
Real-Time Fault Detection and Operational Optimization in Three-Phase Induction Motors: A Proactive Approach to System Protection

Shujaat Ali*, Syed Saad Ali**, Asad Khan**, Faizullah Mahar **, Aftab Ahmed Almani**, Natesh Kumar**

* School of Electrical and Information Engineering, Tianjin University, China

** Department of Electrical Engineering Nazeer Hussain University, Karachi.

shujaat.fachol110@yahoo.com, saad.ali@nhu.edu.pk, asadkhan00619@gmail.com,

faizullah.mahar@nhu.edu.pk, aftab.almani@nhu.edu.pk, natesh.kumar@nhu.edu.pk

Abstract

In the modern era of industry, the effective monitoring and protection of 3 phase electrical motors is of major importance for continued efficiency. This study discovers the beginning and completion of a specific system planned for the supervision and protection of three-phase electrical motors, undertaking critical safety issues such as overvoltage, overcurrent, overheating of winding temperature leading to tripping, and educating the workers of Variable Frequency Drives (VFDs), motor RPM, and phase sequence. The designed system protects and controls a three-phase induction motor. A major focus is placed on identifying potential risks, such as overvoltage and overcurrent, which have the potential to risk motor integrity and operational reliability. The system can monitor motor performance data and implement corrective and preventive actions to reduce the risk of motor faults, thereby ensuring the safety adherence and reliability of motor function and operations. This study demonstrates the difficulties of variable-frequency drives (VFDs) and their interfacing with motor control systems. The system monitors the motor RPM and phase sequence. This prototype effort aims to provide a complete understanding of the details associated with the supervision and protection of three-phase electrical motors by combining theoretical knowledge with practical implementations. Finally, the visions presented in this study will contribute to the advancement of protection methods for three-phase motors, and the designed prototype can be used to perform experiments related to powersystems and machines.

Index Terms: Protection, Control, Variable frequency drive, Induction motor, Phase sequence

I. INTRODUCTION

Three-phase induction motors are mainly utilized in commercial applications. Phase faults are a major problem in induction motors that cause short circuits. The main problem is overheating, which causes burnt motor winding. The conventional system cannot detect motor faults early. The neural network model predicts induction motor faults using artificial intelligence-based technologies [1]. Industrial innovation and progress uses Supervisory Control and Data Acquisition Systems to remotely operate and monitor the motor. This study provides SCADA-based monitoring and motor control via a human-machine interface system. Conventional systems require improvements to the motor monitoring system. A PZEM module was used to measure the voltage and current. [2]. This study focused on the protection of three-phase asynchronous motors from faults caused by rotor bar breakage and short circuits. There are several faults, including broken rotors, short circuits, phase sequences, and air gaps [3]. Innovations worldwide have improved the efficiency and sustainability of motor control. Unpredicted motor failures harm people's lives and increase the cost of replacing damaged motor parts. This study demonstrates an improvement in the operating efficiency and reliability of three-phase synchronous motors integrated with artificial intelligence-based technology. Experimental results show that the AI-based method achieves early fault detection [4]. This study provides a methodology for regulating

and controlling the DC source for brushless motors using proportional integral derivative controllers. The system utilizes a particle swarm optimization algorithm to minimize errors. This experimental setup improved the motor control to analyze the motor under changes in load and speed parameters [5]. Interruptions in industrial zones affect production efficiency and the economy of the sector. To improve the industrial sector, this study provides machine learning and IoT-based devices that offer real-time data analysis. This study predicts the faults and maintenance alerts of the induction motor and resolves these issues before damaging the motor system. This study involved providing datasheets containing health information and faults in a three-phase induction motor. Different machine learning methods were analyzed to calculate the motor performance. The random forest algorithm achieved the highest accuracy of 91%, followed by the artificial neural network method. The model was evaluated under different conditions for a three-phase induction motor.

The future implementation of networks will further improve industrial sectors [6]. Modern systems require artificial intelligence-based implementation to decrease risk and address future risks [7]. The use of nonlinear loads in grids affects the power quality of the power systems. The harmonics in the current and voltage affect the quality, and the variable-speed drive improves the motor performance and operation. This system includes diodes, transistors,

inductors, and capacitors to enhance power quality and decrease harmonics. The sine pulse width modulation technology switches the system with an optimum control signal to increase power stability. The proposed system was analyzed and verified using MATLAB to test the prototype [8]. The control system requires automation and an artificial intelligence-based robotic system to improve production and monitoring. Machine learning plays an important role in improving conventional control systems for reliable and efficient operation [9]. This study demonstrates the design of a small project for motor-torque measurements. The prototype includes a rotational component, transmitter, and receiver to measure the parameters. The torque parameters were transmitted via a cloud-based system to check the efficiency of the physical components [10]. This study investigated the motor characteristics and performance of the motor. The controller was utilized to robotically adjust the power load level to determine the motor characteristics under the same load conditions. In this study, a small dynamometer was designed to investigate the motor characteristics.

The designed system worked properly with different motors to analyze the operation characteristics [11]. Symmetrical faults in three-phase circuits interrupt the current flow. This interruption affects the stability and efficiency of a system. There is a need for improvements in transmission systems to reduce power system loss [12]. This study focuses on an artificial intelligence-based system. The AI model You only look once the model is utilized in this study to control and monitor the system. Android was designed to monitor parameters via cloud-based technologies [13]. Synchronous drives generate mechanical and reactive powers. There is a need to implement a power factor system to reduce the reactive power of the inductive load. This study demonstrates synchronous drive control via digital optimization to improve starting capacity. The prototype was analyzed and tested, and the operation of a motor with different characteristics was demonstrated [14]. A phase sequence fault is one of the major system failures that cause overheating. Different switchgears are utilized to detect faults at an early stage. This study thoroughly discussed the different faults, including the relays and modes of the motors. The proposed system model was tested using MATLAB Simulink under various conditions and fault analyses. The simulation results show that the proposed model is highly efficient for phase-fault detection [15].

Three-phase induction drives the fault condition and reduces the reliability and stability of power systems. The voltage fluctuations and faults cause grid stability and load imbalances and reduce the life of the drive. The knowledge of induction motors and their faults is thoroughly discussed in this study. The 7.5Kw rated power motor utilized in this study was modeled using MATLAB simulation software. This investigation analyzed the torque and stator current to evaluate the faults [16]. The Pakistani power system is deficient owing to an increase in population. Mismanagement in power distribution causes load shedding and interruption in domestic and industrial sectors. The system requires IoT-and artificial intelligence-based technologies to improve the energy sector. This study provides a small prototype for power monitoring via a cloud-based system. Schematic diagrams were designed using the Proteus software to analyze the system [17].

The global three-phase induction motor fault detection system requires improvements owing to phase angle differences, which cause heating and overloading faults. Overvoltage, imbalanced phases, and voltage fluctuations decrease the life of the motors. This study focused on three-phase motor switchgears [18]. Three-phase induction motors are used in industrial applications. This study focuses on the efficiency and reliability of induction motor operation. Unbalanced voltages, currents, and phase angles decrease the lifespan of the motor. The main cause of faults is their early detection and precise estimation. Voltage symmetrical components were analyzed in this study to validate the motor's different operating characteristics [19]. This study evaluates an algorithm for detecting three-phase induction motor faults that occur widely in stator windings. Stator winding breakdown mainly causes overheating and various major faults. The phase short circuit is one of the major problems that decrease the life span of the motor winding. This study measured different characteristics of the motor [20]. A three-phase induction motor is one of the main components of the industrial sector. Unforeseen breakdowns and safety issues delay production in the industrial sector. The short circuit in these three phases is a major problem for motor winding burnout. This study focuses on the early fault detection of unbalanced angles between the current and voltages. The outcome shows that the analytic tools require improvement to protect the motor windings [21].

This study demonstrates a fault analysis technique for an induction motor using artificial neural network technology. The operational conditions with varying speeds and loads were analyzed, and the phase-imbalance fault was found to be more severe than the other faults. The current and vibration signals detect faults in a three-phase induction motor. A simulation-based ANN model was designed, and three levels were detected: phase angles, signals, and vibrations [22]. The early detection of faults and motor control are major global challenges. This study utilized a resonance controller to control the phase and amplitude of the voltage-current harmonics [23]. Induction motors are the main support for the industrial and commercial sectors. Machine failures result in a loss of economic support. Stator faults damage the motor windings. Early fault detection is required for induction motor [24]. A technique for deliberately evaluating the ability of voltage-based transfer to distinguish conveyed generators associated with circulation frameworks when they are distributed. A set of location time versus receptive power irregularity bends shapes the standard of the procedure. Over-voltages[25].

II. METHODOLOGY

The prototype includes the construction and operation of a three-phase induction motor, current transformer, variable frequency drive, temperature controller, revolution per minute(RPM) meter, overvoltage relay, digital multi-meter, magnetic contactor, Relays and Circuit breakers. The main motive of the design system is motor safety, which operates in a 3- phase framework. In particular, one of the key parts utilized in this study is under-voltage control, which plays an important role in the protection of the motor framework. The overvoltage detection capability is a protection against unnecessary voltage flows. In such cases, the system quickly switches off the

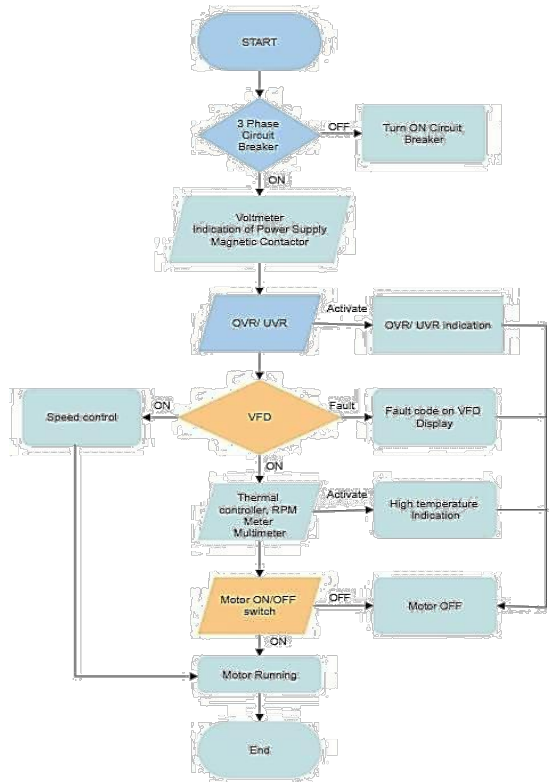


Fig. 1 Control flow

breaker for motor closure to prevent overheating of the motor. The main component integrated in our framework is the monitoring of the phase balance across three-phase connections. The contactors were utilized to analyze the three-phase faults. The speed characteristics varied with the variable frequency drive, which plays an important role in controlling the speed of the 3-phase electrical motors and the forward and reverse parameters.

The VFD identifies currents that inadvertently flow to the motor, posing potential hazards, such as electric shocks. The prompt

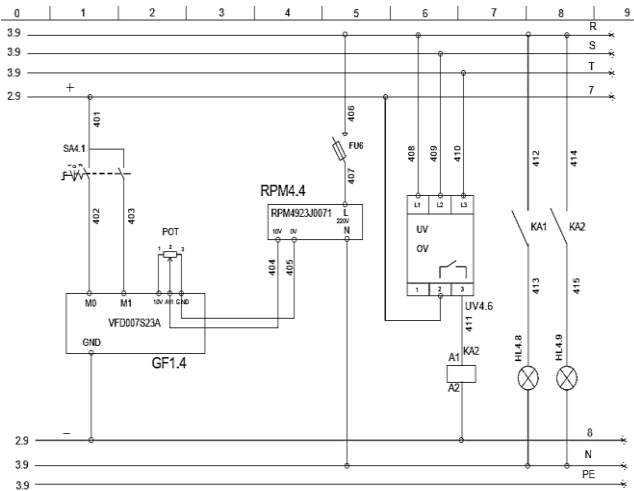


Fig. 2 Schematic diagram



Fig. 3 Three phase induction motor

detection and isolation of a Variable Frequency Drive (VFD) decreases risks and enhances system safety. The RPM Meter (Rotation Per Minute), which displays the Rotation Per Minute of the motor. In cases where the motor experiences overspeed, the RPM meter senses the rotation of the motor, where the VFD will shut down the motor owing to excessive current flow to prevent any damage to the motor and ensure operational safety. The basic capacity of an electrical motor is to provide significant capability to work with various types of electrical and mechanical burdens. During overloading, the temperature controller senses the overheating of the system. This overload condition overflows in the working streams and higher temperatures damage the motor parts. The Protection relay function is utilized for the protection of conventional current, voltage, phase imbalance, and symmetrical faults during operational circumstances.

A) System Flow

Figures 1 and 2 show the control flow and schematic of the designed three-phase induction motor control system:

III. HARDWARE IMPLEMENTATION

The components used in this study are as follows:

- Three phase induction motor
- Current transformer
- Variable frequency drive
- Temperature controller
- Revolution per minute meter
- Over-Under voltage relay
- Digital multi-meter
- Magnetic contactor

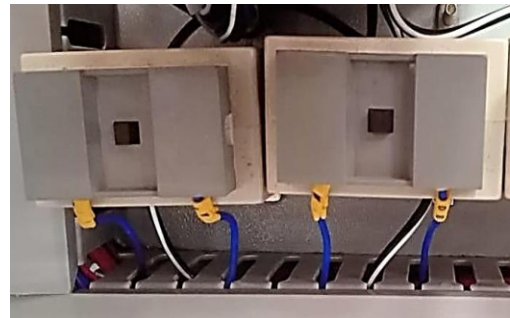


Fig. 4 Current transformer



Fig. 5 Variable frequency drive

- DC relay
- Miniature circuit breaker
- Selector switch
- Potentiometer
- Phase indication lights
- Power Supply

A) Three phase induction motor

A three-phase induction motor transforms electrical energy into usable mechanical power. The designed system protects the motor from phase-angle differences and harmonics.

B) Current transformer

A current transformer (CT) was used for the quantification of alternating current (AC) through the conversion of large currents into a small current. It is typically composed of a primary coil, in which a high current circulates, and a secondary coil linked to a protection mechanism. This system installed a current transformer for employing an ampere meter, sensing the ampere line, and reading the ampere line.

C) Variable Frequency drive

Variable Frequency Drive (VFD) and control drive motor speed characteristics. The use of the VFD along with the motor improves the operating conditions of the system. It also improves soft starting and stopping of the drive with overload protection.

D) Temperature Controller

The temperature controller is safety equipment that detects and displays the heating parameters of the hardware with preset values. It regularly senses the temperature required to cut off a motor.

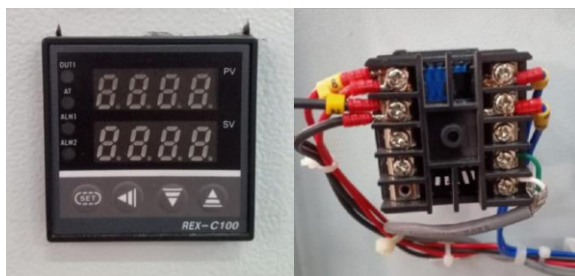


Fig. 6 Temperature controller

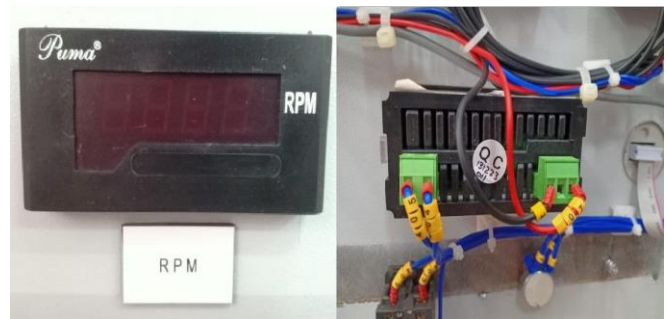


Fig. 7 Current transformer

E) Revolution per minute meter

An RPM Meter is a device used to estimate the rotational speed of a motor shaft. It regularly senses the shaft rotation and displays it on a digital meter.

F) Over-Undervoltage relay

The point at which the voltage surpasses as far as possible overvoltage or down as possible under-voltage, as per the preset value. These electrical relays switch or separate contacts with electrical devices to prevent motor windings.

G) Digital multi-meter

A digital multi-meter (DMM) is a flexible electronic gadget used to display different electrical parameters in an attached circuit. It regularly measures voltage, current, frequency, and power.

H) Magnetic contactor

A three-phase magnetic contactor is an electrically energizing device that has been utilized in three-phase electrical motors. This relay switches the system and protects the motor from overload.

I) DC relay

The 24V DC relay is an electromechanical switch utilizing a control voltage of 24 volts direct current (DC). These DC relays are generally used in different electronic and electrical circuits to control machines and different types of control panels.

J) Miniature circuit breaker

A miniature circuit breaker is utilized to break the circuit automatically during short-circuit or overloading conditions. The electrical switch will trip based on the probability of fire or electrical risks.



Fig. 8 Over-under voltage relay



Fig. 9 Digital multi-meter

K) Selector switch

A selector switch is an electrical instrument used for manual control that normally has a revolving switch that changes the circuit sequence. Selector switches are utilized to control loads and devices to work in different reverse/forward directions for the development of electrical machines and motors.

L) Potentiometer

A potentiometer is a resistor that can vary its resistance by physically moving a contact. It is used to vary the voltage and current parameters of the circuit.

M) Indication lights

The indication light is used to indicate the phase operation and system phase live indication.

N) Power supply

The 24V DC Power Supply is an electrical instrument that converts AC voltage to DC voltage and produces a result of 24 volts. DC power is utilized in the system for relays, actuators, control frameworks, and low-voltage lights.



Fig. 10 Magnetic contactor



Fig. 11 Magnetic contactor

IV. MATHEMATICAL MODELLING

The mathematical model of a three-phase induction system consists of a motor comprising voltage, current, and power factor parameters. The three-phase induction power factor calculations were as follows:

V. RESULTS AND DISCUSSION

A smart three-phase induction motor control system was tested in a laboratory. The results demonstrate that the smart system is operative in controlling and protecting the motor. Digital meters display the electrical parameters of each system. The variable frequency drive (VFD) meter displays the three-phase Voltage, Current, and frequency. A three-phase voltmeter, revolution per minute (RPM) meter, potentiometer for variable frequency, and selector switch for reverse/forward motor direction were installed at the middle front door of the safety panel. The 24V DC 2.5A power supply, over-under Voltage Relay, is utilized for switching and tripping the system. These components are integrated to protect from overcurrent, overvoltage, under-voltage, winding temperature, variable frequency drive for precise control of three-phase motor speed, and an RPM sensor to sense the revolution per minute. This methodology



Fig. 12 Circuit Breaker



Fig. 13 Selector switch

can protect and monitor motors in different modern settings. The protection relay's function is based on the principle of monitoring electrical circuits through conventional current and voltage techniques and subsequently initiates a response in the fault condition. The specific classification of the protection relay analyzes the faults in circuit conditions. The protection relays are capable of activation when the over temperature, overcurrent, overvoltage, under voltage, and unbalanced current.

This study discusses concerns with various industrial applications and examines current solutions for the protection of medium-voltage circuits against excess load current. A thorough assessment of the safety system intended for the monitoring and protection of three-phase electrical motors provides a significant understanding of the present status of exploration, innovative progress, and systems used inside this particular space. Power factor correction is a serious characteristic of improving electrical energy practices in industrialized situations, signifying an active approach to improve power proficiency and decrease operation charges.

$$P = \text{VICOS} \sqrt{3} \quad (1)$$

P is the power in watt.

V is the voltage across the system.

I current through the system.

$\sqrt{3}$ is the factor appears in three-phase power

COS is the power factor in AC system

The three-phase motor generates 400 volts with 50 A and an efficiency of 0.85 to calculate the HP of the motor.

$$P = 400 \times 50 \times 0.85 \times 1 \times \sqrt{3} \times 746$$

$$P = 21 \text{ Kw watt}$$

Now, solve for current

$$I = \frac{21 \text{ kw}}{400 \text{ v}} \quad (2)$$

$$I = 52 \text{ A}$$

For three-phase induction, the horse power calculations are as follows:

$$P(\text{HP}) = \frac{v I \eta \text{ PF} \sqrt{3}}{746}$$

$$P(\text{HP}) = 39.45 \text{ HP}$$



Fig. 14 Potentiometer

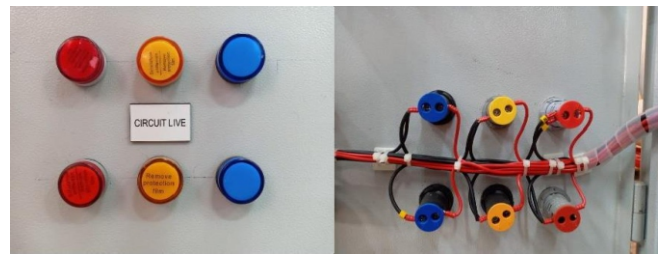


Fig. 15 Indication

In industrialized settings, power systems regularly comprise several motor-based inductive loads. The designed system analyzes the reactive power and leading/lagging conditions in the power factor. The system also works as a trainer for the protection and monitoring of three-phase electrical motors, including power systems and electrical machines-related subjects, to achieve successful educational results. This involves a particular examination of key features to ensure that all relevant topics are effectively addressed and that learning outcomes are maximized. Figure 17 shows the hardware of the proposed system.

VI. CONCLUSION

The design of a prototype smart three-phase induction motor control and protection system plays an important role in industrial motor protection and control. The proposed prototype can protect three-phase electrical motors from overvoltage, overcurrent, and overheating of the winding temperature. The motor RPM, and phase sequence were analyzed by the variable Frequency Drives (VFDs). The designed system protects and controls a three-phase induction motor. The system monitored the motor performance data and ensured the safety and reliability of the motor. The system controls the parameters via variable frequency drive (VFDs) integration with motor control systems. The system monitors key parameters via the motor RPM and phase sequence to prevent overheating of the motor windings.

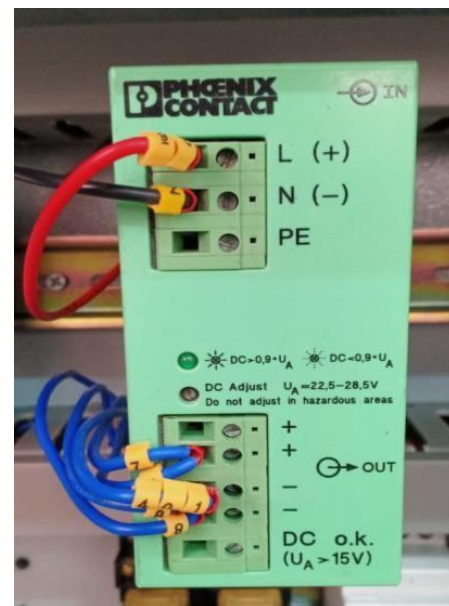


Fig. 16 Power supply

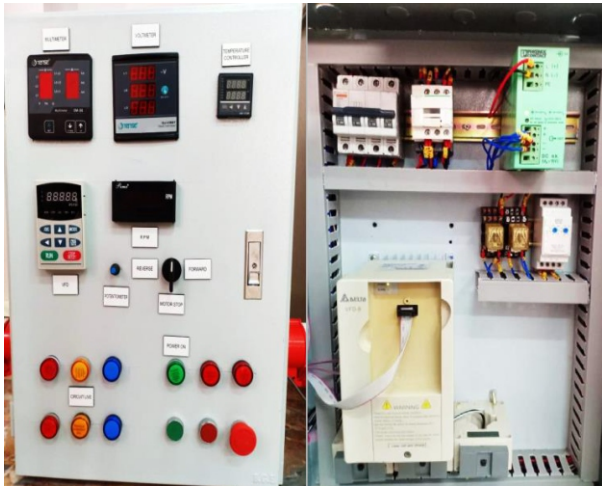


Fig. 17 Hardware design

In summary, this research article indicates an evolutionary move in the domain of motor control and protection. The development of this system provides an experimental and practical setup for power system- and electrical-machines-related subjects. The implementation of this system increases students' learning outcomes and practical exposure.

REFERENCES

- [1] Ahmad, Faizan, Mohaira Ahmad, Faisal Hayat, Sami ud Din, Muhammad Adnan, and Arslan Ahmed Amin. "Modified triple modular redundancy based fault-tolerant three-phase matrix converter design with AI driven diagnostic capabilities." *Results in Engineering* 25 : 104454, 2025.
- [2] A. Sitepu, Trahman, Aulia Salman, Faisal Fahmi Hasan, and Zul Fikri Sofyan. "Design of Scada-Based Motor Monitoring System." *International Journal of Applied Research and Sustainable Sciences* 3, no. 1: 87-96, 2025.
- [3] A. Ali, Hui, Yu Jie, and Lu Weiqiang. "Research on rotor fault diagnosis technology of three-phase asynchronous motor based on NA-MEMD mutual information and SVM." *Measurement and Control* 58, no. 1: 110-118, 2025.
- [4] Abood, Samir, Annamalai Annamalai, Mohamed Chouikha, and Turk Nejress. "Fault Diagnostics of Synchronous Motor Based on Artificial Intelligence." *Machines* 13, no. 2: 73, 2025.



Fig. 17 Hardware design

- [5] Pangerang, Fitriaty, Faizal Arya Samman, Zahir Zainuddin, and Rhiza S. Sadjad. "Variable loaded brushless DC motor with six step commutation PID-based speed controller optimized by PSO algorithm." *Bulletin of Electrical Engineering and Informatics* 14, no. 1: 132-142, 2025.
- [6] Abdulkareem, Ademola, Tochukwu Anyim, Olawale Popoola, John Abubakar, and Agbetuyi Ayoade. "Prediction of induction motor faults using machine learning." *Heliyon* 11, no. 1, 2025.
- [7] Li, Daqing, Anzhuo Yao, Kaifeng Feng, Hang Zhou, Ruixin Wang, Ming Cheng, Hang Li, Dongfang Wang, and Shuiting Ding. "Next Frontiers of Aviation Safety: System-of-Systems Safety." *Engineering*, 2025.
- [8] Nadweh, Safwan, Nabil Mohammed, Obaid Alshammari, and Saad Mekhilef. "Topology design of variable speed drive systems for enhancing power quality in industrial grids." *Electric Power Systems Research* 238: 111114, 2025.
- [9] Zhang, Zhanxiang, Lin Wang, Fengqi Jiang, Shimin Yu, Fengtong Ji, Tianhao Sun, He Zhang et al. "Fully integrated wearable control system for micro/nanorobot navigation." *International Journal of Extreme Manufacturing* 7, no. 3: 035505, 2025.
- [10] Minh, Tran Vu, Nguyen Thi Anh, and Tran Thanh Tung. "Torque Measurement System Design for Step Motor 23HS30-3004S." *Engineering, Technology & Applied Science Research* 15, no. 1 : 19073-19077, 2025.
- [11] Hong, Thong Duc, Phat Tan Truong, Minh Quang Pham, Hoa Nam Ho, Hoang Minh Do Le, and Thang Viet Vu. "Design, development and manufacture of a small electric motor dynamometer." *FME Transactions* 53, no. 1 : 1-14, 2025.
- [12] Zajkowski, Konrad, and Stanislaw Duer. "Problems in Modeling Three-Phase Three-Wire Circuits in the Case of Non-Sinusoidal Periodic Waveforms and Unbalanced Load." 2025.
- [13] Iqbal, Khurram, Syed Saad Ali, Abdul Ahad, Ghulam Mohiuddin Khan, Ahmed Hamza Khan, and SM Yousuf Qasim. "Artificial intelligence based real-time smoke and fire detection and security management algorithms." *VFAST Transactions on Software Engineering* 13, no. 1 : 99-110, 2025.
- [14] Sub irelu, Gheorghe-Eugen, Petre Pistol, Adrian Vintilă, and Cosmin Ionu Toma. "Equipment for Energizing and Controlling the Operation of Synchronous Power Motors." 2025.
- [15] Dawood, Ahmed, Mohamed A. Ismeil, Hany S. Hussein, B. M. Hasaneen, and A. M. Abdel-Aziz. "An efficient protection scheme against single-phasing fault for three-phase induction motor." *IEEE Access* 12 : 6298-6317, 2024.
- [16] Josiah, Chukwudi, Ekom Enefiok, and Imoh Christopher. "Fault Resistance and Adaptive Analysis of Induction Motors under Voltage Variations in Industrial Applications." *Journal of Engineering Research and Reports* 26, no. 12 : 231-248, 2024.
- [17] Ali Shujaat, Syed Saad Ali, Muzammil Ahmad Khan, Muhammad Ahmed Hussain, Masroor Khan, and Hermain Fayyaz Karim. "IoT

- enabled implementation of a smart energy management system for real-time monitoring and controlling." VAWKUM Transactions on Computer Sciences 12, no. 2: 81-98, 2024.
- [18] Efri Wildan Hafiz, Tarigan, A. S. P., & Solly Aryza.. "Improved Microcontroller-Based 3 Phase Induction Motor Protection From A Variety Of Interruptions", International Journal of Economic, Technology and Social Sciences (Injects), 3(1), 227–236, 2022.
- [19] Laadjal, Khaled, Mohamed Sahraoui, Abdeldjalil Alloui, and Antonio J. Marques Cardoso. 2021. "Three-Phase Induction Motors Online Protection against Unbalanced Supply Voltages" Machines 9, no. 9: 203, 2021.
- [20] Alawady, A. A., M. F. M. Yousof, N. Azis, and M. A. Talib. "Phase to phase fault detection of 3-phase induction motor using FRA technique." International Journal of Power Electronics and Drive Systems 11, no. 3: 1241, 2020.
- [21] Adouni, Amel, and Antonio J. Marques Cardoso. "Thermal analysis of low-power three-phase induction motors operating under voltage unbalance and inter-turn short circuit faults." Machines 9, no. 1 : 2, 2020.
- [22] Chouhan, Abhisar, Purushottam Gangsar, Rajkumar Porwal, and Christopher K. Mechefske. "Artificial neural network based fault diagnostics for three phase induction motors under similar operating conditions." Vibroengineering Procedia 30 : 55-60, 2020.
- [23] Li, Zhuohang, Lijian Wu, Zekai Chen, Yang Shi, Lin Qiu, and Youtong Fang. "Single-and two-phase open-circuit fault tolerant control for dual three-phase PM motor without phase shifting." IEEE Access 8: 171945-171955, 2020.
- [24] Abdullateef, A. I., O. S. Fagbolagun, M. F. Sanusi, M. F. Akorede, and M. A. Afolayan. "Detection and classification of stator short-circuit faults in three-phase induction motor." Journal of Applied Sciences and Environmental Management 24, no. 3: 417-424, 2020.
- [25] A. Alahäivälä and M. Lehtonen, "Analysis of open phase condition influence on an induction motor," 2018 19th International Scientific Conference on Electric Power Engineering (EPE), Brno, Czech Republic, pp. 1-6, 2018.

