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Energy Management of a Low-Cost Power Meter using ESP8266 and PZEM-016

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Abstract: The burgeoning significance of the Internet of Things (IoT) lies in its capacity to configure interconnected environments and facilitate human-object interactions through collaborative services. This study proposes an efficient energy management approach leveraging cost-effective technologies like the ESP8266 microcontroller and the PZEM-016 Modbus RTU energy monitoring module. Tailored towards wireless connectivity, this solution is purposefully crafted for diverse sectors operating within constrained budgets, obviating the need for intricate infrastructure. A systematic deployment of the forward engineering research methodology is undertaken to discern the requisites and hurdles inherent in energy management. The amalgamation of ESP8266, PZEM-016, and the MQTT protocol, with RabbitMQ serving as a message broker, forges an efficacious framework for inter-device information exchange. The solution's instantiation entails the interconnection of power meter devices using the MQTT protocol, transmitting data in JSON format. The PZEM-016 sensor constitutes the crux, adeptly measuring voltage, current, frequency, and power with precision. Furthermore, the solution encompasses a prototype Smart Meter fortified with Wi-Fi connectivity to the internet, thus extending network coverage ubiquitously. Economic scrutiny reveals that the resultant power meter device costs less than 100 USD, competitively positioning it against analogous market offerings. This economically optimized design advocates for widespread adoption across multifarious sectors constrained by budgetary limitations, assuaging the complexities inherent in energy management through a trifecta of efficiency, reliability, and affordability.

Keywords: Smart Meter, Internet of Things, ESP8266, Low cost, Energy Management.

1. Preliminary

The Internet of Things (IoT) has evolved into an increasingly pivotal concept in shaping interconnected environments, wherein human-object interactions are facilitated through shared public services. This concept involves smart devices capable of monitoring and interacting with their surroundings, presenting significant opportunities to enhance human interaction with the environment. In this context, Smart Cities have garnered central attention as a strategic manifestation of modern society, where Information and Communication Technology (ICT) services are propelled by real-time data, actively engaging citizens as integral components of the urban landscape (Joshi et al., 2017).

One of the primary aspects of a Smart City is the utilization of Smart Things, particularly IoT devices, which can provide innovative services and applications across various sectors. Key facilities provided by the smart city include Smart Buildings, Smart Health, and Smart Grids. (Iqbal & Manzoor, 2020)(Khajenasiri et al., 2017) As depicted in Figure 1, the focus within the Smart City sector aims to enhance efficiency, security, and comfort.

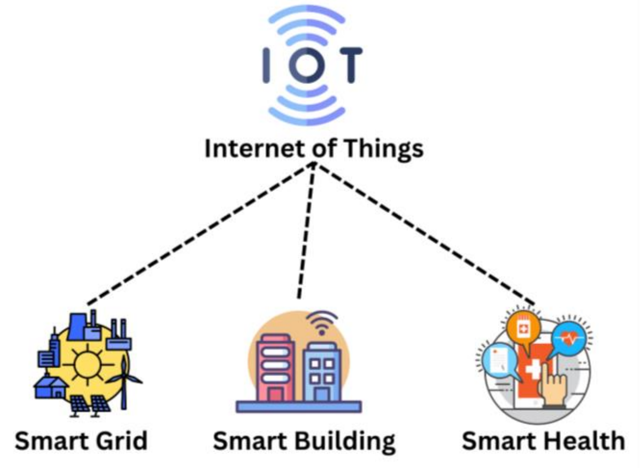

Figure 1. The main services of a smart city (Abate et al., 2019)

However, the development of this technology faces challenges, particularly in the context of increasingly complex energy management. The rising energy consumption across various sectors necessitates innovative approaches to more adaptive and intelligent energy management. Unforeseen energy costs and pressures to reduce operational expenses underscore the importance of cost-effective yet reliable solutions in energy monitoring and control (Morello et al., 2017).

In facing the complexity of energy management, this research proposes an innovative solution utilizing affordable technologies such as the ESP8266 microcontroller and the PZEM-016 Modbus RTU sensor module. This solution is anticipated to be adopted across various sectors, including those with limited budgets, as a proactive step in responding to the need for efficient energy management (Abdel-Basset et al., 2021). With a focus on wireless connectivity using wifi connection to link to the internet embedded in the power meter, this research proposes a solution that can be easily implemented in various environments without requiring complex infrastructure. Wireless connectivity is particularly relevant, especially in the era of the Internet of Things (IoT), where the ESP8266 microcontroller opens up opportunities for integration supporting the concepts of smart building, smart home, and smart industry. (Jeffin et al., 2020)(Mahmud et al., 2019).

Nevertheless, in the context of monitoring 3-phase electrical power, there still exists a primary challenge related to the availability of economical solutions while ensuring adequate accuracy in energy monitoring. Solutions available in the market often come with high costs, prompting this research to strive towards providing an economical yet reliable solution utilizing ESP8266 and PZEM-016 (Cahyono, 2021).

The importance of wireless connectivity is acknowledged as a key factor in ensuring effective monitoring and control (Kumar et al., 2021)(Sayed et al., 2019), especially in environments involving 3-phase electrical systems, this solution not only provides flexibility but also enables users to access and manage energy data remotely.

Taking into consideration the aspect of a compact design, this research is expected to meet the diverse needs of users across various sectors, ranging from industrial to household settings. The easily integrated solution is anticipated to make a positive contribution to effective energy monitoring and control. Thus, this research is directed towards providing an innovative and affordable solution for monitoring and controlling 3-phase electrical energy.

2. Research Methods

In addressing the issues of energy management and monitoring 3-phase electrical power with a low-cost approach, the applied research method is forward engineering. This approach is conducted systematically, encompassing planning, design, development, and implementation tailored to the needs and challenges within the context of escalating energy consumption and the complexity of energy management.

The proposed solution concept is based on an economical approach, utilizing the ESP8266 microcontroller and the PZEM-016 energy monitoring module. Forward engineering enables the development of solutions that can be adopted across various sectors, considering budget constraints without compromising the reliability of energy monitoring.

The implementation of the solution emphasizes economical wireless connectivity using the ESP8266 microcontroller, enabling remote access and management of energy data. The monitoring of 3-phase electrical power is conducted utilizing the PZEM-016 energy monitoring module, which provides an economical yet accurate solution.

Solution evaluation is conducted to ensure effectiveness and reliability, affirming that this low-cost approach can provide an innovative and economical solution in addressing the complexity of energy management and monitoring 3-phase electrical power.

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3. Results and Discussion

3.1. The Internet of Things (IoT) Network Infrastructure

The Internet of Things (IoT) network infrastructure refers to the foundational framework that enables seamless connectivity and communication among various IoT devices. This infrastructure forms the basis for a connected ecosystem of smart devices that exchange data and information. Several components constitute the IoT network infrastructure, as illustrated in Figure 2.

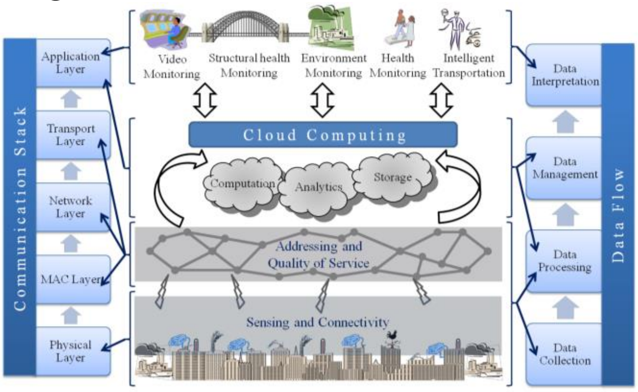

Figure 2. The Internet of Things (IoT) network infrastructure (Jin et al., 2014)

The physical layer in the Internet of Things (IoT) network infrastructure refers to the hardware and physical technologies such as sensors, microcontroller units (MCUs), and other supporting hardware that enable data transmission. This layer serves as the foundation for transferring physical signals between IoT devices. Furthermore, the Media Access Control (MAC) layer is responsible for controlling access to the transmission media, regulating how IoT devices share communication channels by involving specific protocols and rules. The network layer manages routing and addressing settings, enabling IoT devices to communicate in a complex network through protocols and technologies that support determining optimal routes and address management. The transport layer provides mechanisms for data transfer between IoT devices and involves transport protocols such as TCP or UDP to ensure reliable data delivery. (Al-Masri et al., 2020). The application layer, as the top layer, provides an interface for users or specific applications where IoT applications operate and exchange data specific to purposes such as energy monitoring or smart home device management.

By understanding these layers, the IoT network infrastructure can be designed and implemented effectively to support optimal connectivity and data exchange among IoT devices. This infrastructure forms the basis for a connected ecosystem of smart devices that exchange data and information. The components used in this research, which can constitute the IoT network infrastructure, are as follows:

A. PZEM-016 sensor

One of the key components in the IoT network infrastructure for reading voltage, current, frequency, and power values is the PZEM sensor. This sensor plays a crucial role in accurately measuring electrical parameters from the monitored power source. With its sophisticated capabilities, the PZEM sensor can provide precise information regarding the electrical conditions at a load. By installing PZEM sensors on the main lines, this infrastructure can acquire the necessary data for monitoring and measurement purposes. The PZEM sensor operates by utilizing technology capable of reading voltage, current, frequency, and power values in a specific environment. The information obtained from the PZEM sensor serves as the foundation for the infrastructure to manage and analyze electrical data, unlocking the potential for effective and efficient energy monitoring. Thus, the PZEM sensor becomes the core that establishes the groundwork for optimizing energy management and measurement at a higher level through innovative IoT network infrastructure.

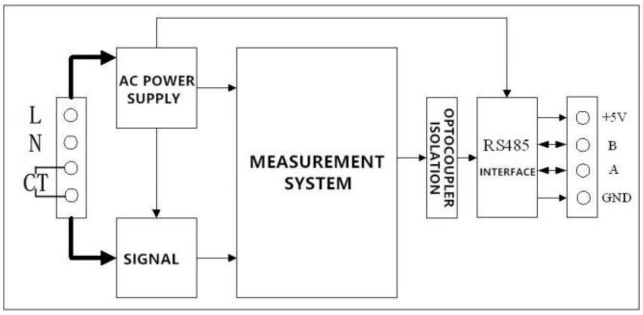

Figure 3. PZEM-016 Sensor Scheme

In the PZEM-016 scheme, as depicted in Figure 3, LN represents the AC input voltage identified as the main input voltage, serving as the parameter for voltage values. Additionally, there is a Current Transformer (CT) acting as a sensor to read the parameter values of the current in the system. The measurement system component is present to process the data and information obtained from the voltage and current, forming a robust framework for further analysis.

To ensure proper safety and isolation, this scheme also incorporates optocoupler isolation features, which play a role in separating the measurement system from the main voltage source. This step is critical in ensuring the accuracy and reliability of measurements. Finally, the RS485 interface is utilized to transmit measurement data to the ESP8266 module, as illustrated in Figure 4. This module, with its wireless connectivity capabilities, serves as a key element in connecting the PZEM-016 scheme to a broader IoT network.

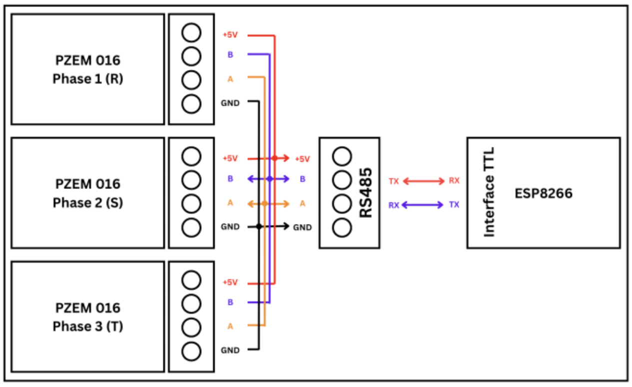

Figure 4. Block diagram of the ESP8266 and PZEM-016 modules

By integrating these various components, the PZEM-016 scheme forms a holistic system for energy monitoring and measurement (Stefanov, G., Kukuseva Paneva, M., & Stefanova, 2023). Each element is carefully arranged to ensure accurate data transfer, effective isolation, and seamless integration with ESP8266 technology. Thus, this scheme reflects a meticulous approach in implementing technology to optimize energy monitoring in a given environment.

B. Connectivity Technology

The connectivity technology employed in this research is MQTT (Message Queuing Telemetry Transport) (Nguyen Quoc Uy, 2019) facilitated through RabbitMQ (Yusuf Aytaş, 2016). MQTT is a communication protocol designed for low-latency message delivery and efficient energy consumption between devices. In the research context, RabbitMQ serves as a message broker supporting the implementation of the MQTT protocol.

The MQTT protocol enables devices to communicate with each other in a lightweight and reliable manner. The use of RabbitMQ as a message broker allows the system to organize, receive, and transmit messages between devices systematically, thereby enhancing the efficiency and reliability of communication.

By implementing MQTT through RabbitMQ, this research leverages reliable connectivity technology to support efficient and real-time information exchange among devices. This solution provides a robust and dependable communication framework to meet research needs by optimizing communication efficiency and speed.

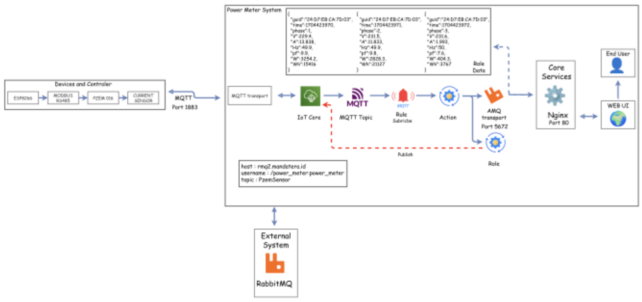

Figure 5. Connectivity Architecture

Furthermore, in Figure 5, the connectivity of the power meter device is implemented using the MQTT protocol. (Al-Masri et al., 2020)(Yoshino et al., 2021), where the transmitted data is in JSON format (Jeffin et al., 2020). In this process, the values obtained from the PZEM device, values such as voltage, current, power, and other parameters obtained from the PZEM device are collected and organized in JSON format before being transmitted via the MQTT pathway (Muhammad Syafri Syamsudin, Lala Septem Riza, 2023). The format can be seen in Table 1.

Table 1. Sensor data transmission format

Data	Format
Power Meter	{"guid":"xxx","time":xxx, "phase":xxx,"V":xxx,"A":xxx,"Hz":xxx, "pf":xxx,"W":xxx,"Wh":xxx}

The implementation of MQTT protocol facilitates the exchange of data between devices with high speed and efficiency. By incorporating connectivity using MQTT, the system can effectively gather data from PZEM devices and package it in a structured JSON format. This data can then be easily accessed, processed, and seamlessly integrated into the system in real-time.

Therefore, the use of MQTT protocol to integrate connectivity for power meter devices paves the way for efficient and organized information exchange. This approach not only facilitates fast and reliable data delivery but also enables the system to easily manage and analyze the values collected from PZEM devices.

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3.2. Smart Meter Prototype

The smart meter prototype represents a developmental phase of the smart meter that integrates its components with the aim of achieving interconnected connectivity and producing a power meter tailored to specific needs. An illustration of the hardware structure of the power meter can be seen in Figure 6.

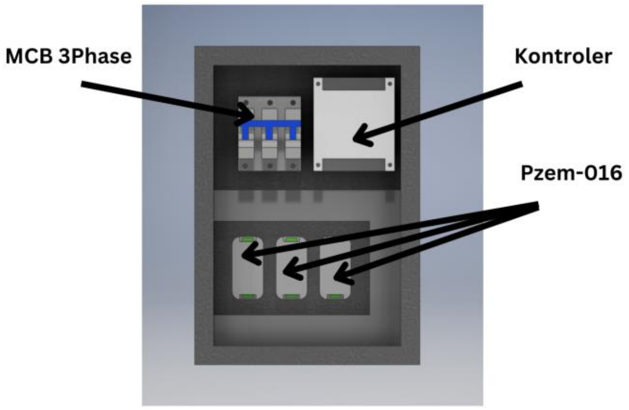

Figure 6. Visual representation of power meter

In Figure 6, there is a visual representation prior to the assembly process, providing a visual overview of the stages before these components are assembled into a cohesive unit (Sayed et al., 2019). Figure 6 plays a crucial role in mapping the design and placement of each component, ensuring the integrity and optimal functionality of the smart meter prototype to be developed.

Next, it is followed by the compilation of the wiring diagram for the power meter. This diagram details the layout and connections of each cable and component involved in the power meter circuit, as illustrated in Figure 7. Creating the wiring diagram is a step to ensure that every electrical connection adheres to the specifications and designs planned beforehand. By paying attention to the details in the wiring diagram, it is expected to create an efficient, reliable, and electrically safe cable configuration. This process is an integral part of the smart meter prototype development, serving as the foundation for accurate and high-performance implementation in the subsequent phases.

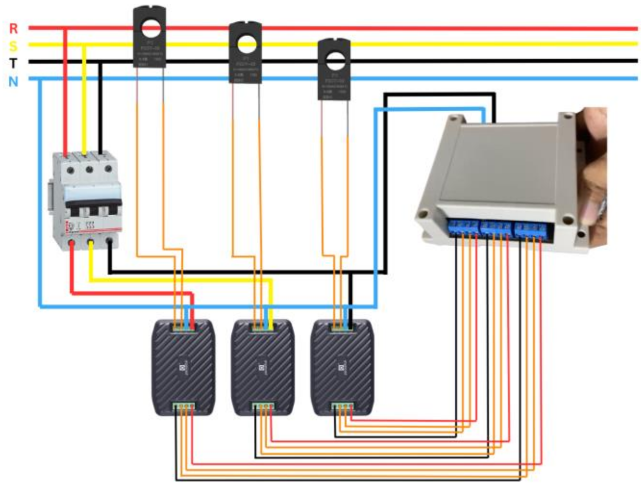

Figure 7. Wiring diagram

After going through the planning stages manifested in visual forms and the compilation of the wiring diagram, the next step is to carry out the implementation of the power meter. The power meter is installed in the main electrical panel of a building with a 3-phase system. This implementation process is carried out carefully and in accordance with the previously planned specifications. Installing the power meter in the main panel aims to monitor and accurately measure electrical energy consumption in an environment involving a 3-phase electrical system. This implementation stage is crucial to ensure that the device operates according to requirements and can provide reliable data related to energy consumption in the building. This approach reflects the methodical principles in research and technology implementation, where early-stage planning and visualization serve as the foundation for executing structured and effective implementation steps.

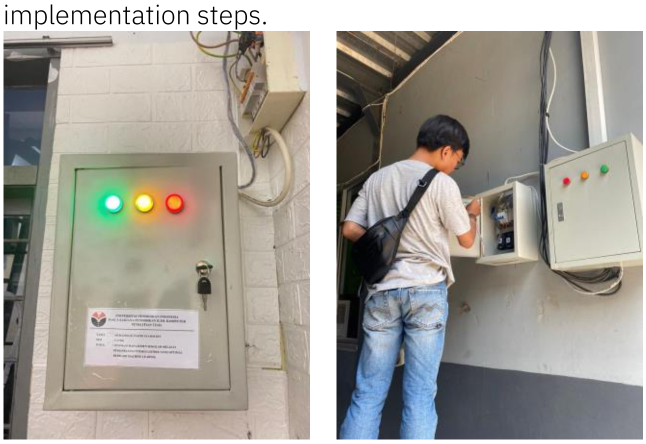

Figure 8. Power Meter Implementation

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3.3. Economic Analysis

Table 2 shows the detailed materials used to design the power meter device. Based on the listed materials in Table 2, the device is constructed at a cost of approximately IDR 1,188,000. Economic analysis of raw material costs indicates that the total cost for designing this power meter device is less than 100 USD. Because the device is made from economical raw materials, the total cost for this device will be competitive with commercially available devices/kits.

Table 2. List of Power Meter Materials

Materials	Qty	Price (Rp)	Price (USD)
ESP8266	1 Pcs	20.000	1.27
PZEM-016	3 Pcs	570.000	36.31
RS485	1 Pcs	8.000	0.51
PCB	1 Pcs	10.000	0.64
Conveter AC to DC	1 Pcs	65.000	4.14
Case	1 Pcs	65.000	4.14
Box Panel	1 Pcs	250.000	15.93
MCB 3 Phase	1 Pcs	125.000	7.96
Pilot Lamp	3 Pcs	15.000	0.96
Duct cable	1 Pcs	30.000	1.91
din rail mcb	1 Pcs	30.000	1.91

3.4. Performance Test

The transmitted data in JSON format, as illustrated in Figure 9, is afterward parsed by an intelligent management application. The results of this parsing process are then presented through the utilization of the PHP programming language, leveraging the Laravel framework.

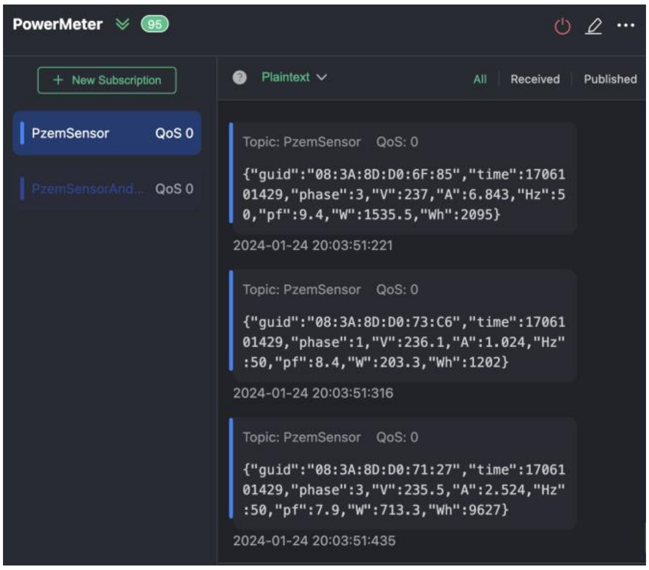

Figure 9. Power meter data

The process of data transmission and processing adheres to the fundamental principles of information management, where the received data in JSON format is dissected and interpreted by the developed management application. The results of this process are then materialized into easily understandable visualizations, leveraging the advantages of Laravel's features to design intuitive and responsive displays, as illustrated in Figure 10. The data structure sent is meticulously organized and processed to generate informative visualizations that can be effectively utilized.

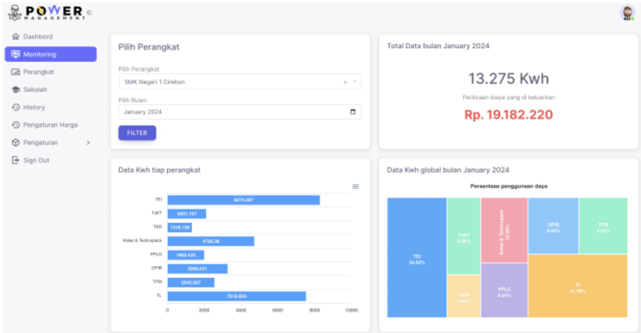

Figure 10. Power meter log visualization

Visualization presents key elements such as voltage, current, power, and energy consumption (Wh), providing a comprehensive understanding of the measured electrical performance and characteristics (Latif et al., 2017). Figure 11 visually presents detailed information about these variables. Involving clear visualization, users can easily monitor and analyze electrical data, supporting a better understanding of technical aspects and energy efficiency-related factors.

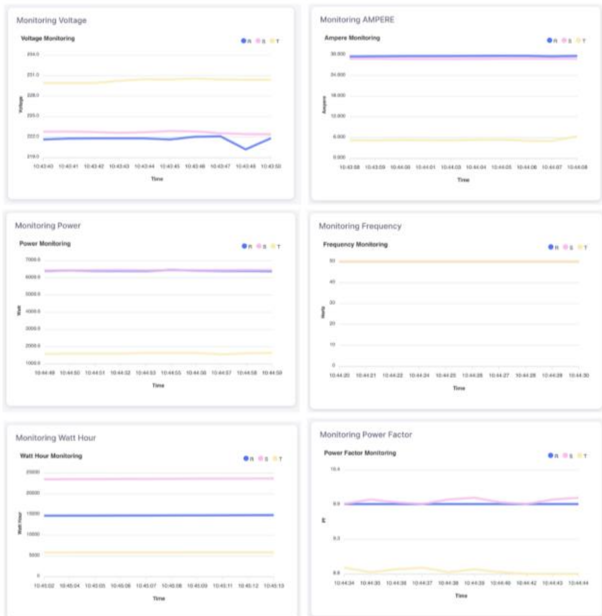

Figure 11. Power meter visualization

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4. Conclusion

This research integrates the Internet of Things (IoT) to build Smart Cities, particularly focusing on energy management. The proposed innovative solution revolves around the utilization of the ESP8266 microcontroller and the PZEM-016 sensor, introducing potential for efficient and affordable wireless connectivity. A Smart Meter prototype has been successfully implemented with information visualization on a 3-phase electrical panel, demonstrating the technology's readiness to monitor and manage energy consumption optimally. Economic analysis indicates cost advantages, with a cost of less than 100 USD, making it a competitive alternative in the market. With its compact design, high efficiency, and affordability, this solution has significant potential for use in various sectors, ranging from industries to households. Furthermore, implementing machine learning algorithms to analyze historical data and predict future energy consumption patterns could be a further research direction. This could lead to more proactive energy management strategies, helping optimize optimal resource allocation.

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6. Bibliography

Abate, F., Carratù, M., Liguori, C., & Paciello, V. (2019). A low cost smart power meter for IoT. *Measurement: Journal of the International Measurement Confederation*, *136*, 59–66. https://doi.org/10.1016/j.measurement.2018.12.069

Abdel-Basset, M., Hawash, H., Chakrabortty, R. K., & Ryan, M. (2021). Energy-Net: A Deep Learning Approach for Smart Energy Management in IoT-Based Smart Cities. *IEEE Internet of Things Journal*, *8*(15), 12422–12435. https://doi.org/10.1109/JIOT.2021.3063677

Al-Masri, E., Kalyanam, K. R., Batts, J., Kim, J., Singh, S., Vo, T., & Yan, C. (2020). Investigating Messaging Protocols for the Internet of Things (IoT). *IEEE Access*, *8*, 94880–94911. https://doi.org/10.1109/ACCESS.2020.2993363

Cahyono, M. R. A. (2021). Design Power Controller for Smart Grid System Based on Internet of Things Devices and Artificial Neural Network. *IoTaIS 2020 - Proceedings: 2020 IEEE International Conference on Internet of Things and Intelligence Systems*, 44–48. https://doi.org/10.1109/IoTaIS50849.2021.9359709

Iqbal, T., & Manzoor, S. (2020). *IoT based Renewable Energy Management and monitoring system for the First Passive House in Newfoundland*. http://research.library.mun.ca/id/eprint/14671

Jeffin, M. J., Madhu, G. M., Rao, A., Singh, G., & Vyjayanthi, C. (2020). Internet of Things Enabled Power Theft Detection and Smart Meter Monitoring System. *Proceedings of the 2020 IEEE International Conference on Communication and Signal Processing, ICCSP 2020*, 262–267. https://doi.org/10.1109/ICCSP48568.2020.9182144

Jin, J., Gubbi, J., Marusic, S., & Palaniswami, M. (2014). An information framework for creating a smart city through internet of things. *IEEE Internet of Things Journal*, *1*(2), 112–121. https://doi.org/10.1109/JIOT.2013.2296516

Joshi, S., Mohanty, S. P., & Kougianos, E. (2017). Everything You Wanted to Know about PUFs. *IEEE Potentials*, *36*(6), 38–46. https://doi.org/10.1109/MPOT.2015.2490261

Khajenasiri, I., Estebsari, A., Verhelst, M., & Gielen, G. (2017). A Review on Internet of Things Solutions for Intelligent Energy Control in Buildings for Smart City Applications. *Energy Procedia*, *111*(September 2016), 770–779. https://doi.org/10.1016/j.egypro.2017.03.239

Kumar, A., Sharma, S., Goyal, N., Singh, A., Cheng, X., & Singh, P. (2021). Secure and energy-efficient smart building architecture with emerging technology IoT. *Computer Communications*, *176*(January), 207–217. https://doi.org/10.1016/j.comcom.2021.06.003

Latif, S., Shabani, A., Esser, A., & Martkovich, A. (2017). Analytics of residential electrical energy profile. *Canadian Conference on Electrical and Computer Engineering, December 2006*, 3–6. https://doi.org/10.1109/CCECE.2017.7946771

Mahmud, S., Ahmed, S., & Shikder, K. (2019). A smart home automation and metering system using internet of things (IoT). *1st International Conference on Robotics, Electrical and Signal Processing Techniques, ICREST 2019*, 451–454. https://doi.org/10.1109/ICREST.2019.8644232

Morello, R., De Capua, C., Fulco, G., & Mukhopadhyay, S. C. (2017). A smart power meter to monitor energy flow in smart grids: The role of advanced sensing and iot in the electric grid of the future. *IEEE Sensors Journal*, *17*(23), 7828–7837. https://doi.org/10.1109/JSEN.2017.2760014

Muhammad Syafri Syamsudin, Lala Septem Riza, R. (2023). *Design and implementation of smart power meters with IoT as smart building monitoring*.

Nguyen Quoc Uy, V. H. N. (2019). A comparison of AMQP and MQTT protocols for Internet of Things. *Proceedings - 2019 6th NAFOSTED Conference on Information and Computer Science, NICS 2019*, 292–297.

Sayed, S., Hussain, T., Gastli, A., & Benammar, M. (2019). Design and realization of an open-source and modular smart meter. *Energy Science and Engineering*, *7*(4), 1405–1422. https://doi.org/10.1002/ese3.361

Stefanov, G., Kukuseva Paneva, M., & Stefanova, S. (2023). *3-PHASE SMART POWER METER IMPLEMENTED IN AN RF NETWORK*. *VI*(August).

Yoshino, D., Watanobe, Y., & Naruse, K. (2021). A Highly Reliable Communication System for Internet of Robotic Things and Implementation in RT-Middleware with AMQP Communication Interfaces. *IEEE Access*, *9*, 167229–167241. https://doi.org/10.1109/ACCESS.2021.3136855

Yusuf Aytaş, D. N. E. A. (2016). *Mastering RabbitMQ*.