Over-Voltage Protection Circuit

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***Abstract*—Overvoltage protection prevents damage when a supply exceeds safe limits. The described circuit uses a dual-comparator (LM393) and relay to monitor a 12 V DC line. If input voltage goes outside preset high or low thresholds, which can be set using potentiometers, the circuit disconnects the load and signals the condition via LEDs. This ensures the protected device (e.g. a router or control unit) is not exposed to harmful voltage levels. In the normal range, the relay remains energized (green LED on), allowing operation. Simulation confirms that above or below the set thresholds the relay de-energizes and the red or yellow LED (for overvoltage or undervoltage respectively) illuminates, effectively isolating the device and indicating the fault.**

Keywords— Overvoltage protection, LM393 comparator, Relay disconnect, 12V DC monitoring, Threshold voltage control, Load isolation, Simulation analysis, LED fault indicators, Safe voltage window, Device protection

I. INTRODUCTION

A. Background and Context

Voltage stability is critical for the safe operation of electronic devices.**Overvoltage** occurs when the supply voltage exceeds a system's design limits, leading to overheating, insulation breakdown, or catastrophic component failure. **Undervoltage** can cause devices to flicker, reset, or behave erratically. Power systems, especially DC supplies, are vulnerable to voltage deviations due to battery charging, load changes or faulty regulators. Protection mechanisms, therefore, are an essential part of modern electrical and electronic system designs. Traditionally, surge protectors, crowbar circuits, and voltage monitoring relays have been used to safeguard equipment.

B. Problem Statement

Sensitive devices such as routers, CCTV control units, and microcontrollers require stable DC input voltage to operate reliably. However, real-world power supplies may experience overvoltage or undervoltage conditions that could damage these devices or degrade their performance. A practical and cost-effective solution is needed to continuously monitor supply voltage and quickly disconnect the load when unsafe voltage levels are detected, ensuring both device protection and system reliability.

C. Objective and Scope

The objective of this project is to design, simulate, and analyze an **overvoltage and undervoltage protection circuit** using simple, widely available components such as the LM393 comparator, transistors, relays, and LEDs. The system will monitor a 12 V DC line and activate appropriate actions—powering the load during safe voltage conditions and disconnecting it during faults, while providing visual indicators. The scope includes both theoretical design, simulation analysis and hardware implementation targeting applications in low-voltage DC systems like battery-powered or automotive environments.

D. Significance and Relevance

Implementing overvoltage protection extends the operational life of electronic devices, enhances safety, and minimizes downtime due to equipment failure. In critical systems such as communication networks, home automation, and embedded control units, ensuring stable supply conditions is vital. The simple design approach detailed here offers an affordable, efficient solution without requiring complex microcontrollers or expensive monitoring equipment, making it highly suitable for educational, industrial, and DIY applications.

II. LITERATURE REVIEW

A. Traditional Overvoltage Protection Methods

Overvoltage protection has been a core topic in electrical engineering for decades. Initial protection systems relied heavily on mechanical solutions such as circuit breakers and fuses, which provided simple and cost-effective protection but suffered from slow response times and irreversibility upon fault occurrence. These devices typically disconnect power after damage has already started, making them unsuitable for sensitive modern electronics.

With advancements in semiconductor technology, protection circuits evolved to use components like **zener diodes** for voltage clamping and **thyristor-based crowbar circuits** for fast, aggressive protection. Crowbar circuits short the supply line to ground when overvoltage is detected, triggering a fuse to blow and isolating the load. While effective, crowbar circuits often result in the need for manual resetting and replacement of fuses, making them less ideal for uninterrupted applications.

Relay-based systems later emerged for better flexibility. Relays can physically isolate the load when triggered by an overvoltage condition detected through sensing circuits. However, traditional relay systems lacked intelligent decision-making capabilities and could not provide detailed fault signaling to users.

B. Modern Comparator-Based Protection Circuits

The development of **comparator-based voltage monitoring circuits** provided a more responsive and modular solution for overvoltage and undervoltage protection. Devices such as the **LM393 dual comparator** allow designers to precisely monitor supply voltages by comparing them against stable reference voltages set through resistor dividers. When the monitored voltage exceeds or drops below predetermined thresholds, the comparator output triggers control actions such as activating transistors, relays, or alarm systems.

In modern designs, **bipolar junction transistors** (BJTs) like the **BC547** and **BC557** are often used in conjunction with comparators to control high-current devices like relays, which handle the disconnection of the protected load. Visual indicators, typically LEDs, are integrated to provide immediate feedback on the system's operational status — signaling normal operation, overvoltage, or undervoltage conditions.

These systems offer significant advantages including low cost, scalability, real-time protection, and minimal maintenance. Moreover, the ability to fine-tune the voltage thresholds allows designers to tailor circuits for specific application needs, ranging from battery-powered electronics to industrial control panel.

III. Design and Simulation

TABLE I

COMPONENTS USED

S. No	Name	Type
1.	LM393	Comparator
2.	BC547	BJT
3.	IN4007,1N4372	Diodes
4.	Zener Diodes	3V
5.	Relay	12V
6.	Variable Resistor	5k Ω
7.	Terminal Block	2-pin, 3-pin
8.	LED's	Red, Yellow, Green
9.	Resistors	1k Ω, 4.7k Ω ,10k Ω

A. Circuit Design

Table I. shows all the components used in the circuit. The core of the circuit is an **LM393 dual comparator** (Fsig. 1.), powered by +12 V. One comparator monitors for low voltage, the other for high voltage. Each comparator input sees the variable supply via a resistor divider and potentiometer: this sets the **threshold voltages**. The threshold pots (5 kΩ) allow fine adjustment of the cutoff points. A 3.3 V Zener diode provides a stable reference for the lower-threshold comparator, improving accuracy. The LM393 outputs are **open-collector** (open-drain) NPN stages : they can only pull their outputs to ground when active, and otherwise float. Hence each comparator output effectively sinks current when its condition is met.

Each comparator output controls an LED indicator and contributes to relay control. A **green LED** (with series

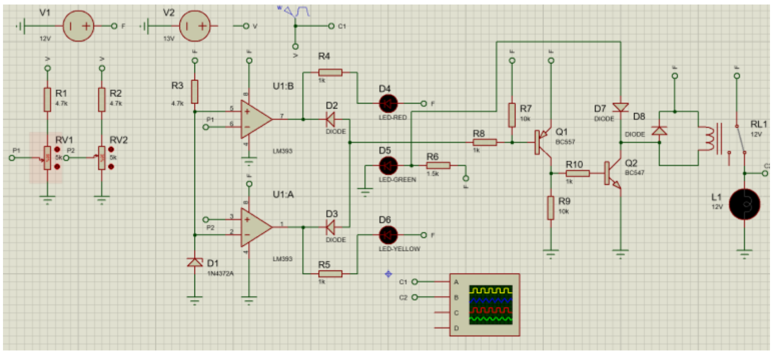

Fig. 1. Circuit's Design in Proteus

resistor) is connected so that it lights only when neither comparator is triggered, indicating normal voltage. A **red LED** indicates an over-voltage event, and a **yellow LED** indicates under-voltage. When a comparator detects an out-of-range condition, its output sinks and current flows through the corresponding LED (from +12 V through a resistor to the output), illuminating it. For example, when the input exceeds the upper threshold, the high-voltage comparator output goes low and lights the red LED. Similarly, the low-voltage comparator output lights the yellow LED when the input drops too low.

The **relay** provides the actual protection by switching the load. A 12 V relay coil is connected to +12 V on one end, and to the collector of an NPN transistor (BC547) on the other. The emitter of the BC547 goes to ground. When the BC547 is driven into conduction, it sinks current and energizes the coil, closing the relay contacts (connecting COM to NO to power the device). When the BC547 is off, the relay coil is de-energized, opening the circuit. A **flyback diode** (1N4007) is placed across the coil to protect against voltage spikes when the coil is switched off.

The BC547's base is controlled indirectly by the comparators and a PNP transistor (BC557). In the safe range (comparator outputs high-impedance), base bias allows the BC547 to turn on (energizing the relay and lighting the green LED). If either comparator output goes low (sinking), it changes the bias so that the BC547 turns off. In effect, the relay only stays on when both comparators report "voltage OK." If the voltage is within a certain limit, the green LED turns on, and the relay can drive an external load. Otherwise, red and yellow LEDs glow for higher and lower voltages respectively. In summary, the LM393 outputs drive the LED indicators and, via the transistor pair, switch the relay: the green LED and relay are active only when Vin is in-range, while an out-of-range condition energizes the appropriate LED and deactivates the relay.

B. Simulation Analysis

The circuit was simulated in Proteus (Fig. 1.) and tested under three cases:

- **Normal Voltage (e.g. 12 V):** Both comparator thresholds are satisfied (voltage above the lower threshold and below the upper threshold). Neither comparator output is pulling low. The green LED, connected to +12 V through a resistor, lights up.

The BC547 is biased on, energizing the relay coil. Thus the relay contact closes and the load is powered. The red and yellow LEDs remain off .

- **Over-Voltage (e.g. 15 V):** The input exceeds the upper threshold. The high-voltage comparator output sinks current, lighting the red LED. This also causes the BC547 to turn off, de-energizing the relay. The relay opens (disconnecting the load), and only the red LED is on. The green LED goes off.
- **Under-Voltage (e.g. 9 V):** The input falls below the lower threshold. The low-voltage comparator output sinks, lighting the yellow LED. The relay is again de-energized, so the load is disconnected. Only the yellow LED is on.

These behaviors match the description in Table II. summarizes the expected states:

TABLE II
SIMULATION RESULTS

Input Voltage	Relay State	Green LED	Red LED	Yellow LED
9V (Low)	Off	Off	**On**	Off
12V (Normal)	**On**	**On**	Off	Off
15V (High)	Off	Off	Off	**On**

The table shows that only when the input is within the preset window does the relay energize (green LED on). If the input is outside (below or above), the relay drops out and the corresponding warning LED illuminates.

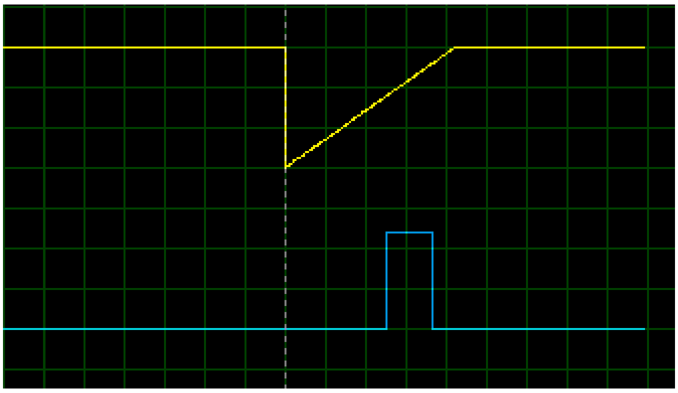

Fig. 2. Simulation Results in Proteus

IV. RESULTS

The expected outcomes are clear, as shown in Fig. 2.; the protected device is powered only when the supply is in range. If tested on a simulator or prototype, the relay should click off and an LED change should occur immediately once a threshold is crossed. In simulation, the transition was instantaneous (driven by the LM393's fast response). The green LED reliably indicated "safe" conditions, and the red/yellow indicators correctly flagged out-of-range. These results confirm the design's **effectiveness** at isolating the load under fault.

A discussion of performance includes noting that the relay contact physically disconnects the load, providing true isolation. The LEDs offer intuitive feedback without microcontrollers. However, one consideration is the lack of hysteresis: if the input voltage hovers near a threshold, the relay or LEDs might chatter. In a refined design, small feedback or hysteresis resistors could be added to the comparators to prevent oscillation at the trip points. The component values (resistors, pot range) determine the sharpness and accuracy of the thresholds; typical tolerances mean cutoffs within a few tenths of a volt of the set value, which is usually acceptable for protection purposes. The power draw of the comparator and transistor stages is low (only a few milliamps for LEDs and base currents), though the relay coil draws ~30–50 mA when on. This should be accounted for in low-power designs.

Overall, the protection behavior is as intended: **disconnect** on fault, **connect** on normal. Compared to purely passive surge protection, this active approach can **completely remove power** from the device, which is a strong safety measure. The referenced sources support this method: the circuit-diy article confirms that under-voltage and over-voltage events activate the yellow or red LED and turn off the relay . Practical reliability depends on stable threshold setting and the LM393's typical input offset (~1–5 mV) and open-collector drive capability (~20 mA) . In application, one would test and adjust the thresholds under realistic load conditions.

V. REFERENCES

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