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IoT based ESP32-C3 Driven Smart Energy Meter

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***Abstract*— The IoT-based Smart Energy Meter, powered by the ESP32-C3 microcontroller, is an innovative solution for monitoring and controlling electricity consumption for both residential and commercial utilization. This smart energy meter enables users to actively monitor their energy usage, thereby reducing costs and promoting eco-friendly practices. It utilizes non-intrusive sensors ZMPT101B and ZMCT103C to acquire real-time data on power consumption, which is then transmitted over Wi-Fi to a cloud-based server, accessible through an intuitive web or mobile interface. Additionally, the system offers power-saving recommendations, robust security measures, and the capacity for scalable expansion, making it an invaluable tool for optimizing energy consumption and contributing to a sustainable future.**

***Index Terms*— Cloud-based server, ESP32-C3 microcontroller, Non-intrusive sensors - ZMPT101B and ZMCT103C, Smart Energy Meter**

I. INTRODUCTION

Smart energy meters are devices that will continuously monitor and measure the power consumption of a load and transmit the data to a remote server using the Internet of Things (IoT) technology [1]. Smart energy meters can provide real-time feedback, billing information, and demand response to the consumers and the electricity suppliers, thereby improving the efficiency and reliability of the power system [2]. In this project, we have designed a prototype of a smart energy meter using ESP32-C3 based on IoT. ThingSpeak is an Internet of Things (IoT) platform and an associated website that enables users to collect, store, analyze, visualize, and share data generated by IoT devices and other sources. ThingSpeak offers a web interface and an API for seamless interaction with the platform [3]. One of the most advanced and versatile development boards available is the ESP32-C3, which has a microcontroller with Wi-Fi and Bluetooth features. It can handle complex and connected applications that need more processing power and communication, such as IoT devices, smart home systems, and industrial automation. The ESP32-C3 does not require any additional Wi-Fi and Bluetooth module, unlike other Arduino and ESP boards, as it already has one built-in. With this meter, the user can monitor their power consumption anytime and anywhere. The aim of this project is to measure how much electricity is used by different appliances.

II. RELATED WORK

Wired systems face challenges, including the need to install communication lines between devices and set up backend infrastructure. This can lead to higher construction and maintenance expenses, potentially reducing user interest in adopting a home automation system [4]. For automatic meter reading, a Bluetooth-enabled energy meter

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was recommended in a work [5]. For reliable and affordable operation, it uses an Analog Devices ADE7756 energy meter and a CSR Bluetooth BlueEZ module. It's important to remember that Bluetooth has a constrained communication range and is not ideal for long-distance applications. In other research, they proposed a wireless appliance control and power consumption monitoring system using the Blynk smartphone app to monitor electricity usage. They used a WeMos D1 Mini with an ESP8266 Wi-Fi module as the IoT hardware to transmit real-time electricity data for visualization on the Blynk app [6]. Various systems have been developed using Arduino and microcontrollers to enhance the efficiency of power consumption measurement. However, cost-effectiveness can be a limiting factor, potentially hindering their suitability for users. These systems may not offer an affordable means for consumers to regularly monitor their energy consumption. Traditional meters also present challenges, including being time-consuming, susceptible to theft, prone to data collection errors, and lacking the ability to provide daily usage updates to consumers [7]. When customers exceed their peak load demand, the smart energy meter will automatically disconnect the electricity supply to the customers [8]. Bibek Kanti Barman et al. introduced an "IoT-based smart meter" that is pivotal for advancing smart grids within power systems. It addresses the limitations of conventional energy meters, particularly the absence of full-duplex communication. Their solution involves a smart energy meter utilizing the ESP 8266 12E Wi-Fi module to calculate and transmit energy consumption data to the cloud [9]. This allows consumers to conveniently monitor their energy usage, enhancing energy management. Furthermore, this system aids in detecting energy losses and contributes to home automation through IoT. Landi et al. introduced an energy management system based on ARM technology. This system incorporates a web server for gathering energy consumption and power quality data, and it connects with devices for load redistribution. Users can access this information to manage power consumption within the system [10]. In contrast to the existing system, our proposed solution not only cuts down on implementation and maintenance costs but also reduces hardware expenses. It aligns with the Internet of Things (IoT) concept by using an affordable energy meter equipped with the ESP32-C3 module, which comes with built-in Wi-Fi and Bluetooth connectivity. This system communicates seamlessly with a cloud platform, such as ThingSpeak [11], enabling real-time automatic data retrieval from the energy meter. Users can conveniently monitor their energy usage on a daily, weekly, and monthly basis through a mobile app. Moreover, it optimizes power consumption as users can disconnect the connected loads when the usage peaks are displayed on the app. It is advantageous for startups and small-scale industries with limited budgets for expensive commercial smart meters.

III. METHODOLOGY

Smart energy meters, leveraging IoT and microcontrollers, advance energy management through real-time data collection on consumption, voltage, and current. IoT enables remote monitoring, two-way communication, demand response, enhanced security, predictive maintenance, scalability, and integration with renewable energy sources [12].To develop a Smart Energy Meter utilizing the ESP32-C3 microcontroller, the proposed methodology involves distinct stages. Firstly, assemble the requisite hardware components. Subsequently, calibrate current and voltage sensors for precise power consumption measurements. Continuously gather and process real-time power consumption data, incorporating Wi-Fi connectivity for smooth data transmission. Establish a cloud-based server for efficient data storage and accessibility. Create user-friendly web and mobile interfaces for seamless user interaction. Significantly, the system is designed to be both cost-effective and space-efficient, minimizing the number of components. Additionally, the sensors are adaptable to accommodate higher electrical loads as necessary. The outcome is consistently uploaded to the ThingSpeak cloud storage platform at specified intervals, enabling users to easily monitor and access the data. A detailed block diagram and schematic overview of the proposed meter are provided in Fig. 1 and Fig. 2.

IV. SYSTEM HARDWARE AND SOFTWARE

A. ESP32-C3

The ESP32-C3 is a single-core microcontroller SoC featuring Wi-Fi and Bluetooth 5 (LE) capabilities. This versatile chip is built upon the open-source RISC-V architecture and has the following advantages [13].

- Low Power Consumption
- Integrated Wi-Fi and Bluetooth
- Cost-Effective Solution
- Security Features
- Wide Operating Voltage Range
- Open-Source Ecosystem

- Single-Core RISC-V CPU
- Scalable I/O Options

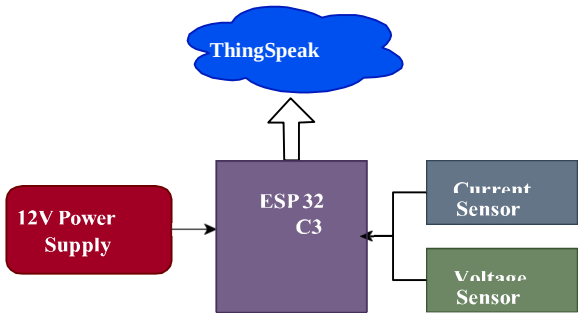

Fig. 1. Block diagram of the proposed system.

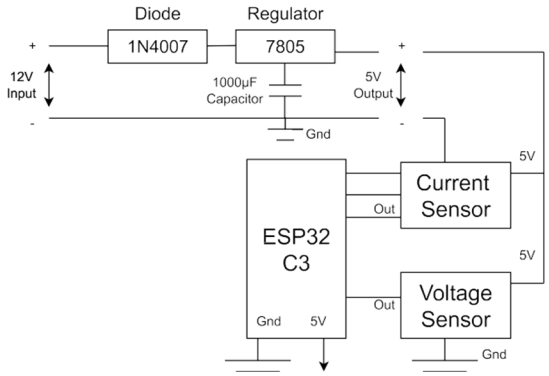

Fig. 2. Schematic diagram of the proposed system.

B. Current and Voltage Sensor

In the proposed system, voltage and current sensors are employed to calibrate the quantity of consumed units. Specifically, we have integrated the ZMPT101B voltage sensor, which relies on a high-precision voltage transformer to provide accurate AC voltage measurements. This sensor module shown in Fig. 4 is compact and lightweight, capable of measuring voltages up to 250 volts. Its operational voltage range spans from 5V to 30V, and it functions effectively within a temperature range of 40°C to 70°C.

A current sensor ZMCT103C shown in Fig. 5 is a device that transforms electrical current into a measurable output voltage, directly proportional to the current it measures. It utilizes a micro current transformer to convert high AC currents into lower-amplitude signals, with a capacity to handle currents up to 5 amperes. In the system, this sensor plays a crucial role in precisely calibrating and determining energy consumption, offering real-time current data through an analog I/O port.

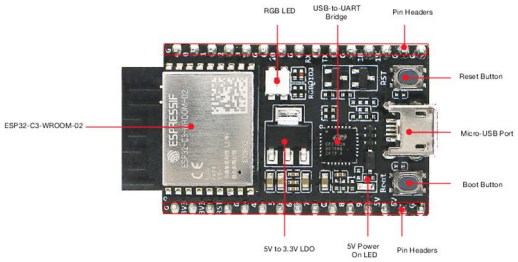

Fig. 3. ESP32-C3.

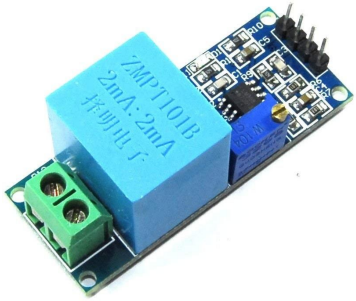

Fig. 4. ZMPT101B Voltage Sensor.

Fig. 5. ZMCT103C Current Sensor.

Fig. 6. Pinout of LM7805 Voltage Regulator.

C. Voltage Regulator and Diode

The voltage regulator 7805 is instrumental in delivering a stable and regulated +5-volt power supply to the metering system. The pinout of 7805 Voltage Regulator is shown in Fig. 6. It takes variable input voltage, typically originating from the grid, and produces a consistent output essential for the accurate measurement of energy consumption by the ESP32-C3 and associated sensors. Simultaneously, the diode 1N4007 acts as a rectifier diode, transforming incoming alternating current (AC) from the grid into direct current (DC) to power the smart energy meter. This diode's one-way current flow rectification ensures that the ESP32-C3 and the meter's components receive a dependable and uniform DC power supply. Together, the 7805 voltage regulator and the 1N4007 diode synergistically contribute to the reliable and efficient operation of the smart energy meter, ensuring precise energy monitoring and management.

D. Software Platform

Arduino is an open-source software that simplifies the creation and testing of code or sketches for various microcontroller boards [14]. It streamlines the code-writing process and provides an easy way to upload sketches

to microcontroller boards. It's compatible with Windows, Linux, and Mac OS X. Notably, the ESP32-C3 package has been integrated into the IDE.
The ESP32-C3 smart energy meter integrates hardware components and software, eliminating the need for human meter reading and reducing labor costs. It enhances electric system control, improves accuracy, and provides real-time power usage data for users to monitor and manage energy consumption, potentially reducing electricity bills.

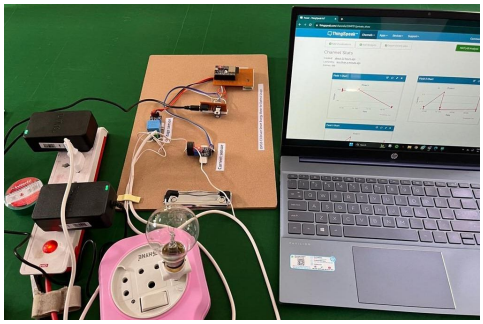

Fig. 7. Hardware Setup.

Fig. 8. Voltage characteristics.

V. Experimental Results

In this section, we describe how the ESP32-C3 electric energy consumption meter operates. The hardware setup is shown in Fig. 7. The user interface dashboard, depicted in Fig. 8 through Fig. 10, is created using the ThingSpeak app. Data from the energy sensor prototype is collected and transmitted to the ThingSpeak server. The AC voltage and AC current sensors detect random voltage and current signals, which are then sent to the microcontroller for displaying the RMS voltage and RMS current on the main interface of the ThingSpeak application. This interface showcases the values of RMS voltage in volts and RMS current in amperes. Using these RMS current and voltage values, the system calculates and displays the average power in watts and the total energy consumption of the load in kilowatt-hours. The user can enhance energy monitoring by exporting a CSV file from ThingSpeak, enabling them to analyze and optimize machinery usage during peak consumption periods, as depicted in the attached screenshot of the exported file shown in Fig. 11.

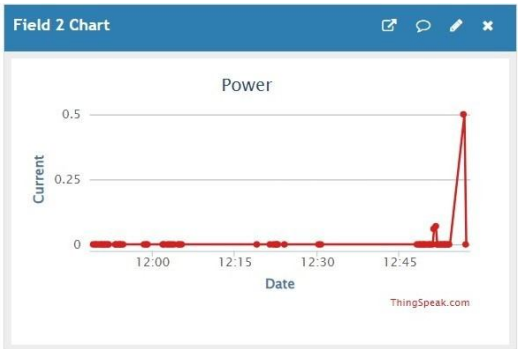

Fig. 9. Current characteristics

Fig. 10. Power characteristics.

VI. Conclusion And Future Scope

In the modern interconnected world, the simultaneous operation of diverse networks with distinct characteristics poses a significant challenge for realizing an automated ESP32-C3 electric energy consumption meter. This study has laid out the architectural framework for energy monitoring. This system offers real-time data accessibility to users, enabling remote access through the input of a channel ID and password key. This smart energy meter encompasses both energy and power consumption awareness. The experimental findings demonstrate the effectiveness of smart energy monitoring system in accurately tracking voltage, current, and power while also providing insights into electricity consumption patterns over time. Future research could enhance this system by delving deeper into energy usage profiles and employing AI techniques for automatic appliance detection. Implementing these advancements in real-time applications holds promising prospects in terms of time and cost savings.

	A	B	C	D	E
1	created_at	entry_id	Voltage	Current	Power
2	2023-11-01 07:08:35 UTC	637	245.5381	0	-0.56
3	2023-11-01 07:08:55 UTC	638	245.4309	0	-0.53
4	2023-11-01 07:09:13 UTC	639	245.5873	0	-0.54
5	2023-11-01 07:09:31 UTC	640	245.6471	0	-0.59
6	2023-11-01 07:09:49 UTC	641	244.927	0	-0.56
7	2023-11-01 07:10:08 UTC	642	244.7264	0.07	16.55
8	2023-11-01 07:10:28 UTC	643	245.1228	0.07	16.51
9	2023-11-01 07:10:46 UTC	644	244.7453	0.07	16.41
10	2023-11-01 07:11:05 UTC	645	246.1308	0	0
11	2023-11-01 07:11:25 UTC	646	245.2566	0	0
12	2023-11-01 07:11:40 UTC	647	244.8813	0	0

Fig. 11. Exported data of the energy monitoring.

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