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Optimal Mechanical Tracking Technique for Renewable Photovoltaic Energy Conversion System

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Abstract- This paper investigates the implementation of mechanical maximum power point tracking MPPT of solar energy conversion systems .There are two mechanical tracking control techniques are propose. The first one is called single axis tracking. While the second one is called digital stepping rotation tracking technique. The first one is based on using two Light dependent resistor LDR elements putted two sides of solar panel .A voltage divider signal condition circuit is designed with LDR element. The values of LDRs are varied with sun intensity which gives variable voltage dividers. A microcontroller is built and programed to get the maximum power point during the rotating of the solar panel via reading of the variable LDRs voltage dividers. Whereupon the position of solar panel is fixed at maximum power point. If the sun intensity changed, the solar panel is moved via DC motor to track the maximum power point using LDRs devices. While main feature of the second one tracking is that the solar panel scans the maximum power point via stepping rotation of the solar panel each ten degrees angle through 180 degrees angle using stepper motor. A current sensor is used to sense the current through the load resistance , whereupon the output voltage is determined . A microcontroller is implemented and programmed to calculate the power via the current sensor and output voltage. At each ten degrees motion angle of solar panel the power is estimated using microcontroller and saved . The microcontroller compares the calculated power through 180 degrees angle motor and determine the maximum power point . Then the microcontroller sends signal to the stepper motor to move the solar panel at degree angle of maximum power point. An experimental set-up of the proposed tracking control techniques is implemented . The results of experimental results of proposed tracking control techniques is compared . Also the two tracking control techniques is compared with fixed position of solar panel . The results prove the effectiveness and powerful of digital stepping rotation tracking technique with respect of the other tracking control techniques in sense of accurate value of solar position and maximum power point

Keywords- Arduino UNO board, Solar Panel, liquid-crystal display (LCD) unit, single axis solar tracker, light depending resistor (LDR) Sensors , maximum power point tracking (MPPT), DC motor, AT mega 328 Microcontroller, photovoltaic(PV),sun tracking, solar energy, maximum power point (MPP)

1-INTRODUCTION

The Solar tracker is advice that keeps photovoltaic in an optimum position perpendicularly to the solar radiations during a day light hours. The use of solar trackers can increase electricity production by around a third, and some claim by as much as 40% in some regions, compared with modules at a fixed angle [1]. While the output of solar cells depends on the intensity of sunlight and the angle of incidence. It means to get maximum efficiency so the solar panels must remain in front of sun during the whole day. But due to rotation of earth those panels can't maintain their position always in front of sun. This problem results in decrease of their efficiency. Thus to get a constant output, an automated system is required which should be capable to constantly rotate the solar panel [2].The Automatic solar tracking system is the possible approach to maximize the solar cell efficiency [3]. Tracker system tracks the location of sun hence it increases the input of sun radiation. Figure (1) shows the fixed photovoltaic and tracking photovoltaic system [4], [5]. The novelty of tracking system of sun energy is to enhance the tilt angle for obtaining the maximum available radiations [6].

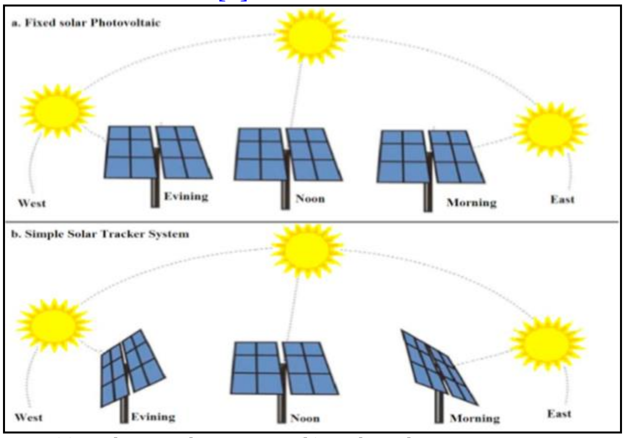

Fig.1 (a) Without tracking system (b) With tracking system

So, there are basically two ways of extracting energy from solar photovoltaic (PV) panels. One is by employing single axis or dual axis tracking technique and the other one is by Maximum Power Point Tracking (MPPT) methods. The MPPT is considered to be one of the effective methods to extract maximum power from solar photovoltaic (PV) panels [7],[8],[9], but its implementation cost is too expensive if it is designed in digital domain by using a Digital Signal Processor (DSP) or Field Programmable Gate Array (FPGA) systems respectively [10], [11], [12], [13]. Hence, it is of utmost importance to look for cost effective solution in order to build a real time prototype of solar tracking kit. Since, most of the systems are implemented in digital domain to acquire accurate results. It is convenient to use a low cost microcontroller to achieve the task of solar power collection. From this point the Single axis or dual axis tracking methods is used sometimes instead of MPPT based methods because of its simplicity and possibility of low cost implementation. Few researchers have already been worked in this area to show its effectiveness [14], [15], [16], [17], [18], [19], [20], [21].But they have used different microcontrollers which are a bit costly. First type of solar tracking system was fixed system. These Solar panels which are used in these systems are only in one way direction. This system generates low power at the output.

2-Single axis mechanical tracking control system

This work is divided into two parts hardware and software system. In hardware part, two light dependent resistors (LDR) functionally are used to detect the utmost light source from the sun. In software part, the code is written by using C programming language and has been sent to the Arduino UNO controller. The outcome of the solar tracker system has analyzed and compared with the fixed or static solar panel in terms of voltage, current and power. Therefore, the voltage , current , power , LDR values are detected to estimate the best max power with its location using DC motor . The system tracks the max intensity of light. When the intensity of sunlight decreases, this system automatic changes its direction to get maximum intensity of sunlight. LDR light detector is used to trace the coordinate of the Sunlight. While to rotate the appropriate position of the panel, a DC-geared motor is used. This mechanical parts use the DC motor and gear to move the solar panel to max light source location perceived by the LDRs. The system is controlled by two motor drive , relays and encoder as mechanical driver and a microcontroller as a main processor .
All the results is displayed such as the voltage, current, power and the LDR values with temperature that generated from panel continuously by LCD display .The single axis tracker generate large amount of energy more than the fixed solar panel which cannot rotate or tilted .As a result of which get more efficient system in terms of compact low cost as well as easy to use.

2.1-Working principal

The main purpose of the single axis tracking to get MPP all of time so the solar panel will move vertical to be perpendicular for sun rays all time so, the architecture system design is depicted as block diagram as shown in figure.(2) consisting two sections: First one is hardware (HW) where it includes solar panel ,dc motor ,current sensor ,temperature sensor ,LDR ,Arduino ,limit switch and LCD display. All this hardware devices is managed by second section called software.
The operation of this implementation starts to adjust solar panel position by interface of microcontroller Arduino to move solar panel position by sending signal to relay kit and motor drive circuit .Then the solar panel tracker starts to move by first angle and hold for 10 sec to measure the current and voltage to get the out power through the current sensor and temperature sensor .All these values go to Arduino and registered so the Arduino shows these results on the LCD display angle ,current ,voltage, power and LDR at this position .All of these pervious repeated from 0 to 180 from start to end.
Single axis tracking method is executed by angle rotation and checked by LDR value .Once this rotation arrives at the end , the limit switch is operating, and the Arduino will know this is the last angle, and then Arduino will compare all results for all angle from 0 to 180 will detect the max power and will give order from MC to move the PV cell at that angle by dc motor then the LCD display show the max power angle by dc motor with LDR at temperature this will occurred periodically at half hours
This operation occurred from sunrise to sunset this contain the LDR that is right to left to detect to start sunrise or hold that at sunset to safe the power consume to make sure by this rotation and double check with LDR we will get max power at of day in all time

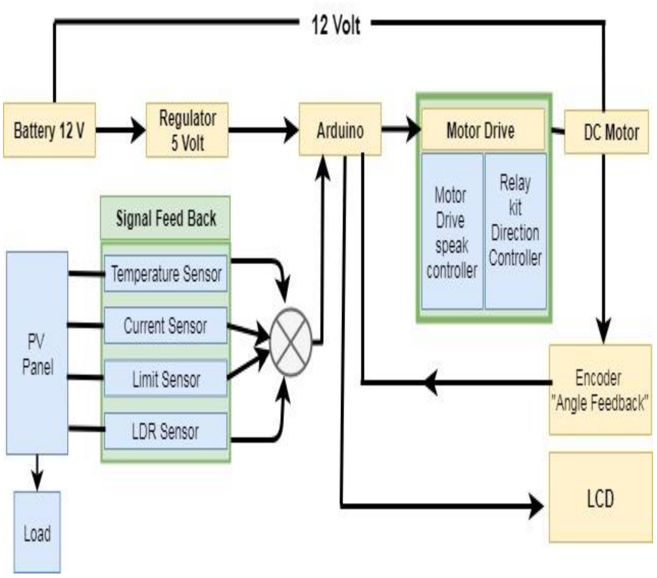

Fig.2 Block Diagram of solar tracking system

3-*Digital stepping rotation tracking control system*

Due to transition of the Sun from east to west, the fixed solar panel may be not able to generate optimum energy. This system is used to get the maximum efficiency of power from solar panel .As the sun rises and sets in the sky, it appears in different locations in different times throughout the day . In order to get the best intensity and maximum power efficiency, the solar panel must be at the right angle to the sun. So, the panel is moved at different angles. The solar panel tracking system use the DC motor and microcontroller to get the maximum power point track (MPPT) is proposed. The tracking systems move the panels throughout the day in order to keep them facing the sun. The longer they are aligned with the sun, the more energy they can produce. After a particular amount of time, the voltage and power efficiency are checked at every angle, and all results showed on LCD display for each angle like current, voltage, power, angle and temperature .After one circle rotation is completed, the angle at which the maximum intensity is selected. After that the panel is aligned to the sun at this angle (Max power position).Finally the LCD display shows the max power with its angle, current, voltage and temperature .The rotating solar panel system scans from one horizon to another to know the current position of the sun and hence the position from which the greater solar energy can be harnessed. The position which has the highest energy capacity. The components used for proposed tracking maximum power point are DC motor, Arduino and current sensor with temperature sensor .This paper shows system architecture which consists of a current sensor which senses current of solar power and voltage which is being given to the Arduino. Controller then takes the decision according to programed algorithm and tilts the panel towards the direction of the max power position given by solar panel rotating using DC Motor. The Motor is used to rotate the panel to detect the max solar power. A Solar Tracker is basically a device onto which solar panels are fitted which tracks the motion of the sun across the sky ensuring that the maximum amount of sunlight strikes the panels throughout the day. After finding the sunlight, the tracker will try to navigate through the path ensuring the best sunlight is detected. It is completely automatic and keeps the panel in front of sun until that is visible. Its active sensors constantly monitor the sunlight and rotate the panel towards the direction where the intensity of sunlight is maximum. 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 system giving the best solar panel orientation at all times of the day every each hour .

4-Solar cell digital stepping rotation tracking control system components description

The rotation tracking control system of solar cell consists of different components. The following sections explain these components as in figure (3).

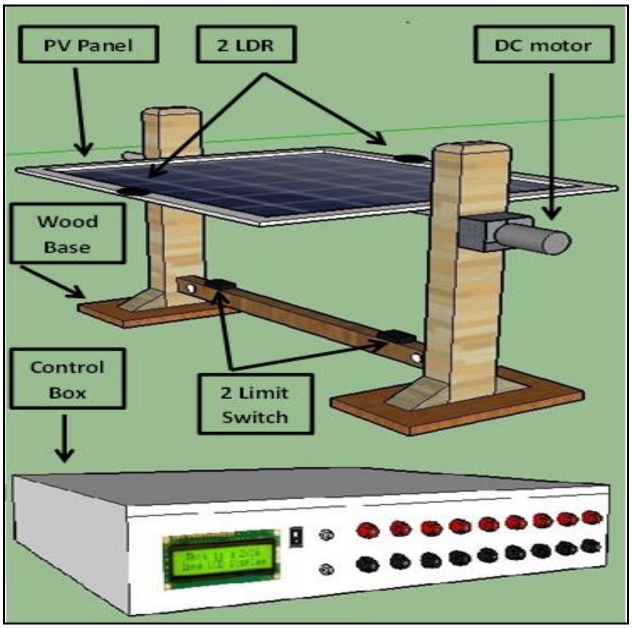

Fig.3 PV panel perspective diagram by AutoCAD 3D.

4.1-Solar Panel

Solar panel is an energy production component which absorbs the sun’s radiation and converts them into electricity. A solar panel comprise of array of photovoltaic PV cells which can be used to generate electricity through photovoltaic effect as shown in figure (3). To get most out of the solar panel, it has to be emplaced directly at the sun’s radiant energy shown in figure (4), the more surface area that is exposed to direct sunlight, the more output the solar panel will furnish. Table (1) shows the specifications of PV. The solar panel will rotate to tracking the sun radiation by DC motor.

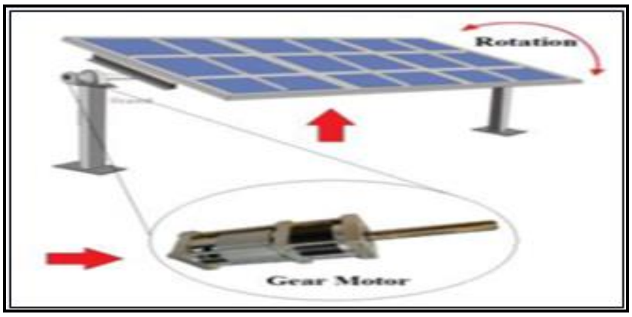

Fig.4 Rotation of solar panel mounting structure

Specification	Quantity
Voltage at Pmax (Vmp)	17.3 Volt
Current at Pmax (Imp)	1.73 Ampere
Short Circuit Current (Isc)	1.88 Ampere
Open Circuit Voltage (Voc)	21.4 Volt
Weight	4.5 Kg

Table.1 Specification of PV panels

4.2. Arduino UNO Microcontroller

The Arduino Uno is capable of reading input and producing outputs i.e. they are able to sense input values from their peripherals and actuate an output based on that of hardware. The Arduino Uno board as shown in figure (5). The Table.2 shows the specifications of Arduino Uno microcontroller boar

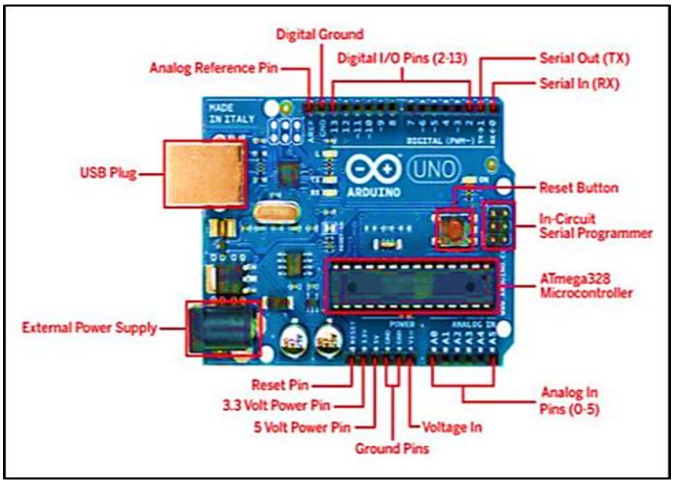

Fig.(5): . The Arduino Uno board

Microcontroller	ATmega328
Operating Voltage	5V
Supply Voltage (recommended)	7-12V
Maximum supply Voltage (not recommended)	20V
Digital I/O Pins	14(of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40mA
DC Current for 3.3V Pin	50mA
Flash Memory	32KB of which 0.5KB used by boot loader
SRAM	2KB
EEPROM	1KB
Clock Speed	16MHz

Table .2 The specification of Arduino Uno.

4.3-LDR (Light Dependent Resistor) sensor

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 the LDRs are separated by opaque surfaces or is called balancer. Figure 6 shows simple LDR circuit used in this work.

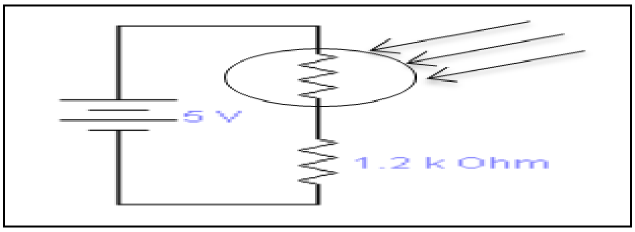

Fig.(6) LDR circuit diagram

4.4- Rotation System of PV Panel

The Table.3 show the rotation positions of the panel with respect to the light intensities of the two sensors. The DC motor rotates in steps and the panel tracks the sun light. Hence, the process of extraction becomes simple and easier. Figure (7) shows the schematic diagram for Arduino connection with two LDR and DC motor.

Light Intensity of Sensors	Rotation
LDR1 intensity is greater than LDR2 intensity	Anti-clockwise rotation
LDR1 intensity is less than LDR2 intensity	Clockwise rotation
Light intensities at LDR1 and LDR2 are equal	Stand still i.e. constant position

Table.3 rotation positions of the panel with respect to the light intensities of the two LDR sensors

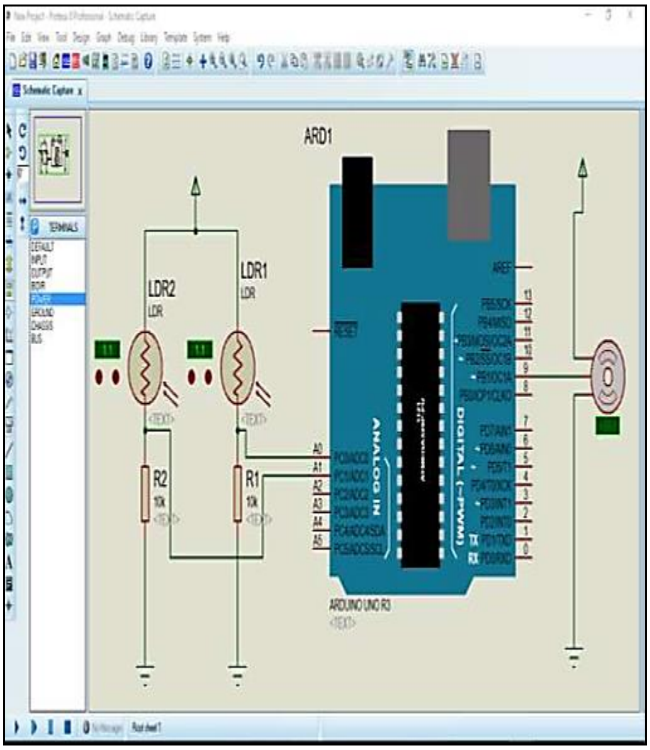

Fig.7 schematic diagram of LDR connection with Arduino and DC motor.

4.5-Current sensor

The ACS712ELC is a current sensor makes current measurement as shown in figure (8). It is powered by the controller board with 5V input voltage [23]. One current sensor is installed. It is used for photovoltaic panel in order to measure the current generated by the systems and the voltage send to Arduino to be show in LCD.

- With Current Limit: 30A
- Sensitivity: 66mV/A

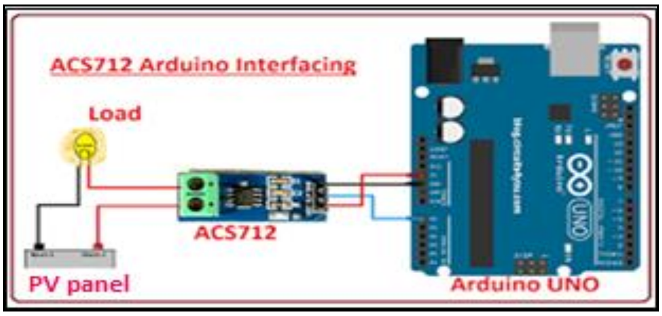

Fig.8 the current sensor connection with solar panel by load controlled through Arduino

4.6-Temperature sensor

The LM35 is temperature sensor of the PV modules is a factor that can influence the production of electricity in the panels [24], so it is a variable that should be monitored. In the present case, a LM35 temperature sensor is used with Micro-Arduino. LM35 send value to Arduino to be shown at LCD as in figure (9).

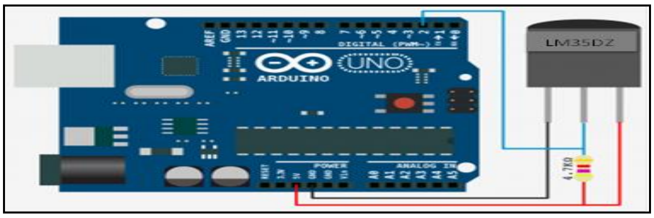

Fig.9 Microcontroller with temperature sensor

4.7-LCD (Liquid Crystal Display)

Liquid crystal display is an electronic display module, and locates an extensive variety of uses since they are effortlessly programmable as figure (10). Those values are read by Arduino and, it sends those values to LCD screen as shown in figure (11) and figure (12) show that L1 represent LDR 1 value by lux and L2 represent LDR 2 value by lux.

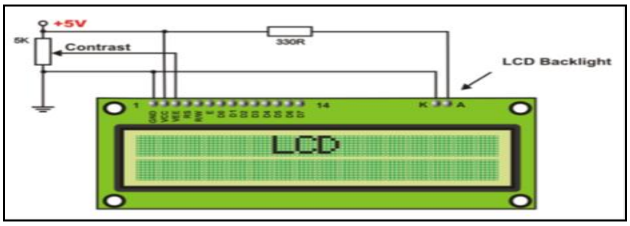

Fig.10 LCD circuit diagram

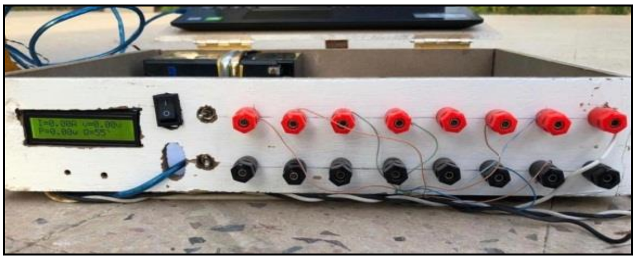

Fig.11 LCD show the voltage, current, power and angel value

Fig.12 LCD shows the temperature and LDR1, 2 values

4.8-DC motor and drive system

The motor controller had been chosen because it can control the motor to rotate clockwise and counter-clockwise easily and vice versa. This PIC programming will give the pulse to the driver to move the motor. Hence the driver bidirectional DC motor control using relay has been used. The DC motor receives the input data from a light power sensor. As Dc motor has high speed and low torque but for rotating solar panel as in figure (13), it is needed low speed and high torque

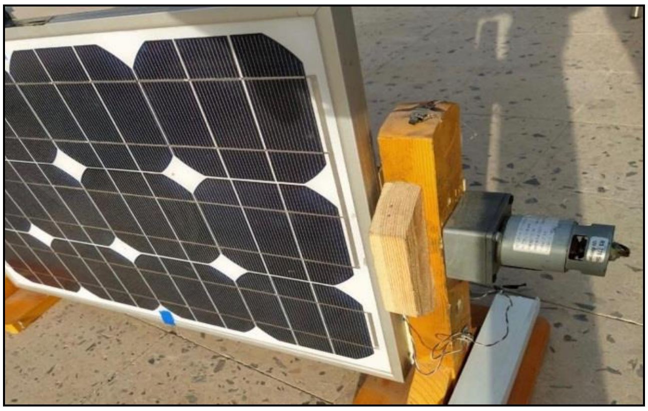

Fig.13 DC motor and tracking system experimental set-up

DC Motor Specifications

Voltage:	6:12 VDC
Output Power	2.2 W
Gear Ratio	1:75
Rated Speed	133 RPM
Rated Torque	25.4 N.cm
Stall Current	3A
Encoder Type	Hall effect quadrature encoder 5v (monitor position and direction of rotation)

Table .4 Specifications of DC

4.11-Relay module (2 Channels - 12V)

The relay module consists of 2 relays as shown in figure (14). Each relay is connected to a current buffer so that it can be connected them directly to a controller as shown in figure (15). The connections to Arduino microcontroller side as below:

- VCC - supply voltage. 12V.
- IN1 – Direction clockwise
- IN2 – Anticlockwise
- GND - ground

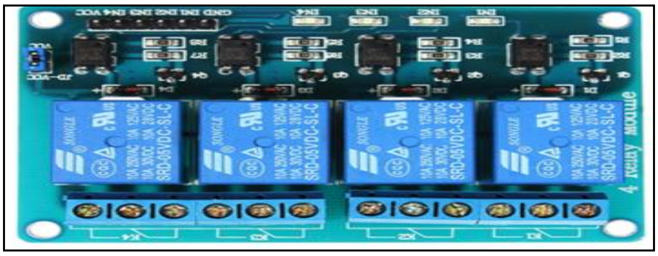

Fig.14 Relay model

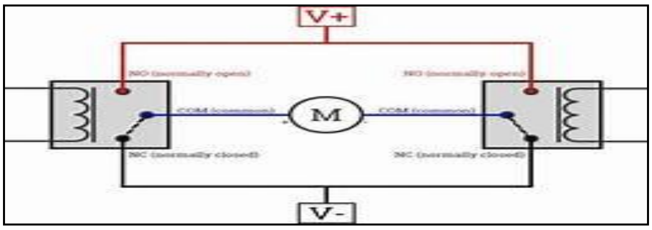

Fig.15 Schematic circuit diagram of relay

4.12-Rotary encoder

The purpose of shaft encoders is shown in figure (16), where a U-shaped photo-couple made of an Infra-Red sender and a matching receiver is positioned in a certain way so that the beam of infrared light passes through one of the small openings in the encoder disk. Figure (16) U-shaped photo couple the encoder disk is firmly connected to the back-shaft of the motor, so that both the shaft and the encoder disk rotate at the same R.P.M.

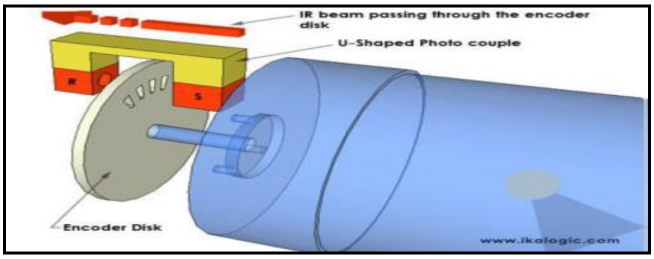

Fig.16 Schematic diagram of rotor encoder operation

5-Overall of solar tracking system

The proposed overall solar tracking system consists of two parts namely software (SW) and hardware (HW) parts. Figure (17) shows the schematic diagram of proposed tracking of solar tracking system and figure (18) shows the schematic diagram of the experimental set-up of the system. The following section describes the two parts.

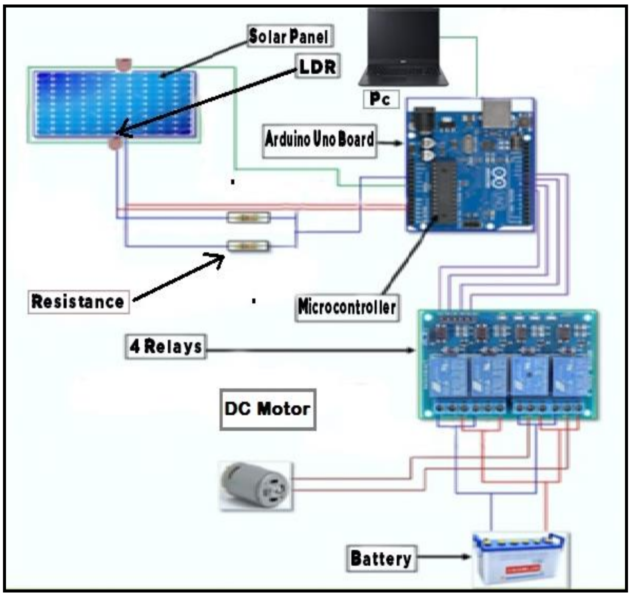

Fig.17 Schematic diagram of solar tracking

Fig.18 Overall solar tracking experimental set-up

5.1- Software part of solar tracking system

Using Proteus software package program is used to simulate the solar cell system to track the best position with respect sun site as in figure (19).

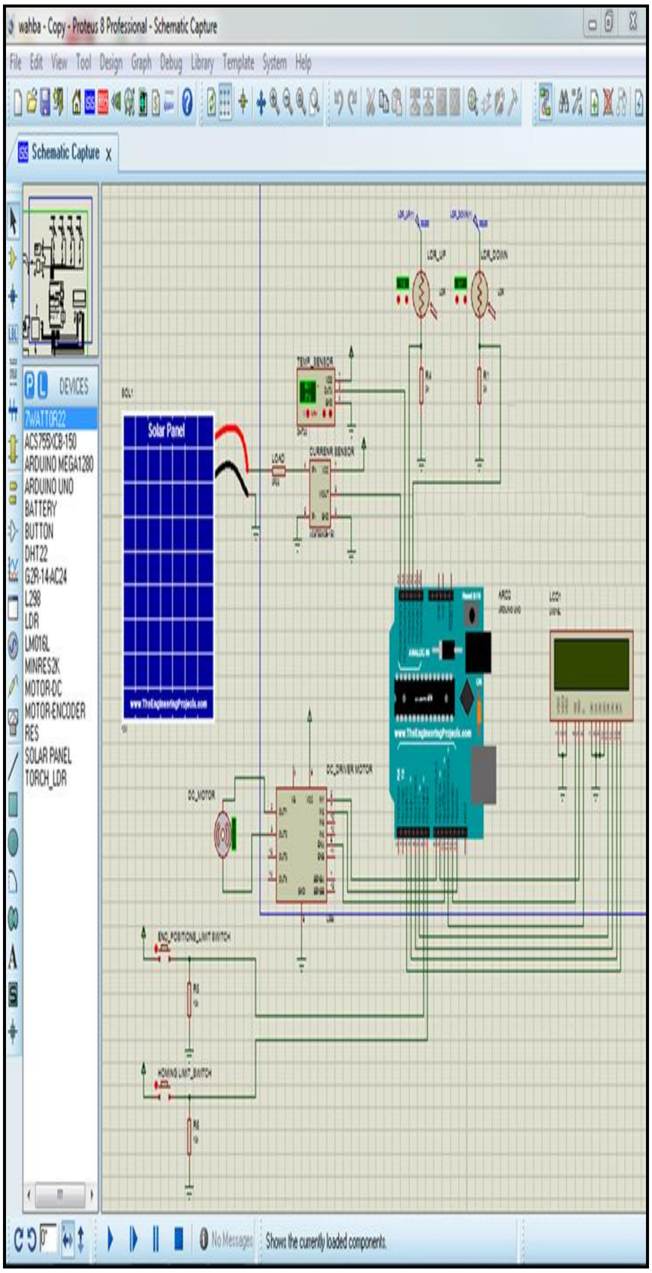

Fig.19 Schematic diagram of solar tracking simulate by Proteus

5.2-Methodology

This proposed tracking system is divided into two parts, hardware and software programming development. Figure (20) shows block diagram of the tracking system.

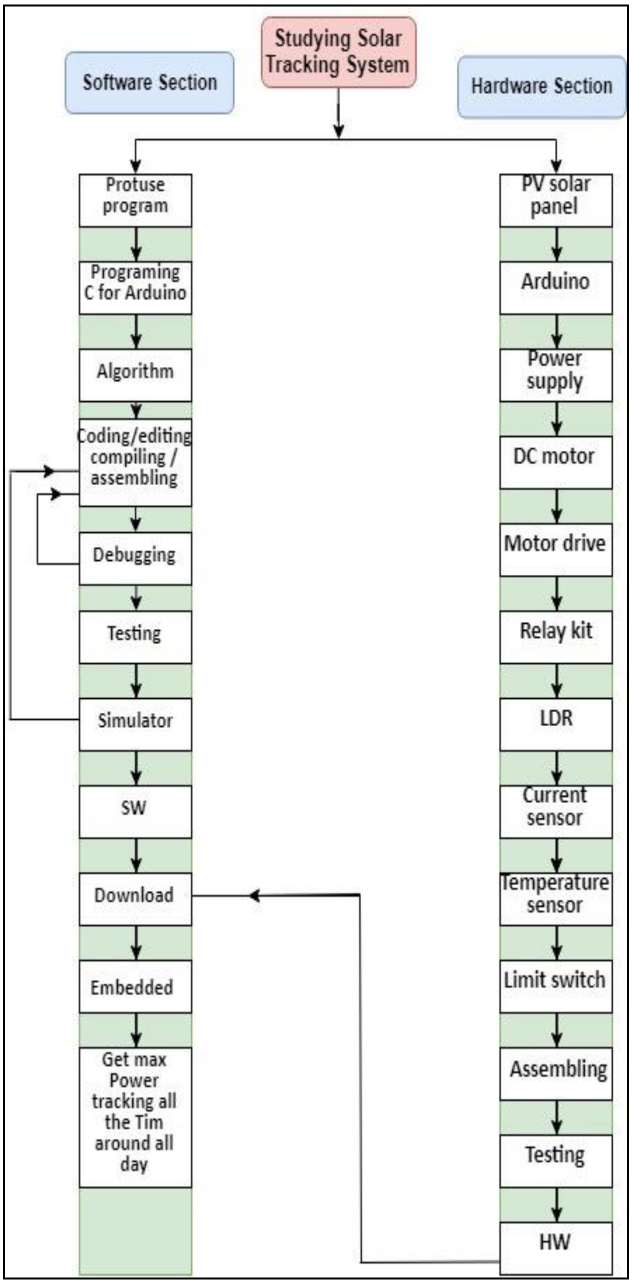

Fig.20 Methodology of solar tracking steps

5.3-Flow chart

The given flow chart shows the order of steps taken in the process for designing and working of solar tracking system. The system is designed in order to respond to the sunlight incident on the solar panel, according to which the movement of solar panel is done. Working of system is controlled by Arduino microcontroller from the flow chart it can be seen that initially the position of both the motors is being set after that the voltage of LDR is checked. After this process the orientation of sun is being estimated, according to which the sunlight falls on the LDR. There are 2 LDR used on 2 sides of solar panel at which sunlight falls, out of these works for vertical movement of panel, as a result of which the panel moves in clockwise/anticlockwise direction. The direction of movement of panel is always in the direction of maximum sun light. So, the solar tracker provides higher efficiency. The following Figure (21) shows the flow chart of solar tracking system

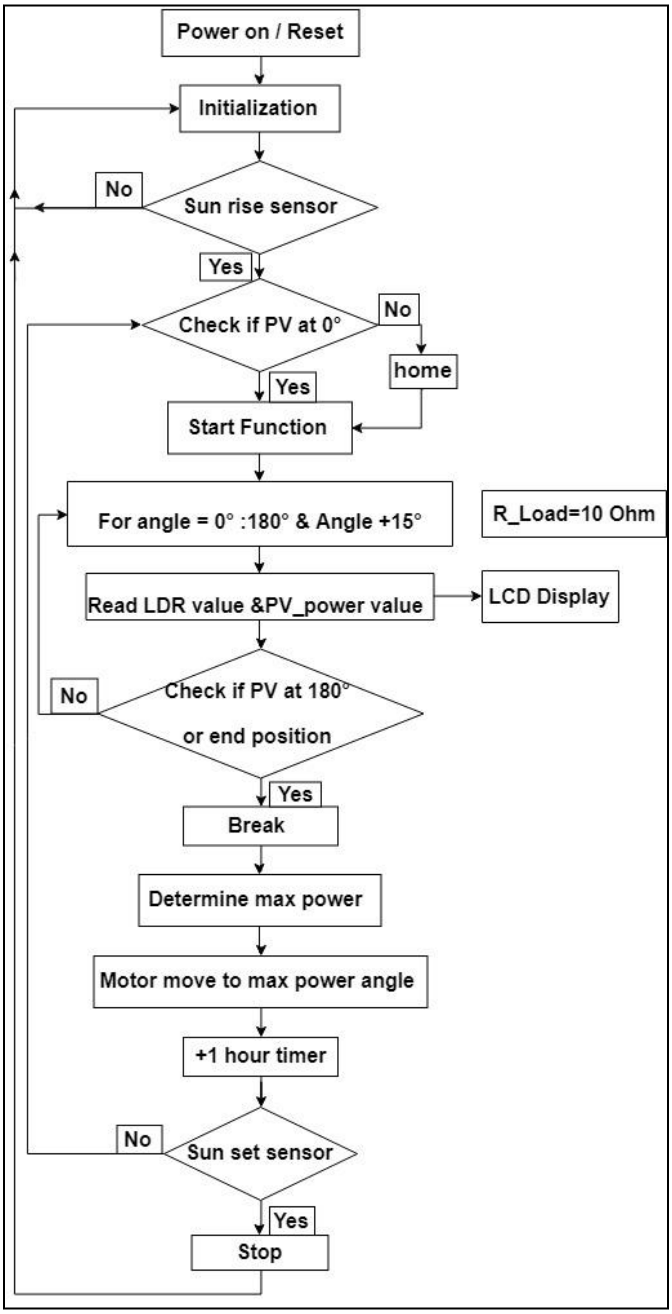

Fig.21 Flow chart of solar tracking

6 Experimental Simulation Results and Discussions

The different proposed mechanical tracking control system of solar panel are simulated experimentally using the current sensor ,Arduino controller, temperature sensor , radiation sensor ,DC motor drive, position encoder and LCD display. There are three tracking control namely, fixed motion tracking control, single axis solar tracking control and digital stepping rotation tracking control system. The following sections yield the experimental results of the three tracking control system.

6.1 Experimental results of fixed tracking control technique

The solar panel is fixed at 60^{o} degree and using the current sensor with resistive load, output voltage and output power of solar panel are reported under one day from 8:00AM to 6:00PM. The voltage and the power are calculated by Arduino and LCD displays the results from Arduino. The table [5] depicts the experimental results. From the table [5] the maximum power happened at 1:00 PM and its value 19.52 watt. The values in table [5] are drawn in Figure (22) to show the relations between the time versus current, voltage and power. From the results it is noted that this tracking control technique cannot give the power values at different positions of solar panel with respect sun site under daily hours.

Table.5 Fixed solar Panel with angle 60 degree from Y axis

Time	Voltage (V)	Current (A)	Power (W)
8:00 AM	15.133	0.15	2.27
9:00 AM	16.263	0.38	6.18
10:00 AM	15.167	0.888	13.47
11:00 AM	14.523	1.11	16.12
12:00 PM	15.760	1.21	19.07
1:00 PM	16.973	1.15	19.52
2:00 PM	16.53	1.17	19.35
3:00 PM	15.60	1.08	16.85
4:00 PM	17.109	0.576	9.86
5:00 PM	12.085	0.52	6.25
6:00 PM	10.9166	0.387	4.23
SUM	**166.0596**	**8.621**	**133.17**

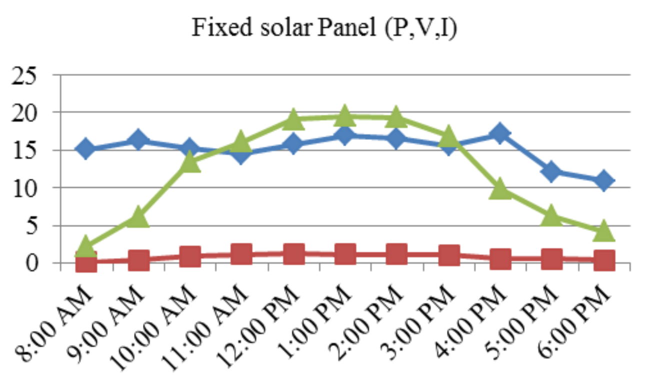

Fig.22 the experimental results of Fixed solar Panel

6.2- Experimental results of Single axis solar tracking control technique

Due to defects in the fixed tracking control, the single axis solar panel tracking control technique is proposed. The two LDR devices are built in the solar panel, one in east and the other in the west. The object of LDR devices to estimate the maximum radiation of the sun on the solar panel. If maximum radiation is displayed on LCD the motor drive move and rotate the solar panel at LDR position which has maximum radiation controlled by Arduino controller. The current values are measured and the output voltage is determined using load resistance. The Arduino calculates the output power at different positions of LDR devices under hours of one day from 8:00 AM to 6:00 PM. The table [6] shows the experimental results. From the table [6] the maximum power occurred at 1:00 PM of 23.16 watts values.

However may be a certain position has maximum power, the single axis tracking control follows it between these positions of single axis tracking control technique. Figure (23) illustrates the relation between day time versus current, voltage and power.

Table.6 The relation between day hours versus output voltage, current and power suing single axis tracking control technique

Time	Voltage (V)	Current (A)	Power (W)
8:00 AM	13.47	0.585	7.89
9:00 AM	14.3	0.785	11.22
10:00 AM	15.975	0.962	15.37
11:00 AM	17.01	1.16	19.71
12:00 PM	17.28	1.25	21.72
1:00 PM	17.16	1.35	23.16
2:00 PM	17.03	1.34	22.85
3:00 PM	16.75	1.20	20.13
4:00 PM	15.625	1.053	16.45
5:00 PM	14.9	0.69	10.35
6:00 PM	10.45	0.53	5.54
SUM	**169.95**	**10.905**	**174.39**

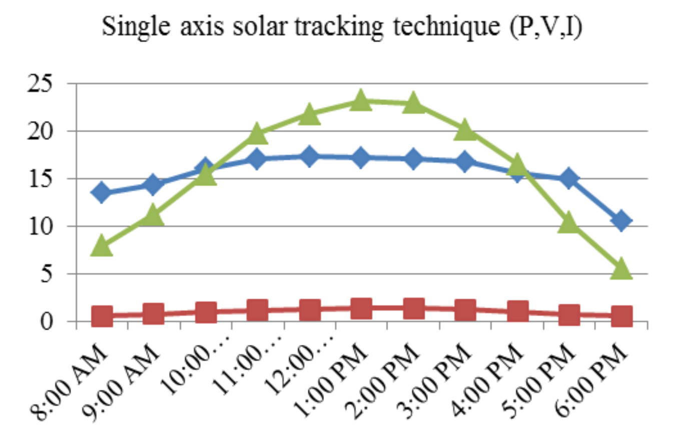

Fig.23 the experimental results of Single solar Tracking Panel

6.3 Experimental results of Digital Stepping Rotation Tracking Technique

The Digital stepping rotation tracking control technique is based on rotating the solar panel every 10^o degree over 180^0 the values of current and output voltage and power is determined with radiation using LDR devices. The motion is carried out using motor drive controlled by Arduino controller. At each step angle rotation, the power is determined for certain daily hour. After 180^o rotation the maximum power is determined, whereupon the solar panel at maximum power is moved and its angle is determined. The table[7] shows the relation between daily hours versus resistive load voltage, current ,power and the angle position of solar panel at maximum power .The proposed tracking control technique has advantages in terms of the maximum power is determined over different position at one hour of the day. Figure (24) depicts the relation between daily time versus current, voltage, power and the best angle of maximum power.

Table.7 The relation between daily hours versus resistive load voltage, current, power and the angle position of solar panel at maximum power

Time	Voltage (V)	Current (A)	Power (W)	Angle (Degree)
8:00 AM	16.29	0.64	10.43	20
9:00 AM	13.29	1.020	13.56	40
10:00 AM	12.29	1.4	17.21	60
11:00 AM	16.99	1.39	23.72	80
12:00 PM	17.22	1.43	24.63	80
1:00 PM	17.24	1.55	26.66	100
2:00 PM	16.86	1.52	25.67	100
3:00 PM	17.205	1.36	23.43	120
4:00 PM	16.54	1.27	21.14	140
5:00 PM	13.59	1.03	13.95	160
6:00 PM	15.87	0.48	7.59	180
SUM	**207.99**	**13.09**	**173.385**	

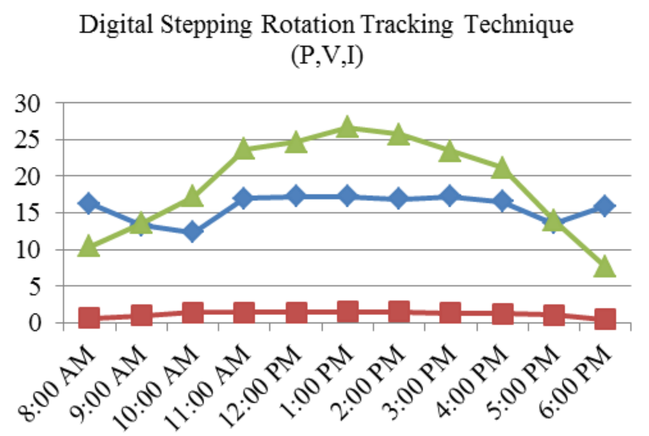

Fig.24 the experimental results of Digital Stepping Rotating Tracking.

6.4-Comparsion Output Power Between Fixed Solar Panel , Single Axis Solar Tracking Technique And Digital Stepping Rotation Tracking Technique

The following section shows a comparison between the proposed mechanical tracking controls of solar panel in terms of out power during daily hours. The results prove the powerful and effectiveness of the proposed digital stepping rotation technique in sense of output power during daily hours as shown in table [8] and Figure.(25).

Table 8 Comparison Output Power between Fixed Solar Panel, Single Axis Solar Tracking Technique and Digital Stepping Rotation Tracking Technique

Time	Power of Fixed solar Panel (watt)	Power of Single axis solar tracking technique (watt)	Power of Digital Stepping Rotation Tracking Technique (watt)
8:00 AM	2.27	7.89	10.43
9:00 AM	6.18	11.22	13.56
10:00 AM	13.47	15.37	17.21
11:00 AM	16.12	19.71	23.72
12:00 PM	19.07	21.72	24.63
1:00 PM	19.52	23.16	26.66
2:00 PM	19.35	22.85	25.67
3:00 PM	16.85	20.13	23.43
4:00 PM	9.86	16.45	21.14
5:00 PM	6.25	10.35	13.95
6:00 PM	4.23	5.54	7.59
SUM	133.17	174.39	207.99

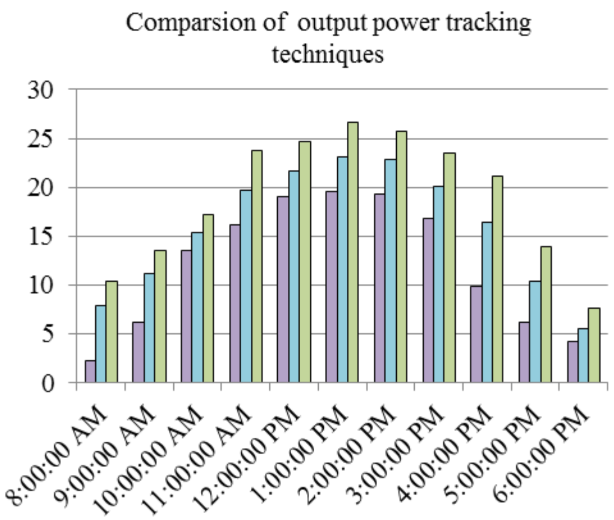

Fig.25 the experimental results of Output Power between Fixed Solar Panel, Single Axis Solar Tracking Technique and Digital Stepping Rotation Tracking Technique

6.5 Comparison the total of output power between Fixed Solar Panel, Single Axis Solar Tracking Technique and Digital Stepping Rotation Tracking Technique

The following graph shows a comparison between the proposed mechanical tracking control of solar panel in terms of total output power during daily hours. The results prove the powerful and effectiveness of the proposed digital stepping rotation technique in sense of the total output power during daily hours as shown in table [8] and Figure.(26).

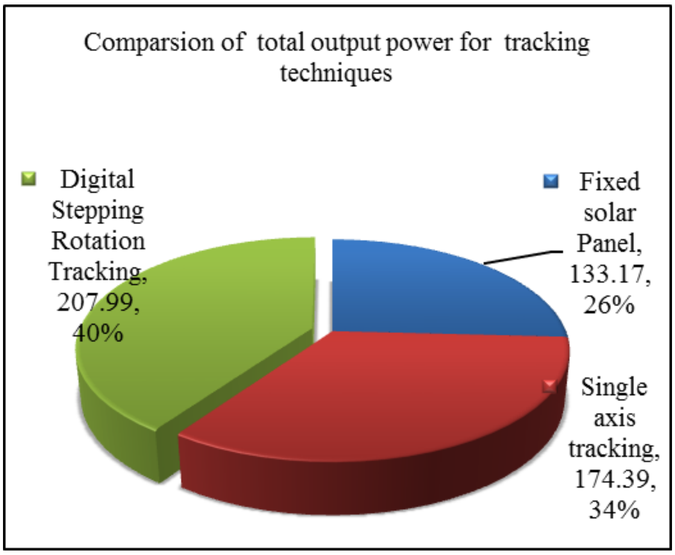

Fig.26 The total output power for tracking techniques

Conclusion

This paper clearly illustrated the effectiveness of tracking of solar power by considering the rotation of the PV panel .Specifically; it demonstrates a working model for maximizing solar PV cell output by positioning a solar array at the point of maximum light intensity. Single Axis Solar Tracking System prototype model has been successfully designed and tested. The main concern is to design appropriate circuits and the circuits supposed to be able to control DC-gear motor rotation direction without considering motor speed. The system is able to track and follow Sunlight intensity in order to estimate maximum solar power regardless of motor speed. The unique of developed system, motor speed is not critical consideration because the DC-geared motor offers low output rated speed and high output rated torque. Therefore any types of DC-geared motor can be used for this system regardless of motor speed controller unit as long as the speed and torque of the motor are following the given specification. The constructed system model can be applied in the residential area for alternative electricity generation especially for non-critical and low power appliances. The proposed system is low cost and compact as compared to the other tracking systems in use for same application. Also it is very easy to program and modify because it is Arduino based and no external programmer is required. Moreover the designed system is easy to use and provides better efficiency of the panel. Also In the developed system real time data is retrieved on the Arduino device.

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