Design and prototyping of dual axis solar tracking system for performance enhancement of solar photo-voltaic power plant

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Abstract. Increase in the world energy demand has made renewable energy source as one of the best option. It is finding wide utility in comparison with the other sources of energy. Solar energy is one of the major source of renewable energy. The abundance of solar energy in India makes it highly desirable to exploit but due to the limitations of technology, only a fraction of the energy can be extracted and used. This paper describes a concept for solar detection sensor implementation in Photo-Voltaic (PV) dual-axis solar tracking systems. The system uses only three units of identical light-detecting- resistors (LDR) arranged on the three sides of tetrahedron geometry and is able to track the light source position at the strongest intensity of visible light. On the basis of comparative study of outputs of all the three LDRs, the panel will tilt so as to get maximum output from the system. This system results in a wide field of view with minimum error and also has advantages in terms of sensor quantity, size of the system, accuracy and effectiveness.

1 Introduction

In India around 470 million tons coal is used in 2017by various thermal power stations which produces lots of pollution.[8] Also, in year 2017-18 the total energy requirement in India was around 915123 million units (MU) but total energy available was around 908650 million units (MU). So, in 2017-18 there was energy shortage of around 6473 million units which is of 0.71% of total energy requirement in India. Similarly, peak demand in India in year 2017-18 was around 164066 Megawatt (MW) and peak met was around 160752 megawatt (MW). So, peak shortage in India in year 2017-18 was around 3314 megawatt (MW) which was of 2% of total peak demand. [8]
In today's era of modern science and technology, the socio-economic development depends on electric energy. However, in developing countries, this electric energy is in demand and very poorly mismanaged. Also now a days there is a shortage of fossil fuels and pollution incurred upon their use. So to reduce this energy crisis the renewable energy can play the very important role. As the solar energy is a clean renewable energy source, it gets more and more attention, especially in the field of electricity generation. There are different tracking systems with several tracking strategies designed and tested by various scientists all over the world.

2 Literature Review

[1] In 2016, Yuwaldi Away and M. Ikhsan from Indonesia newly designed a dual axis sun tracker sensor based on tetrahedron geometry. Three LDRs were arranged on three sides of tetrahedron. Depending upon comparison of outputs of three LDRs, the system rotates to get the equal outputs from all three LDRs. This system is further tested in single and multiple light sources arrangements. It has an advantage of less complexity with less number of LDRs and has wide range of Factor of View (FOV).
[2] In 2017, Meita Rumbayan, Muhamad Dwisnanto Putro from Indonesia proposed asingle axis tracking system to improve the panel efficiency. There were eight LDRs as sensors - four at four corners and four at four sides of a solar panel, a servo motor as actuator and an Arduino as the controller. The proposed system results consists of system design, hardware design andalgorithm design.
[3] In 2014, Shahriar Bazyari, Reza Keypour, Shahrokh Farhangi, Amir Ghaedi, Khashayar Bazyari, compared different photo-voltaic solarpanel tracking systems in Qushm Island. This paper also include the received solar radiation density associated in summer, autumn and in winter. Further it includes the graphical comparison in fixed panel system, single axis tracking system and the dual axis tracking system. Accordingly concluded that the panel with single axis tracker receives 1.35 times more energy than the fixed panel, while the dual axis tracker receives 1.04 times more energy than the single axis tracker.
[4] In 2017, Jerin Kuria kose Tharamuttam, Andrew Keong Ng from Singapore designed an active type solar tracking system which can precisely track the sun positions. The developed system contains the hybrid algorithm strategy which contains both sensor (four LDRs) as well as the mathematical models of the sun position to detect the current position of sun and accordingly Arduino Controller will rotate the panel with the help of two motors. Further the real time monitoring of the solar data is done on the webpage also the graphical

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comparison between the active, chronological, fixed mounted and the proposed hybrid system on sunny as well as on cloudy day is done. This proposed hybrid system has advantage in all-weather condition as compare to the other systems.

[5] In 2014, Yingxue Yao, Yeguang Hu, ShengdongGao, Gang Yang, Jinguang Du designed and prototyped a dual axis solar tracking system which works on both solar time base strategy as well as on sensor based sun positioning strategy. The proposed system rotates 15°/hr. Due to combination of both the strategies, the proposed system requires less energy input with tracking error which is below 0.15°.

[6] In 2014, Jeng-Nan Juang and R. Radharamanan designed & developed a dual axis solar tracking system for standard sized homes as a supplementary power source or as an independent power source. The proposed system contains four LDRs as sensors, two linear actuators and an Arduino Uno as micro-controller. This system has low cost, low power consumption, user friendly light weight structure with wheels mounting.

[7] In 2014, Mayank Kumar Lokhande, designed & developed an automatic single axis solar tracking system for low power and residential usage applications. The proposed system contains the two LDRs as sensors, anew design of controller parts and the geared DC motor as actuator. This system can successfully track the current positions of the sun and can be used for non-critical and low power applications.

The existing tracking systems have complicated sensor strategies so has high cost and maintenance issues. Many researchers from all over the world have developed so many solar radiations sensing devices and tracking strategies but they contain large number of LDRs which makes them complicated. So, use of minimum number of LDRs for the development of Perfect Tracking System is the objective of this work.

3 Problem identification

The common problem in solar Tracking is the complex movement of sun. For a specific longitude, the sun moves from east to west along a fixed solar path everyday. But the sun moves through 46° north and south during 21st June to 21st December which is as shown in below figure 1. A dual axis solar tracker can account for both the daily and seasonal motion of the sun.

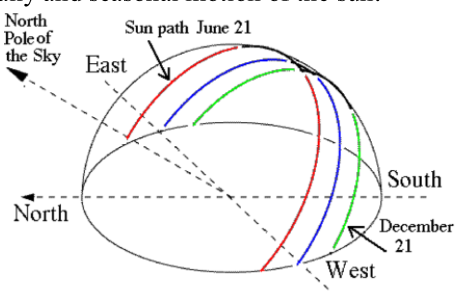

Fig.1 Path of Sun during different seasons[3]

4 Principle of Solar Tracking

In a day, sun moves from east to west and seasonally it also moves in north and south direction. But the PV panel system gives the maximum ammount of power absorption when the panel is perpendicular to the sun rays. So, it is advantageous to have the solar panels track the location of the sun, to get the maximum power output.

There are two types of Solar tracking systems as active & passive. Active solar tracking system uses electronic sensors, actuators to track the current positions of the sun. Whereas the passive solar tracking system uses the liquid od low boiling point so that it gets evaporated due to sun's heat and accordingly the solar tracking is done.

5 Methodology

To achieve the perfect tracking, active type solar trackers are more precise as they work on real time data coming from the sensors. Here, the light sensing sensors such as photodiodes OR Light Dependent Resisters (LDR's) detect the intensity of light. This light intensity is converted into the equivalent resistance by the LDR.

This output of LDR is given to microcontroller which detects the maximum intensity light direction according to the Program fed to it. Microcontroller with the help of program instructions will actuate the motor/s, enabling the system to move to a particular direction.

The block diagram of the system is shown in figure 2. As per the signals coming from microcontroller the motor (in case of single axis tracking system) or motors (in case of dual axis solar tracking) will turn the system to the direction of maximum intensity light.

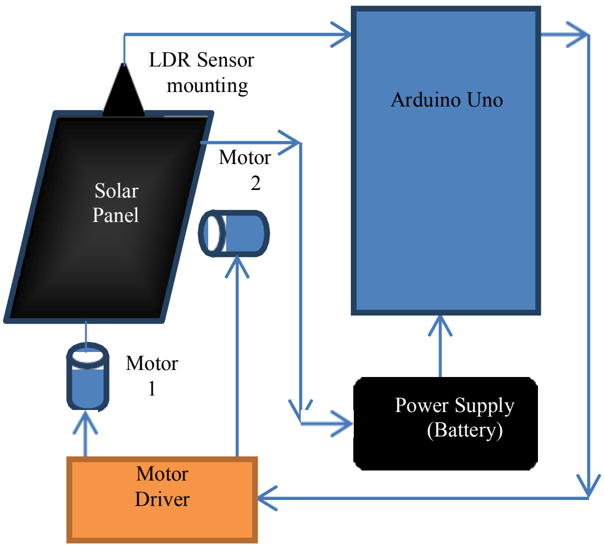

Fig.2 Building Block diagram of the system

6 Design of System

6.1 Modelling in Catia V5R20 Software

The basic model of the proposed system is drawn in Catia V5R20 software as shown in below figure 3. This basic model contains the tetrahedron sensor geometry, Solar panel platform, Two Motors, base plates, etc.

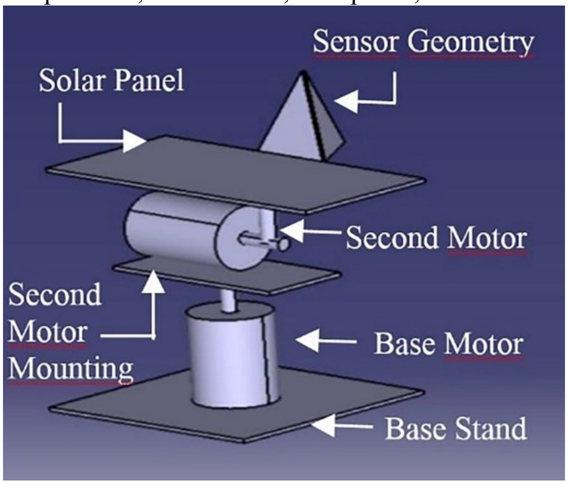

Fig.3. Catia Model of the System

6.2 Energy consumption by system

As system is of active type, it will require energy to operate. The load calculations as well as the system consumption are calculated as given below:

6.2.1 Panel Calculations

Energy generation by a panel
= Solar Irradiance * Solar Cell Area * Cell Conversion Efficiency (1)
Energy generation by a panel
= 5440 Whr/m²/day * (0.17 m * 0.32 m) * 0.16
Energy generation by a panel = 47.4 Whr/day

6.2.2 Battery Calculations

Battery Power = Voltage * Current (2)
Battery Power = 12 V * 14 Ah
Battery Power = 168 Whr

Battery can be dischargeable up to 80 % Therefore,
Actual Power = 168 * 0.8
Actual Power = 134.4 Whr

6.2.3 Motor Torque

Weight of Solar Panel = 1.100 kg

Therefore,
Torque required to rotate the panel
= Weight of panel * perpendicular distance between motor shaft and the panel (3)
Torque required to rotate the panel = 1.100 kg * 5 cm
Torque required to rotate the panel = 5.5 kg-cm

6.2.4 Load considerations

LED bulbs – 3 (5 Watt each) Backup – 8 hours
So,
Load Energy Consumption = 120 Whr

System consumption

Motor Power = P = V*I (4)
Motor Power = P = 12 * 0.3
Motor Power = P = 3.6 Watt

Considering tracking of sun for 12 hours from East to West, total 180˚ (i.e. -90˚ to +90˚)
Therefore,
Angle of rotation per Hour for motor1 = $\frac{\text{Total angle}}{\text{Time}}$ (5)
Angle of rotation per Hour for motor 1 = 180˚/12
Angle of rotation per Hour for motor 1 = 15˚/hour

Motor speed is 3.5 rpm
So, for one revolution motor takes 60 seconds /3.5 rpm =17 seconds
So, to rotate half revolution required time is 17/2 = 8.5 sec. = 0.0025 hr

Therefore,
Energy consumption by motor1=Motor Power*Time (6)
Energy consumption by motor1= 3.6 * 0.0025
Energy consumption by motor1= 0.00875 Whr
Energy consumption by motor1= 8.75 mWhr

On consideration of seasonal tracking motor will rotate 47˚ * 2 = 94˚/year

So,
Angle of rotation per Hour for motor 2 = $\frac{\text{Total angle}}{\text{Time}}$ (7)

Angle of rotation per Hour for motor 2 = $\frac{94°}{24\text{hr}*365\text{days}}$

Angle of rotation per Hour for motor 2 = 0.01˚/hr

As 0.01˚ is so small we can neglect it. Therefore,
Total Energy consumption
= Load Energy Consumption + System Consumption (8)
Total Energy consumption = 120 + 0.00875
Total Energy consumption = 120.00875 Whr

7 Selection of Components

The components used to achieve the dual axis solar tracking are mentioned as follows along with their specifications.

7.1 Light Dependent Resister (LDR)

It is a light sensor whose resistance changes with the change in light intensity. It has wide range of performance, it can sense the small change in light intensity.

Fig.4 Light Dependent Resister (LDR)

7.2 Arduino Uno Development Board

Microcontroller : Atmega328P
Operating Voltage : 5V
Input Voltage (limits) : 6-20V
Digital I/O Pins : 14
Analog Input Pins : 6
Clock Speed : 16 MHz

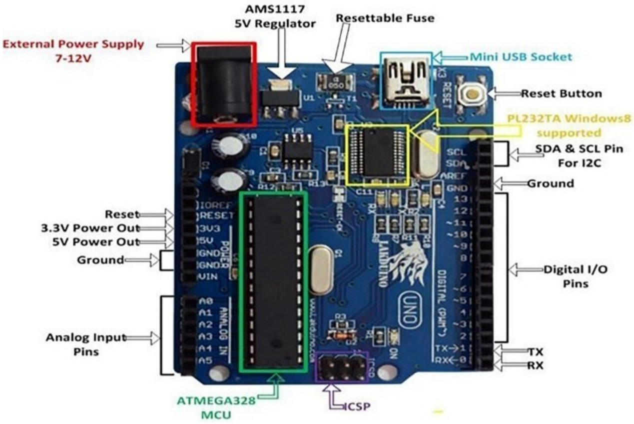

Fig.5 Arduino Uno

7.3 DC Motor

We require a high torque (to withstand the weight of the system) and a low speed (to achieve a precise angle of rotation) motor. So here we use 3.5 rpm geared DC motor.

Specifications and Features:
RPM : 3.5
Operating Voltage : 12 V
DC Gearbox : Attached Spur gearbox
Shaft Diameter : 6mm with internal hole
Torque : 7 kg-cm
No-Load Current : 60 mA
Load Current : 300 mA

Fig.6 DC Geared Motor

7.4 Solar Panel

Panel Technology : Mono crystalline
Output Power : 10 Watt
Operating Voltage : 12 Volt
Cell Conversion Efficiency : 16%
Number of Cells : 36
Weight: 1.100 kg

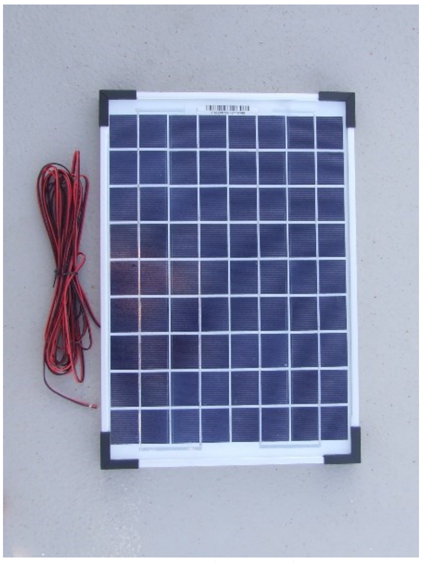

Fig.7 Solar Panel

7.5 Battery

Brand : Exide
Rated Capacity : 7 Ah
Battery Voltage : 12 V
Items in Pack : 2 (Parallelly Connected)

Fig.8 Battery

7.6 H Bridge Motor Driver

L298N Dual Motor Controller Module allows us to control the speed and direction of two DC motors. This can be used with motors that have a voltage between 5 and 35 V DC.
Double H Bridge Driver Chip : L298N
Logical Voltage : 5V
Drive Voltage : 5V-35V
Logical Current : 0-36 mA
Drive Current : 2A

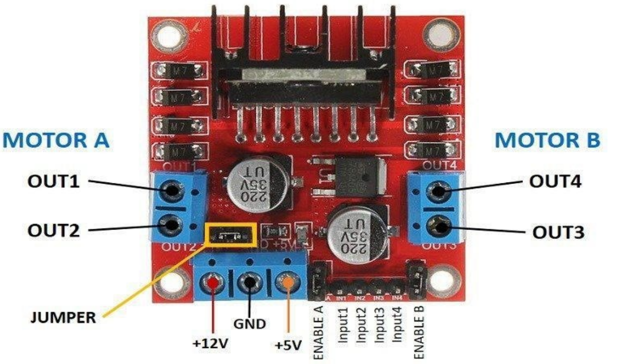

Fig.9 L298N H-Bridge Motor Driver

The all components required for execution of proposed dual axis solar tracking system are listed in the bellow given Bill of Material Table.

Table 1. Bill of Material

Sr. No.	Component Name	Component Description	Quantity
1	Arduino Uno kit	Generic Uno R3 ATmega328P	1
2	H bridge motor controller	L298N Dual Motor Controller Module	1
3	LDRs	10mm Diameter	3
4	Motors	3.5 RPM 12V Geared DC Motor	2
5	Solar Panel	10W Mono-Crystalline Panel	1
6	Battery	Exide 12 V, 7 Ah Lead-Acid Battery	2
7	Wires	3 meter	3
8	LED Bulb	5 Watt DC LED Bulb	1
9	Base Stand	CI material	1
10	Sensor Geometry	Aluminum Sheet	1
11	Black color	Metal Spray Color	1

8 Arduino Programing

First the analog data coming from the three LDR sensors are read and saved to the variable memory locations a, b and c. Then according to the equation given in the Arduino program flow chart the values of X and Y are calculated. According to the values of X and Y variables and the If-Else statements used in the program the further digital outputs are given to the pins 9, 10, 11 and 12 on the Arduino board to ON and OFF the two motors.

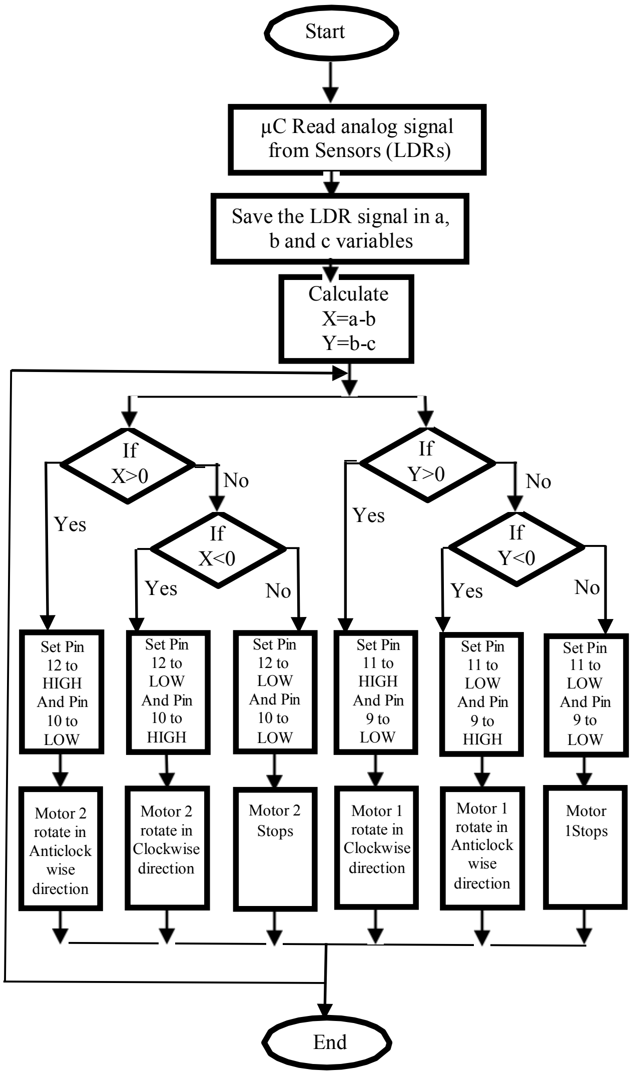

Fig.10 Arduino program Flowchart

9 Fabrication & Assembly

The various components such as sensor geometry, base motor and second motor mounting are done separately and then assembled with each other as well as with the electronic system also.

9.1 Sensor Geometry

The tetrahedron geometry is used to mount the three LDRs on the three sides of tetrahedron and the connecting wires are taken from the base side of the same.[1]

The whole structure of the tetrahedron is made in CR steel material. The one connection of each LDR is connected to the 100 KOhm resister whereas the other connection of LDR is connected to the +5 Volt DC supply. The other connection of 100 KOhm resister is connected to the Ground and the Arduino pin connection is taken from the junction between LDR and Resister. For three LDRs there are three Arduino pin connections and connected to the analog input pins A0, A1 and A2 on the

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Arduino board. The sensor is mounted on the top of the solar panel to get the actual light from the sun.

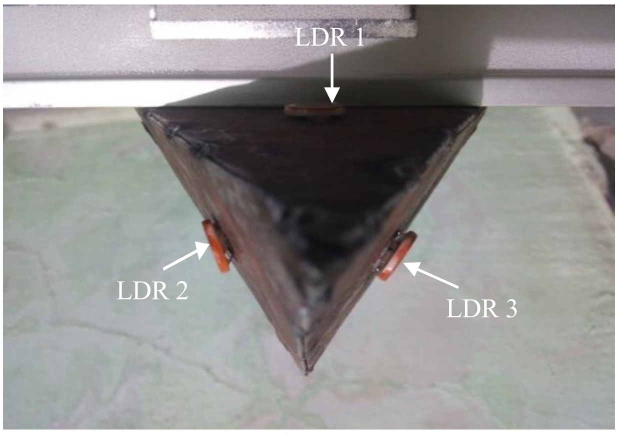

Fig.11 LDR Mountings on Sensor Geometry

9.2 Base Motor Mounting

The base motor is mounted vertically on the base plate to track the sun from East to West that is the daily motion of the sun. The base plate of the second motor is directly weld connected to the shaft of the base motor.

Fig.12 Base Motor Mounting

9.3 Second Motor Mounting

The second motor is mounted horizontally on the first base motor and it will track the sun from south to north which is the seasonal motion of the sun. On the shaft of the second motor, the solar panel is welded through a connecting rod.

Fig.13 Second Motor Mounting

9.4 Solar Panel Mounting

The solar panel is connected from the center with the connecting rod with the help of weld joint. The other end of connecting rod is connected to the second motor shaft with the help of weld joint.

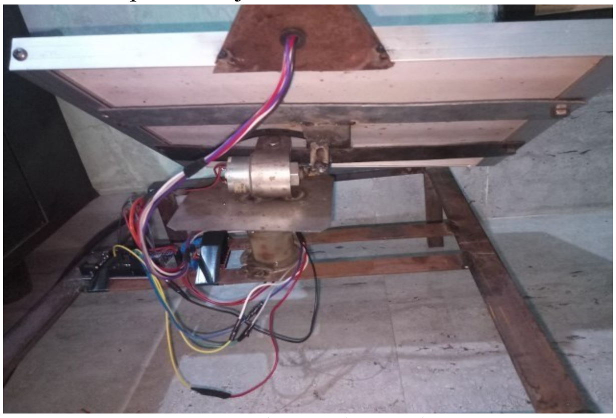

Fig.14 Solar Panel Mounting

9.5 Arduino Uno board connections

The 12 Volt DC supply is given to the Arduino board through the wire from the battery unit. The three LDR output signal wires are connected at the A0, A1 and A2 analog input pins of the Arduino board.

The output signals of Arduino board which are given to the motors as input signals to them are taken from digital output pin numbers 9, 10, 11 and 12.

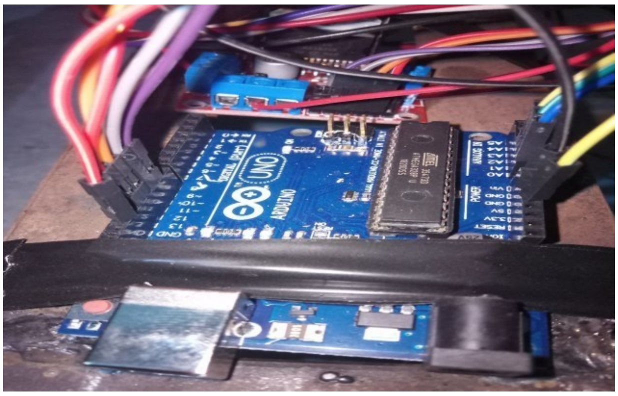

Fig.15 Arduino Uno board connections

9.6 Overall System

The overall system connections & assembly of the prototype of dual axis solar tracking system is as shown in figure 16.

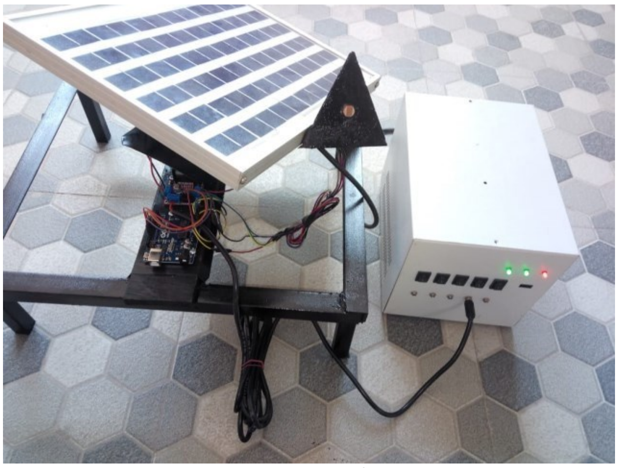

Fig.16 Prototype of System

10. Summary

The manufactured dual axis solar tracking system is tested in solar light as well as in the normal tube light. In both the cases, LDR sensors perfectly detect the direction of maximum intensity light and accordingly rotate the solar panel to that direction. The input energy required to drive the system is as calculated above and which is 0.00875 Whr. The output energy can be calculated from the multi meter readings of voltage and current with respect to the time. Also the efficiency and the net tracking advantage of the system can be calculated from the following equations.

Therefore,

$$\text{Efficiency of the system} = \frac{\text{Output Energy}}{\text{Input Energy}} \tag{9}$$

$$\text{Net Tracking advantage} = \frac{E_t - E_{wt}}{E_{wt}} \tag{10}$$

Where,

E_t = Energy Produced with Tracking

E_{wt} = Energy Produced without Tracking

The manufactured dual axis solar tracking system tracks the current and exact position of sun and which can be cross checked by using Astronomical Equations. The Solar Panel moves from East to West in a day as well as from North to South in a year (according to the seasonal movement) in a direction of maximum light source i.e. Sun. The system uses only three LDRs. Thus, the complexity of tracking strategy is eliminated & system is made simpler.

11. Conclusion

The manufactured dual axis solar tracking system will increase the Energy efficiency considerably as it tracks the daily as well as the seasonal movements of the sun. Due to increase in efficiency, the size of solar panel & cost of power generation will reduce for the same power generation capacity in comparison with the fixed solar panel.

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