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Development of Wireless Smart Current Sensor for Power Monitoring System

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ABSTRACT- The traditional distribution network must be replaced by a smart grid, durable, and dependable, due to the rising demand for power by the customer. The smart grid will need a smart monitoring system based on the smart current sensor at all buildings to determine the power consumption with its costs. This paper proposed a wireless monitoring system for measuring the three-phase currents in the building by using three HW-666 current sensors with Arduino and ESP32 microcontrollers to transmit the data according to the Internet of Things (IoT) technique to the Telegram app on the mobile phone. The power consumption is determined by assuming the constant voltages and power factor at the building that is tested with this monitoring system. The results are scheduled on the personal computer (PC) by using the serial monitor of the Arduino software and also by receiving the message every 20 minutes on the telegram app furthermore, real-time data can be obtained immediately upon receiving transmitted commands from the Telegram application. In addition, this monitoring system is designed to cut off power to the building and sound an alarm if abnormal currents are detected. The proposed monitoring system is given the same results when a comparison with the ammeter with errors not exceeding 10%.

Keywords: Arduino microcontroller, ESP32 microcontroller, AC smart current sensor, smart meter, and monitoring system.

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1. INTRODUCTION

Power monitoring systems are utilized to keep in mind the quantity of energy being absorbed in a certain industry. Traditionally, power meters and other electrical measurement devices have been utilized in the manufacturing industry to maintain a check of energy demand [1]. However, the need for several measurement types of equipment has made meter-based power monitoring devices complex. The work is made easier in this respect by the development of power meters into intelligent power meters, which measure and indicate many kinds of electrical information without the need for additional measurement instruments [2].

Furthermore, to save time, using appropriate smart technology to monitor power consumption rather than manually collecting data enables quick analysis of the electrical power trend. The current Internet of Things (IoT) based technological devices can accomplish this mission more effectively in this situation [3]. Using IoT tools and monitoring systems, diverse electrical information may be immediately collected and shown in graphical form. Various IoT devices, including Arduino, esp32 microcontroller, Raspberry Pi, etc. may be utilized for archiving the data gathered from monitoring systems deployed in various industrial locations for later use [4].

Physical items may be linked to the online world, which can be managed directly from any place, as long as the IoT gadgets or equipment remain attached to the actual world. IoT gadgets are being utilized for a wide range of real-time purposes, including intelligent media, weather monitoring, intelligent manufacturing, educated medicine and health care, smart homes and buildings, power management, transport, etc. This is due to the wireless control of these items [5].

There are several types of IoT gadgets on offer that are utilized for the aforementioned purposes. The application and the job at hand determine which IoT gadgets should be used. However, because of their ease of use and simplicity of operation, Arduino and ESP32 are the most widely used IoT gadgets. Additionally, they are less expensive than other IoT gadgets [6]–[8].

Recently, a lot of individuals attempt to utilize an Arduino due to how simple C++ has been made and how easily you can program, erase, and reprogram an Arduino microcontroller at any moment [9]. Therefore, this paper is using Arduino to save data that can be estimated by sensors for the monitoring system and also uses the ESP32 microcontroller to transmit the received data from Arduino to the internet.

This section will discuss several types of research that have been presented for developing various monitoring system types with various uses in recent years. In [10], an Arduino microcontroller is used to determine a household's total power, voltage, current, and power factor of demand without transferring this data wirelessly but only used Arduino software to display it on a computer.

To make sure that the overall consumed power of the home does not exceed the upper limit. In [2], the Raspberry Pi is utilized to obtain data for power monitoring systems with a variety of electrical information from the industry's current energy meters and saved it via PC or mobile. In [11], power consumption is calculated using a single-phase power meter and sensors for voltages and currents. the data is carried out and shown on the LCD and PC while voltage, current data, and instantaneous power calculation are captured and analyzed using Arduino as the control device.

In [12], is used the Zigbee Protocol with a network of wireless sensors for single-phase electrical monitoring devices. This network has three groups with two sensor units for determining power consumption. Moreover, in [13], a smart meter device with the controlling of individual loads utilizing Arduino, Raspberry Pi, and additional sensors is conceived and built. The last power monitoring device is also outfitted with many capabilities, including the ability to accept payments via PayPal or Visa and the ability to notify the customer if their consumption estimate surpasses a threshold (75%).

Furthermore, in [14] an intelligent meter is designed and put into use to monitor the power consumption of the home, log data in actual time, display the time, and operate any connected devices having power outputs. Additionally, the PC receives data through ZigBee while the power is on and off and a zero-cross of the AC signal is recognized to compute phase shift.

According to the previous survey, the smart network combines a wide range of technologies, and services to electricity user-side appliances with detecting, communication, and control techniques from the producing, transmitting, and distributing parts to control and distribute power in a more efficient, affordable, and secure manner. With a smart meter, every appliance employed in homes and buildings may be monitored with a schedule, remotely governed, and watched over by smart network technology[15]. Therefore, the monitoring smart system will be necessary for the smart distribution network, and monitoring electricity consumption may help lower customer demand for power by promoting a culture of increased electricity consumption while also outlining the associated costs[16]. The current article introduced a new monitoring system that measures the three-phase AC currents in any building utilizing two microcontrollers (Arduino and ESP32) and three current sensors. By assuming constant voltage and power factor and employing the Arduino C++ programming language, the data from the sensor is used to determine the total power usage. Additionally, the ESP32 microcontroller is utilized to constantly communicate data from the Arduino to the telegram app on the phone through the internet.

The following sections of this article are structured as follows. The second portion describes the difficulties' mathematical model. The third section explains the suggested approach for achieving the research goal. The conversations and the simulation's outcomes are contextualized in part four. The results and recommendations for future works are in the *fifth section*.

2. MATHEMATICAL MODEL

This section introduces the mathematical model of the AC current sensor which is a Current Transformer (CT) used in the design of monitoring systems with power consumption calculations. The ability of the CT to accurately reproduce the primary (main) current on the other (secondary) side of the CT in terms of both magnitude and pattern defines the CT's functionality [17]. The Arduino (UNO) was chosen for this project as the control device, and it operates with a maximum DC input voltage of 5V and a maximum current of 40mA [18],[19]. In order to demonstrate how AC analog current with peak value may be transformed to the DC input voltage for AC current measurement, the following equations will be used. The current sensor (HW-666) that is used in this project is shown in *figure 1*.

Figure 1: Current sensor HW-666

The HW-666's secondary terminals are attached to a 200Ω resistor, and it is functioning with a turn ratio of 1000/1 and a minimum/maximum current of 5mA/5A.

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} \qquad (1)$$

Where I_1 and I_2, represent the peak currents of primary and secondary of the sensor.in addition, N_1 and N_2 represent the primary and secondary turns of the current sensor represent the current.

$$V_2 = I_2 R \qquad (2)$$

Where the V_2 represents the peak voltage across the terminal of the sensor and its input to the Arduino microcontroller. R is the resistor in the HW-666 sensor with the value of 200Ω is used to convert the current in the primary to voltage. The following equation is used to convert the peak value to the RMS value I_{rms}.

$$I_{rms} = \text{maximum } (I_2) \Big/ \sqrt{2} \qquad (3)$$

The measured single-phase current (I) is derived by multiplying I_{rms} value by the turns ratio of 1000/1.

$$I = I_{rms} * 1000/1 \qquad (4)$$

$I_{R\text{-line}}$, $I_{S\text{-line}}$, and $I_{T\text{-line}}$ are determined by repeating this process three times with three sensors to get the three phase RMS values of each phase of the building. The power consumption (P) of each phase can be determined by this following formula:

$$P = IV\cos(\theta) \qquad (5)$$

In the design of this monitoring system, (V) which refers to the phase voltage is considered to be constant and equal to the 220V used in Iraq. $\cos(\theta)$ which refers to the power factor is also assumed to be constant and equal to 0.85 [20]. Therefore,

$$P_{R-line} = I_{R-line} * 220 * 0.85 \quad (6)$$

$$P_{S-line} = I_{S-line} * 220 * 0.85 \quad (7)$$

$$P_{T-line} = I_{T-line} * 220 * 0.85 \quad (8)$$

The $P_{R\text{-}line}$, $P_{S\text{-}line}$, and $P_{T\text{-}line}$ are representing the active power consumption in each phase. So the total power consumption in the building (P_{total}) with Watt unit is determined by using this equation [21]:

$$P_{total} = P_{R-line} + P_{S-line} + P_{T-line} \quad (9)$$

3. PROPOSED MONITORING SYSTEM DESIGN AND IMPLEMENTATION

Regardless of the better thermal performance of new being built, changes in the environment and the use of electrical cooling and heating systems are likely to lead to a rise in domestic power usage in future years. Due to the fact that it accounts for approximately a third of total power consumption, a growth in it may pose serious problems for the security of the energy supply. Because of these factors, it is crucial to prepare for anticipated increases in home power consumption caused by modifications in technology adoption, building features, increased demands for thermal comfort, etc. [22].

Therefore, converting the traditional network to a smart network is one of the most essential preparations for the coming years, and a smart monitoring system is one of the most necessary smart network devices[23]. This article describes a new monitoring system design and implementation that makes use of the IoT technique by employing two microcontrollers (Arduino and ESP32) with three HW-666 current sensors to measure load currents and power consumption in three-phase buildings. Furthermore, if abnormal current consumption is detected or if the current exceeds the high level (for example, 100A), the proposed monitoring system is intended to notify the user (alarm buzzer) and cut off the building's power supply within 15 minutes (as design), allowing users to minimize the amount of power consumed. The proposed system is capable of transmitting data on consumption and abnormal currents in real-time. The user, referred to in this context as the supplier, has the ability to commence live data transmission by providing commands to the system. This functionality enables on-demand access to real-time information, allowing for more effective energy management and faster anomaly identification. Furthermore, to ensure real-time data transmission and processing, the system can be set to deliver information at predefined intervals. The proposed system allows the supplier to actively limit the electricity supply to the consumer through the use of real-time cutoff commands. This increased level of control improves system responsiveness and aids in the implementation of efficient energy management strategies. The outcomes are scheduled and displayed in three methods which are LCD display and PC serial monitor by using the Arduino software, with transmitting all outcomes to the telegram program directly by message after connecting the ESP32 to the internet according to the Wi-Fi services as explained in the designed circuit in *figure 2*.

The component that used in this monitor systems as follow:

- Arduino Microcontroller.
- ESP32 Microcontroller.
- Three HW-666 current sensors.
- LCD (16*2) with I2C.
- Wires for connection.
- 5V DC Relay.
- Alarm (Buzzer).

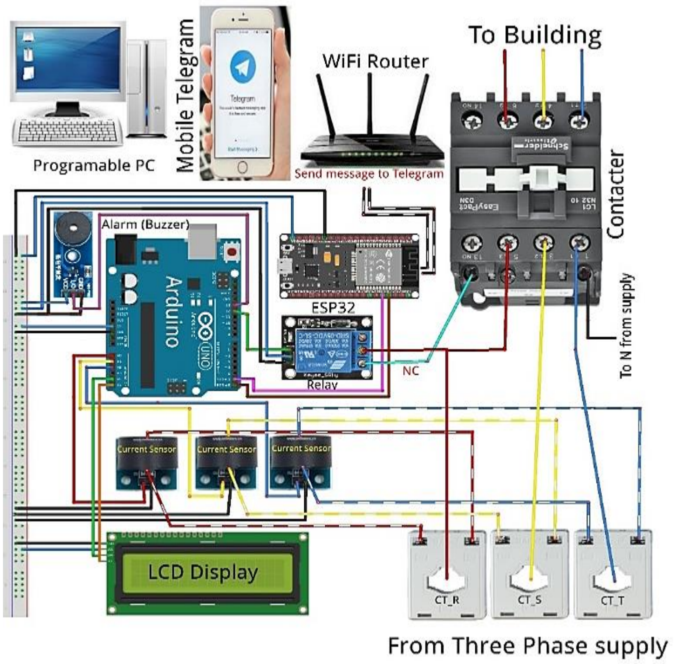

Figure 2: Design circuit of the monitoring system

The block diagram in *figure 3* has explained how the proposed monitor system reads the currents and displays the results at telegram program using the microcontroller.

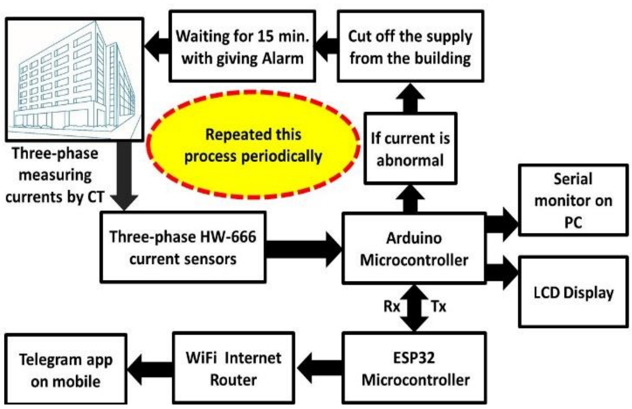

Figure 3: Block diagram of the proposed monitoring system

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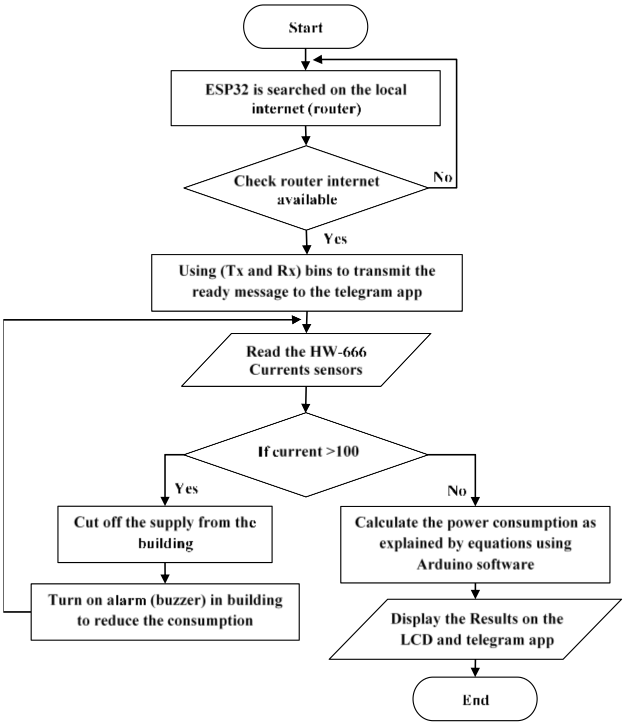

Figure 4: Flowchart of the proposed monitoring system based on smart current sensor

The procedure for calculating the power consumption with the load currents measuring in each phase is described in the following steps:

Step 1: connect the WiFi of the ESP32 to the local internet (router) after inserting the user's name and password by programmable the ESP32 microcontroller by using C++ language .
Step 2: connect the Arduino to the ESP32 according to the pins (Tx and Rx) in the two microcontrollers to exchange the data between them.
Step 3: Read the peak value of the currents by using three HW-666 sensors.
Step 4: convert the peak value of currents to the peak voltages by using *equation (2)* to use it as the input to the analog pins of the Arduino microcontroller.
Step 5: use *equation (3)* in the programmable codes of Arduino to get the RMS values of the load currents.
Step 6: to measure the real load currents in each phase, must be multiplied the values obtained from *step 5* by the factor of the turns ratio of the HW-666 sensors which is equal to 1000/1.
Step 7: check if the measured current (abnormal) exceeds the high level (for example100A), and execute a power supply cutoff to the building within 15 minutes (as per predefined design), enabling users to minimize power consumption.
Step 8: turn on the alarm (buzzer) in the building to allow the user to reduce the consumed power.
Step 9: if the measured current is normal calculate the power consumption in each phase by using *equations (6, 7, and 8)*. Taking into account that, due to the small changes in the voltages and power factors for one building, it is assumed constant.
Step 10: calculate the total consumption of power in the building by using *eq. (9)*.
Step 11: display the outcomes in LCD, Serial monitor in the PC, and transmitting with scheduled all measuring values to the telegram app as a message.

All these steps are explained in flowchart in *figure 4*. In addition, the final implementation of the proposed monitoring system is explained in *figure 5*.

Figure 5: The implementation of monitoring system

4. RESULTS AND DISCUSSION

Three units devices - an LCD, a PC serial monitor, and a WiFi router with ESP32 to link it to a mobile telegram app—are connected to examine this monitoring system. The outcomes of this monitoring system are compared with the manually ammeter to prove the efficiency of the proposed monitoring system. This proposed system is tested in the electrical machinery laboratory at the University of Anbar using the three-phase synchronous machine. To accomplish the objectives of the study, the suggested monitoring system was investigated in two cases as follows:

Case1: Monitoring system without load

This proposed monitoring device has measured the currents of the test three-phase machine by giving the same data which is measured in the ammeter manually in the laboratory which means efficient using this system. The results of currents are equal to zero if the test machine is not operating, this outcome is displayed in the ammeter and also in the LCD, serial monitor of the PC with a received message on the Telegram app as explained in *figure 6*.

Figure 6: Monitoring system with no currents

Case 2: Monitoring system with load

In this case, the monitoring system is reading the currents in each phase of the three-phase synchronous test machine the current in the R-Line (IR) is equal to 0.35A while the currents in the S-Line (IS) and in the T-Line (IT) are equal to 0.31A.

After increasing, the load in the test synchronous machine will increase the three-phase currents to 0.45A as measured in the proposed monitoring system. The ammeter devices in the laboratory are giving approximately the same results of the monitoring system as shown in *table 1*.

Table 1: Monitoring system with load

Cases		IR (R-Line)	IS (S-Line)	IT (T-Line)	Power Consumption
Load one	Monitoring System Measurement	0.35A	0.31A	0.31A	324.3W
	Ammeter Measurement	0.32A	0.31A	0.33A	310.94W
Load two	Monitoring System Measurement	0.45A	0.45A	0.45A	434.0W
	Ammeter Measurement	0.44A	0.43A	0.45A	427.54W

The small differences between the designed monitoring system and the ammeter are normally due to the inaccuracy of the results of ammeters and vary from one device to another. The practical results in the LCD, telegram app, and serial monitor of the PC for this case are explained in *figure 7* while the previous cases are explained in *figure 8* to see the comparison between the proposed monitoring system and ammeter.

Figure 7: Monitoring system with load

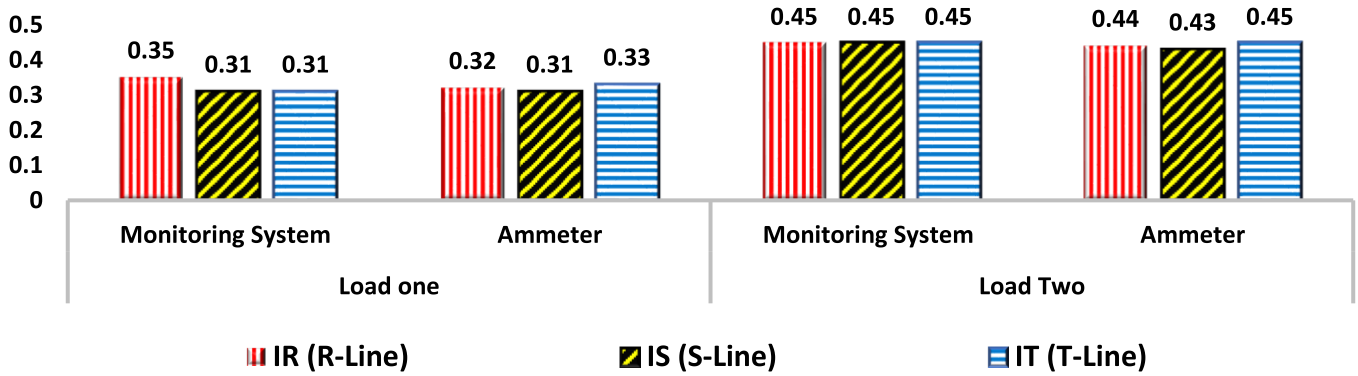

Figure 8: Comparison between monitoring system and ammeter

5. CONCLUSION

In this work, a wireless monitoring system that uses IoT technology and is employed in the smart grid is developed, implemented in practice, and tested. Three HW-666 current sensors are used in the proposed system to measure the AC currents in the three-phase building. Arduino and ESP32 microcontrollers are used to transfer the scheduled data to the Telegram app on the phone. Additionally, the power consumption of the building is computed on the assumption that its voltages and power factor are constant. The suggested monitoring system is designed to alert the user (via an alarm buzzer) and turn off the building's power supply when abnormal current usage is identified or if the current surpasses the high level. When compared to ammeter measurement, the results showed that deploying this monitoring technology in the smart grid was effective. Future modifications to the suggested monitoring system could involve linking multiple buildings to it and using a load-shedding technique between them to prevent the automatic cutting of emergency buildings.

Author Contributions

The first author is putting the paper's background information, dataset collection, editing of the draught, program execution, analytical results, and comparison into practice while also writing the codes for the software. The second author was in charge of supervision, work appraisal, conceptualization, and methodology. The third author was responsible for the designing, execution, and practical outcomes.

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Conflicts of Interest

The authors declare no conflict of interest.

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REFERENCES

[1] K. Matsui, Y. Yamagata, and S. Kawakubo, "Real-time sensing in residential area using IoT technology for finding usage patterns to suggest action plan to conserve energy," Energy Procedia, vol. 158, pp. 6438–6445, 2019, doi: 10.1016/j.egypro.2019.01.171.

[2] M. D. Mudaliar and N. Sivakumar, "IoT based real time energy monitoring system using Raspberry Pi," Internet of Things (Netherlands), vol. 12, p. 100292, 2020, doi: 10.1016/j.iot.2020.100292.

[3] A. H. Alavi, P. Jiao, W. G. Buttlar, and N. Lajnef, "Internet of Things-enabled smart cities: State-of-the-art and future trends," Meas. J. Int. Meas. Confed., vol. 129, no. July, pp. 589–606, 2018, doi: 10.1016/j.measurement.2018.07.067.

[4] Z. S. Ageed et al., "A State of Art Survey for Intelligent Energy Monitoring Systems," Asian J. Res. Comput. Sci., vol. 8, no. 1, pp. 46–61, 2021, doi: 10.9734/ajrcos/2021/v8i130192.

[5] M. U. Farooq, M. Waseem, S. Mazhar, A. Khairi, and T. Kamal, "A Review on Internet of Things," Int. J. Adv. Res. Sci. Commun. Technol., vol. 113, no. 1, pp. 135–144, 2015, doi: 10.48175/ijarsct-2251.

[6] P. Rai and M. Rehman, "ESP32 based smart surveillance system," 2019 2nd Int. Conf. Comput. Math. Eng. Technol. iCoMET 2019, pp. 1–3, 2019, doi: 10.1109/ICOMET.2019.8673463.

[7] Y. Al Mashhadany, A. F. Shafeeq, and K. S. Gaeid, "Design and Implementation of Submarine Robot with Video Monitoring for Body Detection Based on Microcontroller," Proc. - Int. Conf. Dev. eSystems Eng. DeSE, vol. 2020-Decem, pp. 128–133, 2020, doi: 10.1109/DeSE51703.2020.9450796.

[8] A. Holovatyy, "Development of IoT Weather Monitoring System Based on Arduino and ESP8266 Wi-Fi Module," IOP Conf. Ser. Mater. Sci. Eng., vol. 1016, no. 1, p. 012014, 2021, doi: 10.1088/1757-899x/1016/1/012014.

[9] Y. A. Badamasi, "The working principle of an Arduino," Proc. 11th Int. Conf. Electron. Comput. Comput. ICECCO 2014, 2014, doi: 10.1109/ICECCO.2014.6997578.

[10] I. Abubakar, S. N. Khalid, M. W. Mustafa, M. Mustapha, and H. Shareef, "Residential Energy Consumption Management Using Arduino Microcontroller," Adv. Sci. Lett., vol. 24, no. 6, pp. 3887–3893, 2018, doi: 10.1166/asl.2018.11505.

[11] T. M. Chung and H. Daniyal, "Arduino based power meter using instantaneous power calculation method," ARPN J. Eng. Appl. Sci., vol. 10, no. 21, pp. 9791–9795, 2015.

[12] M. F. B. Anbya, M. Salehuddin, S. Hadisupadmo, and E. Leksono, "Wireless sensor network for single phase electricity monitoring system via Zigbee protocol," Proc. 2012 IEEE Conf. Control. Syst. Ind. Informatics, ICCSII 2012, pp. 261–266, 2012, doi: 10.1109/CCSII.2012.6470512.

[13] M. O. Agyeman, Z. Al-Waisi, and I. Hoxha, "Design and implementation of an iot-based energy monitoring system for managing smart homes," 2019 4th Int. Conf. Fog Mob. Edge Comput. FMEC 2019, pp. 253–258, 2019, doi: 10.1109/FMEC.2019.8795363.

[14] M. Burunkaya and T. Pars, "A smart meter design and implementation using ZigBee based Wireless Sensor Network in Smart Grid," 2017 4th Int. Conf. Electr. Electron. Eng. ICEEE 2017, pp. 158–162, 2017, doi: 10.1109/ICEEE2.2017.7935812.

[15] M. B. Mollah et al., "Blockchain for Future Smart Grid: A Comprehensive Survey," IEEE Internet Things J., vol. 8, no. 1, pp. 18–43, 2021, doi: 10.1109/JIOT.2020.2993601.

[16] T. Zhao, C. Zhang, T. Ujeed, and L. Ma, "Online Methodology for Separating the Power Consumption of Lighting Sockets and Air-Conditioning in Public Buildings Based on an Outdoor Temperature Partition Model and Historical Energy Consumption Data," Appl. Sci. MDPI, vol. 11, no. 1031, 2021.

[17] J. Pan, K. Vu, and Y. Hu, "An efficient compensation algorithm for current transformer saturation effects," IEEE Trans. Power Deliv., vol. 19, no. 4, pp. 1623–1628, 2004, doi: 10.1109/TPWRD.2004.835273.

[18] P. R. Manual, "Arduino ® UNO R3 Target areas : Arduino ® UNO R3 Features," Arduino datasheet, pp. 1–13, 2023.

[19] H. Chaudhary, I. R. S. Transformer, and R. Tag, "Advanced CAR Parking System using Arduino," in International Conference on Advanced Computing and Communication Systems, Coimbatore, INDIA, 2017, pp. 1–5.

[20] A. F. Shafeeq and I. I. Ali, "Proper insertion of DSTATCOM in distribution networks based on VSM with network reconfiguration," Indones. J. Electr. Eng. Comput. Sci., vol. 29, no. 1, pp. 66–74, 2023, doi: 10.11591/ijeecs.v29.i1.pp66-74.

[21] A. F. Shafeeq and I. I. Ali, "Simple Strategy for Finding Optimal Location and Size of Distributed Generators and SVC Devices in Radial Distribution Systems," Int. J. Intell. Eng. Syst., vol. 15, no. 5, pp. 261–272, 2022, doi: 10.22266/ijies2022.1031.24.

[22] R. Figueiredo, P. Nunes, M. J. N. O. Panão, and M. C. Brito, "Country residential building stock electricity demand in future climate – Portuguese case study," Energy Build., vol. 209, 2020, doi: 10.1016/j.enbuild.2019.109694.

[23] S. Chen et al., "Internet of Things Based Smart Grids Supported by Intelligent Edge Computing," IEEE Access, vol. 7, pp. 74089–74102, 2019, doi: 10.1109/ACCESS.2019.2920488.

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