

Scilab/Scicos Modeling, Simulation and PC Based Implementation of Closed Loop Speed Control of VSI Fed Induction Motor Drive

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Abstract— Modeling, simulation and implementation of Voltage Source Inverter (VSI) fed closed loop speed control of 3-phase induction motor drive is presented in this paper. A mathematical model of the drive system is developed and is used for the simulation study. Simulation is carried out using Scilab/Scicos, which is free and open source software. The above said drive system is implemented in laboratory using a PC and an add-on card. In this study the air gap flux of the machine is kept constant by maintaining Volt/Hertz (v/f) ratio constant. The experimental transient responses of the drive system obtained for change in speed under no load as well as under load conditions are presented.

Keywords- Induction motor, Mathematical model, Simulation, V/f Control, VSI.

I. INTRODUCTION

INDUCTION machine is the most widely used motor in industry because of its high robustness, reliability, low cost, high efficiency and good self-starting capability. In spite of this popularity, the induction motor has two inherent limitations. They are (i) the standard motor is not a true constant-speed machine, its full-load slip varies from less than 1% (in high hp motors) to more than 5% (in fractional-hp motors). (ii) It is not inherently capable of providing variable-speed operation. These limitations can be solved through the use of adjustable speed controllers. The basic action involved in adjustable speed control of induction motor is to apply a variable voltage magnitude variable frequency to the motor so as to obtain variable speed operation. Both the voltage source inverter and current source inverters are used in adjustable speed ac drives [1, 2].

In this study, VSI fed 3-phase induction motor drive system with constant 'v/f' control method is modeled, simulated and is implemented using PC and an add-on card, as this method provides good running and transient performance [3]. The closed loop speed control of VSI fed induction motor drive system is described in section II. Section III describes the modeling, simulation model developed and simulation results of the drive system using Scilab/Scicos. Section IV describes the implementation of the drive system using PC and an add-on card. The

experimental results are presented in section V and are compared with that of simulation results.

II. DRIVE SYSTEM CONFIGURATION

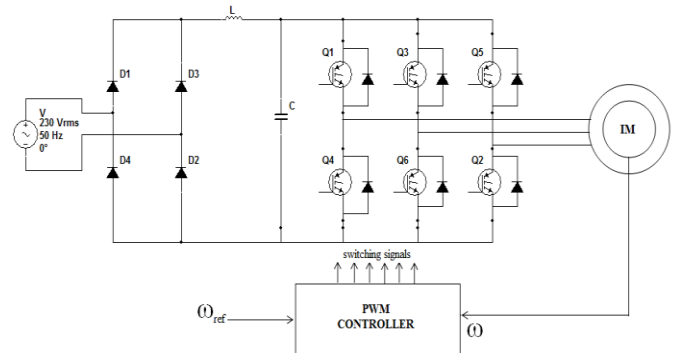


Figure 1. Drive system configuration

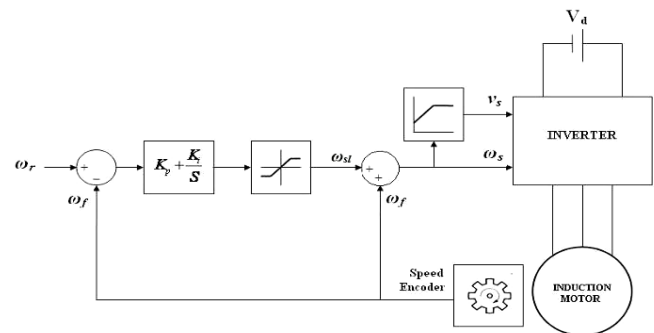


Figure 2. Block diagram of closed loop v/f control

Fig. 1 shows the overall drive system which consists of 3-phase induction motor, converter and controller. The ac voltage from the supply system is rectified using 1-phase diode rectifier and is given as input to the 3-phase VSI. The output of inverter is feeding the induction motor. Block diagram of the drive system configuration is shown in Fig. 2. The actual speed of the induction motor is sensed and is compared with the reference speed. The error so obtained is processed in a Proportional Integral (PI) controller and its output sets the inverter frequency as well as the modulation

index. The slip regulator sets the slip speed command ω_{sl} , whose maximum value is limited to limit the inverter current to a permissible value. The synchronous speed, obtained by adding actual speed ω_f and the slip speed ω_{sl} , determines the inverter frequency. The reference signal for the closed-loop control of the machine terminal voltage V_s is generated from frequency f .

A step increase/decrease in a speed command ω_r produces a positive/negative speed error. The slip speed command ω_{sl} , is set at the maximum value. The drive accelerates/ decelerates at the maximum permissible inverter current, producing the maximum available torque, until the speed error is reduced to a small value. The drive finally settles at a slip speed for which the motor torque balances the load torque.

III. MODELING AND SIMULATION OF DRIVE SYSTEM

Mathematical modeling of system

In order to simulate the drive system using Scilab/Scicos, it is required to model the various components of the system in terms of their mathematical equations.

A. Induction Motor Model

Based on the applied stator voltage and flux linkages the mathematical model of the squirrel cage induction motor in the stationary reference using standard nomenclature as given in [2]:

$$v_{ds} = v_{an} \quad (1)$$

$$v_{qs} = (v_{bn} - v_{cn}) / \sqrt{3} \quad (2)$$

$$L_a = ((1/L_m) + (1/L_{ls}) + (1/L_{lr})) \quad (3)$$

$$L_{ad} = 1/L_{ad} \quad (4)$$

$$L_{aq} = L_{ad} \quad (5)$$

$$d\psi_{ds} / dt = v_{ds} + (R_s / L_{ls})(\psi_{md} - \psi_{ds}) \quad (6)$$

$$d\psi_{qs} / dt = v_{qs} + (R_s / L_{ls})(\psi_{mq} - \psi_{qs}) \quad (7)$$

$$d\psi_{dr} / dt = (R_s / L_{lr})(\psi_{md} - \psi_{dr}) - \omega_r \psi_{qr} \quad (8)$$

$$d\psi_{qr} / dt = (R_s / L_{lr})(\psi_{mq} - \psi_{qr}) - \omega_r \psi_{dr} \quad (9)$$

$$\psi_{md} = L_{ad}((\psi_{ds} / L_{ls}) + (\psi_{dr} / L_{lr})) \quad (10)$$

$$\psi_{mq} = L_{aq}((\psi_{qs} / L_{ls}) + (\psi_{qr} / L_{lr})) \quad (11)$$

$$i_{ds} = (\psi_{ds} - \psi_{md}) / L_{ls} \quad (12)$$

$$i_{qs} = (\psi_{qs} - \psi_{mq}) / L_{ls} \quad (13)$$

$$t_e = (3P/4)(i_{qs}\psi_{ds} - i_{ds}\psi_{qs}) \quad (14)$$

$$\frac{d\omega_r}{dt} = \frac{1}{J} \left(\frac{p}{2} (t_e - t_l) - b\omega_r \right) \quad (15)$$

B. Modeling of Inverter

The inverter output phase voltages and corresponding phase currents are obtained by the following equations:

Three phase inverter output voltages are given by

$$v_{an} = (2v_{ao} - v_{bo} - v_{co}) / 3 \quad (16)$$

$$v_{bn} = (2v_{bo} - v_{co} - v_{ao}) / 3 \quad (17)$$

$$v_{cn} = (2v_{co} - v_{ao} - v_{bo}) / 3 \quad (18)$$

Three phase inverter output currents are given by

$$i_a = i_{ds} \quad (19)$$

$$i_b = (-1/2)i_{ds} + (\sqrt{3}/2)i_{qs} \quad (20)$$

$$i_c = (-1/2)i_{ds} - (\sqrt{3}/2)i_{qs} \quad (21)$$

C. Modeling Of Controller

The controller used is a PI controller. The error in speed is fed to PI controller as input, it generates the slip command ω_{sl} . The working of PI controller is based on the following equation.

$$y(t) = k_p e(t) + k_i \int_0^t e(k) \quad (21)$$

PI controller in discrete form is given by

$$y(k) = k_p \text{error}(k) + k_i \sum_{n=0}^k \text{error}(n) \quad (22)$$

Where k_p and k_i are proportional and integral gain constants.

D. V/f characteristics

V/f characteristics play a prominent role in 'v/f' control mechanism of speed control of induction motor. It provides a relationship between voltage and frequency as shown in Fig. 3. From the figure we observe that upto base frequency the 'v/f' ratio is maintained constant and above base speed voltage is kept constant.

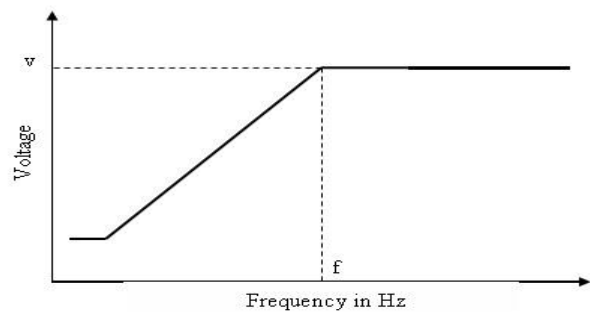


Figure 3. V/f characteristics

E. Scilab/Scicos Simulation

Scilab is a freely distributed and open-source software package providing a powerful computing environment for engineering and scientific applications. Matlab being a commercially expensive simulating tool, Scilab is gaining importance in research centers, educational institutes and industries. Scilab can be downloaded from

<http://www.scilab.org/products/scilab/download>. Scilab consists of Scicos toolbox which provides block diagram editor for constructing simulation models. Scicos is renamed as Xcos in versions above 5.1.1. Models developed by Matlab/Simulink can be reasonably modeled in Scilab/Scicos by moderate additional effort [4, 5]. The simulation model of closed loop speed control is as shown Fig. 4 [6].

F. Simulation Results

The induction motor parameters which are listed in Appendix are determined experimentally using no-load and blocked rotor tests. These parameters are used in Scilab to determine 'v/f' characteristics for frequencies zero to base frequency i.e. rated frequency. Fig 5 shows the simulated 'v/f' characteristics.

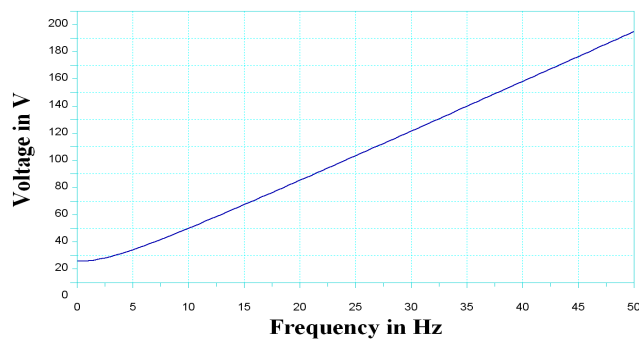


Figure 5. Simulated 'v/f' characteristics.

Fig. 6. Shows the speed response under no load condition, where the speed of induction motor attains the set reference speed 1000 rpm from 0 rpm, it can be observed that the error input to the PI controller reaches 0 rpm from maximum error 1000 rpm as can be seen in Fig. 7. As the error decreases, the speed of the machine builds up. Fig. 8. shows change in the speed with respect to time when reference speed is changed from 0 rpm to

800 rpm and then from 800 rpm to 1000 rpm at no load condition. Here, error is maximum at start, then PI controller corrects the error and the motor picks up the speed equal to new set speed. Fig. 9 shows the drive response obtained for closed loop system when the load torque on the motor is changed from zero to 1 Nm, during its running condition at 1000 rpm reference speed. Here, initially speed drops when load is applied then the error in change of speed is controlled by PI controller and makes the motor to run again at the set reference speed.

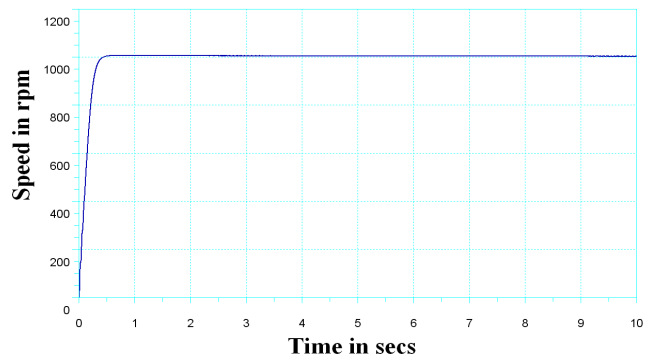


Figure 6. Speed response under no load condition

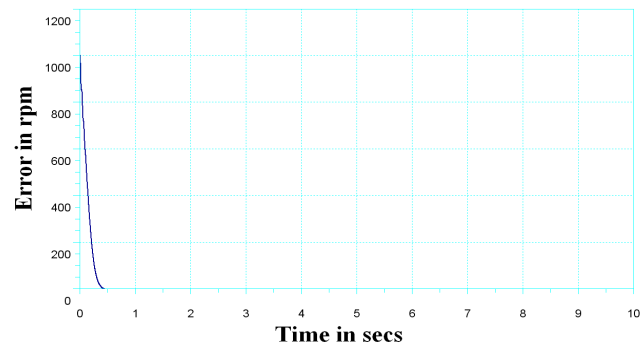


Figure 7. Error versus time under no load condition

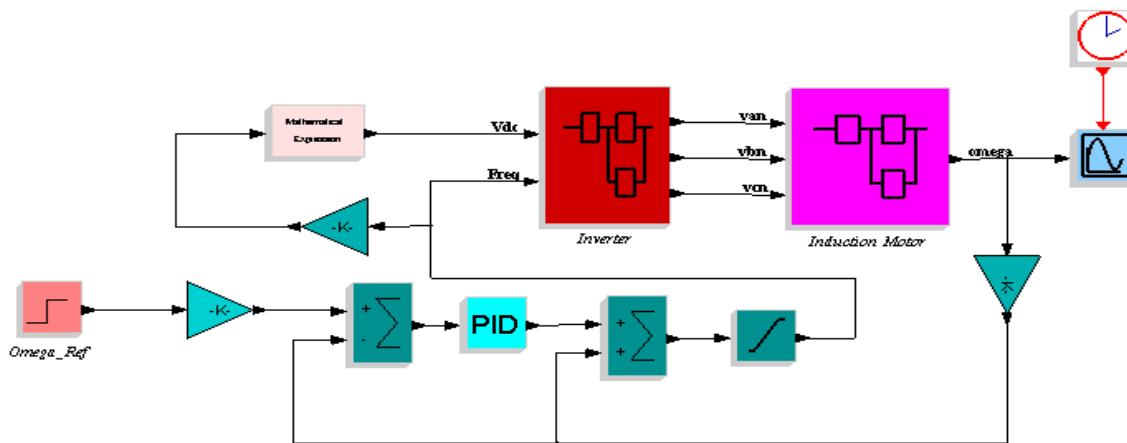


Figure 4. Simulation model of drive system

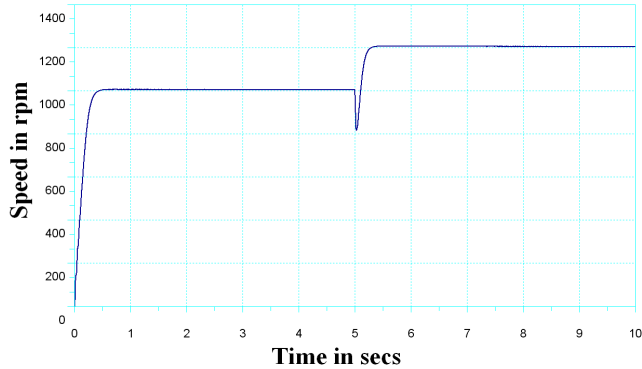


Figure 8. Speed response for step change in speed

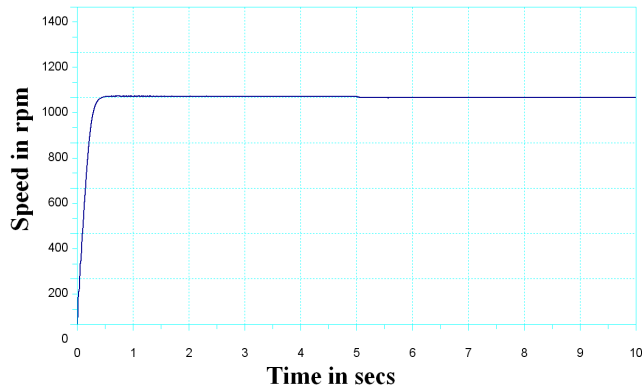


Figure 9. Speed response for step change in load

IV. IMPLEMENTATION OF CLOSED LOOP SPEED CONTROL OF VSI FED INDUCTION MOTOR DRIVE

The ac voltage from the supply system is rectified and is given to three phase voltage source inverter as input which feeds induction motor. The speed of the motor is sensed. The reference speed is set as ω_{ref} and then the error between the required speed and the actual speed is calculated. This error is processed by a PI controller and its output gives the correction which will minimize the error.

A. Implementation

The above mentioned closed loop control system is implemented in laboratory using a PC and its add-on card. PC with an inexpensive add-on card offers the advantages of flexibility and convenient disk storage of data and programs [7]. Add on card consists of analog to digital conversion (12-bit 16 channels), digital to analog conversion (12-bit 2 channels) and digital input output (12 lines). Overall closed loop block diagram is as shown in Fig 10. The required speed is entered as one of the input to the computer. The motor speed is sensed by optical speed sensor, whose output is given to the F to V converter. This signal is fed to one of the ADC channel where it is converted into digital form and is taken as another input to the computer [8]. A 'C' program is developed to implement the closed loop control of the drive. Fig 11 shows the flowchart of algorithm. The experimental setup of the drive system is as shown in Fig. 12.

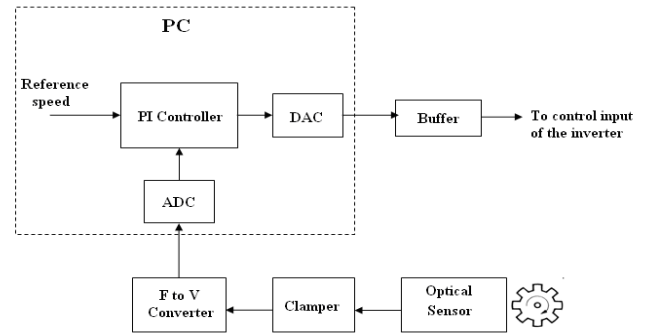


Figure 10. PC based closed loop implementation

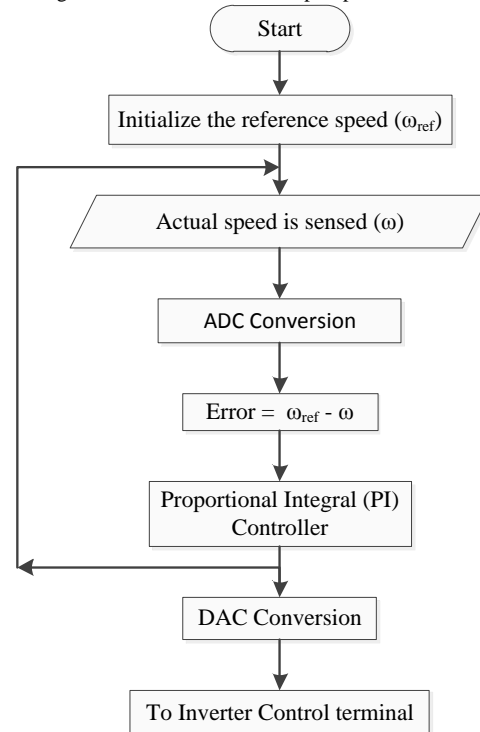


Figure 11. Flowchart of controller program.

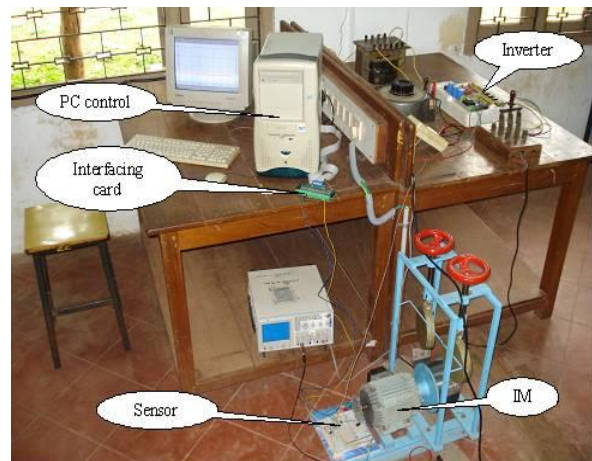


Figure 12. Experimental setup of closed loop VSI fed induction motor drive

B. Experimental Results

Fig. 13. Shows the speed response under no load condition with reference speed as 1000 rpm. Fig. 14. Shows the error response under no load condition Fig. 15. Variation of speed with respect to time under no load condition. The reference speed is changed from 0 to 1000 rpm and then raised from 1000 to 1200 rpm. Fig. 16. shows the speed variation with respect to time under loaded condition. Initially the motor is running at 1000 rpm under no-load condition. The machine is loaded after 187 seconds. From figure it can be seen that, at the instant of loading, the actual speed of machine drops slightly, but then retains set speed of 1000 rpm within 3 seconds.

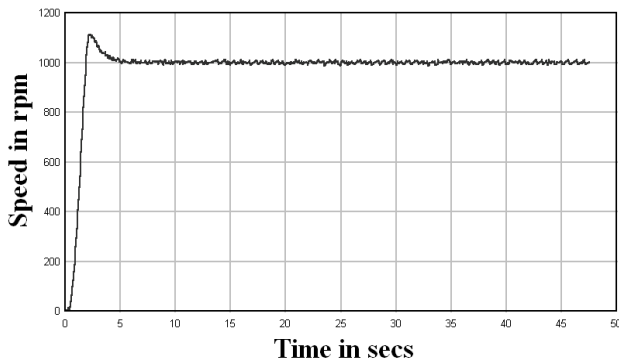


Figure 13. Speed versus time under no load condition

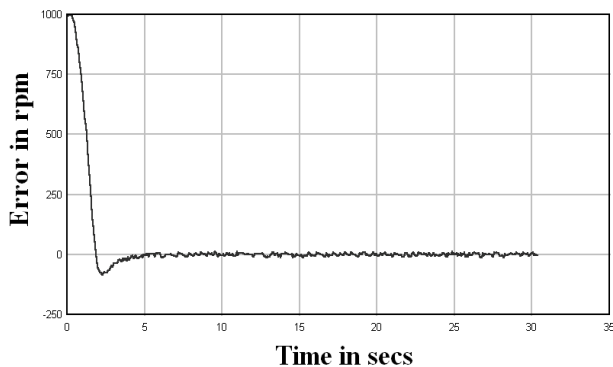


Figure 14. Error response under no load condition

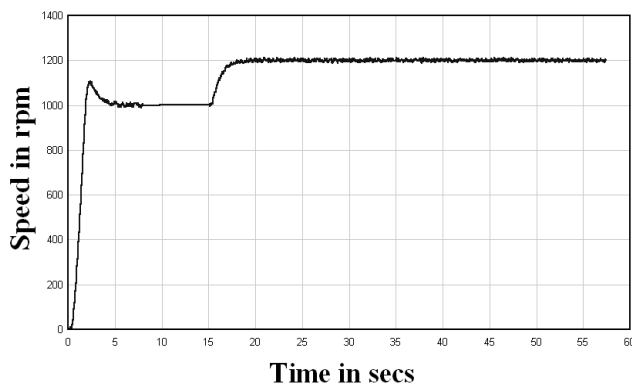


Figure 15. Speed response for step change in speed

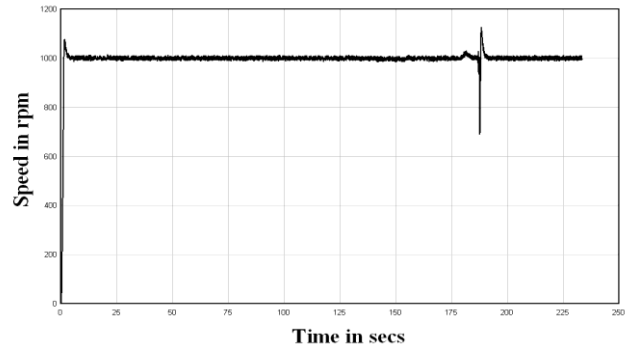


Figure 16. Speed response for step change in load

V. CONCLUSION

The simulation of a VSI fed closed loop 'v/f' method of speed control of an induction motor is studied and the same is implemented in laboratory using PC and an add-on card. The simulation results show that the variable voltage variable frequency control allows induction motor drive with good running and transient performance. Also it is observed that the variation in the speed of induction motor with change in load torque is reduced with the help of closed loop control. The implementation of the same using PC and an add-on card results show that the C program developed to carry out the function of speed control of the system, continuously monitors the actual speed and changes the control voltage in such a way as to make the motor speed and reference speed same.

APPENDIX

Induction motor specifications and parameters at rated frequency: 1 HP , 415 $\pm 10\%$ V, 1.7 A, $50 \pm 5\%$ Hz, 1410 rpm. $R_1=12.38 \Omega$, $R_2=15.3 \Omega$, $X_1=X_2=6.48 \Omega$, $X_m=0.299-j1.227 \Omega$

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