

Research Article

Simulation of High Performance PID Controller for Induction Motor Speed Control with Mathematical Modeling

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Abstract: This study presents the design of high performance PID controller for three phase induction motor V/f speed control with induction motor mathematical modeling. V/f method is a simple method for speed control of induction motor. The control scheme is based on the popular constant volts per hertz (V/f) method using the high performance PID controller. Design of induction motor mathematical modeling and PID controller for Space Vector Pulse Width Modulation inverter are proposed for induction motor V/f speed control. The simulation is carried out by MATLAB/Simulink.

Keywords: Induction motors, mathematical modeling, PID controller, PWM inverter, V/f control

INTRODUCTION

Three-phase induction motors are the most common and frequently encountered machines in industry. Because it has Simple design, high power to weight ratio and easy to maintain. V/f control of induction motor has large applications in industry. The control strategy consists of keeping constant the voltage-frequency ratio of the induction motor supply source. Subhankar *et al.* (2012) discussed about PID controller based closed loop system which makes a squirrel cage induction motor running under constant volt/hertz ratio. In this study motor is modeled according to the transfer function based on inductance matrices or L-matrices of the motor. The motor exhibits to run in the user defined or command speed.

Dazhi *et al.* (2004) discussed about a neural network adaptive PID controller for speed sensor less field-oriented control of induction motor. By measuring the phase voltages and currents in Induction Motor (IM) drive, the multi-step predictive control, neural networks based rotor flux components and speed identification method for IM are used. Ustun and Demirtas (2008) analyzed about a new method of the optimal tuning of proportional integral controller coefficients in the off-line control of a induction motor. Uddin and Hao (2007) discussed about Neuro fuzzy control for induction motor. The main task of this tuning method is to adjust the parameters of the Fuzzy Logic Controller (FLC) in order to minimize the square of the error between actual and reference outputs. Rodriguez *et al.* (2009) discussed about Direct Torque Control (DTC)

based on load angle control. The use of simple equations to obtain the control algorithm makes it easier to understand and implement. Fixed switching frequency and low torque ripple are obtained using space vector modulation.

In this study, therefore, proposes a high performance PID controller for three phase induction motor V/f speed control. The complete mathematical model of three phase induction motor also carried out.

The proposed method was simulated in MATLAB/Simulink environment. PID controller is designed to generate the signals in order to turn on six Insulated-Gate Bipolar Transistors (IGBTs) of a three-phase inverter. The classical square wave inverter used in low or medium power applications suffers from a serious disadvantage such as lower order harmonics in the output voltage. Space vector pulse width modulation with V/f is used for controlling the motor. Because, it includes minimum harmonics according to other PWM techniques.

MATHEMATICAL MODELING OF INDUCTION MOTOR

In the control of any power electronics drive system to start with a mathematical model of the plant is required. To design any type of controller to control the process of the plant mathematical model is required. Lashok *et al.* (2009) have analyzed about the mathematical modeling of induction motor, the power circuit of the 3- ϕ induction motor is shown in the Fig. 1.

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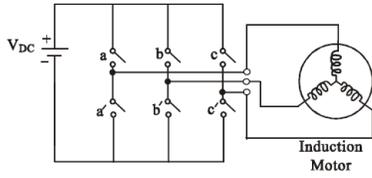


Fig. 1: Power circuit of induction motor

$$V_{sd} = R_s i_{sd} + \frac{d}{dt} \lambda_{sd} - \omega_d \lambda_{sq} \tag{1}$$

$$V_{sq} = R_s i_{sq} + \frac{d}{dt} \lambda_{sq} - \omega_d \lambda_{sd} \tag{2}$$

$$V_{rd} = R_r i_{rd} + \frac{d}{dt} \lambda_{rd} - \omega_{sd} \lambda_{rq} \tag{3}$$

$$V_{rq} = R_r i_{rq} + \frac{d}{dt} \lambda_{rq} - \omega_{sd} \lambda_{rd} \tag{4}$$

V_{sd} and V_{sq} , V_{rd} and V_{rq} are the direct axes and quadrature axes stator and rotor voltages. The flux linkages to the currents are given by the Eq. (5):

$$\begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \\ \lambda_{rd} \\ \lambda_{rq} \end{bmatrix} = M \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix}; M = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \tag{5}$$

The electrical part of an induction motor can thus be described, by combining the above equations we get Eq. (6):

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} = \frac{1}{L_m^2 - L_r L_s} \times \left(\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} + \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_r & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} V_{sd} \\ V_{sq} \\ V_{rd} \\ V_{rq} \end{bmatrix} \right) \tag{6}$$

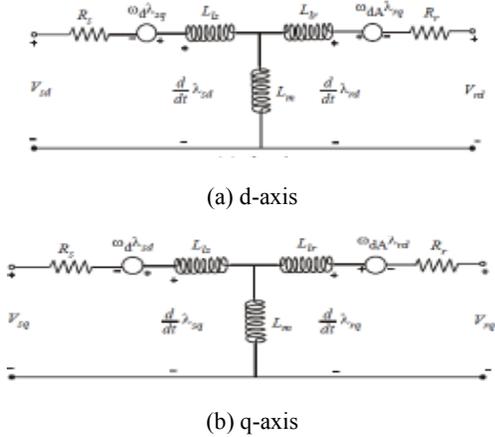


Fig. 2: Equivalent circuit of induction motor in d-q frame

The equivalent circuit used for obtaining the mathematical model of the induction motor is shown in the Fig. 2.

The induction motor model is established using a rotating (d , q) field reference (without saturation) concept. An induction motor model is then used to predict the voltage required to drive the flux and torque to the demanded values within a fixed time period. This calculated voltage is then synthesized using the space vector modulation:

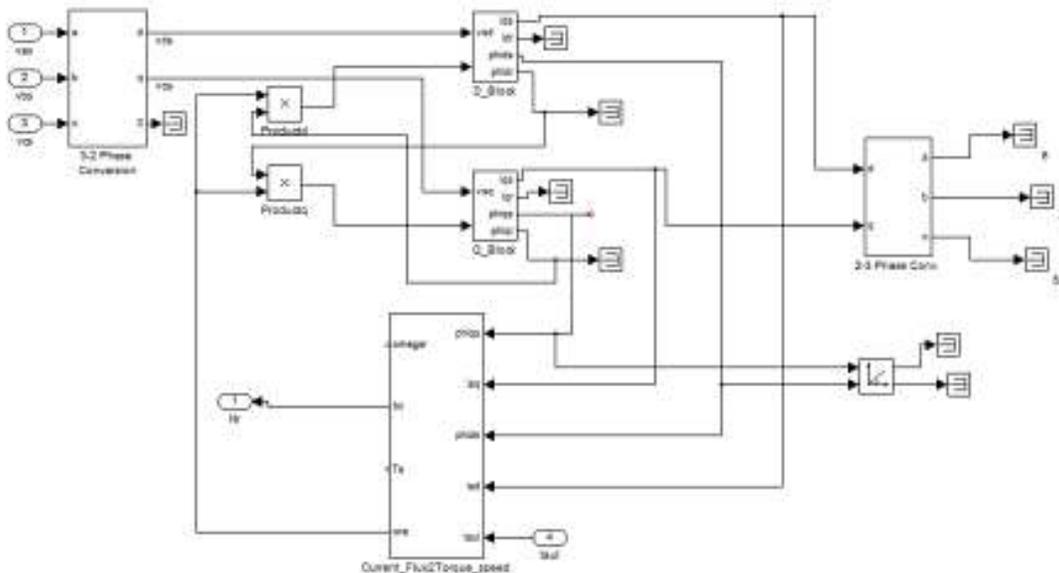


Fig. 3: Three phase induction motor mathematical modeling

where, A is given by:

$$A = \begin{bmatrix} L_r R_s & \omega_{dd} L_m^2 - \omega_r L_r L_s \\ -(\omega_{dd} L_m^2 - \omega_r L_r L_s) & L_r R_s \\ -L_m R_s & L_s L_m (\omega_r - \omega_{dd}) \\ -L_r L_m (\omega_r - \omega_{dd}) & -L_m R_s \\ -L_m R_r & -L_r L_m (\omega_r - \omega_{dd}) \\ L_r L_m (\omega_r - \omega_{dd}) & -L_m R_r \\ L_s R_r & \omega_r L_m^2 - \omega_{dd} L_r L_s \\ -(\omega_r L_m^2 - \omega_{dd} L_r L_s) & L_s R_r \end{bmatrix} \quad (7)$$

The instantaneous torque produced is given by:

$$T_{em} = \frac{P}{2} (\lambda_{rd} i_{rd} - \lambda_{rd} i_{rq}) \quad (8)$$

The electromagnetic torque expressed in terms of inductances is given by:

$$T_{em} = \frac{P}{2} L_m (i_{sq} i_{rd} - i_{sd} i_{rq}) \quad (9)$$

The mechanical part of the motor is modeled by the equation:

$$\frac{d}{dt} \omega_{mech} = \frac{T_m - T_L}{J_m} = \frac{P}{2} \frac{L_m (i_{sq} i_{rd} - i_{sd} i_{rq}) - T_L}{J_m} \quad (10)$$

The mathematical modeling of three phase induction motor is shown in Fig. 3.

This induction motor model is further used to design a controller using fuzzy control strategy.

PID based V/f control system: Block diagram of PID based V/f control system is shown Fig. 4. The PID controller is designed to give control signals to IGBTs. The inverter output is V/f controlled output and it is given as input to three phase induction motor. The speed is taken as feedback and it is compared with the set speed. The error signal is given as input to the PID controller Space Vector Modulation (SVM) was originally developed as vector approach to Pulse Width Modulation (PWM) for three phase inverters.

The main aim of any modulation technique is to obtain variable output having a maximum fundamental component with minimum harmonics. PID based V/f speed control without induction motor mathematical modeling is shown in Fig. 5.

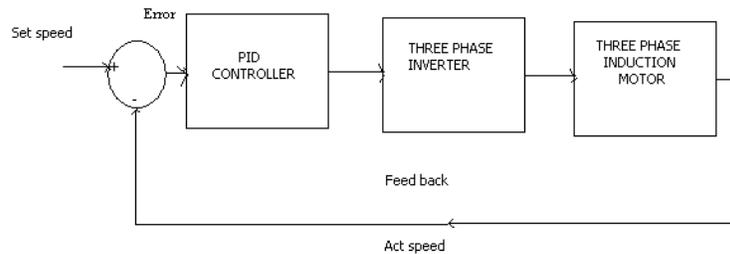


Fig. 4: PID controller based V/f speed control of three phase induction motor

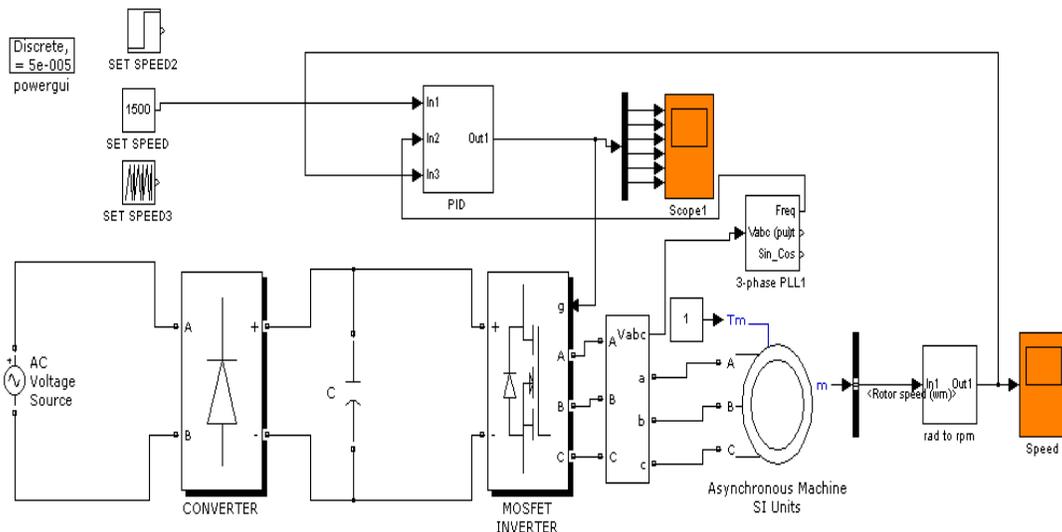


Fig. 5: Simulink model of PID based V/f speed control without induction motor mathematical modeling

Space Vector Pulse Width Modulation (SVPWM) is an optimum pulse width modulation technique for an inverter used in a variable frequency drive applications. It is computationally rigorous and hence limits the inverter switching frequency. Senthilkumar and Vijayan (2012) have designed PID controller for Space Vector Pulse Width Modulation inverter for induction motor V/f speed control without mathematical modeling. The design of PID controller without mathematical modeling is shown in Fig. 5. The design of PID controller for Space Vector Pulse Width Modulation inverter for induction motor V/f speed control with mathematical modeling is shown in Fig. 6. A Proportional-Integral-Derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems.

PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable

and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. PID controller module is shown in Fig. 7.

The Ziegler-Nichols tuning method is used to tune the PID controller. The proportional, integral and derivative terms are summed to calculate the output of the PID controller. Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$u(t) = MV(t) = K_p e(t) +$$

$$K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$$

where,

K_p : Proportional gain, a tuning parameter

K_i : Integral gain, a tuning parameter

K_d : Derivative gain, a tuning parameter

e : Error = $SP - PV$

t : Time or instantaneous time (the present)

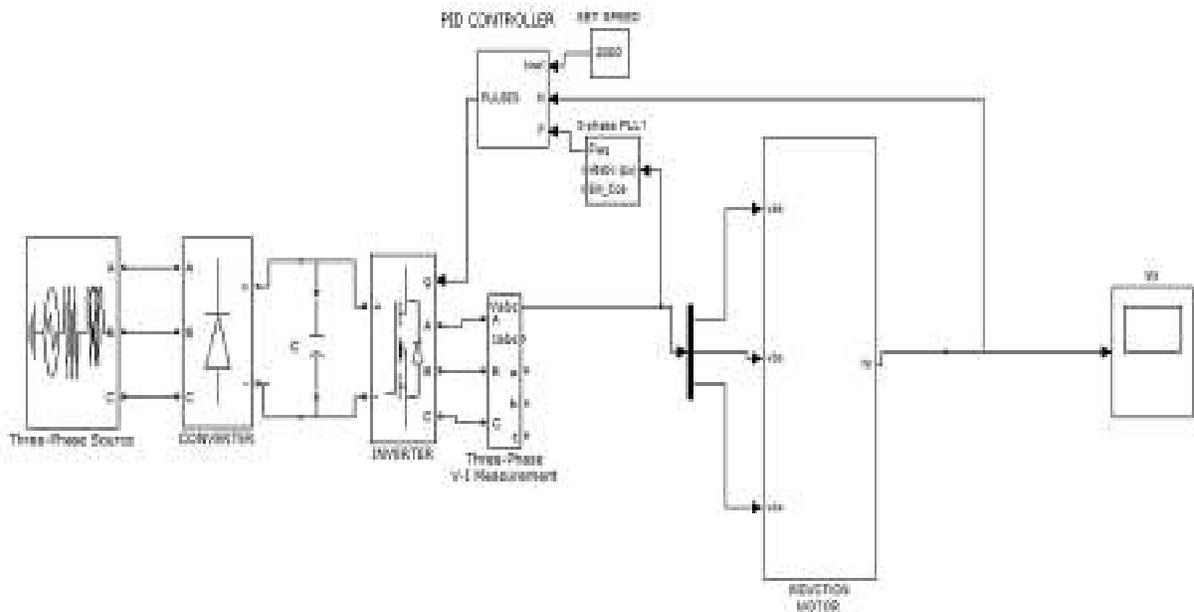


Fig. 6: Simulink model of PID controller based three phase induction motor V/f speed control with induction motor mathematical modeling

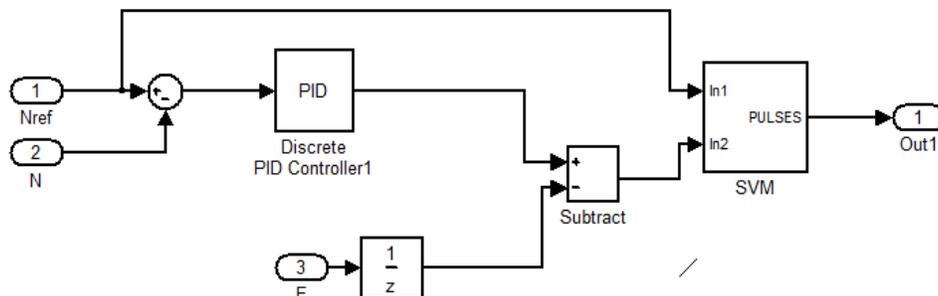


Fig. 7: PID controller

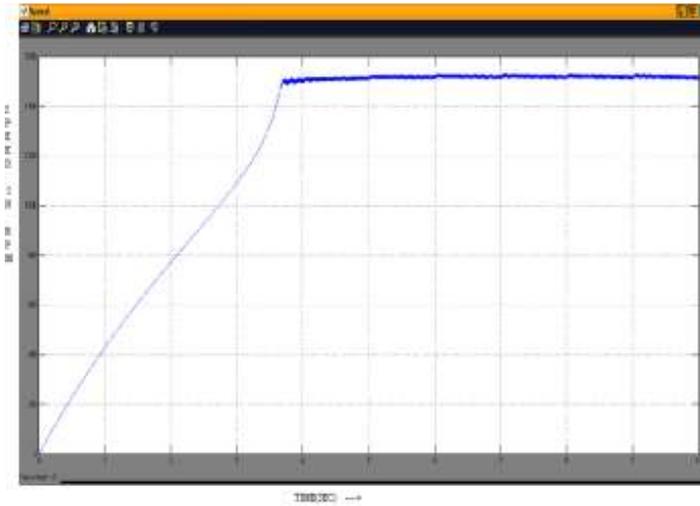


Fig. 8: PID controller response without induction motor mathematical modeling

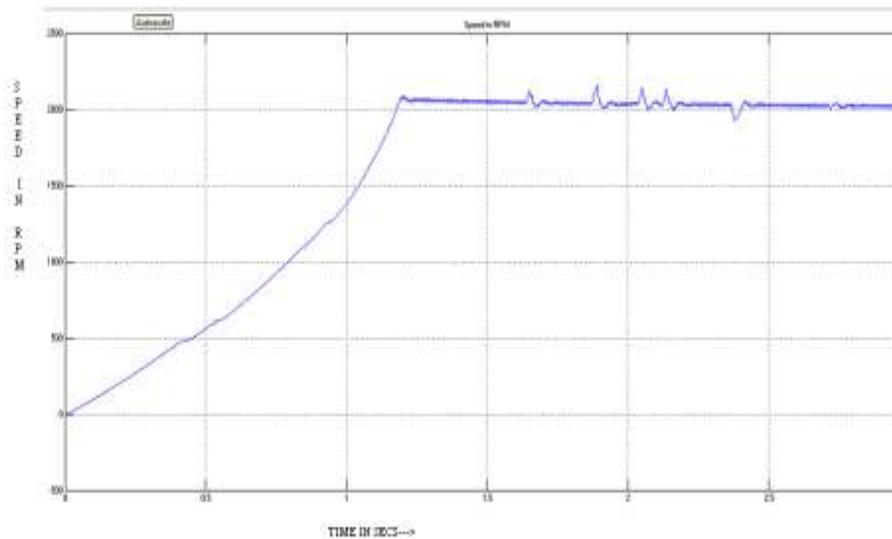


Fig. 9: PID controller response with induction motor mathematical modeling block

RESULTS AND DISCUSSION

Math mathematical modeling of induction motor-parameters: Induction motor parameters are given in Table 1.

PID controller simulation results: The PID controller for induction motor v/f control without mathematical modeling simulation output for a Set speed of 1500 rpm is shown in Fig. 8. X axis time in sec. Y axis speed in rpm.

The PID controller simulation output for a Set speed of 2000 rpm with induction motor mathematical modeling is shown in Fig. 9. X axis time in sec. Y axis speed in rpm.

According to the results, the PID controller with induction motor mathematical modeling and without modeling gives good response.

Table 1: Motor parameters

Parameters	Value
Stator resistance Rs	6.03 Ω
Rotor resistance Rr	6.085 Ω
Stator inductance Ls	489.3e-3 H
Rotor inductance Lr	489.3e-3 H
Poles	4

CONCLUSION

In this study we proposed mathematical modeling of three phase induction motor. We analyzed the V/f control speed response of three phase induction motor with mathematical modeling. This system can be extended with other advanced soft computing techniques. This induction motor modeling can be further used to design advanced controllers for induction motor speed control.

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