

PREPAID ELECTRICITY USING IOT TECHNOLOGY IN WET MARKET OF BARANGAY DON MARIANO PEREZ, BAYOMBONG, NUEVA VIZCAYA

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ABSTRACT

With the continuous growth of urban areas and rising electricity demand, efficient and transparent electricity management is becoming increasingly vital, particularly in public commercial spaces like wet markets. Traditional billing systems in these environments often rely on fixed rates, leading to overcharging and limited control for stall owners. In response, this study presents a Prepaid Electricity Meter and Monitoring System powered by Internet of Things (IoT) technology, specifically designed for the wet market of Barangay Don Mariano Perez, Bayombong, Nueva Vizcaya. The study aimed to (a) design a framework for a prepaid metering system; (b) develop a working prototype utilizing Iot; and (c) test the system to verify accuracy and reliability. The system employed the ESP32-DevKit microcontroller and the Blynk application for real-time monitoring and control, following the Design-Build-Test (DBT) methodology. Ten trials were conducted across four simulated vendor profiles, comparing data from Blynk (expected) with readings from standard instruments (actual). The results showed percentage errors of 0.0741% for voltage, 1.1364% for current, and 1.1383% for power—all within the acceptable 2% range. Independent samples t-tests revealed no significant difference between Blynk and actual measurements, affirming the system's reliability. This study demonstrates the effectiveness of IoT-based prepaid metering in promoting energy accountability, operational efficiency, and consumer empowerment in local market settings.

Keywords: Prepaid electricity, IoT technology, esp32 microcontroller, Blynk application, energy monitoring, smart meter, wet market, real-time data, electrical load management, prepaid metering system

INTRODUCTION

The rapid advancement of Internet of Things (IoT) technology has revolutionized various sectors, including energy management and consumption. In the Philippines, particularly in urbanizing municipalities like Bayombong, Nueva Vizcaya, the integration of IoT-based systems presents a promising solution to long-standing challenges in electricity distribution, billing inefficiencies, and energy wastage. Prepaid electricity systems—where consumers pay for energy in advance—offer an alternative to the traditional postpaid model, granting users greater control over their consumption while enhancing the operational efficiency of utility providers.

Current electricity billing in public markets, such as those in Bayombong, often relies on fixed-rate systems that lead to inaccurate billing and energy misuse. Manual meter reading, a time-consuming process that depends on human labor, further exacerbates inefficiencies and errors. The implementation of IoT-enabled smart meters can address these problems by enabling real-time monitoring, automated billing, and two-way communication between consumers and providers. Such systems ensure transparency, minimize losses due to electricity theft or tampering, and facilitate immediate feedback for both parties.

Previous studies have demonstrated the benefits of automated and prepaid metering systems, including improved accuracy, reduced operational costs, and increased customer satisfaction (Bhavsar et al., 2019; Kumar et al., 2023). Moreover, research by Sahani et al. (2016)

and Toyin et al. (2022) showed that remote monitoring and control capabilities can automatically handle disconnections, send payment reminders, and reduce reliance on manual interventions. The integration of GSM and IoT technologies allows for efficient data transmission and user notifications. Similarly, Rawte et al. (2017) and El-Khozondar et al. (2024) emphasized the potential of web-based and mobile applications to enhance user accessibility and engagement by providing real-time usage updates. Globally, the trend toward smart grids and IoT-based energy systems has underscored the role of technology in promoting sustainable and efficient energy management. The combination of IoT and data-driven analytics supports intelligent decision-making, demand-side management, and renewable energy integration (Ahmad et al., 2021; Rao et al., 2024). These innovations contribute to smart city development and environmental sustainability.

In this context, the present study explored the feasibility and impact of implementing an IoT-based prepaid electricity system at the wet market of Bayombong, Nueva Vizcaya. The system aimed to promote equitable energy access, improve billing transparency, and empower consumers to make informed decisions regarding their energy usage. Furthermore, this research also sought to position Bayombong as a model for smart energy management among local municipalities, contributing to the broader discourse on sustainable urban development and smart city initiatives in the Philippines through an IoT-based prepaid electricity system in the wet market of Bayombong, Nueva Vizcaya.

Conceptual Framework

Figure 1

Conceptual Framework

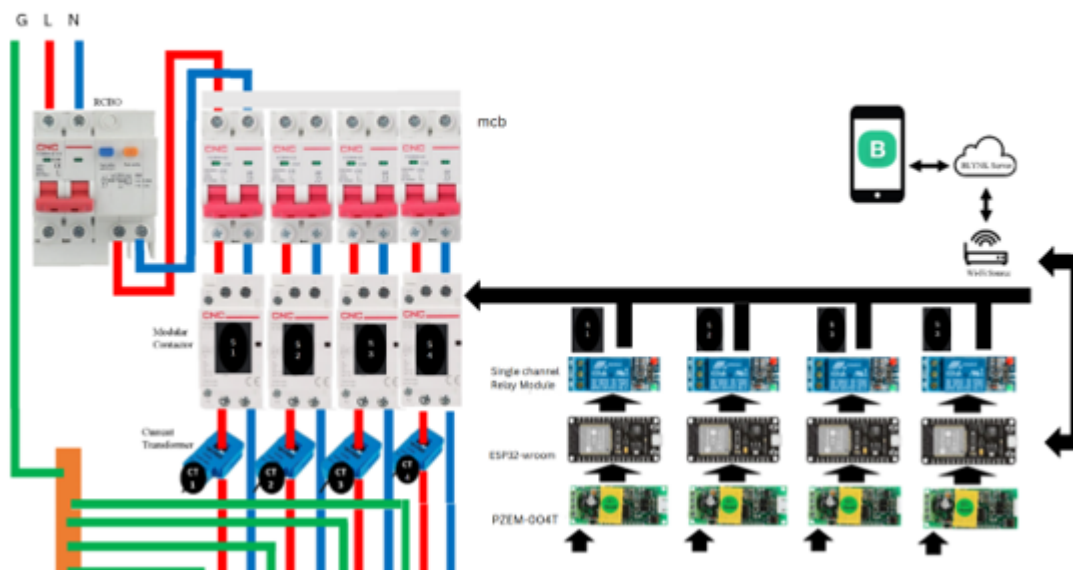
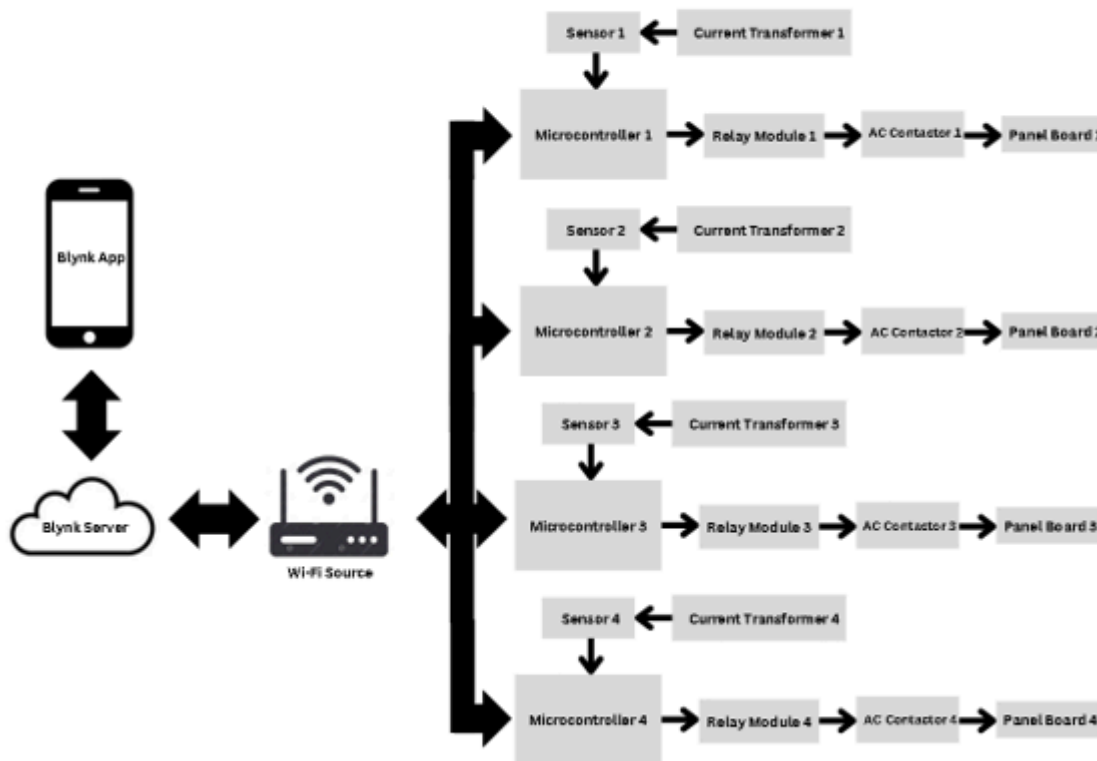


Figure 1 describes how the system works. The prepaid electricity meter is monitored and managed by the ESP32-DevKit C microcontroller, which also makes it easier to transfer the gathered data to the Blynk server. Tenants and the Office of the Municipality of Bayombong can view the monitored electricity meter data via the Blynk application.

Figure 2

Block diagram interconnection of the proposal project

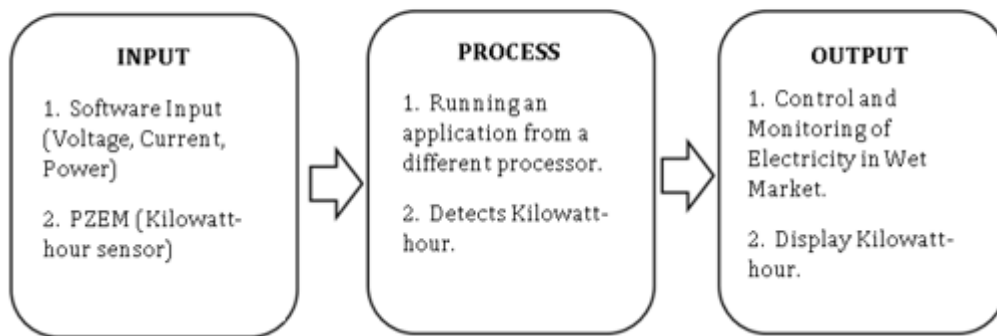


The PZEM-004T sensor primarily processes input data and measures various electrical properties. Measurements from the electricity meter, including voltage, current, power, and kilowatt-hours, are included in this input data. The ESP32-DevKit, which is connected to the PZEM-004T, processes the data before sending it to the Blynk server. In addition to managing data transfer via Wi-Fi and controlling the Single Channel Relay Module through the Blynk application, the ESP32-DevKit is a flexible development board designed for simple prototyping and project building. This relay module is an electromechanical device that controls the circuit breaker by acting as a remote switch for the AC contactor

An IoT-based system design for monitoring electricity consumption at the wet market is shown in Figure 3. The Blynk application, which serves as the input to activate the microcontroller for data collecting, is how the user initiates the procedure. The PZEM-004T sensor, which monitors voltage, current, power consumption, and kilowatt-hours, is then turned on by the microcontroller. The Blynk app shows this data, allowing users to keep an eye on how much electricity they use. A block diagram of the proposed project is shown in Figure 3, which shows how the different parts work together and are connected.

Figure 3

Input, process, and output diagram



METHODOLOGY

Research Design

The research design followed the Design-Build-Test (DBT) Methodology. This iterative development process emphasizes continuous testing and improvement. It begins with defining project requirements, brainstorming solutions, building a functional prototype, and thoroughly testing it to ensure it meets these requirements. If testing reveals design flaws, revisions are made, and the cycle repeats until a satisfactory product is achieved. The research design is shown as three interconnected circles: the first, labeled "Design," represents the initial phase where the researchers conceptualized a Wi-Fi-based system, designed its circuitry, and developed a 3D prototype. The second circle, labeled "Build," involved assembling and constructing the physical prototype. The final circle, "Test," focused on testing the application's parameters and evaluating its notification features. Each stage transitions smoothly to the next, representing the iterative nature of the DBT methodology.

Hardware Design

SketchUp 3D Model

The figure illustrates the interconnection of the prepaid electricity meter system for stalls. The microcontroller box, which serves as the central control unit, is positioned alongside the main panel board. This panel board contains the circuit breakers and contactors that manage power distribution, all of which are operated through control signals transmitted from the microcontroller box.

Figure 4
Prototype 3D Design

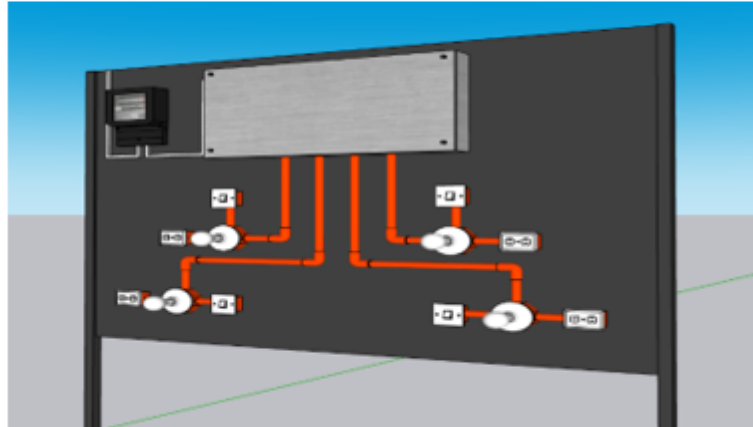


Figure 5
Power flow diagram of the system

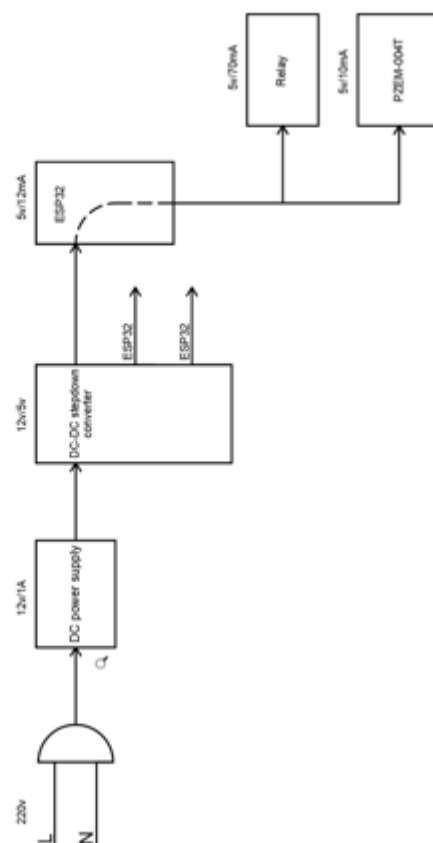
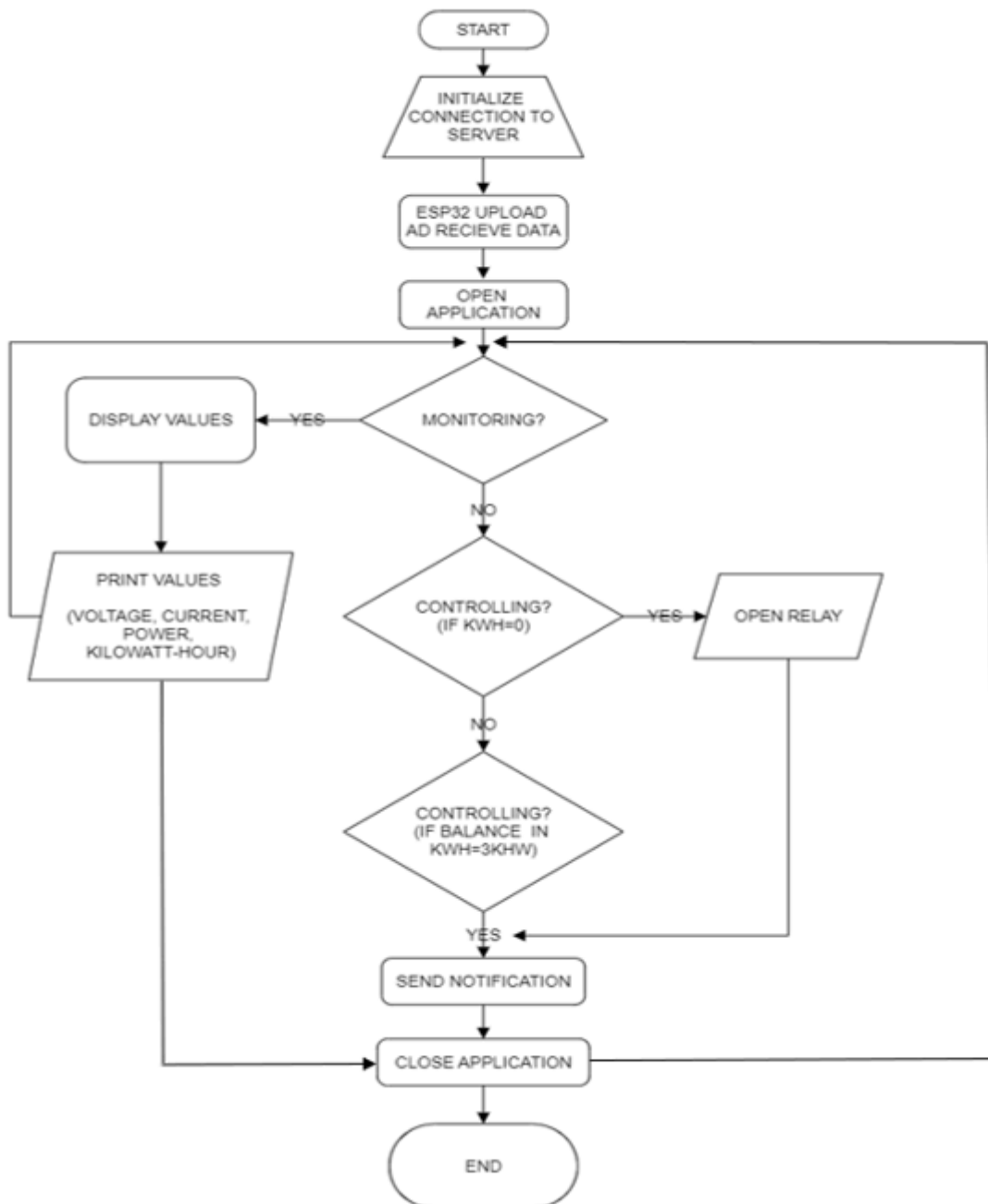


Figure 6

Project Flowchart



Data Gathering

This section describes the methodology used to collect data for the study. Initially, a prototype was developed by integrating various electronic and electrical components to represent the system under investigation. Following this, a series of tests was conducted to evaluate the prototype’s key parameters. These parameters were statistically analyzed using methods such as independent-samples t-tests and group t-tests, allowing comparisons with established standards or with an alternative dataset. To determine the accuracy of the prototype, percentage error analyses were performed. This involved computing the deviation between the expected values—obtained from standard measuring instruments such as

voltmeters and ammeters—and the actual values recorded using the Blynk application. The computed difference was then divided by the expected value and multiplied by 100 to express the error as a percentage. A lower percentage error signified a closer agreement between the expected and actual outcomes. The real-time data collected from the Blynk application served as the basis for assessing the prototype's performance. To enhance data reliability, the prototype was configured to measure voltage and current simultaneously, thereby minimizing inconsistencies.

Treatment of Data

Reliable research requires a foundational understanding of statistical methods, as research involves more than simply conducting experiments and gathering information. Statistical analysis plays a crucial role in organizing and processing data. One essential aspect of statistical analysis is identifying potential errors and outliers using statistical methods. Since every experiment has inherent uncertainty caused by random and systematic errors, these methods are critical for ensuring accuracy (Glen, n.d.).

The researchers compared readings from the Blynk app with the voltmeter's measured voltage and the clamp meter's measured current to determine how closely the reported values align with the actual measurements. To assess the system's accuracy, $df = n_1 + n_2 - 2$ was used to compare the means of two groups and determine whether the difference was statistically significant. Additionally, percentage error calculations were used to assess how closely the measured values matched the expected values.

Equation 1: The formula for percentage error is as follows:

Equation 1:

$$\%error = (|expected\ value - actual\ value| / actual\ value) \times 100\%$$

To calculate the system's percentage error, the researchers used the average of the actual and expected measurements obtained from Blynk and electrical metering tools. Measurements for voltage, current, and power were conducted across ten trials, and the mean values for both the actual and expected parameters were calculated. By applying Equation 1, the overall percentage error of the system was determined.

The Independent Samples t-test was used to compare the means of two independent groups to evaluate whether there was statistical evidence of a significant difference between their population means. This parametric test analyzed two types of variables: the dependent variable (test variable) and the independent variable (grouping variable). It is commonly employed to assess differences between the means of two groups, interventions, or change scores.

The Independent Samples t-test required continuous data for the dependent variable and a categorical independent variable with two categories. The data were also randomly sampled, and the independent and dependent variables should have approximately normal distributions.

The test statistic for an Independent Samples t-test, denoted as t_{tt} , had two forms based on the assumption of equal or unequal variances:

- **Equal Variances Assumed:**

When equal population variances were assumed, the test statistic t_{tt} was calculated as follows:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

Where:

$$s_p = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1+n_2-2}}$$

\bar{x}_1 =The mean of the first sample

\bar{x}_2 =The mean of the second sample

n_1 = Sample size of the first sample

n_2 = Sample size of the second sample

s_1 = Standard deviation of the first sample

s_2 =Standard deviation of the second sample

s_p =Pooled standard deviation

The calculated t-value was compared to the critical t-value from the t-distribution table, using degrees of freedom $df = n_1 + n_2 - 2$. If the calculated t-value exceeds the critical value, the null hypothesis was rejected.

- **Equal Variances Not Assumed:**

When variances were unequal, the test statistic t was calculated as:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

With degrees of freedom:

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1-1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2-1}}$$

In this form, the calculated t-value was compared to the critical t-value, and the null hypothesis was rejected if the calculated value exceeded the critical value. This version did not assume equal variances, resulting in adjustments to the test statistic's denominator and degrees of freedom.

RESULTS AND DISCUSSION

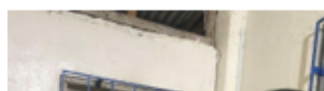
Hardware Development

Constructing the frame

During the construction of the frame, the plyboard was cut using a saw to match the dimensions specified in the 3D model. A wooden frame was assembled to support the plyboard in an upright position, with two wooden stands secured to the plyboard using wood screws. To enhance structural stability, a wooden base was installed between the supporting wooden frames. Lastly, a coat of paint was applied to enhance the finished product's overall appearance.

Figure 7

Installation of components of microcontroller box



Data and Results

As shown in Table 1 below, these values were used to calculate percentage errors and determine the differences between the actual values for PZEM 1-4.

Table 1

Percent Error

	N	MEAN		
		ACTUAL	EXPECTED	%ERROR
VOLTAGE	40	231.658V	231.48625V	0.074139V
CURRENT	40	1.577A	1.59525A	1.136418A
POWER	40	364.49W	368.64W	1.138303W

Blynk Application and Voltmeter Comparison

A voltmeter was connected in parallel with the device to measure its voltage. This configuration was essential because components connected in parallel share the same potential difference. By connecting the voltmeter in parallel, it accurately measured the same voltage drop across the device in the circuit. Comparing readings from the voltmeter with those from the Blynk Application provided insight into the accuracy of the voltage measurements.

Table 2

T-Test Group Statistics of Blynk and Voltmeter

	N	VENDOR (3)		
		MEAN	STD. DEVIATION	STD. ERROR MEAN
BLYNK	10	231.892V	2.25603V	0.71342V
VOLTMETER	10	230.621V	2.44335V	0.77266V

Table 3

T-Test Group Statistics of Blynk and Voltmeter

Tables 2 to 4 present the comparative results of voltage measurements obtained from the Blynk application and a standard voltmeter across three vendors. Each dataset consists of ten trials (N = 10) conducted under similar load and environmental conditions to ensure consistency.

In Table 2 (Vendor 3), the mean voltage reading obtained from the Blynk system was 231.892 V, while the voltmeter recorded a slightly lower mean of 230.621 V. The standard deviations for the Blynk and voltmeter readings were 2.25603 V and 2.44335 V, respectively, indicating minimal variability between the two measuring devices. The small difference in means (≈ 1.27 V) suggests that the IoT-based Blynk system provides voltage readings that closely align with those of conventional measurement instruments, demonstrating good accuracy and reliability.

For Table 3 (Vendor 2), the Blynk application recorded a mean voltage of 232.65 V, while the voltmeter showed 232.59 V. The difference between the two means is only 0.06 V, indicating near-perfect agreement between the IoT-based measurement and the reference device. The standard deviations of 2.02024 V (Blynk) and 2.50561 V (voltmeter) further confirm the consistency of the readings. This minimal deviation implies that the Blynk-based monitoring system can effectively replicate the precision of standard instruments in real-world applications.

In Table 4 (Vendor 4), the Blynk system registered a mean voltage of 231.375 V, compared to 231.952 V from the voltmeter, with a difference of approximately 0.58 V. The standard deviations were 2.83917 V and 3.05062 V for Blynk and voltmeter readings, respectively. The results again indicate a close correlation between the two measurement methods, reflecting stable and reliable data transmission from the IoT device to the Blynk platform.

Overall, across all vendors, the variations between Blynk and voltmeter readings remain within an acceptable margin of error (less than ± 1.5 V). The consistency of results across multiple vendors validates the system’s accuracy in monitoring voltage levels. The relatively low standard deviations and standard errors further support the precision and repeatability of the IoT-based measurement approach.

These findings confirm that the ESP32-DevKit and PZEM-004T sensor, when integrated with the Blynk application, can accurately measure and display voltage data comparable to traditional measurement tools. The results demonstrate the system’s potential as a viable solution for real-time monitoring of electricity consumption at the Bayombong wet market, ensuring reliable and transparent data reporting. Moreover, this alignment with conventional instruments reinforces the system’s feasibility for wider deployment in local energy management and smart metering applications.

Blynk Application and Ammeter Comparison

An ammeter is a device used to measure current. It combines a simple digital multimeter with a current sensor. The clamp part measures current, and the probes check voltage. The meter has a hinged jaw that can open and close around a wire, cable, or conductor. This allows it to measure current without having to unplug or turn off the circuit. To check whether the current readings are correct and reliable, compare the clamp meter data with the values shown in the Blynk app.

Table 5
T-Test Group Statistics of Blynk and Calculated Current

		VENDOR		
		(1)	STD.	STD. ERROR
CURRENT	N	MEAN	DEVIATION	MEAN
BLYNK	10	0.29A	0.052746A	0.01667999A
CALCULATED				
POWER	10	0.30A	0.058274A	0.01842812A

Table 8

T-Test Group Statistics of Blynk and Calculated Current

CURRENT	N	VENDOR (4)		
		MEAN	STD. DEVIATION	STD. ERROR MEAN
BLYNK	10	1.55A	0.16373A	0.05177837A
CALCULATED CURRENT	10	1.57A	0.17748A	0.05612653A
BLYNK	10	0.32A	0.053374A	0.01687865A
CALCULATED CURRENT	10	0.29A	0.0453603A	0.01434418A

Table 7

T-Test Group Statistics of Blynk and Calculated Current

CURRENT	N	VENDOR (3)		
		MEAN	STD. DEVIATION	STD. ERROR MEAN
BLYNK	10	4.21A	1.456060A	0.46044664A
CALCULATED CURRENT	10	4.16A	1.446205A	0.45733030A

Tables 5 through 8 present current measurements collected using both the Blynk system and calculated values, with ten readings per method across four test conditions. In Table 5, the Blynk system recorded a mean current of 0.29A, slightly lower than the 0.30A from the calculated values, with both showing similar variability, as indicated by standard deviations of 0.05275A and 0.05827A, respectively. Table 6 reveals that Blynk had a higher mean (0.32A) than the calculated current (0.29A), with moderate consistency indicated by standard deviations of 0.05337A and 0.04536A. In Table 7, both methods recorded higher currents, with Blynk showing a mean of 4.21A and calculated current slightly lower at 4.16A. The standard deviations are 1.45606A and 1.44621A, indicating higher variability in these readings. Table 8 presents similar results, with Blynk recording a mean of 1.55A compared to 1.57A from calculated values. The standard deviations (0.16373A for Blynk and 0.17748A for calculated) suggest a relatively consistent spread in data. Across all tests, the Blynk system produced readings closely aligned with the calculated values, with only minor deviations in mean and standard deviation. These results support the reliability of the Blynk system for monitoring current in various scenarios.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The researchers conducted comprehensive testing of the developed prepaid electricity metering system to evaluate its functionality, accuracy, and reliability in a real-world market setting. The results confirmed that the study's objectives were successfully achieved. Initially, the system's design was created using SketchUp and AutoCAD to model the interconnection of its primary components. A smartphone-based control system was then implemented, allowing users to load electricity credits and monitor real-time consumption through the Blynk mobile application. This application connects to a microcontroller via Wi-Fi, which automatically cuts off power when the credit is fully depleted—providing both operational control and ease of use. To ensure the system performed as intended, each component was tested both individually and as part of the fully integrated system. Measurement tools were utilized throughout the testing process to minimize error and verify the overall effectiveness, precision, and dependability of the prepaid electricity solution.

Recommendations

To enhance future versions of the prepaid electricity monitoring system, several improvements are suggested. Integration with mobile payment platforms such as GCash and PayMaya allows users to conveniently and instantly reload credits in the application. Strengthening the system's security by implementing user authentication, encrypted communication, and access logging will help ensure data protection and prevent unauthorized access. The system can also be expanded for use in larger applications, such as residential areas or small commercial establishments, and should be supported by additional testing across different environments. In locations with unreliable internet connections, adding offline capabilities, such as SMS-based control or alternative disconnection methods, can help maintain functionality. While the Blynk platform offers basic features, creating a dedicated mobile application with an intuitive interface tailored to local users can improve the overall user experience and accessibility. Lastly, long-term monitoring combined with predictive maintenance notifications can help ensure the continued durability and efficiency of the system.

REFERENCES

- Ahmad, T., Zhang, D. (2021). *Using the internet of things in smart energy systems and networks*. <https://www.sciencedirect.com/science/article/abs/pii/S2210670721000755>
- El-Khozondar, H. J., et.al. (2024). *A smart energy monitoring system using ESP32 microcontroller*. <https://www.sciencedirect.com/science/article/pii/S2772671124002468>
- Elektor, S. (2024). *ESP32 Energy meter: An open-source solution for real-time energy monitoring*. <https://www.elektormagazine.com/labs/esp32-energy-meter-an-open-source-solution-for-real-time-energy-monitoring>
- H. et al. (2024). *ESP32-based control and monitoring*. <https://irjiet.com/Volume-6/Issue-4-April-2022/GSM-Based-Energy-Meter-Billing-System/1018>
- H. et al. (2024). *ESP32-based control and monitoring*. <https://irjiet.com/Volume-6/Issue-4-April-2022/GSM-Based-Energy-Meter-Billing-System/1018>
- KaaIoT. (2023). *IoT in energy management: A vision for sustainable practices*. <https://www.kaaiot.com/iot-knowledge-base/iot-energy-management#:~:text=IoT%20devices%2C%20ranging%20from%20smart,energy%20optimization%20and%20resource%20conservation>
- Karuna, G., Ediga, P., Akshatha, S., Anupama, P., Sanjana, T., Mittal, A., Rajvanshi, S., & Mohammed, I. *Smart energy management: Real-time prediction and optimization for IoT-enabled smart homes*. <https://www.tandfonline.com/doi/full/10.1080/23311916.2024.2390674#:~:text=The%2>

0Smart%20Home%20Energy%20Management,feature%20extraction%20and%20data%20transformation

- Kumar, L., Choudhary, H., Badetiya, H., Aloria, H. K., Jangid, M., Sharma, S. *Smart prepaid energy meter* <https://www.ijert.org/smart-prepaid-energy-meter>
- Omkar V. et al (2019). *Prepaid energy meter based on IOT.* <https://ijrti.org/viewpaperforall.php?paper=IJRTI1903004>
- Rao, C. K., Sahoo, S. K., Yanine, F. F. (2024). *A literature review on an IoT-based intelligent smart energy management system for PV power generation.* <https://www.sciencedirect.com/science/article/pii/S2773207X23001197>
- Rawte, M., Sharma, S. (2017). *Smart prepaid energy meter based on the internet of things.* *International Journal of Computer Applications* 171(2):23–26. https://www.researchgate.net/publication/319170955_Smart_Prepaid_Energy_Meter_based_on_Internet_of_Things
- Sahani, B., Ravi, T., Tamboli, ., Pisal, R. (2017). *IoT-based smart energy meter.* Dept of Electronics & Telecommunication Engineering, SPVP's S.B. Patil College of Engineering. <https://www.irjet.net/archives/V4/i4/IRJET-V4I423.pdf>