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Design, Fabrication, Testing and Performance Evaluation of Double Axis Solar Tracker

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Abstract— The traditional energy sources used from decades for the purpose to generate electricity and fossil fuels depletion fear are the factors making world to search for the alternative energy resources. Pakistan is located in such a region have blessed with high potential of solar energy but due to the expensive initial cost and unpredictable nature of solar energy makes it uneconomical. Shortfall in most of the rural areas because of no access to grid energy. Although some remote communities serve only by fuel generators for a time being, but increase in the price of fuel makes the system non-economical, also the fuel generators have harmful effect by emiting carbon dioxide and carbon mono oxide gases. To decrease dependency on hydrocarbon base generator the Solar systems are used to overcome the shortage as a best solution for harnessing the carbon free energy. To increase the output of the Solar system the dual axes tracker is presented in the research, which is designed, to track the solar energy along both of the axes for a solar PV module. The PV module operates efficiently at maximum power point as Sun light is incident perpendicularly on it. The tracker will keep the PV module just at angle perpendicular to the solar energy to harness it at best possible amount to use for different purposes.

Keywords— Renewable Energy Resources, Solar PV, PV module types, Solar tracker, Dual axis Solar tracker.

I. Introduction

The energy is a basic need in the modern era and has an excessive demand for the daily life activity. The energy can be harnessed form the resources present naturaaly that are the sources for the generation of useful energy. The resources can be differentiated into Non-Renewable and Renewable resources. The Non-renewable resources also called as fossil fuels is a leading source form decades to generate the energy for the survival. But with the passage of time these resources are considered to be vanished in unknown time. In view of the prevailing energy crisis resulting into excessive load shedding and low voltage, the world is using all options to meet the daily demands of energy. To make sure that we can provide the society with the energy that is needed in our everyday life, and to ensure that energy is used without degrading our planet, there is a need to look into the possibilities of using alternative energy sources, in particular carbon free energy. The renewable resources like solar energy, Wind energy, Biomass energy, geothermal energy and tidal energy are harnessed to overcome the shortfall of energy.

A. *Renewable Energy Sources:*

The energy resources which is easily available through out the human time scale and can be renewed either naturaly or some other process in a known time period. The world is full of theses type of resources, explained as follow:

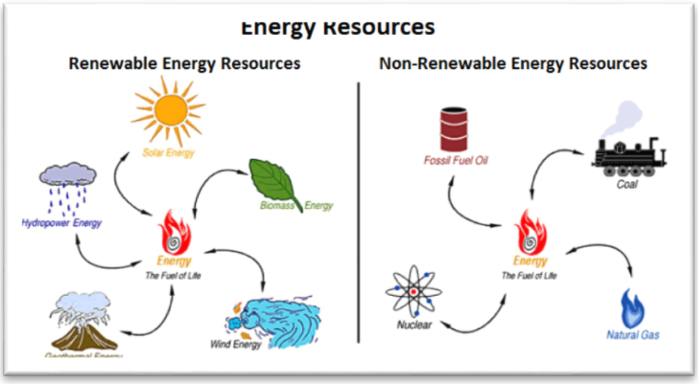

Fig. I.1 (Energy Resources: Renewable / Non-Renewable)

i. Hydro Energy:

The hydro energy also known as the hydroelectric power is harnessed from the flow of water. The water as a natural source has the potential to generate the electric power by using the turbines. The turbines are installed in the path of flowing water. The water flow provides the mechanical energy to rotate the turbines, producing the electrical energy. This energy is transmitted through the transmission lines to the site of utilization.

ii. Wind Energy:

The wind blowing has energy in the form of kinetic energy. This energy can be harnessed through the wind mills having turbines that rotates with the wind, producing electric power. The turbines known as the wind turbines are placed in the areas where there is good wind like the sea site.

iii. Geo-Thermal Energy:

The Earth surface maintains its temperature due to solar radiation. Beneath the Earth surface, there is high temperature., used for the purposes of running the steam engines. The steam produced underground rotates the steam turbine which generates the electric power. The geo thermal energy can be used for the heating purpose. The energy generated from the Earth crust is the Geo-Thermal energy which is clean carbon free.

iv. Tidal Energy:

The tidal energy or tidal power is the power which is extracted from the energy of the tides/ waves of water in the sea, turbines are fixed in water converting the mechanical energy of the waves to electrical power. Tidal energy has traditionally suffered from high costs and limited site availability.

v. Biomass Energy:

The biomass are the organics of the residues of the animals and plants. It is the form of renewable energy which is easily availability in nature. The plants store energy of the sun and convert it to the organic materials stored in them by photosynthesis process. The biomass burned later on releases energy in the form of heat. This heat can be utilized for the purposes of heating and steam generation which in turn can be used to run steam turbines. Also the chemical energy from the biomass can be converted to biogas and can be used for useful purposes like cooking, heating and others.

vi. Solar Energy:

The energy from the Sun is commonly known as solar energy. The solar energy can be harnessed and can be used for different purposes by using different methods. The solar energy can be used for heating purposes like drying of wet clothes and for drying of the fruits. Solar mirrors are used to concentrate/ focus the solar radiation on a point to get the desired working emperatures. The Solar energy can also be converted to the electrical energy by the use of the Solar PV modules[1]. There are different ways of generating electricity from the sun's energy. The most popular are Photo voltaic (PV) Panels, where silicon solar cells convert solar radiation to electricity.

II. SOLAR ENERGY

The energy form the Sun is the Solar energy can be harnessed for different purposes. It can be harnessed by two ways:

a) *Solar Thermal Energy:*

The Solar energy is a continuous sources of heating. The thermal energy we get from the sun directly. This thermal energy can be used for drying the wet clothes, also can be used for the cooking purposes by using the solar concentrators as well as for drying of fruits. The Solar Concentrators are the concave mirrors which focus the Sun light on to specific areas. The Solar concentrators focus the thermal energy at one point for desired purpose. The solar concentrator mirrors shown in Fig.i and Fig.ii are used to collect the thermal energy to heat up the steam engines which run on heat to give the electric energy as output.

Fig.II.1 (Solar Concentrators focus Solar energy on a Fixed tower in center)

Fig.II.2 (Solar concave concentrator Dish focus Solar light on a fixed point)

b) *Solar Electrical Energy:*

The solar energy which is composed of photons converted to electric energy and used for the different applications. The photovoltaic (PV Module) (Fig.iii) used for the purpose gives Electric Energy in the form of Direct Current when the Sun light is incident on the PV module, can be converted to Alternating current by using inverters.

Fig.II.3 (PV module composed of PV cells to generate the direct electric current)

III. SOLAR PV MODULES

The solar PV modules are here by designed for the conversion of the Solar energy to useful electric current directly to be used for different purposes. The PV modules are the assembly of the PV cells, which are connected in series. The PV cells are the basic unit to generate the electric current when the

Sun light is incident on it. The PV cells are basically the photo diodes which energizes as the Sun light is incident.

As the sun light is incident on the PV cell energizing the elctrons make exited form its atomic shell. The electrons energized are collected through the bus bars which is connected to the out terminals of the PV module.

The bus bars passes from each cells collects the Energy from the whole cells of the PV module which is collected at the terminals at the back of the PV module.

i) PHOTOVOLTAIC CELL:

The photovoltaic cells are manufactured of the silicon which is a semiconductor dopped with the periodic table group 3A and group 5A elements making the P-type and N-type materials. The P-type and N-type combines to make a cell. Thus having a P-N junction the PV cell known as the Photo Diode.

Fig.III.1 (Photovoltaic cell; PN Junction Dioded)

a) N-TYPE MATERIAL:

The N-type material is made of the semiconductor element that is the silicon dopped with the elements of Group 5A of periodic table having an excess of electrons, thus the N-type materials having excessive electrons in it.

b) P-TYPE MATERIAL:

The P-type material is made of the semiconductor element that is the silicon dopped with the elements of Group 3A of periodic table having an dearth of electrons, thus the P-type materials having dearth of electrons in it and having holes in surfeit

c) P-N JUNCTION:

The P and N-type materials are then combined togeather making a diode that is the P-N Junction diode also called as the Photo Diode or PV Cell. These cells are then arranged in series making a PV module.

d) GENERAL OPERATION:

The cell equivalent circuit is a current source which is in parallel with a diode, in practice no solar cell is ideal, thus a shunt resistance is connected in parallel with this diode and a series resistance is added. The equivalent circuit of a solar cell is shown in Figure (Fig.III.2)

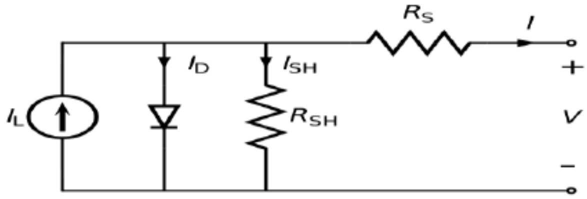

Fig.III.2(PV module cell equivalent circuit considered as current source)

The model in Figure above can be mathematically defined as

$$Ipv = IL - Io\,[eq(Vpv + IpvRs)/nKT - 1] - Vpv + IpvRs/Rsh$$

where Ipv is the output current of the PV cell, which is a function of its output voltage Vpv.

As light rays falls on the diode the solar cell is activated and the energy from the electron is received by the end electrodes which are attached to the cell at the back side. Isc is the short circuit current and Voc is the open circuit voltage. The slopes of the I-V curve can be adjusted by the shunt resistance Rsh and series resistance Rs in the PV cell model. Maximum power point (MPP) exists for each of the curve for the PV array producing maximum of power for a given irradiance and temperature.

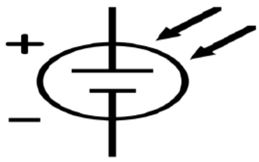

Fig.III.3(Schematic Symbol of Solar Cell)

As light is incident on it the electrons are energized, developing the negative and positive polarity as shown. The cells are arranged in series and parallel to make a module that is called Solar panel. The arrangement of the cells in series mode increases the voltage. The output voltage of one cell is up to 0.5V. When light is incident on these cells it generates energy at the output which is received at the electrodes and is used for different purposes. As the light is incident on the cell, some of the light rays reflect back while some of the rays strike the PN Diode showing below in figure.

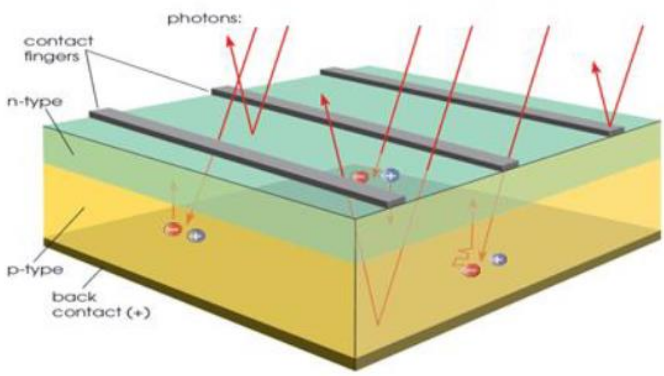

Fig.III.4 (Light rays incident on solar cell)

IV. SOLAR TRACKER

The Solar panels are generally fixed to a pole or the roof top, but the challenge remains to maximize the capture of the solar radiation for conversion into electricity. Most of the panel installations are fixed arrays. As the day passes, the sun moves from east via south to west moving away from the facing position of the panel which normally faces south and thus the power output of the panel decreases. The easiest way to overcome this problem is to adopt a moveable solar panel using sun tracking mechanism, which is relatively simple and can meet the needs of most small applications. The simplest way of getting more energy out of a solar panel is to have it track the Sun.

The PV modules are normally installed in the South direction. The Sun arises from the East daily and sets in the West. It passes from the east to west via the south. The PV modules are placed in the South direction as the Sun is for maximum duration in the South side and having maximum irradiance. In the fixed condition the PV modules should be placed at such an angle on average basis to get the maximum irradiance from the Sun. Normally the PV module is placed in fixed position facing the south direction at a tilt angle* of 30 degrees to get the maximum amount of energy form the Sun. This is placed in this position for the whole year that is in all seasons. The main problem with the fixed position is that we can't get the whole of energy from the Sun for a full day. For this purpose, trackers should be installed to get the maximum energy from the Sun.

In the fixed position we lose energy at the positions in the East and West sides respectively. The tracker is installed to get energy from the rising of the Sun up till it sets back in the West. For this purpose, the single axis trackers are designed to track only the Sun along one axis that is from East to West. The tracker thus moves along with the Sun. But the Sun also changes Zenith angle, so the single axis tracker cannot get the Sun in both the directions. Therefore the dual axis solar tracker is used to track the Sun in two directions that is from East to West and from South to North.

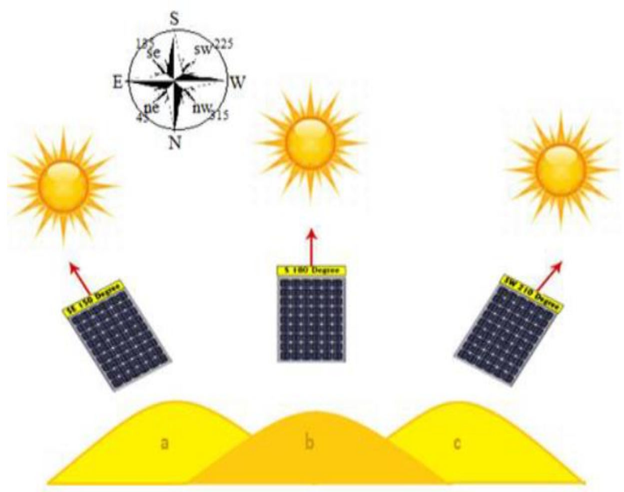

Fig.III.1(PV module at different spots at various angles to Sun)

a) The above figure [Fig.13] shows that if the PV module is placed in the South East direction, the PV module will be able to generate maximum energy in the morning hours but will no longer be able to give good output as Sun moves to the West.

b) In the South direction, the maximum amount of energy will be received from the Sun in the noon hours.

c) In order to get the maximum power in late hours the PV module should be placed in the South West direction.

South PV module needs to be re oriented from time to time to get the desired output at that specific time and direction. So it is desirable to track the sun throughout the day from East to West and South to North.

TYPES OF TRACKERS

Solar trackers are here by differentaied according to the working and the designing of the Tracker. Different trackers designed for the tracking purposes described below as:

a) ACTIVE SOLAR TRACKERS:

The active solar trackers are the ones that use the control circuit which detects the Sun light via sensors and thus rotates the PV module in that direction with the motors and gears interfaced with the control circuit. The control circuit uses the control IC's and sensors. The sensors detect the Sun light and pass a pulse or signal to the circuitry which activates the motors. The other may have the timing relays or programmed as such to move the whole structure accordingly with tim.

b) *PASSIVE SOLAR TRACKING:*

The passive trackers are designed by the use of other methods like using the compressed gas and fluids having low boiling point. As time passes the fluid heats up with the time creating an unbalance position for the structure. In order to remain in balance, the tracker moves in one direction or in the other direction as the fluid cools down.

c) SINGLE AXIS SOLAR TRACKER:

The single axis solar tracker is designed for the tracking of Sun only with respect to one axis such as from the East to West. The single axis solar tracker can not change the tilt angle with the change in the altitude of the Sun. So the tracker should be installed with a tilt angle of 30-35 degrees. The tracker will track the Sun from East to West normally and will be like the fixed structure along the other axis.

d) HORIZONTAL AXIS SOLAR TRACKER:

In this type of tracking system, a long horizontal tube is supported on bearings mounted upon the tube and the tube will rotate on the axis to track the apparent motion of the Sun throughout the day. As they do not tilt towards the equator therefore they are not much effective during the winter midday (unless located near the equator), but these tracking systems are productive during the spring and summer seasons when the solar path is high in the sky. These devices are less effective at higher latitudes.

e) VERTICAL AXLE SOLAR TRACKERS:

In this type of tracking system, the panels are mounted on a vertical axle at a fixed or adjustable tracking elevation angle. Such trackers with fixed or (seasonably) adjustable angles are suitable for high altitudes. This is because at high latitudes the apparent solar path is not especially high but which leads to long days in summer, with the Sun traveling through a long arc.

f) DUAL AXIS SOLAR TRACKER:

The dual axis tracker works like the single axis tracker in tracking the Sun from East to West, but can also track the Sun angularly form South to North. The dual axis solar tracker thus has dual circuitry for tracking or can use one control circuit along with two sets of gears and motors.

g) ALTITUDE AZIMUTH SOLAR TRACKER:

Here the mounting is done in such a way so that it supports the entire weight of the solar tracker and allows it to move in both directions and point towards the sun. As tracking an object from the earth is more complicated due to the rotational movement of the Earth. For this reason computer controlling is required.

h) TWO AXES MOUNT SOLAR TRACKER:

In two axis mount, one axis is a vertical pivot shaft or horizontal ring mount that allows the device to be swung to a compass point. The second axis is a horizontal elevation pivot mounted upon the azimuth platform. Using this combination of the two axes any location in the upward hemisphere can be pointed. Such system needs computer control or tracking sensors to control motor drives that orient the panels toward the Sun.

V. DUAL AXIS SOLAR TRACKER

The dual axis solar tracker is described as the type of the tracker that can track the Sun along both the axes like horizontally and vertically. The vertical tracking is to track the sun in azimuth direction. As the Sun arises daily in East and moves towards the West direction with respect to an axes that is vertical. So the tracker has to follow the path to rotate the panel along the direction of maximum irradiance. Thus the PV module in the presence of the maximum irradiance gives maximum output.

The horizontal tracking is to track the Sun in elevation that occurs from morning to noon and then from noon to sunset following from zero to a maximum of 90o and then back to zero. So the PV module is placed at an angle for maximum irradiance. Both the horizontal and vertical tracking systems combine to makes a Dual Axis tracking system. To track the Sun along both the axes modifications are needed in the structure on which the PV module is placed. The dual axis solar tracker has electric control circuit part and the mechanical structure part described individually.

i) ELECTRIC CONTROL CIRCUIT

The control circuit is the electronic part of the tracker. That is composed of the electronic components to control and track the sun. The control circuit which is the compulsory part senses the Sun light full time using the sensors and moves the trackers in the direction of maximum irradiance. The Electric Control Circuit is a DC operated circuit that works on 12V DC. Electric control circuit is composed of the sensors that are the LDR's used along with the NPN and PNP transistors, Relays and the Motors to rotate the structure.

The electronic circuit composed of the above described components that are Sensors, Transistors, Comparator IC and the relays used for the switching purposes. The circuit is shown below in figure.

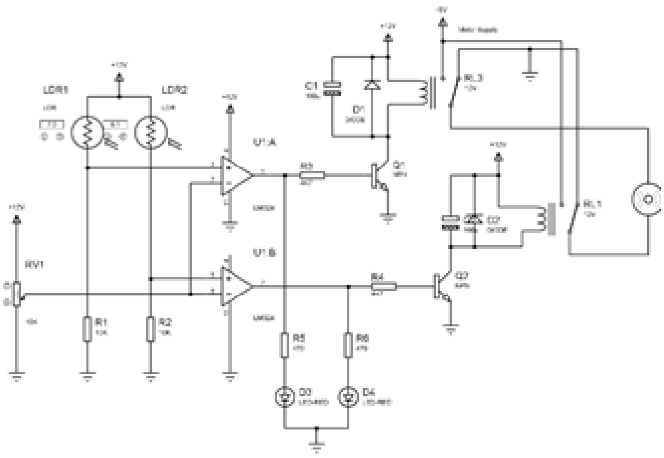

Fig.V.1 (Electronic control circuit at no load or non operational as light is not incident on the sensors or having the same intensity of light on the LDR's)

As dual axes solar tracker needs dual circuitry that is able to run two motors at a time in the direction of sun light. Same circuits are used for the purpose of tracking both in horizontal axis and vertical axis. The tracker circuits are operated as the LDR's are activated. The LDR's that are the Light Dependent Resisters work as light is incident on them. The LDR's have two terminals, one is connected to 12V DC and other to the Comparator IC. Due to high resistance in the absence of light there is no flow so at the input 1 pin of the IC there is low voltage giving no output. The transistor connected to the output of the IC is switched OFF. Due to the OFF condition of the transistor, the relay is not triggered and is in switch off condition as the point is in normally open condition. This Results in the motor not running and the tracking is OFF in the absence of the light.

As the light is incident on the LDR's due to which the resistance becomes low depending on the intensity of the light, giving path to the flow of current and producing a potential at the terminal of LDR connected to the input 1 pin of the Comparator IC. The input 2 of the IC is connected to a reference voltage via the variable resistance, which can be varied for the desired reference voltage. As the Input 1 voltage from the LDR exceeds the reference voltage at Input 2 of the IC, a high voltage is given at the Base of the transistor. The transistor thus switches on and gives a high voltage at the collector as output. The output from the transistor is the input of the Relay trigger point, thus the relay gets triggered and the normally open mode is triggered to normally closed mode connecting the motor to the 12V/5V supply, and thus the motor starts running.

ii) CONTROL *CIRCUIT DESIGN*

The control circuit is designed using the electronic components for a 12volt DC motor that is used in the mechanical frame for the rotation of the whole structure described as above. LDR's are used as sensors that keep the relays in normally open condition through the transistors, which are switch off in normal conditions. The normally open condition of the relay cuts off the path of the current to the motor. As light is incident the transistors are switched ON, triggering the relay to normally closed condition, allows the motor to be connected to the high potential to rotate it. The motor is designed according to the load rotation. The PV module along with the structure that rotates is the load for the motor.

iii) MOTOR DESIGN

The DC motor as mentioned earlier has been selected for the whole tracking system. The DC motor is used in the tracker because of the DC power is produced by the PV module which will be used for the motor to run. The tracker can also be energized from the 12 Volt battery that will be charged from the power generated by the PV module. In the prototype a simple DC motor as described above is used, that there is only a load of a PV module that is quite enough to turn through the motor used. The motor will be able to turn the PV module to track the Sun light.

For the selection of the motor the weight of the PV Module along with the structure is to be calculated to find the power of the motor. The motor will turn the weight of the PV module and the structure in a specific radius in a time T. The power rating can be determined from the standard formula. The power of the to rotate the load it is given as

$$P \text{ (Watt)} = W/t$$

The power is the work done (W) per unit time. This is the Torque (T) on the load to rotate with an angular velocity. Thus power is given as

$$P \text{ (Watt)} = T * \Theta/t$$
$$P \text{ (Watt)} = T * \acute{\omega}$$
$$P \text{ (Watt)} = T * 2\pi * f$$
$$P \text{ (Watt)} = T \text{ (N. m)} * 2\pi \text{ (rad /rev)} * f \text{ (rev/sec)}$$
$$P \text{ (Watt)} = T \text{ (N. m)} * 2\pi \text{ (rad /rev)} * f \text{ (rpm)}/60$$
$$T = I \text{ (Kg.m2)} * \alpha \text{ (rad/sec2)}$$

Where the "I" is the moment of Inertia and the "α" is the angular acceleration. To determine the Power of the motor the load of the PV module along with the gears and Structure should be known. The moment of inertia of load is to be forced to be rotated and the distance of the load attached to the axel of the motor is the radius in which it is rotated.

iv) MECHANICAL STRUCTURE

The mechanical structure is an important part of the tracker as the PV module is placed on it. The motors are fixed in this structure. The mechanical structure has two axes (shown in Figure V.2). The base is fixed beneath on which a motor is fixed with a base plate that rotate a vertical frame. As the motor receive the signal from the relay, which is activated through the LDR's when light is incident on them, it starts the motor rotating in the relevant direction. There are two LDR's for the vertical axis fixed on the base palate. When Sun light is incident on one of the LDR's the motor runs in one of the two directions as the transistor connected to that LDR switches the relay on. If the light is incident on the other LDR, it switches the relay through the other transistor connected to it to run the motor in the opposite direction. For the horizontal axis tracking a frame is fixed on the frame of the base plate which rotates with the rotation of the first motor and holds a horizontal axis for the frame on which the Solar Panel is mounted. The whole frame rotates clockwise or anticlockwise with that of the horizontal motor. For the horizontal axis rotation, another two LDR's are fixed on the Solar panel along with the motor via the gears. The PV module along with the vertical frame rotates in the horizontal plane and with respects to the vertical frame in the vertical plane.

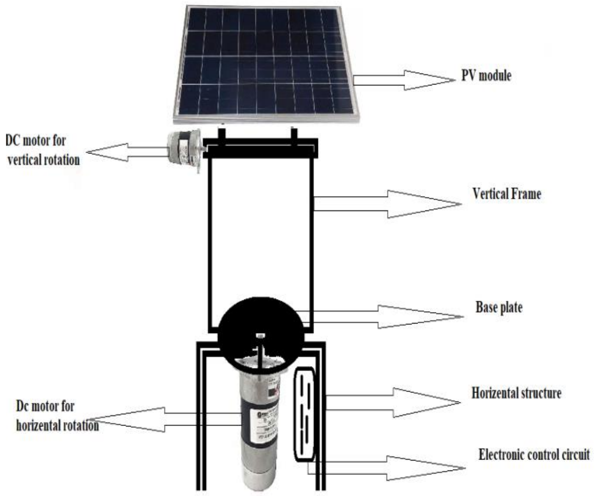

Fig.V.2 (Dual axes solar tracker sketch with mentioned different parts)

CONCLUSION

The tracker is designed that is capable to track the Sun in both of the axes to harness maximum solar energy. Formally dual axis solar trackers were designed using the programmable IC like PIC micro controller and Arduino and the timer relays. The timer relays and the programmable IC track the Sun as time passes. With time the tracker itself changes the direction by moving with a specific angle to track the Sun with respect to each axis to harness the maximum solar energy.

The tracker designed in the current work, uses low cost electronic components. The tracker uses the sensors that are the LDR's to sense the intensity of the solar radiation and rotates the tracker to move the PV module in the direction of the maximum irradiance. The tracker is capable of tracking the Sun along the horizontal and the vertical axes. The circuit is simple to be replicate. The tracker tracks the Sun at every angle and at each direction by sensing the light intensity. The light incident from any side will activate the motor to operate.

COMPARISON

The dual axis auto solar tracker is quite efficient than that of the single axis auto solar tracker and also than the fixed anchored soalr system as the double axis solar tracker trackes the Sun in both of the axis to harness the solar energy through out the presence of the solar energy. Moreover it occupy the same space as the single axis solar tracker. Although the hardware complexity is higher than that of the single axis Solar Tracker but the power efficiency of a double axis solar is around 25% more than that of the single axis solar tracker.

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