PIJCU, Vol. 3, No. 1, December 2025
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Performance Analysis of Touch Voltage Protection System Based on Leakage Current

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Keywords:
Touch Voltage Protection;
Leakage Current;
Recloser Switch;
Current Sensor;
ZMCT103C Sensor

ABSTRACT

Electrical touch due to leakage current is still one of the causes of occupational safety risks in electric power installations. For this reason, a touch voltage protection system needs to be designed to be able to detect leakage currents quickly and accurately. This research aims to test the performance of touch voltage protection systems both without recloser and with recloser that works automatically. The methods used include designing a protection relay-based system, using a ZMCT103C current sensor as a leakage current detector, and testing the circuit with a variety of resistors and tripping currents between 10-30 mA. The hardware is designed using a combination of incandescent lamp loads and relays, while the software regulates the logic of circuit disconnection and recovery through the recloser. The test results show the average relay disconnection time is in the range of 0.27-0.32 seconds in the system without recloser and 0.24-0.36 seconds in the system with recloser. The current sensor has an average error value of 2% with a standard deviation of 1.6 mA readings. The protection success rate reached 100% in the low resistance leakage current test. In conclusion, the tested touch voltage protection system has a fast, accurate response, and is able to provide effective protection against the risk of electric shock.

INTRODUCTION

Electrical installations form a crucial component in the provision of energy needs in modern life, either residential, commercial, or industrial (Kabeyi & Olanrewaju, 2022). The reliability of an electrical installation greatly relies on the quality of equipment installed and the precision in its installation process (Ahmad & Asar, 2021). Electrical protective devices such as leakage current protection, short-circuit protection, and grounding systems play a major role in providing the reliability of electrical installations (Buică et al., 2022). One of the main disturbances in electrical installations is leakage current, which occurs when electrical current flows through insulating mediums due to faulty insulation or missing a grounding system on energized equipment (L. Yang et al., 2024). This leakage current can potentially cause damage to the equipment, fire, and even dangerous electric shock to human beings (Naldi & Firnanda, 2024). Therefore, a protection system that is capable of detecting leakage current quickly and reliably, and de-energizes the electric flow automatically to prevent further hazards, is required (Cheng et al., 2023).One such commonly used leakage current protection device is the ELCB (Earth-Leakage Circuit Breaker) (Nasurdin & Bohari, 2023). Although effective in isolating the electric flow during leakage current, ELCB still has its flaws, such as its susceptibility to being reset manually once again following detection of a fault, reducing the reliability of the system (Nasurdin & Bohari, 2023). Moreover, the ELCB will not identify the faulty group or circuit but rather isolate the entire electrical system, including intact groups(Mehta et al., 2021). This condition interrupts the operation continuity particularly in installations that need an uninterrupted power supply (Purnomoadi et al., 2021).

Amongst one of the solutions to remedy this shortcoming is applying recloser technology, an automatic product that can switch off and on again the supply of electricity after a temporary fault has been rectified. Moreover, the recloser technology can be blended with a stepping trip system to only disconnect the troubled group experiencing leakage current, thereby improving the selectivity and dependability of the electrical installation.

Microelectronics technology development makes it possible to use microcontrollers as the central controller of the leakage current protection system (Anshori et al., 2022). Microcontrollers can be programmed more sensitively and responsively to sense leakage current or touch voltage, and automatically control disconnection and reconnection of the electric circuit (Abu Sneineh & Shabaneh, 2023). The ZMCT103C is one of the sensors that are used today, and it will measure changes in current accurately, even for small leakage currents(El-Khozondar et al., 2024). Hence, the faulty group itself will be disconnected, but other groups will be normal(Hercog et al., 2023).

In addition, the integration of the microcontroller with an auto recloser system can minimize downtime and maximize the efficiency of the electrical system. The system provides flexibility when setting the leakage current detection level, thus it can adapt to diverse installation conditions. This application is foreseen to replace the function of conventional ELCBs, which are fault limited in detection and action, thus improving the general safety and reliability of electrical installations.

With the above backdrop, this research claims to design and develop a leakage current protection relay with recloser and stepping trip for a 1300 VA capacity single-phase power system. The system is expected to identify leakage currents accurately and selectively, only interrupt the faulty group, and restore the electrical supply automatically once the fault has been cleared. Thus, supply stability and continuity can be improved, while the risk of damage to equipment or even fire hazards caused by leakage current can be minimized.

The main innovation of this study is the utilization of a combination of microcontroller, ZMCT103C current sensor, and multi-channel relay modules to selectively switch off according to groups, which has not been utilized fully in small-scale leakage current protection systems. Furthermore, the utilization of an auto recloser system in this research is also expected to enhance automatic temporary fault recovery efficiency without human intervention, which is often an Achilles' heel in conventional ELCB devices. Furthermore, the integration of the microcontroller with an auto recloser and stepping trip system offers not only technical benefits but also practical contributions for end-users. This system functions as an effective safeguard against low-voltage electric shock, thereby enhancing human safety in daily household electricity use. In addition, by being compatible with prepaid kWh meter-based home installations, which often face nuisance trips or reading errors due to ground faults, the system acts as an early warning and protection device, ensuring greater reliability of household energy supply. The availability of multiple adjustable tripping levels for leakage current detection, ranging from 10 mA up to 30 mA, further increases its adaptability to various residential electrical conditions, making it suitable for direct integration into home electrical networks without major modifications.

RESEARCH METHOD

This study utilizes a leakage current protection system consisting of a relay, ZMCT103C sensor, microcontroller, and relay module to ensure accurate fault detection and system reliability.

Leakage Current Protection Relay

The leakage current protection relay functions as a protective device designed to safeguard electrical systems from damage caused by electrical disturbances. This device operates by isolating or disconnecting affected electrical equipment from the network when disturbances occur, thereby preventing further damage to the system (Chu et al., 2022). In addition to its basic disconnection capability, modern protection relays are often equipped with real-time monitoring features that provide operators with accurate system status information (Gaafar et al., 2021). This dual function enhances not only the safety but also the operational reliability and maintainability of electrical installations across various applications, from industrial to residential settings (Esther et al., n.d.).

A leakage current protection relay specifically detects and protects electrical systems from leakage current faults, which occur when electrical flow deviates from its intended path due to insulation failure or unintended grounding (Faisal et al., 2021; Salem et al., 2022; M. Yang et al., 2024). The system operates by comparing incoming and outgoing currents; when the differential exceeds a predefined threshold, the relay triggers to disconnect the power supply (Codoban et al., 2023; Samizadeh et al., 2020). This rapid response mechanism is essential to prevent equipment damage, reduce fire risks, and ensure human safety.

The widespread application of leakage current protection relays—from household systems to industrial infrastructures—underlines their role as a fundamental component of modern electrical safety systems (Alam et al., 2022). Advances in technology have enabled these relays to incorporate remote monitoring and data analysis capabilities, thus improving operational efficiency and supporting safe work practices. Proper implementation of these relays serves not only as an operational safeguard but also as a long-term investment to minimize financial losses and potential human casualties.

ZMCT103C Sensor

Current estimation is fundamental in electrical framework assurance to screen and distinguish inconsistencies such as spillage current . One of the sensors utilized in this inquire about is the ZMCT103C, which may be a Corridor effect-based current sensor coordinates with a total IC circuit . This sensor produces a exceedingly precise and low-noise voltage yield relative to the AC or DC current being measured. The Lobby impact, found in 1879, empowers the change of attractive field quality into corresponding voltage, making this sensor dependable for exact current discovery (Abdel-Raouf et al., 2025; Elsayed et al., 2024).

The ZMCT103C is categorized as a current transformer (CT)-type sensor, which permits for non-invasive current estimation without the ought to cut or alter the circuit wires (Gaikwad et al., n.d.). This characteristic is beneficial in commonsense applications where keeping up circuit astuteness is basic(Naidji et al., 2023). The sinusoidal yield voltage created by the sensor compares specifically to the greatness of the current streaming through the essential conductor, empowering real-time observing of electrical parameters without framework interference (Quan et al., 2021).

Another noteworthy advantage of the ZMCT103C is its analog yield run of 0–5V, making it exceedingly consistent with microcontroller stages. This ease of integration disentangles the framework plan, as the sensor can be specifically interfaces with analog-to-digital converters (ADC) of microcontrollers for advance information preparing (Gaikwad et al., n.d.; Purno et al., 2023). As a result, the ZMCT103C is broadly embraced in different areas, counting car inverters, electronic control controlling frameworks, and mechanical inverters, supporting exact and productive current observing arrangements (Li et al., 2024).

System Design

In the hardware design of this system, two relay modules are used, namely a 1 channel relay as the main circuit breaker when a touch voltage fault is detected and a 4 channel relay that breaks the branch circuit gradually if a leakage current is detected. The ZMCT103C current sensor is used to detect leakage current and the reading results are displayed on the LCD, while the input of the protection current setting value is done through a 4x4 keypad. The whole circuit is controlled by an Arduino Uno ATmega32 microcontroller, with a 220 VAC power supply and 25 W, 60 W, and 100 W incandescent lamp loads, thus allowing simulation of real conditions in household power distribution.

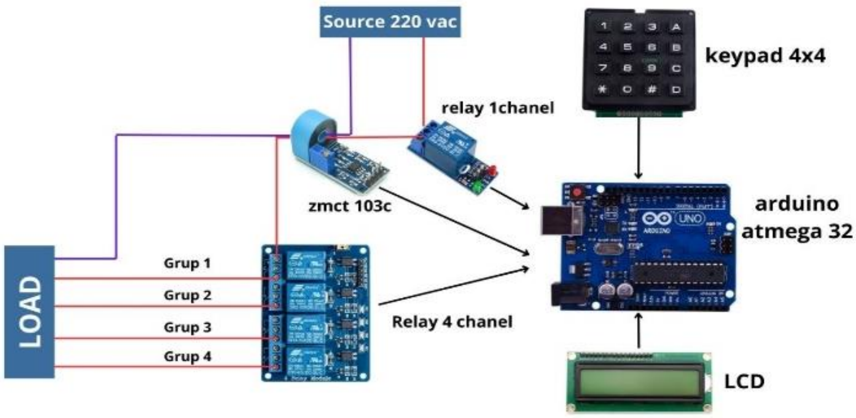

Figure 1. System Design Scheme

Hardware Design

The hardware design in this system is based on Kirchhoff's Current Law (KCL), which states that the total incoming current to a node must equal the total outgoing current. This principle ensures that the sum of currents flowing into a circuit node is balanced by the currents flowing out.

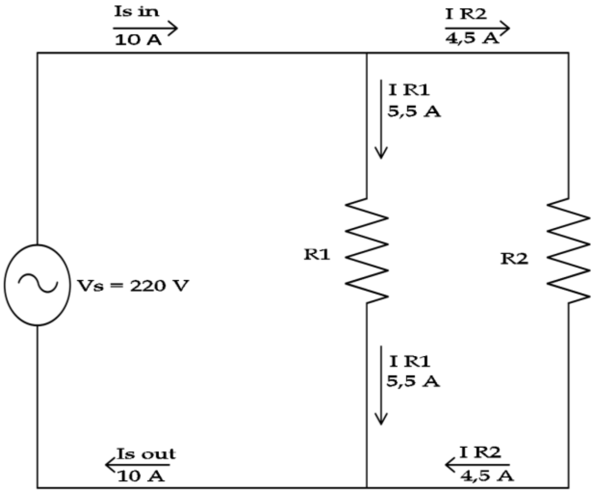

Figure 2. Kirchoff's First Law Electrical Diagram

Under normal conditions, the current entering the phase conductor splits into different branches and returns through the neutral conductor, forming a closed loop. The relationship of this balance can be expressed mathematically as:

$$\text{Is in} = \text{Is out} = \text{I R1} + \text{I R2} \quad (1)$$

$$= 5{,}5\text{A} + 4{,}5\text{A} \quad (2)$$

$$= 10\ \text{A} \quad (3)$$

If a leakage current occurs—such as through insulation damage or unintended contact with ground—then the returning current will be less than the incoming current. This imbalance can be detected as a current loss in the system

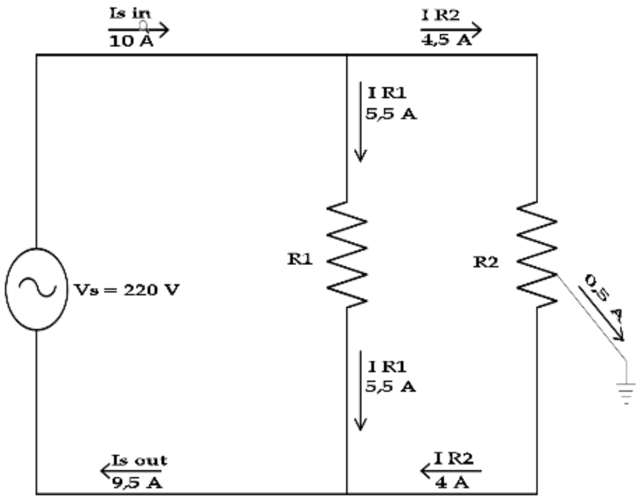

Figure 3. Leakage Current Electrical Diagram

This condition is represented by the following equation, where part of the current (e.g., through R2) leaks to ground:

$$\text{Is in} = \text{I R1} + \text{I R2} \tag{4}$$
$$= 5{,}5\text{A} + 4{,}5\text{A} = 10\text{A} \tag{5}$$

$$\text{Is out} = \text{I R1} + (\text{I R2} - \text{I gnd}) \tag{6}$$
$$= 5{,}5\text{A} + (4{,}5\text{A} - 0{,}5\text{A}) = 9{,}5\text{A} \tag{7}$$

The ZMCT103C sensor plays a key role in detecting this current difference by measuring the combined magnetic field from both phase and neutral wires. Under normal conditions, opposing currents cancel each other, resulting in a zero reading. However, any imbalance—such as when a leakage occurs—produces a detectable signal. This signal is converted into an analog voltage and processed by the microcontroller. If the leakage exceeds a defined safety threshold, the system will automatically disconnect the circuit to prevent electrical hazards.
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PURPHOSE METHODS
In this touch voltage protection relay system, recloser working logic is applied as a layered protection effort to detect and automatically break the leakage current. The recloser design aims to minimize the risk of permanent disconnection due to momentary or fluctuating leakage current disturbances. With the recloser, the system can re-evaluate electrical conditions after the initial disconnection is made, so that the disconnection is not carried out continuously when the detected disturbance is not sustainable. This concept is very important to maintain continuity of electricity supply in household installations or small-scale systems, without reducing the main protection function from the danger of electric shock.
Based on Figure 3.5, the system workflow begins with the process of setting the value of the tripping variable inputted through the 4x4 keypad into the Arduino microcontroller. This tripping value becomes the reference limit for detecting leakage current in the network. The ZMCT103C sensor has the role of reading leakage current data continuously and will send the data to the microcontroller. When the leakage current value is detected to exceed the tripping limit, the 1 channel relay will immediately trip to disconnect the electricity as the first safety measure. This process ensures a quick response when a fault is detected, so that the potential danger of electric shock can be minimized.

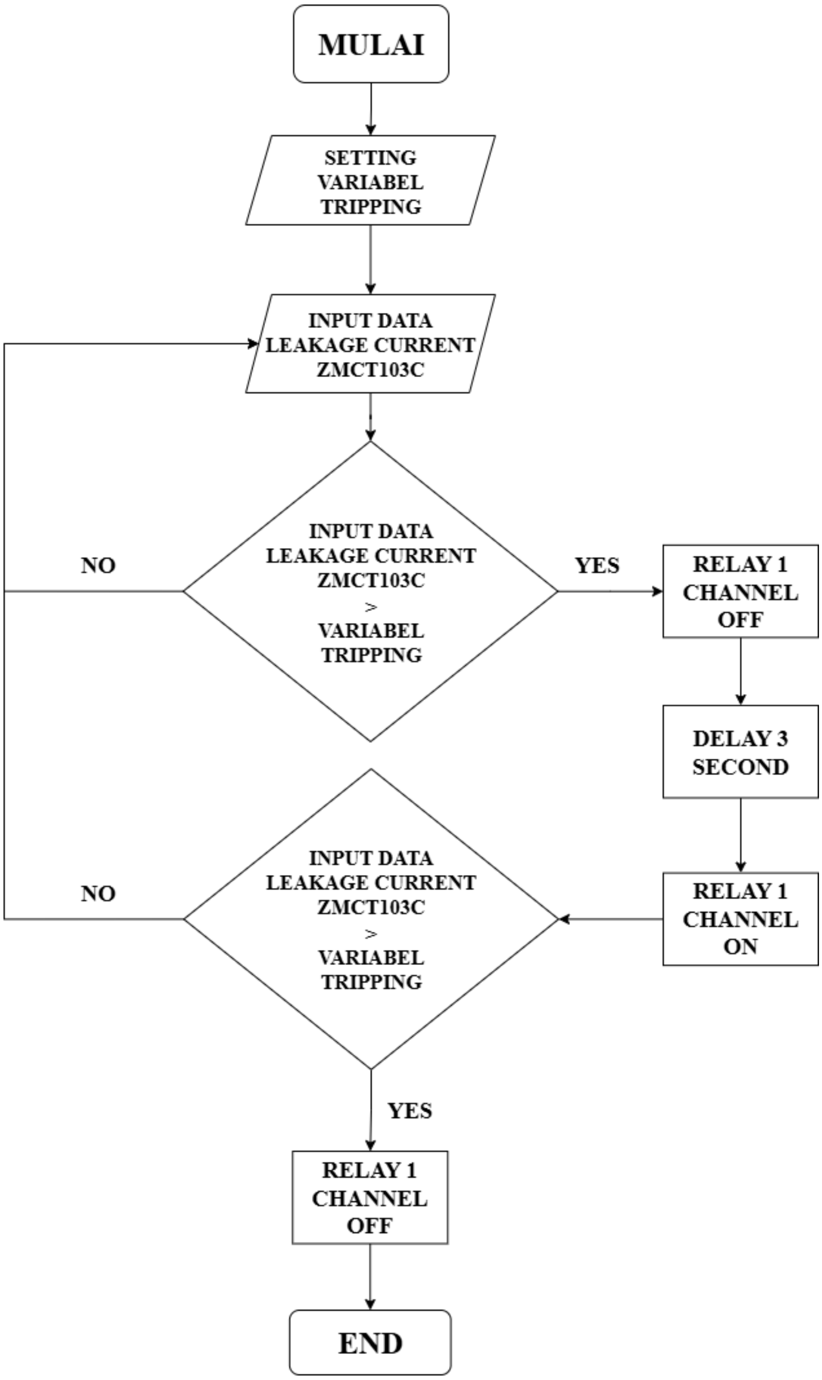

Figure 4. Flowchart of Purphose Methods

RESULTS AND DISCUSSION

This section discusses the results of testing the touch voltage protection system based on two main scenarios, namely without using a recloser and with a recloser. The discussion is conducted comprehensively by examining the experimental data obtained from various parameter variations, such as resistance values, load power, and tripping current. Each test result is analyzed to assess the affectability of the security framework in identifying spillage current faults and its capacity to reply to potential electrical dangers. With this approach, it is trusted that a comprehensive understanding of the adequacy and unwavering quality of the tried security framework in giving security against electric stuns caused by touch voltage can be gotten.

Testing Touch Voltage Discharged before Recloser Works

The purpose of testing the touch voltage protection system without a recloser is to validate the basic performance of the relay circuit in detecting leakage current directly, without automatic recovery intervention. In this scenario, a test resistor is installed to simulate human body impedance or leakage paths, while lamps with varying power ratings (25 W, 60 W, and 100 W) are used to generate current flowing through the circuit. Testing is conducted with five variations of trip current settings ranging from 10 mA to 30 mA. This method focuses on how the relay responds to variations in resistance that affect the magnitude of the leakage current.

In Table 1, with a trip current setting of 10 mA, the results show that for all resistor variations, the main relay is able to detect leakage current and disconnect the circuit with an average time of 0.27 seconds. All Condition 1 scenarios show the relay OFF, while Condition 2 (relay ON) indicates that the disconnection is functioning as intended. This demonstrates high sensitivity at low leakage current thresholds, where resistors with values ranging from 1 kΩ to 11 kΩ still produce currents exceeding the trip threshold.

Table 2, employing a 15 mA setting, appears a comparative design with an normal detachment time of 0.28 seconds. Be that as it may, bizarre information starts to seem at the most noteworthy resistance (11 kΩ), where the most hand-off comes up short to disengage the circuit (remaining OFF), demonstrating that the spillage current not surpasses the edge. This finding is noteworthy because it demonstrates the system's operational restrain where intemperate impedance restrains spillage current underneath the stumbling esteem.

The comes about in Table 1 with a 20 mA trip current setting assist strengthen the system's selectivity design. There are two information focuses at the 9 kΩ and 11 kΩ resistors where the most transfer quickly turns ON without recording a detachment time. This wonder is deciphered as prove that spillage current does not trigger the hand-off, keeping the circuit dynamic. In any case, the normal detachment time remains reliable at 0.27 seconds beneath other conditions, showing the consistency of the relay's reaction over the resistance run that produces noteworthy spillage current.

Testing with trip current settings of 25 mA and 30 mA encourage highlights how the framework gets to be more particular. At this level, as it were half of the information in Table 4.5 and four information focuses in Table 4.6 appear the transfer effectively detaching the circuit. The rest stay ON since the spillage current is not adequately huge. The recorded detachment time for dynamic information ranges from 0.31 to 0.32 seconds, still well underneath the greatest standard of 1 moment, demonstrating that the transfer remains competent of rapidly recognizing spillage current deficiencies surpassing the limit.

Generally, the comes about of this testing without a recloser affirm that the spillage current assurance transfer features a dependable level of affectability. With a normal reaction time extend of 0.27 to 0.32 seconds, the framework is competent of viably, specifically, and accurately hindering the electrical current, giving critical beginning assurance against the hazard of electric stun due to touch voltage. The reality that the hand-off does not continuously disengage the circuit at tall resistance demonstrates that this security framework works based on the rule of particular differential current location, instead of essentially detaching the electrical current aimlessly.

No	Setting Tripping (mA)	Resistance Range (K Ω)	Load Power (W)	First Condition of Relay 1	Second Condition of Relay 1	Average Breaking Time (s)	Response Note
1	10	1-11	25, 60, 100	OFF	ON	0,27	Fast
2	15	1-11	25, 60, 100	OFF	ON	0,28	Stable
3	20	1-11	25, 60, 100	OFF/ON	ON	0,27	Fast
4	25	1-11	25, 60, 100	OFF/ON	ON	0,31	Still Acceptable
5	30	1-11	25, 60, 100	OFF/ON	ON	0,32	Approaching Limit

Table 1. Table of Results Touch Voltage Testing
After Discharge Prior to Recloser Operation

Testing Touch Voltage Discharged after Recloser Works

The second stage of testing was conducted with the recloser installed constantly to verify the performance of the protection system in the event of a continuous leakage current fault. In this procedure, the test resistor was not removed, so that the leakage current remained connected until the system disconnected the circuit through the main relay or until the recloser worked to restore power. The purpose of this test is to ensure that the recloser mechanism can function optimally as an additional layer of protection, keeping the circuit safe by disconnecting and reconnecting the electrical current according to the conditions.

The test comes about in Tables 2. appear how varieties in trip current settings influence the system's reaction. With a trip current esteem of 10 mA, all information show that the most hand-off is within the OFF state and no restoration happens by means of the recloser (Condition 2 is additionally OFF). The normal disengagement time recorded is 0.32 seconds, somewhat slower than testing without a recloser. This illustrates that at moo current levels with the resistor introduced, spillage current remains controlled, causing the framework to proceed disengaging the circuit without reestablishing control stream. A comparative slant is watched in Tables 2 with trip current settings of 15 mA and 20 mA. At moo resistance levels, the hand-off remains OFF with a detachment time extending from 0.33 to 0.36 seconds. In any case, when resistance is expanded (9 kΩ and over), the transfer starts to appear an ON condition specifically, showing that spillage current not surpasses the trip limit, permitting the recloser to reestablish the circuit (Condition 2 ON) This illustrates the system's insights in recognizing between noteworthy and non-significant blame conditions, as well as the recloser's capacity to perform reclosing as it were beneath secure conditions.

At higher trip current settings, namely 25 mA and 30 mA, the recloser's performance becomes increasingly dominant. In Table 2, only four out of ten data points show the disconnection process with varying times between 0.15 and 0.34 seconds. The remaining data indicate that the relay reactivated because the leakage current generated by the resistor was insufficient to trigger disconnection. The average disconnection time at this level even dropped to 0.24 seconds, the fastest in the entire testing procedure.

From the by and large information, the normal disengagement time of the framework, both with and without the recloser, was gotten at 0.3 seconds. This esteem is well underneath the greatest 1-second restrain prescribed by worldwide electrical security measures such as IEC/IEEE. These comes about affirm that joining the spillage current assurance framework with the recloser component not as it were upgrades reaction speed but moreover gives versatile, layered assurance against spillage current unsettling influences, particularly on the off chance that the unsettling influence is brief.

In common, these discoveries emphasize the imperative part of reclosers as progressed assurance components competent of keeping up control supply progression without compromising security angles. The fast and particular reaction illustrated by the transfer and recloser circuitry approves the unwavering quality of the framework plan whereas highlighting its potential for execution over different application scales, from private establishments to mechanical electrical frameworks requiring secure and productive control supply steadiness.

No	Setting Tripping (mA)	Resistance Range (K Ω)	Load Power (W)	First Condition of Relay 1	Second Condition of Relay 1	Average Breaking Time (s)	Response Note
1	10	1-11	25, 60, 100	OFF	OFF	0,32	Still Acceptable
2	15	1-11	25, 60, 100	OFF	OFF/ON	0,33	Approaching Limit
3	20	1-11	25, 60, 100	OFF/ON	OFF/ON	0,36	Approaching Limit
4	25	1-11	25, 60, 100	OFF/ON	OFF/ON	0,31	Still Acceptable
5	30	1-11	25, 60, 100	OFF/ON	OFF/ON	0,24	Fast

Table 2. Table of Results Touch Voltage Testing
Discharged after Recloser Works

Sensor Error Percentage Testing

Current sensor testing was conducted to decide the precision of the ZMCT103C current sensor readings compared to the real current streaming within the circuit. In this test, the sensor was tried by comparing the sensor readings with the readings of a standard measuring gadget, to be specific an ammeter, which incorporates a higher level of precision and has been standardized by the producer. This comparison points to approve that the current sensor utilized is reasonable for usage in assurance frameworks, especially in identifying spillage current or issues.

As appeared in Table 3, the testing was conducted utilizing shifting test resistors extending from 1 kΩ to 10 kΩ. Each resistor variety delivered distinctive current readings on the sensor screen and the clamp meter. The test comes about appear that the contrast between the current readings recorded on the sensor and the real current ranges from 1.0 mA to 2.1 mA. The mistake rate is calculated by partitioning the distinction in readings by the current esteem on the clamp meter, at that point duplicating by 100% to get the blunder rate for each test point.

For illustration, at the 1 kΩ resistor, the current measured on the sensor screen was 275.4 mA, whereas the current on the clamp meter was recorded as 277.0 mA, coming about in a current contrast of 1.6 mA with an blunder rate of 1%. For the 6 kΩ resistor, the perusing mistake expanded to 5% due to a critical diminish in current, from 25.5 mA on the sensor screen to 27.0 mA on the ammeter. This shows that at lower current values, sensor perusing deviations tend to be marginally bigger compared to higher current values.

In general, from the nine test focuses conducted, the normal perusing mistake rate of the sensor was recorded at 2%. This esteem remains inside the satisfactory exactness resilience run for current observing applications utilizing little transformer current sensors such as the ZMCT103C. Hence, the sensor utilized can be considered adequately reasonable for application in spillage current security frameworks and stack observing, because it has moo perusing deviation and is dependable for detecting current changes within the field.

Overall, from the nine test focuses conducted, the normal perusing blunder rate of the sensor was recorded at 2%. This esteem remains inside the satisfactory exactness resilience run for current observing applications utilizing little transformer current sensors such as the ZMCT103C. Subsequently, the sensor utilized can be considered adequately reasonable for application in spillage current assurance frameworks and stack observing, because it has moo perusing deviation and is solid for detecting current changes within the field.

The comes about of these calculations and comparisons moreover bolster the conclusion that the sensor can give current perusing information with satisfactory accuracy, empowering it to be coordinates into assurance circuits for real-time blame discovery. With an normal mistake rate of 2% and inconsequential variety in deviation, the security framework is anticipated to operate ideally to ensure clients from potential electrical stun risks and accurately detect anomalous conditions within the electrical arrange.

NO	Test Resistor (Ω)	Current on Monitor (mA)	Current on Clamp Meter (mA)	Current Difference (mA)	Error (%)
1	1k	275,4	277,0	1,6	1%
2	3k	89,5	91,0	1,5	2%
3	4k	61,4	63,0	1,6	3%
4	5k6	40,9	42,0	1,1	3%
5	6k	37,5	36,0	1,5	4%
6	7k4	28,6	27,0	1,6	6%
7	8k	25,5	27,0	1,5	6%
8	9k	20,8	19,0	1,8	9%
9	10k	18,3	17,0	1,3	8%
10	11k	14,6	13,0	1,6	12%
	Average		61,2	1,5	2%

Table 3. Sensor Reading Error Test Table

CONCLUSION

Based on the test results of the touch voltage protection system without a recloser, it can be concluded that the protection relay used has good sensitivity in detecting leakage current. This can be seen from the results of five test tables with tripping current variations of 10 mA to 30 mA which show the average relay disconnection time is in the range of 0.27 to 0.32 seconds. This fast response proves that the protection system is able to cut off the flow of electricity in under one second, in accordance with international safety standards, even in the absence of an automatic reclose mechanism.

In tests with reclosers installed constantly, the protection system showed increasingly optimal performance with an average relay channel disconnection time between 0.24 to 0.36 seconds. The recloser serves as an additional layer of protection that can automatically disconnect and reconnect the circuit once safe conditions are detected. From the overall test results, the average response time of the protection system, both without and with a recloser, was recorded to be stable at 0.3 seconds, so it can be said that the system has reliable protection capabilities and is in accordance with the design objectives.

In addition, testing of the ZMCT103C current sensor shows that the sensor device has an adequate level of accuracy with an average error of only 2%. The comparison of the current readings on the sensor monitor and the standard measuring instrument proves that the current sensor used is feasible to implement in the leakage current protection circuit. Thus, the entire series of tests in Chapter 4 confirms that the designed touch voltage protection system has good reliability, response speed, and detection accuracy in supporting user safety against electric shock hazards.

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