Optimize Management of Multiple Generating Sources for the Survival of the Critical Load

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Under the guidance

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DECLARATION

I hereby declare that this submission is my own and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of another degree or diploma of the university or other higher learning institute. All the things in the report are by me and I am solely responsible for any plagiarism.

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Roll No: R132221005

Semester: VIII

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CERTIFICATE

This is to certify that Tanishi Pandey, R132221005 student of BTech Electrical Engineering (VIII Semester), from Electrical Cluster, School of Advanced Engineering, UPES, Dehradun (Uttarakhand) have completed her major project entitled “Optimize Management of multiple Generating Sources for the survival of the critical Load” under the guidance of Dr..Devender Kumar Saini - Professor, Electrical Cluster, SOAE, UPES, Dehradun.

Signature:

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Dr. Devender Kumar Saini

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ABSTRACT

This project focuses on the design, development, and demonstration of a smart power management system capable of optimizing multiple energy sources to ensure the uninterrupted operation of a critical electrical load. The core aim is to prioritize and protect a critical 4W load by automatically switching between a grid source and a battery backup system based on availability, ensuring power reliability in case of a grid failure. The system mimics smart infrastructure requirements by using intelligent source switching and load prioritization, enabling energy-efficient operation and prolonged battery backup.

Under normal operating conditions, all three loads (12W, 4W, 12W) are powered via the grid. However, in the event of a grid outage, the system transitions to battery mode, deactivates the non-essential loads, and powers only the critical load, maintaining operational continuity. An integrated BMS (Battery Management System) safeguards the battery by monitoring its charge-discharge cycles and health parameters. The real-time display provides key system insights such as the source of supply (grid/battery), voltage, current, and battery status.

Key components and features include:

1. Dual-source integration: Grid and battery with auto-switching capability.

2. Real-time monitoring and display of system parameters: voltage, current, source status, and battery state.

3. Intelligent load shedding: Critical load management for optimized energy usage.

4. Battery Management System (BMS) for protection and efficient performance.

This project serves as a foundational model for smart infrastructure and micro grid applications, promoting energy reliability and optimized resource utilization in future-ready electrical systems.

CHAPTER 1

INTRODUCTION

In today's technologically driven society, the demand for a continuous and reliable power supply is paramount, especially in mission-critical applications such as healthcare facilities, data centers, and emergency services. Power interruptions, even momentary ones, can lead to catastrophic consequences, including equipment failures, data loss, and compromised safety systems. To mitigate these risks, there is an increasing emphasis on developing intelligent power management systems capable of seamlessly switching between multiple power sources to ensure uninterrupted power delivery to critical loads.

The growing need for continuous power supply in mission-critical applications has spurred the development of smart systems that can handle multiple sources of power. This project seeks to develop a smart power management prototype that guarantees the survival of mission-critical loads by effectively switching between a primary (grid) and secondary (battery) source. With applications to smart infrastructure, microgrids, and disaster-resilient systems, such solutions are essential for industries like healthcare, data centres, and emergency services where even temporary power outages can have serious effects. The system gives priority to a critical load (4W) while serving non-essential loads (12W, 12W) depending on available power, promoting reliability and operating efficiency. This paper describes the control strategies, design logic, and methodology adopted to maximize source utilization while ensuring battery protection and showing real-time parameters.

The relevance of such systems extends beyond individual applications, contributing to the broader goals of smart infrastructure development, microgrid implementation, and disaster-resilient energy systems. By ensuring the continuous operation of critical loads, these systems play a vital role in maintaining the functionality of essential services during emergencies and power disruptions.

1.1 LITERATURE REVIEW

The method of improving the power continuity supply in the area of the power network with the possibility of island operation by implementing BESS in the construction of the selected substation with the backup power function, and to present the authorial method of optimal BESS. This study presents the implementation of Battery Energy Storage Systems (BESS) to enhance the reliability of power networks, especially during emergencies. It discusses integrating BESS into medium voltage substations to provide backup power, improve network reliability, and reduce the frequency of power outages. [1]

BMSs are responsible for monitoring battery parameters, ensuring safe operating conditions, and extending battery life. They highlight the importance of state-of-health monitoring techniques to predict battery performance and prevent failures. [2]

Hybrid power systems combine multiple energy sources to improve reliability and efficiency. By integrating battery sources and the grid, hybrid systems can provide resilient power solutions, especially in disaster-prone areas. [3]

It evaluates the performance and economic viability of grid-charged inverter-battery systems (GBIS) in residential settings. It provides analytical models for technical and economic assessments. GBIS is effective in areas with unreliable grid power supply. [4]

This paper presents an advanced feeder restoration method to restore critical loads using distributed energy resources (DERs). A resilient restoration approach is proposed that jointly maximizes the amount of restored critical loads and optimizes the restoration time. [5]

This highlights the importance of energy management systems (EMS) in microgrids, which are responsible for optimal scheduling and dispatch of energy resources. EMS ensures efficient utilization of available resources, maintaining the balance between supply and demand. [6]

The overall objective to minimize the power consumption from all sources needed to satisfy the system’s power demand by optimizing the switching between the different energy sources. [7]

To get uninterrupted supply nowadays power backups such as inverters and UPS are used commonly. If it is a traditional UPS, it is difficult to know remaining power and time till it can supply energy in terms of power. In order to overcome this issue. The appliances of lights are automatically controlled during power failure according to their priority to ensure optimal utilization of UPS power. This work mainly concentrates on two key points. Firstly, calculating possible time of battery run-away and displaying it on user screen; secondly, prioritizing and operating different appliances according user requirement. [8]

1.2 BACKGROUND

- The requirement of an uninterrupted and continuous supply of power to critical loads is of the highest significance. Power outages can have severe effects on e.g., on medical equipment, safety gear, critical communications.

- The idea of hybrid power systems where the integration of various energy sources increases reliability and efficiency.

- In case of a grid failure and utilization of battery power, the available energy becomes limited which again necessitates intelligent management of the loads to ensure the survival of the critical load for as long a duration as possible.

- The concept of "optimized management" as a means of maximizing the runtime of the critical load by discarding non-critical loads selectively when the main power supply fails.

- The function of a BMS to ensure the safe and effective functioning of the battery, charging, discharging, and protection.

1.3 OBJECTIVES

- Design and develop a smart power management prototype capable of handling multiple power sources Grid and Battery.

- Integrate a Battery Management System (BMS) for ensuring safe operation of the battery pack.

- Use Arduino Nano for control and display functions, including logic implementation and LCD-based status reporting (grid/battery mode, voltage, and current charging/discharging).

- Ensure operational efficiency by isolating non-critical loads during battery operation to conserve energy and extend backup duration.

CHAPTER 2
PROJECT SPECIFICATION

2.1 Components and Functionality:

1) Primary Source (Grid Supply):

   The primary power supply to drive all three loads (12W, 4W, 12W) in a regular condition. The grid feeds the system when available using a step-down transformer and provides voltage to the loads and inverter.

2) Alternate Source (Battery - 3S Configuration):

   Serves as a standby power source in case of grid failure. Provides limited power and is used for energizing only the critical load (4W). Powered through BMS for safety and performance control.

3) Step-Down Transformer:

   Steps down high-voltage AC from the grid to a lower, safer voltage appropriate for operation in the circuits and for sensor input. Provides compatibility with the relay and inverter circuits.

4) Relay Circuit (Load Selection Board):

   - Electromechanical relays utilized to switch on which loads based on the status of the source.
   - Relays are activated to:
     - Supply all loads when the grid is turned ON.
     - Supply just the critical load when operating on the battery.

5) Arduino Nano Circuit (Control & Display Board):

   - Read voltage and current values from sensors.

- Determine the present source of power (grid or battery).
- Control relays based on it.
- Display system status (voltage, current, source, state of battery) on an LCD.

6) ACS Current Sensor & Voltage Sensor:

- ACS712/ACS758: Reports real-time current being consumed by the system.
- Sensor: Tracks voltage from the grid and battery.
- Both sensors input data to Arduino Nano for analysis and decision-making purposes.

7) Battery Management System (BMS):

- Protects battery pack from overcharge, deep discharge, overcurrent, and short circuit.
- Keeps battery within safe margins to extend life and provide reliable backup power.

8) Inverter Circuit (Pre-built Module):

- Inverts DC power from battery to AC power to power loads during grid failure.
- Provides sustained power supply to the 4W critical load in battery mode.

2.2 Block Diagram:

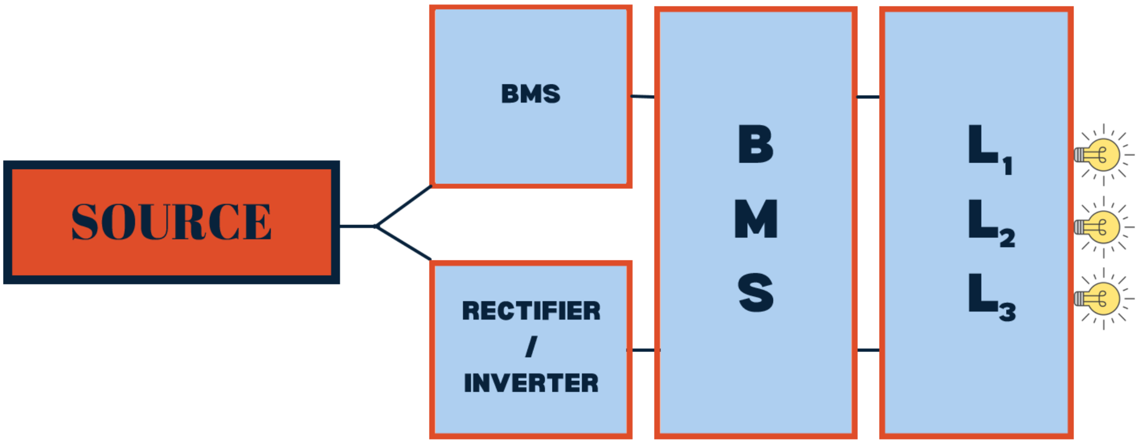


Fig 1: Basic Block diagram

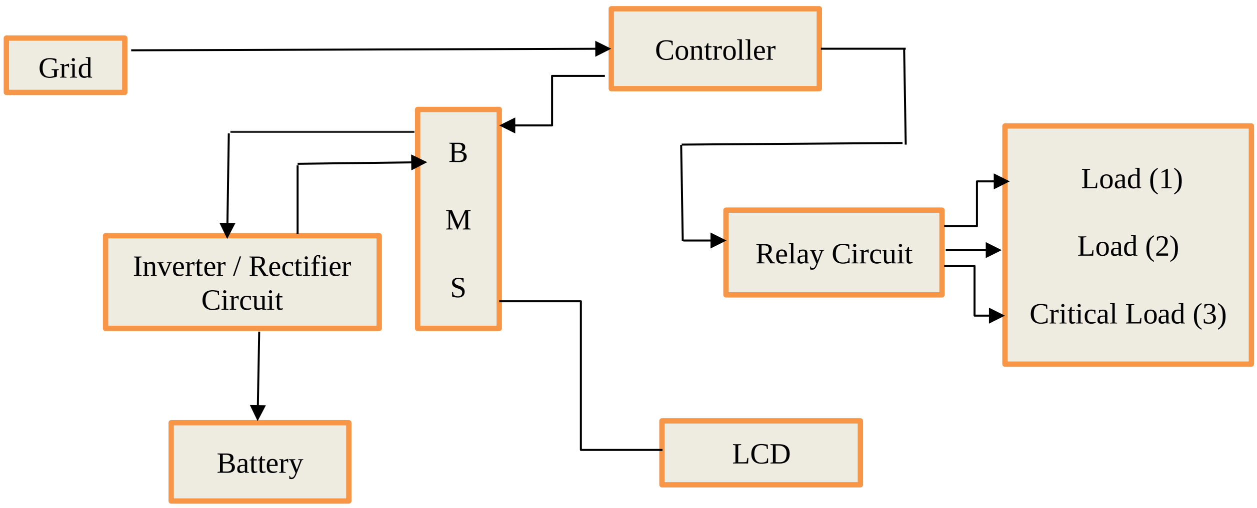


Fig 2: Expanded Block diagram

CHAPTER 3
PROJECT METHODOLOGY

1. Requirement Analysis and Problem Definition

- Identified the real-world need for uninterrupted power supply to critical loads in the event of grid failure.
- Defined the roles of grid power as the primary source and battery backup as the secondary source.
- Selected the 4W load as the critical load, which must survive during power outages.

2. Component Selection and System Design

- Step-down transformer for voltage regulation.
- Relay modules for automatic load switching.
- Arduino Nano for control logic and display handling.
- 3S Li-ion battery pack with BMS for safe secondary power.
- ACS712 current sensor and voltage sensor for real-time monitoring.
- Inverter circuit to power loads with AC output from the battery.
- Designed the block diagram and power flow of the system, ensuring modular functionality.

3. **Circuit Development and Assembly (Three primary hardware circuits)**

- Relay Control Board to switch loads based on power source.
- Arduino Nano Board to interface sensors and drive the LCD.
- Power Board (Inverter + Battery Interface) for power conversion and delivery.

4. **Programming and Logic Implementation**

- Detect power source availability
- Read sensor inputs for voltage and current.
- Drive the relay module to select appropriate loads.
- Display key parameters on the LCD (Voltage, Current, Source Status, Charging/Discharging).

5. **Testing and Validation (under two operating modes)**

- Grid ON: All three loads (12W, 4W, 12W) are powered.
- Grid OFF (Battery Mode): Only the 4W critical load remains operational.
- Verified safe operation of the battery using BMS and validated relay switching logic.
- Monitored voltage/current behaviour and battery performance during source transition.

6. Performance Evaluation and Result Analysis

- Observed smooth source transition and correct load prioritization.
- Ensured stable power delivery to the critical load during grid failure.
- Analysed the display outputs to confirm proper monitoring and reporting.

3.1 Design Methodology:

This multi-layered design approach provides energy efficiency, reliability, and load prioritization—central to smart infrastructure solutions that will be part of future energy management systems.

1. System Architecture Design

- Created a block diagram describing power flow from two sources (Grid and Battery) to three loads with prioritized logic.
- Specified the function of each component and circuit board (Relay board, Arduino board, and Inverter unit).
- Indicated evident demarcation between source control, load regulation, and monitoring/display systems.

2. Power Source Configuration

- Primary Source: Grid Supply was stepped down via a 12V step-down transformer.
- Secondary Source: 3S Battery Pack (11.1V) with a Battery Management System (BMS) for control and protection.
- An inverter module was provided to supply standard loads with battery DC to AC in

case of need.

3. Load Management Design

- Critical Load (4W) – should be operational at all times even in case of grid failure.
- Non-Critical Loads (12W + 12W) – switched off in case of battery backup mode.
- Developed a relay-based switch circuit to control load automatically based on the source power status.

4. Sensor and Monitoring Integration

- Implemented ACS712 current sensor and voltage sensor to monitor power flow, charging/discharging activity.
- Employed Arduino Nano as a microcontroller for:
- Sensor reading.
- Switching decision-making.
- Displaying real-time information on an LCD display (voltage, current, source status, battery mode).

5. Control Logic Development

- Custom logic was implemented on Arduino to:
- Sense grid availability.
- Switch relays appropriately (all loads ON when grid mode; critical load ON when battery mode).

- Display system status (e.g., "Running on Grid" / "Running on Battery", with voltage and current readings).

6. Protection and Reliability Layer

- Protection against overcharge and deep discharge.
- Proper current flow during charging and discharging.
- Isolation using relays prevents arcing and damage to the system.

7. PCB and Hardware Assembly

- Constructed and built custom PCB boards for:
- Relay and load control circuit.
- Arduino control and LCD interface.
- Each component was mounted onto a compact hardware layout, with ideal wiring and marking for demonstration and testing.

8. Simulation and Testing

- Pre-initial logic was simulated (if necessary).
- Hardware testing was conducted in phases:
- Testing grid-to-battery switchover.
- Observing load response.

- Verifying display outputs and system stability during switching.

3.2 Circuit Explanation:

The project setup is based on three circuit modules:

- **Circuit-1 The relay selection circuit**

  This circuit is set up to switch automatically between power from the grid (via a transformer) and power from batteries, based on what is available. The AC output from the transformer is routed in via a green terminal block. This AC voltage is converted to DC through a full-bridge rectifier composed of four diodes. The DC voltage resulting is then smoothed out by a filter capacitor to create a stable supply.

  A green LED is provided to show when grid power is available, and a resistor in series with the LED is used to limit the current flow and safeguard the LED. The primary switching operation is performed by two blue electromagnetic relays. When grid power is present, the relays are powered and permit power from the transformer to flow to the load. In case the grid power goes down, the relays lose power and switch the circuit automatically so the load can be energized from the battery.

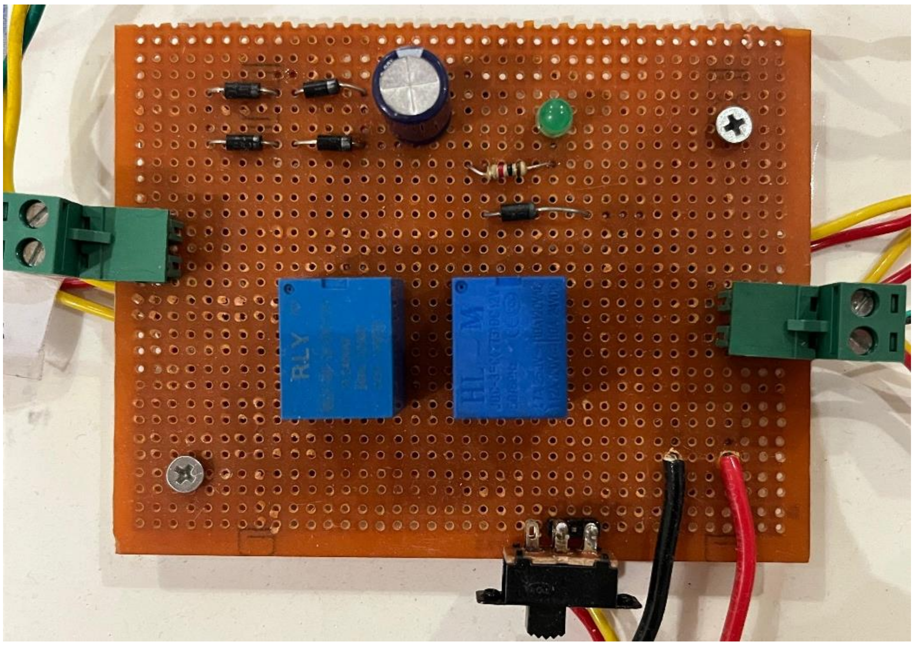


Fig 3: The relay selection circuit

- **Circuit-2 Inverter circuit**

  This inverter circuit is designed to provide the backup power to the critical loads when the grid fails. It consists of a step-up transformer, heatsinked MOSFETs, an oscillator IC, diodes, and terminal blocks for connections. When grid power is cut off and the system goes to battery (via the relay circuit), this inverter draws the DC power from the battery and converts it into AC power. The oscillator IC produces a stream of high-speed pulses that are delivered to the MOSFETs. These MOSFETs quickly switch the DC on and off, producing a square-wave signal simulating AC. The pulsed DC is then supplied to the step-up transformer, which steps up the voltage to an appropriate AC level to suit the load. In this manner, even with a power failure, the system guarantees that a critical load (such as a 4-watt device) is supplied.

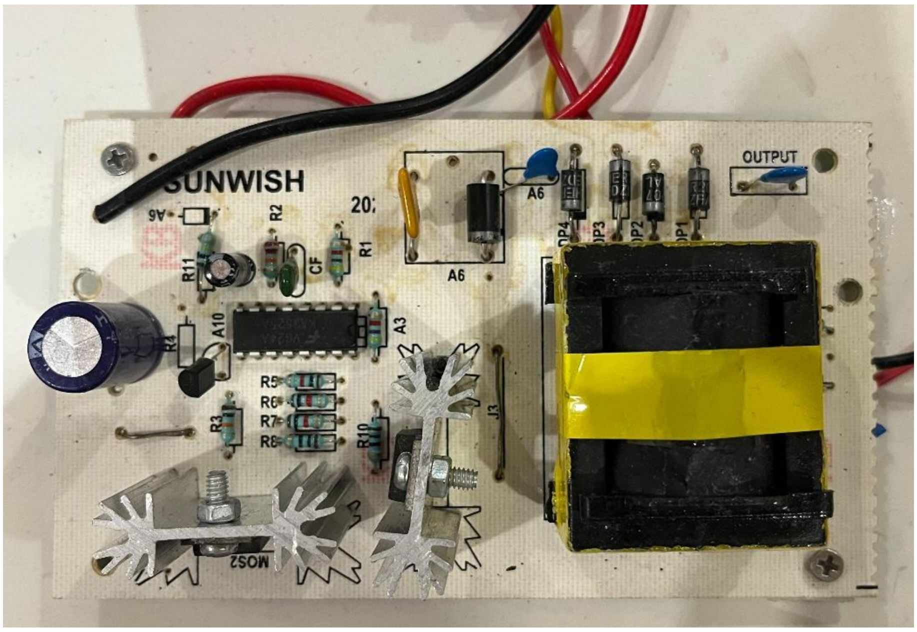


Fig 4: Inverter circuit

- **Circuit-3 Microcontroller circuit**

  This circuit constitutes the intelligent control unit of the project and is constructed around an Arduino Nano microcontroller, which senses system parameters and controls the relays and display accordingly.

  The microcontroller is tasked with determining when to switch between battery and grid, managing the load operations, and updating the display in real time. A buzzer is also interfaced to provide alerts for certain events like power failure or low battery. The circuit has two relays that can be used for other control purposes, e.g., powering only the critical load selectively in battery mode. Other components such as resistors, a voltage-smoothing capacitor, and a voltage regulator provides stable operation for the microcontroller. A current sensor module (ACS712) can be seen, which assists in real-time current monitoring.

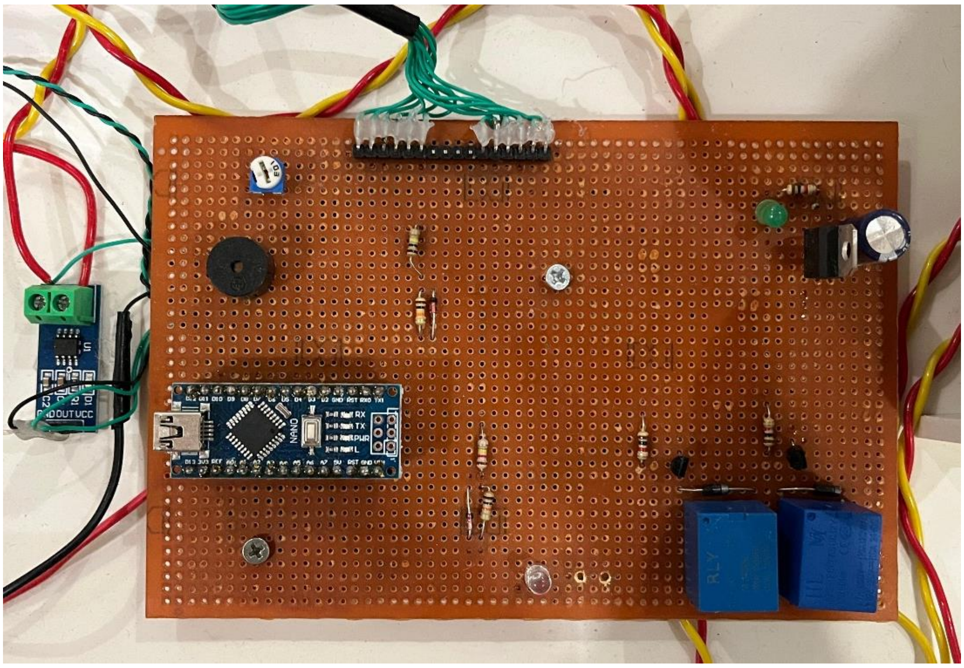


Fig 5: Microcontroller circuit

- ❖ Other parts involve voltage step-down transformer where necessary, a battery pack for energy storage, a Battery Management System (BMS) for protecting and controlling the performance of the battery, and an LCD display for user interface. The load connection consists of three loads (12W, 4W, 12W).

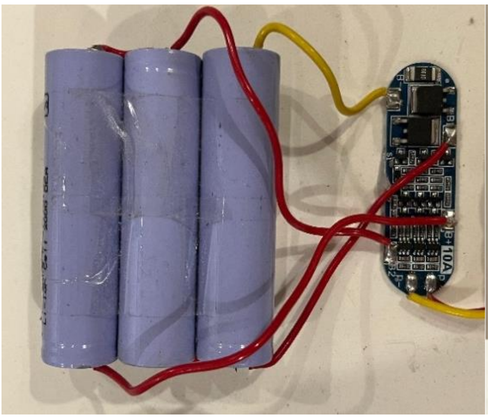


Fig 6: Battery Pack **Fig 6: Load Connection**

3.3 Workflow:

- Define Project Objective
- Classify Loads into Critical and Non-Critical
- Design Block diagram & Circuit Schematic
- Select and Integrate Components
- Develop Control Logic in Microcontroller
- Simulate and Verify Using Software Tools (e.g., Proteus)
- Test Functionality under Grid and Battery Mode
- Analyse Output Results and System Response

3.4 Working:

1. **Power Supply Section**

Central to the circuit is the step-down transformer (TR1), which steps down the input AC mains voltage of 220V into a safer and more manageable 12V AC. This is a critical conversion since the rest of the circuit components are designed to run at lower voltages.

The secondary output of the transformer is then rectified by a full-wave bridge rectifier composed of four 1N4007 diodes (D1–D4). This rectifier reduces the AC voltage to a pulsating DC voltage. To eliminate the ripples and produce a stable DC voltage, a 470μF electrolytic capacitor (C1) is employed for the filtering process. The filtered voltage is then regulated down to a constant 5V with the help of a 7805 voltage regulator (U1). This 5V regulated output is used as the supply voltage by the Arduino Nano and other logic-level devices like sensors, relays, and the LCD.

2. Voltage and Current Sensing Section

Precise sensing of both current and voltage is essential to this system's dynamic switching of sources and load management. The ACS712 (U2) current sensor is included to read the real-time current drawn from the active power supply. It provides an analog voltage in proportion to the current passing through the line, which is read by the Arduino.

To sense the voltage, a voltage divider circuit involving resistors R3 and R4 is utilized. This brings the input voltage down to within the measurable range of the Arduino analog pins. To safeguard the microcontroller against voltage spikes and reverse polarity, a Zener diode (D5) is placed across the analog pin input. This diode clamps the voltage to safe levels, making the sensing unit long-lasting and reliable.

3. Arduino Nano (Control Logic Unit - SIM1)

The Arduino Nano is the controller, collecting inputs from the sensing unit and carrying out control logic based on them. Analog inputs from the voltage divider and the ACS712 sensor enable the Arduino to observe the status of both power sources real-time. From these, the microcontroller decides on using which power source (grid or battery), and on which loads to supply power (critical or non-critical).

Arduino sends digital control signals to the transistors driving the relays (RL1 through RL4). It also controls the LCD and buzzer. The buzzer is used to trigger alarms for fault situations like undervoltage, overcurrent, or when the battery runs low. Early warning is thereby provided and system fault-tolerance is increased.

4. Relay Switching Section (Source and Load Management)

The relay section is the heart of the switching mechanism of the system. It consists of four relays—RL1 to RL4—which are used to dynamically switch between various power sources and loads.

RL1 and RL2 control switching between the battery and grid. When the grid supply is present and within a safe voltage margin, the relays switch the grid to the load. When there is grid failure or abnormal voltage, the Arduino switches the relay that transfers the load to the battery backup source.

RL3 and RL4 manage the isolation of loads. Critical loads (e.g., life-saving appliances or critical communications systems) have priority and will continue to operate as long as any source continues to be present. Non-critical loads will be isolated when power is inadequate in order to save energy.

To make low-power Arduino pins switch high-power relays, transistor drivers (Q1 and Q2 – BC547) are employed. These NPN transistors serve as electronic switches, switching the relays ON or OFF depending on digital outputs from the Arduino.

5. Load Connection Section

Three loads—L1, L2, and L3—are linked to the relay output terminals. Of these, at least one load is a critical load (e.g., L1). The Arduino's programmed logic makes sure that this load stays connected even under battery power only. Non-critical loads (e.g., L2 and L3) are cut off during low battery or emergency conditions to favor the critical load. This constitutes the load-shedding mechanism, which is required for power optimization.

6. LCD Display Unit (LM044L)

For giving user-friendly feedback and real-time system feedback, an LCD module (LM044L) is connected to the Arduino. This alphanumeric 16x4 display indicates important system parameters like:

- Power source status (Grid/Battery)
- Readings of input voltage and output current
- Load conditions (which loads are ON/OFF)
- Battery voltage level or critical alerts

7. Buzzer Alarm

A buzzer module is provided in the circuit for sound alerts. The buzzer triggers when the system detects conditions such as:

- Critically low battery voltage
- Overcurrent conditions
- Grid voltage going beyond the acceptable range

The intention behind this alert system is to inform users in a timely manner, allowing for timely interventions and maintenance measures.

8. Overall System Functionality

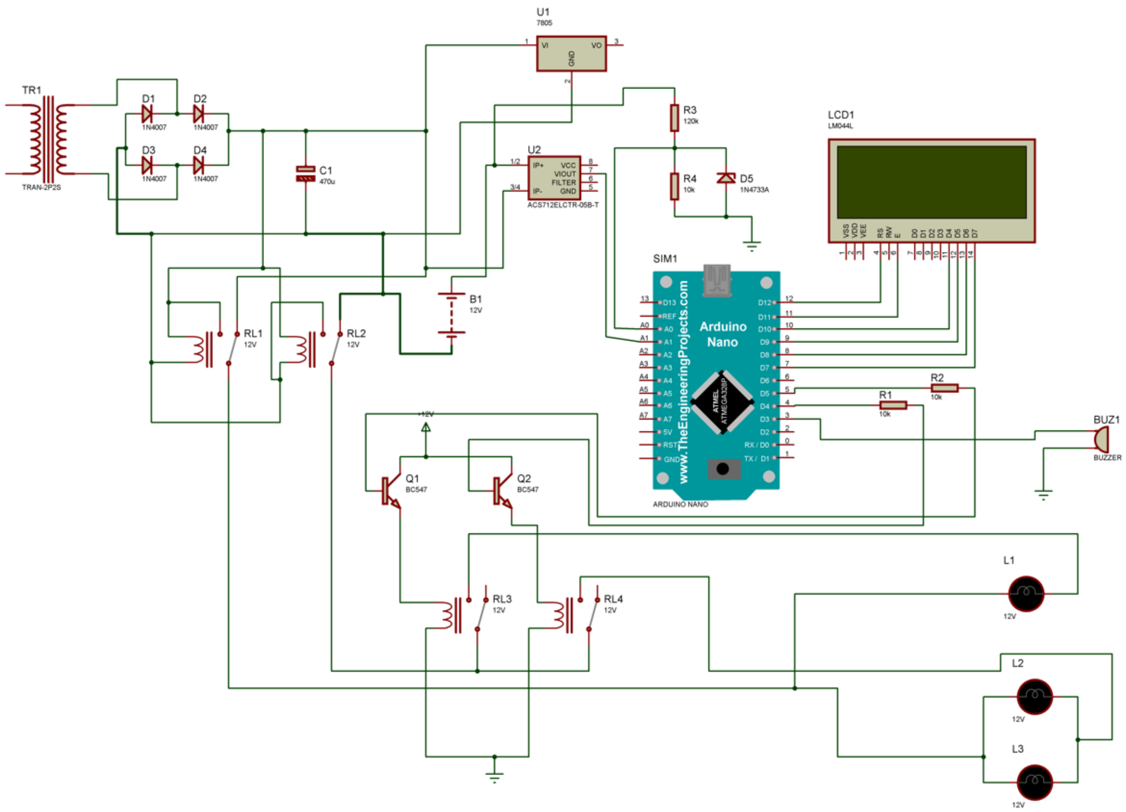
The whole circuit is planned to optimize source control by intelligent monitoring and switching with a view to maintaining continuous supply to the critical loads. The operation of each stage is coordinated through the Arduino, which executes real-time data and makes rapid yet reliable decisions.

CHAPTER 4

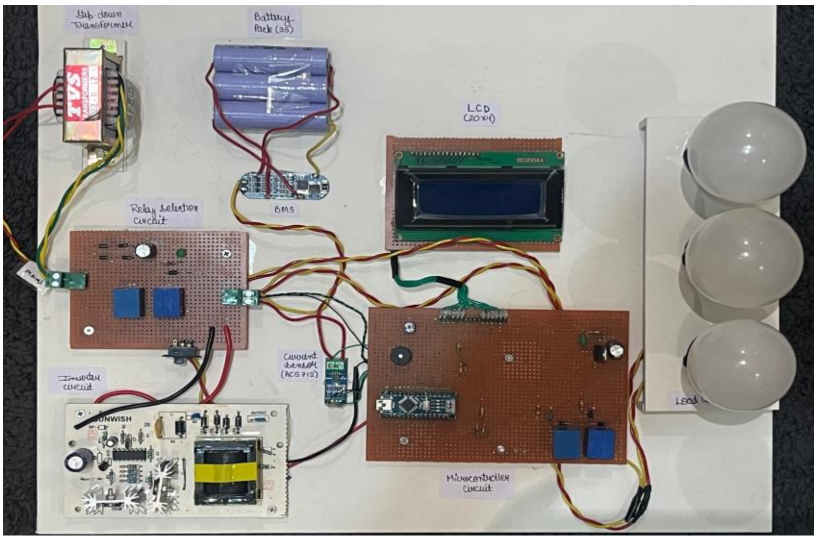
VISUAL DOCUMENTATION

Visual aids will offer insights into the assembly process, functionality and challenges observed in the real time use.

4.1 Circuit diagram:



4.2 Assembled Project



4.3 Code

```
#include<LiquidCrystal.h>
LiquidCrystal lcd(12, 11, 10, 9, 8, 7);
void setup()
{
  Serial.begin(9600);
  lcd.begin(20, 4);
  pinMode(3, OUTPUT);
  pinMode(4, OUTPUT);
  pinMode(5, OUTPUT);
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  pinMode(A2, INPUT);
  lcd.clear();
  lcd.setCursor(3, 1);
  lcd.print("Smart Battery");
  lcd.setCursor(1, 2);
  lcd.print("Monitoring System");
  digitalWrite(3, HIGH);
  delay(200);
  digitalWrite(3, LOW);
  delay(2000);
}
int count = 0;
void loop()
{
  int line = analogRead(A2);
  float v1 = calcV();
  float Amp1 = calAmp(0);
  Serial.println(line);

  if (line < 100)
  {
    digitalWrite(4, LOW);
     delay(100);
    digitalWrite(5, HIGH);
    if (count == 0)
    {
      count = 1;
      digitalWrite(3, HIGH);
      delay(200);
      digitalWrite(3, LOW);
    }
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("System On: Battery");
    lcd.setCursor(0, 1);
    lcd.print("Voltage:");
```

```
    lcd.print(v1,1);
    lcd.print("V");
    lcd.setCursor(0, 2);
    lcd.print("Current:");
    lcd.print(Amp1,1);
    lcd.print("A");
    lcd.setCursor(0, 3);
    lcd.print("Battery: Discharging");
  }
  else
  {
    count = 0;
    digitalWrite(4, HIGH);
    delay(100);
    digitalWrite(5, HIGH);
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("System On: Grid");
    lcd.setCursor(0, 1);
    lcd.print("Battery: Charging");
    lcd.setCursor(0, 2);
    lcd.print("Voltage: ");
    lcd.print(v1,1);
    lcd.print("V");
    lcd.setCursor(0, 3);
    lcd.print("Full load on");
  }
  delay(200);
}

float calcV()
{
  int adc_value = 0;
  adc_value = analogRead(A0);
  float adc_voltage = 0.0;
  float in_voltage = 0.0;
  float R1 = 119000.0;
  float R2 = 10000.0;
  float ref_voltage = 5.0;
  adc_voltage  = (adc_value * ref_voltage) / 1024.0;
  ref_voltage = adc_voltage * (R1 + R2) / R2;
  return in_voltage;
}

float calAmp(int z)
{
  unsigned int x = 0;
```

```
  float AcsValue = 0.0, Samples = 0.0, AvgAcs = 0.0, AcsValueF = 0.0;
  for (int x = 0; x < 10; x++)
  {
    AcsValue = analogRead(A1);
    Samples = Samples + AcsValue;
    delay (3);
  }
  AvgAcs = Samples / 10.0;
  if (z == 1)
  {
    AcsValueF = (2.5 - (AvgAcs * (0.5 / 1024.0)) ) / 0.076;
  }
  else
  {
    AcsValueF = (2.5 - (AvgAcs * (0.5 / 1024.0))) / 0.195;
  }

  if (AcsValueF <= 0.3)
  {
    AcsValueF = 0;
  }
  delay(50);
  return (Samples);
}
```

CHAPTER 5
PROJECT OUTCOME

One of the major achievements of this project is the automatic switching mechanism of the relay, allowing for smooth transitions between power supplies without human interaction or system interruption. This is probably achieved using programmed microcontroller logic to enable reliability and response. The system also provides real-time monitoring via an LCD screen, providing users with clear observations of system condition, voltage, and current states.

The project also confirms load stability, as the system operates in a working condition throughout changes and variations in voltage. This reflects effective load control and ensures that the switching circuit, voltage sensing, and the relay control logic are working as expected.

In all, the project is successful in its goal of constructing a streamlined, self-governing power management system with built-in monitoring and source-switching. This can be optimized further in future implementations with solar charging support or sophisticated battery management algorithms.

1.1 Outcomes

Table below shows the trend in voltage under both charging and discharging conditions, and helps to study the system stability and relay functioning through these auto transitions:

S.No	Mode	Function	Voltage Range (v)	Load Status
1	Grid	Charging	11.0V - 11.5V	Full Load
2	Battery	Discharging	10.6V - 11.0V	Only Critical

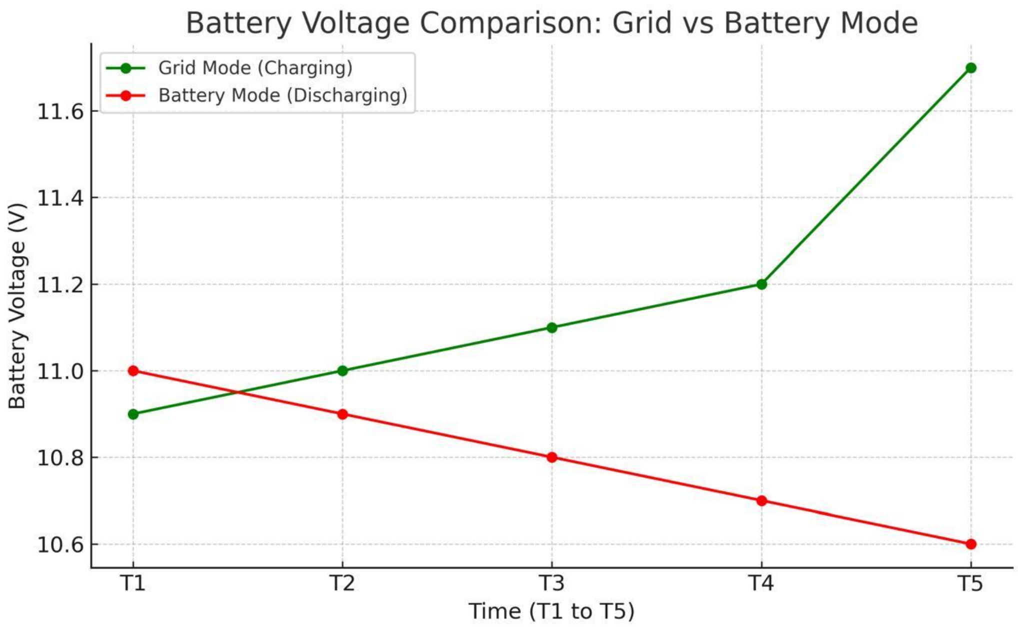


Fig 7: Voltage Comparison: Grid vs Battery

1.2 Challenges

- **Load Prioritization and Management**

  Prioritization and management of critical and non-critical loads was among the main challenges. It was important to make sure critical loads (for example, medical equipment, security systems) kept getting uninterrupted power while dropping non-essential loads during power shortage. Developing a priority-based load shedding system that dynamically adapted to the real-time status of source availability and load demand called for fine-grained logic and precise mapping of power flow.

- **Synchronization of Multiple Power Sources**

  Smooth unification of various generating sources like solar panels, batteries, and grid supply was challenging in terms of maintaining phase, voltage, and frequency synchronization. Changes in voltage levels and intermittent availability of renewables like solar created challenges in achieving smooth transition between sources. Particular care was needed for switching protocols in order to prevent back-feed, voltage surges, or instantaneous outages.

- **Sensor Data Calibration and Reliability**

  The prototype employed different sensors for monitoring voltage, current, and battery states. The accuracy of the sensor measurements was crucial for making real-time decisions. Inaccurate or noisy sensor readings caused by electromagnetic interference (EMI) or component tolerance affected the system with false indications. These could initiate unwanted load shedding or source switching. Noise filters, calibration procedures, and fail-safes needed to be employed.

- **Power Management and Source Health Monitoring**

  Efficient management of power flow from the battery (or backup sources) was a challenging task. SoC monitoring, DoD, and battery temperature were critical to preserve battery life and prevent system crashes. Further circuitry and code had to be created to guard against overcharging, under-voltage, and overheating conditions.

- **Wiring Complexity and PCB Design**

  Given several elements such as relays, sensors, microcontrollers, and switching circuits, wiring organization was a considerable problem. Complexity in the system heightened the risk of improper connections, voltage drops, or shorts. Stable and compact hardware integration required proper routing, labeling, and PCB prototyping.

- **Controller Logic and Code Optimization**

  The heart of the system was developed using a microcontroller (e.g., Arduino/ESP32), executing logic to manage source selection, load prioritization, and fault detection. Writing efficient, modular code to process real-time inputs and respond appropriately was imperative. Preventing the controller from hanging or slowing down due to memory overload or late interrupts necessitated thorough testing and debugging.

- **Testing Under Real Load Conditions**

  Emulating actual power grid failure conditions to verify the switching and load survivability logic in the prototype was another challenge. Producing controlled yet realistic variation in power availability, while verifying the system was responding appropriately without harming components, required iterative testing. The issue was to emulate grid failures and renewable variability without risking hardware.

1.3 Learning Outcomes

- **Familiarity with Smart Power Management:**

  Through this project we have gained practical experience in developing a system that maximizes the utilization of several power sources (grid and battery) in order to maintain an uninterrupted supply to critical loads, a critical notion in contemporary smart grids and renewable energy systems.

- **Practical Implementation of Embedded Systems:**

  I have gained the knowledge to combine microcontrollers, sensors, and relays to implement automatic power control and monitoring the building blocks of industrial automation and IoT-based infrastructure.

- **Effective Load Prioritization and Energy Saving:**

  Through selective load operation during battery backup, you demonstrated how energy efficiency and resource saving are possible in real-time power management systems.

CHAPTER 6

CONCLUSION

The project "Optimize Management of Multiple Generating Sources for the Survival of the Critical Load" is a valuable addition to the field of energy management and smart load control systems. The project focuses on the need to design efficient, automatic systems that automatically prioritize critical electrical loads and provide them with uninterrupted supply, particularly when there is a power outage or fluctuation in the sources. This project was a combination of theoretical principles, hardware development of circuits, sensor interfacing, and microcontroller-based automation.

The objective was to control the power supply from two sources—the grid and a backup battery—and optimize power use to guarantee critical loads are continuously powered, even when the total power available is inadequate. By ensuring successful deployment of this system, the project illustrates how pragmatism in design, coupled with automation, can be applied toward real-world solutions in smart homes, hospitals, data centres, and industrial applications where reliability is essential.

One of the most important learnings from this project was learning the logic of source selection and load prioritization. In normal operating conditions when grid power is present, the system operates all the loads that are specified. But in case the grid supply is lost, the controller monitors the battery status. If the battery is charged, it provides only critical loads. This decision-making process not only maximizes the utilization of resources but also increases the robustness of the system during failure conditions.

Another major accomplishment was the capacity to implement and comprehend real-time monitoring with sensors and the display interface. By reading analogue values from the voltage divider and ACS712 sensor and showing them on an LCD, this project bridged the divide between intangible sensor readings and tangible user interfaces. In addition, working on the Arduino programming for managing multiple inputs and outputs, logical operations, fault conditions, and real-time display helped in reinforcing programming and system logic design abilities.

The project also enhanced problem-solving and troubleshooting capabilities. Challenges such as sensor calibration, relay timing conflicts, and voltage inconsistencies had to be addressed through debugging and system optimization. This iterative problem-solving process mimics real-world engineering development cycles and provides valuable experience for future professional projects.

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