SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Design and Implementation of Real-Time Sensors for Three-Phase Induction Motor Performance Monitoring using Internet of Thing (IoT)

Nundang Busaeri[1,*], Nurul Hiron[1], Hendra[2], Aceng Sambas[3,4], Azwa Abdul Aziz[3], Mohamad Afendee Mohamed[3], Mokhairi Makhtar[3]

[1] Department of Electrical Engineering, Universitas Siliwangi, Tasikmalaya 46115, Indonesia
[2] Department of Civil Engineering, Universitas Siliwangi, Tasikmalaya 46115, Indonesia
[3] Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin (UniSZA), Besut Campus, Besut 22200, Malaysia
[4] Department of Mechanical Engineering, Universitas Muhammadiyah Tasikmalaya, Tasikmalaya 46196, Indonesia

ARTICLE INFO

Article history:
Received
Received in revised form
Accepted
Available online

Keywords:
Induction motor; Internet of Things; sensor; power system

ABSTRACT

This article delves into the design and implementation of cost-effective sensors tailored for real-time monitoring of three-phase induction motor performance. The research primarily centers on the assessment of the operational effectiveness of a suite of sensors, including the PZEM-004t power sensor, MLX90614 temperature sensors, NJK-5002C rotation sensors, and ADXL345 vibration sensors, within the context of three-phase induction motor performance analysis. The monitoring system for three-phase induction motor performance is built around the ESP-32 platform, incorporating the ADXL345 vibration sensor. This article successfully presents the individual sensor performance, which was systematically evaluated through testing on a three-phase induction motor that had been meticulously designed and closely observed. The unit tests reveal that all sensors employed in the experiments exhibit an average error rate of less than 5%. When assessed as an integrated system, the three-phase induction motor performance monitoring system demonstrates robust functionality, effectively measuring critical variables such as voltage, current, power factor, temperature, vibration, and rotational speed.

1. Introduction

In the ever-evolving landscape of industrial operations, the paramount importance of efficiency and dependability cannot be overstated [1]. Nowhere is this significance more pronounced than in the coconut shell briquette sector, where the very sustainability and financial viability of the industry are intrinsically linked to the performance of its machinery, particularly the 3-phase induction motors [2-3]. These motors serve as the linchpin of production, driving critical processes at the core of operations. Their significance extends far beyond mere mechanical components; they are the lifeblood of the industry's performance and profitability [4]. Even the slightest disruption or

* *Corresponding author.*
E-mail address: nundangb@unsil.ac.id

https://doi.org/10.37934/araset.49.2.162175

malfunction in these motors can trigger a chain reaction, resulting in costly downtime and substantial financial setbacks, which can ultimately jeopardize the industry's long-term sustainability [5].

This innovative monitoring system, leveraging cutting-edge IoT (Internet of Things) technology and fortified with classical engineering expertise, represents a significant advancement in the industry's relentless pursuit of heightened performance and sustainability [6-8]. Beyond merely furnishing data, this system provides real-time insights into the operational efficiency of 3-phase induction motors, offering a lifeline to the industry's enduring success [9-10]. It empowers predictive maintenance, facilitating timely interventions to avert disruptions and sustain the seamless flow of production processes. In this pivotal role, the system safeguards the industry's financial stability and ensures its capacity to meet the evolving demands of a dynamic market [11-12].

Numerous scholarly works have addressed the topic of monitoring three-phase induction motor systems. For instance, Kumar *et al*., [13] devised an economical and efficient protection scheme targeting common abnormal conditions—namely, overcurrent, overvoltage, and overtemperature—for three-phase induction motors. Agyare *et al*., [14] proposed a method for detecting and classifying faults in 3-phase squirrel cage induction motors through the application of a fuzzy logic controller. Santhosh *et al*., [15] delineated a protection system for three-phase induction motors employing a RISC microcontroller (PIC18F4520) and integrated a graphical user interface webpage for remote monitoring, control, and parameter adjustments. Işık *et al*., [16] developed a mobile device-centered system for monitoring and controlling the parameters of three-phase asynchronous motors. Their design encompassed asynchronous motors, frequency converters, programmable logic controllers (PLCs), a mobile interface server, and mobile devices. In a similar vein, Birbir and Nogay [17] presented a monitoring and control system for three-phase induction motors utilizing PLC technology. Moreover, Ioannides [18] elaborated on the implementation of a monitoring and control system for induction motors, also grounded in PLC technology. Ioannides [18] additionally provided insights into hardware and software aspects, particularly focusing on speed control and protection mechanisms, substantiating these with outcomes derived from performance tests. In another notable study, Noyjeen *et al*., [19] harnessed Internet of Things (IoT) technology to monitor and diagnose the performance of three-phase induction motors, while simultaneously recording critical operational parameters. Notably, they demonstrated the storage of information in a cloud platform, access through web interfaces, and visualization on smartphones via the MIT application. Abid *et al*. [20] conducted an analysis of induction motor faults using MATLAB/SIMULINK. They proposed an integrated approach to achieve optimal protection, which encompasses both conventional methods and Internet of Things (IoT) technologies. This approach offers flexibility, allowing for both automatic and manual control, thus ensuring full controllability tailored to the specific needs of protection engineers across diverse load scenarios. However, despite the wealth of literature mentioned above, there appears to be a discernible gap in comprehensive discussions related to the amalgamation of a diverse array of sensors—including those designed for power, temperature, rotation, and vibration—in a unified system tailored for the monitoring of three-phase induction motor performance. This lacuna underscores the distinctive contribution and significance of the present study in advancing the field.

The main contribution of this work is to design, implement, and assess a cost-effective three-phase induction motor performance monitoring system employing various sensors, including the PZEM-004t power sensor, MLX90614 temperature sensors, NJK-5002C rotation sensors, and ADXL345 vibration sensors. Specifically, the study aims to evaluate the individual sensor performance, ensuring that they exhibit an average error rate of less than 5%, and to demonstrate the overall effectiveness of the integrated monitoring system in accurately measuring critical parameters such as voltage, current, power factor, temperature, vibration, and rotational speed in real-time.

2. Methodology
2.1 Sensor Selection and Integration

The first step in our methodology involves the careful selection and integration of a suite of sensors crucial for real-time monitoring of three-phase induction motor performance. The sensors employed in this study include the PZEM-004t power sensor, MLX90614 temperature sensors, NJK-5002C rotation sensors, and ADXL345 vibration sensors (See Table 1). These sensors were chosen for their compatibility with the monitoring system and their ability to capture critical motor performance data.

Table 1
Sensor information

Variable	Sensor Type	Reference	
		Brand	Code
Vibration	ADXL345	Samsung	Gyroscope
Temperature	MLX90614	Bosch	GTC 400 C
Power	PZEM-004t	Hioki	PQ3198
Rotation	NJK-5002C	Krisbow	Tachometer KW06-583

Figure 1 illustrates the holistic system configuration, featuring a 3-phase induction motor with a power rating of 2kW as the primary object of observation. The sensing subsystem encompasses a power sensor (PZEM-004t 100A), a three-axis accelerometer vibration sensor (ADXL345), a contactless temperature sensor (MLX90614), and a hall-effect proximity sensor for RPM measurement (NJK-5002C). The core of the system includes a microprocessing unit (MCU) module, with the ESP-32 serving as the publisher, a server service employing MQTT as the Broker, and modules for PC/laptop and smartphone, each functioning as a publisher.

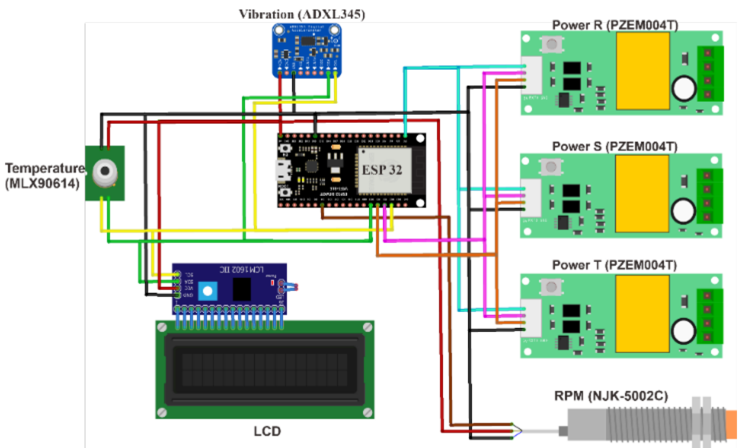


Fig. 1. Electronic schematic for sensor integration

Generally, motor vibration can be quantified using Eqn. (1), in which 'a' represents the vibration acceleration, measured in meters per second squared (m/s^2), 'd^2x' denotes the change in position of the vibrating particle over time, and '*dt*' represents the elapsed time in seconds (s).

$$a = \frac{d^2x}{dt^2} \tag{1}$$

The temperature on the surface of an induction motor can be determined using Eqn. (2), where T represents the motor temperature rise (°C), P is the motor output power (watts), R_{th} stands for the motor thermal resistance (°C/W), A denotes the surface area of the motor acting as a heat source (m²), t represents time in seconds (s), and τ represents the thermal time constant, which is contingent on the motor's thermal characteristics. Furthermore, the temperature resulting from the operation of the induction motor, influenced by the ambient temperature, can be calculated using Eqn. (3), where T_a represents the initial temperature of the motor (°C).

$$\Delta T = \frac{P\,.\,Rth}{A} \tag{2}$$

$$T = T_a + (PR_{th})\,.\,(1 - e^{1(t/\tau)}) \tag{3}$$

The energy within the induction motor is derived from the power contained within the motor's environment and the duration of its operation [21-26]. Two key aspects are considered: electrical power (P_{el}) and mechanical power (P_{me}). The electrical power within a three-phase induction motor is expressed numerically as Eqn. (4), where P_{el} represents the electrical power of the induction motor (W), V_{ph} is the operating voltage of the induction motor (V), I_{ph} is the current flowing through the motor (A), and $cos\ \varphi$ is the power factor, representing the angle between voltage and current.

Mechanical power is represented as shown in Eqn. (5), where T represents the motor torque (N·m), and ω denotes the motor's angular velocity or rotation rate (rad/s). The calculation of electrical energy (E_{el}) is carried out using Eqn. (6), while mechanical energy (E_{me}) is determined using Eqn. (7). Consequently, motor efficiency (η) can be computed through Eqn. (8), and power losses (P_{loss}) can be evaluated with Eqn. (9)."

$$P_{el} = \sqrt{3}\,.\,V_{ph}\,.\,I_{ph}\,.\,cos\varphi \tag{4}$$

$$P_{me} = T.\,\omega \tag{5}$$

$$E_{el} = \int_0^t P_{in}\,dt \tag{6}$$

$$E_{me} = \int_0^t P_{me}\,dt \tag{7}$$

$$\eta = \frac{E_{el}}{E_{me}} \tag{8}$$

$$P_{loss} = P_{el} - P_{me} \tag{9}$$

2.2 System Design and Implementation

The core of our methodology involves the meticulous design and implementation of the three-phase induction motor performance monitoring system. This process includes the development of appropriate interfaces and communication protocols to ensure data accuracy and real-time monitoring capabilities. The system was engineered to collect data from the sensors simultaneously, enabling a comprehensive analysis of motor performance parameters.

Figure 2 illustrates the architectural design of the system, encompassing five essential components. Part 1 represents the measurement entity, in the form of a three-phase induction motor. The second component is the sensor unit responsible for detecting and monitoring parameters such as energy consumption, motor shaft rotation, temperature, and vibration. The third segment acts as the data processing unit, responsible for aggregating sensor data into a coherent digital format that can be seamlessly communicated with the fourth component, referred to as the 'broker.' This intermediary element serves as a bridge, facilitating internet services between the publisher (third part) and the fifth part, which is the subscriber. In simpler terms, the subscriber could be a smartphone or tablet, receiving and interacting with the digital information provided by the system.

The sensor system begins by receiving signals from a three-phase induction motor. These incoming signals are subsequently transformed into digital data and subjected to processing by the ESP-32 microcontroller. Once processed, the data is transmitted to the server through the MQTT service, enabling the presentation of graphical representations, tabulated data, and data logging accessible via both laptops and smartphones.

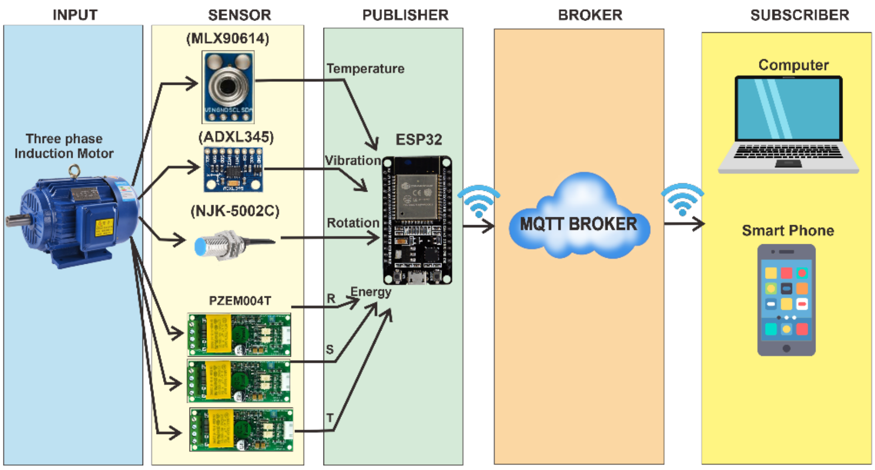


Fig. 2. Implementation of three-phase induction motor using IoT

2.3 Testing and Validation

To assess the performance of the individual sensors and the integrated monitoring system, we conducted rigorous testing on a three-phase induction motor. The motor was selected to represent real-world industrial conditions, and our testing procedures aimed to replicate these conditions as closely as possible. Unit tests were performed to evaluate the accuracy and reliability of each sensor separately, with a particular focus on achieving an average error rate of less than 5%.

3. Results and Discussion

3.1. Hardware Validation

In this section, we present the outcomes of an extensive testing and monitoring initiative conducted on a three-phase induction motor, enhanced with an array of sensors, including power sensors (PZEM-004t), temperature sensors (MLX90614), rotation sensors (NJK-5002C), and vibration sensors (ADXL345). The data processing and management are orchestrated by the ESP32 microcontroller, as depicted in Figure 3. The primary objective of this study was to underscore the pivotal role of real-time monitoring in comprehending the dynamic performance variables of a three-phase induction motor.

We commence by discussing the insights derived from an analysis of power consumption and power quality, leveraging the capabilities of the PZEM-004t power sensor. Real-time power data is harnessed to optimize energy efficiency by implementing requisite adjustments in the motor's operation. Additionally, the identification of power quality anomalies, such as power factor imbalances, bears significant implications for motor performance, reinforcing the sensor's role in preventive maintenance and energy conservation. Next, we delve into the indispensable function of the non-contact temperature sensor, MLX90614, in safeguarding the motor's safe operation. Continuous temperature monitoring offers early warnings regarding potential overheating issues, facilitating timely interventions that are pivotal for both the motor's longevity and operational safety.

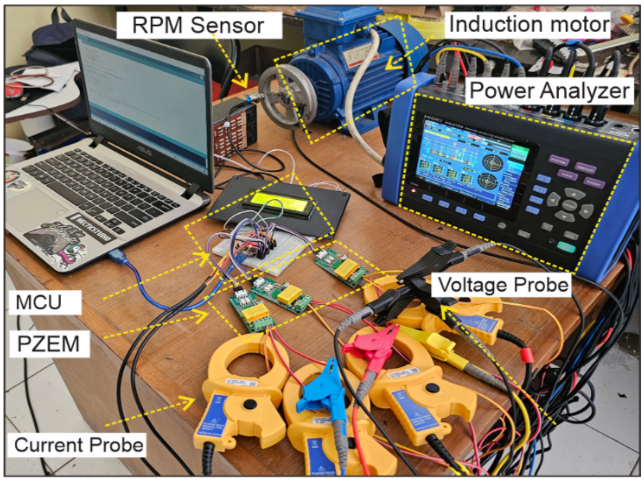


Fig. 3. Hardware of three-phase induction motor using IoT

The incorporation of the NJK-5002C rotation sensor onto the motor's axis empowers us to monitor rotational speed and direction in real-time. This data is instrumental in optimizing motor performance for diverse industrial applications, enabling precise adjustments that enhance both productivity and product quality. We also examine the contribution of the ADXL345 vibration sensor, which excels in detecting and analyzing vibrations in real-time. Rapid identification of irregular vibrations allows for the proactive resolution of mechanical issues before they escalate, thus averting costly motor breakdowns and preserving operational continuity.

Further in our discussion, we elaborate on the central role played by the ESP32 microcontroller as the nerve center for data processing and analysis. The ESP32 efficiently collects data from all sensors, processes it in real-time, and furnishes actionable insights. Its capabilities extend to data logging and threshold monitoring, which prove invaluable for setting up alarms and notifications when predefined conditions are met or exceeded. Moreover, the ESP32 facilitates remote monitoring and control, constituting a comprehensive solution for real-time motor management.

The significance of real-time monitoring of a three-phase induction motor is underscored by its potential to optimize energy efficiency, avert costly downtime, enhance safety protocols, improve overall performance, and enable data-informed decision-making. The real-time data acquisition empowers operators to take immediate actions, ensuring that the motor operates safely within established limits and aligns with production requirements.

In conclusion, this study underscores the paramount importance of real-time testing and monitoring in industrial settings where three-phase induction motors serve as linchpins in various processes. The integration of power sensors, temperature sensors, rotation sensors, and vibration sensors, along with the data processing prowess of the ESP32, offers a holistic solution for maintaining optimal motor performance and safety. Real-time monitoring emerges as a proactive approach that translates into tangible benefits, including cost savings, heightened energy efficiency, and augmented industrial productivity.

3.2. Sensor Validation

The validation of the sensor unit represents a crucial stage in ensuring the suitability of sensors employed within the system. To establish their appropriateness, manufacturer-provided measurement instruments serve as reference standards. A sensor is deemed suitable if its average error, relative to the reference value, is within a tolerance of ≤3%. The ensuing results present the validation outcomes for the ADXL345, MLX90614, PZEM-004T, and NJK-5002C sensors against their respective reference tools.

Figure 4 illustrates the vibration testing of a DC motor, conducted using the ADXL345 vibration sensor in conjunction with a smartphone's gyroscope feature as the measuring instrument (Figure 4.a). The validation of the vibration sensor yields highly satisfactory results (Figure 4.b). Following twelve sampling trials, the quality of the vibration data obtained from the machine proves to be quite robust. Upon a thorough comparison of the vibration sensor's readings with those of the reference measuring instrument, the data analysis reveals that the average vibration reading on the reference measuring instrument is 0.596 (m/s²), while the sensor exhibits an average vibration value of 0.589 (m/s²) with an error rate of merely 1.28%. This minimal error underscores the high suitability of the ADXL345 vibration sensor for subsequent testing and implementation."

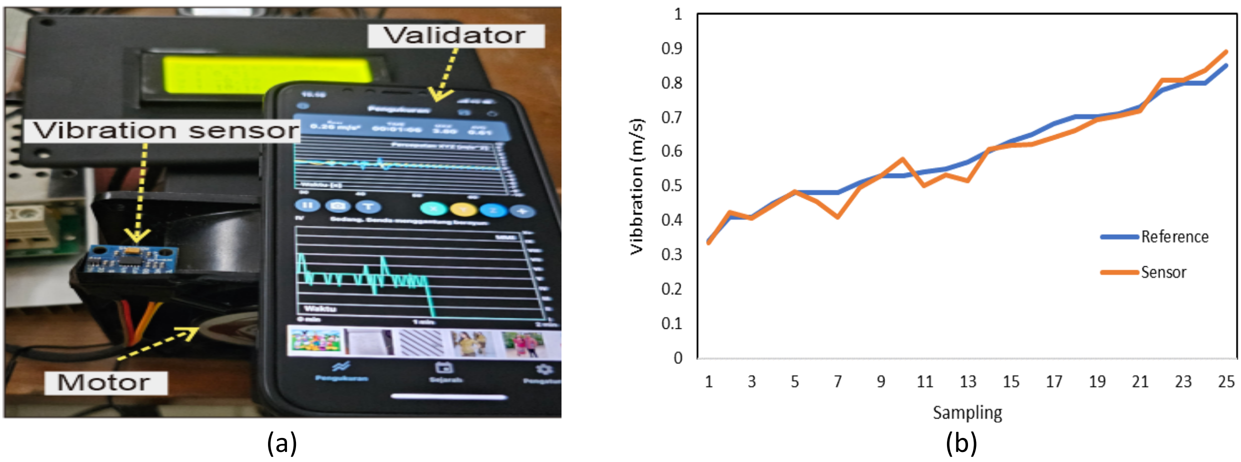
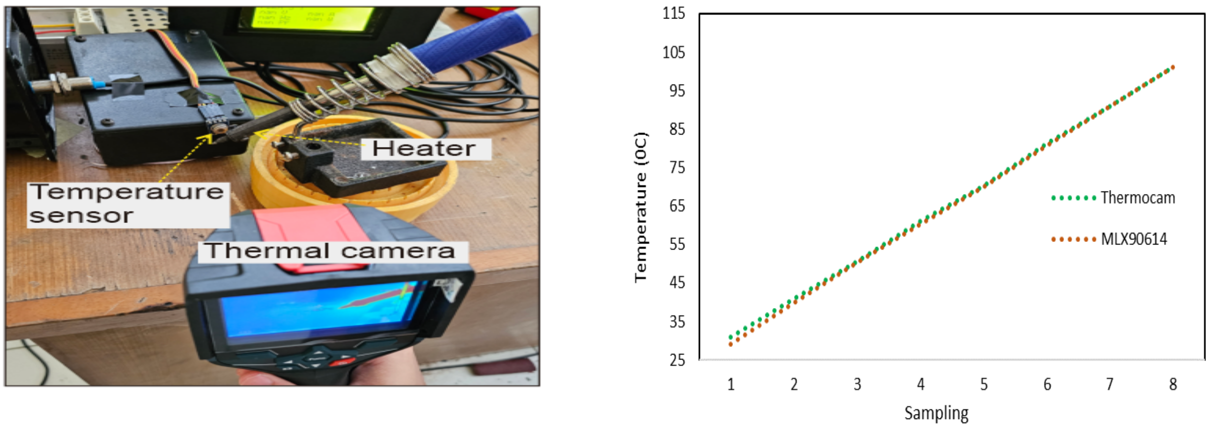


Fig. 4. Vibration system testing and comparison: (a) Hardware for vibration system (b) Measurement comparison

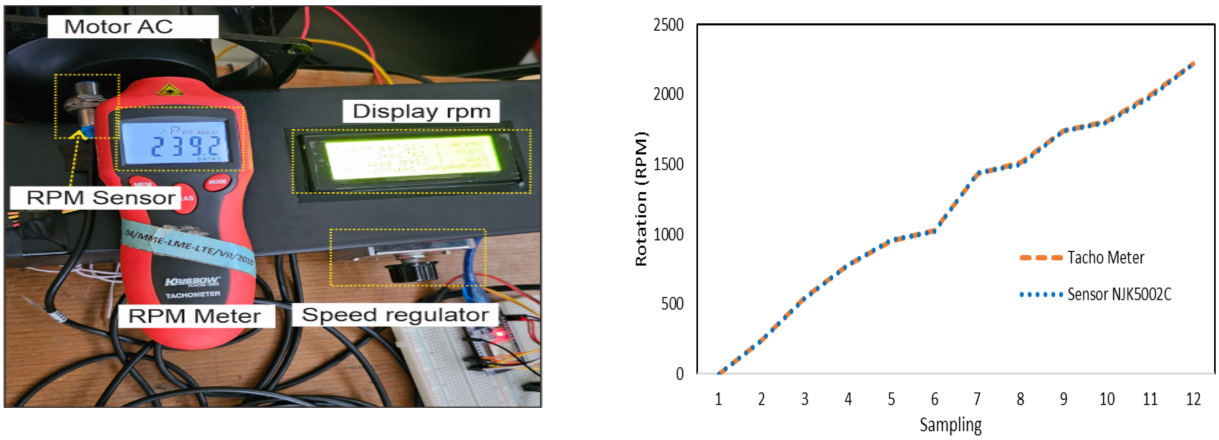
Figure 5 illustrates the testing of the detection system employing an electric solder sample, detected by the MLX90614 sensor in conjunction with the Boech GTC 400 C thermal camera (Figure 5.a). The solder sample is subjected to an alternating current (AC) voltage, with the solder's current being regulated through a dimmer module to allow for adjustable soldering temperatures ranging from 35°C to 105°C. Figure 5.b presents the test results derived from twelve sampling runs, revealing an average error of merely 1.3% in the rotation test. This outcome conclusively demonstrates the suitability of the MLX90614 sensor for subsequent testing and utilization.

Figure 6 presents the assessment of the NJK-5002C sensor system's capability to detect variable-axis rotation in an induction motor, measured in RPM (Revolutions Per Minute). As a reference tool (Figure 6.a), we employed a Krisbow brand tachometer, specifically the KW06-583 model. The results obtained from twelve sampling measurements indicate a remarkable data congruence between the NJK-5002C sensor and the KW06-583 reference instrument, revealing a mere 0.18% average error against the reference measurements. Based on this negligible error margin, it is evident that the NJK-5002C sensor is indeed suitable for further testing and application.



(a) (b)

Fig. 5. Temperature system testing and comparison: (a) Hardware for temperature (b) Measurement comparison

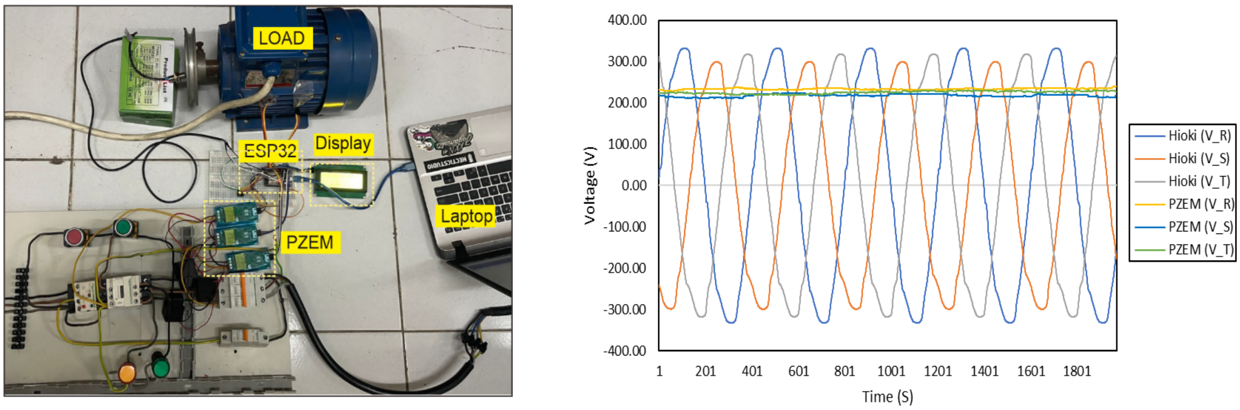


(a) (b)

Fig. 6. Rotation system testing and comparison: (a) Hardware for RPM sensor (b) Measurement comparison

Figure 7 depicts the validation process of the power measurement system. The PZEM-004t sensor is employed to measure the load, represented by a three-phase induction motor, while the comparative instrument used is a Hioki PQ3198 power analyzer (Figure 7.a). The validation results are presented in Figure 7.b. The PZEM-004t module reveals minimal average voltage measurement discrepancies when compared to the Hioki instrument. In phase R, the error is a mere 0.45%, while in phases S and T, it is 0.54%. Similarly, for current measurements, phase R exhibits a 0.5% error, phase S shows only a 0.03% deviation, and phase T registers a slight 0.11% difference. Based on these results, it is evident that the PZEM-004t sensor is well-suited for further testing and application.

Figure 8 illustrates the comprehensive system test conducted on a three-phase induction motor. The motor is equipped with a suite of sensors, including the vibration sensor (ADXL345), temperature sensor (MLX90614), power sensor (PZEM-004t), and rotation sensor (NJK-5002C). The monitoring interface is presented on a laptop, with data processing managed by the ESP32 microcontroller. The test scenario was executed simultaneously, encompassing all sensors and components



(a) (b)

Fig. 7. Power system measurement testing and comparison: (a) Hardware for power system measurement (b) measurement comparison

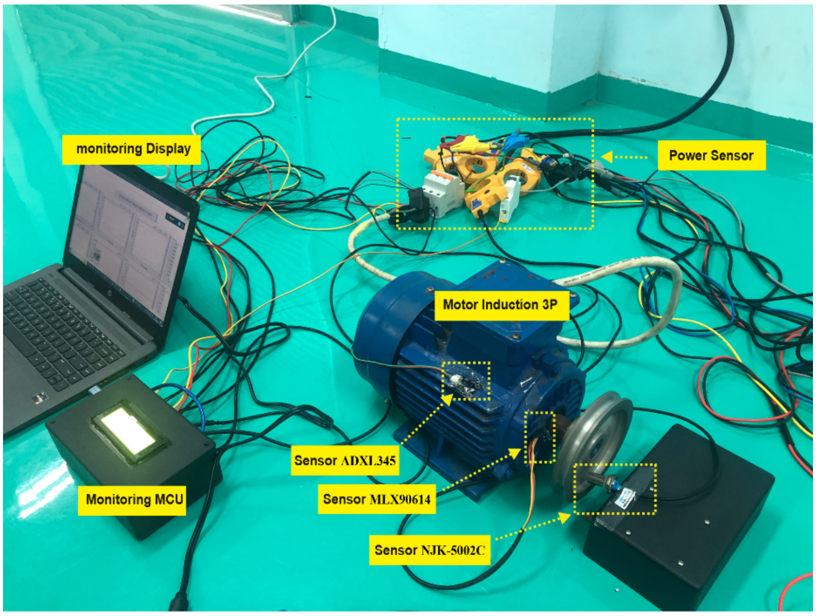
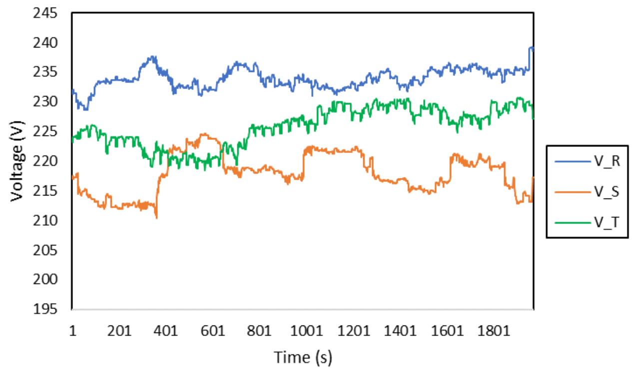


Fig. 8. System test on three-phase induction motor

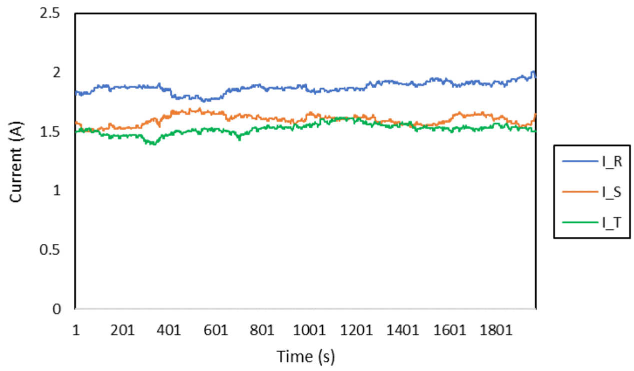
Figure 9 presents the measurement results spanning a duration of 33 minutes, during which the system effectively records the voltage and current values for each phase. A notable observation from the measurements is the lack of constancy in the voltage levels across phases. Phase R exhibits an average voltage of 234 V, phase S averages 214 V, and phase T maintains an average voltage of 225.7 V (Figure 9.a). In terms of current, phase R records an average of 1.87 A, phase S registers 1.6 A on average, and phase T maintains an average current of 1.52 A (Figure 9.b).

The monitoring system additionally provides insights into the power factor values for each phase (Figure 9.c). Examination of variable electrical power (Figure 9.d) reveals that due to the relatively lower voltage and power factor values in phase S, the variable power in phase S remains on the lower side. This observation aligns with the calculations derived from Eqn. (4). Consequently, these results lead to the conclusion that the load on the three-phase induction motor has led to phase imbalances, rendering the motor unsuitable for prolonged usage.

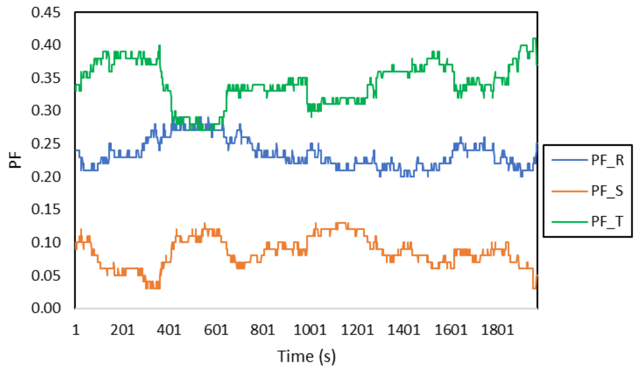
When considering the aspect of energy and total load power, as depicted in (Figure 9.e) and (Figure 9.f), the motor's power measurement, based on Eqn. (4), is verified at 433 W. Meanwhile, energy consumption measurements, as calculated using Eqn. (7), exhibit a progressive increase, reaching an average consumption value of 1200 Wh."



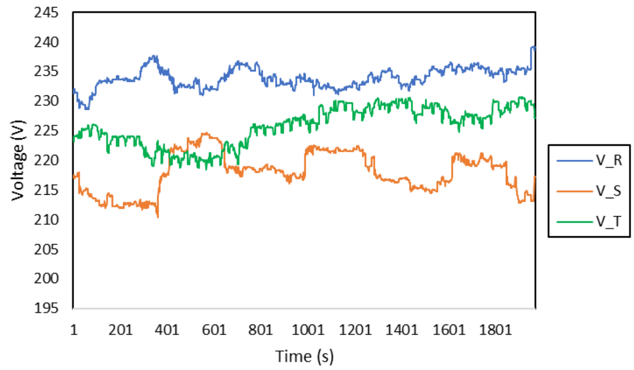
(a)



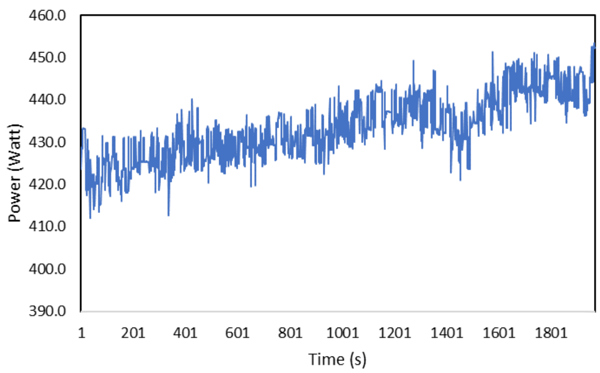
(b)



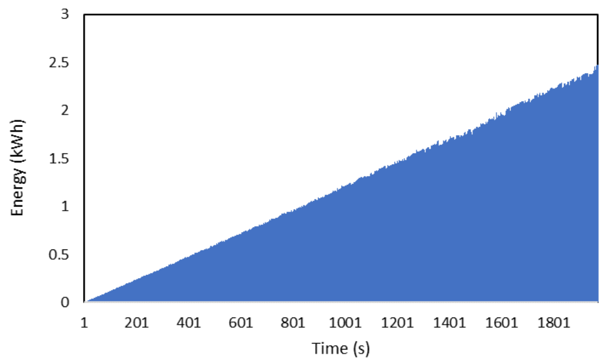
(c)



(d)



(e)



(f)

Fig. 9. Electrical variable measurement results: (a) voltage vs time, (b) current vs time, (c) power factor vs time, (d) voltage vs time, (e), power vs time and (f) energy vs time

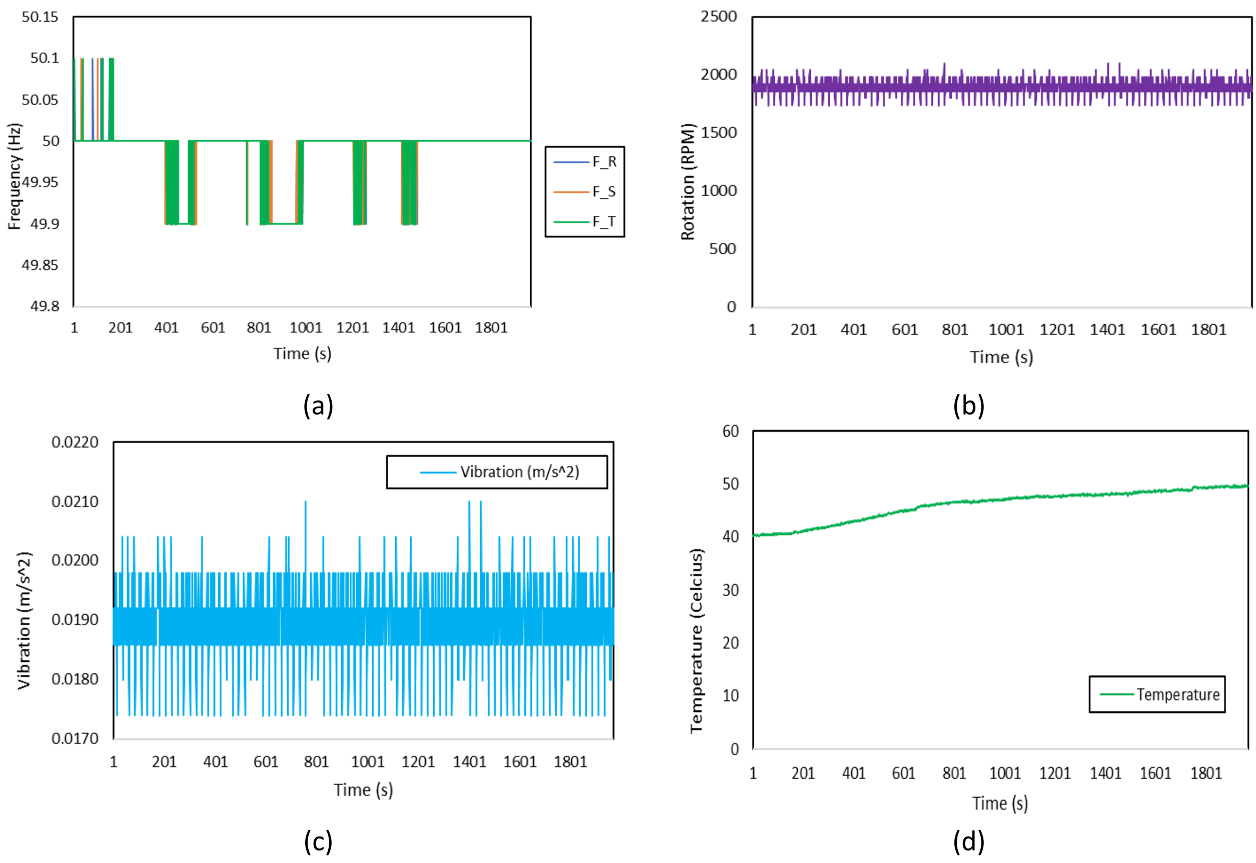


Fig. 10. Measurement results of mechanical variables: (a) frequency vs time, (b) rotation vs time, (c) vibration vs time and (d) temperatures vs time

Figure 10 presents the measurement results of various mechanical variables, including frequency (Hz), rotation speed (RPM), vibration intensity (m/s²), and temperature (°C). The frequency variable exhibits values ranging from 49.9 Hz to 50.1 Hz, with an average motor rotation speed of 1907 RPM. The average vibration intensity detected on the motor body measures at 0.02 m/s², a value consistent with vibration calculations derived from Eqn. (1). This minimal vibration suggests that the motor does not generate significant vibrational forces.

In terms of temperature on the induction motor's body, it is evident that the temperature rises from 40°C and stabilizes at 50°C. This observed trend aligns with the expectations set by Eqn. (2). Upon analysing the mechanical variable measurements, it becomes apparent that there exists a positive correlation between motor power, energy consumption, and the temperature generated on the surface of the three-phase induction motor. However, it is notable that a linear relationship appears to exist between the motor's frequency and the level of vibration experienced on the motor body.

3.3. IoT Platform

The IoT platform shown in Figure 11 is implemented on a three-phase induction motor object. The capture results of the IoT system show several data acquisition variables from the induction motor that can be displayed properly and in real time. The initial display shows the author logo of the program (Figure 11.a). Information on total energy consumption and energy bill is presented properly (Figure 11.b). Voltage and current graphs are presented separately with average voltage and average current values acquired in real time based on each phase R, S, and T (Figure 11.c). The power graph is displayed based on each phase and the power factor graph (Figure 11.d). Temperature and motor rotation graphs are presented in real time (Figure 11.e). Energy consumption and vibration graphs are successfully displayed (Figure 11.f).

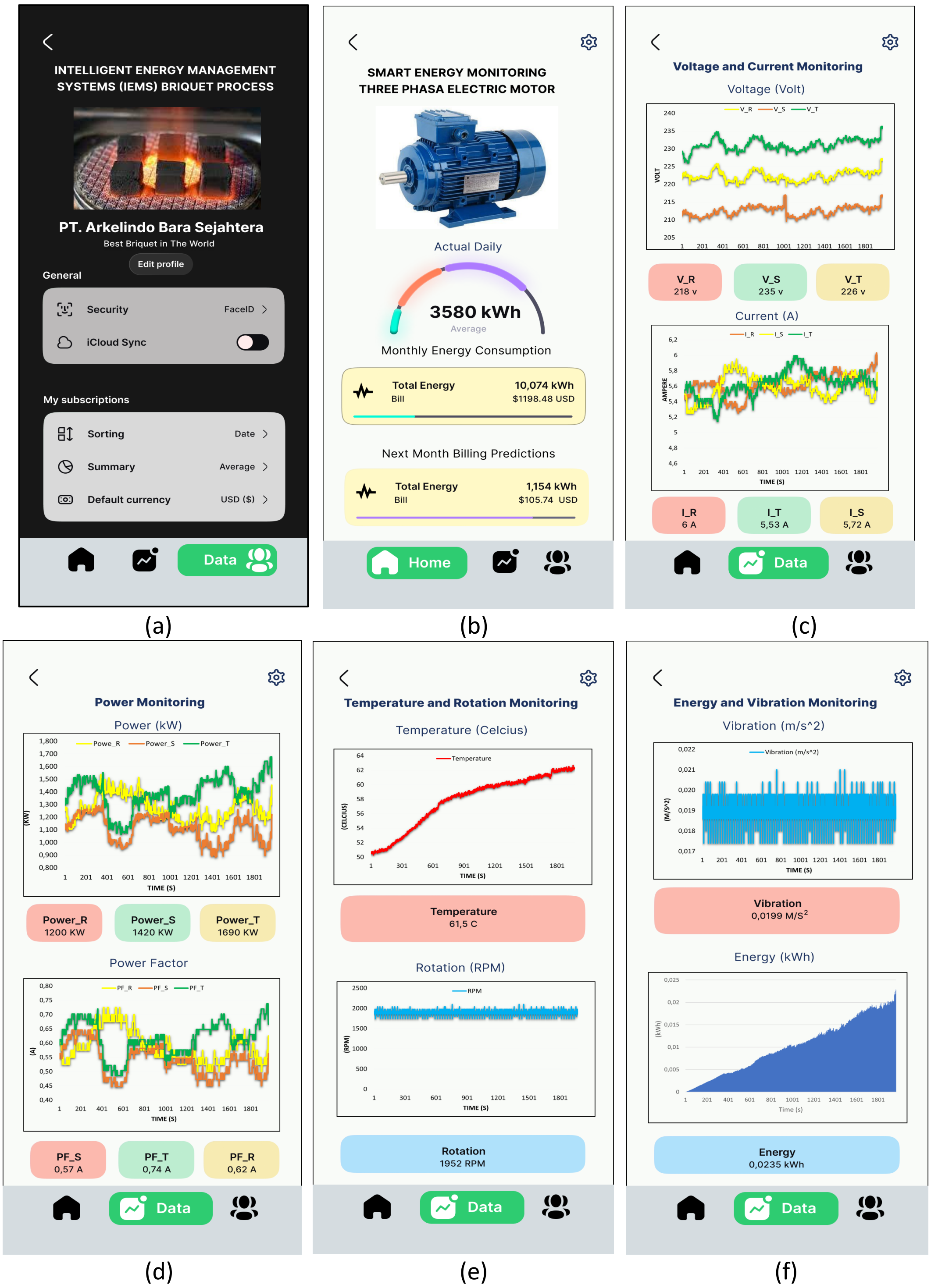


Fig. 11. IoT platform of energy monitoring for three phase induction motor: (a) home section, (b) real time monitoring, (c) voltage and current monitoring, (d) power monitoring, (e) temperature and rotation monitoring, (f) energy and vibration monitoring

4. Conclusions

In conclusion, this research demonstrates the successful design and implementation of a cost-effective sensor system tailored for real-time monitoring of three-phase induction motor performance. Through a comprehensive testing and validation process involving power sensors, temperature sensors, rotation sensors, and vibration sensors, along with the robust data processing capabilities of the ESP32 microcontroller, we have showcased the system's ability to provide crucial insights into motor performance variables. The results indicate that the sensor system is well-suited for monitoring and optimizing energy efficiency, preventing costly downtime, enhancing safety, and improving overall motor performance. Real-time data acquisition empowers operators to take immediate actions, ensuring that the motor operates reliably within established limits and aligns with production requirements. This work represents a significant advancement in the field, offering a holistic solution for industries reliant on three-phase induction motors. By comprehensively integrating a suite of sensors into a unified monitoring system, we have bridged a crucial research gap and provided a novel approach to motor performance analysis. This innovative system holds the potential to revolutionize industrial operations by enabling data-driven decision-making, cost savings, and heightened energy efficiency.

References

[1] Zafar, Usman, Sertac Bayhan, and Antonio Sanfilippo. "Home energy management system concepts, configurations, and technologies for the smart grid." *IEEE access* 8 (2020): 119271-119286. https://doi.org/10.1109/ACCESS.2020.3005244

[2] Sivakumar, Arunachalam, Muthamizhan Thiyagarajan, and Karthick Kanagarathinam. "Mitigation of supply current harmonics in fuzzy-logic based 3-phase induction motor." *International Journal of Power Electronics and Drive Systems* 14, no. 1 (2023): 266-274. https://doi.org/10.11591/ijpeds.v14.i1.pp266-274

[3] Widagdo, Reza Sarwo, Ratna Hartayu, and Balok Hariadi. "Discrete Wavelet Transform Applied to 3-Phase Induction Motor for Air Gap Eccentricity Fault Diagnosis." *Journal of Electrical Engineering, Mechatronic and Computer Science* 6, no. 2 (2023), 111-121. https://doi.org/10.26905/jeemecs.v6i2.10707

[4] Vanga, Jeevesh, Durga Prabhu Ranimekhala, Swathi Jonnala, Jhansi Jamalapuram, Balaji Gutta, Srinivasa Rao Gampa, and Amarendra Alluri. "Fault classification of three phase induction motors using Bi-LSTM networks." *Journal of Electrical Systems and Information Technology* 10, no. 1 (2023): 1-15. https://doi.org/10.3390/electronics12030681

[5] Kuncoro, Aditiyo Hermawan, M. Mellyanawaty, Aceng Sambas, Dian Syah Maulana, and M. Mamat. "Air Quality Monitoring System in the City of Tasikmalaya based on the Internet of Things (IoT)." *Jour of Adv Research in Dynamical & Control Systems* 12, no. 2 (2020): 2473-2479. https://doi.org/10.5373/JARDCS/V12I2/S20201294

[6] Listyarini, Sri, Lina Warlina, and Aceng Sambas. "The Air Quality Monitoring Tool Based on Internet of Things to Monitor Pollution Emissions Continuously". *Environment and Ecology Research* 10, no. 6 (2022), 824 – 829. https://doi.org/10.13189/eer.2022.100616

[7] Ciancetta, Fabrizio, Edoardo Fiorucci, Antonio Ometto, Andrea Fioravanti, Simone Mari, and Maria-Anna Segreto. "A Low-Cost IoT Sensors Network for Monitoring Three-Phase Induction Motor Mechanical Power Adopting an Indirect Measuring Method." *Sensors* 21, no. 3 (2021): 754. https://doi.org/10.3390/s21030754

[8] Sidik, Aryo De Wibowo Muhammad, Ilman Himawan Kusumah, Anang Suryana, Marina Artiyasa, and Anggy Pradiftha Junfithrana. "Design and Implementation of an IoT-Based Electric Motor Vibration and Temperature Disruption Handling System." *FIDELITY: Jurnal Teknik Elektro* 2, no. 2 (2020): 30-33. https://doi.org/10.52005/fidelity.v2i2.108

[9] Ayyappan, G. S., B. Ramesh Babu, Kota Srinivas, M. Raja Raghavan, and R. Poonthalir. "Mathematical modelling and IoT enabled instrumentation for simulation & emulation of induction motor faults." *IETE Journal of Research* 69, no. 4 (2023): 1829-1841. https://doi.org/10.1080/03772063.2021.1875272

[10] Narvios, Wilen Melsedec O., and Y. Q. Nguyen. "Automatic power factor correction for three-phase induction motors with embedded IoT-Based monitoring system." In *AIP Conference Proceedings*, vol. 2406, no. 1. AIP Publishing, 2021. https://doi.org/10.1063/5.0066562

[11] Khan, Talha Ahmed, Faraz Ahmed Shaikh, Sheroz Khan, and M. Farhan Siddiqui. "Real-Time Wireless Monitoring for Three Phase Motors in Industry: A Cost-Effective Solution Using IoT." In *2019 IEEE International Conference on*

Smart Instrumentation, Measurement and Application (ICSIMA), pp. 1-5. IEEE, 2019. https://doi.org/10.1109/ICSIMA47653.2019.9057343
[12] Sabir, Abdullah, Fahad Ilyas, Tauseef Tauqeer, and Muhammad Sohaib. "Energy Conservation of Three-Phase Induction Motors Through IoT-Enabled Intelligent Operation Management System." In *2022 International Conference on Emerging Trends in Electrical, Control, and Telecommunication Engineering (ETECTE)*, pp. 1-6. IEEE, 2022. https://doi.org/10.1109/ETECTE55893.2022.10007358
[13] Kumar, Dileep, Abdul Basit, Aisha Saleem, and Engr Ghulam Abbas. "PLC based monitoring & protection of 3-phase induction motors against various abnormal conditions." In *2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*, pp. 1-6. IEEE, 2019. https://doi.org/10.1109/ICOMET.2019.8673497
[14] Agyare, Ofosu Robert, Ama Baduba Asiedu-Asante, and Adjei Reinhard Biney. "Fuzzy logic based condition monitoring of a 3-phase induction motor." In *2019 IEEE AFRICON*, pp. 1-8. IEEE, 2019. https://doi.org/10.1109/AFRICON46755.2019.9133780
[15] Santhosh, Rahul, M. Vikram Siddharthan, and Sudha Yadav. "Protection and Control of 3 Phase Induction Motors in Industrial Plants with Smart Remote Monitoring and Control on a Centralized System." In *2022 6th International Conference on Trends in Electronics and Informatics (ICOEI)*, pp. 317-326. IEEE, 2022. https://doi.org/10.1109/ICOEI53556.2022.9776889
[16] Işık, Mehmet Fatih, Mustafa Reşit Haboğlu, and Büşra Yartaşı. "Smart Phone Based Energy Monitoring System for 3 Phase Induction Motors." *International Journal of Electronics and Electrical Engineering* 5, no. 1 (2017), 90-93. https://doi.org/10.18178/ijeee.5.1.9093
[17] Birbir, Yasar, and H. Selcuk Nogay. "Design and implementation of PLC-based monitoring control system for three-phase induction motors fed by PWM inverter*." International journal of systems applications, engineering & development* 2, no. 3 (2008): 128-135. http://www.wseas.us/journals/saed/saed-40.pdf
[18] Ioannides, Maria G. "Design and implementation of PLC-based monitoring control system for induction motor." *IEEE transactions on energy* conversion 19, no. 3 (2004): 469-476. https://doi.org/10.1109/TEC.2003.822303
[19] Noyjeen, Ekkawach, Chattapon Tanita, Nattha Panthasarn, Pakpoom Chansri, and Jetniphan Pukkham. "Monitoring parameters of three-phase induction motor using iot." In *2021 9th International Electrical Engineering Congress (iEECON),* pp. 483-486. IEEE, 2021. https://doi.org/10.1109/iEECON51072.2021.9440368
[20] Abid, Ghulam, Shoaib Ahmed Shaikh, Muhammad Fawad Shaikh, Sara Hafeez Rajput, Umar Abdul Majeed, and Abdul Majeed Shaikh. "IOT based Smart Industrial panel for controlling Three-phase Induction motor." In *2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*, pp. 1-8. IEEE, 2020. https://doi.org/10.1109/iCoMET48670.2020.9073809
[21] Hiron, Nurul, Ida AD Giriantari, Lie Jasa, and I. Nyoman S. Kumara. "Fish-ridge wind turbine aerodynamics characteristics in Oscillating Water Column (OWC) system." *Ocean Systems Engineering* 11, no. 2 (2021): 141-159. https://doi.org/10.12989/ose.2021.11.2.141
[22] Hiron, Nurul, Nundang Busaeri, Sutisna Sutisna, Nurmela Nurmela, and Aceng Sambas. "Design of hybrid (PV-diesel) system for tourist Island in Karimunjawa Indonesia." *Energies* 14, no. 24 (2021): 8311. https://doi.org/10.3390/en14248311
[23] Lubis, Hamzah. "Renewable energy of rice husk for reducing fossil energy in Indonesia." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 11, no. 1 (2018): 17-22.
[24] Mondal, Mithun, Djamal Hissein Didane, Alhadj Hisseine Issaka Ali, and Bukhari Manshoor. "Wind energy assessment as a source of power generation in Bangladesh." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 26, no. 3 (2022): 16-22. https://doi.org/10.37934/araset.26.3.1622
[25] Ibrahim, Nurru Anida, Idrus Salimi Ismail, Siti Norbakyah Jabar, and Salisa Abdul Rahman. "A Study on the Effects of Plug-In Hybrid Electric Vehicle (PHEV) Powertrain on Fuel Consumption, Electric Consumption and Emission using Autonomie." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 16, no. 1 (2019): 49-56.
[26] Arulkumar, V., Kavin, F., & Nagu, B. (2024). IoT Sensor Data Retrieval and Analysis in Cloud Environments for Enhanced Power Management. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 38(1), 77-88.