Development of a Real-Time Household Energy Monitoring System

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ABSTRACT:
The rapid increase in energy consumption necessitated innovative solutions for sustainable energy management, particularly in households. This research advanced innovative energy solutions by addressing challenges in current systems, such as high costs and complexity. The proposed system enabled homeowners to monitor their energy usage, reduce expenses, and implement energy-saving strategies. It also offered significant potential for scalability, allowing for integration with renewable energy sources and IoT platforms, thus highlighting its importance in sustainable energy management. This system enabled users to track their energy consumption effectively. Researchers employed an experimental design to create, develop, and evaluate the system's performance. The system was calibrated using standard measuring tools and tested over 15 days, comparing its readings against utility meters and the ThingSpeak platform. The results indicated a Mean Absolute Percentage Error (MAPE) of under 5% for all measured variables, demonstrating high accuracy and reliability. Voltage measurements exhibited an error of just 0.09%. While the current and energy readings were slightly less precise, they remained acceptable, with errors of 3.54% and 3.20%, respectively.
This study contributed to the advancement of innovative energy solutions by tackling issues such as high costs and complexity in existing systems. The new system empowered homeowners to monitor their energy usage, reduce expenses, and adopt energy-saving practices. It was adaptable to various needs and had the potential for integration with renewable energy sources and IoT platforms, underscoring its critical role in sustainable energy management.

Keywords: Data logging, IoT, PZEM-004T, Sensor accuracy

INTRODUCTION:

Energy monitoring has become an essential practice today, as sustainability and energy efficiency are of paramount importance. Energy efficiency is essential as both households and industries are impacted by rising electricity costs. As energy prices continue to rise, some regions face economic strain, resulting in energy poverty for many families. This has driven a greater need for solutions that help consumers monitor and reduce their energy consumption (Gajdzik et al., 2024). The rapid increase in energy consumption is driven by a growing global population, rising urbanization, and the common use of energy-intensive technologies like electric vehicles, smartphones, and cryptocurrency mining (Munoz et al., 2022). Global electricity demand has seen significant growth.

One key obstacle to effective energy management is the inconvenience of traditional energy meters. Joseph (2023) points out that energy meters are often placed in locations that are challenging to reach or obtain access to, leading to a lack of awareness about energy consumption. Farha et al. (2023) support this, noting that most people struggle to interpret and understand the numbers displayed by energy meters. As people often focus on work and various responsibilities, they may neglect to keep track of their energy consumption. This lack of attention can limit efforts to optimize energy use effectively.

In addition to awareness issues, human error in energy billing can worsen the problem. Workers responsible for reading meters and calculating bills are prone to making mistakes, which can lead to overcharging customers. Kotwal et al. (2022) highlight that billing errors can result in significant financial discrepancies. A study by Uswitch (2017) reported that nearly 1.3 million customers in the UK were overcharged by a total of £102 million due to billing errors, with an average overcharge of £79 per customer. This underscores the need for more reliable and accurate energy monitoring systems to mitigate such issues. The development of advanced metering technologies provides an opportunity to address these challenges. Traditional energy meters, while valuable, offer limited functionality in terms of real-time monitoring and data analysis. The expansion of the Internet of Things (IoT) has created new ways to manage energy, enabling the use of digital systems that offer real-time energy insights. Smart devices are independent physical or digital items equipped with sensors, processors, and network functions. Using built-in logic, they can understand their surroundings and interact with people. These devices can sense, record, and interpret events both within themselves and in the world around them. They can act independently, communicate with each other, and exchange information with users (Affum et al., 2021). This connectivity enables physical devices to be monitored and controlled remotely, bridging the differences between the real and virtual worlds (Kotwal et al., 2022).

This study develops a reliable real-time energy monitoring system designed for single households with loads under 100A, incorporating a cooling mechanism to enhance long-term energy management. By facilitating the collection and visualization of real-time data, the system underscores the critical role of smart technology in optimizing energy consumption, particularly in light of rising global demand (Hussien et al., 2021). Affum et al. (2021) emphasize the importance of IoT-based Smart Home Energy Management Systems, especially in developing regions facing inefficient demand-side energy management. The dual-display capability, featuring an LCD screen and integration with ThingSpeak for comprehensive data analysis, enhances user accessibility and enables effective management of energy usage patterns, fostering efficient residential energy practices (Ali et al., 2020; Hasan et al., 2021).

This research offers significant benefits to various stakeholders. Homeowners gain a dependable method for monitoring their energy consumption and can utilize the system's estimated electricity cost feature to aid in budgeting and informed decision-making. Furthermore, the findings may prompt policymakers to create incentives for energy-efficient technologies, facilitating broader community adoption. Utility companies can leverage these insights to promote energy efficiency initiatives and support sustainability goals, ultimately contributing to more effective energy management across residential sectors.

MATERIALS, METHODOLOGY, AND LITERATURE REVIEW

Materials of the Study

The research employed an experimental design to develop and test a reliable and accurate energy monitoring system specifically designed for household use. This approach systematically evaluated the prototype's effectiveness, accuracy, and reliability under real-world conditions. A quantitative methodology was applied to collect and analyze numerical data related to energy consumption and system performance. The design was structured into four key phases:

1. **System Design:** Identification of system requirements and development of architecture to measure electrical parameters accurately.
2. **Prototype Development:** Construction of the energy monitoring system.
3. **Testing and Calibration:** Evaluation of system accuracy using structured data collection and statistical analysis.
4. **Accuracy Validation:** Assessment of reliability using the Mean Absolute Percentage Error (MAPE).

Figure 3 (Research Design Flow Block Diagram of the Proposed Prototype) depicts the detailed flow of the research design.

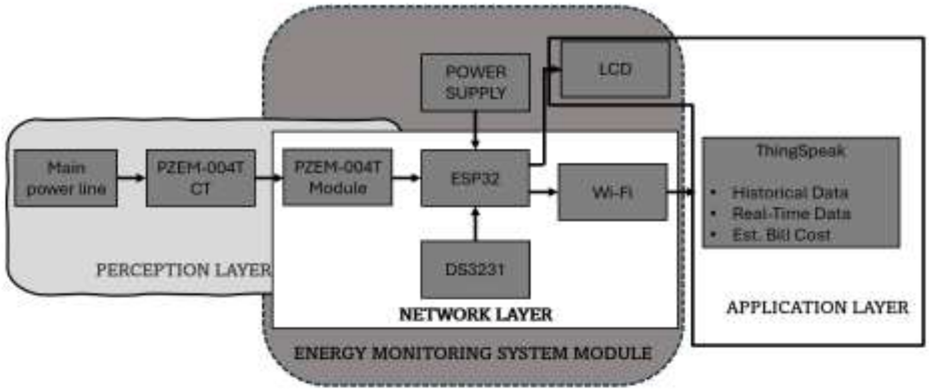


Figure 3 Block Diagram of the Research Design

Design of the Energy Monitoring System

The system was designed to measure and monitor electrical parameters using the PZEM-004T sensor, which can measure voltage, current, power, energy, power factor, and frequency. The sensor is positioned on the household's main circuit breaker, ensuring operation within safe measurement limits. The wiring configuration and component specification are shown in Figure 3.1 (PZEM-004T 100A Wiring Diagram) and Table 4 (Features of PZEM-004T V3.0), respectively.

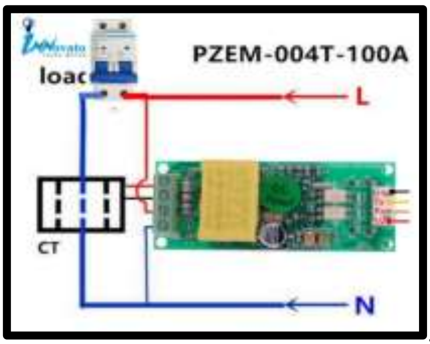


Figure 3.1 PZEM-004T 100A Wiring Diagram.

The ESP32 microcontroller is the system's central processing unit. It collects data from the sensor and transmits it via Wi-Fi to the cloud-based ThingSpeak platform for storage and analysis. The ESP32 was programmed using the Arduino IDE to process metrics and compute estimated electricity costs. The microcontroller is visualized in Figure 3.2 (ESP32 Board and Adapter).

Figure 3.2 ESP32 Board and Adapter.

The system integrates a DS3231 RTC module for precise timekeeping, ensuring accurate timestamps even during power outages. Additionally, a cooling system with a fan regulates the ESP32's temperature, preventing overheating and providing stable long-term operation.

To protect and organize the components, a 3D-printed case with dedicated compartments and ventilation features for effective airflow was designed. The case design is shown in Figure 3.3 (3D Model for the Casing of the System).

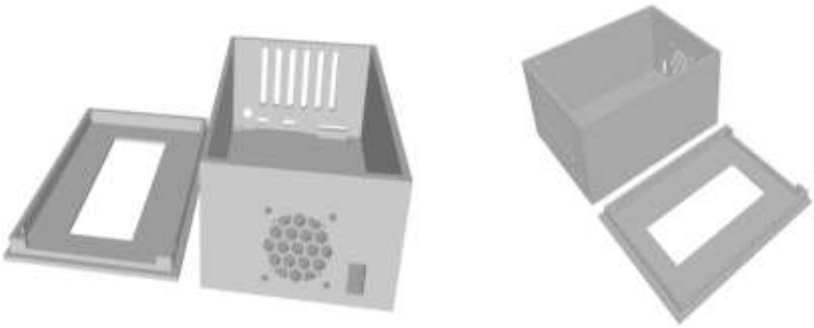


Figure 3.3 3D Model for the Casing of the System

The prototype integrates a dual-display feature: a local LCD for real-time monitoring and ThingSpeak for remote access to historical data.

Development of the Energy Monitoring System Prototype

The PZEM-004T sensor was installed on the main circuit breaker to collect real-time electrical data. The ESP32 microcontroller was programmed to read this data and transmit it wirelessly to ThingSpeak. Calibration was performed to ensure accuracy in measuring voltage, current, and power. An LCD was incorporated into the system to provide users with immediate feedback on energy usage. This display offers metrics such as voltage, current, and total energy consumption. The LCD configuration is shown in Figure 2.5 (LCD Screen Display).

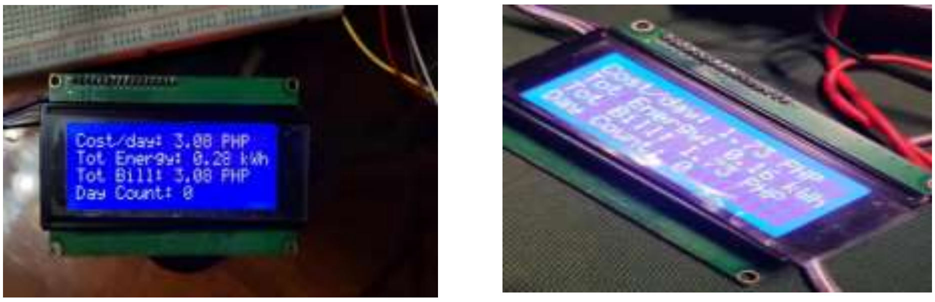
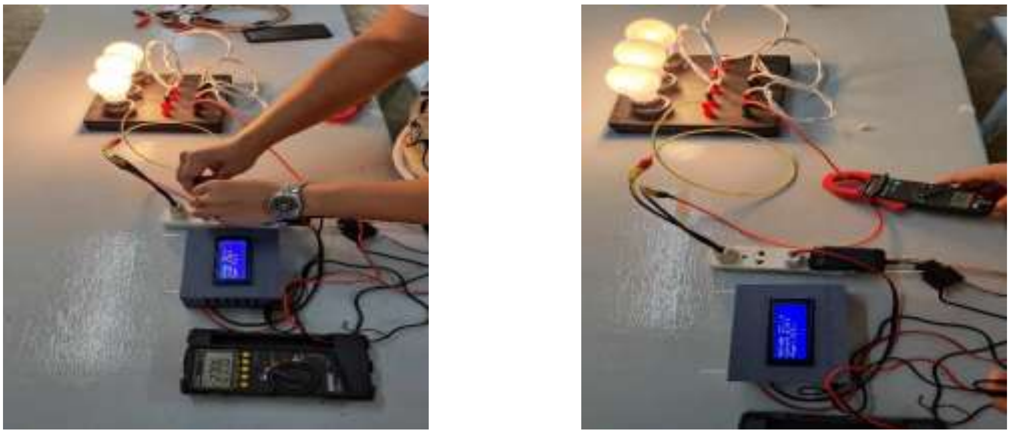


Figure 3.4 LCD Screen Display

The system's dual-display functionality enabled users to view data locally on the LCD and remotely through ThingSpeak, which improved accessibility and usability. The calibration process ensured the system's accuracy by comparing its readings against standard electrical measuring tools such as a digital multi-tester and a clamp meter. The process involved setting up the prototype in parallel with a resistive load and obtaining measurements from both the prototype and standard instruments. Calibration was conducted under various load conditions, ensuring reliability across different scenarios. Any discrepancies observed during this phase were addressed by fine-tuning the prototype's sensors and algorithms. This meticulous approach to calibration validated the precision of the prototype for measuring voltage and current, and the documented results were presented in Table 3.1 and Figure 3.5 (A) Voltage Measurement Comparison and (B) Current Measurement Comparison.



(A)(B)

Figure 3.5 Voltage and Current Measurement Comparisons

Appendix C includes photographic documentation, comparative analysis tables, and details of additional calibration results and test data.

Test the energy monitoring system and compare its performance with ThingSpeak and the utility metering system.

The system was installed in a single household with an electrical load of less than 100A. The installation followed strict safety protocols, including isolating the power supply to prevent electrical hazards. Figure 3.6 (Photo of the System Setup Inside the Panel Board) displays a photo of the system setup.

Figure 3.6 Photo of the System Setup Inside the Panel Board.

Data was collected over 15 days, with simultaneous readings taken from the prototype, utility meter, and ThingSpeak platform. These readings were analyzed using MAPE to evaluate the system's accuracy.

Methodology

To detect important electrical characteristics (voltage, current, power, energy, power factor, and frequency), the PZEM-004T sensor was used in the design of the energy monitoring system. The sensor was mounted on the main circuit breaker in the house. The processing unit was an ESP32 microcontroller that was configured using the Arduino IDE. For remote storage and analysis, it collected sensor data and sent it to the ThingSpeak cloud platform. Additionally, the system calculated local electricity bills. A DS3231 RTC module was incorporated to guarantee precise timekeeping for data logging. A cooling fan system kept everything from overheating. A 3D-printed vented container contained all of the parts. The system had two displays: a local LCD screen for in-person viewing and a ThingSpeak platform for remote access to previous data. Accurate readings were verified via calibration, which required aligning sensor readings with standards and fine-tuning algorithms. The prototype was evaluated using standard measuring instruments (digital multi-tester and clamp meter). Measurements were made under various load circumstances. Lastly, the system was placed in a single residence (less than 100A load) for testing and data collection. Readings were taken concurrently from the utility meter, ThingSpeak, and the prototype (LCD) for a period of 15 days. During installation, safety measures were taken. A structured data flowchart was used to log and compare data from various sources. Mean Absolute Percentage Error (MAPE) for voltage was used to measure accuracy.

Literature Review

Monitoring and managing energy use have become vital strategies to address the challenges associated with energy consumption. Energy monitoring involves tracking and analyzing how energy is utilized, helping identify wasteful practices, reduce unnecessary consumption, and make informed decisions to optimize resource usage. Afzal et al. (2020) emphasizes the role of energy monitoring in promoting sustainable practices and moving toward a more energy-efficient future.

One key obstacle to effective energy management is the inconvenience of traditional energy meters. Joseph (2023) points out that energy meters are often placed in locations that are challenging to reach or obtain access to, leading to a lack of awareness about energy consumption. Farha et al. (2023) support this, noting that most people struggle to interpret and understand the numbers displayed by energy meters. As people often focus on work and various responsibilities, they may neglect to keep track of their energy consumption. This lack of attention can limit efforts to optimize energy use effectively.

In addition to awareness issues, human error in energy billing can worsen the problem. Workers responsible for reading meters and calculating bills are prone to making mistakes, which can lead to overcharging customers. Kotwal et al. (2022) highlight that billing errors can result in significant financial discrepancies. A study by Uswitch (2017) reported that nearly 1.3 million customers in the UK were overcharged by a total of £102 million due to billing errors, with an average overcharge of £79 per customer. This underscores the need for more reliable and accurate energy monitoring systems to mitigate such issues. The development of advanced metering technologies provides an opportunity to address these challenges. Traditional energy meters, while valuable, offer limited functionality in terms of real-time monitoring and data analysis. The expansion of the Internet of Things (IoT) has created new ways to manage energy, enabling the use of digital systems that offer real-time energy insights. Smart devices are independent physical or digital items equipped with sensors, processors, and network functions. Using built-in logic, they can understand their surroundings and interact with people. These devices can sense, record, and interpret events both within themselves and in the world around them. They can act independently, communicate with each other, and exchange information with users (Affum et al., 2021). This connectivity enables physical devices to be monitored and controlled remotely, bridging the differences between the real and virtual worlds (Kotwal et al., 2022).

Despite advancements in energy monitoring technology, many existing systems remain costly, challenging to install, and often face reliability issues over prolonged use (Afzal et al., 2020). This study seeks to address these shortcomings by introducing a novel energy monitoring prototype that features several key innovations:

1. **Custom-Designed Casing:** This casing not only organizes and protects essential components such as the LCD and sensors but also enhances user convenience and system durability.
2. **Real-Time Clock (RTC) Module:** This module maintains accurate timestamps even during power outages, facilitating consistent data logging.
3. **Dual Display Capability:** Users can monitor real-time energy consumption, costs in pesos, and historical data through both an LCD screen and the cloud-based ThingSpeak platform.

By integrating these features, the proposed system considers reliability, affordability, and ease of use, making it accessible for households. It empowers consumers with actionable insights into their daily and total energy consumption, encouraging them to adopt energy-efficient habits. This approach not only aids sustainable energy management but also offers an effective way to lower household energy costs and consumptions.

RESULTS AND DISCUSSIONS

System Design and Prototype Development

The Real-Time Household Energy Monitoring System integrated essential components to effectively achieve its design objectives. Key elements such as the PZEM-004T sensor, ESP32 microcontroller, LCD, and ThingSpeak IoT platform were carefully selected and integrated. The system's dual-display capability allowed real-time visualization of energy metrics on the LCD while providing detailed historical data on the ThingSpeak platform. This dual-access approach ensured accessibility, accuracy, and user convenience, enabling users to monitor their energy consumption straightforwardly and efficiently.

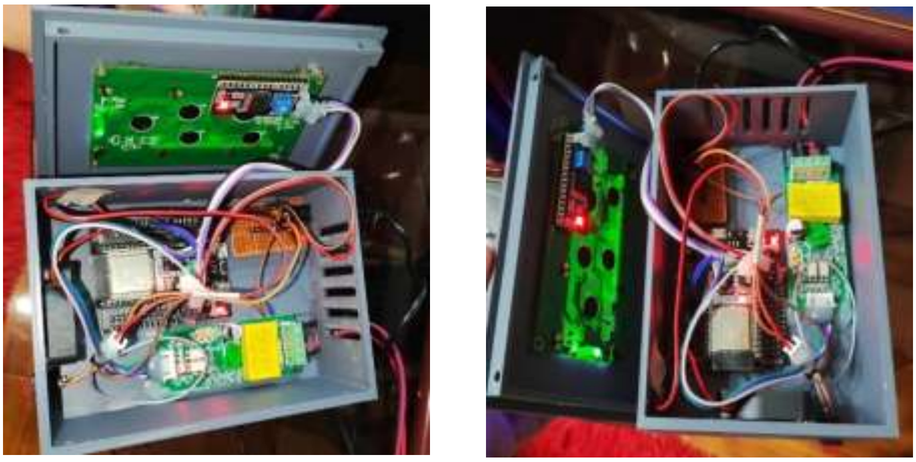


Figure 4 Hardware Setup of the Real-Time Household Energy Monitoring System

Figure 4 illustrates the hardware setup, showcasing the seamless integration of components. During the development phase, particular attention was given to ensuring the durability and practicality of the prototype. Safety measures were implemented to handle household loads of less than 100A. The system's cooling mechanism prevented overheating, while the custom 3D-printed case offered organization and protection for the internal components. The integration of an RTC module further enhanced functionality by enabling accurate data logging, even during power interruptions. Figure 4.1 highlights the system's full integration with the household's main panel board, demonstrating its readiness for real-world application.

Figure 4.1 Fully Integrated Setup of the Real-Time Energy Monitoring System with the Main Panel Board

Additionally, the programming in Appendix A details the implementation of the Arduino IDE code, which enables efficient data acquisition, real-time display, and transmission to the cloud platform. This code ensures synchronization between the LCD, ThingSpeak, and sensors, providing a reliable data flow.

Calibration of the Energy Monitoring System Prototype

The calibration phase was a critical step to validate the system's accuracy and reliability. The prototype's performance was compared against standard electrical measuring tools under various load conditions. Table 2 summarizes the results of these tests, showing a Mean Absolute Percentage Error (MAPE) of

0.261% for voltage and 9.57% for current. This indicates a high level of precision in voltage measurement, although current measurement showed slightly higher variability.

Table 2 Comparison of data from prototype and electrical measuring tools.

Load	Voltage (Prototype)	Voltage (Measuring Tool)	Current (Prototype)	Current (Measuring Tool)
3 – 25W LAMP (parallel)	238.1 V	239.3 V	0.29 A	0.27 A
2 – 25W LAMP (parallel)	239.2 V	239.6 V	0.18 A	0.17 A
1 – 25W LAMP	238.9 V	239.3 V	0.09 A	0.08 A
2 – 25W LAMP (parallel) & 1 – 25W LAMP (series)	239.3 V	239.8 V	0.09 A	0.08 A

Figures 3.5 (A) and 3.5 (B) illustrate the graphical comparison of voltage and current measurements, affirming the system's reliability. However, the slightly higher error in the current measurement suggests that further optimization, particularly in sensor calibration and sensitivity, would enhance performance. Appendix C provides the detailed calibration process and comparative documentation, supporting these findings with meticulous records of calibration across different scenarios.

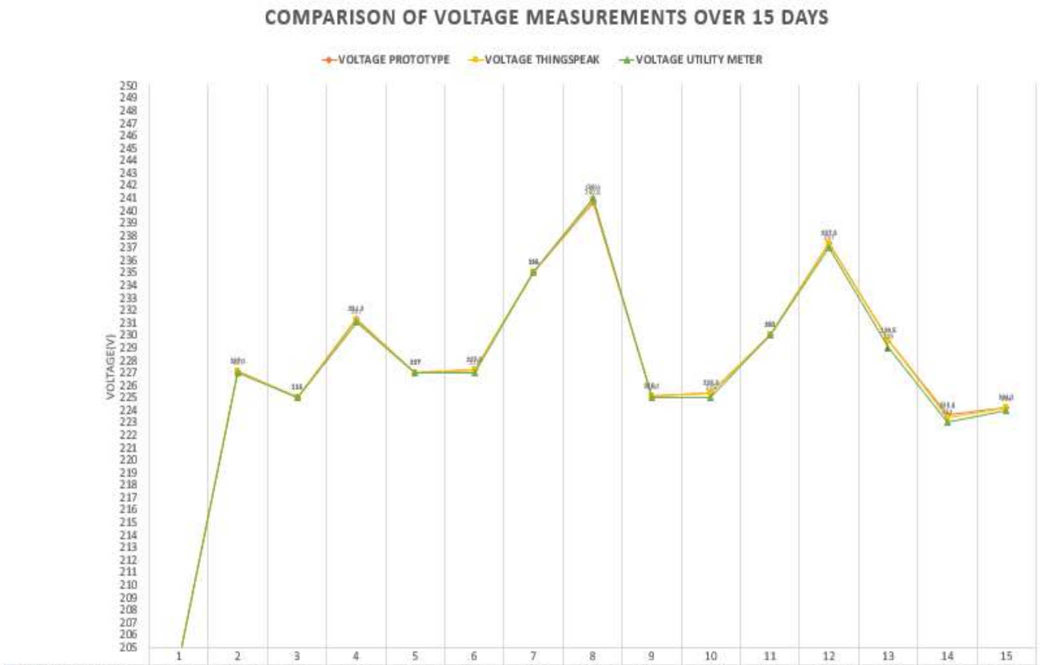
Evaluation of the Energy Monitoring System in Residential Household

To evaluate the system's real-world performance, a 15-day comparative study was conducted between the prototype, the ThingSpeak platform, and the utility meter. Table 3 summarizes the MAPE results for key parameters such as voltage, current, power, and energy.

Table 3 MAPE results for key parameters such as voltage, current, power, and energy.

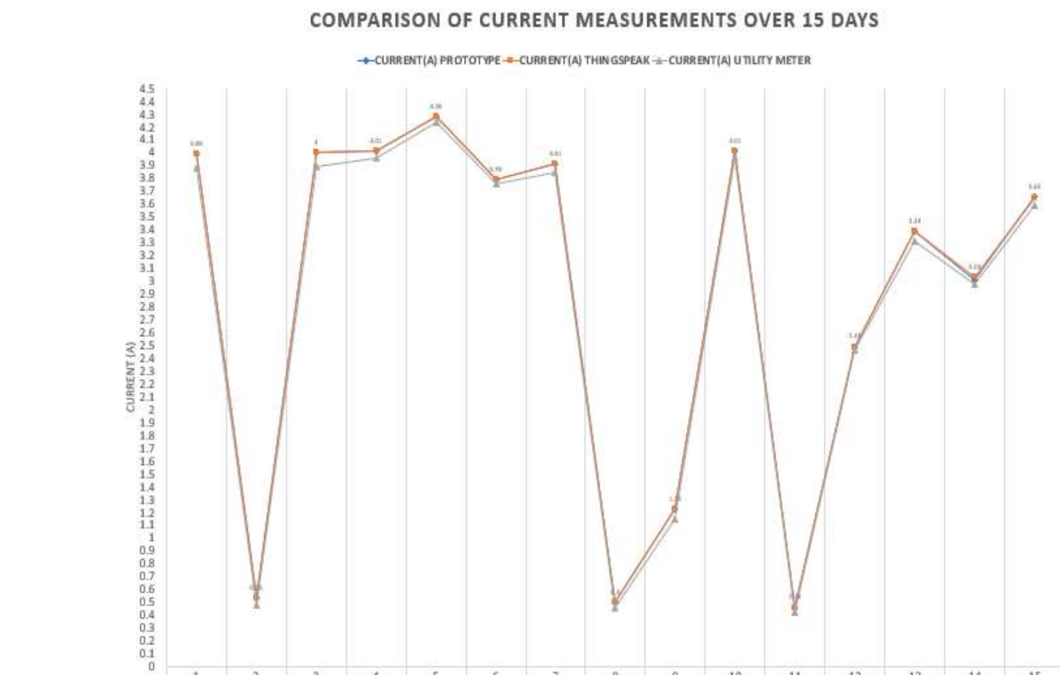
Parameter	Prototype vs. Utility Meter	ThingSpeak vs. Utility Meter
Voltage	0.09%	0.07%
Current	3.54%	3.56%
Power	0.0001%	0.90%
Energy	3.20%	3.20%

Figures 4.2 to 4.5 provide a graphical comparison of these parameters, illustrating a high degree of accuracy and consistency across all measurement platforms. The ThingSpeak platform's 15-second update interval introduces minor latency compared to the prototype's 3-second updates. Despite this, both platforms demonstrate reliable and actionable data.



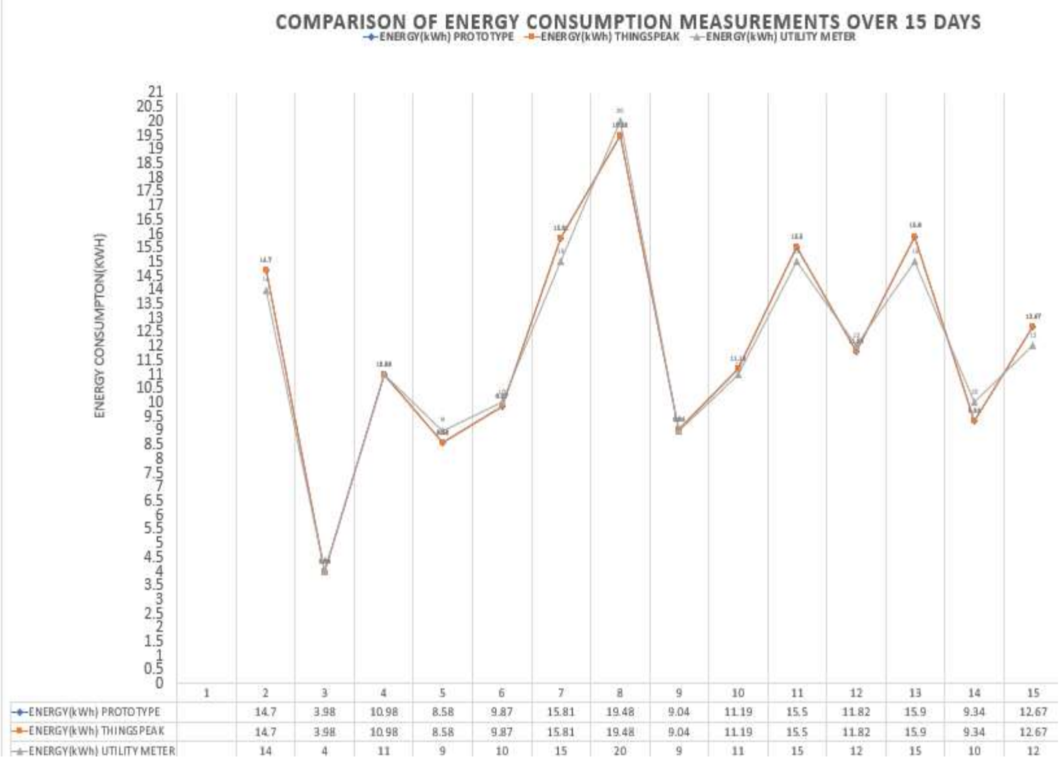
NO. OF DAYS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VOLTAGE PROTOTYPE	204	227.1	225	231.3	227	227.2	235	240.6	225.1	225.3	230	237.3	229.5	223.6	224.2
VOLTAGE THINGSPEAK	204	227.1	225	231.2	227	227.2	235	240.9	225.1	225.3	230	237.3	229.5	223.4	224.2
VOLTAGE UTILITY METER	204	227	225	231	227	227	235	241	225	225	230	237	229	223	224

Figure 4.2 Voltage Measurement Comparison Graph



NO. OF DAYS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CURRENT(A) PROTOTYPE	3.99	0.53	4	4.01	4.28	3.79	3.91	0.5	1.22	4.01	0.46	2.49	3.39	3.01	3.66
CURRENT(A) THINGSPEAK	3.99	0.53	4	4.01	4.28	3.79	3.91	0.5	1.22	4.01	0.46	2.49	3.39	3.03	3.65
CURRENT(A) UTILITY METER	3.88	0.48	3.89	3.96	4.24	3.76	3.84	0.46	1.15	3.96	0.42	2.46	3.31	2.98	3.59

Figure 4.3 Current Measurement Comparison Graph



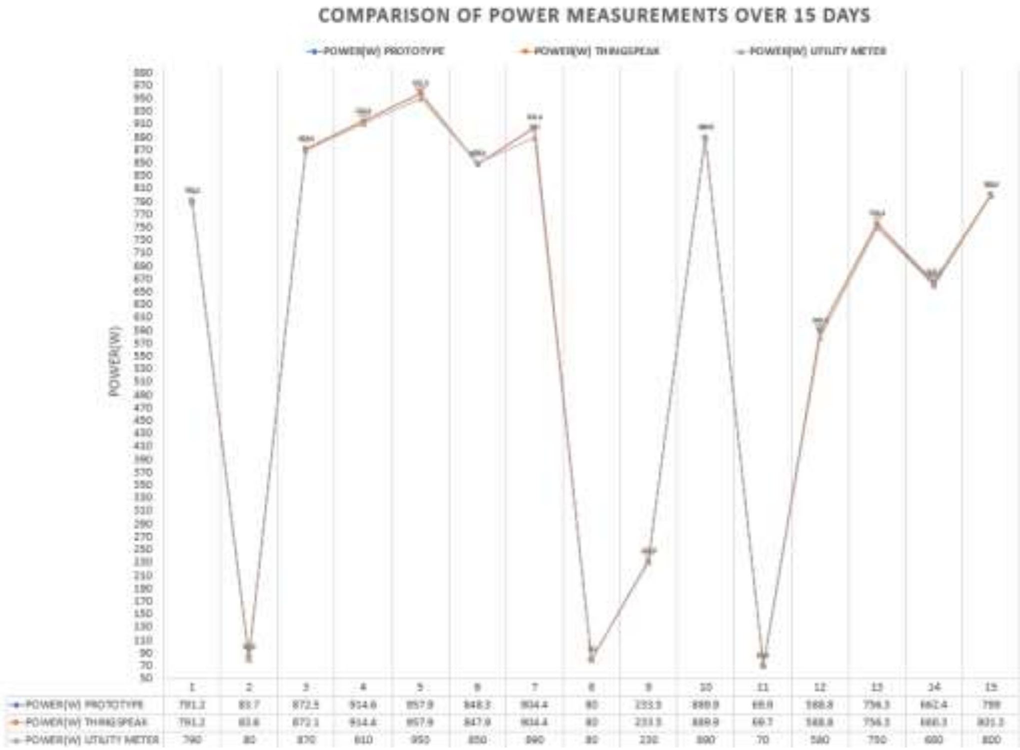


Figure 4.4 Power Measurement Comparison Graph

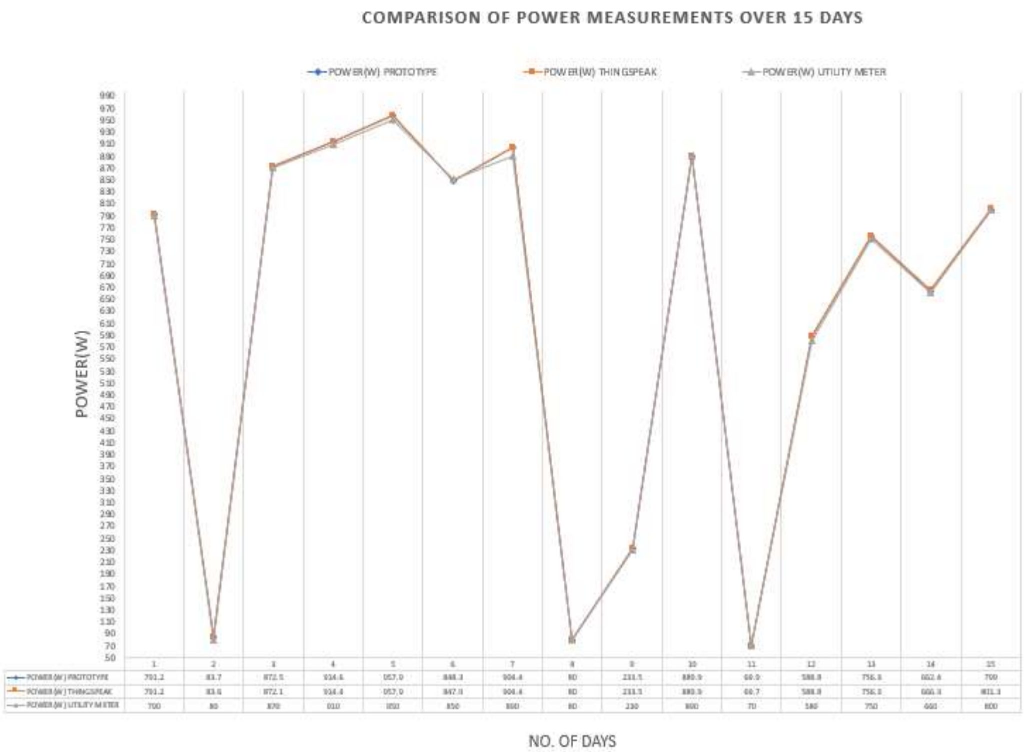


Figure 4.5 Energy Consumption Measurement Comparison Graph

The low MAPE values for voltage (0.09%) and power (0.0001%) highlight the system's exceptional accuracy. However, the slightly higher errors for current and energy measurements (3.54% and 3.20%, respectively) indicate potential improvements in sensor wiring and calibration to minimize resistance and enhance accuracy. The recorded logs from ThingSpeak in Appendix B substantiate these findings, offering insights into daily and cumulative energy usage trends. Photographic validation of energy readings over the testing period is documented in Appendix D, ensuring transparency and accuracy in the evaluation process.

CONCLUSION

The MAPE (Mean Absolute Percentage Error) results presented in the paper indicate that the energy monitoring system developed is highly accurate in measuring voltage, current, power, and energy consumption. The very low errors associated with voltage and power measurements prove that the system has a reliable capability of providing real-time values. Although the error margins for current and energy are higher than those for voltage and power, they are still acceptable. Small differences in the readings could arise due to wire resistance, hardware sensitivity limits, and measurement accuracy differences between the prototype and the reference. In short, the energy monitoring system's goal of accurately and timely monitoring significant electrical parameters in the examined platforms is achieved. The minor differences we see can be accounted for by a system's hardware and timing limitations, and they do not diminish the system's amazing performance in providing reliable high-fidelity data. These results prove that the developed prototype is robust and suitable for energy monitoring applications.

The study, which designs and implements real-time home energy monitoring systems using PZEM-004T and ThingSpeak integration, shows success, but there is still more room for improvement for further study. Recommendations for improvement include:

- Integrate the system with renewable energy sources like solar panels or wind systems.
- Expand the system for use in commercial or industrial applications.
- Connect the system to IoT devices for energy-saving automation.
- Add dynamic control capabilities for real-time adjustment of appliances.
- Develop a user-friendly interface for non-technical users.
- Explore more affordable components to reduce overall costs.

Improvements in these areas can give rise to more robust, scalable, and user-friendly energy monitoring systems that enable smarter energy management and sustainability.

REFERENCES:

1. Affum, E. A., Agyeman-Prempeh, K., Adumatta, C., Ntiamoah-Sarpong, K., & Dzisi, J. (2021). Smart home energy management system based on the Internet of Things (IoT). International Journal of Advanced Computer Science and Applications, 12(2).
2. Afzal, N., Shahid, A., & Yasir, A. (2020). Development of smart home systems for managing electrical energy. International Journal of Electrical and Electronics Engineering, 12(2), 45-55.
3. Ali Hussien, Naseer, et al. (2021). Monitoring the Consumption of Electrical Energy Based on the Internet of Things Applications. International Journal of Interactive Mobile Technologies (IJIM), 15(7), 17. https://doi.org/10.3991/ijim.v15i07.20183
4. Ali, Mubashir, et al. (2020). An IoT-Based Approach for Efficient Home Automation with ThingSpeak. International Journal of Advanced Computer Science and Applications (IJACSA), 11(6). https://doi.org/10.14569/IJACSA.2020.0110615
5. Bedi, G., Venayagamoorthy, G. K., Singh, R., Brooks, R. R., & Wang, K. C. (2018). Review of Internet of Things (IoT) in electric power and energy systems. IEEE Internet of Things Journal, 5, 847–870.
6. Coelho, P., Gomes, M., & Moreira, C. (2019). Smart Metering Technology. In: ZambroniF de Souza, A., Castilla, M. (eds) Microgrids Design and Implementation. Springer, Cham. https://doi.org/10.1007/978-3-319-98687-6_4
7. El-Khozondar, H. J., Mtair, S. Y., Qoffa, K. O., Qasem, O. I., Munyarawi, A. H., Nassar, Y. F., Bayoumi, E. H. E., & Halim, A. A. E. B. A. E. (2024). A smart energy monitoring system using ESP32 microcontroller. *E-Prime - Advances in Electrical Engineering, Electronics, and Energy*, *9*, 100666. https://doi.org/10.1016/j.prime.2024.100666
8. Empowering Sustainability: A Consumer-Centric Analysis Based on Advanced Electricity Consumption Predictions. (n.d.).
9. Espressif. "ESP32 Overview | Espressif Systems." *Www.espressif.com*, 2023, www.espressif.com/en/products/socs/esp32.
10. Farha, A., Ore, J., Pergantis, E. N., Sriram, L., Ziviani, D., & Groll, E. A. (2023). Design and Application of an in Situ IoT-Based Energy Monitoring System for Use in Real-Time Building Modeling. ASHRAE Transactions, 129, 490-497. https://www.proquest.com/scholarly-journals/design-application-situ-iotbased-energy/docview/2973219100/se-2
11. Gajdzik, Bożena, et al. "The Influence of the Global Energy Crisis on Energy Efficiency: A Comprehensive Analysis." *Energies*, vol. 17, no. 4, 18 Feb. 2024, p. 947, https://doi.org/10.3390/en17040947. Accessed 12 Oct. 2024.

12. Gajdzik, Bożena, et al. "The Influence of the Global Energy Crisis on Energy Efficiency: A Comprehensive Analysis." Energies, vol. 17, no. 4, 18 Feb. 2024, p. 947, https://doi.org/10.3390/en17040947. Accessed 12 Oct. 2024.
13. Harahap, P., Pasaribu, F. I., & Adam, M. (2020). Prototype Measuring Device for Electric Load in Households Using the Pzem-004T Sensor. Budapest International Research in Exact Sciences (BirEx) Journal, 2(3), 347-361.
14. Hasan, M. K., Ahmed, M. M., Pandey, B., Gohel, H., Islam, S., & Khalid, I. F. (2021). Internet of Things-Based Smart Electricity Monitoring and Control System Using Usage Data. Wireless Communications and Mobile Computing, 2021(1), 6544649. https://doi.org/10.1155/2021/6544649
15. Huan-Liang Tsai, Le, P. T., & Wei-Hung, H. (2023). Design and Evaluation of Wireless Power Monitoring IoT System for AC Appliances. *Energies, 16*(1), 163. https://doi.org/10.3390/en16010163
16. Joseph, A. (2023). The impact of energy meter placement on consumption awareness and optimization. Energy Management Journal, 45(3), 245-258.
17. Kim, W. H., Park, S. H., & Yoon, J. S. (2011). Energy management system based on a wireless sensor network. IEEE Transactions on Consumer Electronics, 57(1), 10-18.
18. Kotwal, A., Joshte, N., Karwade, B., Wagh, R., & Yadav, N. (2022). IoT-Based Smart Energy Meter: Energy Theft System. International Research Journal of Innovations in Engineering and Technology, 6(3), 157-162. https://doi.org/10.47001/IRJIET/2022.603022
19. Maheepala, S., Fernando, T., & Dias, W. (2018). Real-time electricity consumption monitoring system. IEEE Transactions on Smart Grid, 9(3), 1907-1914.
20. Munoz, O., Ruelas, A., Rosales, P., Acuña, A., Suastegui, A., & Lara, F. (2022). Design and Development of an IoT Smart Meter with Load Control for Home Energy Management Systems. Sensors, 22(19), Article 19. https://doi.org/10.3390/s22197536
21. Musse, M. A., Qays, M. O., Abu-Siada, A., Muyeen, S. M., & Hossain, M. L. (2021). Cost-Effective Design of IoT-Based Smart Household Distribution System. *Designs, 5*(3), 55. https://doi.org/10.3390/designs5030055
22. Naret, S. 1, Annop, T. 1, Supharoek, S. 1, & Thanadon, J. 1 1 I. C. of D. I. (2022). *Visualizing electrical energy consumption with virtual augmented technology and the internet of things*. 012010. https://doi.org/10.1088/1755-1315/1094/1/012010
23. Noor, Z. T., & Badran, A. I. (2023/03//). IoT Based Energy Monitoring and Control System. *International Research Journal of Innovations in Engineering and Technology, 7*(3), 72-77. https://doi.org/10.47001/IRJIET/2023.703009
24. Oluwaseun, I. A., Adejumobi, I. A., Simeon, M., & Azeez, A. A. (2022/12//). Development of a web-based single-phase load monitoring and auditing system. *International Journal of Electrical and Computer Engineering, 12*(6), 6785-6795. https://doi.org/10.11591/ijece.v12i6.pp6785-6795
25. PZEM-004T v3 Module | Arduino & NodeMCU Code, Circuit, Pinout and Library. Innovatorsguru.com, 28 June 2019. https://www.innovatorsguru.com/pzem-004t-v3/
26. Rupesh, M., & N, A. S. (2021/07//). Design of IoT Based Smart Energy Meter for Home Appliances. *Journal of Physics: Conference Series, 1964*(5)https://doi.org/10.1088/1742-6596/1964/5/052001
27. Sámano-Ortega, V., Arzate-Rivas, O., Martínez-Nolasco, J., Aguilera-Álvarez, J., Martínez-Nolasco, C., & Santoyo-Mora, M. (2024). Multipurpose Modular Wireless Sensor for Remote Monitoring and IoT Applications. *Sensors, 24*(4), 1277. https://doi.org/10.3390/s24041277

28. Sathishkumar, V. E., Lee, M., Lim, J., Kim, Y., Shin, C., Park, J., & Cho, Y. (2020). An Energy Consumption Prediction Model for Smart Factory Using Data Mining Algorithms. KIPS Transactions on Software and Data Engineering, 9(5), 153–160. https://doi.org/10.3745/KTSDE.2020.9.5.153
29. Scherz, P., Monk, S., & McGraw-Hill Education. (2016). Practical Electronics for Inventors (4th ed.). McGraw-Hill Education.
30. Statista Research Department. (2023, September 19). Global electricity consumption 1980-2022. Retrieved from https://www.statista.com/statistics/280704/world-power-consumption/#:~:text=The%20world's%20electricity%20consumption%20has,reached%20almost%20eight%20billion%20people.
31. Trotta, G. (2020). Electricity awareness and consumer demand for information. International Journal of Consumer Studies, 45. https://doi.org/10.1111/ijcs.12603
32. Trotta, G. (2021). Electricity awareness and consumer demand for information. International Journal of Consumer Studies, 45(1), 65–79. https://doi.org/10.1111/ijcs.12603
33. Uswitch. (2017). Addressing billing errors in the energy sector: The importance of digital technology. Journal of Energy Management, 45(2), 123-134. https://www.uswitch.com/energy-saving/guides/energy-consumption-patterns-and-cost-saving-strategies
34. Varela-Aldás, J., Silva, S., & Palacios-Navarro, G. (2022). IoT-Based Alternating Current Electrical Parameters Monitoring System. Energies, 15(18), 6637.