ANALYSIS

28(104), February 1, 2015

ISSN 2278–5469 EISSN 2278–5450

Discovery

Speed control of induction motor by using advanced non linear techniques and comparison

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Publication History

Received: 14 December 2014

Accepted: 17 January 2015

Published: 1 February 2015

Citation

Raviteja D, Ayya Rao TSLV. Speed Control of Induction Motor by Using Advanced Non Linear Techniques and comparison. *Discovery*, 2015, 28(104), 48-55

ABSTRACT

The main objective of this paper is to control the speed of the induction motor. The speed can be controlled by scalar control and vector control. Vector control separately regulates the "torque" and "flux" producing components of the motor stator current and is readily suited to implementation with a constant switching frequency. Triggering pulses to the switches of the motor are generated with PWM, Hysteresis based and P+Resonant (PR) controller. The performance of the machine is tested by simulation studies. The results shows the superior performance of the PR controller.

Index Terms—Induction Motor, Speed control, field orientation, PWM Inverter, hysteresis, P+Resonant (PR), vector drive, Matlab/simulink.

List of Symbols

L_s	Stator inductance	L_r	Rotor inductance
L_m	Mutual inductance	L_{ls}	Stator leakage inductance
		L_{lr}	Rotor leakage inductance

R_s	Stator resistance	U_{sd}, U_{sq}	dq-axis component of the stator voltages
R_r	Rotor resistance	i_{sd}, i_{sq}	dq-axis components of the stator currents
R_c	Core resistance	$i_{s\alpha}$, $i_{s\beta}$	αβ-axis component of the stator currents
ω_r	Rotor speed	$\psi_{r\alpha}$, $\psi_{r\alpha}$	αβ-axis component of the stator fluxes
ω_{sl}	Slip frequency	J	moment of inertia of rotor
ω_e	Electrical speed	T_e	Electrical Torque
P	Pole number	T_L	Load Torque
$U_{s\alpha}$, $U_{s\beta}$	α β-axis component of the stator voltages	δ	Rotor flux angle

1. INTRODUCTION

Induction motors are the most common motors used in industrial motion control systems, as well as in main powered home appliances. Simple and rugged design, low-cost, low maintenance and direct connection to an AC power source are the main advantages of induction motors. Induction motors are easier to design than DC motors, the speed and the torque control in induction motors is difficult and complex [12].

There are two methods to control the speed. They are scalar control and vector control. Scalar control of ac drives produces good steady state performance but poor dynamic response. This performance is due to deviation of air gap flux linkages from their set values. This variation occurs in both magnitude and phase. Vector control (or field oriented control) offers more precise control of ac motors compared to scalar control. The superior performance of the vector control makes it more popular and suitable to high performance drives e.g. robotic actuators, centrifuges, servos, etc.[3]

The control and speed estimation of induction motor drive are more complex than those of DC drives, and this complexity increases substantially if high performances are demanded. The induction motor drive system is state variable, nonlinear with internal coupling effect. The stability analysis of induction motor is very complex. The simulation study in matlab/simulink is very useful to investigate the performance of induction motor drive, particularly when a new control technique is developed.

The simulation results show the performance of induction motor drive. Vector or field oriented control (FOC) of induction motor for a PWM voltage-fed inverter identifies the synchronously rotating flux axis from the induction motor and calculate the flux magnitude and rotor flux angle. The control voltages $u_{s\alpha}$, $u_{s\beta}$ controls the currents $i_{s\alpha}$, $i_{s\beta}$ to control speed and torque[3],[8].

2. PRINCIPLES OF VECTOR CONTROL FOR A THREE-PHASE INDUCTION MOTOR

1. Dynamic Model Of Vector Controlled Induction Motor

The vector control principle on induction motor takes advantages of transforming the variables from physical three-phase abc to stationary reference frame (αβ) [1]. The mathematical model of induction motor as differential equations of five state variables presented in (αβ) stationary reference frame is written in equation (1).[4],[8].

$$\left.\begin{aligned}
\frac{di_{s\alpha}}{dt} &= k_1.i_{s\alpha} + k_2.\psi_{r\alpha} + \omega_r.k_3.\psi_{r\beta} + k_4.u_{s\alpha} \\
\frac{di_{s\beta}}{dt} &= k_1.i_{s\beta} + k_2.\psi_{r\beta} - \omega_r.k_3.\psi_{r\alpha} + k_4.u_{s\beta} \\
\frac{d\psi_{r\alpha}}{dt} &= k_5.\psi_{r\alpha} + (-\omega_r).\psi_{r\beta} + k_6.i_{s\alpha} \\
\frac{d\psi_{r\beta}}{dt} &= k_5.\psi_{r\beta} + (-\omega_r).\psi_{r\alpha} + k_6.i_{s\beta} \\
\frac{d\omega_r}{dt} &= \frac{L_m}{L_r J}(\psi_{r\alpha} i_{s\beta} - \psi_{r\beta} i_{s\alpha}) - \frac{1}{J} T_L
\end{aligned}\right\} \quad (1)$$

Where $i_{s\alpha}$, $i_{s\beta}$, $\psi_{r\alpha}$, $\psi_{\beta\alpha}$ and ω_r are the state variables and $u_{s\alpha}$, $u_{s\beta}$ are the input variables and k_1, k_2, k_3, k_4, k_5, k_6 are the constants and these constant parameters are directly given in matlab/simulink .M file.

$$\left.\begin{aligned}
k_1 &= -\frac{R_s L_r^2 + R_r L_m^2}{L_r w} \\
k_2 &= \frac{R_r L_m}{L_r w} \\
k_3 &= \frac{L_m}{w} \\
k_4 &= \frac{L_r}{w} \\
k_5 &= -\frac{R_r}{L_r} \\
k_6 &= R_r \frac{L_m}{L_r} \\
w &= \sigma L_r L_s = L_r L_s - L_m^2
\end{aligned}\right\} \quad (2)$$

From the above equation (1) and (2) the mathematical model of induction motor model is design in Matlab/Simulink as shown in Fig. 1.

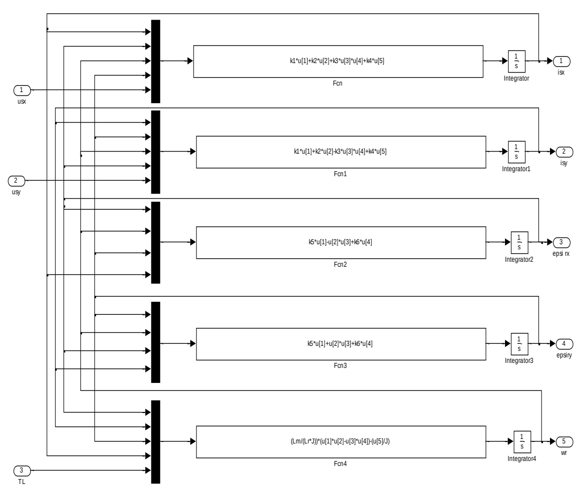

Figure 1 Induction motor model Block in Matlab/Simulink

3. CONTROL STRATEGIES

A. Vector Control induction motor with PWM Inverter control

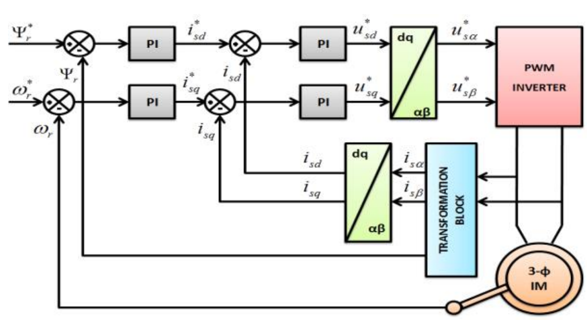

Figure 2 Vector control Induction Motor Block with PWM Inverter-fed controller

Vector or field oriented control (FOC) of induction motor for a PWM voltage-fed inverter identifies the synchronously rotating flux $\psi_{r\alpha}$,$\psi_{r\beta}$ and stator currents $i_{s\alpha}$, $i_{s\beta}$ of induction motor and calculate the rotor flux magnitude, rotor flux angle gama and i_{dq} currents from the transformation block [2], [8].

The flux magnitude ψ_r and rotor speed ω_r are compared with reference flux and speed, and then the error flux and error speed is generated. The generated error flux and speed is given to the PI controller then the stator currents i_{sd}*,i_{sq}* are generated and these currents are compared with actual currents from the induction motor is i_{sd}, i_{sq} and then the error currents will be generated. To generate a voltages u_{sd}*,u_{sq}* the error currents are given to PI controller. The voltages u_{sd}*,u_{sq}* are transformed to αβ-axis stationary voltages to three phase abc voltages [5]. The three phase abc voltages are compared with triangular carrier signal.[6]

when carrier signal is less than or equal to reference signal then +ve pulses are generated and when the carrier signal is greater than or equal to reference signal then –ve pulses are generated this pulses are used to trigger the thyristors of inverter in order to control line side of inverter.

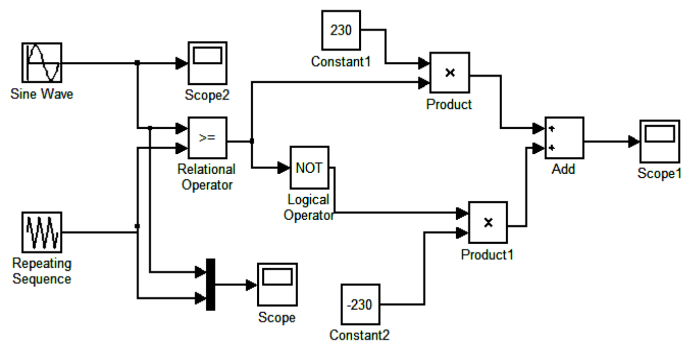

Figure 3 PWM Inverter Logic Block in Matlab/Simulink for 1phase

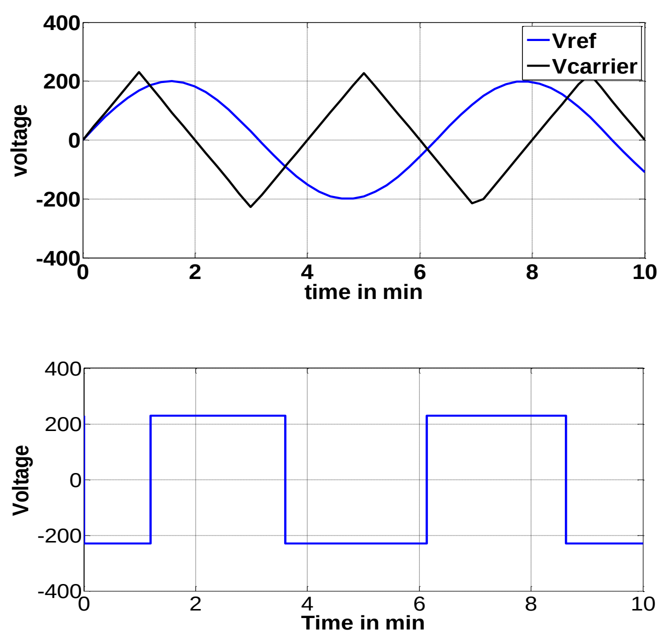

Figure 4 Output pulses for single phase PWM inverter block in Matlab/simulink.

The output voltages of the PI controllers are transformed from a rotating to a stationary frame using the Park transformation. The commanded signals of the stator voltage are sent to the pulse width modulation (PWM) block. Then the voltages are generated like as show in Fig. 4 for single phase inverter logic. The rotor flux magnitude is calculated from the following equation (3) and the transformation block is shown in Fig.

$$|\psi_r| = \sqrt{\psi_{r\alpha}^2 + \psi_{r\beta}^2} \quad (3)$$

From the above equation (3) the transformation block is designed in Matlab/Simulink as shown in below Fig. 5

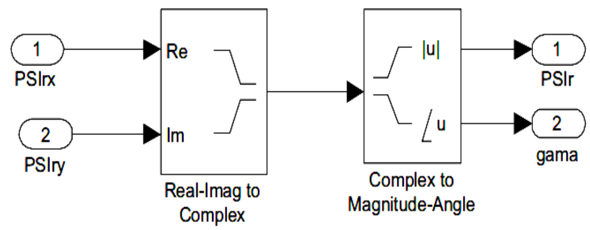

Figure 5 Transformation block in Matlab/Simulink

2. Vector Control Induction Motor with Three-Phase Hysteresis controller

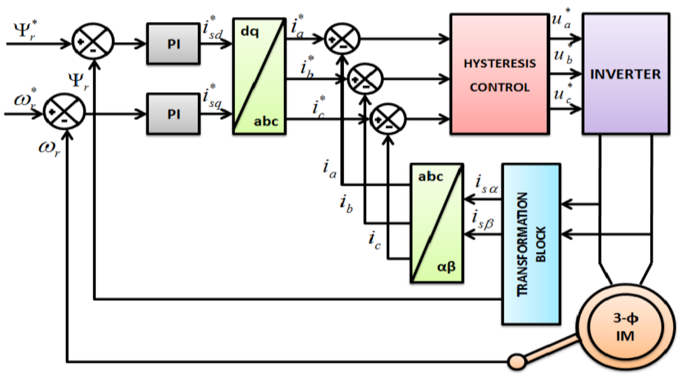

Figure 6 Vector control Induction Motor Block with Hysteresis controller

The three-phase stationary frame currents i_a*, i_b* and i_c* are calculated from the i_d* and i_q* currents. The three-phase reference currents are compared with actual currents and then given to hysteresis band as shown in Fig. 7. The hysteresis upper band limit is 0.1 and lower band limit is -0.1. The hysteresis controller output is control voltages U_a, U_b and U_c which are given to the vector control of induction motor [6], [7].

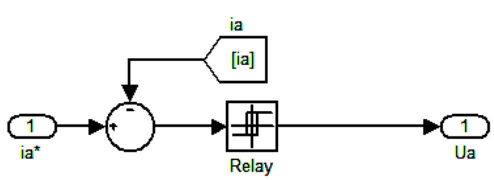

Figure 7 Hysteresis band for single phase in Matlab/Simulink

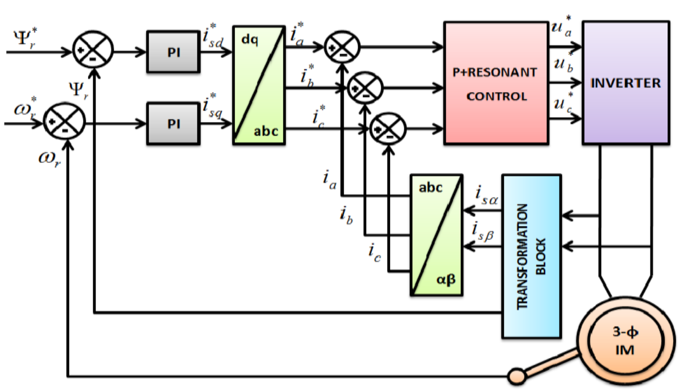

Figure 8 Vector control Induction Motor Bock with PR controller

C. Vector Control induction motor with Stationary Frame Proportional Resonant(PR) controller

In PR control strategy the three-phase reference currents i_a*, i_b* and i_c* are compared with actual currents coming from the induction motor i_a, i_b, and i_c ,then the error currents will produce and these error currents are given to PR controller then the controllable voltages u_a*, u_b*, u_c* will be produce and these voltages are given to vector control induction motor.[6][7]

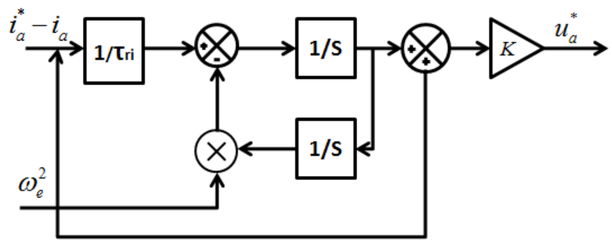

Figure 9 Stationary frame PR controller Block in Matlab/Simulink

$$\begin{bmatrix} u_a^* \\ u_b^* \\ u_c^* \end{bmatrix} = k\left(1 + \frac{s}{\tau_{ri}\left(s^2 + \omega_e^2\right)}\right)\begin{bmatrix} i_a^* - i_a \\ i_b^* - i_b \\ i_c^* - i_c \end{bmatrix} \qquad (4)$$

Where k is the current loop proportional gain, T_{ri} is the current loop integrator reset time constant.

The slip frequency ω_{sl}* is generated from i_{qs}* from equation and this slip speed is added with speed signal ω_r to generate frequency signal ω_e.

$$\omega_{sl}^* = \frac{L_m R_r}{\widehat{\psi}_r L_r} i_{qs}^* \qquad (5)$$

In PR controller the error current with current loop integrator reset time constant is compared with square of electrical speed ω_e is to generate voltages.

4. SIMULATION RESULTS

The following figures representing simulation results for PWM inverter-fed IM, Hysteresis controller and P+Resonant (PR) control technique. Fig. 10(a), (b) and (c) shows the speed performance, and Fig. 11(a), (b) and (c) shows the torque characteristics for PWM inverter-fed IM, Hysteresis controller and P+Resonant (PR) control technique

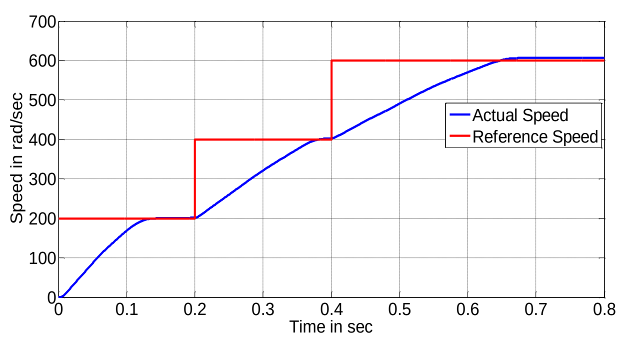

Figure 10(a). Speed response for PWM inverter-fed IM

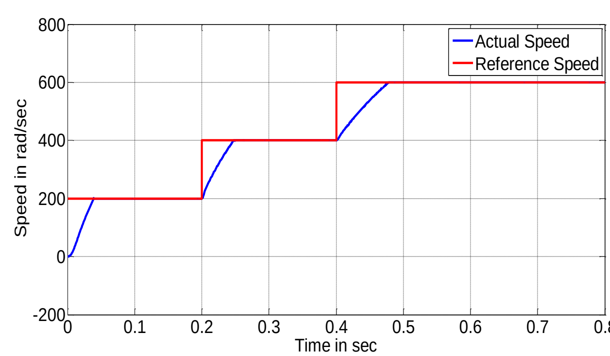

Figure 10(b). Speed response for Hysteresis controller-fed IM

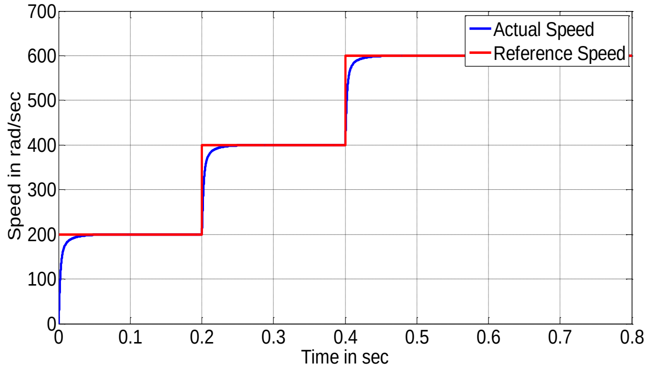

Figure 10(c). Speed response for PR controller-fed Induction Motor

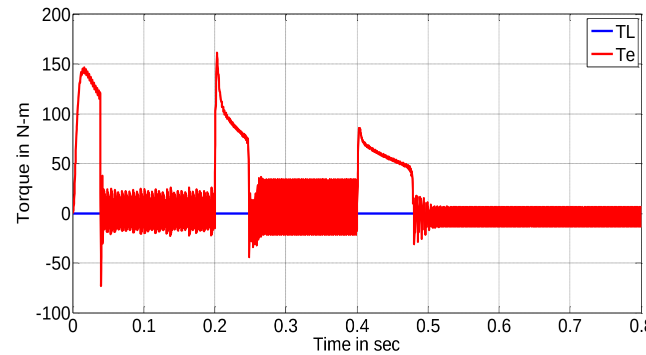

Figure 11(b). Torque characteristics for Hysteresis controller-fed IM

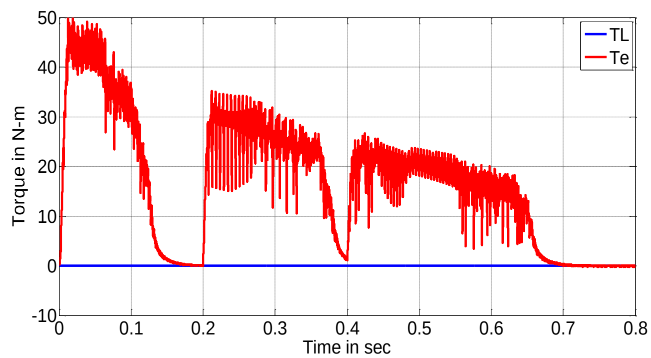

Figure 11(a). Torque characteristics for PWM inverter-fed IM

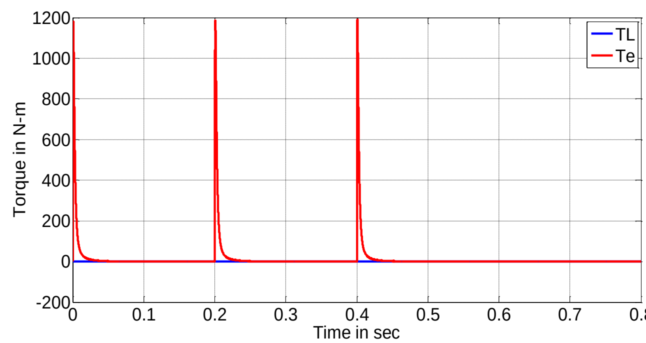

Figure 11(c). Torque characteristics for PR controller-fed IM

Input Parameters of Induction Motor

Sl.No:	Induction Motor Data		
	Parameters	***symbol***	***Value***
1.	Rotor Resistance	R_r	0.39Ω
2.	Stator Resistance	R_s	0.19Ω
3.	Core Resistance	R_c	0.2 Ω
4.	Rotor Inductance	L_r	1mH
5.	Stator Inductance	L_s	0.61mH
6.	Mutual Inductance	L_m	0.4mH
7.	Rotor leakage Inductance	L_{lr}	0.6mH
8.	Stator Leakage Inductance	L_{ls}	0.21mH
9.	Moment of Inertia	J	0.0226kg m^2
10.	Base Frequency	F	50Hz

5. CONCLUSION

The simulation results shows that the performance characteristics of Proportional Resonant (PR) vector control induction motor is improved that is the reduction in torque ripple and speed performance is improved when compared to PWM Inverter-fed vector control induction motor and hysteresis current control-fed vector control induction motor. Application of vector control induction motor with Proportional Resonant (PR) generate significant benefits in performance improvement and energy saving in home and industrial appliances.

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