Speed Regulation and Control of Inverter Fed Induction Motor Drives Using Controllers (PI, PID)

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Authors’ contributions

This work was carried out in collaboration among all authors. Author EA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SK managed the analyses of the study. Author ANB managed the literature searches. Author PKO wrote the literature of the manuscript. All authors read and approved the final manuscript.

ABSTRACT

An induction (or asynchronous) motor is an AC electric motor in which runs at the rated condition but there is indeed of variable speed of motor. There are numbers of methods available for speed control, but there is need for selection of proper controller for obtaining the desired result. Simulation was done in the MATLAB Simulink software.

Keywords: Synchronous speed; inverter; transfer function; controller.

1. INTRODUCTION

There are various methods for the speed control of the Induction motor like pole changing, stator voltage control, supply frequency control, vector control and scalar control [1]; but while designing a such system the most important part is the “CONTROLLERS”. A controller basically responds to an error signal in a closed control loop and tries to adjust the controlled quantity to achieve the desired speed [2]. The machine should be run at maximum efficiency to give the
best performance so the role of the controller is crucial. By using PWM technique and proper choice of filter, the waveform of the output signal of the inverter can be improved to minimize the harmonics and ripple in torque [3]. The signal fed to the induction motor is sinusoidal then induction motor runs at maximum efficiency and losses decreases [4]. Thus the proper selection of type of controller and the input waveform fed to the induction motor is very important.

1.1 Induction Motor

The induction motor runs at a speed which is less than the synchronous speed [5]. The reason is the rotating magnetic field produced in the stator will generate flux in the rotor which helps the rotor to rotate but due to lagging nature of flux, current in the rotor with the flux current in the stator, the rotor never reaches to the synchronous speed (Ns).

\[ N_s = \frac{120f}{p} \]

where \( f \) is frequency (Hz) and \( p \) is numbers of poles of the machine [2].

1.2 Block Diagram and Transfer Function of the Induction Motor

The following figure shows the Per-Phase equivalent diagram of an induction motor circuit referred to stator side.

![Per-phase equivalent circuit referred to Stator side](image)

Where

- \( V_i \) = Stator voltage
- \( E_i \) = Stator induced emf
- \( s \) = slip

Mathematical modelling of induction motor can be obtained by taking all the basic equations.

The electrical equation of machine is

\[ V_a = I_a R_a + jX_s I_a + E_b \] (1)

\[ E_b \propto \frac{d\theta}{dt} \] (2)

Applying laplace transforms,

\[ (s) = (s)(R_a + jX_s) + E_b(s) \] (3)

We know that \( E_b = K_t s \) (s)

Substituting, we get,

\[ \frac{V_a(s) - K_t(s) \theta(s)}{Z_s} = (s) \] (4)

Electrical torque is given by

\[ T_e = \frac{K_b^2 R}{s^2 + X_s^2} \] (5)

Taking laplace transforms,

\[ T_e = E^2 \sin \theta \] (6)

\[ \frac{\theta(s)}{V_a(s)} = \frac{K_t}{(s^2 + 2 s E_2) + s + K_a K_t s} \] (7)

Parameters taken:
- \( K_a = 0.0190 \)
- \( K_t = 0.5 \) J/(Inertia constant) = 0.076 kgm²
- \( R = 4.2 \Omega \)
- \( B \) (Friction coefficient) = 8
- \( L = 3 \text{mH} \)

Transfer function gives

\[ \frac{\theta(s)}{V_a(s)} = \frac{0.0190}{0.228 s + 24.31 s^2 + 33.6 s} \] (8)

Transfer function = \( G(s) = \frac{\theta(s)}{V_a(s)} = \frac{0.000128}{0.0006 7.3 + 0.7 1952 + s + 0} \)

1.3 Inverter

An inverter is an Power Electronic device that converts power in DC form to AC form at desired frequency and voltage output with the help of suitable pulses given to the switches [3].
Fig. 2. Block diagram of induction motor

Fig. 3. Simulink model for three phase Inverter with RL Load

Fig. 4. Output voltage waveform for the 3 phase inverter
   X axis=Output voltage & Y axis=Time
Fig. 5. Simulink model of 3 phase R Load with PWM technique

Fig. 6. Output voltage waveform of Inverter using PWM technique
(Y axis-Output voltage(v) & X axis-Time(s))
1.4 Transfer function of Three Phase Inverter

The inverter is a sampled data system and the transfer function of the inverter is represented by a gain $K$ with the delay time $T_d$. The gain is obtained from the given DC input voltage and the delay time is equal to the average carrier switching cycle time. The transfer function is thus given by [6]:

$$ K \left(1 + sT_d\right) $$

1.5 PI, PID Controller

The proper controller selection plays an important role in designing a system as it helps in obtaining the desired result.

1.6 PI Controller

The PI (proportional plus integral) controller function is most frequently used controller function in practical applications. It does not cause offset associated with proportional control. It yields much faster response than integral action. It is widely used for process industries for controlling variables like level, flow, pressure, those do not have large time constants [7].

The definition for a proportional feedback control is still

$$ U = K_P e \quad (9) $$

where

$e$ = is the "error"
$K_P$ = Proportional gain.

For PI controller the transfer function is generally of the form $K_P + \frac{K_i}{s}$

Total transfer function with PI controller is given by:

$$ \frac{0.00067s + 0.00064}{0.01268s + 0.00064} $$

$$ \frac{0.00067s + 0.00064}{0.01268s + 0.00064} $$

1.7 PID Controller

A Proportional integral derivative controller is a control loop mechanism employing feedback that is widely used in industrial control system.

Overall Transfer function is given by:

$$ K_P + \frac{K_i}{s} + \frac{k_d}{Ts+1} $$

2. MATERIAL

As we know the inverter is being fed by the DC source so it can be powered by Solar PV Modules which is equivalently shown as an DC source.

2.1 Simulation Diagram

The speed characteristic curve of an induction motor is being obtained with the following Simulink model.

Fig. 8. Block diagram of motor model with PID controller
Fig. 9. Speed regulation of 3 Phase induction motor using PWM technique

Fig. 10. Speed characteristic of the inverter fed Induction motor
(Y axis-Speed(RPM) & X axis-Time(s))

Fig. 11. Simulink model of the PI controller
3. RESULTS AND DISCUSSION

The speed waveform was obtained with using the PWM technique but as it contained transient in output waveform of voltage so use RC filter is done to obtain Sinusoidal Wave as shown. The reason is simple as we get the maximum efficiency and less harmonics with the sinusoidal hence the losses will be less at the same time machine is also not being overused.

All the transfer function required for simulation were designed in the MATLAB Simulink. The result obtained is shown below.

We can see that the better responses are given by using the PI controllers than the rest of two.
Table 1. Dynamic response result

| Controller | Rise time(sec) | Settling time(sec) | Overshoot percentage(%) | Peak |
|------------|----------------|-------------------|-------------------------|------|
| PI         | 0.619          | 5.41              | 36.5                    | 1.37 |
| PID        | 13.9           | 17.1              | 1.35                    | 1.01 |

As we know that speed of the system as well as the stability is inversely proportional to the rise time [8]. From the result it is clear that the PI controller has less rise time hence it will be faster and more stable. Thus for better performance of the induction motor PI controller is preferred.

4. CONCLUSION

This paper presents a study of the Speed regulation and speed control of the induction motor with inverter fed with using PWM technique to obtain the speed. The PWM provides desired voltage regulation for the system. Further, the transfer function modelled to study the speed control parameter with using PI, PID controller to enhance the performance of the induction motor drive. Thus, we conclude that PI controller is most suited as controller. The entire work was successfully done in the MATLAB Simulink.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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