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Smart Switchboard with Auto Safety Control

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Abstract

The intelligent smart switchboard, with automatic safety control, is designed as an IoT-based intelligent power management system to enhance electrical safety by providing the user with real-time monitoring of electrical energy consumption and the ability to remotely control electrical loads in their home or small industrial facility. The smart switchboard is built around an ESP32 Microcontroller and uses a PZEM-004T energy meter module to accurately measure voltage, current, power, energy usage, frequency, and power factor for each of the loads. The smart switchboard continuously monitors the electrical parameters of the loads, unlike traditional switchboards which do not provide live monitoring, and will automatically isolate the loads if any anomalies are detected. The Smart switchboard also contains an MQ2 (smoke) Sensor and an Infrared Flame Sensor that can be used for early warning of electrical danger due to smoke or fire, in order to mitigate environmental disasters. As soon as the microcontroller detects an overload, smoke, or fire condition, it will shut off power to the affected load, using a relay-based switching mechanism. The user will be able to view in real-time via an LCD 16x2 display, the real-time value of each of the monitored System Parameters and will be able to access the Blynk IoT Cloud platform to view/control the system via a web-based dashboard.

Keywords: Smart switchboard, internet of things (IoT), auto safety control, ESP32 microcontroller, energy monitoring, overload protection, fire detection, smoke sensor, relay control, home automation, electrical safety, real-time monitoring, fault detection, smart energy management

INTRODUCTION

This study focuses on designing and constructing a smart switchboard with automatic safety control, which will be a new way to ensure electrically safe, automated operation of the electric systems used at home and in factories and provide a more energy-efficient way to use and manage electric systems. The use of electric devices continues to grow, and there continues to be a very poor safety record; this increased use of electric devices presents a high risk of overloading circuits and shorting out a circuit with a fire, creating a need for Intelligent Systems to be built around providing a safer way to use and manage electrical energy.

The use of an ESP32 microcontroller is the main component for building a smart switchboard, which uses various types of sensors, including PZEM, Micro MQ series gas detectors, and flame sensors, to monitor both electrical and fire hazards. There are also a set of automatic cutoff relays (contactor relays) for interrupting the power to an electrical device that malfunctions owing to any abnormal condition [1].

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The Internet of Things (IoT) capability is built into the system, allowing the user to monitor and control any number of connected appliances from a web interface or local unit. In addition, the system includes an LCD that shows the status of each of the local appliances, allowing the user to visually monitor the operational status of each connected appliance. As a result of this system, the user can utilize Smart Energy Management solutions to create a safe and secure environment at home and globally and continue to create smart power-generating systems [2].

Manually operated switchboard systems have been the standard for traditional electrical installations and do not provide any form of monitoring, control, or safeguarding in an automatic manner. Therefore, as the use of electrical devices has increased and electrical loads have been subjected to greater pressure, the number of occasions on which electrical systems have been overloaded, short-circuited, or caught fire has also increased. Furthermore, it is extremely common for people and businesses to react to a potential electrical hazard slowly [3]. This is due to the fact that there is no real-time monitoring of the electric current and electrical faults in current residential and commercial electrical systems. For example, if a device has too much electric current flowing through it, it can be damaged before the owner of the device even realizes there is a problem. Finally, the current residential/commercial systems that are being used in today’s market are not efficient in terms of the amount of energy they waste, as there is currently no way to monitor or control electrical devices that consume too much energy from a remote location [4]. There are many moments when there is a risk of electrical hazards (e.g., overheating, smoking, or igniting a small fire) because there are no sensing devices or alarms to detect electrical hazards until they result in an extreme electrical event. Commercial smart electrical systems are currently available; however, these systems are expensive and difficult to install in homes [5]. Additionally, commercial systems do not provide flexibility for small home use.

RELATED WORK

The paper by Nilanjan Dutta et al. discussed a smart switch and automation system utilizing the Blynk platform for the remote control of household appliances via mobile phones. This system combines a microcontroller (NodeMCU ESP8266) with different sensors and enables users to control devices remotely and in real time (from any location). The system is more convenient, energy efficient, and secure than traditional controlled systems because of its capability to use smart scheduling and provide visual representations of data [6].

In their research paper, a smart switch powered by the IoT, which incorporates voice recognition into both Arduino and Android device controls for seamless appliance management. Unfortunately, there are currently no solutions for adaptive safety automation or multi-sensor fault identification, which presents issues around real-time reporting of potential hazards and intersecting with Smart Protection Relays on the device [7].

The report written by Gunge et al. provided informa- tion about home automation technologies including Wi-Fi, Zigbee, Bluetooth, and cloud systems. Multiple types of microcontroller-based architectures, such as Raspberry Pi and Arduino, have also been discussed. In addition, most smart switchboard products lack safety features, including overcurrent protection and fire protection; these two items should be included in the next generation of smart switchboards [8].

The previous studies analyzed Smart Switch’s effectiveness, particularly in the context of IoT home automation. Due to these limitations, including the fact that the researchers did not include either cyber security or automation safety issues, there is currently a large gap between the current capabilities of Smart Switches and the ability to prevent real-time anomalies and secure communications [9].

The project Jayesh Sonar was a part of, has developed an innovative Smart Switch for Electric Vehicles by utilizing the Internet of Things (IoT) and Arduino technology. This innovative project has produced greater degrees of reliability, thus producing a safer ignition process using Mechanical Actuation in combination with microcontrollers. According to the experimental results, this innovation should improve the reliability of the switch and provide greater security to users [10].

An intelligent switchboard that incorporates features such as scheduling, gas leak detection, and roller window operation by integrating microcontrollers and the Internet of Things (IoT) was developed. Their results demonstrated effective management of energy consumption and an extremely rapid reaction time to gas leaks. Currently, no research has been conducted on multi-fault handling or the use of predictive safety algorithms for concurrent hazard identification and escalation control [11]. A smart Arduino Touch Switchboard using an app running on a smartphone (interface) to control the switchboard wirelessly was developed. However, the research does not include advanced safety mechanisms, such as automatic disconnection of power and fault detection during overload situations, indicating an opportunity for the development of adaptive safety intelligence [12].

METHODOLOGY

Block Diagram

To create a smart switchboard with Auto Safety Control (ASSC) for an electric service, the entire process involves the development of both hardware and software components with real-time monitoring and intelligent automated features to help maintain appropriate and effective levels of safety. The first step in the process is to produce a circuit schematic design, as shown in Figure 1, which includes obtaining a complete checklist of all required hardware components (sensors, relays, microcontrollers (ESP32)) and their compatibility with each other before any actual development of the system begins.

The second phase of development will be to connect each sensor to the controller to allow real-time collection of data from each sensor for continuous load monitoring. The third step of development is to write the embedded C/C++ code in the Arduino IDE as part of the programming phase to program the logic required to incorporate IoT-based monitoring functions and control any faults that occur automatically. Once the programming phase is complete, the final step is to conduct a complete test and calibration of the entire system to ensure that all components are functioning correctly and that the relay control functions and fault detection are working correctly.

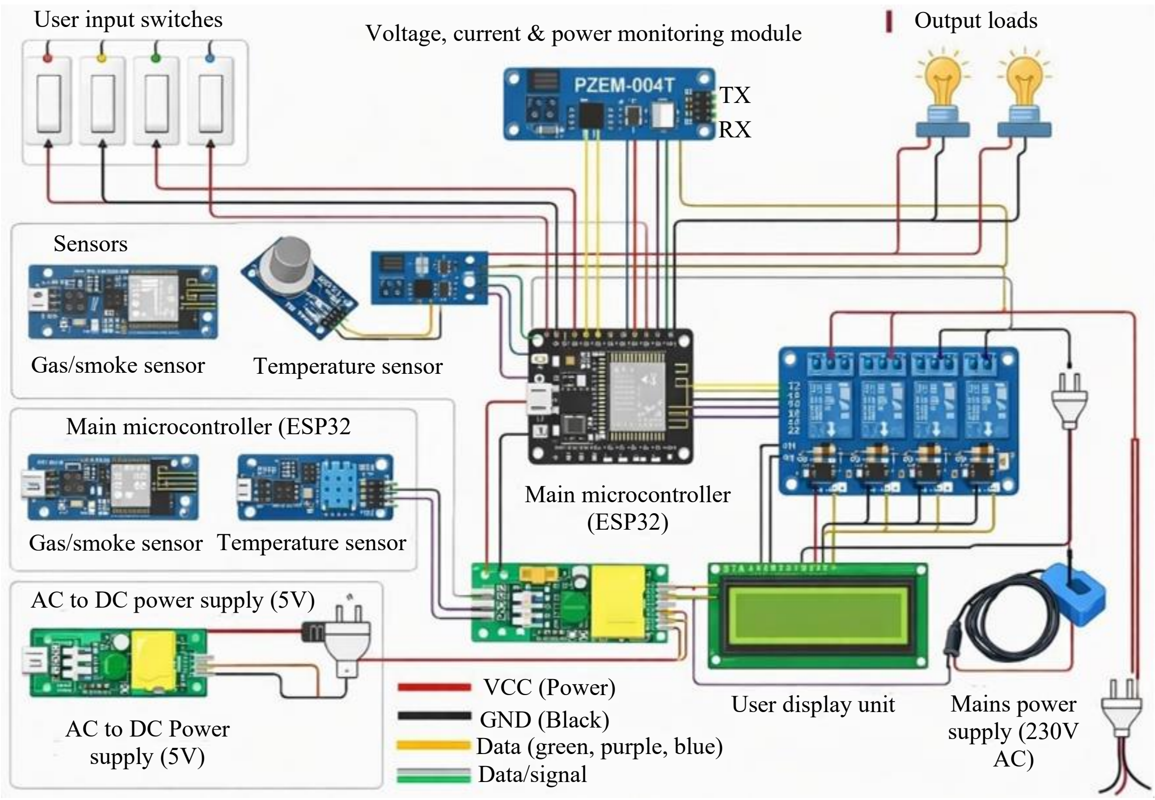

Figure 1. Block diagram.

Hardware Layer

1. *Power supply:* The Power Supply provides the ESP32 microcontroller and all sensors and relays with power from the 230V AC mains to the regulated DC required for operation at 5V or 12V.
2. *ESP32:* The ESP32 acts as the central processing element; it receives all the information from the sensors, controls the relays, and acts as a web server for remote monitoring and control of the system.
3. *PZEM-004T:* An Energy Measurement Module that uses a PZEM-004T to measure the voltage, current, active power, total energy consumed frequency, and power factor of the load. The energy measurement module sends digital signals via UART to the ESP32 and allows it to compute the amount of energy consumed.
4. *Fire/smoke sensors :* A Flame Sensor to detect flames and an MQ2 Sensor to detect smoke/gas. Both sensors provide an early warning of the presence of fire and/or smoke to help prevent possible loss of life, property, or financial damage.
5. *Relay:* The Relay Module provides an electronically controlled switch to turn the load on/off based on the control signals from the ESP32.
6. *16*2 LCD:* 16X2 LCD (LCD) - Displays real-time data regarding load condition (on/off), current level and fault information.

Software Layer

The Wi-Fi and web server libraries together allow the creation of a local web server on the ESP32, allowing the monitoring and control of the operation of the load (e.g., an LED) in real time through a web browser.

Using the web server, the status (ON or OFF) of the load, the current values output by the current, smoke, and flame sensors, and alerts can be checked if an abnormality (error) occurs.

The PZEM and sensor libraries help communicate with the current, smoke, and flame sensors to read the correct values and process the data efficiently.

The Liquid Crystal I2C library from the ESP32 microcontroller allows the sending of data to and from the LCD module on the board to display the data from the various sensors and display additional messages in their proper format.

You will primarily use C/C++ to execute the control logic of your application on the ESP32 microcontroller because these languages allow you to execute your application as efficiently as possible on the microcontroller, access sensor data as accurately as possible, and control the relay precisely.

IMPLEMENTATION

The entire system, consisting of the ESP32 module, PZEM004T power monitor, gas sensor, flame sensor, temperature sensor, relay module, LCD display, and power supply, was connected according to the provided circuit diagrams. The 230 VAC power from the utility company was converted to a stable 5 VDC power supply for all the devices (s) to operate safely with a common ground.

The ESP32 can communicate with the PZEM-004T over a UART (serial) connection; therefore, the data from the PZEM-004T provide real-time voltage, current, and power data for the Switchboard to operate the loads (gas, flame, and temperature) that are connected to the GPIO pins. The relay Module allows for the on/off operation of the appliance (lamp or fan), and a 16×2 LCD is used to display the real-time sensor data from the SSSASC.

In the case of an abnormal event, such as an overload, flame, or gas leak, the SSSASC system will turn off the relay (disconnecting the appliance), generate an alarm displayed on the 16×2 LCD, and send an alarm to the web interface notifying the user of the event. Both local and remote control of the SSSASC system provides a reliable, safe, and efficient method to use electrical appliances.

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Flow Chart

In the flowchart shown in Figure 2, which accompanies the Smart Switchboard System with Auto Safety Control, the process begins at the System Start node, where the ESP32 supplies power to all connected devices (sensors, LCD display, and relay modules) and initializes them. After all devices are initialized, the ESP32 connects to a Wi-Fi network and creates a web server so that the user can monitor and control the Smart Switchboard System remotely. After all devices in the Smart Switchboard System have been initialized, the ESP32 will, at certain intervals (which can be adjusted by the user), poll the interfaces of various sensors (the current sensors with the help of the PZEM module, smoke sensor, and flame sensor) for real-time readings to provide the data required to establish the real-time status of the Smart Switchboard System.

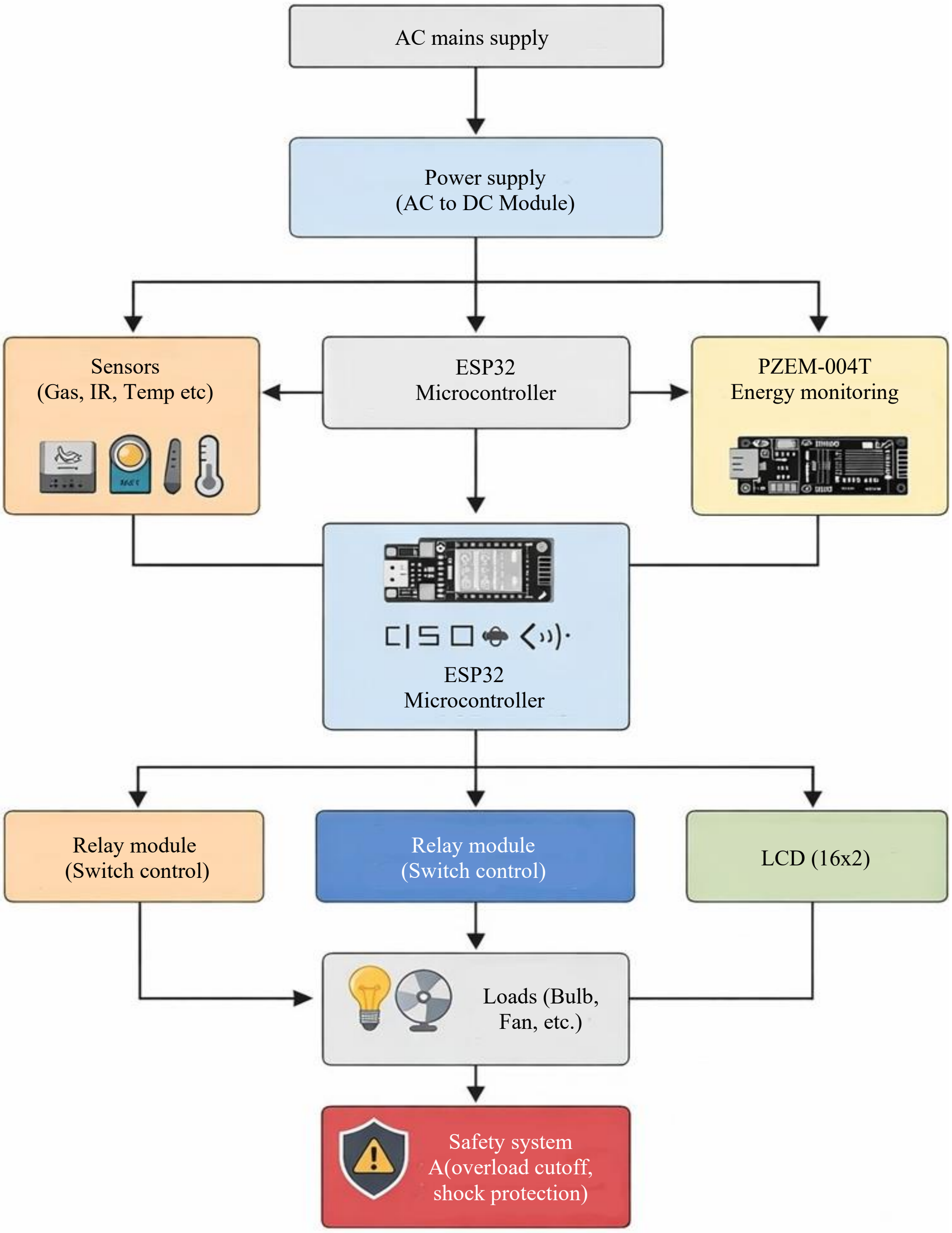

Figure 2. Flow chart.

The next phase of the process will involve checking for the occurrence of overloads using the current readings. If an overload condition exists, the ESP32 immediately deactivates the relay associated with the overloaded load and sets the auto-disable flag for that relay to prevent additional damage to the Smart Switchboard System. If there are no overloads, the system continues to operate normally. The system will then check for any safety issues (e.g., the presence of smoke or flame). If smoke or flame is detected, the ESP32 deactivates all relays, disconnects all electrical loads from the Smart Switchboard System, and provides an indication on the LCD and web interface to warn the user of the safety condition. If no safety issues are detected, the system continues to operate normally. The system updates both its LCD and web displays with live voltage, current, power, and overall system status as soon as it receives the necessary data. After this update is performed, the system looks for any commands from the user (via manual toggle switches or the web interface) that change the relay state (on/off) to control the connected appliances. Once the relay's current state has been established, the system goes back to normal operation. In this way, the system can continue to track both incoming data and relay conditions to provide real-time control and safety. The system runs continuously and will therefore be able to provide a quick and reliable response. Additionally, by running in this continuous loop operation, the system has proven to be a very efficient solution to electrical hazards.

RESULTS AND DISCUSSION

The smart switchboard system with auto-safety control demonstrated complete appliance control, energy monitoring, and safety consolidation into a single solution. The system is based on an ESP32 and utilizes a PZEM- 004T module to read real-time measurements of voltage, current, and power, in addition to interfacing with gas, flame, and temperature sensors to obtain real-time data from those sources. The relay module allows the user to control the related appliances (lighting and fans) via both manual and remote control (Wi-Fi) from outside the appliance. During the test, the system was able to recognize irregular conditions, such as overloading, gas leaks, and extreme temperature changes, and immediately remove power from the relay until the exception was fixed. The LCD and web interface provided both visual and real-time indications for system condition and electrical variables. Overall, the system has proven to be a reliable, responsive, and effective means of creating a safe environment, monitoring energy use, and providing intelligent control of electrical devices, making it a viable option for smart homes and industrial applications, as shown in Figure 3.

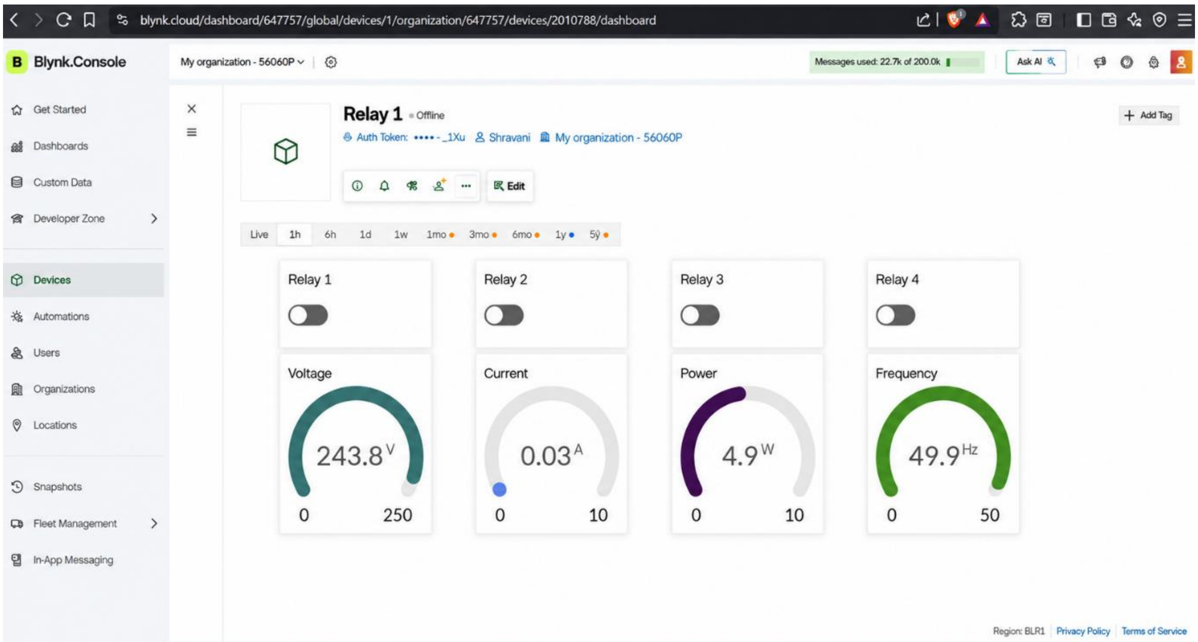

Figure 3. IoT panel.

LIMITATIONS AND FUTURE SCOPE

Limitations

Smart switchboards cannot function without an internet connection, which could lead to poor communication amongst smart switchboard and device connections. Smart switchboards tend to have higher upfront costs than traditional switchboards because they require more sensors, modules, and microcontrollers to function normally. Therefore, smart switchboards have a higher installation cost than traditional ones. Accurate calibration and maintenance of the sensors for a smart switchboard are vital to avoid erroneous or incorrect data read by the sensor systems, which could create false or incorrect fault detection.

The installation and troubleshooting of smart switchboards can be highly technical. If you do not currently know how to operate an IoT system or understand how a microcontroller works, it could be quite difficult to install or repair the smart switchboard without assistance from someone else. Finally, false alarms and/or errors can occur while working with smart switchboards because of sensor noise, latency in the connection between the device and the smart switchboard, or a glitch in the smart switchboard, which can ultimately lead to an unexpected powering off of the smart switchboard.

Future Scope

The Smart Switchboard System with Automatic Safety Controls represents considerable long-term potential owing to numerous possible improvements and applications in daily life. For instance, integrating Internet of Things (IoT) technology into it will provide users with remote access to manage all their devices through dedicated mobile applications and the cloud. The implementation of artificial intelligence (AI) will enable the prediction of fault conditions and the optimization of energy usage based on user behavior. Real-time alerts via SMS, email, or via mobile app will greatly enhance safety by notifying users immediately of hazardous situations. Additionally, users can use voice commands via voice-enabled assistants (for example,

Amazon Echo or Google Home) to control appliances. Users will have improved energy management when using this system with renewable energy sources such as solar. Users will be able to monitor energy use trends over time through data logging and analytics functionality. The combination of increased security, scale, and miniaturization offered by this system will facilitate widespread acceptance through smart home, industry, and smart city applications.

CONCLUSION

The smart switchboard with Auto Safety Switchboard consists of an integrated low-cost device that allows for real-time energy monitoring (RTEM) and remote control of IoT systems, as well as automatic (Auto) Safety Protection for the end user. The switchboard consists of an ESP32 microcontroller, PZEM-004T Energy Meter Module; Relay Load Control; MQ2 Smoke Detector; Flame Detector, and utilizes Blynk Cloud to provide a smart Electrical Management Solution to the consumer. The PZEM-004T energy meter was used to measure the electrical characteristics of the electrical switchboard, that is, Volts, Amperes, Watts, Energy usage, and frequency. The PZEM-004T provides a complete representation of electrical parameters via wireless data transmission. The end user can visualize this information in real time using the IoT dashboard and monitor/control the devices via IoT. In the case of an extreme event (i.e., overload, smoke, or fire), the relay module on the switchboard will automatically disconnect the load from the electrical switchboard for user safety. The Smart Switchboard upgrades the legacy electrical switchboard to a smart, connected energy management solution, providing a safer and more energy-efficient electrical environment through the automation of devices for residential and small industrial applications.

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