Fuzzy – PI controller to control the velocity parameter of Induction Motor

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Abstract - The major application of Induction motor includes the usage of the same in industries because of its high robustness, reliability, low cost, high efficiency and good self-starting capability. Even though it has the above mentioned advantages, it also have some limitations: (1) the standard motor is not a true constant-speed machine, its full-load slip varies less than 1 % (in high-horsepower motors). And (2) it is not inherently capable of providing variable-speed operation. In order to solve the above mentioned problem smart motor controls and variable speed controllers are used. Motor applications involve non linearity features, which can be controlled by Fuzzy logic controller as it is capable of handling those features with high efficiency and it act similar to human operator.

This paper presents individuality of the plant modelling. The fuzzy logic controller (FLC) trusts on a set of linguistic if-then rules, a rule-based Mamdani for closed loop Induction Motor model. The motor model is designed and membership functions are chosen according to the parameters of the motor model. Simulation results contains non linearity in induction motor model. A conventional PI controller is compared practically to fuzzy logic controller using Simulink.

1. Introduction (Induction Motor)
Out of the available motors, Induction Motor is used for variable speed applications. For this purpose to reduce the losses, controller providing maximum torque. Therefore for the above mentioned purpose fuzzy logic controller is more efficient as it can handle non-linearity. In this paper the speed control is accomplished through a Mamdani type fuzzy controller, with 25 rules, taking speed error, e (built with 5 membership Functions- M.F.) and speed error variation, \( \Delta e \) (built with 5 M.F.) as inputs, to produce the change of control, \( W_s \). Simulation results contains non linearity in induction motor model. A conventional PI controller is compared practically to fuzzy logic controller using Simulink.

2. Fuzzy logic controller
Fuzzy Logic controller is a well renowned method of non linear control. The main goal of fuzzy logic is to mimic (and improve on) "human-like" reasoning. "Fuzzy systems are knowledge-based or rule-based systems". Precisely, the key mechanisms of fuzzy system's knowledge base are a set of IF-THEN rules attained from human knowledge and expertise. The fuzzy systems are multi-input-single-output mappings from a real-valued vector to a real-valued scalar.

B. Architecture
The Controller design includes some rules which define the casual relationship between two normalized input voltages and an output one. These are: Error, that is speed error, Change-of-error, that
is derivative of speed error, and output, defined as the change-of-control, that is added to the motor speed is the input to the converter. These error inputs are handled by linguistic variables, which require to be defined by membership functions.

![Figure I. Fuzzy logic based control structure for scalar induction motor](image)

## 3. Dynamic Model Of Induction Motor

The dynamic modelling of Induction Motor is done in Simulink program of Matlab by employing its mathematical equations which are shown below. We have used synchronous frame of reference where:

- $\omega_0 = \text{base freq.}$
- $\omega_m = \text{rotor frame freq.}$
- $\omega_k = \text{dq frame frequency}$
- $\omega_s = \text{synchronous frame frequency (rad/sec)}$
- $\lambda_c = \text{stator flux, } \lambda_r = \text{rotor flux (pu)}$
- $R_s, R_r = \text{stator and rotor resistance (pu)}$
- $v_s, v_r = \text{stator and rotor voltage (pu)}$
- $i_s, i_r = \text{stator and rotor current (pu)}$
- $L_m = \text{magnetizing inductance (pu)}$
- $L_{ld}, L_{ld} = \text{stator and rotor inductance (pu)}$
- $L_{ld} = \text{stator leakage inductance (pu)}$
- $L_{rd} = \text{rotor leakage inductance (pu)}$
- $T_e = \text{electromagnetic torque (pu)}$
- $T_L = \text{load torque (pu)}$
- $B_m = \text{viscous friction coefficient (pu)}$
- $d,q = \text{direct quadrature axis}$
- $p = \text{number of poles}$
- $H = \text{inertia constant (s)}$

### A. Electrical system equations:

\[
v_s = R_s i_s + \frac{1}{W_o} \frac{d\lambda_s}{dt} + \frac{W_k M_s \lambda_q}{2} \tag{1}
\]

\[
v_r = R_r i_r + \frac{1}{W_o} \frac{d\lambda_r}{dt} + (W_k - W_m) M_s \lambda_q \tag{2}
\]

Here \( \lambda = \begin{bmatrix} \dot{\lambda}_d \\ \dot{\lambda}_q \end{bmatrix}, i = \begin{bmatrix} i_d \\ i_q \end{bmatrix}, M_s = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \)

### B. Flux linkage-current relations:

For D axis

\[
\lambda_{sd} = L_s i_{sq} + L_m i_{rq} \tag{3}
\]

\[
\lambda_{sq} = L_m i_{sq} + L_r i_{rq} \tag{4}
\]

For Q axis

\[
\lambda_{sq} = L_s i_{sd} + L_m i_{rd} \tag{5}
\]
\[ \lambda_{rd} = L_m i_{sd} + L_r i_{rd} \]  

Where

\[ L_s = L_m + L_{sl}, L_r = L_m + L_{rl} \]  

C. Mechanical system equations:

\[ T_e = 2H \frac{d w_{mec}}{dt} + B_m w_{mec} + T_l \]  

Where

\[ T_e = \lambda_s X i_s = M_e \lambda_e \ast i_s \]  

Above equation is expressed in cross and dot product

\[ w_{mec} = \frac{2}{p} w_m \]  

4. Model Of Induction Motor Using Simulink

Fuzzy based controller has four major blocks one that computes the error into two input variables, a fuzzification block, an inference mechanism, and the last step is defuzzification. The speed reference control is \( w_m \).

Speed of induction motor is controlled using PI Fuzzy Logic Controller. Here Mamdani Algorithm is used as an inference strategy and centre of gravity for defuzzification. The fuzzy logic controller operation is based on twenty five rules having same value. The control operations are shown in the table given below:

\[ \Delta w_{sl} = K_p \Delta e + K_i \Delta e \]  

![Figure 2. Block Diagram of Fuzzy based Induction Motor in Simulink](image)
Table I. Triangular Membership Function For Output Variable

| Δe  | NL | NS | ZE | PS | PL |
|-----|----|----|----|----|----|
| NL  | NL | NL | NM | NS | ZE |
| NS  | NL | NM | NS | ZE | PS |
| ZE  | NM | NS | ZE | PS | PM |
| PS  | NS | ZE | PS | PM | PL |
| PL  | ZE | PS | PM | PL | PL |

Figure 3. Fuzzy Controller model using Mamdani Algorithm

Figure 3 (a)
5. Induction Motor Test Results
The three-phase sinusoidal excitation can be adjusted in both amplitude and frequency. In the simulation all the initial conditions are assumed to be zero. The motor is started without load at rated voltage and frequency until \( t=1.5 \) s. After this time, and after reaching the steady state conditions, voltage and frequencies are both changed suddenly to 0.7 pu, up to the end. At \( t=2.0 \) s a full load step function is applied.

Figure 3 (b)

Fig. 3. (a) Rules view of Fuzzy Controller Output (Rule Viewer for Input Variable \( e=0.273 \) and \( \Delta e=0.13 \) and Output Variable =0.292) (b) Surface view of Fuzzy Controller Output

Figure 4

Figure 5

Figure 4. Electromagnetic Torque And Load Torque \( T_e, T_l \) (Pu)

Figure 5. Rotor frame frequency (pu)
6. Summary
A new FLC that improve the performance of scalar Induction Motor speed drives has been proposed. This speedcontroller gives maximum torque over the entire speedrange. The method uses the new linguistic rule table in Fuzzy knowledge based controller to adjust the motor control speed, and this FLC can achieve a good system performance of the Induction Motor scalar drive, and it is possible to implement a PI Fuzzy logic controller instead of the traditional PI controller.

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