DUJASE Vol. 3(2) 167-171, 2016 (January)

An FPGA Based Solar Tracking Control System

M. S. Alam, Nilufa Yeasmin, Farjana Ferdous Tonni, Akila Khatun and S. M. Mamun

Department of Electrical and Electronic Engineering, University of Dhaka, Bangladesh

E-mail: msalam@du.ac.bd

Received on 16.08.2015. Accepted for publication on 09.09.2015.

ABSTRACT

To increase the unit area illumination of sunlight on solar panels, we design a Field Programmable Gate Array (FPGA) based solar tracking control system. The design mechanism holds the solar panel and allows the panel to perform an approximate horizontal rotation to track the sun's movement during the day. A model prototype solar cell movement system with mechanical assemble is constructed to move the panel from 180^0 East to West. The electronic circuit is designed to sense the intensity of light and to control servo motor for the panel movement. We use the Altera Quartus-II software to perform solar tracking. The design is programmed and loaded into Altera DE1 FPGA board and tested successfully in the laboratory. This system can achieve more illumination and energy concentration than conventional fixed solar panel and can improve overall efficiency.

Keywords: Control, FPGA, PV panel, Servomechanism, Solar Tracking.

1. Introduction

Solar cell converts solar energy into electrical energy. The amount of energy obtain from PV panel is directly proportional to the amount of sun light acquired by that solar panel [Parida, et al., 2011] Most solar array has a fixed orientation and does not turn to follow the sun. A solar panel receives the most sunlight when it is perpendicular to the sun's rays, but the sunlight direction changes regularly with changing seasons and weather [Luque and Hegedus, 2011, Gevorkian, 2008].

A solar tracker **[**Rubio, et al., 2007] is a device that orients a solar panel system that includes photovoltaic (PV) solar panels, lenses or other optical devices toward the sun. The idea is to be able to tilt the solar panels in the direction that the sun moves throughout the day and, hence, throughout the year as the seasons and weather changes. The functionality is simple – the more the photovoltaic panels can face directly toward the sun, the more power can be generated. In flat-panel photovoltaic (PV) applications, trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced from a fixed amount of installed power generating capacity [Luque and Hegedus, 2011, Gevorkian, 2008]. Sun trackers are classified according to the number and orientation of their axes. They are grouped into single- and dual axis tracking devices. Single-axis trackers [Kalogirou, 1996] have one degree of freedom. They are used to vary the azimuth angle in order to follow the movement of the sun East–West during the day with fixed tilt angle. These types of trackers are more suitable in tropical regions. Dual-axis trackers [Bakos, 2006] with two degrees of freedom can tune the solar panel East–West and North– South to follow the sun's apparent motion anywhere in the world. Furthermore, sun trackers can be subdivided into two categories: passive and active trackers[Lee et al., 2009, Mousazadeh et al, 2009]. Passive trackers [Clifford and Eastwood, 2004] are based on thermal expansion properties of a fluid (often Freon) as a means of tilting the solar panel. When heated by the sun rays, the fluid pressure increases causing the liquid to move inside the tracker from one side to another allowing gravity to rotate the tracker to follow the sun. These trackers do not use motors or control and hence do not consume any energy. They are less accurate and therefore, operate with low efficiency compared to active trackers. These types of trackers are however, unpractical in cold locations. Active trackers on the other hand employ motors and gear trains to direct the PV panel as commanded by the controller[Lee et al., 2009, Mousazadeh et al, 2009]. In concentrated photovoltaic (CPV) and concentrated solar thermal (CSP) applications, trackers are used to enable the optical components in the CPV and CSP systems [Luque and Hegedus, 2011, Gevorkian, 2008]. The optics in concentrated solar applications accept the direct component of sunlight and therefore must be oriented appropriately to collect energy. Tracking systems are found in all concentrator applications because such systems do not produce energy unless pointed at the sun. Solar trackers can potentially make solar panels 25-35% more efficient, which means that more power, can be generated with less space and less panels [Luque and Hegedus, 2011, Gevorkian, 2008]. However, if the location of the installation does not allow the trackers to work effectively, then the cost of purchasing the solar trackers can lead to money wasted.

The output power produced by high-concentration solar thermal and photovoltaic systems is directly related to the amount of solar energy acquired by the system, and it is therefore necessary to track the sun's position with a high degree of accuracy. One of the first automatic solar tracking systems was presented by McFee in 1975 [McFee, 1975]. Since then, many systems have been proposed to track sun's position efficiently. These systems can be broadly categorized into closed-loop and open-loop control. A good literature review on sun tracking systems can be found in [Lee et al., 2009, Mousazadeh et al, 2009]. An FPGA based solar tracking system was presented using astronomical equations to determine the position of the sun in the sky at any time of the day to calculate the azimuth angle and altitude angle for the two axis tracking purposes [Al-Naima and Al-Taee, 2010]. A sun tracking mechanism using fuzzy logic control was designed and implemented on FPGA to track the sun and keep the solar cells always face the sun in most of the day time [Yingzhe, et al., 2007, Hamed and El-Moghany, 2012]. The aim of this research is to utilize the maximum solar energy through solar panel. For this a FPGA based automatic sun tracking system is proposed as discussed in following sections.

2. Design of solar tracking control system

In the proposed solar tracking system, FPGA-based servo motor has been used to drive the PV panel depending on the position of sun sensed by sensor system as shown in Fig. 1. The position of the sun is determined by using a tracking sensor, the sensor reading is converted from analog to digital signal and then it is passed to a controller implemented on FPGA. The controller output is connected to the driver of the servo motor to rotate PV panel in one axis until it faces the sun. We used the Altera Quartus-II software [Altera Corporation, 2015] to perform solar tracking. The design is programmed and uploaded into Altera DE1 FPGA board [Altera Corporation, 2006]. This single axis solar tracking implementation accelerates development while maintaining design flexibility, reduces the circuit board costs and simplifies product testing.

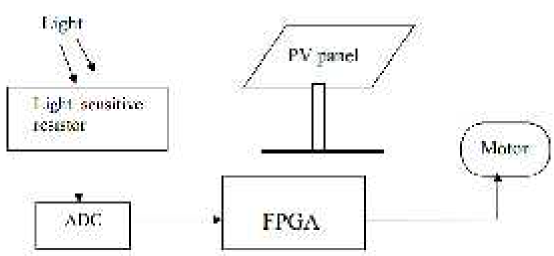

Fig. 1: Block diagram of sun tracking control system.

Light Dependent Resistor

Light dependent resistor (LDR) is used to construct the sensor, because it is the most reliable sensor that can be used for light sensing [Mims, 2004]. LDR is basically a resistor whose resistance varies with intensity of light, so more intensity gives less resistance. Different LDR sensors available in the market are, the biggest size is used to construct the sensor because the more area of the sensor mean more its sensitivity or less time taken for output to change when input changes. Since the sensor tracks the solar light source's orientation, selecting the right tracking sensor is very important. Cadmium sulfide (CdS) sensors (see Figure 2) are cheap, reliable, and photo-sensitive.

Tracking Sensor System Design

The sensor system consists of two similar LDR sensors(see figure 3), which are located at the middle to detect the light source intensity. At the LDR sensor positions, brackets isolate the light from other orientations to achieve a wide-angle search and quickly determine the sun's position [Yingzhe, et al., 2007]. To sense the position of Sun two LDR sensors are mounted on the solar panel and placed in an enclosure. The east and west LDR sensors compare the intensity of received light in the east and west. When sun's position shifts, the light source intensity received by the sensors are different, the system obtains signals from the sensors' output voltage in the two orientations.

The system then determines which sensor received more intensive light based on the sensor output voltage interpreted by voltage type A/D converter (ADC) and ADC0804 device [http://www.ti.com/lit/ds/symlink/adc0804-n.pdf]. The system drives the servo motor towards the orientation of this sensor. If the output values of the two sensors are equal, the output difference is zero and the motor's drive voltage is zero, which means the system has tracked the current position of the sun.

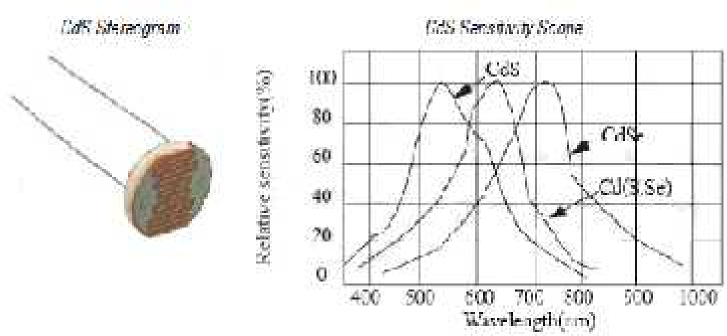

Fig. 2: CdS Stereogram and Sensitivity Scope [Mims, 2004]

Fig. 3: Solar tracking sensor system

Analog to Digital Converter

The output of the tracking sensor system is analog in nature which is required to convert into digital signal to be used in the subsequent sections. IC- ADC0804 is used to convert analog voltage into digital in this work. Figure-4 shows the ADC0804 pin diagram having 20-pins and requiring a 5-V single power supply [Intersil Americas Inc. 2002]. Its analog input voltage scope is 0V to 5V with 8-bit resolution. The power consumption is 15 mW and the conversion time is 100 µs. When both CS and RD are low, digital data is sent to the output port DB0 - DB7. When CS or RD is high, outputs DB0 - DB7 float. When CS and WR are low, the ADC0804 device performs deletion; when WR goes high, the device performs conversion. Pin 4 (CLK IN) is the time sequence input with a frequency scope of 100 to 800 KHz. Pin 5 (INTR) is high during conversion and changes to low when conversion ends. V_{IN} (+) and V_{IN} (-) are differential analog signal inputs, usually single-ended inputs, and V_{IN} (-) is grounded. The ADC0804 device has two ground ends, A GND and D GND respectively. Pin 9 ($V_{REF}/2$) is half of the reference voltage input value if the overhead connection, 2 V_{REF}, is equal to the power supply voltage, V_{CC}. The ADC0804 device is embedded with a Schmitt trigger as shown in Figure 5 [Yingzhe, et al., 2007]. If resistor and capacitor are added to CLK R and CLK IN, the time sequence, which is required by operating the ADC, is generated with the following frequency:

$$f_{CLK} = \frac{1}{1.1\,RC} \text{ (Hz)}$$

Here the time sequence signal is decided by R and C and the signal does not need to be added with CLK IN. The output signals of CdS sensor generated due to the solar illumination are analog in nature and applied to Pin 6 of ADC0804 to be converted into 8-bit digital signal. Figure 6 shows the complete circuit diagram. The digital outputs at DB0- DB7 are used as inputs to the FPGA board.

Servo Motor

A servomotor is a rotary actuator that allows for precise control of angular position, velocity and acceleration, it is a closed-loop servomechanism that uses position feedback to control its motion and final position. The feedback system or error-correction signals help to control mechanical position, speed or other parameters. Servomotor is a specific type of motor and rotary encoder combination that provides position and speed feedback control. The measured position of the output is compared to the command position. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops.

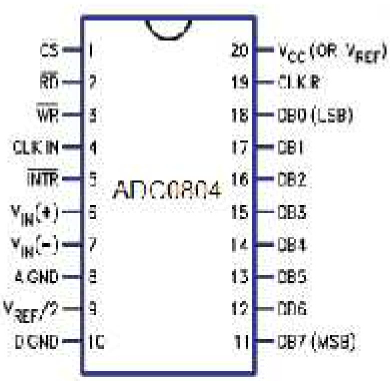

Fig. 4: ADC0804 pin Function Diagram [Kaplan and White, 2003]

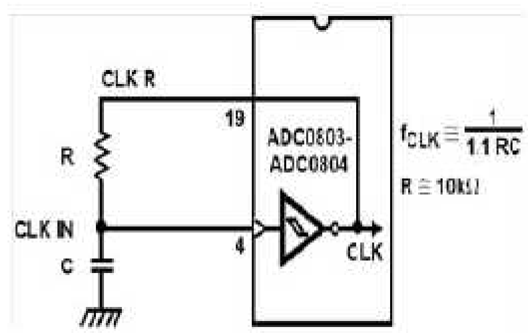

Fig. 5: Time sequence generation circuit [Yingzhe, et al., 2007]

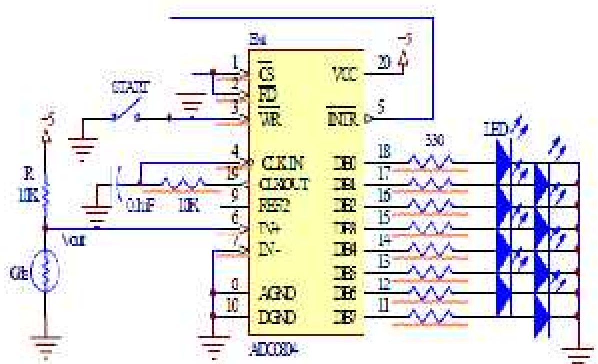

Fig. 6: ADC circuit diagram [Yingzhe, et al., 2007]

Since the sun light illuminates on a CdS light sensitive resistor of the solar tracking device a feedback analog signal will be produced and transformed into a digital signal through analog/digital converter (ADC0804). When the voltage on the eastward-westward direction is different, the differences will be delivered into the FPGA board. As the servomotor has a closed loop servomechanism, it uses the difference signal to control its motion and brings the output shaft to appropriate position.

3. FPGA Program Design

For implementing the hardware control circuit, a hardware description language such as VHDL and Verilog HDL[Brown, 2007] is used to load the control program. During hardware design, we used the Quartus-II [Software Manuals, Altera Inc., 2009] software to compile the logic circuit of the HDL programs. During software design, we used the EDA software development tool and software resources such as header files, library, monitors, and peripheral drivers to generate and edit application code. Using Quartus-II software simulation, compilation and analyze, the whole system is tested carefully in every step while designing the system. The entire steps required for the design of a solar tracker are discussed in following sections.

4. Implementation and Testing

In the work, a single axis solar tracking system has been designed and implemented. The control logic of solar tracking system comprises of the counter module, the comparator module and a pulse generator module. All the modules are designed, verified, synthesized and implemented on FPGA. The design of the solar tracking system combines the FPGA solar tracking system with two ADC and a servo motor. The whole control system can be seen from the “Netlist viewer>>RTL viewer” of the Quartus-II as shown in Figure 7. Figure 8 shows the initial stage interfacing of two LDR sensors and servo motor with Altera DE1 FPGA board. A prototype of the solar tracker has been made for checking the practicability of the design methodology. Figures 9 shows the initial stage and the actual prototype implemented.

5. Conclusion

An FPGA based solar tracking control system has been developed and tested in the indoor environment. The electronic circuit is designed to sense the sun light and to control servo motor for the panel movement. The control algorithm is programmed and loaded into Altera DE1 FPGA board and tested successfully in the laboratory. The designed system can hold the solar panel and allows the panel to move the panel from 180^0 East to West.

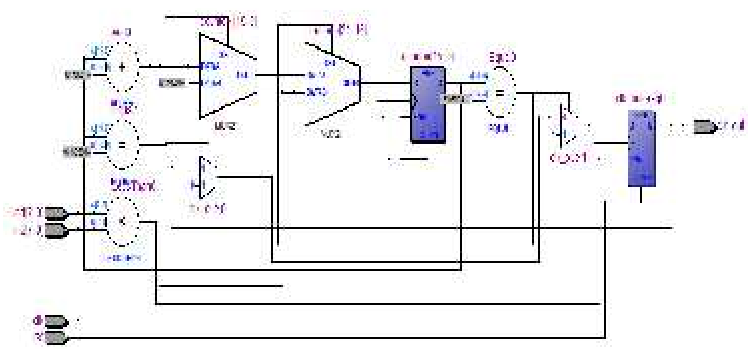

Fig. 7: Overall verilog code generated structure of the project

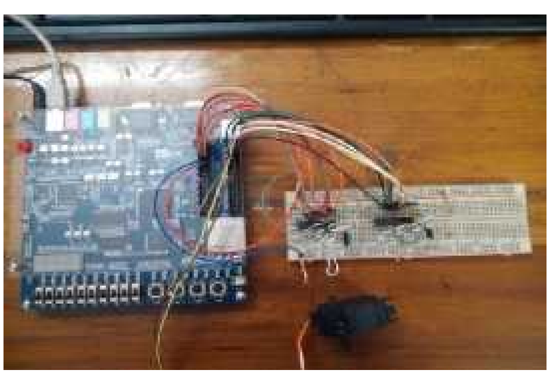

Fig. 8: Working circuit

Fig. 9: Solar tracking system prototype

The main aim behind this project is to improve the efficiency of solar panel. FPGA based sun tracking system tracks the sun all day and rotates the motor to the sun orientation hence acquires maximum sun radiation throughout the day. Hence the designed system can achieve more illumination and energy concentration than conventional fixed solar panel and can improve overall efficiency. The major difference between our design and traditional, single-chip designs (such as the 8051 or PIC device) is that traditional chips cannot write Verilog HDL. If traditional devices and discrete components were chosen for the task, external logic circuits were required to implement the controller which would increase complexity in overall implementation. Moreover, in such case, the control system lacks flexibility, difficult to debug or troubleshoot, in cases of error and may be unreliable due to tolerances of components, environmental and aging effects.

Alternatively, if an FPGA is used, the control system becomes flexible, programmable and more reliable. The FPGA can be programmed to meet design objectives as demanded by desired application. Moreover, additional functionality and user interface controls can be created into the FPGA minimizing the requirement for additional peripheral components due to its flexibility. The control system has been checked with a prototype solar panel and satisfactory results have been obtained as per as tracking is concerned.

The light sensors based tracking systems may lead to error in cloudy or partially cloudy weather, since there will be less or no striking of light on light sensors. In such cases, light sensors may not be able to generate required voltage to run the subsequent stages of the tracking system. This can be handled by time based controlling. However, this research helps the solar power generating equipment to get the maximum sunlight automatically thereby increasing the efficiency of the system. Moreover, this system can achieve more illumination and energy concentration than stationary solar panel and cut the cost of electricity by requiring fewer solar panels, therefore, it has great significance for research and development.

Acknowledgement

The authors would like to acknowledge University Grants Commission (UGC) for financial grant for a project, titled, "An FPGA based smart solar tracking control system" in 2012-2013. The authors would also like to thank IICT, BUET for facilitating a workshop on Embedded System Design & Development under CP:083, HEQEP in 2013.

References

1. Al-Naima, F. M., & Al-Taee, B. R. (2010). An FPGA based stand-alone solar tracking system. In *Energy Conference and Exhibition (EnergyCon), 2010 IEEE International* (pp. 513-518). IEEE.
2. Altera Quartus, I. I. (2009). 9.0 Software Manuals. *Altera Inc., San Jose, CA (www. altera. com)*.
3. Bakos, G. C. (2006). Design and construction of a two-axis Sun tracking system for parabolic trough collector (PTC) efficiency improvement. *Renewable energy*, *31*(15), 2411-2421.
4. Brown, S. D. (2007). *Fundamentals of digital logic with Verilog design*. Tata McGraw-Hill Education.
5. Clifford, M. J., & Eastwood, D. (2004). Design of a novel passive solar tracker. *Solar Energy*, *77*(3), 269-280.
6. DE1 Development and Education Board, User Manual, version 1.1, Copyright © 2006 Altera Corporation, USA.
7. Gevorkian, P. (2008). *Solar power in building design: the engineer's complete design resource*. McGraw-Hill.
8. Hamed, B. M., & El-Moghany, M. S. (2012). Fuzzy controller design using FPGA for sun tracking in solar array system. *International Journal of Intelligent Systems and Applications (IJISA)*, *4*(1), 46.
9. Huang Yingzhe, Yuan Ze, Zhang Xinhong, Wu Zongxian, Yu Zhengda," Intelligent Solar Tracking Control System Implemented on an FPGA", Nios II Embedded Processor Design Contest-Outstanding Designs, Third Prize, pp.217-246, 2007.
10. Intersil Americas Inc. 2002, http://www.intersil.com/content/dam/Intersil/documents/adc0/adc0803-04.pdf
11. Kaplan, D. M., & White, C. G. (2003). *Hands-On Electronics: A practical introduction to analog and digital circuits*. Cambridge University Press.
12. Kalogirou, S. A. (1996). Design and construction of a one-axis sun-tracking system. *Solar Energy*, *57*(6), 465-469.
13. Lee, C. Y., Chou, P. C., Chiang, C. M., & Lin, C. F. (2009). Sun tracking systems: a review. *Sensors*, *9*(5), 3875-3890.
14. Luque, A., & Hegedus, S. (Eds.). (2011). *Handbook of photovoltaic science and engineering*. John Wiley & Sons.
15. McFee, R. H. (1975). Power collection reduction by mirror surface nonflatness and tracking error for a central receiver solar power system. *Applied optics*, *14*(7), 1493-1502.
16. Mims, F. M. (2004). *Electronic Sensor Circuits & Projects*. Master Publishing Inc. USA.
17. Mousazadeh, H., Keyhani, A., Javadi, A., Mobli, H., Abrinia, K., & Sharifi, A. (2009). A review of principle and sun-tracking methods for maximizing solar systems output. *Renewable and Sustainable Energy Reviews*, *13*(8), 1800-1818.
18. Parida, B., Iniyan, S., & Goic, R. (2011). A review of solar photovoltaic technologies. *Renewable and sustainable energy reviews*, *15*(3), 1625-1636.
19. Quartus II Handbook Volume 1: Design and Synthesis Manual, Copyright © 2015 Altera Corporation, USA.
20. Roth, P., Georgiev, A., & Boudinov, H. (2004). Design and construction of a system for sun-tracking. *Renewable energy*, *29*(3), 393-402.
21. Rubio, F. R., Ortega, M. G., Gordillo, F., & Lopez-Martinez, M. (2007). Application of new control strategy for sun tracking. *Energy Conversion and Management*, *48*(7), 2174-2184.
22. http://www.ti.com/lit/ds/symlink/adc0804-n.pdf