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Intelligent Miniature Circuit Breaker

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ABSTRACT

The traditional electrical distribution panel or circuit breaker panel is a system that divides the main electrical power feed and distributes them to subsidiary circuits whiles providing a protective mechanism via the use of miniature circuit breakers, residual current devices, etc. The conventional panel distributes electrical power alright, but the system does not make provision for any form of real time monitoring and feedback of power consumption levels in the home. This paper presents a design of a miniature circuit breaker distribution panel integrated with other electronic devices which helps achieve real time monitoring of power consumption and automatically trips the circuit if there is a fault and reconnects the circuit if the fault is cleared to ensure little to no interruption in electricity to appliances.

Keywords: Breaker Panel, Distribution Panel, Circuit Breaker, Electrical Power, Current Sensor.

1. INTRODUCTION

With the vast production and use of many electrical devices, the relevance of electricity is constantly impressed upon [1]. In the Ghanaian setting where the main source of power is hydroelectricity [2], the traditional electrical distribution panel is often used as centralized hub where power is distributed to the various electrical appliances in a home or facility. Residential and commercial buildings require main supply of electricity from the main utility company and the distribution board is responsible for connecting the end consumer to the main power supply, as the main power supply line terminates at the distribution board [3][4].

Distribution panels are protection devices used for connecting, protecting, and controlling multiple branches of electrical circuits fed from a single primary circuit of wiring installation in a building [5]. These distribution panels protect devices by allowing individual circuits to draw power from correctly rated breakers. They ensure reliability of power supply by isolating faulty lines and circuits, like short-circuits [6], without disrupting the other segments of the power supply. They also provide the capability of monitoring energy consumption in the home [7]. The first generation of distribution panels comprised of several fuses for protecting individual circuits. The fuse in these distribution panels must be replaced once it is blown [8] by a fault condition such as short circuit, earth leakage, overload, among others. With the advent of circuit breakers, resettable distribution panels with higher load bearing capabilities became available [9]. The circuit breakers used in conventional distribution boards are based on the principle of thermal bimetallic lever trip mechanism [10,11]. This mechanism is slow and could take several minutes depending on the percentage of overload [12, 13]. This could cause more serious damage to the circuit if the current flow is extremely high, and therefore, isolation of the circuit quickly is desired [14]. These distribution panels are also based on conventional circuit breakers and require human intervention to resume normal operation after a fault condition is cleared [11].

Several circuit-breaker designs have been proposed over the years to ensure the normal operation of dc circuits. These designs largely fall under mechanical, solid-state and hybrid circuit breakers, with hybrid circuit breakers seemingly the most technically advanced [15][16], however, implementation costs are high as they require a combination of other circuit breaker types [17] and many semiconductor switches [18][19]. This has led to a greater focus on developing solid-state circuit breakers [20].

In this paper we present an Intelligent Miniature Circuit Breaker (IMCB) for residences. The system uses a microcontroller and current sensors (CTS) to provide intelligence to a distribution system panel. The distribution system automatically detects the current flowing through the circuit and trips the circuit if the current is higher than a threshold. The current sensors keep monitoring the current and when the current falls below the threshold, the circuit is reconnected. The system uses a GSM module to send alerts to the user when the circuit trips. Data collected from the system's operation is also sent to the ThingSpeak™ [21] platform for further analysis. The proposed system operates automatically and eliminates the need for the user to manually reconnect the circuit when there is a trip.

The rest of the paper is arranged as follows: Section 2 presents some related works, Section 3 contains the proposed Intelligent Miniature Circuit Breaker (IMCB), Section 4 presents the Software Application, Section 5 contains the Test Results and Discussion, and Section 6 concludes the paper.

2. RELATED WORKS

In the year 2014, the Neurio Energy Monitor was implemented. This system comprises of a Neurio sensor, cloud system and a mobile application. The neurio system is installed in the breaker panel with current transformers. The current transformer measures the flow of electricity inside the home and produces current in its secondary coil which is proportional to the current in its primary. It reduces high voltage current into a proportional low current so the lower value can be safely measured and monitored. The data collected is transmitted via Wi-Fi to the Neurio Cloud [22]. The Neurio Cloud is an online service that stores and analyzes power data from the sensor. The system can observe events and take necessary action. The mobile application displays real time power consumption and historical graphs. It also has smart algorithms to breakdown consumption by appliances with updates every second. The neurio system has the following shortfalls:

i. Limited appliance detection – at least the connected appliance must be 400 watts. It cannot pick out any device below this threshold. This rules out low-powered devices like mobile phones.
ii. Inability of the sensor to detect specific devices in use when multiple devices are consuming electrical power simultaneously.
iii. The technology does not currently support third-party products.

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The computer electricity systems distribution panel was also introduced in India in the year 2014. It was installed as a regular electricity panel at the end user's premises. It replaces the conventional electricity panel and provides scalable monitoring and control capabilities of energy consumption at the customer's premises down to the individual circuit breakers. It has smart switches which automatically or manually connect or disconnect upon current overload, short circuits, and other faults [23]. A major challenge with this system is its complexity and reliance on Wi-Fi only.

Another system called the Powerlink Intelligent Panel was implemented in January; 2016 [24]. This system provides a new level of energy management performance. The Powerlink intelligent panels not only provide savings by controlling lights, but also provide a total infrastructure for measuring and verifying the performance of all the lighting and plug load energy conservation measures [24]. The system consists of a web-based controller and remotely operated circuit breakers. The shortfall here is its high cost of purchase.

Vlasov et al [25], proposed a smart circuit breaker to be used in conjunction with a smart home system. The proposed system is aimed at monitoring and protecting major power user groups. The system reports anomalies that occur within a house or small industrial facility running a smart home system and provides data for causation analysis. The proposed circuit breaker comprises of the electromechanical block, which contains the electromagnetic and thermal protection mechanisms along with transformers to sense current, and the electrical block, which contains the analysis board and integrated circuit.

Alden et al [26], proposed a smart plug, which is capable of not only allowing a connected device to be switched on or off, but also monitors the power consumption. The system is made up of a hall effect current transformer to measure AC current, a voltage transducer to measure voltage, a relay designed for a Raspberry Pi which controls power through the plug and an Arduino Uno microcontroller which is responsible for transmitting signals from the current and voltage sensors, along with the signal from the relay to the Raspberry Pi. The system, however, does not provide automatic switching on or off a connected device.

Mafi et al [27], proposed smart Residual Current Circuit Breaker with Overcurrent protection. The proposed system protects devices against current leakage and overcurrent situations. The system comprises a microcontroller which receives data from sensors and analyzes the data to determine if there is an anomaly with the current, which will cause the circuit to be automatically opened. The system also automatically closes the circuit after the current stabilizes. Overcurrent is determined if the amount of current passing through the circuit is above a set threshold value, whilst current leakage is determined by finding the difference in the entry and exit currents in the circuit. According to the authors, the system has a shorter reaction time than the regular circuit breaker. The system, however, does not collect data for further analysis on energy consumption.

3. MATERIAL AND METHODS

A visual overview of the proposed Intelligent Miniature Circuit Breaker (IMCB) system is shown in figure 1. The IMCB comprises of a smart distribution panel with a microcontroller unit embedded within it to provide intelligence to enable detection of trips and trip locations and the automatic reset switches, thereby avoiding manual reset in case of trips. The system has additionally, a database and analytics service and an android based mobile software application. The IMCB panel also has an LCD screen attached to it to display live values of the current and voltage. There is an efficient communication technology solution based on GSM that is embedded in the IMCB panel. This GSM module acts as a communication tool between the online service and the smartphone device. It routes all voltage and power measurements for further analytics and storage. The online service handles the analytics of power consumed by each home appliance and forwards this information to a mobile software application. With this, consumers know the status of their home power distribution system through the mobile software application.

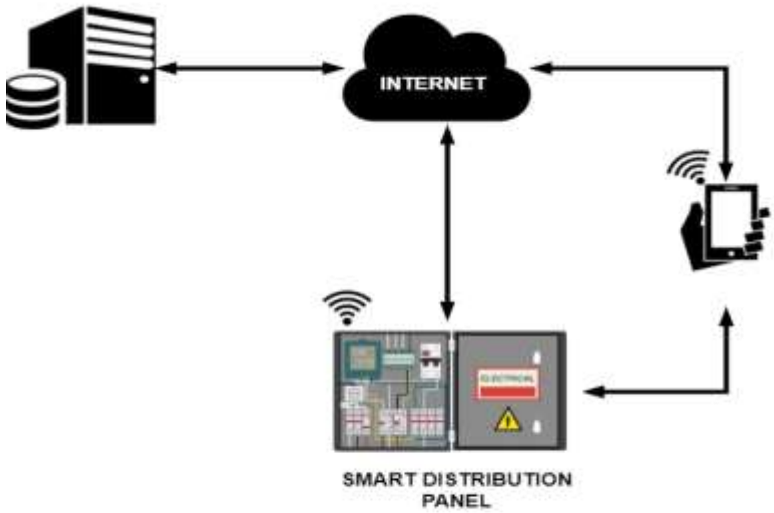

FIGURE 1. Proposed Intelligent Miniature Circuit Breaker

3.1 SYSTEM BLOCK DIAGRAM

A block diagram of the IMCB system panel is as shown in figure 2. The microcontroller, which serves as the intelligence unit of the system, receives data from the sensors i.e., current sensors (CTS). This data is then used to determine if there is a fault, and for that matter the breaker should be activated to trip the circuit or otherwise. The data is also forwarded to the GSM module to be sent via the internet to the database. The database maintains the information received and makes it available via the internet to the mobile software application installed on the user's mobile device.

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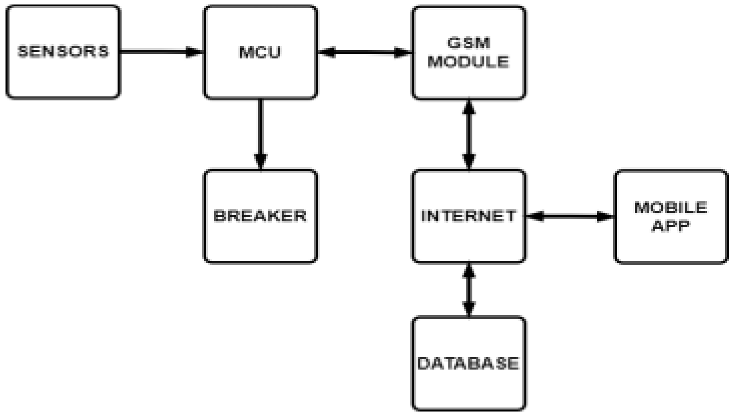

FIGURE 2. IMCB System Block Diagram

3.2 SYSTEM WORKFLOW

Figure 3 represents logical flow of operation of the IMCB system panel. As indicated in the flow chart, on pressing the power button, the system is activated. Checks are run to verify normal operation of the IMCB system. If the IMCB system panel is in a normal state, the status LED shows a green light, and the LCD displays the current and voltage values of the entire circuitry.

On the other hand, if there is a fault, the buzzer sounds and thereafter the status led turns red, after which the system lcd displays the fault and fault location in the IMCB system. The system sensors collect relevant data and send it via the GSM module to the cloud analytics platform for analysis. A fault message is also sent via SMS to the consumer to serve as a notification or an alert. After various analytics, which are usually performed in the cloud using the ThingSpeak™ platform, the data is sent back to the mobile software application for further and detail analysis of the collected data.

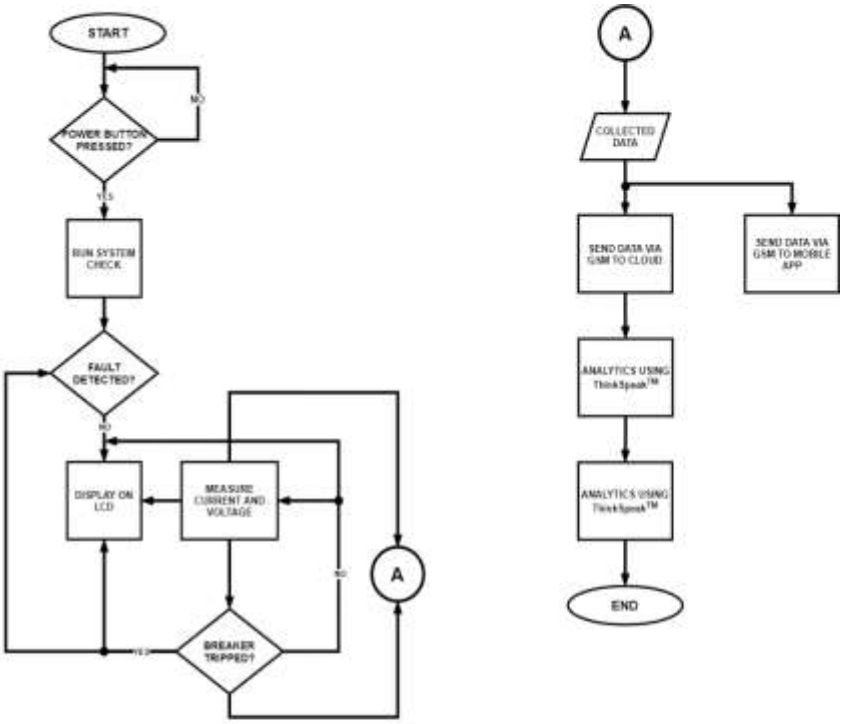

FIGURE 3. IMCB System Flow Chart

3.3 SYSTEM APPLICATION SOFTWARE

To facilitate communication, appropriate display, and transfer of information to users, an API known as ThingSpeak™ was used. The ThingSpeak™ is an Internet of Things (IoT) platform that uses channels to store data sent from applications or devices. Through HTTP calls from the REST API, MQTT Publish method, and the thingSpeakWrite() function from MATLAB, data can be written to the ThingSpeak™ channels. The ThingSpeak™ platform is used for the following:

1. Getting data from the hardware components through the GSM module
2. Analyzing and visualizing received data and
3. Sending the information to the mobile application for users.

3.4 SYSTEM USE CASES

With the IMCB system mobile software application, which is currently android based, power consumption of home appliances can be remotely monitored. As illustrated in the use case diagram in figure 4, the user must first sign up before using the mobile software application. Authentication is done using a unique key provided to the user by an administrator. The unique key is linked to the IMCB system in the home and ensures a secure connection from the mobile software application to the home system.

When the user is done with the various authentications, full access to the mobile application is granted. Users can check the circuit breaker conditions, energy billings

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and graphs of the power distribution in their homes. The information concerning the power values in the panel are fetched from a connected web-based database.

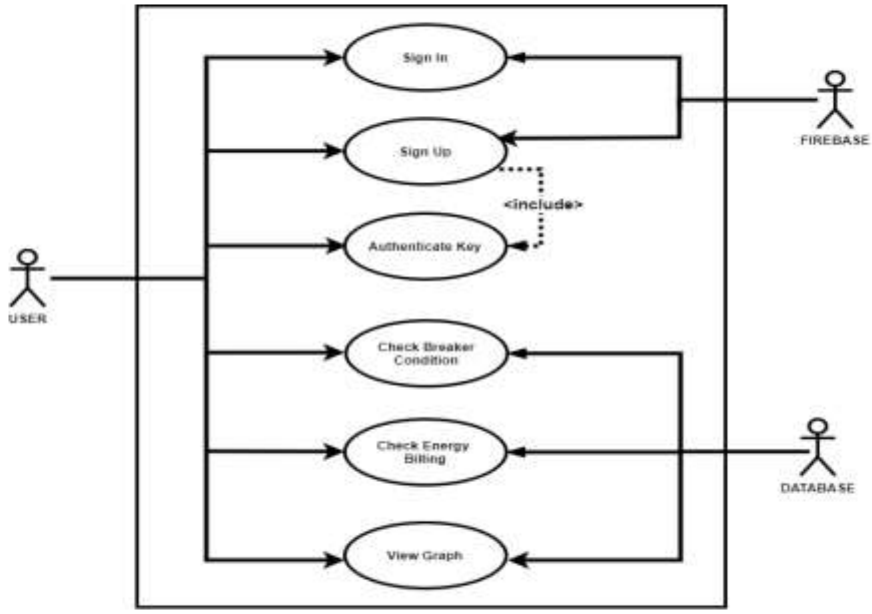

FIGURE 4: System Software Use Case Diagram

3.5 SYSTEM ACTIVITY DIAGRAM

When the mobile software application is launched, a splash screen containing the logo is loaded and if the correct panel key is entered, authentication is done, and the user is moved to the main activity page. Figure 5 shows the software application activity process. On the main activity page, the user can decide to read the energy billings, check circuit breaker condition, or read the graphs of data gathered.

Figure 6 shows various screen shots of the mobile software application. The top row has images of the splash screen, the sign in screen and the new account creation screen. The bottom row has the home screen, consumption rates screen and the energy billings screen. The home screen contains information on the circuit breakers for the various connected electric devices as well as the status of the devices. The consumption rates screen provides information on energy consumption as a bar chart for the week which helps to determine on which days of the week energy was most consumed or least consumed.

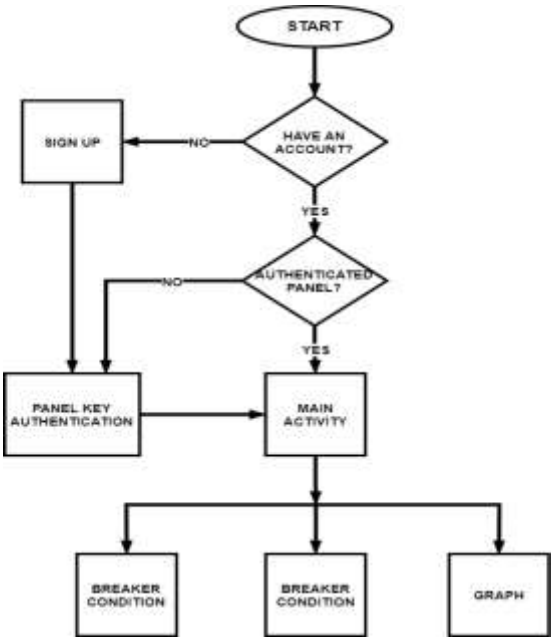

FIGURE 5. IMCB Software Application Activity Diagram

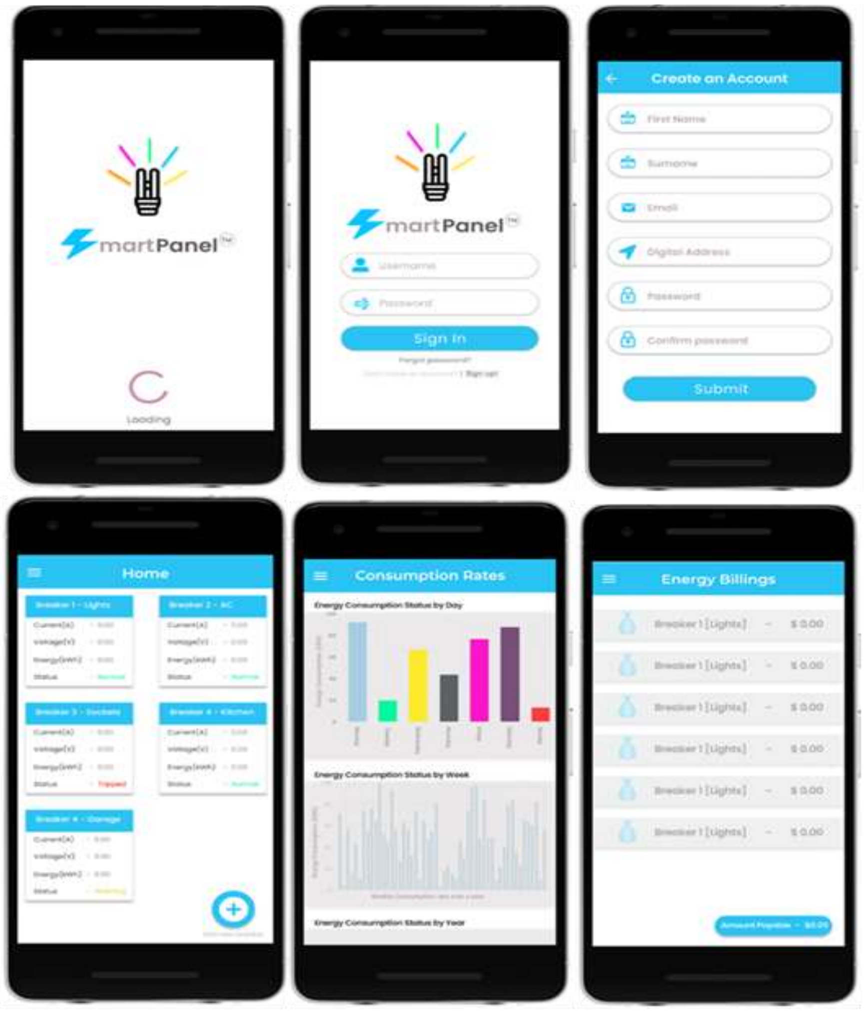

FIGURE 6. IMCB Software Application Screen Shots

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4. RESULTS AND DISCUSSION

A diagram showing the components and their interconnection used as part of a demonstration for the IMCB system panel is shown in figure 7. The components and their various functions are described in table 1. An Arduino Nano microcontroller was used as the central processing unit. An LCD screen to display live readings was attached to the microcontroller. A power button to turn on the system, an RGB LED to indicate the system is turned on and a status LED to show the state of the system were connected to the IMCB system. A buzzer and a GSM module for communication were also connected to the IMCB system. A current sensor CTS to measure the current, a bulb acting as the load and a relay acting as the circuit breaker were used for the test.

Testing was done using the setup in figure 7. Data collected was sent to the ThingSpeak™ online platform via its API. Below in table 2 is a result of the measured currents sensed by the current sensors of varying load input using a potentiometer. The set-up was done to have the relays resetting at a threshold current of 10A.

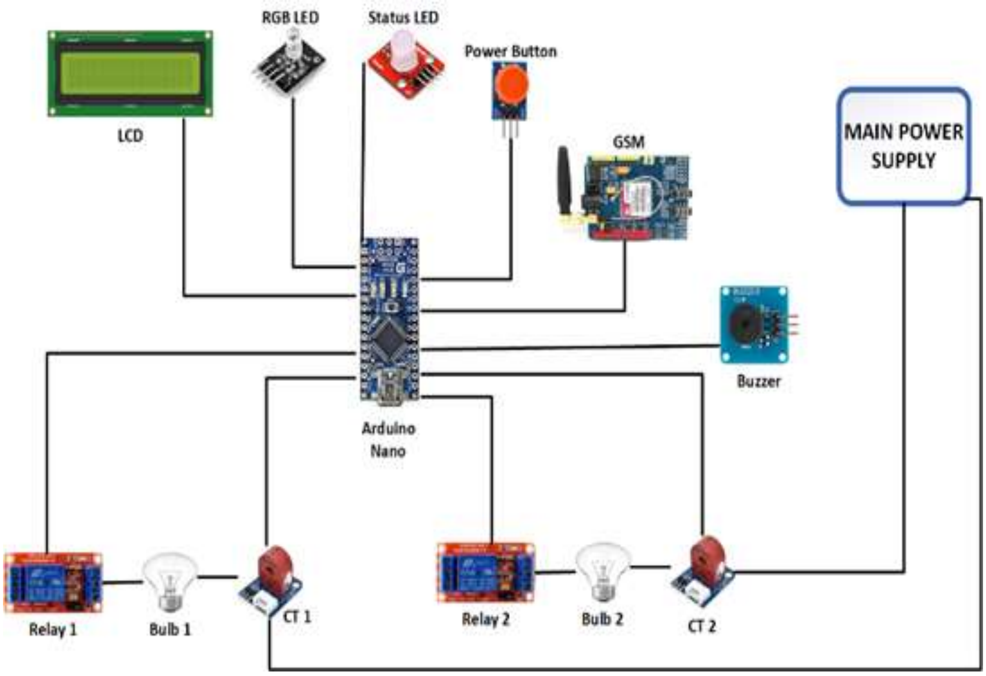

FIGURE 7. Proposed IMCB System Test Diagram

TABLE 1
System Hardware Components and functional description

Hardware Component	Description
Non-invasive AC Current Sensor/Current Transformer (CT)	AC current sensors of different ratings (from 10A to 100A), used for measuring instantaneous current from circuit breakers.
Potentiometer	Acts as an extra load for varying input load demands on the system
Relays	Acts as circuit breakers under this context. Sets and resets based on how system is programmed to operate
Power Button	For powering on/off the system
Bulb	Acts as test load under this context
Arduino Nano	A small, complete, and breadboard-friendly microcontroller based on the ATmega328 [28].
Buzzer	Buzzes to alert user on specific panel events
Power led	Upon illumination indicates that system is powered on
Status led	The differing illumination shows the current state of the system, whether system is okay or there is a problem
SIM 900A GSM Module	GSM module, used for sending data from the system to a remote receiver

TABLE 2
Sample Test Cases of Sensor Reading

#	CTS 1	CTS 2	Comment
1	5.5	4.3	Normal operation
2	9.8	7.7	Normal operation
3	6.7	8.9	Normal operation
4	6.8	10.4	CTS 1:normal CTS 2:trip
5	10.2	5.7	CTS 1: trip CTS 2:normal
6	6.7	8.6	Normal operation
7	8.1	6.8	Normal operation
8	8.4	4.7	Normal operation
9	1.9	8.9	Normal operation
10	9.9	10.2	CTS 1:normal CTS 2:trip

*CTS = Current Transformer Sensor

A circuit breaker trip creates an alert on the mobile software application and furthermore an SMS notification is sent to the user via the GSM module connected to the IMCB system unit.

Figure 8 shows SMS notifications of the circuit breaker trips sent when there is a trip. The ThingSpeak™ platform also enables the user to view additional useful information gathered from the circuit as graphs. Figure 9 shows graphs of the voltage and current which passed through the system as well as energy dissipated over the course of the period in which the IMCB system was active. This information can help a user identify the periods during the day when energy consumption is high.

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FIGURE 8. SMS alerts on breaker trip event

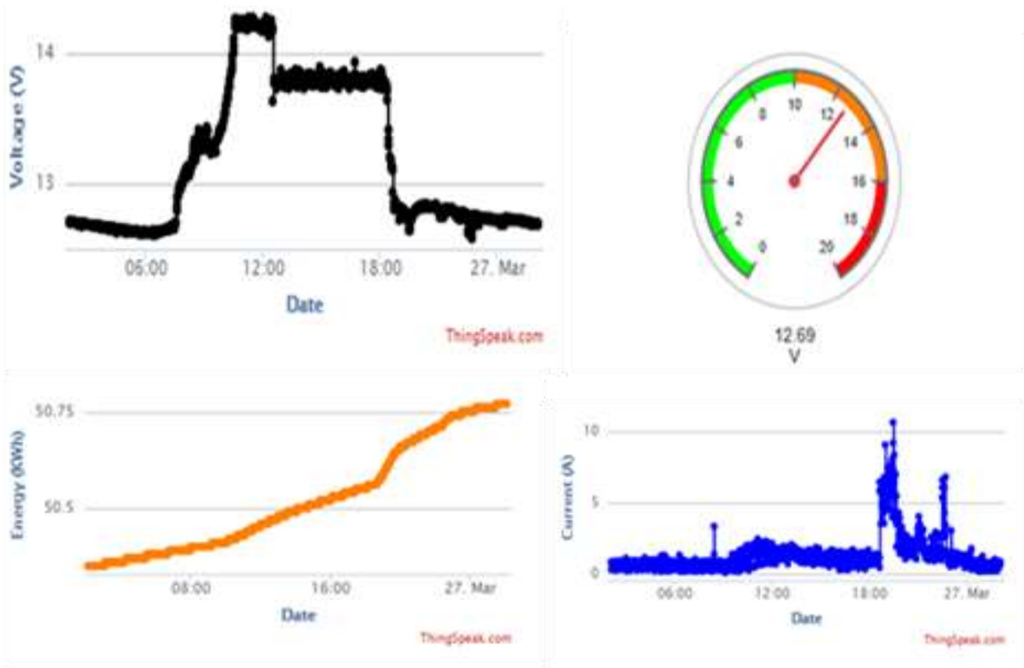

FIGURE 9. IMCB System Information Graphs

5. CONCLUSION

This paper has discussed an Intelligent Miniature Circuit Breaker for residences. The system uses a microcontroller and current sensors to provide intelligence to a distribution system. The distribution system automatically detects the current flowing through the circuit and trips the circuit if the current is higher than a threshold. The current sensors keep monitoring the current and when the current falls below the threshold, the circuit is reconnected. The system uses a GSM module to send alerts to the user when the circuit breaker trips. Data collected from the system's operation is sent to the ThingSpeak™ platform for further analysis. Initial testing was done using bulbs as the load and varying current flowing through the circuit with a potentiometer. The system performed correctly throughout the tests. Further tests will be conducted with additional electronic devices connected to the main power supply.

Further iterations of the system will first include temperature sensors to monitor heating levels of wires to mitigate fire outbreaks due to heating of electrical wires. Artificial Intelligence will also be incorporated to enable for instance, prediction of bill amounts to the user based on their past energy consumption.

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