B3Ø: Blynk-interfaced Three-Phase Smart Energy Monitoring System

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Abstract – *This research is focused on the design and evaluation of an installed three-phase smart energy monitoring system with Blynk integration at a state university in the province of Pampanga, Philippines. The main objective of this project was to design a low-cost, precise, and user-friendly solution for the real-time monitoring of electrical parameters in a 230 V three-phase delta transformer bank power distribution system. The system is capable of monitoring voltage, current, power, power factor, and total energy consumption. The prototype's initial evaluation was done at the distribution utility of Pampanga using a power quality analyzer, and then a field test at the state university, where its performance was compared with the installed utility meter. The test results from different test cases and scenarios indicated that the system possessed a high measurement accuracy, varying within the ANSI C12.1-2008 ±2% threshold. It possessed a low energy measurement error of 0.08% over the testing period. In addition, the system also detected high phase loading imbalances, thus proving its ability to diagnose power distribution inefficiency. Integration of Blynk provides remote monitoring and data visualization, further enhancing its potential in campus energy management. The system was accurate, reliable, and scalable demonstrating itself as a feasible solution for institutional energy monitoring and potential integration into smart grid infrastructures.*

Keywords*: energy monitoring, parameters, power factor, Pzem-004t, three phase*

Article History
Received 20 June 2025
Received in revised form 31 July 2025
Accepted March 15 September 2025

I. Introduction

Energy management is the strategic process of monitoring, controlling, and optimizing energy consumption to regulate electrical parameters such as voltage, current, power, and power factor. It enhances an organization's energy usage by identifying inefficiencies, conserving energy, and minimizing power losses and operational expenses. Prior monitoring and data interpretation are essential to take corrective actions, such as scheduling routine maintenance, transitioning to more efficient equipment, and improving power usage without sacrificing performance. Global electricity utilization in 2024 increased by 4.3%, a 1,100 TWh increase from the already high 25,581 TWh electrical consumption [1]. This number is projected to grow by 6% in the span of 2025 to 2027 [2].

The Philippines alone has had a significant increase in energy consumption. In 2012, the nation consumed 72.92 TWh of energy and had risen to 118 TWh by 2023 [3]. An increase of 45.08 TWh over 11 years. The growing energy demands require the importance of the design of power systems used by organizations and industries. The three-phase AC system utilized in large operations such as factories, institutional compounds, and other high-load buildings is used due to its efficiency in delivering power to large loads [4]. However, the complexity of this wiring system requires close monitoring and servicing to avoid issues such as unbalanced loads, overloading, and equipment damage, all of which can cause costly repairs and reduced operational performance [5]. Moreover, in the effective management of this system, power factor is a crucial parameter for energy conservation. The lack of maintenance can lead to overloading of the three-phase system, damaging equipment and making repair costly due to the poor handling of inductive and capacitive loads, leading to reduced efficiency and useful life of equipment [6]. It is necessary to monitor and rectify power factor discrepancies to sustain system efficiency and extend the lifespan of electrical equipment. Energy monitoring can enable the recording of data to observe unbalance, overloading, and poor power factor performance.

As mentioned earlier, one such contributor to this high energy consumption is institutions. Thus, institutions worldwide are shifting towards energy efficient systems that minimize costs associated with operation, enhance sustainability, and inspire innovation. A state university institution in the province of Pampanga, Philippines relies on a three-phase system for its electrical infrastructure and huge consumption of energy. Despite that, the said university does not have the necessary equipment and systems for monitoring critical electrical parameters. The absence of data by the university's energy facility restricts its ability to detect inefficiencies, energy-saving initiatives, and running advanced analyses, such as voltage and current unbalance, and power factor correction. Moreover, the university cannot properly project each facility's consumption patterns. To address this issue, a three-phase smart energy monitoring system that will record parameters such as voltage, current, power, power factor, and energy within each phase of the system was designed, developed, and implemented in one of the university's facilities.

Specifically, the objectives are to:

1. Design and build a prototype of a three-phase smart energy monitoring system utilizing a backup battery for continuous operation.
2. Enable the system to provide real-time data for energy consumption monitoring, and the identification of power imbalances or inefficiencies.
3. Provide baseline data for future research in energy management and monitoring systems within three-phase electrical infrastructures.

The potential of energy monitoring as key in controlling energy management and enforcing habits of reducing energy waste is backed by Nilsson, Wester, Lazarevic, and Brandt [7] about smart homes adopting home energy management systems (HEMS) that also provide energy feedback and smart features through an in-home display. Greenhouse gas emissions are also another impact of the lack or improper implementation of energy monitoring. Behavioral change is one of the driving forces for the planet towards decarbonization [8] as monitoring systems are only a guide for energy policies. While HEMS do indeed have in-home displays, remote monitoring ensures energy security and safety regardless of location. Attempts have been made at single-phase smart monitoring systems that ensure its feasibility using microcontroller chips such as the ESP8266 [9]-[12]. One such attempt applied a solar cell and a battery for its continuous operation in a residential dwelling [13]. However, load conditions were small-scale, and there was a lack of data towards power factor.

A few attempts have also been made towards creating a three-phase monitoring system concerning those of motor loads [14]-[16]. While the system performed well on low-power electric motor loads, such studies have not included extensive testing in accordance with international standards. Additionally, despite the existence of such attempts, there is an absence of higher load condition testing, long-term data logging, and power factor readings to make informed decisions and implement sustainable energy management policies. This study's novelty is to address this lack of exploration, evaluating it towards the international standards for meters, and installing it under one of the university's three-phase transformer banks, to observe its performance in a practical application.

II. Methods

The idea of monitoring and management for energy efficiency is the base idea of the study and employs an experimental research approach. This three-phase smart energy monitoring system collects data on electrical quantities, specifically voltage, current, power, power factor, and energy consumption. By the analysis of the data gathered, it may contribute to finding inefficiencies and improve energy usage in the future. The creation of the prototype was processed in an ordered framework as shown in Fig. 1.

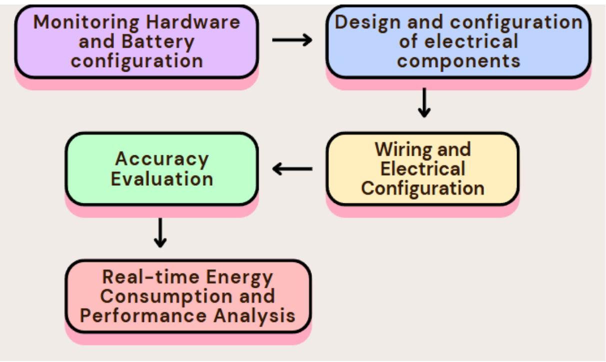

Fig. 1. Methodological Framework

A. *Electrical Cooperative of the Study*

This research makes use of the electrical parameters of its distribution utility service located in Guagua, Pampanga, Philippines. It uses a nominal voltage of 230 V, connected line-to-line in a three-phase delta transformer bank for its large capacity utilization, with a frequency of 60 Hz [17].

B. *System Design*

The system assembly of the proposed energy monitoring system aligns with the predetermined components as shown in Fig. 2, ensuring adherence to electrical safety considerations.

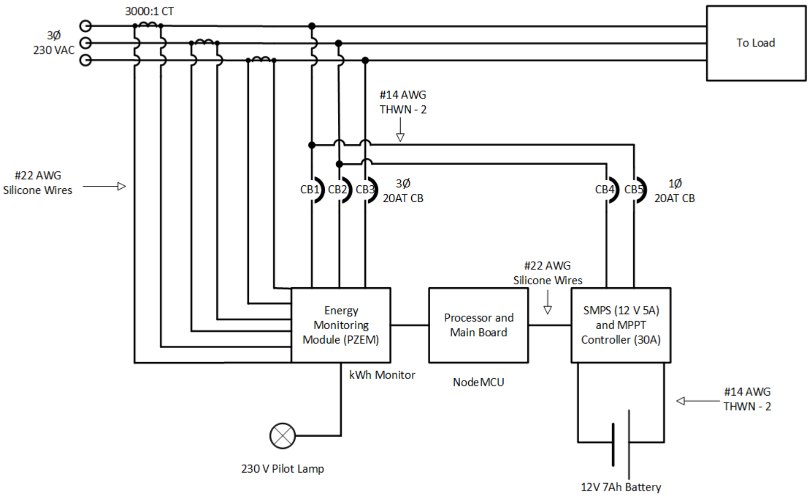

Fig. 2. Three-phase smart energy monitoring system

The project aimed to track one of the university's 37.5 kVA three-phase transformer banks with a peak line current of 282.4 A. To record electrical parameters accurately on the three phases, three PZEM-004T V3.0 AC [18] communication modules were used each to track voltage, current, power, power factor, energy consumption, and frequency per phase. Each of them was used in conjunction with a 300 A split-core current transformer (CT) of 3000:1 ratio, complying with IEC 60044-8 [19]. The CTs were interfaced to the PZEM modules with 0.3 mm^2 (#22 AWG) silicone wire with a standard lead length of 2.4 meters extendable to 30 meters using standardized #18-#22 AWG wire cables carried in conduits [20].

Data transmission was done via three ESP8266 microcontrollers. One ESP8266 board read measurements from all three PZEM-004T modules and computed the total three phase voltage, current, total power, power factor, and energy consumption. The other two ESP8266 boards were used for data transmission: one board was used for Blynk, where values were read every 15 minutes, and the other was used to upload raw measurements to Google Drive. The ESP8266 sends data via Software Serial using pin 0 for RX connections and pin 2 for TX connections [11]. Blynk provided a mobile accessible, customizable dashboard for real-time monitoring, while Google Drive stored daily measurement sheets in year and month folders [21]-[26].

Since the energy module is capable of reading only the power of each phase in the three-phase system, the total power can be computed using (1) [27]:

$$P_T(W) = P_A(W) + P_B(W) + P_C(W) \qquad (1)$$

Where

P_T = total real power in Watts
P_A = phase A real power in Watts
P_B = phase B real power in Watts
P_C = phase C real power in Watts

The total energy consumed (kWh) by the three-phase system can be acquired by summing each energy consumed per phase. Since the total power is also just the summation of each power per phase, the total energy can be computed using (2):

$$Total\ Energy(kWh) = \frac{P_T(W)\times Time(hrs)}{1000} \qquad (2)$$

When both the real power and phase angle are acquired, the apparent power per phase can be computed using (3) and (4), which can then be used to compute the total power factor of the system.

$$Q(VAr) = P(W) \times tan(cos^{-1}(pf)) \qquad (3)$$

$$S(VA) = \sqrt{P(W)^2 + Q(VAr)^2} \qquad (4)$$

Where

Q = reactive power in Volt-Ampere-reactive
P = real power in Watts
pf = power factor
S = apparent power in Volt-Ampere

Adding all the real and reactive power gives the total apparent power that the system is consuming using (5) and (6).

$$Q_T(VAr) = Q_A(VAr) + Q_B(VAr) + Q_C(VAr) \qquad (5)$$

$$S_T(VA) = \sqrt{(P_T)^2 + (Q_T)^2} \qquad (6)$$

Where

Q_T = total reactive power in Volt-Ampere-reactive
Q_A = phase A reactive power in Volt-Ampere-reactive
Q_B = phase B reactive power in Volt-Ampere-reactive
Q_C = phase C reactive power in Volt-Ampere-reactive
S_T = total apparent power in Volt-Ampere

Power calculations will be performed using the theory of apparent and real power to get the total power factor using (7):

$$Total\ Power\ Factor(pf_T) = \frac{P_T(W)}{S_T(VA)} \qquad (7)$$

C. Battery Selection

To provide a backup power system to ensure continuous operation of the smart monitoring system, a backup power supply was provided. A 12 V, 30 A Maximum Power Point Tracking (MPPT) solar charge controller was selected to power the monitoring devices and simultaneously charge a lead-acid battery. Battery sizing was determined using (8) considering a system operational voltage of 5 V and continuous operation for 24 hours. Battery efficiency was outlined to be 0.85, and the depth of discharge (DOD) was set to 0.5, as indicated for lead-acid batteries [28]. System losses were considered to be 0.8. Installation utilized #14 THWN-2 wire for all of the power connections as per NEC 310-16 standards [29]. The battery was sized to sustain a minimum of one full day of outage, thus allowing the system to record the restoration of electricity, inrush currents, and outage duration. The system was energized through the 12 V, 30 A load terminal of the solar charge controller.

$$DC(Wh) = \Sigma Qty \times P(W) \times Time(hrs) \qquad (8)$$

Where

DC = daily consumption in Watt-hour

The determination of battery capacity for a 1-day span of autonomy is outlined in [30] as (9).

$$Battery(Ah) = \frac{DC(Wh) \times (Days\ of\ Autonomy)}{\eta \times DOD \times Nominal\ Voltage(V)} \qquad (9)$$

Where

DOD = depth-of-discharge
η = efficiency

D. Wiring and Electrical Integration

For electrical safety and compliance, the circuit was developed based on the requirement that conductor wires should have an ampacity of at least 125% of the full-load motor current. While the three-phase smart energy monitoring system only supplies 0.1 A, a trip-rated three-phase miniature circuit breaker (MCB) rated 20 A was installed as a safety measure. Wiring utilized 2.0 mm² or # 14 AWG THWN-2 copper wire, as per the Philippine Electrical Code 2017, Sections 2.40.1.6(A) and 3.10.2.6(B)(16) [31]. Power was supplied through the switch-mode power supply (SMPS) with further protection using a single-phase MCB 20 A circuit breaker, complying with IEC 61204-7:2016 standards [32]. Output terminals, which transmit only 0.1 A, also utilized #14 THWN-2 copper wire, as per NEC 310-16 standards [29].

For physical protection, the system was placed in a 300 × 400 × 200 mm metal enclosure that has been rated NEMA 3R and IP24. This enclosure effectively shields the internal components from accidental shock, rain, snow, and dust, and has drainage and lock functions for increased security [33], [34]. Three 230 V green indication lights were installed on the front panel of the enclosure using #14 THWN-2 wire to indicate that power is available for operation; conversely, their absence implies a line power failure or outage. The arrangement of components is illustrated in Fig. 4, illustrating where all the components are placed, ensuring proper working order and utilizing the space of the enclosure optimally. Table I describes each component’s function and role for the monitoring system.

E. System Installation

The three-phase smart energy monitoring equipment was mounted at the university supervised by its electrical distribution service provider. Following Article 11 of the Magna Carta for Residential Consumers [35], which requires meters to be installed between 1.52 and 3 meters from the ground, the monitoring device was installed on the utility pole below the transformer bank at 3.0 meters. The installation was for optimal signal strength and facilitated easy comparison with the mounted utility meter. Fig. 3 illustrates the position of the monitoring system, its height, its placement next to the utility meter, and where each current transformer is installed. The monitoring system and its current transformers are connected in the load side of the service as shown where the wires are located after the current transformer enclosure of the utility meter. Lastly, a ground wire is tapped to the ground wire of the utility meter to ensure safety of and towards the system.

Electrical integration entailed tapping three voltage wires on the load side of the transformer bank using 2.0 mm² THWN-2 copper conductors. The current was measured using three 300 A split-core current transformers (CTs), which were mounted on each of the three-phase main service lines and wired with 22 AWG silicone wire. The feeder lines and corresponding wiring were routed within a 20 mm diameter rigid steel conduit (RSC) for safety purposes and for organizational effectiveness in the system, establishing a good and secure setup.

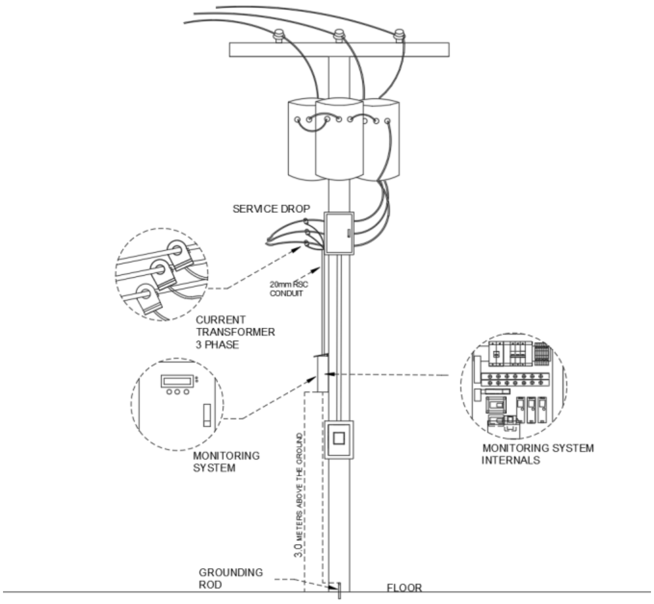

Fig. 3. Front elevation of the system mounting and installation

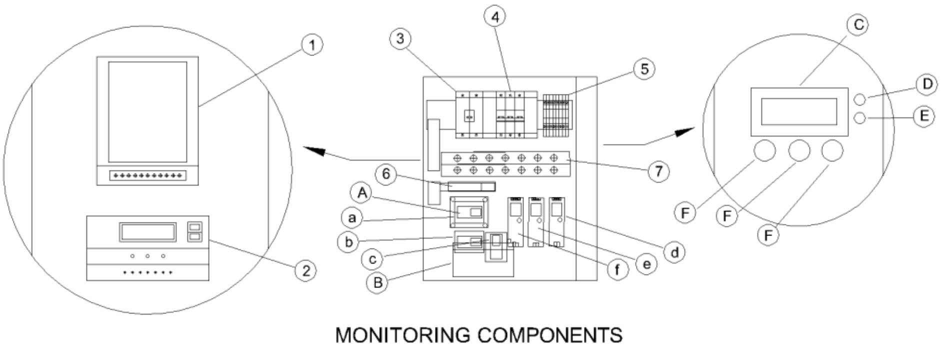

Fig. 4. View of monitoring components

TABLE I
COMPONENTS, FUNCTIONS, AND ROLES AS SHOWN IN FIG. 4

Key	Component	Function & Role
1	Switched-Mode Power Supply (SMPS)	Converts 12 V DC from 220 V AC to supply to the MPPT
2	Maximum Power Point Tracking (MPPT) Controller	Supplies 12 V DC to charge the battery and supply the microcontrollers and sensor modules
3	Single-Phase Circuit Breaker	Trips from overcurrent of 20 A to protect the SMPS
4	Three-Phase Circuit Breaker	Trips from overcurrent of 20 A to protect the sensor modules
5	Terminal Block for Current Transformer	AC current distribution to safely connect and disconnect the current transformers
6	Broadband	Wireless connectivity to receive messages in Blynk and upload data in Google Drive
7	Terminal Block	AC power distribution to safely connect each component in the 230 V lines
A	Micro SD Card Module	Platform for Micro SD Card to connect to microcontroller and log data
B	12 V 7 Ah Battery	Supplies power to the prototype when a power outage happens in the grid
C	20x4 LCD Screen	Displays the most recent data read in the sensor modules
D	Switch Page Button	Push button to switch the pages of the LCD screen
E	Reset Button	Push button to reset the prototype when malfunctioning
F	220 V Green Indicator Lights	Visual indicator for power or power outage

a	ESP8266-1	Responsible for reading each sensor module's data, exporting it to the other microcontrollers, and storing it to the SD Card
b	ESP8266-2	Responsible for reading the exported data to be sent through Blynk
c	ESP8266-3	Responsible for reading the exported data to be sent through Google Drive
d	PZEM-004T-1	Measures electrical parameters in phase AB
e	PZEM-004T-2	Measures electrical parameters in phase BC
f	PZEM-004T-3	Measures electrical parameters in phase CA

F. Evaluation

To determine the performance of the smart energy monitoring system, a comparison test was done at the metering section of the electrical distribution service, where test equipment was installed. The utility-grade load tester of the metering section was used as the reference instrument in determining the accuracy and reliability of the prototype. Measurement was made under normal operating conditions and included single-phase and three-phase load conditions. Instantaneous measurements of voltage, current, power, and energy were accomplished by the prototype and the utility's power quality analyzer (PQA).

Case 1: Using one single-phase load on each PZEM-004T module at 240 V, 10 A with 0.95 power factor.

Case 2: Using a three-phase balanced delta load at 240 V, 10 A per phase with 0.85 power factor.

Ten trials were conducted simultaneously for cases 1 and 2 to ensure proper testing and evaluation, with 20-second duration between each trial. Case 1 tested the functionality of each PZEM-004T module while case 2 tested its capability in a three-phase system. Data collection involved comparing readings from both the monitoring system and PQA together with its flexible current sensor in a laboratory setting (metering section). It was compared per second by recording it in video, yielding average percentage errors for voltage, current, power, and power factor. These power factors were done to test the accuracy of the modules and current transformers in reading power factors not less than 0.85 lagging [36].

Scenario 1: Monitoring performance over a 1-hour duration with 5-minute intervals on a static, continuous 240 V three-phase, 10 A per phase, 0.85 power factor load.

Scenario 2: Energy performance of the smart monitoring system over a 1-month period.

Two test scenarios were set to certify the performance and accuracy of the three-phase smart energy monitoring system. Scenario 1 included testing the unit in the laboratory setting using a static, continuous three-phase load for one hour. Simultaneous comparable readings were taken every five minutes against the readings that were measured from the PQA. Scenario 2 included testing the system under dynamic loads in the actual operating environment of the university. Energy readings (kWh) were directly compared every quarter for a one-month period — from March 31 to April 28, 2025 — against its installed utility meter with a CT ratio of 100:5, located on campus. Quarterly tests were run throughout the month, and the last cumulative energy percent error was tested to confirm the accuracy of the system.

Watt-hour meters must comply with the ANSI C12.1-2008 [37] standard, requiring an accuracy between 98% to 102%, or an error margin of ±2%. The standard requires energy measurement devices to work within specifications under standard operating conditions. Thus, the three-phase smart energy monitoring system was tested against the PQA in the metering section and the utility meter installed at the university.

Determining the prototype's percentage errors relative to the measuring equipment and calibrated distribution meter is essential for ensuring reliable operation. The percentage error [38] is computed using (10):

$$\%\,error = \frac{|E-A|}{A} \times 100\% \qquad (10)$$

Where

$E =$ experimental value
$A =$ accepted value

G. Current Unbalance Assessment

Current consumption monitoring was conducted on all three-phase system lines throughout April 2025 to measure current unbalance and the likely impacts on system performance [39]. The daily peak current of every day was taken throughout all three phases, which is an indication of each day's peak line current demand. The aim was to determine anomalies in load distribution that might cause operational inefficiencies. The percentage of current unbalance was allowable up to 30% [40]-[41]. Current unbalance percentage is calculated using the formula in (11) where the average current is divided by the highest deviation from the average [42].

$$\%\,CU(A) = \frac{|I_{max} - I_{ave}|}{I_{ave}} \times 100\% \qquad (11)$$

Where

$CI =$ current unbalance in percentage
$I_{max} =$ current in phase with maximum deviation from

average current in Amperes
I_{ave} = average current in Amperes

III. Results and Discussions

This section provides data through the results of testing and evaluation on the system that were done simultaneously to assess the performance of the three-phase smart energy monitoring system throughout different cases and scenarios.

A. Reading Performance of the Monitoring System

In Case 1, with the given 240 V, 10 A, 0.95 PF load, each PZEM-004T module had average power reading errors of 1.109%, 0.23%, and 0.132% for PZEM 1, 2, and 3, respectively, as shown in Fig. 5. A similar trend was observed with average current reading errors having 1.508%, 0.105%, and 0.334% errors. PZEM 1's higher percentage errors in power and current readings were observed to be due to the improper placement of the flexible current sensor, leading to small discrepancies in measurements [43], [44]. Regardless, PZEM 1's parameter measurements fall under the ±2% registration accuracy [37]. Average voltage and current errors only reached a maximum of 0.084% and 0.071% respectively. The overall assembly of the monitoring systems was reliable and consistent in providing accurate readings, demonstrating a strong foundation for the continuation of the development of the monitoring system.

Fig. 6 illustrates the mean percentage error on a three-phase load case. The voltage measurements showed an average error of 0.342%. Current measurements demonstrated an average error of 0.218%, indicating that the modules are accurate for three-phase systems. The average error for real power was 0.252%, displaying improved accuracy for three-phase loads. Additionally, the average power factor error was 0.213%, which is compliant with the ±2% standard [37]. This guarantees the prototype's capability to accurately measure the total power factor in three-phase systems. Overall, the results confirm that the modules maintain high precision in collecting power data.

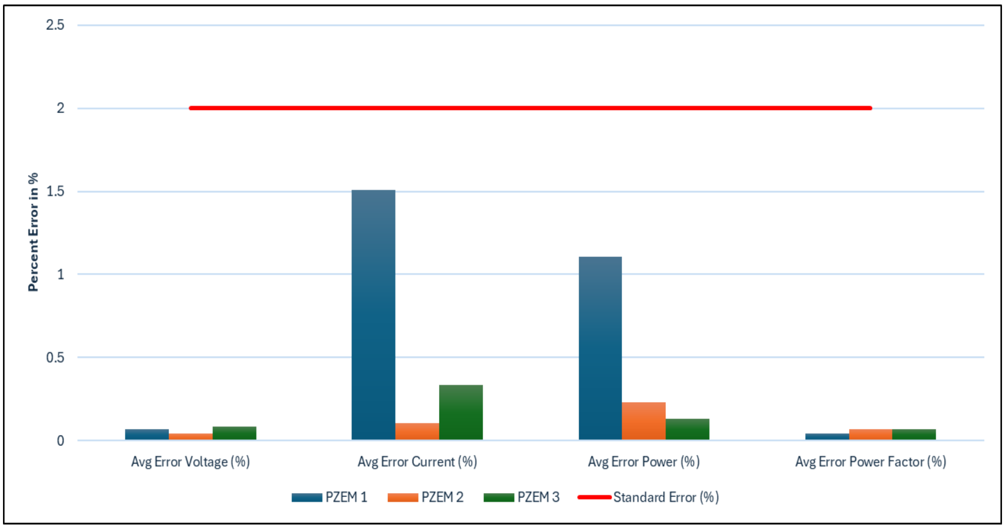

Fig. 5. Performance of the monitoring system against the PQA in Case 1

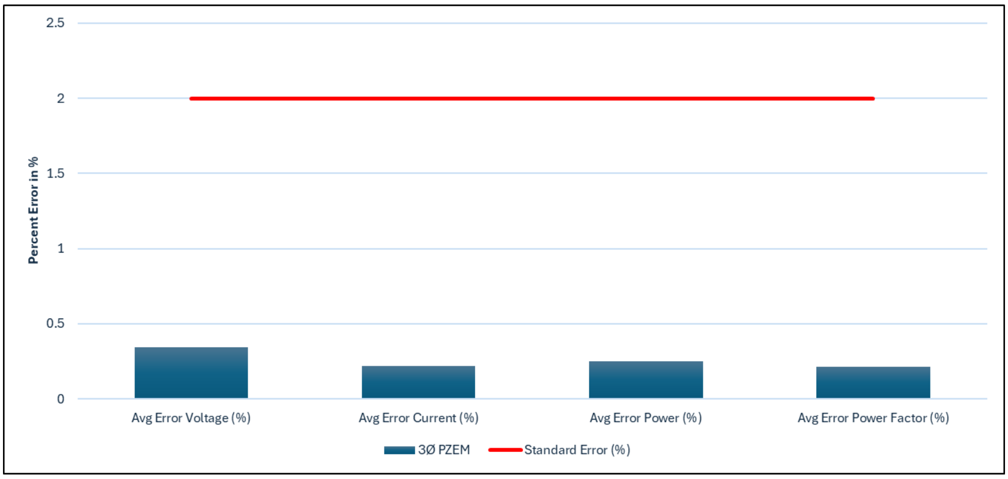

Fig. 6. Performance of the monitoring system against the PQA in Case 2

With the same loading in Case 2, the power percentage error ranged between 0.391% to 1.139%, and 1.124% to 1.787%, for Phase AB and CA respectively. Whereas Phase BC's percentage error started high but gradually decreased between 0.017% to 0.819%, seen in Fig. 7. The summed maximum percentage error for the total power was 0.343%. Test area limitations and the current transformers' sensitivity could have affected the PQA and monitoring system's readings. It is possible that cross talk occurs due to CTs and conductors' proximity with one another [45].

Fig. 8 graphs the percentage errors with regards to per phase and the sum power factor of the test load. Phase AB consistently was nearing around 1.439% to 1.583% and phase CA fluctuated at the 0:40-minute mark with its recorded power factor, having a maximum error of 1.745%. Again, this might be due to the cross talk between current transformers. Phase BC, meanwhile, is continuously consistent with its near accurate readings against the PQA, maxing at only 0.259% while the last 10 minutes had 0% error.

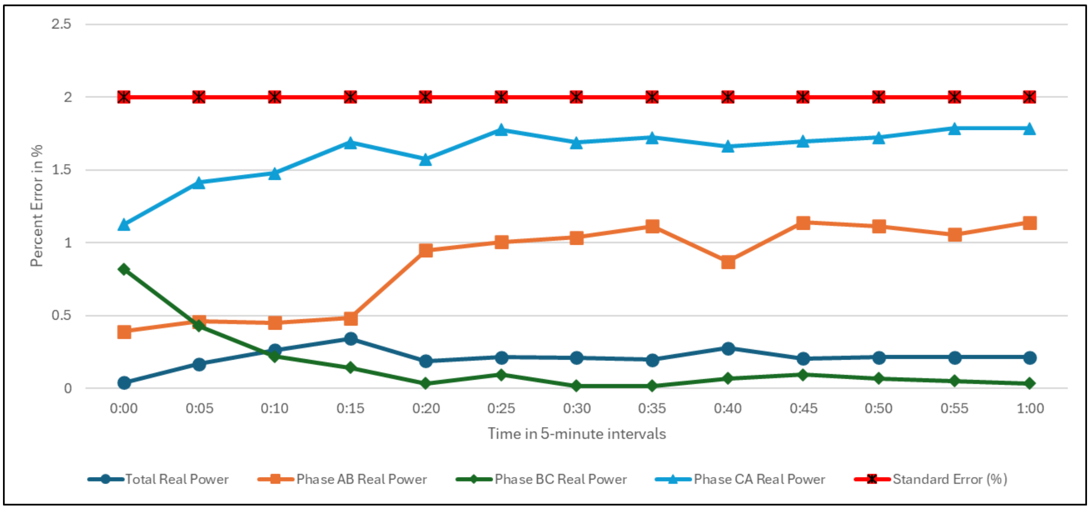

Fig. 7. Performance of the monitoring system in per phase and total real power against the PQA in Scenario 1

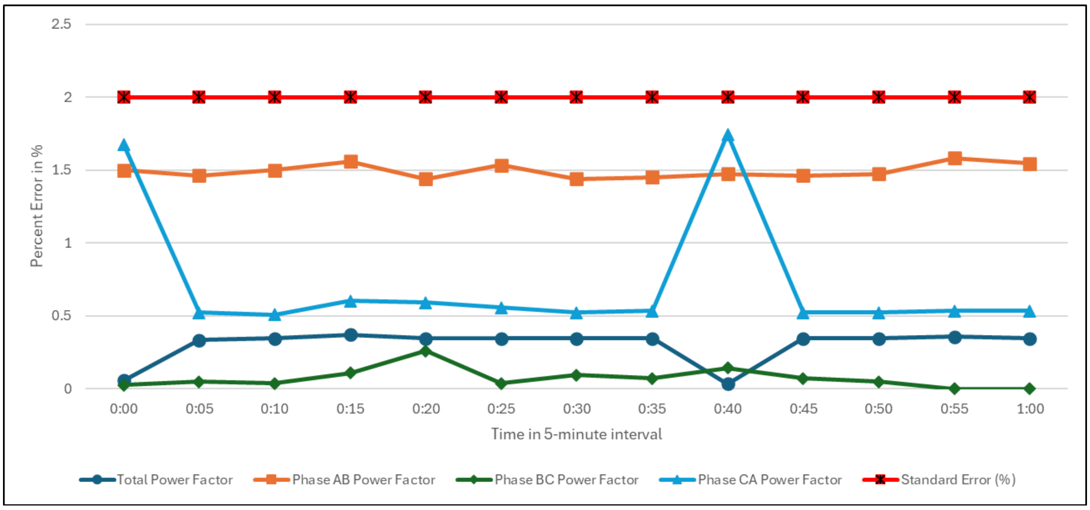

Fig. 8. Performance of the monitoring in per phase and total power factor against the PQA in Scenario 1

In Fig. 9, the monitoring system displayed closely correlated values in comparison with the PQA in total energy consumption through a 1-hour continuous load. The monitoring system's energy reading provided accuracy, with only an error of 0.965%. This accuracy, which is within ±2% standard by ANSI [37], demonstrates the overall monitoring reliability and potential for application in large-scale monitoring.

Utility meters have the advantage of being calibrated to ensure high precision when recording readings before deployment, especially for customers in the industry, whereas the device lacks such frequent calibration, hence the baseline for this study. Electricity billing continues to be recorded through the utility meters for consumers while the smart energy monitoring system aids in tracking and recording real-time monitoring parameters and enforcing energy management protocols.

The overall three-phase results indicate all measurement errors were well within the 2% acceptable threshold, demonstrating the overall reliability of the three-phase system for overall monitoring.

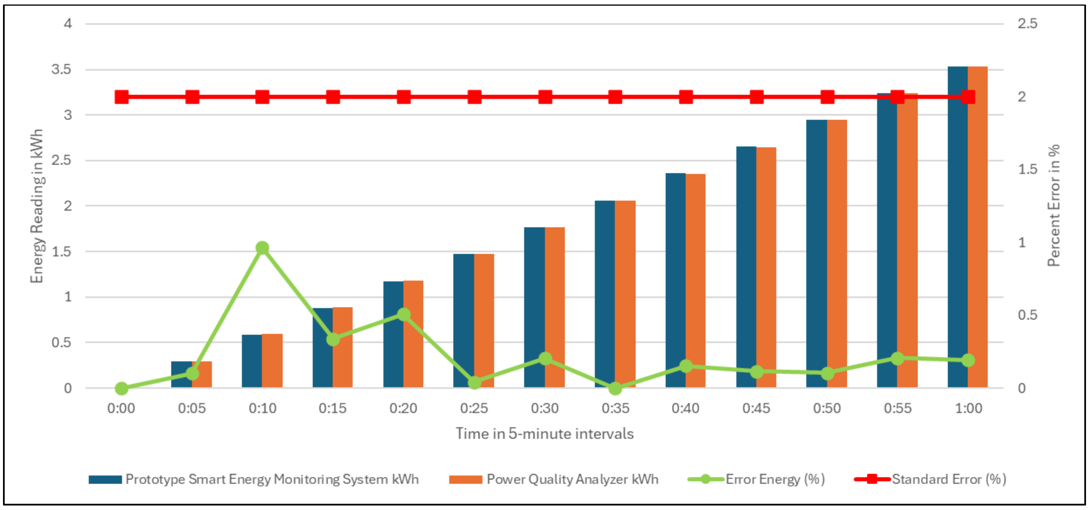

Fig. 9. Performance of the monitoring system in the total cumulative energy reading against the PQA in Scenario 1

The monitoring system recorded a cumulative energy consumption of 7490.072 kWh, while the university's installed meter recorded 7486 kWh as seen in Table II. The result is a percentage error of 0.05%, complying with the ±2% error of ANSI C12.1-2008 [37]. It is also seen through Fig. 10 that all energy readings fall under the percentage criteria. The variation is a result in the difference of CTs used, with energy meters having solid-core revenue grade CTs while the prototype used split-core CTs [46], [47]. Still, maximum deviation was only 4.072 kWh. A month-long assessment was necessary to observe and evaluate the device's performance for practical application.

TABLE II
ACCUMULATED ENERGY (KWH) READING OVER 1-MONTH PERIOD

Period	Smart Energy Monitoring System (kWh)	Installed Utility Meter (kWh)	Error Energy (%)
1	2736.258	2734	0.08
2	4937.328	4934	0.07
3	5660.691	5658	0.05
Final	7490.072	7486	0.05

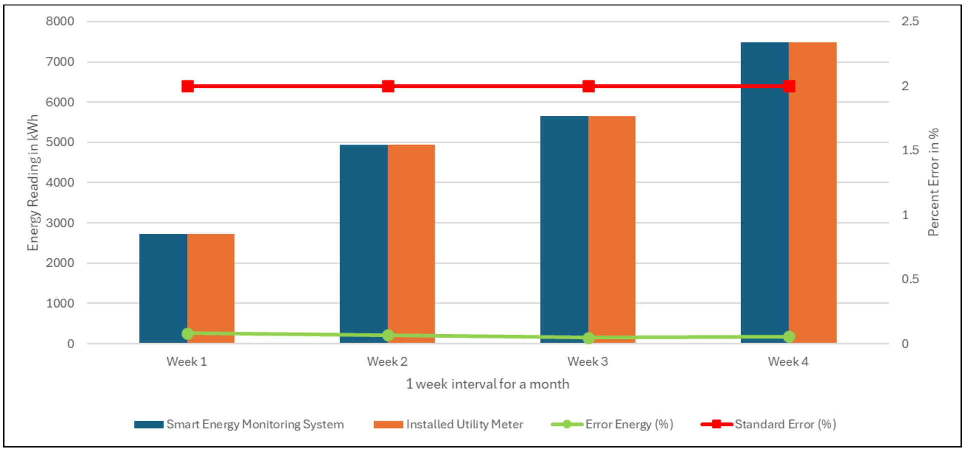

Fig. 10. Performance of the monitoring system in energy reading (Scenario 2) against the university's installed utility meter

B. *Unbalance Phase Current*

The current consumption of each line in the 37.5 kVA transformer bank in the said university reached a maximum demand of 252.753 A in Line B shown in Fig. 11. The day with the highest peak demand for all lines was on April 21, 2025, where 172.788 A, 251.214 A, and 219.069 A were consumed in Line A, B, and C, respectively. These high demands are due to the motor loads of the air-conditioning system throughout its Senior High School Building and College of Arts and Sciences

Building, and high load demands of the latter's general shop room. It was also observed that Line B consistently had a higher current draw, and the maximum current unbalance reached 17.19%, still within the advisable 30% but proceed with caution. Unbalanced loading has negative effects on motor loads and electrical equipment [48], [49]. This current unbalance may also lead to voltage unbalance [39].

C. *Battery Capacity*

The monitoring system's power consumption was measured at 0.2 A at 5 V, which is equivalent to an energy requirement of 24 Wh. A battery capacity of 7 Ah was calculated using (10) but the actual usage only lasted 18 hours. This discrepancy can be due to external factors, such as heat that can cause a negative impact on efficiency and capacity [50].

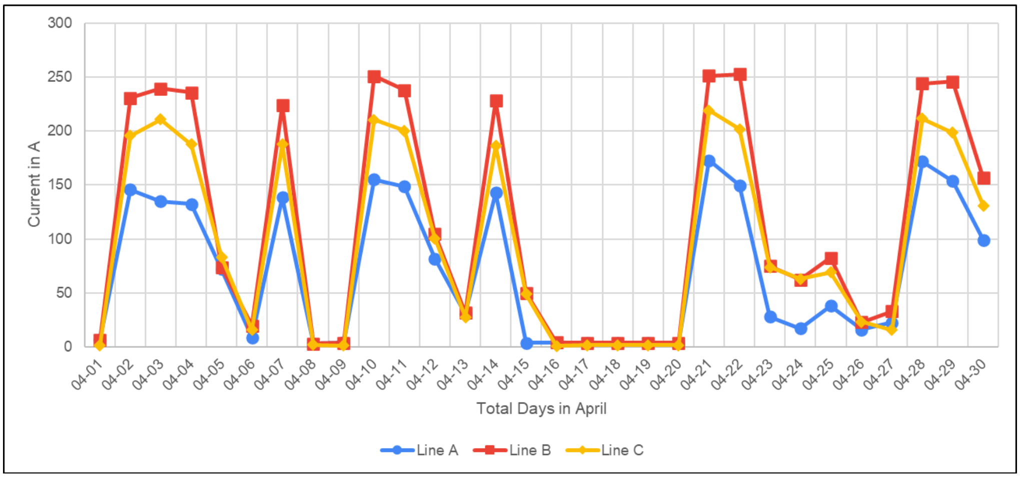

Fig. 11. Maximum current consumption graph of each line in the month of April

IV. Conclusion and Recommendation

The three-phase smart energy monitoring system boasted sustained performance across various electrical parameters including real-time voltage, current, power, power factor, and energy, showcasing its effectiveness in an institutional application. Through these measured parameters, the university was able to observe loading imbalances and energy consumption throughout the day, giving insight and solutions to reduce equipment damage, especially through its transformer banks to reduce circulating currents. Faculties involved in energy monitoring and management have proposed the idea of expanding the prototype as the university moves to primary metering. The university, through the proposed energy monitoring system, can observe consumption patterns in its facilities. It is designed to operate on three-phase 230 V delta systems which support up to 300 A of current per line, and data shows three-phase loading and higher consumption leads to higher accuracy of the system. The month-long energy reading assessment revealed the system's notable performance over an extended period, with accumulated percent errors within ±2% standard. With its battery, it can withstand power interruptions, lasting 18 hours for independent operation. In the future, dynamic testing can be accomplished to determine the prototype's performance in differing conditions. Electrical current detection range can further be improved as well as its enclosure and voltage range. A solar photovoltaic system may also reduce the monitoring system's dependence on the grid with an upgraded battery capacity. Delving into other applications aside from Blynk can increase data monitoring capacity, as well as simplifying the circuit by using other microcontroller options such as the ESP32. Lastly, additional features such as total harmonics distortion, fault detection, automatic load imbalance analysis, and integrated load flow analysis can be implemented in the system.

Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

I. K. I. Cubacub conceptualized the research, conducted the data collection and analysis, designed the experimental cases and scenarios, and lead the writing of the original draft. S. N. C. Caburata, E. K. L. Calaguas, J. A. M. De Leon, and I. F. R. Dizon completed the development of the prototype, funded the research, helped in writing the original draft, and helped in the analysis of data. M. P. Dimaano helped in polishing the research, funding, and proofreading. L. I. Dongallo programmed the prototype and gave insight and inputs on the direction of the research. A. L. Tangcuangco provided full supervision throughout the research, continually reviewed the process and the paper until finalizing results and commenting on the body of the paper itself by conducting proofreading, grammar checking, and reviewing the draft. R. L. D. Parungao gave the resources to pursue the research, guiding the research assembly, and reviewed the draft.

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