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A PV SOLAR TRACKING SYSTEM CONTROLLED BY ARDUINO/MATLAB/SIMULINK

O.C. Ozerdem   A. Shahin

Electrical and Electronic Engineering Department, Near East University, Lefkosa, Northern Cyprus
ozgur.ozerdem@neu.edu.tr, eng.manage.adnan@gmail.com

Abstract- The use of clean energy (solar, wind etc.) in other words renewable energy is becoming more important for lowering the global warming as the world becomes hotter every day as a result of global warming. Use of solar energy either PV panels or concentrated solar power (CSP) to generate electrical energy is becoming more popular. Most of the solar panels that had been used has a static direction. This paper is about a study that developed a "Solar Tracking System" using various methods such as Traditional, PID controller and Solar Orientation based on Location and Time.

Keywords: Renewable Energy, Solar Energy, Simulink, PID, Arduino, LDR.

I. INTRODUCTION

Energy is an essential element in human life. A secure, sufficient and accessible supply of energy is very crucial for the sustainability of modern societies. Most predictions provide for the energy consumption growth of developed nations compounding at around 1% a year; however, for developing nations, consumption is growing by over 5% a year [1].

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sun's energy directly into electricity. Due to the growing demand for clean sources of energy, the manufacture of solar cells and photovoltaic arrays has expanded dramatically in recent years. Solar radiation as intercepted at the earth's surface may be reasonably high in many regions but the market potential for its capture is low due to relatively high cost of solar panels currently [2]. The cost of the PV panels are falling and becoming more reasonable and feasible in recent years.

As seen in Figure 1 in order to get the maximum efficiency from the solar panel, the control system should be able to rotate the solar panel to be in 90 degree with the sun light. Solar tracking is necessary to be able to satisfy this condition. To achieve this purpose various methods can be used [3].

Angle of optimal tilt = 90° - Angle of Sun

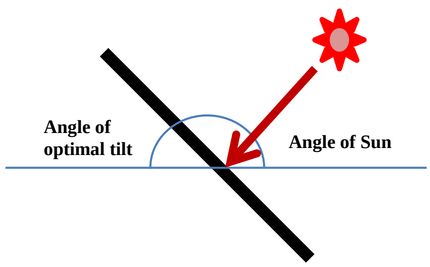

Figure 1. Sun light in 90 degree with solar panel

In this research, the project applied using different control methods to determine the best control method depending on the results.

II. SOLAR TRACKING SYSTEM

For designing the control system, Arduino micro-controller with MATLAB programming / Simulink environments were used. Figure 2 shows the MATLAB graphical user interface designed for the study.

Three control methods are used which are:

- Traditional control method: based on developing a simple MATLAB code / Simulink model to control the system depending on sun angle with the solar cell.
- PID control method.
- Solar Orientation based on Location and Time.

Figure 2. MATLAB application - Graphical user interface

The equipment used for the practical circuit are:
- Servo motor: high torque and easy to control,
- Solar cell,
- Light density resistor (LDR),
- Arduino micro-controller.

Figure 3 shows the bild PV panel circuit.

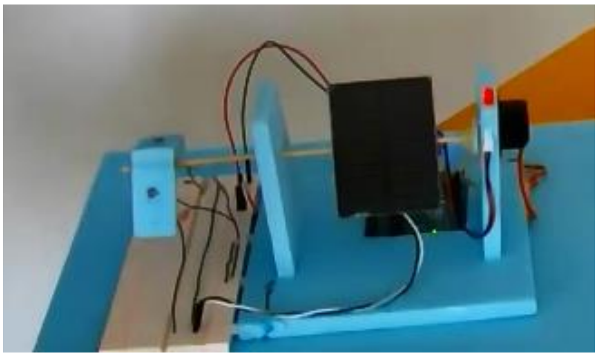

Figure 3. Components of the practical study

III. CONTROL METHODS

As mentioned in introduction, the project was implemented with different control methods, now the methods will be represented to see the performance of the system with each case.

A. Traditional control method.

B. Programming environment: using this method to do the project, we have to build two LDRs (one to east direction and the second one is the west direction) with 90 degree between them. Figure 4 shows the build practical LDR system [4].

One axis sun tracking system use only two sensors, whereas two axis sun tracking system use four sensors. For this purpose the system seen in Figure 5 is build [4].

The main idea is to read the value from LDR1 and compare it with the value of light density from LDR2, then depending on the difference between the two values, the system will decide and send commands to the motor and change its angle in order to make the difference equal zero ($LDR_1 - LDR_2 = 0$) then the angle between sun light and solar panel will be 90 degree. Simulink environment with embedded code: in this system the simulation block given in Figure 6 will be used.

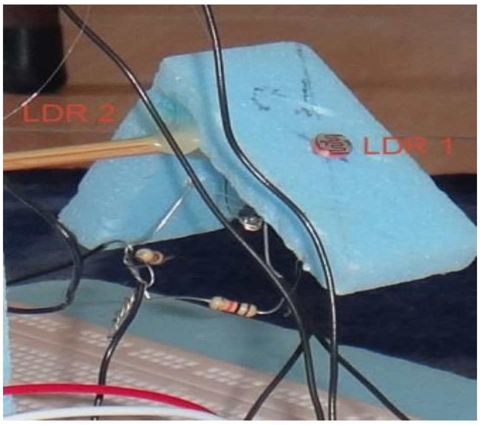

Figure 4. Two LDR (east and west) to test the angle of the solar panel with the sun light

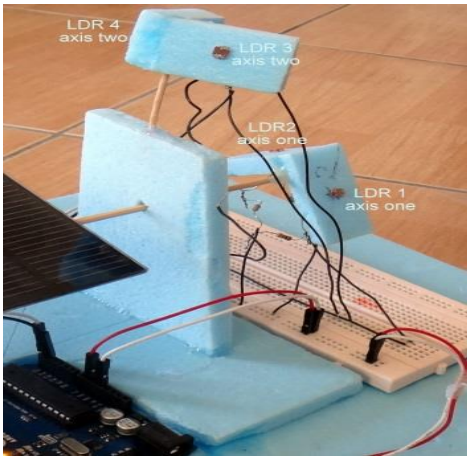

Figure 5. Two LDR (east and west) to test the angle of the solar panel with the sun light

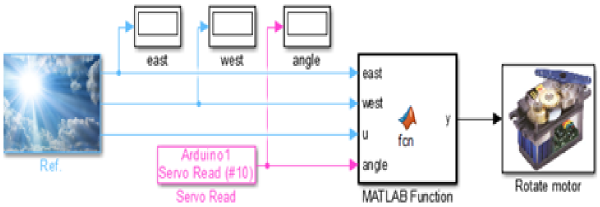

Figure 6. Simulation environment with FCN block

In addition to the above system two more control methods has been applied.

A. PID Control

PID controller consists of three parts use the algorithm given in Figure 7 and the system is composed of:
- P: proportional controller
- I: Integral controller
- D: derivatives controller

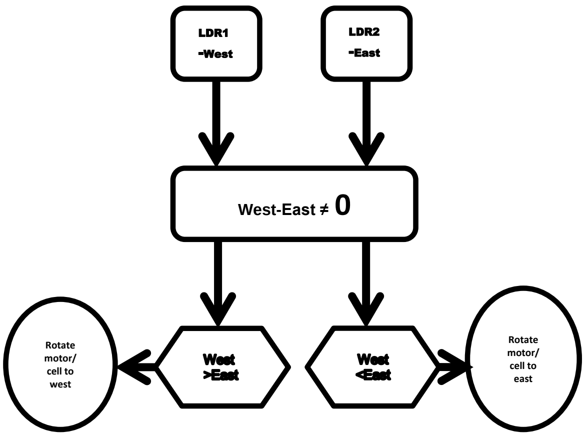

Figure 7. Control algorithm

PID are commonly used to regulate the time-domain behavior of many different types of dynamic plants [4]. Systems requirements determine the controller that must be used. The PID structure is given in Figure 8.

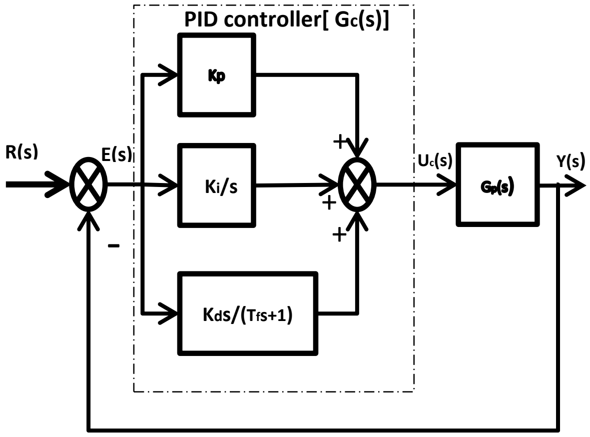

Figure 8. PID structure

The formula of the PID is described by [3]:

$$P+I\frac{1}{s}+D\frac{N}{1+N\frac{1}{s}} \quad (1)$$

where:
P: Proportional
I: Integral
D: Derivative
N: Filter coefficient

The challenge with PID controller is to determine the values of the three PID parameters, because of our project is practical so the determining of the parameters values will be easier, in this research the parameters of PID determined practically using the real values with PID tuning tool in MATLAB [5].

The transfer function of PID control is given by (2):

$$G_{PID}(s)=K_p+\frac{K_I}{s}+K_D s=\frac{K_D s^2+K_p s+K_I}{s} \quad (2)$$

Also with PID, we need LDRs in the design of the system to determine the position of the sun, in this system the difference is the motor drive task is managed by the controller and rotate the solar panel depending on the position of the sun. The PID input is the error signal; it is the difference between the sun angle and solar panel angle.

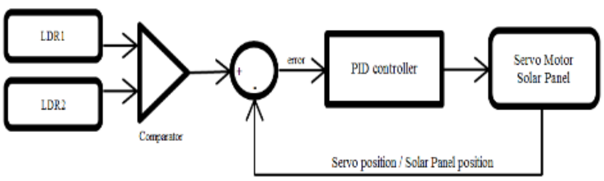

Figure 9. System design

Let us discuss each part of the PID controller, Proportional controller (P) is simple and has fast response time but it cannot correct the error signal, Integral controller (I) is good for slow changing system and can correct the error signal but it is not suitable for fast changing systems, Derivative controller (D) cannot correct the error signal and it increases the noise but it is suitable for fast changing systems that need fast response.

The movement of the sun during the day is slow so we do not need neither derivative controller nor proportional controller, the system just need integral controller to correct the error signal and manage the system to give the best performance as Table 1.

Table 1. The importance of each part of PID controller

	Correct error	Suitable for
Proportional controller (P)	Decrease error	fast changing systems
Integral controller (I)	Remove error	slow changing system
Derivative controller (D)	Not correct error	fast changing systems

The best result for this system is obtained when it is working in continuous-time domain with parameters: *P*=0, *I*=6.3, *D*=0, *N*=100 in parallel form for PID. Figure 10 shows the response curve for the system. Figure 11 shows the MATLAB/Simulink model for the system with PID controller.

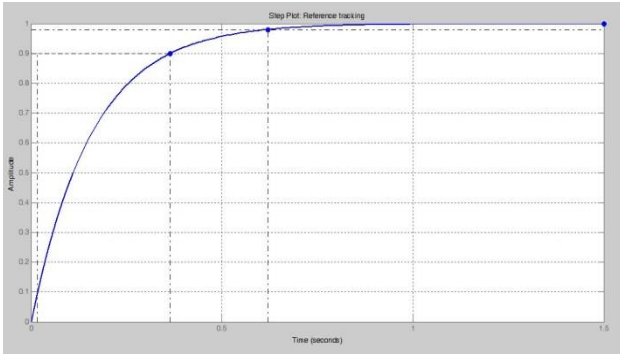

Figure 10. Response curve of the system with PID controller

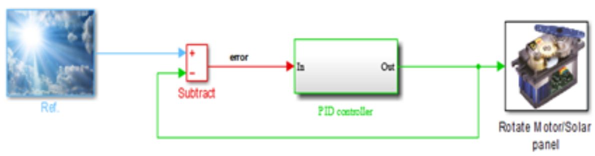

Figure 11. System design with PID

B. Solar Orientation Based on Location and Time

The zenith [6]: is an imaginary point directly "above" a particular location, on the imaginary celestial sphere. "Above" means in the vertical direction opposite to the apparent gravitational force at that location. The opposite direction as shown in the Figure 12.

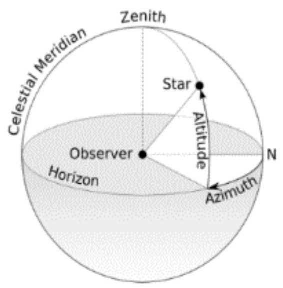

Figure 12. Zenith and Azimuth angles

The Azimuth [6] is an angular measurement in spherical coordinate system. The vector from an observer (origin) to a point of interest is projected perpendicularly onto a reference plane; the angle between the projected vector and a reference vector on the reference plane is called the azimuth which is shown in Figure 12.

Developments in renewable energy have attracted the interest of engineers like the solar energy. In essence, this is a building oriented and designed with solar cells on the roof to absorb a maximum amount of direct sun rays in summer as in Figure 14 and a minimum amount of solar heat during the winters is shown in Figure 13.

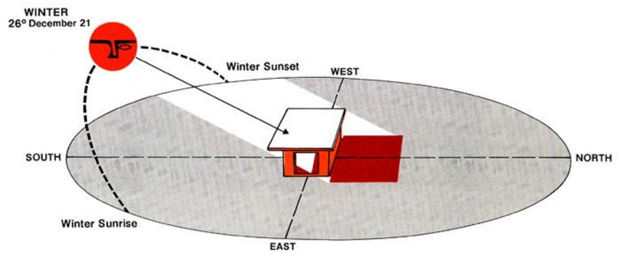

Figure 13. Sun path in Winter

Although successful solar energy can be built with the solar orientation slightly east or west (daily sun path) and south or north (annual sun path with seasons). Solar energy gain will be greater in the morning if the solar panel faces east of South; and, obviously, if the solar panel is oriented west of South, more gain will occur in the afternoon.

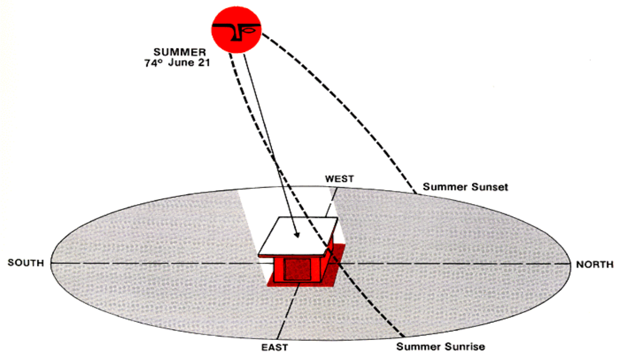

Figure 14. Sun path in Summer

So, in order to control the solar cell to track the sun during the year, we have to take in consideration the value of Zenith and Azimuth angle. For that we need to use two motors, one for east/west movement and the second one for south/north movement with the four seasons.

The relation between solar and standard time [6]: Standard Time is the conventional time for the zone containing the geographical location under consideration. It is measured in hours, minutes and seconds. The intervals are the same throughout the day and the year.

Sun Time is measured by the varying Positions of the Sun above the earth. It is also expressed in hours, minutes and seconds but the length of the Solar Day will vary by seconds. The accumulative effect of these seconds causes the hours of the Solar Day to shift periodically over a range of 30 minutes. Thus Standard Noon can occur 15 minutes earlier or later during the year than Sun Noon. Also Sun Time varies with the longitude within the time zone while Standard Time is uniform throughout [6].

Figure 15. Program interface

The following equation converts Standard Time to Sun Time or vice versa [6]:

$$SuT = StT + ET + 4(SM - L) \quad (3)$$

where:

SuT - Sun Time (hours and minutes)

StT - Standard Time (hours and minutes)

ET - Equation of Time, the factor for the non-uniformity of Sun Time (minutes)

4 - Number of minutes required for the sun to pass over one degree of longitude

SM - Standard Meridian (longitude) for the local time zone

L - Longitude of location

This method is applied in MATLAB depending on the Time/Location of Cyprus.

Figure 16. Cyprus Island

Location of Cyprus parameter [7]:

Longitude = 33.36667

Latitude = 35.16667

Altitude = 128

The function computes the sun position (zenith and azimuth angle at the observer location) as a function of the observer local time and position. This algorithm is based on numerical approximation of the exact equations [6].

IV. RESULTS AND COMPARISONS

Using traditional control method, the performance of the system is not good enough to let the system apply with this control method in real life projects, where the response time is good but the stability and performance are not good, and the error probability is high.

On the other hand, the response time for the system using PID control method is perfect and noticeably better than the response time with previous method, the stability and performance of the system are high and the error probability is low, so clearly using PID control method is better than the traditional.

With the traditional method, the system does not have any controller, it just compare the values and manage the system to make the sun in 90 degree with the solar panel so the probability of error in this case is high because there is no controller to correct the error, and as a result the system will not be stable and any noise signal may cause the system to be unstable, but that is not possible with PID method, because using of integral controller (I) is a guarantee to keep the system stable, integral controller will correct the error and make it as small as possible and as a result the system will be stable and the performance will be high as can be seen in Table 2.

Solar orientations based on Location and Time method gives high precision results and allow to the system to perform with high efficiency because the stability of the system will be high and the error probability low so clearly this method is the best to be used in the field of solar tracking system in renewable energy's power plants, but the cost maybe more than the previous methods because in this case we have to add storage devices to the system to store the database for the sun position changing during ten years at least, but here the use of LDRs, any sensors or feedback system design is not required.

Table 2. Results and comparisons

	Traditional method *	Simulink/PID Table 3	Geographical coordinate Table 4
Response time	Good	Perfect	~
Stability	Bad	High	Very High
Performance	Bad	High	Very High
Costs	~	~	More expensive Need database storage device
Error probability	High	Low	Low

* In the traditional method, the micro-controller will get the values of the light density from east and west direction, the system will compare the values and depend on them the micro-controller will decide to change the angle of the panel, so in the case of the sun at the center of the sky the difference of the sensors reading will be small and that will make the system unstable because the algorithm will face difficulties to determine the real position of the then performance will be bad and the error will increase (because there is no error correction controller).

Table 3. PID controller parameters

Controller Parameters	
P	0
I	6.3096
D	0
Performance and Robustness	
Rise time	0.348 seconds
Settling time	0.62 seconds
Overshoot	0%
Peak	1
Closed loop stability	Stable

Table 4. Geographical coordinate

Performance of the System	
Response time	not exist in this method
Stability and performance	The stability and performance is high as they depend on an existed database value
Error	Less than 1 degree for the panel angle

V. CONCLUSIONS

Solar energy is used in a wide range of modern power plant because they provide huge amounts of clean energy. The maximum efficiency can be obtained by control the angle of the solar panel to be in 90 degree with the sun light, many methods applied in this research for that, and we got different results for each method. Then the result discussed with consideration for the stability, response time, performance, costs and error probability. It can be concluded that Geographical coordinate system is the best system from the technical approach.

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BIOGRAPHIES

Ozgur Cemal Ozerdem was born in Ankara, Turkey in November 1967. He received his B.Sc. degree in Electrical and Electronic Engineering from Eastern Mediterranean University in 1992 and M.Sc. degree from same university in 1994. He worked as Research and Teaching Assistant during 1992-1994. He joined the Near East University, Lefkosa, Northern Cyprus at 1996 and worked as a Lecturer in the Department of Electrical and Electronic Engineering. He received the Ph.D. degree from Department of Electrical and Electronic Engineering, Near East University. He was assigned Assoc. Prof. in 2011. He served as Vice Chairman during 2003-2009, and as Deputy Chairman for 2009-2011 and he has been the

Chairman between April 2011 till October 2013 at Department of Electrical and Electronic Engineering, Near East University. He also act as the Vice Dean of the Faculty of Engineering between 2009-2012. He has been assigned to the TRNC Electricity Authority as a member of Board of Directors in 2009. He has been a member of IEEE since 1996. His research interests are Power systems, HVDC, Power Quality.

Adnan Shahin was born in Kuwait, in May 1989. He studied at the Department of Electrical Engineering in Damascus University, Syria, and then he transferred to get his Diploma degree in Electrical and Electronic Engineering from University of Near East, Lefkosa, North Cyprus. From 2012 to 2013 he worked in Electrical Engineering field at construction sites in Saudi Arabia. Since 2012, he has been trainer of students through distance learning technology. And now he is the supervisor of a network for distance learning to support engineers around the world to improve their skills. In June 2014, he got his bachelor degree and he is planning to start his master degree. His research interests are power electronics, control systems and electrical drive.