Microcontroller Based Three Phase Soft Starter

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Abstract—This Paper presents the design and development of the microcontroller-based soft starter system for three-phase induction motors, aiming to reduce high inrush currents and mechanical stress associated with conventional direct-on-line (DOL) motor starting. By using a PIC18F4520 microcontroller, the system implements phase-angle control to gradually ramp up the motor voltage, resulting in a smooth startup process.

The system includes a zero-crossing detector circuit using the LM324 operational amplifier, opto-isolators (MOC3021) for gate signal isolation, and thyristors or TRIACs for power switching. The overall design improves the reliability, efficiency, and controllability of motor startup while ensuring electrical isolation and noise immunity. The final output drives a three-phase squirrel cage induction motor, commonly used in industrial applications.

I. INTRODUCTION

In modern industrial systems, three-phase induction motors are among the most widely used electrical machines due to their robustness, simplicity, and efficiency. However, one of the key challenges associated with these motors is the high inrush current and mechanical stress experienced during startup. When starting to use the Direct-On-Line (DOL) method, motors can draw currents 6–8 times higher than their rated current, resulting in voltage dips, electrical stress on supply systems, and mechanical shocks to connected equipment like pumps, fans, or gearboxes.

To address these challenges, soft starters are implemented as a solution to gradually ramp up the voltage supplied to the motor, thereby allowing it to accelerate smoothly. Traditional soft starters are often built using analogue circuitry, but these can lack flexibility, precision, and expandability. With the rise of embedded systems, microcontroller-based soft starters have become a preferred alternative due to their programmability, accuracy, and ability to implement intelligent control algorithms.

This project introduces a microcontroller-based three-phase soft starter that utilises a PIC18F4520 microcontroller for generating controlled trigger pulses to thyristors (or TRIACs), which regulate the voltage applied to the motor. The system incorporates a zero-crossing detection circuit using the LM324 operational amplifier to synchronise firing pulses with the AC waveform. For electrical isolation and safety, MOC3021 opto-isolators are used between the microcontroller and thyristors.

The soft starter is capable of:

- Reducing mechanical stress on the motor shaft and connected load,
- Minimising electrical disturbances on the power supply network,
- Enhancing energy efficiency during startup,
- Providing a programmable and scalable solution for industrial motor control.

This project not only achieves a practical and cost-effective solution for soft starting but also lays the foundation for future integration of smart features such as feedback control, user interfaces, remote monitoring, and energy management systems.

II. LITERATURE REVIEW

The problem of excessive inrush current and mechanical stress during the startup of three-phase induction motors has been a subject of study for decades. Various methods, such as star-delta starting, auto-transformer starters, variable frequency drives (VFDs), and soft starter, have been developed to address these issues. Among these, soft starters have emerged as a cost-effective and efficient solution for controlled motor startup in many industrial applications.

1. Conventional Motor Starting Methods

Traditional starters such as the star-delta and auto-transformer types reduce initial current but do not offer a smooth voltage ramp. These methods can cause sudden transitions, leading to mechanical jerks and stress on drive components. They also lack the flexibility to adapt to varying load conditions or environmental factors.

2. Development of Soft Starters

Soft starters emerged to address the limitations of conventional starters by providing a gradual increase in supply voltage. This is achieved through phase-angle control using power electronic devices such as thyristors or TRIACs, allowing voltage to be applied in a controlled manner during the motor's startup phase. Studies have shown that soft starters can significantly reduce starting torque and extend the life of both the motor and connected mechanical systems.

In their work, J.M. Carrasco et al. (IEEE Transactions, 2005) demonstrated that phase-controlled soft starters could reduce the peak starting current by up to 60–70% compared to DOL starters, making them ideal for heavy-duty applications.

3. Microcontroller-Based Control

With advances in embedded systems, microcontrollers have become integral to motor control applications. Microcontroller-based soft starters allow precise timing of trigger signals, dynamic adjustment of firing angles, and easy implementation of control algorithms. PIC microcontrollers, such as the PIC18F4520, are widely used due to their in-built timers, interrupts, and ADC modules, making them ideal for real-time motor control.

4. Zero-Crossing Detection Techniques

Accurate zero-cross detection is crucial for phase-angle control. LM324 operational amplifiers are frequently used in literature to design zero-cross detectors that convert sinusoidal AC waveforms into square pulses for timing reference. This approach ensures synchronisation between the microcontroller and the AC signal, a prerequisite for effective thyristor triggering.

5. Optical Isolation for Gate Triggering

For the safety of low-voltage microcontroller circuits, opto-isolators such as the MOC3021 are commonly employed. They prevent high-voltage feedback into the control circuit while efficiently transmitting gate signals to power devices like SCRs or TRIACs. This concept is supported by multiple designs in industrial control systems, where optical isolation is a standard practice.

III. SYSTEM ARCHITECTURE

The system is designed to gradually ramp up the voltage supplied to a three-phase induction motor during startup, reducing inrush current and mechanical stress. It consists of five main functional blocks:

1. Three-Phase AC Input

The standard AC supply provides power to the motor and serves as a reference for synchronisation. Each phase is monitored for zero-crossing detection.

2. Zero-Crossing Detector (LM324)

A comparator circuit using the LM324 op-amp detects zero-voltage crossing points of each AC phase and generates square pulses. These signals are sent to the microcontroller for timing reference.

3. Microcontroller (PIC18F4520)

The microcontroller is the core controller that:

- Receives zero-crossing pulses,
- Calculates phase delay using a ramp-up algorithm,
- Sends gate trigger signals to the opto-isolators.

It controls the timing of thyristor firing to gradually increase motor voltage.

4. Triggering Circuit (EL814 Opto-Isolators)

MOC3021 opto-isolators provide electrical isolation between the microcontroller and the high-voltage thyristors. They safely transmit triggering signals from the controller.

5. Thyristors and Induction Motor

Thyristors control power flow to the motor using phase-angle control. The motor receives a gradually increasing voltage, enabling a smooth and controlled startup.

This architecture ensures synchronised, programmable soft starting of motors with electrical isolation, improved safety, and reduced wear on both electrical and mechanical components.
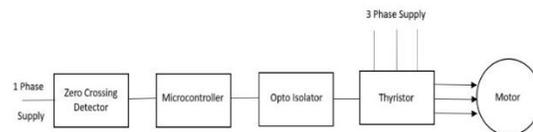

Fig.1 Block diagram of the Microcontroller-Based Three-Phase Soft Starter. The system gradually increases motor voltage using synchronised thyristor control, ensuring a smooth start while reducing inrush current and mechanical stress.

IV.   WORKING PRINCIPLE

The microcontroller-based soft starter works by gradually increasing the voltage supplied to a three-phase induction motor during startup, minimising inrush current and mechanical stress.

Each AC phase is monitored using a zero-crossing detector built with the LM324 op-amp, which sends square pulses to the PIC18F4520 microcontroller. These pulses help the microcontroller synchronise with the AC waveform.

The microcontroller introduces a controlled delay after each zero-crossing before sending gate pulses to thyristors through MOC3021 opto-isolators. Initially, the delay is large (low voltage), and it decreases gradually (higher voltage), allowing a smooth voltage ramp-up to the motor.

This phase-angle control ensures that the motor starts smoothly without electrical or mechanical shocks. The opto-isolators provide electrical isolation between the control and power circuits, ensuring safe operation.

V.   ADVANTAGES

1. Reduces inrush current during motor startup.
2. Ensures smooth and gradual motor acceleration.
3. Increases the lifespan of the motor and mechanical components.
4. Offers a compact and cost-effective design.
5. Provides electrical isolation for safety using opto-isolators.
6. Allows easy programmability and timing adjustments.
7. Improves energy efficiency during startup.
8. Can be integrated into existing industrial systems.
9. Minimises maintenance due to reduced mechanical stress.

VI.   APPLICATION AND FUTURE SCOPE

APPLICATIONS:
1. Industrial three-phase induction motor control.
2. HVAC systems for fans, compressors, and blowers.
3. Water pumps and irrigation systems.
4. Conveyor belts and automated material handling.

RESULT:

Fig2. The diagram of the Zero-crossing Detector.

Fig3. Result of Single Phase Soft starter

VII.   FUTURE SCOPE

This microcontroller-based soft starter can be enhanced by adding feedback sensors for closed-loop control, improving accuracy under varying loads. A soft stop feature could be implemented to reduce stress during shutdowns. User interfaces like LCDs or touchscreens can offer real-time monitoring and control. Future versions may include wireless connectivity for remote access and data logging, as well as smart fault detection for better safety and reliability. These upgrades would make the system more efficient and adaptable to modern industrial needs.

VIII.   CONCLUSION

This paper successfully demonstrates a simple, reliable, and efficient way to implement a soft starter using a PIC microcontroller and discrete electronics. The design is scalable and can be integrated into various industrial motor control systems.

REFERENCES

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