International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 35 العدد
Part 1 المجلد
October 2024 اكتوبر

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ: 5/ 10/2024م وتم نشرها على الموقع بتاريخ: 31/ 10/2024م

Closed-Loop Speed Control of Induction Motors Using Scalar Control

www.doi.org/10.62341/aian1031

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Abstract

In this study, the scalar control approach is applied to the control of induction motors three phase. The approach of scalar control is based on the maintaining a constant ratio between voltage-to-frequency (V/f) ratio, both theoretical and simulation-based analyses were performed to examine the performance of the method, which was seen to be successfully applied in speed control for induction machine, making it suitable for various industrial application. Simulations are performed to change the speed by changing the input voltage and changing the input voltage frequency. Finally, the performance of the V/f controlled three-phase induction motor is investigated. Simulations are performed using different speed references and the results are presented.The results show that the V/f controlled three-phase induction motor has good speed tracking performance. The simulations are performed in MATLAB/SIMULING environment.

Keywords: Induction motor, speed control, scalar control, closed loop, (V/f) control

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التحكم في سرعة المحركات الحثية باستخدام التحكم العددي ذو الحلقة المغلقة

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الملخص

في هذه الدراسة، تم تطبيق فكرة التحكم العددي للتحكم في المحركات الحثية ثلاثية الطور. يعتمد التحكم العددي على الحفاظ على نسبة ثابتة بين نسبة الجهد إلى التردد (V / f)، وقد تم إجراء تحليلات نظرية ومحاكاة لفحص أداء هذه الطريقة، والتي تبين أنها مطبقة بنجاح في التحكم في سرعة آلة الحث، مما يجعلها مناسبة لتطبيقات صناعية مختلفة. يتم إجراء عمليات المحاكاة لتغيير السرعة عن طريق تغيير جهد الدخل وتغيير تردد جهد الدخل. أخيرًا، يتم التحقق من أداء المحرك الحثي المتحكم فيه قياسيًا. يتم إجراء عمليات المحاكاة باستخدام مراجع سرعة مختلفة ويتم تقديم النتائج. تظهر النتائج أن المحرك الحثي المتحكم فيه يتمتع بأداء جيد في تتبع السرعة. يتم إجراء عمليات المحاكاة باستخدام. MATLAB / Simulink

الكلمات المفتاحية: المحرك الحثي، التحكم في السرعة، التحكم العددي، الحلقة المغلقة، التحكم في(الجهد/التردد).

1. Introduction

Induction motors are characterized by their strong structure, uncomplicated structure, easy maintenance, and low malfunctions [1]. In addition, their operating costs are very low, which are widely used in residential and industrial areas and many commercial applications [2]. Because the speed of these motors is affected, especially in scenarios where load conditions vary greatly, by their oscillation and instability, as most applications require a constant speed. Many control methods have been developed to control variable speed drive systems using induction motors, where closed-loop V/f control, also known as numerical control method, is one of the most widely used methods in terms of its simplicity and effectiveness. By using standard closed-loop control, industries can improve motor performance, improve energy efficiency, and achieve greater reliability in their operations [3]. In this paper we will focuses on the closed-loop speed regulation of induction machine using scalar control methods. It provides a description of the main elements of the control system, presents the control algorithm, considers the advantages and disadvantages of this style of electrode control. By applying standard scalar control within a closed-loop control system, industries are able to strengthen motor performance and reliability in their operations efficiency and energy use.

2. Scalar Control Technique Equations for Induction Machines

A-scalar control of induction machines, or speed-torque control, allows the user to control the machine's voltage while adjusting its frequency as well [4]. The following are the key equations used in this method:

2.1 Motor Speed Equation

The synchronous speed (Ns) of an induction motor is calculated as follows:

$$N_S = \frac{120*f}{P} \tag{1}$$

Where:

- N_s = Synchronous speed (RPM)
- f = Supply frequency (Hz)
- P = Number of poles in the motor

The actual rotor speed (Nr) can be expressed as:

$$N_r = N_s - \frac{N_r*\frac{N_r}{N_S}*R_r}{X_s} \tag{2}$$

Where:

- Nr = Rotor speed (RPM)

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- R_r= Rotor resistance
- X_S = Stator reactance

2.2 Voltage to Frequency Ratio

To keep the magnetizing current constant, the voltage-to-frequency ratio must also be constant:

$$K=\frac{V}{f} \tag{3}$$

Where:

- V = Voltage applied to the motor
- f= Frequency
- K = Constant (voltage-to-frequency ratio)

This ratio ensures that as the frequency changes, the voltage is adjusted accordingly to maintain the magnetic flux in the machine.

2.3 Torque Equation

The electromagnetic torque (T_e) generated by the induction motor can be approximated by:

$$T_e = \frac{3}{\omega_s} * \frac{V^2}{R_r + jX_s} \tag{4}$$

Where:

T_e = Electromagnetic torque (Nm)

ω_s = Synchronous angular speed ($\omega_s = \frac{N_s - N_r}{N_s}$)

V = Stator voltage

2.4 Slip

The slip (s) of an induction motor is defined as:

$$S = \frac{N_s - N_r}{N_s} \tag{5}$$

Slip is crucial in scalar control as it indicates the difference between the synchronous speed and the actual rotor speed [5].

3. Motor Parameters Dynamic Model

The dynamic model of the induction motor can be expressed in state-space form or through differential equations. The rotor dynamics are described by:

$$J\,\frac{d\omega_r}{dt} = T_m - T_L - B\omega_r \qquad (6)$$

Where:

- J = Moment of inertia
- ω_r = Rotor angular speed
- T_m = Electromagnetic torque
- T_L= Load torque
- B = Viscous friction coefficient

3.1 Mathematical Modeling

In this study, we will use a 20 HP three-phase, four-pole induction motor operating at 220V and 60Hz, with the following parameters listed in Table 1.

Table 1: Induction motor parameters [6]

V	Rated Voltage	220V
f	Rated Frequency	60Hz
P	Number of Poles	4 Poles
R_S	Stator Resistance	0.1062 Ω
R_r	Rotor Resistance	0.0764Ω
X_m	Magnetizing Reactance	5.834Ω
X_S	Stator Reactance	0.2145Ω
X_r	Rotor Reactance	0.2145Ω
J_{rotor}	Rotor Inertia	$2.8K_gm^2$

These parameters represent typical values for a 20 HP induction motor, which may vary by manufacturer.

Figure 1 provides valuable insights into the performance of an induction motor under closed-loop speed control. It assists to understanding how different parameters interact and how the motor behaves under various operating conditions.

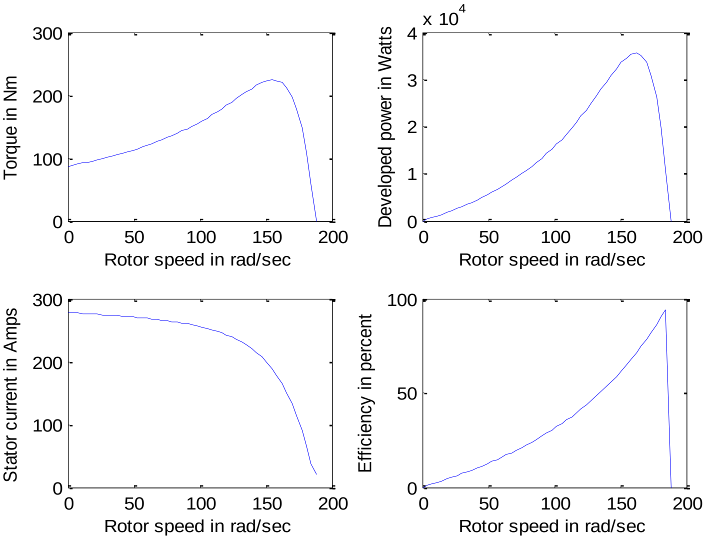

Figure1. Steady state characteristics of 20hp, 220v, four pole motor

3.2 Closed-Loop Volts/ Hertz Speed Control

Closed-loop volts/hertz (V/f) speed control is a prevailing method for the control of the speed of induction motors. This process is based on the ordinary relationship of voltage to frequency, which is required for efficient operation at variant speeds [7]. The system operates by modulating the voltage as the frequency varies to ensure the correct performance and responsiveness of the motor, thus the system is compatible with a variety of applications like speed control. This mechanism stabilizes the operation and conserves energy mostly in applications with varying load conditions. Figure 2, illustrates the Simulink simulation, which is configured to model the closed-loop control of rotor speed.

4. Simulation Results

The general block diagram of the speed control system is given in Figure 2. illustrates a comprehensive closed-loop control system for an induction motor, utilizing scalar control principles. Within the V/f block, a fixed V/f ratio is provided depending on a reference speed value.

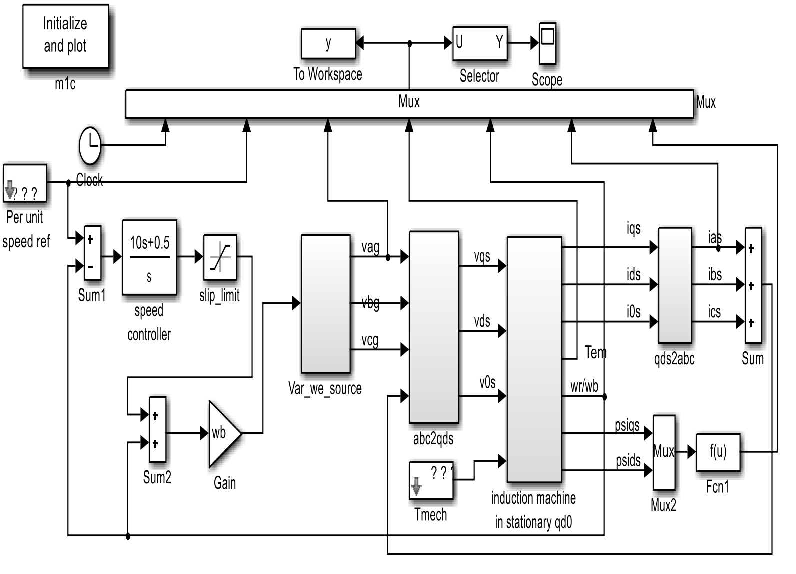

Figure 2. Block diagram of closed loop volts/hertz speed control drive

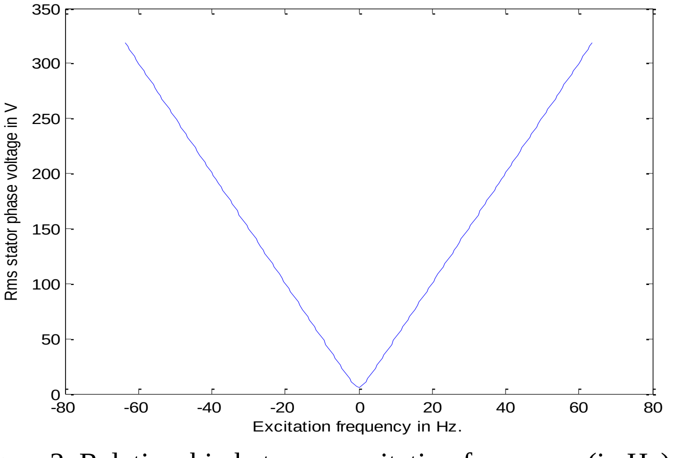

Figure.3, Relationship between excitation frequency (in Hz) and the phase voltage of an induction motor's stator.

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The V-shaped curvein figure.3, illustrates that as the excitation frequency approaches zero, the phase voltage decreases notably, showcasing the motor's response to changes in frequency.

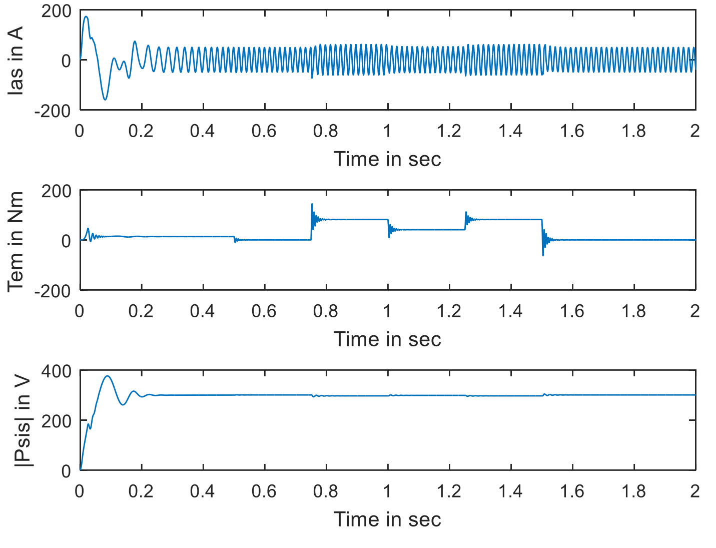

Figure.4. Relationship between Current, Torque and **Phase** Voltage

The provided graphs in Figure.4, display three different parameters over time:

- **Current (I)**: The top graph is the current in amperes demonstrating oscillations over time for which simulation run.
- **Torque (T)**: The middle graph is the torque as newton-meters which show a nearly constant level with some bumps.
- **Phase Voltage (V)**: The lower graph depicts the voltage in volts, after an initial change decreasing then settling.

In totality, these plots give the dynamic behavior of induction motor for this conditions.

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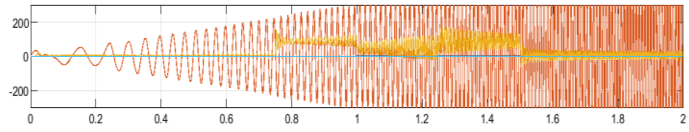

Figure 5. Damped oscillatory signal over Time

Figure 5 presents a complex signal over time, showing an oscillatory behavior that gradually diminishes in amplitude. Key features include:

- **Oscillations**: The signal exhibits rapid oscillations, indicated by the alternating colors.
- **Damping Effect**: There is a noticeable decrease in the amplitude of these oscillations as time progresses, suggesting a damping effect.
- **Overall Trend**: The signal appears to approach a stable level towards the end of the time period.

This type of graph typically represents a system's response to a disturbance, showcasing how it stabilizes over time.

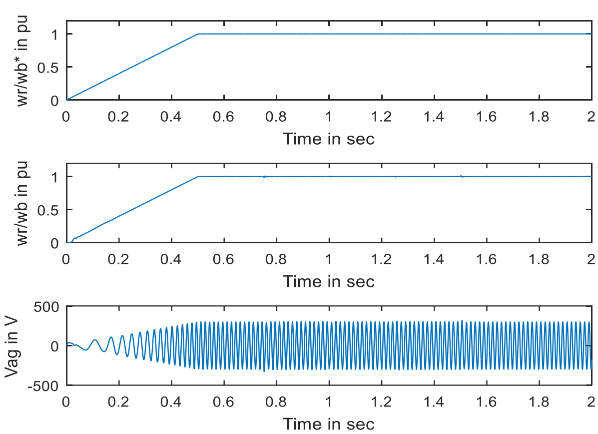

Figure 6. Mechanical Power, Rotor Speed and Voltage

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Figure 6 showing three characteristic parameters as a function of time:

- **Mechanical Power (P):** Graph above shows Mechanical power in per unit (pu) and it follows the rising shape then leads into a steady value.
- **Middle:** Nominal rotor speed (ω) in per unit, you can observe an increase before reaching a stable state.
- **Voltage (V):** The bottom graph shows the voltage in volts and there is a clear pattern of oscillations.

In combination, these plots summarize how the system behaved over this time.

5. Conclusion

In this study, an application of Closed-Loop using Scalar Control technique on speed control of induction motors are presented. The applications are shown step-by-step in detail and the performances of the designs are shown graphically.

A scalar control of induction motors offers an efficient and practical way to regulate speed across various industrial applications.This method of control will work by keeping a constant voltage-to-frequency (V/f) ratio so motors remain effective while offering reliable operation, even with fluctuating load conditions. The voltage/frequency ratio (V/f) applied to the motor was controlled and the speed of the motor was controlled. For this purpose, the Simulink simulation program created was run at different V/f ratios to obtain speed changes of the motor and the results were given. From the simulation results, it was seen that the motor with V/f control showed good performance.

References

[1]-Hughes, Austin, and Bill Drury. "Variable Frequency Operation of Induction Motors." Electric Motors and Drives (2013): 205-253.Francis.

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[2]."Control of Induction Motors," IEEE Transactions on Industrial Electronics, vol. 54, no. 4, pp. 1234-1240, 2007.

[3]. Chee-Mun, Ong. "Dynamic simulation of electric machinery using MATLAB/SIMULINK." Ed. Prentice Hall-1998 (1998).

[4]. W. Leonhard, *Control of Electrical Drives*, 3rd ed. Berlin: Springer, 2012.

[5]. G. R. Slemon, Electric Machines: Analysis and Control, 2nd ed. New York: John Wiley & Sons, 2011.

[6]. J. W. Dixon, "The Variable Frequency Drive," IEEE Industrial Electronics Magazine, vol. 5, no. 2, pp. 18-25, 2011.

[7]. H. S. Lee, K. S. Kim, and J. H. Park, "Scalar Control of Induction Motor Drives," Journal of Electrical Engineering & Technology, vol. 7, no. 4, pp. 485-493, 2012.