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Design and Implementation of Solar Tracking System

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***Abstract*— The dual threats of fossil and oil resources limitation and global worming place the renewable energy resources to become the center of public interest. Solar energy is one of the most energy resource used wide spread, to make solar energy more viable, the efficiency of solar array systems must be maximized. A feasible approach to maximizing the efficiency of solar array systems is sun tracking. In this work an effort has been made to develop an electromechanical system programmed using C++ programming language that controls the movement of a solar array so that it is constantly aligned towards the direction of the sun whereas the maximum energy of a solar panel can be produced by making the sun irradiation exactly perpendicular to the solar panel. The solar tracker designed and constructed in this work offers a reliable and affordable method of aligning a solar panel with the sun in order to maximize its energy output and its efficiency by 31% comparing to the fixed solar panel.**

***Index Terms*— Solar tracking, Sensors, Arduino Microcontroller, Electrical Design, Mechanical Design**

I. INTRODUCTION

With the rapid increase in population and economic development, the problems of the energy crisis and global warming effects are today a cause for increasing concern. Moreover, a large amount of energy is available within the core of sun. The energy that is received from sun in an hour is more than that is consumed by us in a year. If human is able to capture even 1% of the total energy which sun delivers then one can cater the need of our race for decades [1]. Thus, the utilization of solar energy resource is the key solution to these problems. As it is considered one of the primary sources of clean, abundant and inexhaustible energy that not only provides alternative energy resources, but also improves environmental pollution.

Solar (photovoltaic) energy solutions are becoming increasingly popular and their implementation is more wide spread. They can be found in different form of solar energy extraction devices such as solar panels, solar water heaters, solar cookers etc... Most of these devices consist of a solar receptor that is kept facing the sun during the day with the help of a sun tracking mechanism operated by an electrically driven unit consisting of a sensor, an actuator and a controller. The physics of the photovoltaic (PV) cell (also called solar cell) is very similar to the classical pn junction diode. The PV cell converts the sunlight directly into direct current (DC) electricity by the photovoltaic effect [2]. Main factors that affect the efficiency of the collection process are solar cell efficiency, intensity of source radiation and storage techniques [3]. The efficiency of a solar cell is limited by materials used in solar cell manufacturing. It is particularly difficult to make considerable improvements in the performance of the cell, and hence restricts the efficiency of the overall collection process. Therefore, the increase of the intensity of radiation received from the sun is the most attainable method of improving the performance of solar power.

As mentioned by Lakeou et. al. [4], and it is known, the position of the sun with respect to that of the earth changes in a cyclic manner during the course of a calendar year. Tracking the position of the sun in order to expose a solar panel to maximum radiation at any given time is the main purpose of a solar tracking PV system, and this allows the increase of energy production. Many research studies can be found that consider design and optimal operation of solar trackers and correspondingly electricity generation. Solar tracking systems are designed to track the position of the sun and rotate the PV panel according to sun position so that PV panel become parallel to sun and sun radiation makes 90º angles with PV panel, this help making the illumination very strong, to achieve this, an ideal tracker would compensate for changes in both sun's altitude and latitudinal angles through both day and seasonal changes and changes in azimuth angle. Some of the research studies focused on developing, and analyzing models of solar trackers systems using software packages such as Simulink/Matlab and proteus in addition to fabrication of a scaled down laboratory prototype [2], [5] – [9] for simulation, experimental and research studies. On the other hand, a fabrication mechanism has been developed by others [1], [4], [10]. The important part in solar tracking problem is the control solar panel to follow the position of the sun throughout the day to harness the power, thus a lot of research is conducted on controlling the solar panel movement using PID controller [5], fuzzy logic technique [3], [6], [11], and traditional microcontrollers [12] – [14], and for more information on solar tracking systems refer to [15]. In this work, we attempt to develop an automated solar tracking system prototype, which automatically provides best alignment of solar panel with the sun to generate maximum electricity power.

II. DESIGN OF SOLAR TRACKING SYSTEM

The solar tracker system requires movement in different directions, and uses electric motors as prime mover, based on this; solar tracker system motion control is simplified to electric motor motion control.

A. Electrical components design of solar tracking system

The main components in the solar tracking system are standard photovoltaic solar panels (PV), a deep cycle rechargeable battery, microcontroller, signal conditioning

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circuits, and motor drive, these components are connected to the sensors and the solar rotation mechanism as shown in Fig. 1.

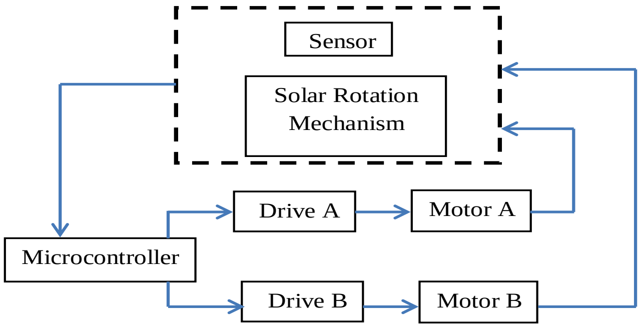

Figure 1 Solar tracking block diagram.

In solar tracking system design, any light sensitive device can be used as input sensor unit to detect and track the sun position, based on sensors readings, and generated sun tracking error, the control unit generates the voltage used to command the circuit to drive the motor, that outputs the rotational displacement of electric motor, which is the motion of solar tracking system. Thus the solar tracking system consists of mechanical part and electrical part. The electrical part components are:

1. Microcontroller (Arduino Mega 2560).

Arduino is used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical outputs. Arduino projects can be stand-alone, or they can communicate with software running on the computer (e.g. Flash, Processing, MaxMSP.) The boards can be assembled by hand or purchased preassembled; the open-source IDE can be downloaded for free. Moreover, The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 . It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. In addition, the Arduino programmer is based on the processing integrated development environment (IDE) and uses a variation of the C and C++ programming languages, and C++ was used for programming our Arudino microcontroller.

2. Actuator and drivers.

Electric motors most used for solar tracker are PMDC and stepper motors, the proper selection of motor and drive combination can save energy and improve performance. A suitable, available, easy to control and interface selection is PMDC motor. For bidirectional driving, a motor can be driven via H-bridge drive formed by two pairs of Darlington transistors, or H-Bridge in IC's, e.g. L298n , which is 16 pin chip dual H-Bridge motor driver, so with one IC we can interface two DC motors. The current output of microcontroller is too low and delicate to drive a high current DC motor, the motor will damage the controller since the output posts of the microcontroller is not designed to drive high current devices. A high current driver interface is thus required that drives the motors from an external source such as a battery or mains supply. Pulse width modulation (PWM) is a very efficient way to change the direction and speed on DC motors for the solar tracking operation. PWM signals are used for a wide variety of control applications, such as controlling DC motors, valves, pumps, hydraulics, and other mechanical parts. Relay shield is small current signal control power equipment commonly used electronic module, enabling high-power single-chip control devices are widely used in SCM system to make smart home project; and can be directly plugged into the Arduino compatible the use of various types of motherboards, eliminating the patch cable troubles.

3. Light sensor selection and circuit.

Light detecting sensor that may use to build solar tracker include; phototransistors, photodiodes, LDR and LLS05-A light sensors, a suitable, inexpensive, simple and easy to interface sensor is analog LDR. Two main solar tracking system arrangements; one-axis (one directional) sun tracking system using two light detectors and two-axis (two directional) sun tracking system using four light sensitive sensors, in both cases, sensors are mounted on the solar panel and placed in an enclosure, the LDRs are screened from each other by opaque surfaces. The sensors that were used in this work are the photo resistors. Photo resistors are semiconductors (just like solar panels) and have a reduced resistance when light is incident upon them. This, when paired with a resistor of a fixed value in a voltage divider became very useful. Fig. 2 shows how the voltage divider is set up.

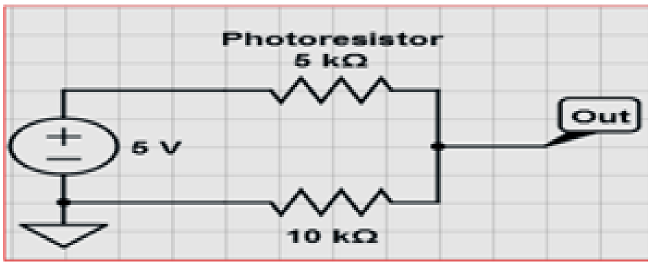

Figure 2 Circuit diagram of the light detection system.

Using four set-ups like this, it has been found that we could compare the voltage outputs, labeled "Out" (representing V_{out}), to determine which photo resistor had the most light shining on it. The relationship between the voltage at V_{out} is given by Eq. (1);

$$V_{out} = V_{in}\left(\frac{R_{fixed}}{R_{fixed}+R_{photoresistor}}\right) \quad (1)$$

To utilize this knowledge, we took the four total voltage dividers and arranged them on each side of the solar panel. By arranging them in this manner, we were able to compare the voltages at Vout from the left and right sides (one axis) as well as the top and bottom sides (second axis) to see which ones had more light exposure. If one side is getting more light than another, the incident photons must be striking the panel at some angle φ. The goal of this tracking system is to reduce this angle, along both axes, to zero, making the incoming photon perpendicular to the panel.

4. MPDC Motors.

In a dc motor, an armature rotates inside a magnetic field. Basic working principle of DC motor is based on the fact that whenever a current carrying conductor is placed inside a magnetic field, there will be mechanical force experienced by that conductor. All kinds of DC motors work in this principle only. Hence for constructing a dc motor it is essential to establish a magnetic field. The magnetic field is obviously established by means of magnet. The magnet can by any types i.e. it may be electromagnet or it can be permanent magnet. When permanent magnet is used to create magnetic field in a DC motor, the motor is referred as permanent magnet dc motor or PMDC motor.

5. Battery.

The energy storage is required in most of PV systems, because the energy generation and consumption do not generally coincide, moreover, the solar power generated during the day is very often not required until the evening and therefore has to be temporarily stored, for this reason an electrical storage batteries are commonly used in PV systems. Ideally, a battery bank should be sized to be able to store power for 5 days of autonomy during cloudy weather. If the battery bank is smaller than 3-day capacity, it is going to cycle deeply on a regular basis and the battery will have a shorter life. System size, individual needs and expectations will determine the best battery size for any system by Eq. (2).

$$Battery\ size = \frac{\frac{W_{el}}{System\ voltage} * Autonomy\ Days}{n_B * Max.DOD} = AH \qquad (2)$$

Where;
Wel : power from PV.
Autonomy Days: Number of days of non-sunshine often 2 days.
n_B: is the battery efficiency often (80%).
DOD: depth of discharge (80%).
The main aim of our design is to design automated solar tracking system. For this purpose we used Arduino microcontroller, four LDR for finding the light intensity and two PMDC motors for the horizontal and vertical movement, in addition, we implemented one application program using embedded C++ and loading the program into the Arduino microcontroller. The block diagram of the electrical system components is illustrated in Fig. 3 where the simulation has been conducted on Proteus simulation package. In the simulation, the light sensitive LDR device is used as input to detect and track the sun position, based on sensors reading and generated sun tracking error, the Control unit (Arduino) generates the voltage used to command the circuit to drive the motor that outputs the rotational displacement of electric motor, which is the motion of solar tracking system.

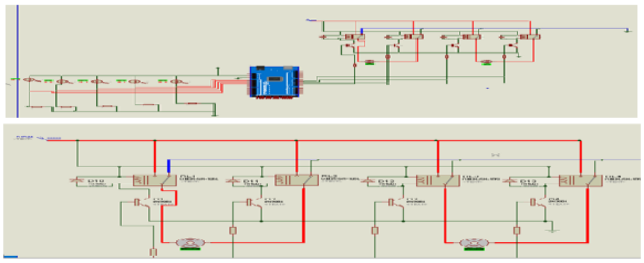

Figure 3 Simulation of the electrical system of the solar tracking.

B. Mechanical components design of solar tracking system

Mechanical engineering parts of the solar tracking system shown with free body diagram in Fig. 4 (a, b). Our analysis of the solar tracking system is focused on static analysis of all parts of the system. The static analysis considers the center of gravity for the all parts, forces that affect the balance of the solar tracking system, and calculation of the torques needed for lifting the solar panel in horizontal and vertical axis. Moreover, the static analysis considered the effect of winds on the solar panel. The first and necessary step in static analysis is obtaining the center of gravity for the following mechanical parts.

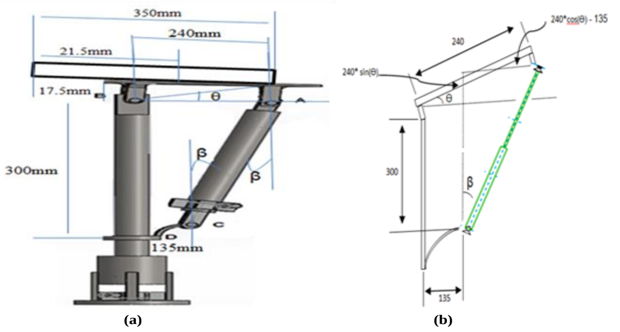

Figure 4 Solar tracking system: (a) mechanical parts (b) free body diagram.

1. Vertical moving part: that has a T structure (Fig. 5) obtained using Eq. (3). Fig. 6 shows the center of PV cell that its support obtained using Eq. (4).

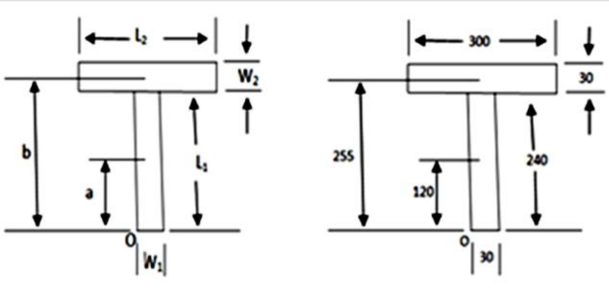

Figure 5 Structure of the vertical moving part.

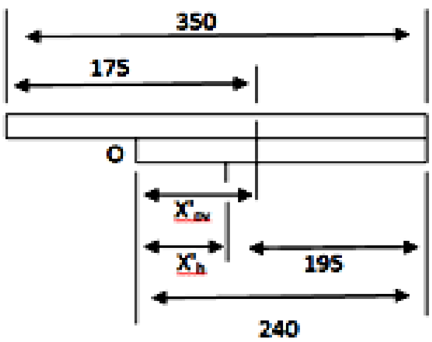

Figure 6 Structure of the PV cell and its support.

$$X'_h = \frac{(l_1 * W_1) * a + (l_2 * W_2) * b}{(l_1 * W_1) + (l_2 * W_2)} \qquad (3)$$

$$X'_1 = \frac{M_{pv} * X'_{pv} + M_h * X'_h}{M_{pv} + M_h} \qquad (4)$$

2. By assuming that the weight of slide does not have an effect at the center of mass of actuator, the center of mass of actuator was obtained by Eq. (5).

$$X'_{ACT} = \frac{M_{DC} * X'_{Dc} + M_{act} * X'_{act}}{M_{DC} + M_{act}} \quad (5)$$

By knowing that (θ) angle change from 0 to 90° (moving up and down) as shown in Fig. 4, the angle (β) was calculated by Eq. (6).

$$\beta = \tan^{-1}\left(\frac{(240*\cos(\theta)) - 135}{300 + (240*\sin(\theta))}\right) \quad (6)$$

3. The forces in Eq. (7) effecting the moving vertical part at point A was obtained by moment balance about point B and knowing the mass of the PV panel.

$$F_a = \frac{(W*0.05833*\cos(\theta)) - (0.030*W*\sin(\theta))}{(0.240*\sin\left(90 - \left((90-\theta) + (90-\beta)\right)\right))} \quad (7)$$

4. By Assume the weight of slide in the inclined bar does not affect its center of mass, and using the force balance on this bar the force at point c was obtained by Eq. (8).

$$F_c = F_a + W * \cos(\beta) \quad (8)$$

5. The torque that is needed to move the PV panel up and down was calculated by Eq. (9).

$$T_r = \frac{F_c * d_m}{2} * \left(\frac{(l + (f * d_m \sec\alpha))}{\pi * d_m - f * l * \sec\alpha}\right) \quad (9)$$

Where, F_c : Reaction at point C, *l*: lead and d_m : mean diameter.

Based on all previously obtained information about forces and torque, the mechanical parts were fabricated in the mechanical workshop at Sana'a University, moreover, from the dimension of the parts and calculated torque needed a specification of PMDC and necessary gears and screw were obtained.

III. Practical Work Results

The final efforts of our project results in a prototype design shown in Fig. 7 that has been developed based on the information given in table 1 in addition to the Arduino and software program developed using C++ for this purpose of controlling movement of the solar tracking system in one axis or tow axis as needed.

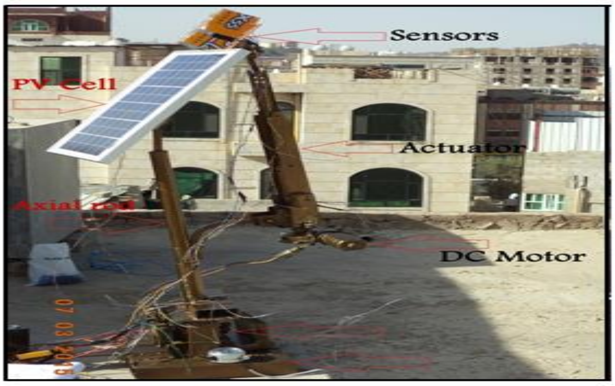

Figure 7 Prototype of the solar tracking system

Table 1 Description of mechanical parts of the solar tracking system.

Part		Weight (kg)
PV Cell	350	2
PV Cell Support	295	1
Actuator	Minimum (200)	2
DC Motors		0.5
Axial rod	500	1.5

Some practical work has been conducted on the solar tracking prototype to find the power produced form the system during the day, the power produced from the system is shown in the following Fig. 8 for the case of fixed PV cell and dual tracking PV cell system. It can be seen from the figure that the power produced from the PV cell tracking system is increased for the most of the day compared to PV cell fixed system.

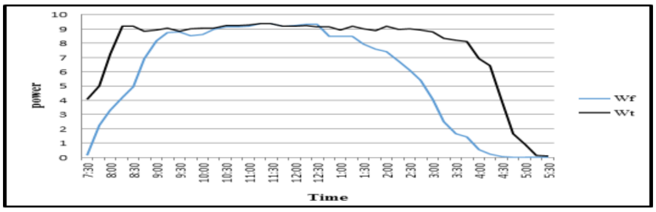

Figure 8 Power produced by fixed PV cell and solar tracking PV cell.

Energy gain is the most important factor in evaluation a tracking system, thus, the energy produced by fixed PV cell system was equal to 58.51673 W. h, while the energy produced by dual solar tracking PV cell system was equal to 78.87495 W. h with power difference of about;

$W_{diff} = W_t - W_f = 78.87495 - 58.51673 = 20.35823$ W. h

The energy consumption for motors to work has been calculated based on the following specification V = 12 V, I_{ave} = 1.250192 A and take 51 sec for one rev, and using Eq. (10) for the horizontal movement and the change in current is shown in Fig. 9.

$$W_{motors1} = V * I_1 * Time * Factor\ for\ starting\ current = 12 * 1.250192 * \frac{51}{3600} * 2 = 0.425\ W.h \quad (10)$$

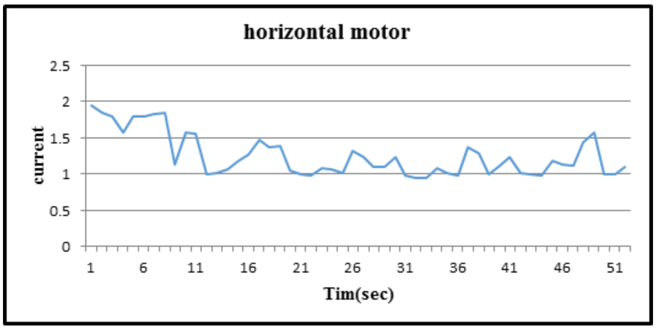

Figure 9 Current changes for the motor of horizontal motion.

Using the same motor voltage specification and take 108 sec for up and down movement, the energy consumption has been calculated for the up and down motion using Eq. (10) as following :

$$W_{(motor2)down} = V * I_{down2} * Factor\ for\ starting\ current = 12 * 2.237667 * \frac{54}{3600} * 2 = 0.761\ W.h$$

and

$$W_{(motor2)up} = V * I_{up2} * Factor\ for\ starting\ current = 12 * 2.171167 * \frac{54}{3600} * 2 = 0.738\ W.h$$

And the change of current shown in Fig. 10.

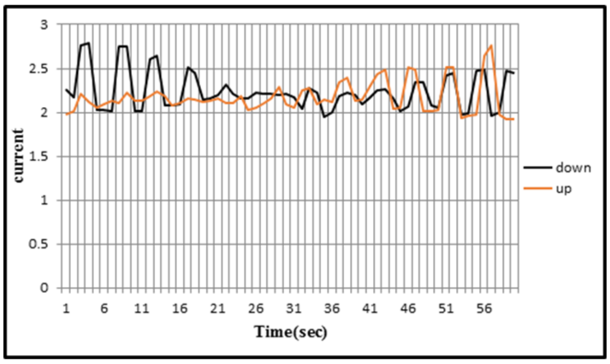

Figure 10 Change of current for the motor of vertical up and down motion.

Thus the power consumed by the motor of vertical motion is

$$W_{(total)motor2} = W_{(motor2)up} + W_{(motor2)down} = 0.738 + 0.761 = 1.499\ W.h$$

The net power produced from the PV cell using dual solar tracking system was obtained from the following equation

$$W_{net} = W_{diff} - W_{motor1} - W_{motor2} = 20.35823 - 0.425 - 1.499 = 18.43423\ W.h$$

The efficiency of developed dual solar tracking system compare with fixed system become

$$\eta = \frac{W_{net}}{W_f} * 100\ \% = \frac{18.43423}{58.51673} * 100\ \% = 31.502\ \%$$

The efficiency that we get from our design is better than that of fixed PV cell, but still is not that satisfactory for improving the whole efficiency and this could be due to some defects in our model and wrong position establishment of the sensors used.

IV. Conclusions

An effort has been made to design and construct a solar tracking system consisting of mechanical part fabricated in the mechanical engineering workshop at Sana'a University and electrical part. The heart of the system is Arduino microcontroller with a software program developed on C++ programming language. Moreover, the proposed design of utilizes a four quadrant light dependent resistors (LDR) sensors to sense the position of the sun generating an error signal to the control system to continuously receive the maximum solar radiation on the solar panel. The effectiveness of developed sun tracking system has been confirmed experimentally for maximizing the power output of the PV cell and increased it energy efficiency by about 31%.

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