ESTIMATION OF STATOR RESISTANCE OF INDUCTION MOTOR FOR DIRECT TORQUE CONTROL SCHEME USING ADAPTIVE NEURO-FUZZY INFERENCE SYSTEMS

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Abstract: Direct torque control (DTC) is a relatively novel induction motor control method, that is relatively easy to implement and that enables high performance to be achieved. However, the conventional DTC technique has some drawbacks such as large torque ripple in the low speed region according to the change of motor parameters. The sensitivity of the DTC to temperature variations, leading to stator resistance changes, is eliminated by online estimation of stator resistance. This paper describes an adaptive Neuro-fuzzy method of stator-resistance estimation of an Induction motor. In this paper, an estimator is designed through Adaptive Neuro-Fuzzy Inference Systems (ANFIS) for stator resistance estimation with reference to the temperature. Better estimation of stator resistance results in the improvement of Induction Motor performance using DTC, thereby facilitating torque ripple minimization.

Key words: Induction motor, Stator resistance, Direct torque control, ANFIS

1. NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>T</td>
<td>Load Torque</td>
</tr>
<tr>
<td>N_p</td>
<td>Number of pole pairs</td>
</tr>
<tr>
<td>δ</td>
<td>Torque angle</td>
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<tr>
<td>L_s</td>
<td>Stator self inductance</td>
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<tr>
<td>L_r</td>
<td>Rotor self inductance</td>
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<tr>
<td>M</td>
<td>Mutual inductance</td>
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<tr>
<td>Φ_s</td>
<td>Stator flux</td>
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<tr>
<td>Φ_r</td>
<td>Rotor flux</td>
</tr>
<tr>
<td>I_s</td>
<td>Stator current</td>
</tr>
<tr>
<td>R_s</td>
<td>Stator Resistance</td>
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2. INTRODUCTION

In recent years, many techniques have been developed to find out different solutions for the induction motor control having the features of precise and quick torque response and reduction of complexity of field oriented algorithms. Recently, sensorless vector control of induction motor drives is receiving wide attention in the literature. The estimation of stator flux, speed and frequency for flux oriented vector control methods, becomes inaccurate due to stator resistance variation. The inaccurate flux vector computation gives error not only in the flux magnitude, but in the phase angle also, which affects response of the drive. The direct torque control method of the induction motor drive is similarly affected by the error in stator flux estimation. This method is recently gaining more importance because of the feedback signal estimation accuracy is dependent only on the stator resistance variations.
The stator–winding resistance primarily varies with winding temperature, which is given by the following equation:

\[ R_t = R_{to} + \alpha R_{to} (T_t - 25 \degree C) \]  

(1)

Where \( R_t \) is the resistance at \( T \degree C \), \( R_{to} \) is the initial resistance at room temperature, \( T_t \) is the stator–winding temperature and \( \alpha \) is the temperature co-efficient of resistance of copper, which is equal to \((1.121 \times 10^{-3}) / \degree C\).

If a temperature-sensing thermistor is inserted in a distributed manner in the stator winding, the stator winding temperature can be monitored and correspondingly, stator resistance can be estimated accurately by using (1). However, the use of such temperature sensors in direct torque control drive is not acceptable. The stator winding temperature with reasonable accuracy can be predicted by using adaptive systems. Basically, the losses in the machine contribute to stator winding temperature rise, and those losses classified as stator copper loss, rotor copper loss, stator iron loss, rotor iron loss and some amount of stray loss. The heat generated by the losses flow through distributed parameter thermal equivalent circuit of the motor and cause temperature rise at different parts. The stator copper and iron losses will contribute to stator winding temperature rise. In this paper, stator resistance is derived from adaptive neuro fuzzy inference system based estimation of stator winding temperature. The estimation algorithm has been developed for 5-hp induction motor.

3. PRINCIPLE OF DIRECT TORQUE CONTROL

Direct torque control of induction motor is based on the theory of field oriented control (FOC) and direct self control (DSF). The core of DTC consists of hysteresis controllers of torque and flux, optimal switching logic, precise motor model. The motor model calculates the torque, stator flux and shaft speed based on the measurement of two-phase currents and the intermediate circuit dc voltage. Torque and flux references are compared with these values, and control signals are produced using a two-level hysteresis. The optimal switching logic defines the best voltage vector based on torque and flux references.

The expression for the developed torque of an induction motor is given by (2).

\[ T = \frac{N_p M \Phi_s \Phi_r \sin \delta}{\sigma L_s L_r} \]  

(2)

Where \( \sigma = 1 - \frac{M^2}{(L_s L_r)} \)

\( \Phi_s \) = stator flux

Stator flux is a computational quantity, which is obtained using the stator measured current ‘I_s’ and voltage ‘V_s’.

\[ \psi_s = \int_{0}^{t} (V_s - I_s R_s) \, dt \]  

(3)

where \( R_s \) is a known value. The DTC is based on the evaluation of two quantities that are stator flux and torque. Exact evaluation of \( \psi_s \) requires accurate measurements and good evaluation of \( R_s \). The value of \( R_s \), which varies with temperature, needs either an accurate thermal model or an evaluation and estimation method. A comprehensive thermal model for the induction motor, capable of estimating \( R_s \), requires detailed information about the motor that is usually unavailable. Estimation is the only method used recently.

4. SYSTEM MODELING

Figure (1) shows the complete estimation block diagram of stator resistance, which includes a thermistor for calibration of the stator winding
temperature. The system is modeled mathematically using software package MATLAB / SIMULINK. At this package ANFIS system is used. Its operation can be resumed in two steps:

1. The set of membership functions has to be chosen: their number and corresponding shape.
2. The input-output training data is used by the ANFIS. It starts making a clustering study of the data to obtain a concise and significant representation of the system’s behaviour.

Stator current

ANFIS Estimator

Measured Temperature

Thermistor Network

Estimated Stator Resistance

Stator winding Temperature

Figure 1. Block diagram of stator Resistance estimation using ANFIS estimator.

It is important to note that the system has a good modeling if the training set is enough representative, i.e., it has a good data distribution to make possible to interpolated all necessary values to the system’s operation. After set the number of clusters that are estimated to compose the data, the cluster’s centers are searched in an iterative way based on minimizing an objective function. This represents the distance between a data value to the cluster’s center. Here, we used the technique of subtractive clustering to estimate the number of clusters.

5. SIMULATION PROCEDURE

Induction motor considered for the simulation is a 5 h.p. machine. The complete model developed and simulated using ANFIS, which is a function available in MATLAB. The inputs given to the model are stator current, stator temperature with respect to time and the output of the model is stator resistance. Values are entered in matrix form in m-file. Once the stator temperature and the corresponding stator-resistance estimator were designed and iterated by simulation study, they were calibrated extensively with the thermistor generated data at different stator current under both steady state and dynamic conditions, and the estimation accuracy was found to be very good. To get accurate results, for the inputs, membership functions are generated. Membership functions generated for temperature and stator current input variables are shown in figure 8 and 9 respectively.

Figure 2. Surface plot of the estimator model with varying stator current at a constant speed of 918 r.p.m.
6. RESULTS AND DISCUSSIONS

The behavior of the estimator model is studied for varying temperature. Stator resistance of the motor is 0.5814Ω at rest. The critical values of stator resistance are chosen from the simulation results. The surface plots of the model with varying stator current and temperature at constant speeds 918, 725 and 357 rpm are shown in the figures 2, 3 and 4 respectively. The surface plot of the critical values of the stator resistance with varying time is also shown in the figures 5, 6 and 7.
7. CONCLUSION

The paper describes a method of induction motor stator-resistance estimation, where adaptive neuro-fuzzy approach has been implemented. The neuro-fuzzy algorithm estimates the stator winding temperature at steady state as a function of stator current. The estimator is modeled using ANFIS, which is a function used in MATLAB/SIMULINK. The simulation result shows that the estimation of stator resistance is more accurate. The estimated values of stator resistance are compared with the experimental values and observed that the estimated values are very close to the practical values. The results demonstrate the effectiveness of the model.

8. APPENDIX

Induction motor parameters
5 HP, 415V, 1500 rpm, 4 poles, 50Hz
Rs = 0.5814 Ohm
Rr = 0.4165 Ohm
Is = 12.7 A
Rated stator flux, Φs = 0.45 Weber.

9. REFERENCES


