EMPOWERING SMART GRID FOR THE FUTURE OF URBAN CENTERS

Capstone Project

AY 2021-25

GITAM (Deemed-to-be) University

Major Project
Project ID: P1

Department of Electrical Electronics and Communication Engineering

Project Team:

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Objective and Goals

Objective

1. **To advance** from simulation to hardware implementation, renewable energy sources like solar and wind turbines integrated with battery storage for a sustainable power supply.
2. **To integrate** IoT devices (ESP32, Arduino Mega, and sensors) for real-time monitoring, fault detection, control, and two-way data exchange to enhance grid reliability.
3. **To reduce** fuel dependency and carbon footprints by leveraging renewable energy and IoT technologies in urban smart grids.

Goals

Main Goals

1. Enhance Grid Scalability and Flexibility
2. Promote Sustainable Development
3. Improve Grid Reliability and Efficiency
4. Empower Real-Time Monitoring and Control

Additional Goals

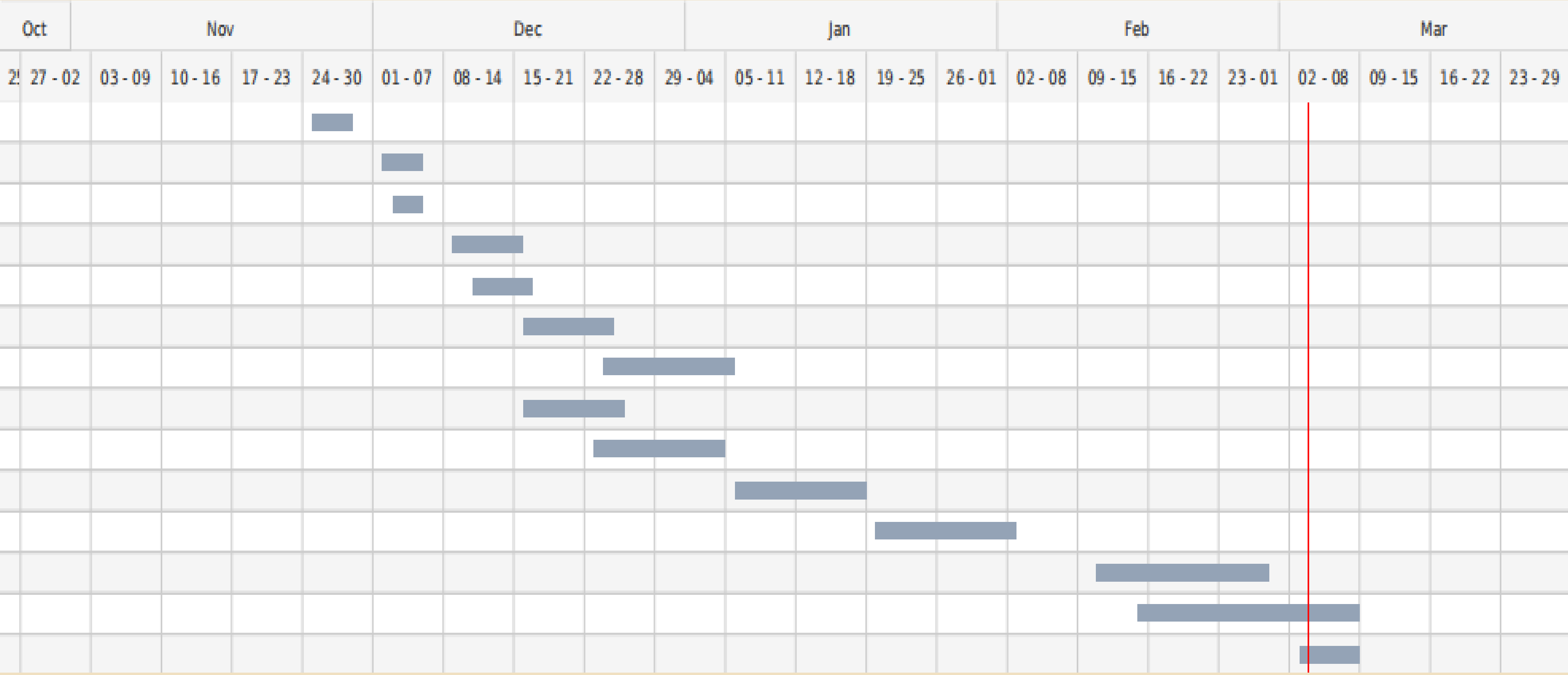
1. Learn about circuit design, Wind turbine design, and implementation
2. Learn how to effectively integrate and manage IoT devices within the smart grid to enhance monitoring, control, and efficiency.

Project Plan

Gant Chart - Milestones and Activities

Resources : https://www.officetimeline.com/gantt-chart/how-to-make/excel & https://www.teamgantt.com/

ID	Title	Start Time	End Time
1	Wind turbine type selection	11/25/2024	11/29/2024
2	Abstract	12/02/2024	12/06/2024
3	Permission and wind speed t	12/03/2024	12/06/2024
4	Making the circuit diagram	12/09/2024	12/16/2024
5	Theoretical calculation and t	12/11/2024	12/17/2024
6	designing the wind turbine	12/16/2024	12/25/2024
7	Purchasing components and	12/24/2024	01/06/2025
8	Component procurement an	12/16/2024	12/26/2024
9	Circuits design	12/23/2024	01/05/2025
10	Components purchases and	01/06/2025	01/19/2025
11	Wind turbine testing and re	01/20/2025	02/03/2025
12	Circuit assembling	02/11/2025	02/28/2025
13	Coding	02/15/2025	03/09/2025
14	Testing	03/03/2025	03/09/2025

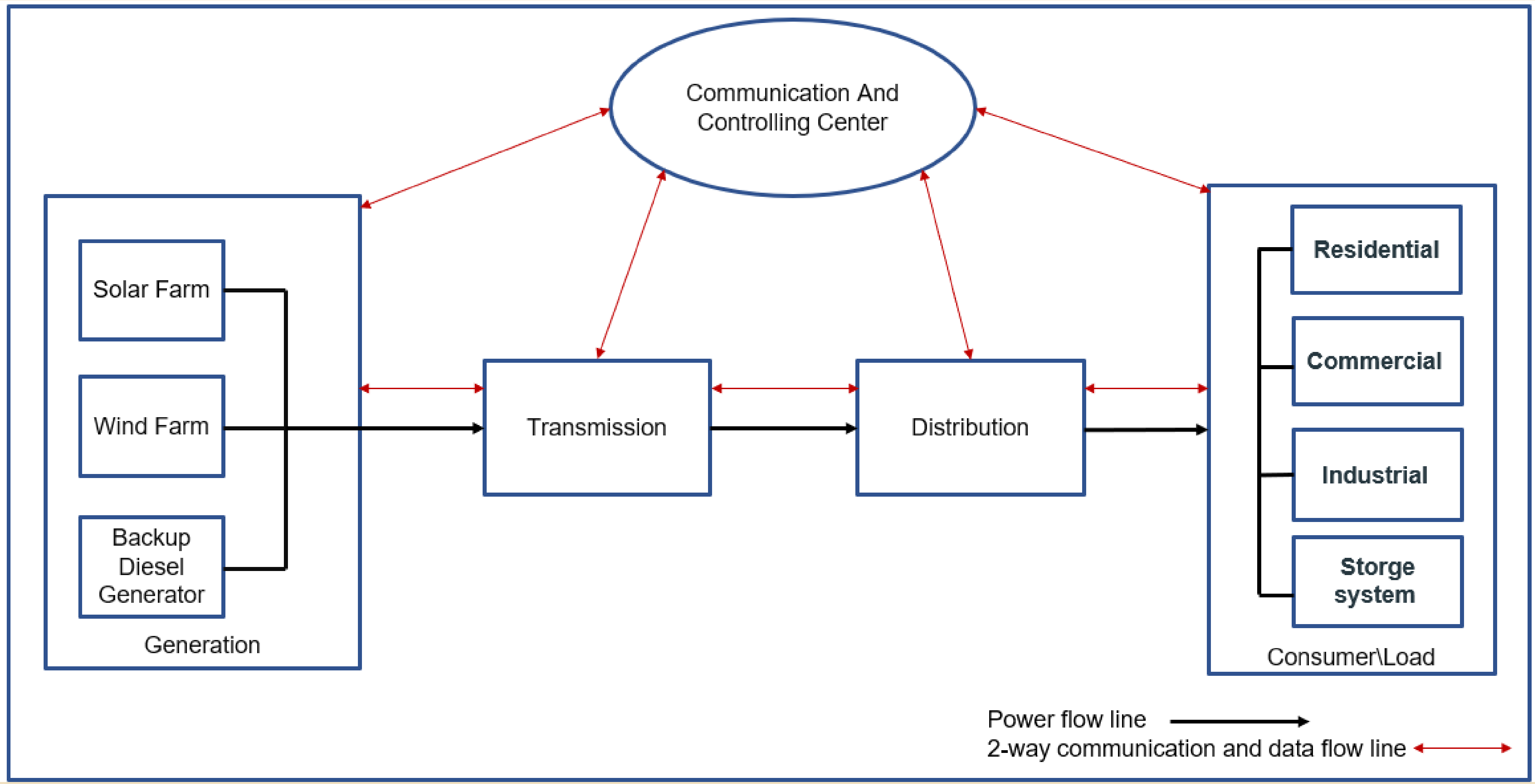


Literature Survey

Key Publications

S.No	Article	Authors	Published on	Description
1	Investigating the use of MATLAB/SIMULIK and LabVIEW in Microgrid Modelling and Simulation	Mahmoud Laban	25 Aug 2017	He has modeled and simulated a microgrid using MATLAB/Simulink, but he did not integrate the IoT devices that enable two-way communications.
2	Recent advancement in smart grid technology: Future prospects	Osama Majeed Butt, Muhammad Zulqarnain, Tallal Majeed Butt	7 July 2020	Future research in smart grids focuses on improving forecasting, optimizing power flow, enhancing communication, integrating microgrids, managing energy demand, and automation.
3	Solar power integration in Urban areas: A review of design innovations and efficiency enhancements	Emmanuel Augustine Etukudoh, Zamathula Queen Sikhakhane Nwokediegwu, Aniekan Akpan Umoh, Kenneth Ifeanyi Ibekwe, Valentine Ikenna Ilojianya, Adedayo Adefemi	16 Jan 2024	Integrating IoT devices into the smart grid is a future trend, including smart city technologies to optimize solar energy capture and grid reliability in urban environments.
4	Modeling and Control for Smart Grid Integration of Solar/Wind Energy Conversion System	Emad Natsheh, Alhussein Albarbar, Javad Yazdani	______________	Novel model of a smart grid-connected PV/WT hybrid system incorporating photovoltaic arrays, wind turbines, and control components, utilizing the P&O algorithm for MPPT.

Previous Architecture



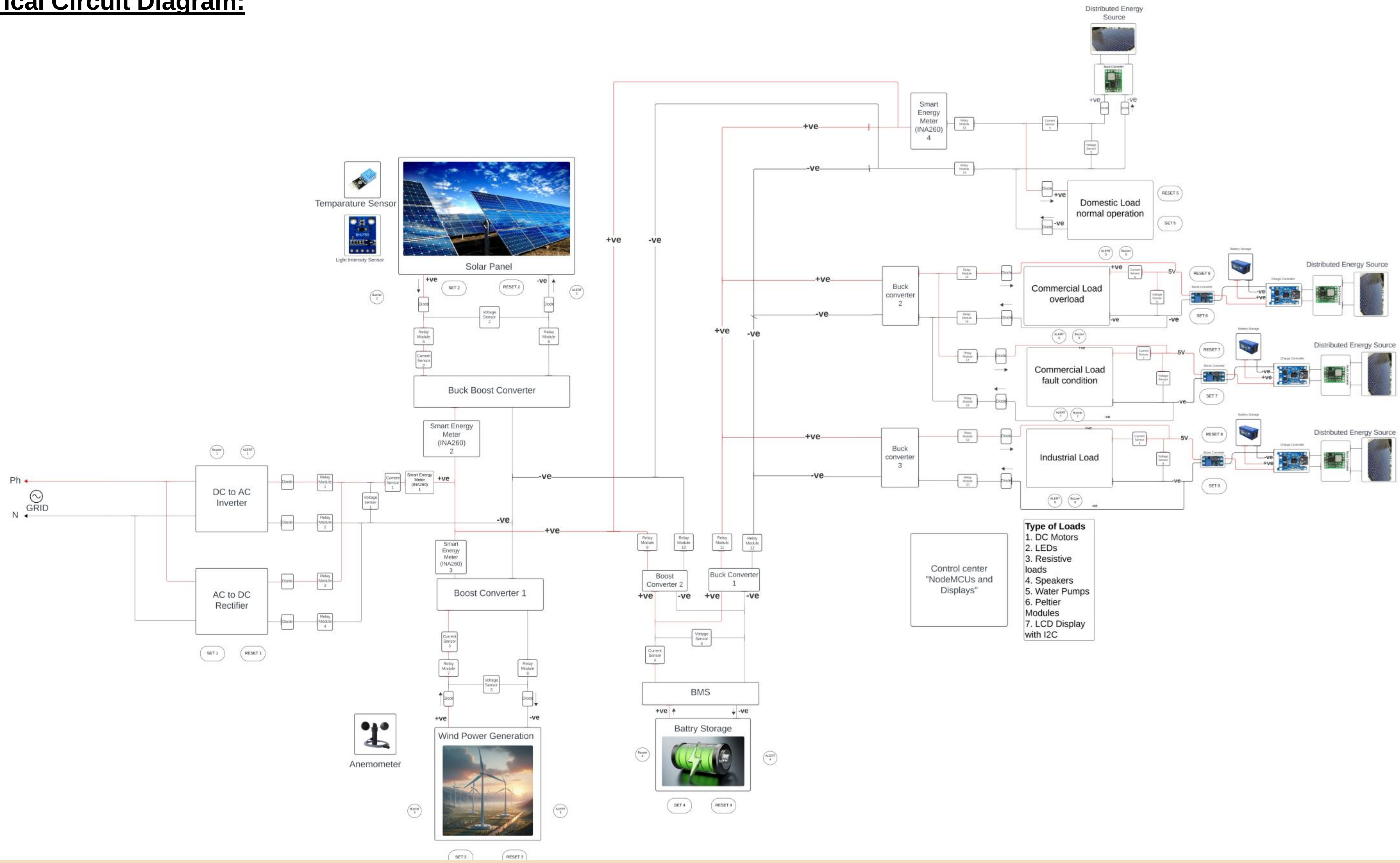
List Of the Used Components:

NO	Name	Description	Quantity
1	Relays	5V	20
2	LCD Display With I2C	20*4	3
3	Push Button	5v	16
4	Current Sensor	ACS712 - 30A	8
5	Voltage Sensor	0-25V	8
6	Power Sensor	INA 260	4
7	Buzzer	5v	8
8	Diodes	10A	18
9	Led	5V	8
10	Light Sensor	BH1750	1
11	Temperature Sensor	DHT11	1
12	Arduino	Mega	1
13	ESP 32	Wi-Fi - Bluetooth MC	1
14	Logical Level Converter	TXS0108E	1
15	Jumper Wires	-	200

NO	Name	Description	Quantity
16	Solar Panel	50W	1
17	Inverter	200W	1
18	Rectifier	60W	1
19	Battery	12.8V-12Ah	1
20	Mini Solar Panel	10W	2
21	Micro Solar Panel	3.5W	3
22	Buck Converter	LM2596	4
23	Buck Converter	Mini 360	4
24	Boost Converter	MT308	3
25	Small Battery	3.8V- 2000mA	3
26	Charging Module	5V	3
27	Buck Converter	XL4005	1
28	Boost Converter	400W-15A	1
29	Hybrid Buck Boost Converter	LTC3780	1
30	DC Motor	5V	3
31	Led	8V	3
32	Wind Turbine	50W	1
33	Anemometer	GM816	1

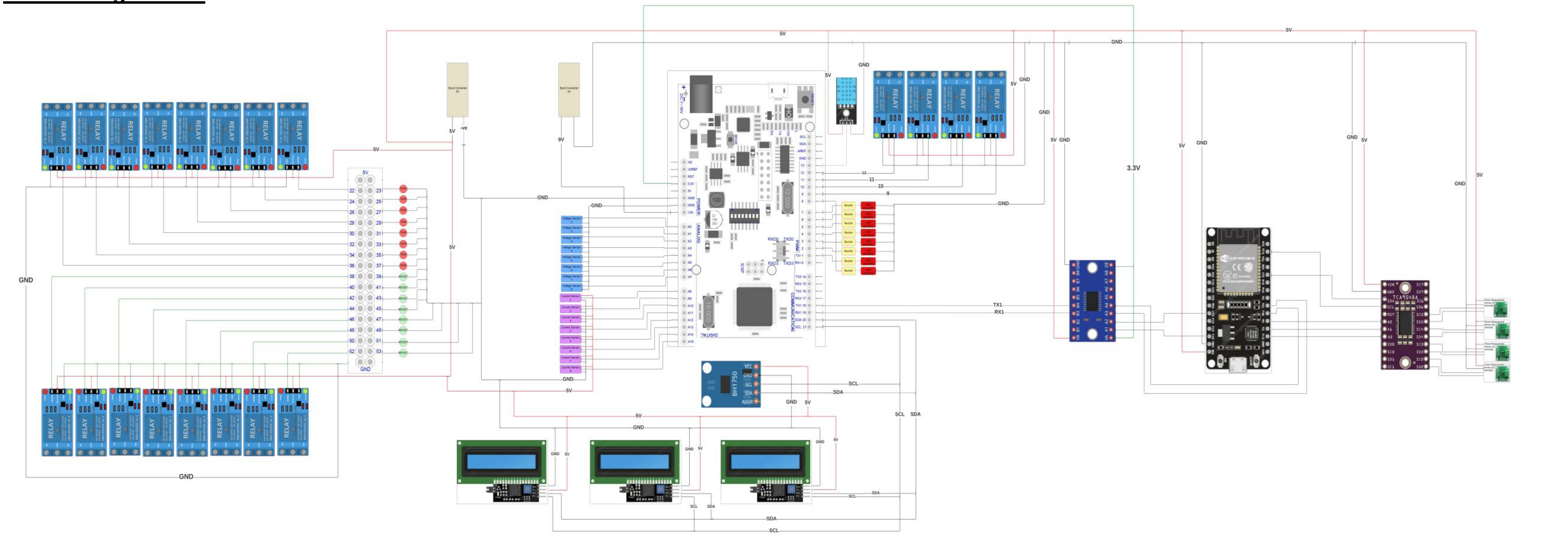
Architecture

Electrical Circuit Diagram:

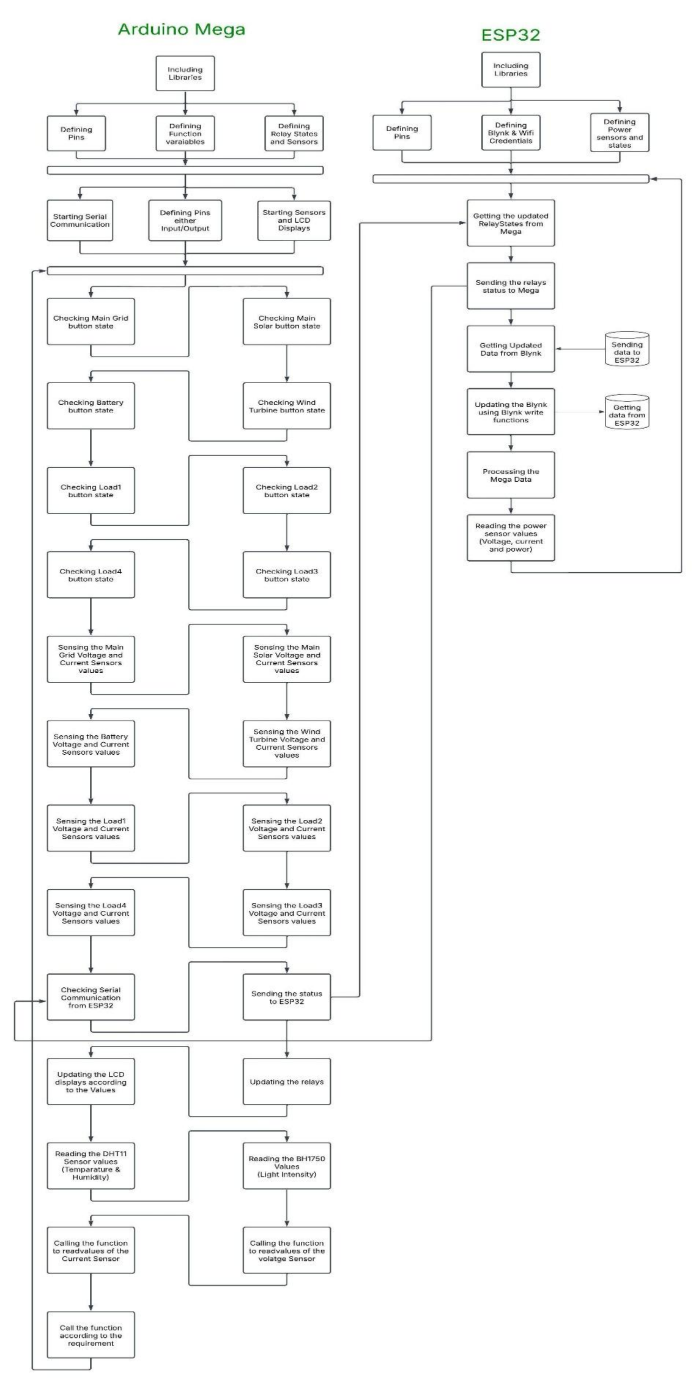


Architecture

Controlling Circuit

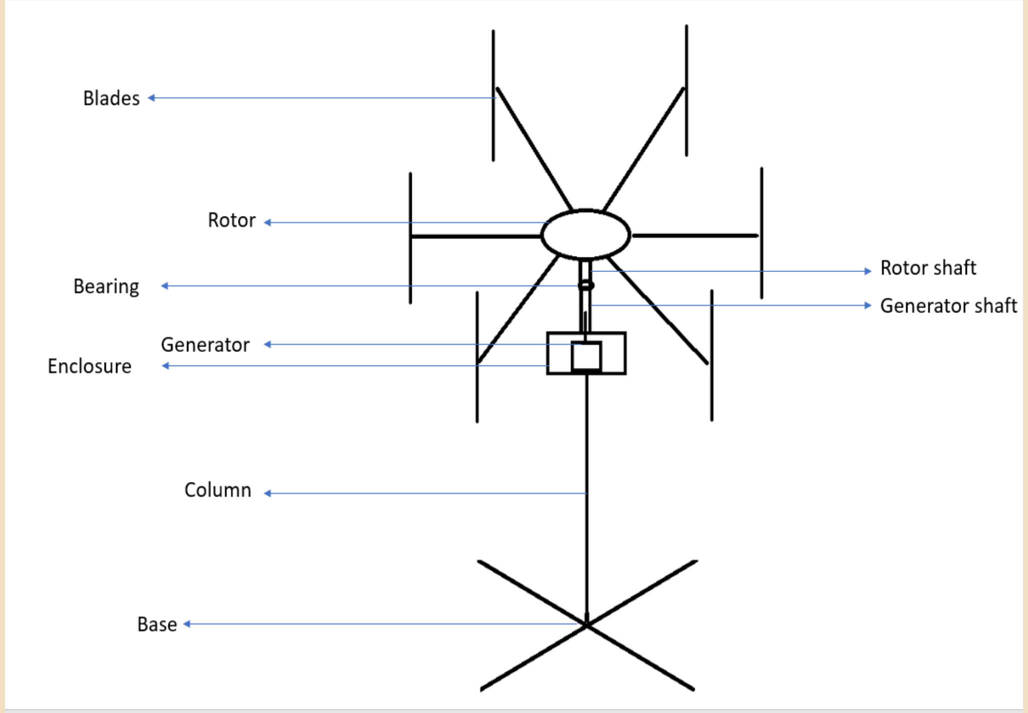


- **Code flow Chart**



Implementation

- **Wind Turbine Implementation:**
- **Wind Turbine Specifications**
  - **Type:** Vertical Axis Wind Turbine (VAWT) – H Rotor
  - **Main Supporting Column:**
    - **Diameter:** 60 mm
    - **Length:** 1.2 m
  - **Rotor Shaft:**
    - **Diameter:** 25 mm
    - **Length:** 30 cm
  - **Rotor Dimensions:**
    - **Rotor Diameter:** 80 cm
  - **Blades:**
    - **Number of Blades:** 6
    - **Height:** 60 cm
    - **Semi-circle Area (per blade):** ≈91.1 cm^2
- **Mechanical Components**
  - **Base:** Metal (for stability & support)
  - **Rotor Shaft:** Seamless pipe (Ø25mm, L=30cm)
  - **Rotor Bars:** Aluminum (structural support)
  - **Rotor Blades:** PVC (6 blades, H=60cm, W=6-inch)
  - **Bearings:** 2 (friction reduction & smooth rotation)
  - **Gears:** 16T to 98T (torque & speed adjustment)
- **Electrical Components**
  - **Generator:** 50W DC Motor (1500 RPM)
  - **Boost Converters:** Voltage step-up for system compatibility
- **Integration & Testing**
  - **Rotor assembly completed & tested for stability**
  - **Load testing to measure power generation efficiency**
  - **Voltage regulation ensured with boost converters**



Wind turbine Block Diagram:

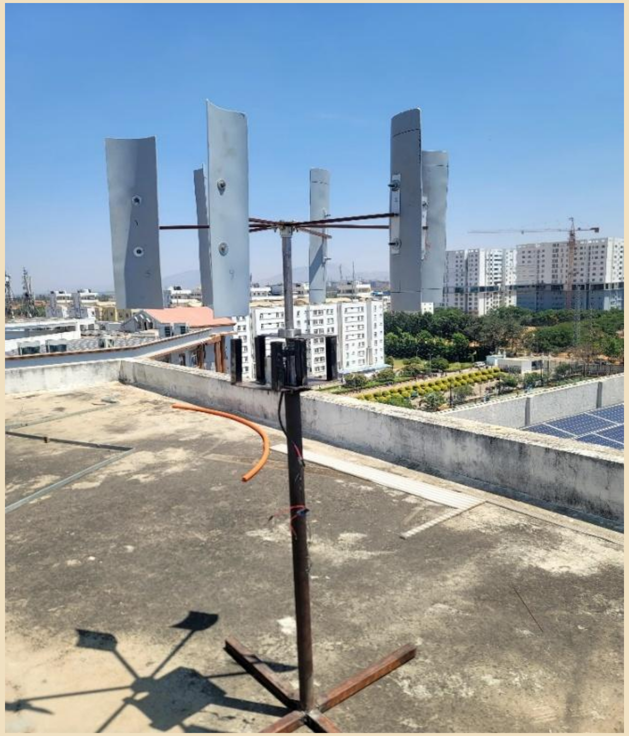
Fusion 360 Design

Implementation

Turbine’s Blade

Top View of the Gear Box and Bearing

Top View of the Gear Box and Bearing



Full View of the Turbine

Implementation

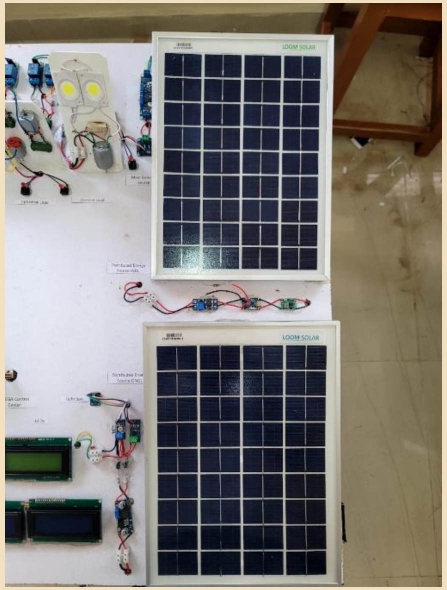
- **Smart Grid System Implementation**
- **Wiring & Hardware Assembly**
- **Two-layered wiring system:**
  - **Upper Layer - Electrical Circuit Wiring** (Power generation, storage & distribution)
  - **Lower Layer - Control Circuit Wiring** (Automation & monitoring via microcontrollers & sensors)
- **Electrical Circuit Wiring - Key Components**
- **Main Power Sources:**
  - 50W Solar Panel
  - 50W Wind Turbine
  - 200W Inverter
  - 60W Rectifier
  - 12.8V / 12Ah Battery
- **Bus System:**
  - Bidirectional 12V electrical bus.
- **Distributed energy sources in load side:**
  - On-Grid Load (10W)
  - Industrial load (10W)
  - Fault Detection Loads (Overvoltage & Short Circuit 10W)

- **Voltage Regulation & Load Distribution**
- **Voltage Regulation:**
  - Boost Converter (12V → 13.6V) for battery charging
  - Buck Converters for stable 12V output
  - Additional converters for industrial & short-circuit loads
- **Load Distribution:**
  - On-Grid Load (10W)
  - Industrial load (10W)
  - Fault Detection Loads (Overvoltage & Short Circuit 10W)
- **Control Circuit Wiring - Components**
- **Microcontrollers:**
  - Arduino Mega (System Control)
  - ESP32 (Remote Monitoring)
- **Sensors:**
  - Voltage, Current, and Power Sensors
- **Relays:**
  - Automated power source switching
- **LCD Displays & Communication Modules:**
  - Live status updates

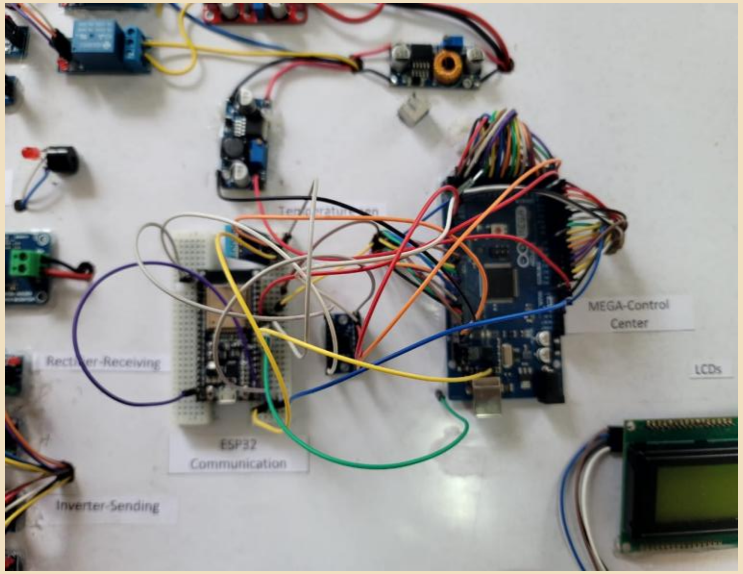
Implementation

Entire setup

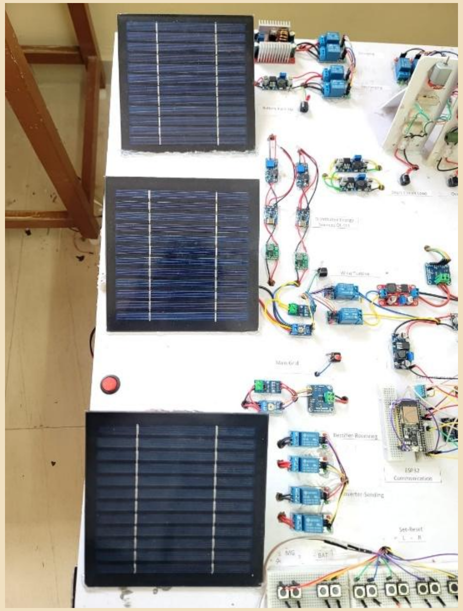
Implementation



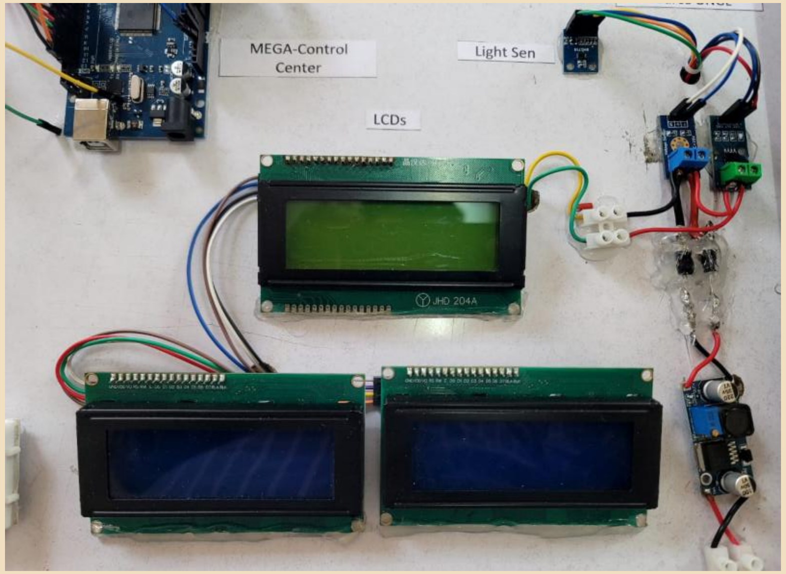
Distributed Energy Sources (Industrial Load and On-Grid Load)



Control Center

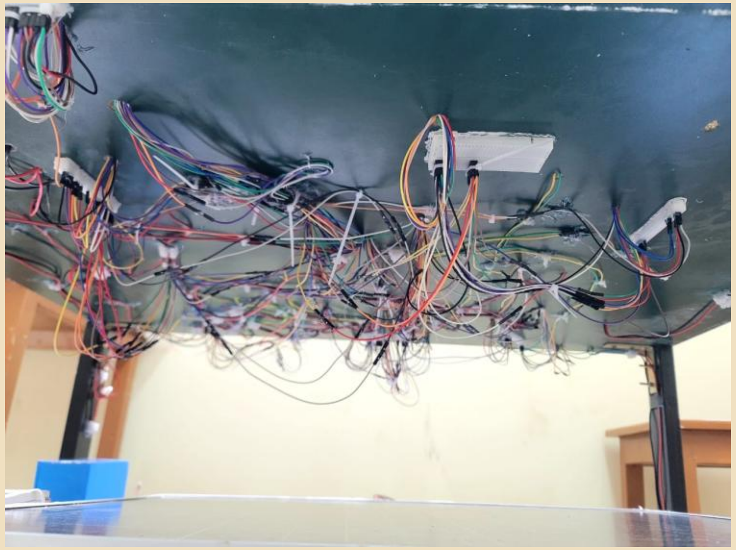


DES (Over Load and Short Circuit Load)

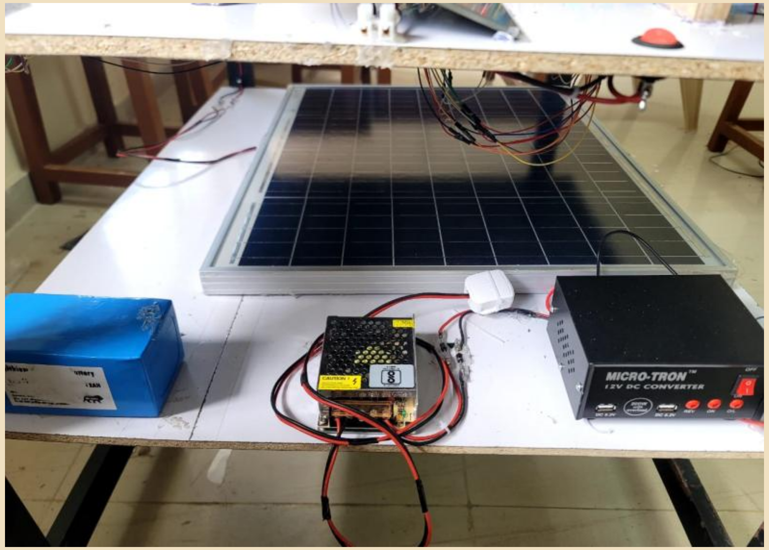


Monitoring System

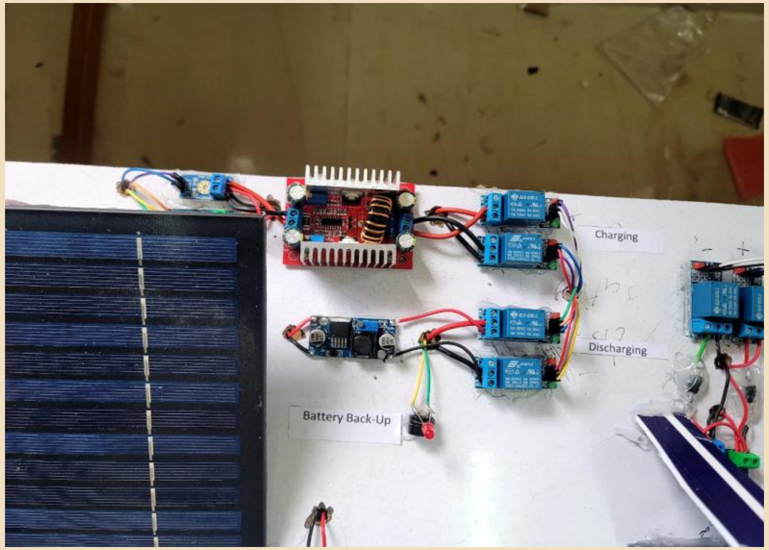
Implementation



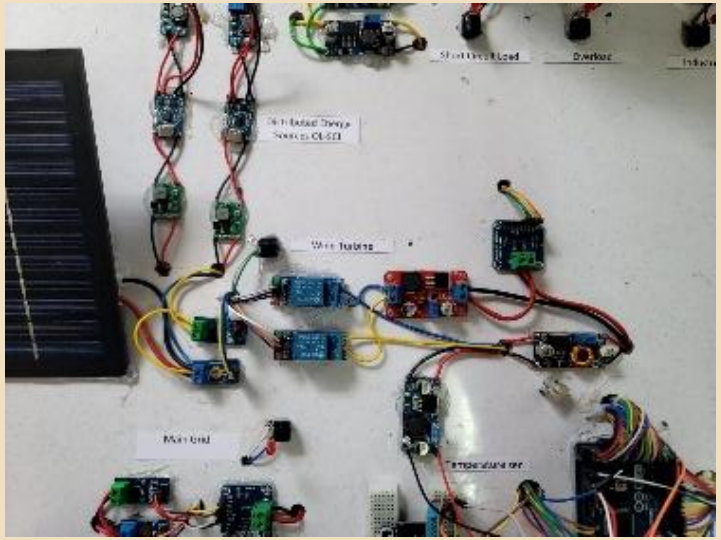
Wiring



Battery-Rectifier-Inverter-Main solar panel



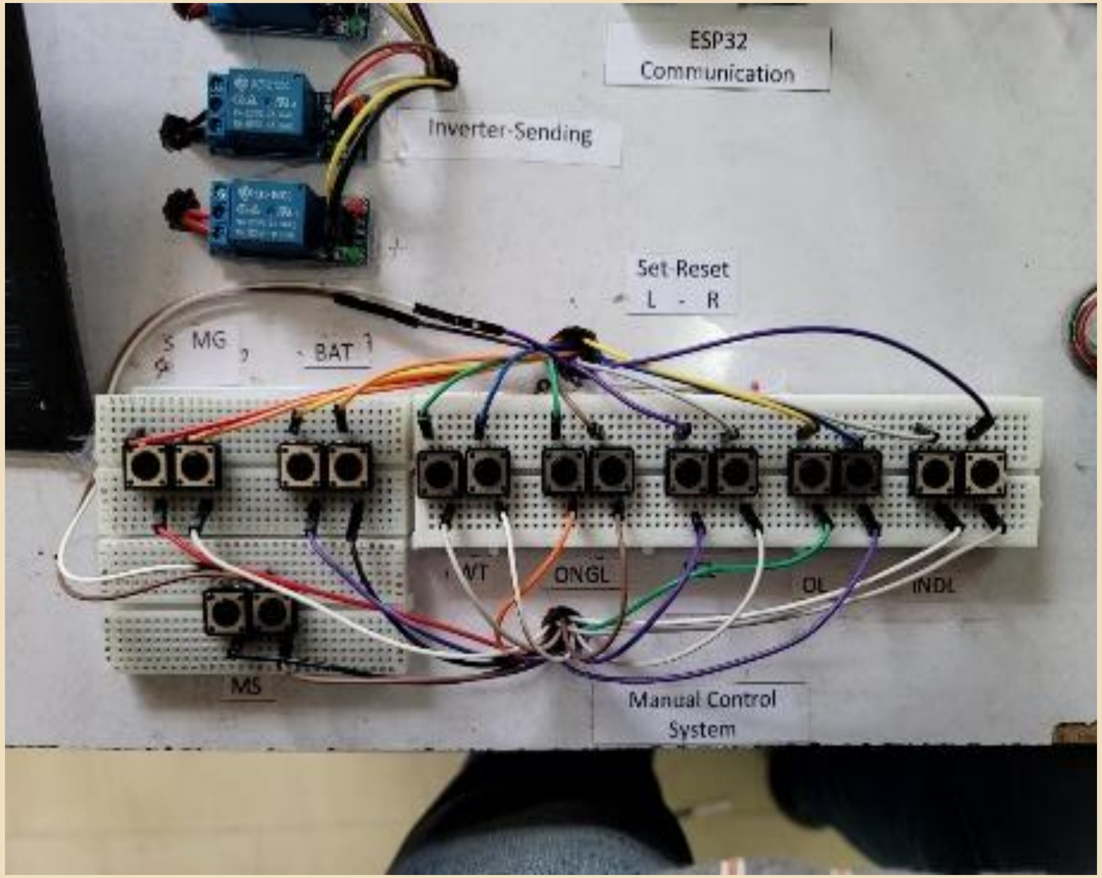
Battery Setup



Wind-Turbine Setup

Implementation

Different types of loads-ONGL-INDL-OV-SCL



Manual Controlling system

Use Cases & Testing

Use Cases

1. **Solar and Wind**:

These renewable sources generate electricity based on real-time data (solar irradiance for solar panels and wind speed for wind turbines).

2. **Energy Storage**:

The battery system stores excess energy produced by solar and wind, supplying it during periods of high demand.

3. **Load Management**:

As a smart grid, the system adjusts the distribution of energy from these sources according to real-time load requirements, ensuring efficient supply based on demand.

Test Cases

1. **Different Environmental Conditions for Renewable Sources:**

Test power output variability with changing solar irradiance, temperature, and wind speeds.

2. **Different Types of Loads:**

Test grid response with inductive, capacitive, and resistive loads for power balance.

3. **Grid Fault Condition Testing:**

Simulate faults (e.g., short circuits) to check fault detection and recovery

Results

Outcomes:

1. **Scalability & Flexibility** – Integrated multiple power sources for a stable energy supply.
2. **Renewable Energy Integration** – Reduced fossil fuel dependence and emissions.
3. **IoT-Based Monitoring & Fault Detection** – Enabled real-time data acquisition and reliability.
4. **Real-Time Control & Optimization** – Ensured efficient power switching and load management.
5. **Automation** – Sensors and relays dynamically managed energy flow

Project overview

Generation Side Results

- **Main Solar Panel**

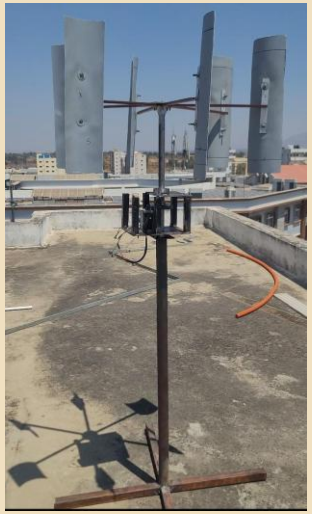
Solar:
Voltage: 11.78 V
Current: -2.50 A
Power: 30.00 W

50W Solar Panel

The solar panel generated 30W, contributing significantly to the smart grid’s renewable energy mix. It adjusted power output based on grid requirements, reducing dependence on conventional energy sources.

- **Wind Turbine**

Wind:
Voltage: 12.10 V
Current: -0.16 A
Power: 19.00 W



50W Wind turbine

The wind turbine generated 19W, supplementing solar power. The low current value indicates moderate wind speeds during the test. The combined use of solar and wind enhanced energy stability and availability.

➢ Battery Performance

Battery Charging

```
Battery

Voltage:   13.50 V
Current:   -1.81 A
Power:     -24 W
Battery Percentage: 80.00 %
Battery Charging
```

Battery Discharging

```
Voltage:   13.36 V
Current:   -0.93 A
Power:     -12 W
Battery Percentage: 70.00 %
Battery Discharging
```

The battery efficiently stored excess energy and supplied power when needed. Its reliable charge-discharge cycles ensured grid stability and reduced dependence on the main grid.

Battery

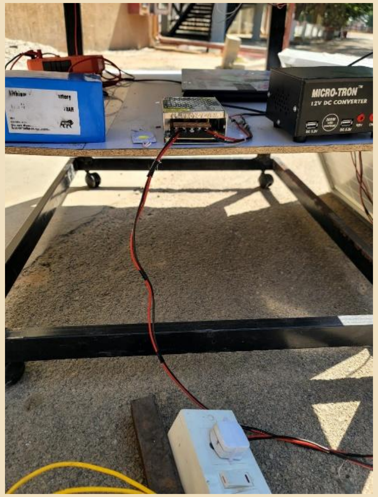
➢ Main Grid Contribution

Receiving Mode

```
Main Grid:
Voltage: 11.35 V
Current: 2.61 A
Power: 29.65 W

Status: Receiving
```

Sending Mode

```
Main Grid:
Voltage: 9.47 V
Current: -4.71 A
Power: 44.84 W

Status: Sending
```



Inverter- Rectifier (Grid)

The grid acted as both a backup and distributor. It received 29.65W when renewable generation was low and supplied 44.84W back to the system during excess generation. This bidirectional energy exchange improved efficiency and cost savings.

Load Side Results

- **On-Grid Load Performance**

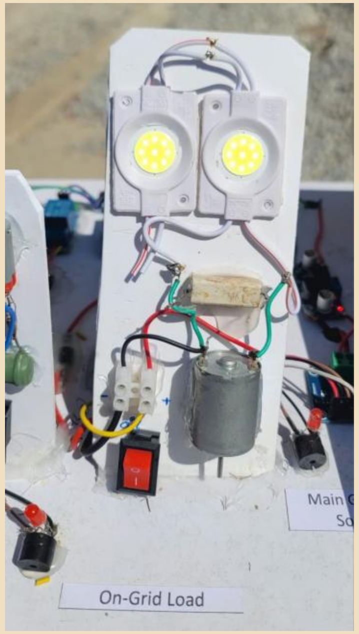
Sending Power to grid

```
Grid Load:
Voltage: 12.02 V
Current: -0.27 A
Power: 3.20 W
Status: Sending
```

Receiving Power from grid

```
On Grid Load:
Voltage: 11.74 V
Current: -0.26 A
Power: 3.08 W
Status: Receiving
```

The on-grid load managed power distribution efficiently, maintaining stability and minimizing fluctuations. The system dynamically switched between receiving and sending power, optimizing energy usage and reducing costs.



On-Grid Load

- **Industrial Load**

```
Industrial Load

Voltage:  5.42 V
Current:  3.96 A
Power:    21 W
```

The industrial load consumed 21W, demonstrating the grid's capability to supply high-demand consumers reliably. This was achieved using both solar energy and grid power for cost optimization.

Industrial Load

➢ Overload Condition

```
Over Load

Voltage:  5.36 V
Current:  2.54 A
Power:    13 W

Over Load Load2
```

The system successfully detected and managed an overload condition using relays and sensors. Automated regulation prevented system failure and ensured uninterrupted power to other loads.

Overload

➢ Short Circuit Load:

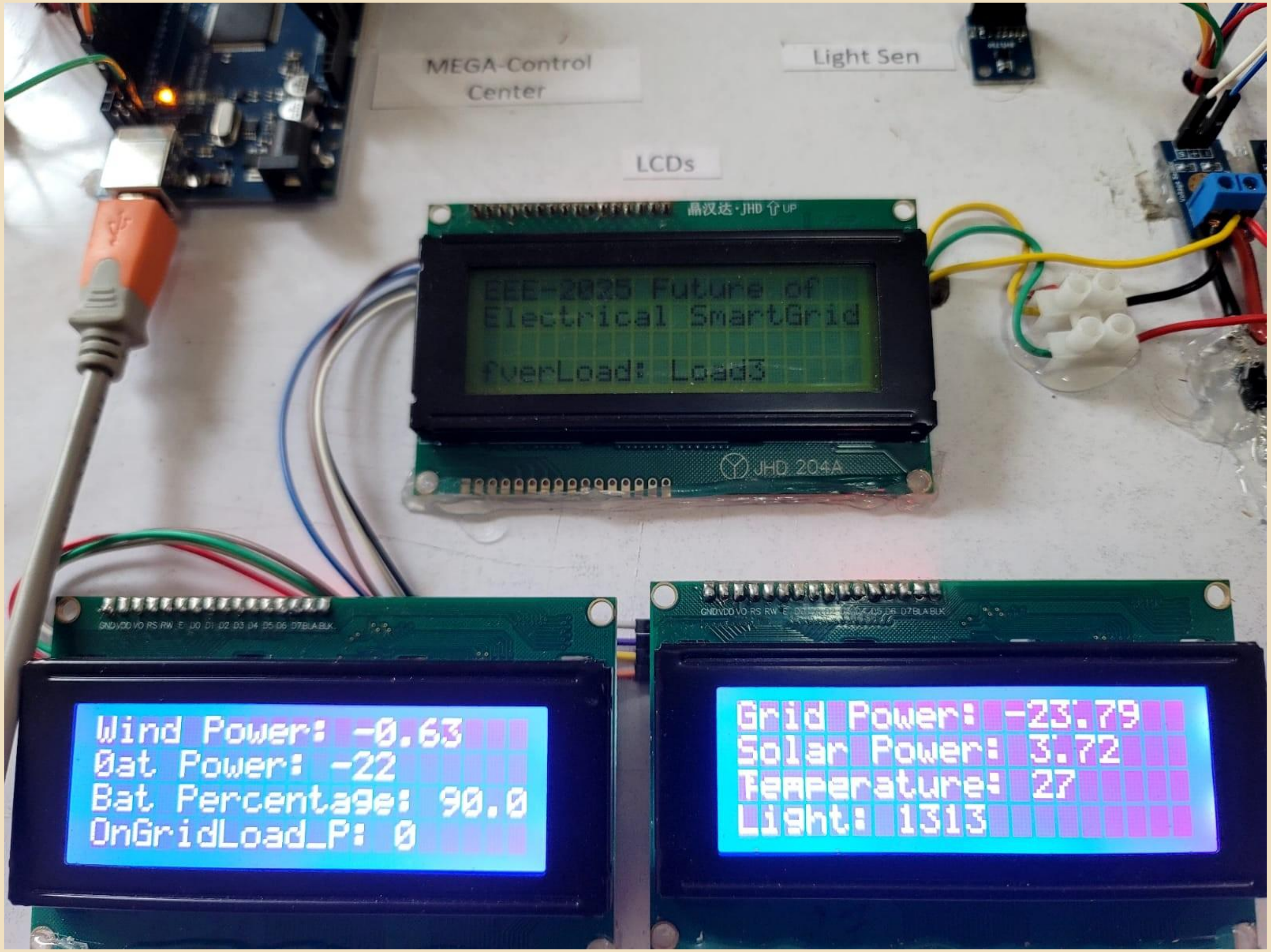
```
Fault Load

Voltage:  7.10 V
Current:  6.16 A
Power:    43 W

Short Circuit Load3
```

The short circuit protection system responded effectively by disconnecting the affected section, preventing damage due to high current surges. This aligns with the objective of **enhanced fault detection and protection**.

Short Circuit Load

Monitoring System Results

The smart grid monitoring system tracks power, consumption, and environmental data using sensors and relays. LCD displays provide real-time updates on power sources, battery status, temperature, and light intensity.



Power Generation & Consumption Monitoring

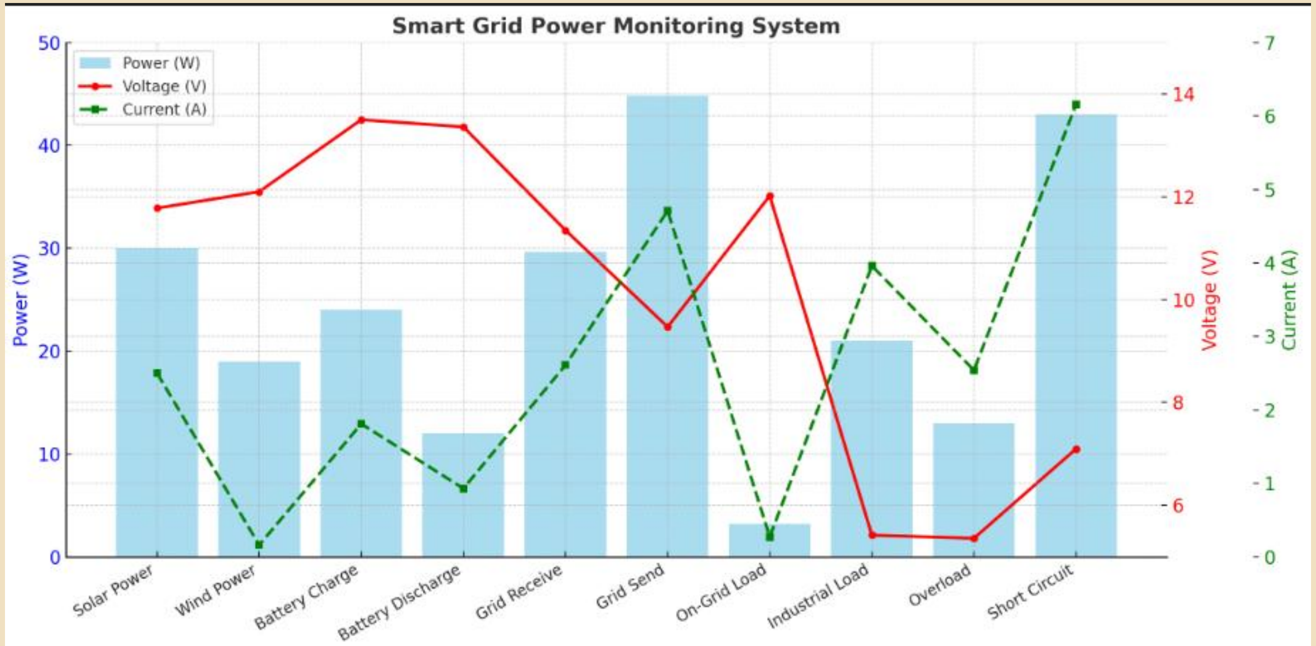
1. **Wind Power:** -0.63W (No active wind generation)
2. **Solar Power:** 3.72W (Active solar contribution)
3. **Grid Power:** -23.79W (Drawing power from the grid)
4. **Battery Power:** -22W (Discharging to support loads)
5. **Battery Percentage:** 90% (Sufficient backup)
6. **On-Grid Load Power:** 0W (No current supply)

Environmental Monitoring

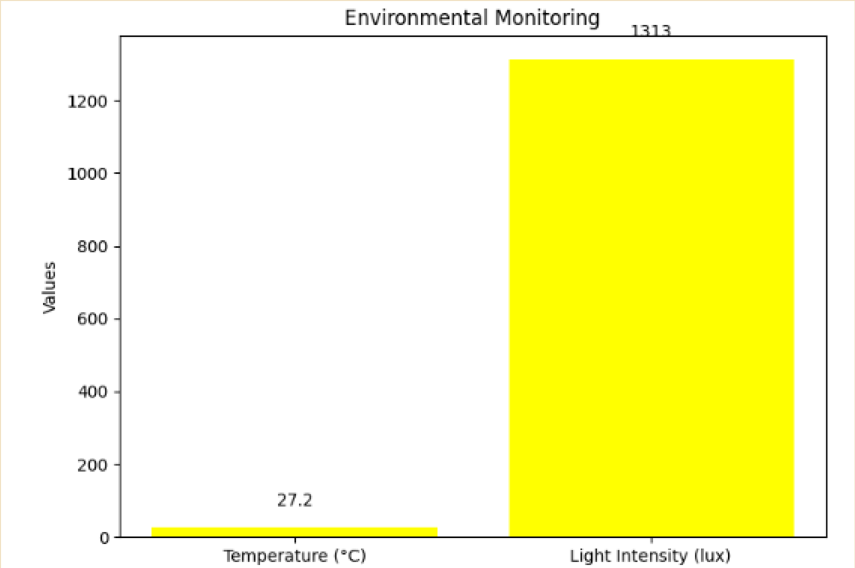
1. **Temperature:** 27.2°C (Affects solar & battery efficiency)
2. **Light Intensity:** 1313 (Indicates strong sunlight for solar generation)

Interpretation of results

This section analyzes the power generation, storage, and load distribution performance of the smart grid system based on the recorded values.



Different Sources VS Current , power Voltage



Temperature and light intensity

Performance Analysis Graphs

Analysis & Interpretation

1. Generation Side

•**Solar Panel:** Generated 30W, adjusting output to meet grid demand.
•**Wind Turbine:** Produced 19W, supplementing solar power for stability.
•**Battery:** Stored excess energy and discharged when needed, ensuring reliability.
•**Grid Contribution:** Exchanged power bidirectionally, improving efficiency..

2. Load Side

•**On-Grid Load:** Optimized energy flow by dynamically switching power sources.
•**Industrial Load:** Consumed 21W, balancing between solar and grid power.
•**Overload Protection:** Detected and controlled excess load, preventing failures.
•**Short Circuit Protection:** Isolated faults to prevent damage from high currents.

3. Environmental Monitoring

•**Temperature:** Affected solar panel efficiency and battery performance.
•**Light Intensity:** Strong sunlight enabled optimal solar power generation.

GITAM
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Contribution

Team Progress and Movement

1. Wind Turbine Type Selection
2. Abstract Preparation
3. Circuit Diagram Development
4. Theoretical Calculations and Wind Turbine Design
5. Component Procurement and Purchasing
6. Circuit Design
7. Wind Turbine Testing and Data Recording
8. Circuit Assembling
9. Coding
10. Final Testing and Validation

Individual Contribution

1. Team Member Name: Ahmed Abdulrahman Abdullah Bin Alfaqeeh **(BU21EECE0200026)**

- Team leader
- Wind turbine design
- Circuit design
- Wiring and Assembling
- Testing
- Data collection
- Documenting

2. Key contributions: SEEPALA SIVA KUMAR **(BU21EECE0200038)**

- Coding
- Circuit design
- Testing

3. Key contributions: YASHWANTH M **(BU21EECE0200033)**

- Assembling
- Testing
- Data collection

Conclusion & Future Work

Summary and Conclusion

The successful implementation of a smart grid model integrating solar, wind, battery storage, and grid contribution with IoT-based monitoring has demonstrated significant improvements over traditional systems. The system enhances efficiency, reliability, and sustainability through renewable energy, real-time data, and automated control.

Key Outcomes:

1. Successful hardware implementation, validating practical feasibility.
2. Real-time IoT monitoring, improving energy management.
3. Effective solar and wind integration, ensuring continuous renewable supply.
4. Optimized battery storage for seamless power transition during fluctuations.
5. Bidirectional power flow, enhancing grid flexibility.
6. Improved fault detection and load management, ensuring grid stability.

Future Work

1. Integrate AI for automated operation, demand prediction, and fault detection.
2. Use machine learning to analyze energy patterns and optimize renewable utilization.
3. Implement blockchain for secure energy transactions.
4. Expand with vehicle-to-grid (V2G) technology for improved grid stability.
5. Explore edge computing for faster data processing and enhanced cybersecurity.
6. Conduct scalability tests for large-scale deployment.

These advancements will transform the smart grid into a self-sustaining, intelligent, and resilient energy network, paving the way for sustainable urban energy solutions.

THANK YOU

Have a Great Day !