Signal and Image Processing Letters
Vol. 6., No. 1, 2024, pp. 1-10
ISSN 2714-6677
https://simple.ascee.org/


# Microcontroller-based Soft Starter and Overcurrent Detector for Enhancing Performance of Induction Motor

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ARTICLE INFO

ABSTRACT

When an induction motor starts up, it draws a large current, which can damage it and cause a voltage dip effect that interferes with other electrical equipment. The machine, however, has numerous applications, particularly in the industrial sector, due to its low cost, robustness, and dependability. Induction motor performance must be improved to reduce starting current surges and protect against overcurrent. Thyristors are used in the developed system to control the voltage level. The microcontroller's trigger pulse causes a ramp-up in supply voltage, resulting in a soft-starting effect in a 1-phase induction motor. The system detects overcurrent using the popular current sensor module. This research results in a high-performing soft starter and overcurrent detector. When compared to supplying the motor directly online, the soft-starter unit can reduce the starting current by 55%. Meanwhile, the embedded overcurrent detector performs admirably, accurately detecting motor overcurrent and cutting off the power supply when the motor reaches overcurrent.

**Keywords**
Induction Motor
Microcontroller
Overcurrent Detector
Ramp-up Voltage
Soft-starter



## 1. Introduction

Induction motors are the most widely used electric machines in various fields, ranging from applications in household environments to large industries. Initially, the industry's motors mainly used DC motors because it was easier to control the rotational speed. However, because maintenance and prices were relatively more expensive, the industry switched to induction motors. Induction motors have various advantages, including being reliable, robust, and relatively cheaper for the same power [1]. Many industrial applications have widely used induction motors due to their robustness, versatility, and performance [2].

Even though they have advantages, induction motors cause problems when operating. When starting up in direct-online-supplied mode, this machine draws a considerable current and can reach 6 to 8 times; even for large power motors, it can be up to 10 times the nominal current [3]. So, applying an electric voltage supply directly to an induction motor hurts the machine and the electrical system as a whole [4]. When the motor starts up, overshooting a current can cause a dip effect, which is a voltage drop that interferes with electrical equipment connected to the same power line.

To reduce current and torque surges at start-up, equip the motor with a soft starter unit. One option is to install a thyristor semiconductor device in a back-to-back configuration on the power line entering the motor, acting as a driver in an induction motor controller. Setting the thyristor ignition angle controls the expected motor voltage value [5]. A soft starter operates by gradually allowing the motor to run, applying the supply voltage gradually until the motor achieves a stable condition [6]. A microcontroller can adjust the firing angle of the thyristor to obtain a gradient voltage value (ramp-up), thereby reducing the starting current. This technique has proven to mitigate inrush current by reducing the starting current by around 42 percent [7]. This method will reduce current and torque surges when the motor starts up.

Torque control is another technique for soft starting. An optimized capacitor-resistor pair is connected in series between the motor and the power supply to eliminate low-frequency transient components in the stator and rotor currents, which are the source of transient torque pulsations. This method has been shown to reduce torque and current spikes when the motor starts [8].

Aside from that, if the start-up condition is exceeded and the motor is operating at an increasing load, the motor may experience a stall, which is a condition in which the voltage is still applied but the rotor stops rotating. If the stall is not detected quickly by turning off the input voltage supply, it can damage the motor. Installing a fault detector or stall detector unit in the control system, which detects the presence of overcurrent, can improve an induction motor's performance. The motor must have an overcurrent sensor that sends feedback to the microprocessor system. If the load on the motor exceeds the maximum limit, the microcontroller will detect a stall condition via a current sensor and immediately cut off the voltage supply to the motor.

The ACS712 current sensor module is one example of an easily accessible electronic module that can be used as current sensors to support the implementation of a microcontroller-based fault detector system on induction motors. Its application to a protection system based on the 89S52 microcontroller yields satisfactory results; the motor performance improves, responds quickly, and is less expensive [9]. A study was also conducted on using this sensor in an Arduino microcontroller-based system. As a result, the system can keep induction motors safe from low voltage, overvoltage, overload, and overheating [10]. It can also track these metrics in real time using an IoT (Internet of Things) connection [11]. This current sensor, when combined with ESP 32 microcontroller-based protection system sensors, can accurately monitor temperature, voltage, vibration, and motor current [12].

Other research reveals that a microcontroller's induction motor protection system can protect the machine against heat, voltage, and low voltage, thereby increasing service life and efficiency [13]. Microcontroller hardware-based protection systems for induction motors are more accurate than traditional protection, which makes electrical machines more efficient and raises their power factor [14]. Using the PIC18 microcontroller as the central brain of the protection control system against over/undercurrent, overheating, and phase disturbances has provided good results in protecting the machine from these disturbances [15]. This study delves into the development of a soft-starter and fault-detector control system, which utilizes a current sensor of the ACS712 type and an ATMega16 microcontroller processing unit. Researchers have used this microcontroller chip to trigger a TRIAC in a speed control system [16] and to protect a 1-phase induction motor [17]. This processor type has also been part of an induction motor's vibration-based fault identification system [18].

## 2. Method

### 2.1. Hardware System

In general, this research's hardware system uses thyristors to control motor voltage. Figure 1 depicts the structure of the hardware system being developed. The hardware structure depicted in the figure includes the following subsystems.

#### 1) Microcontroller ATMEGA16

This device functions to generate thyristor trigger pulses [19] according to the soft-starter algorithm. The firing angle is determined based on the reference pulse generated by the zero-crossing detector circuit. The microcontroller, as a fault detector controller, will send a relay breaker signal if it detects an overcurrent sent by the current sensor. Fig. 2 shows the microcontroller system used.

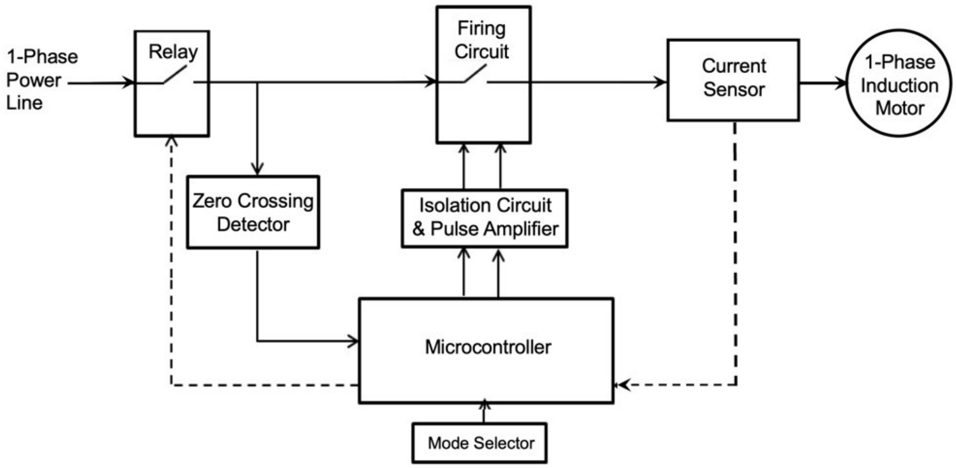


**Fig. 1.** Block diagram of hardware structure

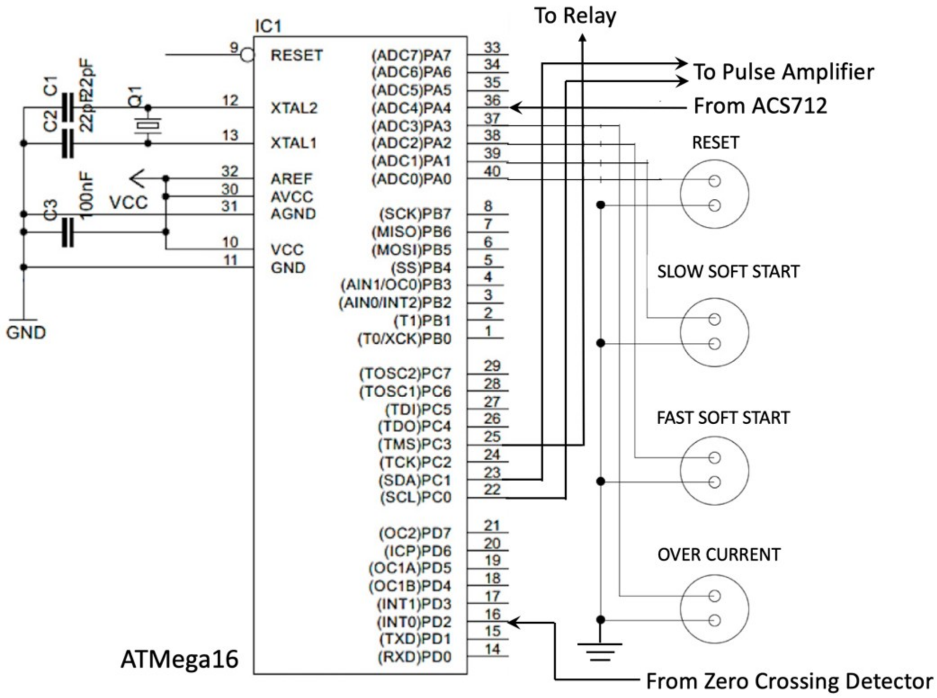


**Fig. 2.** Wiring on the microcontroller system

### 2) Zero Crossing Detector Circuit

This unit has a 6-volt AC wave input and a 5-volt DC output. The microcontroller will use the output of the zero-crossing detector as an input to determine the generation of the trigger signal. Fig. 3 visualizes the zero-crossing detector circuit.

### 3) Isolation Circuit and Pulse Amplifier

To trigger the thyristor stably, we must first strengthen the weak current from the microcontroller's pulses. The circuit uses a pair of Darlington transistors on the ULN 2003A chip. This device consists of 7 n-p-n Darlington pairs with a high voltage output equipped with clamp diodes for inductive load switching [20], according to the Data Sheet Book. Each pair's nominal current is 500 mA. Fig. 4 shows the isolation and pulse amplifier circuits.

Signal and Image Processing Letters
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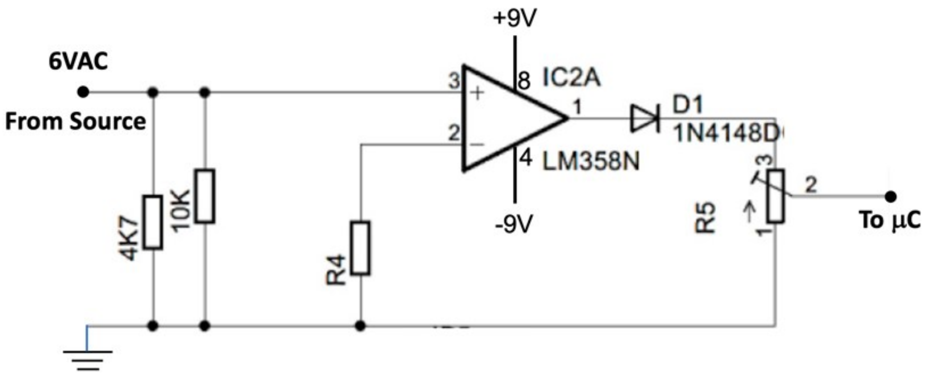


**Fig. 3.** Zero crossing detector circuit

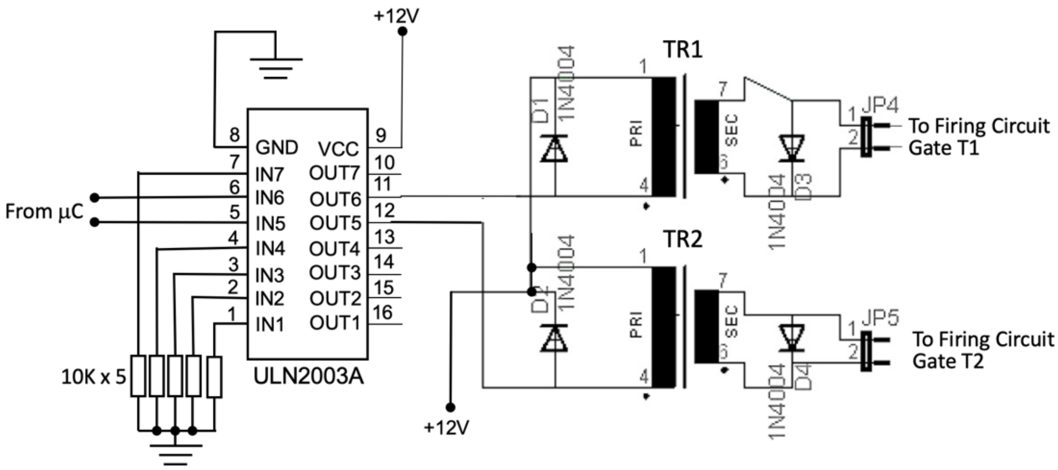


**Fig. 4.** Pulse amplifier and isolation circuit

### 4) ACS712 Current Sensor

This unit functions to detect current entering the motor. The microcontroller receives the detected current and generates a relay breaker signal. People widely use the ACS712 module due to its high linearity with a sensitivity of 66 mV/A, its ability to measure both direct current (DC) and alternating current (AC), and its low noise level [21]. Fig. 5 displays the current sensor module.

### 5) Firing Circuit

The firing circuit uses a pulse amplifier and isolation circuits to inject pulses from the microcontroller into the thyristor gate. The output of this circuit is the ramp-up voltage resulting from the triggering process, which will become the motor supply to run the motor with a soft start. Fig. 6 illustrates the firing circuit.

### 6) Relay Circuit

When the motor is in a stall state, the relay circuit cuts off the current and voltage sources from the motor. Fig. 7 shows the relay circuit.

### 7) Induction Motor

As shown in Fig. 8, the motor used in this study has the following specifications: single phase, power 0.25 HP, voltage 220 V, current 2.4 A, and frequency 50 Hz.

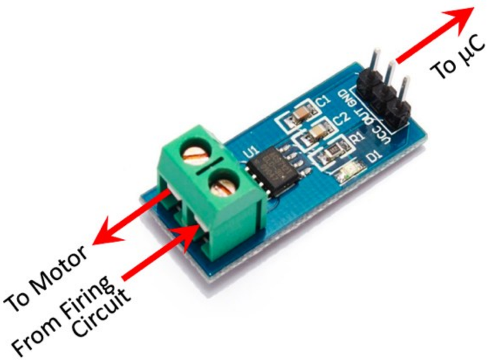


**Fig. 5.** CS712 current sensor module

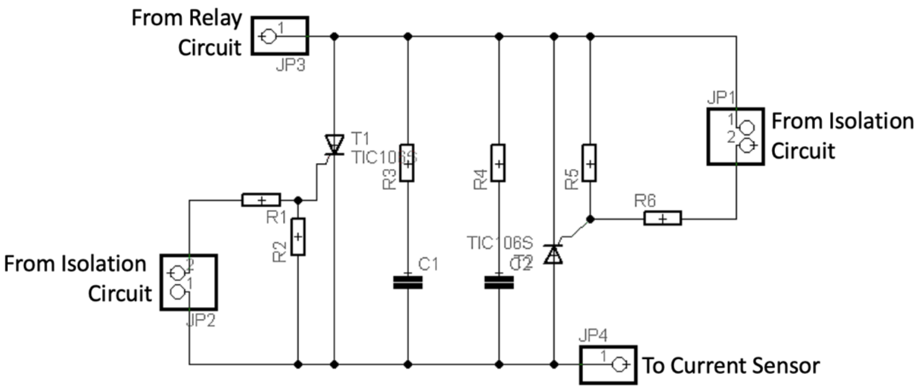


**Fig. 6.** Thyristor firing circuit

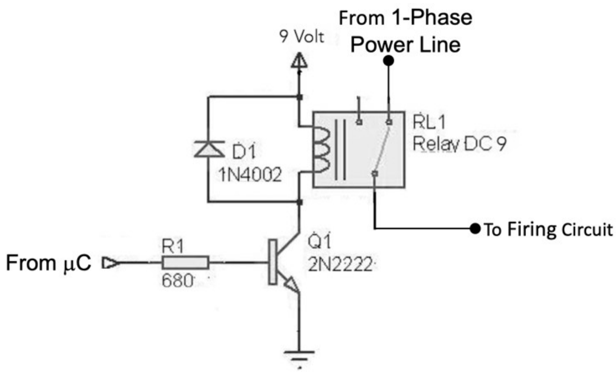


**Fig. 7.** Relay circuit

**Fig. 8.** Physical body of the induction motor used

## 2.2. Software System

The system consists of a soft-starter unit and an overcurrent detector for its function. Fig. 9 illustrates the software design that controls the prepared hardware.

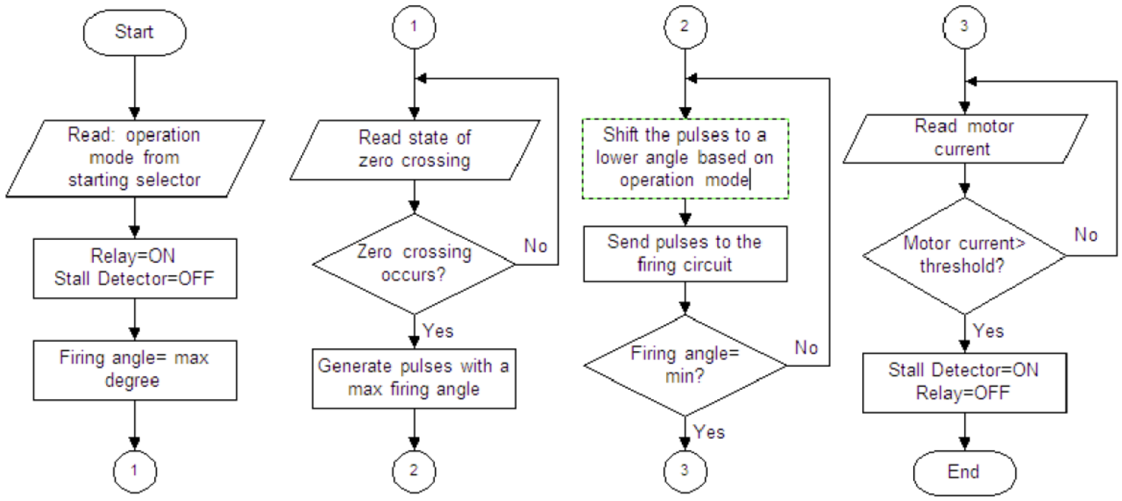


**Fig. 9.** Flowchart of the software system

## 2.3. Tools of Experiment

Various tools were used in this research, including Codevision AVR software for programming, PC/laptops to write and repair program codes on microcontrollers, analog and digital multimeters to measure voltage and current as well as test components before use, analog oscilloscopes to observe wave output on each desired section, and PC scopes to see the current and voltage waveforms of the motor at start-up.

## 2.4. System Testing

This study used two types of testing methods: functional testing and overall system performance testing. Functional testing determines whether the implemented system can carry out its operational functions by testing each component. Meanwhile, overall system performance testing seeks to obtain several parameters that can demonstrate the system's ability and dependability in carrying out its operational functions.

Functional testing includes evaluations of the power supply, zero crossing detector circuit, pulse and isolation amplifier, minimum microcontroller system, firing circuit, and current sensor circuit. The overall testing procedure consists of observing the waveform to understand the relationship between the trigger angle and the voltage wave, testing the soft-start performance to determine the effectiveness of reducing the starting current, and testing the overcurrent detector performance.

# 3. Results and Discussion

Functional testing results show that all units are working well. The zero-crossing detector circuit can convert a sine wave into a square wave, which is in phase with the input wave and has an intersection at the zero line. The microprocessor sends pulses to the amplifier circuit, which amplifies them from 5V to 12V to trigger the thyristor. The minimum microcontroller system has also worked as expected, generating pulses with varying trigger angles based on the zero cross-reference that occurs. As shown in Fig. 10, testing the firing angle circuit using an electric light load produces data. Fig. 10 shows that the microcontroller's provision of varying trigger angles on the thyristor causes varying output voltages to appear, with a relationship pattern that is almost entirely linear. The lower the alpha value, the higher the voltage generated. This research concludes that the developed thyristor triggering circuit can function very well.

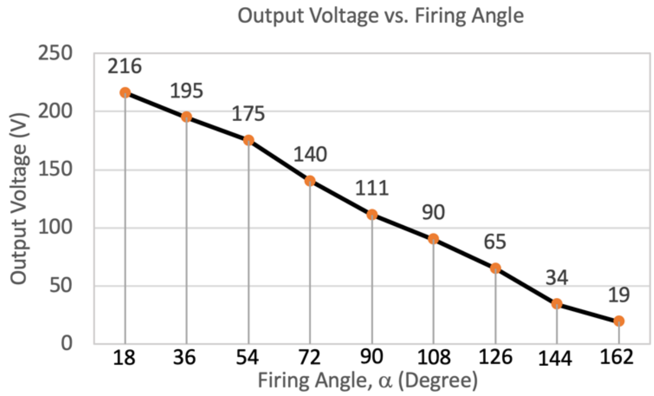


**Fig. 10.** Output voltage produced by thyristor triggering

The current sensor circuit is tested by comparing motor current measurements taken with an ammeter to the readings displayed on the LCD. Both measurements yield relatively similar results, implying that the current sensor performed satisfactorily and can support the stall detection system.

The system is tested as a whole after each component is tested separately. This test is designed to determine whether the system and programs are operating properly and as intended. The system load in this test is powered by a one-phase induction motor.

### 3.1. Determining the Minimum Alpha

To produce a perfect sine voltage waveform for a motor supply in steady-state conditions, one must determine the minimum alpha value. Experiments can yield the output voltage waveform for various alpha trigger angles, as illustrated in Fig. 11.

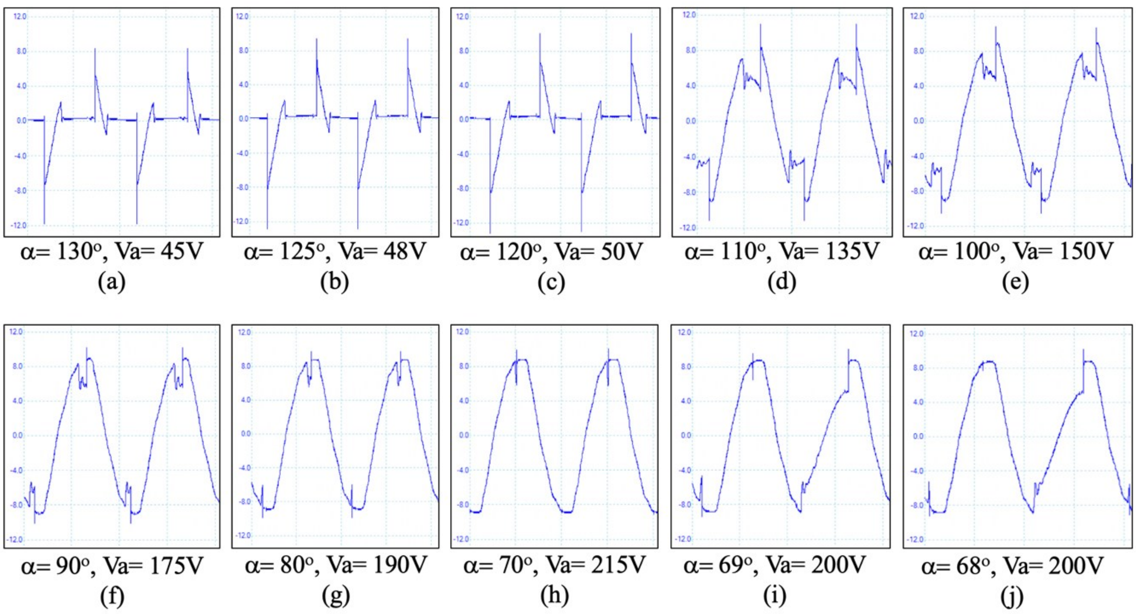


**Fig. 11.** Waveform of thyristor output voltage

According to Fig. 11, before reaching minimum alpha, the thyristor output waveform does not form a perfect sine. A thyristor controls a motor by combining the ON voltage with the back EMF that appears in the non-conducting corner area of the thyristor. Fig. 11. (a), (b), and (c) show that the back EMF is still negative; another picture shows the condition when the back EMF is positive. This voltage waveform shows the thyristor motor control system has worked well [22], [23].

When the motor starts, a soft starter regulates the power supply by providing voltage ranging from a low to a high or a high to a low trigger angle. The voltage generated by the minimum firing angle is the motor voltage supply in steady-state conditions, so it must be determined first. The image shows that the maximum voltage with an almost perfect sine wave shape is achieved at a firing angle of 70 degrees (Fig. 11 h); above and below this value, the voltage waveform does not have a perfect sine. In the soft-starter algorithm, the pulse shift from high alpha to lower alpha should not be less than 70 degrees.

### 3.2. Testing of Soft-Starter

After ensuring that all units are operational, the soft-starter unit is tested to determine how much it can reduce starting current. The data for this test was collected using a PCScope-type digital oscilloscope. The experimental results, as shown in Fig. 12, provide information on the time response of the motor current during soft-start. Fig. 12.a shows a fast-type soft-starter with a low-voltage initial supply and a trigger angle of 150 degrees. The analysis shows that the soft-starter provides a starting current surge of 5.4 p.u., peak-to-peak. Compared with a nominal current of 2 PU, peak-to-peak, the surge occurs only 2.7 times. While Fig. 12.b depicts a motor with a higher starting voltage but the same ramp-up time of approximately 15 seconds, both experiments showed the same results. If the direct on-line supply causes a spike six times, installing a soft-starter unit on a 1-phase induction motor controller can reduce the current by up to 55%. A soft-starter circuit significantly reduces the starting current [24]. The ramp-up voltage timing did not have a significant effect on reducing the starting current surge. Fig. 12.c shows that the ramp-up time is quite long, around 8.5 seconds, but still gives the same spike. However, to provide a longer ramp-up time, motor starting becomes smoother.

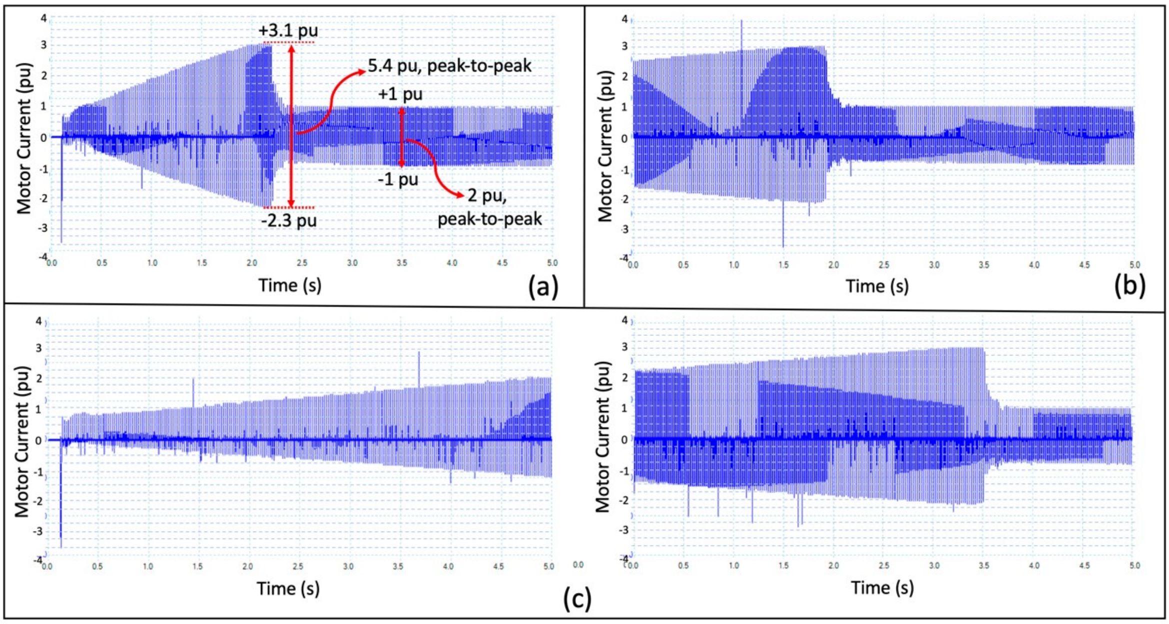


**Fig. 12.** Motor time responses controlled by a soft-starter: (a) and (b) for fast, and (c) for slow response

### 3.3.Testing of Overcurrent Detector

This test is performed by gradually increasing the motor voltage until it reaches a specific voltage that is thought to cause an overcurrent. This study determines two different current values: 2.5 times and 2.7 times the nominal value, or 5pu and 5.4pu peak-to-peak, respectively. Figure 13 depicts the results of testing the overcurrent detector unit on the system being developed. Based on Fig. 13.a, the findings of this study show that when the voltage exceeds the specified current limit, which is 5pu peak-to-peak, the system switches the relay to OFF. The system responds the same way with a peak-to-peak current limit of 5.4pu, as shown in Fig. 13.b. These two experiments demonstrate that the overcurrent protection unit embedded in the microcontroller-based motor control system functions properly and can protect the motor from overcurrent. Future studies of induction motor protection systems must incorporate modern algorithms, such as machine learning algorithms [25].

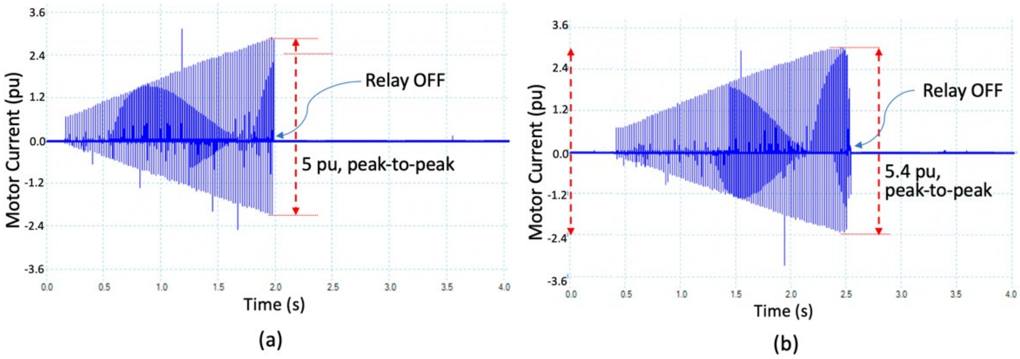


**Fig. 13.** Induction motor time responses controlled by a overcurrent detector: (a) 5pu peak-to-peak, and (b) 5.4pu peak-to-peak

## 4. Conclusion

The study discovered that implementing a microcontroller-based control system with voltage regulation on a single-phase induction motor can decrease the initial current to as low as 55% of the rated current. The overcurrent detector, an integrated protective component within the system, effectively interrupts the motor's power supply in the event of an overcurrent situation. Utilizing a microcontroller-based thyristor to regulate an induction motor offers design convenience and enhances the operational efficiency, reliability, and safety of the motor.

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