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Research Article

Performance of Induction Motor by Indirect Vector Controlled Method using PI and Fuzzy Controller

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Abstract

This paper mainly deals with the fuzzy control approach for the control and observation of induction motor. Control of induction motor is a challenging problem for due to internally nonlinear and high order nature of the motor. The fuzzy logic controller is chosen because of following advantages as: (i) a wider range of operating conditions can be covered using FLCs. (ii) they are easier to adapt in terms of natural language. (iii) they are economically advantageous to develop. For indirect vector control of induction motor a reference speed has been used and control architecture includes some rules. These rules provides relationship between two inputs and an output. These are speed error(e) and rate of change of the speed error(Δe) are considered as the input linguistic variables and the torque-producing current component(i_q) is considered as the output linguistic variables. The errors are evaluated according to rules in accordance to defined member functions. The complete vector control scheme of the IM drive incorporating the FLC is implemented using MATLAB simulation. The performances of the proposed FLC-based IM drive are determined and compared to those obtained from the conventional proportional-integral (PI) controller-based drive theoretically at different dynamic operating conditions such as sudden change in command speed, step change in load, etc.

Keywords- *Indirect Vector control, Fuzzy Logic Intelligent controller, PI controller, Induction motor, Speed control*

1. Introduction

The electromagnetic strengths or torques created in the driving engine have a tendency to engender movement of the drive framework. This movement might be uniform if the direct speed or the precise speed is steady. Hence the electrical drives great element execution is compulsory in order to react the adjustments in charge velocity and torques. The most generally utilized controller for the speed control of Induction motor is proportional in addition to Integral (PI) controller. In any case, the PI controller has a few negative marks, for example, the high beginning overshoot; affectability to controller picks up and slow reaction because of sudden unsettling influence. To overcome these problems, replacement of PI controller by an intelligent controller based on fuzzy set theory is proposed in this work. The fuzzy logic has certain advantages compared to the classical controllers such as simplicity of control, low cost, and the possibility to design without knowing the exact mathematical model. The analysis design and simulation of the controller is carried out based on the fuzzy set theory. This can be accomplished by vector control of induction motor, which emulates the performance of dc motor and brushless dc motor servo drives. Compared to dc and brushless dc motors, induction motors have a lower cost and a more rugged construction. Operation of the drive with constant full torque below base speed and above base speed with reduced flux. Torque is the fundamental variable of an induction machine, to get the accurate control of speed and position by controlling the torque of induction machines. This paper investigates the successful application of the FLC for normal speed control of IM drives. The complete vector control scheme of IM incorporating the FLC has been successfully implemented in MATLAB Simulink. The performances of the proposed drive have also been compared with those obtained from the conventional PI controller both theoretically and experimentally. It is found that the proposed FLC is insensitive to temperature changes, inertia variations, and load torque disturbances. This FLC could be a suitable replacement for the conventional PI controller for high-performance drive system.

2. Motor dynamics and control strategy

The mathematical model for a three-phase Y-connected squirrel-cage IM is described by following equations in de-qe synchronously rotating reference frame

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$$T_e = \frac{3}{2}\frac{P}{2} L_m\left(i_{qs}^e i_{dr}^e - i_{ds}^e i_{qr}^e\right) \quad (1)$$

$$T_e = J_m \frac{d\omega_r}{dt} + B_m \omega_m + T_L \quad (2)$$

$$\frac{d\theta_r}{dt} = \omega_r \quad (3)$$

Where v_{qs}^e, v_{ds}^e are d, q axis stator voltages, respectively, i_{ds}^e, i_{qs}^e, are d,q axis stator currents, respectively,i_{dr}^e, i_{qr}^e, are d,q axis rotor currents, respectively, R_s, R_r are the stator and rotor resistances per phase, respectively, L_s, L_r are the self inductances of the stator and rotor, respectively, L_m is the mutual or magnetizing inductance, ω_e is the speed of the rotating magnetic field, ω_r is the rotor speed, P is the number of poles, p is the differential operator, T_e is the electromagnetic developed torque, T_L is the load torque, J is the rotor inertia, B_m is the rotor damping coefficient, and Θ_r is the rotor position.

The two-axis stator voltages and currents are related to the three-phase representations by the following equation:

$$\begin{bmatrix} x_{qs}^e \\ x_{qs}^e \end{bmatrix} = \begin{bmatrix} -sin\omega_e t & cos\omega_e t \\ cos\omega_e t & sin\omega_e t \end{bmatrix} \begin{bmatrix} \frac{2}{3} & \frac{-1}{3} & \frac{-1}{3} \\ 0 & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} x_{as} \\ x_{bs} \\ x_{cs} \end{bmatrix} \quad (4)$$

where x may represent the current or voltage. The key feature of the field-oriented control is to keep the magnetizing current at a constant rated value by setting i_{dr}^e=0. Thus, the torque-producing current component can be adjusted according to the torque demand. With this assumption, the mathematical formulations can be rewritten as:

$$\omega_{sl} = \frac{R_r}{L_r}\frac{i_{qs}^e}{i_{ds}^e} \quad (5)$$

$$i_{qs}^e = -\frac{L_m}{L_r} i_{qr}^e \quad (6)$$

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\lambda_{dr}^e i_{qs}^e \quad (7)$$

where ω_{sl} is the slip speed and λ_{dr} is the d- axis rotor flux linkage. The block diagram of FLC based indirect vector control for IM shown in fig.1

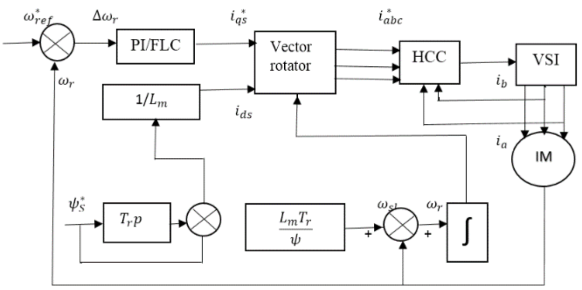

Fig.1. FLC-based IM drive

The speed error and rate of change of the speed error are processed by the fuzzy controller to generate the torque-producing current component commandi_q^*(n). the phase current commands i_a^*,i_b^* and i_c^* are then compared with the actual currenti_a,$i_b$and $i_c$to generate PWM signals, which will fire the power semiconductor devices of the three-phase inverter to produce the actual voltages to the motor.

3. Design of FLC for induction motor

For the proposed FLC, the speed error and rate of change of the speed error are considered as the input linguistic variables and the torque-producing current component is considered as the output linguistic variable. Thus, the functional relation of the FLC can be expressed as,

$$i_q(\text{n}) = \int \Delta i_q(\text{n}) = f(\Delta\text{e(n)}, \Delta\omega_r(n)) \quad (8)$$

where $\Delta\text{e(n)} = \Delta\omega_r(n) - \Delta\omega_r(n-1)$is the changing speed error, $\Delta\omega_r(n) = \omega_{ref}^* - \omega_r(n)$represents present speed error, $\Delta\omega_r(n-1)$represents past speed error signal, $\omega_r(n)$is the actual speed ,$\omega_{ref}^*$is the command speed and function is nothing but nonlinear function.The main objective of control strategy is to follow the command speed by providing the proper torque-producing current component i_q depends on the operating conditions.The rotor position of induction motor can be expressed as:

$$\theta_e = \theta_r + \theta_{sl} \quad (9)$$

whereΘ_e is the position of rotating field, Θ_r be the rotor position andΘ_{sl}represents slip position of induction motor. In the next step the most important part is to choosing fuzzy membership function of $\Delta\omega_r(n)$,Δe(n) and $i_q^*(n)$.The trapezoidal membership functions are used as a membership functions for fuzzy sets which reduces the computation for implementation. The rules used for induction motor specific algorithm are shown in Table II. Depending on these rules, the fuzzy rule based matrix is defined in Table I. For this paper use Mamdani-type fuzzy inference is used. Choosing the particular membership functions, fuzzy sets for different input/output values and the rules used selected by trial and error to obtain the optimum motor performance. For this paper we make use of center of gravity method for defuzzification. The output is given as,

$$output\ (i) = \frac{\sum_{k=1}^{N} i\mu_{c(k)}(i)}{\sum_{k=1}^{N} \mu_{c(k)}(i)} \quad (10)$$

Table 1 fuzzy rule based matrix

Δωr Δe	NH	NL	ZE	PL	PH
NE	NH	NL	NC	PM	PH
ZE	NH	NL	NC	PM	PH
PS	NH	NL	PL	PM	PH

Table 2 Fuzzy rules

i) If $\Delta\omega_r(n)$ PH (positive high), $i_q^*(n)$ is PH(positive high).
ii) If $\Delta\omega_r(n)$ PL (positive low), $i_q^*(n)$ is PM(positive medium).
iii) If $\Delta\omega_r(n)$ NL (negative low), $i_q^*(n)$ is NL(negative low).
iv) If $\Delta\omega_r(n)$ NH(negative high),$i_q^*(n)$ is NH(negative high).
v) If $\Delta\omega_r(n)$ ZE(zero) and Δe ZE (zero),$i_q^*(n)$ is NC(no change).
vi) If $\Delta\omega_r(n)$ ZE(zero), Δe ZE(negative), $i_q^*(n)$ is NC(no change).

4. Results and discussion

In this paper we have to check response of IM with FLC as well as conventional PI controller. Designing of speed control loop and simulated. Check the speed responses under different operating conditions such as change in reference speed, step change in load etc. The PI controller is tuned to give optimum response under rated conditions, the FLC provides better performances like faster response time, improving settling time, reduces overshoot etc. Also the fuzzy logic controller is not affected by change in command speed and hence provides good tracking speed is obtained with FLC. Whereas the PI controller is affected by change in reference speed.

Fig 2 shows the PI and FLC with a command speed of120 rad/sec applied with no load condition. The PI controller shows an overshoot and takes longer time to settle down at the nominal value. The FLC shows a smooth response to the command speed and it settles down in small time.

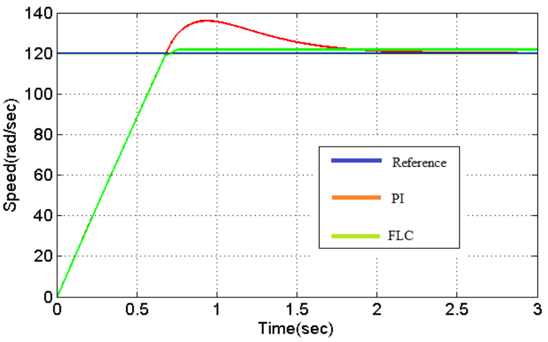

Fig.2 Simulated response of drive with no load

Fig 3 shows the response of the motor at loaded condition. The motor speed is set as 120 rad/sec and the load of 200 Nm is applied at 1.8 sec. The PI controller response shows a huge decrease in speed of the induction motor during loaded condition. The FLC has a low drop in response compared to the PI controller.

Fig.4 shows the response of the induction motor to pulse signal with load of 200N-m and the reference speed of 120rad/sec.

Fig 5 shows the response of the induction motor to variable command speed applied to it under no load condition. The PI controller shows overshoot in both responses. The FLC shows a smooth and fast response to the change in command speed.

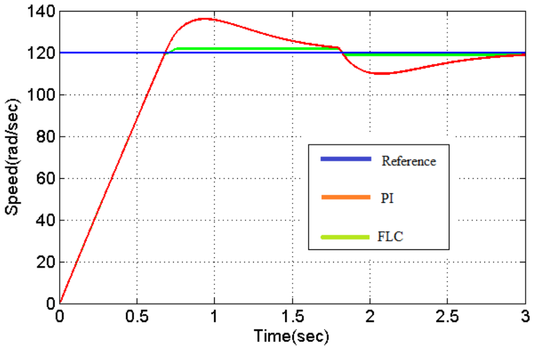

Fig.3 Simulated response of drive with load

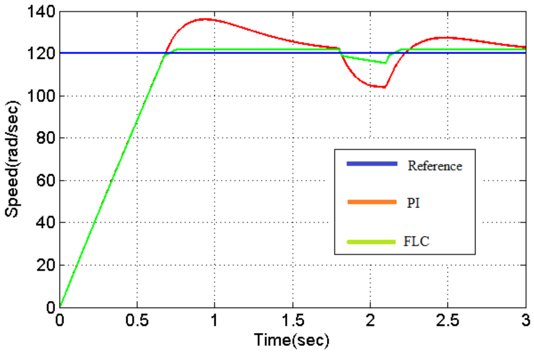

Fig.4 Simulated response of drive with pulse load

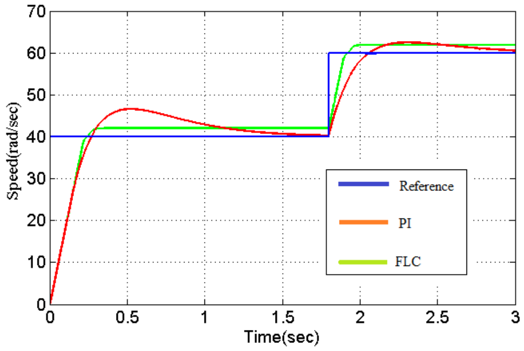

Fig.5 Response of drive with two reference speeds

Conclusion

A FLC-based indirect vector control of an IM has been presented in this paper. The FLC has been designed for a speed-control loop. The simulation has been carried out using the Simulink Fuzzy Logic Toolbox Manual Guide. The FLC has shown superior performances over the PI controller.The simplification or linearization of the non-linear system under consideration has to be performed by the conventional control methodologies like PI, PD and PID since their construction is based on linear system theory. Hence, these controllers do not provide any guarantee for good performance. They require complex calculations for evaluating the gain coefficients. These controllers however are not recommended for higher order and complex systems as they can cause the system to become unstable. Hence, a more heuristic approach is required for choice of the controller parameters which can be provided with the help of fuzzy logic, where we can define variables in a subjective way. Thus we can avoid the numerical complicacy involved in higher order systems. Fuzzy logic provides a certain level of artificial intelligence to the controllers since they try to imitate the human thought process. This facility is not available in the conventional controllers

Appendix

Motor Parameters

1hp,3phase,265Volts,60Hz,$P=4$,$R_s=0.087\Omega$,$R_r=0.228\Omega$, $L_m=0.3489H$,$J_m=1.662Kg\text{-}m^2$

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