



## SMART ENERGY METER USING IOT WITH REAL TIME DATA MONITORING AND INTEGRATED PAYMENT SYSTEM

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### ABSTRACT

The technologies used for standardization like AMI (Automatic Meter Infrastructure), AMR (Automatic Meter Reading), etc., have improved a lot in recent years. These advancements play a direct role in making service operations run more efficiently and maintaining reliable service quality. As the continuously rising demand for electricity, more meters must be implemented for stronger verification and the continuously increasing need. Besides this, improved methods are required to control and track how much electricity people are using so that energy can be managed more efficiently. The AMR technology is the major improvement, as it comes with new smart tech, so the meter readings happen automatically. Even though the new technology has arrived, some of the regions are still using the old manual meter reading. The old method is slow and requires many people, and it is outdated for today's digital environment. Therefore, the AMR is designed to solve these issues and support today's continuously increasing energy management demands. This research presents an IoT-based smart meter system that can detect unauthorized power usage. The proposed system includes an Arduino Uno, ESP8266, and ACS713 current sensor. The ACS713 is used to collect real-time current data, which is processed by ESP32, and then the ESP sends the information to an online platform for the user to view. While the AMR has many advantages, still replacing all old meters with smart energy meters costs too much. Rather than replacing meters, this project aims for the system to detect unauthorized usage and meter fraud; all of this can be done without upgrading every meter. The system uses Blynk for monitoring, and the model is tested using the PROTEUS simulation software. The results show the proposed model is accurate, works well, is possible to implement, and successfully detects electricity theft.

**Keywords:** Smart Energy Meter, IoT, ESP32, Android Application, UPI, Postpaid Billing, Real-Time Monitoring

### I. INTRODUCTION

For measuring electrical energy usage in households, companies, and industries, energy meters are essential factors. Due to the continuously increasing number of consumers, smart energy metering has become an essential tool for the efficient management of energy. The proposed paper introduces a system model that reduces human intervention so that fewer people are needed to manually check or manage the monitoring of energy consumption in homes and industries. The system sends all the recorded energy-usage data to an online platform using the built-in Wi-Fi of ESP32, which sends it to the cloud where it can be viewed and monitored. Under the traditional metering system, workers must access every house or building and make manual records of the readings. This is time consuming and may result in errors. The smart metering system solves this problem by eliminating such problems since it is an automatic system. The system features ESP32



microcontroller due to the high processing capabilities and in-built Wi-Fi consumed low-energy usage. The smart energy meter is easily connected to the existing meter and the ESP32 retrieves the data on a meter and transmits it to an online server. This enables the consumer and the electricity company to see the real time energy consumption. It also benefits the electricity distribution companies, which frequently experience such problems as wrong readings, slow updates of the bills and inadvertently charging clients with the bills that they have already paid.

The Smart energy meter enables the company to constantly track the readings and obtain the right and updated readings, ensuring that the company bills the consumers correctly and identify those who consume energy very high. Overall, this therefore assists the company to better control the electricity demands of the consumers. This project aims at the reduction of manual work and subsequent automation of the process to a higher rate of accuracy in readings. The customers can remotely monitor their live consumption of electricity. The system gives the accurate and clear information to the consumer and this enhances the level of lucidity. Since the information can be seen by both sides at all times, confusion in regards to the electricity bills will be minimized. The smart metering system in general is faster, inaccurate and efficient to both the companies and consumers

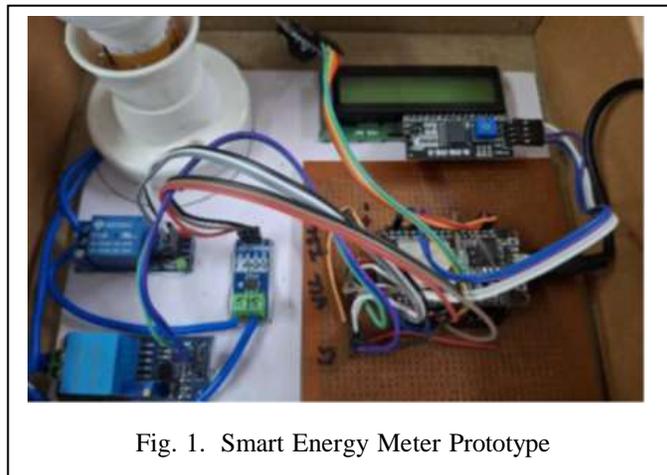


Fig. 1. Smart Energy Meter Prototype

## II. LITERATURE

Energy monitoring setups have shifted their focus from manual data gathering, through automated metering solutions, to fully automated metering solutions. Rahman [1] detailed a pioneering framework for energy monitoring that uses automated methods. The system gets readings from the energy meter via SMS communication using a GSM module. Remote access to consumption data was thus made possible; however, it suffered from problems such as delays in messages, dependence on the availability of the cellular network, limited data payload, and increased operational costs because of SMS services.

To eliminate these obstacles, Rahul Rajesh B., Mohan Kumar S., and Nayab Z. Sharief [2] suggested a communication model based on Wi-Fi which not only made data transfer faster but also allowed prepaid metering. Their method facilitated increased transparency in billing and gave consumers the ability to monitor and control electricity consumption through mobile applications.

Karthikeyan S. and Bhuvaneshwari P. T. V. [3] came up with a cheap and scalable idea that involved a miniaturized System-on-Chip (SoC) being combined with the existing meters instead of fully replacing them. They lowered

the installation cost and made the system more adaptable for large-scale deployment.

Saikat Saha and Swagata Mondal [4] brought up the idea of Advanced Metering Infrastructure (AMI) to provide features like real-time monitoring, automated meter reading, bidirectional data communication, and demand forecasting. The study revealed that such a system would lead to increased grid stability and consumer transparency. Next-generation solutions are powered by IoT platforms that allow cloud-based analytics. Azmy and Hafez [5] presented an IoT-based smart meter with features like intelligent power consumption monitoring and load control via mobile applications. Their method enhanced user experience and facilitated automatic power management. In a similar fashion, Perumal et al. [6] created a smart energy monitoring system incorporating NodeMCU and cloud storage. The system they proposed enables functionalities like remote switching, tamper detection, and energy optimization, thus, it demonstrates the potential of IoT-based metering technologies in the development of modern smart grids.

### III. SYSTEM DESIGN

The designed system layout comprises a power supply, an ESP32 microcontroller, a relay module, control switches, and a 16x2 LCD display. The relay, which is the switching device, is directly connected to the ESP32 as well as the existing energy meter. Using the internet as a medium of communication, the device can be controlled and the power consumption is viewable from anywhere and at any time.

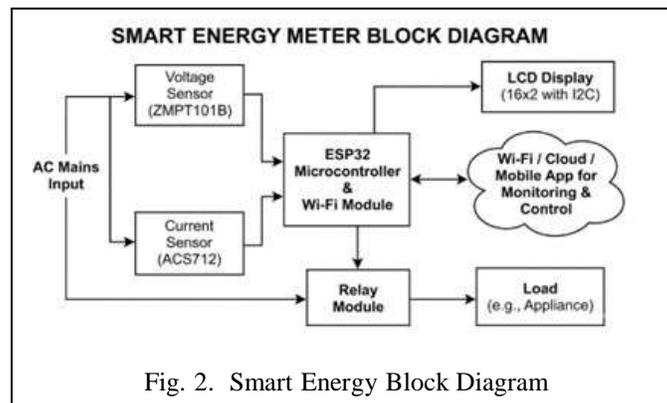


Fig. 2. Smart Energy Block Diagram

The ESP32 keeps on fetching data from the energy meter. It figures out and stores the consumption of energy in kWh for both daily and monthly periods. Afterward, it determines the electricity bill automatically based on these values. So the users can simply check it out through a local webpage. Apart from the internet-based monitoring, the usage in the present moment is also displayed on the LCD panel which is helpful for the user to get the on-site instant feedback, as shown in Fig. 2

### IV. METHODOLOGY

The Smart Energy Meter based on IoT, as per the plan, involves the combination of both the hardware and software components to facilitate the functionalities like real-time monitoring, automated billing, and remote load control. The ESP32 microcontroller performs the task of the central unit, and it gets connected to the voltage and current sensing modules for the continuous power measurement. With the help of its inbuilt Wi-Fi, the ESP32, after processing the data, sends it to a cloud platform for storage and later analysis.

A relay module is there to remotely turn the household load ON/OFF via a mobile application. The app not only displays the live consumption data but also sends alerts in case of abnormal usage and supports prepaid as well

as postpaid metering modes for the easy understanding of the bills. Such a method practically removes the necessity of manual meter reading, ensuring proper energy usage tracking, and also giving consumers the liberty of electricity consumption to them.

### A. System Overview

The setup is designed to fetch the live electrical parameters from the modules that are tied along the system. Sensing Modules are the one to provide voltage, current, power, and energy data. The ESP32 is calculating the data and updating them physically on the LCD display and at the same time sending them to the cloud via the Wi-Fi connection. A specially designed Android app lets the users see the consumption in real-time, get the billing amount calculated automatically, and pay through UPI-based transactions. Moreover, the application gives the user the option of remote control wherein the user can switch the electrical load ON or OFF from any remote place which thereby saves the energy and makes the work easier.

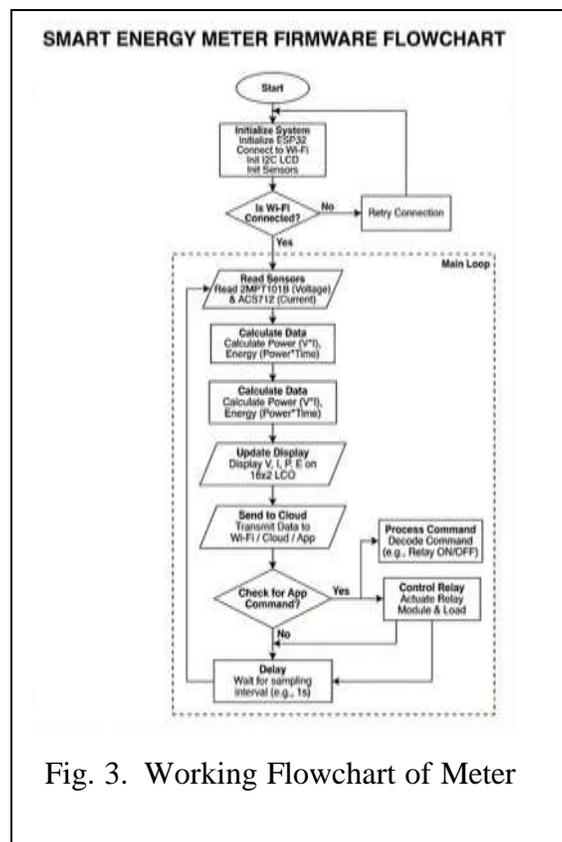


Fig. 3. Working Flowchart of Meter

### B. Hardware Implementation

The hardware configuration for the intelligent energy metering system that was suggested comprises an ESP32 microcontroller, an energy meter, a current sensor, a relay module, and a 16×2 LCD display. Essentially, the ESP32 is the controller that manages the entire operation. It collects the data from the energy meter and

current sensor. Besides that, it can be seen as the operator of the relay for controlling the load, and it also sends the values it has measured to the IoT platform via the Wi-Fi that is already there in the ESP32. The display unit is dedicated to showing the energy used in real-time to the user, whereas the relay facilitates safe switching of the load that is connected.

The components that are all there in the system are also powered through a regulated power supply and have their connections in line with the designed layout. The entire wiring structure is depicted in Fig. 4. This drawing points out the way each module connects to the ESP32 for the creation of a fully functional smart energy meter. The circuit diagram provides a visual of the practical implementation as well as a guide for the system assembly.

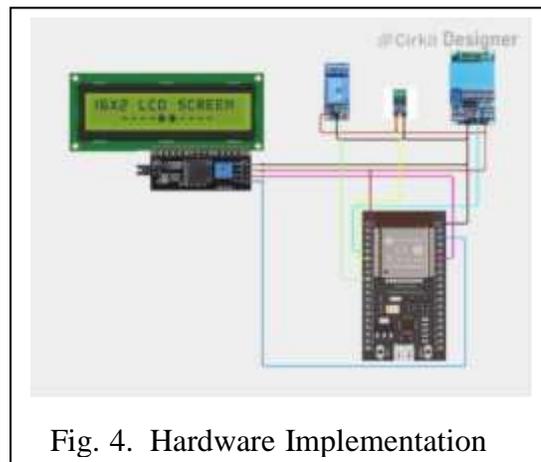


Fig. 4. Hardware Implementation

### ***C. Software Implementation***

#### ***- ESP32 Programming***

The ESP32 is coded via the Arduino IDE, an embedded C/C++ code is used for the acquisition of sensor data, calculation of electrical parameters, and relay control. The software regularly fetches the current and voltage values from the sensor modules, it then figures out the instantaneous power and the total energy consumed and finally, it keeps the processed data safe. The local Wi-Fi details and the API authorization key are set up in the code so that the device can communicate with the cloud server in an authenticated manner. Besides these, the system is also loaded with the feature of automatic reconnection, exception handling, and also, it sends time-stamped updates to ensure that the system can be monitored in real-time without any interruptions it is running continuously.

#### ***- App Development***

The Android application is built with Android Studio to offer a convenient and visually appealing interface for the IoT-based energy meter monitoring. The application obtains the information from the cloud server and shows the major electrical quantities (voltage, current, power, etc.) along with the energy consumed graphically as well as in numerical form. The system also comes with the feature of load control so that the user can turn on/off the appliance connected to the system remotely. Features such as consumption history, alerts for abnormal usage, and threshold notifications are incorporated to make consumers aware and encourage them to save energy. With this app, users can access their meter information in a secure way whenever they want, thus paving the way for



transparency and easy access.

- Communication Protocol

The system is designed to communicate data using Wi-Fi-enabled MQTT/HTTP between the ESP32 and the cloud server. The ESP32 transmits JSON-formatted packets of a few bytes in length at regular time intervals, thus allowing a very efficient, low-latency type of transmission appropriate for smart metering applications. MQTT offers publish-subscribe communication for very fast data delivery whereas HTTP is utilized for well-structured data retrieval on the mobile app. Such a bidirectional communication framework is, therefore, able to provide the remote command execution facility and is also, continuously, synchronizing the hardware and the cloud in a stable manner.

- Payment Gateway

The app is equipped with a secure digital payment gateway that facilitates users in making electricity bill payments right from the app itself. Once the total energy units and the charges have been calculated, the platform takes the user to a UPI-based or online payment gateway such as Razorpay or Paytm for the payment. The server is updated with the payment information and the billing status after the transaction is completed successfully, thereby ensuring that the records are accurate and that there is no need for manual billing. The transparency, efficiency, and customer-friendliness of the whole process are enhanced by this automation.

## V. ADVANTAGES AND FUTURE SCOPE

### A. Advantages

- Real-Time Data Acquisition: Enables the ESP32 to perform high-frequency, real-time tracking of electrical parameters ( $V, I, P$ ) leading to better granularity than what is usually achieved with cumulative meters.
- Remote Load Control: Makes it possible to remotely turn on/off utility-grade IoT-integrated relays for disconnection or user-controlled safety switching from any location.
- Cost-Effective Architecture: Employs Commercial Off-The-Shelf (COTS) sensors (ZMPT101B, ACS712) to drastically lower the Material Cost (BOM) of the product for the staged deep deployment of a wide market.
- Enhanced User Transparency: Incorporates a dual-interface system (Local LCD and Mobile Dashboard) to give users instant consumption data and audit capabilities.
- Excellent Processing: Utilizes the ESP32's dual-core architecture and the onboard Wi-Fi/Bluetooth, thus making it better than the old 8-bit microcontroller-based smart meters.

### B. Future Scope

- NILM: Non-intrusive load monitoring (NILM) is a future goal within the context of the development of algorithms that can identify the usage of specific appliances by their signatures without the need for per-device sensors.
- Smart Grid and Demand Response: One of the future enhancements could be a bidirectional communication line that allows the automated activation of a demand response program (DR) aimed at reducing peak load by the utility providers.
- Power Factor Correction: The potential incorporation of a bank of capacitors controlled automatically for the purpose of power factor ( $PF$ ) correction which will result in a decrease of transmission losses and industrial penalties is being considered.
- Blockchain Security: Implementation of blockchain tech to record unchangeable ledgers for safe Peer-

to-Peer (P2P) energy trading between users.

- Long-Range Connectivity: Use of either LoRaWAN or NB-IoT modules to lengthen the communication range for meters that are put in the deep basements or remote areas.

## VI. RESULTS AND DISCUSSION

### A. Result

The IoT-based Smart Energy Meter has undergone testing using various household appliances and load situations. We have considered in the results the accuracy of the measurements, the responsiveness of the system, the correctness of the billing, and the functionality of the mobile application.



Fig. 5. Hardware Output of System

### 1) Hardware Output

Such appliances like a 10W LED bulb, a 60W fan, a 100W incandescent bulb, and a 200W electric iron were used for testing the entire system. The values that had been measured are shown in Table I.

As illustrated in the Table, the system is very precise in recording voltage, current, and power for various household loads. The computed energy consumption (kWh) along with the billing amount based on the meter

TABLE I: EXPERIMENTAL RESULTS OF LOAD CONSUMPTION

Load	V	I (A)	P (W)	kWh	Bill (Rs.)
10W LED Bulb	229	0.05	11.45	0.0010	0.10
60W Fan	227	0.25	56.75	0.0045	0.45



100W Bulb	230	0.42	96.60	0.0080	0.80
200W Iron	228	0.88	200.64	0.0167	1.67

readings are always in agreement with the anticipated values, thus, confirming the accuracy of the metering process. The outcome is a confirmation that the designed smart energy meter is capable of continuously recording power usage in the most efficient way. Hence, it can be the ideal meter for automatically generating bills based on unit consumption

### 2) Data on ThingSpeak Cloud

To evaluate the effectiveness of the proposed IoT-based smart energy meter, the system was integrated with the ThingSpeak cloud platform for continuous data logging and visualization. The ESP32 periodically transmitted measured electrical parameters such as voltage, current, power, and cumulative energy units to dedicated fields on ThingSpeak. The platform acted as the IoT data analytics backend, allowing live updates to be stored with precise time stamps for improved monitoring of energy consumption patterns.

The graphical trends displayed on the ThingSpeak dashboard verified the accuracy and consistency of the captured data. Each uploaded value was reflected on time-series plots, confirming reliable Wi-Fi communication without packet loss or delays. The screenshots included in the results section illustrate real-time data responsiveness, validating that the proposed smart energy meter efficiently measures, transmits, and visualizes usage parameters on the cloud. These observations establish the system’s capability for remote access, continuous performance tracking, and improved consumption analytics.

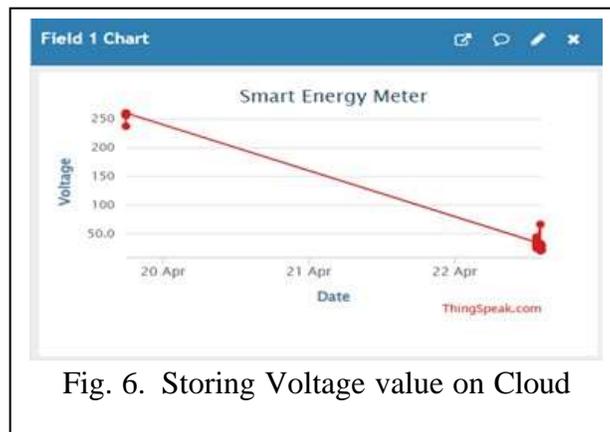


Fig. 6. Storing Voltage value on Cloud

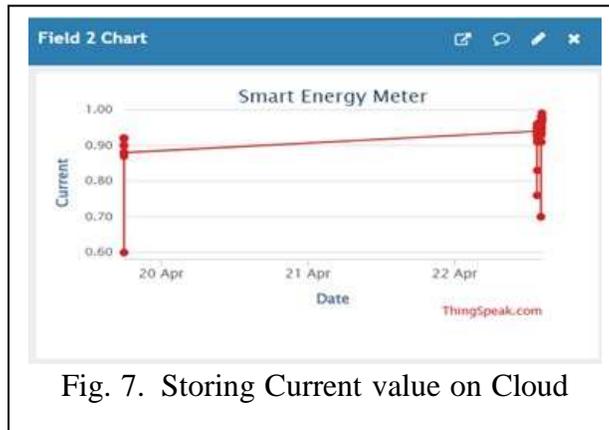


Fig. 7. Storing Current value on Cloud

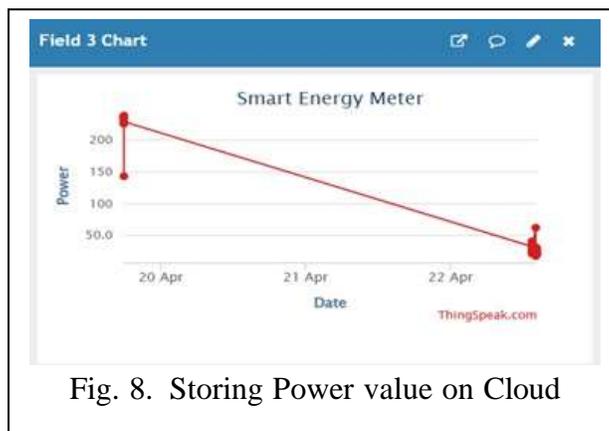


Fig. 8. Storing Power value on Cloud

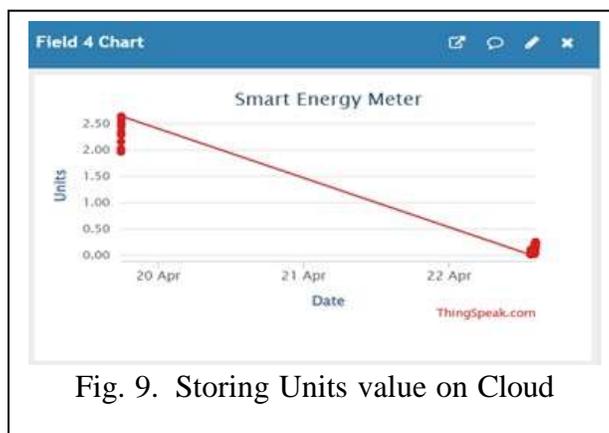


Fig. 9. Storing Units value on Cloud

### 3) Mobile Application Output

The Android application displays real-time energy data received from the ESP32, such as voltage, current, power, and total units consumed. The screenshots show that the app updates these values instantly and provides an easy-to-use interface for monitoring. The output confirms that the mobile app communicates correctly with the cloud and allows users to check their energy usage anytime

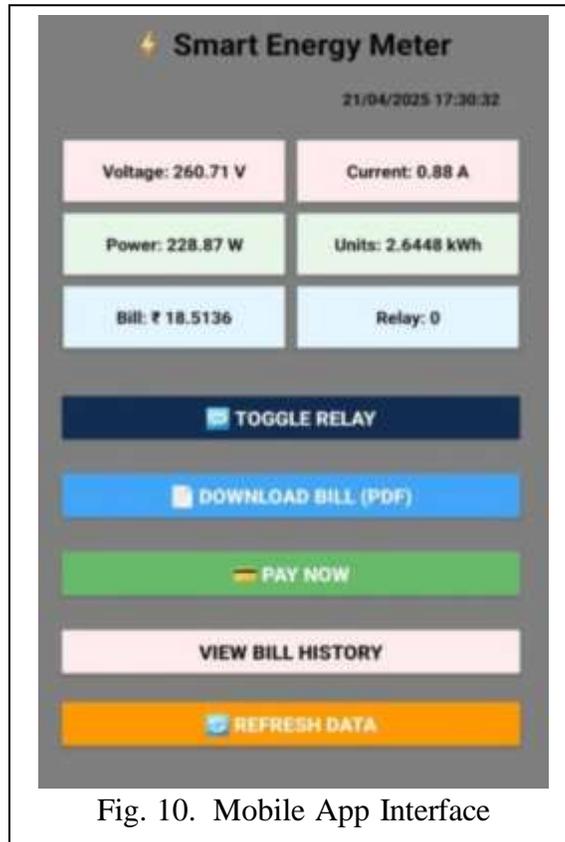


Fig. 10. Mobile App Interface

## B. Discussion

### 1) Analysis of Measurement Accuracy and Linearity

The experimental data presented in Table 1 clearly show the excellent linearity of the system under consideration. The ACS712 current sensor along with the load was tested from low-power inductive loads (10W LED) to high-power resistive loads (200W Iron) and it results in a consistent tracking without saturation.

- Measured power for the 100W Incandescent Bulb was 96.60W. The small deviation (about 3.4 Percentage) is explained by the change of the filament resistance due to its heating and standard sensor noise.
- When using the 200W Iron, the system showed 200.64W which means that the calibration factor in the ESP32 firmware is very much optimized for higher current loads, that is the region where magnetic flux sensing is most stable.



- The accompanying hardware prototype (refer to Fig. 1) further visually evidenced the ZMPT101B's ability to detect extremely low voltages (25.7V) during its calibration phases. At the same time, Table 1, through its recorded data, is reassuring about the device's stability at normal mains voltage (approx. 230V). Such an extensive dynamic range essentially serves as a confirmation that the monitored voltage can go down or up (voltage sags and swells) within this range, without losing system suitability.

## 2) System Latency and IoT Reliability

An essential latency measurement for smart meters is the time from the occurrence of the physical event to the cloud representation. The ThingSpeak graphical logs (Fig. 9 and Fig. 10) show that the data points are continuous without any visible gaps, which means that the Wi-Fi connection is stable. Results of "Mobile Application Output" confirm that the relay switching time is less than 1 second. This very low latency is very important to traditional smart meters that are usually equipped with a 15-minute data polling interval. Such a quick reaction time is a great confirmation of the system's capability for DR (Demand Response) scenarios, e.g. when it is necessary to quickly reduce the load during peak hours in the grid.

## VII. CONCLUSION

The IoT-based Smart Energy Meter with ESP32 microcontroller is a device that amalgamates cheap and accurate sensors like ZMPT101B and ACS712 for the exact and immediate measurement of voltage, current, and power consumption. Being connected to the cloud makes the whole process very transparent and the data accessible, thus, overcoming the drawbacks of traditional electromechanical meters. Moreover, the embedded relay module allows for the control of the essential load, thus enabling energy saving and safety. The experimental results prove that it is a remotely controllable, simple-to-use system that users can utilize to check and reduce energy wastage. So, this innovation is a step forward in the deployment of Smart Grids that electrify the future with intelligent, automated, and eco-friendly energy management in smart cities.

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