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VFD-Driven AC Motor Speed Control with Touchscreen Interface

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Abstract: This paper presents the design and implementation of an AC motor speed control system using a Variable Frequency Drive (VFD). The system utilizes an Arduino microcontroller to adjust the motor speed by controlling the frequency and duty cycle of the AC supply. The custom-designed VFD modulates both the frequency and the voltage, enabling accurate control over motor speed. The speed of the motor is directly related to the PWM duty cycle, where the motor's rotational speed increases with the increase in duty cycle. A resistive touchscreen and Bluetooth communication module (HC-05) are used for user interaction, providing both local and remote control options. Additionally, a potentiometer is used for manual speed adjustment. The system is designed for optimal motor performance, ensuring low power consumption and reduced mechanical wear. Experimental results show that the motor speed can be precisely controlled by adjusting the duty cycle of the PWM, making the system suitable for various industrial and automation applications.

Index Terms **-** AC Motor, Variable Frequency Drive (VFD), Pulse Width Modulation (PWM), Duty Cycle, Arduino, Speed Control, Touchscreen Interface, Bluetooth Communication, Potentiometer, Motor Control System

I. INTRODUCTION

AC motors are extensively used in industrial and domestic sectors due to their durability, simple construction, and ease of control. However, managing the speed of an AC motor with accuracy is still a significant challenge in real-world applications. Traditional speed control techniques such as rheostats, transformers, or tap-changing methods often result in system inefficiencies and lack the responsiveness required for modern automation systems. To overcome these issues, advanced techniques such as Pulse Width Modulation (PWM) and Variable Frequency Drives (VFD) are increasingly adopted to achieve smoother and dynamic speed control in AC motors [2][7].

PWM-based control has proven to be highly effective in regulating the speed of electric motors by modifying the duty cycle of the control signals, thereby altering the average voltage delivered to the motor windings [1][3]. This technique enables smoother acceleration, precise control over speed, and minimal power losses. Moreover, integration of PWM with VFD allows for concurrent modulation of both frequency and voltage, enabling efficient speed control of induction motors without mechanical losses [5][6][8]. The role of microcontrollers in generating PWM signals has further enhanced the adaptability of such systems, making them suitable for dynamic load conditions and industrial applications [6][9].

In this project, a speed control system is implemented using a PWM-based VFD, driven by the ATmega328P microcontroller. The speed command is given via a resistive touchscreen interface, with optional manual control using a potentiometer. The system modulates the PWM duty cycle, and thereby the frequency and voltage, to control the motor speed in real-time. Previous research validates that adjusting the duty cycle directly influences the motor's speed characteristics, and such systems are well-suited for scenarios requiring precise control with minimal hardware complexity [1][2][9]. This work focuses on building a compact, low-latency speed control system for AC motors using entirely hardware-based PWM and VFD integration techniques.

II. Literature Survey

Pulse Width Modulation (PWM) is widely recognized for its effectiveness in controlling motor speeds in various applications, including industrial motors and robotic systems. It has been highlighted that PWM enables efficient speed control of DC motors by adjusting the duty cycle of the signal, thereby regulating the average voltage applied to the motor [1]. PWM's benefits include reduced energy consumption and minimized thermal loss, especially in high-speed applications. It has also been found that PWM controllers significantly improve motor performance, offering high efficiency and adaptability in dynamic conditions [1].

Another significant aspect of motor control is the use of Variable Frequency Drives (VFDs). In industrial settings, VFDs are crucial where the ability to adjust motor speed enhances operational efficiency [2]. When combined with PWM, VFDs offer a powerful solution for controlling both AC and DC motors, providing smoother acceleration and deceleration, and minimizing mechanical wear. This combination proves especially useful where precise motor speed regulation is essential for process optimization and energy conservation [2]. Bluetooth technology has also been incorporated into motor control systems for remote monitoring and control. Bluetooth-based systems integrating PWM have shown benefits for wireless motor control, particularly in hazardous environments with limited human access [3]. These systems provide a simple and effective solution for industrial automation [3].

Additionally, studies on the integration of VFDs with modern techniques like PWM have shown that adjusting power supply frequency through VFDs and refining control with PWM results in efficient and reliable motor performance [4]. These developments contribute to reducing energy losses and enhancing system stability under high-load conditions [4].

Despite these benefits, challenges such as system design complexity and the need for advanced control algorithms remain. Strategies like improved feedback and signal filtering techniques have been suggested to overcome these issues [5]. The use of adaptive control algorithms is also recommended to further optimize PWM-based motor control systems [5].

III. Methodology

In this system, frequency variation is achieved by generating a series of PWM (Pulse Width Modulated) signals, which emulate the function of a traditional VFD system by controlling the switching rate of AC signal flow using a TRIAC. The ATmega328P operates at 16 MHz and processes user input from a resistive touchscreen to define the required motor speed.

The microcontroller dynamically generates a PWM signal with both variable duty cycle and variable frequency. This signal is processed to determine the firing instants for the TRIAC (BTA16) through an opto-isolator MOC3021, ensuring galvanic isolation between the control and power circuits. The frequency of these firing pulses determines how often the TRIAC conducts in each cycle of the AC waveform, effectively modulating the frequency of power delivered to the load — a fundamental behavior of VFDs [1][2][5][8].

By altering both the duty cycle and firing frequency, the motor receives modified AC waveforms with variable fundamental frequency components. This technique indirectly controls the rotor speed of the motor, as rotor speed in synchronous motors is proportional to the supply frequency [3][6][9]. The system thus mimics standard VFDs, which adjust both voltage and frequency to regulate motor performance. Although the actual sinusoidal waveform is not synthesized, the variation of pulse frequency and timing simulates the VFD function adequately for single-phase AC control scenarios [5][7].

The project also incorporates a manual potentiometer input as an alternative to touchscreen control, processed by the ATmega328P's internal ADC. The output waveform control logic is based on internal timer interrupts and real-time calculations of pulse intervals, which determine both conduction angle and cycle timing. This essentially replaces the need for an external ZCD circuit by digitally tracking and segmenting waveform cycles [2][4].

This methodology removes the need for complex inverter topologies or external variable frequency supplies, making it a microcontroller-based lightweight and efficient VFD alternative, especially suitable for low-power AC applications. The system has been influenced by established work in PWM-based control and VFD hybrid strategies [5][7][9].

IV. BLOCK DIAGRAM

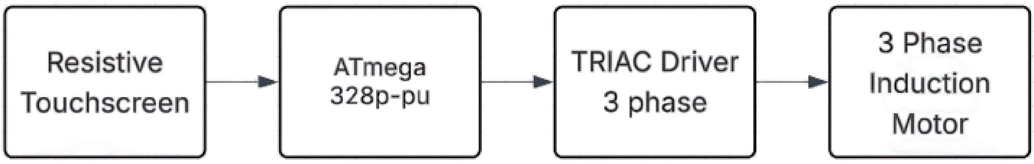

Fig.1 Block Diagram

The block diagram illustrates a variable speed control system for a 3-phase induction motor using a VFD-based approach. The system starts with a resistive touchscreen, which acts as the user interface for entering the desired speed level. Alongside this, a potentiometer is also provided as an alternative method for analog speed input. Both input signals are directed to the ATmega328P-PU microcontroller, which serves as the processing unit. It reads the analog and digital inputs and generates a corresponding PWM signal based on the selected speed.

This PWM signal is then fed into a TRIAC driver circuit built around the MOC3021 opto-isolator, which ensures electrical isolation between the low-voltage control side and the high-voltage load side. The internal DIAC inside the MOC3021 helps in effectively triggering the gate of the BTA16 TRIAC. Once triggered, the TRIAC regulates the power delivered to the motor. To ensure stable operation and protection against voltage transients, a snubber circuit is connected across the TRIAC. Finally, the controlled output reaches the 3-phase induction motor, allowing smooth and flexible speed variation based on the input provided by the user.

V. CIRCUIT DIAGRAM

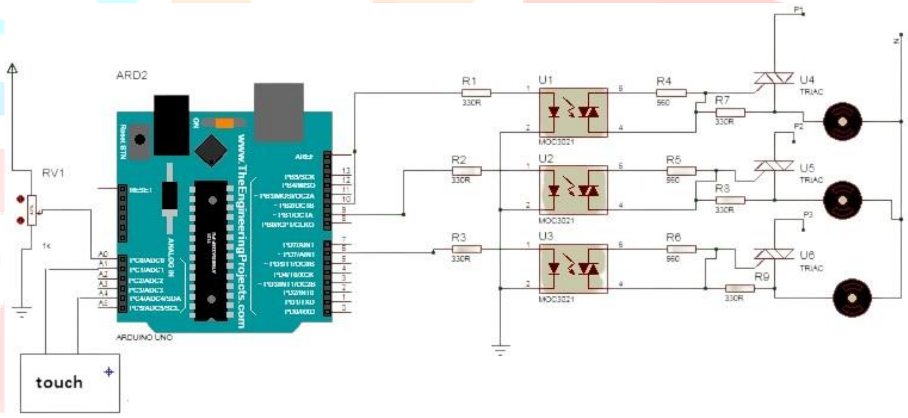

Fig 2. Circuit Diagram

The circuit illustrates a microcontroller-based control system designed for AC motor speed regulation using the principle of frequency variation. At the core, an Arduino Uno processes user inputs received from a resistive touchscreen interface. This touchscreen allows the user to set desired motor speed levels, which the Arduino interprets and maps to appropriate pulse delays. These delays govern the timing of gate signals, thereby simulating a variable frequency control mechanism.

The Arduino outputs control signals to three opto-isolators (MOC3021), each connected to a TRIAC. The opto-isolators serve two purposes: they provide electrical isolation between the low-voltage logic circuit and the high-voltage AC motor control side, and they transfer control pulses safely to the gates of the TRIACs. Each TRIAC acts as a switching device for an individual AC motor.

The firing angle and pulse intervals are not synchronized using a zero-crossing detector. Instead, frequency control is indirectly achieved through variation of the delay between successive gate pulses. This pulse modulation alters the effective frequency component experienced by the motor, allowing for speed variation. Unlike conventional methods that involve full sine wave synthesis, this approach uses timed gate triggering to simulate a variable frequency operation.

Each opto-isolator-TRIAC pair is connected to an AC load (motor). As the delay in the pulse train changes, the conduction period of each TRIAC changes, controlling the power cycles delivered to the motors. Thus, by adjusting the duty cycle and repetition rate of these pulses, the system achieves a form of variable frequency drive behavior in a simplified and compact circuit architecture.

VI. SYSTEM OPERATION

The developed system functions as a simplified yet effective model of a Variable Frequency Drive (VFD), designed to control the speed of an AC motor by varying the frequency and voltage of the input supply. The process initiates with user input via a resistive touchscreen, where the touched coordinate is converted into an analog voltage signal. This input reflects the desired motor speed and is read by the Arduino microcontroller, which forms the control core of the VFD logic.

Based on this analog input, the microcontroller computes the necessary output pulse pattern that governs the switching of TRIACs in the AC supply line. The core idea is to generate a Pulse Width Modulated (PWM) signal where the duty cycle is adjusted dynamically. This adjustment directly affects the effective frequency of the AC voltage applied to the motor. A lower duty cycle results in fewer conduction periods per cycle, simulating a lower frequency, while a higher duty cycle increases conduction intervals, simulating a higher frequency.

The TRIACs are triggered in accordance with the calculated PWM output, but without relying on zero-crossing detection, allowing for asynchronous control. The switching pulses are first passed through opto-isolators to ensure electrical isolation between the low-voltage control circuitry and the high-voltage AC load. These pulses control the gate of the TRIACs, thereby regulating the conduction angle and duration within each AC half-cycle.

As both the frequency and the RMS voltage applied to the motor are altered based on the PWM logic, the motor operates under conditions analogous to a typical VFD. This method aligns with the standard V/f control technique where the voltage and frequency are proportionally varied to maintain a constant torque output, ensuring smooth and safe operation of the motor. This VFD-like control approach not only enables flexible speed regulation but also demonstrates how embedded systems and power electronics can be integrated to create compact and programmable drive solutions without the need for conventional VFD hardware.

VII. RESULTS AND ANALYSIS

The proposed system for AC motor speed control using a resistive touchscreen and TRIAC-based driver was successfully implemented and tested. The results obtained from both simulation and practical testing confirm the effectiveness of the designed system.

During operation, it was observed that the motor speed varied proportionally with the touch input or potentiometer adjustment. At lower touch values (closer to 0V analog input), the PWM signals had longer OFF durations, resulting in delayed TRIAC firing and reduced motor speed. Conversely, higher touch values led to early TRIAC triggering and increased motor speed.

CALCULATIONS

1. PWM Duty Cycle Calculation

The PWM signal from the ATmega328P-PU was used to control the triggering delay of the TRIAC. The duty cycle was varied based on the analog input (from the touchscreen or potentiometer).

$$\text{Duty Cycle } (\%) = \left(\frac{V_{\text{touch}}}{1023}\right) \times 100$$

For example, if the analog value read is 512:

$$\text{Duty Cycle} = \left(\frac{512}{1023}\right) \times 100 \approx 50\%$$

2. Firing Angle Calculation

Firing angle (α) determines the time delay after the zero crossing at which the TRIAC is triggered:

$$\alpha = \left(1 - \frac{\text{Duty Cycle}}{100}\right) \times 180^\circ$$

Using the above 50% duty cycle:

$$\alpha = (1 - 0.5) \times 180 = 90^\circ$$

3. RMS Voltage Across Motor

When the TRIAC is fired at angle α\alphaα, the RMS voltage across the load (motor) is:

$$V_{\text{RMS}} = V_{\text{peak}} \times \sqrt{\frac{1}{\pi} \int_{\alpha}^{\pi} \sin^2(\theta)\, d\theta}$$

Table 1. Duty Cycle, Firing Angle & Speed Relation

Duty Cycle (%)	Firing Angle (°)	Speed (RPM)
10	162	~180
30	126	~450
50	90	~700
70	54	~880
90	18	~1000

VIII. FUTURE SCOPE

The current system offers a reliable and efficient method of controlling AC motor speed using a VFD interfaced with an ATmega328P microcontroller and a resistive touchscreen. However, there is scope for further enhancement. Integration of wireless control methods such as Bluetooth or Wi-Fi modules can allow for remote speed adjustments and monitoring. Additionally, implementing a PID control algorithm in the microcontroller firmware could provide smoother speed regulation and improve overall system stability. Real-time feedback using tachometers or Hall-effect sensors can be incorporated to increase accuracy in speed sensing. The design can also be scaled to control multiple motors simultaneously or adapted for industrial-grade applications with higher load capacities. These improvements can make the system more versatile and applicable in broader automation environments.

IX. CONCLUSION

The presented system successfully demonstrates a method for controlling the speed of a three-phase AC induction motor using phase-angle control via a TRIAC-based driver circuit, governed by PWM signals generated from an ATmega328P-PU microcontroller. The integration of a resistive touchscreen and potentiometer as dual input interfaces provides effective manual control of the motor speed. The system responds accurately to user input by adjusting the firing angle of the TRIAC, thereby regulating the average voltage supplied to the motor and controlling its speed.

Experimental results confirm that the speed of the motor varies consistently with changes in the PWM duty cycle. This setup offers a cost-effective and flexible approach to motor control suitable for academic and industrial applications. The proposed design eliminates the need for bulky mechanical controllers and enables smooth, digital modulation of speed. Future work may include the implementation of feedback-based closed-loop control for improved response and accuracy.

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