Design and implementation of a sensorless dual axis solar tracking system based on solar sun chart algorithm using arduino

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***Abstract*— Due to unlimited existence and environmental friendly nature, solar energy has drawn interest as one of the major sustainable energy resources. The challenge of reducing the cost of converting sunlight to electricity through photovoltaic cell lies in improving the efficiency of conversion. In this context, the solar tracking system plays a significant role for efficiency improvement. This work aims at design and implementation of a sensor-less dual axis solar tracking system based on solar sun chart program using Arduino Uno to capture maximum sunlight. Solar sun chart program predicts exact position of sun in a particular time by using latitude of a particular coordinate. With the help of solar sun chart algorithm, tracking strategy will be exact irrespective of nature. It can track sun in cloudy weather accurately. Two servo motors were used to rotate the panel according to the algorithm developed based on solar map in both horizontal and vertical directions. One motor was used to change the azimuth angle and the other motor to change the altitude angle. This improved control strategy known as open-loop control will reduce the complexity, cost and components required in comparison to a sensor based closed-loop control system. Our prime concern is to ensure the proper integration of all the electronic system in the mechanical hardware model and thereby develop an improved electromechanical system for solar tracking in photovoltaic applications.**

***Keywords*— solar tracking, dual axis, arduino, altitude, azimuth**

I. INTRODUCTION

Demand of energy is increasing day by day. But, due to their limited resource & environmental unfriendliness, conventional or non-renewable energy sources such as coal, gas and oil are losing their popularity now-a-days. In the near future, the problem will be more acute.

To reduce CO2 emission in the environment, which is responsible for global warming & greenhouse effect, renewable energy sources are becoming alternatives of conventional sources. Solar energy is the most efficient and consistent of all the renewable energy sources. Solar Photovoltaic (PV) cells convert energy of sunlight into electrical energy. But overall efficiency of a solar system is not up to the mark compared to the non-renewable energy sources. Efficiency of a solar PV system can be improved either by improving the solar cell efficiency or by using tracking system to track the sun rays [1]. Maximum output from a PV system will be achieved if sunrays strike the panel perpendicularly [2].As atmospheric condition is the key factor to determine the solar radiation reaching earth's surface, it can't be controlled. But, proper utilization of solar radiation can be ensured by tracking the sunlight with the help of an efficient tracking system [9]. For this purpose, tracking system is introduced to capture sunlight in order to improve the overall efficiency. But the main challenge is to compensate between the efficiency improvement & overall increase of cost & complexity of system [3].

Basically there are two types of sun tracking system: a) single axis tracking system, which has one degree of freedom and captures only direct sunlight and tracks the daily motion of sun[2] b) Dual axis tracking system, which has two degrees of freedom and tracks the daily and seasonal motion of sun. As a result, dual axis tracker is more accurate in tracking [2] and efficiency can be improved up-to 40%.Dual axis tracking system can be classified into mainly two types, the closed-loop and the open-loop controlled tracking system. Between these two types, closed loop tracking system involves photo-sensors and feedback control techniques to track the sun precisely whereas open loop tracking system depends on mathematical equations named "solar map equations" to determine the position of sun for any location at any instant for tracking properly [9]. Solar map shows the exact apparent position of sun for certain latitude at any particular time. So, open loop tracking system is more accurate than a closed loop tracking system in all weather conditions. Besides, it is less costly than the other system as it does not require photo sensor equipments, circuit, feedback controller. In addition to that, open loop tracking system is less complicated.

In this paper, we aimed to develop a dual axis sensor-less electromechanical solar tracking system based on solar sun chart algorithm, with lower cost, less complicated mechanism and low energy consumption. After studying all the related literature, we have developed a control strategy that tracks the sun from 8 A.M to 4 P.M using solar sun chart algorithm having an interval of one hour in every rotation of tracking system.

During our research, we verified the solar map equations data with the data obtained from National Renewable Energy Laboratory (NREL) for our latitude 22.46^0 N to ensure more precision.

After verifying all the theoretical calculations, our focus was to develop a hardware model consisting of a mechanical structure, two low power consuming DC servo motors to rotate the solar module in both axis, an Arduino board to give instructions to the motors according to the developed algorithm. Real Time Clock (RTC) was used to serve time and date information to Arduino. After developing the tracking system, a comparison was made between the theoretical and practical data to uphold the accuracy of the system.

II. THEORY TO DETERMINE SUN'S POSITION

To specify sun's position, three specific co-ordinates are to be defined. If the distance from the sun to the earth is to be assumed constant, then two co-ordinates will describe the position, the solar Altitude & the Azimuth. Solar altitude, α is the angle between the horizon & the incident solar beam in a plane determined by the zenith & the sun [Figure-1]. The solar azimuth angle is the angle, measured clockwise on the horizontal plane, from the north-pointing coordinate axis to the projection of the sun's central ray [Figure-1].

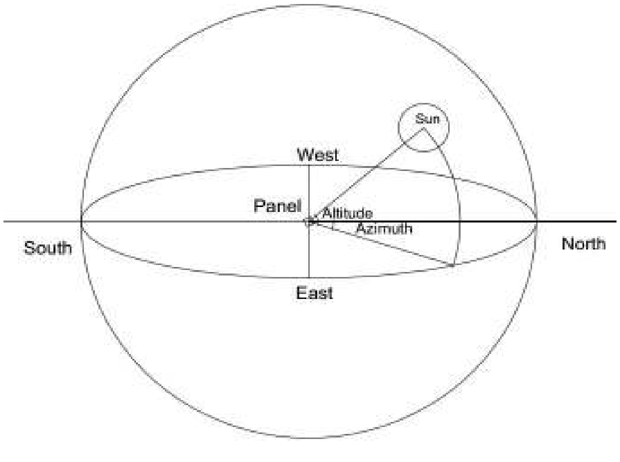

Figure-1: Sun's position indication

The angle of deviation of the sun from directly above the equator is called the declination, δ. If angles north of the equator are considered as positive and angles south of the equator are considered negative, then at any given day of the year, n, the declination can be found from

$$\delta = 23.45^\circ \sin\left[\frac{360}{365}(284+n)\right] \tag{2-1}$$

Another advantageous angle in describing the position of the sun is the angular displacement of the sun from solar noon in the plane of apparent travel of the sun. The hour angle is the difference between noon and the desired time of day in terms of a 360° rotation in 24 hours. To compute that

$$\omega = \frac{12-T}{24}\times 360^\circ = (12-T)\times 15^\circ \tag{2-2}$$

Where T is the time of that day with respect to solar midnight, on a 24-hour clock.

Note that if δ, Φ and ω are known, then the position of the sun, in terms of α and ψ at this location at this date and time, can be determined from

$$\alpha = a\sin(\sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega) \tag{2-3}$$

$$\psi = 180^\circ + a\sin\left(\frac{-\sin\omega\cos\delta}{\cos\alpha}\right) \tag{2-4}$$

where, α & ψ are in degrees [4] [5].

III. BLOCK DIAGRAM OF THE SYSTEM

Solar map equations, discussed in the previous section, are used to determine the apparent position of sun at any particular instant. Azimuth and Altitude angles, which are vertical and horizontal angles respectively, provide necessary information of sun's position. Angle values for a particular time at any given locations are calculated using the equations provided with the help of Arduino, which is considered as the heart of this research work. Real Time Clock (RTC) was used to provide time and date data to Arduino for calculation purpose. According to our instructions given, Arduino commanded the low power servo motors to rotate according to its command.

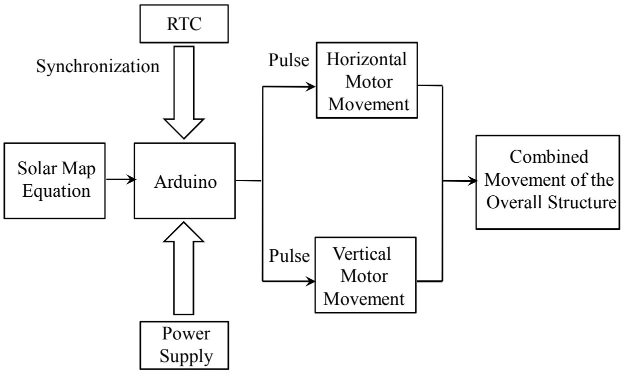

Figure-2: Block diagram of the system

Pulse generated from Arduino activates the motors to rotate the solar module according to solar sun chart algorithm. Horizontal Motor rotates the solar module to vary the altitude angle calculated from horizontal plane whereas the vertical motor to vary the azimuth angle calculated from true North. Combined movement of motors rotate the solar module along with the mechanical structure to capture maximum sunlight in every hour from 8 am to 4 pm.

IV. METHODOLOGY

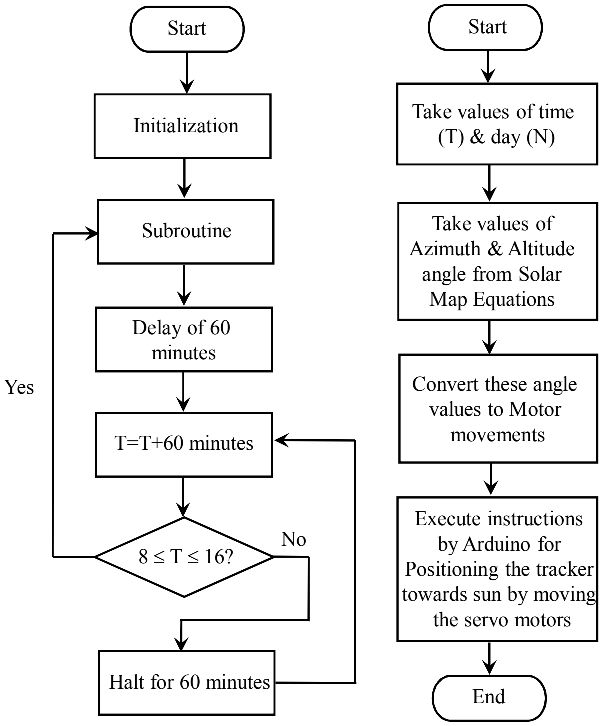

Figure-3: Flowchart of the process

Total process of sun tracking is shown step by step in flowchart (Figure-3). During start up, Arduino first initializes subroutine program where Time (*T*, hour) & Date (*N*) is read from Real Time Clock (RTC module). For this specific day, declination angle δ is calculated using equation (2-1). Since our goal is to track sun in between 8.00 am to 4.00pm, hence hour angle, ω is to be known for specific time (*e.g.* 45^0 at 9am) [using equation (2-2)] for further calculation. Now for any given latitude, ϕ altitude angle, α and azimuth angle, ψ is calculated using equation (2-3) & (2-4) respectively. This calculated angle is then converted to motor movement through arduino. Arduino program is set up to track sun after every one hour. If the time isn't between 8.00 am to 4.00 pm, arduino doesn't generate any position data and motors hold their present position.

V. SYSTEM DESIGN

A. *Mechanical design*

The structure was designed with provision of two degrees of freedom in order to rotate in both axes to change the values of altitude angle and azimuth angle. The solar panel was mounted on the fixed base. Provision of adding two motors was provided on the structure. The structure was made of stainless steel, so it was stable. Bearings were added for proper rotation in vertical axis to resist the vibration created from the weight of solar module. The design was done considering both vibrational and resonance factors.

Figure-4: Solid works model & Practical model showing horizontal & vertical motor

B. *Electronic design*

Arduino is a single-board microcontroller, intended to make the application of interactive objects or environments more accessible. Arduino is chosen in this project over conventional microcontroller system. Programs are written in arduino board using C language which makes it easy to use for general purpose. In our developed program, data is being calculated from given equations which are easy to write using C language. Arduino has a large storage capacity while compared to microcontroller. Another advantage of arduino is that its interfacing with USB is quite simple. Moreover Arduino has a dedicated library to control servo motor, which makes this program simpler. Arduino Uno is the heart of our developed model, which generates pulses according to angles obtained from equations for both motors to rotate the panel toward sun.

C. *Electrical design*

Total electrical system consists of one 6.24V dc battery, two servo motors & one bread board. Servo motors are used to rotate the panel in both axes. One motor rotates according to the azimuth angle movement and the other does the same task to set altitude angle. Other necessary Instructions of proper controlling is provided to Arduino through program. Basically, dc servo motors and stepper motors are used in solar tracking systems. We have chosen dc servo motor over stepper motor for better accuracy (Feedback system assures proper angular movement). In addition to that, servo motor has advantage of higher holding torque and does not create resonance and vibration. So stability of this electromechanical system is confirmed.

VI. ERROR ANGLE ANALYSIS

After implementation of our project, we have plotted both theoretical & practical values of angles in the same curve from which it can be seen that the value of error angle is low. To ensure more precision we have also compared the azimuth and altitude angle values found from solar map equation (theoretical) with data which were obtained from National Renewable Energy Laboratory (NREL) website[8] for a particular date(25th September,2014). Accuracy of our designed model is reflected in Table-1 & Table-2 in which we demonstrated our calculated angle values. Azimuth angle & Altitude angle were measured practically using two windows phone applications named "Level" & "Quick Angle"[7].

Table-1

Time	Altitude Angle			Azimuth Angle		
	Angle in degree (From solar map equation)	Angle in degree (From NREL)	Error (%)	Angle in degree (From solar map equation)	Angle in degree (From NREL)	Error (%)
8 am	28.72	30.80	6.75	103.13	105.26	2.02
9 am	44.10	43.83	0.62	115.42	114.66	0.66
10 am	53.75	55.63	3.73	126.39	129.14	2.13
11 am	62.68	64.38	2.64	152.32	153.88	1.01
12 pm	66.00	66.38	0.57	187.47	190.09	1.40
1 pm	61.11	60.21	1.5	219.37	221.01	0.74
2 pm	50.98	49.48	3.0	237.72	239.43	0.72
3 pm	38.27	36.87	3.8	248.87	250.68	0.72
4 pm	25.67	24.51	4.73	256.92	258.57	0.64

To analyse the error, graphs are plotted using data from Table-1 and Table-2 which are shown in Figure-5 and Figure-6 respectively. In Figure-5, calculated values of azimuth and altitude angle from solar map equation are compared to the values found from National Renewable Energy Laboratory (NREL). The graph demonstrates that the two values are really close having negligible error angles of maximum 2-3 degrees.

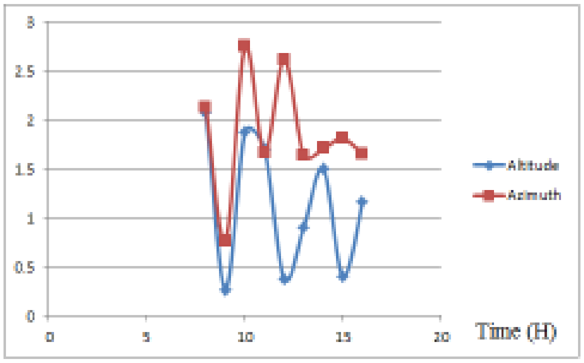

Figure-5: Error angle plot (between NREL data and calculated values from Solar Map Equation)

In Figure-6, experimental data obtained from hardware model using the Windows phone applications are compared with data found from National Renewable Energy Laboratory (NREL). This graph also shows that error is negligible. Thus, both the error graphs ensure the accuracy of the developed solar tracking system.

Table-2

Time	Altitude Angle			Azimuth Angle		
	Angle in degree (Experimental)	Angle in degree (From NREL)	Error (%)	Angle in degree (Experimental)	Angle in degree (From NREL)	Error (%)
8 am	31.5	30.80	2.27	103.1	105.26	2.05
9 am	42.4	43.53	2.59	115.4	114.66	0.65
10 am	53.0	55.63	4.73	126.4	129.14	2.12
11 am	62.5	64.38	2.92	152.3	153.88	1.03
12 pm	66.9	66.48	0.63	187.5	190.09	1.36
1 pm	60.1	60.21	0.18	219.4	221.01	0.73
2 pm	51.3	49.47	3.69	237.7	239.43	0.72
3 pm	37.7	36.87	2.25	248.9	250.68	0.71
4 pm	24.9	23.51	5.91	256.9	258.57	0.65

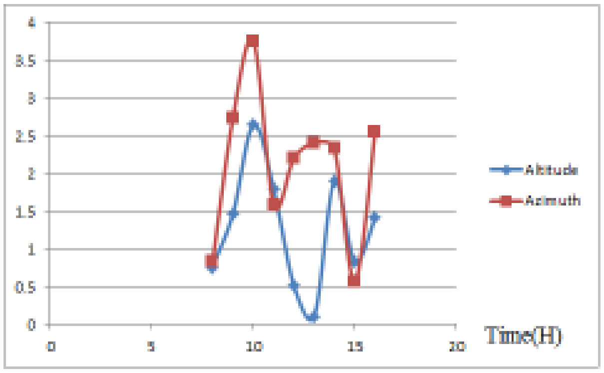

Figure-6: Error angle plot (between NREL data and experimental values)

VII. CONCLUSION

This paper has demonstrated a unique control strategy for tracking the sun precisely in both axes. There are several advantages. First of all, our model is completely independent of the weather conditions as it tracks the sun in a fixed path enlightened by solar sun chart algorithm. As it does not require involvement of photo-sensors to track, the overall cost is reduced. This research work uses Arduino, which is a low powered electronic device to interface between the algorithm and servo motors. After synchronizing properly with RTC to obtain hour and date information, Arduino calculates the position of sun using solar map equations and generates pulse to drive the motors.

The map we used for tracking purpose was referred to the latitude of 22.46^{0}N. For other latitude locations, this tracking strategy can be also be applicable by making a small change in the program. So, the designed system is less complicated.

From the error angle analysis, it is observed that the difference between practical values and theoretical values is quite negligible thus ensuring accuracy of the proposed model.

This low powered system can be applicable to medium sized solar arrays. To ensure tracking accuracy, system should be calibrated properly before positioning to the initial value, as it does not have feedback controller. Efficiency will be substantially increased with proper utilization of the proposed control strategy.

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