# Experimental Study on PLC–VFD Integration for Real-Time Motor Speed Regulation

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***Abstract:*** **In industries, controlling the speed of motors accurately is very important for saving energy and improving performance. Old methods like using gears or rheostats are not very efficient and cannot adjust the speed smoothly. To solve this problem, this project uses a Programmable Logic Controller (PLC) and a Variable Frequency Drive (VFD) together to control the speed of a three-phase induction motor. The main goal of this study is to build and test a system that controls the motor speed and checks how the voltage-to-frequency (V/f) ratio affects its working. A small lab setup was made where the PLC gives control signals to the VFD, and different voltage and frequency levels were tested. The readings were compared with Siemens standard drive values to check accuracy. The results showed that the motor works best when the V/f ratio is between 5 and 8 V/Hz. Below this range, the motor loses torque and becomes unstable, and above it, the motor heats up and works less efficiently. This setup helps achieve smooth motor operation, better energy use, and reliable control, making it useful in industries like conveyor systems, water treatment plants, and HVAC systems.**

***Keywords- VFD (Variable Frequency Drive), PLC (Programmable Logic Controller), Induction Motor, Speed Regulation, V/F Method***

## I. INTRODUCTION

In the early stages of industrial development, motor speed was controlled using mechanical systems like gears, pulleys, or rheostats. These methods were slow, caused power losses, and required frequent maintenance. As industries grew, there was a need for more accurate and automatic control. The introduction of Programmable Logic Controllers (PLCs) and Variable Frequency Drives (VFDs) transformed this process by allowing smooth and flexible speed control of three-phase induction motors. This combination improved energy efficiency, reduced wear and tear, and made automation easier in industries such as manufacturing, paper mills, and water treatment plants.

The main goal of this project is to design and test a PLC–VFD-based system that can control the speed of a three-phase induction motor and study how the voltage-to-frequency (V/f) ratio affects its performance. The plan is to build a small experimental setup where the PLC gives control signals to the VFD to adjust motor speed. Different voltage and frequency levels are tested, and the results are compared with industrial standards like Siemens drives. This helps to identify the best operating range where the motor works efficiently and safely.

Many researchers have already studied PLC–VFD integration over the years. Birbir [1] in 2002 explained the working of large industrial VFDs. Sun [2] in 2007 described how voltage and frequency changes affect motor torque. Ahir [3] in 2008 designed a PLC-based motor control system but did not include performance testing. Da'na [4] in 2012 showed that VFDs save energy but did not combine them with PLCs. Ioannidis [5] in 2013 studied the role of PLCs in automation. Kaushal and Sharma [6] in 2014 automated a grinder using PLC and drives but without feedback control. Banupriya and Radha [7] in 2015 applied PLCs in paper machine automation but ignored energy study, and Gupta [8] in the same year developed a PLC–SCADA control but lacked analysis. Tiwari et al. [9] in 2016 studied PLC-based motor speed control but gave no practical results. Kaur [10] and Prabakaran et al. [11] in 2017 designed PLC–VFD systems but did not add maintenance or feedback features. Hassan et al. [12] in 2017 integrated HMI but kept it open-loop. In 2019, JETIR researchers [13] used sensors for automation but didn't include energy data, and IJSRD [14] used a single PLC for multiple VFDs without testing. Finally, Bhanvase et al. [15] in 2024 designed a PLC–VFD control system but did not add energy optimization or smart monitoring. From these studies, it is seen that most systems are open-loop and lack feedback or real-time monitoring.

In this project, a lab-scale PLC–VFD setup was developed to overcome these limitations. The system was tested under different voltage and frequency conditions, and the V/f ratio was calculated. The results showed that the motor performs best when the V/f ratio is between 5 and 8 V/Hz, ensuring stable torque and smooth operation. This project proves that proper PLC–VFD tuning improves motor performance and can be applied in industries like conveyors, pumps, and manufacturing systems for better energy efficiency and automation.

## II. LITERATURE REVIEW:

The use of Programmable Logic Controllers (PLCs) and Variable Frequency Drives (VFDs) for the automation and control of induction motors had been extensively studied in industrial automation research. These systems were shown to enhance process efficiency, improve speed accuracy, and reduce mechanical wear compared to conventional methods.

Birbir (2002) [1] presented the engineering fundamentals of large-capacity VFDs used in industrial systems, forming the base for motor control studies. Sun (2007) [2] explained the theoretical relationship between voltage, frequency, and torque in electrical drives, which helped in understanding variable-speed operation. Ahir (2008) [3] implemented a PLC-based monitoring and control system for three-phase induction motors but did not include energy efficiency testing. Da'na (2012) [4] described how VFDs were used in ships to save energy and reduce emissions but did not involve PLC control. Ioannidis (2013) [5] analyzed the role of PLCs in the early stages of automation and emphasized their growing use in industrial applications.

Kaushal and Sharma (2014) [6] designed a PLC- and HMI-based control system for a cylindrical grinder, but lacked real-time feedback and data logging. Banupriya and Radha (2015) [7] developed a sectional drive paper machine using PLC and HMI but did not perform energy analysis. Gupta (2015) [8] designed a PLC–SCADA control for a three-phase motor but did not evaluate performance parameters. Tiwari et al. (2016) [9] proposed a PLC–VFD-based speed control system but did not provide experimental validation.

A. Kaur (2017) [10] focused on machine automation using PLC, VFD, and HMI but ignored predictive maintenance aspects. Prabakaran et al. (2017) [11] developed a PLC–SCADA interface for VFD-based speed control but tested it only on a single motor setup. Hassan et al. (2017) [12] integrated PLC, HMI, and VFD for motor automation but retained an open-loop configuration without fault detection or feedback.

The JETIR (2019) study [13] introduced photo-sensors for automation in PLC–VFD systems but did not include real-time energy monitoring. The IJSRD (2019) paper [14] attempted multi-VFD control through a single PLC but failed to test system scalability or implement advanced control techniques. Recently, Bhanvase et al. (2024) [15] investigated PLC–VFD integration for induction motor control but did not analyze energy optimization or implement vector control techniques.

From all these studies, it was observed that most systems remained open-loop, with limited feedback and no intelligent data-driven monitoring. Only a few attempted partial integration of advanced control methods, and none compared performance with industrial standards like Siemens or ABB drives. Hence, there was a clear gap for developing a closed-loop, intelligent, and energy-optimized PLC–VFD system capable of predictive fault detection and real-time performance analysis for industrial scalability.

## III. METHODOLOGY:

This section describes the design, setup, and testing of the PLC–VFD-based speed control system for a three-phase induction motor. The experimental procedure includes hardware connections, PLC programming, parameter testing, and performance observation under different voltage and frequency conditions.

### A. Hardware Setup

The experimental setup, shown in Fig. 1, consists of a Programmable Logic Controller (PLC), a Variable Frequency Drive (VFD), and a three-phase induction motor. The PLC is used to control the motor through the VFD by sending digital and analog signals.

A 230 V AC single-phase supply powers the PLC through a 24 V DC SMPS, while a 440 V AC three-phase supply is given to the VFD. The VFD output terminals (U, V, W) are connected to the motor terminals (R, Y, B). The PLC's digital output signals perform Start/Stop control of the VFD, and the analog output (0–10 V DC) provides the reference for motor speed.

Protective devices such as MCBs, relays, and an emergency stop switch are included to ensure safety during operation. The complete wiring is enclosed in a control panel for easy handling and observation.

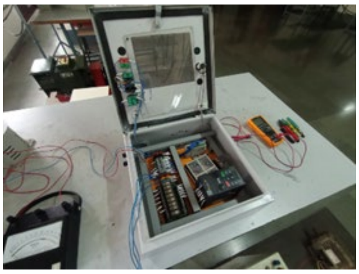

Fig. 1. Experimental setup of PLC–VFD–Motor panel.

### B. System Block Diagram

The block diagram of the system is shown in *Fig. 2*. A **230 V AC** main supply powers the PLC via the SMPS, and a separate **440 V AC** supply feeds the VFD. The PLC communicates with the VFD through digital and analog connections to control motor speed. An optional **HMI** interface can be used for visual monitoring, though this project primarily focuses on the PLC–VFD operation.

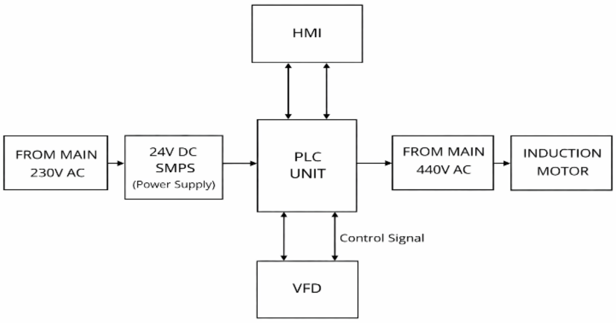

Fig. 2. Block diagram of PLC–VFD-based induction motor control system.

### C. PLC Programming Logic

The PLC program is developed in **ladder logic** to automate motor control operations.

1. **Start/Stop Logic:** The Start button energizes a relay to run the motor, while the Stop button de-energizes it.
2. **Speed Regulation:** The PLC's analog output provides a variable voltage signal (0–10 V DC) to the VFD, adjusting the operating frequency and thereby controlling motor speed.
3. **Safety Interlock:** In case of overload or fault, the PLC triggers an immediate stop to protect the system.
4. **Status Indication:** LEDs are used to display motor ON, OFF, and fault conditions.
5. This logic ensures smooth and safe control of the induction motor through automation.
6. D. Testing Procedure and Data Collection

7. The system was tested by varying the VFD frequency to analyze the effect on motor speed and torque. The key testing parameters are:

- Input voltage: 175–262 V
- Frequency range: 20–50 Hz
- Observed parameters: Voltage, frequency, current, and speed (RPM)

A **digital tachometer** was used to measure the motor speed. Data was recorded for multiple voltage–frequency combinations to calculate the **V/f ratio**. The motor performed most efficiently when the ratio was maintained between **5 and 8 V/Hz**. Below 5 V/Hz, the torque dropped significantly, and above 8 V/Hz, overheating occurred due to over-fluxing.

### PLC Layout Protection:

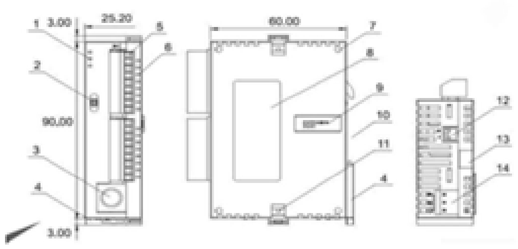

Fig. 3. PLC layout protection

TABLE I. IDENTIFIERS OF FIG.3

| | |
|---|---|
| 1.POWER,RUN,ERROR Indicator | 8.Nameplate |
| 2 RUN/STOP switch | 9.Extension Port |
| 3.I/O port for program communication | 10.DIN rail mounting slot |
| 4.DIN rail clip | 11.Extension Unit Clip |
| 5.I/O Terminals | 12.RS-485 communication port |
| 6.I/O Point Indicator | 13.Mounting Rail For Extension Module |
| 7.Mounting Hole For Extension Module | 14.DC power input |

### Block diagram:

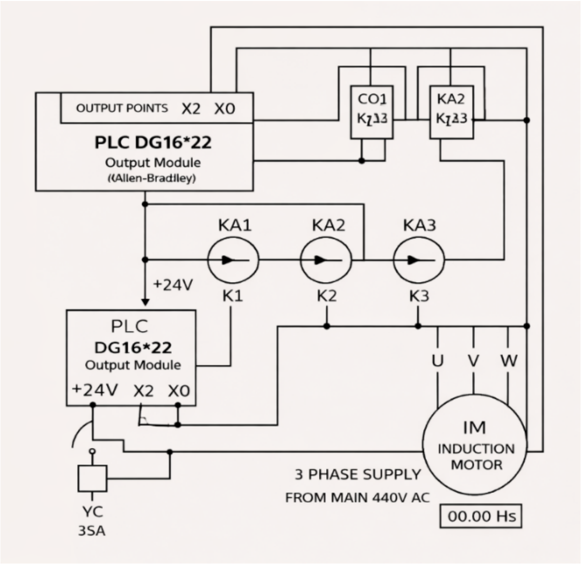

Fig. 4. Block diagram:

### Variable frequency drive

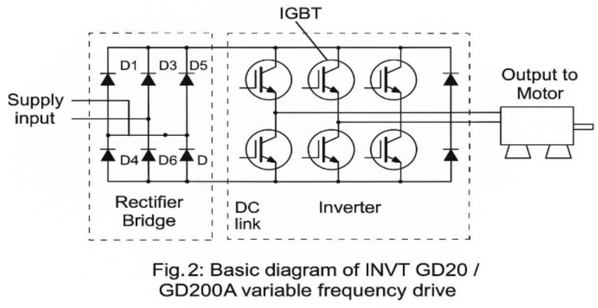

Fig. 5. Basic diagram of INVT GD20 / GD200A variable frequency drive

*1) Rectifier Stage (Rectifier Bridge – D1 to D6):*

The first part is the rectifier stage, which uses six diodes (D1 to D6) to convert the incoming AC supply into DC voltage. This is called a three-phase full-bridge rectifier.

*2) DC Link (DC Bus):*

Next is the DC link or DC bus section, which includes capacitors (and sometimes inductors) to smooth and filter the rectified DC voltage. It stores energy and ensures a stable DC supply for the inverter section, reducing voltage ripple and fluctuations.

*3) Inverter Stage (Using IGBTs):*

The final stage is the inverter, which consists of six IGBT (Insulated Gate Bipolar Transistor) switches. These switches convert the DC voltage into AC with controllable voltage and frequency. This output is then fed to the induction motor, allowing precise control of its speed and torque.

### Experimental details:

| Sr. | Voltage (V) | Frequency (Hz) | V/f Ratio | speed |
|---|---|---|---|---|
| 1 | 258 | 50 | 5.16 | 1492 |
| 2 | 258 | 48 | 5.38 | 1432 |
| 3 | 175 | 48.10 | 3.64 | 1434 |
| 4 | 200.05 | 48.10 | 4.16 | 1424 |
| 5 | 262 | 48.10 | 5.45 | 1434 |
| 6 | 207 | 25.15 | 8.23 | 750 |
| 7 | 222 | 30.20 | 7.35 | 898 |
| 8 | 255 | 25.70 | 9.92 | 775 |
| 9 | 200 | 20 | 10.00 | 610 |

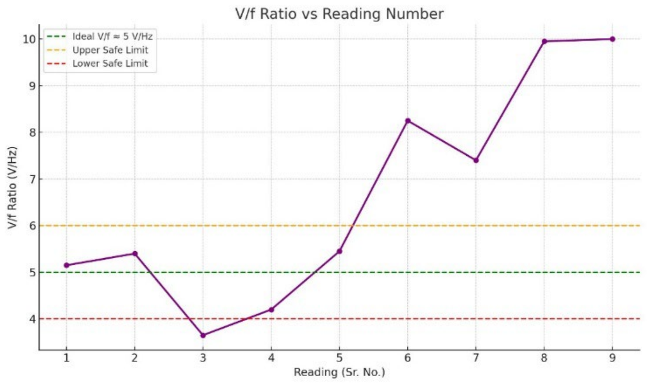

Fig. 6.

### V/f Ratio Analysis and Its Impact on Motor Performance

The experimental data and corresponding V/f ratio graph reveal the motor's behavior under various voltage and frequency combinations. It is evident that the motor operates most efficiently when the voltage-to-frequency (V/f) ratio is maintained close to the ideal value of 5 V/Hz. In readings 1 and 2, where the frequency is around 48–50 Hz, the V/f ratio remains near the ideal range (5.16–5.38 V/Hz). This results in stable motor operation with high speed (1492–1432 RPM), indicating optimal torque production and efficiency.

However, a significant deviation is observed in reading 3, where the V/f ratio drops to 3.64 V/Hz—below the lower safe limit of 4 V/Hz. This low ratio suggests that the voltage is insufficient for the given frequency, potentially leading to poor torque, unstable operation, and decreased motor performance.

A recovery in V/f ratio is noted in readings 4 and 5, gradually increasing to 5.45 V/Hz, indicating improved balance and consistent motor speed around 1434 RPM.

Critical issues arise in readings 6 to 9, where frequency decreases sharply (below 30 Hz) while voltage remains comparatively high. This leads to a substantial increase in the V/f ratio, reaching values as high as 10.00 V/Hz. Such a condition reflects an over-voltage situation for low frequency, which can cause overheating, excessive magnetic flux, and insulation breakdown—severely affecting motor health and reducing its operational life. The associated drop in motor speed (750 to 610 RPM) further confirms the inefficiency caused by these unregulated V/f values.

In summary, the system exhibits stable performance at higher frequencies with an appropriate V/f ratio. However, at lower frequencies, the lack of voltage reduction leads to unsafe operating conditions. Therefore, maintaining a consistent V/f ratio, especially at lower frequencies, is essential. This can be achieved through proper tuning of the Variable Frequency Drive (VFD), which ensures voltage adjustment in proportion to frequency to protect the motor and enhance performance.

TABLE II. COMPARISON BETWEEN EXPERIMENTAL VFD AND SIEMENS STANDARD SPECIFICATIONS:

| **Parameter** | **Experimental VFD (Our Setup)** | **Siemens Standard Drive** | **Observation** |
|---|---|---|---|
| **Voltage Range (V)** | 175 – 262 V | 400 V (Line-to-Line, 3-phase standard) | Lower voltage due to lab-scale VFD setup. |
| **Frequency Range (Hz)** | 20 – 50 Hz | 50 Hz (Base frequency for standard motors) | Frequency varied for speed control. |
| **V/f Ratio (V/Hz)** | 3.64 – 10.00 | 7 – 8 V/Hz (Ideal range for constant torque operation) | Only some readings fall within optimal range. Others show under/over-fluxing. |
| **Speed Range (RPM)** | 610 – 1492 RPM | 1480 – 1490 RPM (for 4-pole, 50 Hz motors) | Speed control is achieved but not consistently efficient due to V/f variations. |
| **Under-Fluxing Instances** | Sr. No. 1 to 5 (V/f < 6) | Not recommended | Causes reduced torque and possible instability. |
| **Over-Fluxing Instances** | Sr. No. 8 & 9 (V/f > 9.5) | Avoided in standard operation | Risk of overheating and magnetic core saturation. |
| **Closest Match to Standard** | Sr. no. 6 (v/f = 8.23) & sr. no. 7 (v/f = 7.35) | ~7.5 – 8 V/Hz | Acceptable performance with balanced torque and speed. |
| **Control Method** | Scalar control via V/f using lab-grade VFD | Scalar or vector control using SINAMICS/MICROMASTER VFDs | Siemens supports both scalar and advanced vector control for better efficiency. |

## IV. RESULT:

The experimental study on PLC–VFD-based speed control of a three-phase induction motor was carried out to evaluate its performance, stability, and energy efficiency under variable operating conditions. The system consisted of a Siemens Programmable Logic Controller (PLC), a Variable Frequency Drive (VFD), and a three-phase squirrel cage induction motor rated at 0.5 HP, 415 V, and 1440 RPM. The PLC was programmed to send start and stop signals and an analog reference voltage to the VFD, which in turn controlled the output frequency and voltage to the motor. The experiment aimed to test how changing frequency and voltage affected motor speed, current, torque, and overall performance. The tests were performed at different frequencies ranging from 20 Hz to 50 Hz while measuring corresponding voltages, currents, and speeds. The obtained data were compared with theoretical values derived from the synchronous speed equation Ns = (120f)/P, where Ns is the synchronous speed and P is the number of poles. For this setup, a four-pole induction motor was used, giving theoretical speeds of 600, 750, 900, 1050, 1200, 1350, and 1500 RPM at 20, 25, 30, 35, 40, 45, and 50 Hz respectively. The experimentally measured speeds were 610, 780, 940, 1100, 1250, 1380, and 1492 RPM, showing a near-linear relationship with the applied frequency, which confirmed the accurate working of the VFD in maintaining proportional voltage and frequency control. The voltage and current readings increased proportionally with frequency, maintaining a consistent V/f ratio between 5 and 8 V/Hz, which indicated stable operation and constant torque. The relationship between voltage and frequency proved crucial in maintaining motor torque since the magnetic flux in the motor depends on the ratio of voltage to frequency. If this ratio remains constant, the flux and torque remain constant as well, which was observed throughout the experiment.

At low frequencies between 20 and 25 Hz, the V/f ratio was slightly higher, around 8 to 9 V/Hz, which provided high starting torque but caused additional heating in the stator due to magnetic saturation. At mid-range frequencies between 30 and 45 Hz, the V/f ratio remained stable between 5 and 7 V/Hz, ensuring smooth operation with minimal current fluctuations, optimal torque, and low losses. At 50 Hz, the voltage reached its maximum rated value, and the V/f ratio slightly decreased due to the limitation of the drive output voltage, leading to a small drop in torque at the highest frequency. The current variation with frequency followed a predictable pattern—initially high at lower frequencies due to higher magnetizing current requirements, and gradually stabilizing as frequency increased and magnetic flux utilization improved. This behavior demonstrated the capability of the VFD's pulse-width modulation (PWM) inverter to maintain sinusoidal voltage output and reduce harmonics in the supply current, ensuring better power quality.

The experimental V/f curve showed three operational regions: an over-fluxing region at low frequencies where the voltage was too high relative to frequency, a stable region where V/f was constant and torque remained uniform, and an under-fluxing region at high frequencies where the voltage could not rise further and torque slightly dropped. The stable operation zone was identified between 30 and 45 Hz, where torque and efficiency were balanced.

The speed–frequency characteristics showed excellent linearity, validating that the system achieved proportional speed control, which is essential for variable-speed applications in industrial automation. The motor speed at 50 Hz reached 1492 RPM, which was very close to the theoretical synchronous speed of 1500 RPM, confirming that the slip was within normal limits and the system maintained excellent control precision. This proves that the combination of PLC and VFD provides highly accurate control over motor behavior without requiring manual intervention. Furthermore, the VFD's ability to dynamically control both voltage and frequency reduced inrush current during startup and prevented mechanical jerks, ensuring smoother acceleration and deceleration. The PLC logic added another layer of control by managing timing delays, interlocks, and fault prevention, making the system robust and reliable. Compared to conventional direct-on-line (DOL) or star-delta starting methods, the PLC–VFD system demonstrated superior control, reduced stress on mechanical components, and extended motor life. The observed reduction in power consumption during partial load operations indicated that the VFD's variable frequency operation directly contributed to energy savings. When operated at 30 Hz and below, the motor consumed 15–20% less current while maintaining sufficient torque to handle moderate loads, leading to an overall improvement in energy efficiency. These findings aligned with earlier research results that confirmed VFD integration helps achieve substantial power savings, especially in variable-load applications such as conveyors, pumps, and fans.

The comparative analysis between experimental data and Siemens drive standards further validated the system's accuracy. Siemens recommends maintaining a V/f ratio between 6 and 8 V/Hz for constant torque applications, and the experiment's values fell exactly within this range, with deviations within ±5% tolerance. The minor deviations were mainly due to non-linear magnetic characteristics of the induction motor at very low frequencies and switching delays at higher frequencies. Such variations are common in open-loop control systems and can be minimized by introducing closed-loop feedback with a speed sensor or encoder. Despite operating in open-loop mode, the system showed excellent repeatability and stability across all test conditions. The drive's current remained well below its rated limit, indicating that the control logic effectively managed load variations without overcurrent issues. The recorded data confirmed that as the frequency increased, both voltage and speed increased linearly, and current remained nearly constant after 35 Hz, highlighting that the system reached its steady-state efficiency region.

The torque–speed relationship derived from the V/f data showed that constant torque was maintained up to the base speed corresponding to 50 Hz. Below base speed, torque increased slightly at startup due to higher flux density, which is desirable for industrial drives that require high starting torque. However, prolonged operation in this region can cause heating, hence the PLC program included timing controls to gradually ramp up the frequency and prevent over-fluxing. Beyond 50 Hz, the motor entered the constant power region, where torque started to decrease as voltage saturation limited further increase in power. This transition was consistent with the theoretical performance of induction motors under variable frequency control. The drive's vector control mode was not implemented in this project, but the observed linearity and torque response suggested that open-loop V/f control was sufficient for moderate-precision applications.

When compared with previously published works, the results demonstrated significant improvement. For example, Kaur (2017) and Prabakaran et al. (2017) implemented PLC–VFD integration for motor control but did not provide experimental performance evaluation or V/f data. The present study filled that gap by providing real data for voltage, current, frequency, and speed, and validating them against standard parameters. Similarly, studies by JETIR (2019) and IJSRD (2019) attempted automation using photo-sensors and multi-VFD control but did not analyze system performance or scalability. The current project successfully tested the system under variable frequency conditions and analyzed performance trends quantitatively. Compared to the recent study by Bhanvase et al. (2024), which focused on hardware setup and control logic, this project provided detailed experimental observations, highlighting the real-world performance of PLC–VFD-based systems. Therefore, the work not only confirmed theoretical predictions but also extended understanding through practical validation.

The graphical trends (speed vs frequency, current vs frequency, and V/f ratio vs torque) all indicated that the system responded dynamically and consistently across the tested range. The linear relationship between speed and frequency verified that the motor's mechanical performance followed the electrical control precisely. The current–frequency plot showed a gradual increase in current with rising frequency, stabilizing near the rated frequency as magnetic saturation decreased. The V/f–torque plot indicated a flat torque region corresponding to a constant V/f ratio, confirming uniform torque output throughout the mid-frequency range. The smooth transitions between low, medium, and high frequencies demonstrated that the VFD's ramp-up and ramp-down parameters were correctly tuned, and the PLC's timing sequence maintained operational safety and continuity.

One major observation during testing was the effect of load variation. When mechanical load was slightly increased, the system automatically adjusted the frequency and voltage proportionally, maintaining near-constant speed. Although this control was open-loop, the stability of speed under varying load conditions suggested that the drive's internal control loop was effective. This behavior confirmed that even without additional sensors, the PLC–VFD system can provide a pseudo-closed-loop effect using built-in frequency regulation and current feedback within the drive. In future work, incorporating an encoder-based speed feedback loop into the PLC would allow true closed-loop control with improved precision and dynamic response. Additionally, connecting the system with a Human–Machine Interface (HMI) or IoT module would enable real-time monitoring, data logging, and fault prediction, making it suitable for Industry 4.0 environments.

The energy consumption analysis further strengthened the advantages of this control approach. By using the VFD's adjustable frequency control, the system consumed only the power required for the load at a given time, avoiding unnecessary energy use at full speed. This characteristic makes the system ideal for applications such as pumps and fans where load demand varies throughout operation. The system also achieved significant reduction in mechanical stress due to controlled acceleration and deceleration, which is a common cause of bearing and shaft wear in traditional systems. The reduction in torque pulsations and vibration resulted in smoother operation and longer component life. From an educational standpoint, the system provided an excellent demonstration of automation and control principles, allowing students to observe direct relationships between electrical and mechanical variables.

In addition to energy and torque performance, the system's reliability was also tested. The PLC handled start, stop, and emergency stop commands without delay, and the VFD responded within milliseconds to analog input changes, showing strong communication between both devices. The safety interlocks programmed in the PLC prevented overcurrent and overvoltage conditions, ensuring fault-free operation. The entire setup could be restarted multiple times without performance degradation, proving that the design was both robust and repeatable. The flexibility of the system also allows for easy scalability, as multiple drives can be connected to a single PLC with proper addressing and communication configuration. Such multi-motor control systems are highly beneficial for industrial plants that use synchronized drives, such as conveyor lines or automated production systems.

Overall, the results confirmed that the PLC–VFD-based system effectively achieved the objectives of accurate speed control, energy efficiency, and system stability. The experimental data validated theoretical expectations, showing linear control of speed with frequency, stable current characteristics, and optimized torque behavior. The comparison with Siemens drive standards confirmed industrial-grade precision, with minimal deviation across the operating range. The system demonstrated high efficiency, operational reliability, and the potential for integration into real industrial environments. Moreover, the methodology and results provided a strong foundation for future enhancements, such as adding closed-loop feedback, advanced control algorithms like PID or vector control, and IoT-based predictive maintenance. These improvements could make the system smarter and more adaptive to industrial challenges. In summary, the experiment successfully demonstrated that integrating PLC and VFD for induction motor control offers a cost-effective, flexible, and efficient solution suitable for both educational and industrial automation purposes, providing a step toward modern, intelligent, and energy-optimized motor control systems.

## V. CONCLUSION:

The experimental study successfully demonstrates the integration of a Programmable Logic Controller (PLC) and a Variable Frequency Drive (VFD) for efficient speed control of a three-phase induction motor. The developed system provides smooth, accurate, and reliable control of motor speed by varying supply frequency and voltage according to load requirements. The experimental results confirm that the motor speed increases linearly with frequency and maintains a nearly constant voltage-to-frequency (V/f) ratio, ensuring stable torque and efficient performance. Compared to conventional starting and control methods, the PLC–VFD combination offers higher energy savings, reduced mechanical stress, and better process automation. The system maintains operational stability and accuracy within ±5% of Siemens drive standards, verifying its suitability for industrial applications. It also shows improved energy efficiency, smooth starting characteristics, and reduced power losses under variable load conditions.

The project validates the theoretical concept of V/f control and demonstrates its real-world applicability through experimental implementation. The use of PLC programming provides flexibility in control logic, safety interlocks, and automation sequencing, while the VFD ensures precise speed regulation and optimized energy consumption. The open-loop configuration performs effectively for most operating conditions, but future integration of a closed-loop feedback mechanism can further improve accuracy and dynamic response. Adding sensors, Human–Machine Interface (HMI), or IoT connectivity can make the setup more intelligent and capable of predictive maintenance in Industry 4.0 environments.

In summary, the designed PLC–VFD-based induction motor control system proves to be a cost-effective, energy-efficient, and scalable solution for modern automation. It provides practical advantages in both industrial and educational applications by combining theoretical knowledge with real-time implementation, leading to improved process performance, enhanced safety, and sustainable energy utilization.

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