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Speed Measurement for Three-Phase Induction Motor Drive Based on Arduino Uno

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Abstract

This study aims to design and test a three-phase induction motor speed measurement device based on Arduino Uno. Three-phase induction motors are often used in industry because of their reliability, high efficiency, and easy maintenance. However, these motors have weaknesses, namely low starting torque and difficulty in regulating speed, which can cause operational instability. Therefore, this study developed an Arduino Uno-based control system capable of regulating motor speed by changing the frequency of the electrical supply. This research is quantitative in nature and uses an experimental method. The results of the study show that the designed device is capable of improving the stability and operational efficiency of three-phase induction motors. The use of an LM393 speed sensor aligned with the motor rotor allows the system to respond to load changes in real-time, maintain a constant speed, and reduce energy consumption. Based on these results, it can be concluded that the development of an Arduino Uno-based speed measurement device is effective in addressing the challenges of controlling the speed of a three-phase induction motor and has broad application potential in industry.

Keywords: *LM393 Sensor, Speed Measurement, Three-Phase Induction Motor*

Abstrak

Penelitian ini bertujuan untuk merancang dan menguji alat pengukur kecepatan motor induksi tiga fasa berbasis Arduino Uno. Motor induksi tiga fasa sering digunakan dalam industri karena keandalannya, efisiensi tinggi, dan perawatan yang mudah. Namun, motor ini memiliki kelemahan, yaitu torsi awal yang rendah dan kesulitan dalam mengatur kecepatan, yang dapat menyebabkan ketidakstabilan operasional. Oleh karena itu, penelitian ini mengembangkan sistem kontrol berbasis Arduino Uno yang mampu mengatur kecepatan motor dengan mengubah frekuensi suplai listriknya. Jenis penelitian ini adalah kuantitatif dengan metode eksperimen. Hasil penelitian menunjukkan bahwa alat yang dirancang mampu meningkatkan stabilitas dan efisiensi operasional motor induksi tiga fasa. Penggunaan sensor kecepatan LM393 yang sejajar dengan rotor motor memungkinkan sistem merespons perubahan beban secara real-time, menjaga kecepatan tetap konstan, dan mengurangi konsumsi energi. Berdasarkan hasil ini, dapat disimpulkan bahwa pengembangan alat pengukur kecepatan berbasis Arduino Uno efektif dalam mengatasi tantangan pengaturan kecepatan motor induksi tiga fasa dan memiliki potensi aplikasi yang luas di industri.

Kata Kunci: Sensor LM393, Pengukuran kecepatan, Motor Induksi Tiga Fasa

Introduction

Three-phase induction motors are among the commonly used motors in various industrial applications due to their simple design, high durability, ease of maintenance, and high efficiency [1]. Three-phase induction motors do, however, have certain drawbacks, such as poor beginning torque and trouble managing speed, despite these benefits. In industrial settings, motor speed control is essential for adapting to the changing needs of the manufacturing process. Furthermore, energy efficiency has become a major focus in modern industries, where three-phase induction motors, being one of the largest energy consumers, require proper control to reduce energy consumption and enhance operational efficiency.

Many industrial applications involve dynamic load changes over time, such as in conveyor systems or automated transportation, where the load being transported can vary. Therefore, responsive and adjustable speed control is vital to address these load variations [2]. A three-phase induction motor's torque increases with increasing load, which raises the induced current in the rotor and increases the amount of slip between the rotor and the spinning magnetic field [3]. This change in load often leads to instability in the motor's speed, necessitating a control system that can maintain a stable speed, thus improving efficiency and performance [4]

Both supply voltage and frequency can be controlled to maintain a steady motor speed under changing loads; frequency adjustment is a popular technique for speed control. Reducing the starting current, reducing vibrations, and minimizing mechanical shocks during motor startup can all be achieved by varying the supply frequency [5]. This research focuses on developing a control system for regulating the speed of a three-phase induction motor by varying the frequency of the supplied electrical power [6]. Three-phase induction motors are a common choice in industry due to their simple design, durability, and high efficiency, but they have the disadvantages of low starting torque and difficulty in regulating speed [7]. Motor speed control is essential to match the production process and save energy [8]. To overcome variations in the load of the three-phase motor that can cause speed instability, a responsive control system is needed [9]. One way to control the speed of a three-phase motor is to change the frequency of the power supply that enters the motor [10].

The system uses a speed sensor mounted parallel to the motor rotor to detect changes in rotation in real-time. Data from the sensor is processed by Arduino Uno and displayed on the LCD. The results show that this tool is able to improve the stability and operational efficiency of the motor with high measurement accuracy, as shown by the very small average error value (about -0.43%) compared to the tachometer. This research aims to develop a speed measurement system for three-phase induction motors based on Arduino Uno, for the intention of delivering precise speed information for ongoing motor performance monitoring. With this efficient measurement system, it is expected to reduce the risk of motor damage, improve operational efficiency, and lower energy consumption. Furthermore, the Arduino Uno-based system is anticipated to offer a more affordable solution compared to more complex commercial systems. It is hoped that this research will contribute significantly to improving operational efficiency, reducing the risk of damage, and providing more accurate and responsive speed control [6].

Method

a. Research Design

This study's research is quantitative, which kind of study technique known as the descriptive quantitative approach uses numerical data to express the findings in phrases. This study uses a quantitative approach with an experimental method consisting of several structured stages. The first stage is Hardware Design, in which components such as Arduino Uno, Variable Frequency Drive (VFD), and LM393 sensors are assembled to ensure the efficiency of the device. Next, in the Software Design stage, the researcher created a program code using Arduino Uno software to measure speed and display the results on an LCD. After the design was completed, the device was tested in the laboratory to test the overall functionality of the system. During testing, the VFD frequency was adjusted to control the motor speed, which was then measured by the LM393 sensor. The final stage was Data Collection and Analysis, where the speed data obtained from the LM393 sensor was recorded and then compared with the results from the tachometer to calculate the error value using the specified formula. The research flowchart is a diagram that illustrates the sequence of steps in the research. The sequence of this research process is depicted in Figure 1.

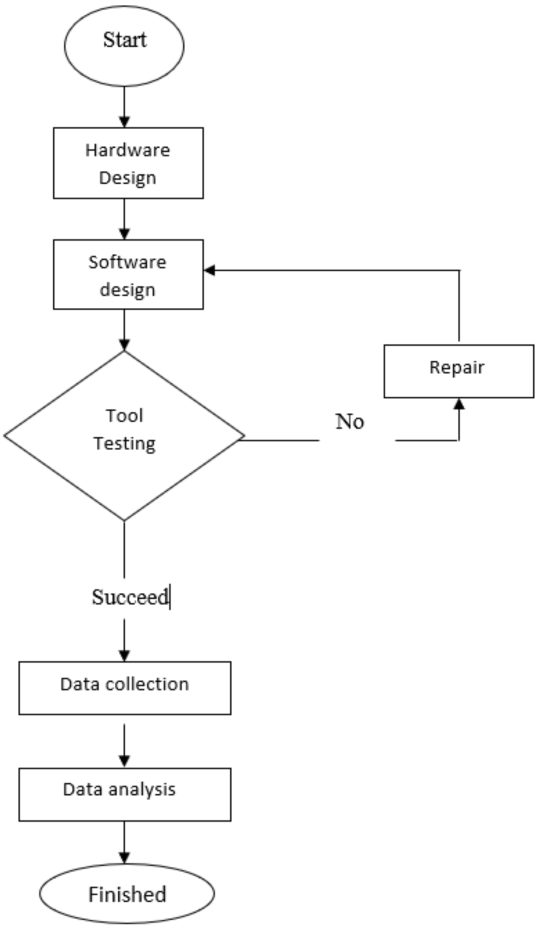

Figure 1. Research Flowchart

The workflow diagram illustrates the sequence of steps or actions occurring throughout the entire system. The operational process of the device is described in Figure 2.

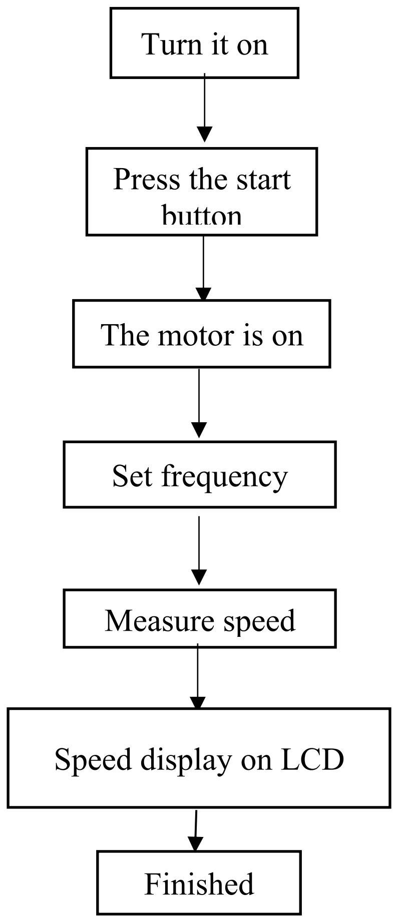

Figure 2. Flow of the Speed Measurement Tool Work System

In this study, testing stages were carried out to evaluate the performance of the designed device. This testing involved measuring the motor speed at various frequencies generated by the VFD (Variable Frequency Drive), ranging from 30 Hz to 60 Hz [11]. The measurement results from the LM393 sensor were then compared with measurements using a tachometer as a reference tool. Each change in frequency on the VFD resulted in a change in motor speed measured by the sensor, with the data processed by the Arduino Uno and displayed on the LCD. The testing showed that the LM393 sensor had high accuracy with an average error value of approximately -0.43% compared to the tachometer [12]. These results prove that the designed device can provide measurements that are very close to the actual values and has a fast response to frequency changes. The LCD display testing also ensures that motor speed data can be displayed clearly and accurately, and updated quickly according to the data received from the Arduino Uno.

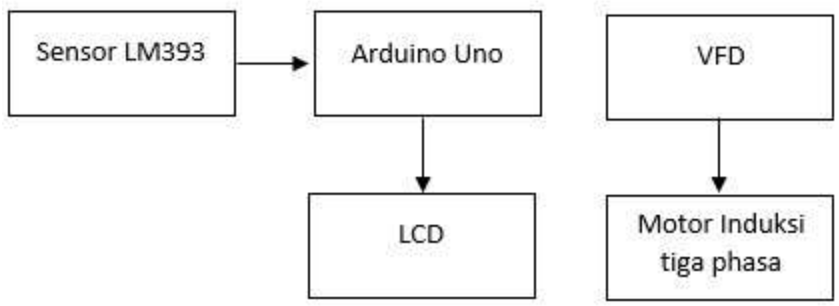

Figure 3. Block Diagram Compilation Speed Measurement

b. Research Instruments

Data collection in this study was conducted through observation, which is the process of systematically observing and recording the phenomena being investigated. The main instrument used was the LM393 sensor, which measures the rotational speed of an induction motor. This sensor is directly connected to an Arduino microcontroller, which collects data from the sensor, stores it in memory, and then displays it on an LCD screen. To ensure accuracy, the measurement results from the LM393 sensor are compared with a standard measuring device, namely a tachometer.

c. Data Analysis Techniques

Next, the data collected from the observation table was analyzed. The researcher examined the accuracy of the data produced by the LM393 sensor by comparing the output values of motor speed (RPM) displayed on the LCD with measurements obtained using a tachometer [13]. To calculate the error value of the LM393 sensor compared to the tachometer, the following formula was used:

$$Error\ (\%) = \frac{\text{Sensor reading} - \text{Measuring instrument reading}}{\text{Measuring instrument reading}}\ x\ 100 \ldots\ldots \text{(Eq 3.1)}$$

Explanation:

Sensor Reading : Value obtained from LM393 sensor

Measuring instrument : Value obtained from the tachometer.

Result and Discussion

a. Design Results

The LM393 sensor functions as a rotational speed measurement device for the motor [14]. The circuit diagram of the LM393 sensor is shown in Figure 4.

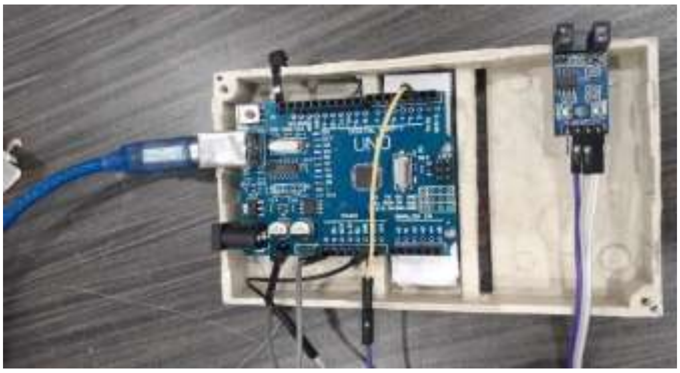

Figure 4. LM393 Sensor Circuit

As shown in Figure 4. the LM393 sensor is connected to the Arduino. This sensor circuit consists of the LM393 module and an encoder disk mounted on the rotor shaft of the induction motor. The LM393 module receives input voltage from the Arduino Uno through the 5V DC pin, and the sensor output is sent back to the digital pin of the Arduino Uno [15]. This configuration functions to detect the motor's rotational speed by reading the motion of the encoder disk as it rotates.

The LCD circuit functions to display the motor speed measurement results obtained by the LM393 sensor and processed through the Arduino. The LCD circuit is shown in Figure 5.

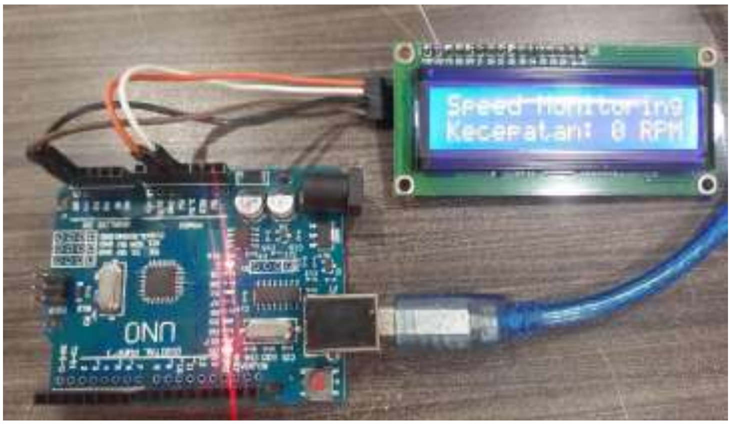

Figure 5. LCD Circuit

As shown in Figure 5, the LCD is connected to the Arduino, where the LCD GND is connected to the Arduino GND pin, the LCD VCC is connected to the Arduino 5V pin, the LCD SDA is connected to the Arduino A4 pin, and the LCD SCL is connected to the Arduino A5 pin. Variable Frequency Drive (VFD) Circuit with Three-Phase Induction Motor. The VFD functions to control the frequency of the three-phase induction motor. In this study, a VFD is used that is directly connected to the three-phase motor. The circuit diagram can be seen in Figure 6.

Figure 5. VFD Circuit with 3 Phase Induction Motor

In the figure above, the front panel of the VFD is shown with several control buttons. An MCB is connected to both the power line and the motor, serving as an additional protection component in the circuit. A terminal block is also present, indicating the connections for the power supply (R, S, T, N) and the motor (R, S, T). These serve as the main connection points for wiring the power source and the motor.

b. Test results

The Arduino Uno-based three-phase induction motor speed measurement device showed effective and accurate performance based on the test results. The test was conducted by comparing the LM393 sensor readings with the tachometer in the VFD frequency range from 30 Hz to 60 Hz [16]. Accuracy Test Results At low frequencies (30 Hz), there was a measurement error of 8.82%, where the sensor reading (816 RPM) was lower than the tachometer (895 RPM).

This error is likely caused by motor inertia or sensor limitations at low speeds. At medium frequencies (35 Hz to 50 Hz), accuracy improves significantly. The lowest error recorded was 0.38% at 35 Hz (sensor 1050 RPM, tachometer 1046 RPM). At the nominal frequency of 50 Hz, the error is only 0.53%, indicating nearly perfect sensor performance. At high frequencies (55 Hz–60 Hz), there is a slight tendency for the sensor reading to be higher than the actual value. The error was 1.10% at 55 Hz and 1.34% at 60 Hz. Overall, the average measurement error between the LM393 sensor and the tachometer is approximately -0.43%. This indicates that the device provides measurements that are very close to the actual values and can be relied upon for applications involving the measurement of three-phase induction motor speed. To provide a clearer understanding, the results of the testing and the measurement comparison of the motor speed error values (RPM) can be seen in Table 1.

Table 1. Motor Speed (RPM) Comparison: LM393 vs. Tachomete

No	VFD Frequency (Hz)	Output Voltage (V)	Motor Speed (RPM)		Error (%)
			Sensor Value	Tachometer Value	
1	30	216	816	895	8,82
2	35	253	1050	1046	0,38
3	40	291	1209	1193	1,34
4	45	327	1353	1344	1,12
5	50	370	1503	1495	0,53
6	55	408	1653	1642	1,10
7	60	415	1815	1793	1,34
Average error value					0,43

The explanation of Table 1, which presents the test results comparing the motor speed values (RPM) obtained from the LM393 sensor readings and the tachometer. In the 30 Hz test, there is a noticeable difference between the speed readings from the sensor and the tachometer. The sensor measured a speed of 816 RPM, while the tachometer showed 895 RPM, resulting in an error of 8.82%. This error indicates that the sensor reads a lower speed than the actual value. In the 35 Hz test, the difference between the sensor and the tachometer was minimal. The sensor recorded 1050 RPM, while the tachometer recorded 1046 RPM, resulting in an error of 0.38%. This indicates better accuracy at frequencies higher than 30 Hz. In the 40 Hz test, the sensor recorded a speed of 1209 RPM, while the tachometer showed 1193 RPM. This result yields a positive error of 1.34%. A positive error indicates that the sensor provided a slightly higher reading compared to the actual value. At a frequency of 45 Hz, the resulting error was 1.12%, with the sensor indicating a slightly higher speed than the tachometer (1353 RPM vs. 1344 RPM). Similar to the 40 Hz test, this difference remains relatively small and within an acceptable tolerance range. At a frequency of 50 Hz, which is the nominal frequency for many induction motors, the error was only 0.53%, with the sensor recording 1503 RPM and the tachometer 1495 RPM. This indicates that at nominal frequency, the sensor's performance in detecting motor speed is nearly accurate. At a frequency of 55 Hz, the sensor recorded 1653 RPM, while the tachometer recorded 1642 RPM, resulting in an error of 1.10%. At a frequency higher than the nominal, the sensor again showed a tendency to overestimate, with a relatively small difference. At the maximum tested frequency of 60 Hz, the sensor recorded a speed of 1815 RPM, while the tachometer recorded 1793 RPM. The error of 1.34% indicates that the sensor provided a slightly higher reading compared to the actual speed.

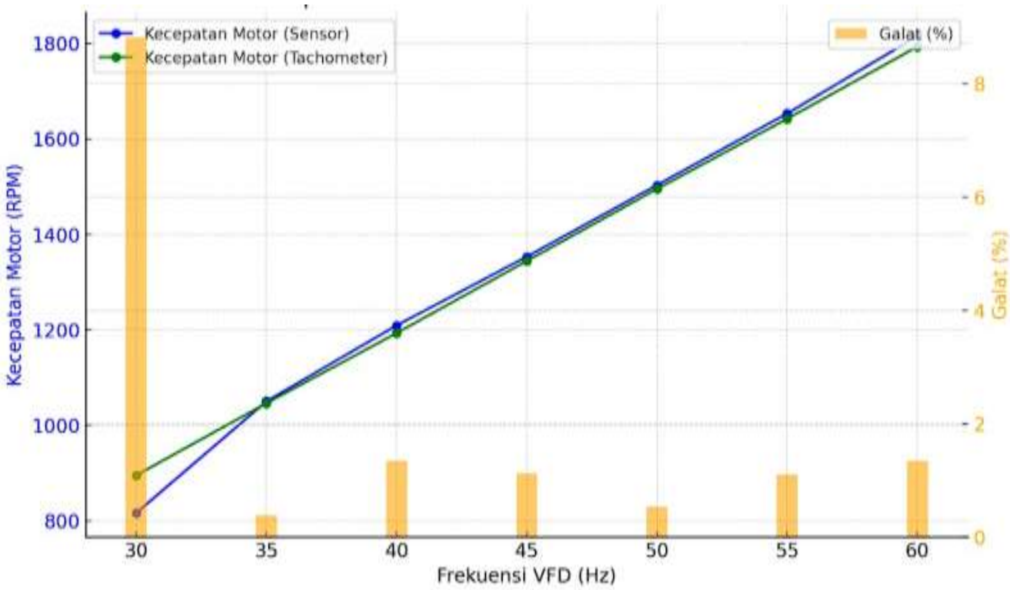

Figure 6. Motor Speed (RPM) Comparison: LM393 vs. Tachometer

Based on the test results, the device is effective in overcoming the challenges of controlling the speed of three-phase induction motors. Although there is a significant error at low frequencies (30 Hz), the accuracy of the device increases rapidly at higher frequencies. The very small average error (-0.43%) shows that this device can be relied upon for accurate motor speed measurements. Another advantage of this system is its fast response to frequency changes and its ability to display data in real-time via an LCD. However, this device has limitations as it only functions to monitor speed without automatic control features to maintain a stable speed when load changes occur.

This study has a different focus from several previous studies that tended to emphasize more complex control and analysis aspects. Several previous studies focused on the feasibility analysis of 3-phase induction motors, such as the study by Alfian Oktavianto and Joko (2024) [17], which used insulation resistance analysis and polarity index. Another study published in the journal TESLA (2022) discusses electrical testing of induction motors to ensure readiness before repair [18]. Additionally, there is research exploring speed control using inverters, as published in the journal JUSTI (2024) [19]. There are also studies discussing induction motor modeling for specific applications such as electric vehicles, developed after the discovery of vector control technology, and analyzing the influence of torque on the performance of three-phase induction motors using MATLAB [20]. Thus, this research fills a gap by providing specific and affordable solutions for speed measurement, rather than for control or more in-depth performance analysis.

Conclusion

This study successfully designed and tested a speed measurement device for three-phase induction motor drives based on Arduino Uno. This device combines components such as the LM393 sensor and Variable Frequency Drive (VFD) to enable precise motor speed measurement. The user interface consists of an LCD screen that displays speed data in real time. Test results indicate that the device functions according to the designed specifications. The LM393 sensor provides measurement results with a high level of accuracy. The average measurement error (error) compared to a tachometer as the standard measurement tool is approximately -0.43%. This demonstrates that the device can provide measurements that are very close to the actual value and reliable. Additionally, the system demonstrates quick response to frequency changes controlled via the VFD, along with an easy-to-read and rapidly updated LCD display. As a recommendation, researchers suggest further testing under varying operational conditions, such as extreme temperatures or different motor loads, to ensure the device's reliability in real-world scenarios. It is also recommended to add IoT connectivity features to enable remote monitoring and control in industrial environments.

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