**DEPARTMENT OF ENERGY & ENVIRONMENT**

**NATIONAL INSTITUTE OF TECHNOLOGY TIRUCHIRAPALLI-620015**

**PROJECT REPORT**

**DEPARTMENT** : Mechanical Engineering (Section-A)

**COURSE NAME** : Energy & Environmental Engineering

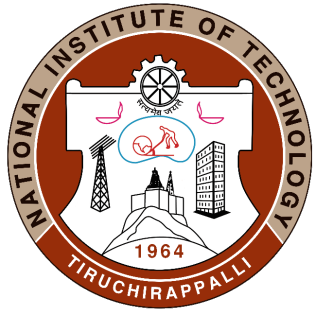
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**THEME OF PROJECT:** SOLACE- A Dual-Axis Solar Tracker with Weather Monitoring Station

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**INTRODUCTION**

Solar energy is a renewable and abundant source of power that harnesses the sun's energy to generate electricity. With the growing concern for climate change and the need for sustainable energy solutions, solar power has gained immense popularity. One efficient way to maximize the solar energy conversion is through the use of solar trackers. Solar trackers are devices that orient solar panels to follow the sun's movement throughout the day, optimizing the amount of sunlight captured and increasing energy production. By continuously adjusting panel angles, solar trackers enhance energy output, delivering higher efficiency and cost-effectiveness. Their ability to enhance solar power generation makes solar trackers an invaluable component in harnessing the full potential of solar energy.

**PROJECT GOALS & OBJECTIVES**

* This project aims to optimize the performance of a solar PV system by maximizing the efficiency through continuous tracking of the position the sun and accordingly adjusting the orientation of the panels throughout the day. This causes the system can capture more amount of direct solar radiation which is normal to the panel.
* In addition to this, it also aims to monitor weather conditions such as temperature, humidity and rainfall. The analysis of this data will trigger the shutdown of the system in case of extreme weather conditions like high-wind speeds, hailstorms, or lightning strikes which can potentially damage the solar panels, tracking system, and other components. This further ensures longevity of the system thereby significantly reducing maintenance costs.
* Apart from these aspects, this project also creates awareness and promotes sustainability by encouraging the use of solar power. By increasing the efficiency of solar panels, the system can help reduce reliance on non-renewable energy sources and promote a cleaner, greener and more sustainable future.

**CHALLENGES OF CONVENTIONAL SOLAR PANELS (NON-TRACKING WITHOUT WEATHER MONITOR)**

* Conventional solar panels have been widely used for electricity generation, but they have faced several challenges. One of the major challenges is their efficiency in converting sunlight into electricity. The maximum theoretical efficiency of a solar panel is around 33% while the practical efficiency of most commercially available solar panels is between 15% and 20%.
* Another challenge is their fixed orientation, which means that they only capture sunlight optimally for a limited period of the day while during other periods, the solar panels are not as effective in generating electricity, leading to a loss in potential energy production.
* Yet, another significant challenge is that conventional solar panels are often impacted by weather conditions like clouds, rain, and snow can reduce the amount of sunlight that reaches the solar panels, reducing their overall efficiency and increasing maintenance costs. High temperatures can also impact solar panel efficiency by causing a reduction in output and potentially damaging the panel.

**HOW THIS PROJECT CAN ADDRESS THESE CHALLENGES?**

* To address these challenges, solar tracking systems have been developed to improve the efficiency of solar panels. These systems use motors and sensors to adjust the angle and orientation of the solar panels continuously, ensuring that they are always aligned with the sun's position. As a result, solar tracking systems can increase the efficiency of solar panels by up to 30%.
* Furthermore, weather monitoring can play an important role in improving the efficiency and safety of solar energy generation. By providing real-time information on local weather conditions, such as wind speed, temperature, and cloud cover, solar energy systems can be optimized to generate electricity more efficiently and safely. For instance, if the weather is cloudy or the wind speed is too high, the solar tracking system can adjust the angle of the solar panels to minimize the risk of damage or failure.

**THEORETICAL FORMULATIONS**

The mathematical formulation used in solar tracking is based on the principles of celestial mechanics, which describe the motion of objects in space. Specifically, the position of the sun relative to the tracker can be calculated using the equations for the altitude and azimuth angles of the sun. These calculations allow the solar tracker to determine the precise position of the sun in the sky and adjust the position of the solar panels accordingly to maximize the amount of solar energy they can capture.

wherein,

is the altitude angle, which is the angle between the horizon and the sun's position in the sky

ϕ is the azimuth angle, which is the angle between true north and the sun's position in the sky

δ is the declination angle

φ is the latitude of the tracker's location

H is the hour angle, which is the difference between the local solar time and the solar noon

Once the position of the sun has been determined, the tracker can be adjusted to follow the sun using an actuation mechanism like motor actuation (servo motors), fluid actuation (compressible fluid) or linear actuation (rack and pinion).

**SOLAR PANEL OUTPUT EQUATION**

Assuming we know the effective solar irradiance () at the given time and location, we can estimate the power output () using the following equation:

wherein,

is the effective solar irradiance incident on the panel

is the total surface area of the panel

is the solar conversion efficiency

is the correction/loss factor

**Note** that, according to Lambert’s cosine law the effective irradiance () received on a surface is the component of incident irradiance () along the normal vector of that surface.

Mathematically speaking, wherein is the angle between the incident irradiance and normal vector of surface

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Corresponding to this law, we can say that

Here, , where is the solar constant approximately equal to 1361 W/m2 and ζ denotes the zenith angle, which is the complement of altitude angle,

Thus,

The -factor consists of several corrections and/or losses due to various factors like temperature of panel, shading, soiling, spectral distribution, wiring resistance etc.

Finally, the equation becomes as follows:

**GRAPHICAL ANALYSIS**

1. Power Output v/s Incident Angle:

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**Observation:** The power output is higher with the tracker than without it for all angles of incidence, but that difference becomes more prominent at high angles of incidence.

1. Power Output v/s Solar Irradiance:

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**Observation:** The power output is higher with the tracker than without it for all zenith angles. The without tracker curve is perfectly cosine as 0while without tracker curve is distorted cosine due to cosine of incident angle which itself depends on other constantly fluctuating angles

1. Power Output v/s Time:

A graph of solar panel with blue and orange lines

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**Observation:** The power output is constantly fluctuating in both cases as all factors are variable. However, with tracker curve is always above the without tracker curve therefore ensuring more power output

**METHODOLOGY**

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**DESIGN**

The design process is the first crucial step as it involves determining the necessary components, dimensions, and placement of the system. This step ensures that the solar tracking system is functional, efficient, and safe for operation. The various components used in the design of the system:

1. **Arduino Board:** An Arduino microcontroller board, such as Arduino Uno which will serve as the brain of the solar tracker and weather monitoring system.
2. **Servo Motors or Stepper Motors:** Motors that will be used to control the movement of the solar panels. Servo motors are commonly used for smaller setups, while stepper motors are preferred for larger and more precise tracking systems.
3. **Light-Dependent Resistors (LDRs):** LDRs or photoresistors are used to detect the intensity and direction of incident solar radiation to track the position of the sun.
4. **Weather Monitoring Components:** This includes an I2C module and DHT11 sensor (weather sensor) for monitoring weather conditions, such as temperature, humidity, rainfall, wind speed, etc. and LCD screen for displaying output.
5. **Solar Panels:** The solar panels themselves, which will be mounted on the solar tracker and capture sunlight to generate electricity.
6. **Breadboard or PCB:** A breadboard or printed circuit board (PCB) to assemble and connect the various components of the system.
7. **Jumper Wires:** These are required for making connections between the components on the breadboard or PCB.
8. **Power Source:** A power source, such as a battery or a power supply is required to power the Arduino Uno board, motors, and sensors.
9. **Mounting and Construction Hardware:** The framework or the skeleton of the entire assembly which will provide a neat and organized appearance is made using hardware such as cardboard, PVC board or foamboard.
10. **Tools:** Basic tools for assembly, such as a screwdrivers, soldering iron, wire cutters, multimeters (for continuity checks) and pliers may be required for various purposes.

**ASSEMBLY**

Assembly is the next crucial step as it involves the actual construction of the system from the individual components identified during the design phase. It is of two types namely mechanical assembly and electrical assembly

1. **Mechanical assembly** involves the physical construction of the system involving constructing a sturdy frame to support the solar cell and sensors, along with mounts for the motors that will drive the movement of the solar cell. This may require cutting and shaping the construction hardware, drilling holes for bolts or screws, placing couples and brackets for components and other aspects.
2. **Electrical assembly** is concerned with installation of electronic components and proper wiring to create a functional system. This involves tasks such as soldering of wires to breadboards, making electrical connections of sensors with jumper wires and proper installation of power supplies, switches, motors and other circuitry components for the system to operate as intended.

**ARDUINO ALGORITHM DEVELOPMENT**

POSITIONING ALGORITHM LDR SENSING AND MOTOR

ACTUATION ALGORITHM

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**ARDUINO PROGRAM DEVELOPMENT**

Development of Arduino program is the third crucial step which involves developing the necessary code for the microcontroller to process the inputs from the sensors and control the motors. Arduino IDE (Integrated Development Environment) interface is used for programming the Arduino UNO board. The steps associated in this process are:

**LOGIC:**

* The Arduino programming language is based on C++, and the code is typically written in IDE.
* The code for the solar tracking system typically involves reading data from the various sensors, calculating the position of the sun, and adjusting the orientation of the solar panel accordingly.
* The Arduino code also includes the logic for the weather-monitor, which determines whether the system should be shut down in case of extreme weather conditions.
* Once the code has been written, it is uploaded to the Arduino microcontroller using a USB cable or wireless connection,

1. Solar Tracking Code:

#include <Servo.h>

//defining Servos

Servo servohori;

int servoh = 90;

int servohLimitHigh = 160;

int servohLimitLow = 20;

Servo servoverti;

int servov = 90;

int servovLimitHigh = 160;

int servovLimitLow = 20;

//Assigning LDRs

int ldrtopr = A2; //top left LDR green

int ldrtopl = A3; //top right LDR yellow

int ldrbotr = A1; // bottom left LDR blue

int ldrbotl = A0; // bottom right LDR orange

 void setup ()

 {

  servohori.attach(10);

  servohori.write(90);

  servoverti.attach(9);

  servoverti.write(90);

  delay(500);

 }

void loop()

{

  servoh = servohori.read();

  servov = servoverti.read();

  //capturing analog values of each LDR

  int topl = analogRead(ldrtopl);

  int topr = analogRead(ldrtopr);

  int botl = analogRead(ldrbotl);

  int botr = analogRead(ldrbotr);

  // calculating average

  int avgtop = (topl + topr) / 2; //average of top LDRs

  int avgbot = (botl + botr) / 2; //average of bottom LDRs

  int avgleft = (topl + botl) / 2; //average of left LDRs

  int avgright = (topr + botr) / 2; //average of right LDRs

  if (avgtop < avgbot)

  {

    servoverti.write(servov +1);

    if (servov > servovLimitHigh)

     {

      servov = servovLimitHigh;

     }

    delay(10);

  }

  else if (avgbot < avgtop)

  {

    servoverti.write(servov -1);

    if (servov < servovLimitLow)

  {

    servov = servovLimitLow;

  }

    delay(10);

  }

  else

  {

    servoverti.write(servov);

  }

  if (avgleft > avgright)

  {

    servohori.write(servoh +1);

    if (servoh > servohLimitHigh)

    {

    servoh = servohLimitHigh;

    }

    delay(10);

  }

  else if (avgright > avgleft)

  {

    servohori.write(servoh -1);

    if (servoh < servohLimitLow)

     {

     servoh = servohLimitLow;

     }

    delay(10);

  }

  else

  {

    servohori.write(servoh);

  }

  delay(50);

}

1. Weather Monitoring Code:

//infinite Xpro

// firstly need to add i2c library

#include <LiquidCrystal\_I2C.h>

LiquidCrystal\_I2C lcd(0x27,16,2);  // set the LCD address to 0x27 for a 16 chars and 2 line display

byte degree\_symbol[8] =

              {

                0b00111,

                0b00101,

                0b00111,

                0b00000,

                0b00000,

                0b00000,

                0b00000,

                0b00000

              };

int gate=11;

volatile unsigned long duration=0;

unsigned char i[5];

unsigned int j[40];

unsigned char value=0;

unsigned answer=0;

int z=0;

int b=1;

void setup()

{

 lcd.init();                       // initialize the lcd

 lcd.init();

 lcd.backlight();

 lcd.print("Temp = ");

 lcd.setCursor(0,1);

 lcd.print("Humidity = ");

 lcd.createChar(1, degree\_symbol);

 lcd.setCursor(9,0);

 lcd.write(1);

 lcd.print("C");

 lcd.setCursor(13,1);

 lcd.print("%");

}

void loop()

{

 delay(1000);

 while(1)

 {

  delay(1000);

  pinMode(gate,OUTPUT);

  digitalWrite(gate,LOW);

  delay(20);

  digitalWrite(gate,HIGH);

  pinMode(gate,INPUT\_PULLUP);//by default it will become high due to internal pull up

 // delayMicroseconds(40);

  duration=pulseIn(gate, LOW);

  if(duration <= 84 && duration >= 72)

  {

      while(1)

      {

        duration=pulseIn(gate, HIGH);

        if(duration <= 26 && duration >= 20){

        value=0;}

        else if(duration <= 74 && duration >= 65){

        value=1;}

        else if(z==40){

        break;}

        i[z/8]|=value<<(7- (z%8));

        j[z]=value;

        z++;

      }

    }

answer=i[0]+i[1]+i[2]+i[3];

if(answer==i[4] && answer!=0)

{

lcd.setCursor(7,0);

lcd.print(i[2]);

lcd.setCursor(11,1);

lcd.print(i[0]);

}

z=0;

i[0]=i[1]=i[2]=i[3]=i[4]=0;

 }

}

**DATA LOGGING AND VISUALIZATION**

**Data logging** involves feeding some input and then collecting data from the sensors and components of the system and thereafter storing it in a database. This data includes information such as the system's orientation, LDR reading, the amount of solar radiation received, system's power output, weather-monitoring data, etc.

**Visualization** refers to the process of presenting the data collected from the system in a tabular and/or graphical format. This can include charts, graphs (bar, line, histograms), and other visual representations of the system's performance.

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Description automatically generatedBy logging and visualizing the data, it becomes easier to identify any patterns or trends in the system's performance and to determine whether any adjustments need to be made.

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**TESTING AND CALIBRATION**

This is the final step involved. Testing involves verifying whether the system is functioning as intended. Through testing, any issues with the system can be identified and corrected beforehand. This helps to minimize downtime and reduce the risk of damage or failure.

* **Motor & Sensor Testing:** The motors used in the system should be tested to ensure that they are functioning properly and can handle the load of the solar panel. The sensors used in the system should be tested to ensure that they can accurately detect changes properly.
* **MCU Testing:** The MCU used in the system should be tested to ensure that it can accurately process data from the sensors and control the movement of the solar panel.
* **Continuity Testing:** It is used for testing an electrical circuit to determine whether the current flows through it without interruption. It is done to check if there are any breaks or short circuits in the wiring using a digital multimeter. The beep sound in the multimeter ensures continuity between the connected test points in the circuit.

Calibration involves adjusting the system appropriately to ensure that the system is measuring and responding accurately. It is essential for accurate measurements and performance, which is critical for the overall success of the system.

* **Motor Calibration:** This involves measuring and adjusting various motor characteristics such as speed, torque, current, and voltage to ensure that the motor is operating at its maximum efficiency and performance.
* **Sensor Calibration:** This involves adjusting the sensitivity of the sensors.

**WORKING PRINCIPLE OF SOLAR TRACKER & SCHEMATIC BLOCK DIAGRAM**

The principle on which the idea of solar tracking is based is known as **Maximum Power Point Tracking** (MPPT). This technique is used in solar PV systems to optimize the power output from the solar panels. The MPPT system uses a control algorithm that continuously adjusts the load impedance to obtain the maximum power output from the solar panels.

The Maximum Power Point (MPP) is the point on the I-V curve of a solar panel where the product of current and voltage is maximum, resulting in the highest power output. In other words, it is the point at which a solar panel operates most efficiently and produces the maximum amount of power for a given amount of solar radiation.

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**OPERATING MECHANISM**

* SOLAR TRACKER:

The solar radiation is incident on the solar cell which is detected by the four LDRs. The resistance of LDR decreases as the intensity of light increases, and this change in resistance can be used to measure the intensity of light. Resistors varying from 1-10 kΩ is used to limit the current flowing through the LDR, which helps to ensures stable output voltage of the circuit. The data from the LDR is sent to the MCU as analog signals and it then converts it into digital signals which is processed by the Arduino program. This relays the information to actuate the movement of two servo motors (along two axes) which continuously adjusts the orientation of the solar panel accordingly as the sun moves across the sky. This maximizes the amount of solar radiation that is incident on the solar panel thereby improving its efficiency.

* WEATHER STATION:

The DHT11 (Digital Humidity and Temperature Sensing v. 11) sensor measures the temperature (in C) and humidity (in %), while the rainfall sensor measures the precipitation levels (in mm). Both sensors are connected to the Arduino using the I2C (Inter-integrated circuit) module. The I2C protocol is used to communicate between the Arduino and the sensors. The MCU then reads the data from the sensors and displays the output on an LCD screen. The collected data is processed by the MCU via an Arduino algorithm, and then visualized using tools such as Matplotlib (a plotting library for the Python programming language).

**ADVANTAGES**

* **Increased Energy Output:** Solar tracking panels can track the movement of the sun throughout the day, positioning themselves to catch the most sunlight possible. They can capture sunlight at the ideal angle by continuously altering their position, which increases energy production compared to fixed panels. Depending on the precise design and location, studies have shown that solar tracking systems can improve energy output by 20% to 40% or more.
* **Extended Solar Window:** Fixed solar panels only receive direct sunlight for a short period of time each day, usually from mid-morning to mid-afternoon when the sun is at its zenith. Solar tracking panels, in contrast, can continually shift their position to capture sunlight from sunrise until sunset. By extending the solar window, energy can be produced for a longer period, making the most of the available daylight.
* **Enhanced ROI (Return on Investment)**: Although solar tracking systems may be more expensive initially and need more intricate installation than fixed panels, over time their higher energy output can lead to a higher return on investment. Particularly in areas with high electricity rates or in which space is at a premium, the additional energy produced by monitoring panels might balance the initial expenditure and result in quicker payback times.
* **Higher Energy Density:** Solar tracking panels provide more energy per unit area, maximizing the usage of available space. set panels may have shade or space restrictions and occupy a set location. Tracking systems, on the other hand, can make better use of available space by moving with the sun, reducing the impacts of shade, and increasing energy density.

**DISADVANTAGES**

It's important to keep in mind that solar tracking systems could also have some drawbacks, like greater initial costs and potential dependability difficulties.

* **Higher Initial Costs:** Compared to fixed solar panels, solar tracking systems are typically more expensive to install. The system's initial expenses are raised by the extra parts and mechanisms needed for tracking. Due to this, solar tracking may not be as economically viable for some projects or installations with limited funding.
* **Dependability and Strength Concerns:** Moving parts in solar tracking systems create more possible failure spots. Over time, mechanical parts like motors and gears may need to be replaced or repaired, lowering the system's overall reliability. The tracking system may experience greater wear and tear due to exposure to the environment and constant movement, which could shorten its lifespan.

**BUDGET & COST ANALYSIS**

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**CONCLUSIONS**

* Solar trackers play a crucial role in maximizing solar energy generation and increasing efficiency.
* Solar trackers increase energy yield by up to 25% compared to fixed solar panels.
* The ability to adjust panel angles enables solar trackers to optimize sunlight absorption and minimize energy losses.
* Solar trackers extend the duration of peak energy production, capturing sunlight from dawn to dusk.
* Solar trackers are particularly beneficial in regions with shorter daylight hours or extended electricity demand.
* Integration of weather monitoring systems enhances the performance and reliability of solar energy systems. Real-time weather data allows solar trackers to adapt to changing weather conditions and optimize panel orientation.
* Weather monitoring systems enable proactive adjustments to maximize sunlight exposure and minimize the impact of adverse weather conditions.
* Solar trackers improve the cost-effectiveness of solar energy projects by increasing energy output and return on investment.
* The integration of solar trackers and weather monitoring systems enhances the efficiency, reliability, and sustainability of solar energy as a power source.

**RESULTS**

* Solar trackers increase energy yield by up to 25% compared to fixed solar panels.
* The performance of solar trackers is dependent on the type and design of the tracking system.
* Dual-axis trackers offer higher energy yield than single-axis trackers by allowing for better alignment with the sun's movement.
* The use of weather monitoring systems significantly enhances the performance and reliability of solar energy systems.
* Real-time weather data enables solar trackers to adjust panel angles and optimize sunlight absorption.
* Solar trackers combined with weather monitoring systems minimize the impact of adverse weather conditions on energy production.
* The integration of solar trackers and weather monitoring systems improves the financial viability and return on investment of solar energy projects.
* The efficiency and reliability of solar energy systems are increased through the use of solar trackers and weather monitoring systems.

Overall, the results indicate that solar trackers, when integrated with weather monitoring systems, offer substantial benefits in maximizing solar energy generation, improving efficiency, and enhancing the reliability of solar energy systems. The combination of solar trackers and weather monitoring systems is a promising approach to harnessing the full potential of solar energy and advancing its adoption as a sustainable power source.

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