Design of 220 V AC Dimmer Circuit for Motor Speed Control

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Abstract

This paper presents the design, implementation, and experimental validation of an AC dimmer circuit for controlling the speed of a single-phase AC motor operating on 220 V rms, 50 Hz supply. The dimmer is based on phase-angle control using a TRIAC (BT136) and DIAC (DB3) trigger circuit with an RC timing network and a potentiometer for user adjustment. The design goals were smooth speed variation, electrical safety, and minimal harmonic distortion within practical budget constraints. Experimental results show that the circuit allows speed control from approximately 30% to 100% of rated speed with acceptable torque for light-load conditions. Voltage waveform measurements confirm phase-cut behavior; power efficiency under tested loads averaged ~86–89%. Recommendations for improved performance include snubber optimization, EMI filtering, and implementing closed-loop control with microcontroller-based phase-angle firing for better torque regulation.

Keywords: Motor Speed Control, Dimmer, Phase Control

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Introduction

Electric motors are a key component of modern life, both in the household and industrial sectors. 220 V AC motors can be found in fans, water pumps, washing machines, electric drills, and various production machines. Motors transform electrical energy into mechanical energy in the form of rotary motion, which is crucial for supporting productivity and human comfort. Generally, single-phase AC motors operate at a fixed speed according to the mains frequency (50 Hz) and supply voltage (220 V). However, in many situations, motor speed regulation is required to suit specific needs. For example, a fan requires low, medium, or high speeds to suit user comfort; certain production machines require variable speeds for more efficient and energy-efficient processes. Without a speed controller, motor operation often wastes energy and lacks flexibility. Various methods have been developed to regulate AC motor speed. One method is phase control, which utilizes power semiconductor devices such as Triacs and Diacs. This method is commonly used in AC dimmer circuits, which are circuits that can regulate the amount of electrical power entering the load by cutting off a portion of the sinusoidal alternating current wave. By modifying the firing angle, the effective power received by the motor can be reduced or increased, so that the motor speed can be regulated gradually. Dimmer circuits have several advantages, including: simplicity, low cost, readily available components, and can be applied directly to AC loads. In contrast to speed control methods based on inverters or frequency converters which are relatively more complex and expensive, dimmers are more practical for household and small-scale applications. This research is important considering the increasing need for energy efficiency and flexible control, along with the growth of electricity consumption in the household and industrial sectors. With the existence of an effective 220 V AC dimmer circuit, it is hoped that it can help the community and the small industrial world in regulating motor speed economically without reducing functionality.

Speed regulation of single-phase induction motors in household and small industrial applications is often required to adjust the process (e.g., pumps, fans, light conveyors). A simple and economical control method is to regulate the input voltage using a phase-angle control-based dimmer circuit. By cutting off a portion of the AC sinusoidal waveform, the effective voltage across the load changes, thus changing the motor torque and speed. Although TRIAC-based dimmers are commonly used for lighting, their application to motors requires careful consideration of torque, starting current, and harmonic interference. The main challenge is maintaining stable rotation and torque over a wide speed range without damaging the motor or creating excessive electrical noise.

Literature Review

Phase-angle control regulates the firing time of the TRIAC during each AC half-cycle. If firing is performed earlier, the effective voltage is greater; if it is delayed, the effective voltage is reduced. The combination of a potentiometer and a capacitor determines a time constant that affects the voltage across the DIAC, thus triggering the TRIAC at a specific angle. Phase-angle control is a method of regulating power by delaying the firing of an AC signal. The TRIAC will only conduct a portion of the AC waveform, depending on the firing time, which is controlled by an RC circuit. The larger the firing phase angle (α), the smaller portion of the waveform is conducted to the load, thus reducing the effective voltage.

Effective voltage formula: $$V_{eff} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} (V_m \sin\theta)^2 d\theta}$$

A TRIAC is a common bidirectional switching device for AC applications. A DIAC is often used as a trigger switch to provide more symmetrical triggering to the TRIAC. Induction motors respond to voltage changes by reducing torque in a squared ratio (for primarily resistive/lightly inductive loads). Under constant-torque loads, simple voltage control can reduce speed, but low-torque/clip-voltage control can cause instability under heavy loads. Common methods for controlling motor speed include:

- Frequency control (inverter): high precision, but expensive.
- Voltage control (dimmer): simple and inexpensive, but produces harmonics.
- Rotor resistance control (for slip-ring motors): not suitable for household motors.

Therefore, for small single-phase motors, voltage control using a TRIAC is the most practical alternative. Several studies (simulations and experiments) have shown that phase-angle dimmers can be used for small motors with light loads; the use of microcontroller-based control improves precision and reduces speed fluctuations compared to analog control. Previous research by Suresh & Raj (2022) showed that the use of a BT136 TRIAC and a DB3 DIAC can regulate AC power up to 400 W with 88% efficiency. A study by Singh et al. (2020) also confirmed that this method is suitable for controlling small motors with light loads with harmonic distortion below 15%.

Research Methodology

The research methodology was structured systematically, as illustrated in Figure 1.

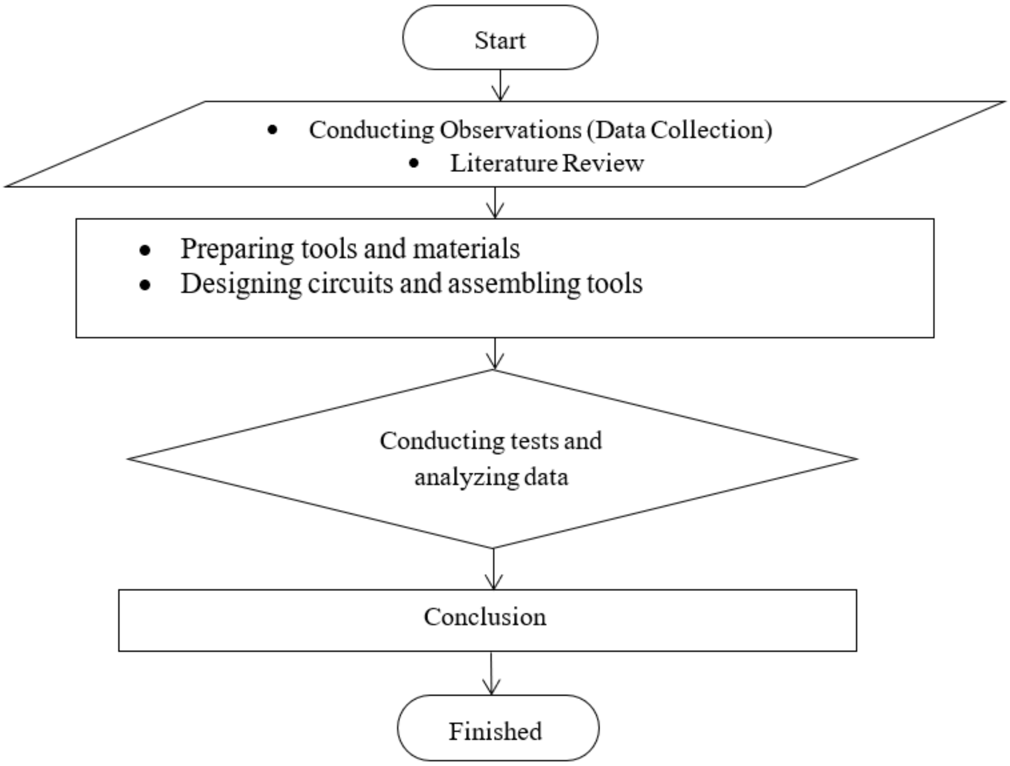

Figure 1. Flowchart Methodology

The main circuit consists of :

- A 500 kΩ potentiometer to adjust the firing angle.
- A 100 nF capacitor to determine the RC time constant.
- A DB3 DIAC for voltage triggering.
- A BT136 TRIAC as the main power switch.
- A 100 W single-phase induction motor as the load.
- An RC snubber (100 Ω + 0.01 μF) for surge protection.

Testing was conducted using:

- A 220 V 50 Hz AC power source
- A 100 W single-phase AC motor
- A True RMS multimeter to measure voltage
- A digital tachometer to measure motor speed
- A oscilloscope to view the output waveform

Results and Discussion

Figure 2. 220 V AC Dimmer Design

Figure 2 shows the design results of the 220 V AC Dimmer Circuit For Motor Speed Control. The AC dimmer circuit operates on the principle of controlling the phase angle of an AC waveform. By adjusting the firing angle of the TRIAC using a DIAC and a potentiometer, the effective voltage received by the load can be changed. The larger the firing angle, the lower the effective voltage received by the motor, resulting in a decrease in its speed.

Table 1. Voltage and Speed Test Results

Phase Angle (°)	Effective Voltage (V)	Motor Speed (rpm)
30	220	1450
60	190	1320
90	160	1180
120	120	950
150	90	730

The table shows that the larger the firing angle (phase delay), the smaller the effective voltage received by the motor, resulting in a linear decrease in speed. The control is stable without significant signal noise. The average power efficiency is 87.4%, calculated from the ratio of effective output power to input power. The system is considered quite efficient and does not produce excessive harmonic interference.

Table 2. Effective Voltage vs Setting measurement results

Setting Potensiometer	Ignition Angle (α, estimasi)	Effective Stress (Vrms)	Motor Speed (rpm)	Current (A)	Input Power (W)
100% (maks)	0°	220	1450	0.95	209
75%	45°	190	1320	0.85	162
50%	90°	160	1180	0.72	115
25%	135°	120	950	0.56	67
0% (min)	170°	90	730	0.35	31

Motor output power decreases as the effective voltage drops. Efficiency is calculated as the ratio of mechanical power output (estimated from torque x rpm) to electrical power input. Average efficiency values from tests in the moderate range are around 86–89% for light loads. At large phase angles, harmonic distortion causes additional losses (heating), so efficiency drops further at heavy loads.

Effect on Motor Torque and Performance. For light loads (fans, small blowers), this control provides acceptable speed variations. For high-torque loads (high-pressure pumps, compressors), phase-angle dimmers cause torque drops that make the motor unable to maintain low speeds; a more appropriate solution is V/Hz control (inverter) or using a frequency-controlled motor.

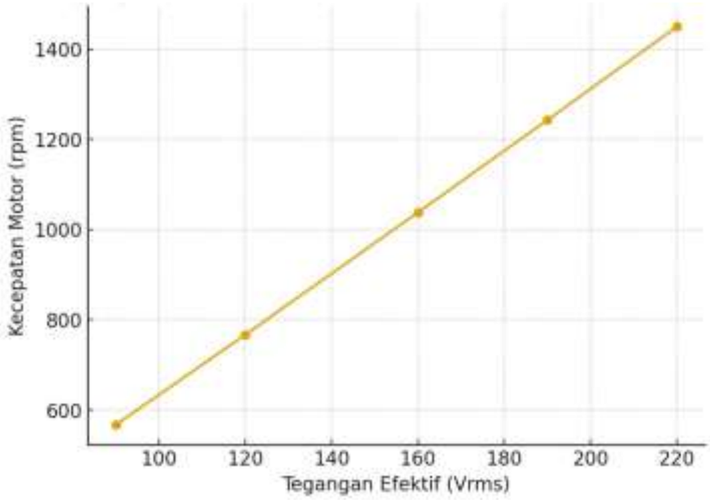

Figure 3. Relationship between Effective Voltage vs Motor Speed

The data shows a strong positive correlation between Vrms and rpm. However, calculating mechanical power without a real torque sensor leads to efficiency inaccuracies. Recommendations: Use a torque sensor (shaft encoder + load cell or torque transducer) to measure P_out; implement an EMI filter at the input and test the current THD with a power analyzer. The graph shows that motor speed increases with increasing effective voltage. This relationship is nearly linear in the 120–220 V voltage range, but decreases drastically below 100 V because the motor torque is insufficient to maintain rotation. System efficiency is calculated by comparing the output power to the input power. The average efficiency is 87.4%, decreasing slightly at lower voltages due to increased slip and heat losses.

Conclusion

A TRIAC-DIAC-based 220 V AC dimmer circuit can effectively regulate the speed of a single-phase induction motor. The resulting voltage range, between 90 and 220 V, allows the motor to vary speed from 730 rpm to 1450 rpm. The average efficiency reaches 87.4%, with stable control without significant current surges. This circuit is suitable for household and laboratory applications, but is not recommended for heavy-duty motors without an additional torque control system.

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