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## FPGA Controlled Stator Resistance Estimation In IVC of IM using FLC

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# FPGA Controlled Stator Resistance Estimation In IVC of IM using FLC

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**Abstract** - In this paper online estimation of stator resistance in indirect vector control (IVC) of Induction motor (IM) is proposed using fuzzy logic controller (FLC). It is renowned that stator resistance of Induction motor which is sensitive to temperature rise in machine leads to performance deterioration as resistance used in controller is dissimilar from actual stator resistance. Here the effect of change in stator resistance is examined in terms of stator current, rotor flux and torque and corrected using fuzzy logic controller algorithm. The proposed algorithm was tested using MATLAB/SIMULINK software and practically implemented in Field programming Gate array (FPGA) Controller.

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## I. INTRODUCTION

The superior performance of separately excited D.C motor in terms of dynamic control had become the work horses for an Industry. Later after development of power electronic converters Induction motors which are rugged in construction replaces the D.C motors even for Adjustable speed applications, i.e., D.C machine like performance was obtained by Induction motor by using vector control, where the three phase stator quantities has been resolved into d-q axes, one resembles torque producing quantities and other flux producing quantity. Therefore the independent control of torque and flux is possible in vector control. However flux position in vector control is essential. There are basically two types of vector control based on how the rotor flux is determined. In direct vector control it is found by direct flux sensors where as in indirect vector control it is found in feed forward manner. However rotor flux which is majorly affected by stator resistance variation which is dependent on temperature rises [40-50%] in machine. In [1] BEMF (Back Electromotive force Detector) was proposed, in [2] calculation of flux including stator resistance was accounted, in [3] by treating the rotor speed and stator voltages and currents are the inputs to flux estimator was proposed. In [4] Stator resistance tuning based on error between actual and measured values proposed using full order observer. In [5] Model reference adaptive system (MRAS) based estimation of Rs. In this paper Flux

estimated from the voltage model is compared with the flux estimated from the current model and error and change in error is given as inputs to the fuzzy controller and the output is taken as change in stator resistance and estimated stator resistance is found by adding the actual resistance.

## II. INDUCTION MOTOR MODEL WITH VECTOR CONTROL

Considering the modeling equation of Induction motor in stationary reference frame, the condition for ensuring vector control is

$$\left. \begin{aligned} \Psi_{dr} &= \Psi_r \\ \Psi_{qr} &= 0 \end{aligned} \right\} \quad (1)$$

The decoupled stator voltages  $v_{ds}$  and  $v_{qs}$  are given by

$$v_{ds} = R_s i_{ds} + \sigma L_s \frac{di_{ds}}{dt} + \left(\frac{L_m}{L_r}\right) \frac{d\Psi_{r ref}}{dt} - \omega_s \sigma L_s i_{qs} \quad (2)$$

$$v_{qs} = R_s i_{qs} + \sigma L_s \frac{di_{qs}}{dt} + \omega_s \left( \left(\frac{L_m}{L_r}\right) \Psi_{r ref} + \sigma L_s i_{ds} \right) \quad (3)$$

$$\omega_{sl} = \left( \frac{L_m i_{qs ref}}{T_r \Psi_{r ref}} \right) \quad (4)$$

$$\omega_s = \omega_r + \omega_{sl} \quad (5)$$

Where  $R_s, R_r$  are stator and rotor resistance values and  $T_r = \frac{L_r}{R_r}$  is rotor time constant,  $\omega_{sl}$  the slip frequency,  $\omega_s$  and  $\omega_r$  the stator rotor angular frequency,  $L_s, L_r, L_m$  the stator and rotor mutual inductance,  $p$  the number of pole pairs,  $\sigma = 1 - \frac{L_m^2}{L_s L_r}$  is the leakage coefficient.

From equations (2) and (3)

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Examining the equation (8) and (9) which also dependent on Rotor resistance which also simultaneously varies with the temperature rise but in this case it with an effort to determine stator resistance variations by assuming rotor resistance effect is constant. An algorithm was developed for stator resistance estimation shown in Fig.2. In the present controller Mandani Fuzzy controller method was used for the estimation of stator resistance. It employs two inputs one is error produced by reference current generated by current model and actual feedback motor currents and the other is change in error produced by same. The rule base acts upon the inputs to produce the given outputs. The linguistic labels are divided into seven groups. They are Negative big, Negative medium, Negative small, Zero, Positive small, Positive medium, Positive big, which are generally expressed as NB,NM,NS,ZE,PS,PM,PB respectively. The rule base mapping of fuzzy inputs to derive require output is shown in table.1. Normally the output obtained produced is fuzzy in nature and has to be transformed into crisp value by using defuzzification method. Here Mean of Maximum method is used at the defuzzification stage.

Table 1 : Computation of outputs using fuzzy rules

e/Δe	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NB	NB	ZE	PB	PM
ZE	NB	NM	NS	ZE	PB	PM	PB
PS	NM	NB	ZE	PB	PB	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

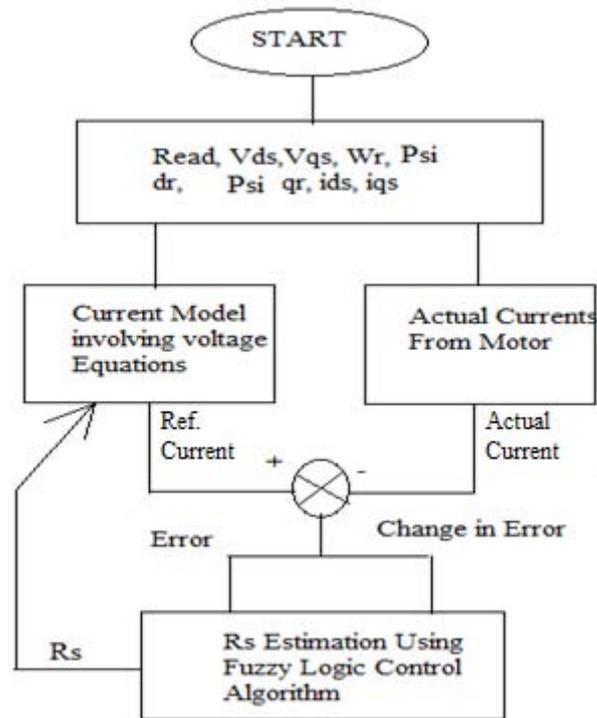


Figure 2 : Stator Resistance Algorithm

## V. SIMULATION AND EXPERIMENTAL ANALYSIS

The performance of 1H.P 3-φ Slip ring Induction motor with Indirect Vector control is simulated using MATLAB/Simulink software. After obtaining the satisfactory results, with an effort to analyze the performance of Induction motor with stator resistance variation an additional resistance is added in terms of step manner the response of rotor flux, torque, and steady state stator currents were analyzed. Initial stator resistance 10.6Ω, an additional resistance of 5Ω is added in step manner, the response in torque is decreased to be 32 N-m from 33.075 N-m, and similarly the rotor flux deviates to 1.08T from its actual value of 0.9T, correspondingly the stator current deviated to 2.1A from its rated value of 2.4A. Next the same results were analyzed experimentally using SPATRAN 3A FPGA Controller with the full rated torque of 33.075N-m. In this case to examine the effect of stator resistance variation an additional resistance of 5Ω is added abruptly in series with the star connected stator winding and abrupt changes in rotor flux, motor torque, and stator currents were experimentally verified and found to be similar to simulated results. Next by implementing Stator resistance algorithm using Fuzzy logic control stator resistance was estimated and adapted to current modeling equations, so estimated stator resistance was found to similar to actual resistance value and thus performance of machine was improved.

Table 2 : Induction motor parameters

3 phase voltage	415V
Rated Current	2.4A
Number of poles	4
Rotor resistance	18.1 Ω
Stator resistance	10.6 Ω
Stator Inductance	0.654H
Rotor Inductance	0.311H
Rated torque	33.075N-m



Figure 3 : Experimental Setup of Indirect Vector control with stator resistance estimation

VI. RESULTS

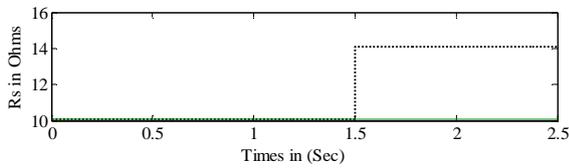


Figure 4 : Change in Stator Resistance at 1.5sec

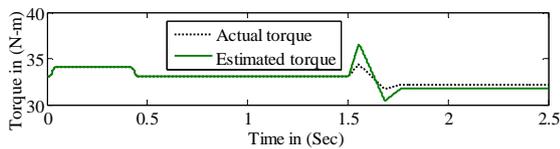


Figure 5 : Torque deviation at 1.5sec

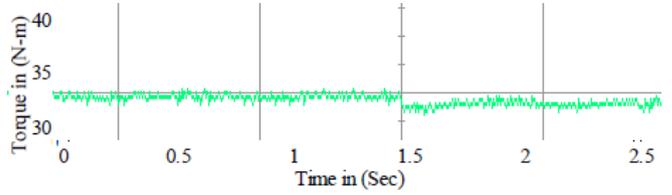


Figure 6 : Torque deviation (Experimental)

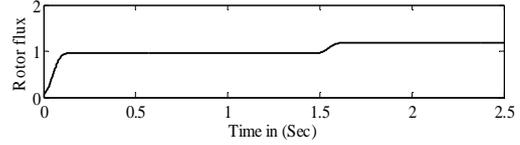


Figure 7 : Rotor Flux deviation at 1.5sec

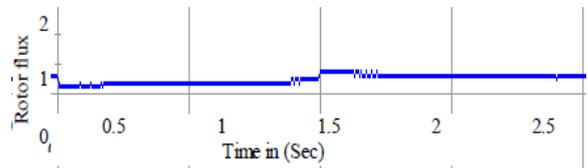


Figure 8 : Rotor Flux deviation at 1.5sec (Experimental)

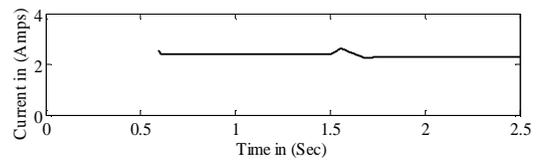


Figure 9 : Deviation in Current at 1.5sec

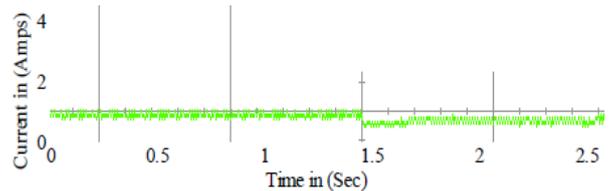


Figure 10 : Deviation in Current at 1.5sec (Experimental)

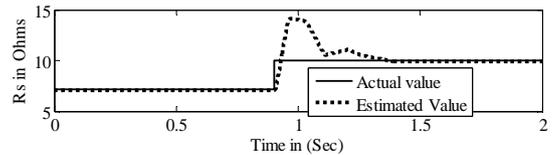


Figure 11: Estimated value converges to actual value adapted at 0.9sec

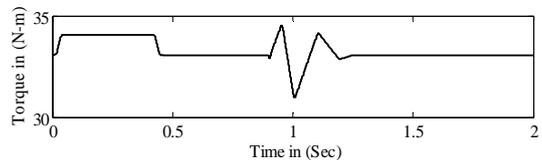


Figure 12 : Torque compensates at 0.9sec

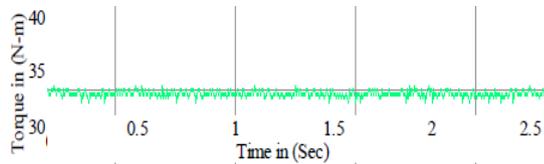


Figure 13 : Torque compensates at 0.9sec(Experiment)

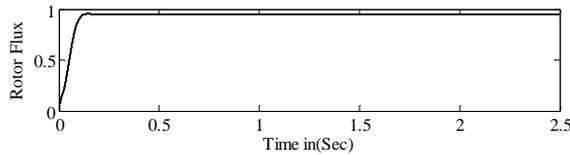


Figure 14 : Flux compensates at 0.9sec

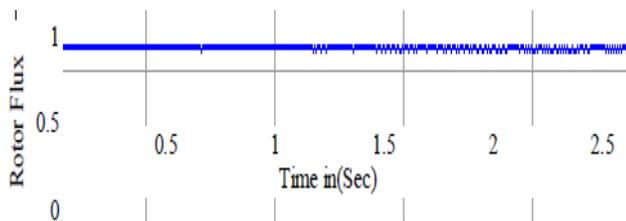


Figure 15 : Flux compensates at 0.9sec (Experimental)

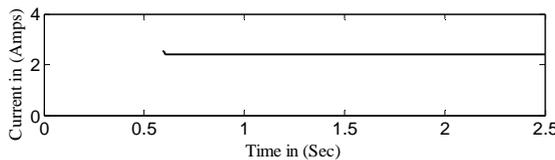


Figure 16 : Stator current compensates at 0.9 sec

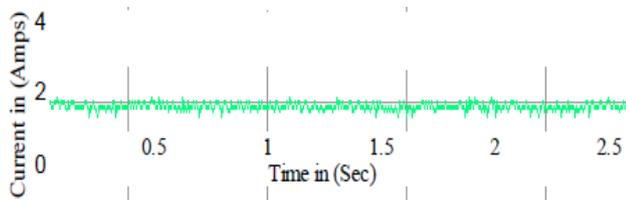


Figure 17 : Stator current compensates (Experiment)

## VII. CONCLUSION

The main drawback of Indirect Vector control technique is stator and rotor resistance variations. In the paper the effect of stator resistance is investigated using MATLAB/Simulink Software as well as experimentally by using FPGA SPATRON 3A controller and also compensated by developing Fuzzy Algorithm.

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