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Abstract

The rapid growth of urban populations necessitates reliable and sustainable energy solutions. Our project, **"Empowering Smart Grid for the Future of Urban Centers,"** has transitioned from simulation to hardware implementation, focusing on integrating wind turbines and solar panels as primary energy sources, supported by battery storage systems for uninterrupted power supply. The hardware setup includes wind speed testing, circuit design, component procurement, and prototype assembly. To enable real-time monitoring and control, IoT devices such as ESP32, Arduino Mega, relays, and sensors are used to establish a two-way communication network, optimizing energy production, storage, and consumption. The system also incorporates fault detection mechanisms and automated response systems to maintain grid reliability and minimize downtime. By successfully implementing renewable energy integration, IoT-based control, and real-world testing, this project demonstrates a scalable and efficient smart grid model for urban applications. The outcomes include improved energy efficiency, enhanced grid stability, and practical insights for future urban energy planning.

Background

Growing Urban Energy Demand

- Rapid urbanization is increasing electricity consumption, stressing traditional grids.
- Conventional power grids rely on fossil fuels, leading to inefficiency and high emissions.

Challenges in Traditional Power Systems

- Lack of real-time monitoring and automation reduces grid responsiveness.
- Power fluctuations and outages affect energy reliability in the electrical grid.

Renewable Energy Integration

- Solar panels and wind turbines provide clean, sustainable energy solutions.
- Battery storage ensures a stable power supply by mitigating fluctuations.

Role of IoT in Smart Grids

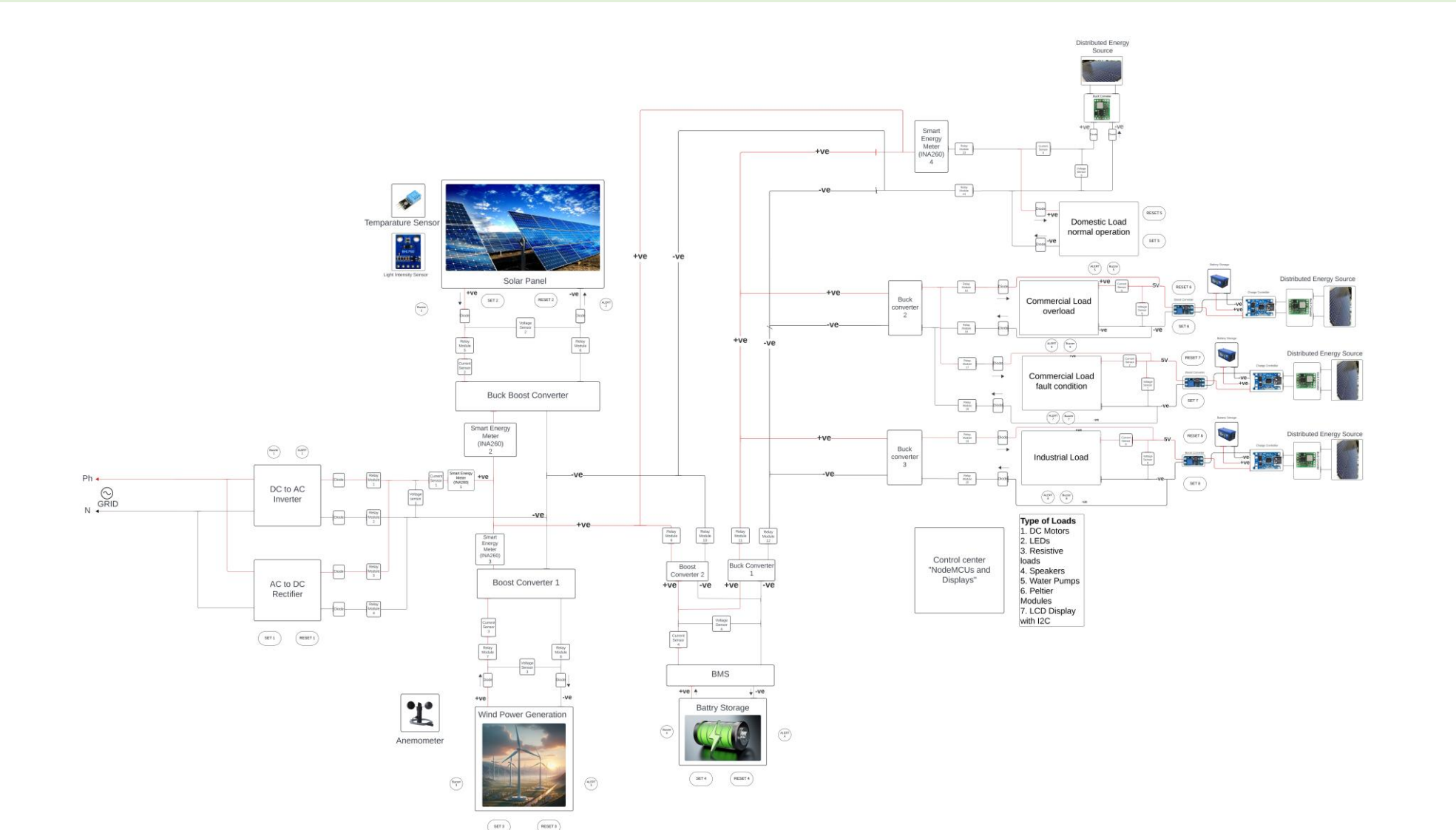
- IoT devices like ESP32, Arduino, and sensors enable real-time data acquisition.
- Two-way communication allows optimized energy production, storage, and distribution.

Project Focus

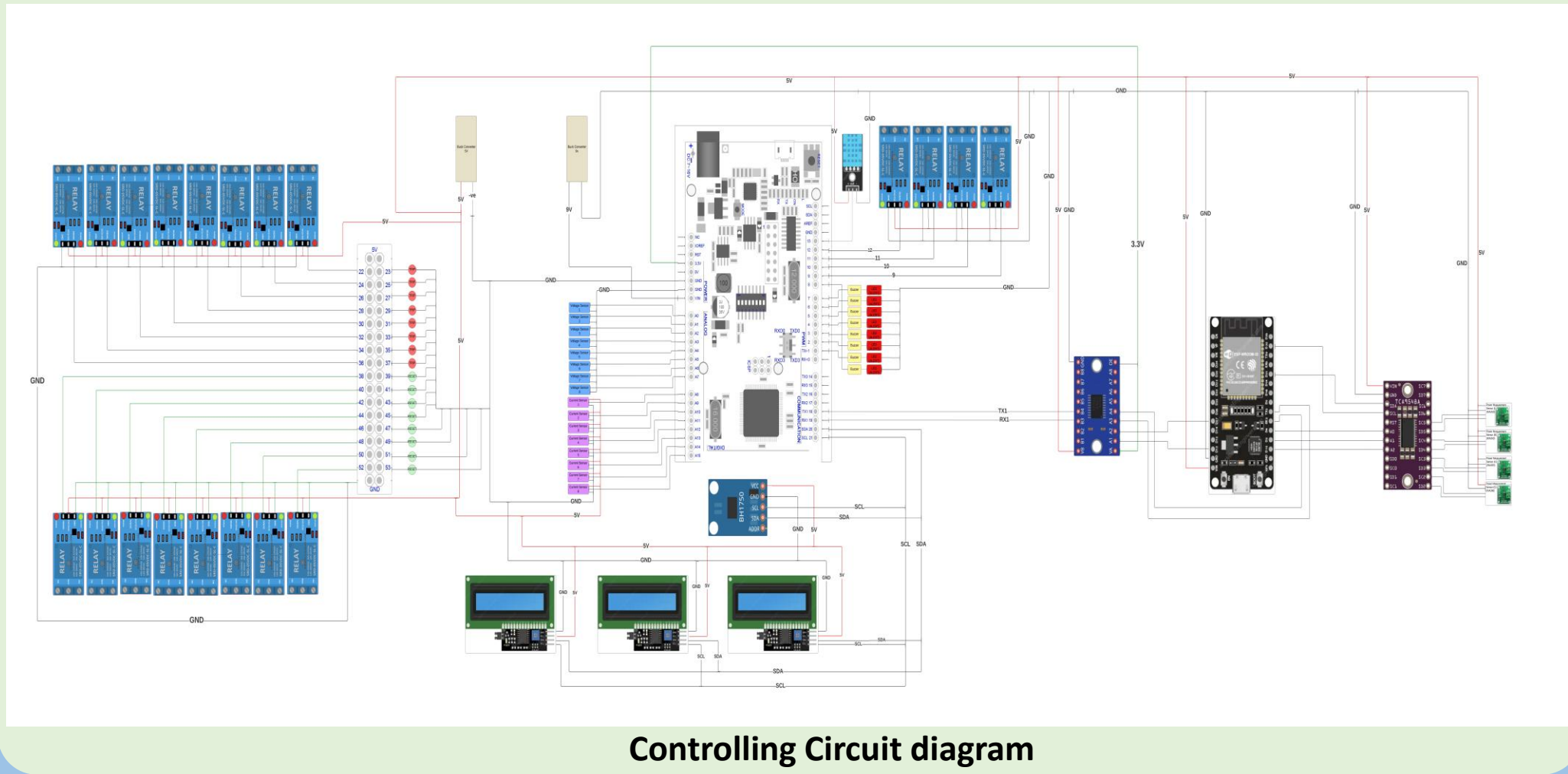
- Hardware implementation of a smart grid integrating renewables, battery storage, and IoT control.
- Enhances energy efficiency, grid stability, and sustainable urban power management.

Methods

- **System Overview**
 - A **170W smart grid system** integrating solar, wind, battery storage, and automated control.
 - Operates **automatically via relays** based on sensor inputs with manual control when needed.
 - **Blynk IoT** enables **real-time monitoring & remote control**.
- **Energy Flow & Components**
 - ❖ **Power Sources:**
 - **50W Solar Panel** + **50W Wind Turbine** → Charges **12.8V/12Ah Battery** or supplies load/grid.
 - **200W Inverter** → Sends excess power to the grid **+60W Rectifier** → Draws power when needed.
 - ❖ **Loads:**
 - **On-grid Load (10W Solar Panel)** – Grid-connected.
 - **Fault Detection Load (10.5W Micro Solar Panels)** – Monitors overvoltage & short circuits.
 - **Industrial Load (10W Solar Panel)** – Independent.
- **Control & Automation**
 - **Arduino Mega:** Manages sensors, relays & energy distribution.
 - **ESP32:** Enables **Wi-Fi & Blynk** for remote control & data logging.
 - **Relays:** Automated based on real-time sensor readings for protection & stability.
- **Key Hardware & Sensors**
 - **Voltage, Current, and Power Sensors** – Monitor grid & loads.
 - **Power Converters (Buck, Boost, Buck-Boost)** – Regulate voltage for stable operation.
- **Software & Communication**
 - **Arduino IDE:** Coding
 - **Blynk App:** Live data dashboard & remote control.
 - **Lucidchart & Fusion 360:** Circuit design & 3D modeling.
- **Protection & Fault Handling**
 - **Automated Fault Detection:** Trips relays in overvoltage, overcurrent & short-circuit cases.
 - **LEDs, Buzzers, & Push Buttons:** Alerts & manual override when needed.



Electrical Circuit Diagram



Controlling Circuit diagram

Future Perspectives

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. Explore edge computing for faster data processing and enhanced cybersecurity.

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

Impact on Society

Sustainable Energy Adoption

- Lowers air pollution, improving public health and environmental quality.

Enhanced Energy Reliability

- Reduces power outages, ensuring a stable electricity supply for homes and businesses.

Improved Urban Living Standards

- Supports smart city development by enabling efficient public services like street lighting and EV charging.

To know more

GitHub link: [Please Click here](#)

Video link: [Please Click here](#)

Results

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 bidirectional, 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.



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.

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