Design and Implementation of Automatic Solar Tracker Using a Novel Sensor for a PV System

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Abstract

Energy production has become a challenge for modern day engineers and researchers. The conventional, non-renewable, ways of producing energy are proving to be both insufficient and hazardous to the environment. Hence, a prudent solution is to shift to renewables. The most viable choice is solar energy as it is abundant and environment friendly. Solar energy is produced using silicon wafer based solar panels. Traditionally, solar energy was produced using static solar panels. This is a complication as the sun does not remain in normal to the solar panels all day. A solution, to actuate the panels. A similar approach is taken in this study where a dual axis solar tracking system is designed and implemented on a 2KW solar power system. The study starts off with modelling and controller design of the tracking system. Which is then followed by the design of lab mockups. LDR sensor is used as primary detection sensor in the first lab mockup, but the LDR has its drawbacks. Hence, a novel PV-panel based sensor assembly is designed and implemented in the second lab mockup. This system proved to be sufficient to be implemented on the final 2KW system. The main part of the sensor assembly design was the design of the differential shade. It is responsible for the detection of the sun at any given instance. A complete study regarding this design process was conducted and a final inner angle and dimension of the differential shade was acquired. The design, when implemented on the full-scale system, was fully functional and through a power test it was calculated that the dynamic system was able to produce an efficiency advantage of 5%.

Index Terms—Automatic solar tracking, LDR, PV Panels, Renewables, Solar energy.

I. INTRODUCTION

The modern age is considered as the era of technology and automation. With each advancement in the field of technology, the requirement for energy keeps on increasing. In Pakistan, a major chunk of energy that is being produced is from non-renewables.

Fig. 1 shows the Energy production mix of Pakistan for 2020. It can be clearly seen that renewables are contributing very little to total energy production. The energy production mix is dominated by the non-renewables. At the current rate, it is estimated that the reserves of fossil fuels will deplete in the next 50 years and natural gas will deplete in the next 53 years [2]. In addition, burning of fossil fuels leads to global warming. Fig. 2 shows the change in maximum average temperature of Pakistan. It also shows the precipitation in mm annually.

Another alarming fact is the energy production to usage ratio. Pakistan is facing an increase in energy demand whereas, the production rate is not up to the mark.

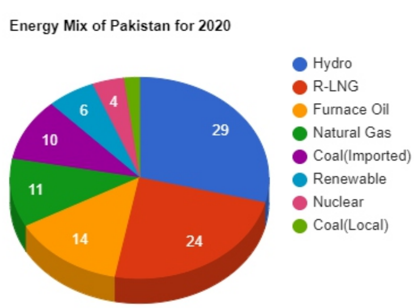

Fig: 1 Energy production mix of Pakistan for the year 2020 proposed for implementation [1]

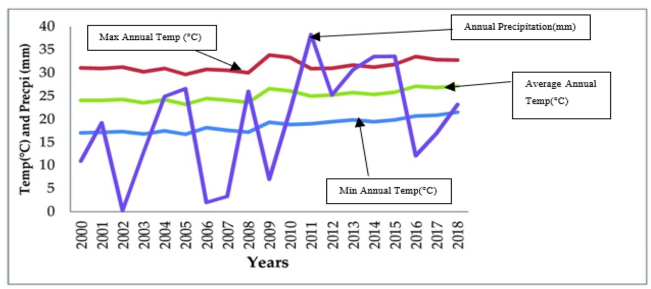

Fig: 2 Average temperature of Pakistan from 2000 to 2018 proposed for implementation [3]

To overcome these complications, it is required that non-renewables should be replaced with renewables. Renewables have a lot of potential. Pakistan, due to its geographical location, is an optimum location for the production from renewables. The most fitting option from renewables for Pakistan is solar energy. This is because of the geographical location of Pakistan and its environment friendly nature.

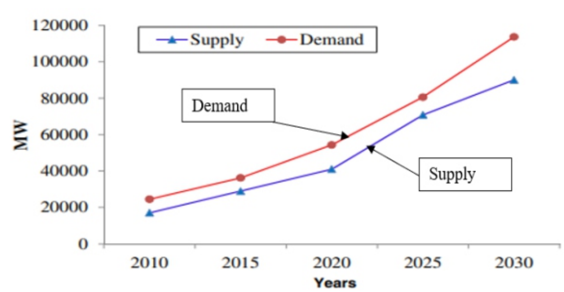

Fig: 3 Energy production and demand vs years [4]

A) Utilization of Solar Energy

Earth receives solar energy as electromagnetic radiation of a short wavelength between 0.3 and 3µm. At sea level solar radiation intensity ranges from 0 to 1070W/m^2 throughout the day [63]. This level of intensity reaches mainly on clear summer days. This everlasting source of energy can be used in the following major processes.

1. Heliothermal
2. Heliochemical
3. Helioelectical

1) Heliothermal

In this process, solar radiation is absorbed from the sun and converted into heat energy. This heat energy is used for many purposes such as distilling seawater into potable water, house heating, generation of electricity by vapor absorption cycle and attaining high temperature in furnaces.

2) Heliochemical

In this process, solar radiation can be used to facilitate chemical reactions. Chemical reactions include oxidization reaction and reduction reactions. It can also be used to detoxify toxic waste, sustain growth of plants, and can also increase the rate of reactions.

3) Helioelectical

In this process, solar energy by using photovoltaic cells can be directly converted to electricity. This electricity is then used for domestic purposes and for industrial applications.

B) Solar Radiation Intensity

The average distance of earth from sun is 150 million km and solar radiation intensity on the surface normal to the sun is 1370 ±3 W/m^2[11] .This value is known as solar constant.

The solar radiation incident on the earth depends on the length of path and different substances in atmosphere. The solar radiation that reaches the earth surface is partially absorbed, reflected by different substances such as air molecules, water vapor, ozone, dust particles clouds, and pollution. The radiation reaching the earth surface mainly consist of relected, diffused and directs the solar radiation which is then used for different purposes.

C) Solar Radiations in Pakistan

Pakistan, due to its position on the world map, is ideal for production of energy from the sun. Pakistan receives an astonishing 1500 W/m^2 to 2000W/m^2 of solar radiations per day [6]. This level of radiation is ample for the production of energy from the sun. Moreover, the temperature levels in Pakistan and its average temperature are ideal for the solar energy production

D) Production of Energy from the Sun

The radiation from the sun can produce energy. This can be achieved with the help of PV solar panels. The solar cells contain a pair of silicon wafers. One doped with phosphorous which acts as a negative and one doped with boron which is positive. This is the basic principle

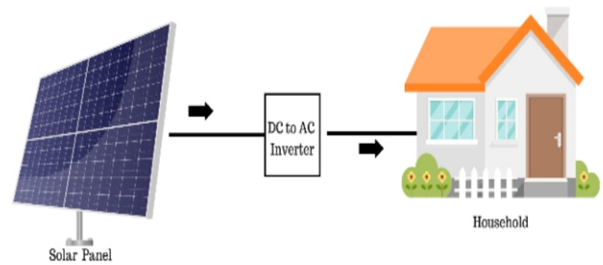

Fig: 4 Energy production and flow of electricity from solar panel to household

of generation of electricity using solar panels. When sunlight is incident on the solar panels, it generates an electric field. The electricity that is generated flows towards the edge of the panel, this further flows into a conductive wire. This electricity is then fed to the inverter. The inverter then changes the DC to AC. This AC can be used to power home appliances.

E) Types of Solar Collector

Solar Collector is a device that produces heat energy when sunlight is incident on them. There are three types of solar collector.

1. Flat Plate Collector
2. Focusing Collector
3. Passive Collector

1) Flat Plate Collector

This is the most common type of collector. There are solar panel assemblies arranged in a simple plan. It has an output that is directly related to some variables like size, coating, and cleanliness. Usually, this type of collector has automated machines to turn it towards the sun.

2) Focusing Collector

It is essentially a flat collector with optical devices arranged to maximize the radiation incident on the focus of the collector. It is currently only used in approximately dispersed areas. Solar ovens are examples of this type of collector. Although it can produce a much greater amount of energy at a single point than the flat plate collector, it loses some of the radiation that the flat plane does not produce. The focus collector is ideal for a solar furnace providing contamination-free environments for research and industrial use. The solar ovens are well suited for the

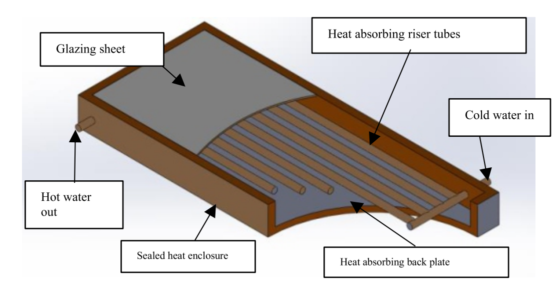

Fig: 5 Flat plate collector [55]

destruction of hazardous waste. By focusing a concentrated beam of light on hazardous waste, a variety of toxic chemicals are broken down, including dioxins and polychlorinated biphenyls (PCBs).

3) *Passive Collector*

The passive collector absorbs radiation and naturally converts it into heat without being designed and built for it. All objects have this property to some extent, but only some objects (like walls) can generate enough heat to make it worthwhile. Oftentimes, their natural ability to convert radiation into heat is improved in one way or another (e.g., by black paintwork) and a system to transfer the heat to another location is usually added. The simplest type is the intermediate heat trap. The idea is to let the maximum amount of light in a window and let it fall on the floor. During the day the area stays cool as the floor absorbs most of the heat, and during the night the area stays hot because the stone gives off the heat it absorbed during the day.

F) *Tilt Altitude Calculations – A review*

Solar panels need to be adjusted at a certain angle. This is to maximize the power output of the solar panel. The calculation of tilt angle can be segregated into the following categories:

1. *Tilt Angle Measurement via Altitude and Range*

This is the oldest way of determining the tilt angle. This technique uses the altitude of the solar panel and the range of sun to measure the tilt angle. This technique uses basic trigonometric relation of tangent to find the angle of tilt of the solar panel.

2. *Radiations Absorbed by the Solar Panel*

For the selection and calculation of the lean angle or tilt angle of the solar panel, a technique which is most commonly used is via maximizing the absorbed solar radiation. Solar radiation from the sun can be separated into three types: beam radiation, diffused radiation and reflected radiation. The beam is the direct sunlight hitting the solar panel. The diffused radiation is the one that hits the solar panel after passing through some translucent material or film. And lastly, the third category is reflected solar radiation. This is the one which hits the solar panel after being reflected. The beam radiation, because they come directly from the sun, produce the maximum power. Hence, while selecting the tilt angle of the solar panel, the solar panel's tilt angle is so adjusted that it gets hit by the beam radiation the most. This increases the efficiency of the solar panel to a great extent. This technique is mostly used for locations having cloudy weather. In such locations, the frequency of cloud appearance and their depth are taken into consideration.

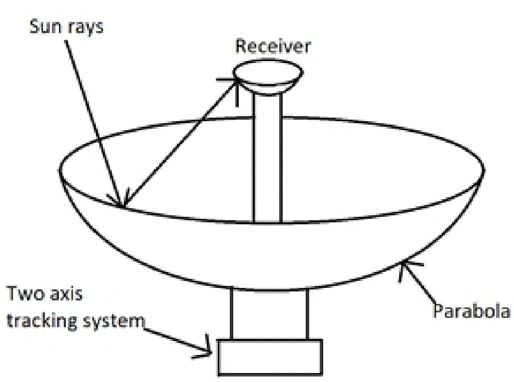

Fig: 6 Focusing plate collector [54]

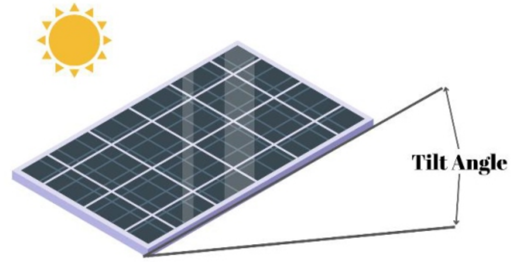

Fig: 7 Generic tilt angle of a solar panel

G) *Importance of the Lean Attitude in Cloudy Situations*

The previously defined strategies for tilt attitude calculations have targeted certain regions. They are positioned among the latitudes of 5 N and 40 N. This puts them on the belt which receives maximum sun radiation. The radiation acquired throughout the globe varies extensively and is inconsistently dispersed. This is because of the variables that are under consideration and the time of day, and the winning atmospheric situations. They are decided via cloud insurance and stage of pollution. In the Northern hemisphere, the best quantity of radiation is acquired from the places located among latitudes 15 N and 35 N, for example Egypt, with an extra ninety percentage arriving as direct beam radiation. The subsequent favorable belt lies among 15 N and the equator which incorporates Central America. Countries positioned among the latitudes 35 N and 45 N, along with Spain or Turkey, experience good sized seasonal versions ensuing in much less radiation acquired.

The least favorable places are located past 45 N, for example, Northern Europe, as they acquire the least quantity of direct radiation. Many international locations in Northern Europe are positioned in this belt along with Ireland, England, Norway, and Sweden. Approximately 1/2 of the radiation arrives on the floor as diffuse radiation because of common heavy cloud cowl. For this reason, strategies that pick the lean attitude via way of means of maximizing the beam or extraterrestrial radiation are unsuitable, as they do now no longer take atmospheric situations into consideration. For weather prone to overcast skies, wherein the beam radiation is eliminated, a brand-new technique is important that takes into consideration the frequency of clouds. The proposed technique combines hourly observations of cloud situations with month-to-month sunshine hour's facts to decide the frequency of clear, partially cloudy, and the lean altitude may be selected that optimizes the sun overcast skies to calculate the sun radiation. Using those sun radiation values and information of cloud situations, radiation among the beam radiation on sunny days and the diffuse radiation on overcast days. The place to begin for those tilt altitude strategies for the calculation of sun radiation and its constituent components. The diverse strategies for estimating sun radiation might be defined inside the subsequent section.

H) *Types of Solar Panels*

The types of solar panels can be segregated into two categories; Types of solar panels based on cells used and types of solar panels based on their actuation.

1) *Types of Solar Panels Based on Cells Structure*

Solar cells are used to convert solar energy into electrical energy. Solar cells are made up of semiconductor material i.e., silicon and modern photovoltaic technology is based on electron hole creation theory. First of all, sunlight falls on the p-type and n-type junction of solar cell. Sunlight comprises of photons that have sufficient amount of energy to transfer electrons from one layer to another. This results in the creation of electron hole which is responsible for electricity generation [60].

There are basically three types of Solar panels based on cells used in the assembly:

1. Monocrystalline
2. Polycrystalline
3. Amorphous

a) *Monocrystalline*

A monocrystalline solar panel is made up of a single crystal of silicon. Since monocrystalline is composed of single crystal electron can move freely which results in efficient energy production. These types of solar panels are considered more efficient because of their pure composition. Monocrystalline solar cells have efficiency over 23%. Monocrystalline solar cells are expensive since they are formed from solidification of silicon which is a complex phenomenon.

b) *Polycrystalline*

Polycrystalline solar panels are made up of many crystals of silicon in a single PV cell. Several pieces of silicon are melted and then combined to make wafers of polycrystalline solar panels. They are also known as multi-crystalline solar cells. Polycrystalline has lower efficiency because of its rigid structure having less room for motion of electron. These solar cells have efficiency below 20%.

c) *Amorphous*

The amorphous solar panels do not contain cells. Rather they are formed using deposition of silicon on glass base. It can be explained as spraying silicon on glass base. These types of solar cells have high absorption capacity and have small thickness of layer. These cells have an efficiency of 13%.

d) *Comparison*

Table I - Comparison of monocrystalline, polycrystalline and amorphous solar cells

	Monocrystalline	Polycrystalline	Amorphous
Composition	Single Crystal	Many Crystal	Thin layer
Efficiency	23%	20%	13%
Life span	25+years	25+years	Shorter than the other two
Aesthetic	Black hue	Blue-ish hue	Brown
Cost	Premium	Value	Economy
Temperature Coefficient	Lower	Higher	Highest
Size	Small	Larger	Largest

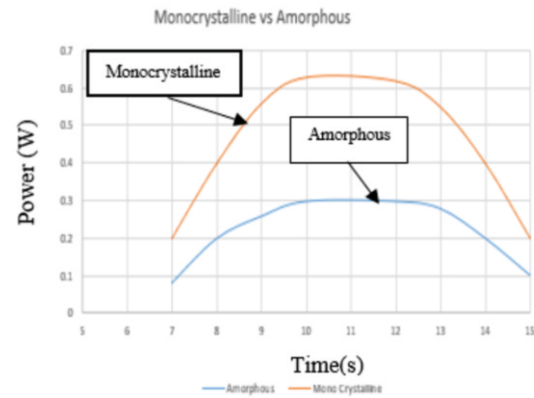

Fig: 8 Graph of monocrystalline panel vs amorphous panel [8]

The two graphs show that the monocrystalline panels are the most efficient type of panels [8].

The above graph shows a comparison between monocrystalline and polycrystalline solar panels. The graph shows the solar radiation absorbed by both the types of solar panels. It clearly shows that the monocrystalline solar panel absorbs more solar energy and in turn produces more energy.

2) *Types of Solar Panels Based on Actuation*

There are two basic types of solar panels when differentiated in terms of actuation. They are

1. Single axis solar trackers
2. Dual axis solar trackers

a) *Single Axis Solar Trackers*

Single axis solar tracking system is a system of actuation of solar panels in which the solar panel actuates in one axis only. Either it would be azimuth axis or elevation axis. The axis used in the actuation solely depends upon the location and the trajectory that the sun follows over that particular location. The locations, which are closer to the equator, have a sun trajectory relatively vertical. At these locations, elevation axis actuation is most suitable. And at locations where the sun does not go high up in the sky, azimuth axis actuation is more reliable. Mostly, such locations are away from the equator line.

According to a study, single axis solar trackers can have an efficiency of about 30% [9].

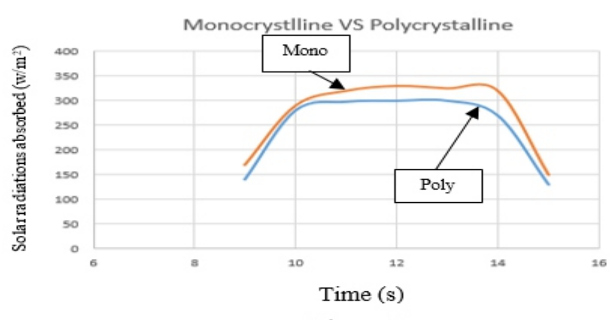

Fig: 9. Graph of monocrystalline vs polycrystalline panel [8] *b) Dual Axis Solar Trackers*

The sun rises from the East and sets in the West. This motion needs to be followed by the solar panel while solar tracking. But that is not all. The sun also changes its trajectory from summer to winter. In areas which are closer to the equator, the sun is almost vertical in the summers and becomes angular in the winters. This motion also needs to be followed as it changes its trajectory from summer solstice to winter. This actuation in which the solar panels move in both the axes is known as dual axis solar tracking.

Fig: 10 Azimuth axis actuation of solar panel assembly

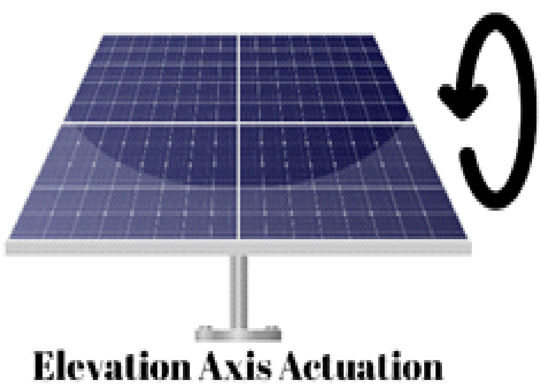

Fig: 11 Elevation axis actuation of solar panel assembly

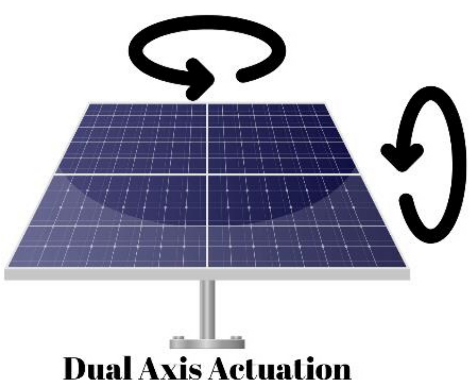

Fig: 12 Dual axis solar tracker

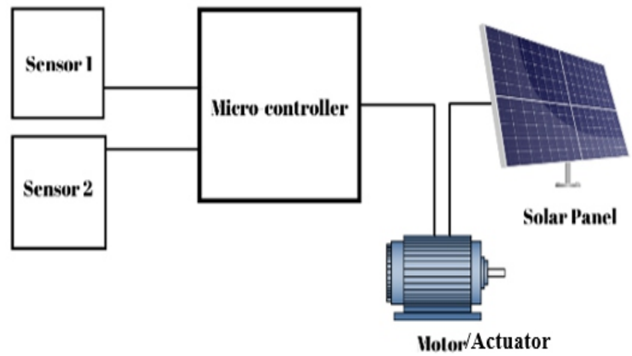

Fig: 13 Generic schematic diagram of solar tracking system equipped with end sensors

I) Solar Tracking via Microcontroller

Solar actuation requires a microcontroller to control the system. Microcontrollers can be open loop and closed loop. This solely depends upon the sensor assembly. If the sensors are used in the system, it becomes a closed loop otherwise it is called open loop. The closed loop system is much more accurate as it checks the position of the solar panel through the feedback system.

II. SUN POSITION STUDY FOR ISLAMABAD

The trajectory of the sun throughout the day is of vital importance as it governs the actuation of the solar panel. To gain maximum output from the solar panel, the sun should remain normal to the solar panel. This orientation will ensure maximum production of energy from the panels. The angles from the sun are of great importance are the azimuth angle of the sun and elevation angle of the sun.

J) Azimuth Angle

Azimuth angle of the sun refers to the angle change of the sun when it moves from East to West throughout the day. A reference position is taken and from which the angle of the sun is measured. This angle is of prime importance as it dictates the solar tracking and actuation of the PV panel.

Fig. 12 is generated by taking the sun's position at sunrise as reference. This graph dictates the sun tracking and instantaneous position of the PV panel w.r.t the sun.

K) Elevation Angle

Elevation angle of sun refers to the vertical angle change of the sun throughout the day. The sun rises from the horizon and gains a top position and the sets again in the horizon. This gain in height is referred as the sun's elevation angle. Its study is also important for a dual axis system.

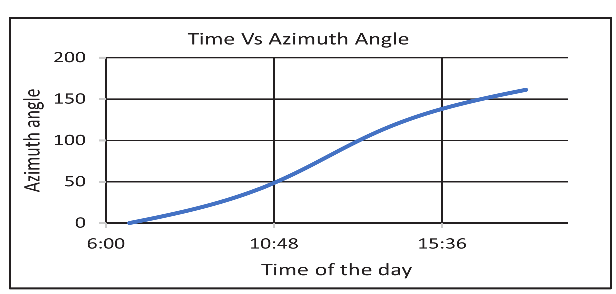

Fig: 14 Graph of azimuth angle vs time

III. MATHEMATICAL MODELLING

The mathematical model of a solar tracking system consists of a DC motor, gears, and a microcontroller for the actuation of the system. Modeling dual-axis solar tracking system comprises a model for both azimuth and elevation angle. Since the transfer function for both the axis is similar so the mathematical model of only one axis is derived which is as follows.

For the azimuth axis of the system

$$e_a = i_a R_1 + L_1 \frac{di_a}{dt} + e_b$$

$$e_b = K_b \frac{d\theta_m}{dt}$$

Where K_T is the torque constant and K_b is the electromotive force constant

Now

$$e_a = i_a R_1 + L_1 \frac{di_a}{dt} + K_b \frac{d\theta_m}{dt}$$

The mechanical system has the following mathematical model Viscous damper coefficient of the bearing=$B_t = B_{m1} + B_{m2}$

$$T_m = J_1 \frac{d^2\theta_m^2}{dt^2} + B_1 \frac{d\theta_m}{dt}$$

$$T_m = K_T i_a$$

J_t= moment of inertia for motor

$$K_T i_a = J_1 \frac{d^2\theta_m^2}{dt^2} + B_1 \frac{d\theta_m}{dt}$$

Now Laplace transform of the equation

$$E_a(s) = I_a(s) R_1 + L_1 s I_a(s) + K_b s \theta_m(s)$$

$$K_T I_a(s) = J_1 s^2 \theta_m(s) + B_t s \theta_m(s)$$

After further mathematical formulation equivalent transfer function is obtained as follows

$$\frac{\theta_m(s)}{E_a(s)} = \frac{K_T}{J_t L_1 s^3 + (J_t R_1 + B_t L_1) s^2 + (B_t R_1 + K_T K_b) s}$$

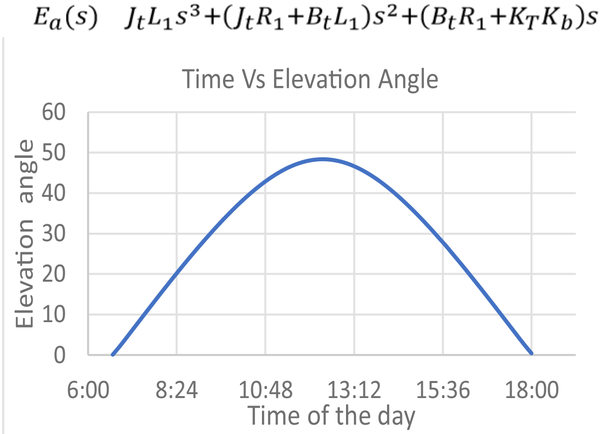

Fig: 15 Sun elevation angle vs time

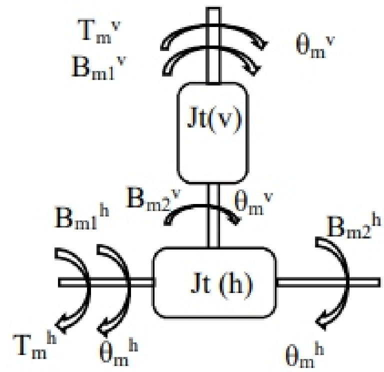

Fig: 16 Mechanical Model of Dual Axis Solar Tracker

Viscous damper coefficient of the bearing is neglected since its value is small now equation becomes.

$$\frac{\theta_m(s)}{E_a(s)} = \frac{K_T}{J_t L_1 s^3 + (J_t R_1) s^2 + (K_T K_b) s}$$

Values of system parameters are:
K_T =0.07, J_t= 8.6, L_1 =1*10^{-5}, R_1 =10, K_b=5
The above values are generic values for this type of system.
So,

$$\frac{\theta_m(s)}{E_a(s)} = \frac{0.07}{0.000086 s^3 + 86 s^2 + .35 s}$$

1) Step Response

Step Response of system using MATLAB is found as follows by applying step input

IV. TEST SETUP DESIGN AND IMPLEMENTATION

To design and implement solar tracking on a physical 2KW system, it is first required to design lab mockups. The reason is that designing lab mockups gives the notion of how the system will behave under given conditions. Moreover, design improvements made in lab mockups is easier compared to the real system.

During this study, two test setup were made:

1. Light Dependent Resistor (LDR) based
2. PV solar sensor based

Both these lab mockups were identical. Both of them had Arduino UNO as micro controller.

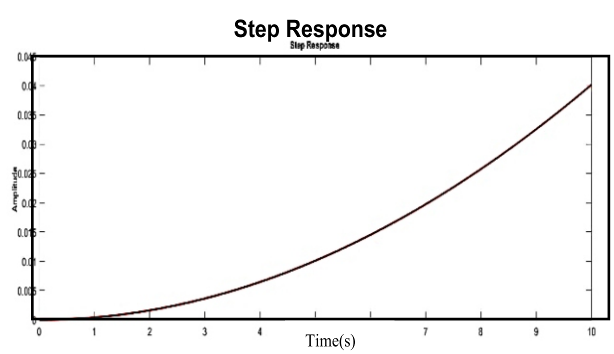

Fig: 17 Step response

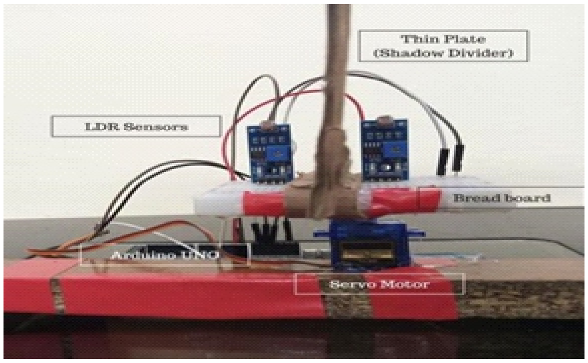

Fig: 18 LDR based test platform

L) Light Dependent Resistor Based Lab Mockup

The first test setup was developed to understand the basics of solar tracking. This model had two LDR sensors which were separated by a shading element. This shading element will cast a shade on one of the LDR sensors. The code is so designed that the system will move towards the LDR sensor that is getting full light. The system will move towards that side until both the LDRs get equal light.

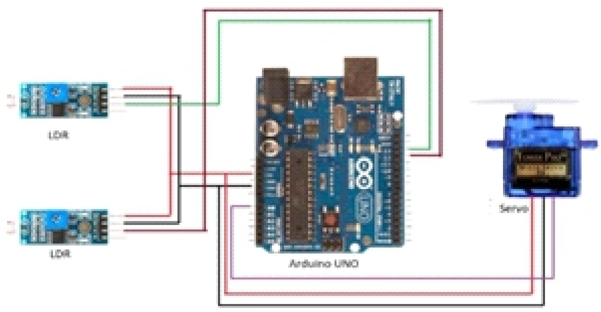

Fig: 19 Proposed Circuit diagram of LDR based test setup

Arduino IDE was used for coding of the Arduino board and the code was implemented.

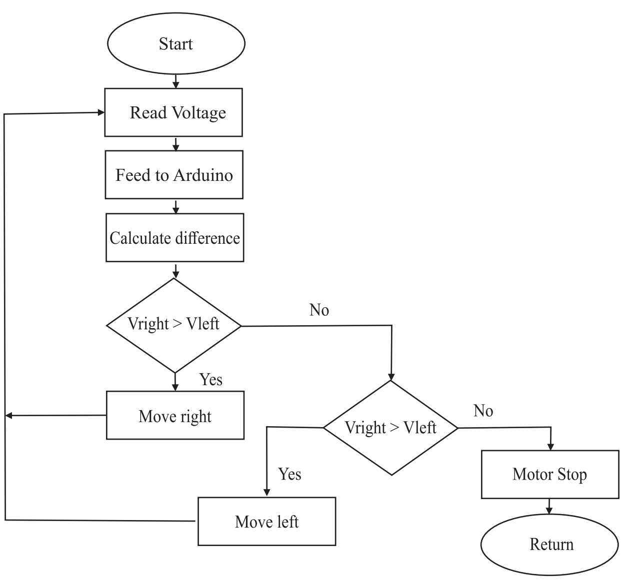

Fig: 20 Flow diagram

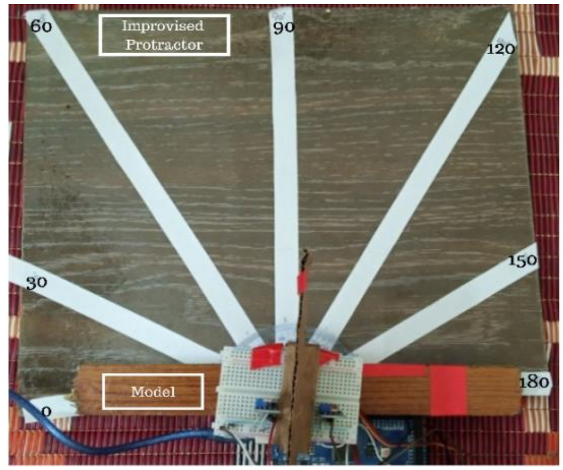

Fig: 21 Test assembly

a) Testing

Figure shows the test assembly which was used to test the LDR based lab mockup. A light source was used in this test. The light source was placed at each point marked on the testing assembly.

When the light source was placed on a mark, the lab mockup changed its position accordingly. This motion was captured in form of a graph.

In the Figure, it seen that the dotted line lags the continuous line. This is because of the shade that was used. If the area of the shade is increased, the accuracy would increase.

M) Solar Sensor Based Test Setup

LDRs had some drawbacks. The proved to be non-viable for implementation on the full-scale model as it was placed outside. A comparison of LDR and proposed novel sensor is given below:

The second lab mockup that was designed was in accordance with the concerned 2KW system. This lab mockup had a DC motor and a motor driver. The previous lab mockup had a servo motor. The following is the snap of this lab mockup:

This Lab mockup was in accordance with the targeted 2KW system. With the integration of this lab mockup with the 2KW system, solar tracking could be achieved.

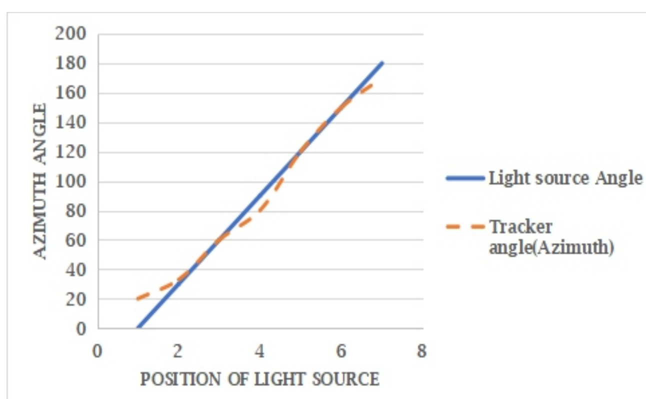

Fig: 22 Azimuth angle of the test setup vs position of the light source

Table II- Comparison of LDR and PV Solar sensor

	Light Dependent Resistor	PV Solar Sensor
Composition	Photosensitive semiconductor	Two types of semiconductors, called p-type and n-type silicon.
Sensitivity	Sensitivity of LDR cannot be manipulated	Sensitivity of solar sensor can be manipulated
Resistivity to Weather condition	Affected by weather conditions	Resistant to harsh weather condition
Life Span	Not predictable	30 years
Protection	Protection reduces sensitivity	Protection increases life span
Durability	Not Durable	Durable

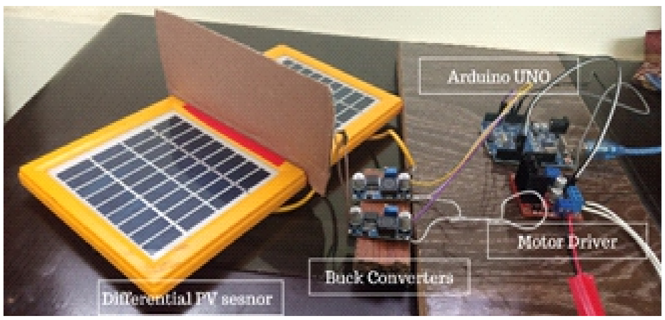

Fig: 23 Differential PV-senor based test setup

The code implemented on this system is so designed that when light is incident on the West side solar panel, the DC motor rotates in the clockwise direction and vice versa. Hence, a light source was used to test this.

V. PHYSICAL IMPLEMENTATION

After successful modelling and development of lab mockups, the next was to implement these onto the concerned 2KW system. The system was so designed that its azimuth axis can be actuated using a motor whereas, its elevation axis is operated manually. This is because in Islamabad, the elevation angle changes throughout the year are not drastic. This change can easily be incorporated via manual operation of this axis.

The system under consideration was equipped with a gear system and a 12V DC motor which were responsible for the movement and actuation of the motor.

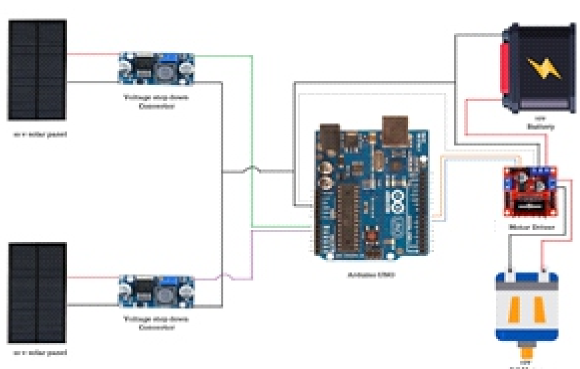

Fig: 24 Circuit diagram of proposed differential PV-sensor based test setup

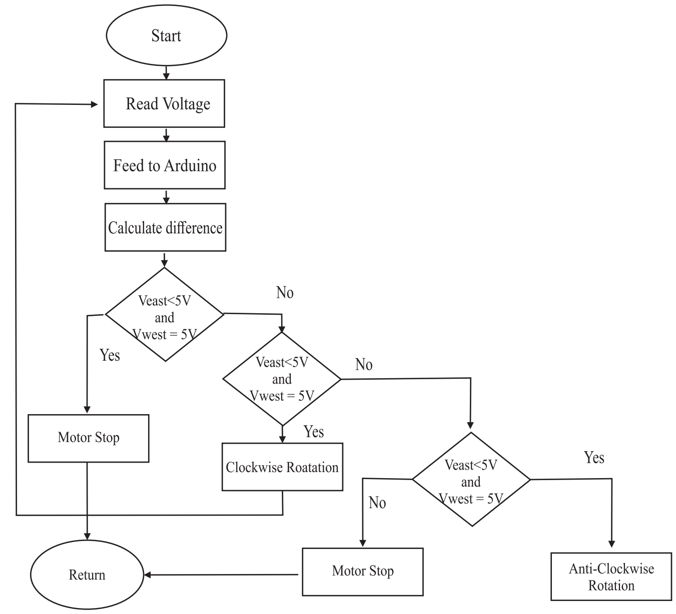

Fig. 25 Flow diagram of proposed differential PV-sensor test setup

The actuation of the motor was controlled via micro controller. Arduino UNO was used as a micro controller in this system. Also, solar sensors were used as sensing element in the feedback loop. These sensors were responsible for the position sensing of the sun.

N) Novel Sensor Design and Implementation

As mentioned earlier, a set 5V solar sensors were used as sensing element. The reason for using 5V sensors is that the LDR sensor gets

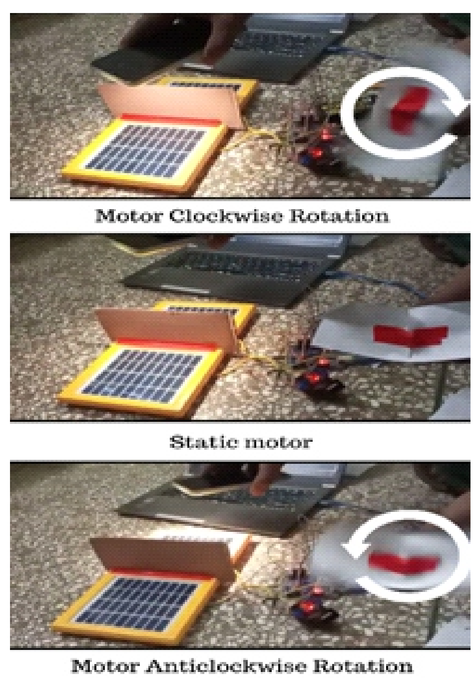

Fig: 26 Motor rotation w.r.t incident light

Table III- Comparison of 1st and 2nd test setups

Specification	1st test setup	2nd test setup
Arduino type	UNO	UNO
Sensor	LDR	Differential PV sensor
Motor	360-degree rotation servo motor	DC motor
Motor Driver	No	Yes
External power source	No	Yes
Shade type	Straight	Straight
Buck Converter	No	Yes
Input type	Digital (0,1)	Analog (0 to 1023)

damaged from the harsh weather. This leads to the failure of the system. Whereas the PV sensors are not easily damaged. They can withstand these harsh weathers and are long lasting. Also, the sunlight is dispersed in all directions. This makes it difficult for the LDR to judge the change in sun position. But the PV sensor can judge this change more accurately. Finally, the reason for using 5V sensors is that Arduino can only input 5V. It cannot input a signal more than 5V. Hence, Buck converters were used to ensure proper 5V signal propagation from the sensor to the Arduino board.

The shading element used in the sensor assembly was changed from the conventional straight shape to an indigenously designed V shape. The reason is that the straight plate was not able to cast the shadow in required time. It was taking excessive time to generate the voltage differential in the sensors. This would cause the system to lose its efficiency as the sun would not remain normal to the solar panels. A solution that was proposed by the authors was to use a V shape shading element. This V-shape was adequate to cause the voltage differential at the required time. This increased the accuracy and consequently the efficiency of the concerned system. The V shaped shade has a greater efficiency of tracking. The quicker the voltage differential comes between the two sensors, the quicker the system will move and the more efficient the sun tracking will be. The reason for keeping the shape like a "V" rather than a "T" or straight is because the V shape casts a shadow more quickly and its shadow is much denser than the "T" shape or any other shape. The Voltage output of a PV sensor is also dependent on the how dense the shadow is. If the shadow is not dense enough, there will not be a voltage

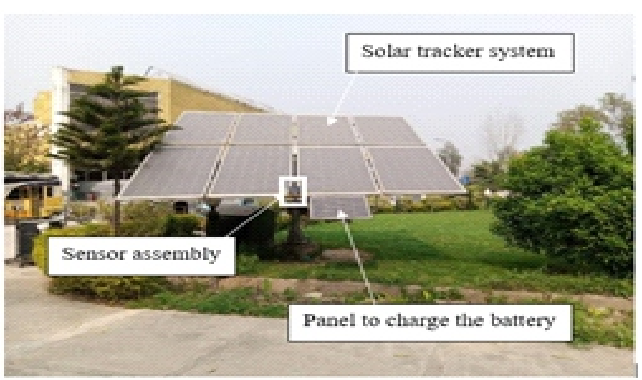

Fig: 27. Concerned 2KW solar power system

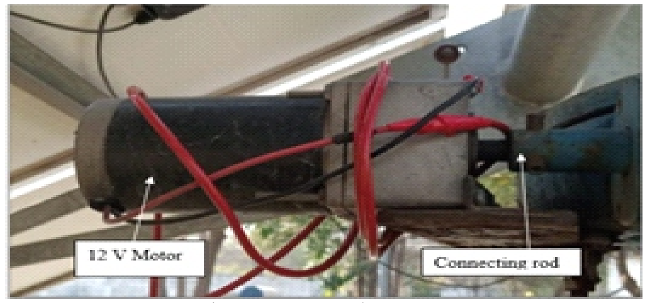

Fig: 28. Motor and gear system

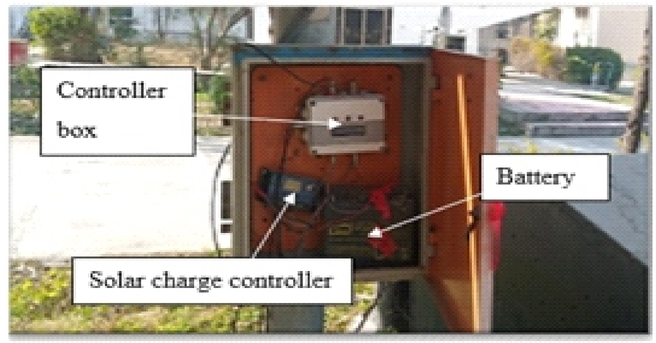

Fig: 29 Main control panel

differential. The angle of the V shape was determined using a shade made from soft material (Cardboard). Cardboard is soft and its shape can be easily changed. The angle was changed from 70 degrees and was decreased until an angle of 30 degrees was found to be sufficient. At the end, the 30 degrees shade was fabricated.

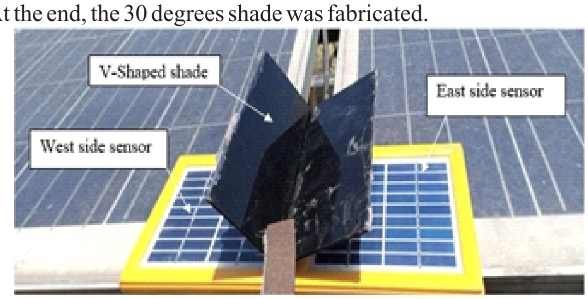

Fig: 30 Sensor assembly

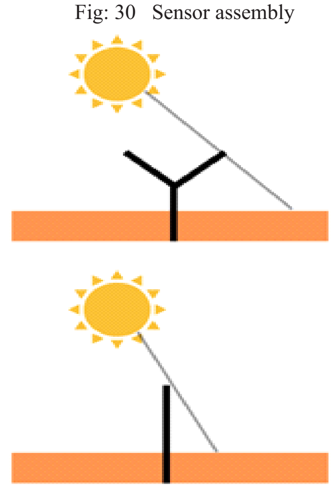

Fig: 31 Significance of V-shaped shade

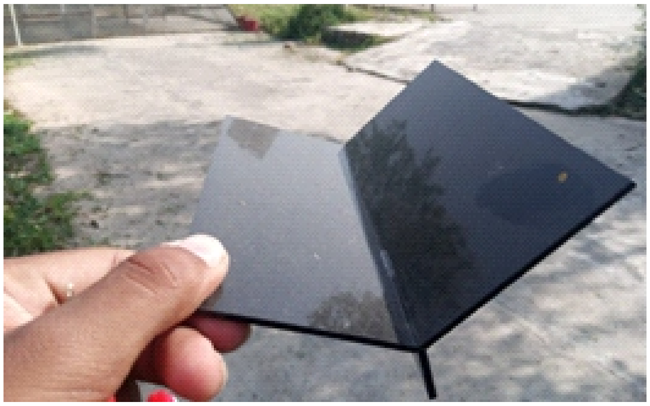

Fig: 32 V-shaped shade

The dimensions of the differential shade were carefully obtained through experiments. The main objective of the differential shade, as explained earlier, is to bring a difference in output voltage of the two end PV sensors. A straight, vertical shade can do the job. But it takes a lot of time to bring this difference in voltage. Hence, a V shaped shade was introduced as a novel idea. But the internal angle and the length and width of the shading element was still a question mark. For that reason, a test was conducted in which different sizes and different inner angles were put under experimentation and the optimum i.e., the one taking less time for the differential was taken and implemented in the final system.

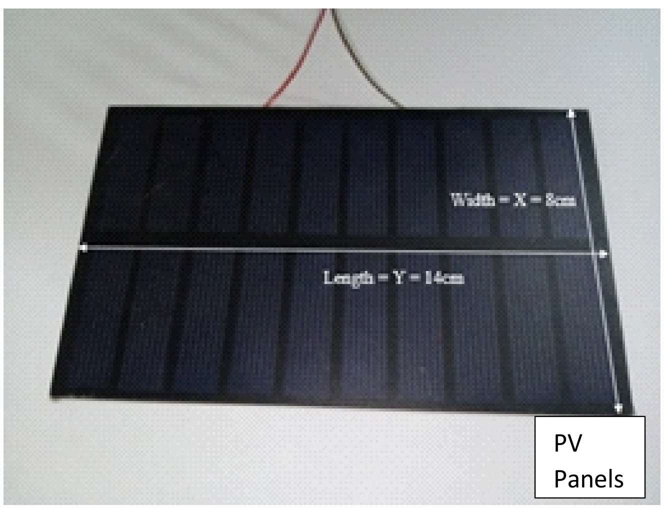

Fig: 33 PV panel used as sensor in testing design

Table IV– Time required for voltage differential to appear under different test conditions

Testing Arrangement	Time for the voltage differential
Straight Shade with length = Y and width = X/2	1 Hour, 30 mins
Straight Shade with length = Y and width = 3X/4	1 Hour, 20 mins
Straight Shade with length = Y and width = X	1 Hour, 10 mins
V-Shaped Shade with inner angle of 35°, length = Y and width = X/2	1 Hour, 20 mins
V-Shaped Shade with inner angle of 35°, length = Y and width = 3X/4	1 Hour, 05 mins
V-Shaped Shade with inner angle of 70°, length = Y and width = X/2	50 mins
V-Shaped Shade with inner angle of 70°, length = Y and width = 3X/4	35mins

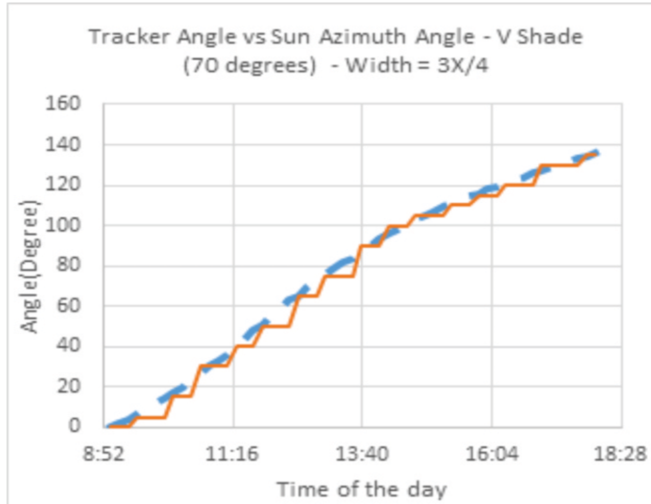

Fig: 34 Sun azimuth angle vs Tracker angle throughout the day

The length of the sensor is denoted by Y and its width is denoted by X. This is because a generic form of the dimension of the shade are required. The dimensions of the differential shade will be in correspondence to these X and Y value so that if the dimensions of the sensor change, the dimensions of the differential shade can be extracted from them.

There were seven test conditions on which the system was tested. They were:

1. Straight Shade with length = Y and width = X/2
2. Straight Shade with length = Y and width = 3X/4
3. Straight Shade with length = Y and width = X
4. V-Shaped Shade with inner angle of 35°, length = Y and width = X/2
5. V-Shaped Shade with inner angle of 35°, length = Y and width = 3X/4
6. V-Shaped Shade with inner angle of 70°, length = Y and width = X/2
7. V-Shaped Shade with inner angle of 70°, length = Y and width = 3X/4

From the tests, it was concluded that the test condition 7 was the most optimum dimension for the differential shade. This was concluded from the results tabulated in the following table:

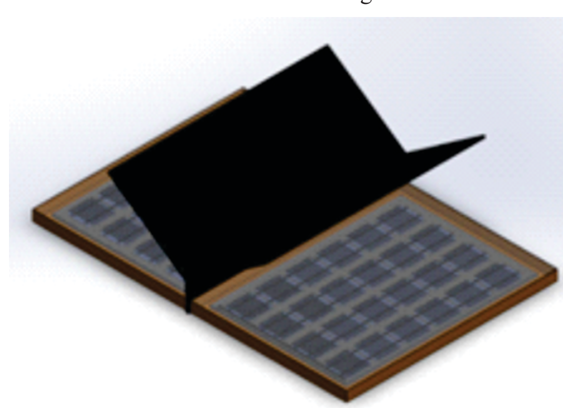

Fig: 35 Isometric view of novel sensor assembly generated on solidworks

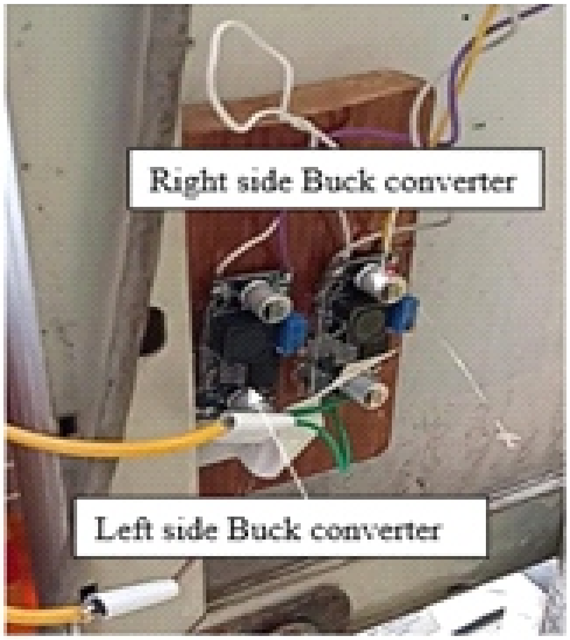

Fig: 36 Buck converters

This was further tested to see how this sensor assembly, coupled with a controller and actuator, could track the sun. The following graph was generated:

O). Buck Converters

Buck converters are like transformers which can step up or step down the incoming voltage. They were used to ensure that the full light output of the solar sensors is restricted to 5V.

P) Junction Box

A junction box was used to cover the Arduino UNO and motor driver as they can be affected by the outdoor conditions. The junction box was both water and dust proof. This junction box ensures the sustainability and long-lasting nature of the circuit.

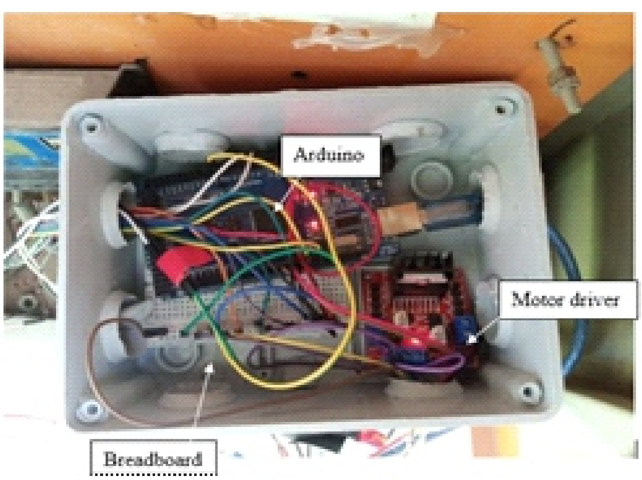

Fig: 37 Inside snapshot of the junction box

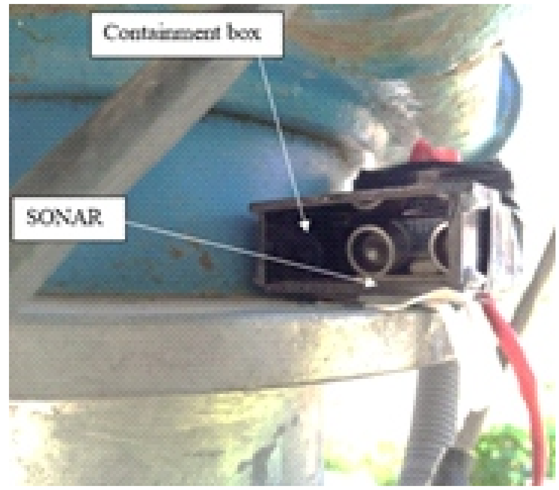

Fig: 38 SONAR sensors

Q) Proximity Sensors

The sun moves from East to West throughout the day. This motion, if measured in terms of angle, is less than 180°. Hence, the system must not go beyond this value. So, SONAR sensors were used to set the proximity limits of the concerned system.

Also, when the sun sets, the system would be facing the West. Whereas, the next morning, the sun would rise from the East. Hence, the system should face the East before the next morning. So, a reposition function was added to the code of the Arduino UNO. This ensured that the system would face the sun when it came out the next day. The SONAR sensors also assisted in that domain. They set the proximity and stop the system at the starting position.

R) Circuit Diagram

The most important part of designing a circuit is its circuit diagram. The circuit diagram of a system shows the components and wire connections used in designing the circuit.

There are a total of three Solar sensors used in this circuit. The first one was responsible for weather conditions detection. If the weather is cloudy, this sensor will ensure that the system would remain stationary. It will only track the sun when the weather is sunny. The next two are the differential PV sensors which sense the position of the sun. Arduino UNO is used as micro controller. SONARs are used for proximity. Motor driver is used to control the speed and direction of the motor and lastly, the battery is used to power up the whole circuit.

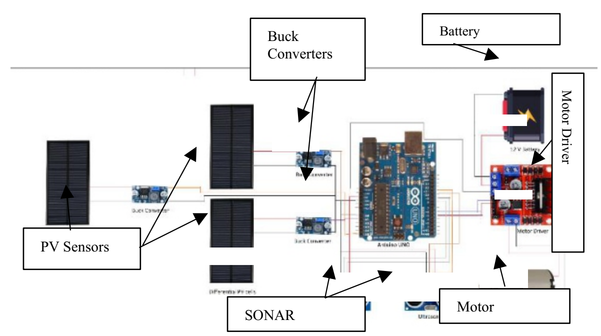

Fig: 39 Circuit diagram

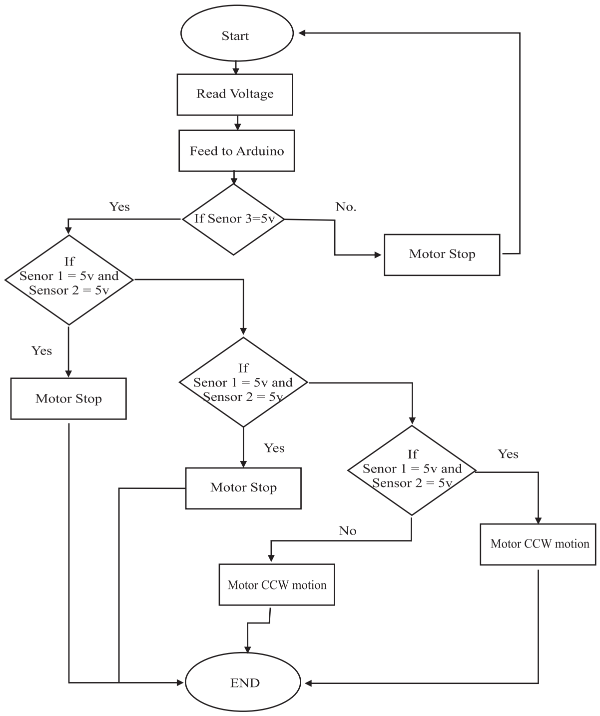

Fig: 40 Flow diagram

*S) Code and Flow Diagram*No

In the code, sensor 3 is of prime importance as it decides the flow of code. The sensor 3 will give a 5V value on sunny conditions. When this sensor is giving its complete 5V value, the flow will move towards the solar tracking. If not, the system will remain stationary.

VI. TESTING AND RESULTS

An important aspect of engineering design is its testing. There were two types of tests which were done on the concerned 2KW solar power system. They were

1. Angle test
2. Power test

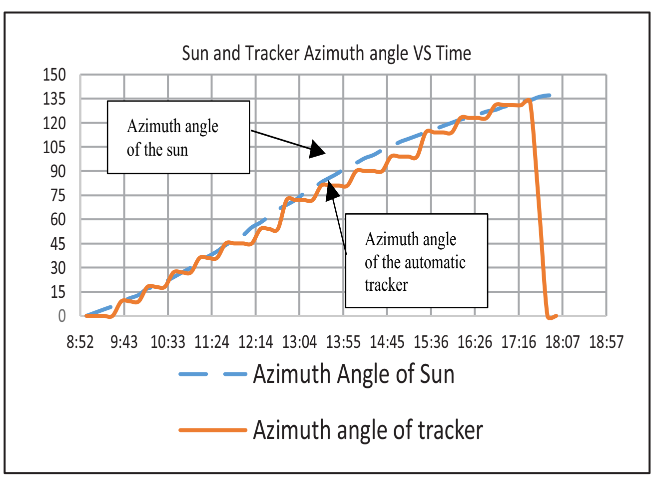

Fig. 41 Azimuth angle of the sun and the tracker vs time of day

T) Angle Test

The 2 KW solar power system was supposed to track the sun. This was achieved using the circuit that was implemented. The azimuth angle of the sun and the yaw angle of the solar power system were calculated throughout the day and were displayed on a graph

Fig. 43 shows the solar tracking nature of 2KW solar power system. Here the blue line shows the sun azimuth angle from 9 AM in the morning to 6 PM in the evening. Whereas the orange line shows the yaw angle of the solar tracker. The azimuth angle of the sum is continuous whereas, the yaw angle of solar tracker is not. This is because the solar tracker does not constantly move throughout the day. It only changes its position when a voltage differential comes up in the end sensors. Hence, this ladder type response is obtained. At the end of the solar tracker's motion, it is seen that the system drops to position zero. This is called the reposition function. This function repositions the solar tracker to face the East so that when the sun rises next day, the solar tracker would be facing the sun.

U) Power Test

The next test that was conducted was the power test. In this test a test sensor was used to judge if solar tracking throughout the day would be of any advantage. Here the test sensor was once placed static against a West facing wall and once it was made to track the sun throughout the day placing it on the solar tracking system.

In Fig. 54, the blue line shows the static oriented power output of the test solar panel whereas, the orange line shows the dynamic oriented or tracking orientation of the test solar panel. It can be seen clearly that the tracking power output is greater.

An efficiency advantage of 5.55% is gained while tracking. This means that solar tracking is feasible.

VII. CONCLUSION

In full scale study, a solar tracking control system was designed, developed and fabricated for a 2KW solar power system. The study comprises of basic literature survey of the topic and the geographical data for the selected location. Also, complete mathematical modelling was done to ensure the design of the control system according to the system at hand. Furthermore, some test setups were designed and fabricated to assist in the physical implementation of solar tracking on the full scale 2KW system. There were two test setups. One was based on LDR, and the other was based on 5V differential solar sensors. The LDR based system was a generic prototype made to understand light tracking. It was able to track a light source and the results were plotted. After which a 2nd lab mockup was designed which was in accordance with the concerned 2KW system. It consisted of a small battery and a small DC motor.

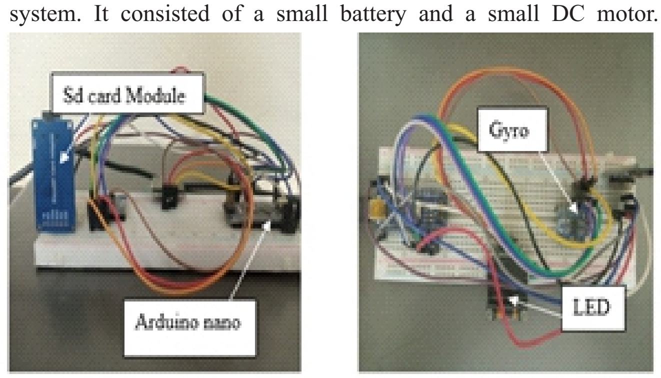

Fig: 42 Gyro module

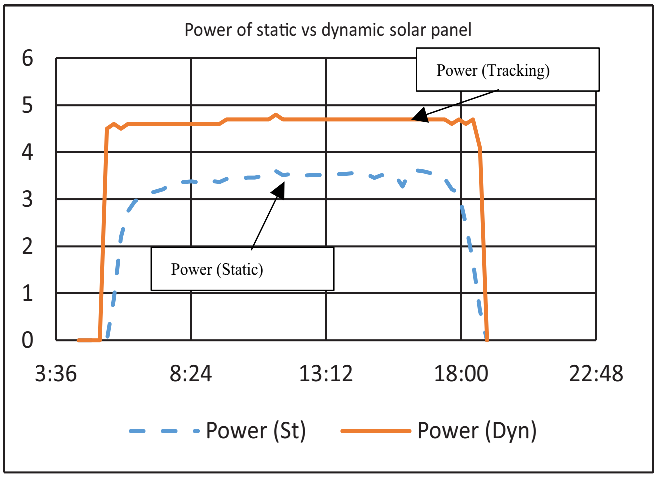

Fig: 43 Graph of power test

Table V- Power output

Power Output (Dynamic)	4.24981
Power Output (Static)	2.898433
Power Input	24.31275
Eff Dynamic	17.47976
Eff Static	11.92145
Eff Advantage	5.558308

These two things would be changed for the 2KW system, the rest would be the same. Moving on, was the physical implementation in which the 2KW solar power system was combined with the control system, it was made to track the sun. At the end, two tests were conducted in which the angle change and power output advantage was calculated and displayed in terms of graphs. An efficiency advantage of over 5% was gained which confirmed that the solar tracking of the system was feasible and may be implemented on other systems.

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