IMPLEMENTATION & SIMULATION OF FUZZY LOGIC CONTROLLERS FOR THE SPEED CONTROL OF INDUCTION MOTOR AND PERFORMANCE EVALUATION OF CERTAIN MEMBERSHIP FUNCTIONS

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ABSTRACT

The development in Power Electronic devices, converters, advancements in IC Technologies, advanced control methodologies, modeling and simulation tools made a dynamic evolution in the design and control of electric drive systems. The basic requirements of IM drives include fast response of the system. The objective of this paper is to investigate the effect of certain membership functions in the developed Simulink model of both Mamdani & Sugeno model based fuzzy control for an Induction motor drive. The built in membership functions of Matlab were selected for evaluation. The evaluation is done using the developed 49 fuzzy rules through the implementation in Matlab/Simulink model. The results of voltage, current, rotor speed and torque of the Induction motor are compared. The performances of triangular and trapezoidal membership functions on Sugeno model based fuzzy control are very close and better compared to other membership functions as far as the fast response and starting currents are concerned for the developed model.

Keywords: Fuzzy logic control, Mamdani model, Sugeno model, Simulink model, Induction motor drive

I. INTRODUCTION

Induction motors are used as drive motors to a wider range of applications in industries due to its advantages over other motors. Variable-speed drives require both wide operating range of speed and fast response, regardless of load variations. PWM controlled Voltage source inverters are commonly used for the variable speed drive applications. The SVPWM control has been widely used in many applications which is an advanced,
computation intensive PWM method. Fuzzy logic control has found many applications in the past decades, which overcomes these drawbacks. Fuzzy logic systems follow human like reasoning approaches to knowledge based intelligent systems. In this paper both mamdani and sugeno fuzzy controllers with different membership functions are compared for their performance through simulation of Matlab/Simulink models.

II. MODEL OF INDUCTION MOTOR

The mathematical model of drive motor is required to further to design or select the type of controller. The induction motor drive system used in this work consists of space vector PWM voltage source inverter, induction motor, direct flux and the torque control. Sluggish response due to the coupling effect in the control of IM and the instability due to higher order system effect can be solved by using Vector control or field oriented control strategy for better performance. By using only current and voltage measurements, it is possible to estimate the instantaneous stator flux and output torque.

![Power Circuit Connection Diagram for the IM](image1)

The power circuit of the 3 phase induction motor is shown in the Fig.1.

The equivalent circuit used for obtaining the mathematical model of the induction motor is shown in the Fig. 2.

![Equivalent Circuit of Induction Motor in d-q Frame](image2)
An induction motor model is then used to predict the voltage required to drive the flux and torque to the demanded values within a fixed time period. This calculated voltage is then synthesized using the space vector modulation. The stator & rotor voltage equations are given by

\[ V_{sd} = R_{s} i_{sd} + \frac{d}{dt} \lambda_{sd} - \alpha_{s} \lambda_{sq} \]  
\[ V_{sq} = R_{s} i_{sq} + \frac{d}{dt} \lambda_{sq} - \alpha_{s} \lambda_{sd} \]  
\[ V_{rd} = R_{r} i_{rd} + \frac{d}{dt} \lambda_{rd} - \alpha_{r} \lambda_{rq} \]  
\[ V_{rq} = R_{r} i_{rq} + \frac{d}{dt} \lambda_{rq} - \alpha_{r} \lambda_{rd} \]  

Squirrel cage induction motor is used for the simulation study in this paper, so the d and q axis components of the rotor voltage are zero. The fluxes to currents are related by the equation

\[
\begin{bmatrix}
\lambda_{sd} \\
\lambda_{sq} \\
\lambda_{rd} \\
\lambda_{rq}
\end{bmatrix} = M \begin{bmatrix}
i_{sd} \\
i_{sq} \\
i_{rd} \\
i_{rq}
\end{bmatrix}; 
M = \begin{bmatrix}
L_z & 0 & L_m & 0 \\
0 & L_z & 0 & L_m \\
L_m & 0 & L_r & 0 \\
0 & L_m & 0 & L_r
\end{bmatrix}
\]  

The electrical part of an induction motor is described by combining equations (1) – (5):

\[
\begin{bmatrix}
i_{sd} \\
i_{sq} \\
i_{rd} \\
i_{rq}
\end{bmatrix} = \frac{1}{L_m^2 - L_r L_z} \times 
\begin{pmatrix}
L_z & 0 & L_m & 0 \\
0 & L_z & 0 & L_m \\
L_m & 0 & L_r & 0 \\
0 & L_m & 0 & L_r
\end{pmatrix} \begin{bmatrix}
V_{sd} \\
V_{sq} \\
V_{rd} \\
V_{rq}
\end{bmatrix}
\]  

Where, \( A \) is given by
The instantaneous torque developed in the induction motor is given by

\[ T_{em} = \frac{P}{2} \left( \lambda_{q} i_{rd} - \lambda_{rd} i_{q} \right) \]  

(8)

The electromagnetic torque expressed in terms of inductances in given by

\[ T_{em} = \frac{P}{2} L_{m} \left( i_{q} i_{rd} - i_{rd} i_{q} \right) \]  

(9)

The mechanical part of the motor is modeled by the equation

\[ \frac{d}{dt} \omega_{mech} = \frac{T_{em} - T_{k}}{J_{eq}} = \frac{P}{2} L_{m} \left( i_{q} i_{rd} - i_{rd} i_{q} \right) - T_{k} \]  

(10)

Where,

- \( J_{eq} = \) Equivalent M.I.
- \( \omega_{rd} = \omega_{stg} = \omega_{s} - \omega_{m} \)
- \( \omega_{m} = \frac{P}{2} \omega_{mech} \)
- \( \omega_{s} = \omega_{s} \)
- \( L_{e} = L_{s} + L_{m} \)

A 3 phase bridge inverter has 8 permissible switching states as shown in fig.3. Table 1 gives the summary of the switching states and the corresponding phase to neutral voltage of isolated neutral machine.
III FUZZY LOGIC CONTROL SCHEME

Fuzzy controllers are simple, low cost and can be designed without knowing the mathematical model of the process. Fuzzy logic is one of the successful applications of fuzzy set in which the variables are linguistic rather than the numeric variable. A fuzzy logic controller is based on a set of control rules called as the fuzzy rules among the linguistic variables. These rules are expressed in the form of conditional statements. The basic structure of our Fuzzy logic controller is shown in fig.4. The necessary inputs to the decision making unit block are the rule base unit and the data base block unit. The fuzzification unit converts the crisp variable into a linguistic formats. The decision making unit decides in the linguistic format with the help of logical linguistic rules supplied by the rule base and the relevant data supplied by the data base. The error and change in error is modeled using the equation (11) as

\[ e(k) = \omega_{\text{ref}} - \omega_r \quad \text{and} \quad \Delta e(k) = e(k) - e(k-1) \]  

where \( \omega_{\text{ref}} \) is the reference speed and \( \omega_r \) is the actual speed of rotor, \( e(k) \) is the error and \( \Delta e(k) \) is the change in error.
The output of the decision making unit is given as input to the de-fuzzification unit and the linguistic format of the signal is converted back into the numeric form of data in the crisp form. The decision making unit uses the conditional rules of “IF-THEN-ELSE”. In the first stage, the crisp variables \( e(k) \) and \( \Delta e(k) \) are converted into fuzzy variables. The fuzzification maps the error, and the error changes to linguistic labels of the fuzzy sets. The proposed controller uses the following linguistic labels: { NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big)}. Each fuzzy label has an associated membership function.

Figure 5 FIS Fuzzy editor with two inputs and one output (Mamdani model)

Figure 6 FIS Fuzzy editor with two inputs and one output (Sugeno model)

Rule base for the decision making unit is written as shown in the table 2.
IV. Simulink Model

Fuzzy logic controller is developed using the fuzzy logic tool box available in Matlab / Simulink. Fuzzy logic controller employs the speed error and change of speed error as the inputs. The change in the speed component of current that drives the induction motor is obtained as the output. The developed simulink model in MATLAB is shown in Fig. 8 and 9.

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Table 2: Rule base for controlling the speed

Figure 8 Developed Simulink model
Figure 9 Fuzzy logic block

V. SIMULATION RESULTS AND DISCUSSIONS

The simulations are carried out in Matlab with Triangular & Trapezoidal membership functions for both models and Gaussian membership function for Sugeno model. The response curves of voltage, stator current, rotor speed & torque v/s time are shown in Figs. 10-13. From the results, it is observed that the speed response takes less time to settle and the starting current is less in Sugeno model with Triangular & trapezoidal membership functions. For other membership functions the responses were not good.

Figure 10. Responses of Sugeno model with Triangular membership function
Figure 11. Responses of Sugeno model with Trapezoidal membership function

Figure 12. Responses of Sugeno model with Gaussian membership function
VI. CONCLUSION

Simulink model of both Mamdani & Sugeno model based fuzzy logic controllers were implemented for an Induction motor drive. Certain built in membership functions of Matlab were selected for simulation. The simulation results of voltage, stator current, rotor speed and torque of the Induction motor are compared. The settling time of the speed & torque and the stator current during starting are less for the triangular and trapezoidal membership functions on Sugeno model based fuzzy control compared to other responses.

REFERENCES


AUTHOR PROFILE

M.Gowrisankar was born in the year 1956 and he received the B.E. degree in Electronics & Communication Engg. (ECE) from PSG College of Technology, Coimbatore, Tamilnadu, India from Madras University in the year 1979 and the M.E. Degree in Applied Electronics from PSG College of Technology, Coimbatore, Tamilnadu, India in the year 1985. He has got a teaching experience of 31 years. Currently, he is working as Professor & Head of the Department of Computer Science and Engineering in Karpagam College of Engineering, Coimbatore, Tamilnadu, India & simultaneously doing his Ph.D. (Research) in Electrical & Electronics Engg. from the Anna University of Technology, Coimbatore, Tamilnadu. He has published two papers in international conferences. His areas of interests are neural networks, fuzzy logic, artificial intelligence, power electronics and Drives, control systems, Matlab, etc.

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