# Robust stall detection of three-phase induction motors using transient-aware current-speed monitoring

**Muchlas[1], Herman Dwi Surjono[2], Tole Sutikno[3], Barry Nur Setyanto[1]**
[1]Department of Vocational Electronics Engineering Education, Faculty of Teacher Training and Education, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Department of Electronics and Informatics Engineering Education, Faculty of Engineering, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
[3]Department of Electrical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia

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**ABSTRACT**

Reliable stall detection is essential for protecting three-phase induction motors from thermal damage while maintaining uninterrupted industrial operation. Conventional threshold-based protection methods often struggle to distinguish transient overload events from sustained stall conditions, resulting in nuisance trips or delayed fault detection under dynamic operating conditions. This paper proposes a robust transient-aware stall detection framework that combines stator current monitoring, rotor speed monitoring, startup inhibition, adaptive activation logic, and hold-time verification within a lightweight threshold-based decision process. The proposed algorithm was implemented and evaluated using a MATLAB/Simulink model of a three-phase squirrel-cage induction motor under representative operating scenarios, including motor startup, temporary overload, and sustained stall conditions. Simulation results demonstrate that the proposed framework successfully suppresses unnecessary trips during short-duration overloads by allowing the motor to re-accelerate after transient disturbances. Conversely, when abnormal operating conditions persist beyond the predefined hold time, the algorithm reliably identifies an actual stall and activates the protection relay to disconnect the motor. By integrating temporal verification with simultaneous current and speed monitoring, the proposed framework effectively discriminates recoverable transient events from sustained stall conditions while maintaining low computational complexity. These characteristics make the proposed method suitable for practical real-time induction motor protection in industrial automation applications.



***Corresponding Author:***

Muchlas
Department of Vocational Electronics Engineering Education, Faculty of Teacher Training and Education
Universitas Ahmad Dahlan
Jl. Ring Road Selatan, Tamanan, Banguntapan, Bantul, Yogyakarta, Indonesia
Email: muchlas.te@uad.ac.id

## 1. INTRODUCTION

Induction motors are among the most widely used electrical machines in industrial applications because of their simple construction, high reliability, durability, and low maintenance requirements [1]. The motors play a vital role in manufacturing systems, process industries, transportation, pumping stations, and energy conversion systems [2], [3]. Since these motors frequently operate in mission-critical processes, unexpected failures may interrupt production, reduce operational efficiency, increase maintenance costs, and compromise workplace safety [4]. Consequently, improving the reliability of induction motor protection has become an important research topic in modern industrial automation and smart manufacturing environments systems [5], [6].

Among various abnormal operating conditions, motor stall is one of the most severe faults because it causes a rapid increase in stator current while simultaneously reducing rotor speed. If the condition persists, excessive copper losses lead to rapid temperature rise, insulation deterioration, reduced motor lifetime, and eventually catastrophic failure [7]–[10]. Therefore, stall protection systems must detect the fault accurately and disconnect the motor before irreversible thermal damage occurs [11].

Conventional motor protection schemes commonly employ thermal overload relays, overcurrent protection, and fixed current-threshold monitoring to detect abnormal operating conditions [12]–[14]. These methods have been successfully implemented in many industrial systems because of their simplicity and low implementation cost [15]–[17]. More recently, research has focused on advanced stall detection techniques, including motor current signature analysis (MCSA), slip estimation, torque monitoring, vibration analysis, data-driven fault diagnosis, and machine-learning-based methods [18], [19]. Although these approaches generally provide higher diagnostic capability and improved fault classification performance, they often require additional sensing devices, complex mathematical models, extensive training datasets, or intensive computational resources. Such requirements may limit their practical implementation in low-cost industrial controllers and real-time motor protection systems, where computational efficiency, robustness, and implementation simplicity remain essential.

Among various monitoring strategies, current- and speed-based monitoring remains one of the most practical approaches for industrial motor protection because both signals are readily available in most commercial motor drives without requiring additional sensing hardware [20]–[24]. Nevertheless, achieving reliable stall detection under dynamic operating conditions remains challenging. During motor start-up, temporary overloads, or sudden load variations, induction motors naturally experience high stator current and reduced rotor speed, resulting in operating characteristics that closely resemble actual stall conditions. Consequently, conventional threshold-based protection schemes may generate nuisance trips, while most existing threshold-based approaches primarily focus on fault detection rather than on robust discrimination between transient operating conditions and actual stall events. Furthermore, relatively little attention has been devoted to integrating startup inhibition and temporal verification into a lightweight threshold-based decision framework suitable for practical industrial applications. Therefore, there remains a need for a computationally efficient stall detection strategy capable of reliably distinguishing recoverable transient events (false stalls) from sustained stall conditions while remaining suitable for real-time industrial implementation.

To address the identified research gap, this paper proposes a transient-aware stall detection framework for three-phase induction motors based on simultaneous monitoring of stator current and rotor speed. Rather than introducing new sensing variables or complex artificial intelligence techniques, the novelty of the proposed method lies in integrating startup inhibition, adaptive activation logic, and temporal hold-time verification into a lightweight decision framework that reliably discriminates recoverable transient events from persistent stall conditions. The proposed framework incorporates these mechanisms into a unified decision process to improve robustness against transient disturbances and measurement uncertainty. Unlike conventional threshold-based protection that reacts immediately to abnormal measurements, the proposed algorithm performs temporal verification to determine whether abnormal operating conditions persist long enough to be classified as an actual stall. Consequently, the proposed method effectively differentiates transient overload events (false stalls) from sustained stall conditions while maintaining low computational complexity suitable for real-time implementation in industrial motor protection systems.

The proposed method is particularly suitable for industrial applications requiring reliable motor protection without expensive sensing hardware or computationally intensive artificial intelligence algorithms. By reducing unnecessary protection trips while maintaining dependable fault detection, the proposed approach has the potential to improve production continuity, reduce maintenance costs, extend motor service life, and support predictive maintenance strategies within Industry 4.0 environments. The proposed framework is validated through comprehensive Simulink-based simulations under representative operating scenarios, including normal operation, motor start-up, transient overload, and sustained stall conditions, demonstrating its effectiveness for practical induction motor protection. The remainder of this paper is organized as follows. Section 2 presents the proposed stall detection algorithm. Section 3 describes the simulation model, experimental scenarios, and parameter selection. Section 4 discusses the experimental results and performance analysis under various operating conditions. Finally, section 5 concludes the paper and outlines future research directions.

## 2. THE PROPOSED ALGORITHM

This section presents the proposed transient-aware stall detection framework for three-phase induction motors. The framework combines stator current monitoring, rotor speed monitoring, startup inhibition, and hold-time verification to achieve reliable stall detection while minimizing nuisance trips caused by transient operating conditions. The overall framework, mathematical formulation, decision algorithm, and parameter selection are described in the following subsections.

### 2.1. Overall framework

Figure 1 (in Appendix) illustrates the overall architecture of the proposed transient-aware stall detection framework. The proposed framework was developed to provide a reliable, computationally efficient, and practically implementable solution for detecting stall conditions in three-phase induction motors while minimizing nuisance trips caused by startup transients and temporary load variations. Unlike advanced fault diagnosis techniques that require additional sensing hardware, complex mathematical models, or computationally intensive artificial intelligence algorithms, the proposed method relies solely on stator current and rotor speed measurements, which are readily available in most industrial motor drive systems [20]–[22].

As illustrated in Figure 1(a), the proposed algorithm consists of four sequential decision stages: i) startup inhibition, ii) stator current threshold evaluation, iii) rotor speed threshold evaluation, and iv) temporal hold-time verification. Startup inhibition temporarily disables stall detection during motor acceleration to suppress false alarms caused by inrush current. After the startup period has elapsed, the algorithm continuously evaluates the measured stator current and rotor speed against predefined threshold values. When both abnormal conditions are simultaneously satisfied, hold-time verification is initiated. A trip signal is generated only if the abnormal operating condition persists longer than the specified hold time; otherwise, the timer is reset and normal monitoring resumes. Figure 1(b) illustrates the implementation framework in which the measured stator current and rotor speed are processed by the proposed stall detection unit to control the breaker relay. Under normal operating conditions, the breaker remains closed to supply power to the induction motor. Once an actual stall is confirmed, the relay opens to disconnect the motor from the three-phase power source.

Although industrial motor drives may employ various sensing devices, including current, speed, and DC-link voltage sensors, the proposed algorithm utilizes only stator current and rotor speed measurements because these signals sufficiently represent the electrical and mechanical characteristics associated with motor stall while maintaining low implementation complexity. Under normal operating conditions, the stator current remains close to its rated value and the rotor speed approaches the rated operating speed. Conversely, a stall condition is characterized by a substantial increase in stator current accompanied by a significant reduction in rotor speed, resulting in excessive copper losses and rapid thermal stress if the condition persists [23].

A practical challenge arises because similar electrical and mechanical characteristics also occur during motor startup and short-duration overload conditions. During these transient operating states, the motor naturally experiences high inrush current while the rotor speed is still relatively low. Consequently, protection schemes relying solely on instantaneous current or speed thresholds may incorrectly classify these transient events as stall conditions, leading to unnecessary protection trips. Therefore, reliable discrimination between transient operating conditions and actual stall events is essential for practical industrial motor protection.

This sequential decision strategy improves robustness against transient disturbances and measurement uncertainty while maintaining low computational complexity suitable for real-time industrial implementation.

### 2.2. Mathematical formulation

To improve the reproducibility and analytical clarity of the proposed stall detection framework, the decision logic is formulated mathematically using the measured stator current, rotor speed, startup status, and hold-time verification. A stall condition is declared only when all decision criteria are simultaneously satisfied.

a. Current threshold evaluation

The first stage continuously monitors the stator current. An abnormal current condition is detected when the measured stator current exceeds a predefined threshold,

$$I(t) \geq I_{th} \quad (1)$$

where, $I(t)$ is the measured stator current (A) and $I_{th}$ is the current threshold.
The threshold current is defined as (2):

$$I_{th}=2.5\ I_n \quad (2)$$

where $I_n$ denotes the rated stator current of the induction motor.

b. Speed threshold evaluation

The second stage evaluates the rotor speed. A low-speed condition is detected when:

$$\omega(t) \leq \omega_{th} \tag{3}$$

where, $\omega(t)$ is the measured rotor speed and $\omega_{th}$ is the minimum allowable rotor speed.
The speed threshold is defined as (4):

$$\omega(t) = 0.1\ \omega_n \tag{4}$$

where $\omega_n$ represents the rated rotor speed.

c. Startup inhibition logic

To prevent false stall detection during motor acceleration, stall monitoring remains disabled throughout the startup period. The startup status is represented by (5):

$$S(t) = \begin{cases} 0, & t < t_s \\ 1, & t \geq t_s \end{cases} \tag{5}$$

where, $S(t)$ denotes the activation status of the stall detector and $t_s$ is the startup inhibition period.
The stall detection algorithm becomes active only when $S(t) = 1$.

d. Hold-time verification

When both abnormal current and low-speed conditions are simultaneously detected, a hold timer is initiated. The timer continues counting as long as both abnormal conditions persist. A stall is confirmed only when:

$$T_{ab} \geq T_h \tag{6}$$

where, $T_{ab}$ is the accumulated duration of the abnormal operating condition and $T_h$ is the predefined hold time.

e. Final stall decision

The final trip decision is generated only when all decision criteria are satisfied simultaneously,

$$Trip = (I \geq I_{th}) \wedge\ (\omega \leq \omega_{th}) \wedge (S = 1) \wedge (T_{ab} \geq T_h) \tag{7}$$

where *Trip* is a binary decision variable indicating whether the motor is declared to be in a stall condition.

In (7) shows that the proposed algorithm integrates electrical information (stator current), mechanical information (rotor speed), startup inhibition, and temporal verification into a unified decision framework. This combination improves robustness against transient disturbances while maintaining low computational complexity suitable for real-time industrial motor protection.

### 2.3. Stall detection algorithm

The proposed stall detection algorithm operates sequentially by evaluating the startup status, stator current, rotor speed, and hold-time verification. The decision process is designed to ensure reliable discrimination between transient operating conditions and persistent stall events while maintaining low computational complexity suitable for real-time industrial implementation. Initially, the algorithm continuously measures the stator current and rotor speed. During the startup period, stall detection remains disabled to prevent false alarms caused by the naturally occurring inrush current and low rotor speed. Once the startup inhibition period has elapsed, the algorithm compares the measured stator current and rotor speed with their respective threshold values defined in subsection 2.2.

If the measured stator current exceeds the predefined current threshold while the rotor speed simultaneously falls below the minimum allowable speed, the algorithm activates a hold timer. The abnormal operating condition must persist continuously throughout the specified hold time before the motor is classified as being in a stall condition. If either the current or speed returns to its normal operating range before the hold time expires, the timer is immediately reset and the monitoring process resumes. This temporal verification mechanism prevents nuisance trips caused by temporary overloads, startup transients, or measurement noise. A trip signal is generated only when four decision criteria are satisfied simultaneously: i) the startup inhibition period has elapsed, ii) the stator current exceeds the predefined threshold, iii) the rotor speed falls below the minimum allowable threshold, and iv) the abnormal operating condition persists longer than the specified hold time. This sequential decision strategy improves detection reliability by suppressing false stall alarms while preserving the fast response required for practical induction motor protection.

### 2.4. Parameter selection

The performance of the proposed stall detection algorithm depends on three principal parameters: the stator current threshold, the rotor speed threshold, and the hold-time duration. These parameters were selected based on induction motor operating characteristics, practical industrial protection practices, and recommendations from established motor protection standards to achieve a balance between detection sensitivity and robustness against transient disturbances.

a. Current threshold selection

The stator current threshold was set to 2.5 times the rated current. During motor startup, induction motors normally experience transient inrush currents that may exceed the rated current for a short duration [25]. Therefore, selecting a threshold significantly higher than the rated current reduces the possibility of nuisance trips while maintaining sufficient sensitivity to detect sustained stall conditions. The selected threshold is consistent with common industrial motor protection practices and the principles described in IEEE Std C37.96 for AC motor protection [13].

b. Speed threshold selection

The rotor speed threshold was selected as 10% of the rated speed [25]. When the rotor speed falls below this level while the stator current remains abnormally high, the motor is generally incapable of producing sufficient electromagnetic torque to recover normal operation. Consequently, this operating condition is considered representative of a persistent stall rather than a temporary load disturbance.

c. Hold-time selection

A hold time of 1 s was adopted to distinguish transient operating conditions from sustained stall events. Short-duration overloads, startup transients, and measurement noise may temporarily satisfy the current and speed threshold conditions without indicating an actual stall [13]. Therefore, the abnormal operating condition must persist continuously for at least 1 s before a stall alarm is issued. This temporal verification improves detection reliability by suppressing nuisance trips while ensuring timely protection against prolonged thermal stress.

The selected parameters provide an appropriate compromise between rapid stall detection and immunity to temporary disturbances. Although fixed threshold values were employed in this study for simplicity and practical implementation, the proposed framework can readily accommodate adaptive threshold selection for different motor ratings and operating conditions.

## 3. EXPERIMENTAL SETUP

### 3.1. Simulation model

The proposed stall detection framework was validated using a simulation model developed in the MATLAB/Simulink environment. The simulation model represents a three-phase squirrel-cage induction motor supplied through a direct-on-line (DOL) starter and protected by the proposed stall detection algorithm. Figure 2 illustrates the overall simulation model used for experimental validation. The induction motor is supplied by a three-phase voltage source through a breaker relay controlled by the proposed stall detection unit. During simulation, the stator current and rotor speed are continuously monitored and processed by the detection algorithm to determine whether a trip command should be issued.

The data include the rms stator current ($I_s$) in A, the rotor rotational speed ($\omega$) in rpm, and the electromagnetic torque ($T_e$) in N · m. Simulink directly presents these data as graphs of the induction motor's dynamic characteristics, including $I_s$ versus $t$, $\omega$ versus t, and $T_e$ versus t.

### 3.2. Motor specification and simulation parameters

A three-phase squirrel-cage induction motor was selected as the test system for evaluating the proposed stall detection framework. The motor specifications are summarized in Table 1. In addition to the nameplate, the table provides information on the motor's nominal current and torque calculated using basic formulas [26].

The simulation parameters used in the experimental scenarios are summarized in Table 2. Prior to conducting the simulations, the induction motor model and the proposed stall detection framework were configured according to the selected operating conditions. The simulation setup includes the normal load torque, overload torque, initial and final loading times, startup inhibition period, current threshold, rotor speed threshold, and hold-time duration. These parameters were selected to represent practical industrial operating conditions while enabling systematic evaluation of the proposed stall detection framework under both transient overload and sustained stall scenarios.

The current threshold and rotor speed threshold were determined according to the parameter selection procedure described in subsection 2.4, where the current threshold was set to 2.5 times the rated current and the rotor speed threshold was defined as 10% of the rated speed. Likewise, the startup inhibition period and hold-time duration were configured to prevent false stall detection during motor acceleration while ensuring reliable protection under prolonged stall conditions. The resulting parameter settings provide a consistent basis for comparing the algorithm performance under different operating scenarios.

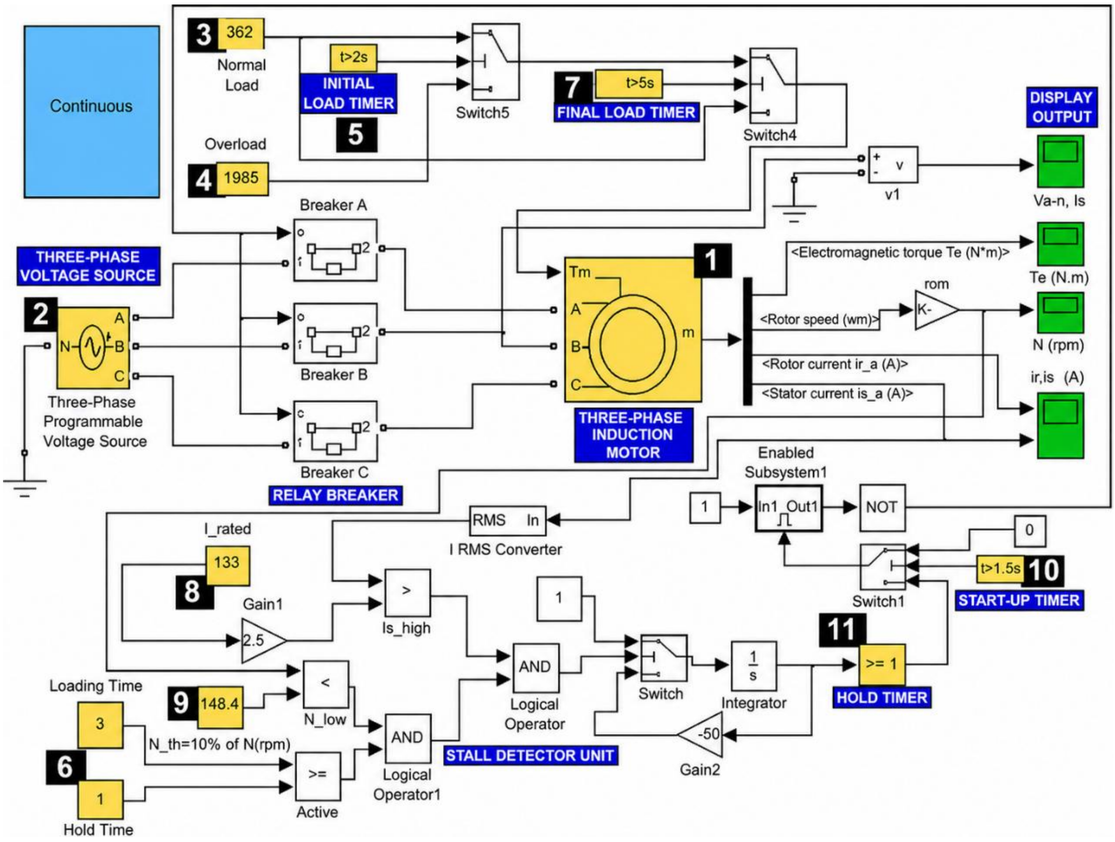


Figure 2. MATLAB/Simulink model used for validating the proposed stall detection framework

Table 1. Nameplate of the sample motor

| $P_{rated}$ (HP) | $P_{rated}$ (kW) | $V_{LL}$ (V) | $F$ (Hz) | $\omega_{rated}$ (rpm) | $I_{rated}$(A) | $Te_{rated}$ (N.m) |
|---|---|---|---|---|---|---|
| 100 | 75 | 400 | 50 | 1484 | 132 | 483 |

Table 2. Experimental parameter settings

| Case | Normal load (N.m.) | Over-loaded (N.m.) | Initial loading time (s) | Final loading time (s) | Loading time (s) | $I_{rated}$ (A) | $\omega_{Th}$ (rpm) | Start-up time (s) | Hold time (s) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 362 | 1985 | 2 | 2.5 | 0.5 | 133 | 148.4 | 1.5 | 1 |
| 2 | 362 | 1985 | 2 | 3.5 | 1.5 | 133 | 148.4 | 1.5 | 1 |

### 3.3. Experimental scenarios

Two representative operating scenarios were designed to evaluate the effectiveness of the proposed stall detection framework under transient and sustained overload conditions. Both scenarios begin with the induction motor operating under a normal load of 362 N.m (75% of the rated torque), which represents a typical industrial operating condition where induction motors achieve high efficiency [27]. To simulate severe operating conditions, an overload torque of 1985 N.m (approximately four times the rated torque) was subsequently applied [25]. The current threshold, rotor speed threshold, startup inhibition period, and hold-time duration used in both scenarios were configured according to the parameter selection described in subsection 2.4.

Scenario 1 (false stall condition): the motor initially operates under normal loading before being subjected to a temporary overload lasting 0.5 s, which is shorter than the specified hold-time duration. This scenario represents a transient operating disturbance in which the stator current temporarily exceeds the current threshold while the rotor speed decreases significantly. After the overload is removed, the motor is expected to re-accelerate to its normal operating speed without activating the protection relay. This scenario evaluates the capability of the proposed algorithm to suppress nuisance trips caused by temporary overloads while maintaining uninterrupted motor operation [28]–[30].

Scenario 2 (actual stall condition): the motor initially operates under the same normal loading condition before experiencing a sustained overload lasting 1.5 s, which exceeds the specified hold time. Under this condition, the stator current remains above the current threshold while the rotor speed remains below the speed threshold for a sufficiently long duration, representing an actual stall event. In this scenario, the proposed algorithm is expected to generate a trip signal that disconnects the motor from the three-phase power supply through the breaker relay, thereby preventing excessive thermal stress and potential motor damage.

The two experimental scenarios were selected to demonstrate the ability of the proposed transient-aware stall detection framework to discriminate between recoverable transient disturbances and persistent stall conditions under representative industrial operating conditions.

## 4. RESULTS AND DISCUSSION

The proposed transient-aware stall detection framework was evaluated using the two experimental scenarios described in subsection 3.3 to verify its capability to discriminate transient overload events from sustained stall conditions. The evaluation focused on the algorithm's ability to suppress nuisance trips during temporary overloads while ensuring reliable protection during prolonged stall events. The corresponding performance evaluation criteria are summarized in Table 3.

Table 3. Performance evaluation criteria

| Scenario | Overload duration (s) | Operating condition | Expected motor response | Expected relay action |
|---|---|---|---|---|
| 1 | 0.5 (< hold time) | False stall | Motor re-accelerates to normal operating speed | Relay remains closed (no trip) |
| 2 | 1.5 (> hold time) | Actual stall | Sustained stall is detected | Relay trips and disconnects the motor |

### 4.1. Capability to detect false stall and re-acceleration

Figure 3 illustrates the dynamic response of the induction motor under Scenario 1 (false stall condition). The motor initially operates under normal load during the startup period ($0<t<2$ s). At $t$=2 s, a temporary overload is applied for 0.5 s, causing a significant increase in stator current and a rapid decrease in rotor speed toward the predefined threshold values. Although these electrical and mechanical characteristics resemble an actual stall condition, the overload duration remains shorter than the specified hold time. Consequently, the proposed protection algorithm does not generate a trip command, and the breaker relay remains closed. After the overload is removed at $t$=2.5 s, the motor successfully re-accelerates and gradually returns to its normal operating condition. These responses demonstrate that the proposed transient-aware stall detection framework effectively suppresses nuisance trips while maintaining continuous motor operation.

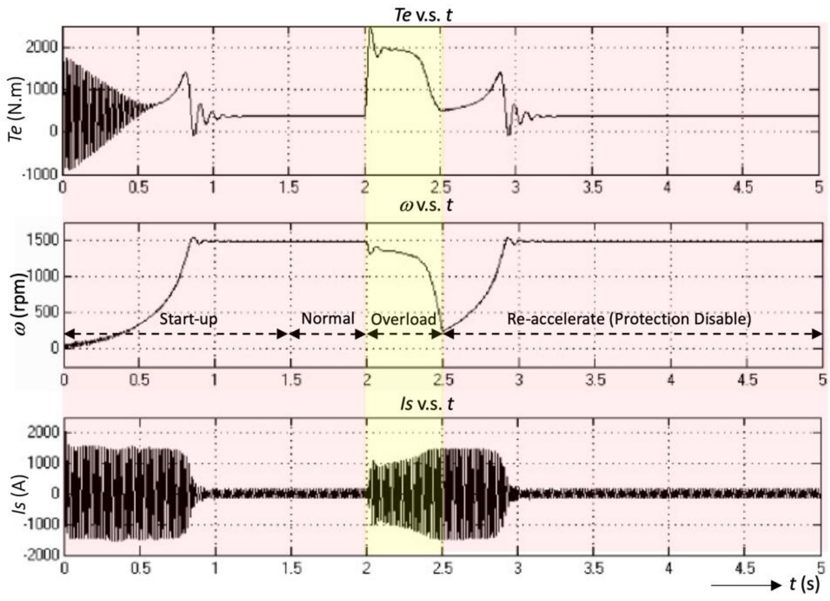


Figure 3. Data analysis results for Case 1

These results demonstrate that the proposed transient-aware stall detection framework effectively discriminates transient overload events from actual stall conditions without activating unnecessary protection actions. The system achieves this capability by incorporating a hold timer, which introduces a delay to verify the persistence of the stall condition. When a stall-like disturbance occurs, the system does not immediately classify it as an actual stall. Instead, it evaluates the condition over the hold time interval. If the stall condition does not persist continuously, the system allows the motor to re-accelerate and return to normal operation.

Figure 4 further demonstrates that the rotor speed may temporarily decrease to nearly zero during a severe transient overload. Nevertheless, because the overload duration remains shorter than the predefined hold time, the proposed algorithm correctly classifies the event as a recoverable transient rather than an actual stall.

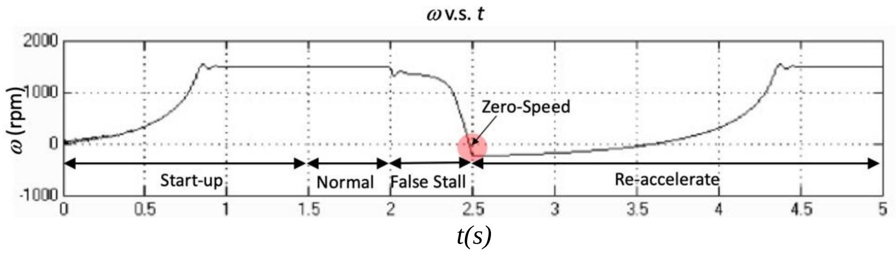


Figure 4. Motor speed under heavy overload condition (2000 N.m)

Once the overload is removed, the motor is able to develop sufficient electromagnetic torque to re-accelerate and gradually return to its normal operating condition. This behavior aligns with previous studies [31] demonstrating the system's robustness. Although the motor may momentarily exhibit stall-like characteristics, the short duration of the event (below the hold time threshold) prevents the protection system from activating, allowing the motor to resume normal operation.

The findings confirm that the proposed method effectively differentiates between transient disturbances and sustained stall conditions. Short-duration overload events can produce electrical and mechanical responses similar to stall conditions, including high current and low speed. However, such events should not be classified as faults if the motor retains its ability to recover. This type of condition is commonly referred to as a false stall, as opposed to a sustained or actual stall.

This result is consistent with the fundamental behavior of induction motors, in which temporary load disturbances may cause transient speed dips without resulting in permanent stalling [32], [33]. Previous studies have shown that detection methods based solely on a single signal, such as stator current, may lead to inaccurate or false identification under transient operating conditions [34], [35]. Therefore, integrating temporal criteria, such as hold time, significantly improves the reliability of stall detection.

The use of a hold-time mechanism in this study aligns with industrial practices and the recommendations in IEEE C37.96-2012, which emphasize the importance of time-delay elements to avoid nuisance tripping during transient events. By introducing a verification interval, the system ensures that only persistent abnormal conditions are classified as faults, thereby enhancing operational reliability [36].

Furthermore, the observed re-acceleration capability indicates that the motor remains within a stable operating region despite temporary disturbances. Previous studies demonstrate that induction motors can recover from short-term overloads when sufficient electromagnetic torque is maintained [37]. The proposed system's ability to tolerate such transient conditions without unnecessary tripping underscores its robustness compared to conventional protection schemes.

### 4.2. Capability to detect actual stall and activate the protection system

Figure 5 illustrates the dynamic response of the induction motor under Scenario 2 (actual stall condition). The motor initially operates under normal load during the startup period ($0<t<2$ s). At $t$=2 s, a sustained overload is applied for 1.5 s, causing the stator current to remain above the predefined current threshold while the rotor speed falls below the speed threshold. Because the abnormal condition persists longer than the specified hold time, the proposed algorithm confirms the occurrence of an actual stall and initiates the protection sequence. After the one-second hold-time interval has elapsed, the breaker relay receives a trip command and disconnects the motor from the three-phase power supply, preventing further thermal stress and potential motor damage.

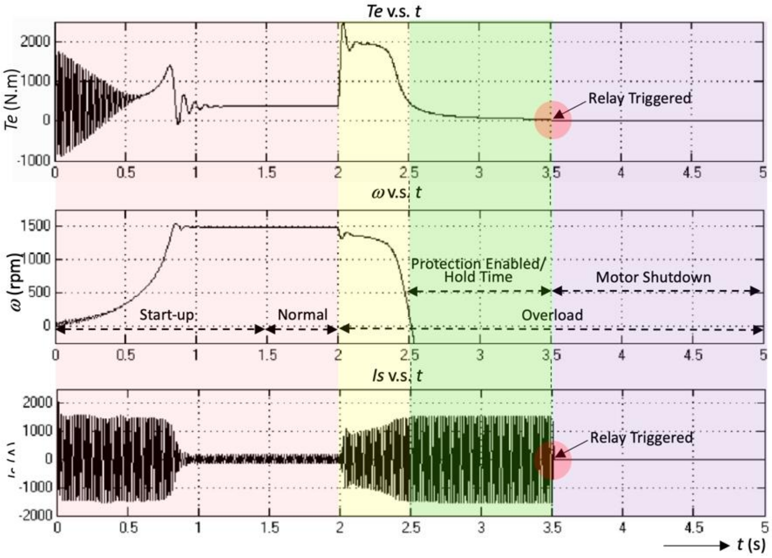


Figure 5. Data analysis results for Case 2

In Case 2, the motor initially operates under normal load during the start-up phase (0<t<2 s) before transitioning to an overload condition in the interval 2 s<t<5 s, as shown in Figure 5. This overload results in a significant increase in stator current and a corresponding decrease in rotor speed. Since the overload duration exceeds the predefined hold time, the system identifies the condition as a continuous actual stall starting from t=2.5 s. To ensure the stall condition persists, the system intentionally introduces a 1s delay before initiating a trip action. During the interval 2.5 s<t<3.5 s, the system activates the protection mechanism and subsequently sends a tripping signal to the relay driver, causing the motor to disconnect and stop.

These results demonstrate that the proposed method can accurately detect sustained stall conditions under prolonged overload. This observation is consistent with established motor protection theory, which characterizes a stall condition by a combination of high stator current and a significant reduction in rotor speed [32], [33]. Furthermore, previous studies have shown that detection methods based solely on current signals may lead to false identification during transient events such as start-up or short-term load fluctuations[34]. Therefore, integrating multiple parameters, such as current and speed, enhances detection reliability [38], [39].

Furthermore, the incorporation of a hold time mechanism in this study aligns with industrial protection practices. According to IEEE C37.96-2012, time-delay elements are essential to differentiate between transient disturbances and sustained fault conditions. In this work, introducing a 1-second delay ensures that the stall condition persists before the protection system is triggered, thereby reducing the likelihood of false tripping [36].

Compared to conventional overload relays, which often exhibit slow response times and limited sensitivity to dynamic operating conditions, the proposed method demonstrates improved responsiveness and robustness. Recent studies have also reported that traditional protection schemes face challenges in systems with variable-speed drives, where transient dynamics complicate fault identification [40], [41]. The findings of this study support these observations, as the proposed approach successfully detects stall conditions under varying load profiles.

Finally, the experimental results confirm that the protection system operates effectively by issuing a tripping signal to the relay driver and disconnecting the motor when the stall condition persists beyond the hold time. This behavior is consistent with prior studies highlighting the importance of coordinated detection and protection strategies to prevent thermal damage and mechanical stress in induction motors [42].

## 5. CONCLUSION

This paper presented a practical transient-aware stall detection framework for three-phase induction motors based on the combined monitoring of stator current and rotor speed. Rather than introducing additional sensing variables or computationally intensive artificial intelligence techniques, the proposed method enhances conventional threshold-based protection by integrating startup inhibition, adaptive activation logic, and a hold-time verification mechanism into a unified lightweight decision framework. This integration enables reliable discrimination between recoverable transient disturbances (false stalls) and sustained stall conditions (actual stalls) while maintaining low computational complexity suitable for real-time industrial implementation. Simulation results under representative operating scenarios demonstrated that the proposed framework successfully suppresses nuisance trips during temporary overloads while reliably detecting sustained stall conditions requiring protective action. The incorporation of temporal verification significantly improves protection reliability by ensuring that only persistent abnormal operating conditions activate the breaker relay, thereby reducing unnecessary interruptions without compromising fault protection. Overall, the proposed framework provides a practical and robust solution for induction motor protection under dynamic operating conditions. Owing to its low computational requirements and reliance on commonly available current and speed measurements, the method is well suited for implementation in industrial motor drives, programmable logic controllers, and embedded motor protection systems. Future work will focus on experimental validation using hardware-based test platforms and the evaluation of the proposed framework under variable-speed drive operation, parameter uncertainty, and measurement noise encountered in practical industrial environments.


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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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| Herman Dwi Surjono | | | | ✓ | | ✓ | | | | ✓ | | ✓ | | |
| Tole Sutikno | | ✓ | | ✓ | ✓ | | | ✓ | | ✓ | | ✓ | | |
| Barry Nur Setyanto | | | | ✓ | ✓ | ✓ | | | | ✓ | ✓ | | | |

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

The authors declare that in writing this manuscript, there is no conflict of interest in the form of financial, personal, political, religious, ideological, academic, or intellectual.

## DATA AVAILABILITY

As part of our commitment to supporting open research, the authors make the data publicly available. No third-party data were used; all data were collected directly by the researchers through this study.

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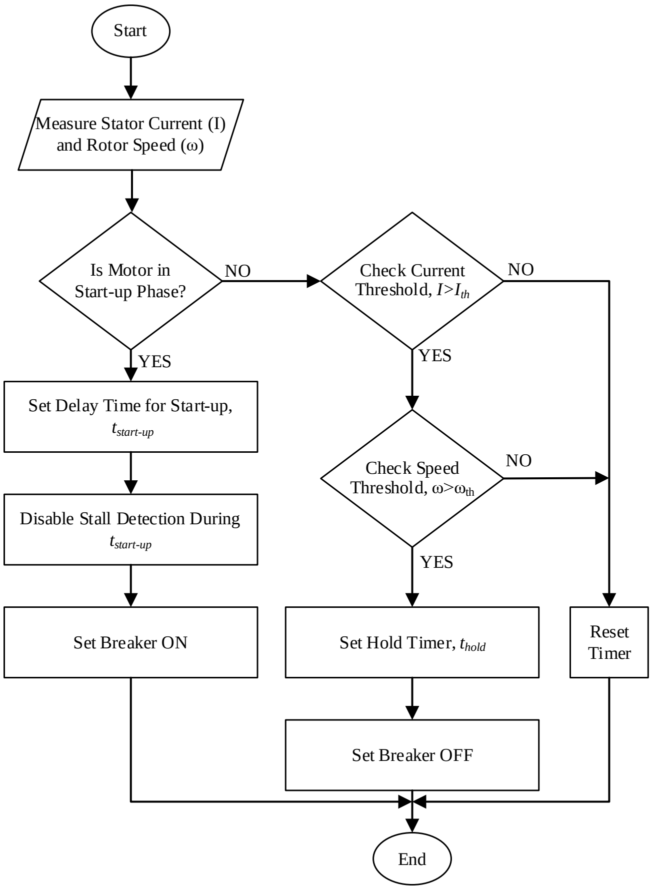
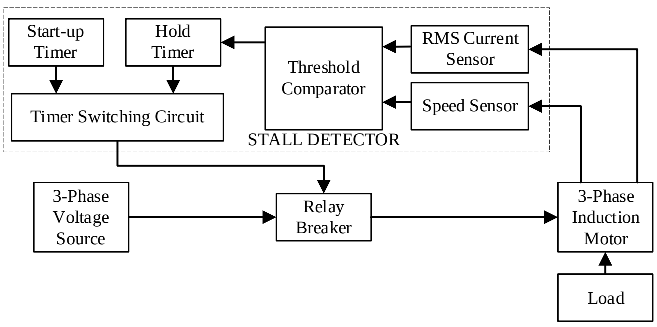
## APPENDIX




(a)




(b)

Figure 1. Proposed transient-aware stall detection framework: (a) decision flowchart and (b) implementation block diagram

## BIOGRAPHIES OF AUTHORS

**Muchlas** is a Professor in the Department of Electronics Engineering Vocational Education, Universitas Ahmad Dahlan, Yogyakarta, Indonesia. He earned his Master's degree in Electrical Engineering from Universitas Gadjah Mada, Indonesia, in 1998, and his Doctorate in Technical and Vocational Education from Universitas Negeri Yogyakarta, Indonesia, in 2013. His current research interests include digital engineering, robotics, programming, electronics engineering education, and vocational education studies. He can be contacted at email: muchlas.te@uad.ac.id.

**Herman Dwi Surjono** is a Professor in the Department of Informatics Engineering Education/Electronics Engineering Education, Universitas Negeri Yogyakarta, Indonesia. He earned his Bachelor's degree from the same institution in 1986. He obtained two Master of Science degrees, from Iowa State University, USA (1994) and Universitas Gadjah Mada, Yogyakarta, Indonesia (2000). He earned his Ph.D. in Information Technology from Southern Cross University in Australia in 2006. His research focuses on multimedia learning and e-learning. He can be contacted at email: hermansurjono@uny.ac.id.

**Prof. Ir. Tole Sutikno, Ph.D., MIET, IPM., ASEAN Eng.** is a full professor in the Department of Electrical Engineering at Universitas Ahmad Dahlan (UAD) in Yogyakarta, Indonesia. He has held this position since 2023, having previously served as an associate professor from 2008. He earned his bachelor’s degree from Universitas Diponegoro in 1999, his master’s degree from Universitas Gadjah Mada in 2004, and his Ph.D. in Electrical Engineering from Universiti Teknologi Malaysia in 2016, where his doctoral research focused on advanced digital power electronics and intelligent control systems. From 2016 to 2021, he served as the Director of the Institute for Scientific Publishing and Publications (LPPI) at UAD, where he led initiatives to strengthen research visibility, journal management, and international collaboration in scholarly publishing. Since 2024, he has served as the head of the master's program in electrical engineering at UAD, following his leadership of the undergraduate program in electrical engineering in 2022. He is also the founding leader of the Embedded Systems and Power Electronics Research Group (ESPERG), which actively collaborates with both national and international institutions on topics such as fault-tolerant embedded systems, FPGA-based control, and renewable energy integration. He is widely acknowledged for his contributions to digital design, industrial electronics, motor drives, robotics, intelligent systems, and AI-based automation. His interdisciplinary research emphasizes practical deployments in industrial and healthcare contexts, covering FPGA applications, embedded systems, power electronics, and digital libraries. He has published 380 peer-reviewed articles in high-impact journals and conferences indexed by Scopus. As of 2025, Google Scholar indicates over 6,000 citations, with an H-index of 36 and an i10-index of 174. In recognition of his global research impact, he has been listed among the Top 2% of Scientists Worldwide by Stanford University and Elsevier BV from 2021 to the present, a distinction based on standardized citation metrics across all scientific disciplines. He can be contacted at email: tole@te.uad.ac.id.

**Barry Nur Setyanto** is an assistant professor at the Department of Electronics Engineering Vocational Education, Universitas Ahmad Dahlan, Yogyakarta, Indonesia. He graduated from Universitas Negeri Yogyakarta, Indonesia, with an M.Pd. in Electrical Engineering Education in 2018. Currently, his research interests include digital signal processing, and power electronics. He can be contacted at email: barry.setyanto@pvte.uad.ac.id.