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Fuzzy Logic Control of Three Phase Induction Motor Using Rotor Resistance Control Method

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Abstract— This work is based on an intelligent speed control system with the application of fuzzy logic on a three phase induction motor. Fuzzy logic was applied to traditional method of speed control of three phase induction motor such as Rotor Resistance Control where inputs such as rotor resistance, line voltage and two loads attached to the motor were varied. With the variations in the inputs, it was observed that appropriate variations in outputs such as speed, slip, torque, output power and efficiency were achieved. By using the Mamdani Fuzzy Model, an analysis of rule-based Fuzzy Logic Controller was applied in which the system can be taught to predict the output depending on the variations in the input variables.

Keywords- *Fuzzy Logic Controller, Mamdani Fuzzy Model, Speed Control, Rotor Resistance Control, Three Phase Induction Motor.*

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I. INTRODUCTION

Induction motors are the most popular choice of most industries mainly for their ruggedness, reliability, efficiency, size, ease of maintenance and cost. Their applications range from various industrial processes to robotics as well as house hold appliances. With respect to their speed control, various traditional methods such as Volts/Hertz control, Rotor Resistance Control have been established and already in use. This paper deals with one of the methods of speed control, viz., Rotor Resistance Control and the fuzzification of this method so as to obtain a flexible control system which predicts the output variables depending on the combination of various input factors.

The conventional Boolean logic of true or false has been extended to include the concept of partial truth for the values which lie between being “completely true” and “completely false”. For such values, a concept of degree of membership has been introduced wherein they are slotted into their membership functions depending on the range in which they fall. The concept of fuzzy logic is interesting since it eliminates complicated hardware installation of plant modelling. Instead, it relies on a set of If-then rules with an attempt to replicate human thought processes in technical environments.

Fuzzy control also supports nonlinear design techniques used in motor control. Machine learning techniques are applied to fuzzy rules in which the understanding of procedure is automatically learned from sample cases. Fuzzy logic controller block diagram is shown in Figure 1.

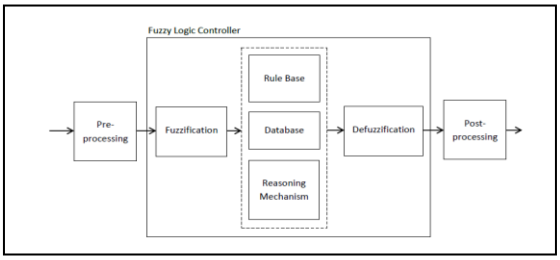

Figure 1 Fuzzy Logic Controller Block Diagram

II. RELATED WORKS

M. A. Badran et al [1] wrote a paper regarding fuzzy logic based speed control of a three phase induction motor about how conventional methods, while showing good results yet requires fine tuning to obtain optimum results. Therefore, using recent methods such as fuzzy\logic controller to improve the performance of induction motor drives was designed with MATLAB/SIMULINK software which was tested for operating conditions such as disturbance in load and changes in reference speed. **E. Abdelkarim et al [3]** presented a paper on accurate loss model based controller of an induction motor wherein the motor speed performance was improved by means of a fuzzy logic speed controller instead of a PI controller. The simulation was done using the fuzzy control interface block of MATLAB/SIMULINK program and the control algorithm was experimentally tested in a PC under RTAI-Linux. **P. Tripura et al [9]** presented a paper on intelligent speed control system based on fuzzy logic for an induction motor drive. Contrary to traditional PI regulator in outer speed loop, it was found that low precision of speed regulator reduces the performance of the entire system. Therefore, the PI controller was replaced with an intelligent fuzzy logic controller whose performance was checked for various operating conditions such as changes in speed and torque. The MATLAB/SIMULINK results prove that the performance of the system was thus enhanced using the proposed fuzzy logic controller than traditional methods.

C. T. Raj et al [7] wrote a paper on energy efficient control of a three phase induction motor in which a review of the developments in the field of efficiency optimization of three phase induction motor was studied through optimal control and design techniques. The use of artificial intelligence techniques such as Fuzzy Logic, Artificial Neural Network and Genetic Algorithm were also reviewed in this paper. The experimental and simulation results on energy optimization were illustrated. **K Devi et al [12]** presented a paper on a rule-based fuzzy logic controller applied to an induction motor with slip regulation and its simulation results and compared the result with a traditional PID controller method. Using Fuzzy MATLAB toolbox and SIMULINK, the simulation was developed for speed control of the induction motor. **R Maloth [10]** wrote a paper on speed control of induction motor using fuzzy logic controller in which a rule-based fuzzy logic controller was applied to a scalar closed loop V/f induction motor control with slip regulation and its simulation results were also observed accordingly. Using fuzzy logic controller, the system performance was improved with the capability to control nonlinear, uncertain systems even in the case of absence of mathematical model for the control system. **M. A. Mannan et al [15]** presented a paper on fuzzy logic based speed control of induction motor considering core loss into account. Here the flux and torque decoupling strategy was decoupled with regards to magnetizing current to reduce the effect of core loss. The performance of the system has been verified with the help of computer simulation.

The above mentioned work highlights that intelligent controller such as Fuzzy Logic can be applied in place of traditional methods and the system can be trained to learn the various possible combinations of inputs in order to predict the output over a period of time.

III. EXPERIMENTAL WORK

A. *Experimental Setup*

Machine used – For the experiment, a three phase squirrel cage induction motor was used with the following specifications as listed in Table 1

Table 1 Induction motor specifications

Sl No	Specification	Rating
1	KW/HP/KVA	3.7KW/5HP
2	Voltage	415 V
3	Current	8.2 A
4	Speed	1400 rpm
5	Star/delta	Delta

For a given induction motor, the operating characteristics are governed by its rotor resistance, airgap length and shape of its stator and rotor slots. By varying its rotor resistance, we aim to control the speed and other such parameters of the induction motor.

The figure for the experiment is given in Figure 2.

Figure 2 Three phase induction motor with method of Resistance Speed Control: top view

B. *Input Variables Selected* :-

- Rotor Resistance
- Line Voltage
- Load 1 Resistance
- Load 2 Resistance

C. *Output response* –

- Motor speed in rpm
- Slip
- Torque
- Output power
- Efficiency

IV. OBJECTIVES AND OVERVIEW OF THE PROPOSED MECHANISM

A) *Objectives*

The three phase squirrel cage induction motor is the most widely used motor in the industry therefore it is desirable to study its characteristics under different load conditions. At no load, the stator current is around 30% to 50% of the full load current and this no load current consists of two parts, a large magnetizing current which supplies the rotating flux and a small active current which supplies mechanical and iron losses. Due to the large magnetizing current, considerable reactive power is required to create the revolving flux. Therefore, power factor is low at no load which ranges from 0.2 lagging for small motors to 0.05 lagging for large motors.

During load condition, both magnetizing current and reactive power are the same as at load but the active power of the motor increases in direct proportion to the load. As the mechanical load increases, the power factor of the machine also increases and at full load, it ranges from 0.7 lagging for small motors to 0.9 lagging for large motors.

The efficiency of the motor at full load is very high and reaches upto 98% for very large motors.

Specimen calculations:

Input power $P_1 = (W_1 + W_2)$ Watts

where W_1 = first wattmeter reading

W_2 = second wattmeter reading

Output torque T = s * 9.81 * 0.117 Nm

where 0.117 m is the radius

Output power $P_O = \frac{2\pi Nt}{60}$ Watts

$W_1 + W_2 = \sqrt{3}VIcos\Theta$

So $cos\Theta = \frac{W1+W2}{\sqrt{3}VI}$

B) *Overview of the proposed mechanism*

The three phase induction motor is connected to a three phase supply of 440 V and 50 Hz AC. Two wattmeters W_1 and W_2 are connected across two of the phases of the mains. The shaft of the motor is connected across a belt with which two loads S_1 and S_2 are attached as shown in Figure 3.

By varying the inputs such as rotor resistance, line voltage and two loads attached to the motor, it was observed that

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appropriate variations in outputs such as speed, slip, torque, output power and efficiency were achieved.

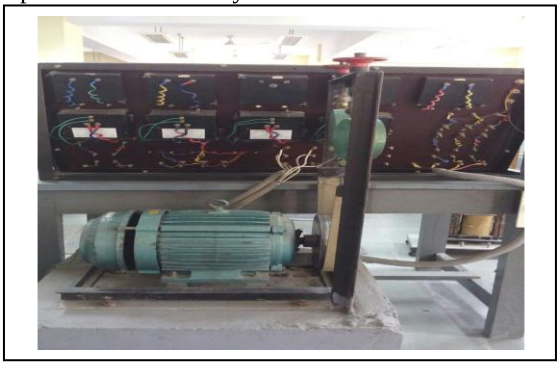

Figure 3 Three phase induction motor with method of Rotor Resistance Speed Control: back view

The experiment was carried out in the laboratory and for various values of rotor resistance, the inputs viz., line voltage, Load 1 and Load 2 were varied. Accordingly, the outputs in terms of motor speed in rpm, slip, torque, output power and efficiency were obtained as shown in Table 2.

Table 2 Experimental data obtained

Sl No	Wattmeter Reading W1	Wattmeter Reading W2	Voltage in Vol	Total output	Speed in rpm	% Efficiency	Power Factor
1	700	-400	360	0	1495	0	0.8
2	800	-300	360	683	1495	50	0.75
3	1100	0	360	1172	1487	72	0.6
4	1500	200	360	3126	1487	79	0.5
5	1800	400	360	3927	1485	82	0.47
6	2000	600	360	4326	1440	87	0.43
7	2300	800	360	4461	1375	80	0.39
8	2800	1100	360	4979	1335	78	0.37

C) Fuzzy Logic Controller

Fuzzy logic is based on a series of "If-Then" rules in which IF there is a certain input, the fuzzy controller should THEN take a particular action. These rules slot each input variable into Membership Functions in such a way that every membership function is not a crisp set but rather they overlap each other. There are three main parts of the fuzzy inference system as shown in Figure 4

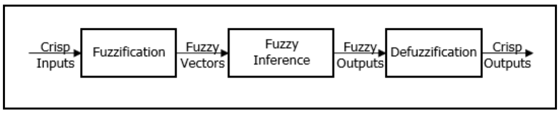

Figure 4 Fuzzy Control System

i) Fuzzification
The process in which crisp sets are converted into overlapping Membership Functions, also known as fuzzy sets is known as fuzzification.

ii) Fuzzy Inference System
The process in which input fuzzy sets are correlated to output fuzzy sets with the help of "If-Then" rules in order to achieve reasonable outputs is known as fuzzy inference system. The most common method is Mamdani fuzzy inference system, which is used in this paper, which has the advantage of intuition, acceptance and suitability to human input. As shown in Figure 5

e \ δe	NL	NS	ZE	PS	PL
PL	ZE	PS	PL	PL	PL
PS	NS	ZE	PS	PL	PL
ZE	NL	NS	ZE	PS	PL
NS	NL	NL	NS	ZE	PS
NL	NL	NL	NL	NS	ZE

Figure 4 Typical rules of fuzzy logic

iii) Defuzzification
The process in which a crisp output is derived from a fuzzy set through fuzzy inference is known as defuzzification. There are many methods such as centroid, average of maxima, midpoint of maxima, median, area, height, etc. The most commonly used method out of all these is the centroid defuzzification as shown in Figure 5, whose expression is given as follows:

$$x * = \frac{\int \mu i\ (x) x\ dx}{\int \mu i (x) dx}$$

where x* is the defuzzified output

μi(x) is the aggregated membership function
x is the output variable

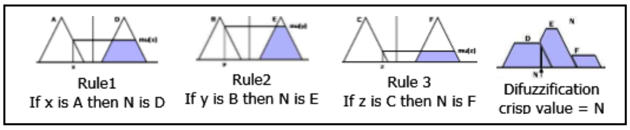

Figure 5 Max min inference of centroid defuzzification

V. RESULT AND DISCUSSION

A) Graphs depicting input-output parameter relationship

Based on the Table 1, as the input parameters such as line voltage, rotor resistance, load 1 and load 2 were varied, the output parameters such as motor speed, slip, torque, output power and efficiency were also observed to vary as shown in Figure 6.

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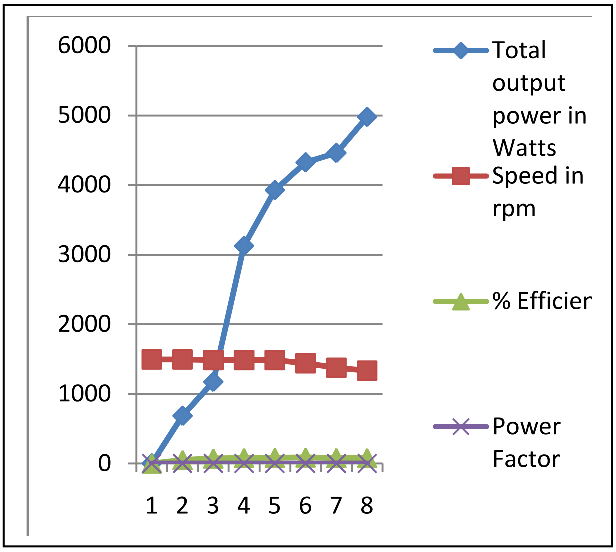

Figure 6 Graph between input-output parameters relationship

B) Fuzzy Logic Toolbox design

The first step in this method was to create a Fuzzy Logic Toolbox design using the specified values of inputs and outputs. Four inputs viz., rotor resistance, line voltage, load1 and load2 were defined as the inputs which controlled five outputs viz., speed, slip, torque, output power and efficiency. This toolbox design is shown in Figure 7.

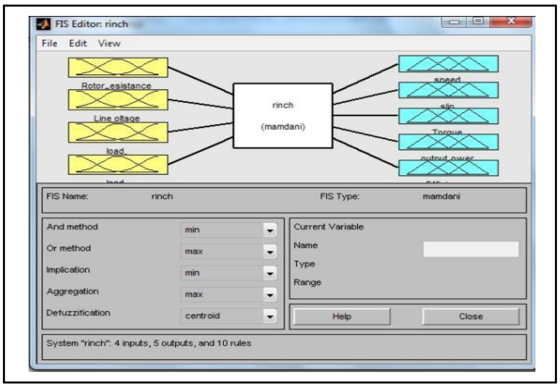

Figure 7 Fuzzy Logic Toolbox design

C) Fuzzy Logic Membership Function

The design of a Fuzzy Logic Controller requires that Membership Functions should be chosen for each input function and they should be chosen such that they cover the whole area of discourse. Membership functions must overlap each other so as to avoid any form of discontinuity with respect to the minimal changes in the inputs. In order to achieve finer control, the membership functions near the zero region should be made visibly narrow. Also, wider membership functions away from the zero region ensures that there is faster response to the system. After this, a rule based fuzzy logic should be created which consists of a number of If-Then rules which defines the behaviour of the system in every respect. These rules resemble the human thought process, therefore providing a kind of artificial intelligence to the whole process.

With the help of the data obtained in the experiment in the laboratory, membership functions are defined for each of the input and output variables as shown in Figure 8

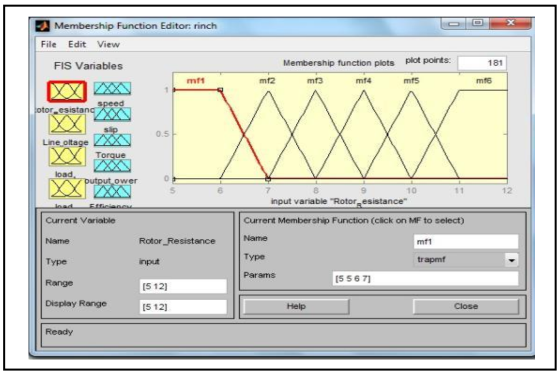

Figure 8 Fuzzy Logic Membership Functions

D) Fuzzy Logic Rules

With the reference to the experimental data collected from the laboratory, a fuzzy logic rule has to be established for each set of reading. Here, the network is being trained so that if the input variables follow a certain trend of values, the output variables should have these appropriate values accordingly. With this factor, the network will be trained to predict even those values of output whose input have not been yet considered. The fuzzy logic rule editor has been shown in Figure 9.

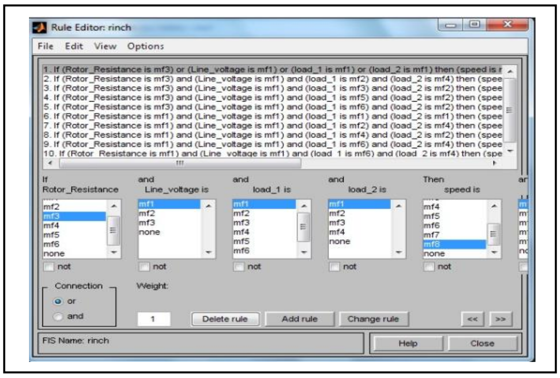

Figure 9 Fuzzy Logic Rules

E) Fuzzy Logic Rule Viewer

With the reference to the experimental data collected from the laboratory, the fuzzy logic rule viewer gives a comprehensive sighting between various input and output variables. By changing any one input, the prediction of the values for the rest of the outputs is changed accordingly. The rule viewer is shown in Figure 10.

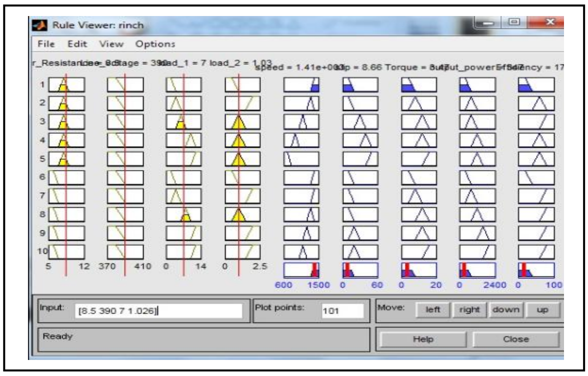

Figure 10 Fuzzy Logic Rule Viewer

F) Fuzzy Logic Surface Viewer

The surface viewer is a three dimensional plot of the control surface which will predict the outcome of any output variable depending on the values of two input variables, shown in Figure 11.

In this figure, it can be seen that for various values of line voltage and rotor resistance of the induction motor, Fuzzy Logic Controller can be applied to predict the output, which is the motor speed in rpm.

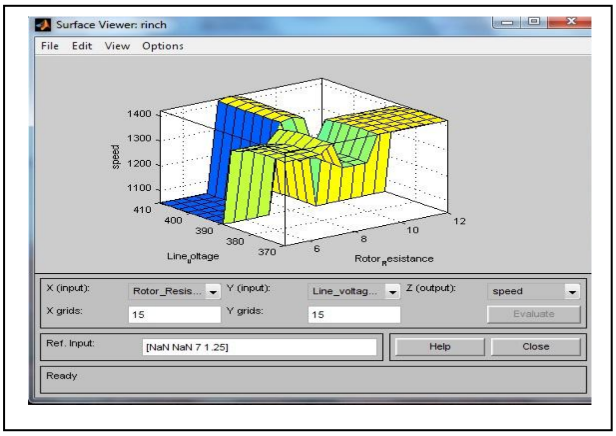

Figure 11 Fuzzy Logic Surface Viewer

VI. CONCLUSION

This paper investigated the effects of rotor resistance control on the speed of a three phase induction motor by conducting the said experiment in the laboratory. Later on, fuzzy logic controller was applied to the same experiment so as to train the system to predict the output viz., motor speed when different input parameters are changed accordingly.

In conclusion, the Fuzzy Logic Controller using the Mamdani Fuzzy Model is quite convenient and does not require any cumbersome procedures. Thus, we have seen that the designing of a Fuzzy Logic Controller requires:

1. The selection of appropriate inputs and their fuzzification.
2. The definition of the input and output membership functions.
3. The definition of the Fuzzy Rule Base.
4. The defuzzification of the output obtained after the processing of the linguistic variables with the help of a proper defuzzification technique. Each of them has to be designed based on the result that is desired from the system.

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