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An IoT Based Power Consumption and Losses Monitoring Technique Applied for a Mini Scale Electrical Network

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ABSTRACT. *Consumption of the electrical energy increases significantly per year in many consumer segments including a residential power consumption sector, educational institution, industry sectors and government. Calculation and reporting tasks of the up-dated information regarding the power consumption is a crucial issue both for the electrical power service provider and end users. Those require fairly data recording and appropriate computation. In practice, the reported power consumption of each user does not appropriately indicate the actual electrical energy utilized as for the intended purposes. The power electrical consumption profile might be also contributed from the power losses encountered in the entire mini scale electrical network such as house electrical power installation network, building, offices and so on. The traditional standardized method to monitor the electrical power consumption and to analytically compute the corresponding power losses is straightforwardly performed by recording several important electrical parameters indicated on a power electrical meter module well known as kWH meter. To obtain the accurate value of actual power losses it is required the following wasting time and complicated procedures by observing whole particular electrical installation network and recording all data variabilities. Through the extensive conventional monitoring and analytical computing the intended power losses could be obtained. The novel attractive, efficient and robust technique to allow users' to real-timely monitoring the amount of energy consumption and losses for daily basis was proposed in the manuscript. So far, several energy monitoring systems have been developed but have not been able to calculate the amount of lost energy. This information is very important for analyzing energy consumption. In this paper, an Internet of Things-Based Energy Monitoring System is built using the PZEM-004T sensor module which can monitor the amount of energy consumption and lost energy simultaneously. After testing, the built-up monitoring system provided an incredibly high accuracy of 97.96% from the comparison results with two different conventional electrical meter units. The significant impact of*

using the developed energy monitoring system that the users can simultaneously monitor the consumption and lost energy, at any time and accessed from anywhere via the available internet connection in a flexible and real-time way.
Keywords: Energy Monitoring System, Energy Consumption, Power Loss, Internet of Things (IoT), and Sensors Network

1. **Background and Previous Work.** Based on data from the U.S. Energy Information Administration (EIA), electrical energy consumption throughout the world from the years of 2015 to 2018 has increased by an average of 5% each year [1]. In general, the uses of electrical energy are majority existed for the regular uses in building lighting, transportation, industry and household electronic devices [2].

Consumption of electrical energy does not necessarily support the increase daily productivity which in turn causes energy wastage. One of the causes of energy wastage is that users have difficulty calculating the amount of energy that has been consumed every time so that they cannot properly control the use of electrical energy. In addition to difficulties, users also faced problem boredom in checking energy consumption through conventional electrical energy meter devices installed on building sites [3-5]. Lost Energy is also one of the factors that causes an increase in the use of electrical energy consumption, so it is very important for users to know the amount of energy lost in their energy consumption [6-8].

The Energy Monitoring System (EMS) is a solution to face the problems that have been described previously to be able for overcome difficulties of users in monitoring conventional electrical energy consumption. EMS show energy usage digitally, making it easier for users to know the amount of energy consumption. Utilization of the Internet of Things system that has been applied in several studies [9-15] makes the system accessible anywhere and anytime so that users can be more flexible in checking their energy consumption.

Several studies have been carried out to develop an EMS, as has been done by Sergio H. M. S. Andrade, et al. [16] build a monitoring system for electrical energy consumption through a mobile application in real time using Arduino Uno as a microcontroller and LoRa EXP32 SX1278 as internal communication between other nodes. The Central Unit transmits data to the Internet using the ESP8266 module. Eslam Al-Hassan, et al. [17] establish a smart power socket to monitor energy consumption of household electrical devices using Arduino Nano with Xbee module as a Zigbee communication. Shaojun Gan, et al. [18] build an IoT-based energy consumption monitoring system using the ABB B24 digital power meter as a measurement of energy consumption and the Raspberry Pi 2 as a controller and LoRa as the main communication system for the Industrial environment. Lusi Susanti, et al. [19] developed an IoT-based electrical energy consumption monitoring system using a current sensor SCT013 and Wemos D1 as a central unit that stores data to a website application. Siriwat Wasoontarajaroen, et al. [20] establish an IoT device to monitor electrical energy consumption using the PZEM-004T sensor that measures voltage and current, Arduino Uno as a controller and ESP8266 as a device that sends data to the internet and data will be received in a mobile application.

The EMS that has been developed only focuses on monitoring energy consumption, whereas the energy lost is also an indicator that needs to be monitored in order to increase the effectiveness of the use of electrical energy. In this paper, an Energy Monitoring System is developed that can monitor consumption and lost electrical energy, after that the accuracy of sensor on the system is tested by comparing the measurement results to electrical meter devices. The implementation of the EMS that has been established, it is hoped that users can find out the amount of energy consumption that has been used at any time and know the amount of energy lost. This system can help users to analyze causes energy loss beyond standard limits which can increase electricity payments and excessive energy wastage.

In part one of this paper describes the background and related work, second part explain about method to build the EMS, third part discusses results and analysis, and fourth part describes the conclusions of this research.

2. **Method.** The robust configuration of the constructed real-time IoT based power consumption and losses monitoring system was schematically visualized in FIGURE 1. This IoT monitoring system was assembled from eight main electronical functional parts including MCB unit, several electrical sensor parts, central processor unit ESP-8266, the electrical appliances, IDE Arduino © module, WiFi internet connection, and the real-time dashboards power monitoring system installed both in PC Webserver and Smart Phone Web Applications. Two power sensors are placed on the electrical meter unit, one is placed on the MCB line to calculate energy consumption and second is placed on the ground line to calculate energy lost. Data from sensor will be forwarded to the central unit for data processing and then sent to web server as a sensor data storage center. Users can access consumption and energy lost data through a website application that can be accessed via Internet. The system architecture can be seen in Figure 1.

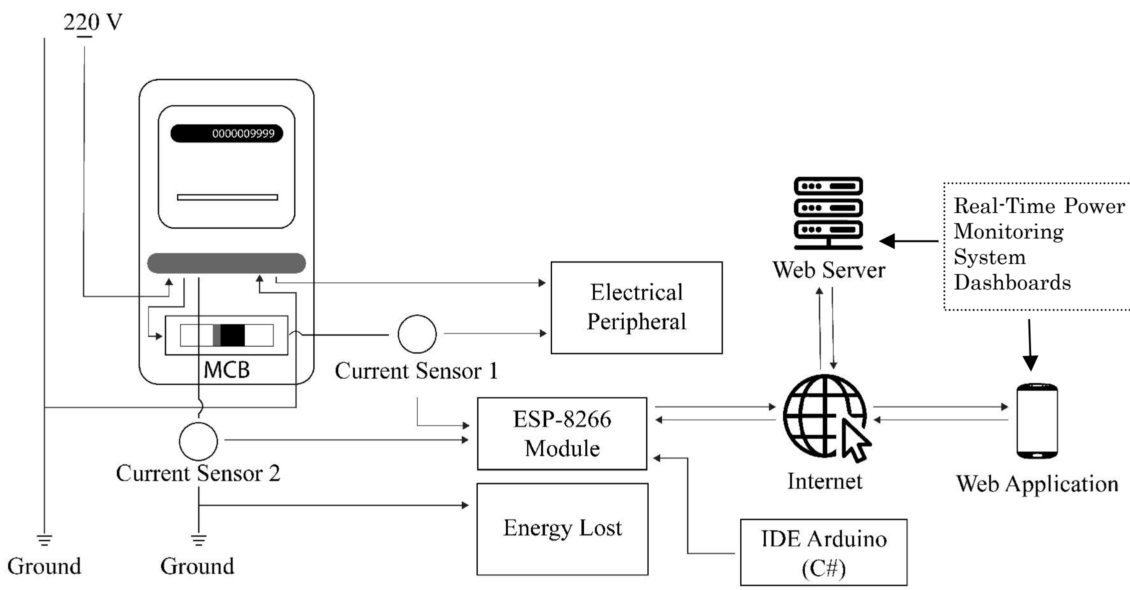


FIGURE 1. A Typical Architecture of Real-Time Power Monitoring System

The power sensor using PZEM-004T was applied to measure voltage, current and power electrical energy [21]. While Wemos D1 Mini has been embedded with ESP8266 module [22] as a central device unit. The device receives data from sensors and later transmits it to a web server using Wi-Fi communication. This way is perfectly cheaper one and compatible on whole system compared to ESP32 [23]. The series of hardware components configured was portrayed in Figure 2 and Figure 3 shows the whole principal operation of the real-time monitoring system. In general, the constructed system will continuously execute the computing algorithms to allow the generation of the up-dated power consumption and losses, respectively. At the first computing stage, whole monitoring system will be set-up to ensure all hardware and software parts operated in an appropriate condition. The process is then followed by reading the current value at MCB module and the leakage current passing through the grounding part using PZEM-004T sensor. All recorded current data are finally fed forwardly to the internet server for further processing.

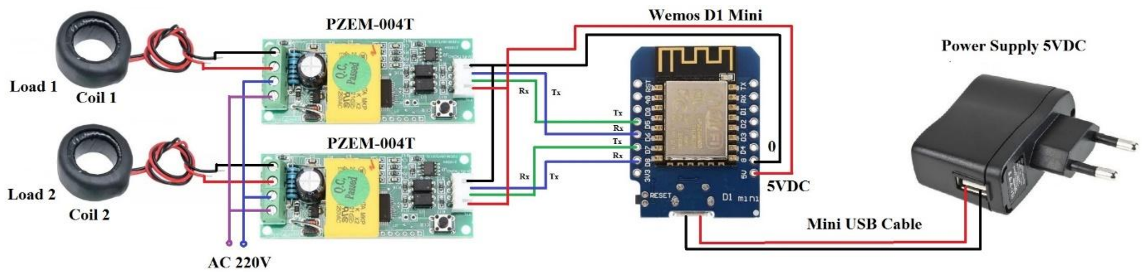


FIGURE 2. Schematic Block Diagram of Electrical Power Sensing Hardware

The prototype of energy monitoring system was implemented in residential homes that have a voltage of 220 V with a current of 6 A. This may contribute to the power capacity that can be achieved is approximately 1320 W. This study conducted two monitoring tests, namely testing on sensor accuracy for measuring energy consumption and energy lost.

1) Energy consumption test: PZEM-004T Sensor is placed on the cable coming from the electricity meter to determine the amount of power, voltage and current value in real time at any time so that the amount of energy consumption used can be recorded. Validation of sensor testing was also carried out by comparing the measurement results of two electricity meter units with the type MELCOINDA MS-98E [24] and MELCOINDA MF-97E [25] using the error rate equation to determine the accuracy of the PZEM-004T sensor for calculating the amount of power every hour (kWh).

$$Error\ Rate = \frac{Sensor\ Value - Electrical\ Meter\ Value}{Electrical\ Meter\ Value} \text{ x } 100\% \qquad (1)$$

2) Lost energy testing: The PZEM-004T sensor module is placed on a cable that goes to ground for calculate the amount of current that occurs in real-time then multiplied by the amount of static voltage of 220V so that the result is the amount of power wasted every hour (kWh).

3. **Result and Discussion.** PZEM-004T sensor module with number one was used to calculate the amount of energy consumption and PZEM-004T sensor module with number two was used to calculate the amount of lost energy. Both sensors are connected to Wemos D1 as Central Unit (CU) to process sensor data that will be sent to web server using ESP8266 module embedded in CU. The system was equipped with energy reserves using a power bank to anticipate power outages so that the EMS can operate according to the desired purpose. The prototype was connected to two electricity meter units which are used to validate the sensor measurements. The prototype system model that has been established can be seen in Figure 4.

Users can monitor the amount of energy consumption and lost energy in real time, anywhere and anytime through the website application that has been built. This application is designed with a simple user interface and the data displayed is in accordance with user requirements so that users are easy to operate. The monitoring application has two menus, namely Dashboard and Overview.

1) Dashboard: This interface shows the power, power factor, voltage and current value monitored in real-time. The values mentioned can be seen in terms of the amount of energy consumption that is being used and the lost energy is calculated. The dashboard is also equipped with a graph of the amount of energy consumption and lost energy over time.

2) Overview: The total value of energy consumption and lost energy in detail starting from the real-time value, yesterday's value, the current value to the last month and the last month's usage value are displayed on the Overview menu. The overview display is also equipped with a chart that displays the amount of usage per hour and day in terms of energy consumption and lost energy. The dashboard display in part (a) and overview in part (b) can be seen in Figure 5.

After testing the energy monitoring system for seven days, it was found that the average amount of energy consumption used through the PZEM-004T sensor module measurement was 16.39 kWh and the average energy consumption through the MELCOINDA MS-98E

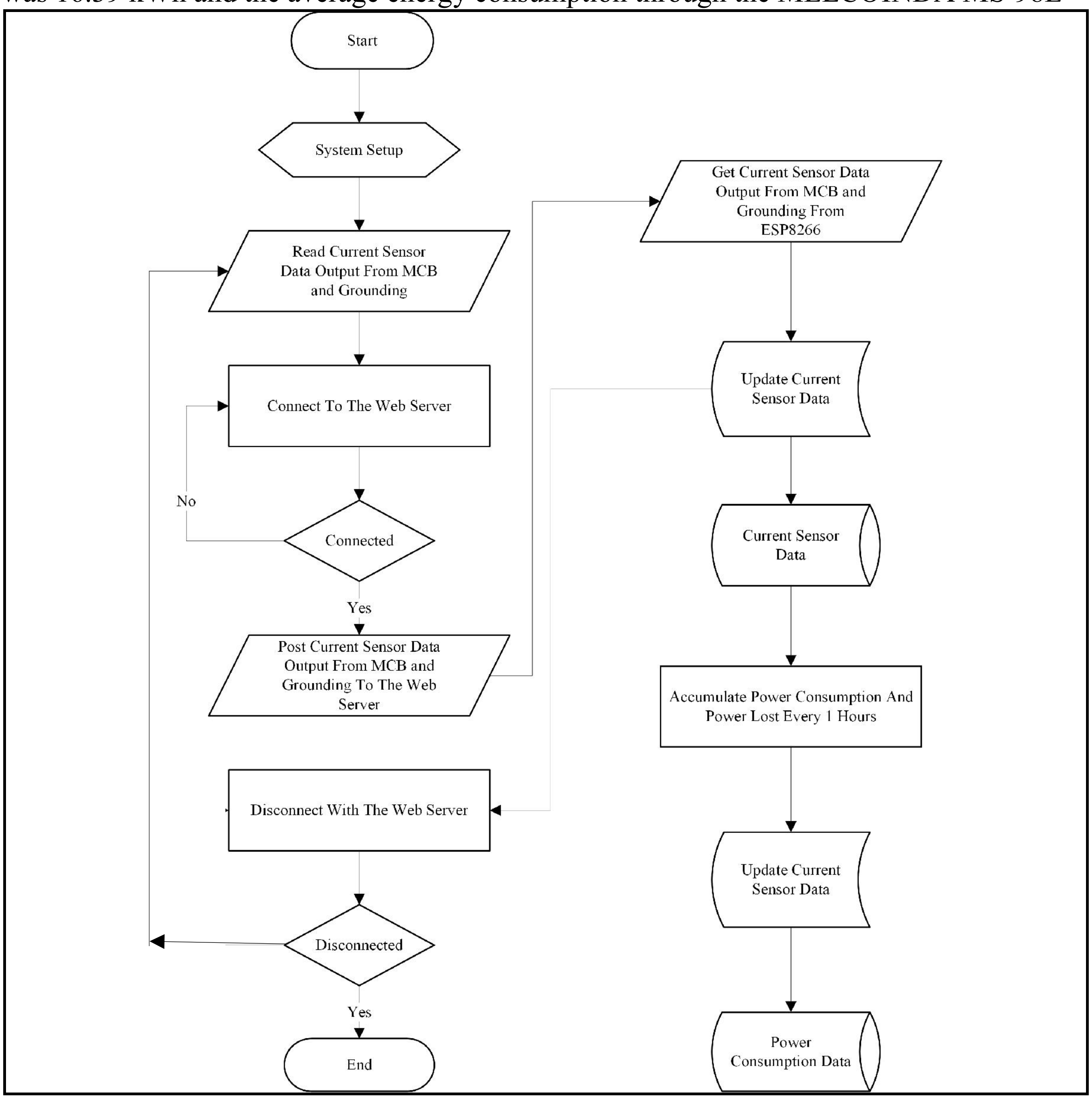


FIGURE 3. Flowchart of the Working System

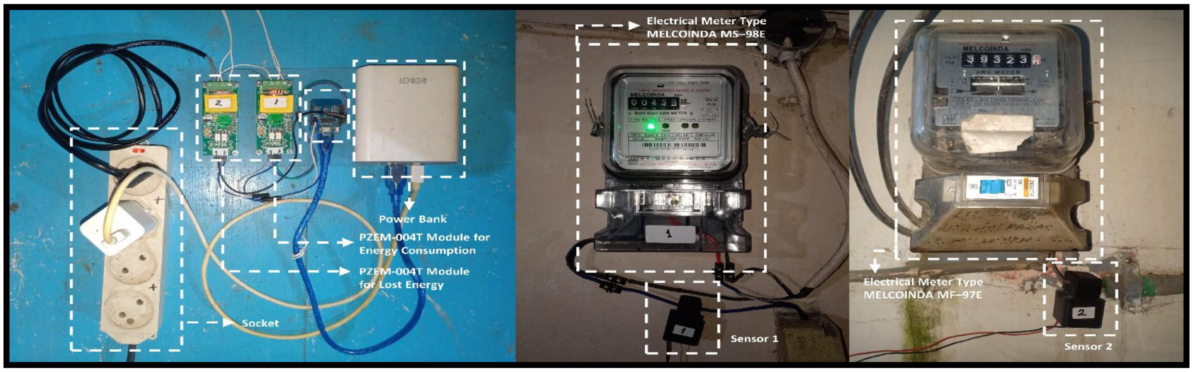
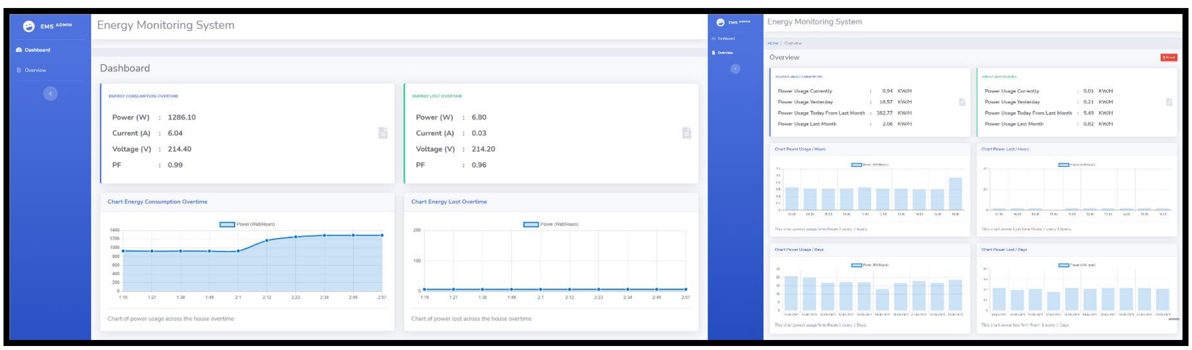


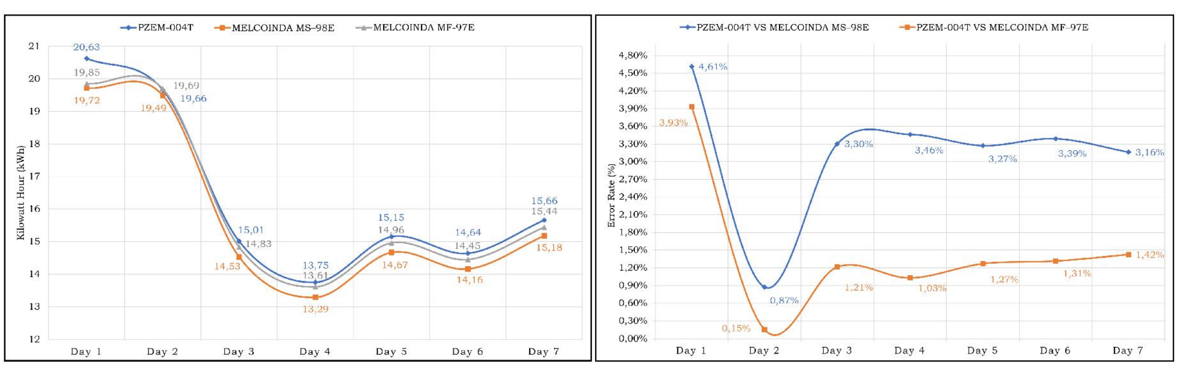
FIGURE 4. Prototype System

electrical meter measurement was 15.86 kWh and the MELCOINDA MF-97E type was 16.12 kWh. The average accuracy value based on the error rate of the PZEM-004T sensor module for the MELCOINDA MS-98E type electrical meter is 3.15% and for the MELCOINDA MF-97E type as a validation reference for the PZEM-004T sensor module, the average error rate value is quite smaller which the value is about 1.48 %. For more details, Figure 6 in part (a) shows the energy consumption value for seven days from three measurement tools used and part (b) regarding the percentage error rate for the PZEM-004T sensor module measurement with MELCOINDA MS-98E and PZEM-004T sensor module with MELCOINDA MF-97E.



(a) (b)

FIGURE 5. (a) Dashboard dan (b) Overview Interface on the website application for monitoring consumption and lost electrical energy



(a) (b)

FIGURE 6. (a) Energy Consumption Graph using Three Measurement Device with average value is 16.11 kWh in seven days (b) Error Rate Graph with average value is 2.31%

The test results from measuring the value of energy lost for seven days using the PZEM-004T sensor module, obtained an average value of 0.22 kWh. Figure 7 shows the value of lost energy for each day.

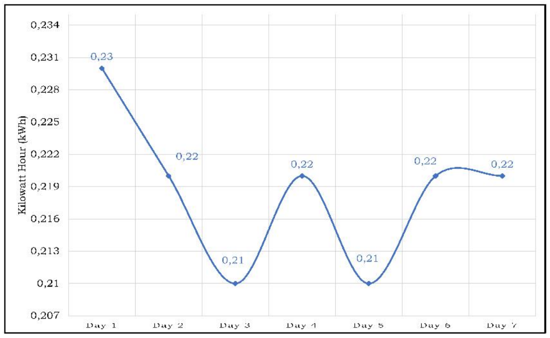


FIGURE 7. Lost Energy Consumption Graph using PZEM-004T module sensor

5. **Conclusions.** This research has succeeded in developing a monitoring system for energy consumption and lost energy using the PZEM-004T sensor based on the Internet of Things. The results of the sensor accuracy test were obtained with an average error rate of 2.31% from the results of the validation by two electrical meter units with type MELCOINDA MF-97E and MELCOINDA MS-98E. This indicates that this monitoring system has an accuracy of truth in detecting energy consumption of 97.69%. EMS detects an average kWh value for seven days of 0.22 kWh for lost energy. This system can be implemented in real terms as a flexible monitoring tool for electricity energy consumption and lost energy. In future research, it can be tried to use other power sensors to increase the accuracy of readings in the energy monitoring system.

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