LeakShield: Current Leakage Detection System

Shrirang Rekhate
Electronics and Telecommunication Enginnering
Shri Guru Gobind Singhji Institute of Enginnering and Technology
Nanded, Maharashtra, India
Email: shrirang27official@gmail.com
ORCID: 0009-0008-2212-0421

***Abstract*—This paper introduces "LeakShield", an Current leakage detection and monitoring system that detects the short circuit conditions using the ZMPT101B sensor module and an ESP32 microcontroller. The system detects voltage between the ground and neutral phases, pre-processes the signal to measure voltage amplitude, and initiates protective measures via the relay when voltage levels crosses the predefined threshold which happens in case of short circuit. Applications include power line protection, short circuit protection, overload/undervoltage protection, and automatic shutdown in critical systems.**

***Index Terms*—ZMPT101B, IoT-based Safety Systems, Voltage Monitoring, Short Circuit Protection, Current leakage detection.**

I. Introduction

Current leakage detection is essential for the safety and reliability of electrical systems. Current leakage cause short circuits in appliances, system malfunctions, or even cause fire hazards. Low-budget installations rarely incorporate real-time Current leakage detection, along with automatic protective actions.

Despite the existence of various commercial substitutes, these tend to be costly or hard to implement in small-scale embedded systems. Investigations now focus on industrial quality hardware, with room for cost-effective bespoke solutions.

The LeakShield project addresses the problem by using the ZMPT101B voltage sensor in conjunction with an ESP32 microcontroller to sense abnormal AC voltage levels between ground and neutral terminals, and subsequently activating a relay to break the system connection in case of short circuit. It offers a simple, effective, and scalable solution to ongoing voltage monitoring and protection.

II. System Overview

A. *Hardware Components:*

*1) **ESP32**:* The ESP32 is a powerful and low-cost microcontroller developed by Espressif Systems. It features a dual-core Tensilica LX6 processor with integrated Wi-Fi and Bluetooth capabilities, making it highly suitable for IoT applications and embedded system projects.

ESP32 performs the following key tasks in this project:

- **Analog-to-Digital Conversion (ADC)**: Taking analog signals from the ZMPT101B voltage sensor module.
- **Data Processing**: Calculate RMS voltage based on sampled ADC values in real time.
- **Relay Control**: Activates or deactivates a digital pin to control a relay for load isolation if voltage crosses the threshold.
- **Serial Communication**: Sends voltage readings to the serial monitor for real-time monitoring and alerting.

Key Specifications:

- 32-bit dual-core LX6 microprocessor (up to 240 MHz)
- 12-bit ADC channels (for reading analog values from ZMPT101B)
- Multiple GPIO pins for digital I/O
- Integrated Wi-Fi and Bluetooth (used wifi for websocket connection.)
- Operating voltage: 3.3V
- Supports various development environments including Arduino IDE and PlatformIO

*2) **ZMPT101B AC Voltage Sensor Module**:* ZMPT101B is a precision voltage sensor module specifically designed for AC voltage detection. Galvanic isolations are present on both the high-voltage (AC input) and low-voltage (microcontroller input) sides of the module, which is beneficial for safe and precise voltage sensing in embedded systems.

In this project, the ZMPT101B is used to measure the AC voltage. ADC of ESP32 reads its analog output to determine the actual-time RMS voltage. Based on the value, the system triggers a relay if the voltage exceeds safe range which happen in case of short circuit.

Key Features:

- Based on the ZMPT101B transformer for voltage sensing
- High input impedance and excellent linearity
- On-board signal conditioning with op-amp and calibration potentiometer
- Analog output voltage proportional to AC input
- Fully isolated between high and low voltage sides

Usage in Project:

- The Ground and Neutral wires are connected to the terminal block on the module.
- The module's analog output is connected to ESP32's ADC pin.
- Calibration is performed by adjusting the potentiometer.
- The module ensures safe sensing by keeping the high voltage isolated from the ESP32 circuit.

This sensor enables the system to safely monitor live AC voltage and react accordingly, making it a core component in the LeakShield design.

*3) **Relay Module**:* The relay module is an electromechanical switch through which the ESP32 microcontroller can drive high-voltage circuits via low-voltage digital signals. The relay module is utilized for the isolation of the circuit in case of an excess of voltage.

In this project, the relay is operated by the ESP32 based on voltage readings from the ZMPT101B sensor. The relay is activated when it crosses some predefined levels, breaking the circuit, separating the load from the supply and making the system safe.

Key Features:

- Uses an electromagnetic relay capable of switching 220V.
- Isolation of circuitry is provided
- On-board transistor and diode for relay driving
- LED indicator to show relay status (ON/OFF)
- Controlled by a digital HIGH/LOW signal from the ESP32
- Operating Voltage: 5V DC
- Trigger Voltage: 3.3V–5V (compatible with ESP32 logic levels)
- Maximum Switching Voltage: 250V AC / 30V DC
- Maximum Current: 10A

Usage in Project:

- The common (COM) and normally open (NO) terminals are wired in series with the AC phase line, so the load is powered only when the relay is ON
- When the ESP32 detects unsafe voltage, it sets the relay pin HIGH to disconnect the load

This module ensures that high-voltage switching is done safely and automatically based on real-time voltage analysis, making it essential for protection in the system.

III. Working

A. Input

The excess current from the circuit in case of a short circuit will start flowing through the ground terminal, increasing the voltage between the neutral terminal and the ground terminal. Usually it is near zero, but in the case of a short circuit, this voltage between the neutral and ground terminals increases. So the ZMPT101B sensor detects this AC voltage and provides a corresponding analog value to the microcontroller. Ideally, the value varies between 512 and 1023.

B. Data Processing

1) Read analog value:

$$\text{ADC}_i = \texttt{analogRead(pin)}$$

2) Compute zero point (average over one cycle):

$$V_{\text{zero}} = \frac{1}{N}\sum_{i=1}^{N} \text{ADC}_i$$

3) Center signal:

$$V_i = \text{ADC}_i - V_{\text{zero}}$$

4) Compute RMS in ADC units:

$$V_{\text{rms, ADC}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} V_i^2}$$

5) Convert to real voltage:

$$V_{\text{real}} = \frac{V_{\text{REF}}}{1024} \cdot V_{\text{rms, ADC}} \cdot \text{Calibration\_factor}$$

C. Output

- The output data is sent to a web page hosted by the ESP32 in real-time .
- Users can monitor voltage through any browser on the same local network.
- The ESP32 checks the voltage between ground and neutral.
- If it exceeds the threshold of 15V, the relay is triggered.
- The relay disconnects the the system to prevent damage.

D. Circuit Diagram

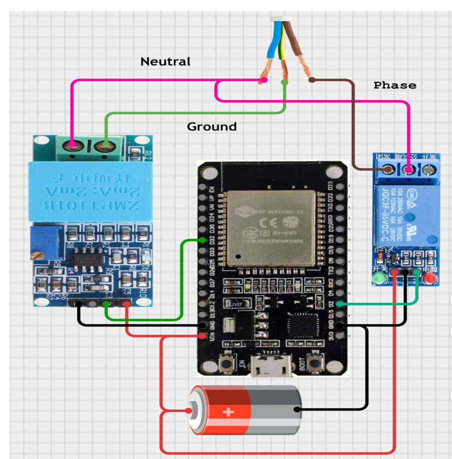

Fig. 1. Circuit Diagram

E. Code

- Github:https://github.com/ShrirangRekhate/LeakShield-Current-Leakage-Detection-and-Monitoring-System

IV. Conclusion

In this project, I developed LeakShield, a system that detects current leakage and protects other electrical systems by isolating the system in case of short circuit. By using ZMPT101B voltage sensor and ESP32 microcontroller, the system calculates the RMS voltage and triggers a relay on short circuit for safety.

A. Findings

The circuitry properly identifies and isolates the system in the case of overvoltage beyond defined limits, providing an automatic solution to short circuit. Low-cost components such as ESP32 and ZMPT101B make it an affordable solution for real-time voltage monitoring.

B. Limitations

Some of the limitations are the accuracy of the ZMPT101B sensor, static voltage levels, and lack of remote monitoring. Power optimization is also possible in the system.

C. Future Research and Policy Implications

Future work can focus on improving the precision of the sensors, integrating wireless communication for online monitoring of the system, and minimizing power consumption. Policymakers can promote the application of such protection systems in the domestic and industrial sectors for enhancing electrical safety.

In summary, LeakShield provides an easy yet efficient method of voltage protection with possible future applications and long-lasting use.

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