ANALYSIS AND SIMULATION OF THREE-PHASE ASYNCHRONOUS MOTOR CONTROL WITH SWITCHING DEVICES FOR FORESTRY APPLICATIONS IN SIMULINK

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RESEARCH ARTICLE

Abstract
This study analyses the start-up performance of a 5 kW, 400 V, 50 Hz three-phase induction motor driving circular steel saw blades of 300 mm, 600 mm, and 1200 mm diameters. A MATLAB Simulink model with a star–delta starter was developed to assess how blade inertia affects motor dynamics while limiting inrush current. Each blade was modelled as a thin steel ring, and its inertia was added to the motor rotor inertia. Simulations were conducted under no-load conditions to isolate inertial effects on current, torque, and acceleration.

Keywords: Three-phase asynchronous motor, Simulink simulation, Timber cutting start-up, Forestry machinery, Switching devices
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INTRODUCTION

In modern forestry machinery, electric drive systems must operate reliably under harsh environmental and mechanical conditions. Three-phase asynchronous (induction) motors are widely used in this field due to their robustness, simplicity, and cost-effectiveness. However, direct-on-line (DOL) starting can produce extremely high inrush currents and torque peaks, leading to mechanical stress, voltage drops, and reduced overall system efficiency (Deesor, et al., 2022).

The star–delta starting method offers a practical and economical solution to these issues. By initially connecting the stator windings in a star configuration and then switching to delta once the motor reaches a certain speed, this method effectively reduces starting current and mechanical stress. Despite its simplicity, the switching period can introduce transient effects that influence performance, especially under variable load conditions typical in forestry applications (Goh, H.H., Looi, M.S. & Kok, B.C., 2009).

This study presents a simulation-based analysis of a three-phase asynchronous motor controlled through a star–delta scheme using MATLAB/Simulink. The model focuses on capturing the dynamic behavior during the switching process and evaluating key parameters such as torque, speed, and current. The results provide valuable insights for optimizing start-up performance and improving the reliability and efficiency of electric drives used in forestry equipment.

MATERIAL AND METHOD

The study used a 5 kW, 400 V, 50 Hz, three-phase induction motor with a rated torque of approximately 32.9 N·m at 1500 rpm. A star-delta starter was included in the simulation to reduce inrush current during start-up. For the purpose of this study, the same motor was used for all blade sizes. This approach allows a clear understanding of how blade inertia affects start-up dynamics while maintaining consistent electrical and mechanical motor parameters. Three steel circular blades were analysed with diameters of 300 mm, 600 mm, and 1200 mm. Each blade was approximated as a thin steel ring, and its moment of inertia was calculated using:

$$I = m \cdot R^2$$

where m is the mass and R is the radius of the blade. The blade inertia was added to the motor rotor inertia in the simulation. Start-up simulations considered no mechanical load, meaning the motor only accelerated the rotor and attached blade. Required torque for acceleration was determined by:

$$T_{start\text{-}up} = I_{total} \cdot \alpha$$

Where:

$$I_{total} = I_{motor} + I_{blade}$$

and α is the angular acceleration needed to reach rated speed (~1500 rpm). Mechanical power during start-up was calculated as:

$$P_{start\text{-}up}=T_{start\text{-}up}\cdot\omega$$

with ω as the angular velocity in rad/s. Using the same motor allows clear observation of how blade inertia influences start-up behaviour without confounding factors.

Start-up torque requirements and motor capabilities for each blade size are summarized in Table 1. Results confirm that the **5**-kW motor can start all blades unloaded, although larger blades accelerate more slowly due to higher inertia.

Table 1.

Saw Blade Start-up based on diameter

Blade Diameter	Blade Inertia (kg·m²)	Startup Torque (N·m)	Motor Rated Torque (N·m)
300 mm	0.0015	3.4	32.9
600 mm	0.0117	9.7	
1200 mm	0.094	30.5	

The motor start-up control system was modelled and simulated using MATLAB Simulink, as seen in Figure 1, to implement a star-delta starter based on the saw blade diameter. The schematic consists of motor winding configurations for both star (Y) and delta (Δ) connections, represented by dedicated subsystems for each mode. Input signals corresponding to three-phase voltages are processed through RMS measurement blocks to monitor the current and voltage values accurately.

A user-selectable parameter for saw blade diameter (300 mm, 600 mm, and 1200 mm) was integrated into the model to adjust the motor start-up parameters accordingly. The transition from star to delta connection is controlled by logic blocks that analyse the measured RMS values and apply timing delays to ensure smooth switching, minimizing mechanical stress and electrical surge.

The motor is modelled with its electrical characteristics, and the torque output is monitored to evaluate performance during the start-up sequence. The model includes continuous mode operation, enabling sustained motor running post start-up.

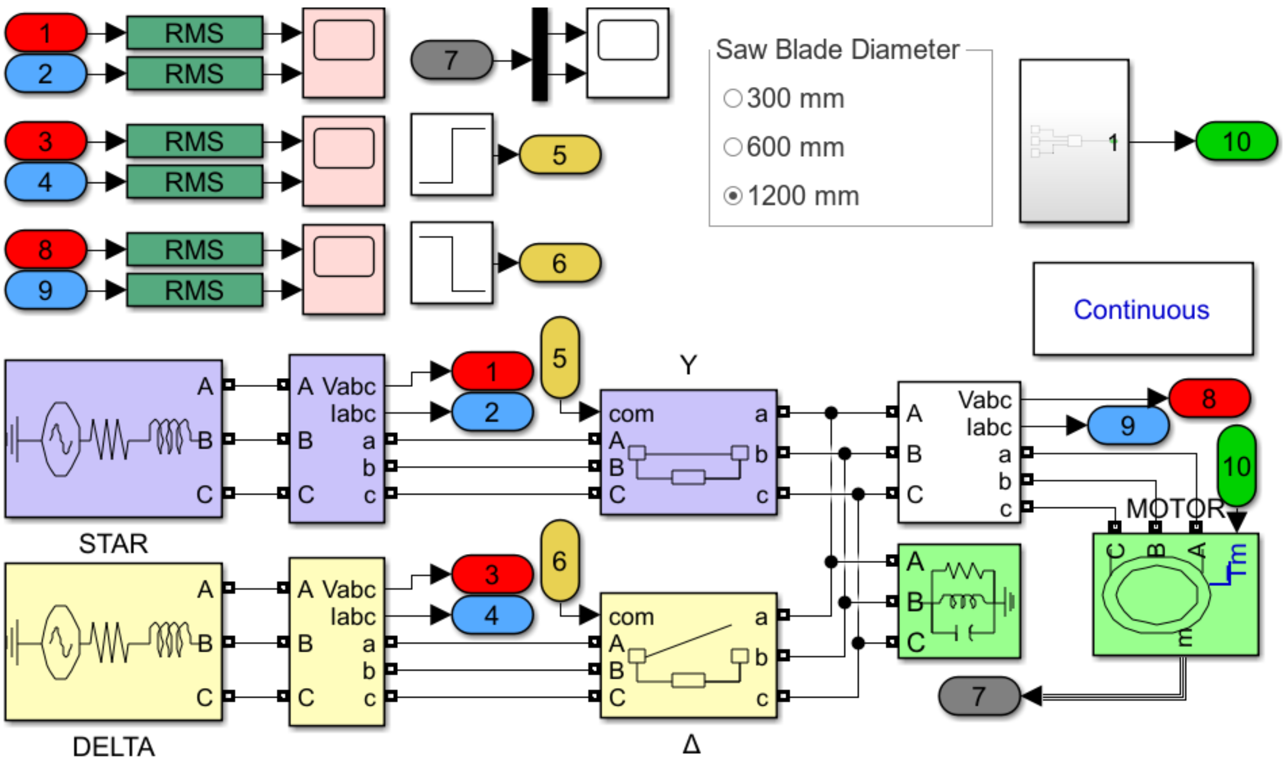

Figure 1 **Motor start-up control syst**

RESULTS AND DISCUSSIONS

Figure 2 shows the RMS current profiles during start-up for the three blade sizes. At initial energization (t ≈ 0 s), the motor draws a peak inrush current of approximately 35–40 A, which quickly settles to around 17–18 A during the star connection period. Around t = 1.0 s, the star–delta transition occurs, resulting in a transient spike of similar magnitude before the current gradually decreases as the motor reaches steady-state operation.

The decay rate of the current differs noticeably across blade sizes. The 300 mm blade settles to its steady-state current (~9 A) by t ≈ 1.45 s, while the 600 mm and 1200 mm blades reach the same condition around t ≈ 1.55 s and t ≈ 1.7 s, respectively. This demonstrates that increased inertia prolongs the current draw period, as the motor requires more time to accelerate heavier blades. The star–delta configuration effectively limits current magnitude throughout the process, preventing excessive inrush and ensuring safe operation.

The speed characteristics shown in Figure 3 further illustrate the influence of inertia on acceleration. All three blades follow a similar speed trajectory during the star connection phase, achieving roughly 250–300 rpm by t = 1 s. Once switched to the delta connection, acceleration increases sharply until rated speed is achieved. The 300 mm blade reaches 1500 rpm at approximately 1.45 s, the 600 mm blade at 1.55 s, and the 1200 mm blade at 1.7 s. Although all blades ultimately attain synchronous speed, larger diameters require longer acceleration times due to higher moments of inertia. At energization, the torque exhibits oscillations with peak magnitudes of approximately ±25 N·m, stabilizing near 5–8 N·m during steady-state star operation. A strong transient is visible at t = 1 s, corresponding to the star–delta switching instant. The 1200 mm blade shows the highest post-transition torque peak of about 40 N·m, whereas the 300 mm blade peaks near 30 N·m before settling smoothly. These transients are characteristic of mechanical and electromagnetic coupling effects during reconfiguration of the supply voltage. After approximately t = 1.6–1.8 s, torque for all configurations stabilizes around the rated value of 32.9 N·m, confirming that the motor achieves normal operating conditions. The higher torque oscillations observed with the 1200 mm blade are attributed to its higher inertia, which demands greater torque to maintain equivalent angular acceleration.

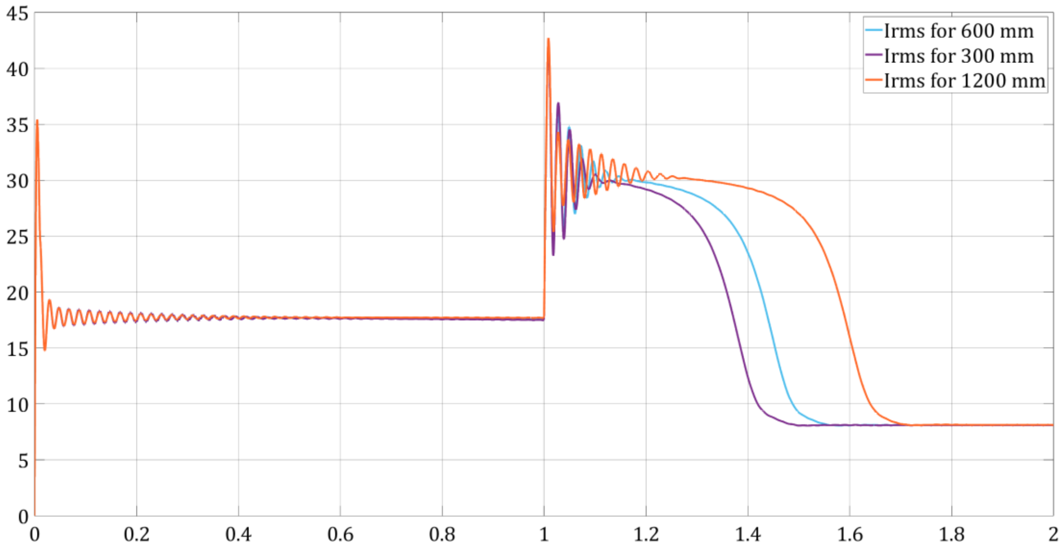

Figure 2 **RMS current profiles during start-up for the three blade sizes**

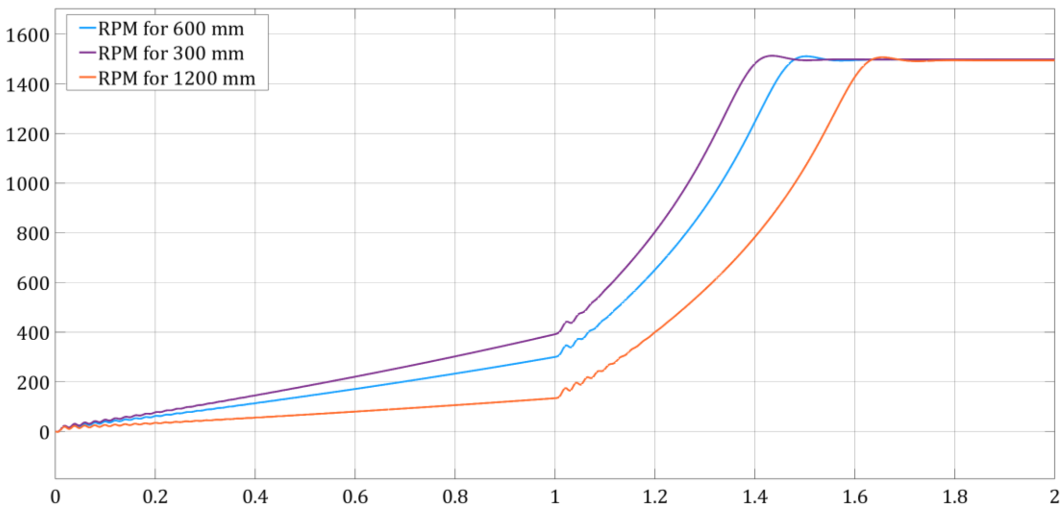

Figure 3 **Speed characteristics current profiles during start-up for the three blade size**

CONCLUSIONS

This study examined the start-up performance of a 5 kW, 400 V, 50 Hz three-phase induction motor driving circular steel saw blades of different diameters using MATLAB Simulink. The model employed a star–delta starter, one of the most practical and widely used reduced-voltage methods in industrial and forestry machinery, to evaluate its ability to minimize inrush current and torque transients. The simulation results confirmed that the star–delta configuration effectively limits starting current while maintaining sufficient torque for acceleration, consistent with earlier analyses comparing DOL, star–delta, and autotransformer starting methods (Deesor et al., 2022; Goh et al., 2009).

Three blades, 300 mm, 600 mm, and 1200 mm—were analyzed to evaluate the effect of load inertia on motor start-up. Greater inertia resulted in longer acceleration times and higher transient torque. The 300 mm blade (0.0015 kg·m^2) reached rated speed (1500 rpm) in 1.45 s, while the 600 mm (0.0117 kg·m^2) and 1200 mm (0.094 kg·m^2) blades required approximately 1.55 s and 1.70 s, respectively. Peak inrush currents ranged between 35–40 A, and torque peaks reached 40 N·m before stabilizing near 32.9 N·m. These findings confirm that the star–delta method provides a reliable and economical solution for high-inertia loads typical of sawmill and forestry applications. The study further emphasizes the importance of electrical contact behavior and switching transients in determining overall motor reliability. Variations in contact resistance can alter efficiency and lifetime performance (Stasac et al., 2019), while mechanical vibration and fluctuating temperatures influence contact wear and mechanical stability (Labelle et al., 2019). Investigations into the thermal and vibrational effects on electrical contacts (Hoble et al., 2017) demonstrate that improved contact materials and protective configurations are essential for motors operating in demanding forestry environments. These insights suggest that a combination of mechanical robustness and precise control is required to ensure optimal performance.

Although the present work is simulation-based, it provides a strong foundation for future experimental validation. Laboratory studies focusing on switching currents, contact heating, and vibration impacts could verify the predicted torque and current responses under real operating conditions. In such investigations, the methodologies proposed by Stasac and Hoble (2021) and the broader framework for sustainable and efficient drive systems outlined by Šušnjar et al. (2022) and Wasilewski et al. (2023) may serve as valuable references. Overall, the results contribute to improving the design, reliability, and sustainability of electric drive systems in forestry machinery and align with the sector's transition toward hybrid, intelligent, and energy-efficient technologies.

Continued integration of simulation and experimental research will be key to advancing robust, adaptable, and environmentally responsible electric drives for next-generation forestry applications.

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