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Hybrid Energy Management System Using Photovoltaic For Domestic Load

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Abstract: A reliable electricity supply is essential for all aspects of modern life, including residential applications, research facilities, and healthcare services. As energy demand continues to rise and non-renewable resources become increasingly scarce, the adoption of sustainable, hybrid energy systems has become crucial. This project presents the design and implementation of an automated system that seamlessly switches between multiple power sources solar, mains, and generator to ensure uninterrupted power supply and cost-effectiveness. The system employs a microcontroller-based circuit integrated with transmitters to intelligently monitor and manage power inputs. This approach enhances the reliability and resilience of power delivery, minimizing the risk of outages and system failures.

Index Terms: Microcontroller, solar-battery, mains, generator, switching

I. Introduction

An Automatic Power Supply Switching System is an intelligent control mechanism designed to ensure uninterrupted electrical power by managing multiple energy sources without requiring manual intervention. This system is particularly vital in regions prone to frequent power outages or where renewable energy is integrated with traditional power grids. It operates on a priority-based logic, selecting the most optimal power source from a set that includes solar-powered batteries, the mains grid, and a generator. The priority is structured to Favor renewable energy primarily solar before switching to conventional sources, thus promoting energy efficiency and sustainability. At the heart of the system is the ESP32 microcontroller, which acts as the core processing unit. It reads voltage levels and checks the availability of each power source through connected sensors. Based on this data, it makes real-time decisions and executes source switching using relays. The main components of the system include voltage sensors to monitor the condition of each power source, relays for directing the AC load, and the three primary power sources: solar, grid, and generator. This smart switching system is widely applicable in areas such as rural electrification, smart homes, small industries, telecom base stations, and healthcare facilities, where maintaining continuous power supply is essential. By maximizing the use of clean energy and minimizing dependence on generators, the system not only improves reliability but also contributes to cost savings and environmental sustainability.

II. Methodology

The first step in this project involves setting up the hardware, which includes connecting relays and voltage sensors to the GPIO pins of the ESP32 microcontroller and supplying power to the device. Once the hardware is in place, the next phase focuses on firmware development. This involves installing the Arduino IDE and writing code to read voltage and power data from the sensors. For demonstration purposes, the system is configured as if it is receiving input from three completely independent power sources, achieved by connecting all three inputs in parallel. To simulate source failure, three electrical switches are used each representing the failure of a specific power source and are interfaced with the ESP32. When any of these switches is pressed, it signals the microcontroller that the corresponding source is unavailable.
In this setup, the ESP32 acts as the central controller. It processes input signals and sends corresponding output signals to the ULN2803 relay driver, which is capable of controlling up to four relays. The relays used in the system are 12V relays, and the operational status of the output is indicated by a lamp. If one power supply fails, the system automatically switches to an alternative source, ensuring that the lamp remains lit without interruption. The power supply to the system is managed through a 230V to 12V step-down transformer. This AC voltage is converted to DC using a bridge rectifier. A capacitor filter smooths out voltage ripples, and a 7805voltage regulator maintains a constant +5V output, which is essential for powering the microcontroller and other components in the system.

III. Block Diagram

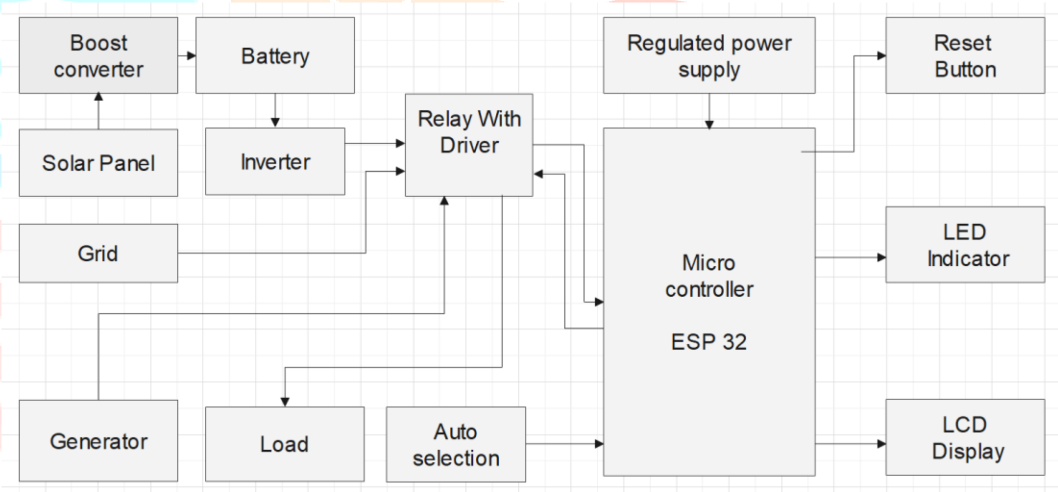

Fig 1: Block Diagram

Block Diagram Description

The Uninterrupted Power Supply control system is designed to maintain continuous power to a connected load by automatically switching between multiple power sources based on a predefined priority, without causing any interruption. The system uses an ESP32 microcontroller to monitor the availability of three power sources connected in parallel: Solar Inverter (highest priority), Mains Supply (medium priority), and Generator (lowest priority). It ensures that the load, typically represented by a bulb, remains powered by the priority based available source at any given time.
To simulate the failure of each power source, the system includes three push-button switches. When the system is powered on, the ESP32 detects a high signal, which prompts it to send a low output to the first relay driver. This action energizes the first relay, allowing the solar inverter to supply power to the bulb, which then lights up. If the solar source fails (simulated by pressing the first button), the controller detects this and switches the load to the next available source, the mains supply. The microcontroller again generates a low output to activate the second relay driver, energizing the second relay and ensuring the bulb remains lit. If the mains supply also fails (second button pressed), the system automatically transfers the load to the generator by energizing the third relay through a similar process. The bulb continues to stay on as long as at least one power source is

available. However, if all three sources fail, all relays are de-energized, cutting off power to the bulb and turning it off. Throughout this operation, a 16x2 character LCD screen provides real-time updates on the status of each power source and the condition of the load, ensuring transparency and easy monitoring. This intelligent switching mechanism guarantees uninterrupted power delivery and efficient source management, making the system suitable for applications where continuous operation is critical.

- **Flow-Chart**

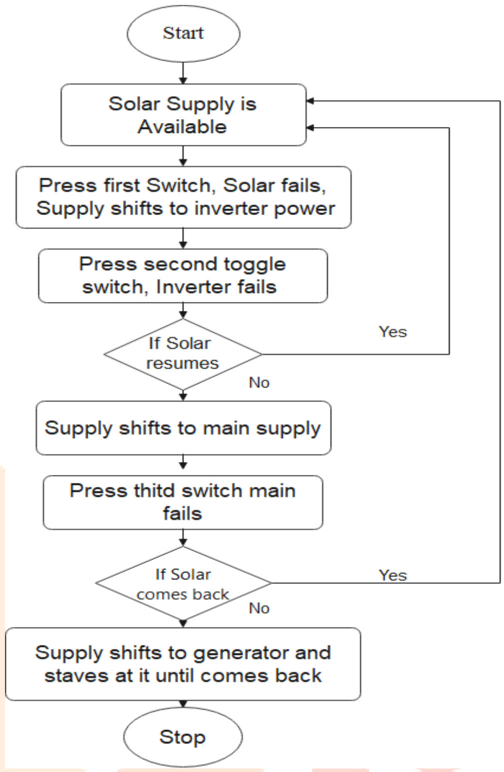

Fig 2: Flow Chart

- **Circuit Diagram**

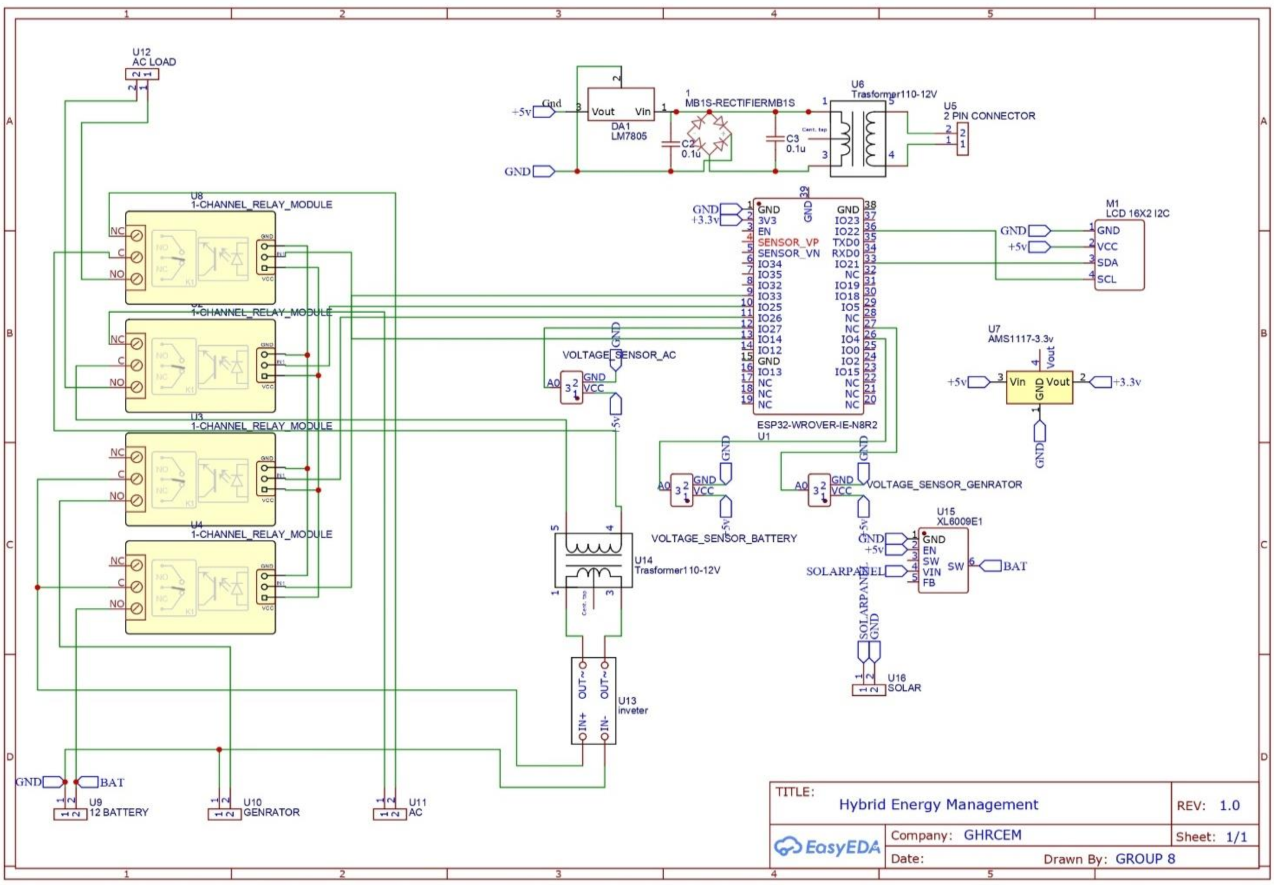

Fig 3: Circuit Diagram

IV. Components Used

- **ESP 32 module**

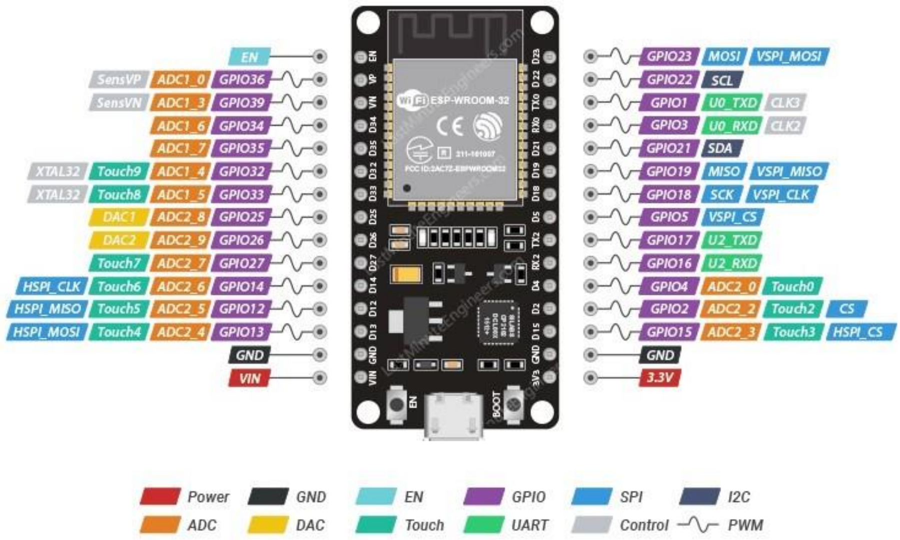

Fig 4: ESP 32 Configuration

The ESP32, developed by Espressif Systems, is a powerful and affordable system on a chip (SoC) that improves upon the popular ESP8266. It features a 32-bit Tensilica Xtensa LX6 microprocessor available in single-core or dual-core versions, running at speeds up to 240 MHz with 520 KB of SRAM and support for external flash memory, the ESP32 is capable of handling complex applications with ease.
It includes built-in Wi-Fi (802.11 b/g/n) and Bluetooth (Classic and BLE), providing robust wireless communication options. The chip supports a wide variety of interfaces such as multiple GPIO pins, ADCs, DACs, UART, SPI, I2C, PWM, and CAN bus, offering great flexibility for developers. Security is a key focus, featuring secure boot, flash encryption, and hardware-accelerated cryptographic functions. Its ultra-low power consumption modes make it especially suitable for battery-powered devices. The ESP32 is widely adopted across IoT, smart home systems, industrial automation, and robotics. It is supported by popular programming environments like Arduino IDE and MicroPython, making it a preferred choice for both hobbyists and professionals.

- **Solar**

Fig 5: Solar Panel

A 12 V solar panel is a photovoltaic (PV) module designed to deliver a nominal voltage of about 12 volts, making it suitable for charging 12 V battery banks in small off-grid setups, RVs, boats, and remote lighting applications. Typically, a "12 V" panel consists of 32 to 36 solar cells connected in series, producing an open-circuit voltage (Voc) of around 18 V and a maximum power voltage (Vmp) close to 17 V under standard test conditions. These panels usually have power ratings ranging from 20 W up to 200 W or more, with peak current (Imp) values between 1 and 12 A, depending on the panel's size and cell efficiency.

- **Relay Module**

Fig 6: Relay

An electromagnet is commonly used to control an electrical switch within a power relay module. A low-power signal from a microcontroller activates the electromagnet, which pulls a movable armature to open or close an electrical circuit. A basic relay consists of several key components: an iron yoke that provides a low-reluctance path for magnetic flux, a movable iron armature, a coil of wire wound around a soft iron core (forming a solenoid), and one or more sets of electrical contacts. The armature is mechanically connected to both the yoke and the movable contacts. When the relay is not energized, a spring holds the armature in its default position, maintaining a gap in the magnetic circuit. In this state, one set of contacts is closed while the other is open. When current flows through the coil, it generates a magnetic field that pulls the armature, reversing the state of the contacts—those that were open become closed, and those that were closed become open. When power is removed from the coil, the spring (or gravity in some designs) returns the armature to its original position.
Most power relays are engineered for rapid switching and reliable performance. GEP Power Products is a leading manufacturer in this space, specializing in high-power relay modules for power distribution in high-current applications. Their relays can handle up to 70 amps and are designed for easy integration into high-power systems. Features such as built-in mounting brackets simplify installation, while options like terminal position assurance (TPA) ensure secure wire connections. GEP is widely recognized for its innovation and technical expertise, especially in delivering power distribution solutions for the off-road and industrial sectors.

- **Inverter Circuit**

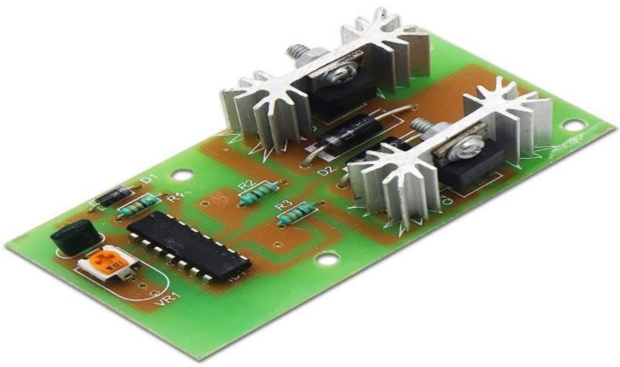

Fig 7: Inverter Circuit

An inverter board is a compact module designed to convert low-voltage DC power typically from a 12V battery or solar panel into high-voltage AC output (usually 220V AC) suitable for running household appliances and lighting. At the heart of the inverter is a high-frequency H-bridge circuit, typically built with MOSFETs or IGBTs, controlled by a PWM controller or gate driver IC. This circuitry generates a pulsed waveform that is either stepped up using a boost converter and output transformer or passed directly through a high-frequency transformer. To reduce switching noise and ripple, the AC output is filtered using a combination of LC and π filters, including inductors, capacitors, and ferrite beads. A feedback system often consisting of optocouplers and either an analog error amplifier or a microcontroller monitors the output voltage and dynamically adjusts the PWM duty cycle to keep the voltage stable under changing load conditions. To ensure reliable and safe operation, inverter boards are equipped with built-in protections against overloads, short circuits, overheating, and low battery levels. These features are supported by components such as heat sinks and thermal sensors, making the board suitable for continuous and demanding use.

- **Battery**

Fig 8 : Lead Acid battery

A liquid acid battery commonly known as a lead-acid battery—is one of the oldest and most widely used types of rechargeable batteries. It consists of a positive plate made of lead dioxide (PbO_2), a negative plate made of sponge lead (Pb), and a liquid electrolyte made from sulfuric acid (H_2SO_4) diluted with water. During discharge, a chemical reaction between the electrodes and the electrolyte generates electrical energy, while the reverse reaction occurs during charging to restore the battery's capacity. Lead-acid batteries are known for their reliability, cost-effectiveness, and ability to provide high surge currents. These qualities make them ideal for use in applications such as starting vehicle engines, providing backup power, and storing energy in off-grid or renewable energy systems.

- **Voltage Sensor AC / DC**

Fig 9: Ac voltage sensor

Fig 10: Dc voltage sensor

This sensor is designed to monitor, measure, and determine voltage levels, capable of detecting both AC and DC voltages. The sensor accepts voltage as its input and provides various types of outputs, such as switching signals, analog voltage, current signals, or audible alerts. The sensor has two main input pins positive and negative which connect to the corresponding voltage source terminals. On the output side, it typically provides a supply voltage (Vcc), ground (GND), and an analog output signal representing the measured voltage level.

V. Software Design Technique

Fig 11: BLYNK Display

Blynk is an advanced Internet of Things (IoT) platform built on a client-server architecture, with its mobile application serving as the client interface. The app communicates with the Blynk cloud server over the internet using standard protocols such as HTTP and WebSocket, enabling real-time interaction between users and their connected devices. The platform offers RESTful APIs that adhere to the principles of Representational State Transfer (REST), allowing developers to control devices and retrieve sensor data through structured requests to the cloud. Blynk operates on an event-driven model, where user interactions such as pressing a button or adjusting a slider trigger event that are processed by the cloud and converted into corresponding hardware actions. To ensure responsive and efficient performance, Blynk utilizes asynchronous programming techniques. This approach enables the application to handle multiple operations simultaneously, minimizing latency and improving user experience. Security is a foundational aspect of the Blynk platform. It incorporates robust authentication and authorization mechanisms, including token-based access and SSL/TLS encryption, to safeguard user data and ensure secure communication channels. Blynk's architecture is modular and highly extensible, allowing developers to implement custom features, integrate plugins, and support a wide range of devices tailored to specific applications. The platform supports both iOS and Android, providing a consistent and seamless user experience across mobile devices.

VI. Result

An automatic power-selection system intelligently manages three energy sources solar-battery, utility mains, and a backup generator to ensure uninterrupted and cost-effective power delivery. It continuously monitors the status of each source and follows a user-defined hierarchy of thresholds and timing delays to determine the optimal power supply. During daylight hours, the system prioritizes solar-battery power, using the inverter to run connected loads and recharge the battery. If the battery's state of charge falls below a set threshold, the system switches to utility mains provided that the grid voltage remains stable for a predefined period to recharge the battery to a safe level before returning to solar power. If utility power is unavailable when the battery is low, the system automatically starts the backup generator. It waits for the generator's voltage and frequency to stabilize, then transfers the load using fast-acting solid-state or relay-based switches. Once the battery is sufficiently charged or solar generation resumes, the system switches back to inverter mode and shuts down the generator after a programmed cool-down delay. To ensure smooth transitions, the system uses hysteresis in voltage thresholds, enforces minimum source run times, and applies interlock delays to prevent rapid switching ("chatter") between sources. Integrated safety features including overload, undervoltage, and over-temperature protections help maintain reliable operation and safeguard critical loads.

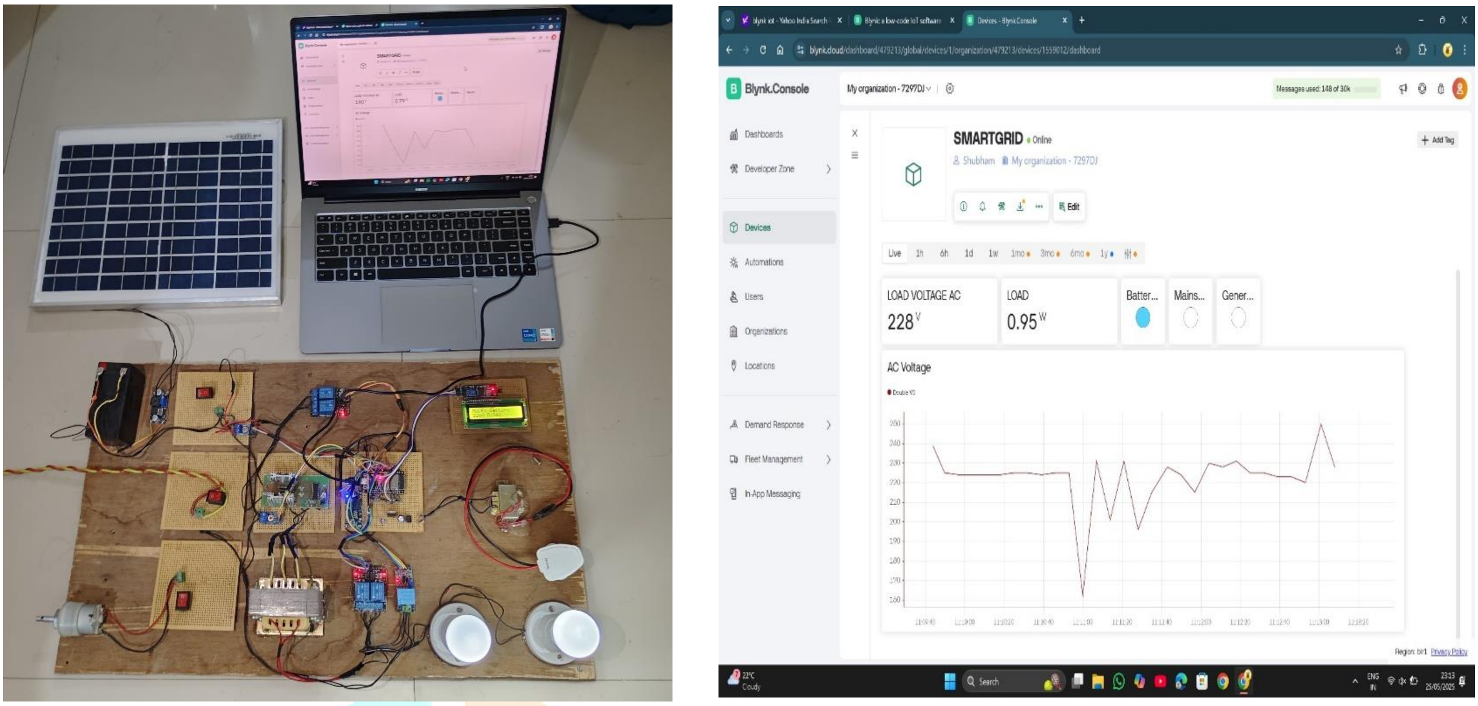

Fig 12: Prototype

VII. Conclusion

Worldwide energy demand is rapidly increasing, while energy generation capacity struggles to keep up. As a result, electricity providers are turning to nonconventional energy systems to bridge the gap. Integrating renewable energy sources with nonconventional power supplies not only improves system reliability but also enables meeting higher power demands efficiently. To optimize usage and cost-effectiveness, the various energy sources must be prioritized based on factors such as availability, operational costs, and their impact on other equipment like noise from generators, emissions, and environmental hazards. This prioritization can be implemented as an algorithm programmed into a microcontroller, which automatically selects and switches between energy sources via relays controlled through a relay driver circuit. This project involves three distinct energy sources, each with different parameters, allowing the microcontroller to evaluate and choose the most suitable source for continuous power supply.

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