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Speed Performance of Three Phase Induction Motor by using Simplified Vector Control method

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***Abstract*: -- Three phase induction motors are the most commonly and frequently encountered drives in the industry. This type of machines has the simple design and less maintenance. The performance of the motor is based on the simplified vector control method by using PI and PID controllers in MATLAB software. The controller has then been tuned by trial and error method and simulations have been run using the tuned controller. Using simplified vector control method, the performance of induction motor has been carried out and analyzed on the basis of torque and speed. Implementation by using various proportional controllers using vector control scheme has been done. The PI, PID controller has been used to develop the simplified control system. The performance of three phase induction motor is carried out for no load and full load condition. For various load condition and various system design using the proportional controller, overall performance is the drive is figured out. On the basis of simulation results without feedback system controllers are designed with specific values. The performance of three phase induction motor is improved with the use of PID which gives better settling time with the reduction in overshoot as compared with PI controller. Comparison of the various system designs has been done.**

***Keywords*: - Three Phase Induction Motor, Vector Control Method, MATLAB, PI & PID.**

I. INTRODUCTION

Usage of induction motors has increased tremendously since the day of its invention. They are being used as actuators in various industrial processes, robotics, house appliances (generally single phase) and other similar applications. Three phase induction motors are the most common and frequently encountered machines in industry, because this type of machines has a simple design and less maintenance.

In addition, induction motors are robust and have better performance in high speed and torque. Induction motor drives, especially squirrel cage rotor-type, have been the workhorses in industry. The complex dynamics of ac machines, machine parameter variations, and the difficulties of processing feedback signals in the presence of harmonics create this complexity. Induction motor can be controlled like a separately excited dc motor, brought a great improvement in the high-performance control of ac drives especially with the invention of vector control in the beginning of 1970s. Because of major advantages of vector control, this method of control will oust scalar control, and will be accepted as the industry-standard control for ac drives.

The speed control of induction motor is traditionally handled by fixed gain PI and PID controllers. There are many control strategies use for speed control of induction motor. The inverter-fed induction motor drive can be controlled by using various schemes depending on the application, desired performance, and controller design complexity. Out of which a vector control scheme is used for the speed control of three phase induction motor drive. The work is based on inverter fed induction motor scheme. The inverter consists essentially of six power switches , depending on the drive power capacity and the inverter switching frequency. The inverter converts the DC link voltage into an adjustable three-phase AC voltage. Different control schemes can be used to control the inverter output voltage and frequency. One of the most utilized schemes is pulse width modulation (PWM) in which three-phase variable sinusoidal voltage waveforms are obtained by modulating the on and off times of the power switches. With the use of different controller's i.e. conventional PI and PID controller, the speed response is checked and compared with respect to settling time, overshoot, undershoot steady-state error etc. The induction motor is an attractive piece of equipment in many industrial applications due to its ease of speed controllability. So we are going to control the speed of induction motor in open loop and closed loop system using PI and PID controllers.

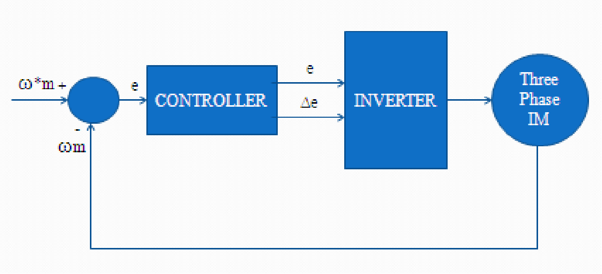


Fig. 1: Block diagram of Induction motor speed control system

For speed control of induction motor different controllers such as conventional PI and PID controllers are used. When the load is applied on the motor the motor speed decreases. This decreased speed will be feedback to the summation block. The summation block consists of two inputs, whichare the feedback speed and the reference speed. The error signal is developed from both this inputs which is fed to the PI and PID controllers where all these controllers acts and brings back the speed to the reference value. Therefore the closed loop system using PI and PID controller has been achieved in this project scheme. After getting the speed response for different controllers, the results are compared. Speed control techniques for induction motor drive which we are using in this project:

1. Speed response of induction motor in open loop system.
2. Speed control of induction motor in closed loop system using PI Controller.
3. Speed control of induction motor in closed loop system using PID Controller.

II. SPEED CONTROL STRATEGIES OF INDUCTION MOTOR

The speed control of induction motors involves more complicacy than the control of dc motor, especially if comparable accuracy is desired. The main reason for the same can be attributed to the complexity of the mathematical model of the induction machine, as well as the complicated power converters supplying this motor. Variable speed induction motor drives employ various control algorithms. In industrial drive applications, the PWM inverter operates as a three-phase variable-frequency, variable-voltage source with fundamental frequency varying from zero to three times the motor nominal frequency. In some control schemes where a three-phase, variable-frequency current source is required, current control loops are added to force the motor currents to follow an input reference (usually sinusoidal).The inverter-fed induction motor drive can be controlled by using various schemes. The most utilized schemes are:

1. Stator V/f control
2. Stator currents and open loop flux control
3. Vector control (field-oriented control)
4. Direct torque control (DTC)

Vector control (Field-oriented control)

A variable-speed induction motor drive using field-oriented control is one the most frequently used technique. In this control scheme, a d-q co-ordinates used to achieve decoupling between the motor flux and torque. They can be thus separately controlled by stator direct-axis current and quadrature-axis current respectively, like in a DC motor. The induction motor is fed by a current-controlled PWM inverter, which operates as a three-phase sinusoidal current source. The motor speed $\omega$is compared to the reference ω* and the error is processed by the speed controller to produce a torque command Te*. As shown in, the rotor flux and torque can be separately controlled by the stator direct-axis current i_{ds} and quadrature -axis current i_{qs}, respectively.

The stator quadrature-axis current reference $i_{qs}*$ is calculated from torque reference T_e*as

$$i_{qs}* = \frac{2}{3}.\frac{2}{p}.\frac{L_r}{L_m}.\frac{T_e*}{|\Psi_r|_{est}}$$

Where Lr is the rotor inductance, L_m is the mutual inductance, and $|\Psi_r|_{est}$is the estimated rotor flux linkage given by

$$|\Psi_r|_{est} = \frac{L_m i_{ds}}{1 + \tau_r s}$$

Where $\tau_r = L_r/R_r$ is the rotor time constant.

The stator direct-axis current reference i_{ds}* is obtained from rotor flux reference input $|\Psi_r|^*$.

$$i_{ds}* = \frac{|\Psi_r|^*}{L_m}$$

The rotor flux position θ_e required for coordinates transformation is generated from the rotor speed ω_m and slip frequencyω_{sl}.

$$\theta_e = \int(\omega_m + \omega_{sl})dt$$

The slip frequency is calculated from the stator reference current i_{qs}* and the motor parameters.

$$\omega_{sl} = \frac{L_m}{|\Psi_r|_{est}}.\frac{R_r}{L_r}.i_{qs}*$$

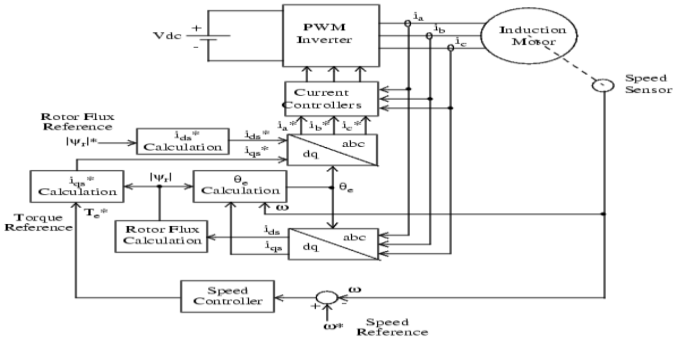


Fig. 2: Field-Oriented Variable-Frequency Induction Motor Drive

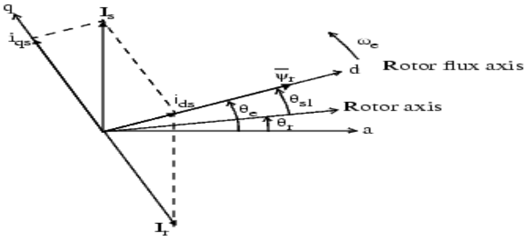


Fig. 3: Field-Oriented Control Principle

The i_{qs}* and i_{ds}* current references are converted into phase current references i_a*, i_b*, i_c* for the current regulators. The regulators process the measured and reference currents to produce the inverter gating signals. The role of the speed controller is to keep the motor speed equal to the speed reference input in steady-state and to provide a good dynamic during transients.

III. TYPES OF CONTROLLERS

A closed-loop control system utilizes an additional measure of the actual output to compare the actual output with the desired output response. The measure of the output is called the feedback signal. A feedback control system is a control system that tends to maintain a relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control.

3.1. PI CONTROLLER

A proportional–integral controller (PI controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PI controller calculates an "error" value as the difference between a measured process variable and a desired set point.

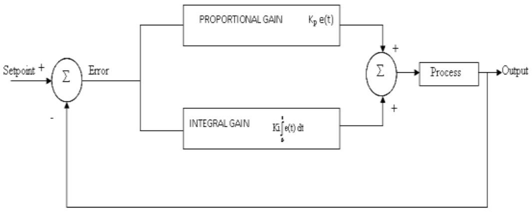


Fig. 4: Block diagram of PI controller

The PI control scheme is named after its two correcting terms, whose sum constitutes the Manipulated variable (MV). The proportional and integral terms are summed to calculate the output of the PI controller. Defining u(t) as the controller output, the final form of the PI 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
P_{out}: Proportional term of output
K_p: Proportional gain, a tuning parameter
K_i: Integral gain, a tuning parameter
e: Error = $SP - PV$
t: Time or instantaneous time (the present)

3.2 PID CONTROLLER

A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The PID controller calculation algorithm involves simply putting; the values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV).

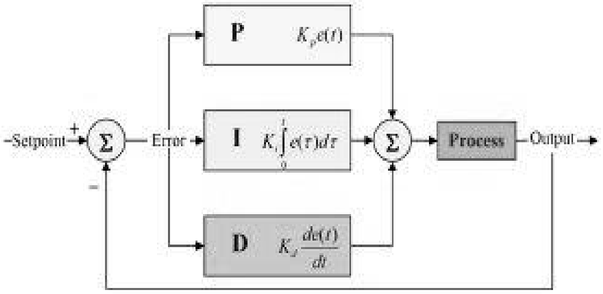


Fig. 5: Block diagram of PID controller

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)
τ : Variable of integration; takes on values from time 0 to the present *t*.

IV. MATLAB SIMULATION AND RESULTS

The speed and torque performance of induction motor is analyzed using MATLAB simulation. In first simulation, the induction motor is run with and without controller.

4.1. INDUCTION MOTOR DRIVE SYSTEM WITHOUT ANY CONTROLLER

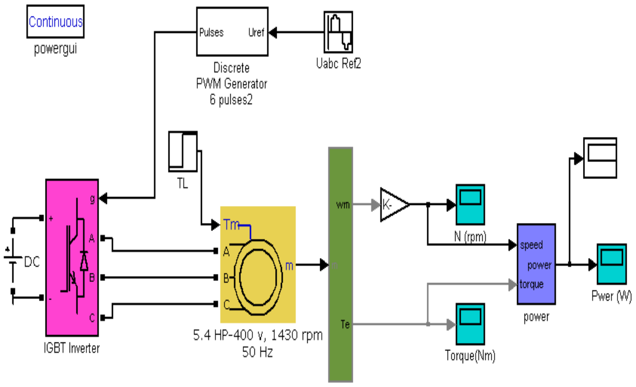
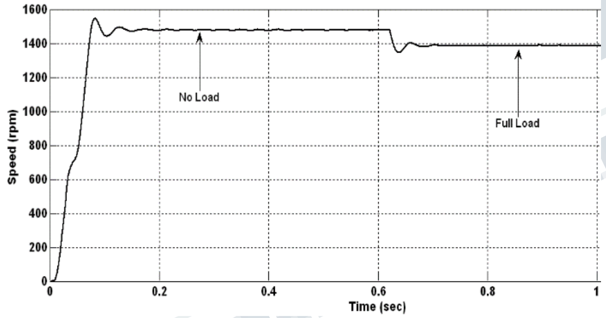


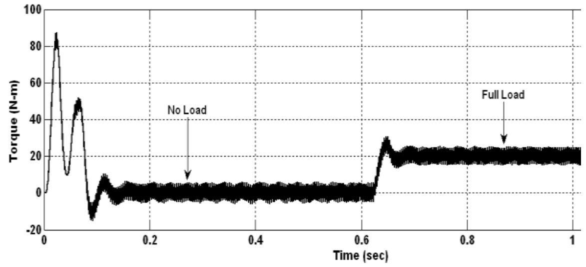
Fig. 6: MATLAB Model for speed control of IM without any controller

In open loop control system of induction motor, IGBT inverter is used for providing three phase supply to induction motor using reference pulse triggering signal. The PWM generator provides pulse triggering signal to IGBT. The power block measures the total output power of the system. The 5.4 HP, 400 V, 1430 rpm, 50 Hz, induction motor is used for the analysis of system.

4.1 Result Analysis of Induction Motor Drive System without Any Controller



(a) Speed Variation



(b)Torque Variation

Fig. 7: Dynamic Performance of Speed Control of Induction Motor Without Any Controller

Table No. 4.1: Analysis of Performance of Speed Control of Induction Motor Without any Controller

Parameters	No Load	Full Load
Speed	1480 rpm	1385 rpm
Settling Time	Not Settled	Not Settled
Overshoot	4.5%	--
Undershoot	--	2.88 %
Steady State Error	95	
Power	3052 W	

The performance of induction motor without using any controller which is shown in figure. The speed of induction motor ia not settled and have overshoot and undershoot of 4.5 % and 2.88 % respectively. Without using any controller the steady state error is 90. So as to improve the results with respect to settling time, steady atate error, overshoot and undershoot.

4.2 INDUCTION MOTOR DRIVE SYSTEM WITH PI CONTROLLER

The induction motor drive using PI controller is shown in fig. In close loop system, the gate triggering pulse signal is provided by using PI controller block. PI controller block consist of proportional and integral term with vector control drive system.

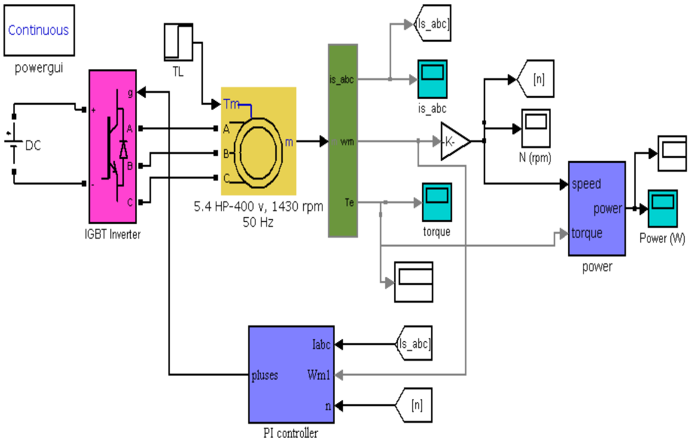
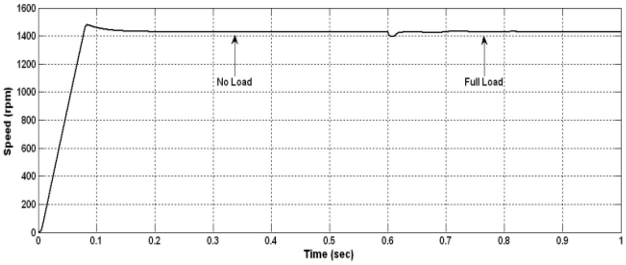


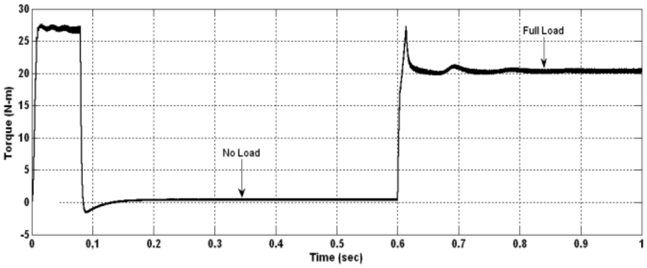
Fig. 8: MATLAB model for speed control of IM with PI controller

In PI controller blockcurrent (I$_{abc}$) and speed (ω_m) is given as input for the theta calculation and for the formation of reference I_d^* and T_e^*. From the phir and T_e^*, I_a^* is generated. Again, this I_a^*, I_d^* and theta produce I_{abc}^*. This I_{abc}^* is compared with I_{abc} which is output of the motor and the desired triggering pulses for IGBT inverter is generated. These pulses given to the inverter and output of inverter is changed with respect to the motor output. Hence desired controlling of induction motor using PI controller is achieved which is explained with the help of table shown below.

4.2.1 Result Analysis of Induction Motor Drive System with PI Controller



(a)Speed Variation



(b)Torque Variation

Fig. 9: Dynamic Performance of Speed Control of Induction Motor with PI Controller

Table No. 4.2: Analysis of Performance of Speed Control of Induction Motor With PI Controller

Parameters	No Load	Full Load
Speed	1430 rpm	1430 rpm
Settling Time	0.2 sec	0.22 sec
Overshoot	3.35%	--
Undershoot	--	2.4%
Steady State Error	Eliminated	
Power	3063 W	

The bolck diagram of speed control of induction motor with PI controller is as shown in fig.2. with the use of this controller the steady state error is completely eliminated which we can see in fig.. The speed is settled at 0.2 sec for no load and 0.22 sec for full load. The overshoot and undershoot are also reduced to 3.35% and 2.4 %.

4.3 INDUCTION MOTOR DRIVE SYSTEM WITH PID CONTROLLER

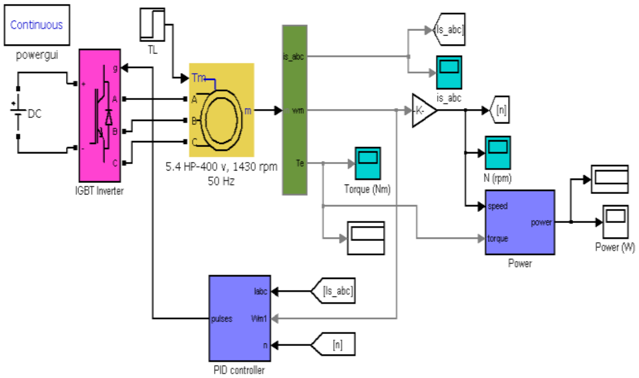
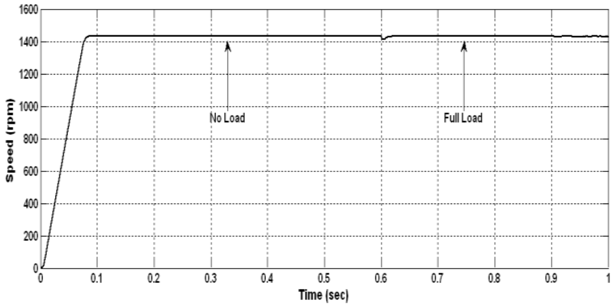


Fig. 10:MATLAB model for speed control of IM with PID controller

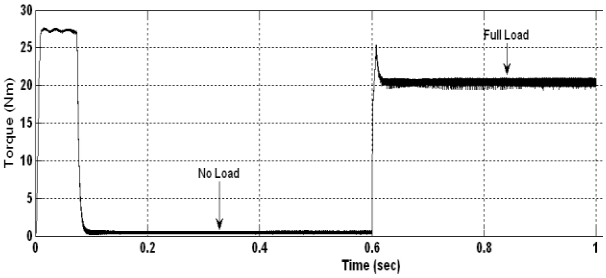
The MATLAB simulation diagram of speed control of induction motor with PID controller is as shown in fig. Again the gate triggering pulse signal is provided by using PID controller. PID controller block consist of proportional, integral and derivative term with vector control drive system. As shown in fig above, from the output of the motor the current I_{abc} and speed ω_m is given as a input to the PID controller block. And the results which are obtained is explained in fig below.

4.1 RESULT ANALYSIS OF INDUCTION MOTOR DRIVE SYSTEM WITH PID CONTROLLER

The performance of IM is shown in fig. above. This performance is analyzed and is explained with the help of table shown below.



(a) Speed Variation



(b)Torque Variation

Fig. 11: Dynamic Performance of Speed Control of Induction Motor With PID Controller

Table No. 4.3: Analysis of Performance of SpeedControl of Induction Motor WithPID Controller

Parameters	No Load	Full Load
Speed	1430 rpm	1430 rpm
Settling Time	0.1 sec	0.04 sec
Overshoot	0.21 %	--
Undershoot	--	1.259%
Steady State Error	Eliminated	
Power	3081 W	

With the use of this controller the steady state error is completely eliminated. The speed is settled at 0.1 sec for no load and 0.04 sec for full load. The overshoot and undershoot are also reduced to 0.21 % and 1.259 %.

4.4 INDUCTION MOTOR PARAMETERS

The motor used is a 3 phase Induction Motor,
Rotor type-squirrel cage, Reference type- Stationary,
5.4 HP, 1430 rpm, 400V, 50 Hz, 4 poles, J (Inertia) =0.0131Kg.m^2

Table 4.4.1: Induction Motor Parameter

Parameter	Rating
Stator Resistance(R_s)	1.405Ω
Rotor Resistance(R_r)	1.395 Ω
Stator Leakage Inductance(L_{ls})	0.005839 H
Rotor Leakage Inductance(L_{lr})	0.005839 H
Magnetizing Inductance(L_m)	0.1722 H

V. CONCLUSION

The project work has been done totally in MATLAB environment in order to test the system behavior before actually implementing it. The simulation consists of inverter fed induction motor drive in which the performance of the motor is tested with respect to speed and torque parameter. Thus, the work is divided into four sections.

1. Induction motor drive system without any controller
2. Induction motor drive system with PI controller
3. Induction motor drive system with PID controller

The performance of 3-phase induction motor is first tested without using any controller. The results are carried out on no load and on full load condition. On full load condition the rated speed is not achieved. Also it contains overshoot, undershoot, steady state error and the speed is not settled. So to overcome all the drawbacks different controllers are used.

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