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Solar Tracking and Hybrid Wind Energy Generation with Battery Storage Optimization

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Abstract- The study looks at the difficulties that renewable energy sources, which aren't always available, can cause for keeping the power grid stable and supplying electricity in areas not connected to the main grid. It suggests a Hybrid Renewable Energy System (HRES) that combines solar power with a special tracking system, wind energy, and a well-designed battery storage system. this system consisting of dual-axis solar tracking, which helps collect more sunlight and can boost energy production to up to 40% compared to regular fixed solar panels. This smart tracking also lets wind energy fill in when solar isn't generating enough, helping to handle changes in weather and time of day. The main focus of this research is a framework that tries to cut down the cost of energy over time while making sure there's never a chance of losing power. Use P&O (Perturb and Observe) or Incremental Conductance algorithms.

Index Terms- Solar tracking, Hybrid Renewable Energy System, Solar–Wind Energy Generation, Battery Storage Optimization, Maximum Power Point Tracking (MPPT), Energy Management System, Off-Grid Power Supply.

I. INTRODUCTION:

A. In general, India has a relatively long sunny day for more than ten months and partly cloudy sky for most of the days of the rest two months. This makes our country, especially the desert sides in the west, which include Rajasthan, Gujarat, Madhya Pradesh etc. very rich is solar energy. Many projects have been done on using photovoltaic cells in collecting solar radiation and converting it into electrical energy but most of these projects did not take into account the difference of the sun angle of incidence by installing the panels in a fixed orientation which influences very highly the solar energy collected by the panel. As we know that the angle of inclination ranges between -90º after sun rise and +90º before sun set passing with 0o at noon. This makes the collected solar radiation to be 0% at sun rise and sun set and 100% at noon. This variation of solar radiations collection leads the photovoltaic panel to lose more than 40% of the collected energy. [1][2]

Problem Statement and Motivation: Despite the growing use of solar and wind energy, both face challenges because of their natural variability and limited energy output. This affects the stability of the power grid and the reliability of systems that rely on these sources without a connection to the main grid. Traditional solar panels that don't move lose a lot of efficiency—up to 40%—because they can't follow the sun's path and capture the most sunlight. Wind energy is also unreliable, as it changes with the weather and can be very inconsistent during different times of the day. Plus, current systems that combine solar and wind with **storage often** don't **work together well**. This **leads** to **problems** like batteries wearing out faster because they're not managed properly, and energy being wasted when it's not used at the right time.

To solve these problems, there's a need for a better energy management system

.

This system should include advanced solar tracking that follows the sun's movement, along with wind power generation, and an intelligent way to manage the stored energy. The goal is to get more energy out of the system, make the batteries last longer, and ensure a steady supply of power. These issues can be studied in more depth through three key technical challenges that could form the basis of a thesis or project report.

A. The "Misalignment" Problem (Solar Tracking)

1.The Issue: Fixed solar panels only reach peak efficiency for a small window around solar noon.

2.The Goal: Implementing a tracking system (single or dual-axis) to maintain a 90° angle of incidence, theoretically increasing energy harvest by 25% to 45%.

B. The "Complementary Gap" (Hybrid Synergy)

1.The Issue: Solar is only available during the day; wind is often stronger at night or during storms when solar is zero.

2.The Goal: Designing a hybrid controller that can smooth out the "duck curve" (the imbalance between peak demand and renewable supply) by blending the two sources in real-time.

C. The "Storage Paradox" (Battery Optimization)

1.The Issue: Batteries are the most expensive and fragile part of the system. Rapid charging/discharging or deep discharges significantly shorten their lifespan.

2.The Goal: Developing an optimization algorithm (like Particle Swarm Optimization or Genetic Algorithms) to decide when to store energy, when to use it, and when to bypass the battery to protect its health.

II. Proposed Frame Work: The primary goal of solar tracking is to maintain the **Angle of Incidence** near zero, ensuring that sunlight hits the panel perpendicularly for maximum irradiance.

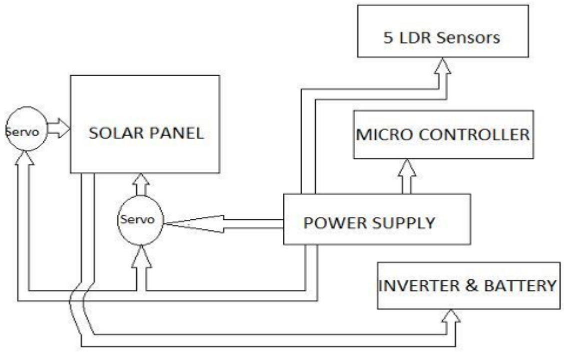

Fig. 1 Block Diagram of Solar Tracking.

The solar tracker's main goal is to accurately follow the sun's movement so that solar panels can collect the most sunlight. This particular solar tracker uses a closed-loop system with five Light Dependent Resistors (LDRs) that send information back to a microcontroller. The microcontroller takes in the data from the LDRs and creates two Pulse Width Modulation (PWM) signals to control the servo motors. These motors then move the solar panel to face the direction where there is more sunlight. The whole setup runs on a 12-volt power source. At the start, the microcontroller gets five separate analog readings from the LDRs before sending out the PWM signals to adjust the solar panel's position via the servo motors.

1.Dual-Axis Tracking with LDR & Arduino: Proposed Solution:

A hybrid control system that uses Light Dependent Resistors (LDRs) for fine-tuning on sunny days and GPS-based astronomical algorithms for "blind" tracking on cloudy days.

2.Efficiency Gain**:** Increases energy yield by **35% to 45%** compared to fixed-tilt systems.

3.Bifacial Panel Integration: Using solar trackers with bifacial modules allows for the capture of albedo (reflected light) from the ground. When combined with dual-axis tracking, this can further boost output by another 10–15%.

Hybrid Generation & Energy Management

In these systems, solar and wind are complementary: solar peaks during the day, while wind often peaks at night or during stormy weather. Multi-Input Converters: Use a single power electronic interface to handle both DC (Solar) and AC (Wind) inputs. This reduces component count and conversion losses.

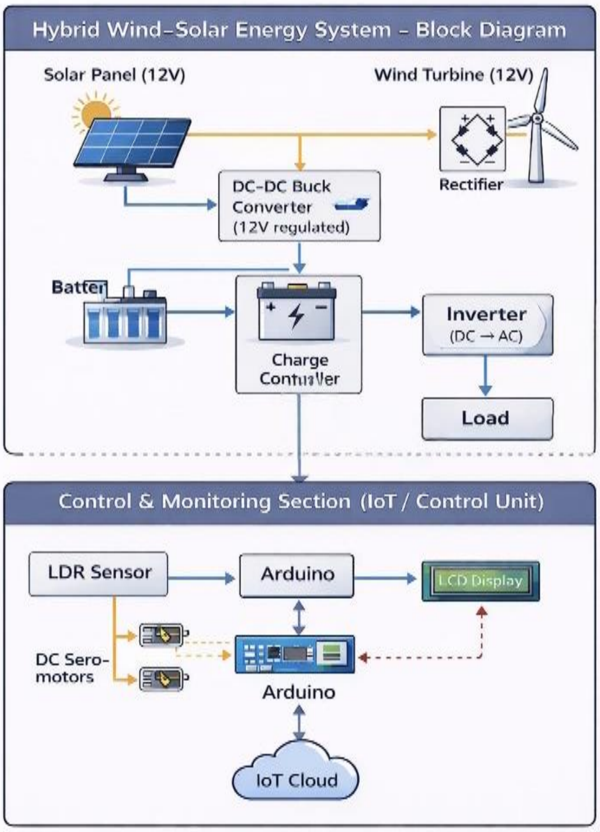

Fig. 2 Block Diagram of hybrid wind solar energy system

1.MPPT (Maximum Power Point Tracking):

A. Solar**:** Use P&O (Perturb and Observe) or Incremental Conductance algorithms.

B. Wind**:** Implement Tip Speed Ratio (TSR) control for the wind turbine to ensure the blades operate at peak aerodynamic efficiency.[7][8][13]

C. Battery Storage Optimization

The "Optimization" phase focus on the State of Charge (SOC) and the Depth of Discharge (DOD) to prolong battery life and reduce the Levelized Cost of Energy (LCOE)

Methodology: In this section, we will talk about all the methods used to carry out the research on the MPPT technique, specifically the perturb and observe method. This chapter will cover the technique used in MPPT to find the maximum power point, what we expect to learn from this analysis, and how the data collected from this research is assessed. It will also explain how irradiance and temperature data are predicted and provide details on the model used for the PV cell. Additionally, the flowchart of the P&O algorithm is included in this chapter.

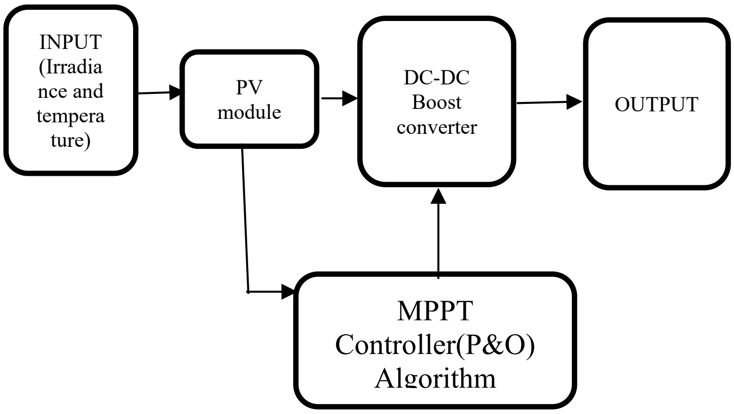

Figure .3 Block diagram of the PV module with P&O MPPT Technique

In this section, Figure 9 shows a block diagram of the PV cell along with the MPPT controller. The PV cell receives input in the form of irradiance and temperature. It then produces an output voltage. To control this voltage, the MPPT controller is used. The MPPT controller extracts the maximum power from the PV cell by comparing the input voltage with the Vamp. It tracks the maximum power point of the PV cell using the P&O algorithm. The MPPT then creates a PWM signal and sends it to the IGBT MOSFET in the DC-DC Boost Converter. The MOSFET performs a switching action to adjust the voltage and achieve PMPP. The PMPP is studied to assess the performance of the PV module. This research uses the SDM PV model. The SDM model has less capability to reach maximum power compared to the DDM model. Therefore, this model is suitable for analyzing the P&O algorithm to improve solar cell accuracy. The design of the SDM circuit can be seen. The current source is connected in parallel with a diode. The photocurrent (I_{ph}) produced by the current source is directly proportional to the amount of light falling on the cell. The current flowing through the diode is known as the diode saturation current, which plays a key role in determining the IV characteristics of the cell.

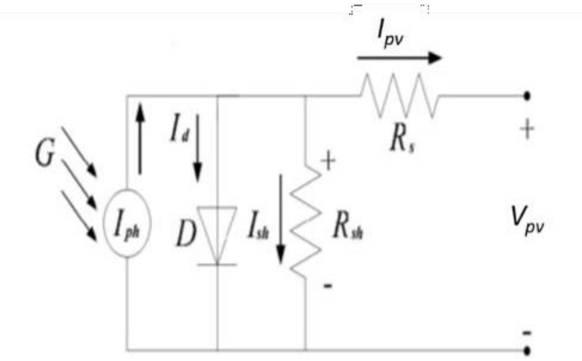

Figure 4 Single Diode PV Model Circuit

The DC-DC boost converter shown in Figure 10 is used to control the voltage from the photovoltaic source, V_{pv}. It increases the voltage based on the duty cycle (D) sent from the MPPT. The circuit includes an inductor (L), a diode (D), a capacitor (C), a load resistor (RL), and a control switch (S).

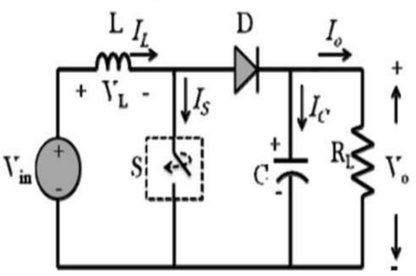

Figure. 5. DC-DC Boost Converter

Duty ratio (1)

$$D = 1 - \frac{V_{in}}{V_o}$$

Inductor value (2)

$$L = \frac{V_{in} \cdot D}{\Delta I_L \cdot f_s}$$

Output capacitor value (for given ripple) (3)

$$C_{out} \approx \frac{I_o \cdot D}{\Delta V_o \cdot f_s}$$

The MPPT controller will use the P&O algorithm to manage the solar PV output. The P&O algorithm is simple to implement and has good tracking efficiency. This analysis will look at how the PV I-V curve behaves when the P&O algorithm is used. With this method, the MPPT controller checks the PV output power and changes it slightly, either increasing or decreasing, based on whether the PV voltage or current is going up. The algorithm compares the current power value with the previous one to find the difference in power. It keeps adjusting the PV voltage slightly. If the change in power (ΔP) is positive, it moves toward the maximum power point and continues adjusting in that direction. If the change in power (ΔP) is negative, it moves away from the maximum power point and the direction of adjustment is reversed. There are various techniques and algorithms, as mentioned earlier, that can be used to track the maximum power point. One of them is the Perturb and Observe (P&O) method.

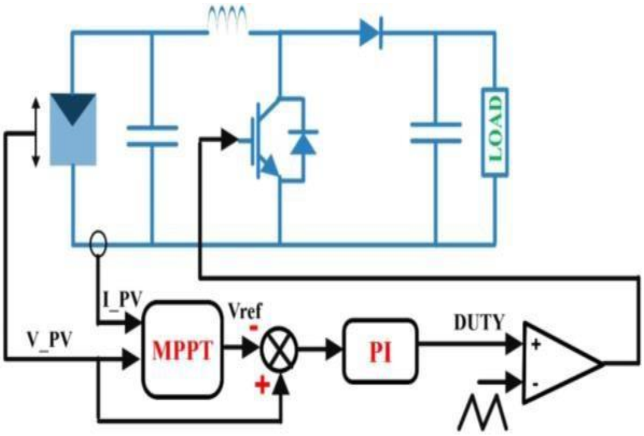

Figure .6. MPPT circuit design

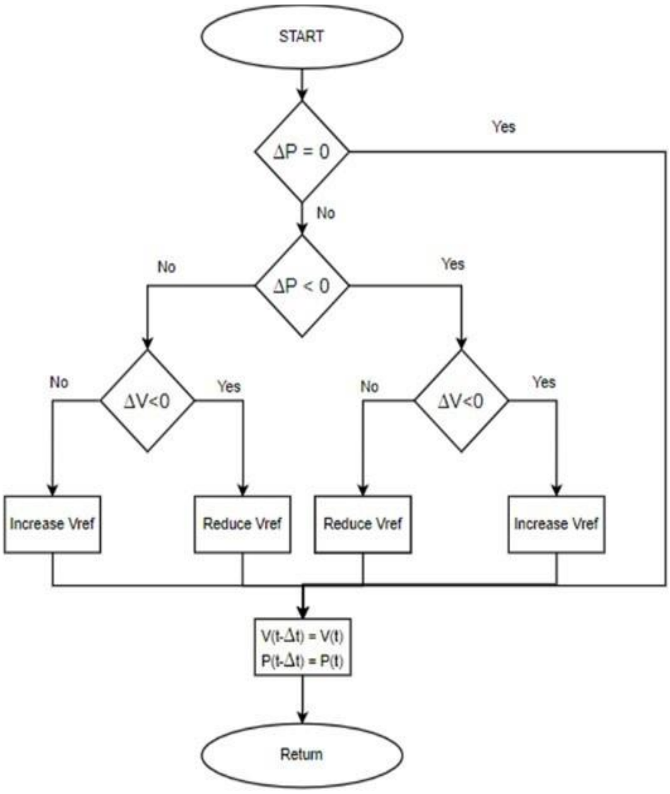

Figure. 7. Perturb and Observe (P&O) flowchart

III. CONCEPTS OF SOLAR RADIATION

Understanding solar radiation is important for solar tracking systems The sun emits energy with a surface temperature of around 5800 K. This energy reaches planets in the solar system. Sunlight includes direct beam radiation, which makes up about 90% of the solar energy, and diffuse radiation, which is the remaining part. Diffuse radiation increases on cloudy days. Direct radiation, also called beam radiation, is straight sunlight that hasn't been blocked. Diffuse radiation includes light that has been scattered in the atmosphere, which is why the sky appears blue. Reflected radiation is the portion of both direct and diffuse radiation that bounces back from the Earth's surface. The total of direct, diffuse, and reflected radiation is called global radiation. For best solar energy collection, solar panels should face the sun for long periods since most of the energy is in the direct beam.[14]

The declination of the sun is the angle between the Earth's equator and a line from the Earth's center to the sun's center. It reaches a maximum of 23.45° during the summer and winter solstices, specifically on June 21 and December 22 in India. This angle, represented as δ, changes throughout the year due to the Earth's tilted axis and its orbit around the sun. Without the tilt, the declination would always be 0°. The declination is 0° only during the equinoxes in spring and fall.

Formula of declination angle

$$\delta \approx 23.45 \times \sin\left((360/365) \times (n - 81)\right) \text{ degree} \tag{4}$$

where:

δ = solar declination angle (in degrees)

n = day number in the year (1 = 1 January, 365 = 31 December)

The Hour Angle is the amount the Earth has turned in one day, measured in degrees. It's 15 degrees for every hour that passes after local solar noon. This idea is based on the fact that the Earth takes 24 hours to make a full 360-degree turn. The solar hour angle is zero when the sun is straight overhead. Before noon, it has negative values, and after noon, it becomes positive. Noon is exactly at 12:00

$$\text{Hour angle } H = 15 \times (\text{Solar time} - 12) \text{ degrees} \tag{5}$$

where:

H = hour angle (in degrees)

Solar time = current time in 24-hour format measured from local solar noon (so 12:00 is noon, 10:00 is 10, 15:00 is 15, etc.).

Before noon: H is **negative** (morning).

After noon: H is **positive** (afternoon).

The solar altitude is the angle between the horizontal line and the line pointing directly to the sun. This angle changes during the day, starting at 0 degrees at sunrise and sunset when the sun is just above the horizon, and reaching its highest point of 90 degrees when the sun is straight overhead, directly above. The solar altitude depends on several things, like the location's latitude, the sun's declination angle, and the hour angle, which shows where the sun is in relation to the local time. Knowing how these factors connect is important for things like solar energy use, studying the climate, and astronomy.

Solar altitude (θz = elevation) (6)

$\theta z = 90^\circ - \theta z$-zenith

Solar Azimuth (Î¸A) - The azimuth angle is the angle measured in the horizontal plane, starting from either true South or true North. It is measured clockwise from the zero-azimuth direction. For instance, if you're in the Northern Hemisphere and the zero azimuth is set to South, the azimuth angle will be negative before solar noon and positive after solar noon.

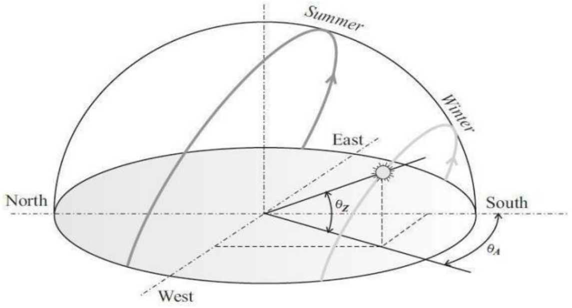

Figure .8. Solar altitudes and azimuths typical behavior of sun path

Solar zenith angle (θz-zenith) (7)

$$\cos(\theta z\text{-zenith}) = \sin(L) \times \sin(\delta) + \cos(L) \times \cos(\delta) \times \cos(H) \quad (8)$$

L = latitude

δ = declination angle

H = hour angle

Insolation is the total amount of solar energy that reaches a certain area over a period of time. It is measured in units like MJ/m^2 or J/cm^2, and in the solar energy industry, Wh/m^2 is often used. This measurement gives a value known as irradiance, which is expressed in W/m^2. On average, the amount of solar radiation in Earth's atmosphere is about 1366 W/m^2, but at the surface, especially on clear days when the sun is shining directly, this drops to roughly 1000 W/m^2. Insolation can also be measured in 'Suns,' where one Sun is equal to 1000 W/m^2

Projection Effect: The amount of solar energy that hits a surface is greatest when the surface is directly facing the Sun. As the angle between the surface and the sunlight changes, the amount of solar energy decreases in relation to the cosine of that angle. This is why areas closer to the poles are much colder than those near the equator. On average, the poles get less solar energy than the equator because the Earth's surface at the poles is tilted away from the Sun.
Effective irradiance on panel ≈ Incoming solar irradiance × cos(θ) (8)
where:
θ = angle between the Sun's rays and the panel's normal (perpendicular) direction.
When **θ = 0°**, cos (0°) = 1 → full irradiance.
When **θ = 60°**, cos (60°) = 0.5 → only half the energy reaches the panel.

Need For Solar Tracker: The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the panel. The table no.1 shows the Direct power lost (%) due to misalignment (angle i).

Misalignment (angle i)	Direct power lost (%) =1-cos(i)
0°	**0**
1°	**0.015**
3°	**0.14**
8°	**1**
23.4°	**8.3**
30°	**13.4**
45°	**30**
60°	**>50**
75°	**>75**

Table No-1 Direct power lost (%) due to misalignment

The sun moves across the sky from east to west in a full 360° arc each day, but from any fixed spot-on Earth, the part of the sky we can see is only 180° during half a day. However, because of the way the horizon limits our view, the actual movement of the sun appears to be about 150°. If a solar panel is fixed in position between the earliest morning and latest evening sun angles, it will track the sun's movement across 75° on each side, leading to a loss of about 75% of potential energy in the morning and evening. By rotating the panels to face east and west, these losses can be recovered. A tracker that moves in the east-west direction is called a single-axis tracker. Additionally, the sun also moves north and south by about 46° over the course of a year. If the same panels are positioned at the midpoint between the northernmost and southernmost sun angles, they will track the sun's movement across 23° on each side, resulting in a loss of roughly 8.3%. A tracker that adjusts for both the daily east-west movement and the yearly north-south shift is called a dual-axis tracker.

IV. PROTOTYPE

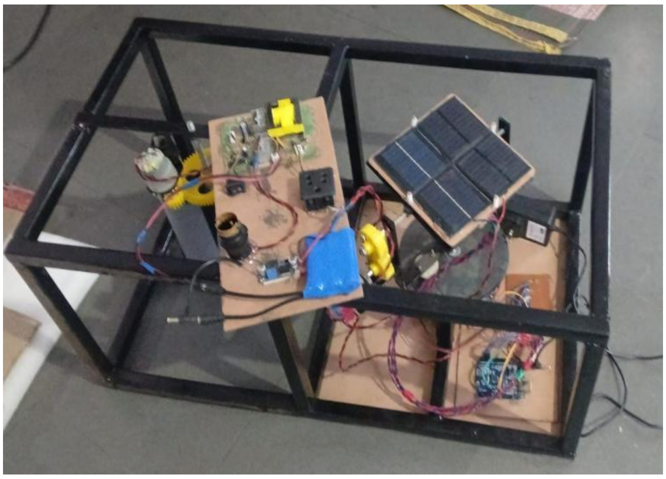

Fig.9 Solar Tracking and Hybrid wind Energy Generation with Battery Storage Optimization.

Hardware Specifications:

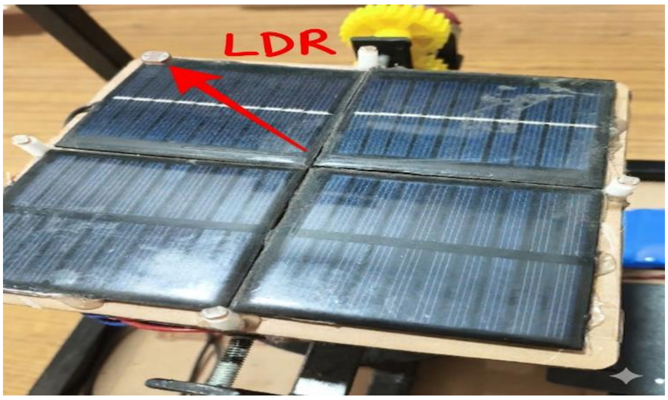

Fig.10 solar panel in build with LDR Sensors

Electrical Output Specifications:
Maximum Power (P_{max}): About 6W to 10W, calculated from four panels each providing 1.5W to 2.5W.

Operating Voltage (V_{mp}): Usually 12V to 13.5V DC, designed to efficiently charge a 12V lithium-ion or lead-acid battery.
Open Circuit Voltage (V_{oc}): Between 15V and 18V DC when measured with no load connected and in full sunlight.
Maximum Power Current (I_{mp}): Around 450mA to 600mA, which can vary based on how the panels are connected in series or parallel.
Short Circuit Current (I_{sc}): Approximately 700mA, which is the highest current the system can produce when exposed to direct sunlight perpendicular to the panels.

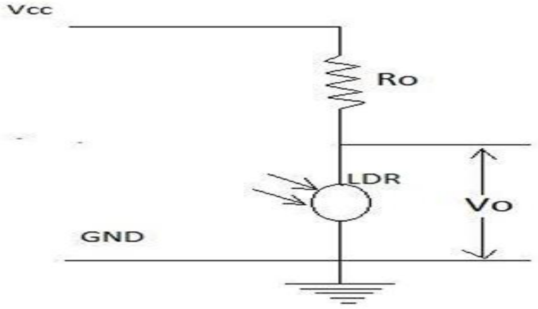

Fig.11. circuit diagram of LDR

Each LDR is connected to power supply forming a potential divider. Thus, any change in light density is proportional to the change in voltage across the LDR's. LDR is a passive transducer hence we will use potential divider circuit to obtain corresponding voltage value from the resistance of LDR. LDRs, or Light Dependent Resistors, change their resistance based on how much light they receive. When there's more light, their resistance goes down, and when there's less light, their resistance goes up. The Arduino uses a 10-bit Analog to Digital Converter, which means it can read values from 0 to 1023 because 2 raised to the power of 10 is 1024. To get the voltage from the LDR, we use a voltage divider circuit. This setup creates an output voltage that depends on the LDR's resistance. More light makes the LDR's resistance lower, which lowers the output voltage, and less light makes the LDR's resistance higher, which raises the output voltage. The Arduino also has an 8-bit Pulse Width Modulation generator, which can produce 256 different levels of PWM signal. To control a servo motor, the Arduino creates a PWM signal based on the desired angle. The Arduino's servo library simplifies this by letting you set the angle between 0 and 180°. The library takes care of the PWM calculations, ensuring a smooth and accurate signal for the servo to move to the correct position

Active Tracking Systems: Active solar tracking is a way to position a solar collector, such as a photovoltaic panel or a concentrator, by using powered parts like motors, actuators, and sensors. This allows the collector to move and follow the sun's position throughout the day, ensuring it captures the most sunlight possible.[12]

There are two main types of active solar trackers:

single axis and double-axis**.** Single-axis trackers use motors and gears that are controlled by a system that changes the tracker's position based on where the sun is. The motors run only when needed to make the system more efficient. There are two main types of single-axis trackers: horizontal single-axis trackers (HSAT) and vertical single-axis trackers (VSAT). A horizontal-axis tracker has a long, horizontal bar where solar panels are attached and it moves slowly from side to side to follow the sun. This type works well in areas near the equator where the sun is high in the sky at noon and also in places where the sun stays high for most of the year. However, it works less well in areas farther from the equator. Vertical-axis trackers, on the other hand, are better for places far from the equator where the sun is lower in the sky, especially during the summer when days are longer. Dual-axis trackers can move in both directions—horizontally and vertically—so they can always point directly at the sun, no matter where you are. This makes them more effective, but they need precise components to work properly.[2]

Fig.12. Dual axis solar tracker

Dc Servo Motor and Motor Driver Theory: The tracking systems would require two motors to adjust the position the array, along with a control circuit, either analog or digital, to manage the motors. The next sections will look at different types of motors that might be suitable for this kind of use.

DC Motors: The tracking systems used for applications like sun tracking arrays need a strong setup that includes dc servo motors two motors for controlling position, along with a control circuit, which can be either analog or digital, to manage these motors. There are several types of motors that can be used for this, such as DC motors and DC servomotors. However, standard DC motors aren't great for the precise control needed in sun tracking arrays because they spin freely, making it hard to get them to stop exactly where they need to. Even if the timing is right, the armature can be slow to respond, leading to slow stabilization with gradual speeding up and slowing down. Adding gears can help reduce overshooting but doesn't completely fix the problem, leaving the final position possibly inaccurate. For better accuracy, using a servomotor setup is better. A servomotor is a system that includes a standard DC motor, a gear reduction unit, a position-sensing device like a potentiometer, and a dedicated control circuit.

Fig.13 DC Servo Motor

Electrical Specifications

Operating Voltage: Usually 6V to 12V DC, with most industrial and hobby versions optimized for 12V.

Rated Speed: 3.5 RPM (this is the speed after the internal gear reduction).

No-Load Current: 30mA to 60mA

Load Current: 200mA to 500mA.

Stall Current: Up to 1.5A at 12V.

Micro Controller: The ATMEGA-168 is a modified Harvard architecture 8-bit RISC single chip microcontroller which was developed by Atmel. It uses on-chip flash memory for program storage, as opposed to one-time programmable ROM, EPROM, or EEPROM used by other microcontrollers at the time.**[9]**

Fig. 14 Microcontroller

Software Requirement:

Arduino Ide: The Arduino integrated development environment (IDE) is a cross-platform application (for Windows, mac OS, Linux) that is written in the programming language Java. It is used to write and upload programs to Arduino compatible boards, but also, with the help of 3rd party cores, other vendor development boards. The source code for the IDE is released under the GNU General Public License, version 2. The Arduino IDE supports the languages C and C++ using special rules of code structuring.

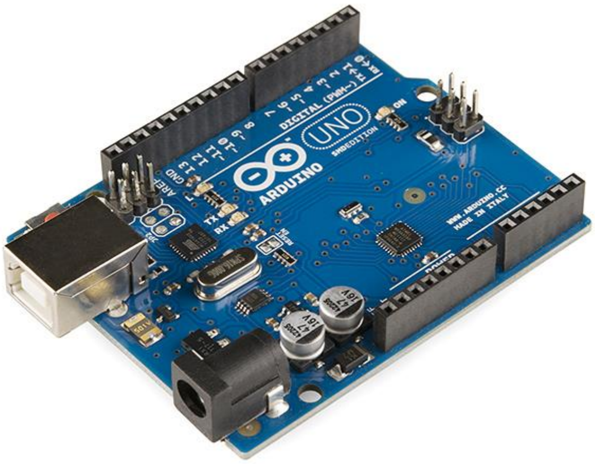

Fig. 15 Arduino IDE:

Communication: The Arduino/Genuine Uno has several ways to communicate with computers, other Arduino boards, or microcontrollers, mainly through the ATmega328 microcontroller. This microcontroller provides UART TTL (5V) serial communication using digital pins 0 (RX) and 1 The board also includes an ATmega16U2 chip that allows serial communication through USB, making it appear as a virtual COM port to the computer. The firmware on the ATmega16U2 uses standard USB COM drivers, so no extra drivers are needed, though Windows users need a .inf file for setup. The Arduino Software (IDE) has a serial monitor that lets you send and receive simple text between the board and the computer. The board also has RX and TX LEDs that show data being sent through the USB-to-serial chip and the USB connection, but these lights don’t blink when data is being sent through pins 0 and 1.

L298N DUAL H-BRIDGE MOTOR DRIVER MODULE

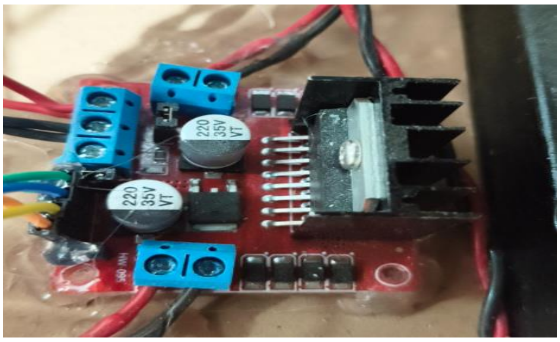

Fig.16.L298N Dual H-Bridge Motor Driver Module

This dual H-bridge configuration with the ST L298N integrated circuit.

Operating Voltage (V_S): It works with a motor power supply ranging from 5V to 35V DC.

Logic Voltage (V_{SS}): It is compatible with a standard 5V logic level.

Output Current: It can provide up to 2A of continuous current per channel, with a peak of 3A.

Logic Current Consumption: It uses between 0mA and 36mA of current.

Maximum Power Dissipation: It is rated for 20W of power when the junction temperature is 75°C.

Voltage Drop: There is usually a voltage drop of 1.5V to 2.0V between the input and output because of the internal bipolar transistor resistance.

MINI WIND TURBINE 12V for Prototype)

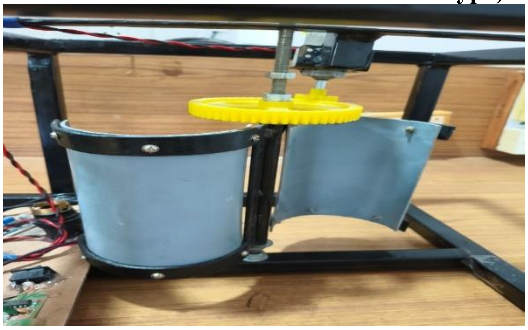

Fig. 17 Mini Wind Turbine:

ELECTRICAL SPECIFICATIONS

Generator Type: Permanent Magnet DC (PMDC) Motor. Rated Output Voltage:12 volts DC

Operating Voltage Range: From 0 volts to 15 volts DC, which depends on the RPM and wind speed.

Maximum Current Output: Between 500 milliamps and 1.5 amps, which is typical for small educational setups.

Rated Power Output: >Between 6 watts and 18 watts, calculated by multiplying voltage by current (P = V I).

Internal Resistance: Low armature resistance to reduce heat during power generation.
Rectification: Includes a bridge rectifier if using an AC alternator, or provides direct DC output from a brushed motor.

The power output of a wind turbine is given by[10]

$$P = \frac{1}{2} \rho A v^3 \quad (9)$$

1.ρ is the air density (kg/m3)

2.A is the air swept area of the rotor (m2), calculated as A = π * D^2 / 4 (D is rotor diameter in m)

3.V is the wind speed (m/s)

4.Cp is the power coefficient (dimensionless, max ~0.59 per Betz limit)

BATTERY BANK (12V, Lithium-Ion)

The battery bank is an important part of the hybrid solar and wind energy storage system, used to store electricity from these renewable sources.

Electrical Specifications

Chemistry: Lithium-Ion (Li-ion).

Configuration: 3S (3 cells in series) to achieve a **12.6V peak / 11.1V nominal** output.

Capacity: Typically, **2200mAh to 4400mAh** (depending on the internal cell arrangement).

Nominal Voltage: 11.1V – 12V DC.

Charging Voltage: 12.6V DC (standard for a 3S pack).

Discharge Cut-off Voltage: Approximately 9V to 9.6V (to prevent cell damage).

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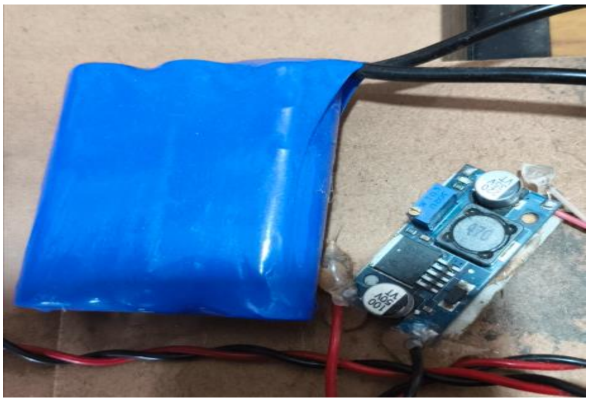

Fig.18. 12v Lithium Ion Battery

LM2596 DC-DC BUCK CONVERTER MODULE

Fig. 19. LM2596 DC-DC Buck Converter Module

This part is an LM2596 DC-DC Buck Converter Module, which is a type of voltage regulator that steps down a higher input voltage, such as from a 12V battery, to a lower and steady output voltage.

Key parts shown in your **image include**:

LM2596 IC (a black chip with five pins): This is the main component that controls the conversion of electrical power.

Blue Potentiometer (with a brass screw): You can turn this knob to adjust the output voltage manually—turning it clockwise or counter-clockwise will change the voltage level.

This component stores energy during the conversion process, helping to keep the output voltage smooth and steady.

Working: The system uses a 12V solar panel that moves in two directions to follow the sun. It adjusts both east-west and north-south to stay aligned with the sun throughout the day. Sensors or a control unit detect how much sunlight hits each side of the panel, and small motors turn the panel until it gets the most sunlight. This setup produces more electricity than a panel that stays still because it keeps facing the sun directly most of the time. Once the solar panel generates electricity, it sends the power to a charge controller This device manages the 12V electricity and stops the battery from getting too much charge. The battery saves extra electricity when there's a lot of sunlight and provides power when there's not enough, like at night or on cloudy days. In a hybrid system, other energy sources such as wind or the power grid can be used together with solar power to keep the supply steady the controller decides when the battery should charge, discharge, or rest. It can use solar power directly for the connected devices, save extra power in the battery, and avoid deep discharging to make the battery last longer. This results in a steady 12V power supply, better use of energy, and dependable electricity for small off-grid uses.

V. RESULT

The project called "Solar Tracking and Hybrid Wind Energy Generation with Battery Storage Optimization" offers a fresh and efficient way to generate renewable energy. It combines solar tracking technology with wind energy systems, which together produce more energy than if each system worked alone. The system uses battery storage to keep the power supply steady, helping to deal with times when there's not enough sun or wind, which makes the energy supply more reliable and consistent. Smart optimization methods are used to make the most of the energy, reduce losses, and help the batteries last longer, making the system more efficient. This mixed approach reduces dependence on traditional fuel sources and helps cut down on pollution. As a whole, this project is a smart, affordable, and eco-friendly energy solution that works well for homes, rural areas, and small businesses.

VI. CONCLUSION

A system that uses both solar tracking and a mix of energy sources along with smart battery storage provides a better way to meet today's energy needs. The solar tracking part helps collect more sunlight by moving the panels to face the sun directly. The combination of different energy sources makes sure there's a steady supply of power. The battery system is designed with smart controls to manage energy use efficiently, which helps the batteries last longer and use less energy waste. Altogether, this setup produces more electricity, works more reliably, and uses less from traditional power sources, making it perfect for smart power networks and eco-friendly buildings.

Future Scope: This paper "Solar Tracking and Hybrid Wind Energy Generation with Battery Storage Optimization" has a great future ahead because there's a growing need for clean and dependable energy. In the years to come, the system can be improved by using Artificial Intelligence and Machine Learning to forecast solar energy levels, wind speeds, and electricity demand, which will help manage energy more effectively. Adding IoT-based remote monitoring and cloud connectivity will allow real-time tracking of the system's performance and quick identification of any issues. The system could also be upgraded to a smart hybrid model that connects to the grid with net metering features to use energy more efficiently. Using advanced MPPT algorithms and modern battery solutions like lithium-ion or solid-state batteries can boost efficiency and storage capability. Moreover, the system can be expanded to support electric vehicle charging, rural power supply, and microgrid setups, making it ideal for smart cities and sustainable industrial energy systems in the future.

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