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Harnessing Solar Power with a Smart Flower Prototype: Design and Fabrication

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***Abstract:** Globally, renewable energy has grown remarkably. In the upcoming years, significant growth in the use of renewable energy is anticipated in India. With the majority of installations, solar energy led the renewable energy market, followed by wind energy. This demonstrates India's dedication to making the switch to a cleaner, more sustainable energy future. This research article discusses the design and fabrication of a prototype of a smart solar electricity generator flower i.e., the Smart Solar Flower (SSF), a unique and effective solar energy solution. It examines the features, advantages, and design of the SSF. The SSF, which was designed after flowers, autonomously tracks the sun to maximize energy harvesting. Photovoltaic panels, a solar tracking system, energy storage, a smart control unit, a self-cleaning mechanism, and sensors are some of its parts. The scalable and adaptive SSF may support energy-dependent systems, charge electric vehicles, power devices, and provide lighting. Intelligent sensor technology, machine learning, and Internet of Things connectivity enable autonomous adjustment based on the weather and energy consumption. Reduced reliance on fossil fuels, lower carbon emissions, and a sustainable future are all advantages for the environment. Installation expenses, energy savings, and money production are taken into account for economic viability. Efficiency, durability, and cost are explored along with challenges and prospects for the future. The SSF has significant promise for generating sustainable energy and revolutionizing the use of solar power to tackle global energy concerns.*

***Keywords:** Solar Tracking, Renewable Energy, Automation, Sensors*

I. INTRODUCTION

Global renewable energy capacity was expected to have increased by more than 330 gigawatts by 2022. India produces the majority of its electricity from a variety of sources. In the past, coal has dominated the nation's energy mix and served as the primary source of electricity generation. It has been working to boost the proportion of renewable energy sources in its electrical output, though. India has advanced significantly in the deployment of renewable energy during the last few years. The potential for renewable energy in the nation increased dramatically between 2018 and 2021, especially for solar and wind power. By 2021, India's renewable energy capacity was expected to be around 94 gigawatts. India adopted a number of programs and regulations to support renewable energy during this time, with the audacious goal of reaching 175 gigawatts of renewable energy capacity by 2022. In addition to encouraging market circumstances, the government's initiatives attracted large investments and accelerated the installation of renewable energy sources throughout the nation. In recent years, solar energy has become extremely popular [1]. The solar tracking system is one of many methods being developed to produce electricity from solar radiation. A solar tracking system is a piece of equipment that moves reflecting surfaces or the solar panel's face to line up with the sun as it crosses the sky. These tracking systems have undergone numerous improvements that have improved their efficiency. The smart solar flower is one of these systems' most recent innovations [2-4].

The name "Smart Solar Flower" refers to its appearance. The term "solar flower" refers to the arrangement of the solar cells on distinct "petals" that emerge at the start of each day to resemble flowers. The petals of the intelligent solar flower fold up when the sun sets, and a self-cleaning procedure begins. The smart solar flower system includes solar cells in addition to a dual-axis tracker that enables the petals to move with the sun throughout the day. According to the website for the smart solar flower, this tracking ability allows it to generate up to 40% more electricity than a rooftop solar panel system of comparable size. Alexander Swatek, the inventor of Smartflower in Austria, had the idea for the device while discussing the challenging setup of conventional rooftop systems. The flower bloom design of the smart solar flower was created in an effort to introduce the first all-in-one highly efficient solar system.

In contrast to previous ground-mounted solar panel systems with tracking capabilities, the prototype which we have developed of the smart solar flower has two distinctive qualities.

The first is that it features a self-cleaning feature that makes sure that any dirt or grime on the panels won't result in less energy being produced [5],[6]. The second is that it has an innovative layout and an open architecture that aid in resolving the heating problem in conventional solar tracking systems. Its visually appealing design encourages the usage of solar power [7]. These were the major goals we had when developing this smart solar flower prototype. The paper discusses the problems that this ground-breaking prototype of solar tracking system design resolved and how it was developed. Fig.1 below shows an image of the smart solar flower.

Fig .1 Smart Solar Flower

II. LITERATURE REVIEW

Patil, A., Dhavalikar, M., Dingare, S., and Bhojwani V. [1] in their study made a dual-axis solar tracking system using a tetrahedron configuration of light-detecting resistors (LDRs) designed and prototyped. The benefits of tracking systems over fixed panels are discussed, a dual-axis tracker is suggested to accommodate the sun's complex motion, the principle of solar tracking is described, the methodology is described using real-time LDR data and an Arduino microcontroller, the system design is visualized through a 3D model, the energy consumption is calculated, and a list of the components is provided. In general, it offers insights into the technique, concept, design, and energy usage of the system.

Prof B H Band, and Prof A D Ingole [2] in their study introduced a smart solar flower water pump system based on the Internet of Things. The technology generates 40% more electricity than conventional solar panels by using photovoltaic panels set up like a flower and a dual-axis tracker. While sensors guard against bad weather and optimize water use, IoT technology integration provides remote monitoring and control. A servo motor driving circuit, embedded software, and light-dependent resistors are all components of the solar tracker system. The system includes a battery for energy storage, solar panels, and main power supply charging devices. This low-cost technology combines solar energy generation, effective tracking, and Internet of Things connectivity for automated and sustainable water pumping.

A. Rajkumar, J. Nagendran, J. Subramaniyan, and R. Jai Ganesh [3] in their article suggested a solar-powered seven-level inverter system to provide sinusoidal output voltage with good quality and efficiency. The device produces an output voltage waveform with seven levels by using an active inverter and reversed condenser clamping. Compared to typical seven-level inverters, the design is simplified because only a few switches are utilized. In order to maximize energy production, the article also offers a solar smart flower architecture that uses a double-axis tracker. In comparison to ordinary solar panels, the smart floral design produces more energy and has a self-cleaning cycle. LDRs are used by the system to track and manage the location of the solar panels. The suggested system showcases enhanced IoT-based energy-generating and monitoring capabilities. The article's main objective is to increase solar energy production and protection through innovative design and control techniques.

Tatang Mulyana, Darwin Sebayang, Fildzah Fajrina, and Raihan, M. Faizal [4] in their paper discuss the design and analysis of a solar smart-flower created with the Solidworks program presented in this research article. The purpose of the study is to investigate how the smart flower is used, maintained, repaired, supplied with components, and manufactured. The design of the Smart-flower is discussed in the article, along with its simulation in Solidworks, including body battery drop testing and static simulation. The simulation's findings show that the smart flower’s design is acceptable and can move forward with fabrication.

The study advances our knowledge of solar smart-flower system design and simulation, which is helpful for expanding renewable energy sources and raising Indonesia's electrification rate. Overall, this study sheds light on how smart-flower technology might be used in the context of solar energy production.

Muhammed J. Adinoyi, Syed A.M. Said, [5] in their paper look into how the Eastern Province of Saudi Arabia's dust problem affects the performance of PV modules. A build-up of dust on PV modules limits transmittance, which lowers the amount of solar radiation that reaches the cells. Leaving modules dirty for longer than six months might cause a 50% reduction in power production. It is suggested that you clean frequently—every two weeks—to ensure peak efficiency. Rainfall is not enough to sufficiently clean the research region. Analyses of the dust identified several components. During off-peak hours, solar trackers can reduce the impact of dust by 50%. The backside temperatures of PV modules on trackers are greater than those on permanent stands, with polycrystalline modules slightly higher than monocrystalline.

Rizwan Arshad, Salman Tariq, Muhammad Umair Niaz, and Mohsin Jamil [6] in their study suggest a viable method to increase solar panel efficiency using concentrated photovoltaic technology (CPV) with mirrors and cooling mechanisms presented in the research article "Improvement in Solar Panel Efficiency Using Mirrors and Cooling". CPV uses fewer solar cells than non-concentrated systems to produce the same amount of power. The study highlights temperature and solar irradiance (W/m2) as important variables impacting panel performance. An experimental set-up using low-cost mirrors and a cooling system shows increased effectiveness. For additional improvements, the report suggests incorporating maximum power point tracking (MPPT) and optimizing the cooling system. In general, it emphasizes the benefits of CPV and related methods for raising solar panel efficiency.

Mohammad Bani Khalid1, Nabil Beithou, M.A. Sh. Al-Taani, Artur Andruszkiewicz, Ali Alahmer, Gabriel Borowski, and Sameh Alsaqoor [7] in their study offers a novel ecosystem for controlling open-air public spaces in hot, humid climates. It removes moisture using a solar-powered dehumidifier control device, producing cool, dry air for outdoor air conditioning. The moisture that is captured is used to hydrate plants and make drinking water. A comfortable outdoor atmosphere with 50% relative humidity and a temperature of 24 °C is what the Integrated Eco-Friendly Cooling System (IEFCS) attempts to produce. It is environmentally friendly, self-sufficient in water and energy, and provides advantages such as a better microclimate, illumination at night, and water supply. A water-generating device, an air mixing and distribution system, clever solar umbrellas, and carefully placed trees and plants for beauty and shade make up the system. The abstract merely gives a brief overview; additional information, methods, and results are accessible in the complete case study.

III. PROBLEM IDENTIFICATION

Traditional solar tracking systems are difficult to transport and have a heating problem. According to research, dust adversely affects PV cells by decreasing their effectiveness. It has been found in numerous studies that dust can cause an efficiency loss of up to 40%.

IV. WORKING PRINCIPLE OF SOLAR TRACKING SYSTEM

The smart solar flower is a type of solar tracking system. By pointing solar panels or collectors at the sun all day long, a solar tracking system maximizes their exposure to sunlight. It functions using a variety of parts and mechanisms. The system includes sensors to measure the direction and strength of the sun's rays, which are then processed by a control system. The control system chooses the best location for the solar panels or collectors based on this data. Actuators, such as electric motors or linear actuators, physically change the position of the panels in accordance with the commands of the control system. Solar tracking systems can work in single-axis or dual-axis modes, varying the elevation angles and tilting the panels along one or both axes to track the sun's movement throughout the day. The control system's tracking algorithms use sensor data and estimations of the sun's position to find the best angles for the panels while taking location, time, and solar angles into account. The system's mechanical design supports the panels and allows for precise tracking motion, maintaining stability against wind loads. Solar tracking systems increase energy production compared to fixed-mounted systems, especially in regions with changing solar radiation patterns, by continuously optimizing the location of the panels. This maximizes the use of solar energy resources.

V. METHODOLOGY

The smart solar flower is an active solar tracker that uses sensor input to continuously follow the movement of the sun. The Light Dependent Resistors (LDRs) sensor is the one that makes this possible. It is a photo-resistor, and as the light level rises, the resistance falls. Any semiconductor material with high resistance is used to create an LDR or photo-resistor. The fact that so few electrons are free and able to move, while the vast majority are trapped in the crystal lattice and unable to do so, accounts for its high resistance. Consequently, there is significant LDR resistance in this state.

The semiconductor lattice absorbs light photons when they strike it, transferring some of their energy to the electrons in the process. Some of them receive enough energy from this to dislodge the crystal lattice and begin conducting electricity. As a result, the semiconductor resistance and thus the overall LDR resistance are reduced. The action is cumulative; as more light hits the LDR semiconductor, more electrons are freed to conduct electricity and the resistance decreases. When the light level is at its lowest, the Arduino microcontroller reads the resistance value, and the threshold value is specified in the coding part. When the light is present and the threshold level is broken, the Arduino rotates the N20 gear motor anticlockwise through the L293D Driver for a specific delay mentioned in the code, and when the delay is over, the panel stops rotating and is in the fully opened position. The other four LDRs sensor the light in accordance with the sun's rotation, and send data to the Arduino, which analyses it, and then causes the servo motors to rotate. The servo can rotate a maximum of 170 degrees. The fifth LDR senses data once more at dusk, but this time the procedure is carried out in reverse. As soon as the LDR data drops below the threshold level, Arduino When the second limit switch is pressed, rotate the N20 motor anticlockwise until the servo is operating in the home position. When light is available the next day, repeat the process. Fig. 2 below shows the block diagram of the smart solar flower system.

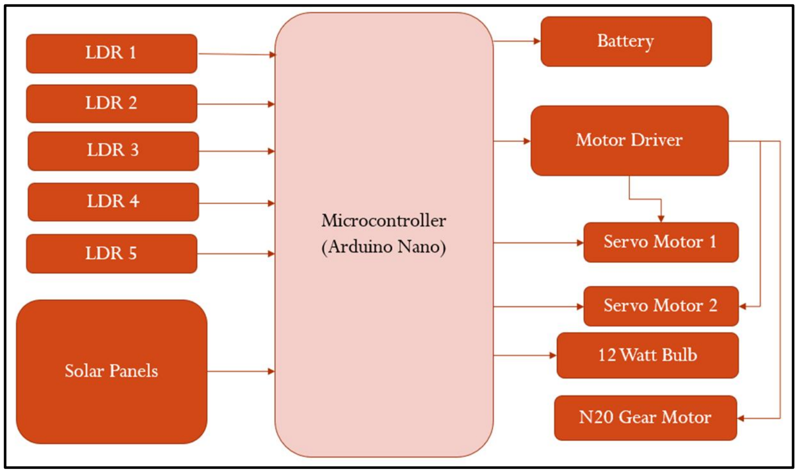

Fig .2 Block Diagram of Smart Solar Flower

VI. SYSTEM DESIGN

A. CAD Modelling

Autodesk Fusion 360 software was used to make the conceptual design of the prototype of the smart solar flower. The CAD model shows us the positions of sensors, two servo motors, the N20 gear motor, solar flower petals (solar panels), and the base of the system. Refer to Fig. 3 to get a better understanding.

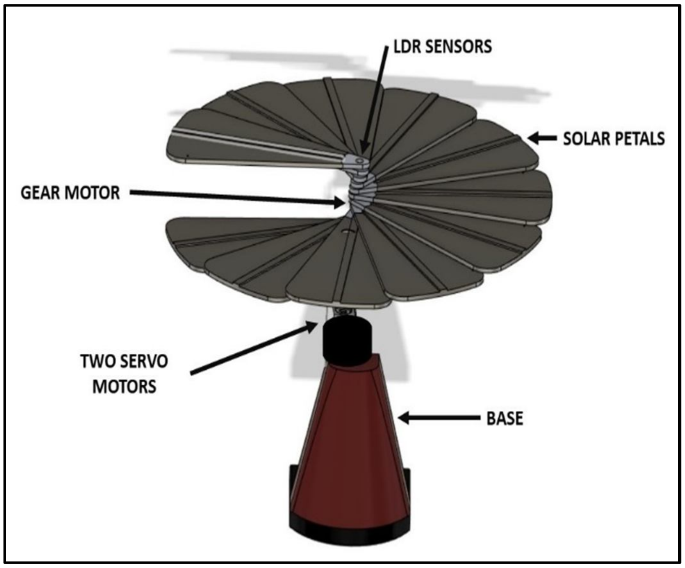

Fig .3 Conceptual Model of the Smart Solar Flower using Fusion 360

B. Calculations of the System

1) Solar Panel Calculations

Energy generation by a panel = Solar Irradiance * Solar Cell Area * Cell Conversion Efficiency Energy generation by a panel = 5440 Whr/m²/day *[(0.08 m * 0.04 m) *6 + (0.07m * 0.07m) *6] * 0.16

Energy generation by a panel = 42.3 Whr/day

2) Battery Calculations

Battery Power = Voltage * Current
Battery Power = 11.1 V * 11.4 Ah
Battery Power = 126.54 Whr
The battery can be dischargeable up to 80 %
Therefore, Actual Power = 126.5 * 0.8
Actual Power = 101.232 Whr

3) Load Considerations

LED bulbs – 1 (12 Watt) Backup – 1.5 hours
So, Load Energy Consumption = 18 Whr

4) Energy Consumption by Motors (Servos and N20 motor)

Motor Power = P = V*I
Motor Power = P = 6 * 0.01
Motor Power = P = 0.06 Watt
Considering tracking of the sun for 12 hours from East to West, a total of 180˚ (i.e. -90˚ to +90˚) Therefore,
The angle of rotation per Hour for motor1 = Total angle / Time
The angle of rotation per Hour for motor 1 = 180˚/12
The angle of rotation per Hour for motor 1 = 15˚/hour
Motor 1 (23sec/60°)
So, for one revolution motor takes 138 seconds
So, to rotate half revolution required time is 138/2 = 69 sec. = 0.0192 hr
Therefore, Energy consumption by motor1=Motor Power*Time
Energy consumption by motor1= 0.06 * 0.0192
Energy consumption by motor1= 0.001152 Whr
Energy consumption by motor1= 1.152 mWhr
On consideration of seasonal tracking, the motor will rotate 47˚ * 2 = 94˚/year
So, the Angle of rotation per Hour for motor 2 = Total angle / Time
The angle of rotation per Hour for motor 2 = 94°/ 24hr∗365days
The angle of rotation per Hour for motor 2 = 0.01˚/hr
As 0.01˚ is so small we can neglect it.
Motor power of N20 gear motor-
Motor Power= Voltage * Current
Motor Power= 12*0.75
Motor Power= 9W
The speed of the motor is 100RPM
So, 1 revolution takes 1.66 sec
As the motor will revolve twice in a day i.e., 720°
Therefore, 2 revolutions= 3.33 sec = 0.0009 hrs
Therefore, the Energy consumption of the gear motor = Motor power* Time
= 9* 0.0009
= 0.0081 Whr

5) *System Consumption*

Total Energy consumption = Load Energy Consumption + Consumption by motors

Total Energy consumption = 18 + 0.001152 + 0.0081

Total Energy consumption = 18.01 Whr

VII. SELECTION OF COMPONENTS

A. *Solar Panels*

1) 6V-60mAh
2) Quantity- 12

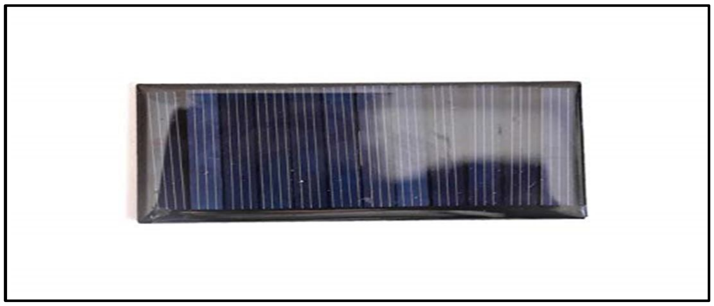

Fig. 4 Solar panel

B. *Li-Ion Battery Pack (Oseltech Individual battery cell)*

1) Input Voltage: 3.7 V
2) Output voltage: 11.1 - 12v DC
3) Output Current: About 1-3A
4) Capacity: 3800 mAh
5) Quantity of cells: 3

Fig. 5 Li-Ion Battery

C. *Arduino Nano*

1) Soldered Nano v3.0 atmega328 compatible, Nano Cable USB Mini B to USB A (cable color might change from the one shown in the picture)
2) Microcontroller: Atmel ATmega328P
3) Operating Voltage (logic level): 5V Input Voltage (recommended): 7V ~ 12V Input Voltage (limits): 6V ~ 20 V
4) Digital I/O Pins: 14 (of which 6 provide PWM output) Analog Input Pins: 8 DC Current per I/O Pin: 40mA
5) Flash Memory: 32KB (ATmega328) (of which 2 KB is used by bootloader) SRAM: 2KB (ATmega328) EEPROM: 1KB (ATmega328) Clock Speed: 16MHz USB to Serial Converter: CH340

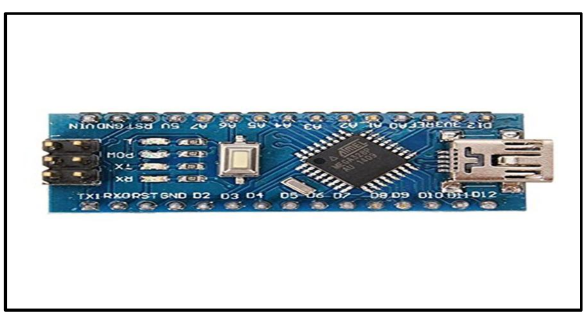

Fig. 6 Arduino Nano

D. L293D Driver

1) L293D IC Voltage:4.5V TO 36V
2) 600-mA Output Current

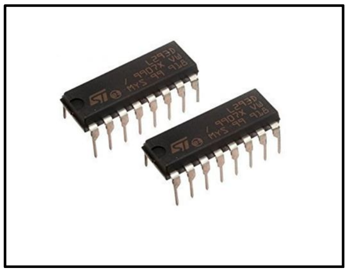

Fig. 7 L293D Driver

E. LDR Sensors

1) Maximum voltage: 150 Volt DC
2) Light resistance (10 Lux): 50-100 Kohm

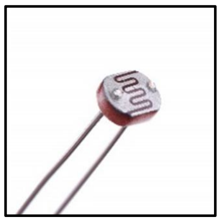

Fig. 8 LDR Sensor

F. Servo Motors (MG995)

1) Stall Torque: 3.2 kg/cm (4.8V), 4.1 kg/cm (6.0V)
2) Operating Speed: 23 sec/60° (4.8V), 19 sec / 60° (6.0V)
3) Operating voltage: 4.8-7.2V
4) Quantity- 2

Fig. 9 Servo Motor

G. N20 Gear Motor

1) Model: GA12-N20
2) Nominal voltage: DC3V
3) Rotate speed: 100rpm

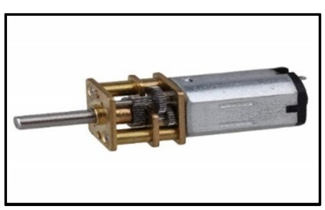

Fig. 10 N20 Gear Motor

H. LM2596S DC-DC Buck Converter Power Supply

1) Input voltage: 3-40V
2) Output voltage: 1.5-35V(Adjustable)
3) Output current: Rated current is 2A, maximum 3A
4) Switching Frequency: 150KHz
5) Conversion efficiency: 92%(highest)

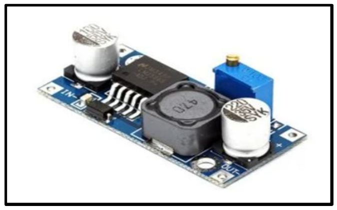

Fig. 11 LM2596S DC-DC Buck Converter Power Supply

VIII. FLOWCHART OF ARDUINO PROGRAMMING

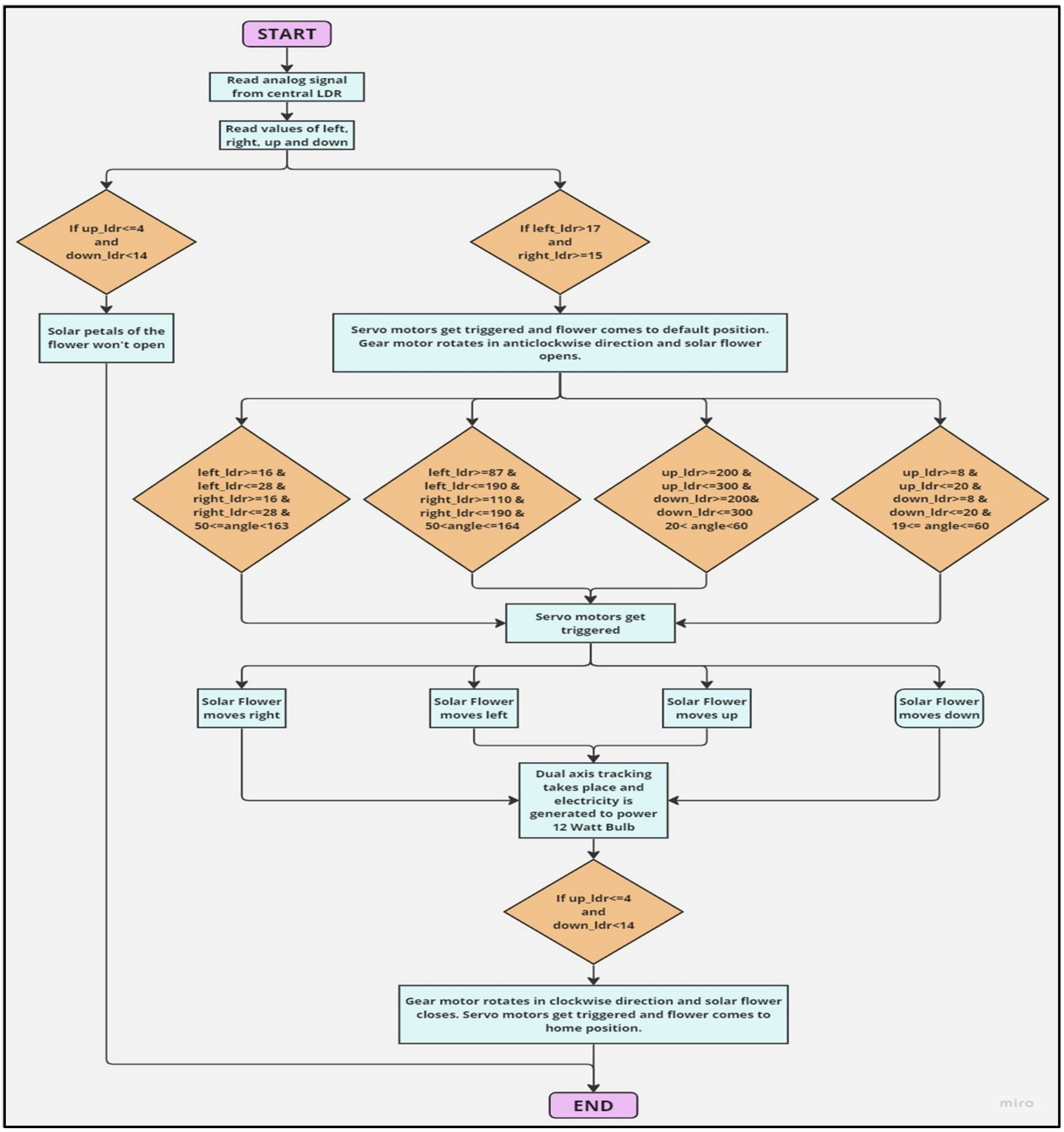

Fig. 12 Flowchart of the Arduino Program

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Reading the analog signal from the central LDR, which detects the existence of light and establishes the solar flower's home position, is the first step in starting the flowchart. It is followed by two if statements that specify when the petals of the sun will close and open. The tracking mechanism is the only item that determines which way the solar flower must turn if the petals open again. There are four more if conditions. These circumstances make it easier for the motor driver and microcontroller to activate the servo motors. An energy-producing device is utilized to power a 12-watt bulb. Finally, the solar flower closes by activating the gear motor once more and returns to its home position when light is not detected. Refer to Fig. 12 for more understanding. (Note: The values of LDR selected in the code are subject to the surroundings around the system)

IX. ASSEMBLY AND FABRICATION OF THE SYSTEM

A. Sensor Mounting

The sensors are positioned so that a central LDR, which senses the presence of light and establishes the system's home position, is present. The remaining four LDRs are arranged around this central LDR so that two are on the right and left, one is on top, and the other is at the bottom. Refer to Fig. 13 below, for the sensor mountings.

Fig. 13 Sensor Mounting

B. N20 Gear Motor and Servo Motor Mountings

For sun tracks from east to west, the first servo motor is positioned vertically in the base groove. The first servo motor is mounted with the second servo motor holder. For south-to-north sun tracking, this second servo motor is mounted to this holder horizontally. Additionally, the second servo motor has an N20 gear motor placed on it that aids in opening and closing the solar petals. Refer to Fig. 14 below, for the motor mountings.

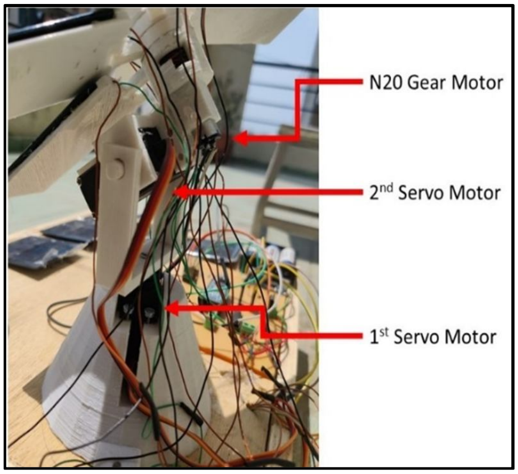

Fig. 14 Motor Mountings

C. Cleaning Mechanism

This prototype contains a cleaning mechanism that aids in preventing dust from getting on the solar panel, which is detrimental. Each solar petal has a sheet of cleaning supplies taped behind it. Therefore, these sheets rub against succeeding solar petals as they open and close. This helps prevent electricity generation losses and keeps the panels clean. Twice a day, this cycle occurs. Fig 15 below shows the actual image of the prototype with solar petals having cleaning material pasted behind.

Fig. 15 Cleaning Material Sheet behind Solar Petal

D. Circuit Design and PCB Development

Fig. 16 below shows us how various components are connected to each other and how they are interfaced with Arduino Nano.

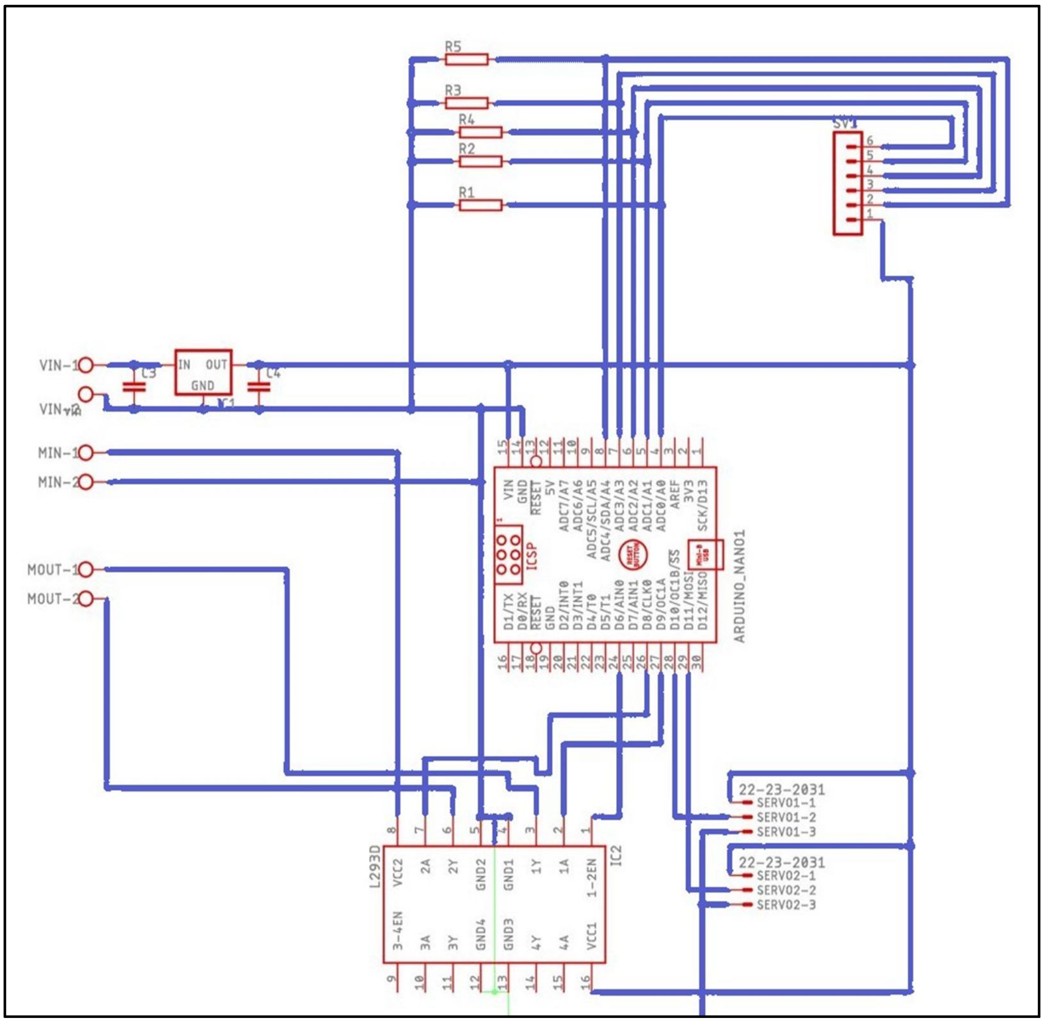

Fig. 16 Circuit Schematic Diagram

The system's printed circuit board was created utilizing the etching procedure. The circuit schematic routing is initially created using a laser printer in this technique on a piece of paper. After using metal shining powder to clean the copper-clad board, the printout of the circuit adheres to it. The printing is heated further before being adhered to the board. The circuit outline is embossed on this board after it has been submerged in water for a while and the paper has been peeled off of it. The board is then immersed in a solution of ferric chloride and water for a while. Finally, the board is thoroughly cleaned after being removed from the solution, and the PCB is ready. Refer to Fig. 17 for the board circuit diagram.

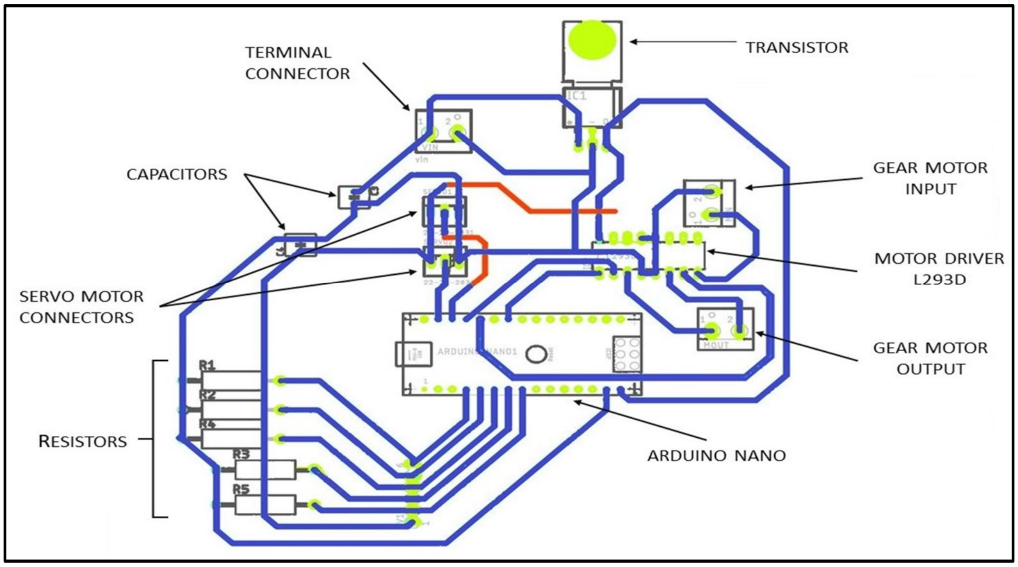

Fig. 17 Board Circuit Diagram

Fig 18 and 19 below show us the manufactured PCB using an etching process. It shows the individual components and how they are integrated into one another.

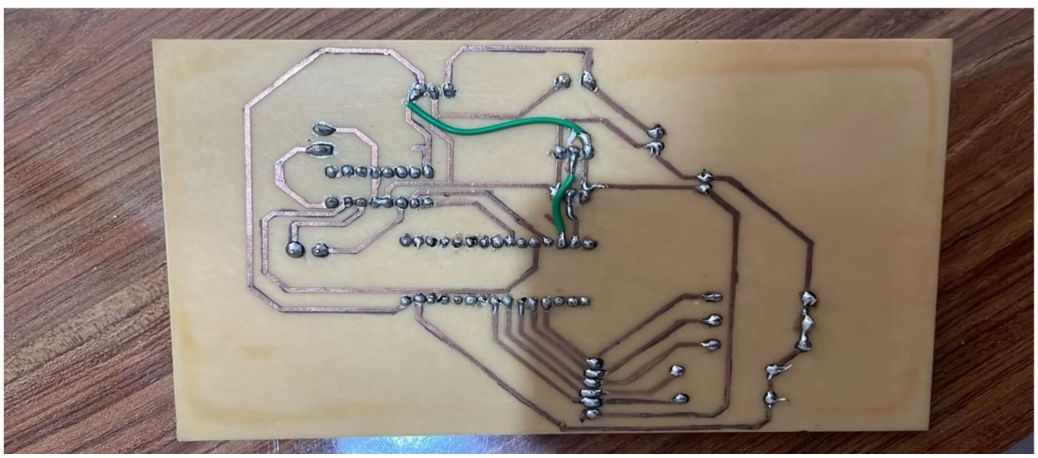

Fig. 18 Manufactured PCB (Back Side)

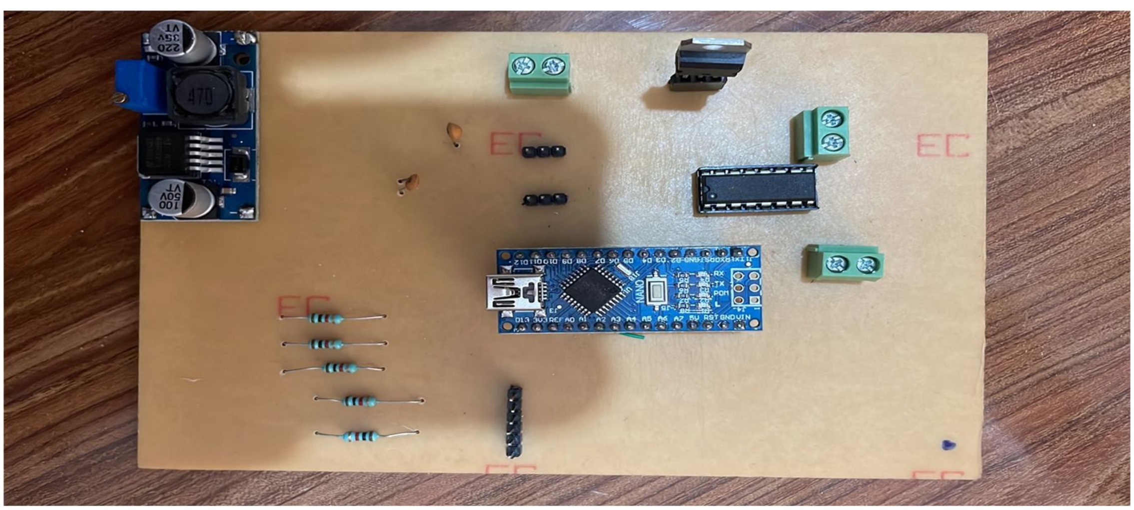

Fig. 19 Manufactured PCB (Front Side)

Below in Fig. 20 is the whole smart solar system.

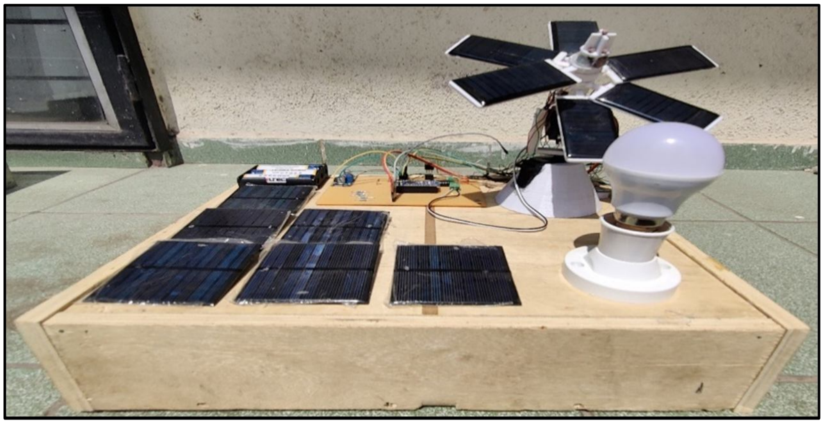

Fig. 20 Prototype of the System

X. RESULTS AND DISCUSSION

This prototype's dual-axis tracking requirement and the need that the solar petals to open and shut in response to sunlight were two of its key goals. The many positions the solar flower attained throughout the course of a day are seen in Fig. 21 and 22 below.

Fig. 21 System at Home Position

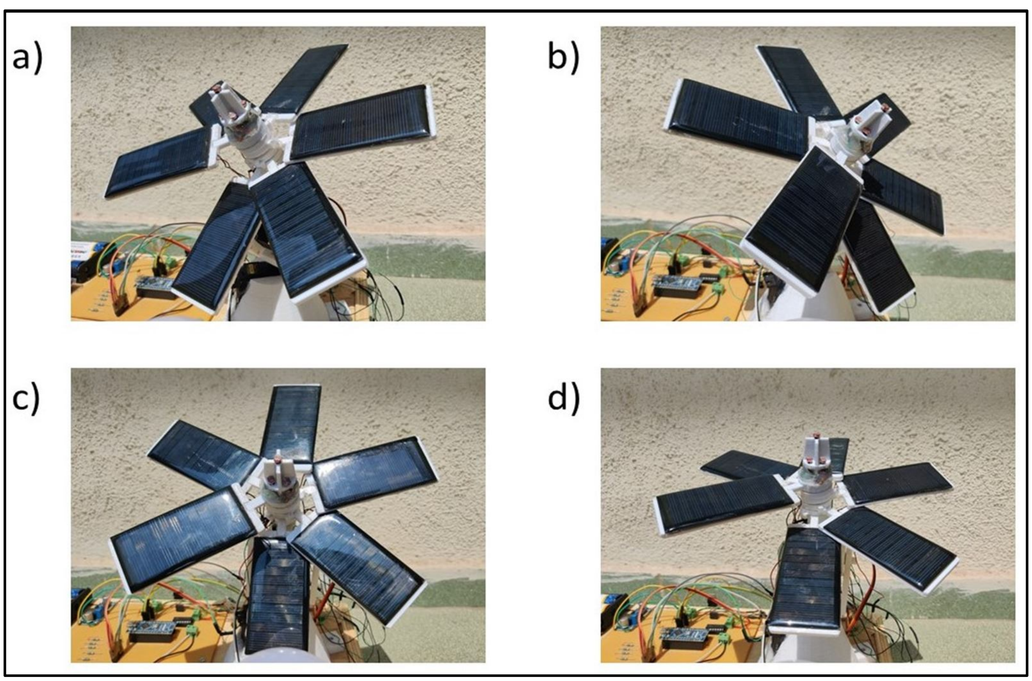

Fig. 22 Positions of the System a) Right b) Left c) Down d) Up

The efficiency of the system can be calculated as follows,

The efficiency of the Smart Solar Flower = Output Energy / Input Energy

$$= P_{out} / P_{in}$$
$$= [(V * I) / Area] / (1000W/m^2)$$
$$= \{[(13.59 * 0.55)/ 0.0486] / 1000\} * 100$$
$$= 15.38\%$$

Below are the readings of the system which were taken for 5 consecutive days. These readings were taken every hour starting from 9:00 am to 5:00 pm daily. It is followed by two graphs of which one is showing Output Voltage vs Time and the other is Power vs Time.

Table. 1 below shows us the output voltage readings over time.

Table. 1 Reading of Voltages with Respect to Time

Time	Vout (V)				
	Day 1	Day 2	Day 3	Day 4	Day 5
9AM	12.71	12.85	12.26	12.59	12.65
10AM	13.04	12.5	12.74	12.08	12.85
11AM	13.43	13.24	12.53	12.64	13.01
12PM	13.59	13.28	13.27	13.1	13.33
1PM	12.64	12.98	13.1	12.95	13.05
2PM	12.15	13.05	13.04	12.84	12.98
3PM	12.35	12.92	12.95	12.77	12.85
4PM	12.21	12.28	12.57	12.45	12.31
5PM	11.85	11.75	12.01	12.12	11.9

Fig. 23 below shows us the graph of the output voltage to time. We can observe various peaks and troughs. On day 1 and day 4, we can see a sudden plunge in the graph which is due to cloudy weather and less sunlight incidence.

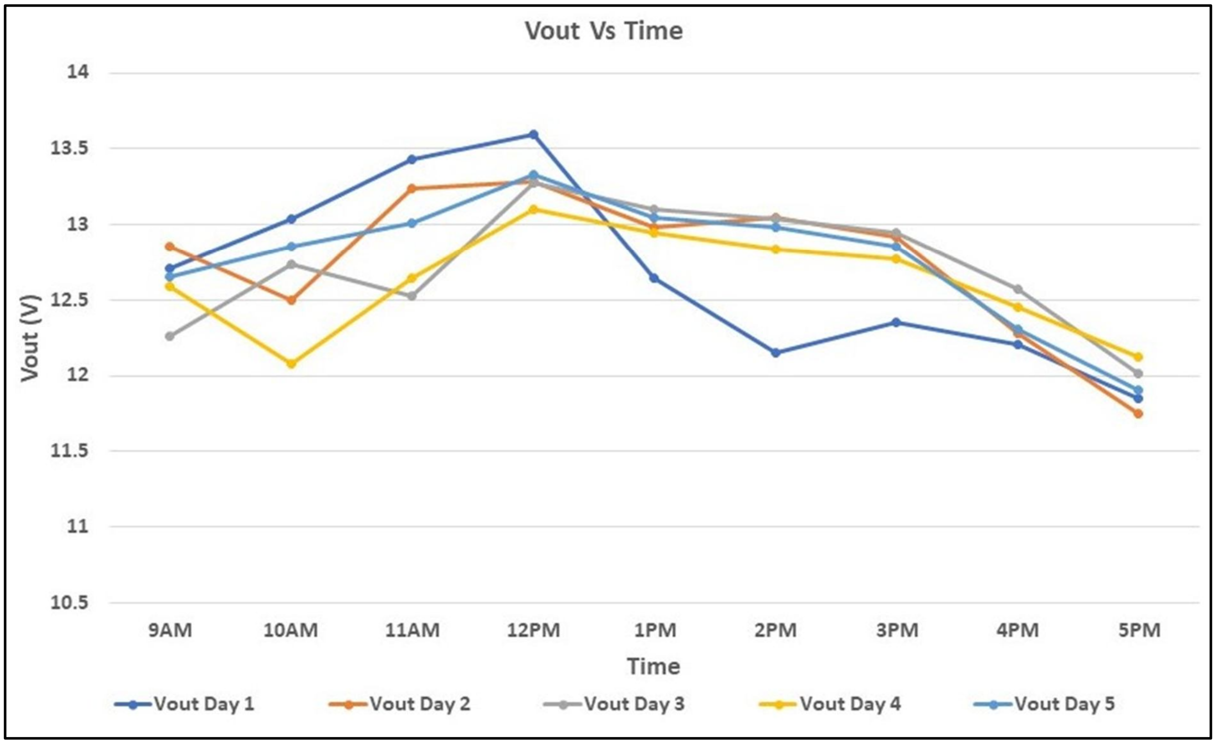

Fig. 23 Vout vs Time Graph

Table 2 below shows us the output voltage readings over time.

Table. 2 Reading of Powers with Respect to Time

Time	P (Watt)				
	Day 1	Day 2	Day 3	Day 4	Day 5
9AM	5.97	5.4	2.94	3.78	4.93
10AM	6.91	3.25	3.94	4.95	5.78
11AM	7.25	7.28	3.51	5.81	6.37
12PM	7.47	6.71	6.5	6.55	7.06
1PM	6.32	6.36	7.21	5.31	6.65
2PM	5.59	6.4	5.87	6.03	6.1
3PM	4.82	5.94	5.31	5.5	5.78
4PM	3.3	4.3	4.27	4.5	4.06
5PM	2.72	3.41	3.48	3.63	3.33

Fig. 24 below shows us the graph of the power to time. We can observe various peaks and troughs. On day 2 and day 3, we can see a sudden plunge in the graph which is due to cloudy weather, low current value, and less sunlight incidence.

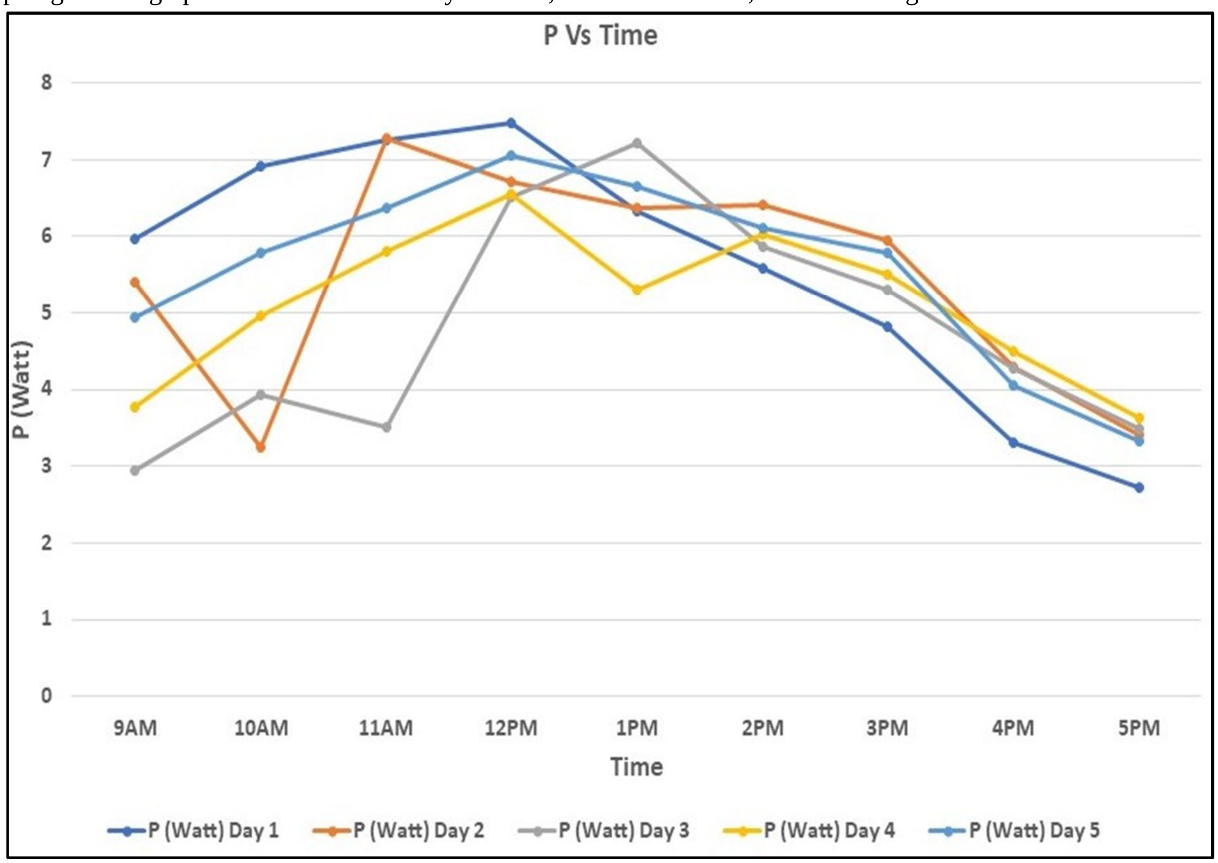

Fig. 24 Power vs Time Graph

XI. CONCLUSION

In conclusion, the creation of a smart solar flower prototype signifies a tremendous advancement toward effective and sustainable energy solutions.

By utilizing solar energy and incorporating smart technologies, the smart solar flower provides a number of advantages. It provides clean, renewable energy while also adding aesthetic appeal to any outdoor area. The prototype demonstrates the possibility of integrating solar panels, sensors, a self-cleaning system, and intelligent controls to maximize energy generation and consumption. The smart solar flower shows the potential of a wired and green future with its capacity to measure sunlight, modify location, and communicate with other devices. Smart solar flowers have the potential to be widely adopted and integrated into our daily lives as more developments are achieved in the sector. By embracing such cutting-edge technologies, we may work towards a greener, more sustainable environment for future generations may work towards a greener, more sustainable environment for future generations by embracing such cutting-edge technologies.

XII. ACKNOWLEDGMENT

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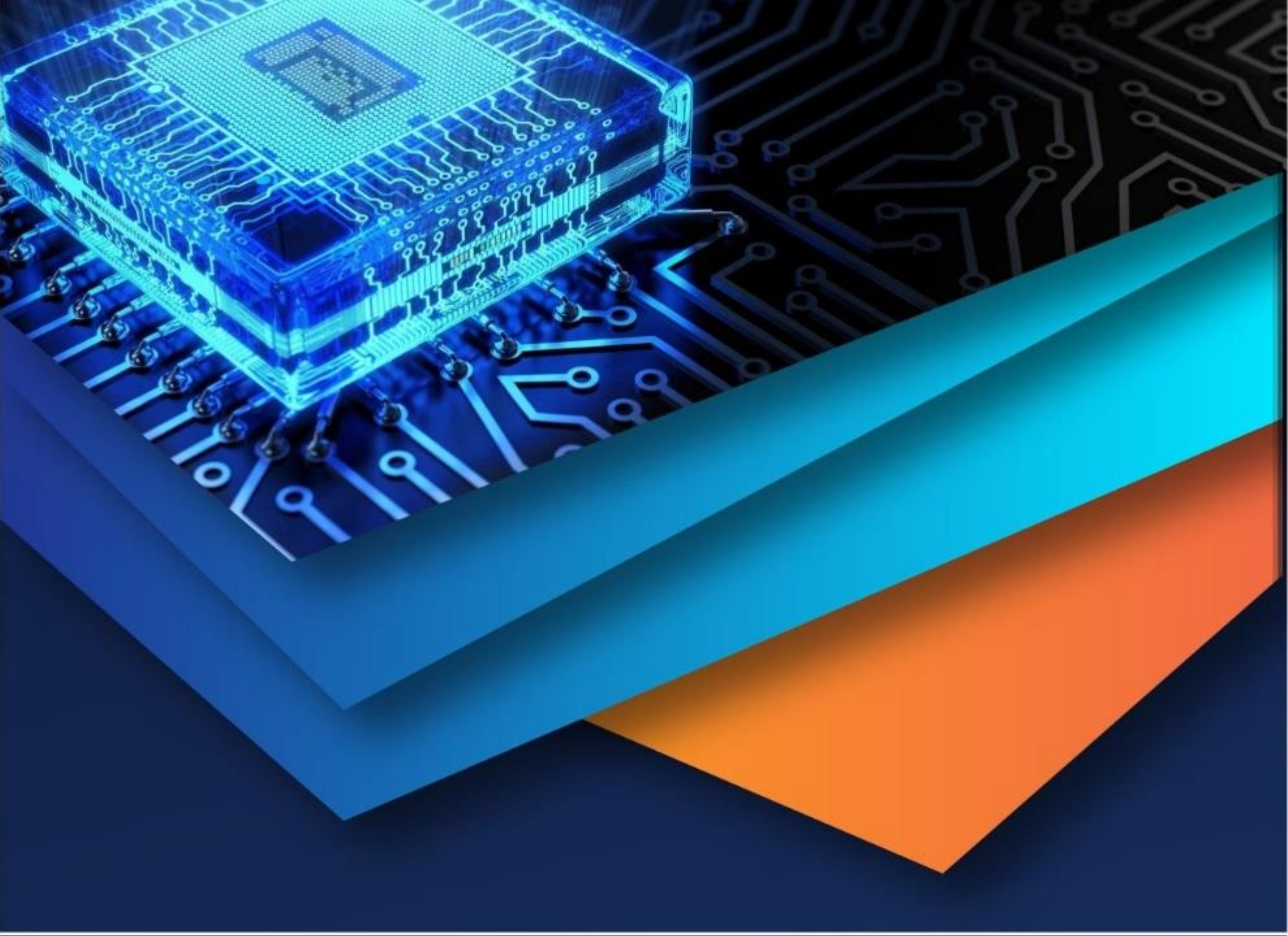

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