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Hardware Implementation of Multiple Energy Source Fed BLDC Motor

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Abstract - In recent years, the growing demand for efficient, sustainable, and uninterrupted energy supply systems has led to the integration of multiple energy sources for motor-driven applications. This project presents a hardware-based implementation of a Brushless DC motor powered by multiple energy sources such as battery and external source with an automatic source-switching mechanism using solid state relays. The system is designed to ensure continuous operation of the BLDC motor by automatically shifting between energy sources based on their availability and priority logic. The control logic is implemented using a microcontroller that continuously monitors the voltage levels of each power source. When the primary source (Battery) drops below a preset of the system voltage, seamlessly switches to the next available (External source) using relays, thereby minimizing downtime and maximizing energy efficiency. A prototype circuit is built that includes a BLDC motor drive, relay switching circuit, voltage sensing units, and a microcontroller (Arduino UNO). The performance of the system is evaluated under various loading and power conditions, and the results is reliable and stable operation of the BLDC motor with minimal switching delay and no manual intervention. This project demonstrates a cost-effective and practical approach to energy redundancy in motor control applications, especially beneficial in areas with unstable power supply or remote installations relying on renewable energy sources.

Key Words: Battery, Boost converter, Two channel relay module, ESC, BLDC motor

1.INTRODUCTION

The conservation of energy and environmental protection have emerged as global imperatives. Consequently, governments worldwide have devised strategies to reduce Greenhouse gas emissions from the transportation sector. Technological advancements, particularly in electric vehicles (EVs), are rapidly progressing to meet increasing electricity demand. Internal combustion engine (ICE) vehicles emit significant amounts of CO2 due to fuel combustion, posing a grave environmental threat. Although electric vehicles employ different power sources, their integrated thermal management system (ITMS) aims to reduce emissions, maximize fuel efficiency, and achieve high energy efficiency by using control techniques over the interconnected system. For these purposes, there is a necessity for the integration of various energy-storage devices. Similarly, hybrid energy-storage systems (HESSs) are being explored to segregate power and energy services, as a single energy-storage system may compromise performance and efficiency. Lithium-ion (Li-ion) batteries have become the backbone of modern EVs due to their superior performance. Li-ion and nickel–metal hydride (NiMH) batteries are the primary technologies being used in EVs, with Li-ion batteries being favored for their compactness despite their higher cost and temperature limitations Li-ion batteries offer increased cycle life, higher energy density and a wide range of speed. However, the time required to charge the battery, life span and environmental impact should be considered while selecting a battery. BLDC motors are widely used in electric vehicles, drones, and industrial applications due to their high efficiency, reliability, and compact size. However, their performance is highly dependent on the stability of their power source. To overcome power disruptions and increase reliability, using multiple energy sources is an effective solution

2. EXISTING TOPOLOGY

The hybrid energy-storage system proposed herein comprises a battery, a supercapacitor. DC-DC converters are interfaced with energy-storage devices to enhance power control and voltage regulation in electric vehicles. Illustrates the schematic configuration of the power electronic converter-based system under examination, with all components interconnected in a parallel topology. This proposed model, parallel combinations of battery and supercapacitors are employed for simulation purpose.

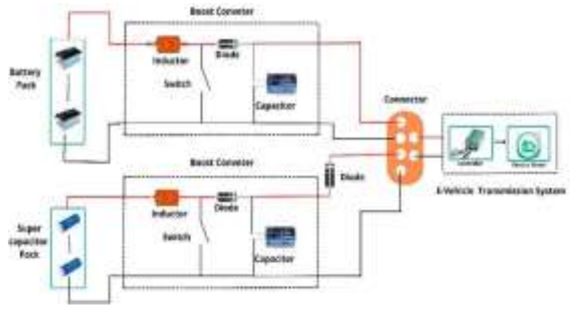

Figure 1.1 Existing topology block diagram

The supercapacitors are connected in parallel via the boost converter. To safeguard against reverse voltage within the system a diode is incorporated between the battery and supercapacitors parallel configuration.

3. OBJECTIVE

Design and Develop a Power Management System: To design and implement a power management circuit that can efficiently integrate multiple energy sources (battery, External source) to feed a Brushless DC (BLDC) motor.

Implement Source Switching Operation: To develop a control strategy for smooth switching or simultaneous operation of multiple energy sources based on availability, load demand, or priority.

Drive a BLDC Motor Using Hybrid Sources: To operate and control a BLDC motor using the power supplied by the integrated multiple energy sources, ensuring stable performance and torque-speed characteristics.

Hardware Prototype Realization: To construct a physical hardware prototype that demonstrates the practical feasibility of the hybrid energy source-fed BLDC motor system.
Ensure System Efficiency and Reliability: To evaluate the efficiency, reliability, and response time of the energy management system under different load and source conditions.
Incorporate Protection Mechanisms: To implement safety and protection circuits for over-voltage, under-voltage and safeguard the system components.
Control and Monitoring Interface: To develop a basic user interface or display (LCD) for real-time monitoring of energy sources, load status, and system performance.

4. DESIGN ASPECTS

Boost Converter

Boost converters are a type of DC-DC switching converter that efficiently increase (step-up) the input voltage to a higher output voltage. By storing energy in an inductor during the switch-on phase and releasing it to the load during the switch-off phase, this voltage conversion is made possible. Power electronics applications requiring a greater output voltage than the input source, in particular, depend on boost converters.

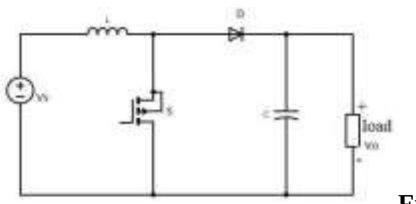

Figure.3.1
Boost Converter Circuit Diagram

The basic principle of operation for a boost converter can be understood through the following two stages:

Switch-on period (S1 closed, S2 open): During this stage, the input voltage (Vin) is applied across the inductor (L), causing the current through the inductor to increase linearly. The energy stored in the inductor builds up, and the diode (D) is reverse-biased, preventing current flow to the load. The inductor current can be expressed as:

$$\Delta I_1 = \frac{V_{in}}{L} * T_{on} \quad (4.1)$$

where ΔIL is the change in inductor current, L is the inductance, and t_{on} is the duration of the switch-on period.

Switch-off period (S1 open, S2 closed): When the switch S1 opens, the inductor current must continue to flow. This forces the diode D to become forward-biased, and the inductor releases its stored energy to the load (R) and the output capacitor (C). During this period, the voltage across the inductor (VL) is equal to the difference between the output voltage (V_{out}) and the input voltage (V_{in}). The inductor current decreases linearly as the energy is transferred to the load, and the equation for the inductor current becomes:

$$\Delta I_1 = \frac{(V_{out} - V_{in})}{L} * T_{off} \quad (4.2)$$

where t_{off} is the duration of the switch-off period. By equating the inductor current equations for both stages and rearranging the terms, we can derive the voltage conversion relationship for the boost converter:

$$V_{out} = \frac{V_{in}}{(1-D)} \quad (4.3)$$

where D is the duty cycle, defined as the ratio of the switch-on time (t_{on}) to the total switching period (T), or

$$D = \frac{T_{ON}}{T_{ON} + T_{OFF}} \quad (4.4)$$

This equation shows that the output voltage can be controlled by adjusting the duty cycle of the switching waveform, allowing for a higher output voltage than the input voltage.

Voltage Gain:

The voltage gain of a boost converter can be approximated by the following equation:

$$\frac{V_{out}}{V_{in}} = \frac{1}{(1-D)} \quad (4.5)$$

Where:

- V_{out} = is the output voltage
- V_{in} = is the input voltage
- D = is the duty cycle of the switch, defined as the ratio of the ON time to the total switching period.

Inductor Selection Formula

The inductance (L) in a boost converter depends on the following parameters:

- V_{in} = Input voltage
- V_{out} = Output voltage
- I_{out} = Output current (load current)
- f_s = Switching frequency
- ΔI_L = Ripple current in the inductor (typically taken as 20-40% of the output current)

$$L = \frac{V_{in}(V_{out} - V_{in})}{F_s * \Delta I_L * V_{out}} \quad (4.6)$$

Inductor Current Rating

The current rating of the inductor is important to prevent saturation. The peak current through the inductor in a boost converter can be calculated as

$$I_{SW(Max)} = \frac{\Delta I_L}{2} + \frac{I_{out\,(max)}}{(1-D)} \quad (4.7)$$

Where:

- D = duty cycle.
- $I_{out(max)}$ = maximum output current.
- Δ_{IL}= inductor ripple current.

Inductor Ripple Current (ΔIL)

The ripple current (Δ_{IL}) should be carefully selected to balance between efficiency and size. It is generally set as a percentage of the output current, typically 20%-40%. The ripple current can be approximated using the following equation

$$\Delta I_L = \frac{V_{in} * D}{L * F_s} \quad (4.8)$$

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Where:

- L = selected inductor value
- V_{in} = minimum input voltage.
- D = duty cycle
- f_s = minimum switching frequency of the converter.

For good performance, the ripple current is usually designed to be around 20 to 40% of the output current.

$$\Delta I_L = (0.2 \text{ to } 0.4) * I_{out(max)} * \frac{V_{out}}{V_{in}} \qquad (4.9)$$

- ΔI_L = inductor ripple current
- $I_{out(max)}$ = maximum output current

Selection of Capacitors:

The selection of the capacitor in a boost converter is a crucial part of the design, as it plays a key role in filtering the output voltage and stabilizing the converter's operation. The capacitor smooths out voltage ripple caused by the switching process and ensures a steady output voltage for the load.

Formula for Output Capacitor Selection

The output voltage ripple ΔV_{out} is primarily determined by the ripple current (C_{out}) flowing through the capacitor. The relationship between output voltage ripple and capacitor can be approximated as:

$$C_{out(min)} = \frac{I_{(out)max} * D}{\Delta V_{out} * F_s} \qquad (4.10)$$

The output capacitor should be chosen based on:

- ΔV_{out} = desired output voltage ripple
- $I_{out(max)}$ = maximum output current
- f_s = minimum switching frequency of the current
- D = duty cycle
- $C_{out(min)}$ = minimum output capacitance.

Consideration of Equivalent Series Resistance (ESR)

The ESR of the capacitor also plays a significant role in the ripple voltage. The ESR causes losses in the capacitor, which contribute to additional ripple in the output voltage. The voltage ripple due to ESR can be approximated as:

$$\Delta V_{out\,(ESR)} = ESR * \left[\frac{I_{out(max)}}{(1-D)} + \frac{\Delta I_L}{2}\right] \qquad (4.11)$$

Where:

- $\Delta V_{out\,(ESR)}$ = output voltage ripple due to capacitors ESR.
- ESR = equivalent series resistance of the used output capacitor.
- $I_{out(max)}$ = maximum output current.
- D = duty cycle
- ΔI_L = inductor ripple current.

Choosing the Input Capacitor (C_{in})

The input capacitor helps reduce the voltage ripple at the input of the boost converter. It filters out the high-frequency switching noise and stabilizes the input voltage, ensuring proper operation of the converter.

The size of the input capacitor depends on the input current and the voltage ripple requirements. A general approach is to use the following formula to estimate the capacitance.

$$C_{in} = \frac{I_{in}}{V_{in} * F_s} \qquad (4.12)$$

Where:

- I_{in} = input current.
- ΔV_{in} = input voltage ripple.
- f_s = switching frequency.

(3.9)

5. DESIGN ASPECTS

Introduction

The proposed system for this project is a modelling of battery based modified boost converter fed Electric vehicle (EV). The modified boost converter is a DC-DC converter topology that combines the advantages of the Boost converter. The modified boost converter topology consists of a boost stage integrated with conventional converter and a switch (MOSFET) that controls the output voltage. The converter operates in continuous conduction mode and discontinuous conduction mode.

The system consists of two power sources:

- **Primary Source** – Battery
- **Secondary Source** – External Power (e.g.AC- DC adapter)
- A relay switching circuit monitors the presence of voltage from the primary source.
- If the voltage drops below a threshold (battery drains or disconnects), the relay disconnects the battery and connects the BLDC motor to the external power source. (3.10)
- This switching can be automated using a microcontroller (like Arduino) which checks voltage levels and controls the relay accordingly.
- The relay ensures electrical isolation between both sources, preventing back feeding.
- The BLDC motor receives continuous power, ensuring no interruption in operation.

Power Source Inputs: Each source is connected through a diode to prevent reverse current.
Relay Control: Relay is controlled using a transistor switch driven by a comparator/microcontroller.
Voltage Sensing: Voltage divider circuits feed real-time voltage levels to the controller or comparator.
Protection: Diodes and capacitors are added for surge protection and voltage smoothing.

Implementation

1. Connect both power sources to the relay circuit through blocking diodes.
2. Design a comparator circuit or program an Arduino to detect battery voltage.
3. Control the relay coil through a transistor switch.
4. Interface the relay output to the BLDC driver input.
5. Connect the motor and test operation under both source conditions.

Source Shifting Condition

- If Battery voltage ≥ 5-6 V → Use Battery

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- If Battery voltage < 5 V → Switch to External Source

Block Diagram of the Proposed System

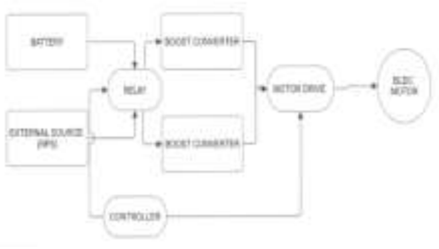

Figure 4.1 block diagram of proposed system

Circuit Diagram of the Proposed System

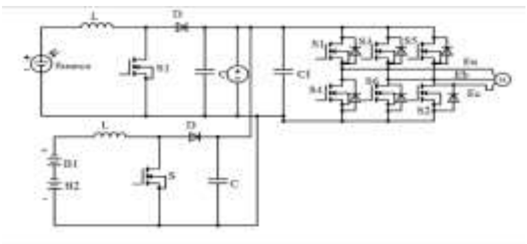

Figure 4.2 Circuit diagram of proposed system

SOURCE 1 (BATTERY)

Introduction

A 6V 4.5Ah lead-acid battery is a rechargeable energy storage device commonly used in low-power DC systems. It is a type of sealed lead-acid (SLA) or valve-regulated lead-acid (VRLA) battery, designed for safe and maintenance-free operation.

Working Principle

The battery stores energy through a chemical reaction between lead plates and sulfuric acid. It consists of positive plates (lead dioxide) and negative plates (spongy lead) submerged in electrolyte (diluted sulfuric acid).

During discharge:
Chemical energy is converted to electrical energy.

- Sulphate ions move to the plates and form lead sulphate.

During charging:

- An external DC source reverses the reaction.
- Lead sulphate is converted back to lead and lead dioxide.

Battery Capacity (Ah Rating)

- The 4.5Ah rating means the battery can theoretically supply 4.5 Amps for 1 hour, or 0.9A for 5 hours, etc.
- This is under ideal conditions; real performance varies based on temperature, discharge rate, and age.

Charging Recommendations

- Use a constant voltage charger with current limiting.
- Charging voltage: 6.8V to 7.2V
- Avoid overcharging or deep discharging (voltage should not fall below 5.4V).

Source 2 (External source) – (RPS)

Introduction

A regulated power supply is an essential electronic device or circuit that delivers a constant and stable output voltage regardless of changes in input voltage or variations in load current. It is widely used in electronic systems where precise and steady voltage is required to ensure safe and reliable operation.

Purpose

The main purpose of a regulated power supply is to:

- Provide a fixed DC voltage to sensitive electronic components or circuits.
- Protect devices from voltage fluctuations that could cause malfunction or damage.
- Ensure consistent performance of circuits like microcontrollers, sensors, and motor drivers.

Flow chart

[AC Supply]
↓
[Transformer] → [Rectifier] → [Filter] → [Voltage Regulator] → [DC Output]

Main Components

i. Transformer

- Steps down the high-voltage AC (e.g., 230V) to a lower AC voltage (e.g., 12V or 24V).
- Provides electrical isolation between input and output.

ii. Rectifier

- Converts AC voltage to pulsating DC.
- Common types: Bridge rectifier or Half-wave/Full-wave rectifiers.

iii. Filter

- Removes the ripple from the rectified DC voltage using capacitors and sometimes inductors.
- Provides smooth DC voltage.

iv. Voltage Regulator

- Maintains a constant output voltage (e.g., 5V, 12V, 15V) even if the input voltage or load changes.
- Examples: 78XX series (for positive voltage) and 79XX series (for negative voltage), or LM317 (adjustable).
- Can also use switching regulators (SMPS) for higher efficiency.

6. Dc Link

A DC link is a connection which connects a rectifier and an inverter. These links are found in converter circuits and in Variable Frequency Drive (VFD) circuits. The AC supply of a specific frequency is converted into DC. This DC, in turn, is converted into AC voltage. In the first stage when this AC is converted to DC, the DC voltage is made available in a DC bus.

This bus acts as a link between the converter and the inverter circuit. This DC voltage is called the 'DC link voltage.

7. Two Channel Relay Module:

Two -channel relay module allows you to control two separate electrical devices using a microcontroller like an Arduino. A relay is an electromagnetic switch that uses a small control signal (from a microcontroller) to switch a larger load (like a motor) on or off.

2-channel relay modules include:

Control Pins:

- **IN1** – Controls Relay 1
- **IN2** – Controls Relay 2
- **VCC** – Power supply for the relay (typically 5V or 3.3V)
- **GND** – Ground connection

Relay Output Terminals (per relay):

- **NO (Normally Open)** – Open when relay is inactive; closed when active
- **COM (Common)** – The common terminal
- **NC (Normally Closed)** – Closed when relay is inactive; open when active
- **Relay 1**: COM1, NO1, NC1
- **Relay 2**: COM2, NO2, NC2

Figure: 7.1 Two channel relay module

These relays act as switches, allowing a microcontroller or other control circuit to activate them independently, turning on or off different devices.

• Send **LOW** to IN1 → Relay 1 turns **ON**
• Send **HIGH** to IN1 → Relay 1 turns **OFF**

8. BLDC Motor

- A brushless DC motor (known as BLDC) is a permanent magnet synchronous electric motor which is driven by direct current (DC) electricity and it accomplishes electronically controlled commutation system (commutation is the process of producing rotational torque in the motor by changing phase currents through it at appropriate times) instead of a mechanically commutation system. BLDC motors are also referred as trapezoidal permanent magnet motors.
- The armature coils are switched electronically by transistors or silicon-controlled rectifiers at the correct rotor position in such a way that armature field is in space quadrature with the rotor field poles. Hence the force acting on the rotor causes it to rotate.
- The specifications of the BLDC motor used in this study

$V_a = I_aR_a + Ldi_adt + e_a$

$V_b = I_bR_b + Ldi_bdt + e_b$

$V_c = I_cR_c + Ldi_cdt + e_c$

BLDC motors have two torque parameters: peak torque and rated torque. The continuous running of the motor allows it to reach at its rated torque. This demand occurs for a short time period, particularly when the motor starts from a standstill or accelerates. During this interval, more torque is required to overcome the inertia of the load and rotor. The motor may reach maximum torque by following the speed torque curve. The motor maintains a continuous torque zone until it reaches its maximum torque value at the specified speed. After surpassing the rated speed, the motor's torque diminishes. Stall torque is the point on the graph when the torque is maximal but the shaft does not rotate. The no-load speed is the motor's maximum output speed. The speed is primarily controlled by voltage and may be adjusted by adjusting the supply voltage. PWM controls the voltage, thus maintaining the speed-torque characteristics for both continuous and intermittent operation. Figure 8 illustrates the speed-torque characteristics of a BLDC motor.

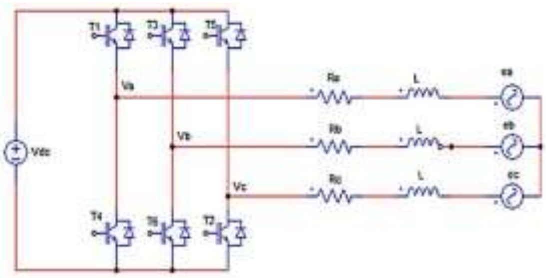

Figure 8.1 Equivalent circuit diagram of BLDC motor

9. SIMULATION DIAGRAM

The configuration of the battery and external source connected in parallel**.** In the Simulink model, the external source output is directed through a controller to the DC-DC converter. thus, ensuring that the battery bank is supplied while maintaining a constant DC output voltage. Under typical operational conditions where the external source output is adequate to meet the load demands, the battery bank remains floating, implying that it is fully charged.

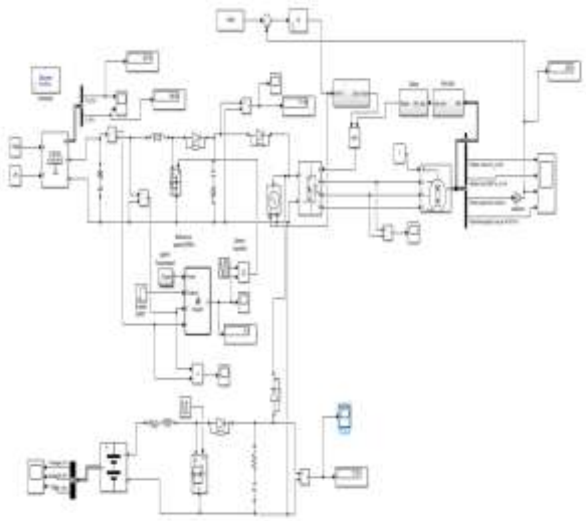

Figure 9.1 Simulation diagram for the proposed system

Simulation Result of BLDC Torque, Speed, Emf:

Simulation Output waveform for Stator current, torque and speed and EMF

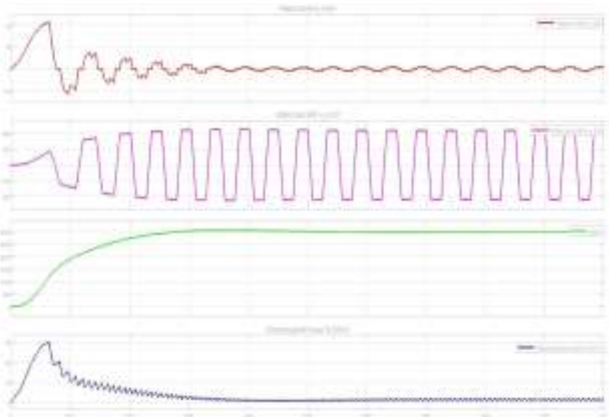

Figure 5.2 simulation output waveform

9.3 Simulation Result of External System:

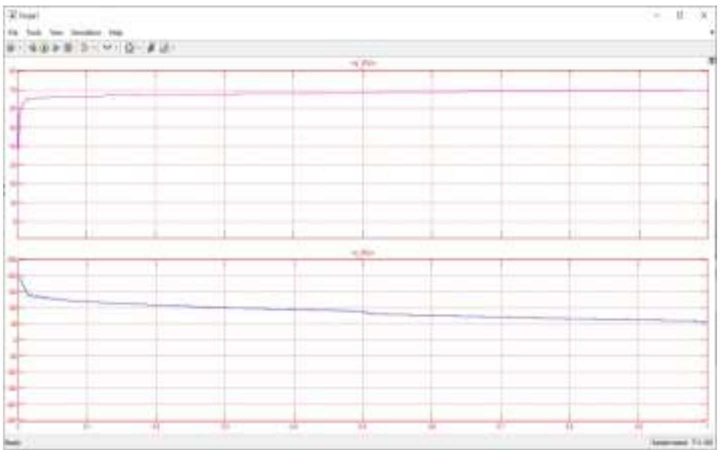

Figure 5.3 source 1 output waveform

9.4 Simulation Result of Battery Output:

Figure 5.4 Battery output waveform

10. HARDWARE DIAGRAM

Hardware Implementation Components Used:

Component	Specification
BLDC Motor	12V, 3-phase, 1500 RPM
Battery	6V, 4.5Ah Lead Acid
External Source	Battery / RPS
Relay	Solid state relay 5V DC Relay
Microcontroller	Arduino Uno
Motor Driver	ESC
Diodes	U1630
Capacitors	For voltage smoothing
Converter	Boost Converter

Table 10.1 list of hardware parameters

10.2 Relay Switching Tabulation:

PARAMETER	CONDITION	ACTION	MOTOR CONDITION
Battery Voltage	Above cutoff (e.g., > 6V)	Use Battery (Relay R1 ON, Relay R2 OFF)	ON
Battery Voltage	Below cutoff (e.g., ≤ 5V)	Switch to External (Relay R1 OFF, R2 ON)	ON

External Source	Not available	Motor turns off if battery is also low	OFF

10.3 HARDWARE DIAGRAM:

Source 1 Circuit Diagram:

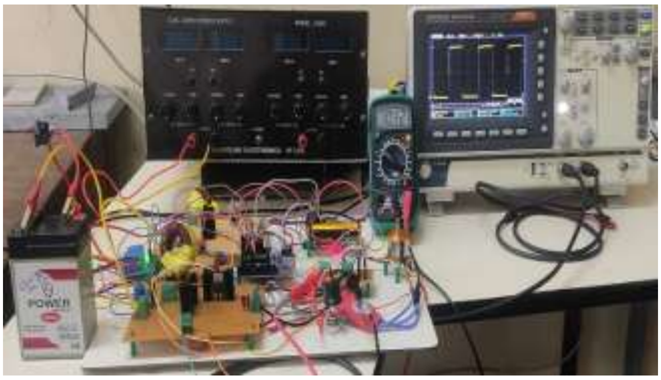

Figure 10.1 Battery used circuit diagram

This Diagram is battery to power a BLDC (Brushless DC) motor, but the battery voltage isn't high enough, so you use a boost converter to increase the voltage. A potentiometer is used to control the speed of the BLDC motor.

Source 2 Circuit Diagram

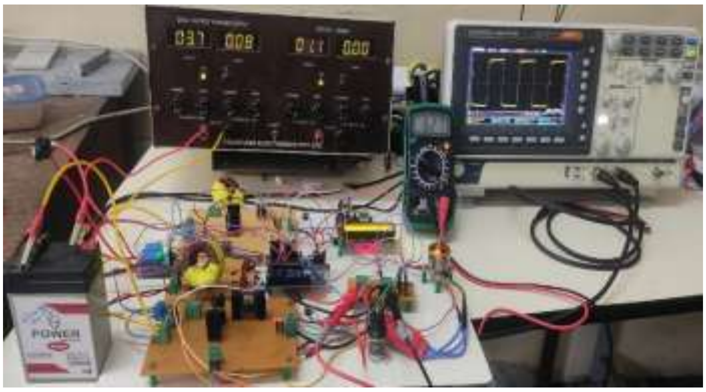

Figure 10.2 External source used circuit diagram

In this source diagram external power source (like a RPS supply), step up the voltage with a boost converter, and control a BLDC motor's speed using a potentiometer.

10.4 Result of BLDC Motor:

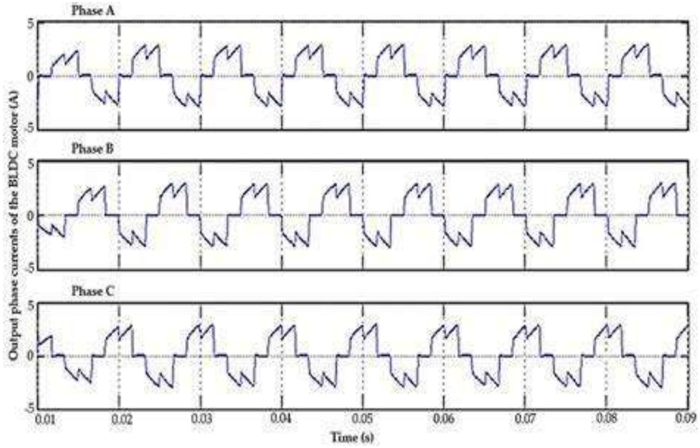

Figure 10.3 Output waveform of BLDC motor

CONCLUSION

The successful hardware implementation of a multiple energy source system for a BLDC motor using relay-based automatic source shifting demonstrates an effective approach for ensuring uninterrupted power supply and enhanced system reliability. By integrating various energy sources such as battery and solar. The system automatically transitions between sources based on availability and priority, without manual intervention. The use of relays provides a cost-effective and simple control mechanism for source selection.

This approach enhances the operational efficiency of BLDC motors, especially in applications where power continuity is critical, such as electric vehicles, renewable energy systems. Experimental results confirm that the motor operates seamlessly during source transitions with minimal delay and no significant voltage drop or performance degradation. Overall, this system offers a robust, scalable, and energy-efficient solution for modern motor-driven applications requiring multiple power inputs.

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