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FPGA BASED SOLAR TRACKING MECHANISM FOR RESIDENTIAL APPLICATIONS

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ABSTRACT: This work describes a dual axis tracking system based on astronomical equation. The position of the Sun at any time is a function of azimuth and altitude angle values collected off line. A prototype of dual axis solar tracking system is developed on FPGA to implement the proposed idea. The system comprises of digital clock module, rise time module and two pulse generator modules which employ pulse width modulation (PWM) technique for controlling two stepper motors for tracking the azimuth and altitude angles. The functionality of various blocks of the system is described in VERY HIGH SPEED DESCRIPTION LANGUAGE (VHDL).The control logic has been successfully implemented on Spartan 3E FPGA device.

Keywords; FPGA, suntraker, steppermotor , dualaxis

I. INTRODUCTION

Solar tracking system is an electromechanical device that is used to turn the solar devices to face the Sun as it moves across the sky. Solar radiations are absorbed most efficiently when it strikes the photovoltaic cells at 90° angles. It becomes very essential that the solar panel should be correctly positioned to collect the maximum energy. By accurately tracking the Sun, the incident solar irradiance can be effectively increased..The Sun rises each day from the East, and moves across the sky to the West. When the Sun is shining, it is sending energy to us, and the heat is felt. However its position varies with the time of day and the seasons. Thus, if we could get a Solar cell to turn and look at the Sun all day, then it would be receiving the maximum amount of sunlight possible and converting it into electricity[1]. A solar tracker is a device that is used to align a single photovoltaic panel or an array of PV modules with the Sun, so a solar tracker can improve a system's power output by keeping the sun in focus throughout the day thus improving effectiveness of such equipment over any fixed position. The light sensors based tracking systems lead to error in partially cloudy weather, since there will be less or no striking of light on light sensors hence satisfactory voltages may not be available at junctionpoint [1]. Time based controlling is an attractive feature of the solar tracking system. In the proposed two axis tracker, light sensor is not used, instead, control logic implemented on FPGA chip is controlling all the modules. The proposed tracking system is facing the Sun even in very cloudy day and will be ready at the beginning of the next day. The proposed and developed practically comprehensible solar tracking system is relatively simple with minimal cost.

II. DESCRIPITION OF THE PROPOSED SYSTEM

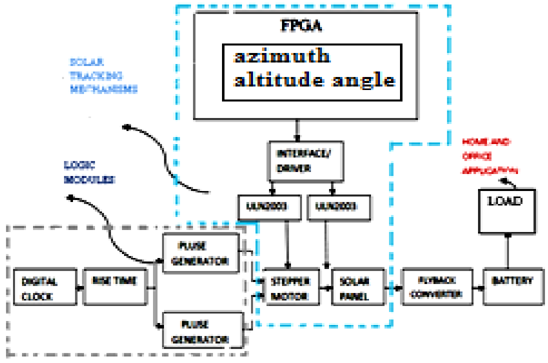

Fig 1. Block diagram of dual axis solar tracking

The system comprises of digital clock module, rise time module and two pulse generator modules. Pulse generator modules employ Pulse Width Modulation (PWM) technique for controlling two stepper motors for tracking the azimuth and altitude angles. The functionality of various blocks of the system is described in Very High Speed Integrated Circuit (VHSIC) Hardware Description Language (VHDL). The control logic has been successfully implemented on Spartan 3E FPGA device. Xilinx ISE 9.1 suit is used for design entry, synthesis and burning the bit stream file into FPGA device. The functional verification has been performed using Xilinx simulator[2].

A. Modeling of the movement the Sun

In Northern hemisphere of the Earth, the Sun rises in the East, moves across the Southern sky and sets in the West. The position of the Sun can be described at any time by two angles, the altitude and azimuth angles[3]. The solar altitude angle (α) is the angle between a line collinear with the Sun's ray and the horizontal plane. The solar azimuth angle (ψ) is the angle between a due South line and the projection of the site to the Sun line.

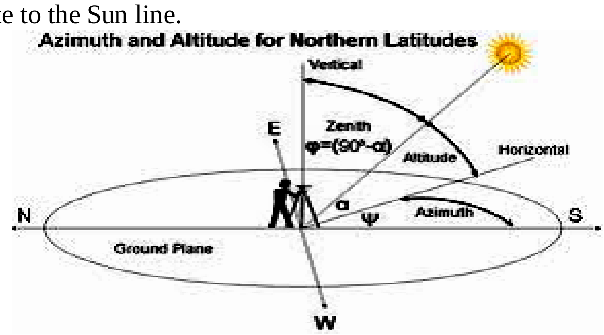

Figure 2: The Sun position depicted by Azimuth and Altitude angles

The following mathematical equations (1) and (2) are used to calculate azimuth and altitude angles of the Sun respectively[4] .

Azimuthangle=$cos^{-1}[sin\delta cos\emptyset - cos\delta sin\emptyset \cos(HRA)]/cos\alpha$
(1)

Altitudeangle=$sin^{-1}[sin\delta cos\emptyset + cos\delta cos\emptyset \cos(HRA)]$
(2)

where, δ is the declination angle, ∅ is the latitude of location of interest. HRA is the hour angle and α is the elevation angle[5].

B. Solar tracking system- Principle of working

The recognition of position of the Sun goes through several steps. The astronomical equations for calculating the azimuth and altitude angle contain trigonometric functions, so implementation of these equations in hardware is both time consuming and difficult. To overcome this problem, PHP language based solar position calculator is used to calculate the values of azimuth and altitude angles of the Sun for the year 2015.

TABLE 1: Calculation of Azimuth and Altitude Angles Using Solar position Calculator

TIME	AZIMUTH	ALTITUDE
6:00 TO 7:00	110°	-3°
7:00 TO 8:00	114°	+11°
8:00 TO 9:00	119°	+24°
9:00 TO 10:00	123°	+31°
10:00 TO 11:00	129°	+37°
11:00 TO 12:00	139°	+48°
12: 00 TO 13:00	159°	+56°
13: 00 TO 14:00	185°	+58°
14: 00 TO 15:00	209°	+54°
15: 00 TO 16:00	227°	+46°
17: 00 TO 18:00	245°	+2°
18:00 TO 19 :00	250°	+8

The lists values of variations in azimuth and altitude angles for the 1st group of days after a delay of every 1 hour. The "+" sign indicates the upward trajectory of the Sun from morning till noon i.e. 0° to 90° whereas "–" sign indicating the downward trajectory of the Sun from noon to evening i.e. 90° to 0° for altitude angle.

C. Design of real time clock using VHDL

The digital clock starts when the tracking control circuit is turned on. The operation principle of this module is based on the time control method. The real time clock consists of the three fields: hour, minute and seconds. Each field is stored in a 8-bit register and further used for tracking solar by comparing different azimuth and altitude angle of the Sun at different timings.

D. Design of rise time module

This module is utilized to create the rise time for each group. Internal rise time control signal is fed by this module. This control signal will control the forward and reverse direction of motors. When the rise time signal becomes HIGH, motor sets for azimuth angle and will start rotating from the East to the West and from the West to the East when signal becomes LOW. Same thing happens for tilt angle which will rotate the motor anticlockwise when signal becomes HIGH.

E. Design of pulse width modulation movement controller for stepper motor

Pulse generator modules send the stepping pulses to stepper motor for movement of motor in azimuth and altitude direction. During start position tracker will wait for 15 minutes and generates pulses for stepper motor.

F. Interfacing of stepper motor through ULN2003 with FPGA:

Stepper motors are widely used in the robotics industry & position control applications. Stepper motors move a known interval for each pulse. These pulses are provided by Pulse generator and are given to a ULN driver chip (ULN 2003) for current amplification and are referred to as a step. For each step the motor moves a known distance which makes the solar panel for repeatable positioning [6] .The performance of stepper motor is strongly dependent on the drive circuitry. The stepper motor driver circuitry regulates the current and flux direction in the phase windings and makes a convenient amount of current to flow through the windings. It also allows short current rise and fall times as feasible for better high speed performance [7].

III. SIMULATION RESULTS

A. SIMULATION RESULT OF PV MODULE

The IV and PV curves for various irradiance but a fixed temperature (27°C) is shown below in figures 3,4 and 5 The characteristic I-V curve

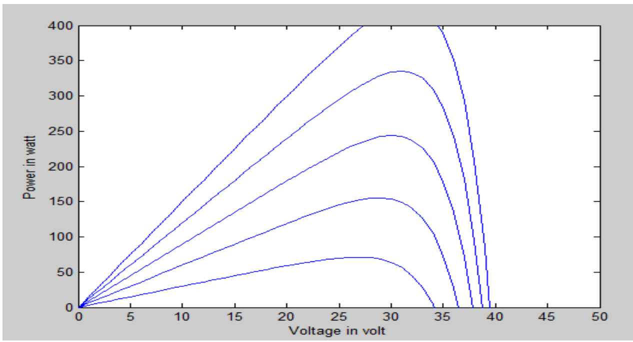

Figure 3 P-V Characteristics

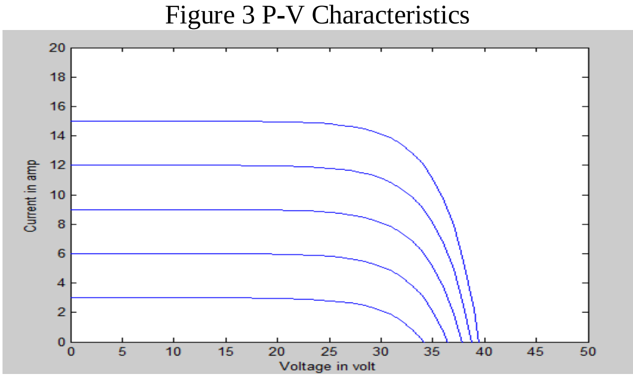

Figure 4 I-V characteristics

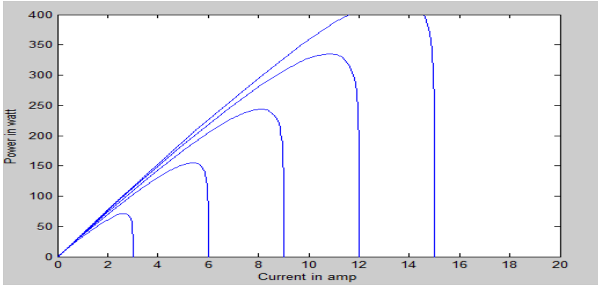

Figure 5 P-I characteristics

The characteristic I-V curve tells that there are two regions in the curve: one is the current source region and another is the voltage source region. In the voltage source region (in the right side of the curve), the internal impedance is low and in the current source region (in the left side of the curve),the impedance is high. Irradiance temperature plays an important role in predicting the I-V characteristic, and effects of both factors have to be considered while designing the PV system where as the irradiance affects the output, temperature mainly affects the terminal voltage. From the PV characteristics it can be observed that, there is a point at which the power output is maximum for a given condition of irradiance and load. The operation of PV panel at this region gives the maximum efficiency.

B. SIMULATION RESULT OF REAL TIME CLOCK USING VHDL

The Figure 6 shows the simulation result of the real time clock which consists of the three fields ,such as hour, minute and second. Each field is stored in a 8-bit register and further used for tracking solar by comparing different azimuth and altitude angle of the Sun at different timings.

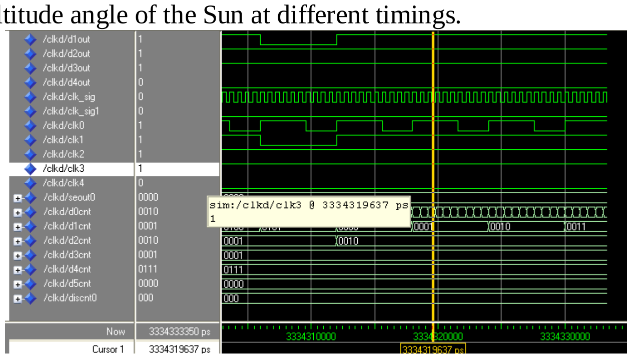
Figure 6 Simulation result of real time clock.

C. SIMULATION RESULT OF STEPPER MOTOR INTERFACING USING VHDL

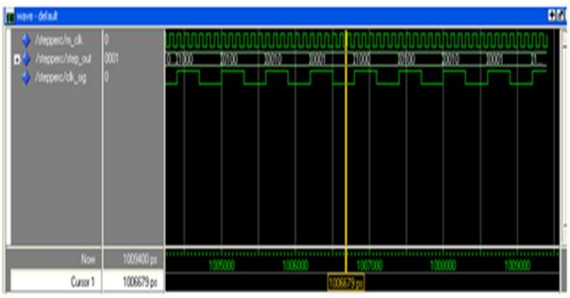
Figure 7 Simulation result of stepper motor

The Figure 7 shows the simulation result of DC stepper motor Movement of each windings are controlled by Pulse Width Modulation(PWM) signal which is having 50% duty cycle .The direction of stepper motor can be controlled by "Direction" signal ;if direction ='1' then the stepper motor moves in forward direction. If direction= '0' then stepper motor moves in reverse direction.

IV. HARDWARE IMPLEMENTATION


Figure 8 Experimental setup without tracking

Table 2 Experimental setup specification

COMPONENTS	SPECIFICATION
SOLAR PANEL	12V 20W DC
SOLAR CHARGE CONTROLLER	12V 6AMPS
BATTERY	12V 7.2Ah
LED KIT(LOAD)	12V 10W COOL WHITE

Table 3 Panel & battery voltage without tracking

TIME	PANEL VOLTAGE WITHOUT TRACKING	BATTERY VOLTAGE WITHOUT TRACKING
10:00am	10.7V	10.6V
11:00am	10.8V	10.7V
12:00noon	10.9V	10.2V
1:00pm	11.2V	10.9V
2:00pm	11.3V	10.1V
3:00pm	11.1V	10.2V
4:00pm	11.0V	10.3V

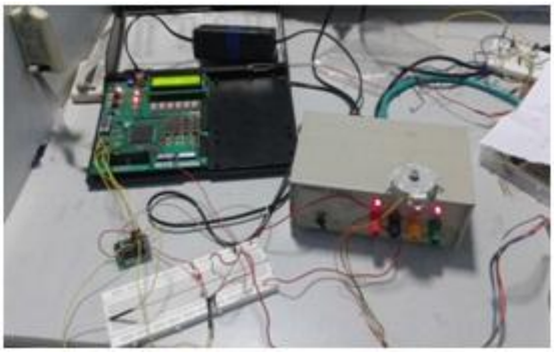

Figure 9 Stepper motor interfacing with SPARTAN 3E

Figure 10 Experimental setup for solar tracking

Figure 11 Complete experimental setup with solar tracking

Table 4 Panel and battery voltage with tracking

TIME	PANEL VOLTAGE WITH TRACKING	BATTERY VOLTAGE WITH TRACKING
10.00am	13.7V	12.7V
11.00am	13.9V	12.9V
12.00noon	14.0V	12.9V
1.00pm	13.8V	12.7V
2.00pm	13.9V	12.8V
3.00pm	13.6v	12.6v
4.00pm	13.1v	12.1v

V. CONCLUSION

Time based controlling is an attractive feature of this solar tracking system. In this project, a prototype of dual axis solar tracking system is developed. The control logic is implemented on FPGA chip is used to control all the modules in the system .The system is facing the Sun even in very cloudy day and will be ready at the beginning of the next day. The solar tracking system developed is practically comprehensible and relatively simple with minimal cost.

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