FLC based speed control of Induction Motor

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Abstract. Speed control of induction motor is utilized for blowers, fans and many other applications. AC voltage regulators are used in induction motors to arrange the speed. This technique features the shrewd controllers such as the Fuzzy controller ac voltage controllers to produce the firing signals for thyristors concerning a given operating torque, speed of the motor, and the load. Fuzzy models have been intended to accomplish the proposed calculation. MATLAB/SIMULINK is utilized to reproduce the proposed strategies. The upside of such controller is its straightforwardness, security, and high precision contrasted with the regular numerical figuring of the firing signals which is a complex and tedious errand particularly in online control applications. The significant attribute of the FLC system is to improve robustness. The mathematical model of the drive framework is created utilizing the phase variable model. The created model is simulated using MATLAB/SIMULINK; since it provides a convenient tool to analyze the system precisely so the outcomes obtained are very satisfactory and promising.

Keywords: Control System, PID controller, Fuzzy logic control, Framework Modeling, Induction Motor (3-phase), MATLAB / SIMULINK

1. INTRODUCTION

Three phase Induction motor has wide application and demand in today’s life as in residential, commercial and industrial application. It is utilized in lifts, cranes, hoists, large capacity exhaust fans, lathe machines, crushers, oil extracting mills and textile industry etc.[1,2] So the performance of three phase induction motor is quite remarkable which can be affected by the large rotor current. If it cannot be controlled or monitored, it would affect extremely in the area of high power demand.

AC regulator which is the combination of thyristors, TRIAC, SCRs can be used to overcome such situations. The ac voltage regulator changes the fixed voltage and fixed frequency of the input to a variable voltage. Ac voltage-controller-based starters have some merits over conventional starters as: smooth acceleration, which reduces the stress on the mechanical drive system [3]. An adaptive approach using Adaptive Pole Placement Control was applied for con- trolling speed of three-phase induction motor [4], which shows better performance than PID controller. Slip and speed control via
fuzzy logic techniques was described [5] by sudden change of load from zero to rated value. It decreases the stun on the driven load due to high starting torque [6] due to which the products can be damaged. So, an adjustable acceleration (ramp time) and starting torque is necessary for optimal starting performance that provides enough torque to accelerate the load while minimizing both mechanical and electrical shock to the system [6].

Some schemes for speed control utilize speed sensor. But due to cost and bulkiness, speed sensors reduce the advantage of an induction motor drive. Also in some applications, speed sensors cannot be applied, as motor drives in hostile environments and high speed motor drives. Due to these disadvantages researchers made a lot of effort for developing induction motor drives without speed sensor [7].

The angular shaft speed control of three-phase induction was presented (8) using output feedback controller that was based on sliding nodes and indirect adaptive control. AC voltage controller permits the machine to start, vary its speed, and rejects the electrical stress on the apparatus. It is possible by the variation in terminal voltage of induction machine. However, altering the voltage to accomplish an operating condition for fixed speed and torque is a troublesome activity. Also there is a limitation of increasing torque as the induction machine has increasing load torque so the voltage controllers are not preferred for constant torque applications.

To modify the terminal voltage, the firing angle $\alpha$ of the SCRs will be determined for each working condition. Some techniques for closed-loop control to accomplish this have been introduced. But it is difficult to calculate the exact value of $\alpha$ [9]. Some researchers have proposed and built up a strategy of optimal starting without a speed sensor in which sensing of thyristors voltages is very much required [10]. Simple ways to regulate wound rotor induction motor speed was introduced by adding some resistance in the rotor circuit [11]. A simulink model is presented in this paper, which is designed with fuzzy logic to control the speed of three phase induction motor to overcome above mentioned conditions.

2. LITERATURE REVIEW

2.1 Induction Motor

Electrical motors generate straight or rotational torque, expected to push some outer system, such as a fan or an elevator. An electric motor is commonly intended for consistent revolution or linear movement over a critical distance contrasted with its size. Electrical motors are classified by their capacities as servo motors, gear motors, etc., and by their electrical design parameters such as DC motor and Induction motor. AC technology was established by Michael Faraday’s and Joseph Henry’s which states that an electric current can be induced by varying the magnetic field in any circuit.

Some attributes of AC motors are the equivalent, similar to inertia, physical structure, and its shaft qualities. The speed of these motors which are utilized for the control systems is almost the same. It has executed a PI controller and fuzzy logic interface model respectively at the variable working circumstances to the simulation model that has been arranged by the Matlab developers for improvement of the motor execution.

2.2 Description of Fuzzy Logic Controller

Fuzzy logic is utilized in machine control widely. Fuzzy logic works on the concept of “linguistic variables”. The concept of Fuzzy theory was first proposed by Prof. Zadeh in 1965. Fuzzy logic is explained as the combination of “IF-THEN” rules and human language. It is not compulsory to have a mathematical model for fuzzy logic controller. It is the reason to adapt the Fuzzy Logic Controller [12].

Fuzzy logic controller utilizes the concept of fuzzy logic that can be derived by the experts to implement an automatic controlling technique. Although fuzzy logic does not require any complex mathematical calculations but it can show accurate performance in machine control [13]. FLC is more reliable as compared to the conventional control techniques and it covers a wide range of operating conditions. Due to its ease of application, it is used in industry widely. The rules and the membership
functions of a fuzzy logic controller depend on the experience or database. A lot of work has already been done to analyze the fuzzy control rules and membership function parameters [14].

Various approaches have been developed to utilize fuzzy logic in the area of machine control. Therefore it is the best technique to face the challenges in the field of controlling of machines.

Major parts of fuzzy logic controller are shown in Figure 1 and mentioned below:

- **Fuzzifier**: It is used to change the crisp input variables into fuzzy logic sets.
- **Fuzzy Knowledge Base**: Record of input-output fuzzy sets are stored in it. It contains the function which defines the input variables to the fuzzy rule base which stores the data about processing of input output variables to attain the control goal.
- **Fuzzification Inference**: It simulates the human decisions by some approximate calculations and techniques. Basically it emulates the knowledge based decision by identifying the accuracy for controlling of machine.
- **Defuzzification Inference**: It converts the conclusions given by inference mechanism into the output crisp values to control the device [15].

![Block Diagram of Fuzzy Logic Controller](image)

**Figure 1** Block Diagram of Fuzzy Logic Controller

3. **Generalized Induction Motor Model**:

The equivalent circuit diagram in direct & quadrature axis of the induction motor is represented in Figure-2(a) and 2(b). In the given diagram, all parameters are transferred to the stator side. All stator and rotor variables are in the arbitrary two-axis (d-q frame) reference frame. The parameters are given in a list of symbol.

![Induction Motor q-axis diagram](image)

*Figure 2(a) Induction Motor q-axis diagram*
The model of induction motor in space vector notation revolving with speed $\omega$ in direct & quadrature axis can be represented mathematically as below:

\[
\frac{V}{g_{2927}} = R \frac{I}{g_{2927}} + \omega \phi_{ds}
\] (1)

\[
\frac{V}{g_{2914}} = R \frac{I}{g_{2914}} + \omega \phi_{qs}
\] (2)

\[
\frac{V}{g_{2927}'} = R \frac{I}{g_{2927}'} + \omega \phi_{ds} - (\omega - \omega_r) \phi_{qr}
\] (3)

\[
\frac{V}{g_{2914}'} = R \frac{I}{g_{2914}'} + \omega \phi_{qs} - (\omega - \omega_r) \phi_{qr}
\] (4)

Where, $\omega_r$ : angular speed of the rotor
$\omega$ : angular speed of reference frame which is rotating synchronously.

The stator and rotor winding q and d axis flux are expressed as:

\[
\phi_{qs} = L_{s} i_{qs} + L_{m} i_{qr}
\] (5)

\[
\phi_{ds} = L_{s} i_{ds} + L_{m} i_{dr}
\] (6)

\[
\phi_{qr} = L_{r} i_{qr} + L_{m} i_{qs}
\] (7)

\[
\phi_{dr} = L_{r} i_{dr} + L_{m} i_{ds}
\] (8)

The equivalent stator inductance is expressed as

$L_s = l_{ds} + l_{m}$

Equivalent rotor inductance is expressed as

$L_r' = l_{ds}' + l_{m}$

The electromagnetic torque is given as

$T_e = 1.5 \rho (\phi_{ds} i_{qs} - \phi_{qs} i_{ds})$

4. CONTROLLER DESIGN

4.1 Three Phase Induction Motor Parameters

Star Connected, Squirrel-Cage, 4-KVA, 3-phase induction motor has the following parameters:

- Rotor type - Wound
- $P = 4$ No. of poles
- $F_s = 50$ Base frequency (Hz)
- $V_s = 380$ Rated Voltage (V)-Line to Line
- $I = 8.1$ Rated Current (Amp)
- $\cos \phi = 0.87$ Power factor

Parameter referred to the stator side
Rs=0.9  Stator winding resistance (Ω)
Ls=3.45 Stator winding inductance (Ω)
Rr=1.0  Rotor winding resistance (Ω)
Lr=3.45  Rotor winding inductance (Ω)
Xm=50  Mutual Inductance (Ω)
J=0.010  Load inertia coefficient (Kg.m²)

4.2 Simulink Model
The simulink model of FLC to control the speed of Induction motor is represented in Figure 3.

4.3 Fuzzy Controller Design Parameters
Major designing parameters are given as:
(1) Fuzzification inference
(2) Database
(3) Rule base
(4) Decision making logic
(5) Defuzzification inference (defuzzifier)

4.3.1 Fuzzification
Fuzzification is the procedure which transforms the actual crisp fuzzy input set to the linguistic variables that can be accomplished by recognizing the different deterministic variables. The variables that should be controlled are error and change in error. The input variables in PI fuzzy speed controller are error in motor speed e(k) and the change in error Δe(k).

The error and change in error for current and speed are scaled utilizing proper scaling factors. These scaled input set is collected and observed as the level of fuzzy sets. The linguistic variables, used for the input data are:
Positive High: PH
Positive Medium: PM
Positive Low: PL
Zero: ZO
Negative High: NH
Negative Medium: NM
Negative Low: NL

Figure 3. Fuzzy logic controller to control the speed of Induction Motor
4.3.2 Database

The fuzzy set is characterized by fixing the grade of membership values to each component. There are a number of membership functions.

- **NH**: {-0.1667, 0, 0.1667}
- **NM**: {0.002646, 0.1693, 0.3359}
- **NL**: {0.1667, 0.3333, 0.5}
- **ZO**: {0.3333, 0.5, 0.6667}
- **PL**: {0.5, 0.6667, 0.8333}
- **PM**: {0.6667, 0.8333, 1}
- **PH**: {0.8333, 1, 1.167}

The membership functions for error and change in error are shown in Figure 3 (i) and Figure 3 (ii). These functions are considered same for both input data set and Figure 3 (iii) output data.
4.3.3 Fuzzy Control Rules

The fuzzy control rules depend on experience rather than the accessibility of the system model. If \( E \) is \( W \) and \( CE \) is \( Q \), \( de \) is \( C \)

In which \( de \): change in the control input (which is actually the output of the fuzzy controller) \( W \), \( Q \) and \( C \) are the fuzzy subsets for \( e \), \( ce \) and \( de \) respectively.

The linguistic parameters for the output signal \( de \) and their associated quantities are:

- Negative High (NH): \{-0.1667, 0, 0.1667\}
- Negative Medium (NM): \{0.002646, 0.1693, 0.3359\}
- Negative Low (NL): \{0.1693, 0.3359, 0.5026\}
- Zero (ZO): \{0.3333, 0.5, 0.6667\}
- Positive Low (PL): \{0.5, 0.6667, 0.8333\}
- Positive Medium (PM): \{0.6667, 0.8333, 1\}
- Positive High (PH): \{0.8333, 1, 1.16\}

The rule set of FLC is shown in Table 1.

| E   | NH | NM | NL | ZO | PL | PM | PH |
|-----|----|----|----|----|----|----|----|
| CE  | NH | NH | NH | NH | NM | NL | ZO |
| NH  | NH | NH | NH | NM | NL | ZO | PL |
| NM  | NH | NH | NH | NM | NL | ZO | PL |
| NL  | NH | NH | NM | NL | ZO | PL | PM |
| ZO  | NH | NM | NL | ZO | PL | PM | PH |
| PL  | NM | NL | ZO | PL | PM | PH | PH |
| PM  | NL | ZO | PL | PM | PH | PH | PH |
| PH  | ZO | PL | PM | PH | PH | PH | PH |

4.4 Defuzzification

Defuzzification is the inverse process of fuzzification. Defuzzification is the operation of reducing fuzzy set into crisp set. A defuzzification technique expects to deliver a crisp fuzzy output which shows the possibility of distribution of fuzzy control action. Many methods are available for defuzzification process such as the maxima criteria, the mean of maximum, winner claims all, and center gravity methods.

5. EXPERIMENTAL RESULTS

The fuzzy logic controller based control mechanism has been concentrated by the reproduction to approve the plan and to assess the exhibition. The result of simulation is achieved by the fuzzy logic controller which provides a decent execution for a consistent load, speed response as shown in Figure 4. As a result, the fuzzy logic controller gives quicker reaction and lesser overshoot. Figure 5 represents response of torque of the induction motor. Figure 6 represents two-axis rotor current of the motor. Figure 7 represents two-axis stator current of the motor.
Figure 4. Motor speed with FLC at 8Nm

Figure 5. Motor torque with FLC at 8Nm

Figure 6. Two-axis Rotor current of the motor with FLC at 8Nm
6. CONCLUSION

In this paper a controller utilizing fuzzy logic is designed for speed control of induction motor. Simulation results show constant speed response. The maximum overshoot is minimized by 0.05%. The designing components and process of the fuzzy logic controller has been described and their performance is evaluated using simulation. The results which are shown have momentous improvement for holding the performance of induction motor nearly to zero overshoot with minimum time of stabilizing.

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