

PI and Fuzzy Based Sensorless Speed Control of Induction Motor

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Abstract: In this paper speed control of induction motor without using speed sensor is presented. Speed is controlled by using both PI and Fuzzy Logic Controllers. Observer method of speed estimation is done for estimating the actual rotor speed. Speed of the induction motor is estimated by measuring stator currents and voltages. The estimated rotor speed is compared with actual speed using PI controller. The rise time, settling time and peak over shoot for the induction motor to attain the actual speed is high. When PI controller is replaced by Fuzzy Logic Controller, rise time, settling time and peak over shoot are reduced and speed is controlled efficiently. The simulation is done using MATLAB/SIMULINK software.

Index Terms: Induction motor (IM), Space Vector Pulse Width Modulation (SVPWM) inverter, Proportional-Integral (PI) Controller, Fuzzy Logic Controller (FLC).

I. Introduction

Induction motors are most widely used in all industries. The speed of the induction motor has to be varied according to application requirement [1], [3]. So it is necessary to control the speed of induction motor efficiently. The speed of the motor can be measured using sensor or speed can be estimated by measuring stator current/voltage. Recently sensor less speed control method is widely used [1]-[3]. PI controller is the most commonly used controller for speed control of induction motor. PI controller has demerits of high peak over shoot and response will be sluggish when there is sudden load disturbance. The problems are reduced by using fuzzy logic controller instead of PI controller and the simulation results are compared.

II. Induction Motor Drive

In earlier days DC motor have been used for variable speed applications. Speed control of DC motor was simple as the flux of both armature and field were decoupled in nature.

The ac-dc converter cost got increased with the invention of new semiconductor devices. When the supply is given directly to induction motor, the motor runs at constant speed according to supply frequency. Later AC motor evolved from constant speed motor to variable speed motor with the invention of variable voltage variable frequency drive.

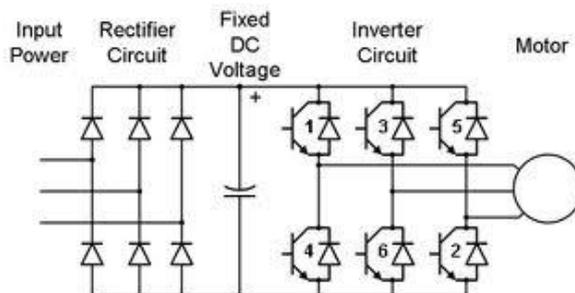


Fig.1. Variable Voltage Variable Frequency Drive

The input supply of constant voltage constant frequency is first converted into fixed DC voltage. The DC voltage is then converted to variable voltage variable frequency supply to the induction motor using inverter circuit as shown in Fig 1. Pulse Width Modulation (PWM) controls switching of power semiconductor devices in inverter so that variable voltage and variable frequency are obtained.

III. Speed Control of Induction Machine

Induction motor is a rugged motor with simple construction and requires only little maintenance. Two methods of speed control of induction machine are i) scalar control and ii) vector control. Constant V/F method of speed control comes under scalar control method. The V/F ratio is maintained constant so that the air gap flux is maintained constant and also the torque will remain constant for all speed range.

The performance of Induction motor is limited by simple control method like scalar control. The dynamic performance of machine can be obtained by complex control schemes like vector control. Vector control provides efficient and accurate control of the motor's speed and torque [7], [12].

Vector control includes i) Field Oriented Control and ii) Direct Torque Control. Torque generation and magnetization functions of induction machine are decoupled using mathematical transformations. Such decoupled control is commonly called rotor flux oriented control or Field Oriented Control (FOC) [14].

IV. Open Loop and Closed Loop Speed Control

In open loop control by varying the supply voltage and frequency the speed of induction motor is varied. V/F method comes under open loop control of induction motor. Poor precision is the major disadvantage of open loop control.

In closed loop control the actual rotor speed is measured and feedback. The actual speed is compared with reference speed at which the motor should run. The error signal is sent to controller. According to the controller output the motor runs at desired speed. The closed loop speed control can be done using speed sensor or without using speed sensor. The actual speed of rotor can be measured by using sensor like encoder or proximity sensor. But recently the speed is estimated without using sensor by measuring stator voltage/currents.

V. Speed Estimation Methods

There are various methods of speed estimation. Some estimation methods are rotor slot harmonics, injecting probing signal in to stator terminal voltage and/or current to detect the rotor flux and consequently the motor speed [5],[15],[17]. Both of these methods have demerits of large computation time and complexity. Alternatively speed information can be obtained by using the machine model and its terminal quantities like voltage and current. These include different methods such as the use of simple open loop speed calculators, MRAS, Extended Kalman filters, adaptive flux observer, Artificial Intelligent techniques and sliding mode observer[7],[12],[14],[16].

VI. Existing Method

The 3 phase supply of 400V which is phase shifted by 120 degree is fed to induction motor through a rectifier and inverter circuit. Indirect Field Oriented Control (IFOC) method is used where the rotor flux is estimated from model of induction machine. Switching of power electronic devices in the inverter is done by space vector pulse width modulation method (SVPWM).

The 3 phase stator currents are converted to 2 phase currents using abc- $\alpha\beta$ transformation. Stator and rotor flux are estimated from (1), (2), (3), (4) and (5). Torque and angle are estimated using (6) and (7). Simple observer system is used and speed is estimated [14],[16],[19] and [21].

$$\text{Stator flux, } |\psi_s| = \sqrt{\psi_{s\alpha}^2 + \psi_{s\beta}^2} \quad (1)$$

$$\text{Where } \psi_{s\alpha} = \int (v_{s\alpha} - R_s i_{s\alpha}) dt \quad (2)$$

$$\psi_{s\beta} = \int (v_{s\beta} - R_s i_{s\beta}) dt \quad (3)$$

$$\text{Rotor flux, } |\psi_r| = (\psi_s - \sigma L_s i_s) / K_r \quad (4)$$

$$\text{Where } K_r = L_m / L_r; \sigma = (1 - L_m^2) / L_s L_r.$$

$$\text{Magnitude of rotor flux, } |\psi_r| = \sqrt{\psi_{r\alpha}^2 + \psi_{r\beta}^2} \quad (5)$$

$$\text{Torque, } T_e = (3/2)P(\phi_{sd} i_{sq} - \phi_{sq} i_{sd}) \quad (6)$$

$$\text{Estimated angle, } \alpha = \tan^{-1}(\phi_{sq} / \phi_{sd}). \quad (7)$$

The 2 phase currents and voltages are used to estimate the speed, torque, angle and flux from the above equations. The stator currents are separated into torque and flux producing components. The estimated speed and flux are compared with reference values and error signal is given to PI controller. The output of controller is two phase voltages. The two phase voltage is again converted to three phase voltage using inverse transform and fed to SVPWM block.

VII. Space Vector Pulse Width Modulation

This is the advanced method of pulse width modulation with inverter switching states of V0,V1,V2,V3,V4,V5,V6,V7 where V0,V1 are null vectors and rest are active vectors. The vectors are used to generate space voltage vectors as shown in Fig 2.

The magnitude of six active voltage vector is given by $(2/3)V_{bus}$ which corresponds to maximum phase voltage. The input to the SVPWM block is the 2 phase voltage output from PI controller.

Active vector is selected according to time interval which is less than one half carrier period. In order to control the inverter switches, reference voltage V_{out} and PWM period T should be calculated.

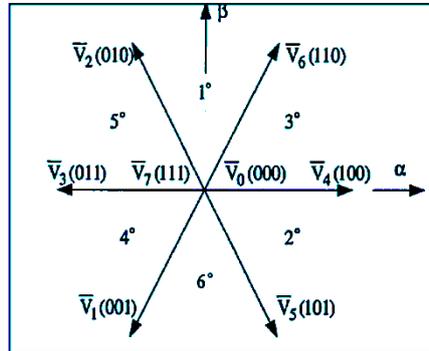


Fig.2. Vector diagram representing voltage vectors in SVPWM.

If the reference vector lies sector 3 then V out and T are determined from the equations (8) and (9).

$$T = T_4 + T_6 + T_0 \tag{8}$$

$$V_{out} = (T_4 / T)v_4 + (T_6 / T)v_6 \tag{9}$$

Where T denotes the time period of corresponding voltage vectors.

VIII. Types of Controllers

Mainly the controllers are classified into two types as Linear Type controller and Non-linear type controller. In linear type controller the output depends directly on the changes in input. The controller is already tuned and the gain value for the controller is fixed. PI controller, State feedback controller, Predictive controller with constant switching frequency controllers come under linear type controller [25].

Hysteresis controller and Predictive controller with online optimization come under non-linear type controller. The output of these controllers depends not only on changes in input but also the controller parameters [25].

Fuzzy logic and Neural Network based controllers are recently developed controllers.

IX. Simulation Work of Sensorless Speed Controlled Induction Motor Using Pi Controller

The simulation work is done in MATLAB software. Induction motor of rating 4000W is selected. Parameters of induction motor are shown in Table.1

PARAMETER	VALUE
Number of pole pairs, p	2
Stator resistance, Rs	0.5Ω
Rotor resistance, Rr	0.25Ω
Stator inductance, Ls	0.0415H
Rotor inductance, Lr	0.0412H
Mutual inductance, Lm	0.0403H
Leakage inductance, Lsc	0.0018H
Power, P	4000W
Supply voltage, V	400V
Frequency of input supply, f	50Hz

Table.1. Parameters of Induction Motor

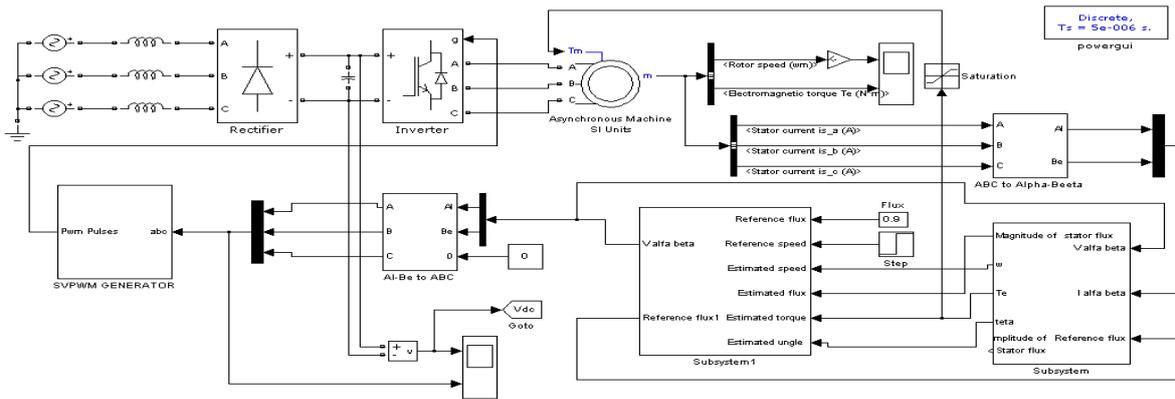


Fig.3. Simulation of sensor less speed control of Induction motor using PI controller.

Universal blocks are used for rectifier and inverter circuits. Asynchronous machine in SI unit is selected. The actual speed of motor and torque are displayed in scope1. The dc output voltage and the input supply voltage to SVPWM block is displayed in scope 2. The overall Simulation is shown in Fig.3

Clarke transformation is done by using the formula:

$$\begin{bmatrix} V_{\alpha} \\ V_{\beta} \end{bmatrix} = (2/3) \begin{bmatrix} 1 & 1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \quad (10)$$

Simulation for Clarke transformation is shown in Fig 4.

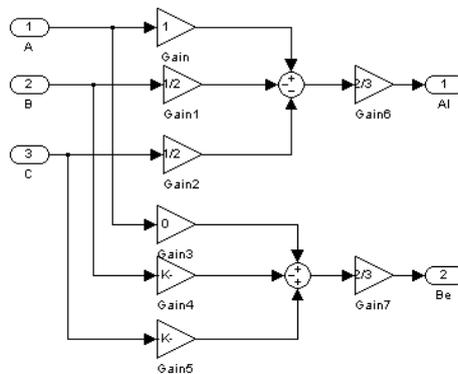


Fig.4. abc to αβ transformation

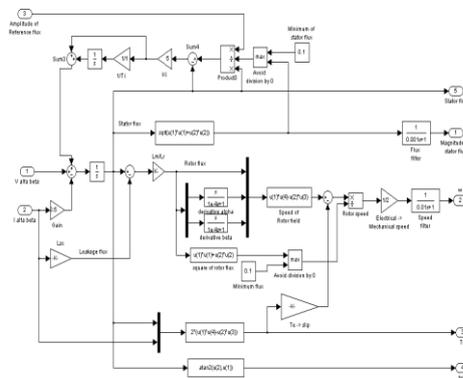


Fig .5.Estimation Block.

Speed, torque, stator flux and rotor flux are estimated using observer system as shown in Fig 5. Parameter variation in induction motor due to load changes or temperature changes should not affect the speed estimation. Similarly at low speeds the inaccuracy in speed estimation should not occur as the flux produced will be low. Observer system is designed such that it over comes the above problems.

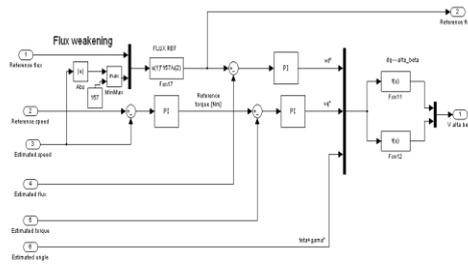


Fig.6.Controller block

Reference speed and estimated speed are compared and error value is fed to PI controller to produce reference torque according to the equation (11)

$$T_{ref} = \omega_{ref} - \omega_{estimated} \quad (11)$$

The PI controller is tuned to the values of $K_p=1/0.3$ and $K_i=80$. Reference torque and estimated torque are compared and the error value is again fed to PI controller which is tuned to values of $K_p=1/0.05$ and $K_i=1$. The output of this controller is the voltage value in quadrature axis as in (12).

$$V_q = T_{ref} - T_{estimated} \quad (12)$$

$$V_d = \phi_{ref} - \phi_{estimated} \quad (13)$$

Reference flux and estimated flux are compared and error value is fed to PI controller to produce voltage value in direct axis as in (13). The Simulation work using PI controller is shown in Fig 6.

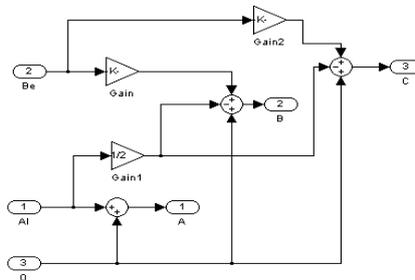


Fig .7.αβ to abc transformation.

Inverse transformation is done for converting voltage from αβ to abc co-ordinates. This value is given as input to SVPWM block. The switching states are varied to the inverter only from SVPWM block. Simulation for Inverse transformation is shown in Fig 7.

PI controller for generating reference torque is replaced by Fuzzy Logic Controller. The error values of speed and differentiation of error value is taken as input and the rules are framed and the output of the FLC is the frequency which is again converted reference torque value and the voltage values are generated for SVPWM block.

X. SIMULATION RESULTS

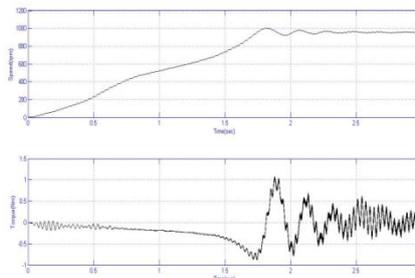


Fig.8. Output for sensor less speed controlled IM.

The output for the Simulation is shown in the Fig.8. The rise time to reach reference speed is about 2 sec and settling time is about 1sec. when PI controller is replaced by FLC the output is expected such that rise time is reduced to 0.5 sec and settling time also reduces to 0.5 sec and smooth speed control is obtained.

XI. Conclusion

The sensor less speed estimation method is done by using observer system. The estimated speed is against parameter variations. The speed control is obtained from very low speed to rated speed. When PI controller is used the performance of IM to attain reference speed is quite low. When PI controller is replaced by FLC the performance of the motor to attain reference speed is improved.

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