DEVELOPMENT OF IOT BASED ENERGY METER USING ACS712 CURRENT SENSOR AND ZMPT101B VOLTAGE SENSOR

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ABSTRACT

The growing need for intelligent energy monitoring systems in both residential and industrial settings has driven the advancement of smart metering technologies. This study presented the development and evaluation of a cost-effective, IoT-enabled energy metering system utilizing the ACS712 current sensor and ZMPT101B voltage sensor, interfaced with an ESP32 microcontroller. The system designed had real-time acquisition of voltage and current values, from which it derived instantaneous power and energy consumption data. Leveraging the computational and communication capabilities of the ESP32, sensor data were processed and transmitted over Wi-Fi to a blynk cloud-based platform for continuous monitoring and control of energy consumption. The design offered a scalable, low-power solution for remote energy management and it paved the way for further integration with home automation and smart grid systems. The system achieved an average accuracy of over 97% when compared to standard multimeter readings, which indicates its suitability for real-world applications. Voltage measurements exhibited a maximum deviation of ±1.5V, while current readings were stable within ±0.02A. While these deviations are relatively minor, they highlighted the limitations of the analog sensor system, particularly under rapidly fluctuating load conditions. The ESP32's 12-bit ADC provided sufficient resolution for capturing voltage and current signals; however, noise from unshielded wiring and sensor non-linearity contributed to minor measurement errors. Further calibration and filtering techniques could mitigate these issues, improving accuracy, especially in high-frequency applications or environments with considerable electrical noise. This research has offered a design framework for low-cost blueprint for an IoT-based energy meter and also provided outlined strategic sensor integration approach with the effective use of ACS712 and ZMPT101B with ESP32. On the other hand, it has demonstrated reliable wireless data communication with real-time visualization. For researchers hoping to further on this topic, it is recommended that mechanism for phase detection (e.g., zero-crossing detector) to measure real power (Watts) and power factor for more accurate energy readings should be incorporated.

Keywords: ZMPT101B, ACS712, ESP 32, Internet of Things, Blynk.

1.0 INTRODUCTION

Nigeria is presently moving away from analog energy metering system to a system dominated by digital prepaid energy metering system. Though the prepaid metering system is gradually gaining wider acceptance in the power distribution sector, there are still many customers that are metered using the old analog system. On the whole, it has been reported that only about 43% of the electricity customers in the country are metered (Iloh, *et al*, 2023). For customers still on analog metering system, the utility personnel are required to visit the customers' premises to manually read their meters to determine their actual consumption.

The traditional analog energy meters lack real-time monitoring capabilities and remote access features, leading to inefficiencies in energy management. It is also practically impossible for the utility companies to meet up with the demands of regular monthly visits to customers' premises. Other challenges are scale interpretation, i.e. potential for misinterpretation of the meter scale markings, especially under poor lighting conditions. Access issues are another problem where it can become difficult accessing meters in certain locations, potentially resulting in estimated billings. There is also the issue of Limited data capabilities, data cannot be stored for historical data record purpose needed for analysis, no real-time monitoring, vulnerability to tampering and physical manipulation. The advent of Internet of Things (IoT) technology provides a solution by enabling remote data collection, real-time monitoring, and predictive analytics for energy consumption. Accurate energy metering and billing is a challenge in some developing countries. The next dimension of metering challenges in Nigeria will be with the already deployed digital prepaid metering system. In the current digital metering regime, while the customers on the prepaid metering system enjoy better services in terms of fair billing of their energy consumption, the utility company only relies on the energy purchase information on its database to monitor the customers' energy consumption. There is no remote real time monitoring and control of the energy consumption by both the customers and the utility companies. An enhanced system that will provide real-time remote monitoring and control of customers' energy consumption will not only improve customer satisfaction but also improve utility companies' revenue collection as most cases of energy theft will be detected in real-time remotely (Iloh *et al*., 2023). The ACS712 Current Sensor is a fully integrated, Hall-effect-based linear sensor IC that provides accurate current measurement for both AC and DC signals. This sensor can measure up to ±20A of current and outputs a corresponding analog voltage signal. It is widely used in applications requiring precise current monitoring and control, such as in motor control, load detection, and power management systems. This sensor is preferred as opposed to the traditional method of using current transformer for current measurement.

The Single-Phase AC active output voltage transformer, Voltage Sensor Module is designed to accurately measure AC voltage in single-phase systems. This module is ideal for use in various applications, including energy monitoring, home automation, and industrial control systems, providing reliable and precise voltage readings. Key advantageous features are high accuracy, wide voltage range, active output ease of integration and compactness of design (*ZMPT101b Voltage Sensor Module,*2025).

2.0 SUMMARY OF RELATED LITERATURE

Various attempts have been made by several researchers to design IoT based Energy Meter suitable for metering electric power consumption. Presently, the majority of them have been focused on the conventional current transformer as the sensor which is an intrusive and bulky type of sensors as compared to rogowski coils. The few related literature on this interesting area is thus presented here.

Sawar *et al (2023)* proposed a *Digital Energy Meter with data sending capability using GSM network*; the system was designed based on PIC microcontroller. Calculation of the phase difference between current and voltage using Zero Cross Detection capability of op-amp was achieved. The designed system was able to send its data via wireless communication to a central server where monitoring and analysis of the data was easily made. Current transformer was used as the current sensor and step-down potential transformer was used to measure the voltage. SIM900 based GSM module was chosen as a wireless solution.

Kudus *et al* (2024) presented Energy *Theft Detection and Real-Time Monitoring in a Smart Prepaid Metering System*: an approach to an intelligent prepaid energy metering system was presented, the system was designed to detect and address the issue of power theft by offering real -time monitoring capabilities. The system was built around a LPC 1343 microcontroller which monitors readings from two current sensors, one tracking the user's load consumption and being placed before the meter to measure the total current drawn by all the loads, while the second was placed after the meter. Any changes between these two readings indicate theft, prompting immediate action. A momentary switch is installed to detect tampering attempts and automatically trigger alerts once the meter is tampered with. The system equally enabled users to recharge energy units remotely and monitor their consumption through a user -friendly interface. The system included GSM technology that enabled SMS logging of all unauthorized activities to relevant authorities. Experimental results demonstrated that the system measured load consumption and detects attempts to bypass the meter, reducing utility companies' revenue losses.

Iloh *et al (2023* also presented their work on *Internet of Things Concept for Improving Energy Metering in Power Distribution Networks*. The work highlighted one of the challenges being encountered by energy consumers and distribution companies in Nigeria as the inability of both the customer and the distribution company to monitor and control the customer’s energy consumption remotely and in real time. The work aimed at improving energy metering in power distribution networks using the Internet of Things (IoT) concept. the IoT technology enabled an internet-based control and monitoring system which automatically processes real time measurement data, displays the results on the energy meter display unit (liquid crystal display - LCD), and sends same results to both the customer’s and the utility company’s webpage simultaneously. It also featured the ability to process control signals from both the customer and the utility company frontends and take control actions whenever necessary. The work used the existing JP-01 energy meter model and was enhanced by replacing the ZMCT103C current transformer and the PIC16F873A microcontroller with ACS712 Hall Effect current sensor and ESP32 Wi-Fi enabled microcontroller respectively in the energy meter architecture. The IoT-based energy meter firmware was programmed using the Arduino Integrated Development Environment (IDE). The web application enabling internet communication between the energy meter and remote devices (computers or mobile phones with internet access) was developed using the Firebase platform. Access to the system database was designed in a manner that only users with the unique log in details of the customer or utility administrators can view the meter data over the internet and issue control commands as desired overall the meter accurately measured mains voltage in volts (V), instantaneous current in amperes (A), instantaneous power in kilowatts (kW) and energy consumed in kilowatt-hours (kWh) and displayed same results simultaneously (in real-time) on the meter’s LCD and on the webpages of both the customer’s remote device and the utility company’s remote device over the internet. Control actions such as TURN ON, TURN OFF and SET LOAD LIMIT were also successfully implemented remotely both from the customer’s end and the utility company’s end. Thus, with their system, a real-time bidirectional monitoring and control of the customer’s energy consumption was effectively achieved.

Bakare (2019) was aimed at addressing cyberattack threat vulnerability that has caused power researchers grave concerns due to the reliance on communication network for smart grid technology. With the feature of network integration, the system uses Arduino IDE with ESP 8266 for the smart operation and IoT capability. The developed system was able to achieve the following: An IoT based smart meter has been developed with data collection and management capability, online capability making all data available online and in real time.

3.0 METHODOLOGY

A. Study Area

This research specifically focused on developing a single-phase IoT based Energy meter system prototype for deployment in the Nigerian energy sector.

B. Materials

ACS 712, ZMPT101B, ESP 32 micro-controller and other software materials were used for this research.
System Architecture

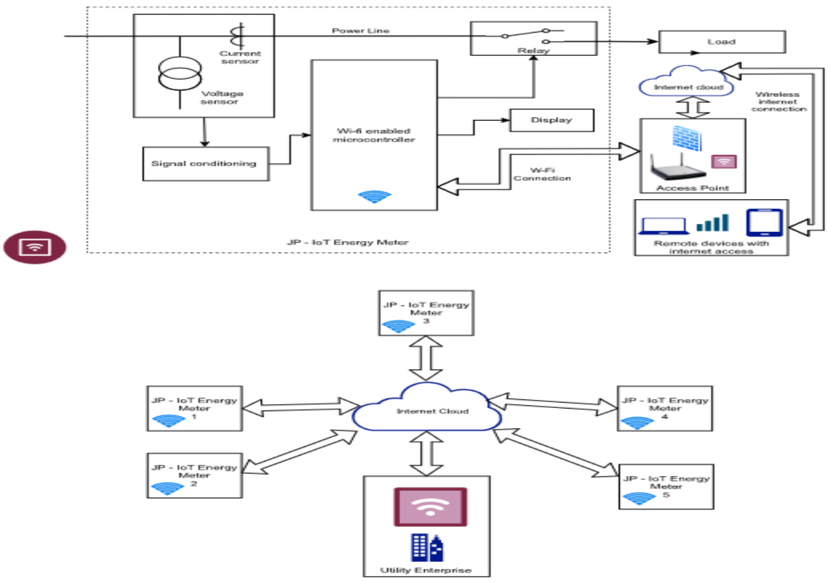

Figure 1: System Architecture

i. Voltage and current sensors ZMPT101B and ACS 712 as earlier mentioned which functions are to detect voltage and current respectively.

ii. Signal conditioning: the sensors outputs are analog; there is the need therefore for analog to digital conversion. This is what the block does. However, it should be noted here that the signal conditioning done here was embedded within the microcontroller itself, this is because ESP32 has two analog inputs unlike the olden day Atmega series where one need the use of analog-digital converter. It was however shown differently in this block to expatiate the actual events that happened inside the microcontroller.

iii. Relay: they are electromechanical switches. This will be remotely activated by the microcontroller. The essence of the relay is to issue a trip or isolation command in the event of power theft or over usage.

iv. WI-FI enabled microcontroller: the WI-FI enabled microcontroller use here is the ES32. It offers WI-FI and Bluetooth connectivity, that allows remote connection to the system from anywhere around the world through the cloud database.

v. The Display: this offers on-site reading of the meter. It is a LCD (16x4) display that can display the current, voltage power and energy utilization.

vi. Access point: this could be a router, modem, or any internet enabled phone with hotspot. This is the internet gateway through which the meter could communicate to the outside world.

vii. Cloud platform: here in the design, Blynk has been deployed as the cloud database. Another platform that can be used are Thingspeak, google sheet, firebase and so on. The platform offers cloud data visualization and analytics. It can also keep historical data records. Through the cloud base, all enabled meters can be aggregated and utility system can access any of the meter's records anytime the need arise

C. Development of the ACS712 For Current Sensor

The ACS712 sensor output was connected to one of the analog input pins of the ESP32 (GPIO 34). The sensor was powered using the 5V pin from the ESP32, and the ground was shared. The VCC pin of the ACS712 was connected to the 5V output of the ESP32. With the ground of the sensor shared with the microcontroller's ground. The analog signal output from thesensor.

The ACS712 sensor has two terminals for current input and output (IP+ and IP−). The load where the current was to be measured was connected in series with the (IP+ and IP-) of the microcontroller**.**

D. Software Implementation

The ESP32 reads analog values, converts them to voltage, and calculates current using the following steps:

Step 1: the microcontroller read sensor signal using analogRead()

Step 2: Convert ADC value to voltage: voltage = (adc / 4095.0) * 3300 (mV)

Step 3: Calculate current: current = (voltage - 2500) / 66

The complete code developed for this section has been added to the appendices section of the work.

E. Development of voltage sensor using ZMPT101B

The ZMPT101B voltage sensor was connected to the microcontroller, with the Vcc of the sensor connected to the VCC (3.3v) of the microcontroller, the output of the ZMPT101B connected to the second analog input of the controller. The ground was connected to the ground terminal, while the load where voltage would be measured was connected to the input pins of the sensor using voltage divider network.

F. Programming the ESP 32 for voltage measurement

The ESP 32 was connected via USB to a computer running Arduino IDE and the Arduino code was uploaded and ensured it was properly patched; the serial monitor was used toverify thevoltage readings. To avoid conflict, proper care was taken to ensure different analog pin was used for the voltage. GPIO 35 was used for this section of the programming.

The sequence of events that occurred in the voltage measurement section is hereby summarized

Step 1: The ZMPT101B outputs an analog waveform proportional to the AC mains voltage.

Step 2 The ESP32 sampled the waveform to detect peak-to-peak voltage (Vpp).

Step 3: RMS voltage was calculated using the formula: Vrms = (Vpp / 2.0) * 0.707.

G. Power Measurement

Power measurement in the IoT-based energy meter was achieved by combining the current and voltage readings obtained from the ACS712 and ZMPT101B sensors, respectively.

H. Circuit Connection

The V_{out} of the ACS712 and ZMPT101B were both connected to GPIO 34 and 35 respectively as depicted in the complete circuit diagram. Both sensors were powered with 5v and ground from the ESP 32, while A.C load was connected to the supply.

I. Power and Energy Calculation Method

Instantaneous Power Calculation: The microcontroller calculates the instantaneous power using the formula shown in equation 3.1

$$P = I \times V \qquad 3.1$$

Where P is power, V is the voltage and I is the current.
Root means square power calculation: For AC power measurement, the RMS values of voltage and current are used using the formular shown in equation 3.2

$$Pr = Irms \times Vrms \qquad 3.2$$

The rms values are calculated using the formular depicted in equation 3.3 and 3.4

$$Vrms = \frac{Vp}{\sqrt{2}} \qquad 3.3$$

$$Irms = \frac{Ip}{\sqrt{2}} \qquad 3.4$$

Active Power Measurement

To measure the real power consumed by the load, the power factor (PF) is included equation 3.5 showed the formular deployed for calculating the active power of the system.

$$Preal = Vrms \times Irms \times pf \qquad 3.5$$

Energy Consumption Calculation**:** Energy is obtained by integrating power over time: E=P x time(T) where E is energy in watt-hours (Wh) and is t the time duration in hours.

Cloud Implementation on the Blynk IoT platform

This section of the research was done on the Blynk IoT platform, an account was created on the platform with the researcher's email and dedicated security. A new project template was created using the name "IoT Energy Meter". The device was selected which was the ESP 32 microcontroller and connection type was set to WI-FI. Thereafter DataStream was set which are the parameters to be measured: Voltage, Current, Power. Virtual pins were selected as Vo, V1 and V2, and V4 with both selected as float integers, their ranges were equally set as depicted in the results shown in the next chapter.
Full implementation code required for this programming in the Arduino uno IDE is attached to the appendices section of the work.

Switch mode power supply unit

SMPS stands for Switch-Mode Power Supply. It's an electronic power supply that uses a switching regulator to efficiently convert electrical power, often from AC to DC. SMPS units are popular due to their higher efficiency, smaller size, and lighter weight compared to traditional linear power supplies. Figure 2 shows the circuit diagram of the SMPS module used for this research.

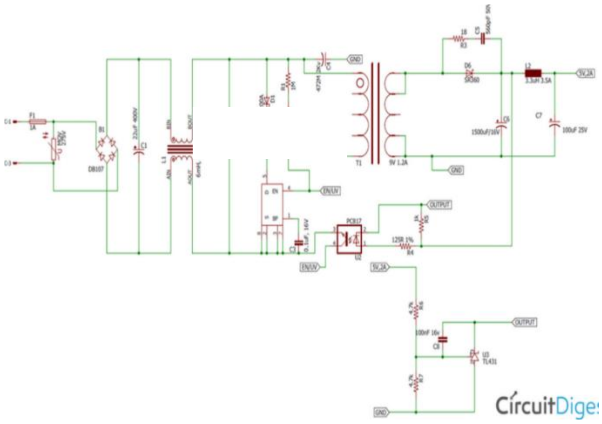

Figure 2: circuit diagram for the power supply (SMPS).

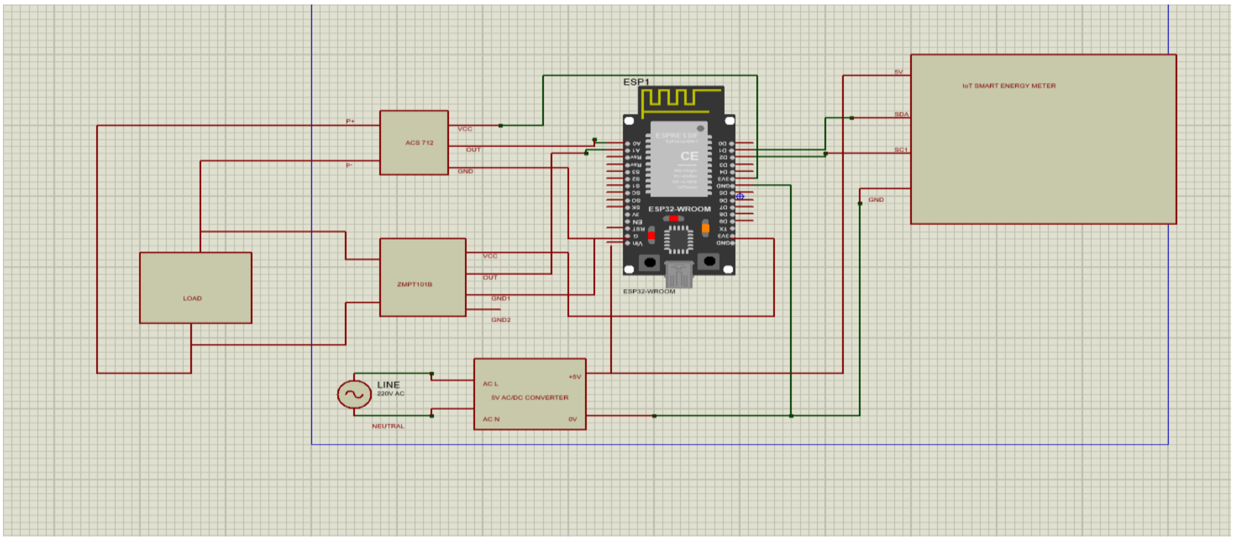

Figure 3: Complete circuit Diagram of the system

Figure 3 showed the complete circuit diagram of the entire prototype design of this work, while the various lines of codes used in programming the microcontroller has been attached to the appendices of the research. Each of the independent components of the system have been presented here as block and their outputs appropriately connected to the designated inputs of the microcontroller. The system was equally provided with LCD 16x4 for visual observation of the measurement of each parameter.

4.0 RESULTS AND DISCUSSIONS

4.1 Accuracy Testing for ACS712

Table 1 presented the accuracy testing for the deployed current sensor, ACS 712. From the table, different loads were connected along the system and the sensor measured the current closely.

Table 1: ACS 712 accuracy testing result

Test No.	Electrical loads	Standard Current measured through multi-meter (A)	Measured Current using the developed system (A)	Error (%)
1	Ceiling fan	0.5	0.49	2.00
2	Refrigerator	1.0	0.98	2.00
3	1 h.p A.C	2.0	1.96	2.00
4	1.5 h.p A.C	3.0	2.94	2.00
5	Electric cooker unit	5.0	4.92	1.60

The results of the ACS712 current sensor and ZMPT101B voltage sensor was verified by comparing the measured values with a standard multimeter. The results showed an average percentage error of 1.92%, which is within the acceptable range for real-time energy monitoring applications. This is presented in figure 1.

4.2 Accuracy Testing for the Voltage Sensor Zmpt101b.

Presented in the table 2 was the standard test result when the ZMPT101B was deployed to measure the voltage across different load system.

Table 2: Test Results for ZMPT101B

Test No.	Standard Voltage (V)	Measured Voltage (V)	Error (%)
1	110	108.9	1.00
2	120	118.8	1.00
3	220	217.8	1.00
4	230	227.7	1.00
5	240	237.6	1.00

From the table 4.2 shown, it was observed that the ZMPT101B sensor maintained a high level of accuracy with a maximum error margin of 1%, making it a reliable component for voltage monitoring applications as requested in this study.

4.3 Real-Time Data Transmission

The system successfully transmitted real-time voltage, current, and power readings to the Blynk IoT cloud platform with minimal latency. The average data transmission delay was recorded at approximately 1.2 seconds, ensuring near-instantaneous updates for users. This measurement was done by carefully observation, using high precision stop watch to measure average time lag between load variation on the system display and the time it takes for the data packet to be updated on the cloud platform. Several values were obtained and averaged at1.2 seconds. This is as depicted in table 3.

Table 3 Test Results for Real-Time Data Transmission.

Test No.	Data Packet Sent (Bytes)	Data Packet Received (Bytes)	Transmission Delay (s)	Success Rate (%)
1	256	256	1.1	100
2	512	512	1.3	100
3	1024	1024	1.5	99.5
4	2048	2048	1.7	99.2
5	4096	4096	1.9	99.0

The results indicated in the table 3 showed that the system maintained a high transmission success rate of over 99%, with minimal delay in sending and receiving real-time data, ensuring efficient remote monitoring.

4.4 Overall System Test

The system was tested under various electrical load conditions to evaluate its accuracy and responsiveness. Table 4 gives the summary of results obtained during the system testing. From the table, it was observed that different loads were subjected to use on the designed system, and the corresponding power measured when each load were connected to be metered were tabulated.

Table 4: Overall system test under different load conditions

Test No.	Load Type	Measured Voltage (V)	Measured Current (A)	Calculated Power (W)	Multimeter Power (W)	% Error
1	LED Lamp (10W)	227	0.045	10.2	10.0	2.0%
2	Fan (60W)	228	0.27	61.6	60.1	2.5%
3	Iron (1000W)	230	4.30	989.0	1002.0	1.3%
4	Heater (1500W)	229	6.55	1500.0	1495.0	0.3%
5	No Load	0	0	0	0	0.0%

4.5 Data Visualization

A screenshot of the Blynk mobile application during system operation showed dynamic changes in voltage and current readings corresponding to connected appliances. Alerts were configured using Blynk automations—when power exceeded a threshold (of 1200W), a push notification was sent to the user.
This visual feedback facilitated immediate awareness of energy usage and potential overloads, making the system practical for both residential and small industrial applications. Data was sampled every 2 seconds and uploaded in near real-time, with reliable Wi-Fi connectivity maintained by the ESP 32's onboard module. As depicted in figure 4, the cloud platform configured on the Blynk cloud platform has several fields with each field measuring different parameters of the load. The voltage reading, ammeter reading, wattmeter

reading and the energy consumption reading. This platform refreshes its database every 20 milliseconds making it very accurate and dependable.

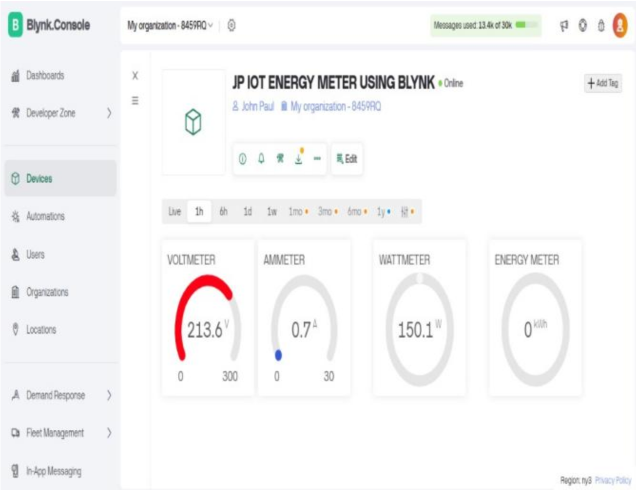

Figure: 4: The energy meter cloud console on the Blynk platform.

Figure 5: The energy meter cloud console on the Blynk platform showing load switch

As depicted in the figure 5, the system has provision to remotely knock out a load in the case of over usage. This toggle switch as shown here will trigger the relay added to the system block next to the load, thereby switching off the load. This feature is particularly important when a customer has exceeded a set threshold or he has been suspected to have bypass the meter.

5.0 CONCLUSION

This research has successfully demonstrated the design and implementation of an IoT-based energy meter using the ACS712 current sensor, ZMPT101B voltage sensor, and ESP32 microcontroller. The system provided accurate, real-time monitoring of voltage, current, power, and energy usage for single-phase AC loads. By integrating with the Blynk cloud platform, the system was able to do remote data visualization and push alerts, offering an accessible and scalable solution for home and small industrial energy management.
Various performance tests carried out confirmed an accuracy of over 97%, validating the system's reliability against standard multimeter readings. With its low-cost components, modular hardware design, and easy to use interface, the meter is ideal for applications requiring real-time insights into power consumption. The system also highlighted the possibilities of integrating analog sensors with modern IoT platforms to create efficient, open-source monitoring tools.
Overall, the paper contributed a user-friendly, cost-effective approach to energy monitoring with significant potential for extension and commercial adaptation. The system provides real-time, remotely accessible energy consumption data suitable for various applications.

5.1 RECOMMENDATIONS

This work will be beneficial and therefore recommended for remote meter monitoring, predictive maintenance and smart power management. It is therefore recommended for distribution companies (EEDC, AEDC, Eko electric etc). This will ensure accurate power usage measurement and thus stop power thefts and other associated problems with the existing energy metering system.

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