

## Design a tracking system for optimum solar energy

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**Abstract:** Environmental and economic problems caused by over dependence on fossil fuels have increased the demand and request for green energy produced by alternative renewable sources. Solar energy systems have emerged as a viable source of renewable energy over the past two or three decades, and are now widely used for a variety of industrial and domestic applications. Such systems are based on a solar collector, designed to collect the sun's energy and to convert it into either electrical power or thermal energy. Solar energy is predictable to play a great role in the infrastructure as a distributed source, due to the fact that it is an easily available renewable source of energy. In Jordan, natural conditions for solar are excellent, with an intensity of direct solar radiation with 5 to 7 kWh/m<sup>2</sup>. The main purpose of the present study to estimate the performance of a solar tracking photovoltaic (PV) panel of dual axis type, through designing, construction and testing of a solar tracking system which automatically searches the optimum PV panel position with respect to the sun by means of a DC motors controlled by Arduino Mega board that receives input signals from dedicated Light Dependent Resistor (LDR), and compare the results with fixed PV panel. The results showed that the use of the Dual-Axis Tracking System can produce about 37.37% gain of power output, compared with a fixed system inclined at 30° to the horizon.

**KEYWORDS:** SOLAR ENERGY, PV, TRACKING SYSTEM, FIXED SYSTEM, DUAL AXIS, OPTIMUM SOLAR ENERGY

**Background:** In this technologically based world, electric power plays the sole role of providing energy for the operations of machines, either commercial based or industrial based. However, the generation of electricity often leads to environmental destruction. It is related with aspects as deforestation control, protection of ozone layer, reduction of CO<sub>2</sub> emissions and others. The environmental issues are now being regarded as the most crucial problem. Therefore, the goal of obtaining good energy supplies of electric power is to be emphasized [1]. According to that goal and considering additionally the exhaustion of the energy reserves and the global heating of the planet to promote and improve systems sourced with renewable energies is a must. A good energy source prospect for industrial continuous processes needs to be: more or less constant energy throughout the year; highly reliable and needs little maintenance; low cost to build and operate; virtually no environmental impact; modular and thus flexible in terms of size and applications; landscape friendly. A solar electric system—also known as photovoltaic (PV) systems—fulfils this entire characteristic [2]. Photovoltaic power generation is achieved using solar panels which are composed of a number of solar cells made up of a photovoltaic material. Materials currently used for photovoltaic include amorphous silicon, copper indium gallium selenide/supplied, cadmium telluride, mono-crystalline silicon, and polycrystalline silicon. Due to the continuous increase in demand for renewable energy sources, the manufacturing of Solar Cells and Photo-Voltaic Arrays has considerably advanced over the past few years [3]. The output of a Photo-Voltaic panel is non-linear in nature as well as the output greatly varies with environmental changes like temperature, solar insolation, etc. [4]. This poses a huge threat during its use. The entire Photovoltaic array does not receive equal amount of radiations at all times. Sometimes parts of the array is under shading due to clouds, tree, towers, dust, etc. This results in occurrence of multiple peaks in the Power v/s Voltage characteristics of the array which hinders the proper functioning on maximum power point tracker [5]. Considerable power loss will be experienced if local maximum power point is tracked and nor the global maximum. Hence it is pertinent to track the optimal operating voltage of the Photovoltaic array for better efficiency PV generators. The Photovoltaic array for better efficiency of PV generators. The PV array gives different output at different time of day for different orientations depending upon the amount of sunlight falling on the module and on the angle at which rays fall on it [6]. Thus the angle at which the module is placed with respect to the ground can be optimized so as to obtain maximum output from the module at all time. Radiation with 5 to 7 kWh/m, [14]. fossil fuels [7]. With extensive growth of population, in Jordan, natural conditions for solar are excellent, with an intensity of direct solar.

**Statement of the problem:** Design, Construction and testing a tracking system for optimum photovoltaic (PV) will be the main part of this work. The topic proposed in this paper refers to the design of a dual axis solar tracker system that automatically

searches the optimum PV panel position with respect to the sun by means of DC motors controlled by an intelligent drive unit that receives input signals from a light intensity sensor. Also design a fixed PV system for comparison purpose. For many years, several energy companies and research institutions have been performing solar tracking for improving the efficiency of solar energy production. A variety of techniques of solar energy production used have proven that up to 30% more solar energy can be collected with a solar tracker than with a fixed PV system [15].

**Motivation of the Study:** Jordan is a non-oil-producing country and imports 96% of the energy used. As a consequence, energy imports accounts for roughly 22% of the GDP (Gross domestic product). The population's growth rate is high; about 2.3% per year. This causes the demand on energy sources, mainly oil products to increase rapidly. Implementation of renewable energy resources such as solar and wind energy, will lead to economic, social and environmental benefits [16].

**Objectives of the Study:** The main objective of this work is to estimate the performance of a solar tracking PV panel of dual axis type. While the sub-objectives are:

- Increases solar panel output
- Maximum efficiency of the panel
- Maximum power per unit area
- Able to grab the energy throughout the day
- Compare results obtained from the tracking system with the fixed system.

**Research Methodology:** In order to achieve the overall objectives of the research, it is always important to have a systematic approach for the framework of research implementation. Thus, the following approach is adopted in the current research. Literature review: The understanding and evaluation of the current state of the research is one of the most fundamental and important step in any research activity. Development of conceptual design of proposed system. Experimental study and measurements. Comparison between tracking PV and fixed PV systems results.

**Solar Tracking Technologies:** Solar tracking is the act of making a solar collection surface change its orientation with the movement of the sun in the sky. There are two significant relative motions in the earth-sun system. The first is the diurnal movement due to the earth's rotation about its axis, causing day and night. This is responsible for the hourly variation of incident solar radiation on a surface [3]. The second is the much slower movement due to the earth's elliptical voyage round the sun. Two factors in this motion combine to affect incident radiation. First, the actual sun-earth distance affects the extra-terrestrial radiation in accordance with an inverse square law [4]. Secondly, the angle between the earth's equatorial plane and its orbit causes an apparent seasonal north-south range of travel of the sun in the upper celestial hemisphere [5]. Full control of solar harvest surface orientation is therefore a 2-degree of freedom problem. In practice, control is achieved by manipulating rotations about 2 of any 3 orthogonal axes. Commonly used axes are: West-East; North-South in the horizontal

plane and the vertical Nadir-Zenith, [6-13] among others – report the following pairs to constrain the rotation as to keep the surface facing the sun all day long.

- W-E and S-N
- S-N and Nadir – Zenith
- Nadir – Zenith and W-E

Rotation about these axes affects the surface slope  $\beta$  and its azimuth  $\psi$ . Tracking manipulates these angles to vary with the sun angles: The elevation and the solar azimuth  $\psi_{ss}$ . These are dependent on the time and day of year. Hence, from a tracking point of view, they are independent variables, see figures- 1 and 2.

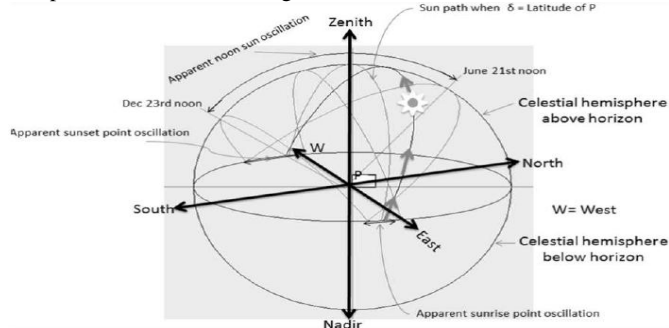


Figure-1: Apparent sun motion on the 'inside' surface of an inverted celestial hemisphere for a place 'P' within the tropics [14]

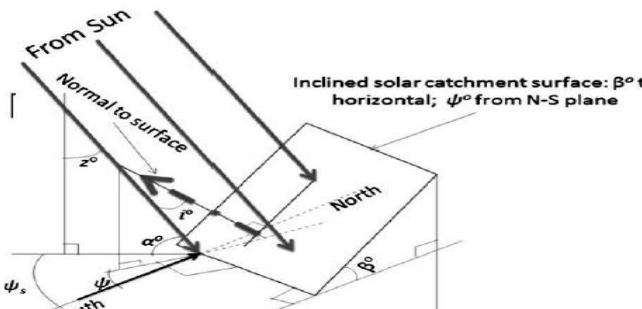


Figure-2: Important angles for a solar tracking surface: 'i' is the incidence angle to be minimized [14]

Broadly, the angles  $\beta$  and  $\psi$  track  $\alpha$  and  $\psi_s$  using mechanisms classified according to two criteria [15, 16].

- Passive or Active tracking
- One axis or Two axes tracking

When the radiation catchment plane or aperture is adjusted without use of electrical power, the tracking is said to be passive.

**Solar Tracker System Design and Calculations:**

**1- Annual motion of the sun**

There are many motions for the sun during a year, the first one is motion in winter and the second one in summer as shown in the figure-3. So in winter the sun doesn't rise as high as in summer. Hence the sun rising hours in summer are more than in winter so the quantity of radiation absorbed in summer is more than in winter.

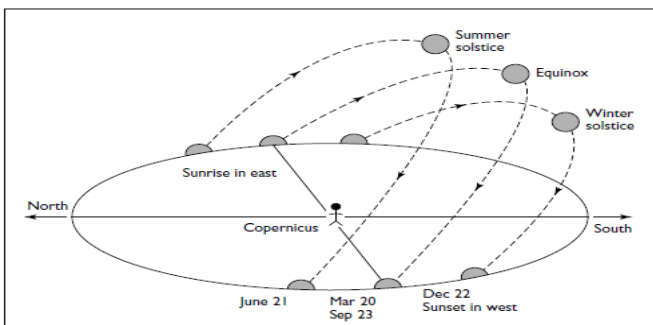


Figure-3: Annual motion of the sun [17]

**Sun- earth angles:** The energy flux of beam radiation on the surface with arbitrary orientation can be obtained from the knowledge either on the surface perpendicular to the sun rays or in the horizontal surface. Consider the flux incidence on the plane surface is  $(I * \cos \theta)$ , where  $\theta$  is the angle between surface and incident beam, and  $I$  is the incident beam [18]. Latitude angle ( $\Phi$ ): defined as the location where the angle made by the radial line joining the given location to the center of the earth, the latitude angle is positive for the northern and negative for the southern hemisphere. Declination ( $\delta$ ): defined as the angle between joining center of the sun and the earth, and its projection on the equatorial plane. Slope ( $\beta$ ): is the angle between the plane surface and the horizontal [19, 20]. It is positive for surfaces sloping toward the south and negative for surfaces sloping toward the north. Angle of incidence ( $\theta_z$ ), is the angle between beam radiation on the surface and normal to that surface.

**2- Solar tracker system design and its components:** The system consists of many components which are:

**(a) Battery:** A solar battery is a rechargeable that integrates a solar cell with battery power storage. In this project, sealed acid rechargeable battery is used for solar system (12 V ,7 Ah). The number of battery needed, as follows:

$$\begin{aligned} \text{Estimated Watt demand} &= \text{DC Amps} \times \text{System Voltage} \dots\dots\dots(2) \\ &= 1.76 \text{ A} \times 12 \text{ V} = 21.12 \text{ Watt} \\ \text{Watt-Hours per day} &= \text{Watts} \times \text{Hours} \dots\dots\dots(3) \\ &= 21.12 \text{ Watt} \times 3 \text{ hours/day} = 63.36 \text{ Wh/day} \\ &= \frac{\text{Watt-Hours per day} \times \text{battery loss factor}}{\text{system voltage}} \dots\dots\dots(4) \\ &= \frac{63.36 \times 1.2}{12} = 6.336 \text{ Ah /day} \end{aligned}$$

$$\begin{aligned} \text{So, the number of battery needed} &= \frac{\text{total Amp /day}}{\text{battery Amp rating}} \dots\dots\dots(5) \\ &= \frac{6.336}{7} = 0.905 \approx 1.0 \end{aligned}$$

**(b) Solar panel:** The type of solar panel used is polycrystalline module, the panel produces peak power values at an irradiance level of 30 Watt. Those are for solar radiation of 1000 W/m<sup>2</sup> at 25°C.

$$\begin{aligned} P_{\max} &= 30 \text{ W} \\ V_{oc} &= 21.6 \text{ V} \\ I_{sc} &= 1.83 \text{ A} \\ V_{mp} &= 18.00 \text{ V} \\ I_{mp} &= 1.67 \text{ A} \end{aligned}$$

The number of panel needed: Sun hours per day = 4.5 hours

$$\begin{aligned} \text{Total Amp} &= \frac{\text{total Amp /day}}{\text{Sun hours per day}} \dots\dots\dots(6) \\ &= \frac{6.336}{4.5} = 1.408 \text{ am} \end{aligned}$$

$$\begin{aligned} \text{So the number of panels} &= \frac{\text{total Amp}}{I_{mp}} \dots\dots\dots(7) \\ &= \frac{1.408}{1.67} = 0.843 \approx 1.0 \end{aligned}$$

**(c) Charge controller:** A charge controller is a device used to control the rate at which electric current is added to or pulled from electric batteries. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifetime, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life

$$\begin{aligned} \text{The number of charge controller needed} &= \frac{I_{mp}}{\text{Rated charge current}} \dots\dots\dots(8) \end{aligned}$$

$$= \frac{1.67 \text{ A}}{10 \text{ A}} = 0.167$$

**(d) Motors:** In the solar tracker system two types of motor have been used

**(1) DC motors:** DC motors were the first type widely used, since they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing

the value of current in its field windings. The DC motor that used in this work is ASMO (873410.073) which have these specification:

- Torque = 2 N.m
- Voltage = 24 V
- Current = 85 mA
- Output speed = 1.8 r/min

**(2) Actuator:** An actuator is a compact of machine that is responsible for moving or controlling a mechanism or system. It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion. An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple, software-based, a human, or any other input. There are varieties of actuators and they are Mechanical actuators, Hydraulic actuators, Pneumatic actuators, Electro-mechanical, Linear motor etc. In our system we have used linear actuator because linear actuator creates motion in a straight line, in contrast to the circular motion of a conventional electric motor.

**Torque needed to rotate the panel:**

Panel weight = 3 kg  
 Dimensions of panel: 670 mm × 410 mm × 25 mm  
 $torque = T = r \times F$  ..... (9)

$$T = \frac{mgr}{2}$$
 ..... (10)

$$g = 9.8 \text{ ms}^{-2}$$

$$r = \frac{Width}{4} = \frac{410}{4} = 102.5 \text{ mm} = 0.1025 \text{ m}$$

$$T = \frac{3 \times 9.8 \times 0.1025}{2} = 1.771 \text{ N.m}$$

**3- Control System:** To control the motion of the panel in order to be faced to the sun. So, need a control system is required. This system contains:

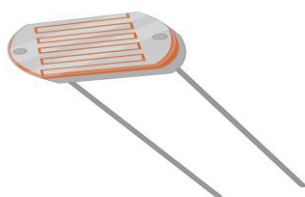
**(a) Arduino Mega Board**



**Figure -4:** Arduino mega board

The Arduino Mega is a microcontroller board based on the ATmega1280. It has 54 digital input/output pins, 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. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila. Figure-4, shows the Arduino mega board.

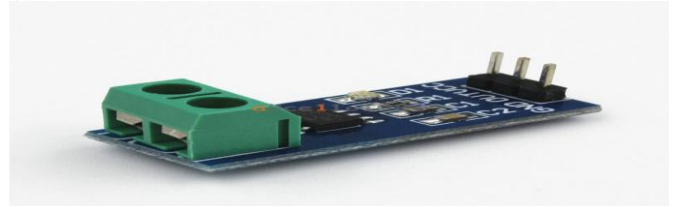
**(b) Light Dependent Sensor**



**Figure- 5:** Light Dependent Resistor

A Light Dependent Resistor (LDR) or a photo resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices, as shown in figure-5. A light dependent resistor works on the principle of photo conductivity. Photo conductivity is an optical phenomenon in which the materials conductivity is increased when light is absorbed by the material. When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band.

**(c) Current Sensor**

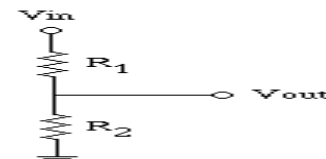


**Figure-6:** Current sensor

A current sensor as in figure-6, is a device that detects electric current (AC or DC) in a wire, and generates a signal proportional to it. The generated signal could be analog voltage or current or even digital output. It can be then utilized to display the measured current in an ammeter or can be stored for further analysis in a data acquisition system or can be utilized.

**(d) Voltage Sensor (voltage divider):** A voltage divider is a simple circuit which turns a large voltage into a smaller one. Using just two series resistors and an input voltage, we can create an output voltage that is a fraction of the input. Voltage dividers are one of the most fundamental circuits in electronics.

Figure-7, shows the voltage divider circuit.



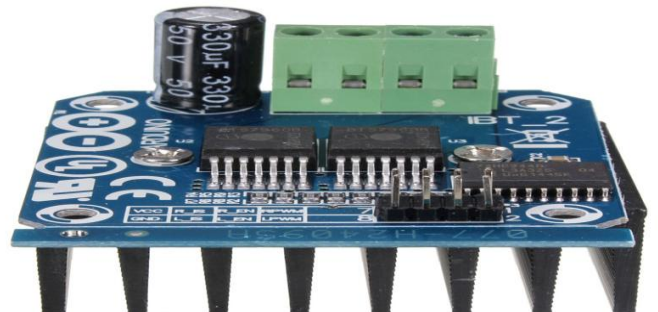
**Figure-7:** Voltage divider circuit

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2}$$
 .....(11)

$$5 = 18.5 \times \frac{R_2}{R_2 + 10}$$

$$R_2 = 4.7 \text{ k}\Omega$$

**(e) Motor Driver (H-bridge)**



**Figure-8:** Motor Driver

Motor driver is a little current amplifier; the function of motor drivers is to take a low-current control signal and then turn it into a higher-current signal that can drive a motor. Shown in figure-8.

**(f) SD Card Shield:**



**Figure-9:** SD Card Shield

The Arduino SD Card Shield is a simple solution for transferring data to and from a standard SD card. The pin out is directly compatible with Arduino, but can also be used with other microcontrollers. It allows users to add mass storage and data logging to their project. SD Card Shield is shown in figure-9.

**4- Installation and Programming**

This section is dedicated to reflect how to used research and design to build prototype of the sun tracking system. After an intensive research on all the available techniques and components, to meet the requirement of the desired sun tracking system and to satisfy the prime objective of the project, suitable methods and components were selected and implemented through electrical circuits. In our system we have a control circuit controlled by the microcontroller in Arduino system with the following components:

a) **Electrical circuits:** Solar tracker system consists of many electrical circuits which are:

- **LDR circuit:** The LDR gives out an analog voltage when connected to Vcc (5V), which varies in magnitude in direct proportion to the input light intensity on it. That is, greater the intensity of light, greater will be the corresponding voltage from the LDR. Since the LDR gives out an analog voltage, it is connected to the analog input pin of the Arduino. The Arduino, with its inbuilt ADC (Analog to Digital Converter) then converts the analog voltage (from 0-5V) into a digital value in the range of (0-1023). Thus, when there is sufficient light in its environment or on its surface, the converted digital values read from the LDR through the Arduino will be in the range of 800-1023. LDR circuit shown in figure-10.

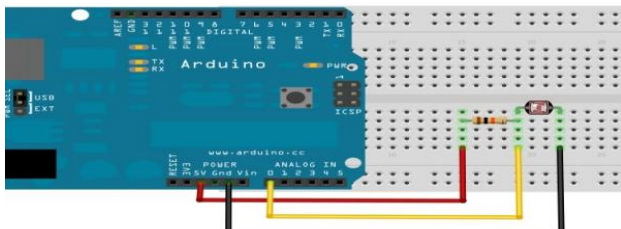


Figure-10: LDR Circuit

- **Current sensor circuit:** This circuit used for Read, Sense and Control current flow in the system. Figure-11, shows the current sensor circuit.

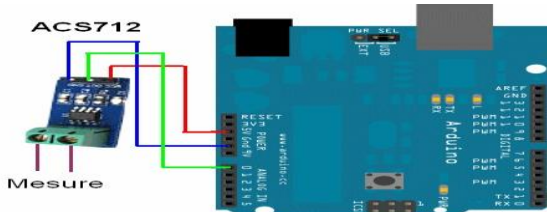


Figure-11: Current Sensor Circuit

- **Voltage Divider Circuit:** This circuit works as a voltmeter, which is measure the voltage between two points in the circuit and, with digital electronics, this is an analog range from zero to the level of the power supply (Vcc). Digital voltmeters work by converting the analog value to a digital value using an analog to digital converter (ADC). A typical Arduino has several of these converters on the board. Figure-12, shows the circuit.

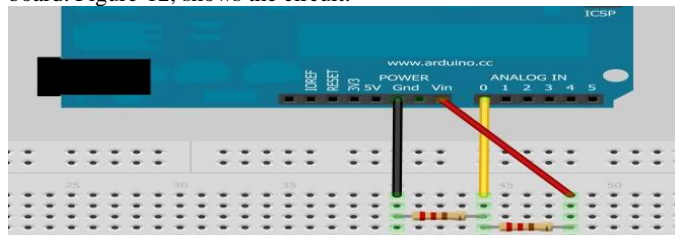


Figure-12: Voltage Divider Circuit

- **Motor Driver Circuit:** Figure-13 illustrates the wiring. B+ and B- at the top of the diagram represent the power supply for the motor. A 5 k or 10 k potentiometer is used to control the speed.

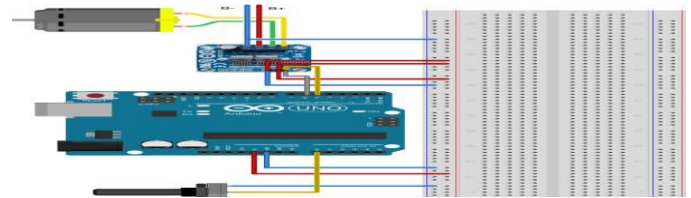


Figure-13: Motor driver circuit

-**SD Card Shield Circuit:** This circuit used to save the data collected from current and voltage sensors into SD card. Figure-14, shows the circuit.

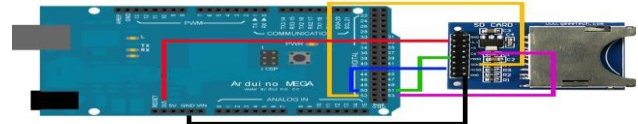


Figure-14: SD Card Shield Circuit

b) **Arduino programming**

In proposed system Arduino 1.6.9 version for

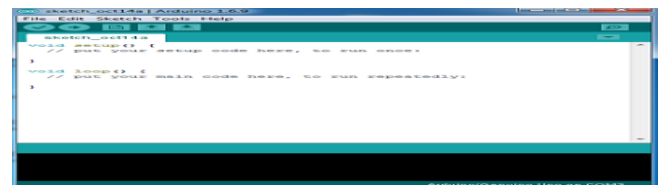


Figure-15: Empty sketch book of the Arduino

programming has been used, figure-15. That is an open project that allows writing and debugging codes efficiently which is also immensely supported by vast library files. The library files assisted us in designing algorithms from a sketch books and example's directory. Verification and compilation of error is smooth and easily accessible. By opening Arduino mega 2560 sketch book we can select specific board and upload programming codes. Solar tracker system operation and the flow chart are shown in figures-16 and 17. LDR detect the sun light and send signals to the Arduino which is send signals to the motor drivers to derive the motors that moves the solar panel toward the sun.

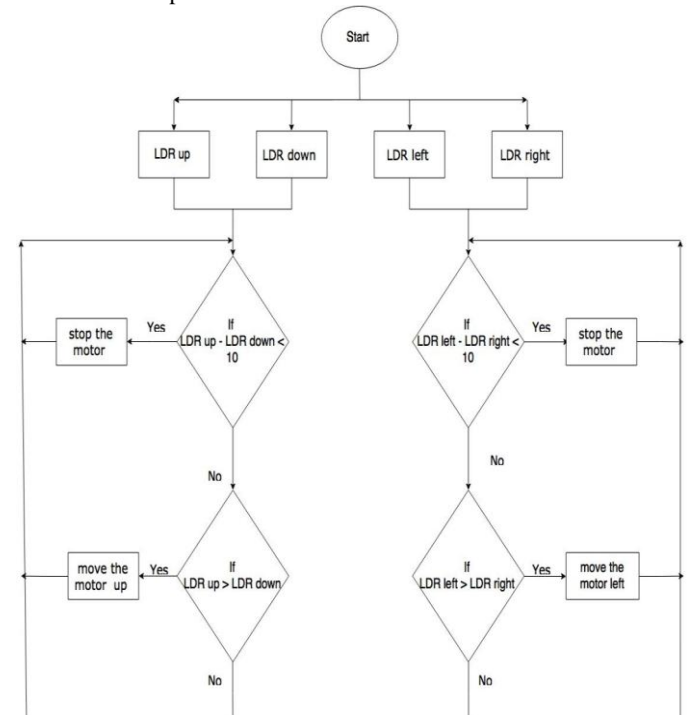


Figure-16: The block diagram of the operation of the whole proposed system

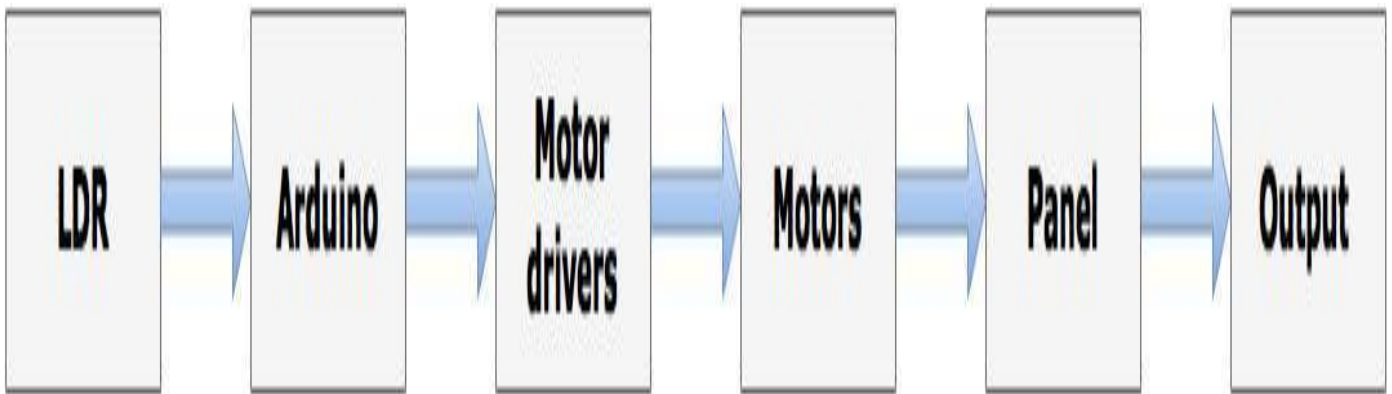


Figure-17 Shows The Flow Chart of Arduino Program

**5-Final Solar Tracking System Components:**

Figures – 18 to 21 show the final design of the solar tracking system of this work.

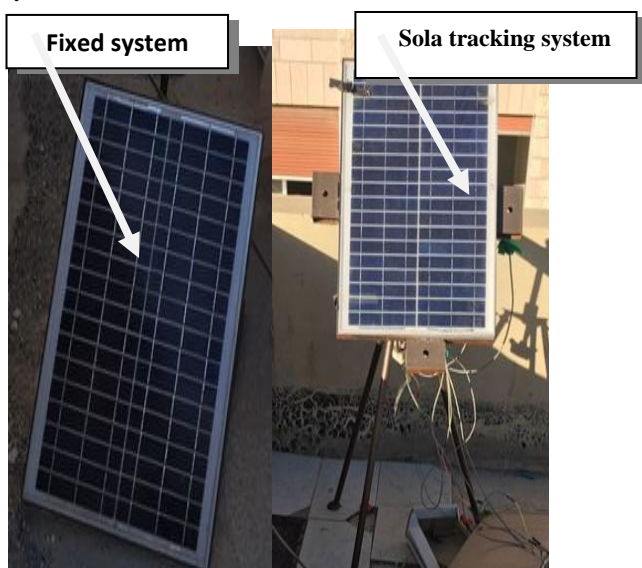


Figure-18: Solar Tracking PV System and Fixed PV System



Figure-19: LDR That Used in The System

LDR

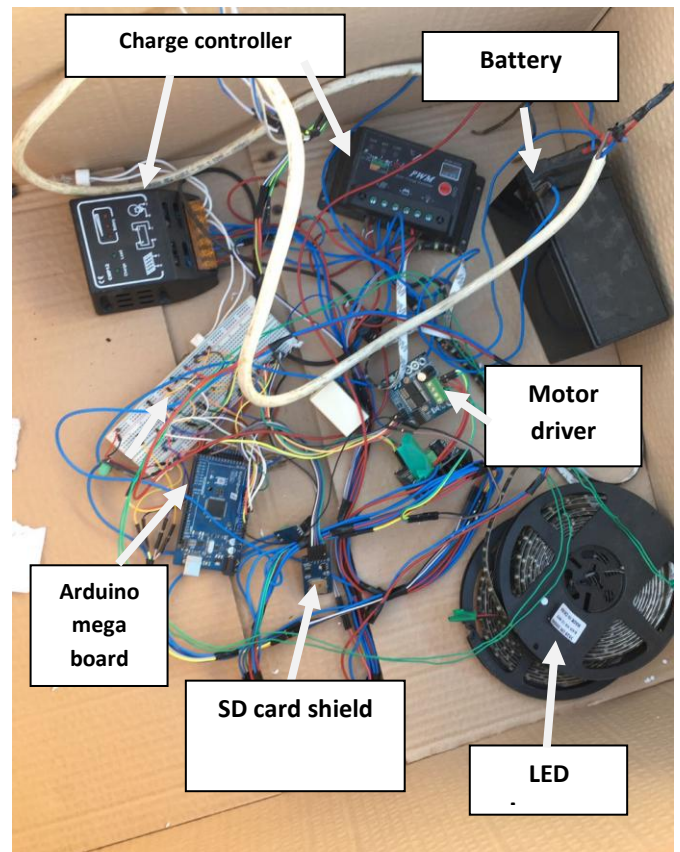


Figure-20: Electrical Circuits

**Results and Data Analysis:**

The experimental investigation was carried out in order to compare the performance of the solar tracking PV panel in comparison with a fixed PV panel of the same type. The two PV panels were subjected to the same solar irradiation conditions in the same time and the energy output of each panel was monitored and compared. The experimental measurements were carried out in different meteorological conditions with the purpose of comparing the supplementary output power obtained in case of a PV panel equipped with a solar tracking mechanism. The experimental study of the solar tracking prototype has used a modern Data Acquisition System (DAS) composed of a SD card module, that can read and write, and save the data that have been collected. The software interface for the management of the measurement system was developed using Arduino development platform since it is characterized by a high compatibility with many types of data acquisition boards. The recorded data can be saved in TXT files, that can be analyzed separately. Since the studied application could entail very long data acquisition

running time. The experiment was performed at different meteorological conditions. The system takes the measurement every 6 minutes. The data were setup to determine the percentage difference in power output between fixed position (30 degrees to the horizontal) and dual-axis tracker. Figures 22- 29 show the power output of two systems, fixed and dual-axis tracker at sunny, dusty, partially cloudy and cloudy days. The average power output was greater in favor of the dual-axis tracker than fixed one.

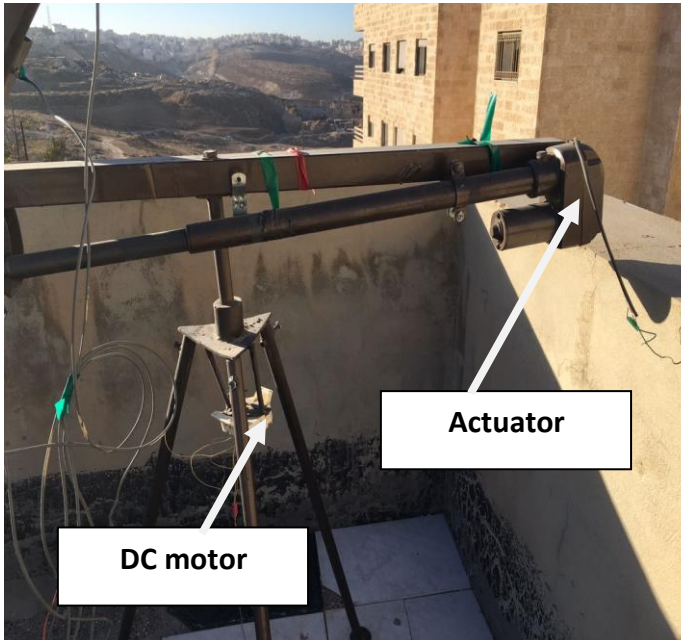


Figure-21: Motors That Used in The System

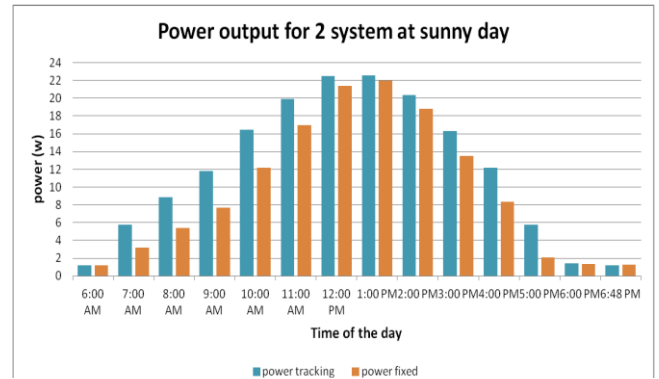


Figure-24: Power output for 2 systems at sunny day

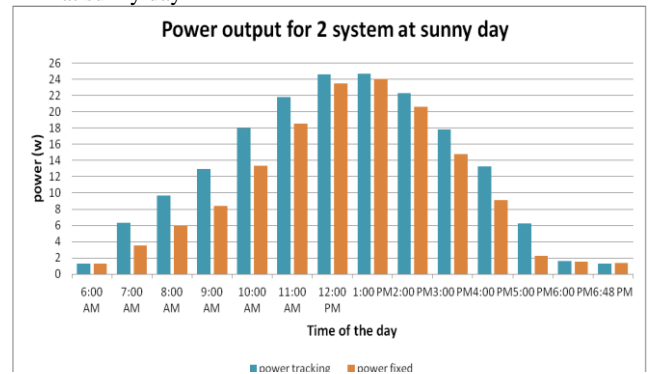


Figure-25: Power output for 2 systems at sunny day

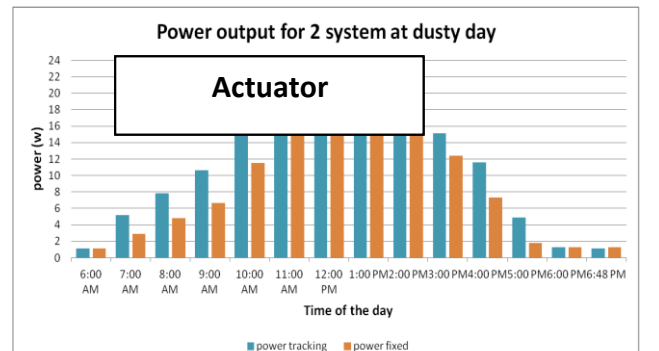


Figure-26: Power output for 2 systems at dusty day

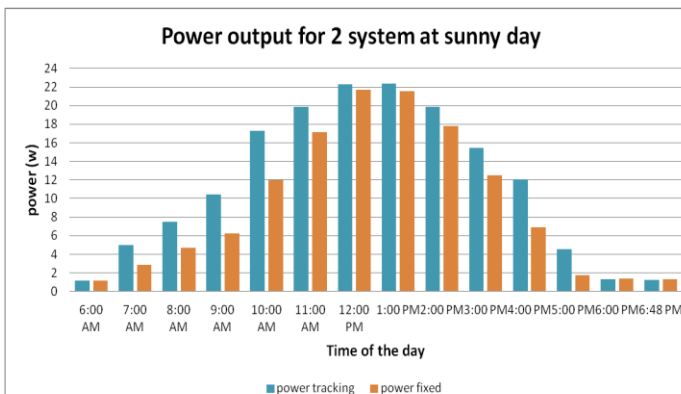


Figure-22: power output for 2 systems at sunny day

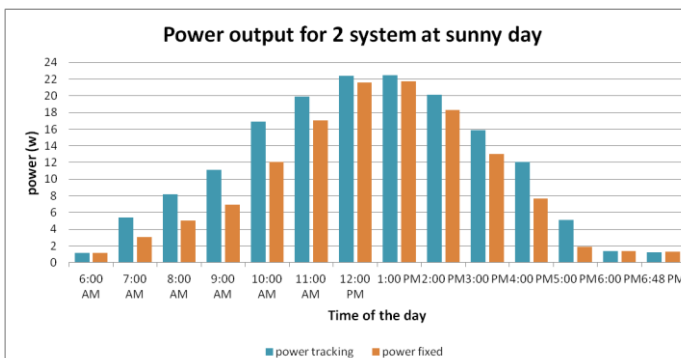


Figure-23: power output for 2 systems at sunny day

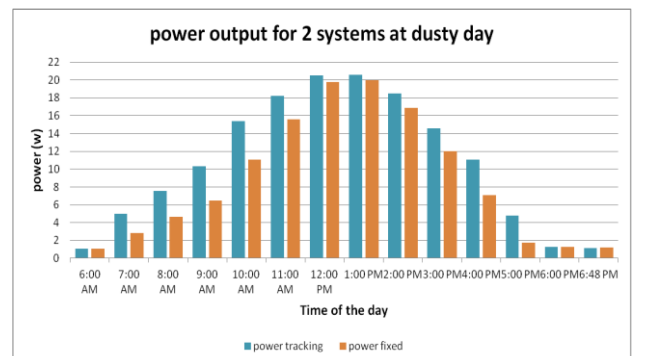
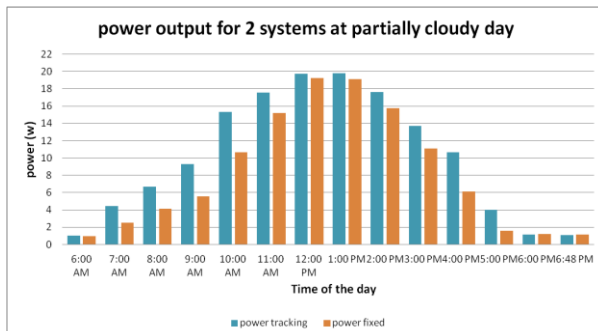
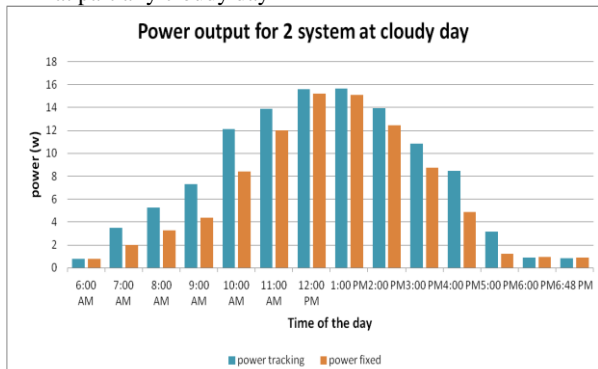


Figure-27: Power output for 2 systems at dusty day



**Figure-28:** Power output for 2 system at partially cloudy day



**Figure-29:** Power output for 2 systems at cloudy day

Within the day the power was nearly zero at sunrise and sun set for the two systems because there is no sun light. At noon the power generates by two systems was almost the same because the fixed PV panel is directly faced to the sun like the tracked PV panel. The power generated by the two systems affected by the metrological conditions like dust and clouds. Regardless the time periods of linear increasing and decreasing of power output, the monotonic power output region, the period of time chosen was between 6:00 and 19:00. By employing dual-axis tracker the average of increasing was calculated to be 39.8%, 35.4%, 36.91%, 36.4%, 36.95%, 36.86%, 37.63% and 37.628% over the fixed one due to 8 days.

### Conclusions :

From the results of this work the following conclusions can be drawn:

- Analysis of data showed that a significant gain of the power output when using tracking system in comparison with the fixed axis. Also confirmed that the dual- axis tracking system oriented PV modules perpendicularly to the sun had a tremendous performance improvement on PV panel output.
- The amount of the collected global solar radiation and the produced electricity by the different systems depends on the system, the sky state conditions and the orientation parameters. Also the results revealed that the employment of the Dual-Axis Tracking System can produced 37.37% gain of power output, compared with a fixed System inclined at 30° to the horizontal

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