9 shows RTL view of clock module of solar tracking system. This is one of the module of the solar tracking system here Clk_in and sw1 are inputs and module provide outputs in minutes, hours, day, and day5.here day5 indicate group of five days, So in year 365days divided into 73 groups. Figure 10 shows the Simulation result of digital clock module.

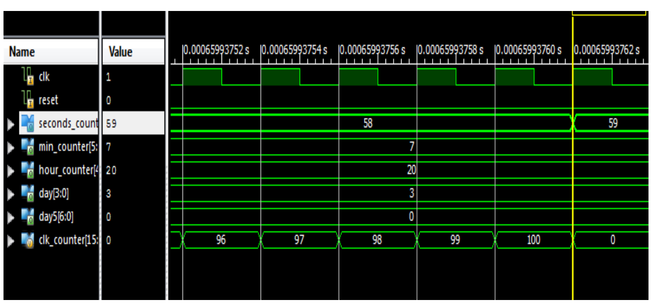

Figure. 10. Simulation result of digital clock module

Figure 11 shows RTL view of top module which contain clock module and rise time module. Rise time module have hour counter,day5,minute counter as input and rise as output port which gives the rise time of sun during a year.

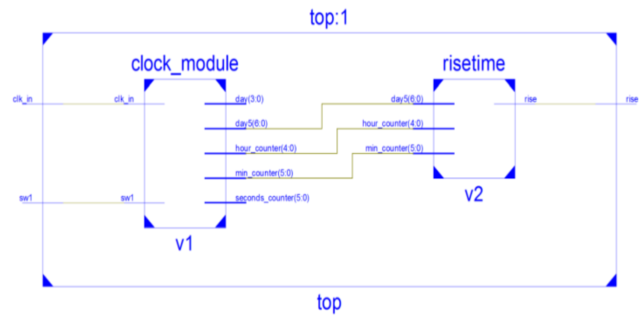

Figure 11. RTL view of top module

Figure 12 shows Simulation result of top module, here output of this module is rise. Sun rise time and sunset time of sun varies during a year so here the module is design that gives us rise time of the year. For example rise time of 1[st] group is 7 and set time is 18 so during this period rise become high then it goes to low.

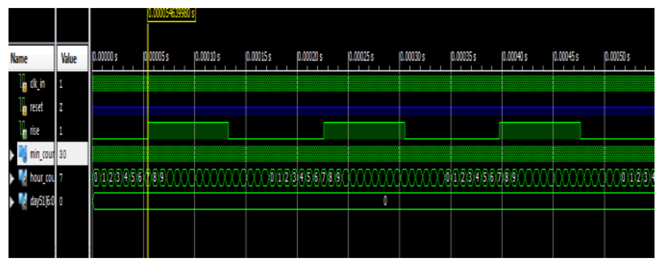

Figure 12. Simulation result of top module

Figure 13 shows the RTL view of the proposed system. Figure 14 illustrates the results of the design. First rise signal is high at 7 for the 1st group,then set of PWM pulses are generated with some delay to drive the stepper motors to track the azimuth angle.

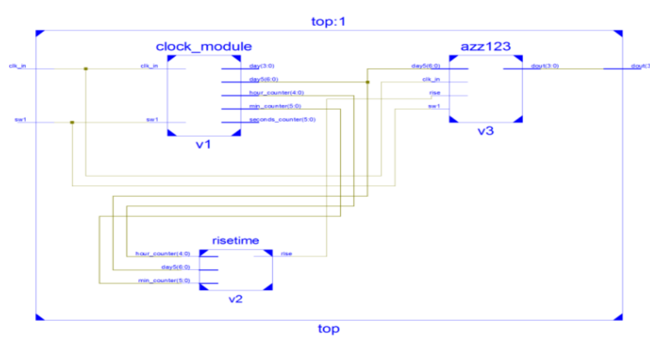

Figure 13. RTL view of solar tracking system

Figure 14. The pulse generated of the azimuth

Figure 15. Technology Schematic of solar tracking system

IX. Conclusion & Future Work

Solar panel efficiency was substantially improved with a sun tracker. Timing based controlling is an attractive feature. In this design totally depends on time rather than use of light sensor. The logic is implemented on FPGA sparten 3E kit successfully. Timing base control system is advantageous because tracking system lead to no error in partially cloudy weather. Because using light sensor if there is less or no light strike on sensor then you will not get satisfied result. Thus this design is facing the sun even in cloudy weather. This design has very less cost and easy to design.

In this prototype I have designed modules of solar tracking system with the help of verilog code for design entry has been done by Xilinx 14.2 tool and the functional verification has been done using Xilinx simulator also dump the code on FPGA Spartan 3E kit.

Main Goal of tracker is to rotate panels smoothly. To construct an emergency light inverter circuit.

Acknowledgments

I would like to thank my guide Ms.Rachna Jani**,** Associate Professor, Department of electronics and communication, CHARUSAT, for her suggestions and guidance in implementing the project. She has remained a constant source of inspiration, guidance and encouragement to me. I also thank all staff members of Electronics & Communication Department, for their moral support and kind co-operation.

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