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Effectiveness Analysis of Soft Starter in Reducing Starting Current of 400 kW Three-Phase Induction Motor for Chipper Machines in the Wood Processing Industry

Resti Savira[1*], Akbar Abadi[1], Yani Kamisa Putri[1], Aldi Rahman[1] and Dinda Sukra Alhamda[1]

[1] Electrical Engineering, Electrical Faculty, Padang State Polytechnic, Padang, Indonesia

*Corresponding Author, email : restisavira@pnp.ac.id

Abstract

The wood processing industry heavily relies on three-phase induction motors to drive high-power equipment such as chipper machines. One of the major challenges in operating these motors is the high inrush current during startup, which can destabilize the power system and accelerate equipment wear. This study aims to analyze the effectiveness of using a soft starter as a starting method for a 400kW induction motor in a chipper application. The research method is an experimental case study involving direct field observation and theoretical calculations of electrical parameters such as nominal current, current limiting, torque, and trip class. The observation results show that the actual starting current of 1,216.15 A remains below the calculated current limiting threshold of 1,575 A, while the trip class value of 2,835 A provides optimal protection. The use of a soft starter proves effective in reducing inrush current, maintaining voltage stability, and enhancing the reliability and efficiency of motor operation. This research supports the application of soft starters as a suitable solution for high-power motor starting in heavy industrial settings.

Keywords: Three-Phase Induction Motor, Soft Starter, Starting Current, Wood Processing Industry.

1. Introduction

The wood processing industry is a manufacturing sector that heavily relies on high-powered mechanical equipment. These machines are essential for carrying out various operations such as cutting, smoothing, drilling, and polishing. The efficiency and reliability of these processes are largely influenced by the type of electric motor system in use. Among the available options, the three-phase induction motor stands out as the preferred choice due to its high efficiency, durability, and ease of maintenance [1][2].

The three-phase induction motor is one of the most widely used types of electric motors in industrial applications due to its simple design, low cost, robust construction, and easy maintenance. It is well-suited for heavy-duty operations in harsh industrial environments. Despite the growing interest in newer technologies such as permanent magnet synchronous motors (PMSM), the three-phase induction motor remains the dominant technology in the industry because of its proven reliability and cost-effectiveness. However, it also has some drawbacks, including low starting torque, relatively low efficiency, and a poor power factor compared to other motor types [3].

A wood chipper is a mechanical device engineered to transform tree trunks or wooden branches into small, uniform pieces commonly referred to as woodchips. This machine typically comprises several essential components, including a hopper for feeding raw materials, a cutting mechanism, and a container to collect the processed output. It is widely utilized in the wood processing industry, paper manufacturing, and biomass waste treatment, owing to its ability to handle large volumes of material swiftly

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and efficiently. With a production capacity of around 600 to 700 chips per minute, the choice and design of its drive system—especially the implementation of a three-phase electric motor—are critical in ensuring the chipper operates with optimal performance and reliability [4].

However, the use of induction motors—particularly those with high power ratings—often encounters challenges during the initial startup phase. One common issue is the occurrence of inrush current, a sudden surge of electrical current that can reach six to seven times the motor's nominal current [5][6][7]. This surge not only places a significant load on the electrical system but can also lead to voltage dips that disrupt the overall stability of power distribution. In addition, the sudden torque generated during startup poses a risk of excessive mechanical stress on machine components, which can accelerate wear in the transmission system and, over time, contribute to motor overheating [8][9].

Various methods have been developed to address these challenges, including the use of autotransformers, line resistors, line reactors, wye-delta starters, and variable frequency drives (VFDs). One modern solution that is increasingly adopted in industrial applications is the soft starter. A soft starter allows for a gradual increase in voltage during motor startup, enabling a smoother and more controlled transition from standstill to full operating speed [10]. The use of this device has proven effective in reducing inrush current, minimizing torque shock, and preventing overheating. As a result, it helps extend motor lifespan while also enhancing efficiency and ensuring greater continuity in the production process.

The implementation of a soft starter is particularly relevant for large induction motors, such as those used in chipper machines within the Woodyard Maintenance unit [2]. This motor is used to drive the cutting blades in a chipper machine, which are responsible for slicing logs into small wood chips after they have passed through the cleaning stage in the debarking drum. These chips are then further processed into raw materials for products such as paper and cardboard. The blades in a chipper are designed to be large, heavy, and highly durable to ensure efficient cutting of the wood. These characteristics result in a substantial initial load on the motor during startup [11].

As noted in [5], the soft starting method has been shown to be the most efficient in terms of cost, energy consumption, and reliability in reaching steady-state conditions when compared to other techniques. Meanwhile, in [12], the implementation of soft starting using an IGBT-based soft starter with sine-triangle and sine-sawtooth PWM successfully reduced starting current. However, under steady-state conditions, the Direct-On-Line (DOL) method provided better motor speed performance.

Therefore, this study aims to demonstrate that employing a soft starter is an effective solution for addressing startup issues in three-phase induction motors—particularly in chipper motor applications, which are characterized by heavy loads and the need for stable, continuous operation in the field.

2. Material and methods

This study employs an experimental case study approach conducted within a wood processing industry to analyze the performance of a soft starter during the startup of a 400 kW three-phase induction motor used in a chipper machine. Data were collected through direct observation of electrical parameters such as starting current, voltage, active power, and power factor from the soft starter panel. Theoretical calculations were then performed to determine the nominal current, current limiting, as well as starting and stopping torque, which were subsequently compared to actual field data. The analysis aims to evaluate the effectiveness of the soft starter in reducing current surges, maintaining power system stability, and enhancing the overall efficiency and reliability of motor operations.

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2.1 Soft Starter Module

A soft starter is used to initiate the operation of a three-phase induction motor with reduced torque and lower starting current. The soft starter activates the motor as soon as the start command is issued ($t1$). During the ramp-up period (from $t1$ to $t3$), current flows through power semiconductors (switching elements), allowing the motor to start smoothly.

The soft starter module is equipped with an internal startup recognition feature. If the system detects that the motor has already started before the ramp-up period ends, the motor voltage is immediately increased to 100% of the line voltage ($t2$). At this point, internal bypass contacts close, and the power semiconductors are bypassed—placing the soft starter into bypass mode.

Canceling the start command ($t4$) initiates the stop mode, causing the motor to shut down. The power semiconductors also ensure a smooth deceleration of the motor. During the active stop time (from $t4$ to $t5$), power continues to be supplied to the motor. It may take additional time for the motor to come to a complete stop ($t6$).

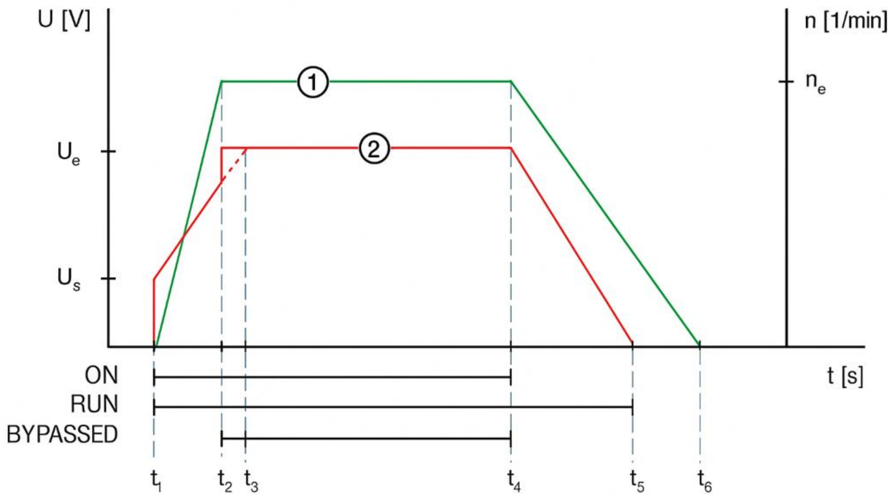

Figure 1. Soft Starter Function Graph

Table 1. Soft Starter Parameters

Parameter	Motor Chipper
Nominal Current	I_N
Starting Mode	Voltage Ramp + Current Limitting
Current Limitation	400%
Ramp-Up Time	40 s
Initial Torque	40%
Stop Torque	10%

2.2 Chipper Motor

To operate the chipper drive, four motors are required as the main drivers. Since these motors are started using a grouped starting system, it is essential that all four motors have identical specifications. In this setup, the group starting method involves operating two motors within each group: Motor 1 and Motor 4 form the first group, while Motor 2 and Motor 3 make up the second group.

There is a short delay between the activation of the first and second groups, which is controlled by the Distributed Control System (DCS). This delay is crucial to ensure synchronization during operation. If motors with differing specifications are used, or if both groups are activated simultaneously, it can lead to operational issues—one of the most significant being motor overheating.

If any of the motors differ in specification, they will likely produce a different RPM. A reduction in RPM typically results in increased torque. Since torque and current are directly proportional, a rise in torque will also cause a rise in current. This increase in current leads to higher temperatures both in the conductors and within the motor itself. The same issue can arise if all four motors are started at the same time without the proper delay between groups.

Table 2. Chipper Motor Specifications

Power	400 kW
Phase	3
Voltage	690 V
Frequency	50 Hz
Cos phi	0.85
Pole	4
RPM	1500

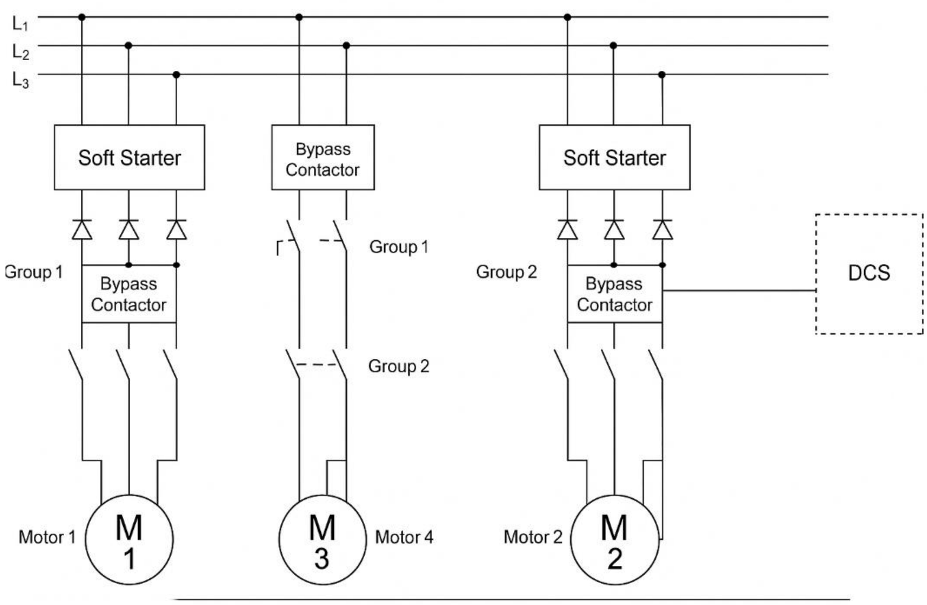

Figure 2. Single-Line Diagram of the System

3. Results and discussion

The calculations performed include determining the nominal current, current limitation, torque, starting torque, stopping torque, and trip class. The following are the calculations carried out:

a. Nominal Current Calculation

The calculation of nominal current is based on the active power formula under a three-phase power supply,

$$P = \sqrt{3}\, VIcos\varphi \quad (3.1)$$

the nominal current can be determined using the following formula:

$$In = \frac{P}{\sqrt{3}\ VIcos\varphi} \quad (3.2)$$

$$In = \frac{400.000}{\sqrt{3}x690x0.85}$$

$$In = \frac{400.000}{1.015,8478}$$

In = 393,759774 A

b. Current Limitation Calculation

Current Limitation = 400% x In (3.3)

Current Limitation = 400% x 393,759774

Current Limitation = 1575,0391 A

c. Torque Calculation

$$Torque = \frac{(5250\ x\ Hp)}{n} \quad (3.4)$$

$$Torque = \frac{(5250\ x\ 536,19)}{1500}$$

$$Torque = \frac{(2.814.997,5)}{1500}$$

Torque = 1,876,6 Nm

d. Initial Torque Calculation

Initial Torque = 40% x Torque (3.5)

Initial Torque = 40% x 1.876,6

Initial Torque = 750,64 Nm

e. Stop Torque Calculation

Stop Torque = 10% x Torque (3.6)

Stop Torque = 10% x 1.876,6

Stop Torque = 187,66 Nm

f. Trip Class Calculation

Trip Class = 7,2 x In (3.7)

Trip Class = 7,2 x 393,759774

Trip Class = 2.835,07037

Table 3. Comparison of Current and Voltage Values During Starting and Normal Operation of Chipper Motor

Parameter	Starting Value	Nominal Value
Voltage (V)	583,9 V	683,8 V
Current (A)	1216,15 A	138,58 A

Table 4. Theoretical vs Actual Starting Values of the Chipper Motor

Parameter	Teori	Field Data	Deviation (%)
Current Limiting (A)	1575	1216	-22,8%
Trip Class (A)	2835	No Trip Occurred	Within Specification

Based on the calculations performed and theoretical analysis drawn from various sources, a comparison can be made between the calculated values, theoretical expectations, and actual field data as follows:

1. The working principle of a soft starter, as described in theory, involves gradually varying the supply voltage during motor startup. According to this principle, when the voltage is low, both current and torque tend to be high. This is consistent with the observed parameters, where at startup, the voltage measured was 583.9 V while the current reached 1,216.15 A. In contrast, under normal operating conditions, the voltage was 683.8 V and the current dropped significantly to 138.58 A.
2. When comparing the current limiting value obtained from theoretical calculations to the value shown on the module display, it is evident that the current limiting function has been applied correctly. The calculated current limit was 1,575.0391 A, while in the field, the peak current recorded during startup was only 1,216.15 A—well below the calculated threshold. This outcome is considered beneficial, as operating beyond the current threshold in real-world applications may lead to frequent system trips, potentially interrupting the continuity of the production process.

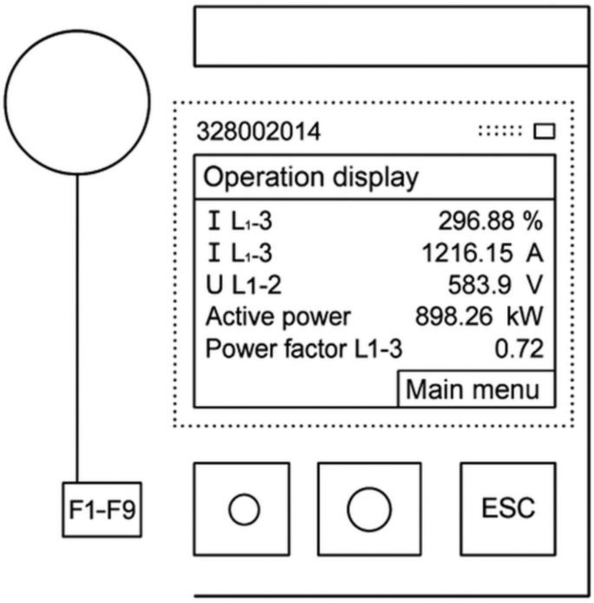

Figure 3. System Display Interface

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3. Since the starting current does not exceed the current limiting value, it can be concluded that the selected trip class is appropriate for the motor's operational requirements in the field. Based on field measurements, the inrush current during startup did not exceed 300%—well below the typical surge range of 400% to 700%—indicating that the installed trip class is properly matched and aligned with the soft starter's specifications.

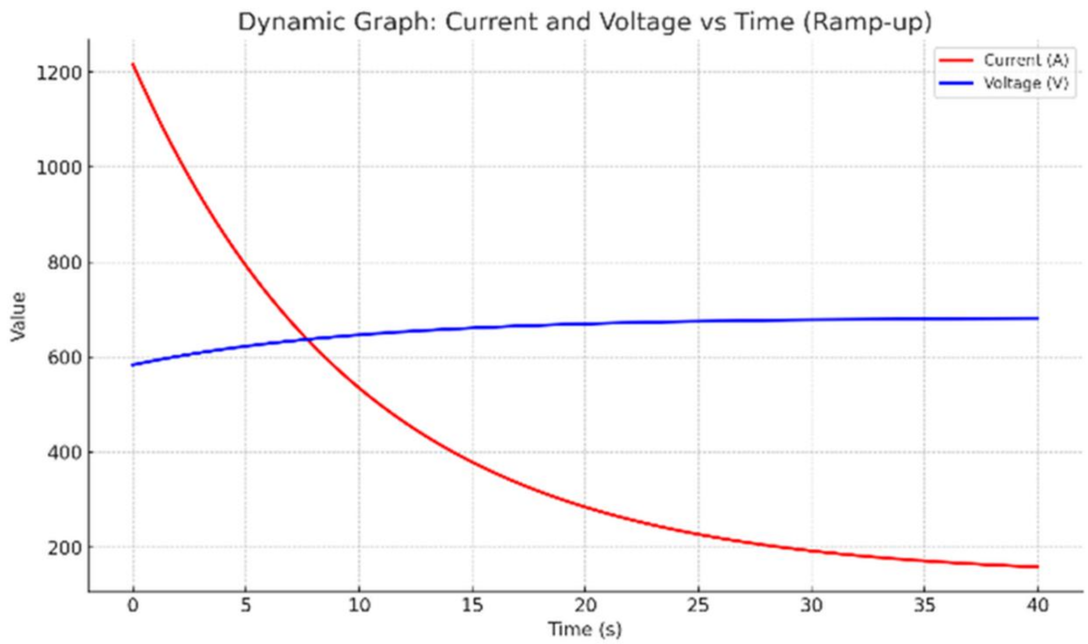

Figure 4. Dynamic Graph of Current and Voltage versus Time during Soft Starting Process

The following figure presents a dynamic graph illustrating the changes in current and voltage during the soft starting process of a 400 kW three-phase induction motor. The red line represents the gradual decrease in current from an initial starting value of 1,216 A down to its nominal level of approximately 138 A. This reduction follows an exponential pattern, aligning with the operating characteristics of a soft starter designed to manage inrush current.

Meanwhile, the blue line shows a gradual voltage increase from 583 V to the nominal voltage of 683 V over a ramp-up period of about 40 seconds. This smooth rise in voltage results from the soft starter's voltage ramp function, which enables a controlled and stable transition in voltage during startup.

Overall, the graph clearly demonstrates the effectiveness of the soft starter in maintaining electrical system stability throughout the motor's startup phase. By reducing current surges and supplying voltage incrementally, the soft starter not only lessens mechanical and thermal stress on the motor but also minimizes the risk of disturbances in the power distribution network—ultimately supporting the system's reliability and operational efficiency.

4. Conclusion

Based on the results of analytical calculations and field data, it can be concluded that the application of a soft starter in the startup system of a 400 kW three-phase induction motor in the wood processing industry is effective in reducing inrush current and preventing excessive torque shock. The measured starting current of 1,216.15 A remained well below the current limiting threshold of 1,575 A, as determined by theoretical calculations, indicating that the startup configuration using voltage ramp and current limiting methods is appropriate and safe. Additionally, the recorded trip class value of 2,835 A provides optimal protection without causing unnecessary tripping. These findings further support that the soft starter system contributes to maintaining network voltage stability and enhances the overall reliability of motor operation. For future research, it would be beneficial to investigate the long-term operational impacts of soft starter implementation under varying industrial load conditions. Additionally, examining the comparative performance between soft starters and other motor starting technologies, such as VFDs, across different motor capacities could provide practical insights. This study was limited to a single case and specific motor rating; hence, broader application may require further validation in different industrial contexts.

Author contribution

Resti Savira* led the conceptualization, methodology, and writing of the original draft. Akbar Abadi and Aldi Rahman were contributed to the data curation, validation, and formal analysis. Yani Kamisa Putri and Dinda Sukra Alhamda were contributed to project administration, resources, and helped with supervision and final manuscript review. All authors have read and agreed to the published version of the manuscript.

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Competing interest

The authors declare that there is no conflict of interest regarding the publication of this paper

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Nomenclature

cos φ	meaning of power factor
P	meaning of Power
In	meaning of Nominal Current
t	meaning of Ramp-Up Period
Nm	meaning of Newton Meter
I_L	meaning of Current Line
U	meaning of Voltage Line