Simulation of Fuzzy Sliding Mode Controller for Indirect Vector Control of Induction Motor

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Abstract—Because of the low maintenance and robustness induction motors have many applications in the industries. Most of these applications need fast and smart speed control system. This paper introduces a smart speed control system for induction motor using fuzzy Sliding mode controller. The fuzzy-logic with sliding mode speed controller is employed in the outer loop. The performance of Fuzzy Logic control technique has been presented and analyzed in this work. The fuzzy logic controller is found to be a very useful technique to obtain a high performance speed control. The indirect vector controlled induction motor drive involves decoupling of the stator current in to torque and flux producing components. The analysis, design and simulation of the fuzzy logic controller for indirect vector control of induction motor are carried out based on fuzzy set theory. The model is carried out using Matlab/Simulink. The simulation results shows the superiority of fuzzy sliding mode controller in controlling three phase Induction motor with indirect vector control technique.

Key words: Fuzzy logic, Sliding mode controller, PI controller, Induction motor drive.

I. INTRODUCTION

The induction motor is considered since its discovery as actuator privileged in the applications of constant speed, and it has many advantages, such as low cost, high efficiency, good self-starting, its simplicity of design, the absence of the collector brooms system, and a small inertia. However, induction motor has disadvantages, such as complex, nonlinear, and multivariable of mathematical model of induction motor, and the induction motor is not inherently capable of providing variable speed operation. These limitations can be solved through the use of smart motor controllers and adjustable speed controllers, such as scalar and vector control drive Field Oriented Control (FOC). Vector control was invented in the late 1960. As the induction motors were controlled using scalar control methods like the volt hertz control, the magnitude and frequency of the stator voltages are determined from steady-state properties of the motor, which leads to poor dynamic performance. In FOC the magnitude, frequency and instantaneous position of voltage, current and flux linkage vector are controlled and valid for steady state as well as transient conditions. Conventional control of an induction motor is difficult due to strong nonlinear magnetic saturation effects and temperature dependency of the motor’s electrical parameters. As the conventional control approaches require a complex mathematical model of the motor to develop controllers for quantities such as speed, torque, and position. Recently, to avoid the inherent undesirable characteristics of conventional control approaches, Fuzzy Logic Controller (FLC) is being developed. FLC offers a linguistic approach to develop control algorithms for any system. It maps the input-output relationship based on human expertise and hence, does not require an accurate mathematical model of the system and can handle the nonlinearities that are generally difficult to model. This consequently makes the FLC tolerant to parameter variation and more accurate and robust.

The complete paper is demonstrated as follows, section II describes the indirect vector control of Induction motor. The design and description of intelligent controllers are provided in section III the simulation results are presented in section IV, section V concludes the work.

II. INDIRECT VECTOR CONTROL OF INDUCTION MOTOR

Fig. 2.0: Indirect Vector Control of Induction Motor.

Fig. 2.0 shows an Indirect Vector Control Method [2]. It consists of a slip frequency calculation, Inverter Voltage and Current Elements, sensing integrator of error speed signal and the corresponding Phase diagram is shown in Fig.2.2.

The Vector control techniques have made possible the application of induction motors for high-performance applications, where traditionally only DC drives were applied. The vector control scheme enables the control of the induction motor in the same way as separately excitation DC motors. As in the DC motor, torque control of induction motor is achieved by controlling the torque current component and flux current component independently. In the indirect vector control method, the rotor field angle and thus the unit vectors are indirectly obtained by summation of the rotor speed and slip frequency [2].

Fig. 2.1: Block Diagram of Fuzzy Sliding Mode Controller
For high performance drive the indirect method of vector control is preferred. The indirect vector control method is essentially same as the direct vector control except that the rotor angle $\theta_e$ is generated in an indirect manner using the measured speed $\omega_r$ and the slip speed $\omega_s$. To implement the indirect vector control strategy, it is necessary to take the following dynamic equations into consideration [3,4,5]. With respect to phasor diagram of Indirect Vector Control method of induction motor, this is shown in Fig.2.2.

The rotor equations:

$$\frac{d\psi_r}{dt} = \frac{1}{L_r} \left[ i_q - \frac{R_r}{L_r} \psi_r - \frac{L_m}{L_r} i_d \right]$$

$$\frac{di_d}{dt} + \frac{R_r}{L_r} i_d = \frac{L_m}{L_r} \omega_s$$

For de-coupling control $\theta_{dq}=0$, So that the flux $\psi_r$ directs on the $d$-axis

Now from equations (2.1) and (2.2), we get

$$\frac{d\psi_r}{dt} + \frac{R_r}{L_r} \psi_r = \frac{L_m}{L_r} \omega_s$$

As well, the slip frequency can be calculated as

$$\omega_s = \frac{L_m}{L_r} \frac{d\psi_r}{dt}$$

The slip gain is

$$K_s = \frac{L_m}{L_r} \omega_s$$

It is found that the ideal decoupling can be achieved if the above slip angular speed command is used for making field orientation. and the constant rotor flux $\psi_r$ and $\frac{d\psi_r}{dt}=0$ can be substituted in equation 2.4, so that the rotor flux sets as

$$\psi_r = L_m i_d$$

The electromagnetic torque is given by

$$T_e = \frac{L_m}{L_r} \left[ i_q \psi_r - i_d \psi_q \right]$$

Figure 2.1 shows the block diagram of Fuzzy sliding mode controller for Indirect vector control of Induction motor The control aim to design a suitable control law so that the motor speed $\omega_r$ can track desired speed commands $\omega_{r_d}$.[4]

III. DESIGN AND DESCRIPTION OF CONTROLLERS

A. Fuzzy Logic controller

FLC is a technique to embody human-like thinking into a control system. FLC can be designed to emulate human deductive thinking, that is, the process people use to infer conclusions from what they know[6]. The implementation of offline tuning of PI controller is difficult in dealing with continuous parametric variation in the induction motor as well as the nonlinearity present in the entire system. However, the fuzzy logic based intelligent controller is used instead of the PI controller; excellent control performance can be achieved even in the presence of parameter variation and drive nonlinearity. In addition, the fuzzy logic possesses the following advantages: (1) The linguistic, not numerical, variables make the process similar to the human think process. (2) It relates output to input, without understanding all the variables, permitting the design of system more accurate and stable than the conventional control system. (3) Simplicity allows the solution of previously unsolved problems. (4) Rapid prototyping is possible because, a system designer doesn’t have to know everything about the system before starting work. (5) It has increased robustness. (6) A few rules encompass great complexity.

Fig 3.0 shows the block diagram of Fuzzy logic based speed control system. Such a fuzzy logic controller consists of four basic blocks: Fuzzification, Fuzzy Inference Engine, Knowledge base and defuzzification.

1) Input/ Output variables

The design of the fuzzy logic controller starts with assigning the input and output variables. The most significant variables entering the fuzzy logic speed controller has been selected as the speed error.

2) Fuzzification

In this stage, the crisp variables are converted into fuzzy variables respectively. The membership functions associated to the control variables have been chosen with triangular shapes in this paper, as shown in figure 3.1(a). The universe of discourse of all the input and output variables are established as (-1,1). The suitable scaling factors are chosen to bring the input variables to this universe of discourse. The universes of discourse are divided into 3 overlapping fuzzy sets.

Here the sliding surface $S$ be the input linguistic variable and fuzzy hitting control law be the output linguistic variable. The proposed controller uses the following variables : P (positive), N( negative), Z (zero) for the input variable $S$, as shown in figure 1.1. The universe of discourse of all the input and output variables are established as (-1,1). The suitable scaling factors are chosen to bring the input variables to this universe of discourse. The universes of discourse are divided into 3 overlapping fuzzy sets.

The rule base involved in the fuzzy sliding mode system is given as follows

- Rule1: If $S$ is P, then $U_f$ is PE.
- Rule2: If $S$ is N then $U_f$ is NE.
- Rule3: If $S$ is Z then $U_f$ is ZE.

Here the membership function is a triangular shape. Figure 3.1 shows the membership function diagram.
3) Knowledge Base and Inferencing
Knowledge base involves defining the rules represented as IF-THEN rules statements governing the relationship between inputs and output variables in terms of membership functions. Inferencing stage also includes application of fuzzy operator AND, OR, NOT, implication and aggregation.

4) Defuzzification
A defuzzification interface, which converts the conclusions of the inference mechanism into actual inputs for the process[6]. Hence, In defuzzification stage the fuzzy variables are converted into a crisp variable. This stage introduces different inference methods that can be used to produce the fuzzy set value for the output fuzzy variable \( U \).

B. Sliding mode controller:
Sliding Mode Controller is a Variable Structure Controller (VSC). Basically, a VSC includes several different continuous functions that can map plant state to a control surface, and the switching among different functions is determined by plant state that is represented by a switching function [5]. Without lost of generality, consider the design of a sliding mode controller for the following second order system: Here we assume \( b > 0 \) . \( u(t) \) is the input to the system. The following is a possible choice of the structure of a sliding mode controller, the system is controlled in such a way that the tracking error and rate of change of error \( \dot{e} \) always move towards a sliding surface. The sliding surface is defined in the state space by the scalar equation.[4]

\[
s(e,\dot{e},t) = 0
\]

Where, the sliding variable, \( S \) is

\[
\dot{S}(t) = \dot{e}(t) + \lambda \dot{e}(t)
\]

Referring to (3.2), the control effort being derived as the solution of \( S(t) = 0 \) without considering the lumped uncertainty (\( L(t) = 0 \)) to achieve the desired performance under nominal model and it is referred to as equivalent control effort as follows

\[
U_{eq}(t) = B^T_p \left[ \dot{\omega}_r(t) - A_p \omega_r(t) \right] + \lambda \dot{e}(t)
\]

However, the indirect vector control is highly parameter sensitive. Unpredictable parameter variations, external load disturbance, unmodelled and nonlinear dynamics adversely affect the control performance of the drive system. Therefore the control effort cannot ensure the favorable control performance. Thus auxiliary control effort should be designed to eliminate the effect of the unappreciable disturbances.

The auxiliary control effort is referred to as hitting control effort as:

\[
U_h(t) = g_h \text{sgn}(S(t))
\]

Where \( g_h \) is a hitting control gain concerned with upper bound of uncertainties, and \( \text{sgn}(\cdot) \) is a sign function. Now, totally sliding mode control law is as follows

\[
U_{SMC}(t) = U_{eq}(t) + U_h(t)
\]

But this controller gives unacceptable performance due to high control activity, resulting in chattering of control variable and system states. To reduce chattering a boundary layer is generally introduced into SMC law, and then the control law of equation (3.5) can be rewritten as

\[
U(t) = \frac{g_h S(t)}{S(t) + \gamma}
\]

Where \( \gamma \) is the width of the boundary layer. Stability inside the layer cannot be ensured and the inadequate selection of the boundary layer may result in unstable tracking response. Therefore fuzzy sliding modes control system, in which a fuzzy logic mechanism is used to follow the hitting control law.

C. Generalized design of PI controller
The proportional controller is a device that produces an output signal which is proportional to the input signal. It improves the steady state tracking accuracy, disturbance signal rejection and relative stability. It also decreases the sensitivity of the system to parameter variations. The PI controller produces an output signal consisting of two terms: one proportional to input signal and the other proportional to the integral of input signal [2].

\[
U_p(t) = K_p e(t) + \frac{K_i}{s} \int e(t) dt
\]

IV. MATLAB MODEL OF INDIRECT VECTOR CONTROL OF IM DRIVE

Fig. 4.0: Matlab Simulink diagram of indirect vector Control using Fuzzy Sliding Mode Controller

Fig. 4.1: Matlab Simulink diagram of Conversion of abc-dq
Where,
\[ f(u) = 2*(\cos(u(4))*u(1) + \cos(u(5))*u(2) + \cos(u(6))*u(3))/3 \]

Fig. 4.2: Matlab Simulink diagram Figure Sliding mode Controller

Fig. 4.3: PI-I_qq conversion

Fig. 4.4: Matlab Simulink diagram of showing Park transformation

Fig. 4.5: Matlab Simulink diagram of SVPWM technique

V. SIMULATION RESULTS

Fig. 4.6: Speed response for periodic command with fuzzy sliding mode controller

Fig. 4.7: Torque response for periodic command with fuzzy sliding mode controller

VI. CONCLUSION

This paper has successfully demonstrated the application of the proposed fuzzy sliding mode control system to an indirect field-oriented induction motor drive for tracking periodic commands. The design and description of the classical sliding mode controller (SMC) is presented in detail. Then, the fuzzy logic control is used to mimic the hitting control law to remove the chattering. However, the developed fuzzy logic control with indirect vector control of induction motor drive shows fast response, smooth performance, and high dynamic response with speed changing and transient conditions.

REFERENCES