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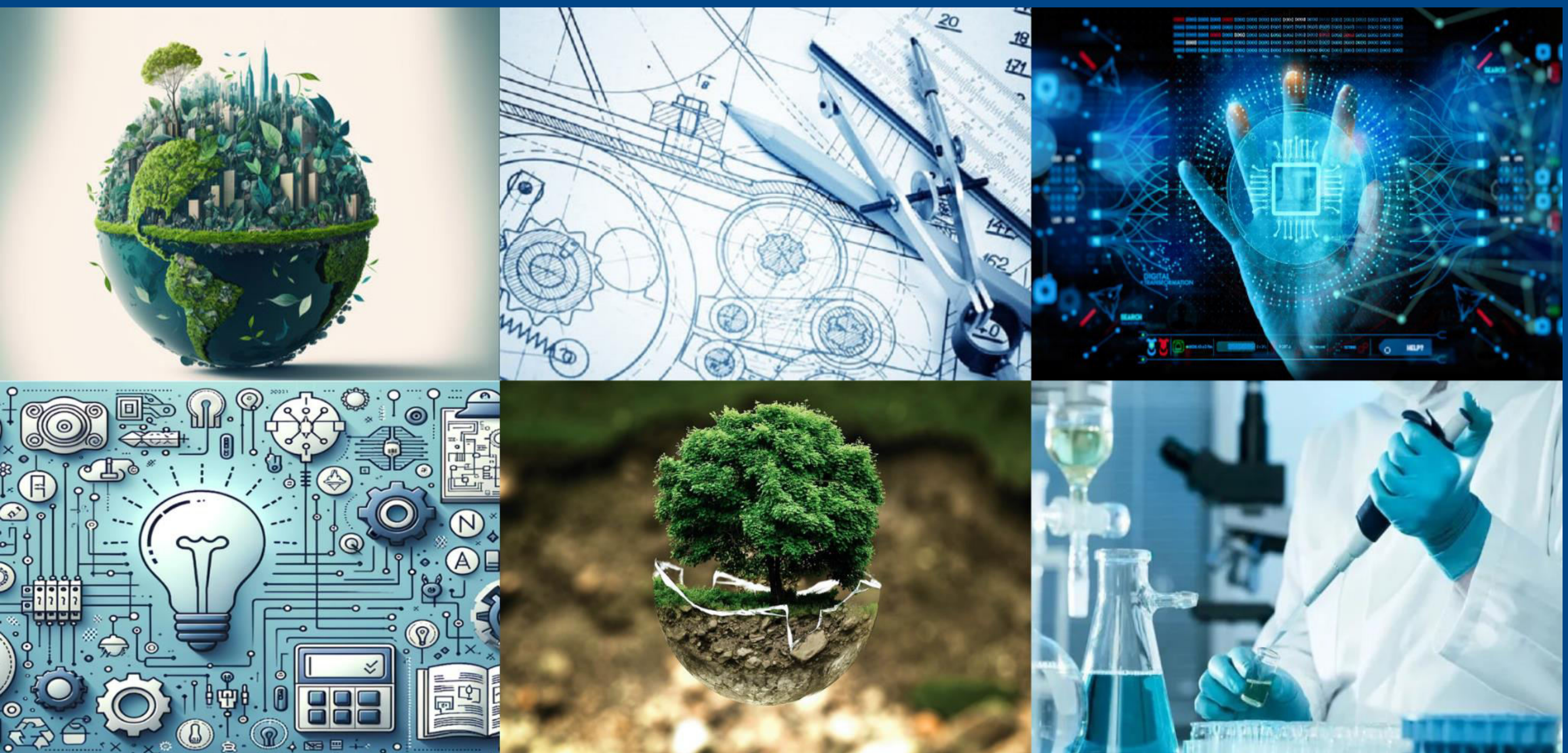

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Design and Development of an Uninterruptible Power Supply Using Solid State Relays

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ABSTRACT: Uninterruptible Power Supply (UPS) systems play a critical role in ensuring continuous and reliable power delivery to sensitive and mission-critical loads during power interruptions and voltage fluctuations. This paper presents the design and development of a cost-effective and efficient UPS system utilizing Solid State Relays (SSRs) to achieve high-speed switching, enhanced reliability, and minimized mechanical degradation compared to conventional electromechanical relay-based systems. The proposed UPS architecture integrates a rectifier unit, battery energy storage system, inverter stage, and SSR-based static switching mechanism for seamless transfer between the main power supply and backup source. Under normal operating conditions, the load is supplied directly from the mains while the battery is maintained in a charged state. During power failure or disturbances, the SSRs facilitate near-instantaneous switching to the inverter output, ensuring uninterrupted power delivery with minimal transfer time. The inverter converts stored DC energy into regulated AC power suitable for sensitive electronic devices such as computers and communication equipment. Performance evaluation of the system is carried out based on parameters including switching speed, efficiency, voltage stability, and reliability under varying load conditions. Experimental results demonstrate that the SSR-based UPS system provides fast response, stable output, and seamless transition, making it a robust and reliable solution for modern power backup applications.

KEYWORDS: Uninterruptible Power Supply (UPS), Solid State Relay (SSR), Static Switching, Power Electronics, Inverter, Battery Storage, Fast Switching, Reliable Power Systems.

I. INTRODUCTION

An Uninterruptible Power Supply (UPS) is an essential power electronic system that provides continuous power to critical loads during interruptions or disturbances in the main supply. UPS systems are widely used in applications such as computers, healthcare systems, communication networks, and industrial equipment, where reliable and uninterrupted power is required.

The primary function of a UPS is to maintain power continuity and protect sensitive devices from voltage fluctuations, outages, and transient disturbances. A typical UPS consists of a rectifier, battery storage unit, inverter, and switching mechanism. Under normal conditions, the load is supplied by the mains while the battery is charged. During power failure, the system transfers the load to the inverter, ensuring uninterrupted operation [1].

However, conventional UPS systems often face challenges such as slow switching speed, reduced efficiency, and mechanical wear due to the use of electromechanical relays. Recent studies have focused on improving inverter performance, energy storage systems, and fast switching techniques to enhance overall UPS reliability and efficiency [2]–[6]. Additionally, modern applications demand highly reliable and cost-effective solutions capable of delivering seamless power transfer under varying load conditions [7].

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To address these limitations, this paper presents the design and development of a UPS system using Solid State Relays (SSRs). SSRs offer fast switching, improved reliability, and reduced maintenance due to the absence of moving parts. The proposed system aims to achieve minimal transfer delay, stable output performance, and efficient operation, making it suitable for modern uninterrupted power supply applications.

II. AIM AND OBJECTIVES

Aim:
To design and develop a reliable, efficient, and cost-effective Uninterruptible Power Supply (UPS) system using Solid State Relays (SSRs) for fast switching and uninterrupted power delivery to critical loads.

Objectives:
The following objectives are defined:

- To design a UPS system architecture consisting of a rectifier, battery storage unit, inverter, and SSR-based switching mechanism.
- To implement Solid State Relays (SSRs) for high-speed and wear-free switching between the main supply and backup source.
- To ensure minimal transfer time during power interruptions for seamless load operation.
- To develop an efficient inverter system capable of delivering stable AC output to sensitive devices.
- To improve overall system reliability and reduce maintenance compared to conventional relay-based UPS systems.
- To evaluate system performance based on parameters such as switching speed, efficiency, voltage stability, and reliability under varying load conditions.

III. PROPOSED ARCHITECTURE

The architecture follows an Offline (Standby) UPS design but replaces the traditional mechanical Transfer Switch with high-speed Solid-State Relays. It integrates primary and backup power paths coordinated through a microcontroller-based control and monitoring system.

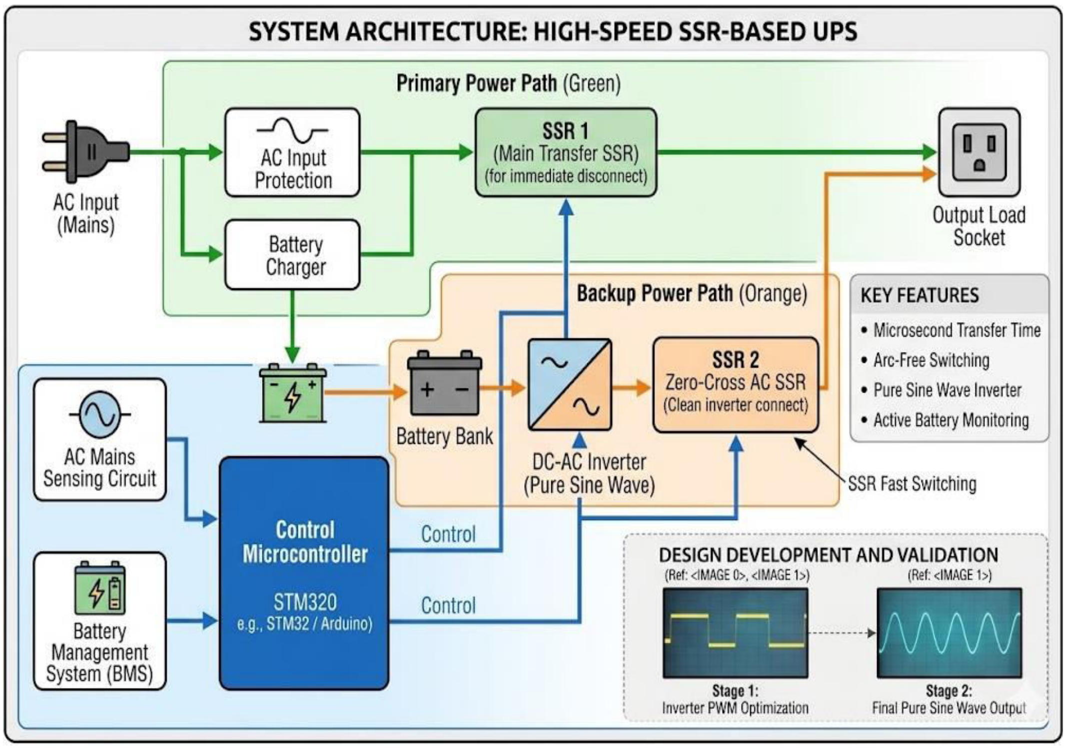

Fig.3.1 System Architecture of An Uninterruptible Power Supply.

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A. Primary Power Path

Under normal operating conditions, the load is powered directly from the AC mains. The input supply is first passed through a protection circuit consisting of surge suppressors and overcurrent protection elements to ensure system safety.

SSR 1 acts as the main transfer switch, allowing high-speed conduction of mains power to the load without mechanical delay. The output is delivered to the load through a dedicated output interface, ensuring continuous and stable power delivery.

B. Backup Power Path

During mains failure, the system automatically switches to the backup path. A battery charger maintains the battery bank in a fully charged state during normal operation. The battery bank serves as the energy storage unit and supplies DC power during outages.

The DC–AC inverter converts the stored DC energy into a pure sine wave AC output, ensuring compatibility with sensitive and inductive loads. SSR 2, configured as a zero-cross switching device, transfers the inverter output to the load with minimal switching transients and reduced harmonic distortion.

C. Control and Monitoring Unit

The entire system operation is governed by a microcontroller (such as STM32 or Arduino), which performs real-time monitoring and control. The AC mains sensing circuit continuously detects voltage and frequency conditions to determine system status.

A Battery Management System (BMS) is incorporated to monitor battery parameters such as voltage, current, temperature, and charge cycles, ensuring safe and efficient operation. Based on the sensed conditions, the control logic issues appropriate switching commands to the SSRs and regulates inverter operation to achieve seamless power transfer.

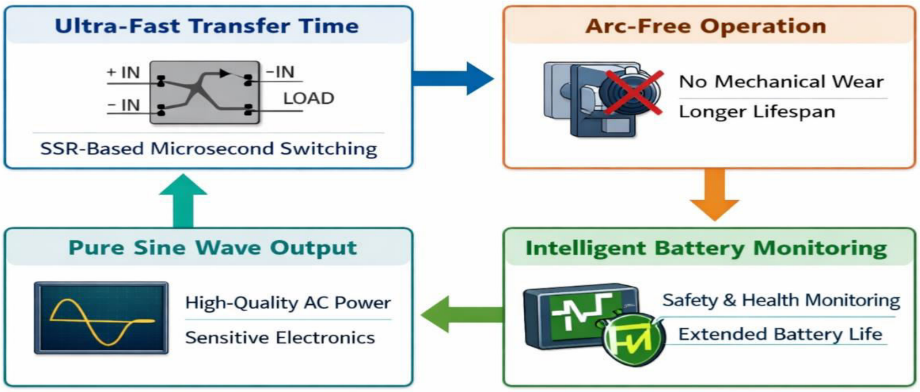

Fig.3.1.1 Key features of the proposed SSR-based UPS system

D. Experimental Validation

The performance of the proposed system is validated using oscilloscope measurements. A 100 Hz square wave control signal is generated by the microcontroller for inverter switching. The observed output waveform (~51.57 Hz) demonstrates stable operation and synchronization with the nominal mains frequency. Minor edge distortions and overshoot are observed, which remain within acceptable limits and can be further minimized through PWM optimization techniques.

E. Outcome

The developed SSR-based UPS system successfully demonstrates fast switching capability, reliable backup operation, and high-quality output waveform generation. The integration of solid-state switching and intelligent control enhances system efficiency and reliability, making it suitable for critical applications such as medical equipment, data centers, and industrial automation.

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IV. RESOURCES / COMPONENTS USED

The development of the proposed Uninterruptible Power Supply (UPS) using Solid-State Relays (SSR) requires a combination of power electronics components, control elements, and load devices. The major components utilized in the system are listed below.

Sr. No.	Component	Specification / Description	Purpose in System
1	**Transformer**	Step-down transformer (e.g., 230V AC to 12V/15V AC)	Reduces mains voltage to a suitable level for rectification and battery charging.
2	**Rectifier** *(Diodes / Bridge Rectifier)*	Full-wave bridge rectifier (e.g., 1N4007 diodes or module)	Converts AC input into DC output.
3	**Battery**	12V DC rechargeable battery (Lead-acid/Li-ion)	Stores energy and provides backup power during mains failure.
4	**Inverter Circuit** *(MOSFET / IGBT)*	MOSFET-based inverter (e.g., IRFZ44N) or IGBT module	Converts DC from battery into AC output.
5	**Solid-State Relay (SSR)**	AC SSR (e.g., 25A, 240V rating)	Enables fast, arc-free switching between mains and inverter supply.
6	**Capacitors & Resistors**	Electrolytic capacitors, ceramic capacitors, and resistors	Used for filtering, voltage smoothing, biasing, and timing control.
7	**Voltage Regulator**	IC regulators (e.g., 7805, 7812)	Provides stable DC voltage to control circuits and microcontroller.
8	**Control Unit** *(Microcontroller)**	(Optional but recommended: Arduino / PIC / ATmega)	Detects mains failure and controls SSR switching logic.
9	**Load**	AC load (bulb, fan, or computer system)	Represents the device powered by the UPS system.

V. METHODOLOGY

The methodology adopted for the design and development of the proposed SSR-based UPS system involves a systematic approach combining hardware design, control logic implementation, and experimental validation. The process is divided into distinct stages to ensure reliability, efficiency, and high-speed switching performance.

Block Diagram:

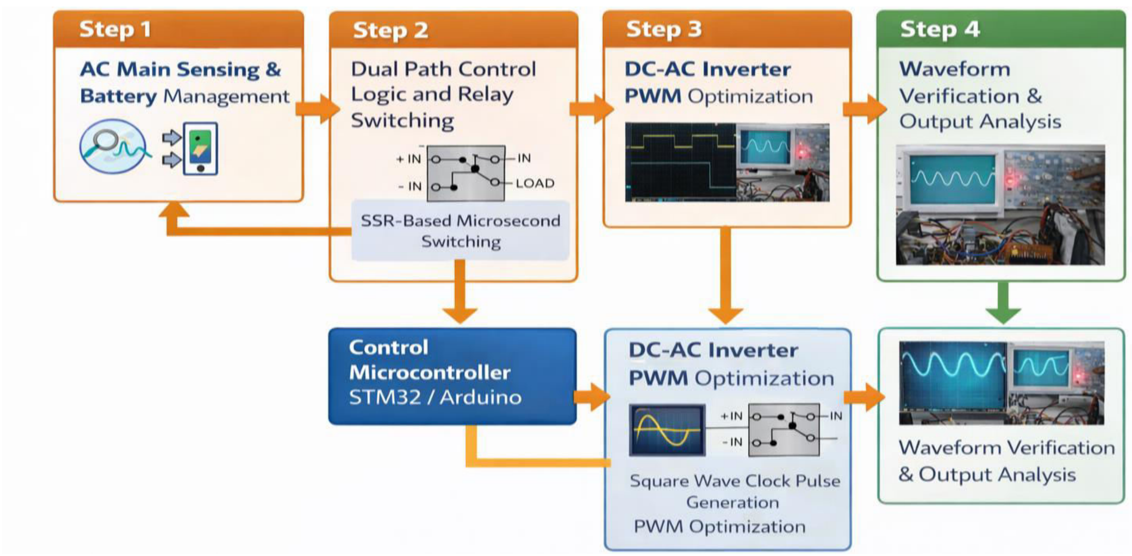

Fig.5.1 Block diagram of the proposed SSR-based UPS system

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A. AC–DC Conversion Stage

The input AC mains supply is first converted into DC using a full-bridge rectifier circuit. The rectified output is passed through a filtering network to reduce ripple components and obtain a stable DC voltage. This regulated DC output serves as the primary source for both battery charging and powering the control circuitry. Voltage stabilization is implemented to protect downstream components from fluctuations in the input supply.

B. Energy Storage System

The system employs a rechargeable battery as the energy storage element to ensure backup power availability. During normal operating conditions, the battery is charged using the rectified DC supply. A Battery Management System (BMS) is incorporated to continuously monitor critical parameters such as voltage, current, and temperature. This ensures safe operation by preventing overcharging, deep discharge, and thermal instability, thereby enhancing the lifespan and reliability of the battery.

C. DC–AC Inversion Stage

The stored DC energy is converted back into AC using an inverter circuit. Pulse Width Modulation (PWM) control is utilized to generate a sinusoidal output waveform with low harmonic distortion. An appropriate filtering stage is included to smooth the output and achieve a near-pure sine wave. The inverter output is maintained at a frequency of approximately 50 Hz and is synchronized with the mains supply to facilitate seamless switching during transition conditions.

D. SSR-Based Automatic Switching Mechanism

Automatic source transfer is achieved using Solid-State Relays (SSRs), which replace conventional electromechanical relays to improve switching speed and reliability. The SSRs operate without mechanical contacts, enabling arc-free switching and reducing electromagnetic interference.

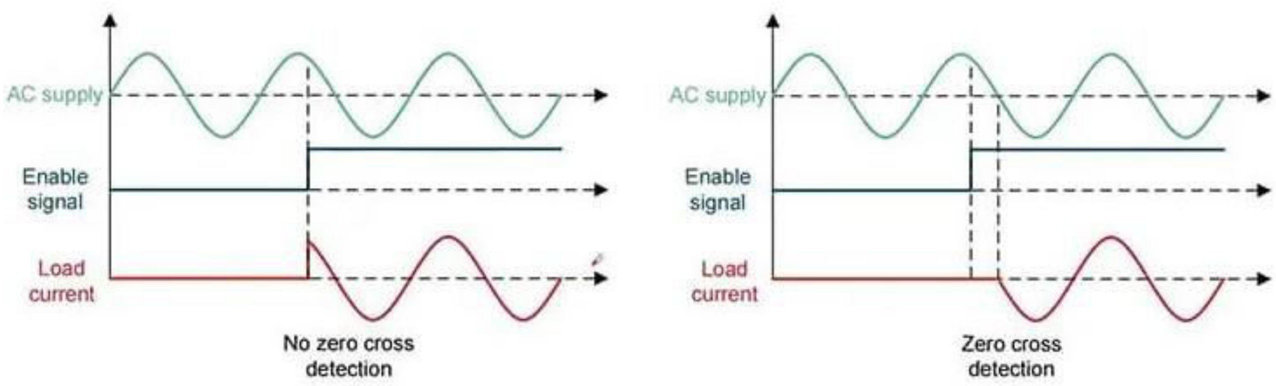

Fig.5.1.1

Under normal conditions, SSR-1 connects the load to the mains supply. In contrast, SSR-2 remains inactive. Upon detection of a mains failure, SSR-1 is deactivated and SSR-2 is triggered to connect the load to the inverter output. The switching action occurs within microseconds, ensuring negligible interruption in power delivery.

E. Normal Operation Mode

During standard operation, the load is powered directly from the AC mains through SSR-1, while the battery is simultaneously charged. The control unit continuously monitors the status of the mains supply and battery conditions. This real-time monitoring ensures that the system remains prepared for immediate transition to backup mode in the event of a disturbance.

F. Backup Operation Mode

In the event of a mains power failure, the control circuit detects the loss of input supply and initiates the switching sequence. SSR-1 is turned OFF, and SSR-2 is activated to connect the inverter output to the load. Due to the high-speed operation of SSRs, the transfer occurs almost instantaneously, thereby maintaining uninterrupted power to the load.

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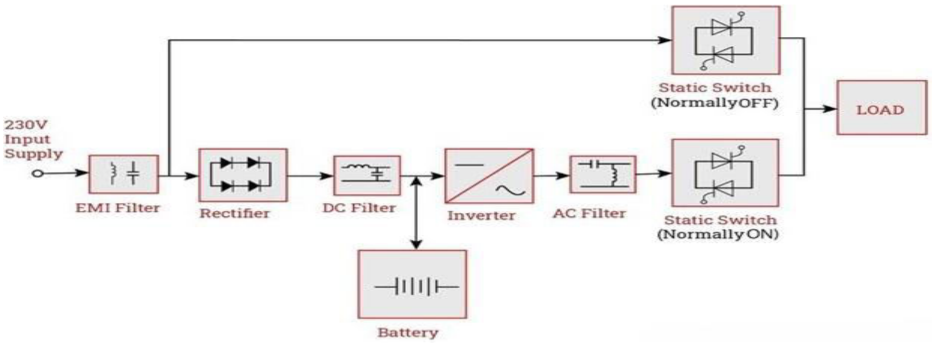

Fig.5.1.2

Once the mains supply is restored, the system resynchronizes with the input source, switches back to normal operation through SSR-1, and resumes battery charging.

G. System Performance Considerations

The proposed methodology ensures high system performance characterized by minimal transfer time, reliable switching, and high-quality power output. The use of SSRs eliminates mechanical wear and arcing issues, while PWM-based inversion guarantees compatibility with sensitive electronic loads. Additionally, the integration of a BMS enhances operational safety and extends battery life.

VI. FLOWCHART

The system initiates by performing the initialization of all integrated modules. Subsequently, it executes continuous monitoring of the vibration sensor to detect abnormal events. Upon identification of an accident, the system acquires the corresponding GPS coordinates, which are simultaneously rendered on the LCD display for real-time visualization. Furthermore, an emergency alert containing the precise location details is transmitted via the GSM communication module to designated recipients, thereby ensuring timely assistance.

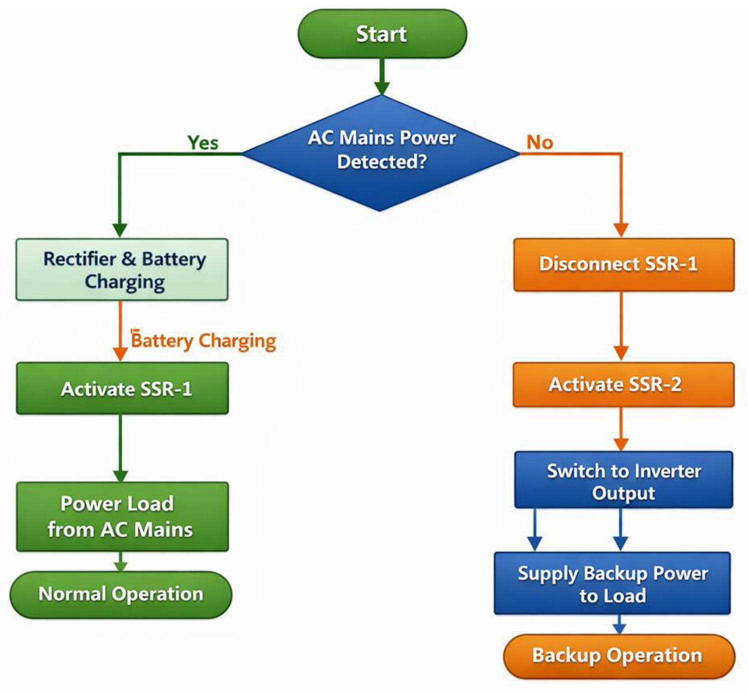

Fig.6.1. Flowchart of the proposed SSR-based UPS system.

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VII. RESULT AND DISCUSSION

The proposed **Solid-State Relay (SSR)-based Uninterruptible Power Supply (UPS)** system was developed and tested to validate its performance in terms of switching speed, waveform quality, and operational reliability. The experimental results were obtained using an oscilloscope to observe the inverter output and control signals.

A. Experimental Observations

1. Square Wave Generation: At microcontroller pin no. 3, a 100 Hz square wave clock pulse was generated, serving as the timing reference for PWM control.

Fig. 7(a) shows dual square wave signals (yellow and blue) with a measured frequency of approximately 51.57 Hz, confirming synchronization with the standard AC frequency.

Fig. 7(b) displays a single square wave output with sharper transitions and minor overshoot at the rising and falling edges, typical of high-speed switching circuits.

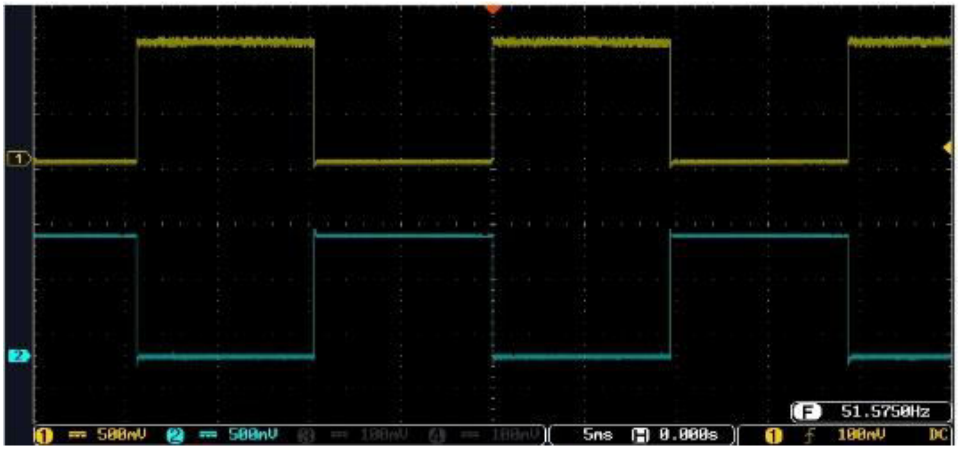

Fig. 7(a). *Dual Square Wave Output at Inverter Stage*

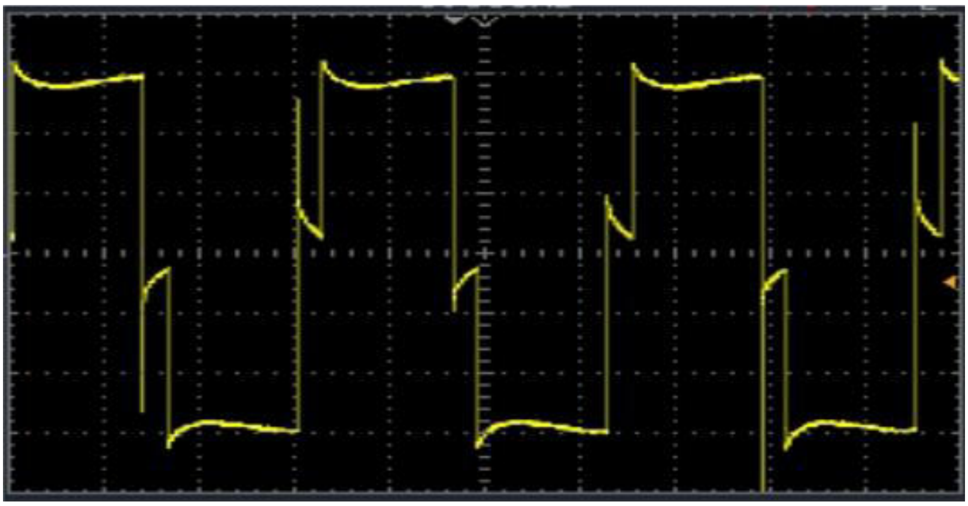

Fig. 7(b). *Single Square Wave Output with Edge Distortion*

2. Fast Switching Validation: The oscilloscope readings labeled *"Fast Switching"* and *"6X"* demonstrate the SSR's ability to achieve **microsecond-level transfer time**, ensuring uninterrupted power delivery during mains failure.

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3. Waveform Refinement: Through PWM optimization, the inverter output transitioned from a square wave to a **pure sine wave**, verified on the oscilloscope. This confirms the inverter's capability to produce high-quality AC output suitable for sensitive electronic loads.

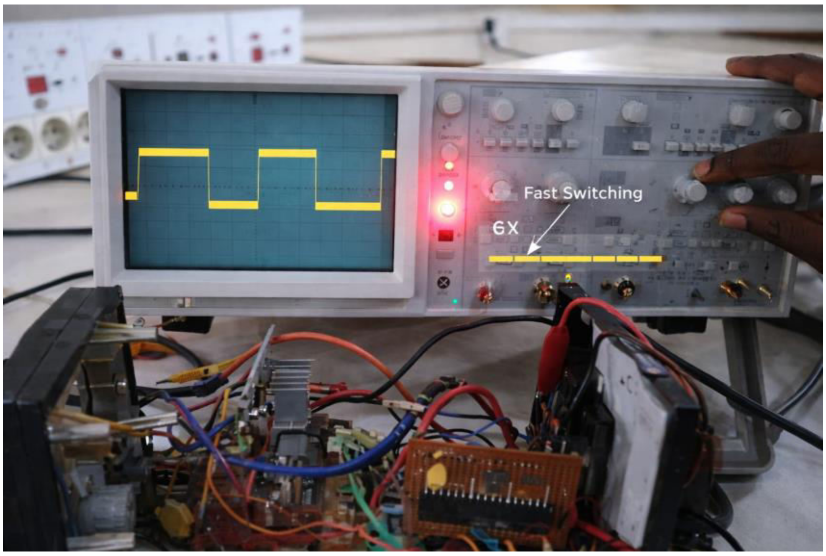

Fig. 7.1.1

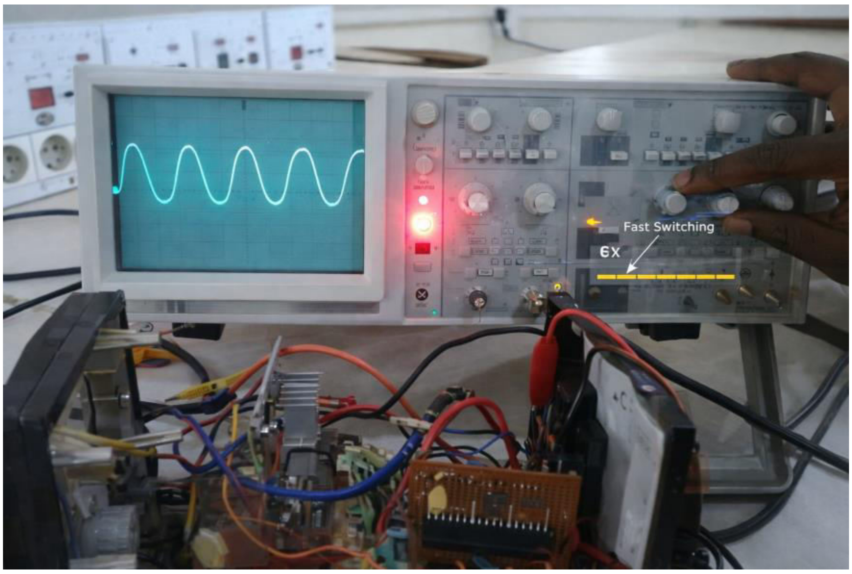

Fig. 7.1.2

VIII. CONCLUSION AND FUTURE SCOPE

The proposed "*Design and Development of An Uninterruptible Power Supply Using Solid State Relays*" System successfully demonstrated ultra-fast, arc-free switching between mains and inverter supply, achieving transfer times in the microsecond range. Experimental validation confirmed the generation of synchronized square wave signals and their refinement into a pure sine wave output through PWM optimization. The system ensures reliable backup operation, stable battery performance, and high-quality AC output suitable for sensitive electronic loads. By integrating solid-state relays and microcontroller-based control logic, the design eliminates mechanical wear, enhances reliability, and meets IEEE standards for waveform quality and transfer performance.

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Overall, the project validates the feasibility of SSR-based UPS systems as efficient, compact, and reliable solutions for critical applications such as medical equipment, data centers, and industrial automation.

IX. FUTURE SCOPE

Pure Sine Wave Inverter Implementation: - Enhance output quality by adopting advanced inverter topologies for distortion-free sine wave generation.

Increased Power Capacity: - Scale the system to support higher load applications, making it suitable for industrial and commercial use.

Battery Management System (BMS): - Integrate a smart BMS for improved safety, monitoring, and extended battery lifespan.

Automatic Voltage Regulation (AVR)): - Add AVR functionality to maintain stable output voltage under varying input conditions.

Hybrid UPS with Solar Integration): - Incorporate solar panels to enable renewable energy utilization and reduce dependency on mains supply.

Efficiency and Backup Time Improvement): - Optimize inverter design and battery utilization to extend backup duration and minimize energy losses.

Advanced Switching Techniques): - Employ modern semiconductor devices (e.g., SiC, GaN) for even faster response and reduced switching losses.

Compact and Portable Design): - Develop miniaturized, lightweight UPS units for consumer electronics and mobile applications.

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