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IoT Enabled Single-Phase Load Monitoring

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Abstract*:* *In recent years, the proliferation of Internet of Things (IoT) technology has revolutionized various aspects of daily life, including the management and monitoring of electrical systems. In this context, this paper proposes an IoT-enabled single-phase load monitoring system aimed at enhancing the efficiency and reliability of electricity usage in residential and small-scale commercial settings. The proposed system employs IoT devices equipped with sensors to collect real-time data on electrical parameters such as voltage, current, power factor, and frequency. These sensors are installed at strategic points within the electrical network to capture comprehensive information about individual loads and overall consumption patterns.*

Keywords: Internet of Things (IoT), Load Monitoring, Single Phase, Energy Efficiency, Real-time Monitoring, Data Analytics, Remote Accessibility, Alerts and Notifications, Scalability

I. INTRODUCTION

The rapid advancement of technology, particularly in the domain of the Internet of Things (IoT), has ushered in a new era of smart and interconnected systems. Among the myriad applications of IoT, the monitoring and management of electrical systems have emerged as pivotal areas for innovation and improvement. In this context, the focus on single-phase load monitoring has garnered significant attention due to its relevance in residential and small-scale commercial settings. Traditional methods of load monitoring often involve manual readings or rudimentary devices that provide limited insights into energy consumption patterns. However, with the advent of IoT-enabled solutions, there exists a transformative opportunity to revolutionize the way electricity usage is monitored, analyzed, and managed. The essence of IoT lies in its ability to connect physical devices and sensors to the internet, enabling seamless communication and data exchange. When applied to single-phase load monitoring, IoT facilitates the deployment of intelligent sensors and meters that continuously gather real-time data on various electrical parameters. These parameters typically include voltage, current, power factor, frequency, and sometimes even harmonics. By harnessing this wealth of data, IoT-enabled load monitoring systems offer a multitude of benefits. Firstly, they provide granular insights into individual loads, allowing users to identify energy-intensive appliances or equipment. This level of visibility empowers users to make informed decisions regarding energy conservation measures and load optimization strategies. Moreover, IoT facilitates remote accessibility, allowing users to monitor electricity usage and control devices from anywhere with an internet connection. This capability not only enhances convenience but also enables proactive management of electrical systems, thereby mitigating the risk of potential issues such as overloading or voltage fluctuations. Furthermore, the integration of advanced analytics techniques with IoT data enables predictive maintenance and anomaly detection. By analyzing historical usage patterns and identifying deviations, these systems can anticipate potential failures or inefficiencies, allowing for timely intervention and preventive measures. In addition to operational benefits, IoT-enabled single-phase load monitoring systems contribute to energy efficiency and sustainability goals. By promoting awareness of energy consumption patterns and facilitating optimization strategies, these systems help reduce wastage and promote responsible usage practices. However, despite the numerous advantages offered by IoT-enabled load monitoring, challenges such as data privacy, security, and interoperability must be addressed to realize its full potential. Nonetheless, with ongoing advancements in IoT technology and increased adoption rates, the future of single-phase load monitoring appears promising, promising a paradigm shift towards smarter, more efficient electrical systems.

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II. WORKING PRINCIPLE

The system operates based on the principles of measuring voltage and current in the electrical circuit to calculate power consumption and other relevant parameters. To power the SCT-013 Current Sensor and ZMPT101B Voltage Sensor, their VCC and GND pins are connected to the Vin and GND pins of the ESP32, respectively, utilizing a 5V power supply. The connection setup involves linking the output analog pin of the ZMPT101B Voltage Sensor to GPIO35 of the ESP32, and similarly, the output analog pin of the SCT-013 Current Sensor is connected to GPIO34. This configuration allows the ESP32 to effectively capture analog readings from both sensors, enabling accurate monitoring of voltage and current in the electrical circuit. By assigning specific GPIO pins for each sensor, the ESP32 can efficiently process the acquired data and perform necessary calculations for load monitoring purposes. Additionally, the circuit necessitates two 10K resistors, one 100-ohm resistor, and a 10uF capacitor. This configuration ensures proper voltage and current sensing, enabling the ESP32 to acquire analog readings from the sensors accurately. By connecting the sensors to specific GPIO pins, the ESP32 can efficiently process the data and perform calculations for monitoring electrical parameters such as voltage, current, power, and energy consumption. The inclusion of resistors and a capacitor in the circuit serves various purposes. The 10K resistors may be employed for voltage division or pull-up/pull-down purposes, depending on the specific requirements of the sensors and the ESP32's input/output characteristics. The 100-ohm resistor may be utilized for current sensing or impedance matching purposes, depending on the application. The 10uF capacitor may be used for filtering or decoupling purposes to stabilize the power supply and reduce noise in the circuit. Overall, this circuit configuration, along with the appropriate components, facilitates reliable and accurate monitoring of electrical parameters in a single-phase load system using the ESP32 Wi-Fi Module, SCT-013 Current Sensor, and ZMPT101B Voltage Sensor. To accurately measure current and voltage, it's essential to connect the AC wires to the input AC Terminal of the Voltage Sensor. Conversely, for the Current Sensor, only a single live or neutral wire needs to be inserted inside the clip part. This setup ensures that the sensors can effectively capture the electrical signals without interference, allowing for precise monitoring of current and voltage levels in the electrical system. The VCC and GND pins of the LCD Display should be connected to the ESP32's 5V and GND pins, respectively. Additionally, the SDA and SCL pins of the LCD Display should be connected to GPIO21 and GPIO22 of the ESP32, respectively. Adjustment of the LCD contrast can be achieved by utilizing a 10K potentiometer located at the back of the I2C Module.

Alternatively, the data from the ESP32, SCT-013 Current Sensor, and ZMPT101B Voltage Sensor can be monitored via the Blynk Application without the necessity of connecting the LCD display. Blynk offers a user-friendly interface for remotely monitoring and controlling IoT devices, making it a convenient option for accessing real-time energy meter data from the sensors without the need for a physical display.

III. HARDWARE IMPLEMENTATION

To implement an IoT-enabled single-phase load monitoring system utilizing an ESP32 WiFi Module, ZMPT101B AC Voltage Sensor, SCT-013-030 Non-invasive AC Current Sensor, and a 20x4 I2C LCD Display, several steps must be taken to ensure proper hardware integration and functionality.

1. Power Supply Setup: Connect the VCC and GND pins of all components to the 5V and GND pins of the ESP32, respectively, using jumper wires. It's crucial to ensure a stable power supply to prevent any erratic behavior.
2. ESP32 Connectivity: Establish connections between the ESP32 and other components according to their specifications using jumper wires. Connect the ESP32 to a computer via USB for programming purposes.
3. ZMPT101B Voltage Sensor Connection: Connect the ZMPT101B's VCC pin to the ESP32's 5V pin. Connect the GND pin of the ZMPT101B to the GND pin of the ESP32. Connect the output analog pin of the ZMPT101B to a GPIO pin on the ESP32, such as GPIO35.
4. SCT-013-030 Current Sensor Connection: Connect the SCT-013-030's VCC pin to the 5V pin of the ESP32. Connect the GND pin of the SCT-013-030 to the GND pin of the ESP32. Pass either the live or neutral wire through the current sensor's clip part. Connect the output analog pin of the SCT-013-030 to a GPIO pin on the ESP32, such as GPIO34.

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5. 20x4 I2C LCD Display Connection: Connect the LCD Display's VCC pin to the ESP32's 5V pin. Connect the GND pin of the LCD Display to the GND pin of the ESP32. Connect the SDA pin of the LCD Display to GPIO21 of the ESP32. Connect the SCL pin of the LCD Display to GPIO22 of the ESP32. Adjust the LCD contrast using a 10K potentiometer located at the back of the I2C Module.
6. Assembly and Testing: Mount all components securely on a breadboard or suitable platform. Ensure that all connections are firmly secured and insulated to prevent short circuits. Test the system by uploading appropriate firmware to the ESP32, configuring it to read data from the sensors and display it on the LCD Display.
7. Calibration and Optimization: Calibrate the system to ensure accurate readings by adjusting parameters such as voltage and current scaling factors. Optimize the firmware to efficiently handle sensor data and transmit it to a remote server or display it on the LCD as required.
8. Integration with Blynk: Integrate the system with the Blynk application to monitor data remotely without the LCD Display. Configure the ESP32 to communicate with the Blynk server and display data on the Blynk app interface.

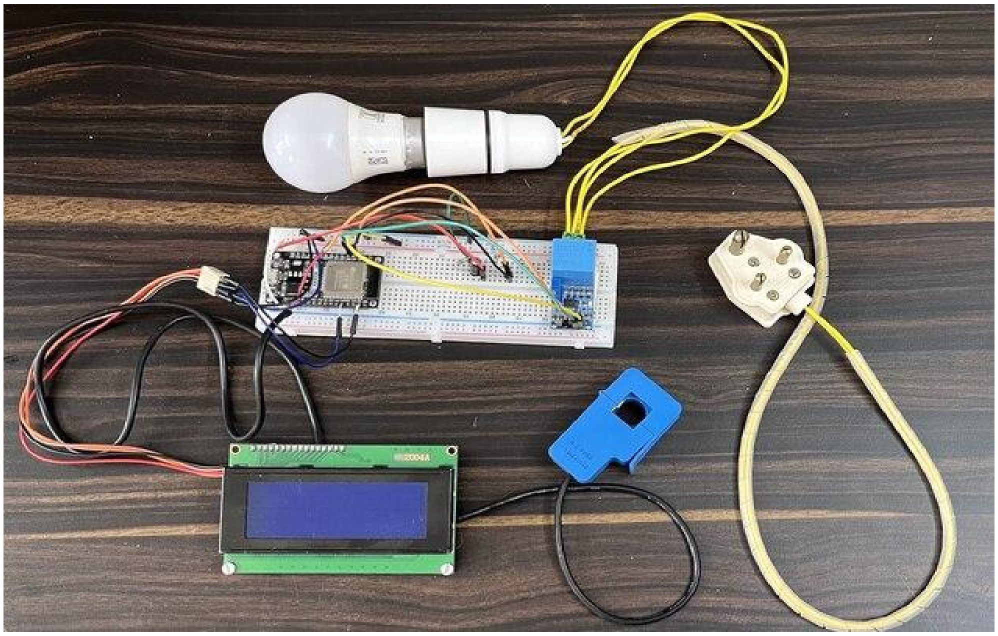

Fig 1. Hardware connection

IV. RESULTS

Creating a new template in the Blynk web dashboard involves defining the template's name, hardware, connection type, and setting up widgets to display data from the ESP32 microcontroller. The following steps outline the process:

1. Create New Template:

- Open the Blynk web dashboard and navigate to the Templates section.
- Click on "Create New Template" and assign a name to the template, such as "Single-Phase Load Monitoring."
- Select the appropriate hardware platform, in this case, "ESP32" from the available options.
- Choose the connection type, which could be either Wi-Fi or Ethernet, depending on the ESP32's connectivity method.

2. Add Gauge Widgets:

- Once the template is created, navigate to the template editor.
- From the widget library, locate the Gauge widget and add four instances of it to the template.
- Assign each Gauge widget to display the value of Vrms, Irms, Power, and KWh respectively.

3. Configure Widget Settings:
- Select each Gauge widget and configure its settings as follows:
- For Vrms, Irms, Power, and KWh widgets, set the input pin to the corresponding virtual pin number where the ESP32 will send the data.
- Adjust the range and scale of the Gauge widget to match the expected range of values for each parameter.

4. Finalize and Save:
- Review the template to ensure all widgets are correctly configured.
- Save the template to apply the changes.

By following these steps, the Blynk web dashboard will be set up to receive data from the ESP32 microcontroller and display it using Gauge widgets for Vrms, Irms, Power, and KWh values. This setup allows for real-time monitoring of electrical parameters and provides a user-friendly interface for data visualization.

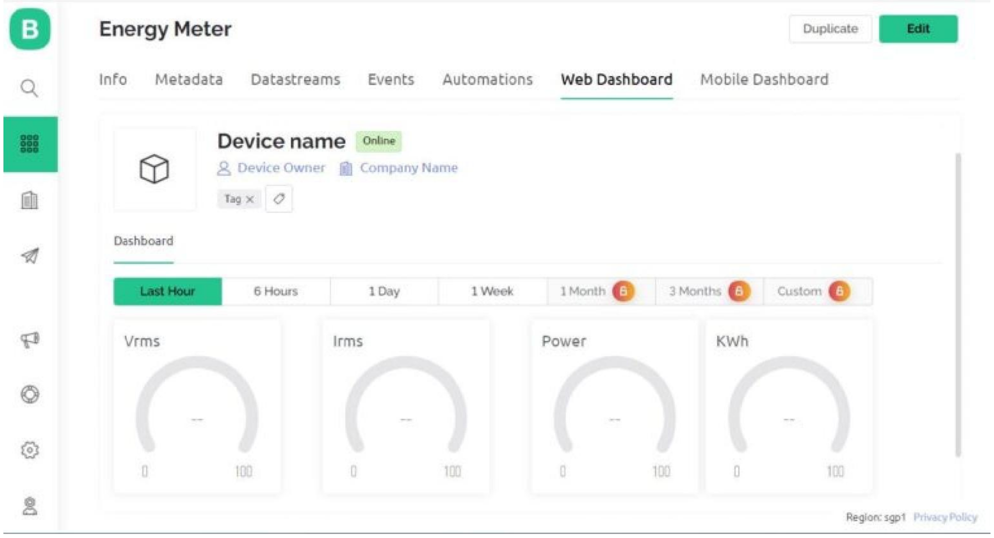

Fig.2 Blynk setup

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Vrms: 184.74 V
Irms: 0.6576 A
Power: 121.4783 W
kWh: 0.12655 kWh
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Fig.3 Output on LCD

V. VOLTAGE SENSOR OUTPUT

Initially, calibrate the ZMPT101B Voltage Sensor using an Arduino UNO/Nano Board. As it lacks pre-calibration, utilize the Arduino UNO/Nano's linear ADC pin for this purpose. Connect the sensor to analog pin A0 of the Arduino. Upload the provided code to the Arduino Board. Open the Serial Plotter; if no sine wave appears, adjust the potentiometer to calibrate. Upon displaying a proper sine wave, consider it appropriately calibrated.

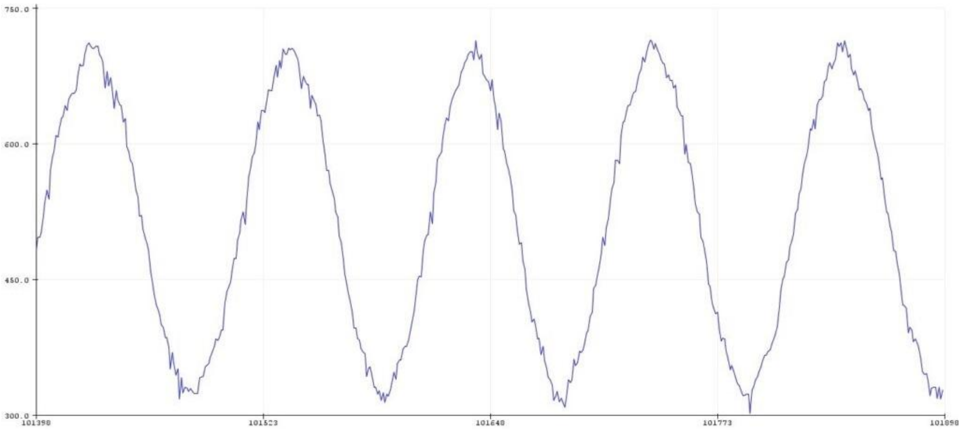

Fig.4 ZMPT101B Calibration

VI. CONCLUSION

In conclusion, IoT-enabled single-phase load monitoring represents a groundbreaking approach to comprehending and enhancing energy utilization at the level of individual appliances. Throughout our discourse, we have delved into the fundamental aspects and advantages associated with this technology, emphasizing its potential to revolutionize energy efficiency, appliance management, and overall consumer awareness. Primarily, IoT-enabled single-phase load monitoring systems deliver unparalleled granularity in energy consumption data. By capturing real-time information from each appliance, these systems offer insights into usage patterns, peak demands, and standby power consumption. This detailed data empowers users to make informed decisions about energy usage, identifying inefficiencies and optimizing consumption habits. Moreover, the incorporation of IoT in load monitoring significantly contributes to energy conservation endeavors. By identifying energy-intensive appliances or inefficient behaviors, users can proactively take steps to minimize their overall energy footprint. This not only leads to cost savings but also supports broader sustainability objectives by reducing carbon emissions and environmental impact. Furthermore, IoT-enabled load monitoring systems enable predictive maintenance and fault detection. Through continuous monitoring of appliance performance, these systems can identify deviations from normal operation and flag potential issues before they escalate. This proactive approach extends the lifespan of appliances and minimizes the risk of unexpected breakdowns, enhancing overall reliability and convenience for users. Another notable benefit of IoT in single-phase load monitoring is its role in fostering smart home ecosystems. By integrating with other IoT devices and platforms, load monitoring systems can facilitate automated responses based on real-time data. For example, a load monitoring system detecting high energy usage from a water heater can trigger a smart thermostat to adjust heating settings, optimizing energy usage without compromising comfort. Despite these advantages, challenges persist in the widespread adoption of IoT-enabled load monitoring systems. Issues such as data privacy, interoperability, and cost-effectiveness must be addressed to ensure accessibility and acceptance among consumers. Additionally, standardized protocols and regulations governing data collection, sharing, and usage in IoT ecosystems are necessary to foster trust and accountability.

VII. FUTURE SCOPE

The future scope of IoT-enabled single-phase load monitoring is promising, with advancements anticipated in various aspects. Enhanced sensor technologies will provide more accurate and real-time data, enabling precise energy consumption analysis and optimization. Integration with artificial intelligence and machine learning algorithms will enable predictive maintenance and anomaly detection, further improving system reliability. Additionally, increased connectivity and interoperability among IoT devices will facilitate seamless integration into smart grid systems, enabling dynamic load management and demand response. Overall, the future holds opportunities for IoT-enabled load monitoring to play a pivotal role in achieving energy efficiency goals and shaping the future of smart energy management.

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