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(Research Article)

Closed loop speed control of a three-phase induction motor with load

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Abstract

Closed loop speed control methods are very essential in adjustable industrial speed drive systems. They require a variable voltage and frequency supply from a three-phase voltage source inverter (VSI). This paper presents the speed control of an induction motor fed by a three-phase VSI using the sinusoidal pulse width modulation (SPWM) method and a universal bridge. A PI controller is designed to minimize the steady-state error in speed. The performance analysis of the closed-loop speed control system is conducted in MATLAB-Simulink. As the load torque increases, the motor's speed decreases momentarily but returns to the same level in a very short settling time with minimal undershoot. The simulation results indicate that the speed controller exhibits a superior dynamic response and can effectively control the induction motor's speed and torque. Volts/Hertz (V/f) control of a three-phase induction motor is a popular control method, despite its low dynamic performance, due to its simplicity and cost-effectiveness. A closed-loop system, incorporating an appropriate controller, is employed to achieve effective speed control. The Proportional-Integral (PI) controller is commonly used, and a well-designed controller necessitates an accurate mathematical model of the system. Consequently, achieving a robust controller may compromise the simplicity of the V/f control system.

Keywords: Closed Loop Control; SPW Modulation; PI Controller; Induction Motor; Dynamic Load

1. Introduction

Three-phase induction motors are electrical machines that act as the workhorses of industry. Induction motors are the most commonly used type due to their durability, low maintenance, and the absence of sparks resulting from the lack of commutators and brushes. Three-phase induction motors are especially favored because of their self-starting capability. Typically, induction motors operate at a constant or desired speed, regardless of fluctuations in load torque. The most prevalent methods for controlling the speed of induction motors are vector control and scalar control, also referred to as V/f control.

Closed-loop speed control guarantees that, regardless of load conditions within the motor's rated capacity, the speed will adhere to the desired reference or set speed. This method is widely utilized for regulating motor speed in response to fluctuating load conditions. It employs feedback to enhance the motor's performance, safety, and efficiency. According to [1], industrial drives necessitate very precise speed variations, which can be achieved with an electrical motor to an accuracy of 1%. An electrical drive is easy to maintain and can even operate in a contaminated environment. Such a system that utilizes electric motors is known as an electrical drive. In electrical drives, various sensors and control algorithms are employed to manage the motor's speed using suitable speed control methods.

In [2], when a 3-phase power supplied to the stator windings, it produces a rotating magnetic field (RMF) that induces an electromotive force (EMF) in the rotor bars and generating a current. The interaction between the RMF and the

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current in the rotor creates torque, causing the rotor to rotate. The motor's speed is determined by the power frequency and the number of poles in both the stator and rotor. Three-phase induction motors offer several advantages, including high efficiency, low maintenance, high reliability, and cost-effectiveness. They are widely utilized in various applications, such as industrial automation, power generation, transportation, and agriculture. In industrial automation, they are employed in conveyor belts, pumps, and fans, while in power generation, they are used in wind turbines and hydroelectric power plants. In transportation, they are found in electric vehicles and rail systems, and in agriculture, they are applied in irrigation systems and farm equipment.

In [3], MATLAB simulations were conducted to determine the most effective method for controlling the speed of a Three-Phase Induction Motor using a Three-Phase Inverter. Two distinct methods were employed in this study. The first method involved generating a standard pulse through a pulse generator, while the second utilized SPWM (Sinusoidal Pulse Width Modulation), which is further categorized into i) open-loop control and ii) closed-loop control. The objective is to regulate the speed of a three-phase induction motor with the assistance of a three-phase inverter. To achieve this, a review of various pulse width modulation techniques mentioned above and their simulations was performed. It was observed that the pulse generator exhibited a high total harmonic distortion of load current, a value that decreased when SPWM was simulated. Between the open-loop and closed-loop controls, the closed-loop method is favored because it allows for parameter adjustments without stopping the process each time.

In [4], the developed hardware and software were tested for validity under various operating conditions. We observed that both the hardware and software coordinated closely. To validate this, the drive was tested under different operating conditions. In a closed-loop scenario, when the input command was set to a speed of 1450 rpm, the output speed recorded was approximately 1400 rpm (as shown on the digital display meter). Experiments were repeated at various speeds, and the results were found to be close to the set value. A paper [5] on the speed control of an induction motor fed by a three-phase voltage source inverter using the pulse width modulation method and a universal bridge. To control the peak DC link voltage of the voltage source inverter, a PID controller was designed. The performance analysis of both open-loop and closed-loop speed control systems was carried out in MATLAB/Simulink. The simulation results show that the speed controller has a good dynamic response and can successfully control the induction motor with improved performance.

In [6], the paper discusses the speed control of three-phase induction motors. There are several methods for this process, some of which include: i) Stator voltage control method, and ii) Rotor resistance control method. However, the most preferred and widely used method for speed control of induction motors is the v/f control method, which leads to optimal performance and high efficiency. In cases of electricity shortages, it is essential to conserve unnecessary energy. The volts/hertz control of three-phase induction motors is a popular method, despite its lower dynamic performance, due to its simplicity and cost-effectiveness. A closed-loop system, incorporating an appropriate controller, is employed to achieve effective speed control. The proportional-integral (PI) controller is commonly utilized, and a well-designed controller necessitates an accurate mathematical model of the system. The paper [7] presents the speed control of induction motor using in the industrial drives. The voltage and frequency are varied to control the speed of the motor. This present performance and evaluation of voltage source inverter feed induction motor drive. The PWM system is use to vary voltage and frequency. The frequency compensation control was used in [8]. The three-phase induction motor has been operated at constant torque mode. It was observed that using a closed-loop scheme with a PI controller gave a very superior way of controlling the speed of an induction motor while maintaining a constant maximum torque.

1.1. Problem Statement

The speed control of AC motors is a more complex process compared to that of DC motors. Various methods, such as indirect vector control and scalar control, are employed to regulate motor speed. Scalar control is a simple open-loop type of control; however, it responds slowly to transients and is unsuitable for motors with dynamic behavior. Open-loop speed control methods lack stability for continuous and intermittent duty cycles of motors. Closed-loop control, utilizing speed as a feedback signal, is essential for dynamic AC drives in industrial applications.

1.2. Objectives

The following objectives are framed to answer the problem statement:

- To operate an induction motor in a closed loop with a three-phase inverter under variable load conditions.
- To implement a speed controller using a PI controller that regulates the motor torque to achieve the desired speed response.

2. Material and Methods

2.1. Development of the Simulink Model

Closed-loop speed control of a three-phase induction motor utilizes a feedback mechanism to continuously monitor the motor's speed and adjust the control inputs to reach the desired speed. This model focuses on the implementation of a three-phase VSI for variable frequency induction motor drive in MATLAB-Simulink.

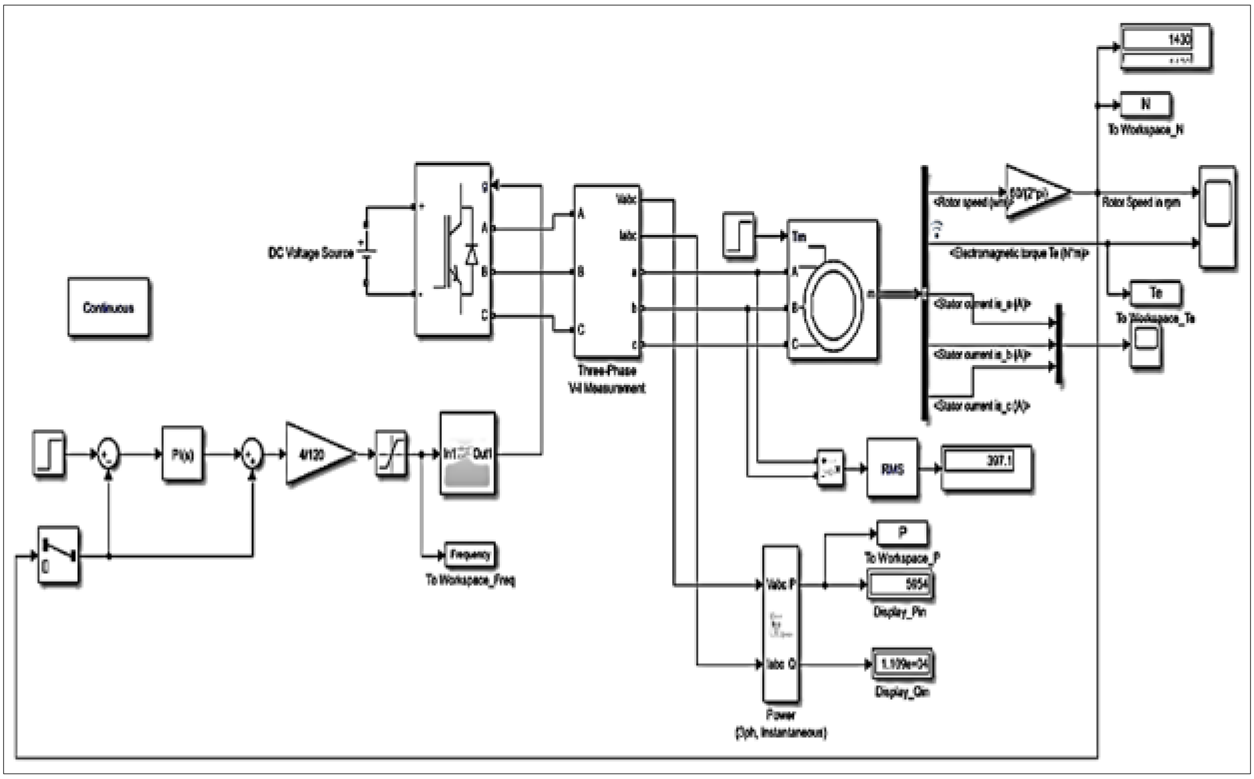

Figure 1 Simulink model of speed control of three phase induction motor

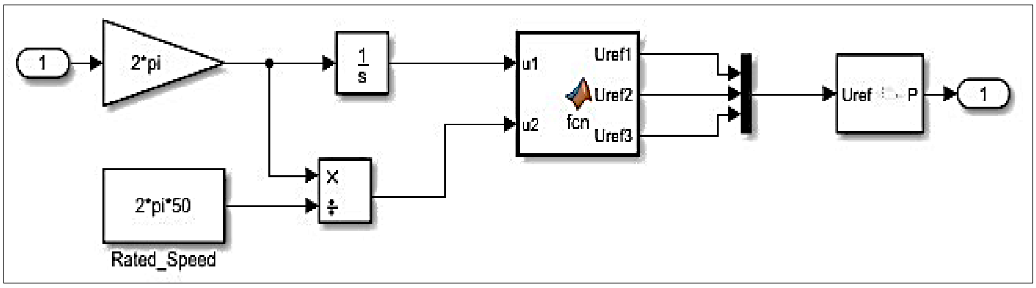

Figure 2 Simulink of PWM generator

2.2. Algorithm

Procedure to draw the Simulink model with entries and simulation

- Open the MATLAB-Simulink window, select blank/new model file.
- Go to the library browser, select the components from the Simulink library or typing the name of the component in the model file.
- Place the components and make the connection as per the circuit diagram.
- Save the model file with correct name and extension.mdl.
- Make the following entries of respective components as shown in Table 1.
- Simulate the model file with simulation time 2 sec., observe the characteristics in Scope and variable files in the workspace window.

- To plot the characteristics, open the new script or m-file, enter the following MATLAB code and save the file with correct name and extension.m.

```
clc
plot (tout, N)
axis ([0  2  0  1800])
title (Rotor Speed of 3-phase Induction Motor')
xlabel ('t in sec');
ylabel ('N in rpm')

clc
plot (tout, Te)
axis ([0  2  0  40])
title (Electrical Torque of 3-phase Induction Motor')
xlabel ('t in sec');
ylabel ('Te in N-m')
```

- Run the m-file and observe the characteristics in the figure window.

Table 1 Components Data

Component	**Select / enter the values by double click on component**
Asynchronous Machine	Configuration: Rotor type: Squirrel-cage Squirrel-cage preset model:15: 5.4HP (4kW), 400V, 50 Hz, 1430rpm Mechanical input: Torque Tm Reference frame: Rotor
DC voltage source	Parameters: Amplitude(V): 400/sqrt (3) *sqrt (2) *2
Three Phase Voltage Source Inverter	Parameters: Configuration: Yg Phase-to phase voltage (Vrms): 400 Phase angle of phase-A (degree): 0 Frequency (Hz): 50 (Disable/uncheck Impedance: Internal)
Step	Step time: 0.5, Initial value: 0, Final value:1, Sample time: 0
Bus Selector	Remove default signals. Select signals in the bus: Stator measurements: Stator current Ia (A) Mechanical: Electromagnetic torque (N-m) Rotor speed ωm (rad per sec)
RMS	Fundamental frequency (Hz): 50
PID Controller	Controller: PI Time domain: Continuous time Controller parameters: Source: Internal Proportional (P): 0.5 Integral(I): 8 Select tuning method: Transfer function based initial conditions Source: internal, Integrator: 0 External reset: none
Scope	Right click: Signals and ports: Number of input ports: 3
Gain	Gain4: 60/(2*pi), Gain1: 100, Gain3: 100, Gain2: 1/735.5
To Workspace	Variable name: Name of the respective output variable (Example: Te) Save format: Array

The direct current voltage source is converted to an alternating current source using a VSI. The direct current source comes from a renewable energy source, specifically a solar panel, which is integrated with a battery. The VSI is then connected to a three-phase V-I measurement system that displays voltage and current. This setup is linked to the stator of a squirrel cage three-phase induction motor. The induction motor outputs, such as speed, electromagnetic torque, and stator currents, are selected from a bus selector. The rotor speed, measured in rad/sec, is converted to rpm. This rotor speed serves as a feedback signal connected to the switch. The error detector calculates the steady-state speed error relative to the reference speed. This error is processed through a PI controller to minimize the steady-state error. The resulting signal is added to the actual speed and converted into frequency. It is then fed into a frequency limiter and converted into rad/sec. This signal is integrated and divided by the rated speed, producing two control signals (u1 and u2) for the sinusoidal pulse width modulator (PWM). The PWM generates gate pulses for the IGBTs in the three-phase VSI, ensuring that the voltage-to-frequency ratio remains constant.

3. Results and Discussion

3.1. Case-1: Reference Speed = 1400 rpm (step change in speed 1430 to 1400 rpm) at a load torque of 20 Nm

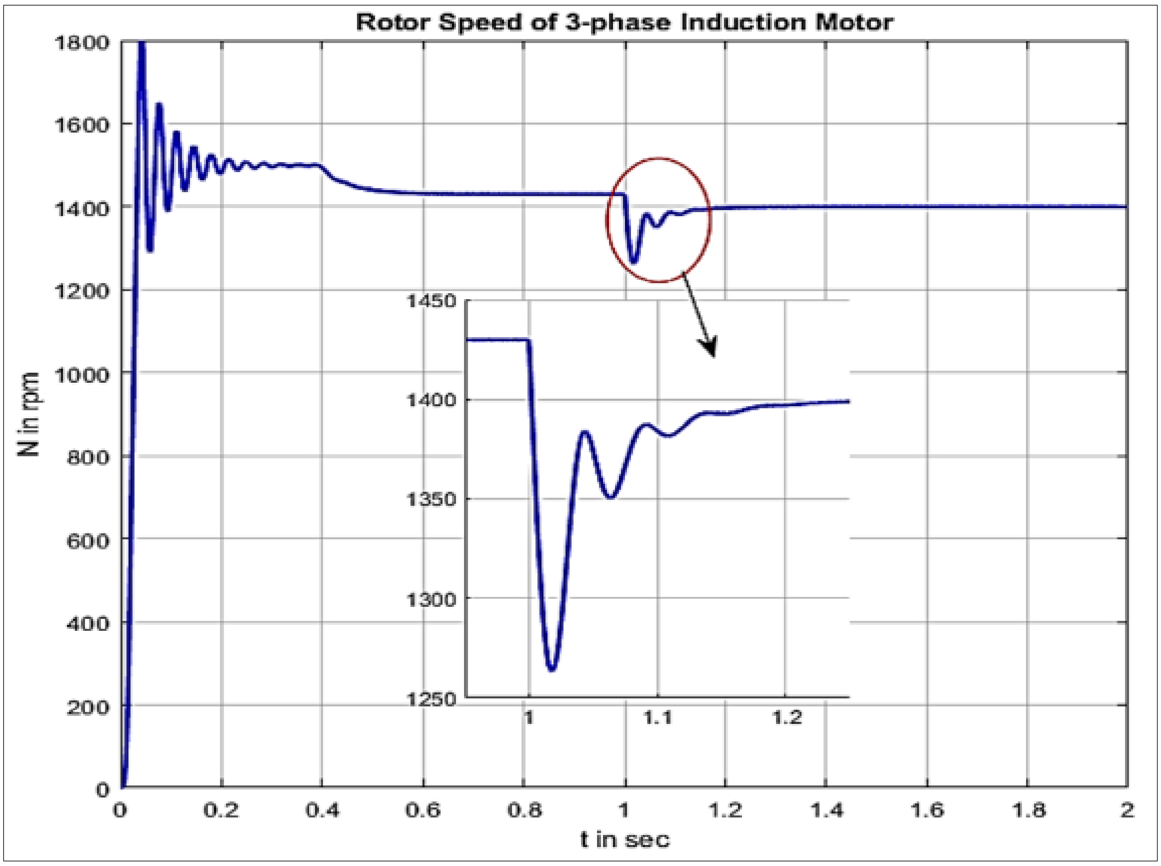

Figure 3 Time v/s rotor speed characteristics

Figure 3 shows the time v/s rotor speed characteristics of induction motor. At initial stage speed of the rotor is 1430 rpm. At time t = 1 sec, a step change in speed of 1430 to1400 rpm at constant torque T = 20 Nm.

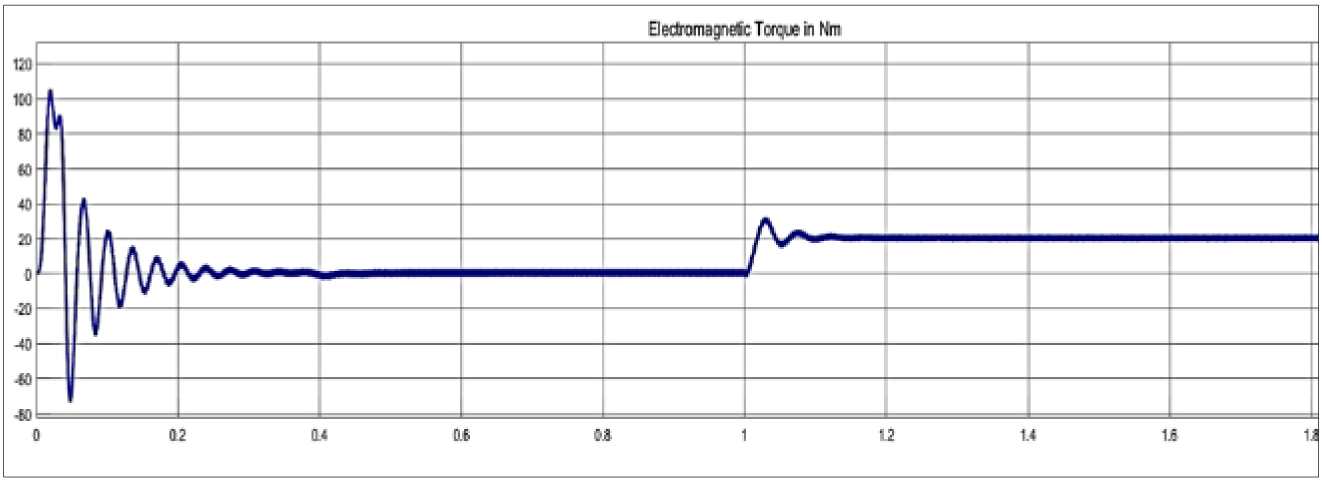

Figure 4 Torque with respect to time at 1400 rpm

Figure 4 shows the comparison of rotor speed and torque with respect to time. At time t = 1 sec, the load torque increases from 0 to 20 Nm, the rotor speed decreases and runs at reference speed of 1400 rpm. The settling time is less than 0.2 sec.

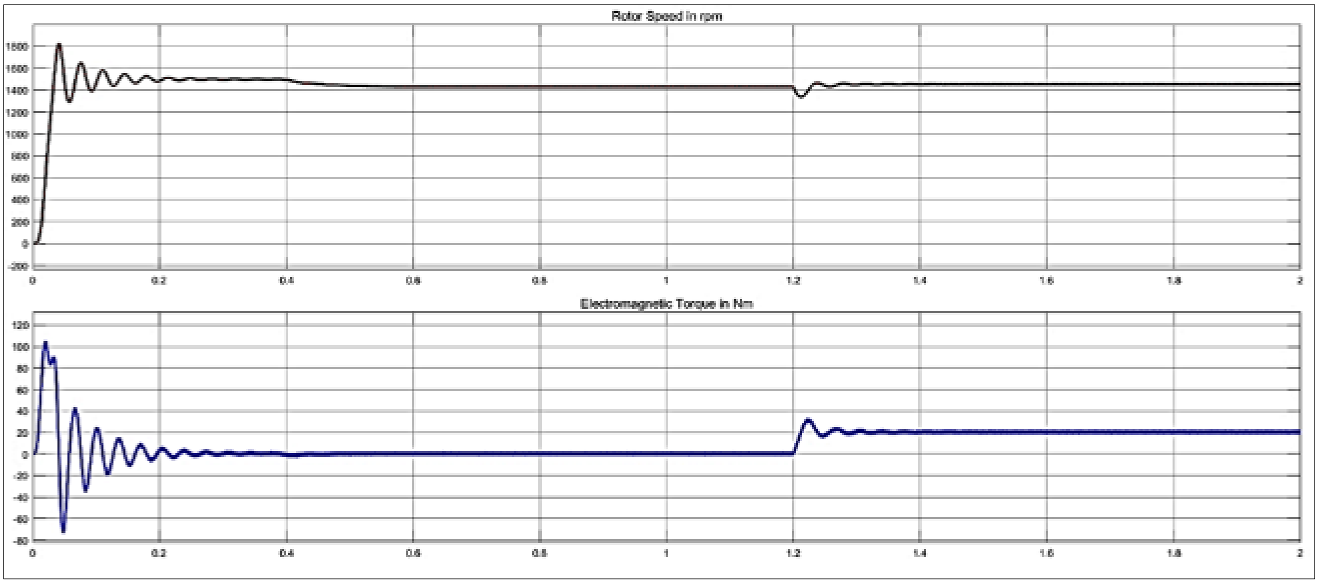

Figure 5 Comparison of rotor speed and torque with respect to time at 1480 rpm

At time t = 1.2 sec, the load torque increases, the rotor speed decreases and runs at reference speed of 1480 rpm with the same load of torque T = 20 Nm. The settling time is less than 0.2 sec, as shown in the Figure 5.

3.2. Case-2: Torque = 20 Nm (step change in torque from 0 to 20 Nm) at reference speed 1430 rpm

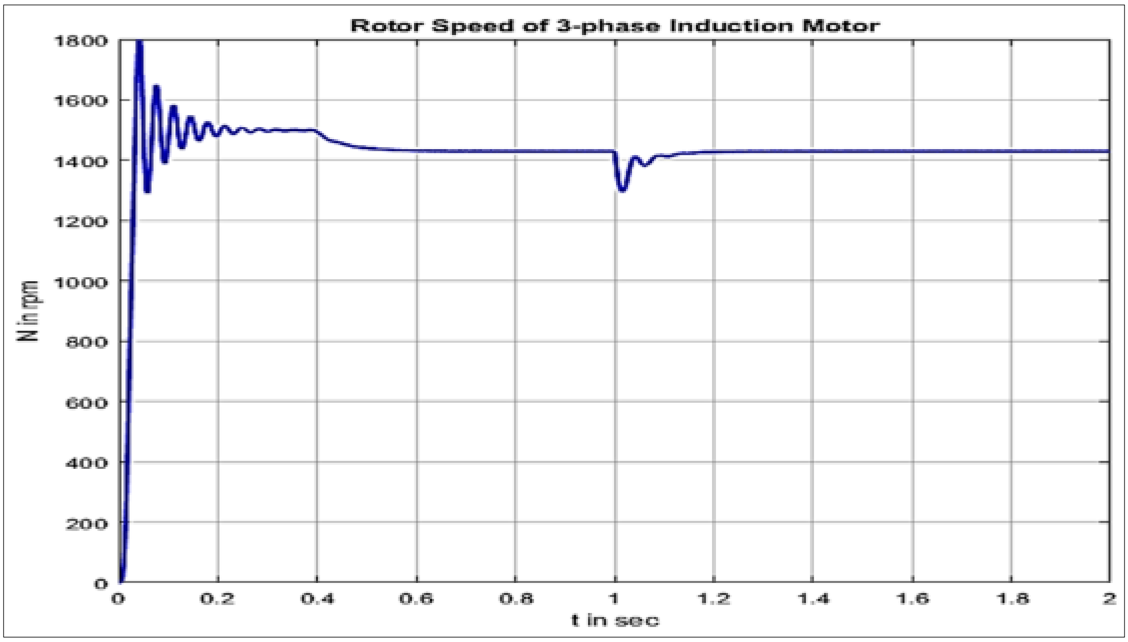

Figure 6 Time v/s rotor speed characteristics at 20 Nm

At initial stage reference speed of rotor = 1430 rpm. At time t = 1 sec, a step change in load torque from 0 to 20 Nm, the motor runs with the same reference speed 1430 rpm, as shown in Figure 6. In this case also, the settling time is less than 0.2 sec.

In Figure 7, at time t = 1 sec, the load torque increases, rotor speed decreases and runs at constant or reference speed of 1430 rpm with torque T = 20 Nm. Figure 8 shows the characteristics of time v/s stator current. At time t = 1 sec, the load torque = 20 Nm, the stator current increases a peak value of 9.5 A.

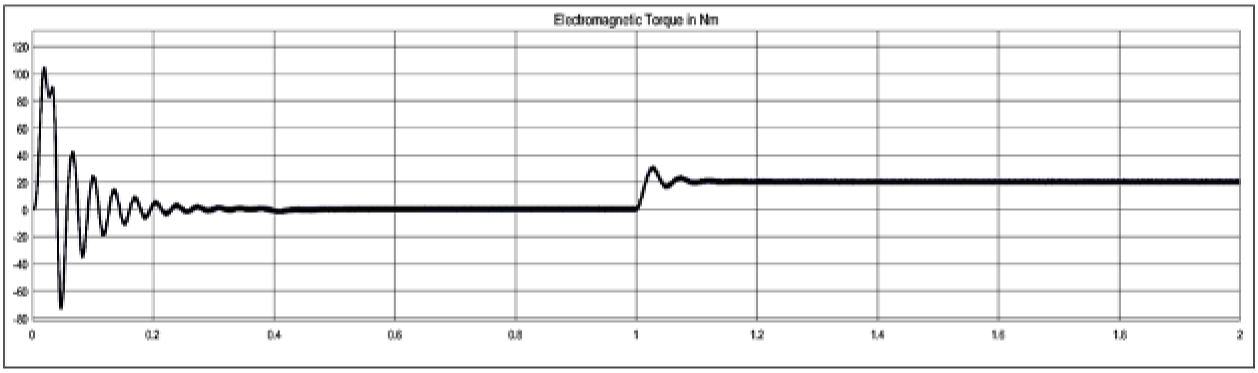

Figure 7 Torque (20 Nm) with respect to time at 1430 rpm

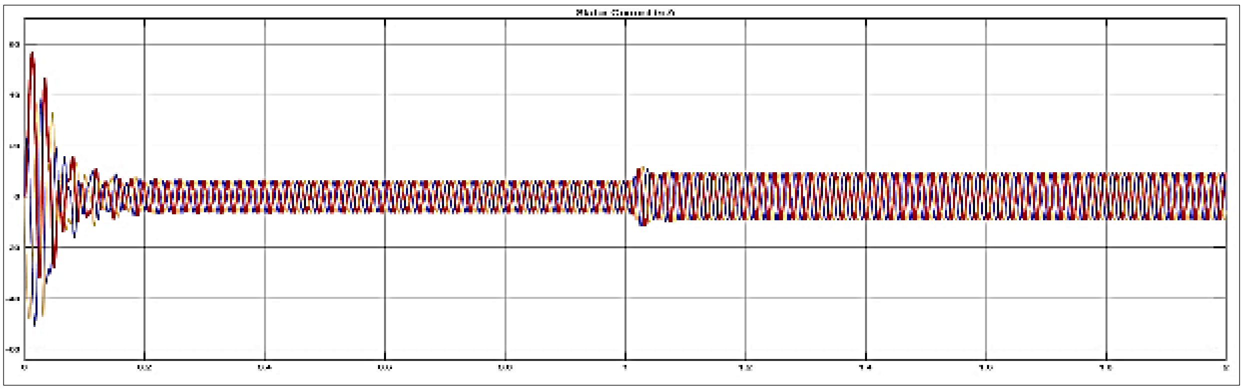

Figure 8 Time v/s stator current at 20 Nm

In Figure 9, at time t = 1.2 sec, the load torque increases from 0 to 26 Nm, rotor speed decreases and runs at constant or reference speed of 1430 rpm. In both the cases, the settling time is less than 0.2 sec. In the closed loop operation, the PI controller reduces the steady state speed error very quickly.

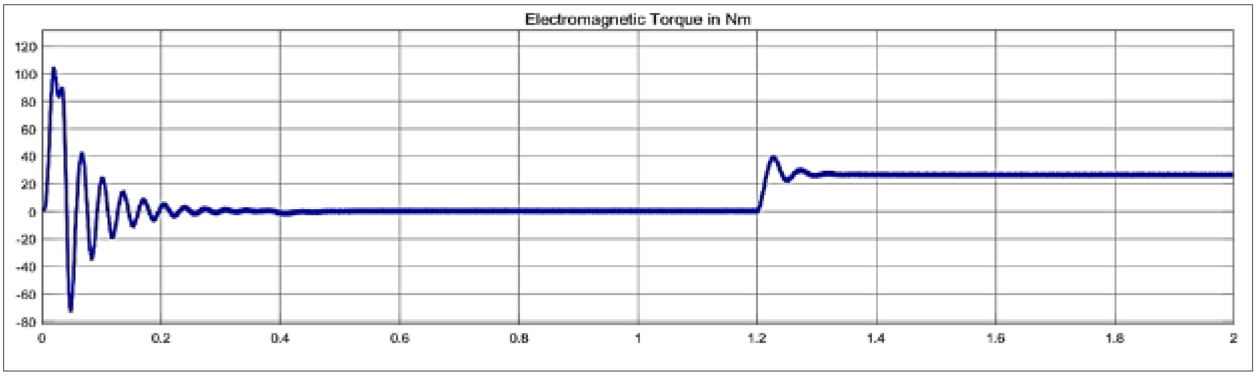

Figure 9 Torque (26 Nm) with respect to time at 1430 rpm

Figure 10 shows the characteristics of time v/s stator current. At time t = 1.2 sec, the load torque = 26 Nm, the stator current increases a peak value of 11 A.

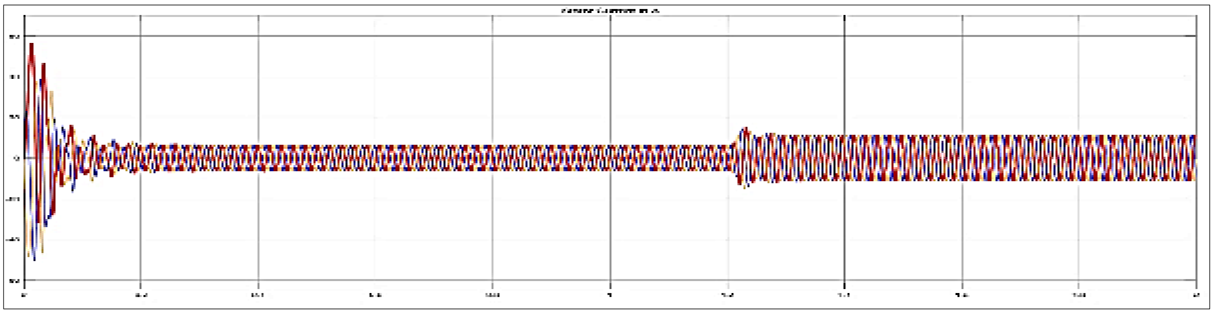

Figure 10 Time v/s stator current at 26 Nm

4. Conclusion

The Simulink model for closed-loop speed control of a three-phase induction motor has been developed. A sinusoidal pulse width modulation technique is employed to regulate speed in a closed loop. This scheme offers more efficient and reliable operation for both continuous and intermittent duty cycles, ensuring smooth speed control across various industrial applications. A straightforward V/f control method for the three-phase induction motor is proposed.

The simplicity of the proposed closed-loop control system relies on the nearly linear relationship between load torque and slip speed of the induction motor at constant stator flux linkages. When the load torque is slightly increased, the motor speed decreases, resulting in the output of direct and quadrature axis currents. The transient responses of current, torque, and speed are analyzed under case 1 and case 2, and the methodology for speed control of the induction motor and tracking its speed is also developed. Based on the results of this model, a closed-loop SPWM system is the most effective method for controlling the speed of a three-phase induction motor using a three-phase inverter.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Theodore Wildi, Electrical Machines, Drives and Power Systems, Pearson, 6th Edition, 2014.

[2] I.J.Nagrath and D.P.Kothari, Electric Machines, 4th Edition, McGraw Hill, 4th Edition, 2012.

[3] Mohit Desai, Deepak Mishra, and Rohan Patel, MATLAB Simulation of closed–loop speed control of three–phase induction motor using slip control method and sinusoidal PWM technique, International Journal of Engineering Research and Technology, 2021, 10(9), 2278-0181.

[4] Rajkumar Yadav, Manoj Kumar Kar, and Arun Kumar Singh, Speed control of a three-phase IM with closed–loop control scheme, In Book: Recent advances in power electronics and drives, 2022, 852., 43-55.

[5] H Hartono, R I Sudjoko and P Iswahyudi, Speed control of three phase induction motor using universal bridge and PID controller, Journal of Physics: Conference Series Indonesia, 2019, 1381, 1-8.

[6] G N Madhu, PatelaNaik L., Speed control of induction motors using proposed closed loop v/f control scheme, International Research Journal of Engineering and Technology, 2019, 06, 2395-0072.

[7] Bhagat B, Singh G., Performance and evaluation of voltage source inverter feed induction motor drives, International Research Journal of Engineering and Technology, 2019, 6(2), 1168-1171.

[8] Koga K, Ueda R, Sonoda T., Constitution of V/f control for reducing the steady-state speed error to zero in induction motor drive system, IEEE Transaction on Industry Applications, 1992, 28(2), 463–471. https://doi.org/10.1109/28.126757.

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