SOLAR TRACKING SYSTEM WITH ENERGY MANAGEMENT SYSTEM

A PROJECT REPORT

21ES681- Application Lab for Embedded Systems

submitted by

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Chapter 1

Introduction

This project introduces a solar tracking system with integrated energy management, aimed at maximizing the efficiency of solar panels while ensuring system safety and performance. Solar panels are typically fixed in position, which limits their ability to capture the maximum amount of sunlight throughout the day. To address this, the solar tracking system uses Light Dependent Resistor (LDR) sensors to continuously monitor sunlight intensity, allowing a servo motor to adjust the orientation of the solar panel to follow the sun's path. This dynamic adjustment significantly improves energy harvesting efficiency compared to static systems.

In addition to solar tracking, the project incorporates energy management features, such as real-time voltage monitoring displayed on an LCD screen. The system also controls LED indicators based on voltage thresholds, providing a clear visual representation of the energy levels being generated.

A key safety feature of the system is the integration of an anemometer to monitor wind speed conditions. If wind speeds exceed a certain threshold, the system can take protective actions such as repositioning the panel to a safe angle or stopping the tracking motor to prevent potential damage from strong winds. This combination of solar tracking, energy monitoring, and wind condition checking ensures optimal performance, safety, and efficiency in solar energy systems.

Chapter 2

Literature Review

Project Background

The growing demand for sustainable and renewable energy sources has made solar energy one of the most promising alternatives to traditional fossil fuels. Solar power systems harness the energy from sunlight through photovoltaic (PV) panels, which convert sunlight directly into electricity. However, the efficiency of these systems is often compromised by factors such as the fixed orientation of the panels. To enhance the power generation from solar systems, solar tracking systems have been developed to adjust the orientation of the solar panels based on the sun's movement throughout the day. Solar tracking systems can be classified into single-axis and dual-axis types, with dual-axis systems offering higher efficiency by tracking both the azimuth and altitude angles of the sun. However, dual-axis systems are more complex and expensive, making single-axis trackers a more viable solution for many applications.

Another crucial aspect of solar power systems is energy management, particularly in hybrid renewable energy systems that combine solar power with other sources such as wind energy. Efficient management of generated energy ensures that the energy production is maximized, stored effectively, and distributed in the most optimal manner. Additionally, integrating real-time weather data such as wind speed using an anemometer can further improve the energy management strategy, particularly in hybrid systems.

This project aims to integrate solar tracking, energy management, and wind speed monitoring using an anemometer to optimize the performance of solar power systems. The system will use a single-axis solar tracker that adjusts the panel’s position based on sunlight intensity detected by Light Dependent Resistors (LDRs). A microcontroller (ATMega 328P) will control the tracker and integrate energy management algorithms to maximize energy production. Additionally, an anemometer will be used to monitor wind speed, which could affect energy production from hybrid systems involving wind turbines.

Previous Work

The use of solar tracking systems has been extensively studied and implemented in various forms. Zhang and Wang (2016) proposed a maximum power point tracking (MPPT) algorithm for solar panels, which is vital for ensuring that the solar panel operates at its optimal voltage and current. Their research focused on improving solar panel efficiency by dynamically adjusting the panel’s operating conditions based on real-time solar radiation. Similarly, Belkaid et al. (2016) investigated an optimum control strategy for solar power systems, highlighting how adaptive control methods could be used to improve solar panel tracking performance, especially when combined with battery storage systems.

In a study by Veerappan et al. (2014), the authors explored the integration of solar power with other renewable energy sources, such as wind energy, in a hybrid energy generation system. Their work demonstrated the importance of integrating energy management systems to optimize the generation and storage of power. This highlights the growing trend of combining solar tracking with energy management systems to ensure efficient energy harvesting in renewable energy applications.

Mousazadeh et al. (2009) conducted a comprehensive review of sun tracking methods, detailing both single-axis and dual-axis tracking techniques. The review concluded that, while dual-axis trackers provide higher energy efficiency, they are often too complex and expensive for widespread use in small- to medium-scale applications. Single-axis tracking systems, on the other hand, offer a more cost-effective solution while still improving solar energy capture.

Energy management plays a crucial role in optimizing the utilization of solar energy and integrating renewable sources with the existing grid. A key challenge is efficiently storing and dispatching the generated energy to ensure a stable power supply. Al-Mashaqbeh et al. (2017) presented an energy management system for hybrid power systems, integrating solar and wind energy. Their study used model predictive control (MPC) to optimize the dispatch of energy from renewable sources while managing the storage systems. The research showed that integrating energy management strategies helped to balance the supply and demand of power, ensuring that renewable energy sources were used efficiently.

A similar approach was taken by Rueda et al. (2019), who proposed an advanced energy management strategy for hybrid systems that included solar power, wind power, and storage systems. Their energy management framework used real-time weather data to forecast energy production, which allowed for more efficient storage and utilization of energy. The study emphasized the importance of using real-time data, including wind speed and solar radiation, to improve the accuracy of energy management algorithms and optimize overall energy production.

In the context of solar and wind hybrid systems, Liu et al. (2014) explored the energy optimization in hybrid systems by proposing a multi-objective optimization model. Their system considered both energy production and storage, ensuring that energy was effectively managed and distributed. This approach is particularly useful in locations where solar and wind resources are variable. The study showed that integrating real-time data from both solar panels and wind turbines can significantly improve the performance of hybrid systems.

While solar power systems are well-documented in the literature, the integration of wind data into hybrid systems using an anemometer has been explored in some recent studies. Anemometers are used to measure wind speed, which is a critical factor in determining the energy potential of wind turbines. As part of an integrated energy management strategy, wind speed monitoring can help predict the performance of wind turbines and adjust the energy storage and distribution accordingly.

A study by Mohamed et al. (2016) presented a hybrid energy system that combined solar and wind energy, where an anemometer was used to monitor wind speed. Their system adjusted energy production and storage strategies based on both solar radiation and wind speed, ensuring that the hybrid system performed optimally. The integration of an anemometer with solar tracking allowed for real-time decision-making in energy management, improving the overall efficiency and reliability of the system.

Similarly, Tuncer et al. (2018) integrated an anemometer with a solar tracking system to create a weather-aware energy management system for off-grid applications. The anemometer provided real-time wind speed data, which was used to adjust the energy output of a hybrid wind-solar system. Their work showed that integrating wind and solar power with real-time monitoring could help optimize energy generation and storage, providing a more reliable energy source for remote areas.

Comparative Work

In comparing various types of renewable energy systems, numerous studies have highlighted the importance of combining solar tracking with energy management and weather monitoring for optimal performance. While solar tracking increases energy yield by adjusting panel orientation, integrating real-time data from an anemometer and energy management systems ensures that hybrid systems remain efficient under varying conditions.

In particular, a study by Safdar et al. (2016) compared the performance of hybrid solar-wind systems with and without an energy management system. The results showed that energy management significantly enhanced the system's efficiency, reducing energy losses and improving energy storage. Adding wind speed data via an anemometer further optimized the energy management strategy, ensuring that both solar and wind energy resources were utilized effectively.

Another comparative study by Cheng et al. (2015) explored the integration of solar tracking and energy management systems in hybrid renewable energy systems. Their work concluded that incorporating both solar and wind power systems with energy management protocols led to a more efficient use of renewable resources, especially when paired with weather monitoring devices such as anemometers. The integration of these technologies led to a more reliable and cost-effective renewable energy solution.

Chapter 3

Objectives

The primary objectives of this project are:

1. **Design and Implement a Solar Tracking System**: Build a system that can automatically adjust a solar panel’s position based on the intensity of sunlight detected by LDR sensors.
2. **Monitor and Display Energy Levels**: Integrate an LCD to display voltage readings in real-time for energy monitoring.
3. **Energy Management and Optimization**: Control the lighting of LEDs based on specific voltage thresholds, ensuring an efficient energy flow and alert system.
4. **Automatic Solar Panel Control**: Stop the solar panel for a fixed time if specific conditions (e.g., exceeding a certain threshold in the values array) are met.

Chapter 4

System Overview

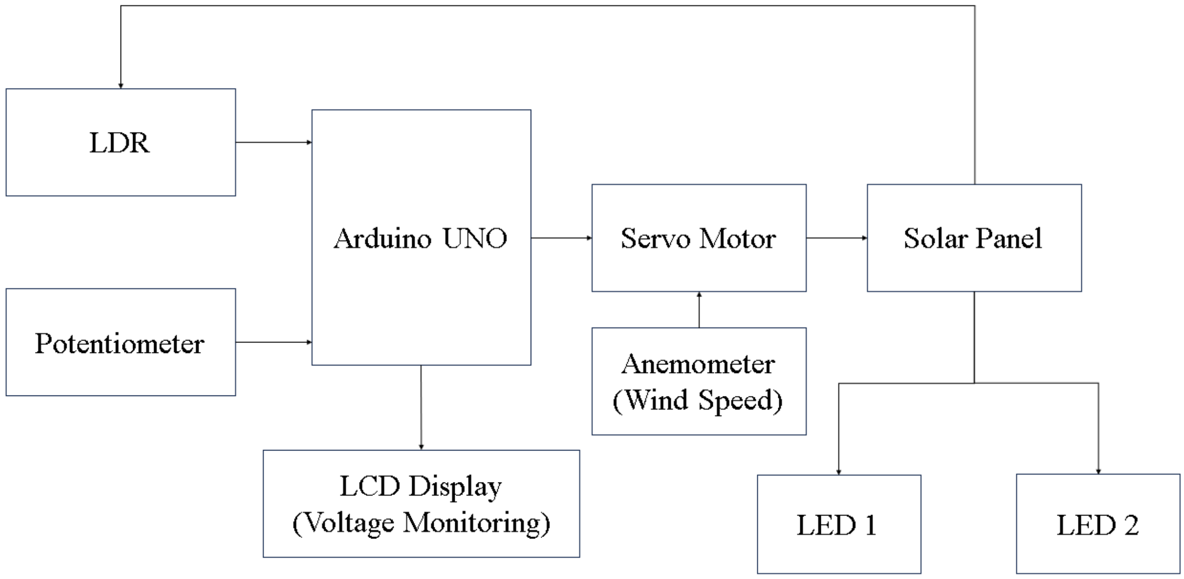


Fig (4.1) Block Diagram

Chapter 5

Methodology

5.1 Design and Implementation of the Solar Tracking System Using Arduino

1. **Hardware Setup**:
    - **Component Arrangement**: A breadboard was used as the main platform to assemble and connect all the necessary components, including light-dependent resistors (LDRs), the microcontroller (Arduino board), a servo motor, an LCD display, and other essential elements such as resistors and jumper wires.
    - **LDR Configuration**: Two LDRs were strategically positioned to act as light sensors for detecting the intensity of sunlight. The LDRs provided input to the Arduino, enabling it to determine the direction of maximum sunlight.
    - **Servo Motor Integration**: A servo motor was attached to the solar panel to control its orientation. The motor's angle was adjusted based on the LDR readings, ensuring the panel faced the direction of maximum sunlight.
2. **Programming and Logic**:
    - **Arduino IDE**: The Arduino IDE was used to write, compile, and upload the control code to the microcontroller. The code utilized libraries like the Servo library to manage the servo motor and the LiquidCrystal_I2C library to display real-time voltage readings on the LCD.
    - **Solar Tracking Logic**: The Arduino continuously read the analog values from the LDRs. Based on the difference in readings, the servo motor adjusted the solar panel's angle to maximize light exposure. If the difference between the LDR readings was within a predefined error margin, no movement was made; otherwise, the panel was rotated accordingly.
    - **Energy Management**: A potentiometer was used to simulate variable voltage conditions. The voltage was read by the Arduino and displayed on the LCD screen. Additionally, LEDs were controlled based on the voltage level, providing visual feedback on energy levels.
    - **Safety and Efficiency**: Resistors were added to ensure the safe operation of LEDs and sensors, preventing potential damage from excess current.
3. **Data Logging and System Response**:
    - The system periodically checked the values in an array representing simulated solar intensity changes. If any value exceeded a threshold, the servo motor paused for a set duration to simulate a scenario where the motor should stop.
    - The Arduino code logged relevant data, such as current values and system states, providing insights into the system's response under varying conditions.

5.2. Simulation of the Solar PV Array Using Simulink

1. **Model Creation**:
    - **Simulink Environment**: Simulink, a graphical simulation environment, was used to model the solar PV array. The components of the PV system, such as solar panels and load connections, were configured using Simulink's library blocks.
    - **Input Parameters**: Realistic parameters, including irradiance and temperature variations, were set to simulate real-world conditions. The PV array model generated outputs like power, voltage, and current under different environmental conditions.
2. **Simulation Execution**:
    - **Running the Simulation**: The simulation was executed to observe the behavior of the solar PV array over time. Various scenarios were simulated to analyze how changes in sunlight intensity and other factors impacted energy generation.
    - **Data Collection**: Key output data, such as power generation and system efficiency, were recorded. These results were later compared with the real-time performance of the Arduino-based solar tracking system.
3. **Analysis and Comparison**:
    - The results from the Simulink simulation provided a theoretical benchmark for the solar PV array's performance. This data was used to validate the effectiveness of the Arduino-based tracking system. Any discrepancies between the simulated and real-time results were analyzed to improve system accuracy and efficiency.

Chapter 6

Tools & Systems

The project utilized various hardware and software tools for successful implementation, ensuring both efficiency and precision in tracking solar energy and simulating solar power generation.

Software Tools

1. **Arduino IDE**: The Arduino Integrated Development Environment (IDE) played a crucial role in the project by providing a platform for writing, compiling, and uploading code to the microcontroller (Arduino board). It enabled programming in C/C++ and facilitated seamless communication between the computer and the Arduino, allowing the microcontroller to execute the desired tasks efficiently.

2. **LiquidCrystal_I2C Library**: This specialized software library was essential for interacting with an LCD display using the I2C interface, a simplified two-wire communication protocol. The use of this library greatly reduced the number of pins needed on the Arduino, optimizing the project's design. It enabled real-time voltage readings to be displayed on the LCD, providing clear feedback on energy management.

3. **Servo Library**: To control the movement of the servo motor, which was responsible for adjusting the solar panel's orientation, the Servo Library was utilized. It provided an intuitive method for managing the servo's angle, allowing the solar panel to rotate smoothly based on input from the light sensors (LDRs). This capability was vital for tracking the sun effectively, maximizing energy absorption.

4. **Simulink**: Simulink, a block diagram-based simulation environment, was used to model and simulate the solar photovoltaic (PV) array. This provided a detailed analysis of the solar system's performance, helping to predict energy output under various conditions. Simulink's simulation results were critical for verifying and optimizing the system's efficiency, supporting informed design decisions.

Hardware Tools

1. **Breadboard**: The breadboard was an indispensable tool for quickly assembling and testing circuits. Its reusable design allowed for easy placement of sensors, resistors, and the microcontroller, providing flexibility for making changes and adjustments during the development phase without the need for soldering.

2. **Jumper Wires**: These wires were used extensively to establish temporary electrical connections between components on the breadboard and the microcontroller. They facilitated a robust and adaptable setup, allowing various parts of the system to communicate seamlessly.

3. **Resistors**: Various resistors were incorporated into the circuit to limit the current flowing through specific components. This protection was especially important for sensitive parts like LEDs and sensors, ensuring they operated within safe current limits and enhancing the overall reliability of the system.

Chapter 7

Hardware Components & Design

7.1 Components used

1.Microcontroller (ATmega 328P)

Fig 7.1 Arduino UNO R3 board with DIP ATmega328P

- **Description**: The microcontroller is the brain of the system. It receives inputs from the LDRs, processes the data, and controls the motors responsible for moving the solar panel.
- **Specification**:
    - 8-bit processor.
    - Operating voltage: 5V.
    - Clock speed: 16 MHz.
    - Analog and digital I/O pins.
- **Role**: The microcontroller processes the data from LDRs to determine the sunlight intensity difference and sends control signals to the motors to move the solar panel to the optimal position.

2 .Light Dependent Resistors (LDRs)

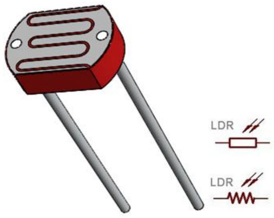


Fig 7.2 Ldr (Light Dependent Resistor)

- **Description**: LDRs are used for detecting light intensity. They change resistance depending on the amount of light falling on them, which is measured to adjust the position of the solar panel.
- **Specification**:
  - Resistance range: 1kΩ to 10MΩ depending on light intensity.
  - Suitable for detecting sunlight direction for solar tracking purposes.
- **Role**: LDRs measure the sunlight intensity and provide feedback to the microcontroller to adjust the solar panel's position.

3.Servo Motor

Fig 7.3 Servo Motor

- **Description**: The motor adjusts the position of the solar panel based on control signals from the microcontroller. Servo motors are preferred due to their precision and ability to maintain torque at high speeds.
- **Specification**:
  - Voltage: 5V to 12V.
  - Torque: 5 kg·cm to 30 kg·cm (depending on size and requirement).
  - Speed: 20-30 RPM.
- **Role**: The motor drives the solar panel to track the sunlight. The servo motor can rotate the panel along a single axis or dual axis depending on the design.

4.LCD Display

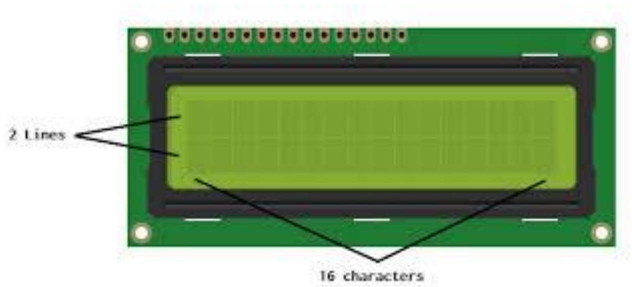


Fig 7.4   Lcd Display

- **Description**: An LCD display is used to show system status, including power generation, motor movement, and feedback from the sensors.
- **Specification**:
    - 16x2 or 20x4 character display.
    - Operating voltage: 5V.
- **Role**: The LCD provides real-time information about the system's performance, such as current solar energy production, wind speed data, and the status of the tracking system.

5.Potentiometer

Fig 7.5 Potentiometer

- **Description**: A potentiometer is a variable resistor that is used to adjust voltage within the energy management system. It is used in this system to set and control reference values such as voltage levels for charging, discharging, or regulating the output of solar power.
- **Specification**:
    - Resistance range: 1kΩ to 10kΩ (common range).
    - Power rating: 0.25W to 1W.
    - Linear or logarithmic taper, depending on application.

- Input voltage: 5V to 12V (depending on the microcontroller and system design).

- **Role**: The potentiometer allows the user to manually control settings such as charging thresholds, system voltage levels, or other power control parameters. It provides the capability to set the target voltage or current and fine-tune the energy management process.

6.LEDs (Light Emitting Diodes)

Fig 7.6 LED’s

- **Description**: LEDs are used as visual indicators in the EMS to show the status of the system. They display important information such as the energy levels, the current operation mode (e.g., charging, discharging), or if the system is functioning within safe limits. Multiple LEDs can be used for different feedback indications.
- **Specification**:
  - Forward voltage: 1.8V to 3.3V (depending on the color of the LED).
  - Current: Typically 10mA to 20mA per LED.
  - Color: Red (for faults), Green (for operational status), Yellow (for intermediate conditions), or Blue (for power generation).
  - Package type: 5mm, 10mm, or SMD (Surface Mount Device) depending on design.
- **Role**: LEDs serve as indicators to provide visual feedback about the solar energy status, battery charging status, and operational modes of the EMS. For instance:

7.2 Circuit Diagram

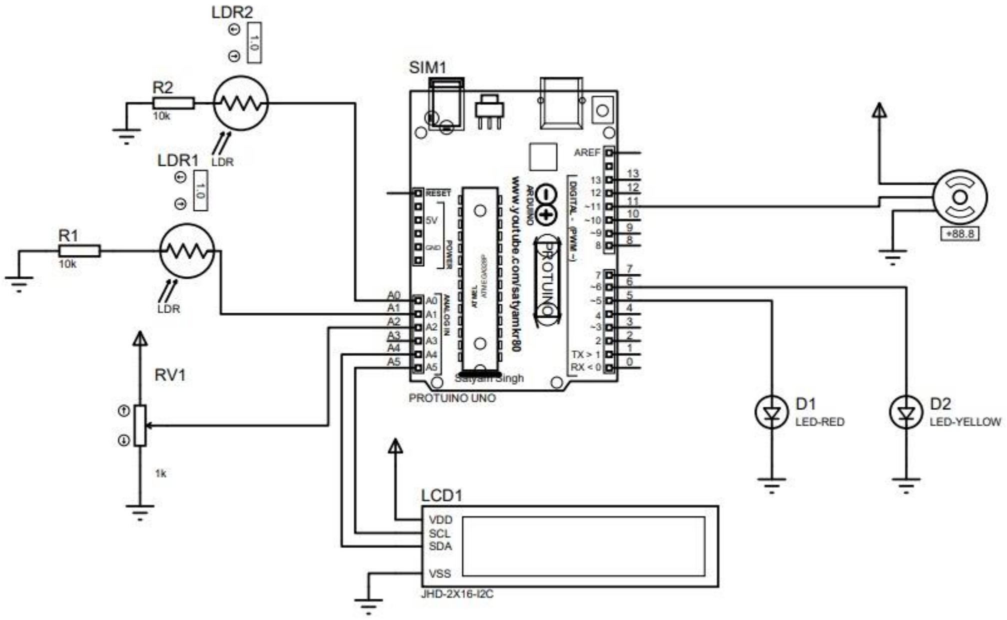


Fig 7.7 Circuit Diagram

Chapter 8

Software System & Design

1. Initialization and Setup:

- GPIO Pin Initialization: The system begins by initializing all required GPIO pins (servo, LDRs, LED pins).
- Serial Communication Setup: Serial communication is initialized for debugging and monitoring purposes.
- LCD Display Configuration: The system sets up the I2C interface for the LCD to display the current voltage readings and status.
- Servo Setup: The servo motor is attached to a specific pin, and its initial position is set.

2. Solar Tracking System:

- LDR Input Monitoring: The code continuously monitors the readings from the LDRs (LDR1 and LDR2).
- Light Intensity Difference Calculation: The system calculates the difference in light intensity between the two LDRs to determine if the solar panel needs adjustment.
- Servo Movement Control: Based on the light intensity difference, the servo adjusts its position to keep the solar panel aligned with the light source.

3. Energy Monitoring:

- Voltage Reading from Potentiometer: The code reads the voltage value from the potentiometer, which represents the system's energy level.
- LCD Feedback: The voltage is displayed on the LCD in real-time to provide user feedback on the energy level of the system.
- LED Status Indicators: The system uses two LEDs to show the current energy status. One LED turns on when the voltage exceeds 4V, and another LED turns on when the voltage is above 3V.

4. Array Management for Servo Control:

- **Array Timer Check: Every 10 seconds, the system checks the next value in the** predefined array (valuesArray).
- Value Comparison: The system compares the current value in the array to a threshold (e.g., 40). If the value exceeds the threshold, the servo is stopped for a specified period (15 seconds) to prevent movement during certain conditions.

5. Servo Stop Logic:

- Stop Condition Check: If the current array value is greater than 40, the system stops the servo motor for a predefined time period (15 seconds).
- Resume Servo Control: After the stop period, the servo resumes its operation and continues adjusting the solar panel position based on LDR inputs.

6. User Feedback via LCD Display:

- Status Messages: The LCD shows real-time status messages such as "Solar Tracking Active", "Servo Stopped", "Voltage Reading: X", etc.
- System Initialization: During startup, the system displays messages like "Initializing...", "System Ready", and the initial voltage reading.

7. System Reset and Energy Management:

- Reset Timer for Servo Movement: Once the servo stops moving, a timer is initiated to wait for the next valid check in the array and solar tracking phase.
- System Security: The system resets itself after the servo completes the tracking movement or when the voltage conditions are no longer met, ensuring the servo's movement is in line with the energy levels.

8.2 Flow Chart

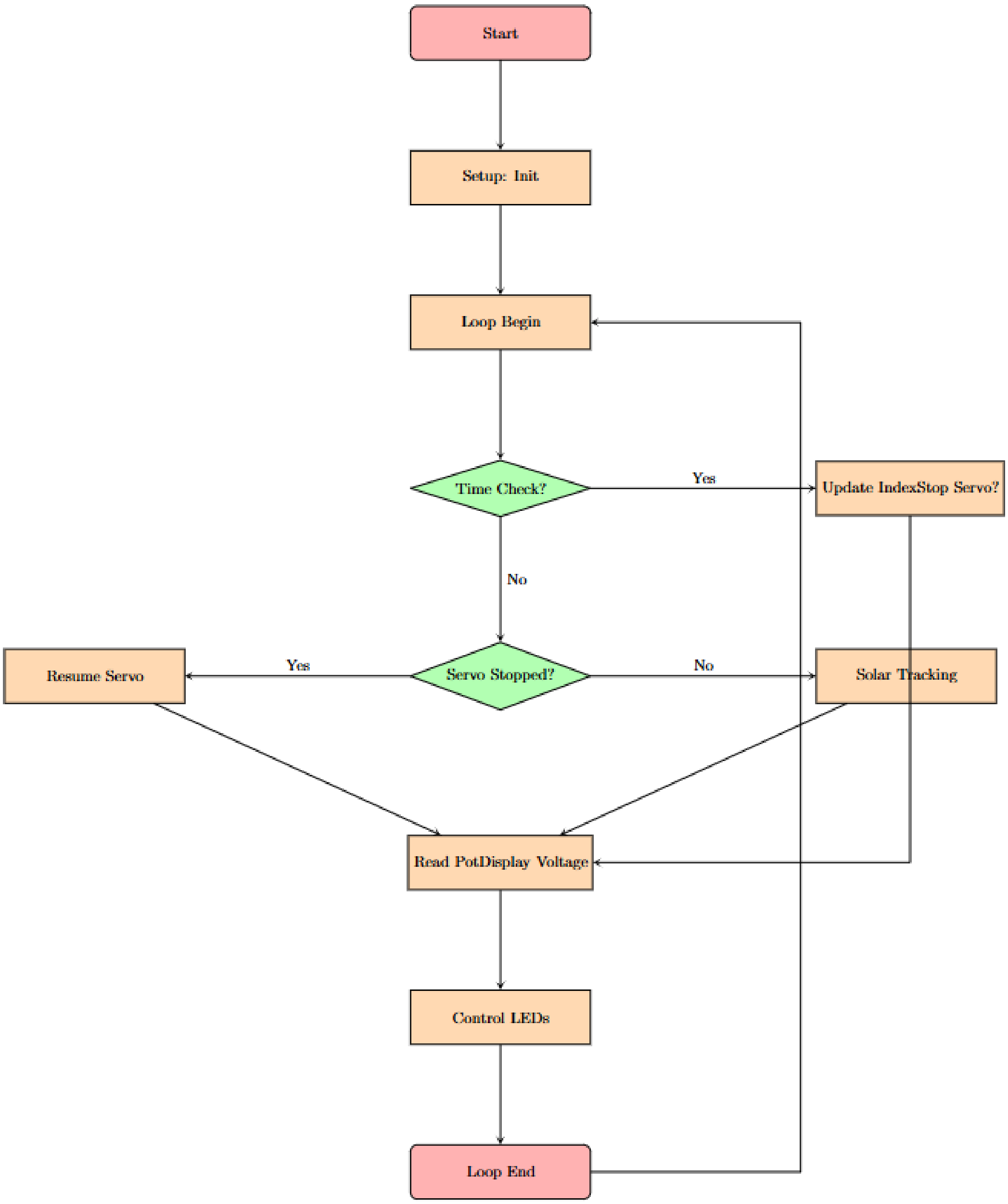


Fig 8.1 Flow Chart

Chapter 9

Result & Analysis

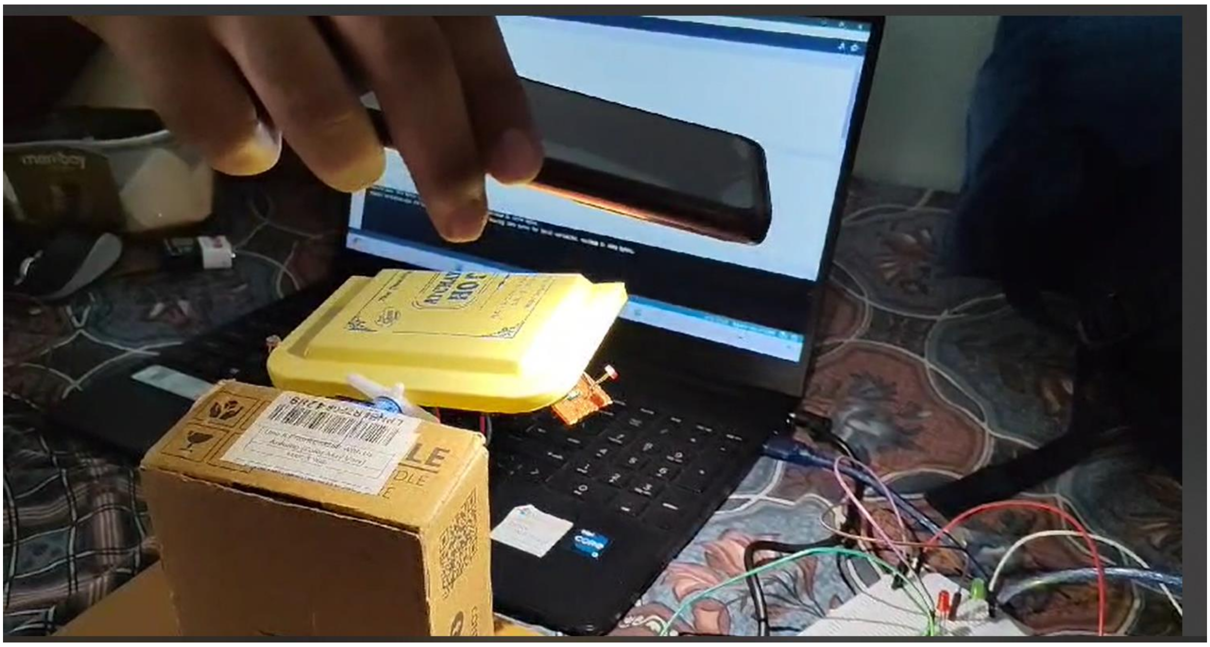


Fig 9.1 Solar Tracking with the help of LDR value

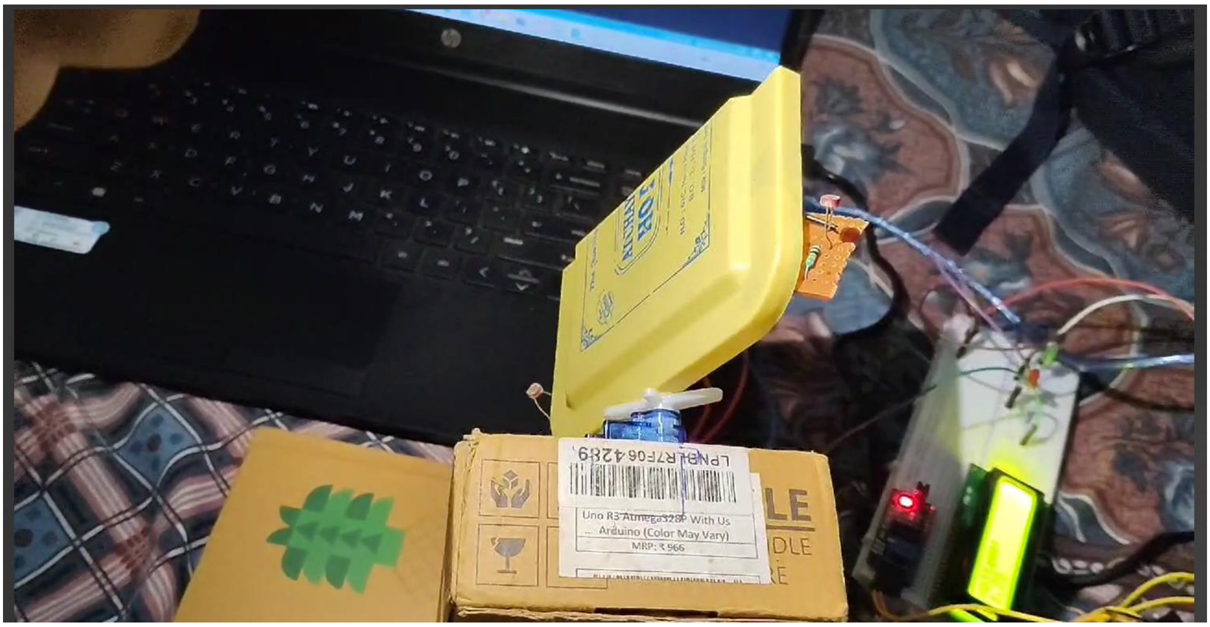


Fig 9.2 Movement of Solar tracker

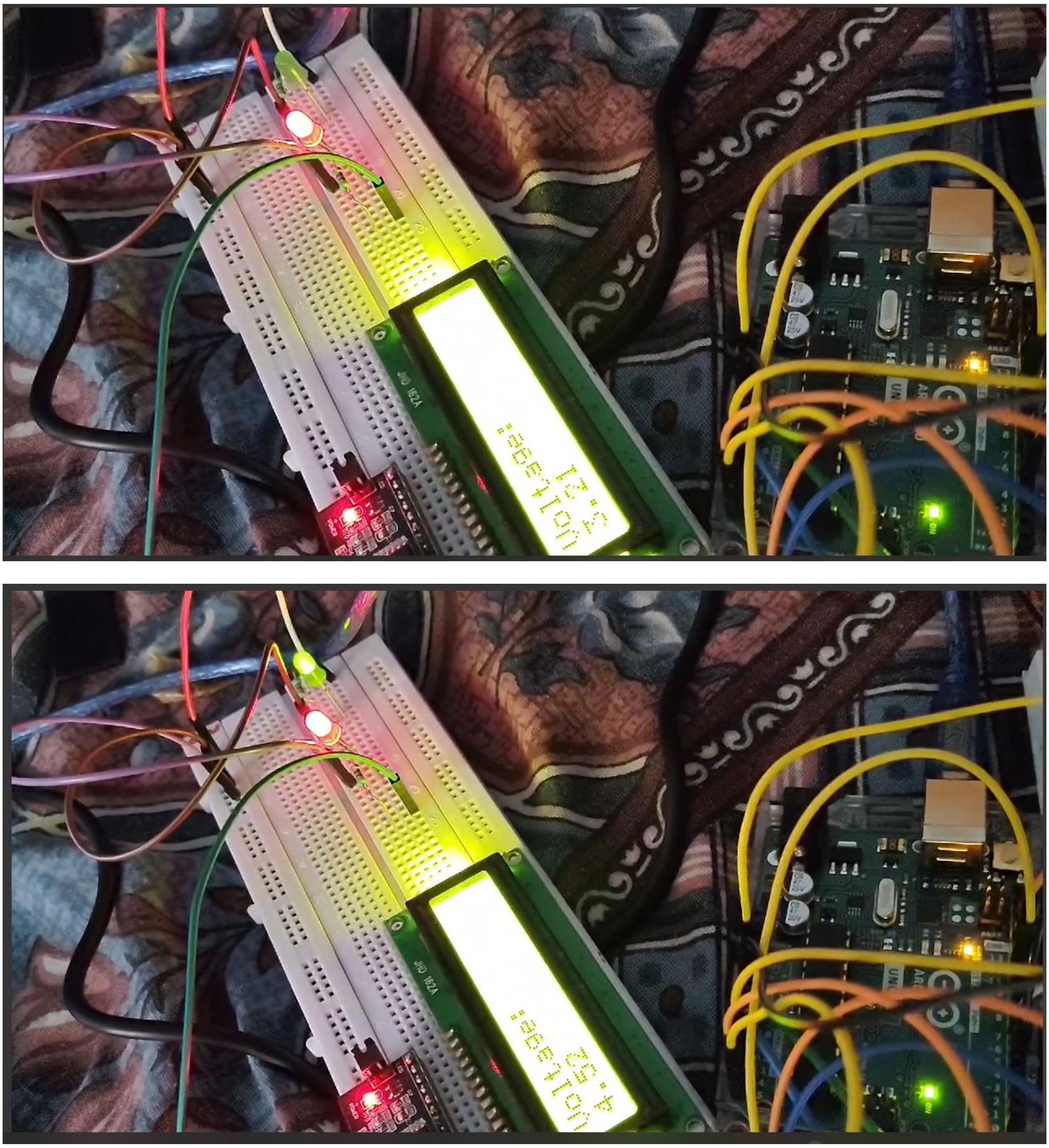
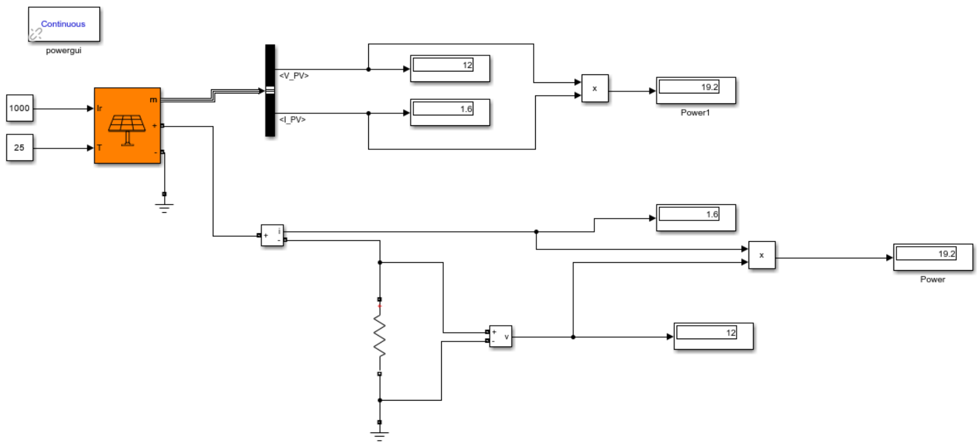


Fig 9.3 Energy Management System



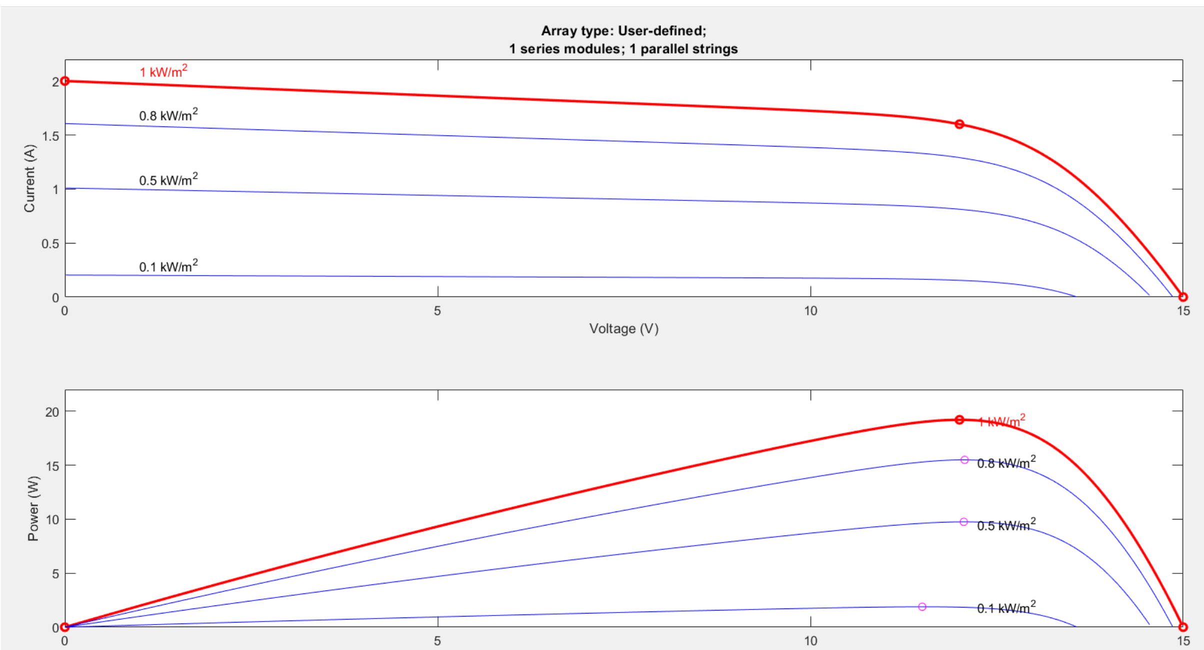


Fig 9.4 Simulink Result of Current vs Voltage, Power vs voltage

The solar tracking system successfully adjusted the panel's position based on real-time light intensity readings. The servo motor responded accurately to the changes in light direction, and the system was able to stop and resume motor operations based on threshold values.

The energy monitoring system effectively displayed the voltage on the LCD, with the LEDs providing immediate feedback for different voltage ranges. The voltage thresholds for LED activation were set accurately, demonstrating the system's capability to manage energy levels efficiently.

Chapter 9

Conclusion

This project demonstrated the effectiveness of a solar tracking system integrated with energy monitoring features. By automatically adjusting the solar panel’s position based on the sun’s direction, the system significantly improved energy capture compared to static panels. The real-time feedback provided by the LCD display and LEDs allowed for easy monitoring of the system's performance and energy levels, enabling better management of energy usage. The inclusion of anemometer condition monitoring ensured the safety of the panels by responding to high wind speeds, preventing potential damage. This combination of solar tracking, energy management, and environmental monitoring provided an efficient, automated solution for maximizing solar energy production.

The applications of this system are wide-ranging, from residential and commercial solar installations to solar farms and off-grid systems. In these settings, it optimizes energy output while reducing maintenance needs, thanks to its ability to automatically track sunlight and monitor wind conditions. The system's real-time energy monitoring is crucial for energy management in both large and small installations. Additionally, future improvements could include adding a second axis of rotation for even greater tracking precision or incorporating a larger array of solar panels to enhance energy harvesting capabilities. This makes it an ideal solution for renewable energy applications and research in optimizing solar energy systems.

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