

Internet of Things (IoT) based Electrical Power Monitoring System for Solar Power Plants using the Telegram Application

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ABSTRACT

Indonesia, with its tropical climate, possesses substantial solar energy potential. However, traditional monitoring of solar power systems in Indonesia still relies on manual observation, making the process inefficient, time-consuming, and prone to error. To address these limitations, this study proposes the design and implementation of a real-time Internet of Things (IoT)-based monitoring system for solar power plants using the Telegram application as the user interface. The system integrates the ESP32 microcontroller and the Pzem-004 T sensor to measure AC electrical parameters, including voltage, current, power, energy, frequency, and power factor. Unlike previous studies that used platforms such as Blynk or ThingSpeak, this research introduces Telegram as an innovative messaging-based monitoring platform, offering greater accessibility, simplicity, and user familiarity. The monitoring system was tested on a single-phase off-grid solar power setup, utilizing five types of household electrical loads, to validate its accuracy and reliability. The ESP32 communicates with the Telegram bot through Wi-Fi, and users can retrieve real-time data via predefined commands. Experimental results demonstrate high measurement accuracy, with average errors of 0.07% for voltage, 0.1% for current, and 0.08% for power. These results confirm that the system provides reliable data transmission and sensor readings. This work contributes a low-cost, efficient, and user-friendly alternative to conventional monitoring systems, particularly for decentralized renewable energy systems in remote or off-grid areas. The integration of Telegram as a communication medium for energy monitoring adds a novel dimension to IoT-based power system applications.

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1. INTRODUCTION

Energy is an essential component of modern life and serves as the foundation for development across all sectors, including transportation, industry, healthcare, and communication [1]. The global demand for energy continues to rise due to rapid population growth, urbanization, and technological advancements [2]. Indonesia, as a developing country, faces an increasing energy demand to support its economic growth and improve the quality of life of its citizens [3]. Unfortunately, much of this demand is still met through conventional fossil fuels, which are finite, environmentally harmful, and contribute significantly to climate change [4]. The global energy crisis and the pressure to reduce carbon emissions have forced many nations, including Indonesia, to transition toward cleaner and more sustainable energy sources [5]. New and Renewable Energy (NRE) has emerged as a viable solution to address the sustainability issue. Among various NRE options, solar energy has gained considerable attention due to its abundance, accessibility, and compatibility with decentralized applications. Government programs and international agreements, such as the Paris Agreement, also play a significant role in accelerating the adoption of renewable energy. For countries located in the tropics,

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harnessing solar energy offers both ecological and economic benefits [6]. Therefore, transitioning toward solar-based energy systems is not only a necessity but also an opportunity for long-term national energy security.

Indonesia is geographically located on the equator, receiving high solar irradiation throughout the year, making it an ideal country for solar energy development [7]. Based on national energy assessments, Indonesia has a total renewable energy potential of approximately 3,686 gigawatts (GW), with solar energy accounting for the largest portion at 207.8 GW. The average daily solar radiation in most regions is around 4.8 kWh/m², with eastern parts reaching up to 5.1 kWh/m² per day [8]. These figures indicate that Indonesia can rely heavily on solar energy as a sustainable energy source, especially in rural and remote areas where access to the national electricity grid is limited. Solar photovoltaic (PV) technology is relatively simple to install and can be implemented in both on-grid and off-grid configurations [9]. The government has launched various initiatives to promote rooftop PV installations and village-scale solar power plants. However, the potential of solar energy remains underutilized due to challenges in system management, maintenance, and monitoring [10]. One of the main obstacles is the limited ability to monitor system performance in real-time, which affects both operational efficiency and reliability [11]. To optimize the use of solar energy, real-time monitoring systems must be in place to detect faults, track performance, and prevent energy losses. As Indonesia moves toward energy digitalization, leveraging digital technology becomes imperative to unlock the full potential of its solar energy resources [12].

Monitoring energy systems is crucial for ensuring optimal performance, longevity, and cost-effectiveness of energy infrastructures [13]. A monitoring system enables users to collect, analyze, and respond to data in real-time, helping prevent damage and optimize energy consumption [14]. In solar energy systems, monitoring parameters such as voltage, current, power, energy consumption, power factor, and frequency is essential [15]. Without accurate monitoring, users may face issues such as inefficient energy usage, unplanned downtime, and reduced system lifetime [16]. Traditional methods of energy monitoring typically involve manual meter reading or on-site inspection, which are time-consuming, labor-intensive, and prone to error [17]. Moreover, these manual systems do not provide real-time feedback, which is critical for systems installed in remote locations or used in dynamic load environments. Automation and digital communication are now widely adopted in energy systems to address these challenges [18]. Modern monitoring systems are increasingly shifting towards remote sensing and wireless technologies to enable data-driven decisions [19]. Additionally, user-friendly platforms are essential to ensure that monitoring tools are accessible not only to engineers but also to general users [20]. Therefore, integrating intelligent monitoring solutions into solar power systems is a crucial step toward achieving energy efficiency, enhanced system transparency, and sustainable operation. To fulfill this goal, the implementation of affordable, scalable, and user-oriented monitoring technologies is necessary [21].

The Internet of Things (IoT) has emerged as a transformative technology in various sectors, including energy, agriculture, healthcare, and manufacturing [22]. IoT enables physical devices to communicate and share data over the internet, allowing real-time monitoring, automation, and control. In energy applications, IoT facilitates seamless integration between sensors, microcontrollers, communication modules, and user interfaces [23]. The adoption of IoT in solar energy systems enables continuous data acquisition and transmission, eliminating the need for human intervention. It also allows users to monitor system performance remotely, identify anomalies, and make decisions based on real-time insights [24]. Over the past decade, several studies have explored IoT-based monitoring systems using platforms such as ThingSpeak, Blynk, and custom-built web servers. These systems often rely on microcontrollers such as NodeMCU, Raspberry Pi, or ESP32 for data processing and communication [25]. The ESP32 microcontroller, in particular, offers built-in Wi-Fi and Bluetooth capabilities, making it suitable for low-cost and compact IoT applications [26]. Despite the growing body of research in this domain, most systems still require external dashboards or web interfaces, which may not always be accessible to users in low-connectivity or rural areas. Hence, there is a growing need to explore alternative, lightweight, and intuitive platforms for data interaction in energy monitoring. IoT-based innovations continue to evolve, offering new possibilities to make solar energy systems more innovative, more efficient, and more accessible [27].

Although many IoT-based solar monitoring systems have been developed, several limitations persist, particularly in terms of user accessibility and platform reliability [28]. Most existing systems rely on custom-built dashboards, which require stable internet access and regular maintenance [29]. These systems may not be ideal for non-technical users, especially in rural communities where user training is minimal. Additionally, many platforms require web hosting or third-party services that can introduce additional cost and complexity. The systems often lack flexibility in interaction and are not designed for mobile-centric usage [30]. As a result, users may struggle to access and interpret system data efficiently. Furthermore, monitoring systems rarely include user-friendly notifications or command-based interactions, which limits the system's responsiveness. Security is another concern, as many existing IoT platforms lack sufficient encryption or user authentication mechanisms [31]. These limitations indicate a gap between technical system development and real-world usability, particularly in emerging markets [32]. For solar power systems to be more inclusive, the monitoring

platform must be easy to use, free of charge, widely accessible, and adaptable to existing mobile devices [33]. Addressing these challenges requires an innovative approach that leverages popular communication tools to deliver system information more intuitively and reliably [34].

To address the limitations mentioned, this study proposes a novel solar power monitoring system that utilizes the Telegram messaging application as its primary interface. Telegram is a widely used platform that supports bots, automation, and command-based interactions, making it an ideal choice for displaying real-time IoT data. The system integrates the ESP32 microcontroller and the Pzem-004 T sensor to collect AC electrical parameters from an off-grid solar power system. Sensor data—including voltage, current, power, energy, frequency, and power factor—is transmitted via Wi-Fi to the Telegram bot, allowing users to retrieve real-time information by sending simple commands such as /voltage or /energy. This approach simplifies the user experience by eliminating the need for dedicated dashboards or web interfaces. Additionally, the Telegram bot can send daily notifications and respond to user queries, establishing a two-way communication channel. The system is tested using various household electrical loads to evaluate accuracy and responsiveness. Compared to conventional methods, this approach offers a low-cost, efficient, and user-friendly solution for energy monitoring. The use of Telegram as a data interface represents a novel contribution to IoT-based energy systems, particularly in low-resource or remote environments. It also opens possibilities for future integration with other messaging or mobile platforms to enhance intelligent energy management.

The primary objective of this research is to design and implement a real-time, IoT-based solar energy monitoring system that utilizes Telegram as its communication platform. The study aims to demonstrate the feasibility, accuracy, and practicality of using widely available mobile applications for energy data retrieval and user interaction. The key contributions of this paper include: (1) the design of an integrated monitoring system using ESP32 and Pzem-004t, (2) the development of a Telegram bot for real-time sensor data display and historical data retrieval, and (3) performance validation using various electrical loads and comparative measurements. This work differs from prior studies by leveraging Telegram—a free, secure, and widely adopted platform—as the primary medium for system interaction. The rest of the paper is organized as follows: Section 2 presents a review of related work and the theoretical background of IoT and energy monitoring systems. Section 3 describes the materials, methods, and system design. Section 4 provides results and analysis from system testing. Section 5 discusses the findings, limitations, and future work. Finally, Section 6 concludes the study and highlights potential directions for further development and application.

2. LITERATURE REVIEW

2.1. Internet of Things (IoT)

The Internet of Things (IoT) is a scenario where objects can transmit data/information through networks without human intervention [35]. The development of technology, whether in the form of applications or mobile communication devices, has led to the creation of IoT, promoting information exchange through various applications. IoT represents a revolution across all aspects of life in the transition from Industry 4.0 to 5.0 [36]. The concept of IoT provides internet connectivity, enabling the exchange of information among components in its surrounding environment. The ESP32 is a component based on IoT utilized in the research implementation [37].

IoT is a scientific advancement with significant optimization in life-based smart sensors and smart devices that collaborate through the internet [38]. All tools and the internet can be connected through sensor devices with the assistance of IoT, enabling the identification and management of information acquired from sensors. The functioning of IoT involves programming instructions containing commands in the form of arguments to obtain interaction results between devices, connecting them automatically without human intervention. IoT technology, using wireless data communication such as Wi-Fi, is widely employed for real-time online monitoring [39]. The Internet operates without specified distance limitations, making it a seamless connector between two or more devices that interact with each other. Human tasks are focused on setting up and supervising equipment operation, while the execution of functions is automated [40].

2.2. Microcontroller ESP32

Microcontroller, a functional computer system chip, comprises a processor core, a small amount of RAM, program memory, or both, along with input-output peripherals [41]. Essentially, it features controllable inputs and outputs through programmable code that can be selectively erased. Arduino lacks built-in support for wireless networks, necessitating the use of a WiFi module connected to the board with a specific code to access wireless networks [42].

ESP32, a microcontroller with an internal WiFi module, simplifies IoT application development [43]. It offers features such as WiFi, Bluetooth, and other I/O devices, facilitating the development of IoT applications—the internal WiFi module on ESP32 streamlines internet network connections and data transfers [39]. ESP32 applications are programmed in C/C++ and can utilize various software, including Arduino IDE,

ESP-IDF, and MicroPython. ESP32's power consumption is lower and cost-effective [44]. The hardware components of ESP32 are illustrated in Figure 1.



Figure 1. Modul Wi-Fi ESP32

2.3. Sensor PZEM-004t

PZEM-004T is a sensor designed for measuring the values of current, voltage, power, energy, and power factor in AC electrical usage, offering a reasonably accurate measurement level of 0.5% for voltage, current, active power, live energy, frequency, and power factor, and 1% for power consumption [45]. The ESP32 microcontroller is capable of controlling the PZEM-004T sensor, and it can be integrated with the Telegram application, enabling the transmission of monitoring data and functioning as a practical and efficient information system. Physically, the PZEM-004T board measures 3.1×7.4 cm. The PZEM-004T module can measure currents up to 100A, facilitated by a transformer coil with a diameter of 3mm [46]. The hardware configuration of the PZEM-004T sensor is depicted in Figure 2.

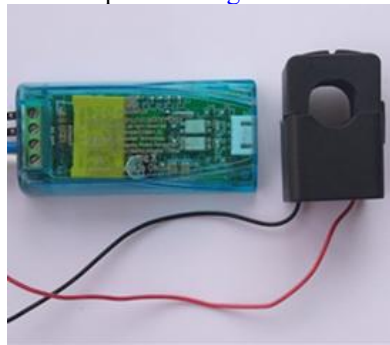


Figure 2. Sensor PZEM-004t

2.4. Bot API

The Bot API (Application Programming Interface) is a third-party application operating within the Telegram messaging app [47]. The Telegram instant messaging application provides a publicly accessible Application Programming Interface (API) without limitations, allowing anyone to utilize it. Telegram also features a Bot API that facilitates the easy creation of programs utilizing Telegram messages as the interface [48]. Users can interact with the bot by sending messages containing predefined commands. Unlike other platforms, Telegram bots do not require specific phone numbers as prerequisites.

A Telegram Bot is a dedicated Telegram account designed to send messages automatically [49]-[52]. The Telegram API provides an authentication code, known as a token, which users obtain upon registering a new account on the Telegram app. Possession of this token is a fundamental requirement for users to employ Telegram bots. Bots offer flexibility in keyboard usage, simplifying interactions between the bot and its users. The programming language used for Telegram bots is not restricted, allowing developers to use any programming language of their choice without limitations [53]-[56].

3. METHOD

3.1 System Overview

This study utilizes an experimental approach to design, implement, and validate an IoT-based monitoring system for solar power plants. The system consists of three main components: (1) the solar power generation system, (2) the IoT-based monitoring hardware and software, and (3) the Telegram application as the user interface. The entire process includes hardware assembly, firmware programming, system integration, load testing, data acquisition, and performance evaluation.

In the design of the monitoring system, an explanation is provided regarding the circuitry and operational steps according to the designed system. The process of developing the system aims to facilitate the assembly of the device and create a structured, effective, and systematic system. Through this system design, there will be interactions with the sensors installed in the monitoring system, which will be integrated with the solar panel, and communication with the Telegram application, serving as an interface to convey information to users. The Block Diagram of the designed system is illustrated in Figure 3.

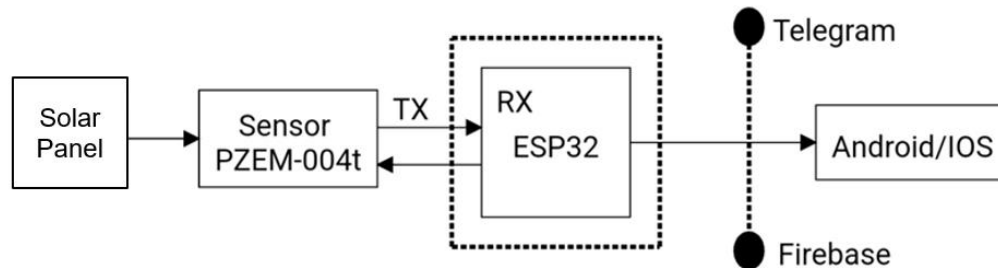


Figure 3. Block Diagram of Internet of Things-Based Electric Power Monitoring System for Solar Panels Using the Telegram Application

The block diagram in Figure 3 illustrates a centralized system centered around the ESP32 microcontroller, which functions as the central brain, possessing both input and output capabilities. When a load is applied to the solar panel, the sensor reads the data and transmits it to the ESP32. This data is then forwarded to the Telegram application through the ESP32 microcontroller, which is connected to the user's token and the internet. Additionally, the ESP32 can send data to the real-time Firebase database using a specific address and API key. Utilizing serial communication between the Pzem-004 T sensor and the ESP32 through TX and RX pins ensures that the data is stored in the ESP32 and remains connected to the internet. This process ensures that data can be received by the Telegram application in real-time or retrieved from the Firebase database.

3.2 Hardware Components

The monitoring device was built using an ESP32 microcontroller, chosen for its built-in Wi-Fi capabilities and compatibility with the Arduino IDE. The Pzem-004t sensor module was used to measure AC electrical parameters, including voltage (V), current (A), power (W), energy (kWh), power factor (PF), and frequency (Hz). The device also included AC plugs for connecting household appliances as test loads. Five electrical loads were used: a soldering iron, an electric fan, a clothes iron, a hair straightener, and a laptop charger.

The design of the system architecture aims to facilitate the integration process of materials from the components used, forming a cohesive unity. The architectural stages are implemented to streamline the correct and efficient application of the device design, as illustrated in Figure 4.

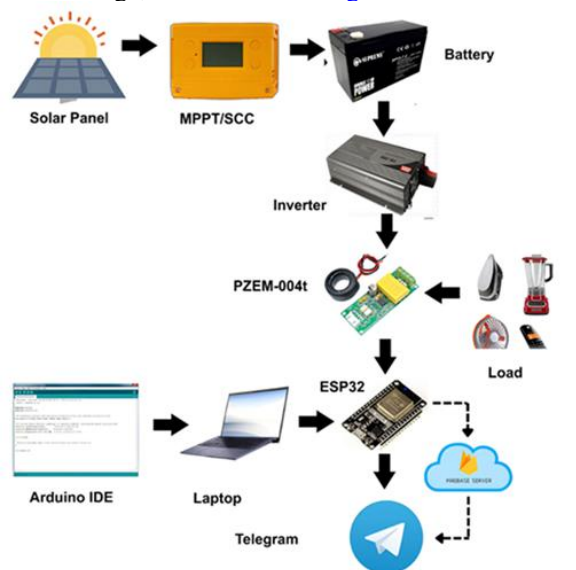


Figure 4. Electric Power Monitoring System Architecture in Solar Power Plants Based on the Internet of Things

This research focuses on an off-grid solar power system (PLTS). The workflow involves harnessing sunlight to generate DC voltage and current from solar panels. The DC voltage is stored in batteries after passing through a Solar Charge Controller (SCC) to regulate the voltage. The SCC component optimizes battery charging to prevent damage. The stored DC voltage in batteries is then converted to AC voltage using an inverter, as the load requires an AC power source. The PLTS serves as both the power source and supply for the power monitoring device. The power monitoring device utilizes an IoT-based system with an ESP32 microcontroller and a Telegram application for communication, leveraging Bot API (Application Programming Interface) features. Users interact with the Telegram bot by sending messages with predefined commands. The ESP32 acts as the brain of the monitoring device, serving as a Wi-Fi module to connect to the internet. The Pzem-004t sensor reads values such as current, voltage, power, energy, frequency, and power factor when connected to an AC load. The ESP32 processes the sensor readings and displays them on the Telegram bot. The ESP32, connected to Wi-Fi, sends the PZEM-004t sensor data to the Telegram application. Additionally, the ESP32 can transmit data to a real-time database in Firebase. The application connected to Firebase can access both real-time and historical energy consumption data retrieved from the Firebase database.

3.3 Software and Firmware Development

Firmware was written using the Arduino IDE with the ESP32 board library installed. The firmware logic includes Wi-Fi connection setup, Telegram bot token integration, sensor reading via serial communication (TX and RX), and real-time data transmission. The Telegram bot was created using BotFather and programmed to respond to commands such as /voltage, /current, /power, /energy, /frequency, /pf, and /all. The system also included a daily energy reset feature, which was triggered automatically at 00:01 WIB.

The program design for monitoring solar panel power is executed using Arduino IDE software. The ESP32 program, as depicted in Figure 3.5, illustrates the flowchart of the solar power monitoring system based on the Telegram application. The initial steps involve installing the ESP32 board on Arduino IDE and aligning the software with the ESP32 microcontroller's requirements. After installation, the user ensures the board's compatibility with the program. The ESP32 program focuses on reading AC sensor data, transmitting it to the Wi-Fi module (ESP32) via the TX pin, and receiving Wi-Fi signals through the RX pin for data transfer to the Telegram application.

Next, the user inputs Wi-Fi data, including the board's name and password on the ESP32. The token generated from the Telegram bot account is inserted into the monitoring system. Telegram provides the BotFather account to offer an open API, and users can obtain the Telegram bot token after registering with BotFather. To acquire token information, users can search for BotFather in the Telegram search bar, click on /start, and BotFather will provide an automated message with selectable menu options. Users can choose /newbot and press /token. After entering the token on the board, compiling the program establishes the connection to Telegram. The ESP32 program flowchart is illustrated in Figure 5.

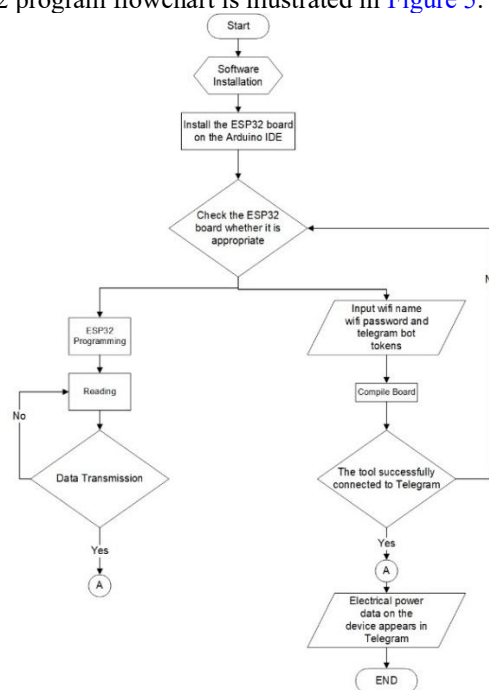


Figure 5. ESP32 Program Flow Diagram

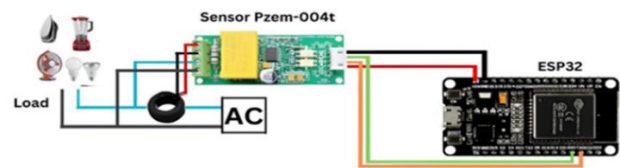


Figure 6. Circuit System

Meanwhile, the flowchart of hardware, firmware, and software integration is presented in [Figure 7](#).

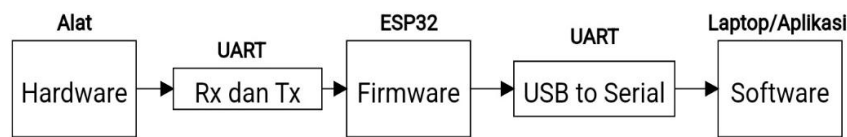


Figure 7. Flowchart for Integrating Hardware, Firmware and Software

3.4 Experimental Testing Procedure

Testing was conducted to validate system performance and accuracy. Each electrical load was connected individually, and measurements were recorded from both the IoT monitoring system (via Telegram) and standard measurement tools (a digital multimeter and a clamp meter). Each load was tested over 60 minutes with data recorded at 10-minute intervals. This resulted in six data points per load, which were compared to evaluate accuracy. The percentage error was calculated using the formula:

$$Error\ (\%) = \frac{Measured_{IoT} - Measured_{Reference}}{Measured_{Reference}} \times 100$$

3.5 Data Validation and Filtering

To ensure data quality, measurements were filtered to exclude readings affected by unstable internet connectivity or incomplete sensor transmission. Valid data were defined as values that remained consistent across three consecutive intervals and matched the reference tool within a $\pm 2\%$ margin. Abnormal or missing readings were removed before analysis.

4. RESULTS AND DISCUSSION

The following are the results of the monitoring tool design for collecting data, as shown in [Figure 8](#).

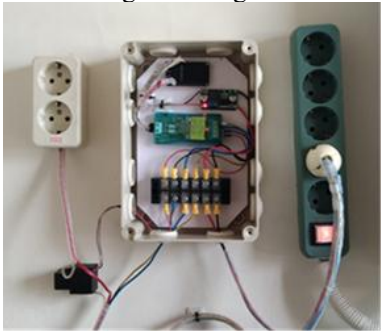


Figure 8. Tool Design Results

4.1 System architecture

The following is a picture of testing a power source, with voltage and current values shown in [Figure 9](#).



Figure 9. Electrical Source Testing

The results of measurements on the solar panels in the form of current and voltage values were carried out when the solar panels were under load, and carried out for one day. In [Table 1](#) are the results of voltage and current testing on the first day

Table 1. Voltage and Current Test Results on PLTS First Day

Time	Solar Panel	
	V (Volt)	I (Ampere)
09.00	24.88	7.8
10.00	26	6.2
11.00	26.6	10.3
12.00	26.8	4.9
13.00	24.92	0.34
14.00	24.79	0.02
15.00	24.79	0.02

The data obtained from the measurement values presented in [Table 1](#) are the current and voltage values produced by the solar panels. The conditions for collecting weather data were sunny from 09:00 to 12:00 WIB, while from 12:01 to 15:00 WIB, the weather was cloudy, and there was rain from approximately 13:40 to 14:38 WIB. Data collection begins at 09:00 WIB and ends at 15:00 WIB. The time interval used for data collection is one hour. The average voltage is 25.54 V, and the average current is 4.23 A. The data results show a drastic decrease in the current value, which is estimated to be due to the battery charging process being completed. As a result, when the battery is fully charged, the current value experiences a decline. Meanwhile, the voltage results are influenced by weather conditions and temperature, which causes the resulting voltage to be less stable. The voltage drops when the weather conditions are cloudy.

4.2 Electrical Load

The stage is carried out by connecting the positive cable of the multimeter to the load and the negative cable to the ground. In this stage, loads are used in the form of soldering irons, fans, irons, hair straighteners, and laptop chargers. The test output is obtained by plugging in a load and then measuring it using a multimeter and clamp. The testing process is conducted to ensure that the plug used for loading functions correctly. The following is a picture of testing the electrical load on the plug, which is shown in [Figure 10](#).



Figure 10. Testing Plugs for Load

4.3 PZEM-004T Sensor

A hardware component is a multifunctional sensor module designed to measure voltage, power, current, energy, frequency, and power factors that occur in an electric current. The configuration used in the installation between the load and the sensor is in the design as shown in [Figure 11](#).

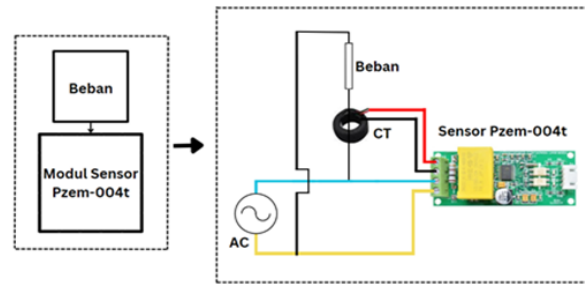


Figure 11. Pzem-004t Load and Sensor Configuration

The sensor module needs to be connected to an AC source to obtain power and electrical energy values that the sensor module can read. From the datasheet, the Pzem-004 T sensor module has working specifications in Table 2 below:

Table 2. Pzem-004t Sensor Specifications

Specification	Value
Voltage	80 - 260 VAC
Voltage test	80 - 260 VAC
Power	100A / 20.000W
Frequency	45 – 65 Hz

4.4 Monitoring System Testing and Configuration

The testing process was conducted to validate the connection of the ESP32 microcontroller to WiFi via the Arduino IDE, which had been previously installed on the ESP32 board. On the board, you need to change the name and Wifi password that have been provided. After inputting information related to Wifi has been completed, compile it to connect to the internet. The following is the process of inputting information related to Wifi as shown in Figure 12.

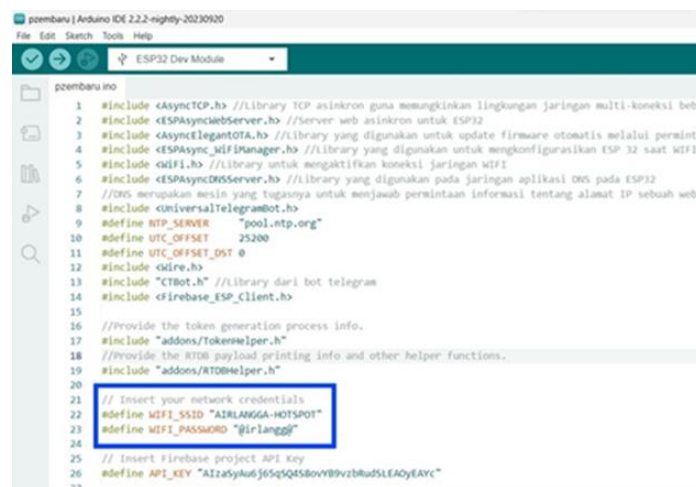


Figure 12. Wifi Connection Input

Through the steps that have been carried out, the ESP32 can connect to the internet automatically. The indicator that the ESP32 is connected to the Wi-Fi network is that the light on the ESP32 board flashes once.

4.5 Data Receiving Platform Testing

The Telegram application is a convenient facility that enables the quick and accurate conveyance of information over long distances. Testing was conducted to validate the connection between the hardware circuit and the platform used, specifically the Telegram application. Users who already have a Telegram bot account can send the /start command, which is used the first time they interact with the bot. Creating bot commands is the primary step to ensure the bot functions properly. The conditions that are met so that the data-receiving platform runs well are as follows:

- a. Controlled electrical equipment and monitoring systems need to be connected to the internet. This condition must be met for the data transfer flow to run smoothly. If there is a disruption, such as one of the devices not being connected to the internet, the monitoring system cannot run properly.
- b. The connection between the Telegram application on the smartphone and the monitoring system controlled by the electricity section has been established, so users can search for bot accounts on the Telegram application as shown in Figure 13 below



Figure 13. Telegram Bot Account

- c. Telegram bot provides button functions according to Figure 4.7, which will make it easier for users to get data information. By pressing the /start function, further button information will be provided regarding the start of the electrical power monitoring circuit. The following button functions are available when the /start button is pressed:
 1. /Voltage: provides information regarding AC voltage data that the PZEM-004 T sensor in real-time has measured.
 2. /Current: provides information regarding AC data that has been measured by the PZEM-004t sensor in real-time.
 3. /Power: provides information regarding electrical power data that has been used and measured by the PZEM-004t sensor in real-time.
 4. /Energy: provides information regarding electrical energy data that has been used and measured by the PZEM-004t sensor in real-time.
 5. /Frequency: provides information related to frequency data that the PZEM-004 T sensor in real-time has measured.
 6. /PF: provides information related to power factor data that the PZEM-004 T sensor in real-time has measured.
 7. /All: provides information related to data containing the values of voltage, current, power, energy, frequency, and overall power factor.
 8. /Data: provides information regarding the function of the new button in the form of /report, which needs to be followed by day, date, and time data in English. The function aims to call the Firebase path to retrieve the history of previously saved data.

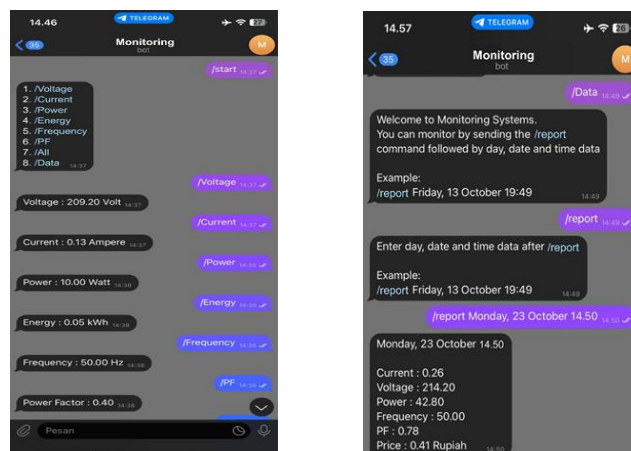


Figure 14. Button Functions on Telegram Bots

- d. Telegram bots can also provide notifications regarding energy resets, which are sent automatically via messaging. The notification will appear at 00:01 WIB, depending on the speed of the internet network

connected to the network. The purpose of an energy reset is to determine the value of energy used within a 24-hour period or over a day.

Based on tests that have been carried out to obtain data results using the Telegram application. Tests will be carried out by installing a load on the electrical power monitoring tool and comparing the measurement results obtained using the IoT-based electric power monitoring tool with those from the Telegram application. Additionally, the results of reading electrical quantities using a multimeter and clamp will be compared. During the data collection process, it was carried out six times with a 10-minute time interval. Below is a picture containing the test results with a load in the form of an iron, which is displayed on the Telegram application and measuring instruments in Figure 15.

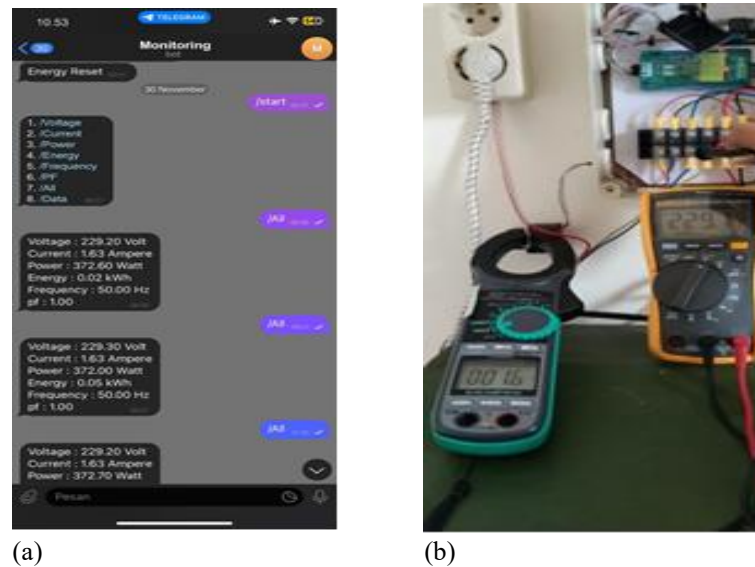


Figure 15. Data Display (a) In the Telegram Application (b) In the Measuring Tool

According to Figure 15, these are the results of the sensor reading process, which are displayed on the Telegram application and measuring instruments. According to Figure 4.9, it is known that picture (a) measures the data on the telegram, and picture (b) measures the data on the measuring instrument. Overall data results obtained using iron weights can be seen in Table 3 below:

Table 3. Iron Load Test Results

Time (Minute)	Pzem-004t Sensor Reading Results						Measuring Instrument	
	V (Volt)	I (Ampere)	P (Watt)	E (kWh)	f (Hz)	Pf	V (Volt)	I (Ampere)
10	229.20	1.63	372.60	0.02	50	1	229.10	1.60
20	229.30	1.63	373.00	0.03	50	1	229.60	1.60
30	229.20	1.63	372.70	0.05	50	1	229.50	1.58
Time (Minute)	Pzem-004t Sensor Reading Results						Measuring Instrument	
	V (Volt)	I (Ampere)	P (Watt)	E (kWh)	f (Hz)	Pf	V (Volt)	I (Ampere)
40	229.10	1.63	372.60	0.6	50	1	229.80	1.57
50	229.40	1.63	373.40	0.08	50	1	229.70	1.58
60	229.20	1.63	372.60	0.09	50	1	229.20	1.60

Table 3 presents the test results obtained by applying a load in the form of iron using a Pzem-004t sensor and measuring instruments, including a multimeter and a clamp. The results of measurements carried out over one hour, with an interval of 10 minutes, showed the Pzem-004t sensor reading, which indicated a stable current value of 1.63 A and a frequency of 50 Hz. Meanwhile, for the current measurement results obtained via the clamp, the values are between 1.57 A and 1.60 A. The voltage obtained based on the Pzem-004t sensor reading data, namely 229.10 V to 229.40 V, is not much different from the measurement obtained via a multimeter. 229.10 V – 229.80 V. The power measurement, taken via the Pzem-004t sensor, yields the most extensive value reading, namely 373.40 Watts. The average energy used for the iron load in one hour is 0.055 kWh.

5. CONCLUSION AND LIMITATION

The monitoring system operates when connected to the internet. The ESP32 microcontroller, pre-programmed through the Arduino IDE software, requires the installation of ESP32 boards in the Arduino IDE for proper functioning. Once the installation process is completed, the next step involves connecting ESP32 to the Telegram application. Creating a new bot account on Telegram is necessary to obtain data within the application. If ESP32 and the Telegram application are not connected to the internet, ESP32 cannot transmit data from the Pzem-004 T sensor to the Telegram application.

When a load is applied to the Pzem-004 T sensor through the socket, it reads values such as voltage, current, power, energy, power factor, and electrical frequency. The ESP32 processes the obtained sensor values and displays them on the Telegram bot. Data collected from the Pzem-004 T sensor readings are sent to the Telegram application using the connected Wi-Fi on the ESP32 microcontroller. Through the Telegram bot, users can access electrical power monitoring data by sending the "/start" command to the bot. This command is then forwarded to the data processing unit, i.e., the ESP32. The ESP32 retrieves data from the installed Pzem-004 T sensor and sends it back to the Telegram bot. Users automatically receive monitoring data through the Telegram bot, including indicators such as current, voltage, power, energy, power factor, and frequency values, all displayed in the Telegram application. Additionally, the device provides information about the energy reset on the Pzem-004 T sensor, performed at 00:01 WIB, and sends it to Telegram. Energy reset is used to determine the daily energy consumption.

The Telegram application can receive sensor reading information via Firebase. Users can send messages or data to connect with Firebase by following instructions to format their writing according to the path in the Firebase real-time database. The /report command instructs the ESP32 microcontroller to retrieve data stored in Firebase. Telegram application responses related to sensor reading data are provided based on the user's specified day, date, month, and time when initially writing it, along with the /report command. This enables users to monitor energy usage in real-time and access previous usage data, thereby minimizing excessive electricity consumption.

This study has several limitations that should be taken into consideration. The monitoring system relies heavily on an active internet connection; if either the ESP32 or the Telegram application is offline, data transmission from the Pzem-004 T sensor will be disrupted, resulting in impaired real-time monitoring. Additionally, the system is designed explicitly for ESP32 and Pzem-004 T sensors, which limits its compatibility with other hardware. From a software perspective, the ESP32 must be programmed using Arduino IDE with the necessary board installation, which may be challenging for users unfamiliar with the platform. Data transmission between the ESP32, Firebase, and Telegram is also dependent on network stability, which can potentially cause delays in real-time monitoring. Furthermore, data storage is managed through Firebase, which may have limitations in capacity and long-term data retrieval.

The system requires predefined commands, such as /start and /report, to access data, restricting flexibility in retrieving specific information. Additionally, the energy reset function is fixed to 00:01 WIB daily, with no customization options available to users. Security risks also exist, as data transmission may be vulnerable without proper encryption, which could potentially lead to unauthorized access. Moreover, the system is only available on Telegram, which limits its usability for users who prefer other platforms. Lastly, its scalability is constrained, as modifications would be required for large-scale industrial applications with multiple ESP32 devices and sensors. Addressing these limitations would enhance the system's flexibility, security, and broader applicability.

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REFERENCES

- [1] W. Chen, M. Alharthi, J. Zhang, & I. Khan, "The Need for Energy Efficiency and Economic Prosperity in a Sustainable Environment", *Gondwana Research*, vol. 127, pp. 22-35, 2024. <https://doi.org/10.1016/j.gr.2023.03.025>
- [2] D. Vo, A. Vo, & C. Hò, "Urbanization and Renewable Energy Consumption in the Emerging ASEAN Markets: A Comparison Between Short and Long-Run Effects", *Heliyon*, vol. 10, no. 9, pp. e30243, 2024. <https://doi.org/10.1016/j.heliyon.2024.e30243>
- [3] T. Anggraini and C. Santoso, "Development of Ocean Renewable Energy Model in Indonesia to Support Eco-Friendly Energy", *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLVIII-M-3-2023, pp. 1-5, 2023. <https://doi.org/10.5194/isprs-archives-xxviii-m-3-2023-1-2023>
- [4] K. Hanifulkhair, A. Priyadi, V. Lystianingrum, & R. Delfianti, "One Day Ahead Prediction of PV Power Plant for Energy Management System Using Neural Network", *2020 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, pp. 107-112, 2020. <https://doi.org/10.1109/isitia49792.2020.9163783>

- [5] R. Ramadhan, M. Mon, S. Tangparitkul, R. Tansuchat, & D. Agustin, "Carbon Capture, Utilization, and Storage in Indonesia: An Update on Storage Capacity, Current Status, Economic Viability, and Policy", *Energy Geoscience*, vol. 5, no. 4, pp. 100335, 2024. <https://doi.org/10.1016/j.engeos.2024.100335>
- [6] I. Apriliyanti, D. Nugraha, S. Kristiansen, & I. Øverland, "To Reform or Not Reform? Competing Energy Transition Perspectives on Indonesia's Monopoly Electricity Supplier Perusahaan Listrik Negara (PLN)", *Energy Research & Social Science*, vol. 118, pp. 103797, 2024. <https://doi.org/10.1016/j.erss.2024.103797>
- [7] G. Dalapati, S. Ghosh, R. Brindha, A. Samanta, T. Wong, S. Chakraborty et al., "Maximizing Solar Energy Production in ASEAN Region: Opportunity and Challenges", *Results in Engineering*, vol. 20, pp. 101525, 2023. <https://doi.org/10.1016/j.rineng.2023.101525>
- [8] R. Delfianti, E. Rovianto, C. Harsito, J. A. Pradana, V. Pongajow, and S. R. . Joshua, "Daily Electrical Energy Forecasting in Rooftop Photovoltaic Systems: A Case Study", *Journal of Soft Computing and Data Mining*, vol. 5, no. 2, pp. 197–207, 2024. <http://dx.doi.org/10.30880/jscdm.2024.05.02.015>
- [9] R. Delfianti, F. Nusyura, A. Priyadi, I. Abadi, & A. Soeprijanto, "Optimizing the Price of Electrical Energy Transactions on the Microgrid System Using the Shortest Path Solution", *International Review on Modelling and Simulations (IREMOS)*, vol. 15, no. 4, pp. 279, 2022. <https://doi.org/10.15866/iremos.v15i4.22712>
- [10] M. Sarker, M. Haram, G. Ramasamy, F. Farid, & S. Mansor, "Solar Photovoltaic Home Systems in Malaysia: A Comprehensive Review and Analysis", *Energies*, vol. 16, no. 23, pp. 7718, 2023. <https://doi.org/10.3390/en16237718>
- [11] E. Rovianto, R. Delfianti, B. Lenggana, & C. Harsito, "Dynamic Optimal Power Flow on Microgrid Incorporating Battery Energy Storage Considering Operational and Maintenance Cost", *Lecture Notes in Mechanical Engineering*, pp. 265-270, 2024. https://doi.org/10.1007/978-981-97-0106-3_44
- [12] M. Sambodo, M. Silalahi, & N. Firdaus, "Investigating Technology Development in the Energy Sector and Its Implications for Indonesia", *Heliyon*, vol. 10, no. 6, pp. e27645, 2024. <https://doi.org/10.1016/j.heliyon.2024.e27645>
- [13] J. Jasiūnas, P. Lund, & J. Mikkola, "Energy System Resilience – A Review", *Renewable and Sustainable Energy Reviews*, vol. 150, pp. 111476, 2021. <https://doi.org/10.1016/j.rser.2021.111476>
- [14] S. Himer, M. Ouaisa, M. Ouaisa, M. Krichen, M. Alswailim, & M. Almutiq, "Energy Consumption Monitoring System Based on IoT for Residential Rooftops", *Computation*, vol. 11, no. 4, pp. 78, 2023. <https://doi.org/10.3390/computation11040078>
- [15] P. Onu, A. Pradhan, & C. Mbohwa, "The Potential of Industry 4.0 for Renewable Energy and Materials Development – The Case of Multinational Energy Companies", *Heliyon*, vol. 9, no. 10, pp. e20547, 2023. <https://doi.org/10.1016/j.heliyon.2023.e20547>
- [16] N. Minh, K. Trung, V. Phap, C. Dinh, Q. Tran, & T. Ngoc, "Assessment of Energy Efficiency Using an Energy Monitoring System: A Case Study of a Major Energy-Consuming Enterprise in Vietnam", *Energies*, vol. 16, no. 13, pp. 5214, 2023. <https://doi.org/10.3390/en16135214>
- [17] H. El-Khozondar, S. Mtair, K. Qoffa, O. Qasem, A. Munyarawi, Y. Nassar et al., "A Smart Energy Monitoring System using ESP32 Microcontroller", *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 9, pp. 100666, 2024. <https://doi.org/10.1016/j.prime.2024.100666>
- [18] M. Mahmood, P. Chowdhury, R. Yeassin, M. Hasan, T. Ahmad, & N. Chowdhury, "Impacts of Digitalization on Smart Grids, Renewable Energy, and Demand Response: An Updated Review of Current Applications", *Energy Conversion and Management: X*, vol. 24, pp. 100790, 2024. <https://doi.org/10.1016/j.ecmx.2024.100790>
- [19] X. Ma, J. Li, Z. Guo, & Z. Wan, "Role of Big Data and Technological Advancements in Monitoring and Development of Smart Cities", *Heliyon*, vol. 10, no. 15, pp. e34821, 2024. <https://doi.org/10.1016/j.heliyon.2024.e34821>
- [20] R. Delfianti, B. Mustaqim, F. Nusyura, A. Priyadi, I. Abadi, & A. Soeprijanto, "Implementation Design of Energy Trading Monitoring Application for Blockchain Technology-Based Wheeling Cases", *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 3, pp. 2931, 2023. <https://doi.org/10.11591/ijece.v13i3.pp2931-2941>
- [21] J. Bhutto, "Solar PV Integrated Power Market Operational Efficiency Improvement through IPM-based SCOPF and TRTC in Green Power Corridors", *Solar Energy*, vol. 275, pp. 112624, 2024. <https://doi.org/10.1016/j.solener.2024.112624>
- [22] P. Rajak, A. Ganguly, S. Adhikary, & S. Bhattacharya, "Internet of Things and Smart Sensors in Agriculture: Scopes and Challenges", *Journal of Agriculture and Food Research*, vol. 14, pp. 100776, 2023. <https://doi.org/10.1016/j.jafr.2023.100776>
- [23] N. Sushma, H. Suresh, L. Mohana, & K. Kumar, "Experimental Investigation on Wireless Integrated Smart System for Energy and Water Resource Management in Indian Smart Cities", *Results in Engineering*, vol. 23, pp. 102687, 2024. <https://doi.org/10.1016/j.rineng.2024.102687>
- [24] M. El-Affifi, B. Sedhom, S. Padmanaban, & A. Eladl, "A Review of IoT-enabled Smart Energy Hub Systems: Rising, Applications, Challenges, and Future Prospects", *Renewable Energy Focus*, vol. 51, pp. 100634, 2024. <https://doi.org/10.1016/j.ref.2024.100634>
- [25] D. Witczak and S. Szymoniak, "Review of Monitoring and Control Systems Based on Internet of Things", *Applied Sciences*, vol. 14, no. 19, pp. 8943, 2024. <https://doi.org/10.3390/app14198943>
- [26] A. Abdullah, H. Man, M. Abdulsalam, M. Karim, S. Yunusa, & N. Jais, "Charting the Aquaculture Internet of Things Impact: Key Applications, Challenges, and Future Trend", *Aquaculture Reports*, vol. 39, pp. 102358, 2024. <https://doi.org/10.1016/j.aqrep.2024.102358>

- [27] M. Fernandez, Y. Go, M. Wong, & W. Fröh, "Review of Challenges and Key Enablers in Energy Systems Towards Net Zero Target: Renewables, Storage, Buildings, & Grid Technologies", *Heliyon*, vol. 10, no. 23, pp. e40691, 2024. <https://doi.org/10.1016/j.heliyon.2024.e40691>
- [28] S. Huda, Y. Nogami, M. Rahayu, T. Akada, M. Hossain, M. Musthafa et al., "IoT-enabled Plant Monitoring System with Power Optimization and Secure Authentication", *Computers, Materials & Continua*, vol. 81, no. 2, pp. 3165-3187, 2024. <https://doi.org/10.32604/cmc.2024.058144>
- [29] T. Saarikko, U. Westergren, & T. Blomquist, "Digital Transformation: Five Recommendations for the Digitally Conscious Firm", *Business Horizons*, vol. 63, no. 6, pp. 825-839, 2020. <https://doi.org/10.1016/j.bushor.2020.07.005>
- [30] K. Jakobsen, M. Mikalsen, & G. Lilleng, "A Literature Review of Smart Technology Domains with Implications for Research on Smart Rural Communities", *Technology in Society*, vol. 75, pp. 102397, 2023. <https://doi.org/10.1016/j.techsoc.2023.102397>
- [31] S. Siraparapu and S. Azad, "Securing the IoT Landscape: A Comprehensive Review of Secure Systems in the Digital Era", *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 10, pp. 100798, 2024. <https://doi.org/10.1016/j.prime.2024.100798>
- [32] A. Aldoseri, K. Al-Khalifa, & A. Hamouda, "AI-Powered Innovation in Digital Transformation: Key Pillars and Industry Impact", *Sustainability*, vol. 16, no. 5, pp. 1790, 2024. <https://doi.org/10.3390/su16051790>
- [33] A. Rehman, I. Alblushi, M. Zia, H. Khalid, U. Inayat, M. Benbouzid et al., "A Solar-Powered Multi-Functional Portable Charging Device (SPMFPCD) with Internet-of-Things (IoT)-based Real-Time Monitoring—An Innovative Scheme Towards Energy Access and Management", *Green Technologies and Sustainability*, vol. 3, no. 1, pp. 100134, 2025. <https://doi.org/10.1016/j.grets.2024.100134>
- [34] S. Kordova and R. Hirschprung, "Effectiveness of the Forced Usage of Alternative Digital Platforms During the COVID-19 Pandemic in Project Communication Management", *Heliyon*, vol. 9, no. 11, pp. e21812, 2023. <https://doi.org/10.1016/j.heliyon.2023.e21812>
- [35] M. Huang, W. Liu, T. Wang, H. Song, X. Li, & A. Liu, "A Queuing Delay Utilization Scheme for On-Path Service Aggregation in Services-Oriented Computing Networks", *IEEE Access*, vol. 7, pp. 23816-23833, 2019. <https://doi.org/10.1109/access.2019.2899402>
- [36] H. Cing and N. Mansor, "Internet of Things (IoT): Real-Time Monitoring for Decision Making Among The Malaysian Contractors", *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 32, no. 3, pp. 455-470, 2023. <https://doi.org/10.37934/araset.32.3.455470>
- [37] M. Babiuch, P. Foltýnek, & P. Smutný, "Using the ESP32 Microcontroller for Data Processing", *2019 20th International Carpathian Control Conference (ICCC)*, pp. 1-6, 2019. <https://doi.org/10.1109/carpathiancc.2019.8765944>
- [38] A. Samosir, A. Rozie, S. Purwiyanti, H. Gusmedi, & M. Susanto, "Development of an IoT Based Monitoring System for Solar PV Power Plant Application", *2021 International Conference on Converging Technology in Electrical and Information Engineering (ICCTEIE)*, pp. 82-86, 2021. <https://doi.org/10.1109/iccteie54047.2021.9650634>
- [39] N. Sugiarta, M. Pradnyana, D. Cantona, I. Sugina, I. Putra, & I. Wiryanta, "Solar DC Power System Monitoring for Thermoelectric Mini-Fridge Using Blynk App", *2021 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation (ICAMIMIA)*, pp. 168-172, 2021. <https://doi.org/10.1109/icamimia54022.2021.9807826>
- [40] M. Kader, M. Mansor, W. Mustafa, Z. Razali, A. Gunny, S. Setumin et al., "Urban Farming Growth Monitoring System Using Artificial Neural Network (ANN) and Internet of Things (IOT)", *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 43, no. 1, pp. 144-159, 2024. <https://doi.org/10.37934/araset.43.1.144159>
- [41] P. Megantoro, B. Pramudita, P. Vigneshwaran, A. Yurianta, & H. Winarno, "Real-Time Monitoring System for Weather and Air Pollutant Measurement with HTML-based UI Application", *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 3, pp. 1669-1677, 2021. <https://doi.org/10.11591/eei.v10i3.3030>
- [42] A. Khan, A. Laghari, T. Gadekallu, Z. Shaikh, A. Javed, M. Rashid et al., "A Drone-Based Data Management and Optimization using Metaheuristic Algorithms and Blockchain Smart Contracts in A Secure Fog Environment", *Computers and Electrical Engineering*, vol. 102, pp. 108234, 2022. <https://doi.org/10.1016/j.compeleceng.2022.108234>
- [43] B. Gopika and S. George, "IoT Based Smart Energy Management System using PZEM-004T Sensor & Node MCU," *International Journal of Engineering Research and Technology*, vol. 9, pp. 45–48, 2021. <https://doi.org/10.17577/IJERTCONV9IS07011>
- [44] I. Allafi and M. Iqbal, "Design and Implementation of A Low Cost Web Server using ESP32 for Real-Time Photovoltaic System Monitoring", *2017 IEEE Electrical Power and Energy Conference (EPEC)*, pp. 1-5, 2017. <https://doi.org/10.1109/epec.2017.8286184>
- [45] A. Muhammed, V. Oisamoje, H. Amhenrior, E. Evbogbai, V. Abanihi, L. Bello et al., "Design and Implementation of an IoT Based Home Energy Monitoring System", *2022 5th Information Technology for Education and Development (ITED)*, pp. 1-7, 2022. <https://doi.org/10.1109/ited56637.2022.10051192>
- [46] S. Wasoontarajaroen, K. Pawasan, & V. Chamnanphrai, "Development of An IoT Device for Monitoring Electrical Energy Consumption", *2017 9th International Conference on Information Technology and Electrical Engineering (ICITEE)*, pp. 1-4, 2017. <https://doi.org/10.1109/iciteed.2017.8250475>

- [47] D. Wijayanto, S. Haryudo, T. Wrahatnolo, & N. Nurhayati, "Rancang Bangun Monitoring Arus Dan Tegangan Pada PLTS Sistem On-Grid Berbasis Internet Of Things (IoT) Menggunakan Aplikasi Telegram", *Jurnal Teknik Elektro*, vol. 11, no. 3, pp. 447-453, 2022. <https://doi.org/10.26740/jte.v11n3.p447-453>
- [48] G. Avisyah, I. Putra, & S. Hidayat, "Open Artificial Intelligence Analysis using ChatGPT Integrated with Telegram Bot", *Jurnal ELTIKOM*, vol. 7, no. 1, pp. 60-66, 2023. <https://doi.org/10.31961/eltikom.v7i1.724>
- [49] W. Santoso, W. Nurjannah, M. Shudhuashar, A. Fadilah, M. Junas, & D. Handayani, "The Development of Telegram Bot Api to Maximize The Dissemination Process of Islamic Knowledge in 4.0 Era", *Jurnal Teknik Informatika*, vol. 15, no. 1, pp. 52-62, 2022. <https://doi.org/10.15408/jti.v15i1.24915>
- [50] M. Abu.Zaid, R. Abdullah, S. Ismail, & N. Dzulkefli, "IoT-based Emergency Alert System Integrated with Telegram Bot", *2023 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS)*, pp. 126-131, 2023. <https://doi.org/10.1109/i2cacis57635.2023.10193550>
- [51] S. Maheswaran, R. Gomathi, S. Sathesh, S. Poovizhi, R. Ridhish, S. Nanthakkumaran et al., "Intelligent Cold Chain Security: Nano Power Temperature Sensors, ESP32 and Telegram Bot Integration for Temperature Assurance and Environmental Harm Prevention", *Journal of Environmental Nanotechnology*, vol. 13, no. 1, pp. 17-25, 2024. <https://doi.org/10.13074/jent.2024.03.241492>
- [52] F. López-Ostenero, J. Martínez-Romo, L. Plaza, & L. Araujo, "Personalized Self-Assessment Tool Using a Telegram Bot: A Case Study on Data Structures and Algorithms", *2024 IEEE Global Engineering Education Conference (EDUCON)*, pp. 1-8, 2024. <https://doi.org/10.1109/educon60312.2024.10578697>
- [53] N. Raghu, I. Miah, & A. Tonmoy, "Ultrasonic Sensor Based Door Security Camera with Wireless Data Transfer in Telegram Bot Using WIFI", *2023 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE)*, pp. 402-405, 2023. <https://doi.org/10.1109/iitcee57236.2023.10090954>
- [54] D. Bestari and A. Wibowo, "IoT Based Real-Time Weather Monitoring System Using Telegram Bot and Thingsboard Platform", *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 17, no. 06, pp. 4-19, 2023. <https://doi.org/10.3991/ijim.v17i06.34129>
- [55] E. Triandini, M. Afrianto, B. Irawan, A. Maricar, & P. Crisnapati, "IoT-Based Automated Environmental Control System for Oyster Mushroom Cultivation Using ESP8266 and Telegram Bot", *2024 Ninth International Conference on Informatics and Computing (ICIC)*, pp. 1-6, 2024. <https://doi.org/10.1109/icic64337.2024.10956269>
- [56] B. Prakosa, A. Hendrawan, I. Setiadi, R. Ritzkal, I. Riawan, & F. Riana, "Implementation of a Real-Time Wi-Fi Voucher Notification System Utilizing Telegram API Bot", *Ingénierie Des Systèmes D Information*, vol. 28, no. 6, pp. 1587-1596, 2023. <https://doi.org/10.18280/isi.280615>

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