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A Numerical Investigation of Inrush Current Reduction in Induction Motors

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Abstract

Induction motors are the most commonly used machines in industries and homes mainly because of its robustness, low cost and easy to maintain. The starting current of induction motors is usually higher than the rated current and this persists for a few cycles which may be detrimental for the machine operation. This paper focuses on the reduction of the starting current using soft starter to limit the inrush current. This paper focuses on the reduction of the starting current using soft starter to limit the inrush current. In accomplishing this task, a design and implementation of a soft starter was carried out using components comprising two Silicon controlled rectifiers (SCRs) which were connected in anti-parallel, contactors, relay, resistors and other electrical and electronic integrated circuit components. The result was achieved by successfully testing the soft starter on a connected single phase induction motor. There was a gradual increase of the voltage during the motor startup which allows the motor to slowly gain speed and acceleration thereby preventing mechanical tear and jerking when the soft starter was applied

1. Introduction

An induction motor is a type of alternating current motor where power is supplied to the rotor by means of electromagnetic induction (Ashwin et al 2019) [1]. Induction motors are the most commonly used machines in industries mainly because of its robustness, low cost and easy to maintain, which has always made it very attractive. However, the starting current is usually six (6) to seven (7) times the rated current and this persists for a few cycles which may be detrimental for the machine and hence there is a need for using starters to limit the starting current (Trivedi et al 2017) [2] As a result of its extensive use in the industry, induction motors consume a considerable percentage of the overall produced electrical energy Otogwung et al 2022 [3]. Due to the fact that it requires least maintenance as compared to other electrical motors, its protection plays an important role in its overall service life Kapil et al 2024 [4]. Dehkordi 2015 [5] presented that small power motors in distribution networks normally have to operate with single-phase a.c. power.

These machines are either series connected d.c. machines or single-phase induction machines (SPIMs), they are used to drive fans, pumps, air compressors, refrigeration compressors, air conditioning fans and blowers, saws, grinders and office machines as well as air conditioning systems used in households that include a condenser unit, a compressor unit and an air handler fan. Both the compressor unit and the fan are run by single-phase induction motors. The starting of three phase squirrel cage induction motor causes peculiar problems due to excessive starting current if switched on directly from the power source, which may cause severe mechanical stress on the shaft of the motor and the load Mahesh and Atul 2021[6]. The magnitude of the torque of the driven equipment will be in excess of 200% of the motor full-load torque, these current and torque surges can be reduced substantially by reducing the voltage supplied to the motor during starting Shinde et al 2017 [7].

The initial current drawn by an induction motor when during starting is referred to as inrush current Habyarimana and Dorrell [8]. Chang et al 2023[8] stated that since a large starting current and a reactive power may lead to a deep voltage drop and cause a potential damage to induction motors and other devices in the same power grid, a novel starting method is proposed for induction motors based on the autotransformer and the magnetically controlled reactor (ATMCR) to reduce the starting current of the induction motor. Sadeghkhan & Sadoughi (2014) [10] evaluated the starting current of induction motors using artificial neural networks. The results shown that the simulation using MATLAB revealed that most developed neural network model can estimate the starting current peak of induction motors with good accuracy. Kumbhar et al (2002) [11] developed soft start of Induction motor using pulse width modulation technique (PWM) which is capable of supplying single-phase a.c induction motor with varying a.c. voltage at the start by mitigating the adverse effects of starting torque transients and high inrush currents of induction motors.

2. Methodology

2.1 Materials and Method Used

This work involves the design and coupling of the various components of electrical and electronic circuits for the actualization of the soft stater. The followings are components used; Resistor (560R, 1K, 2.2K, 3.3K, 4.7K, 10K, 22K, 27K, 100K, 2.2M, 100R/2W), Capacitors (470MF / 35V, 10µF / 63V, 2.2µF / 25V, 0.47µF (470nF) polyester, 0.1µF / 400V polyester), Diodes (IN4007, IN4148), Integrated Circuit (7812, LM339, LM324, MOC3021), IC Base (14 PIN BASE, 06 PIN BASE), Transistor (BC558/BC557, BC547), push button 2 pin, Transformer, Led Red, Led Yellow, Led Green, Male Burge Two Pin, Female Burge Pin, Heat Sink, silicon-controlled rectifier (TYN616 OR TYN612), PCB Connector 3pin, contactors and relays.

To accomplish this, two thyristors, also known as silicon controlled rectifiers (SCRs), are connected in anti-parallel for each phase. One SCR controls the positive half-wave, while the other controls the negative half-wave. In this configuration, the starting voltage is applied over time without considering the current drawn or the speed of the induction motor. In this system, the SCRs for each phase are connected in an anti-parallel arrangement. Initially, the SCRs are triggered to conduct at a delay of 180 degrees during the corresponding half-wave cycle. As time progresses, this delay is gradually reduced until the applied voltage reaches the supplied voltage. The configuration consists of two buttons: a start button and a stop button, the start button is colored green while the stop button is colored red. Pressing the green start button connects the terminals and closes the circuit allowing current to flow. Equally, pressing the red stop button disconnect the terminals and interrupts the circuit, halting the current flow. In addition, various protective components were incorporated which include the Molded Case Circuit Breaker (MCCB) which safeguards the motor coils against short circuit currents. The overload relay is used to protect the motor from excessive loads. Furthermore, a Contactor is integrated to facilitate the switching operations, and it is connected to the start and stop buttons. Thus, the contactor enables the motor to be started or stopped by using the respective green and red buttons.

For a 230 phase voltage connected to the SCR, applying a firing angle of 90˚. Hence the delay by the SCR will be about 5ms and the average output voltage will be

$$V_m = 230x\sqrt{2} = 325.27volt$$
$$V_o = \frac{325.27}{2\pi}[cos90° + 1]$$
$$V_o = 51.768\ volt$$

Now, for an AC output control of the SCR, it is important to the OFF state and the ON state. Consequentially, the time period when the SCR is OFF and when it is on.

f = input supply frequency
$\mathrm{t_{ON}}$ = controller on time = $\mathrm{n \times T}$
$\mathrm{t_{OFF}}$ = controller off time = $\mathrm{m \times T}$
n = two input cycles, thyristors are turned **on** during $\mathrm{t_{ON}}$ for two input cycle
m = one input cycles, thyristors are turned **off** during $\mathrm{t_{OFF}}$ for one input cycle

$$T_o = output\ time\ period = t_{ON} + t_{OFF} = nT + mT$$

We can show that,

$$output\ RMS\ voltage\ V_{o(rms)} = V_{i(rms)}\sqrt{\frac{t_{on}}{T_o}} = V_s\sqrt{\frac{t_{on}}{T_o}}$$

Where $V_{i(rms)}$ is the RMS input supply voltage = V_s.
We can determine the minimum rating of the contactor and the overload relay.
The rating of the contactor is calculated, thus;
output power = 0.75HP = 0.56KW,
maximum applied voltage = 230V,
efficiency =50% and
power factor = 0.85.

$$\eta = \frac{output\ power}{input\ power}$$
$$input\ power = \frac{output\ power}{\eta} = \frac{0.56KW}{0.5}$$
$$= 1.12KW$$

$$KW = cos\emptyset \times KVA$$
$$KVA = \frac{KW}{cos\emptyset}$$
$$KVA = \frac{1.12KW}{0.86}$$
$$KVA = 1.302KVA$$
$$KVA = 1.302KVA = E_{ph} \times I \times 10^{-3}$$
$$I = \frac{1.302}{E_{ph} \times 10^{-3}} = \frac{1.302}{230 \times 10^{-3}} = 5.66A$$

The maximum current consumed by the induction motor is about 5.66A. therefore, the rating of the contactor should not be less than 5.66A.
Calculating the applied voltage supplied by the thyristor of successive firing angle to the induction motor, we have;

$$V_{o(rms)} = V_S\sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$

Where, $\alpha = the\ firing\ angle\ and\ V_S = the\ input\ supplied\ voltage$

The output voltage of the thyristor of firing angle at 80° and 0° , $V_S = 230V$ is determined below:

At , α =80°

In radian, $\alpha = \frac{80\times\pi}{180}$

$$V_{o(rms)} = V_S\sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$

Therefore,

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}\left[\left(\pi - \frac{80\times\pi}{180}\right) + \frac{sin2\times 80°}{2}\right]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[(1.745) + 0.1710]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[1.91633]}$$

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$$V_{o(rms)} = 230\sqrt{0.6100}$$
$$V_{o(rms)} = 179.63V$$

At , α =0°

In radian, $\alpha = \frac{0\times\pi}{180} = 0$

$$V_{o(rms)} = V_S\sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{sin2\alpha}{2}\right]}$$

Therefore,

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}\left[\left(\pi - \frac{0\times\pi}{180}\right) + \frac{sin2\times 0°}{2}\right]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[(\pi - 0) + 0]}$$

$$V_{o(rms)} = 230\sqrt{\frac{1}{\pi}[\pi]}$$
$$V_{o(rms)} = 230\sqrt{1}$$
$$V_{o(rms)} = 230V$$

3. Results and Discussion

The single phase induction motor is rated 0.56KW. The starting ramp time is estimated to be about 4sec before the full applied voltage is supplied to the motor. It is worthy of note that the motor running current has been determined to be 5.66A which implies that the maximum current consumed by the induction motor under investigation is 5.66A. Therefore, the contactor rating should not be less than 5.66A. Further established result shows that the applied voltage decreases with increase in the firing angle. On application of the soft starter, there is a gradual increase of the voltage during the motor startup which allows the motor to slowly gain speed and acceleration thereby preventing mechanical tear and jerking. Moreover, the torque of the induction motor is directly proportional to the square of the current, which in turn depend on the supply voltage

In order to give a definite, orderly and controllable signal pulse to the gate of the thyristors, a zero crossing detection circuit is used. This circuit primarily consist of bridge rectification and a transistor usually an opt coupler or an operational amplifier in a comparator configuration. This device is used to detect the zero crossing point on an ac signal which is the point on the ac signal where the sinusoidal ac voltage crosses from the positive half to the negative and from negative again back to the positive half.

4. Conclusion

This work has successfully carried out inrush current reduction in single phase induction motor using soft starter. There was a gradual increase of the voltage during the motor startup which allows the motor to slowly gain speed and acceleration thereby preventing mechanical tear and jerking when the soft starter was applied. Moreover, the torque of the induction motor is directly proportional to the square of the current, which in turn depend on the supply voltage.

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