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Performance Comparison between Conventional PI and PI-Like Fuzzy Speed Controller for Three Phase Induction Motor

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Abstract

Three-phase induction motor (IM) plays a very important role in today's industry due to its robustness, compact size, low cost, little maintenance requirement, and other features that give it advantage over other types of motors. In industrial applications, it is very important to have a control over IM speed to get a steady response. In this work, dynamic model of three phase induction motor is introduced and simulated using (direct-quadrature) dq transformation in stationary reference frame. Fuzzy logic Controller (FLC) is designed and compared with conventional Proportional Integral (PI) controller. Speed error and its integral are used as inputs to the controller where change in frequency is the output obtained and fed to the inverter to regulate its frequency in order to achieve the desired voltages which control the speed of motor. From results, it is shown that the performance of IM with FLC is more stable than with conventional PI, the speed almost has to be constant even though load torque is applied at specific instant because of the instantaneous response of FLC.

Keywords: Fuzzy Speed Controller; Induction Motor; PI Speed Controller.

1. Introduction

Three-phase Induction Motor (IM) is well known for many years as the workhorse of the industry due to its robustness, compact size, low cost comparing to synchronous and dc motors, very little maintenance requirement, and ability to work under severe environments [1].

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In IM, the current that produces torque and the current that produces fluxes are not decoupled which makes it difficult to control the speed of IM. However, this problem can be solved by introducing a well control methods using Field Oriented Control (FOC). The fundamental principle of FOC is decoupling the flux and torque by using coordinate transformations, and controlling each component individually, as it is done in controlling separately excited DC motors [2]. In general, the conventional Proportional Integral (PI) controller is one of the most public methods for speed control of IM, due to its simplicity, and the clear relationship between its parameters and the response of the system [3]. However, the conventional PI controller design has many problems, it has a high overshoot, requires an accurate mathematical model of the system, and the expected performance is not met because of the load disturbance, motor saturation and thermal variations [3,4].

Fuzzy logic is a technique to embody human-like thinking into a control system. A fuzzy controller can mimic human logical process of thinking, namely, the process to infer deductions from some kind of knowledge [3]. Fuzzy logic controllers (FLC) have many advantages, they have the ability to adapt with nonlinearity, less system overshoot, less effect of the control performance by system parameter variations, and the requirement of accurate mathematical model of the system is not very necessary [4]. FLCs are applied to the control process through certain well defined linguistic descriptions with an IF-Then general structure.

2. Mathematical Model of Three Phase Induction Motor

In order to implement and analyze the IM, it is important to find its mathematical representation first. One approach for modeling IM is to resolve all machine parameters onto the principal direct and quadrature reference frame in the so called d-q modeling method [5]. Transforming 3 phase voltages (abc) into two phases (dq) converts IM to DC-Like machine, which makes it easy to control the speed of IM by controlling flux and torque individually [6].

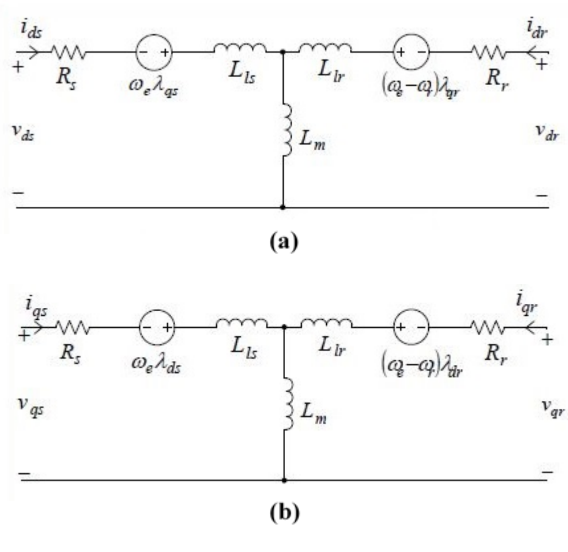

Figure 1: (a) d-equivalent circuit of IM (b) q-equivalent circuit of IM.

For mathematical modeling, the fundamental electromagnetic laws and motion equations are applied to the different windings of the IM and rotor, respectively [7].

$$v_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_e \psi_{ds} \tag{1}$$

$$v_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_e \psi_{qs} \tag{2}$$

$$v_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_e - \omega_r)\psi_{dr} \tag{3}$$

$$v_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_e - \omega_r)\psi_{qr} \tag{4}$$

Currents can be determined by the flux linkage equations as following:

$$i_{qs} = \frac{1}{X_{ls}}\left(\psi_{qs} - \psi_{mq}\right) \tag{5}$$

$$i_{ds} = \frac{1}{X_{ls}}(\psi_{ds} - \psi_{md}) \tag{6}$$

$$i_{qr} = \frac{1}{X_{lr}}\left(\psi_{qr} - \psi_{mq}\right) \tag{7}$$

$$i_{dr} = \frac{1}{X_{lr}}(\psi_{dr} - \psi_{md}) \tag{8}$$

After Substituting Equations (5 – 8) into Equations (1-4), and rearranging yields the equations below [8]:

$$\frac{d\psi_{qs}}{dt} = \omega_b \left[v_{qs} - \frac{\omega_e}{\omega_b}\psi_{ds} + \frac{R_s}{X_{ls}}\left(\psi_{mq} - \psi_{qs}\right)\right] \tag{9}$$

$$\frac{d\psi_{ds}}{dt} = \omega_b \left[v_{ds} + \frac{\omega_e}{\omega_b}\psi_{qs} + \frac{R_s}{X_{ls}}(\psi_{md} - \psi_{ds})\right] \tag{10}$$

$$\frac{d\psi_{qr}}{dt} = \omega_b \left[v_{qr} - \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{dr} + \frac{R_r}{X_{lr}}\left(\psi_{mq} - \psi_{qr}\right)\right] \tag{11}$$

$$\frac{d\psi_{dr}}{dt} = \omega_b \left[v_{dr} + \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{qr} + \frac{R_r}{X_{lr}}(\psi_{md} - \psi_{dr})\right] \tag{12}$$

Where,

$$\psi_{mq} = X_{ml}[\frac{\psi_{qs}}{X_{ls}} + \frac{\psi_{qr}}{X_{lr}}] \tag{13}$$

$$\psi_{md} = X_{ml}[\frac{\psi_{ds}}{X_{ls}} + \frac{\psi_{dr}}{X_{lr}}] \tag{14}$$

$$X_{ml} = \frac{1}{\left(\frac{1}{X_m}+\frac{1}{X_{ls}}+\frac{1}{X_{lr}}\right)} \quad (15)$$

The torque and speed can be determined as:

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \quad (16)$$

$$\omega_r = \int \frac{P_S}{2J}(T_e - T_L)\, dt \quad (17)$$

In stationary reference frame (i.e. ω_e= 0), equations (9 - 12) become as following:

$$\frac{d\psi_{qs}}{dt} = \omega_b \left[v_{qs} + \frac{R_s}{X_{ls}}\left(\psi_{mq} - \psi_{qs}\right)\right] \quad (18)$$

$$\frac{d\psi_{ds}}{dt} = \omega_b \left[v_{ds} + \frac{R_s}{X_{ls}}\left(\psi_{md} - \psi_{ds}\right)\right] \quad (19)$$

$$\frac{d\psi_{qr}}{dt} = \omega_b \left[v_{qr} + \left(\frac{\omega_r}{\omega_b}\right)\psi_{dr} + \frac{R_r}{X_{lr}}\left(\psi_{mq} - \psi_{qr}\right)\right] \quad (20)$$

$$\frac{d\psi_{dr}}{dt} = \omega_b \left[v_{dr} - \left(\frac{\omega_r}{\omega_b}\right)\psi_{qr} + \frac{R_r}{X_{lr}}\left(\psi_{md} - \psi_{dr}\right)\right] \quad (21)$$

3. Fuzzy Controller

The proportional-integral (PI) controller was usually used to control the IM in industrial electrical drives, due to its simplicity, and the clear relationship between its parameters and the system response specifications. However, this type of controller does not give a satisfactory response when there are load disturbances and parameter variations in the system. Fuzzy logic control, which was first proposed by Prof. Zadeh in 1965, is one of several approaches to overcome these problems. FLC is based on a logical system of IF-Then rules that are much closer to human thinking and natural language [9].

The input variables to the FLC are speed error (e) and Integral of speed error ($\int e$) and the output is variation in frequency (Δf) based on certain linguistic rules defined to achieve the reference speed.

The linguistic rules of the fuzzy system can be explained using the following examples:

• If (e is Large) and ($\int e$ is Large), Then (Δf is Large)

• If (e is Zero) and ($\int e$ is Small), Then (Δf is Very Small)

• If (e is Medium) and ($\int e$ is Large), Then (Δf is Large)

and so on.

4. Simulation and Results

a. A Simulink model is built based on equations (18 -21). The speed of IM in open loop without any load is stable at 1800 rpm as shown in Figure 2.

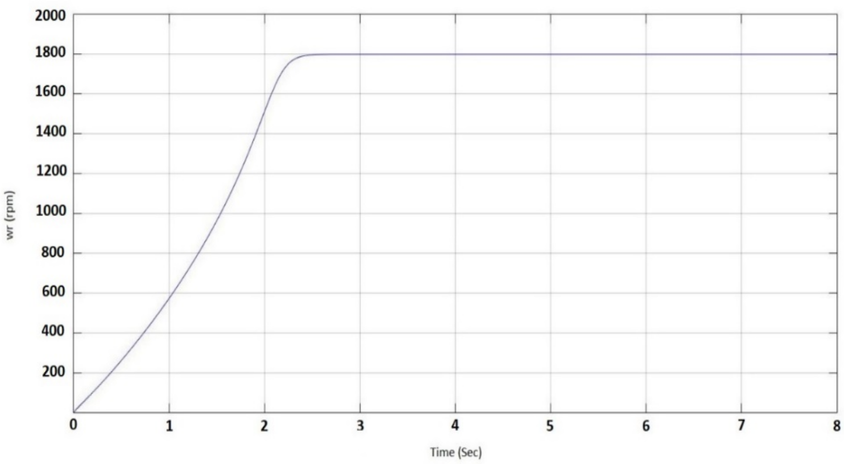

Figure 2: Rotor Speed, open loop system with No Load (r.p.m).

b. Closed Loop System with the PI Controller

After applying 200 N.m torque, speed drops down and the role of the controller is to raise it to its reference value. Figure 3 shows how the PI controller frequency output changes in response to the speed variation, after load is applied at t=5 seconds, the controller rises the frequency from 60 Hz to 65.5 Hz to have the desired speed in its reference value. In Figure 4, the speed drops down after applying the load, and due to the raise of frequency, the speed is rising up till it reaches the reference value.

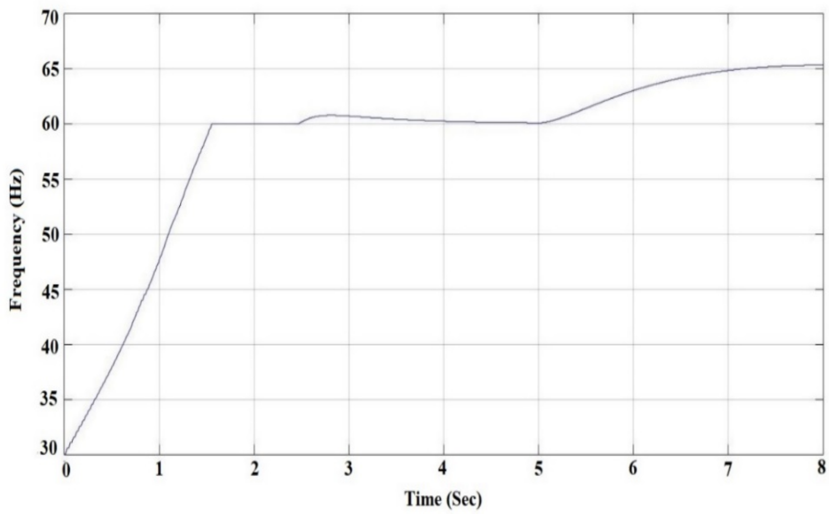

Figure 3: PI Controller Output Frequency.

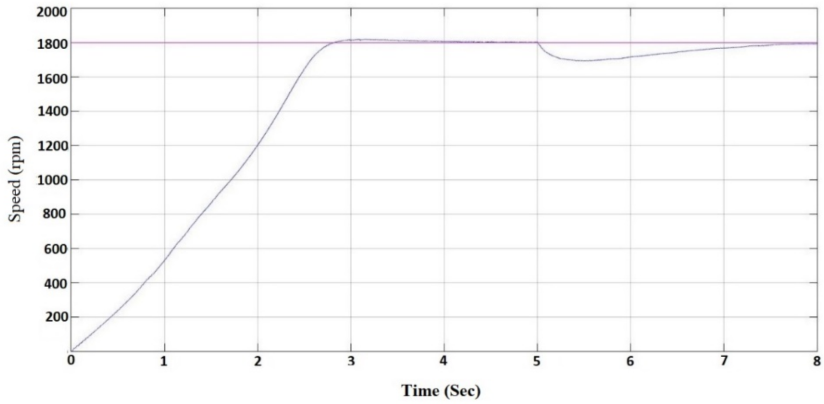

Figure 4: Rotor Speed in Closed Loop with 200 N.m load (r.p.m).

c. Closed Loop System with the PI-Like Fuzzy Controller

The FLC takes the speed error (e) and speed error integral ($\int e\,dt$) as inputs, while the output from the controller is the variation of frequency (Δf) needed to keep the rotor speed at the reference value.

The rotor speed remains approximately constant at its reference value even with torque load. This is the main advantage of the FLC over the conventional PI.

The memberships used in FLC are of triangular shape as in Figure 5 and Figure 6, and rules are described as in Table 1 below. Figure 7 shows the FLC surface.

Table 1: FLC Rules

$\int e$ \ e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NM	ZE	ZE	PM	PB	PB
NM	NB	NM	ZE	ZE	PM	PB	PB
NS	NB	NM	ZE	ZE	PM	PB	PB
ZE	NB	NM	ZE	ZE	PM	PB	PB
PS	NB	NM	ZE	ZE	PM	PB	PB
PM	NB	NM	ZE	ZE	PM	PB	PB
PB	NB	NM	ZE	ZE	PM	PB	PB

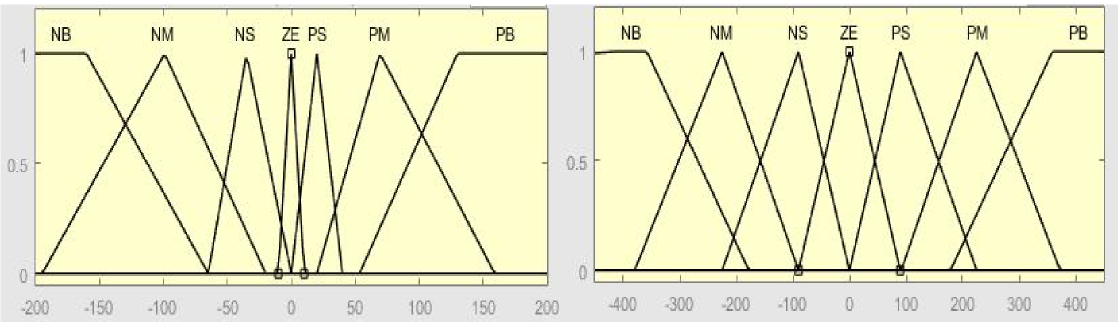

Figure 5: Membership Function of input signals

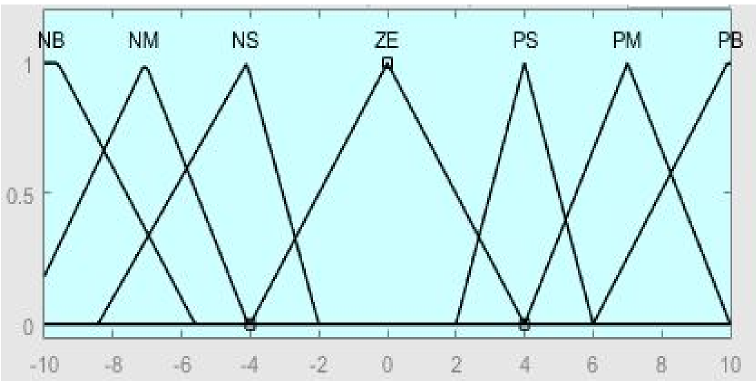

Figure 6: Membership Function of Output Signal

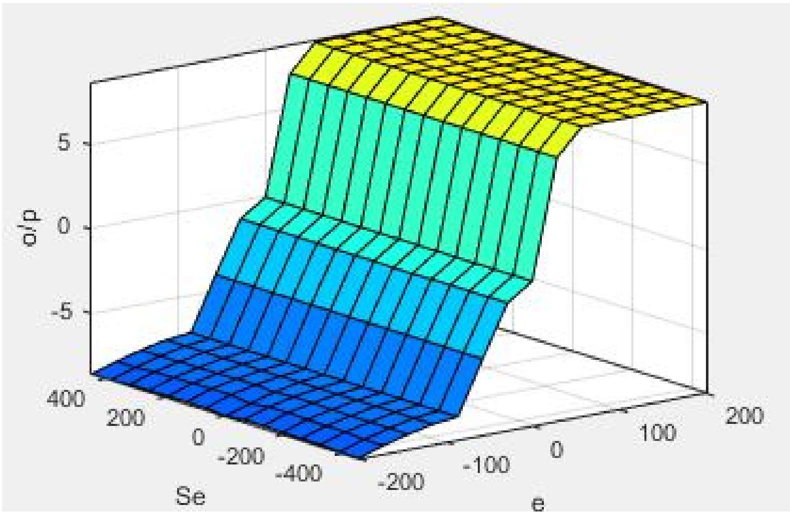

Figure 7: FLC Surface

Figure 8 below shows how the rotor speed is constant even the torque is applied at specific instant. This is because of the instantaneous response of the controller to any sudden change as shown in Figure 9. FLC starts with a high frequency to help the motor reaches its reference speed as fast as possible, when it reaches its goal (i.e. e is near zero), the controller drops the frequency to constant 60 Hz. When the load torque is applied at time (t =5 sec), the controller deals with that very fast following the rules defined in its knowledge base in Table 1 above.

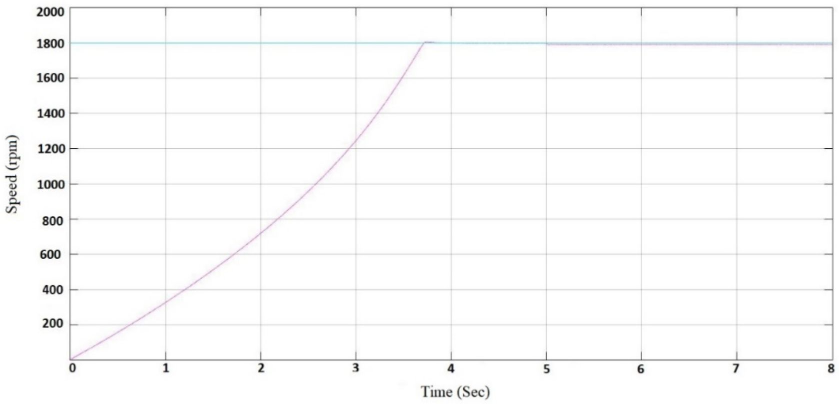

Figure 8: Rotor Speed with FLC (r.p.m)

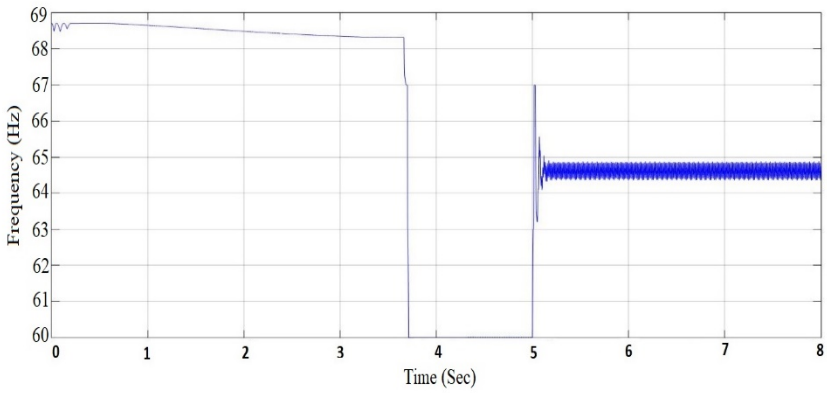

Figure 9: Frequency Change with FLC

5. Conclusions

Conventional PI controller takes 2.5 seconds to raise the speed to its reference value after applying the load, while the Fuzzy controller deals with speed change instantaneously. With FLC, rotor speed remains approximately constant even though the torque is applied while in conventional PI controller, rotor speed drops down and then raise again with the aid of the controller.

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