PORTABLE PRIMARY CURRENT INJECTOR FOR CIRCUIT BREAKER TESTING

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ABSTARCT

Protective device failures and malfunctions are occurring frequently in industrial applications. When component failures occur, it is required to confirm whether it failed or malfunctioned. Therefore, a specially designed testing equipment is required to identify the status of protective devices in such situations, and this equipment is considerably expensive, even for hiring. Therefore, industries tend to develop low-cost protective devices testing equipment based on their requirements. A primary current injector, also known as a primary injection test set, is a specialized piece of equipment used for primary current injection tests in electrical power systems. It is designed to generate high currents and inject them into the system to simulate fault conditions and evaluate the performance of protective devices such as protective relays and circuit breakers. Generally, laboratory-based primary current injectors are used to conduct primary current injection tests, and they encounter certain limitations that need to be addressed. The size and weight are the major limitations in the laboratory based primary current injectors. These limitations are generally arising due to the high currents that they generate. This can make transportation and setup cumbersome, especially if the laboratory has limited space or if the equipment needs to be moved frequently. Apart from the size, the other well-known limitation of the primary current injector is the cost. They often require a significant investment due to their specialized design, high-power capacity and precision. Budget constraints may pose challenges for smaller laboratories or organizations with limited financial resources, and task specific design of primary current injector is good for an industry, based on the requirements. Most of the small-scale industries required 100A range current levels for testing purposes. With respect to such industrial requirement, the laboratory based primary current injectors have higher capabilities than the requirement and the consumers must bear an unnecessary cost. Apart from that, these laboratory-based primary current injectors are not easily movable. Therefore, the aim of this study is to develop a portable 100A primary current injector for the purpose of testing protective devices targeting small scale industrial requirements. The proposed primary current injector design consists of key components such as isolation circuit, converter circuit, control circuit and feedback circuit. It fulfills the fundamental objectives of being able to bring equipment as close as possible to the device under test and only requiring one person to perform the test. Also, the proposed prototype saves the testing preparation time, and it has high efficiency as the power losses are low.

Keywords: Primary current injector, protective device testing, transformer core design

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INTRODUCTION

Protective device failures and malfunctions occur frequently in industrial applications [1]. When component failures occur, it is required to confirm whether it failed or malfunctioned. Therefore, specially designed testing equipment is required to identify the status of protective devices in such situations and this equipment is considerably expensive, even for hiring. Therefore, industries tend to develop low-cost protective devices testing equipment based on their requirements.

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METHODOLOGY

Initially, a comprehensive literature study was conducted to gather information on the design of a primary current injector. Based on the findings, a basic design for the proposed primary current injector system was developed, utilizing a toroidal transformer instead of a stationary laboratory transformer. The proposed primary current injector model is given in Figure 01.

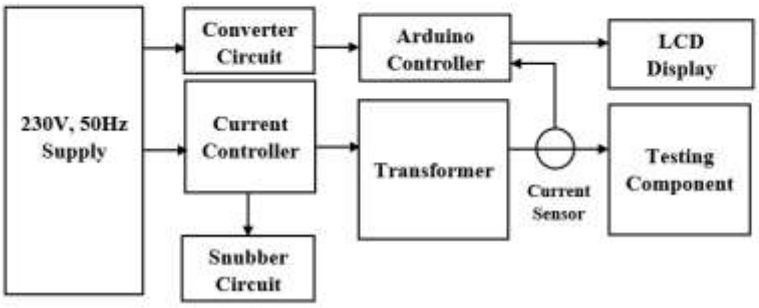

Figure 01: Proposed model of the primary current injector

Once the basic design of the primary current injector design was finalized, the transformer core related calculations were performed to ensure the design would prevent magnetic saturation during the testing period [4]. The selected core type for the application is Cold Rolled Grain

Oriented silicon steel and its flux density was assumed as 1.5 Tesla for the calculations. Therefore, based upon the design criteria, the required power rating of the toroidal transformer core was obtained as 5000 VA.

To validate the functionality and performance, the designed transformer core was simulated using the Finite Element Method Magnetics (FEMM) software. This software allows for detailed analysis of the magnetic field behaviour, providing insights into the performance characteristics and verifying the effectiveness of the design [4][5].

The final part of the primary current injector implementation was to fabricate the current controller. Therefore, the functionality of proposed triac based current controller was verified under the Proteus Platform. The current controlling was achieved by triggering the gate of the triac through a potentiometer connected to a diac. By adjusting the firing angle of the triac, the primary current could be controlled effectively. To get the current measurements, an Arduino module was employed in conjunction with the ACS758 current sensor. This combination allowed accurate measurement of the current flowing through the system. Lastly, a hardware prototype which can handle a current of 100A was implemented. This prototype enabled testing of the system's functionality and performance under real-world conditions. Through these steps, the overall functionality of the primary current injector system was verified, ensuring reliable and accurate control of the primary current in the proposed design.

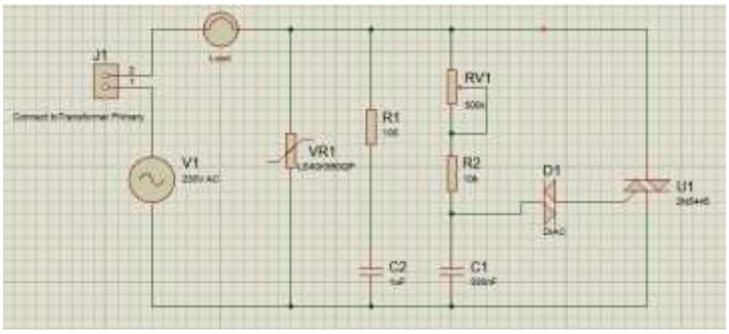

Figure 02: Proposed triac based current control circuit

HARDWARE PROTOTYPE IMPLEMENTATION

The overall hardware design consists of several sub circuits as mentioned in the previous sections. The first circuit is the voltage converter circuit which initially converts 230V input voltage from the main supply to 12V. Then, there is another section in the converter circuit to convert 12V to 5V to power up the Arduino module. This circuit ensures the Arduino operates at the correct voltage level. The second sub circuit of the primary current injector is the current controller which is responsible for controlling the input current of the transformer's primary winding using a triac-based control mechanism. The firing angle of the triac is adjusted by a potentiometer, which is controlled through a diac. This arrangement allows precise control of the primary current as mentioned above. In addition to those circuits, a separate snubber circuit was designed to protect the triac from potential issues caused by the connection to an inductive load. The snubber circuit helps mitigate the effects of inductive load by reducing the phase lag and ensuring a controlled turn-off of the triac.

Overall, the combination of the converter circuit, current controller, and snubber circuit ensures the proper functioning and protection of the system during operation. The design of the toroidal transformer is indeed a critical aspect of the project. It requires thorough analysis of various properties and characteristics to ensure its proper functioning. In this design, the core and primary winding are stationary components, while a flexible cable is used as the secondary winding of the transformer. One key advantage of this design is the ability to change the number of turns in the secondary winding of the transformer. This flexibility allows for adjustments to the transformer's voltage and current output based on specific requirements and applications. To protect the transformer, a Hall-effect current sensor is employed to measure the current flow and provide feedback to the controller [6]. The circuit connection of Hall Effect current sensor with Arduino and LCD is shown in Figure 03.

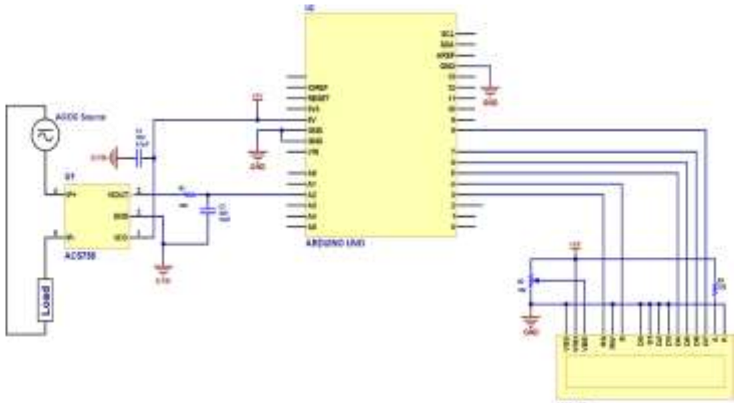

Figure 03: Circuit connection of Hall Effect current sensor with Arduino and LCD

RESULTS AND DISCUSSION

As mentioned earlier, the Proteus software was used to check the basic functionality of the proposed design. The other important design is the transformer core design to avoid saturation. The transformer parameters were calculated and then the developed transformer core model was analyzed with the FEMM software and verified the required toroid core characteristics [4]. Initially, the flex density distribution of the core was checked and shown in Figure 04. Then, the core model was checked with the relevant transformer core material and BH curve was generated as shown in Figure 05. Finally, the current distribution and its path were analyzed and plotted to verify that the constructed transformer had no leakage current. This analysis ensures that the current flows as intended and does not deviate or leak from the desired path within the transformer. By simulating the current distribution with FEMM, it becomes possible to assess the performance and efficiency of the transformer design [7] and check whether the current density of the designed core is within the range as shown in Figure 06.

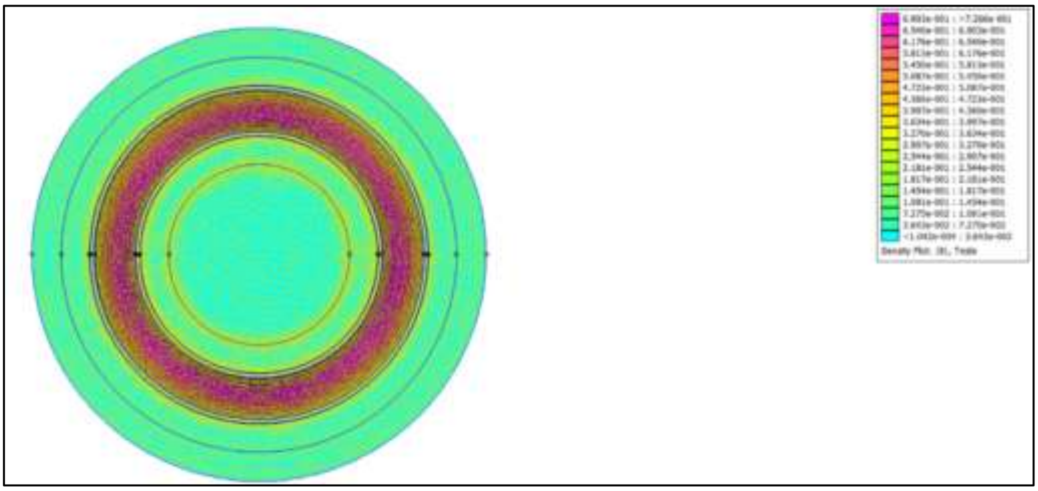

Figure 04: Flux density distribution of the proposed transformer

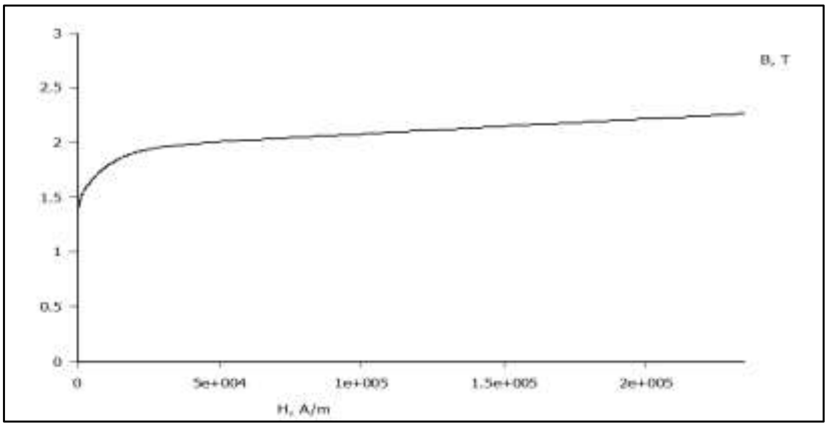

Figure 05: BH Characteristics of the selected core

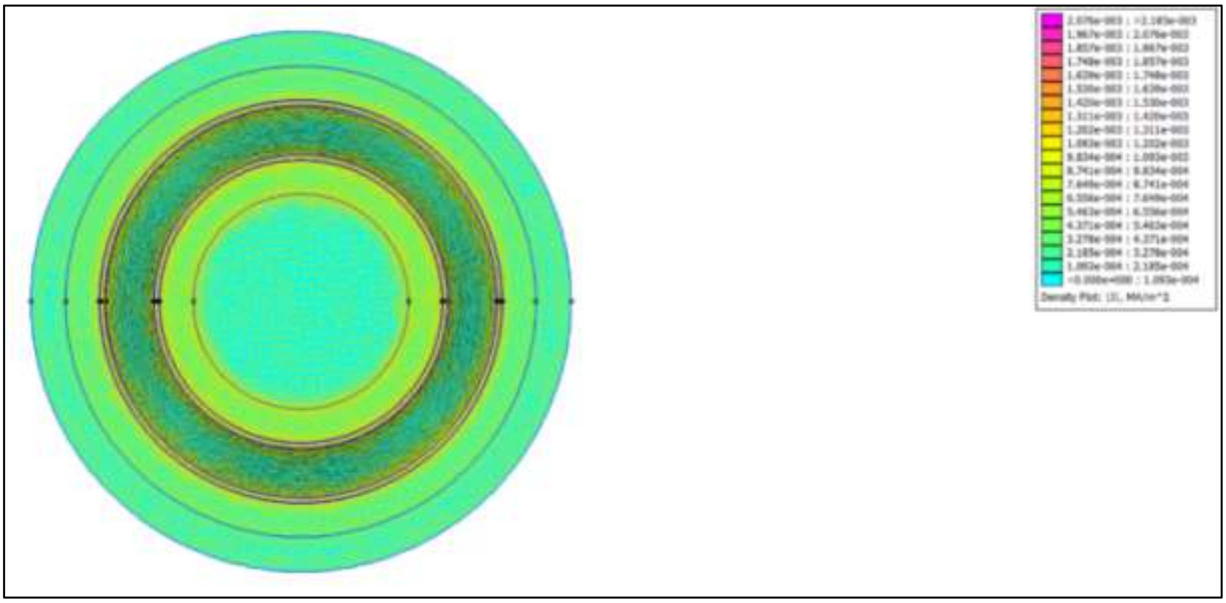

Figure 06: Current density distribution of the core

The implemented hardware prototype was well functioned as it was initially performed under the Proteus platform. However, there is room to improve the accuracy of output current while eliminating controller related technical limitations. The tested hardware prototype is shown in Figure 07. In here, an additional current measurement device was used to measure the output current of the primary current injector.

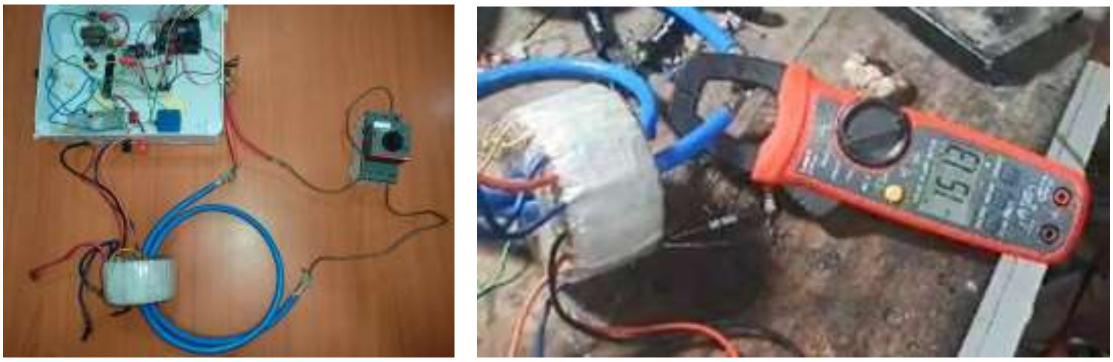

Figure 07: Testing the implemented hardware prototype

CONCLUSIONS/RECOMMENDATIONS

The aim of the research was to design a primary current injector with a 1000A output. This system was implemented after analyzing the functionality of each component individually. According to the simulation results, the proposed system works properly while giving desired outputs. This device can be used to check the operation of protective devices such as circuit breakers to ensure their functionality while avoiding serious equipment damages due to the failures of protective devices. The most important factor is that the proposed primary current injector can be implemented with a lower cost when compared with the available testing devices at the market. Not only that, but also this device can be used in the commissioning sites to fulfil the required current injection purposes. However, the implemented system has a limited degree of control and somewhat low accuracy due to the limitations of the controller. Therefore, the functionality of the proposed current injector can be enhanced while introducing automatic control through a suitable controller. That will eliminate the controller related issues and will give more accurate outputs as desired. On the other hand, this prototype was implemented to check the circuit breakers. However, it is possible to extend the hardware design considering a wide range of applications while selecting suitable components.

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