Simulink Model of Inverse Fuzzy Model Control of Induction Motor

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Abstract – A Inverse fuzzy model based field oriented control approach of the induction motor is presented in this paper. The application of fuzzy logic in modeling of uncertainly dynamical systems is in progress. The authors has made an effort to develop an fuzzy model of the field oriented control applied to the induction motor to successfully improve the classical approach of the field oriented control. The performance of this control method has been demonstrated by simulations performed using a versatile simulation package, Matlab/Simulink. Several numerical simulations have been carried out in a steady state and transient operation on a speed control mode.

Index Terms - Fuzzy Modeling, Field Oriented Control, Induction Moto, Matlab/Simulink.

I. Introduction

Due to its reliability and low cost, the induction motor is widely used in industry. However, this type of motor constitutes a theoretically challenging control problem, since the dynamical system is nonlinear [1][2][4]. The control of induction motor has attracted much attention in the last four decades [2][23], the concept of the field oriented control (FOC) [2][3][16][17][18][23], as a torque-flux decoupling technique applied to the induction motor drives [4][5][23]. This control strategy can provide the same performance as achieved from separately excited direct current (DC) machine.

Due to new developments, the fuzzy modeling is the application of fuzzy set theory (FST) to the representation of the essential features of a system [6][7][11][13][19]. An important characteristic of FST is that it provides a suitable representation of uncertainty in system knowledge and dynamic models. The basic principle of fuzzy modeling was stated by as follows [6][7]:

1- The use of "linguistic variables" in place of or in addition to numerical variables.
2- The characterization of simple relations between variables by "conditional fuzzy statement".
3- The characterization of complex relations by "fuzzy algorithms".

Fuzzy modeling has been investigated by different researchers [8][9][10][11][12][13]. As discussed in [14], there are different approaches to fuzzy modeling found in the literature. In this paper we use a category of description of dynamic process behavior by means of fuzzy functional equations, assuming knowledge about the structure of the process being studies. We concentrate in this paper on fuzzy model of the field oriented control applied to the induction motor to successfully improve a field oriented control and to give a simple model of field oriented control bloc using a fuzzy sets theory such as simplicity of implementation and performance of fuzzy sets.

II. FOC Development

The dynamic model of three-phase, Y-connected induction motor in $(d-q)$ synchronous rotating frame (Fig.1), with (v_{ds}, v_{qs}) as the control input variables and $(i_{ds}, i_{qs}, \Phi_{dr}, \Phi_{qr}, \Omega)$ as the state variables are given by [2][15][16][17][18].

$$\dot{x} = K(x) + g(x).u \tag{1}$$

where:

$$x = [x_1, x_2, x_3, x_4, x_5]^T = [i_{ds}, i_{qs}, \Phi_{dr}, \Phi_{qr}, \Omega]^T ;$$

$$u = [u_1, u_2]^T = [v_{ds}, v_{qs}]^T ;$$

$$K(x)=\begin{pmatrix}K_1\\K_2\\K\\K\\K_5\end{pmatrix}=\begin{pmatrix}-\gamma x_1+\omega_{ss}x_2+\frac{k}{T_r}x_3+pkx_4x_5\\-\gamma x_2-\omega_{ss}x_1+\frac{k}{T_r}x_4-pkx_3x_5\\\frac{L_m}{T_r}x_1-\frac{1}{T_r}x_3+(\omega_s-px_5).x_4\\\frac{L_m}{T_r}x_2-\frac{1}{T_r}x_4-(\omega_s-px_5).x_3\\\frac{pL_m}{JL_r}(x_3x_2-x_4x_1)-\frac{C_r}{J}\end{pmatrix};$$

and

$$g(x)=(g_1(x)\quad g_2(x))=\begin{pmatrix}\frac{1}{\sigma L_s}&0\\0&\frac{1}{\sigma L_s}\\0&0\\0&0\\0&0\end{pmatrix}\quad\text{with}$$

$$T_r=\frac{L_r}{R_r};\ \sigma=1-\frac{L_m^2}{L_rL_s};k=\frac{L_m}{L_rL_s-L_m^2};$$

$$\gamma=\frac{1}{\sigma L_s}.(R_s-\frac{R_rL_m^2}{L_r^2}).$$

The main objective of the vector control of induction motors is, as in DC machines, consists in the control of the torque and the flux independently; this is done by using a ***d-q*** rotating reference frame synchronously with the rotor flux space vector [1][2][3][4][5]. As shown in Fig.2, the ***d*** axis is aligned with the rotor flux space vector, so under this condition we have:

$$\Phi_{dr}=\Phi_r \ and \quad \Phi_{qr}=0 \qquad (2)$$

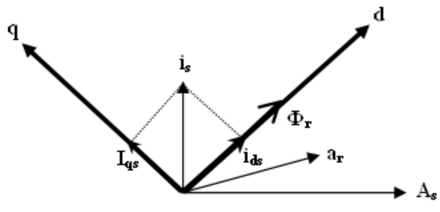

Fig.2 – Vector Diagram of the Induction Motor, Controlled by the Field oriented Control.

Appling the result of (2), namely field oriented control, the torque equation become analogous to the DC machine and can be described as follows [2][3][5][18]:

$$C_e=\frac{pL_m}{L_r}\Phi_r i_{qs} \qquad (3)$$

Consequently, dynamic equation of the induction motor model established in the rotor flux field is then given by

$$\frac{d}{dt}\begin{pmatrix}i_{ds}\\i_{qs}\\\Phi_r\\\Omega\end{pmatrix}=\begin{pmatrix}-\gamma i_{ds}+\omega_{ss}i_{qs}+\frac{k}{T_r}\Phi_r+\frac{1}{\sigma L_s}v_{ds}\\-\gamma i_{qs}-\omega_{ss}i_{ds}-pk\Phi_r\Omega+\frac{1}{\sigma L_s}v_{qs}\\\frac{L_m}{T_r}i_{ds}-\frac{1}{T_r}\Phi_r\\\frac{pL_m}{JL_r}(\Phi_r i_{qs})-\frac{C_r}{J}\end{pmatrix} \qquad (4)$$

using (2), the stator pulsation and desired flux in terms of i_{ds} can be found from

$$\omega_s=\frac{R_r}{p\Phi_r^2}C_e+p\Omega \qquad (5)$$

$$\Phi_{dr}=\Phi_r=\frac{L_m/T_r}{s+1/T_r} \qquad (6)$$

The resulting diagram of the field oriented control system applied to an induction motor is then depicted in Fig.3.

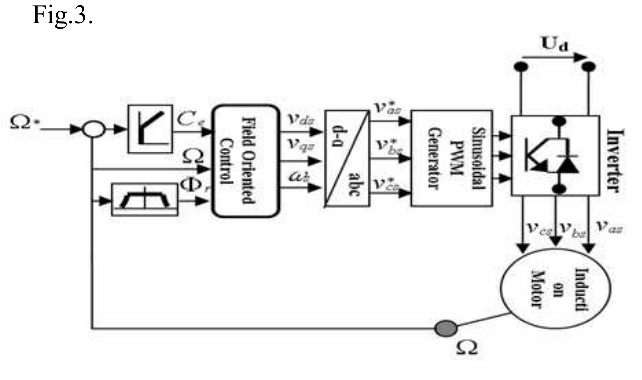

Fig.3 – Block diagram of the Field oriented Control of the Induction Motor

III. Application of the Fuzzy Modeling to the Field oriented Control

We can therefore obtain the fuzzy model of the Field oriented Control (FOC) of the induction motor described in section II.

The expression of the FOC is written as follows:

$$u(t)=f\ (y) \qquad (7)$$

where $t\in\Re_+ := [0,\infty]$ is time, $u=(v_{ds},v_{qs},\omega_s)^T;y=(C_e,\frac{dC_e}{dt},\Phi_r,\frac{d\Phi_r}{dt},\Omega)^T$ is the output vector and the control input vector of the field oriented control (FOC) respectively.

$f=(f_1\ ,f_2\ ,f_3\ )^T$ is the vector function of the FOC bloc.

Considering that the flux of reference Φ_r is constant, this means that:

$$\frac{d\Phi_r}{dt} = 0. \qquad (8)$$

the new control input vector is:

$$y = (C_e, \frac{dC_e}{dt}, \Phi_r, \Omega)^T \qquad (9)$$

The vector function of the FOC bloc is

$$f_1\ (y) = v_{ds} = \frac{R_s}{L_m}\Phi_r - \frac{R_r(L_sL_r - L_m^2)}{L_m p^2}C_e^2 - \frac{(L_sL_r - L_m^2)}{L_m}\Omega C_e \qquad (10)$$

$$f_2\ (y) = v_{qs} = \frac{pL_s}{L_m}\Omega\Phi_r + \frac{(L_rR_s + L_sR_r)}{pL_m}\frac{C_e}{\Phi_r} + \frac{(L_sL_r - L_m^2)}{pL_m}\frac{1}{\Phi_r}\frac{dC_e}{dt} \qquad (11)$$

$$f_3\ (y) = \omega_s = \frac{R_r}{p}\frac{C_e}{\Phi_r^2} + p\Omega \qquad (12)$$

However, in designing the fuzzy representation of the equation (7); we obtain:

$$\tilde{u} = \begin{pmatrix} \tilde{v}_{ds} \\ \tilde{v}_{qs} \\ \tilde{\omega}_s \end{pmatrix} = \tilde{f}\ (\tilde{y}) = \begin{pmatrix} \tilde{f}_1\ (\tilde{C}_e, \tilde{\Phi}_r, \tilde{\Omega}) \\ \tilde{f}_2\ (\tilde{C}_e, \frac{d\tilde{C}_e}{dt}, \tilde{\Phi}_r, \tilde{\Omega}) \\ \tilde{f}_3\ (\tilde{C}_e, \tilde{\Phi}_r, \tilde{\Omega}) \end{pmatrix} \qquad (13)$$

as; $\tilde{C}_e, \frac{d\tilde{C}_e}{dt}, \tilde{\Phi}_r, \tilde{\Omega}$ and $\tilde{v}_{ds}, \tilde{v}_{qs}, \tilde{\omega}_s$: fuzzy variables corresponding to the control input variables $C_e, \frac{dC_e}{dt}, \Phi_r, \Omega$ and to the output variables v_{ds}, v_{qs}, ω_s respectively.

In this case, the number of fuzzy set of output variables $\tilde{v}_{ds}, \tilde{v}_{qs}, \tilde{\omega}_s$ are equal to $M_1 * M_3 * M_4$, $M_1 * M_2 * M_3 * M_4$ and $M_1 * M_3 * M_4$ respectively, ($M_i, i = 1,..,4,$) wich are the number of fuzzy set of control input variables $C_e, \frac{dC_e}{dt}, \Phi_r, \Omega$ respectively.

The rules are then presented as follows:

$$R_{vds}^{(k_1,\ldots,k_4)}: \text{ IF } (C_e, \Phi_r, \Omega) \text{ is } (F_{C_e}^{k_1}, F_{\Phi_r}^{k_1}, F_{\Omega}^{k_3})$$
$$\text{THEN } v_{ds} \text{ is } F_{v_{ds}}^{(k_1,k_1,k_3)}$$

$$R_{vqs}^{(k_1,\ldots,k_4)}: \text{IF } (C_e, \frac{dC_e}{dt}\Phi_r, \Omega) \text{ is } (F_{C_e}^{k3}, F_{dC_e}^{k_2} F_{\Phi_r}^{k_1}, F_{\Omega}^{k_4})$$
$$\text{THEN } v_{qs} \text{ is } F_{vqs}^{(k_3,k_2,k_1,k_4)}$$

$$R_{\omega_s}^{(k_1,\ldots,k_4)}: \text{ IF } (C_e, \Phi_r, \Omega) \text{ is } (F_{C_e}^{k_1}, F_{\Phi_r}^{k_1}, F_{\Omega}^{k_3})$$
$$\text{THEN } \omega_s \text{ is } F_{w_s}^{(k_1,k_1,k_3)}$$

The Schematic diagram corresponds to the designed fuzzy model designed is represented by the figure below.

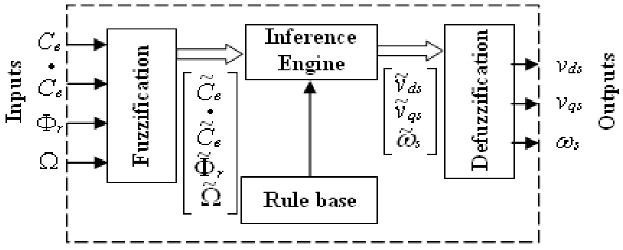

Fig. 4. Schematic Diagram of Fuzzy Model Replaces the Field Oriented Control (FOC)

Theoretically, it is interesting to note that when the number of fuzzy set of inputs increases, the approximation obtained is better. However we can not exceed a certain number of fuzzy sets, we risk loosing the utilities of fuzzy logic, among other things such as the increase in computing time.

IV. SIMULATION RESULTS AND DISCUSSIONS

To study the performance of the developed inverse fuzzy model, to control the speed of induction motor, is simulated using Matlab/Simulink simulation package. The block diagram of the simulink model is shown in Fig. 5.

In order to evaluate the performances of the proposed fuzzy model approach applied to the field oriented control (FOC). A simulation studies were carried out for squirrel-cage induction motor [20][21].

The test it consisted of a no load starting of the motor with a reference speed $\Omega^* = 100 rad/s$ and $\Phi_r = 1Wb$. A load torque $C_r = 10N.m$ was then applied between $t = 0.5s$ and $t = 1s$, followed by an inverse of speed from $\Omega^* = 100 rad/s$ to $\Omega^* = -100 rad/s$ is applied at $t = 1.5s$.

The step changes in the load torque and the speed response cause step change in the torque response without any effects on the rotor flux component response Φ_{dr}, which is maintained constant, due to the decoupled control system between speed and rotor flux. Thus the speed regulations is obtained using such as an fuzzy model in spirit of addition of severe disturbances such as step changing of the load torque and speed reverse.

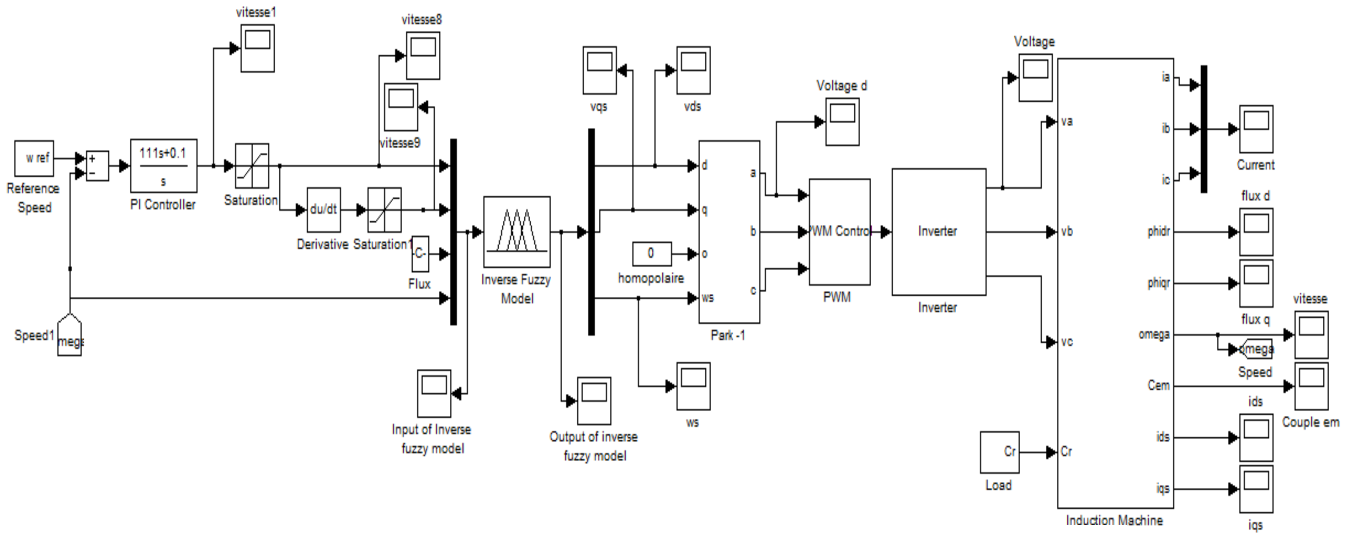

Fig. 5 - Developed model of direct torque control of induction machine

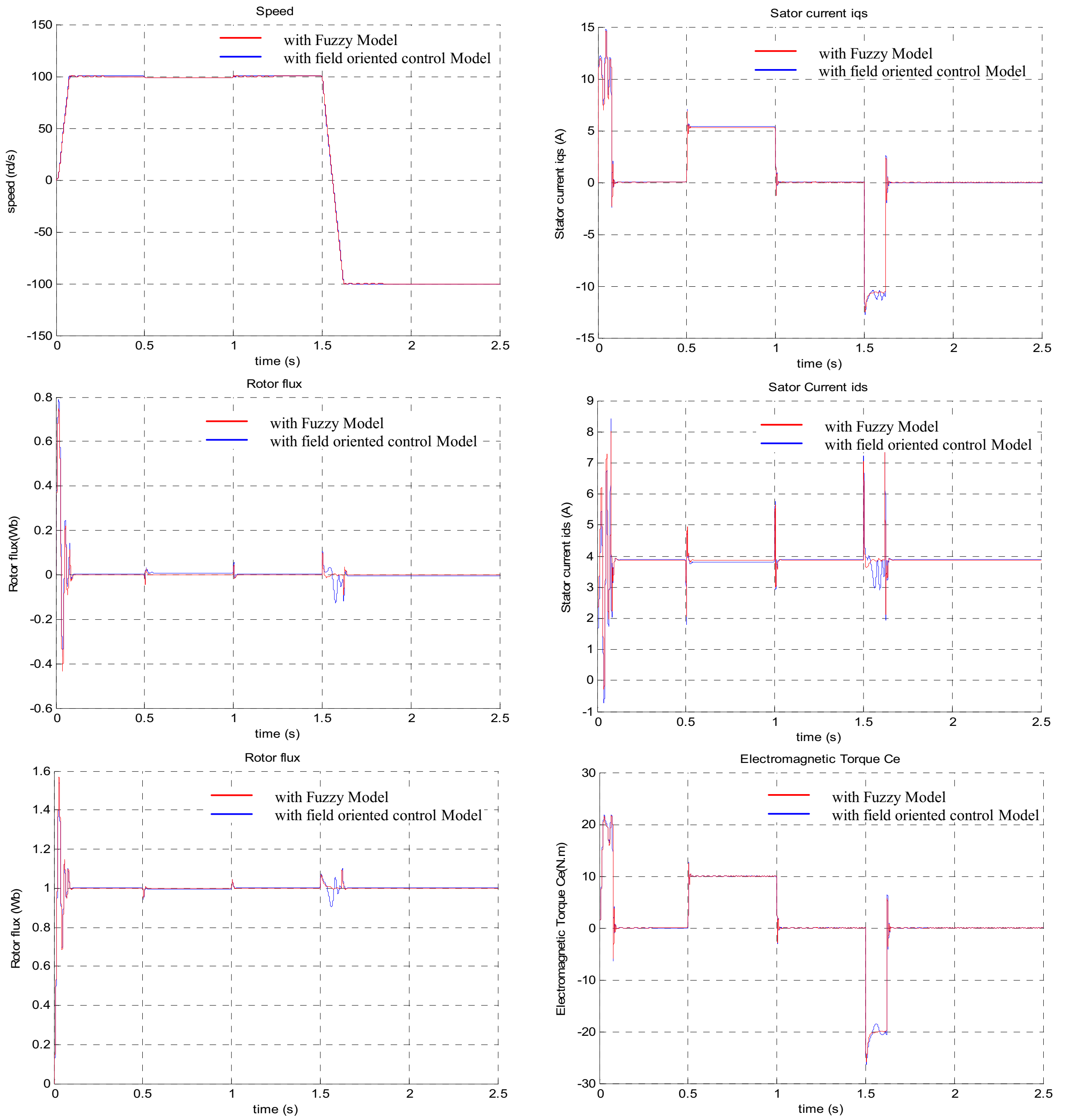

Fig. 6. Simulation results of the comparison between the Fuzzy Model and the Field Oriented control for Induction Motor

V. Conclusions

In this paper we have presented an fuzzy model, another approach to field oriented control; it has revealed very interesting features. This model maintains an effective decoupling between speed and flux for the whole range of speed witch allows obtaining high dynamic performances for constant flux operation similar to that of DC motors. This study has successfully demonstrated the design of the fuzzy modeling approach for the field oriented control on an induction motor.

Further more, comparing to the conventional field oriented control, the fuzzy model is simple to implement as it uses a reduced model, and reduced the time of simulation.

VI. Appendices

Induction Motor Parameters

Following are the parameters of the motor chosen for this simulation.

Electric power: $P = 1.5KW$
Stator voltage: $V = 238/220V$
Number of Poles: $p = 2$
Rated speed: $\Omega = 1420 rev/\min$
Frequency: $f = 50Hz$
Stator resistance: $R_s = 4.85\Omega$
Rotor resistance: $R_r = 3.805\Omega$
Stator inductance: $L_s = 0.274H$
Rotor inductance: $L_r = 0.274H$
Mutual inductance: $L_m = 0.285H$
Moment of inertia: $J = 0.031 kg.m^2$

VIII. References

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