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Microcontroller Based Smart Energy Meter with Data Logger System

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Atmega328p, metering, voltage sensor, current sensor, real time clock module

Abstract

Recent advancements in power systems ensure that the energy being generated is efficiently delivered to meet the growing demand for electricity in many countries. However, determining the proper energy usage by consumers has become a major challenge to utility companies and researchers. Metering is an important aspect of electricity distribution, and it helps to accurately measure and bill customers for their electricity consumption. In this paper, a prototype for an electricity monitoring system using ATMEGA328P as the microcontroller was proposed and developed. The display parameter values are voltage, current, power factor, active and apparent power. A ZMPT101B voltage sensor is used to measure the AC voltage, while an SCT-013 100A current sensor is used to measure the AC current flowing through meter. In addition, a rotary encoder is used to converts the rotational motion into an electrical signal which is used to measure and control various parameters in a system. Real time clock module is based on an internal clock that generates pulses at a fixed frequency. Variety of tests to verify that the system can handle the expected volume of data, can communicate reliably and can secure data were performed, such as logging the energy data to the memory card, testing input sensors, The voltage and current errors for the energy meter are ±0.1% and ±0.3%, respectively while the power value error of ±0.4%, which is acceptable for most metering devices, The use of smart metering system lead to a more sustainable and efficient energy system for achieving a more sustainable future.

1. Introduction

Electrical energy is essential for economic growth and development [1], [2], while access to reliable and affordable electricity is crucial for sectors such as healthcare, education, industry, and agriculture [3], [4], [5] and [6]. Electrical energy distribution system advancements have recently ensured energy is efficiently delivered to the endpoints [7], [8], and utility companies must implement a proper tariff and accurate billing system to provide better services to customers. Smart meters (SMs) are becoming increasingly common in the power distribution sector by providing consumers with real-time information and pricing of their power consumed. Smart Meters (SMs) play a crucial role in response to the rising demand for energy and the imperative to govern and supervise electricity usage because there is a growing necessity for automation in industrial environments and remote monitoring of machinery [9]. SMs are instrumental in monitoring the electricity supply's reliability, identifying disruptions, and quantifying energy consumption [10]. Additionally, SMs facilitate the remote monitoring of electric power systems operating under various circumstances while ensuring the portability and adaptability of the digital signal processing algorithms [11]. SMs can be extended to distributed generation systems, offering more advanced features than the current methods and providing efficient information on power transmission and evacuation. SMs also play a crucial role in a smart grid, which can revolutionize the electricity market by incorporating renewable energy sources and other emerging technologies [12]. The unit of measurement for power is the watt (W), while energy consumed is measured in watthour (Wh) [13]. Recent contributions regarding smart metering systems by scholars are Ekanayake et al. [14] explored the implementation of a smart system based on smart grid technology and smart appliances. Gao and Redfern [15] examined the difficulties associated with voltage regulation in smart grids and metering technologies. Concurrently, Kesav and Rahim [16] introduced an automated wireless meter reading system to supervise and manage power consumption. Sahunkhe et al. [17] concentrated on power factor supervision and load management utilizing smart metering techniques, and Chandler [18] offered an overview of the technological advancement of automated metering and monitoring systems. Livgard [20], Keyer and Leferink [21], and Long et al. [22] are researchers who provide contextual information on SMs and their potential benefits for energy effectiveness. Choi et al. [23] presented a general overview of SMs and their significance in contemporary power systems. Meanwhile, Khan et al. [24] delivered a comprehensive discourse on current SM systems' key obstacles and constraints, encompassing communication, data administration, and security concerns. Mat Tahir and Al Junid [25] devised an automatic measurement reading (AMR) data recorder employing Xbee technology, utilizing Arduino microcontrollers and wireless communication. Likewise, Ahuja and Khosla [26] deliberated on the advantages of smart energy meters and the importance of proficient data analytics in optimizing energy consumption. The researchers propose a framework for data analytics using advanced data processing techniques and the primary area of interests are customer consumption, energy forecasting, and dynamic pricing. Reinhardt and Pereira [27] discussed the employment of smart electricity meters in advanced power grid systems. Burunkaya and Pars [28] introduced an automated energy measurement system utilizing GSM technology, while Truong et al. [29] proposed a groundbreaking design for SMs to collect power measurement data to support end-users in achieving energy savings. The proposed technology quantifies power usage and provides instantaneous statistics, enabling customers to monitor their energy use and optimize equipment performance. Jain et al. [30] proposed an enhanced Internet of Things-based smart energy meter that precisely measures power usage and transmits recorded data to the user. However, several researchers that worked on SM encounter the challenges of effective measurement of electrical quantities and data storage for future usage in their design. This challenge has prompted the proposition of the proposed design. The SM has data storage capabilities and offers real-time voltage, current, power factor and energy consumption monitoring system. Smart electric meter systems present numerous advantages, including effortless data reporting, improved efficiency, and reduced errors associated with manual meter readings.

2. Design Methodology

The proposed block diagram of the energy meter system is depicted in Fig. 1 and employs an Atmega328p microcontroller to compute active power, RMS voltage, RMS current, and power factor. The energy consumed by the load is calculated over time and stored on a secure digital (SD) card every two minutes. Upon power restoration, the microcontroller retrieves the most recent logged energy value from the SD card and adds the new energy value. The meter is designed for a single phase with a voltage, maximum current, and frequency rating of 240 V, 21.2 A, and 50 Hz, respectively, with a maximum power handling capacity of 4.7 kVA at 240V. It is recommended to utilize a current sensor with higher ratings, such as 50 A or 100 A, if a higher current rating is required.

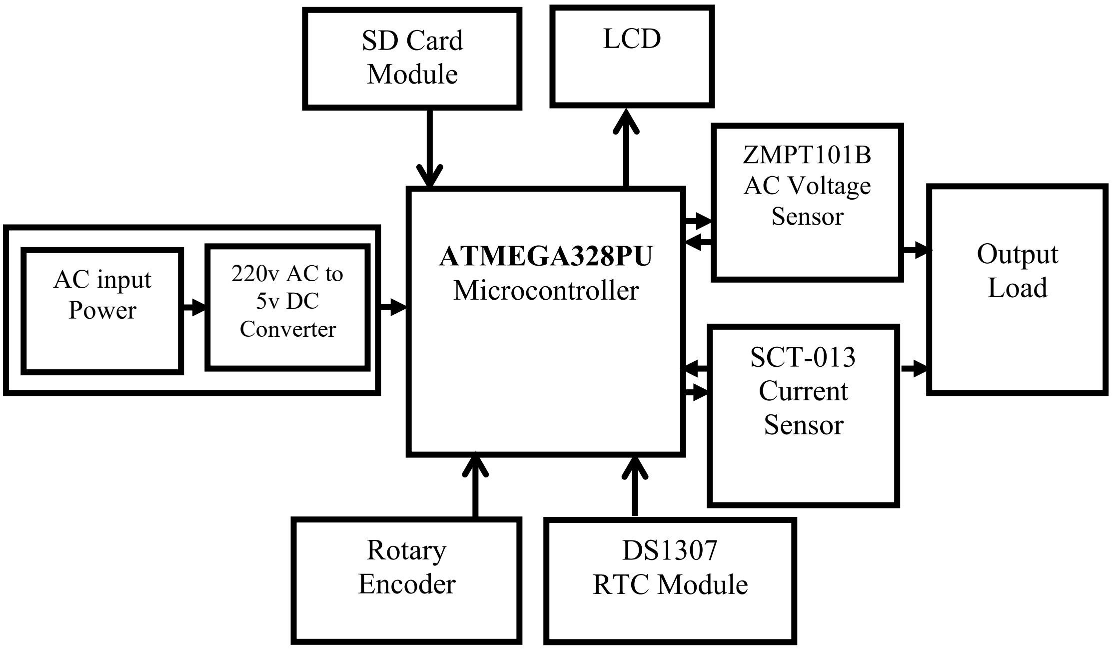


Fig. 1 *Block diagram of a smart metering system*

2.1 Prototype Development of the Meter

A prototype was constructed to replicate the energy meter using Proteus software, as presented in Fig. 2, while the meter development was shown in Fig. 3. The primary components utilized to assemble the prototype incude the power supply, converter, Atmega328pu microcontroller, SD card RTC Module, and Rotary Encoder. Fig. 4a and Fig. 4b illustrate the side and back view of the meter.

2.1.1 AC Input Power Supply and Converter Unit

The AC input power supply is an important section of SM that produces the DC voltage requirement for powering the electronic components in the design. The 220VAC to 5VDC converter typically comprises a transformer, rectifier, and regulator. The transformer converts the voltage from 220VAC to a lower voltage level of 12VAC. The rectifier subsequently converts the AC voltage into a DC voltage, which is then regulated to a stable 5VDC voltage employing a voltage regulator. The 5VDC output from the converter is then supplied to the microcontroller and other components in the smart meter, providing the necessary power for their operation. The converter is usually designed to be highly efficient and minimize power consumption, thereby aiding in reducing the overall energy consumption of the smart meter.

2.1.2 Secure Digital (SD) Card Module

Secure digital card modules are employed in SMs for data storage and logging, facilitating the measurement and recording of electricity usage, consequently generating substantial data for future usage. The microcontroller in the smart meter transmits the data to the SD card module via the Serial Peripheral Interface (SPI) interface. The module subsequently stores the data on the SD card in a file. The microcontroller can also retrieve the data from the SD card by transmitting read commands to the module via the SPI interface.

2.1.3 DS1307 Real-Time Clock Module

The DS1307 Real-Time Clock (RTC) module is connected to the microcontroller and accurately measures time. The RTC module utilizes an external crystal oscillator to ensure precise timekeeping, even without power. Upon powering the smart meter, the microcontroller initializes the RTC module and sets the current time. Subsequently, the RTC module maintains an accurate time measurement, recording energy consumption and other parameters at specific intervals. RTCs find common usage in various electronic devices and systems, such as computers, digital cameras, and embedded systems. The operational principle of an RTC module relies on an internal clock that generates pulses at a fixed frequency. These pulses are counted and utilized to ascertain the present date and time, which the host system can access through an interface.

2.1.4 SCT013 100A Current Sensor

The SCT-013 current sensor operates according to the principle of magnetic induction. When electric current flows through a conductor, it generates a magnetic field in the vicinity of said conductor. The SCT-013 sensor encompasses a coil that detects this magnetic field and produces an output voltage that is directly proportional to the current traversing the conductor. The resultant output from the SCT-013 current sensor is then transmitted to the microcontroller in the smart meter, which calculates energy consumption based on the current measurement. Additionally, the microcontroller can employ the current measurement to determine other parameters, including power factor, voltage, and frequency.

2.1.5 ZMPT101B AC Voltage Sensor Module

The ZMPT101B voltage sensor module employs a voltage transformer to step down the AC voltage to a level that the microcontroller can measure. The output from the voltage transformer is then fed into a voltage divider circuit, which reduces the voltage to a level suitable for the microcontroller. The output of the ZMPT101B voltage sensor module is subsequently directed to the microcontroller, which calculates the voltage level based on the measurement. The microcontroller can exploit the voltage measurement to evaluate other parameters, such as power, energy consumption, and power factor.

2.1.6 Rotary Encoder

A rotary encoder is a system that converts physical movement into electrical impulses. It comprises a code disc, laser source unit, focusing unit, and photodetector array [31]. The code disc modulates laser beams, generating optical code signals. These signals are subsequently transformed into electric code signals via a photodetector array. A rotary encoder consists of an electret unit, electrostatic field sensor, and controller. The electret generates an electrostatic field, while the sensor detects modulation stemming from rotation [32]. The controller oversees sensor activations and encodes rotational position using digital encoding. The microcontroller leverages the input from the rotary encoder to ascertain the selected option or the extent to which a setting needs adjustment [33]. Typically, a rotary encoder provides users with an interface for selecting options and adjusting the meter's settings.

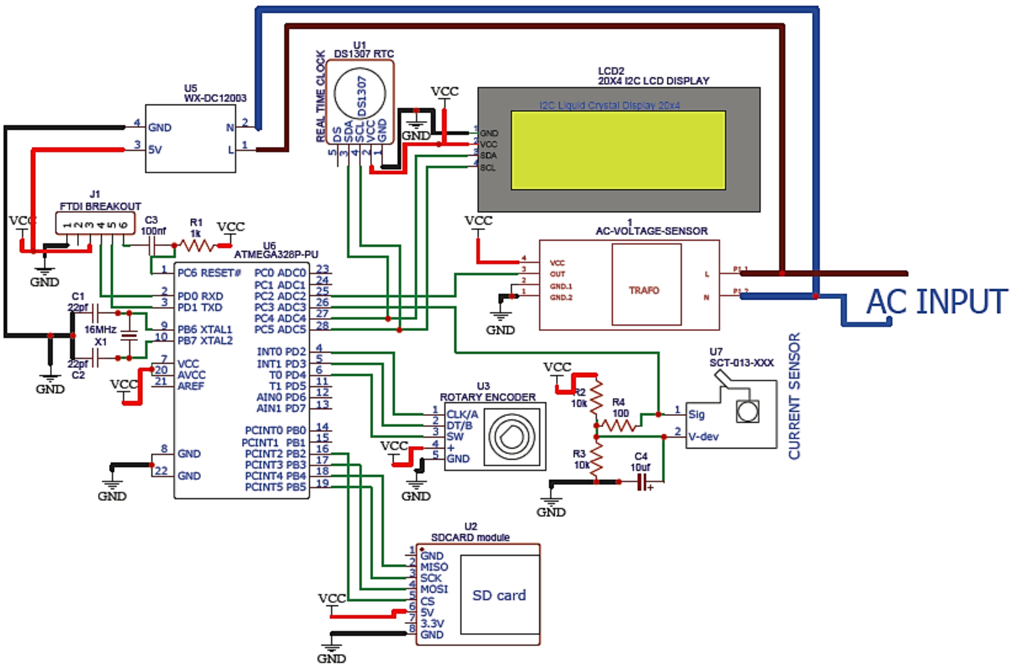


Fig. 2 *Circuit diagram of the smart energy meter*

J. of Advanced Industrial Technology and Application Vol. 4 No. 2 (2023) p. 94-103

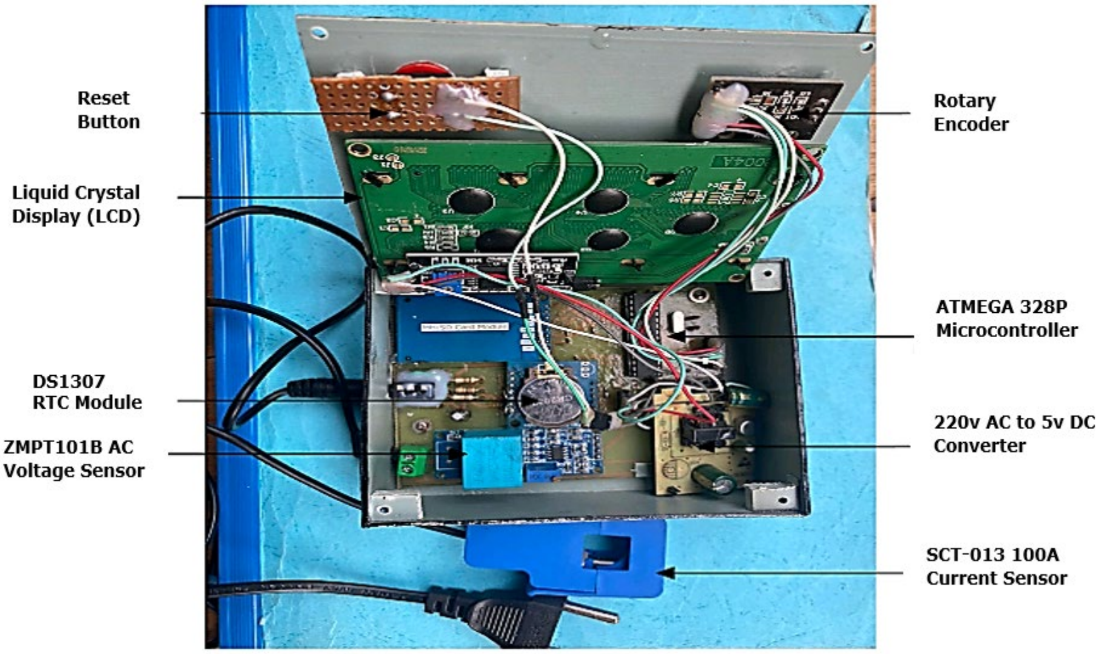
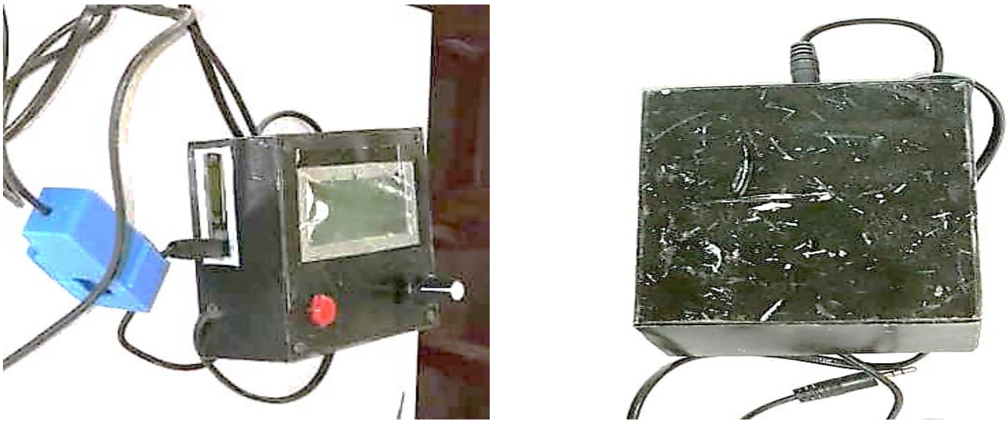


Fig. 3 *Development of smart energy meter*



(a) (b)

Fig. 4 *(a) Side view of the meter; (b) Back view of the meter*

2.2 Flowchart

The flowchart of the system is depicted in Fig. 5. Upon the connection of the SM to the power source, the electrical erasable programmable read-only memory (EEPROM) library is initialized, and the ZMPT101B voltage and SCT-100A current sensor will undergo calibration. Subsequently, the system will examine the SD card. The system will inspect the EEPROM for stored data if the SD card is detected. However, if the card is unavailable, the SD module will conduct an error check and prompt the user to insert the card properly. Once the SD card is detected, all the parameters stored on it will be exhibited on the LCD screen. If the reset button on the meter is pressed, the system will initiate again. The rotary button is then utilized to modify the time interval for data storage on the system.

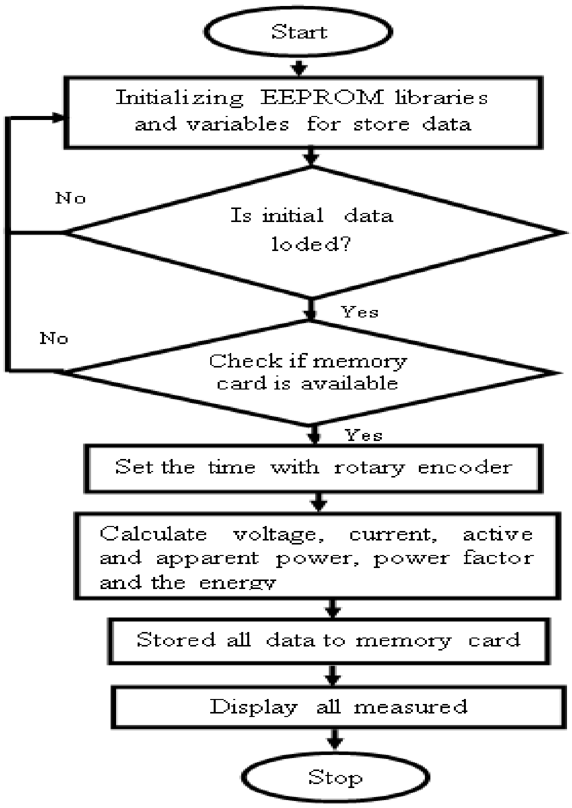
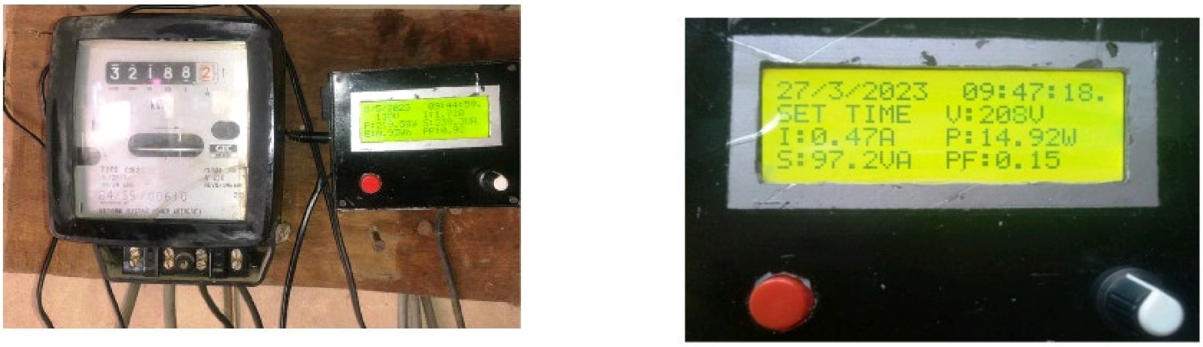


Fig. 5 *Flow chart of a smart metering system*

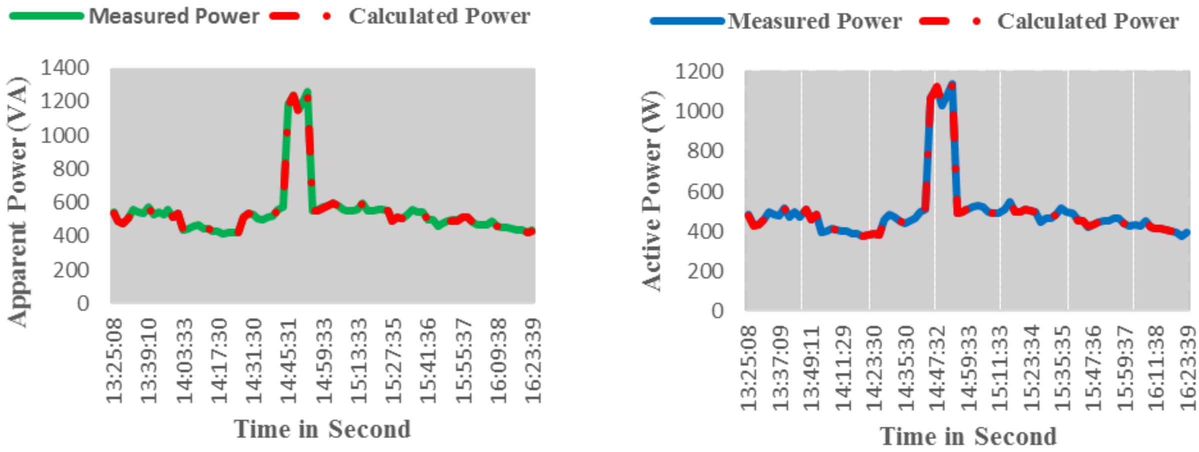
3. Results and Discussion

The developed smart energy meter was connected to a residential building and the power supply was established through the supply to the house. The smart energy meter was connected side by side with an analogue as shown in Fig. 6 (a). The LCDs present various parameters, including date, connection time, supply voltage, current drawn, active power, and apparent measured power and power factor when a load is present, as shown in Fig. 6 (b). The meter was connected at approximately 1.30 p.m. when most occupants were away for work. During this time, the power consumption amounted to 480 W; a sudden increase was observed around 2.35 p.m. when additional appliances were connected. The power consumption readings were automatically logged onto a memory card connected to the system every two minutes over a specific duration. The measured power values were then calculated and plotted alongside the computed values for the building during the specified time. Fig. 7 (a) shows the apparent and calculated power over time. Concurrently, Fig. 7 (b) illustrates the cumulative active power and calculated power consumption over time. The graph displays the running total of units consumed, with each new value being added to the previous value, resulting in a continuously increasing plot. The accuracy of the energy meter is determined by the precision with which it can measure the load voltage and current. The power factor reading is presented in Fig. 8, with the minimum and maximum values being 0.88 and 0.93 respectively.



(a) (b)

Fig. 6 *Smart meter testing with (a) Energy meter; (b) Without energy meter*



(a) **(b)**

Fig. 7 *Measured power and calculated power of (a) Apparent power; (b) Active power of the residential building*

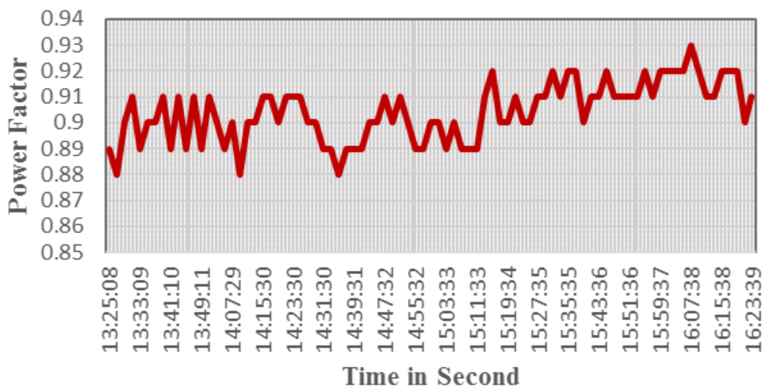


Fig. 8 *Measured power factor of the tested residential building*

Table 1 *Comparative values of power measurement*

Active Power	Values in(W)
Measured Power	43927.31
Calculated Power	43956.72
Apparent Power	Values in (VA)
Measured Power	48471.53
Calculated Power	48614.38

Fig. 8(a) shows the bar graph differences between the apparent measured power and calculated power cumulative consumption of units over time. Fig. 8(b) shows the bar graph differences between the active measured power and calculated power cumulative consumption of units over time. Each new unit consumed is added to the previous value, resulting in a plot of the cumulative units consumed over time. The most recent value on the graph represents the total units consumed by the user until that point. The voltage and current errors for the energy meter are 0.1% and 0.3%, respectively, while the power value error of 0.04%, which is acceptable for most metering devices. These values are less that the single phase meter permissible error which should be ≤ ±2 % as defined in BS 37[34].

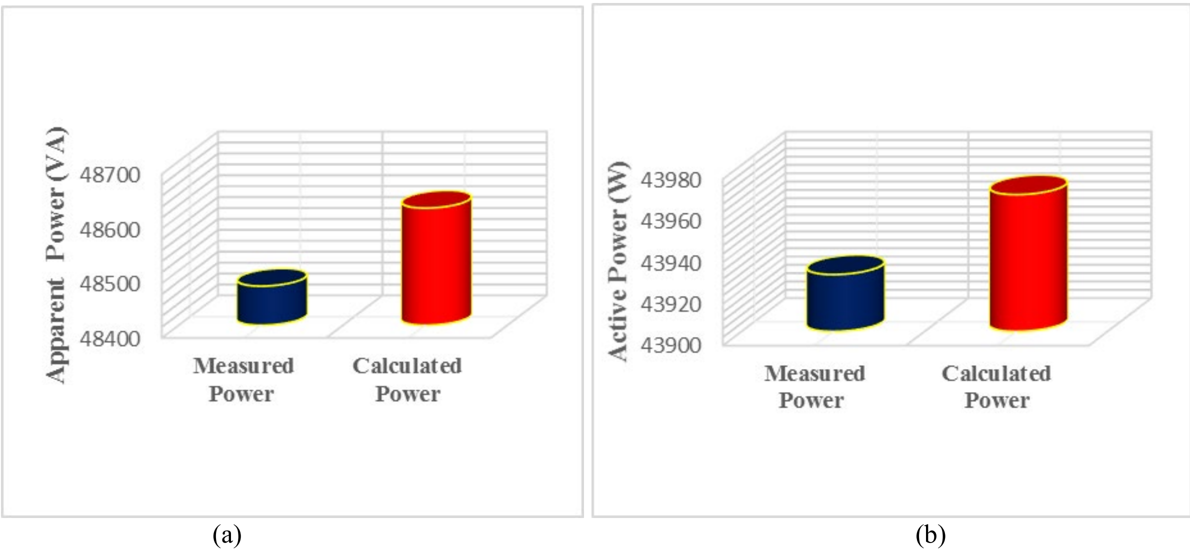


Fig. 8 *Graph measured power and calculated power of (a) Apparent power; (b) Active power*

4. Conclusion

Smart metering systems are deployed globally to enhance energy efficiency, mitigate waste, and curb theft of energy. These systems are also seamlessly integrated with advanced grid technologies like energy storage and renewable energy sources, thus facilitating the development of more sustainable energy systems. The crucial role metering plays in electricity distribution cannot be overstated, as it enables the accurate measurement and billing of customers' electricity consumption. The proposed prototype of SM uses ATMEGA328P microcontroller, which effectively measures voltage, current, power factor, active power, and apparent power. AC voltage measurement is made possible by utilizing a ZMPT101B voltage sensor and an SCT-013 100A current sensor.

Additionally, a rotary encoder is employed to translate rotational movement into electrical signals, with the real-time clock module being built on an internal clock. The system was tested to ascertain its capacity to handle energy data, ensure dependable communication, and guarantee data storage for future usage. Notably, the voltage and current errors associated with the energy meter stand at ±0.1% and ±0.3%, respectively, while the power value error is ±0.4%. Employing a smart metering system contributes to establishing a more sustainable and efficient energy infrastructure, thereby promoting the realization of a sustainable future.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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