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DESIGN OF DUAL AXIS SOLAR TRACKER USING ARDUINO

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Abstract
Energy crisis is one of the prime issues in the third world developing country like INDIA There is an enormous gap between generation and demand of electrical energy. Nearly 50%population of the country is extremely isolated from this blessing. Renewable energy is the only answer to solve this issue. Solar energy is one of the most effective resources of the renewable energy which could play a significant role to solve this crisis. This research presents a performance analysis of the dual axis solar tracking system using Arduino. The main objective of this research is whether a static solar panel is better than solar tracker or not. In hardware part, four light dependent resistors (LDR) are used to detect the utmost light source from the sun. The outcome of the solar tracker system has analyzed and compared with the fixed or static solar panel found better performance in terms of voltage, current and power. The result showed dual-axis solar tracking system produced extra 10.53-watt power compared with fixed and single axis solar tracking system.
Key words: Solar Energy, Arduino, Solar Tracking System, Renewable Energy, Solar Panel

I. Introduction

1.1 Renewable Energy

Renewable energy is the energy that is collected from renewable resources that are naturally replenished on a human timescale. It includes sources such as sunlight, wind, the movement of water, and geothermal heat. Although most renewable energy sources are sustainable, some are not. For example, some biomass sources are considered unsustainable at current rates of exploitation. Renewable energy often provides energy for electricity generation to a grid, air and water heating /cooling, and stand-alone power systems. Renewable energy technology projects are typically large-scale, but they are also suited to rural and remote areas and developing countries, where energy is often crucial in human development. Renewable energy is often deployed together with further electrification, which has several benefits: electricity can move heat or objects efficiently, and is clean at the point of consumption. In addition, electrification with renewable energy is more efficient and therefore leads to significant reductions in primary energy requirements[1]. From 2011 to 2021, renewable energy has grown from 20% to 28% of global electricity supply where as fossil energy shrunk from 68% to 62%, and nuclear from 12% to 10%. The share of hydropower decreased from 16% to 15% while power from sun and wind increased from 2% to 10%. Biomass and geothermal energy grew from 2% to 3%. 3,146 giga watts installed in 135 countries, while 156 countries have laws regulating the renewable energy sector. In 2021, China accounted for almost half of the global increase in renewable electricity. Globally over 10 million jobs associated with the renewable energy industries, with solar photovoltaic's being the largest renewable employer. Renewable energy systems are rapidly becoming more efficient and cheaper and their share of total energy consumption is increasing, with a large majority of worldwide newly installed electricity capacity being renewable. In most countries, photovoltaic solar or onshore wind is the cheapest new-build electricity. Many nations around the world already have renewable energy contributing more than 20% of their total energy supply, with some generating over half of their electricity from renewals. A few countries generate all their electricity using renewable energy. National renewable energy markets are projected to continue to grow strongly in the 2020's and beyond. Studies have shown that a global transition to 100% renewable energy across all sectors -power, heat, transport and desalination is feasible and economically viable. Renewable energy resources exist over wide geographical areas, in contrast to fossil fuels, which are concentrated in a limited number of countries. Deployment of renewable energy and energy efficiency technologies is resulting in significant energy security, climate change mitigation, and economic benefits. However, renewable are being hindered by hundreds of billions of dollars of fossil fuel subsidies. In international public opinion surveys, there is strong support for renewable such as solar power and wind power. But the international energy agency said in 2021 that to reach net zero carbon emissions more effort is needed to increase renewable, and called for generation to increase by about 12% a year to 2030[19].

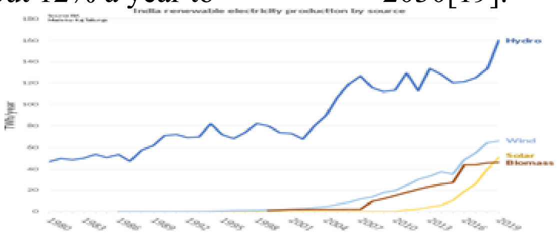

Figure 1: India Renewable Electricity Production by Source

1.2 Solar Energy

Solar energy is radiant light and heat from the sun that is harnessed using a range of technologies such as solar power to generate electricity, solar thermal energy (including solar water heating), and solar architecture. It is an essential source of renewable energy, and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power, and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air. In 2011, the international energy agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits[20]. It will increase countries' energy security through reliance on an indigenous, inexhaustible, and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming these advantages are global".

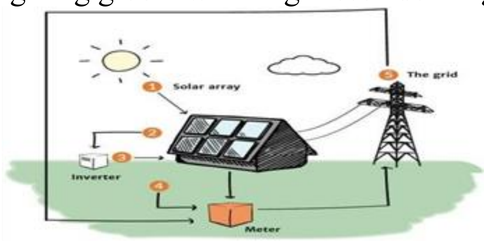

Figure 2: Solar Energy

The global solar energy market has enjoyed growth at an exceptional rate over the recent years, facilitated by the rising solar power output from world's top solar energy producing countries. With the growing demand for alternative and eco-friendly energy that significantly reduces carbon emissions around the world; many major countries have been rapidly increasing the capacity of their solar power facilities and other renewable energy installations over the past few years[2]. While the global solar energy market continues to surge, the world's top solar energy producing countries, including China, Japan, Germany and the USA are expected to maintain their leadership in global solar energy capacity in the future. Within global renewable energy installations, solar power plants have enjoyed the fastest growth in volume over the past few years. Thanks to the vast availability and certainty of sunlight, solar power projects have outperformed other forms of renewable energy sources such as wind and geothermal. Moreover, with the advancements in technologies, including concentrated solar power generation techniques, and a decline in prices of PV modules, solar energy has become the most cost-effective source of renewable energy. According to the report from BP, total solar PV power generating capacity reached 301 GW by the end of 2016, representing a 33.2% increase from 2015[21]. A total 75 GW of new installations were added to the global solar energy capacity in 2016. The largest

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increments in 2016 were recorded in China (34.5 GW) and the US (14.7 GW), together accounting for two-thirds of the growth in global solar capacity. Japan provided the third largest addition (8.6 GW). China also leads in terms of cumulative installed capacity (78.1 GW), with more than a quarter of the global total. Japan (42.8 GW) moved past Germany (41.3 GW) to take second place, with the US (40.3 GW) now close behind Germany.

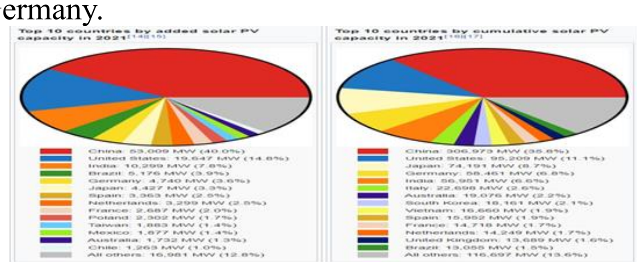

Figure 3: Global Figures

1.3 Solar Panel

A solar cell panel, solar electric panel, photo-voltaic (PV) module, PV panel or solar panel is an assembly of photovoltaic solar cells mounted in a (usually rectangular) frame, and a neatly organized collection of PV panels is called a photovoltaic system or solar array[22]. Solar panels capture sunlight as a source of radiant energy, which is converted into electric energy in the form of direct current (DC) electricity. Arrays of a photovoltaic system can be used to generate solar electricity that supplies electrical equipment directly, or feeds power back into an alternate current (AC) grid via an inverter system.

Figure 4: Photovoltaic Modules

1.4 Theory and Construction

Photovoltaic modules consist of a large number of solar cells and use light energy (photons) from the Sun to generate electricity through the photovoltaic effect. Most modules use wafer-based crystalline silicon cells or thin-film cells. The structural (load carrying) member of a module can be either the top layer or the back layer[4]. Cells must be protected from mechanical damage and moisture. Most modules are rigid, but semi-flexible ones based on thin-film cells are also available. The cells are usually connected electrically in series, one to another to the desired voltage, and then in parallel to increase current. The power (in watts) of the module is the mathematical product of the voltage (in volts) and the current (in amperes), and depends both on the amount of light and on the electrical load connected to the module. The manufacturing specifications on solar panels are obtained under standard conditions, which are usually not the true operating conditions the solar panels are exposed to on the installation site[23]. PV junction box is attached to the back of the solar panel and functions as its output interface to the rest of the system. A USB power interface can also be used.

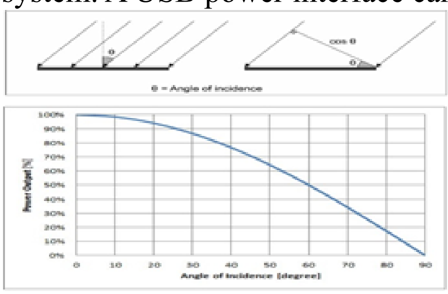

Figure 5: Graph of measured power output of a panel against angle of incidence

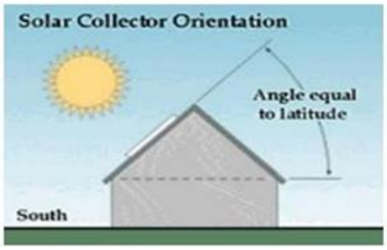

Figure 6: Stationary PV panel orientation[24]

Due to the fact that the earth is rotating on a tilted axis and takes an elliptical path around the sun as shown in Figure 4, a stationary PV panel's output will drastically vary throughout the course of a day and even throughout the year[25].

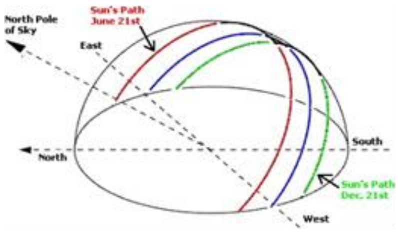

Figure 7: Earth's axis tilt/orbital path affecting solar energy

Because of the sun's movement, a standard PV panel will only observe about 20-35% efficiency under ideal
conditions, while solar tracking has been shown to potentially double that with 50% efficiency under ideal conditions.

1.5 Solar Tracker

A solar tracker is a device that orients a payload toward the Sun. Payloads are usually solar panels, parabolic troughs, Fresnel reflectors, lenses or the mirrors of a heliostat. For flat- panel photovoltaic systems, trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel, sometimes known as the cosine error. Reducing this angle increases the amount of energy produced from a fixed amount of installed power generating capacity. In standard photovoltaic applications, it was predicted in 2008-2009 that trackers could be used in at least 85% of commercial installations greater than one megawatt from 2009 to 2012. As the pricing, reliability and performance of single-axis trackers have improved, the systems have been installed in an increasing percentage of utility-scale projects. According to data from Wood Mackenzie/GTM Research, global solar tracker shipments hit a record 14.5 giga watts in 2017[5]. This represents growth of 32 percent year-over-year, with similar or greater growth projected as large-scale solar deployment accelerates. In concentrator photovoltaics (CPV) and concentrated solar power (CSP) applications, trackers are used to enable the optical components in the CPV and CSP systems.

1.5.1 Types of Solar Tracker Systems

Even though a fixed flat-panel can be set to collect a high proportion of available noon-time energy, significant power is also available in the early mornings and late afternoons when the misalignment with a fixed panel becomes excessive to collect a reasonable proportion of the available energy. For example, even when the Sun is only 10° above the horizon the available energy can be around half the noon-time energy levels (or even greater depending on latitude, season, and atmospheric conditions. Thus, the primary benefit of a tracking system is to collect solar energy for the longest period of the day, and with the most accurate alignment as the Sun's position shifts with the seasons. In addition, the greater the level of concentration employed, the more important accurate tracking becomes, because the proportion of energy derived from direct radiation is higher, and the region where that concentrated energy is focused becomes smaller.

1. Fixed Collector / Moving Mirror

Many collectors cannot be moved, for example high-temperature collectors where the energy is recovered as hot liquid or gas (e.g., steam). Other examples include direct heating and lighting of buildings and fixed in-built solar cookers, such as Scheffler reflectors. In such cases it is necessary to employ a moving mirror so that, regardless of where the Sun is positioned in the sky, the Sun's rays are redirected onto the collector. Due to the complicated motion of the Sun across the sky, and the level of precision required to correctly aim the Sun's rays onto the target, a heliostat mirror generally employs a dual axis tracking system, with at least one axis mechanized. In different applications, mirrors may be flat or concave.

2. Motion Free Optical Tracking

Solar trackers can be built without the need for mechanical tracking equipment. These are called motion free optical tracking, there has been some series of advancements in this technology over the past few decades. Renkube pioneered a glass-based design to redirect light using motion free optical tracking technology. Non-concentrating photovoltaic (PV) trackers Photovoltaic panels accept both direct and diffuse light from the sky. The panels on standard photovoltaic trackers gather both the available direct and diffuse light. The tracking functionality in standard photovoltaic trackers is used to minimize the angle of incidence between incoming light and the photovoltaic panel. This increases the amount of energy gathered from the direct component of the incoming sunlight[6]. The physics behind standard photovoltaic (PV) trackers works with all standard photovoltaic module technologies. These include all types of crystalline silicon panels (either mono-Si, or multi-Si) and all types of thin film panels (amorphous silicon, Cadet, CIGS, microcrystalline).

3. Concentrator Photovoltaic (CPV) Trackers

The optics in CPV modules accept the direct component of the incoming light and therefore must be oriented appropriately to maximize the energy collected. In low concentration applications a portion of the diffuse light from the sky can also be captured. The tracking functionality in CPV modules is used to orient the optics such that the incoming light is focused to a photovoltaic collector. CPV modules that concentrate in one dimension must be tracked normal to the Sun in one axis.

4. Single Axis Tracker

Single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms. There are several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT), horizontal single axis tracker with tilted modules (HTSAT), vertical single axis trackers (VSAT), tilted single axis trackers (TSAT) and polar aligned single axis trackers (PSAT). The orientation of the module with respect to the tracker axis is important when modeling performance.

5. Horizontal Single Axis Tracker (HSAT)

Horizontal single axis tracker with tilted modules in Xitieshan, China commissioned in July 2014.The axis of rotation for horizontal single axis tracker is horizontal with respect to the ground. The posts at either end of the axis of rotation of a horizontal single axis tracker can be shared between trackers to lower the installation cost. This type of solar tracker is most appropriate for low latitude regions. Field layouts with horizontal single axis trackers are very flexible. The simple geometry means that keeping all of the axes of rotation parallel to one another is all that is required for appropriately positioning the trackers with respect to one another. Appropriate spacing can maximize the ratio of energy production to cost, this being dependent upon local terrain and shading conditions and the time-of-day value of the energy produced. Backtracking is one means of computing the disposition of panels. Horizontal trackers typically have the face of the module oriented parallel to the axis of rotation. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation. In single axis horizontal trackers, a long horizontal tube is supported on bearings mounted upon pylons or frames[26]. The axis of the tube is on a north–south line. Panels are mounted upon the tube, and the tube will rotate on its axis to track the apparent motion of the Sun through the day.

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Figure 8: Horizontal Single Axis Tracker

6. Horizontal Single Axis Tracker with Tilted Modules

In HSAT, the modules are mounted flat at 0 degrees, while in HSAT, the modules are installed at a certain tilt. It works on same principle as HSAT, keeping the axis of tube horizontal in north–south line and rotates the solar modules east to west throughout the day. These trackers are usually suitable in high latitude locations but do not take as much land space as consumed by Vertical single axis tracker (VSAT). Therefore, it brings the advantages of VSAT in a horizontal tracker and minimizes the overall cost of solar project[27].

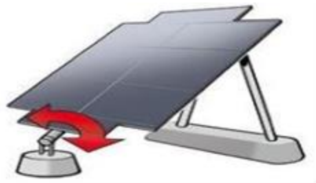

Figure 9: Horizontal Single Axis Tracker with Tilted Modules

7. Vertical Single Axis Tracker (VSAT)

The axis of rotation for vertical single axis trackers is vertical with respect to the ground. These trackers rotate from East to West over the course of the day. Such trackers are more effective at high latitudes than are horizontal axis trackers. Field layouts must consider shading to avoid unnecessary energy losses and to optimize land utilization. Also, optimization for dense packing is limited due to the nature of the shading over the course of a year. Vertical single axis trackers typically have the face of the module oriented at an angle with respect to the axis of rotation. As a module tracks, it sweeps a cone that is rotationally symmetric around the axis of rotation[27].

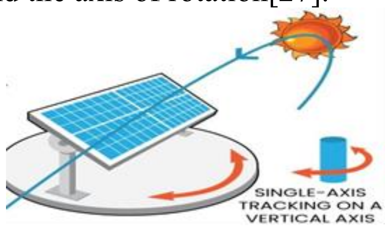

Figure 10: Vertical Single Axis Tracker

8. Tilted Single Axis Tracker (TSAT)

All trackers with axes of rotation between horizontal and vertical are considered tilted single axis trackers. Tracker tilt angles are often limited to reduce the wind profile and decrease the elevated end height. With backtracking, they can be packed without shading perpendicular to their axis of rotation at any density. However, the packing parallel to their axes of rotation are limited by the tilt angle and the latitude. Tilted single axis trackers typically have the face of the module oriented parallel to the axis of rotation. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation.

9. Dual Axis Trackers

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis. There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are tip-tilt dual axis trackers (TTDAT) and azimuth-altitude dual axis trackers (AADAT). The orientation of the module with respect to the tracker axis is important when modeling performance. Dual axis trackers typically have modules oriented parallel to the secondary axis of rotation. Dual axis trackers allow for optimum solar energy levels due to their ability to follow the Sun vertically and horizontally. No matter where the Sun is in the sky, dual axis trackers are able to angle themselves to be in direct contact with the Sun[27].

Figure 11: Dual Axis Solar Tracker

10. Azimuth-altitude Dual Axis Tracker

An azimuth–altitude (or alt-azimuth) dual axis tracker (AADAT) has its primary axis (the azimuth axis) vertical to the ground. The secondary axis, often called elevation axis, is then typically normal to the primary axis. They are similar to tip-tilt systems in operation, but they differ in the way the array is rotated for daily tracking. Instead of rotating the array around the top of the pole, AADAT systems can use a large ring mounted on the ground with the array mounted on a series of rollers. The main advantage of this arrangement is the weight of the array is distributed over a portion of the ring, as opposed to the single loading point of the pole in the TTAT.

II. Literature

Trupti Khavale et.al [7] conducted a study in minimal resources. They build a Dual Axis Solar Tracker, a demo model of solar tracker to track the maximum intensity point of light source so that the voltage given at that point by the solar panel is maximum. Solar Panel is the alternate energy source. The panel senses the light in a sensing zone, beyond which it fails to respond. If multiple sources of light appear on panel, it calculates the vector sum of light sources & moves the panel in that point. Christiner Mario.P et.al[8],done work on the dual axis tracker computer control to obtain maximum power from the solar energy over the conventional static solar panel and without cooling. The system is fabricated and investigated successfully. The proposed technique has an advantage because it uses satellite motor as an actuator device to produce a much higher performance and less power consumption compared to the stepper motor. This system is cost effective, simple, and efficient and it operates automatically. Alazone Smith[3], made a project which consist of four critical components. The solar panel is the foundation of the device which will be mounted and positioned above the base to improve durability and structure competence. The base will provide stability to all the other components. Between the base and the solar panel will be two drivers; a stepper motor and a linear actuator. Each driver will have control of an axis, either vertical or horizontal. True project success will be based on whether the device is able to sense and adjust to the perpendicular angle with a tolerance of 5-10% and absorb at least 10% more energy than the fixed solar panel.

Mishra et.al [9] worked on a project to examine how a system of light sensors can be used as a solar tracker for a solar panel. The light sensors will be mounted to the solar panel rig and be exposed to the sun. By examining which light sensor is exposed to the most sunlight, the solar panel will change both the direction it is pointing and its angle is relative to the ground so that it is pointing towards the sun, and there by capturing more of the sun's energy. Cliffort et.al[10] conducted a study in Amman Jordan focusing on the demand of the sun tracking for solar panels. This study basically discussed about increasing efficiency of PV panels in dessert regions. The author explained that by using part of the power output of the solar panel two degrees of freedom orientation can be achieved. If one considers the symmetry of the system, the kinematics of the system can be controlled using astronomic calculation. Solar tracking sensors and feedback control loops can be used to add close loop control to the system. This solves the problem of cloudy days. The author further explained that special consideration should be given to the grid arrangement of panels in the collecting plants. In another study conducted by Nahar.S et.al [11], a project using ARM7 TDMI processor was explained. The processor did the task of gather input from sensor and giving command to the motor to track the sun. ARM7 TDMI processor was used to design and implement closed loop algorithm which form the bases

of monitoring controller. This resulted in maximum current from solar panel to increase the energy production.
A difference between solar tracking device and a stationary collector was noted by Sarkar et.al[12]The author discussed that in a solar tracking device, the solar radiation struck flat plate collector perpendicularly as compare to stationary collector of same size. This produced average 1.4 times more heat energy. Sarkar et.al[13] introduced a computerized sun tracking device to rotate the solar still with reference to the movement of sun. The researcher demonstrated the comparison between fixed and sun tracked solar stills. The productivity was increased around 22 percent with use of sun tracking because there was 2 percent increase in efficiency. There is an increase in water temperature and decrease in thermal capacity of the water by using the sun tracker. This leads to an increase in evaporation rate as well as in distillation rate. Alexandru.C et.al[14] used a mathematical analysis to achieve optimal operational efficiency of solar photovoltaic module. They focused on design and testing of control system. The study was based on calculated data of the altitude angle at Taif city, Saudi Arabia. The researcher showed that the sun tracking algorithm can be divided into closed-loop and open-loop systems depending on its controlled.
The literature on tracking process for the dual axis sun tracker by a sliding mode control law was reviewed by Mohisin et.al [15]. The power production can be increased up to 40 percent by using this autonomic dual axis sun tracker. The result showed the usefulness of the sliding mode control in the tracking process, its strength and the high quality of the sliding mode observer. It was stated by Chhotan.A et al [16] that the sun is tracked from east to west by single axis tracker whereas the daily east to west movement of the sun and the seasonal declination movement was tracked by two axis trackers. A large area of sunlight is focused into a small beam by using lenses or mirror. Sunlight is converted into electric current using the photo electric current by PV. Titirrsha et.al [18] suggest that the increase in electricity efficiency of monitoring solar plate in everyday is 26 to 38% compared to fixed plate and during cloudy or rainy days it's varies at any degree.
Generally, solar panels are motion less and do not monitor the movement of the sun. In this project a solar tracker device that tracks the movement of sun throughout the sky and tries to maintain the solar panel perpendicular to the rays, ensuring that the maximum quantity of sunlight is incident on the panel during the day. The solar tracking system starts following the sun right from sunrise, in the course of the day until night, and starts all over again from the dawn next day. The solar panels are powerful means of storing energy, their performance at doing so is immediately associated with their perspective with the sun. Because PV cells get the maximum power from facing the solar, a stationary solar panel collects less sunlight one which follows the sun throughout the sky. In this project the dual axis system is used that includes both a horizontal and vertical axis [17].In this project the tracking system can track the motion of sun exactly around the world at any location.

III. Materials

3.1 Components Required For Building Dual Axis Solar Tracker

Arduino Uno 328P, Solar Panel, DC Motor, Rain Sensor, Humidity Sensor, Temperature Sensor, Resistor, Capacitors, Transistors, Cables and Connectors, Diodes, PCB and Breadboards, LED, Transformer/Adapter, Push Buttons, Switch, Rotating wheel, IC Sockets

3.1.1 Arduino Uno

The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc and initially released in 2010. The board is equipped with sets of digital and analogue input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analogue I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by a USB cable or a barrel connector that accepts voltages between 7 and 20 volts, such as a rectangular 9-volt battery. It is similar to the Arduino Nano and Leonardo. The hardware reference design is distributed under a Creative Commons Attribution Share-

Industrial Engineering Journal
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Alike 2.5 license and is available on the Arduino website. Layout and production files for some versions of the hardware are also available.[28]

The word "uno" means "one" in Italian and was chosen to mark a major redesign of the Arduino hardware and software. The Uno board was the successor of the demilune release and was the 9th version in a series of USB-based Arduino boards. Version 1.0 of the Arduino IDE for the Arduino Uno board has now evolved to newer releases. The ATmega328 on the board comes pre-programmed with a boot loader that allows uploading new code to it without the use of an external hardware programmer. While the Uno communicates using the original STK500 protocol, it differs from all preceding boards in that it does not use a FTDI USB-to-UART serial chip. Instead, it uses the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.

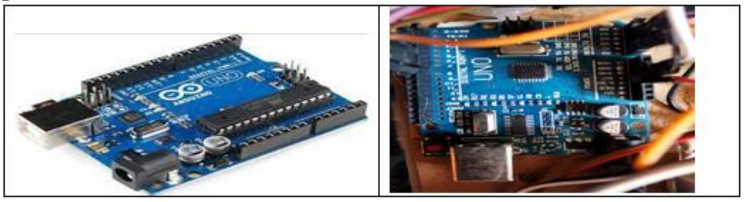

Figure 12: Arduino Uno

3.1.2 The Atmega328P-PU Atmel 8 Bit 32K AVR Micro Controller

The Atmel Atmega328/P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture.[29]

Pin Diagram

Figure13: Atamega 328P-PU Atmel 8 Bit 32K AVR Micro Controller

3.1.3 Pin Layout of Atamega 328P

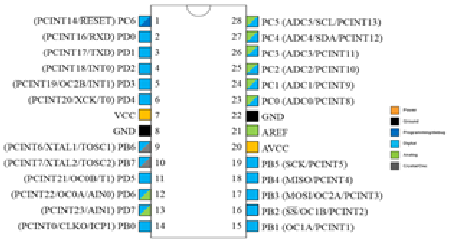

Figure 14: Pin Layout of Atamega 328P[30]

3.1.4 Features of Arduino

- The operating voltage is 5V
- The recommended input voltage will range from 7v to 12V
- The input voltage ranges from 6v to 20V
- Digital input/output pins are 14
- Analog i/p pins are 6
- DC Current for each input/output pin is 40 mA
- DC Current for 3.3V Pin is 50 mA
- Flash Memory is 32 KB
- SRAM is 2 KB
- EEPROM is 1 KB
- CLK Speed is 16 MHz

The Arduino Uno board can be built with power pins, analog pins, ATmegs328, ICSP header, reset button, power LED, digital pins, test led 13, TX/RX pins, USB interface, an external power supply.

Industrial Engineering Journal
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Volume : 53, Issue 2, No. 1, February : 2024

3.1.5 Power Supply

The Arduino Uno power supply can be done with the help of a USB cable or an external power supply. The external power supplies mainly include AC to DC adapter otherwise a battery. The adapter can be connected to the Arduino Uno by plugging into the power jack of the Arduino board. Similarly, the battery leads can be connected to the Vin pin and the GND pin of the POWER connector. The suggested voltage range will be 7 volts to 12 volts.

Input & Output

- The 14 digital pins on the Arduino Uno can be used as input & output with the help of the functions like pin Mode (), digital Write (), & Digital Read ().
- Pin1 (TX) & Pin0 (RX) (Serial): This pin is used to transmit & receive TTL serial data, and these are connected to the ATmega8U2 USB to TTL Serial chip equivalent pins.
- Pin 2 & Pin 3 (External Interrupts): External pins can be connected to activate an interrupt over a low value, change in value.
- Pins 3, 5, 6, 9, 10, & 11 (PWM): This pin gives 8-bit PWM o/p by the function of analog Write ().
- SPI Pins (Pin-10 (SS), Pin-11 (MOSI), Pin-12 (MISO), Pin-13 (SCK): These pins maintain SPI-communication, even though offered by the fundamental hardware, is not presently included within the Arduino language.
- Pin-13(LED): The inbuilt LED can be connected to pin-13 (digital pin). As the HIGH-value pin, the light emitting diode is activated, whenever the pin is LOW.
- Pin-4 (SDA) & Pin-5 (SCL) (I2C): It supports TWI-communication with the help of the Wire library.
- AREF (Reference Voltage): The reference voltage is for the analogI/PS with analog Reference ().
- Reset Pin: This pin is used for reset (RST) the microcontroller.
- Memory
- The memory of this Atmega328 Arduino microcontroller includes flash memory-32 KB for storing code, SRAM-2 KB EEPROM-1 KB.

3.2 Sensor

A sensor is a device that produces an output signal for the purpose of sensing a physical. In the broadest definition, a sensor is a device, module, machine, or subsystem that detects events or changes in its environment and sends the information to other electronics, frequently a computer processor. Sensors are always used with other electronics Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base and in innumerable applications of which most people are never aware. With advances in micro machinery and easy-to-use microcontroller platforms, the uses of sensors have expanded beyond the traditional fields of temperature, Pressure and flow measurement, for example into MARG sensors.

3.3 Light Dependent Resistor

LDR is an acronym for Light Dependent Resistor. LDRs are tiny light-sensing devices also known as photo resistors. An LDR is a resistor whose resistance changes as the amount of light falling on it changes. The resistance of the LDR decreases with an increase in light intensity, and vice-versa. This property allows us to use them for making light sensing circuits. For using an LDR, we always have to make a voltage divider circuit. When the value of resistance of LDR increases in comparison to the fixed resistance, the voltage across it also increases.[31]

Figure 15, LDR Sensor

3.4 DC Motor

A DC motor is any of a class of rotary electrical motors that converts direct current (DC) electrical energy into mechanical energy. The most common types rely on the forces produced by induced magnetic fields due to flowing current in the coil. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic; to periodically change the direction of current in part of the motor.

DC motors were the first form of motors widely used, as they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Small DC motors are used in tools, toys, and appliances. The universal motor, a lightweight brushed motor used for portable power tools and appliances can operate on direct current and alternating current. Larger DC motors are currently used in propulsion of electric vehicles, elevator and hoists, and in drives for steel rolling mills. The advent of power electronics has made replacement of DC motors with AC motors possible in many applications.[31]

Types of DC Motors

- Permanent Magnet DC Motors, The permanent magnet motor uses a permanent magnet to create field flux.
- Series DC Motors, in a series DC motor, the field is wound with a few turns of a large wire carrying the full armature current.
- Shunt DC Motors.
- Compound DC Motors.

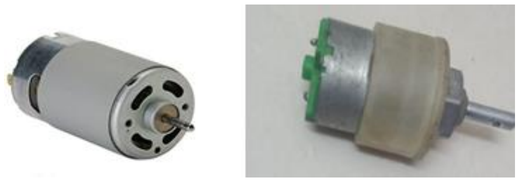

Figure 16: DC Motor

3.4.1 Brushed DC Motors

The classic DC motor design generates an oscillating current in a wound rotor with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of a coil wound around a rotor which is then powered by any type of battery. Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine. The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts. There are three types of dc motor 1. DC series motor 2. DC shunt motor 3. DC compound motor – these are also two type a. cumulative compound b. differential compound

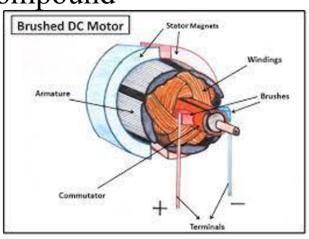

Figure 17: Brushed DC Motor[32]

3.4.2. Brushless DC Motor

Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical “rotating switch” or commutator/brush gear assembly is replaced by an external

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electronic switch synchronized to the rotor's position. Brushless motors are typically 85- 90% efficient, whereas DC motors with brush gear are typically 75-80% efficient. Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical "rotating switch" or commutator/brush gear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85- 90% efficient, whereas DC motors with brush gear are typically 75-80% efficient.
Brushless DC motors are commonly used where precise speed control is necessary, as in computer disk drives or in video cassette recorders, the spindles within CD, CD-ROM (etc.) drives, and mechanisms within office products such as fans, laser printers and photocopiers.

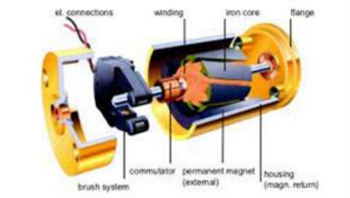

Figure 18: Brushless DC Motor[33]

Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.
3.4.3 Coreless DC Motors
Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is exerted only on the windings of the electromagnets. Taking advantage of this fact is the coreless DC motor, a specialized form of a brush or brushless DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat pancake (possibly formed on a printed wiring board) running between upper and lower stator magnets. The windings are typically stabilized by being impregnated with Electrical epoxy potting systems. Filled epoxies have moderate mixed viscosity and a long gel time. These systems are highlighted by low shrinkage and low exothermal. Typically, UL 1446 recognized as a potting compound for use up to 180C (Class H) UL File No. E 210549. Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air. These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems, like radio-controlled vehicles/aircraft, humanoid robotic systems, industrial automation, medical devices.[34]

Figure 19: Coreless DC Motor

Brushless DC motor (BLDC) is used here. DC motor consists of coils and magnets which are used to drive the shaft and there is a brush over the shaft which takes care of switching the power direction in the coils. Brushless motors don't have these brushes.
They have coils at the centre of the motor, which is fixed to the mounting. They contain a number of magnets mounted to a cylinder on outer side, which is attached to the rotating shaft. So, the coils are fixed. It means, the wires can go directly to them and therefore there is no need for a brush. Brushless DC motor spins at a much higher speed and uses less power than DC motor (at same speed). Also, there is no power loss due to brush transition. In the image given below, one can see 1000KV BLDC

motor which has three input wire. These three wires will be connected with electronic speed controller (ESC).

Brushless motor comes with Kv-rating. It means motor will spin at given RPM (revolutions per minute) if we give V voltage to motor without any load.

RPM= $K_v \times V$

Here, we are using four brushless motors, which have 1400 Kv rating.

3.5 Jumper Wires

A jump wire (also known as jumper, jumper wire, DuPont wire) is an electrical wire, or group of them in a cable, with a connector or pin at each end (or sometimes without them – simply "tinned"), which is normally used to interconnect the components of a breadboard or other prototype or test circuit, internally or with other equipment or components, without soldering.[35]

Figure 20: Jumper Wire

Individual jump wires are fitted by inserting their "end connectors" into the slots provided in a breadboard, the header connector of a circuit board, or a piece of test equipment.

Types of Jumper Wires

Jumper wires come in three versions:

- Male-to-male jumper
- Male-to-female jumper
- Female-to-female jumper

3.6 Solar Panel 12v/5whts

Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation. This energy can be used to generate electricity or be stored in batteries or thermal storage.[36]

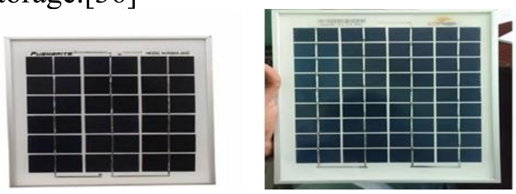

Figure 21: Solar Panel

3.7 Types of PV Systems

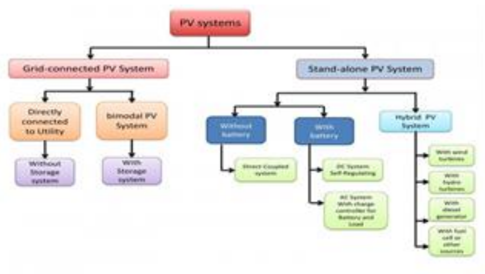

Figure 22: PV System[37]

3.8 Rain Sensor

The Arduino Rain Sensor code is very simple and easy to understand. We just have to read the analog data out of the sensor and we can approximate the average rainfall on top of the sensor. This can be easily done in analog mode. In digital mode, one just need to set the potentiometer and get a digital output. With that, now ready to upload some code to Arduino UNO board and get the Rain Detection Sensor working.

Arduino Code for Processing Incoming Data from Rain Detection Sensor

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The Arduino Rain Sensor code is very simple and easy to understand. We just have to read the analog data out of the sensor and we can approximate the average rainfall on top of the sensor. This can be easily done in analog mode. In digital mode, we just need to set the potentiometer and we will get a digital output. You can verify the digital trigger point just by looking at the onboard LED on the sensor.[38] For demonstration in the mode, we have connected an LED to the digital pin 6 of the Arduino and we will change the brightness of the LED depending upon the water droplets on top of the sensor. We initialize our code by declaring two macros, the first one is for the led where we will connect an LED and the second one is the sensor Pin through which we are reading the data coming out of the sensor.

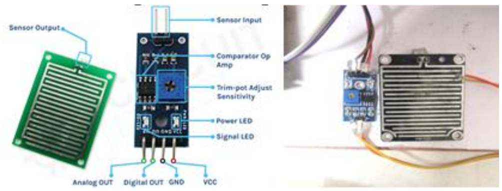

Figure 23: Arduino Rain Sensor Tutorial

3.9 LCD Display

LCD (Liquid Crystal Display) is a type of flat panel display which uses liquid crystals in its primary form of operation. LEDs have a large and varying set of use cases for consumers and businesses, as they can be commonly found in smart phones, televisions, computer monitors and instrument panel.[39]

Figure 24: LCD Display

3.9.1 Connection of Arduino to LCD

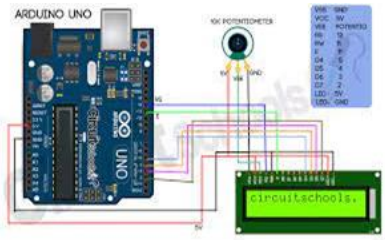

Figure 25: LCD Display with Arduino[40]

3.10 Temperature Sensor

A temperature sensor is an electronic device that measures the temperature of its environment and converts the input data into electronic data to record, monitor, or signal temperature changes. There are many different types of temperature sensors.[41] Some temperature sensors require direct contact with the physical object that is being monitored (contact temperature sensors), while others indirectly measure the temperature of an object (non-contact temperature sensors).

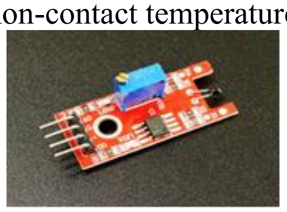
Figure 26: Temperature Sensor

Non-contact temperature sensors are usually infrared (IR) sensors. They remotely detect the IR energy emitted by an object and send a signal to a calibrated electronic circuit that determines the object's temperature. Among the contact temperature sensors are thermocouples and thermistors. A thermocouple is comprised of two conductors, each made of a different type of metal, that are joined at an end to form a junction. When the junction is exposed to heat, a voltage is generated that directly corresponds to the temperature input. This happens on account of the phenomena called the thermoelectric effect. Thermocouples are generally inexpensive, as their design and materials are simple. The other type of contact temperature sensor is called a thermistor. In thermistors, resistance decreases as temperature increases. There are two main types of thermistors: Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC). Thermistors are more precise than thermocouples (capable of measuring within 0.05-1.5 degrees Celsius), and they are made of ceramics or polymers. Resistance Temperature Detectors (RTD) are essentially the metal counterpart of thermistors, and they are the most precise and expensive type of temperature sensors. Temperature sensors are used in automobiles, medical devices, computers, cooking appliances, and other types of machinery.

3.11 Battery

A battery is a source of electric power consisting of one or more electrochemical cells with external connections for powering electrical devices. When a battery is supplying power, its positive terminal is the cathode and its negative terminal is the anode. The terminal marked negative is the source of electrons that will flow through an external electric circuit to the positive terminal. When a battery is connected to an external electric load, a redox reaction converts high-energy reactants to lower-energy products, and the free-energy difference is delivered to the external circuit as electrical energy. Historically the term "battery" specifically referred to a device composed of multiple cells; however, the usage has evolved to include devices composed of a single cell. Primary (single-use or "disposable") batteries are used once and discarded, as the electrode materials are irreversibly changed during discharge; a common example is the alkaline battery used for flashlights and a multitude of portable electronic devices. [42]Secondary (rechargeable) batteries can be discharged and recharged multiple times using an applied electric current; the original composition of the electrodes can be restored by reverse current. Examples include the lead–acid batteries used in vehicles and lithium-ion batteries used for portable electronics such as laptops and mobile phones.

Figure 27: Battery

Batteries come in many shapes and sizes, from miniature cells used to power hearing aids and wristwatches to, at the largest extreme, huge battery banks the size of rooms that provide standby or emergency power for telephone exchanges and computer data centres. Batteries have much lower specific energy (energy per unit mass) than common fuels such as gasoline. In automobiles, this is somewhat offset by the higher efficiency of electric motors in converting electrical energy to mechanical work, compared to combustion engines.

IV Methodology

4.1 Working Principle

• The higher is the intensity of light, lower will be the LDR resistance and due to this the output voltage lowers and when the light intensity is low, higher will be the LDR resistance and thus higher output voltage is obtained.

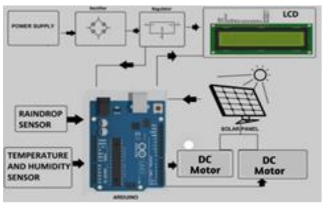

Figure 28: Working Principle of Dual Axis Solar Tracking System using Arduino[43]

- Resistance of LDR depends on intensity of the light and it varies according to it. The higher is the intensity of light, lower will be the LDR resistance and due to this the output voltage lowers and when the light intensity is low, higher will be the LDR resistance and thus higher output voltage is obtained.
- A potential divider circuit is used to get the output voltage from the sensors (LDRs). The circuit is shown here.
- The LDR senses the analogy input in voltages between 0 to 5 volts and provides a digital number at the output which generally ranges from 0 to 1023.
- Now this will give feedback to the microcontroller using the Arduino software (IDE).
- The servo motor position can be controlled by this mechanism which is discussed later in the hardware model.

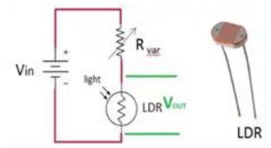

Figure 29: Potential Divider Circuit[44]

- The sensitivity of the LDR depends on point source of light. It hardly shows any effect on diffuse lighting condition.
- Sensors perform necessary perform during this project LDR sensors are utilized in it. The most perform of LDR sensors is sense the sunshine and send the signal to microcontroller. This diagram showing that when the sensing light-weight send the signal to microcontroller.

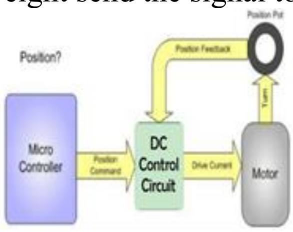

Figure 30: Control Unit[45]

- DC motor tracks the sun linearly subsequently stepper motor do it is own perform that is track the parabolic displacement of sun. The main purpose of this project is to gift which is able to cause higher alignment of PV array with sun light-weight and harvest alternative energy hunter system increase productivity by important margin.
- The tracker finally adjusts its position sensing the maximum intensity of light falling perpendicular to it and stays there till it notices any further change.

4.2 Basic Circuit Diagram

An overview of the required circuit for the Dual-axes solar tracker is shown here.
The 5V supply is fed from an USB 5V dc voltage source through Arduino Board.
Servo X: Rotates solar panel along X direction
Servo Y: Rotates solar panel along Y direction

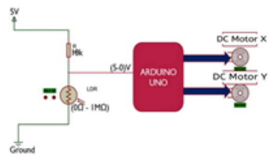

Figure 31: Basic Circuit Diagram[46]

Light Sensor Theory and Circuit of Sensor Used Light detecting sensor that maybe used to build solar tracker include; phototransistors, photodiodes, LDR and LLS05. A suitable, inexpensive, simple and easy to interface photo sensor is analog LDR which is the most common in electronics. It is usually in form of a photo resistor made of cadmium sulphide (CDs) or gallium arsenide (GaAs). Next in complexity is the photodiode followed by the phototransistor.[47]

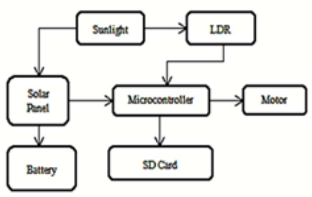

Figure 32: Basic Diagram of the Solar Tracker with Data Logging

4.3 Flow Chart

Based on the below-stated conditions, solar tracker flowchart is shown in Fig. 33. The light intensity of east and west LDR's are compared and accordingly decision is made whether to move the panel in east or west direction. After proper orientation in the east–west direction, south-north orientation is checked and implemented. Each time the position of the sun is changed; the controller repeats the same flowchart algorithm and orients the panel in the sun's direction.[48]

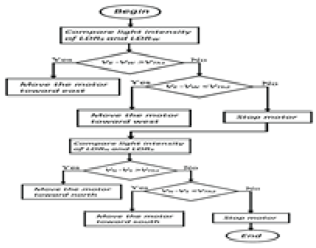

Figure 33: Flow Chart of Dual Axis Solar Tracker

V. Observations and Results

In this Dual Axis Solar Tracker, when source light falls on the panel, the panel adjusts its position according to maximum intensity of light falling perpendicular to it. The objective of the project is completed. This was achieved through using light sensors that are able to detect the amount of sunlight that reaches the solar panel. The values obtained by the LDR's are compared and if there is any significant difference, there is actuation of the panel using a servo motor to the point where it is almost perpendicular to the rays of the Sun.

This is achieved using a system with three stages or subsystems. Each stage has its own role. The stages were;

- An input stage that was responsible for converting incident light to a voltage.
- A control stage that was responsible for controlling actuation and decision making.
- A driver stage with the servomotor. It was responsible for actual movement of the panel.

The input stage is designed with a voltage divider circuit so that it gives desired range of illumination for bright illumination conditions or when there is dim lighting. The potentiometer was adjusted to cater for such changes. The LDRs were found to be most suitable for this project because their resistance varies with light. They are readily available and are cost effective. Temperature sensors for instance would be costly. The control stage has a microcontroller that receives voltages from the LDRs and determines the action to be performed. The microcontroller is programmed to ensure it sends a signal to the servo motor that moves in accordance with the generated error. The final stage was the driving circuitry that consisted mainly of the servo motor. The servomotor had enough torque to drive the panel. Servo motors are noise free and are affordable, making them the best choice for the project.

5.1 Observations of Dual Axis Solar Tracker

A dual-axis solar tracker is a type of solar tracking system that is designed to maximize the amount of solar energy collected by solar panels by following the sun's movement in both the horizontal and vertical axis. Here are some observations of dual-axis solar trackers:

1. Increased Energy Production: Dual-axis solar trackers can increase the energy production of solar panels by up to 40% compared to fixed solar panels. This is because they can track the sun's movement throughout the day and adjust the angle of the solar panels to ensure maximum exposure to sunlight.

2. Precision: Dual-axis solar trackers are more precise than single-axis trackers because they can follow the sun's movement in both the horizontal and vertical axis. This allows them to maintain a more optimal angle of incidence between the solar panels and the sun.
3. Expensive: Dual-axis solar trackers are more expensive than fixed or single-axis solar panels due to their complex design and additional components. The cost of a dual-axis solar tracker can be several times that of a fixed solar panel.
4. Maintenance: Dual-axis solar trackers require regular maintenance to ensure they are functioning correctly. This includes checking the alignment of the panels, lubricating moving parts, and replacing worn-out components.
5. Durability: Dual-axis solar trackers are typically designed to withstand harsh weather conditions, including high winds and heavy snow loads. However, they may be more susceptible to damage than fixed solar panels due to their complex design and moving parts.

Overall, dual-axis solar trackers offer significant advantages in terms of energy production but come with a higher cost and maintenance requirements.

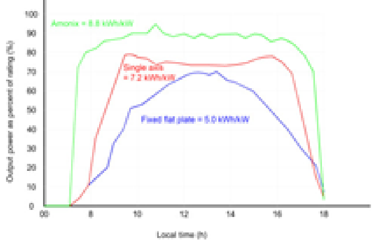

Figure 34: Comparison of Fixed Plate to Single Axis

The graph of a dual-axis solar tracker by output power as a percent rating to local time represents how the power output of the solar panel varies throughout the day as the sun moves across the sky. The x-axis of the graph represents the time of day, typically broken down into 24 hours, and the y-axis represents the percentage of the solar panel's rated power output. At the beginning and end of the day, when the sun is low on the horizon, the power output of the solar panel is relatively low, as the sunlight is passing through more of the Earth's atmosphere, which reduces the amount of energy that reaches the solar panel. As the sun rises higher in the sky, the power output of the solar panel increases, peaking at solar noon when the sun is directly overhead.[49]

In a dual-axis solar tracker, the solar panel is mounted on a mechanism that follows the sun's movement in both the horizontal and vertical axis. This allows the solar panel to maintain an optimal angle of incidence with the sun throughout the day, which maximizes the amount of energy it can collect. The graph of a dual-axis solar tracker by output power as a percent rating to local time will typically show a higher peak power output and a broader peak compared to a fixed solar panel, as the solar tracker can track the sun's movement throughout the day. However, the graph may also show fluctuations in the power output throughout the day due to changes in weather conditions, cloud cover, and other factors that can affect the amount of sunlight that reaches the solar panel.

5.2 Solar Plate and Connecting Load

- Solar panel is placed at the top and connected to a load directly. The load may a led or a voltmeter which could be connected to get the exact voltage which depends on the intensity of light falling on the panel and the position of the tracker.
- Concentrated solar photo voltaics' and have optics that directly accept sunlight, so solar trackers must be angled correctly to collect energy. All concentrated solar systems have trackers because the systems do not produce energy unless directed correctly towards the sun.
- The solar panel is just a mere device to accept the light radiation which is purely controlled by LDR sensors and the load connected depends upon the rating of the panel used.

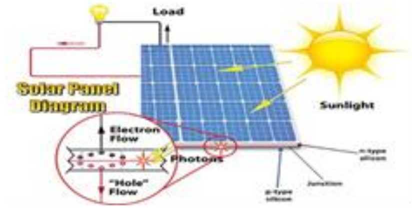

Figure 35: Solar Panel and Connected Load[50]

The information stage is planned with a voltage divider circuit so it gives wanted scope of light for brilliant enlightenment conditions or when there is faint lighting. The potentiometer is acclimated to provide food for such changes. The LDRs were viewed as generally appropriate for this project on the grounds that their opposition differs with light. They are promptly accessible and are cost effective. Temperature sensors for example would be exorbitant. The control stage has a microcontroller that gets voltages from the LDRs and chooses the action to be performed. The microcontroller is modified to guarantee it conveys a message to the servo motor that moves in agreement with the produced blunder. The last stage is the driving hardware that comprised for the most part of the servo motor. The servo motor had sufficient torque to drive the panel. DC motors are noise free and are reasonable, making them the most ideal choice for the project.

5.3 Relation Between Solar Panel Misalignment and Direct Power Loss

Figure 36: Graph between Misalignments to Power Loss

The graph of a dual-axis solar tracker by misalignment angle to power loss represents how much power output is lost from the solar panel as the angle of misalignment between the solar panel and the sun increases. The x-axis of the graph represents the misalignment angle in degrees, while the y-axis represents the percentage of power loss from the solar panel's rated power output.[51]

A dual-axis solar tracker is designed to keep the solar panel pointed directly at the sun as it moves across the sky, which helps to maximize the amount of energy it can collect. However, if the solar panel becomes misaligned due to changes in weather conditions, mechanical issues, or other factors, the power output will decrease. The graph can be used to estimate the impact of different misalignment angles on the solar panel's power output and to help identify potential issues with the solar tracker system. For example, if the graph shows a sharp increase in power loss at a particular misalignment angle, this may indicate a problem with the solar tracker mechanism that needs to be addressed. Overall, the graph of a dual-axis solar tracker by misalignment angle to power loss is an essential tool for understanding the performance of a solar tracker system and optimizing its operation to maximize energy collection.

5.4 Graph of Time to Power Output

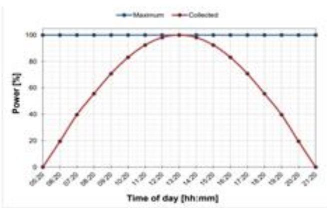

Figure 37: Graph between Time to Power Output

The graph of a dual-axis solar tracker by time of day to power percentage represents how the power output of the solar panel varies throughout the day as the sun moves across the sky. The x-axis of the graph represents the time of day, typically broken down into 24 hours, while the y-axis represents the percentage of the solar panel's rated power output. The graph of a dual-axis solar tracker by time of day to power percentage will typically show a relatively low power output at the beginning and end of the day when the sun is low on the horizon. As the sun rises higher in the sky, the power output of the solar panel will increase, peaking at solar noon when the sun is directly overhead. The graph may also show fluctuations in the power output throughout the day due to changes in weather conditions, cloud cover, and other factors that can affect the amount of sunlight that reaches the solar panel. These fluctuations may be more or less pronounced depending on the location of the solar panel and the time of year.[52] The graph can be used to optimize the performance of the solar tracker system by identifying periods of the day when the power output is relatively low and adjusting the solar panel's angle of incidence to maximize energy collection. For example, the graph may show that the power output is relatively low in the morning, indicating that the solar panel needs to be adjusted to point more directly at the sun during this time. Overall, the graph of a dual-axis solar tracker by time of day to power percentage is an important tool for understanding the performance of a solar tracker system and optimizing its operation to maximize energy collection.

5.5 Experimental Results

Experiment results were performed by placing the designed system in open air. Table I, II & III show the output power for PV systems (stationary module, Single axis tracking and dual axis tracking).The output power data is collected during 8:00 A.M. to 6:00 P.M. In Table IV comparison of output power is shown in tabular form for three cases.

5.5.1 Stationary Module

Time	Voltage(v)	Current(A)	Power(watt)
8:00	7.49	.01	0.074
9:00	8.68	0.09	0.7812
10:00	15.04	1	15.04
11:00	17.04	1.16	19.766
12:00	17.14	1.12	19.196
13:00	17.70	1.14	20.178
14:00	17.68	0.89	15.735
15:00	17.77	0.94	16.7038
16:00	15.02	0.52	7.8104
17:00	6.31	0.12	0.757
18:00	6.3	0.1	0.63

Table 1: Stationary Module Values

The table provides a snapshot of the solar panel's performance at different times throughout the day, allowing users to identify trends and optimize its operation. For example, the table may show that the solar panel has a relatively low power output in the morning when the sun is low on the horizon, but peaks in the afternoon when the sun is directly overhead. This information can be used to adjust the angle of the solar panel to maximize energy collection and increase its overall efficiency.

The table may also show fluctuations in the power output, voltage, and current throughout the day due to changes in weather conditions, cloud cover, and other factors that can affect the amount of sunlight that reaches the solar panel. These fluctuations may be more or less pronounced depending on the location of the solar panel and the time of year. Overall, the table diagram to stationary module of time, power, voltage, current is a useful tool for monitoring the performance of a stationary solar panel and optimizing its operation to maximize energy collection.

5.5.2 Single Axis Tracker

Time	Voltage(v)	Current(A)	Power(watt)
8:00	4.57	.001	.0045
9:00	8.97	0.73	0.5481
10:00	14.7	1.32	19.404
11:00	16.45	1.30	21.385
12:00	14.27	1.35	19.262
13:00	16.47	1.62	26.68
14:00	15.15	1.15	17.42
15:00	15.83	1.13	17.88
16:00	15.85	1.18	18.703
17:00	13.47	0.60	8.08
18:00	5.3	0.16	0.848

Table 2: Single Axis Tracker Values with Respective of Voltage, Current & Power

The table may also show fluctuations in the power output, voltage, and current throughout the day due to changes in weather conditions, cloud cover, and other factors that can affect the amount of sunlight that reaches the solar panel. These fluctuations may be more or less pronounced depending on the location of the solar panel and the time of year. Overall, the table diagram to single-axis solar tracker of time, power, voltage, current is a useful tool for monitoring the performance of a solar panel mounted on a single-axis solar tracker and optimizing its operation to maximize energy collection.

5.5.3 Dual Axis Tracker

Time	Voltage(v)	Current(A)	Power(watt)
8:00	9.16	0.1	0.92
9:00	16.52	1.15	18.99
10:00	21.12	1.44	30.41
11:00	21.78	1.47	32.01
12:00	22.00	1.51	33.22
13:00	22.05	1.64	34.16
14:00	21.39	1.35	28.87
15:00	20.56	1.30	26.72
16:00	20.45	1.26	25.76
17:00	19.52	1.21	23.61
18:00	11.45	0.61	6.98

Table 3: Dual Axis Tracker Values with Respective of Voltage, Current & Power

A table diagram to dual-axis solar tracker of time, power, voltage, current represents the performance of a solar panel mounted on a dual-axis solar tracker over a period of time. The table will typically have several columns that provide information about the solar panel's power output, voltage, and current at different times throughout the day. The "time" column of the table represents the time of day when the measurement was taken, typically broken down into hourly increments. The "power" column represents the power output of the solar panel in watts (W) or kilowatts (kW) at each time interval. The "voltage" column represents the voltage of the solar panel in volts (V), while the "current" column represents the current output in amperes (A).

In a dual-axis solar tracker, the solar panel is mounted on a mechanism that can follow the sun's movement in both the horizontal and vertical axes. This allows the solar panel to maintain an optimal angle of incidence with the sun throughout the day, which maximizes the amount of energy it can collect. The table diagram to dual-axis solar tracker of time, power, voltage, current provides a snapshot of the solar panel's performance at different times throughout the day, allowing users to identify trends and optimize its operation. For example, the table may show that the solar panel has a relatively low power output in the morning when the sun is low on the horizon, but peaks in the afternoon when the sun is at its highest point in the sky. This information can be used to adjust the angle of the solar panel to maximize energy collection and increase its overall efficiency.

5.5.4 Generated Power for Three Cases

Time	Fixed Array	Single Axis	Dual Axis
8:00	0.074	.0045	0.92
9:00	0.78	0.54	18.99
10:00	15.04	19.40	30.41
11:00	19.76	21.38	32.01
12:00	19.19	19.26	33.22
13:00	20.17	26.68	34.16
14:00	15.73	17.42	28.87
15:00	16.70	17.88	26.72
16:00	7.81	18.70	25.76
17:00	0.75	8.08	23.61
18:00	0.63	0.84	6.98

Table 4: Generated Power for Three Cases

Table 4 provides a comparison between output powers for three cases.[53] A graphical comparison for three cases is done by plotting three power curves for three cases with the help of data provided in Table IV. Collected data was simulated in MATLAB and graphical curves are plotted with the help of MATLAB. Graphical comparison of output power for three cases is shown in Figure 38.

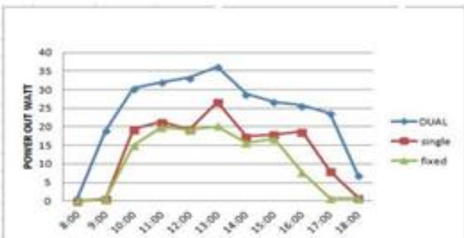

Figure 38: Graphical Comparison

Graphical comparison is clearly showing the improved solar energy conversion for dual axis tracking case. Although single axis solar energy conversion curve is higher above the fixed PV array system but dual axis is showing higher efficiency as compared to single axis. Dual axis system high power capturing property is clear from the graphical comparison.

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5.6 Starting Position of Solar Tracker

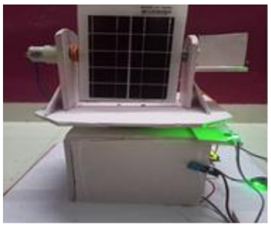

Figure 39: Starting Position of Solar Tracker

5.6.1 Different Types of Angles in Dual Axis Solar Tracker

1. Elevation Angle: The elevation angle is the angle between the solar panel and the horizon. When the solar panel is at a high elevation angle, it receives more direct sunlight and generates more power. However, a high elevation angle also increases the shading of nearby panels, which reduces the overall power output of the system. Therefore, the optimal elevation angle for a dual-axis solar tracker is usually between 30 and 40 degrees.
2. Azimuth Angle: The azimuth angle is the angle between the solar panel and the north-south line. When the solar panel is facing directly south, it receives the most sunlight throughout the day, which generates the highest power output. However, the power output decreases as the solar panel deviates from the south-facing direction. A dual-axis solar tracker can adjust the azimuth angle of the solar panel throughout the day to maximize power output.
3. Tracking Accuracy: A dual-axis solar tracker must be able to accurately track the sun's position to keep the solar panel facing the sun at all times. If the tracker is not accurate, the solar panel may be at the wrong elevation or azimuth angle, which reduces the power output of the system. Therefore, the tracking accuracy of a dual-axis solar tracker is critical to its overall performance and power output.

Figure 40: Maximum Output Angle

5.6.2 Explanation of Maximum Power Output Angle

The results showed that the generated power at the dual-axis position was 3.384 watts per hour (W/h), the 33-degree angle yielded 2.237 W/h, and the zero-degree angle yielded 1.09 W/h. The results confirmed that the performance of a dual-axis solar tracking system is active and efficient. The maximum power output angle of a dual-axis solar tracker depends on several factors, including the latitude and longitude of the tracker's location, the time of day, and the time of year. In general, the maximum power output angle for a dual-axis solar tracker is the angle at which the solar panel is perpendicular to the sun's rays, also known as the solar noon angle. At solar noon, the sun is at its highest point in the sky, and the solar panel should be pointed directly at it to maximize energy collection. However, the angle of the solar panel should be adjusted throughout the day to maintain an optimal angle of incidence with the sun as it moves across the sky. A dual-axis solar tracker can adjust the angle of the solar panel in both the horizontal and vertical axes, allowing it to track the sun's movement throughout the day and maintain an optimal angle of incidence. By constantly adjusting the angle of the solar panel, a dual-axis solar tracker can achieve higher energy production than a stationary solar panel. The specific angle of incidence required for maximum power output will vary depending on the location of the solar tracker and other environmental factors. However, by tracking the sun's movement and maintaining an optimal angle of incidence throughout the day, a dual-axis solar tracker can achieve maximum power output and maximize the amount of energy it can collect from the sun.

5.7 Hardware Results

Hardware part was much harder than the simulation part. Every component had to taste many times and sometimes the components were not working for as usual reasons. But after tasting all the components, the hardware implementation was done and the result was satisfactory and was close to the simulation result. The LDR was not working as fast as in the case of simulation part. It took some delay of 3 - 4 seconds to respond. But the servo motor was working instantly. The entire system can be controlled by Wi-Fi and it was also working accurately.

Figure 41: Welcome Message Which Represents Initial Condition of Starting.

Figure 42: Voltage and Current Output of from the Solar Panel under High Illumination of Sunlight.

Figure 43: Output of Power from the Solar Tracker under High Light Condition.

Figure 44: Voltage and Current Measured from the Solar Panel Under Medium Illumination of Sunlight

Figure 45: Power Output Under Medium Light Condition

Figure 46: Output Voltage and Current under Low Light Condition

IV Conclusions

Technology is always evolving in the modern era. The advancement of technology has improved the comfort and ease of our lives. One of the most pressing issues in a developing country like India is the energy crisis. The difference between electrical energy production and demand is very large. Large number of the population is entirely cut off from this blessing. Renewable energy is the only solution to this problem. Solar energy is one of the most powerful and promising renewable energy sources that could be used to resolve the energy demand to some extent. Since, the proposed system correctly aligns with the direction of the sun and records its movement; the performance of a dual axis tracker has greatly improved. Dual axis solar trackers have high power capture rates throughout the observation period, maximizing the conversion of solar irradiance into electrical energy output. The proposed system is also cost effective because a minor change to the single axis tracker resulted in a noticeable increase in system power. A dual axis solar tracker was successfully simulated and tested, resulting in increased overall power collection efficiency from the tracking devices with the same panel. In terms of real value, this means that the overall cost of a system can be significantly reduced because the solar array combined with a solar tracking device can supply significantly more power. By extracting more power from the same solar panel, the cost per watt is reduced, making solar power much more cost-effective than was previously achieved using fixed solar panels. Approaches to controller design are both cost effective and adaptable. Finally, all of these challenges provided opportunities to practice new problem-solving techniques. There are no negative environmental or societal consequences to this system. It may be a very comfortable and cost-effective system for the consumer if it is designed properly. Considering the present scenario, the future plan is to continue working on this project and to incorporate new features to make the project more effective, so that in can produce positive contribution towards our country.

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