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Implementation of Inverter and Modbus RTU RS-485 Communication in Controlling Induction Motor Speed

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ABSTRACT

As industrial technology continues to advance, the demand for efficient and automated motor control systems is increasing. Three-phase induction motors are widely used due to their durability and efficiency. However, controlling their speed remains a challenge, especially in small-scale applications without expensive systems. Therefore, a precise, affordable, and easy-to-implement motor control solution is needed. This study discusses the implementation of a three-phase induction motor speed control system using the LS G100 inverter and LS XBM-DR16S PLC through the Modbus RTU RS-485 communication protocol. The system is designed without additional expansion boards to simplify the circuit and reduce costs. The methodology used is an engineering and experimental approach, focusing on the measurement of motor electrical parameters such as actual speed (RPM), frequency, voltage, and current. Test results show that the system is capable of precisely controlling motor speed, with an average RPM accuracy of 99.6%, voltage accuracy of 97.2%, and current accuracy of 91.1%. The system has proven to be reliable and efficient for small to medium-scale industrial automation applications and facilitates real-time troubleshooting and monitoring through integrated data communication.

Keywords
Three-phase induction motor, LS XBM-DR16S PLC, LS G100 inverter, Modbus RTU, Motor speed, Industrial automation

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INTRODUCTION

In the manufacturing industry, three-phase induction motors are the primary choice for driving various production machines. This is due to several advantages offered by induction motors, such as simple and robust construction, relatively affordable cost, and ease of maintenance [1],[2]. However, one of their main drawbacks is the difficulty in precisely controlling the rotation speed, as they tend to operate at a constant speed [3].To overcome this limitation, a commonly used solution is to adjust the input frequency of the induction motor[4]. By changing the frequency, it is possible to control the motor speed more flexibly, allowing it to be set according to specific operational needs. As technology advances, industrial control systems have become increasingly complex. To simplify control systems and enhance efficiency, the use of communication protocols such as Modbus RTU has become more widespread. Modbus RTU utilizes RS-485 serial transmission, which requires only two communication wires, thereby reducing wiring complexity and simplifying maintenance[5].

With industrial automation, work efficiency increases significantly[6],[7]. The workload is reduced due to the use of machines controlled by automated systems, which simplify tasks and result in substantial time savings[8]. Automation in the industrial sector has now become one of the main foundations of technological advancement. In this context, the role of control and monitoring systems with data communication is crucial as a key supporting element[9]. Therefore, the efficiency of control systems using the Modbus protocol greatly simplifies aspects such as control wiring diagrams and system monitoring, especially in troubleshooting scenarios. This is because real-time motor data, such as current and voltage readings, can be monitored directly through the PLC.

Previous research discussed the implementation of data communication based on the Omron CP1E PLC. The study utilized more components, namely the Omron CP1E-N30DT-D PLC as the master and the Omron 3G3MX2-AB007-V1 VFD as the slave. Since implementing the Modbus RTU communication interface required extensive use of RS-485 connections, the PLC needed an additional RS-485 option board, specifically the CP1W-CIF11 module [10]. In this study, engineering economics was applied by minimizing the budget without reducing the system's functionality [11]. The system was designed and implemented using the LS XBM-DR16S PLC as the master and the LS G100 inverter as the slave, without using an additional option board (expansion). This approach simplified the circuit and maximized the efficiency of the control system. The LS XBM-DR16S PLC offers several advantages that make it suitable for small to medium-scale industrial automation. It is more affordable compared to other brands. Additionally, the XG5000 software is available for free and is user-friendly, making it ideal for beginner-level technicians. Moreover, LS PLCs support various communication protocols such as Modbus and RS-485 and offer flexible I/O options, making them efficient and practical for use in automated control systems[12].

Proramable Logic Controler (PLC)

A Programmable Logic Controller (PLC) is an electronic device used to control automation processes in industrial environments. PLCs operate based on programmable logic and are used to manage equipment such as motors, sensors, lights, and other actuators [13]. Compared to conventional relay-based control systems, PLCs are more flexible as they can be reprogrammed according to operational needs [14],[15]. Additionally, PLCs offer advantages in terms of response speed, reliability, and ease of maintenance and system development.The PLC functions as the brain of the control system[16]. It can communicate with various devices, including inverters, using the Modbus RTU protocol. By using the XBM-DR16S PLC, it is possible to develop logic programs to control motor speed, monitor operating conditions, and perform corrective actions in the event of a system disturbance.

Inverter/ Variable Frequency Device (VFD)

An inverter, or Variable Frequency Drive (VFD), is an electronic device that functions to convert direct current (DC) into alternating current (AC)[17]-[19]. In industrial systems, inverters play a vital role as motor speed controllers, especially for three-phase induction motors. The LS G100, for example, is a widely used type of inverter that is compatible with the Modbus RTU communication protocol. Applications of this system can be found across various industries, such as the automotive industry, food and beverage processing, and manufacturing sectors [20].

The implementation of a three-phase induction motor speed control system is carried out by integrating an inverter and Modbus RTU RS-485 communication, where the LS XBM-DR16S PLC acts as the master to digitally control and monitor the LS G100 inverter. In addition, this integration process explores how variations in RPM (motor speed) affect current, voltage, and frequency, within a control range of 100 RPM to 1000 RPM. This control is crucial for determining the motor's optimal performance [21]. The observations from this study are expected to provide deeper insight into the performance characteristics of induction motors when controlled through a data communication-based automation system.

Figure 1 is a Schematic the Modbus RTU RS-485 wiring diagram. This schematic serves to provide a general overview of the communication flow, the function of each device, and how the motor speed control and monitoring system is implemented in an integrated manner.

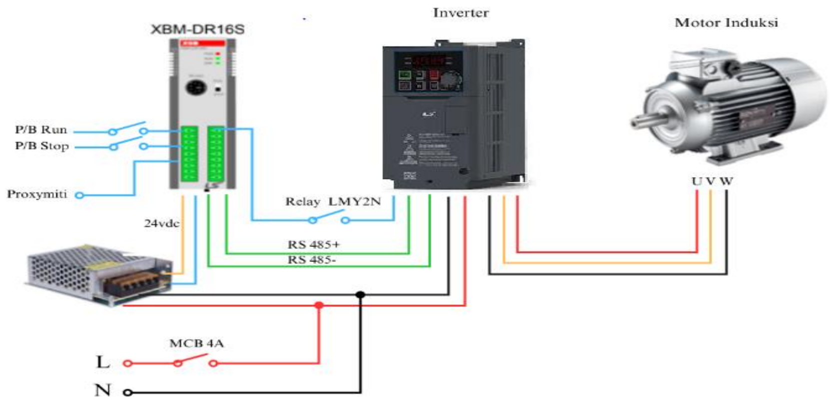

Figure 1. Schematic the Modbus RTU RS-485 wiring diagram

METHOD

This research adopts an engineering and experimental method approach, combining the technical design process with system performance testing [22]. The engineering phase includes needs analysis, hardware and software design, as well as overall system implementation, while the experimental testing is conducted to evaluate the performance of the designed system. This engineering research focuses on the design and implementation of a Modbus RTU RS-485 system, using the LS XBM-DR16S PLC as the master and the G100 inverter as the slave to control the rotation speed of an induction motor. The combination of these two methods is intended to ensure that the resulting system not only meets operational requirements, but also provides reliable and optimal performance in controlling motor speed.

System Design

This system integrates the LS XBM-DR16S PLC and the LS G100 inverter through Modbus RTU RS-485 communication without using any additional expansion boards, a configuration not found in previous references with similar setups. By directly combining the devices and Modbus RTU communication without external modules, the main goal is cost efficiency and wiring simplicity, which are rarely discussed in other implementations. The design of this system aims to simplify the implementation process of creating the equipment. It is expected to minimize troubleshooting and equipment damage during the manufacturing process. There are several materials required to support the smooth running of the research and ensure that the expected goals are achieved. The materials used include several key components that support the processes of measurement, observation, and data analysis, namely: the LS XBM-DR16S Programmable Logic Controller (PLC) as the master, the LS G100 Inverter or Variable Frequency Drive (VFD) as the slave, a 4A MCB (Miniature Circuit Breaker) to ensure that the correct type of current is used for more precise circuit interruption [23]. a 2A fuse holder, Proximity PR08-2DN, 24V DC power supply, 24V DC relay, jumper cables to connect the PLC and Inverter, push buttons for Run and Stop, power cables, USB RS-232 cables, a 220V 180W 4-pole 3-phase induction motor, multitester , and grounding cables for safety and equipment protection. Grounding is a safety system against disturbances commonly occurring in electrical circuits [24]. The software used includes a laptop and XG5000 software, which is used for the programming process. Figure 2 shows the result of assembling the speed control circuit for the induction motor using the Modbus RTU RS-485 protocol.

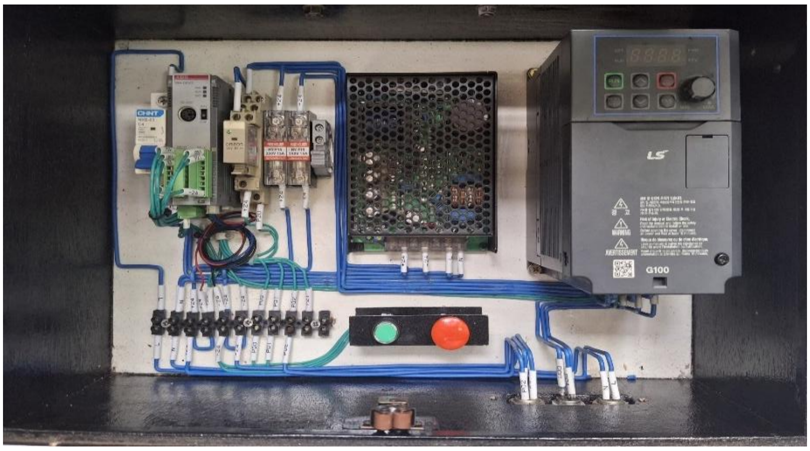

Figure 2. Result of the Circuit assembly.

Modbus RTU RS-485 Communication Mechanism

The Modbus RTU RS-485 communication mechanism operates on a master-slave concept, where the master device, such as the LS XBM-DR16S PLC, initiates communication by sending data requests or instructions to slave devices, like the LS G100 inverter. This communication occurs over a serial RS-485 communication line, which uses two main wires (S+ and S-) to transmit data differentially. Each slave device has an address, and only the device with the matching address will respond to the master's request [25]. The Modbus RTU protocol transmits data in the form of a frame, which consists of the device address, function code, data, and CRC (Cyclic Redundancy Check) for data integrity validation. All communication is done synchronously and sequentially, ensuring efficient and reliable data exchange between devices on the network.

Device Communication Configuration.

PLC LS XBM-DR16S acts as the master in this system, controlling the communication settings such as baud rate, data bits, and parity, which are adjusted to match the LS G100 inverter[26] . This PLC can send and receive data via Modbus RTU, allowing it to issue commands or read the status from the inverter. Table 1 shows the Modbus RTU communication configuration settings in this circuit.

Table 1. Serial Communication Configuration

No	Parameter	Value
1	Baud rate	115200 bps
2	Data Bits	8
3	Parity	none
4	Stop Bits	1
5	Mode	RTU

In communication systems like Modbus RTU, the data bits and parity parameters must be the same across all devices (master and slave). If they are not the same, communication may fail or data may be misread.

Device Address Configuration.

Address configuration on the inverter is done to determine the device's identity within the Modbus RTU network. This address is necessary so that the PLC, as the master, can send commands or read data from the targeted inverter. For example, if the inverter is assigned address 1, then all communications sent by the PLC to address 1 will only be received by that specific inverter. According to Table 2, this shows the DRV Group address on the inverter, which is a set of basic parameters used to operate and monitor the motor's performance. Parameters such as operating frequency (DRV-F), run command (DRV-RUN)[27], are included in this group and are key in the initial configuration process of the inverter.

Table 2. DRV Group Address Configuration on Inverter.

No	Led Display	Parameter Name	Value	Description
1	ACC	Accel time	1.0	Acceleration Time
2	dEC	Decel time	1.0	Deceleration Time
3	Drv	Drive mode	3	RS485 Communication
4	Frq	Frequency setting method	7	RS485 Communication

The Common Parameter Code address configuration needs to be set, The Common Parameter Code on the LS G100 inverter is a set of basic parameter addresses used to control and monitor motor operation via Modbus RTU communication. These parameters include settings for reference frequency, run/stop commands, rotation direction, as well as motor voltage and current values. By using these address codes, the PLC as the master can send instructions and read data from the inverter in real time without the need for additional modules. Table 3 presents the parameters used to configure frequency, acceleration/deceleration time, motor current, and operation mode, which serve as key references in programming and instruction command communication processes within the control system [27],[28].

Table 3. Common Parameter Code Address Configuration.

No	Parameter	Address	Unit
1	Run Comand	D4500	-
2	Output Frequency	D4000	Hz
3	Output Current	D3902	A
4	Output Voltage	D3900	V
5	Output Rpm	D3901	Rpm
6	Acceleration	D2002	Sec
7	Deceleration	D2003	Sec

Ladder Program Configuration and Communication Process

The LS XBM-DR16S PLC, acting as the master, sends commands to configure parameters on the LS G100 inverter, such as instructions to change the motor speed. These commands are executed by sending specific values to the appropriate Modbus registers on the inverter. In addition to sending commands, the PLC can also read parameters from the LS G100 inverter, such as current, voltage, speed, and motor operating status. This data reading is essential for real-time monitoring of the motor's operational condition and ensuring the system functions according to requirements. Accordingly, the programming process must be carried out using the XG5000 software [29]. As shown in Figure 3, it illustrates the ladder diagram used for executing instructions and monitoring the motor status.

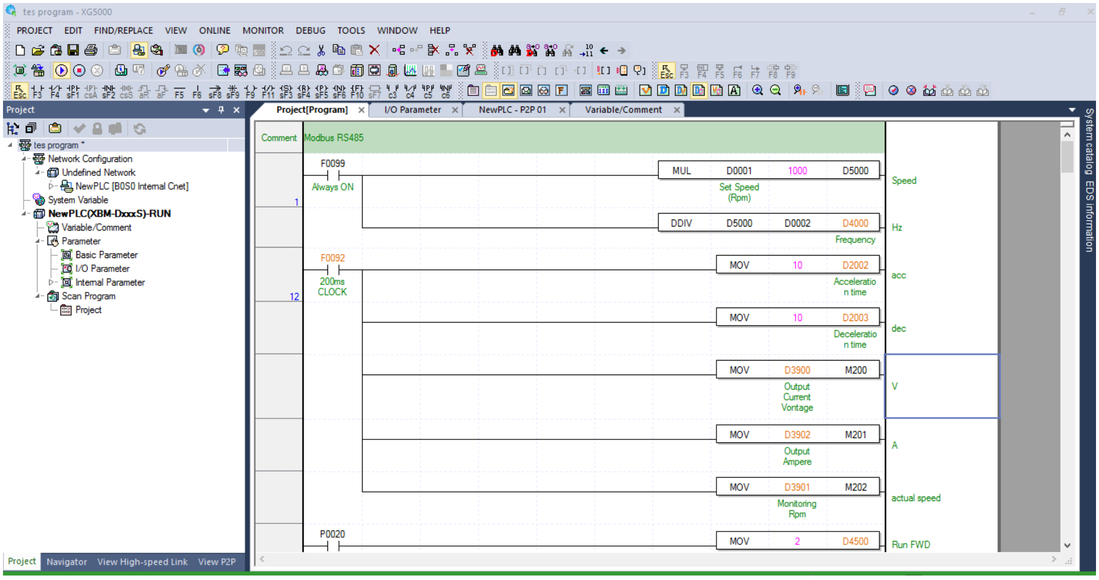

Figure 3. Ladder Program on PLC.

Figure 3 shows the PLC instruction program designed to control and monitor the operation of the inverter. The instructions use register addresses that have been configured according to the device setup, as described in Table 2 and Table 3. This address configuration is essential to ensure proper communication between the PLC as the master and the inverter as the slave in the Modbus RTU system.

In Figure 4, the program the P2P communication configuration used for direct data exchange without the need for additional devices [30]. The configuration is done by setting communication parameters on both the PLC and the VFD, allowing them to automatically send and receive data.

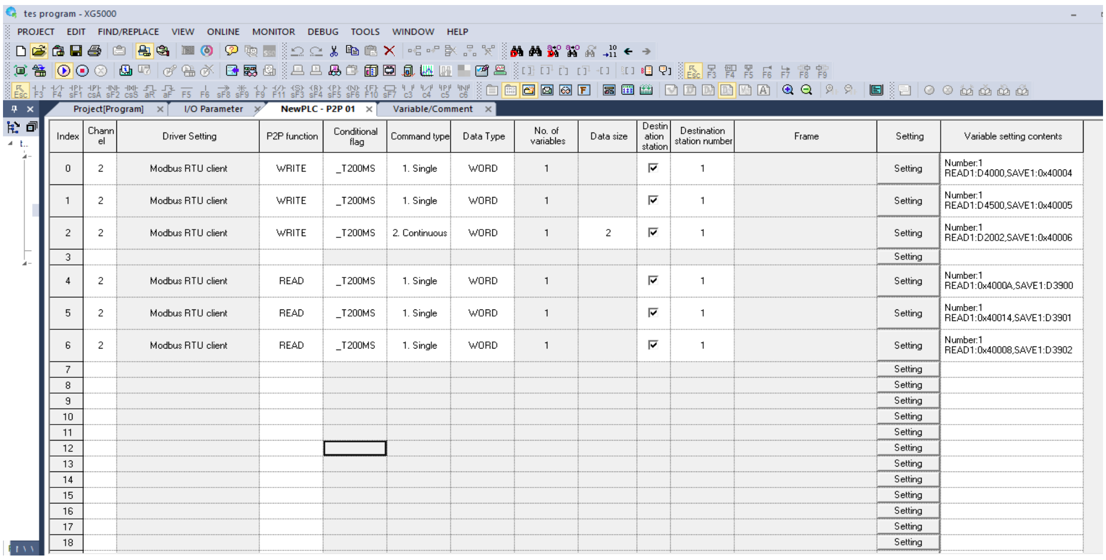

Figure 4. P2P Communication Setup Program

RESULT AND DISCUSSION

This section presents the test results of the three-phase induction motor control system that has been designed and implemented. The testing was conducted to evaluate the system's performance. The obtained results were then analyzed to assess the system's accuracy and reliability, as well as its compliance with the operating principles of induction motors and the intended implementation goals. The testing included measurements of the actual rotational speed (RPM) compared to the set speed values ranging from 100 to 1000 RPM, as well as measurements of the motor's operating frequency, output voltage, and Output current.

This study has several limitations to clarify the scope of the implemented system. The system was tested only on a three-phase induction motor with a power rating of 180W and a voltage of 3 phase 220V, using an LS XBM-DR16S PLC as the master and an LS G100 inverter as the slave, without any additional communication modules. Communication between devices was conducted via the Modbus RTU protocol over RS-485. The parameters controlled and monitored include motor speed (RPM), frequency, output voltage, and electric current, without considering other parameters such as temperature or torque. Testing was carried out under no-load conditions, so the results do not represent the motor's performance under load.

Measurement of Actual RPM and Frequency of a Induction Motor

Table 4 presents the measurement results of the three-phase induction motor speed at set points ranging from 100 to 1000 RPM. The data includes the actual speed recorded by the tachometer, slip percentage, speed control accuracy, and the inverter output frequency. This test aims to evaluate the system's accuracy in controlling motor speed in real time.

Table 4. Measurement Results of Actual RPM and Motor Frequency

No	Speed (Rpm)	Tacometer	Slip (%)	Accuracy (%)	Frequency (Hz)
1	100	101	1	99	3,48
2	200	201	0,5	99,5	6,77
3	300	302	0,6	99,3	10,16
4	400	400	0	100	13,42
5	500	500	0	100	16,77
6	600	600	0	100	20,13
7	700	701	0,1	99,8	23,48
8	800	802	0,2	99,7	26,84
9	900	902	0,2	99,7	30,20
10	1000	1002	0,2	99,7	33,35

Based on the Frequency Test Graph results (Figure 5), it is shown that an increase in the motor's RPM is accompanied by an increase in the frequency output by the VFD. This aligns with the fundamental characteristics of a three-phase induction motor, where speed (RPM) is directly proportional to the supply frequency. With a constant number of motor poles, an increase in speed can only be achieved by increasing the frequency. Therefore, when adjusting the motor speed via the VFD, the device automatically raises its output frequency to increase the motor speed according to the desired value.

Based on the Actual RPM Graph of the motor, the tested motor was able to achieve actual rotational speeds that closely matched the predefined set point values. The test data showed an average accuracy percentage of 99.6%, as illustrated in Figure 6. This high level of accuracy demonstrates the system's reliability and precision in controlling motor speed, reinforcing its suitability for applications that require high-performance and precise speed regulation. Such accuracy is particularly valuable in industrial automation processes where even slight deviations in motor speed can affect overall system performance Output Voltage Measurement.

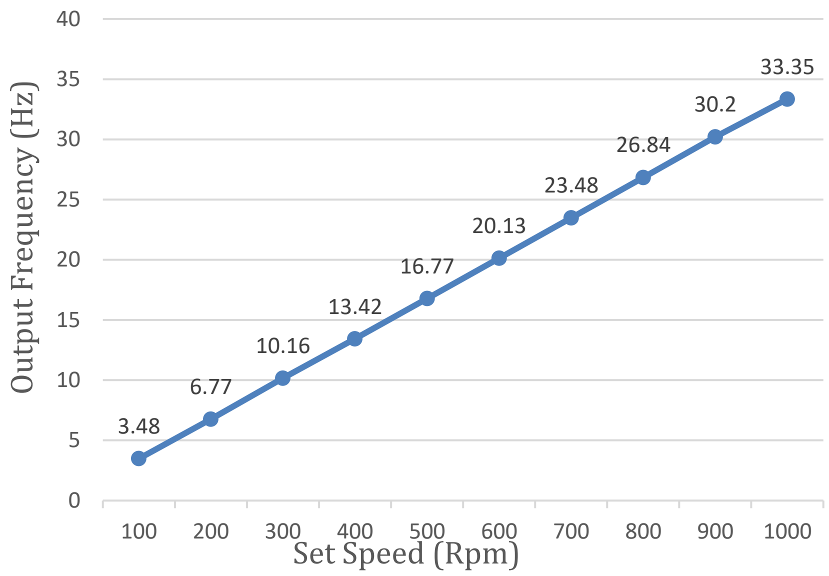

Figure 5. Graph of Frequency Measurement Against Motor RPM.

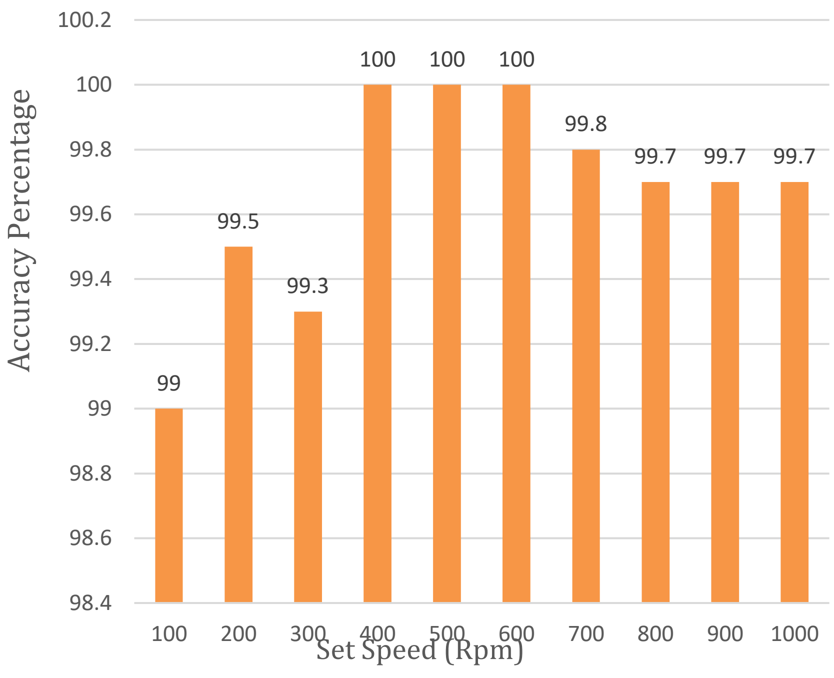

Figure 6. Graph of Actual Motor RPM Accuracy.

Output Voltage Measurement

Table 5 presents the measurement results of the motor output voltage at various rotational speeds (RPM), obtained through experiments using a VFD and compared with readings from a digital multimeter. Each speed level was tested five times to obtain an average value, which was then compared with the actual multimeter readings to determine the system's accuracy. This data is used to evaluate the inverter's voltage regulation accuracy in maintaining motor operational stability.

Table 5. Motor Output Voltage Measurement Results.

No	Speed (Rpm)	Experiment VFD (volt) 1	2	3	4	5	Averange	Multi meter	Accuracy (%)
1	100	19,2	19,2	19,3	19,2	19,2	19,2	23,1	79,9
2	200	33,4	33,4	33,4	33,5	33,5	33,4	32,7	97,9
3	300	48	48,1	48	48	47,9	48	47,2	98,8
4	400	62,1	62,1	62,1	62,2	62	62,1	61,3	98,7
5	500	76,5	76,6	76,8	76,6	76,6	76,6	75,7	98,9
6	600	90,9	91,1	90,9	91,2	91	91	90,4	99,3
7	700	105,3	105,5	105,5	105,4	105,3	105,4	104,9	99,5
8	800	119,9	119,8	119,8	119,8	119,9	119,8	119,6	99,8
9	900	134,3	134,3	134,2	134,2	134,5	134,3	134,3	100
10	1000	148,9	149,2	149,3	149	148,8	149	149,2	99,8

Based on the test results and output voltage measurement graph in Figure 7, each increase in frequency set by the inverter (VFD) is followed by a proportional increase in the motor's output voltage. This pattern indicates a linear relationship between frequency and voltage, consistent with the constant V/f (Volt per Hertz) principle, where the VFD automatically adjusts the voltage to maintain a stable V/f ratio. The purpose of this regulation is to keep the motor torque stable and ensure efficient motor operation across various speeds.

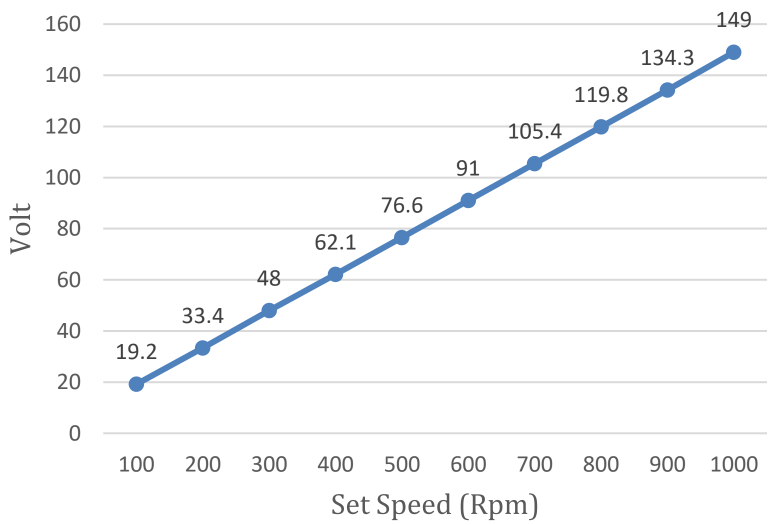

Figure 7. Graph of Motor Output Voltage Measurement

In addition, voltage monitoring was carried out through the PLC program, along with direct measurements using a digital multimeter as a comparison tool. The comparison between the monitored values and the actual measurement results showed an average accuracy of 97.2%, as shown in Figure 8. This value reflects a high level of precision, indicating that the voltage monitoring system via the PLC program has excellent accuracy and can be reliably used for both control and real-time process monitoring purposes.

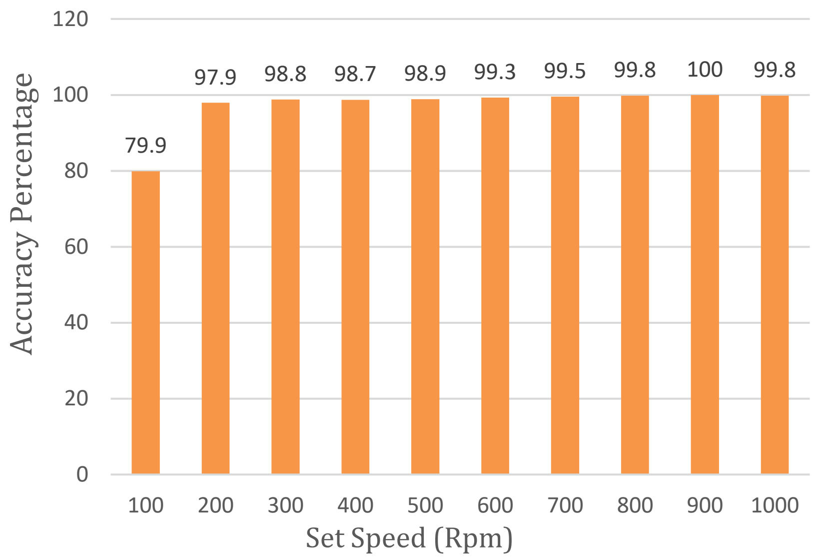

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Figure 8 Graph of Motor Output Voltage Measurement Accuracy

Output Current Measurement

Table 6 presents the measurement results of the output current (amperes) of the induction motor at various rotational speeds (RPM), based on five trials using readings from the inverter (VFD). The average values from these trials were then compared with actual measurements taken using a digital multimeter to determine the system's accuracy. This data is used to evaluate the accuracy of the motor current monitoring system under no-load conditions.

Table 6. Motor Output Current Measurement Results.

No	Speed (Rpm)	Experiment VFD (Ampere)					Averange	Multi meter	Accuracy (%)
		1	2	3	4	5			
1	100	0,4	0,4	0,4	0,4	0,4	0,4	0,47	82,5
2	200	0,6	0,6	0,6	0,6	0,6	0,6	0,63	95
3	300	0,7	0,7	0,7	0,7	0,7	0,7	0,7	100
4	400	0,7	0,7	0,7	0,7	0,7	0,7	0,73	95,7
5	500	0,7	0,7	0,7	0,7	0,7	0,7	0,75	92,8
6	600	0,7	0,7	0,7	0,7	0,7	0,7	0,77	90
7	700	0,7	0,7	0,7	0,7	0,7	0,7	0,77	90
8	800	0,7	0,7	0,7	0,7	0,7	0,7	0,78	88,5
9	900	0,7	0,7	0,7	0,7	0,7	0,7	0,78	88,5
10	1000	0,7	0,7	0,7	0,7	0,7	0,7	0,78	88,5

Based on the no-load current test graph in Figure 9, it was observed that at low speeds (around 100 RPM), the motor current recorded was 0.4 A, while at speeds above 200 RPM, the current stabilized at 0.7 A. This increase occurs despite the absence of external load, indicating that the rising frequency and output voltage from the VFD cause an increase in magnetizing current to maintain motor operation. Additionally, internal motor losses increase at higher speeds, requiring more current for compensation. The inverter (VFD) display readings tend to round decimal values up or down depending on the system's internal logic. Typically, only one decimal place is shown to optimize display speed and readability

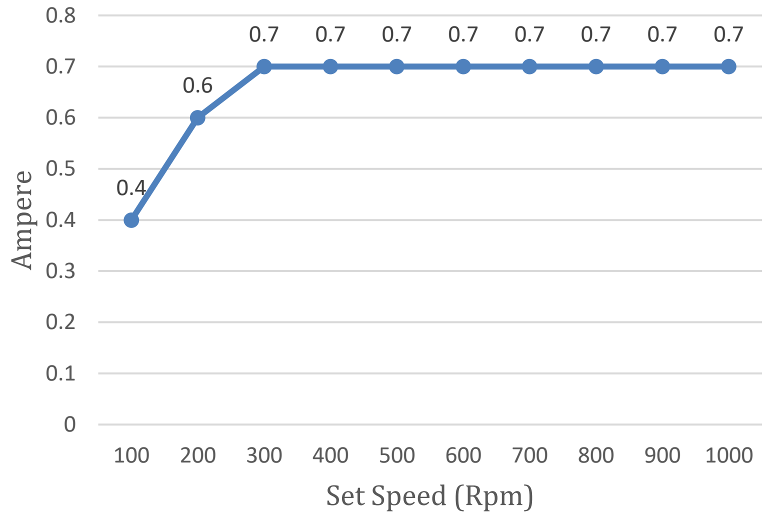

Figure 9. Graph of Motor Output Current Measurement

Based on the comparison graph (Figure 10) between the current monitoring results through the PLC program and direct measurements using a multimeter, an average accuracy rate of 91.1% was obtained. This result indicates that the current monitoring system integrated into the PLC program is capable of representing the actual motor current condition with a fairly high level of accuracy. Although there is some deviation due to rounding and the resolution limitations of the monitoring system, the value still falls within the tolerance limits and can be concluded that the system works accurately and reliably in displaying the motor's electrical current parameters.

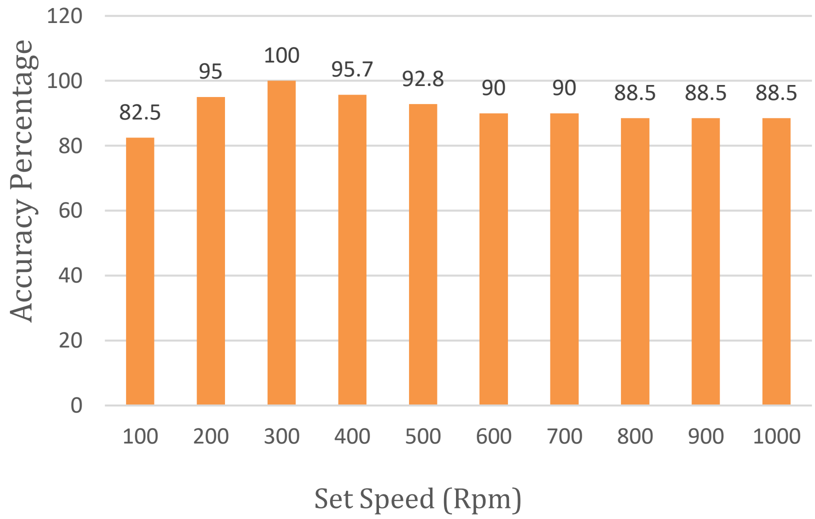

Figure 10. Graph of Motor Output Current Accuracy.

CONCLUSION

This research successfully designed and implemented a three-phase induction motor speed control system using a combination of the LS G100 inverter as the slave and the LS XBM-DR16S PLC as the master, both connected via Modbus RTU RS-485 communication. Notably, the system was able to function effectively without the need for additional option boards. This streamlined design offers significant advantages in terms of cost-effectiveness and simplicity for industrial applications, where reducing the number of additional components can lead to a more efficient setup.

The system is capable of monitoring and controlling key parameters of the motor, including speed (RPM), operating frequency, output voltage, and current (amperes), all in real time. These capabilities are crucial for ensuring that the motor performs optimally under varying operational conditions. The ability to control multiple parameters in real time allows for a more dynamic and responsive control system, which is essential for maintaining desired motor performance.

Testing results showed that the measured actual motor speed (RPM) achieved an average accuracy of 99.6%, indicating that the system is highly precise in controlling motor speed. The output voltage followed a linear relationship with frequency, consistent with the constant V/f principle, and achieved 97.2% accuracy compared to actual measurements. Additionally, the output current (ampere) demonstrated an accuracy of 91.1%, with minor deviations caused by rounding within the VFD system. These results suggest that the system is not only accurate but also stable under real-world conditions.

Overall, the system has proven to be efficient, accurate, and reliable for controlling and monitoring induction motors in industrial automation applications, particularly for small to medium-scale operations. The use of digital communication via Modbus RTU simplifies the wiring process, enhances troubleshooting capabilities, and contributes to the overall efficiency of the control system. This makes the system a suitable choice for industries looking to implement reliable and cost-effective motor control solutions.

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