International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2012 Issue 11 Volume 4 Number 2 Pages 140-144

INDUCTION MOTOR EFFICIENT OPTIMIZATION CONTROL BASED ON NEURAL NETWORK

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Abstract- This paper focuses on increasing efficiency in a three phase induction motor. Induction motor which work below its rated torque, cause core loss to increase. Decreasing the induced rotor flux will decrease the core loss. In this paper a feed forward neural network is used with field oriented control. Training the network depends on Induction Motor (IM) loss model which computes the proper rotor flux value. This model minimizes IM total losses to a certain value of torque and speed. The neural network model presented in this paper calculates the optimal flux quickly. According to results of this paper, presented method has a high accuracy for various loads.

Keywords: Neural Networks (NN), Efficiency Optimization, Induction Motor, Loss Model Control, Flux Optimum.

I. INTRODUCTION

Decreasing the power consumption in the various loads has great variability. When the power consumption is increased, it causes a higher degree of temperature. All efforts are done to preserve the energy and to control its use [1, 2]. Induction motors have been widely used in the industrial drive systems, and they account for 70% among used motors, so their decrease of losses is so essential. The vector control technology provides independent control of torque and flux linkages similar to the DC-motor [3]. The field oriented induction machine drive systems are classified into two categories: the direct field oriented system by flux sensors and the indirect field oriented system. The last one doesn't need any flux sensor [4].

Efficiency optimization in induction motor uses two different methods. The first called search control depends on increasing or decreasing the flux of the stator or the rotor step by step until the measured input power decreases to minimum point [5]. This approach has a relatively long response time but it does not need any model of system. Model based efficiency is dependent on machine parameters and fails by parameter changes.

Several techniques have been proposed to estimate the optimal rotor flux for minimal losses using ANN, for example, E.S. Abdin presents an approach where the optimum flux producing current is obtained using an artificial neural network with vector control [8]. A simple structured neural network for flux position estimation, sector selection and stator voltage vector selection for induction motors using direct torque control (DTC) method is presented in [9]. B. Pryymak, et al. present an IM model with a neural network based on the approach improving efficiency of the induction motor vector control drive. The network has been trained using a complete motor loss model [10, 11, 12].

The remaining parts of this paper consist of these sections. In section II, FOC of induction motor is described. Then, the motor loss analyzes of field oriented control of induction motor used in this paper is exposed in section 3. In section 4, ANN method is used to calculate the optimum flux value which achieves the minimum losses is investigated. The proposed control algorithm has been described in section VI. In this section, the adaptive algorithm for flux determination and flux search control are presented. Simulations and experimental results are shown in section VII and VIII. These results show the superiority of the proposed method.

II. FOC AND MOTOR LOSSES ANALYSIS

FOC is a technique which provides independent control of torque and flux during both dynamic and steady state conditions. In FOC, the stator phase currents are transformed into a d-q synchronously rotating reference frame, and field orientation is achieved by aligning the rotor flux vector along the d-axis of the frame. In ideal induction motor model, the voltage current, flux and torque can be presented mathematically in a d-q reference in the following equations [8]:

$$\begin{cases} v_{ds} = R_s i_{ds} + \dfrac{d}{dt}\lambda_{ds} - \omega_e \lambda_{qs} \\ v_{qs} = R_s i_{qs} + \dfrac{d}{dt}\lambda_{qs} - \omega_e \lambda_{ds} \end{cases} \tag{1}$$

$$\begin{cases} \lambda_{ds} = L_s i_{ds} + L_m i_{dr} \\ \lambda_{qs} = L_m i_{dr} + L_s i_{ds} \end{cases} \tag{2}$$

$$\frac{d\omega_r}{dt} = (T_e - T_L)/J \tag{3}$$

The angular speed of the rotor flux vector and the sliding angular speed are given as follows:

$$\omega_e = \omega_r Z + \omega_s \, ; \; \omega_s = \frac{L_m i_{qs}}{T_r i_{dr}} \tag{4}$$

The relation between torque and rotor flux and q-stator current is:

$$i_{qs} = \frac{2}{3} \cdot \frac{2}{P} \cdot \frac{L_r}{L_m} \cdot \frac{T_e}{\hat{\lambda}_r} \tag{5}$$

The equivalent scheme per phase of an IM is shown in Figure 1, where V_s , i_s , i_r are stator voltage, stator current and rotor current vectors, respectively; R_c is the motor core loss resistance. The electric and magnetic losses, both for stator and rotor are represented in this model.

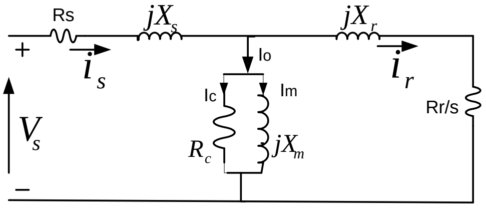

Figure 1. Per-phase induction motor equivalent circuit

The friction, windage and stray losses are little and can be neglected. In steady state conditions, losses in the fixed load and speed are constant and do not change in the proposed algorithm. The total losses of IM consist of copper losses P_{cu} , core losses (P_{Core}) and mechanical losses (P_m) .

$$P_{loss} = P_{core} + P_{cu} + P_m \tag{6}$$

Compounding eddy and hysteresis losses in IM model taking into account stator core losses only because rotor core loses are very small.

$$P_{core} = I_c^2 . R_c \tag{7}$$

The stator and rotor copper losses are essentially determined by the corresponding resistances and currents. In the steady state, there is no leakage inductance. Thus, a typical method to simplify modeling of power loss is to ignore the leakage inductance. Stator and rotor copper losses are given by:

$$P_{cu} = P_{cu,s} + P_{cu,r} \tag{8}$$

$$P_{cu,s} = R_s (I_d^2 + I_q^2) \tag{9}$$

$$P_{cu,r} = I_q^2 K_r^2 R_r \tag{10}$$

Mechanical loss is dependent on mechanical speed and is given as:

$$P_m = k_m \omega_r^2 \tag{11}$$

By modifying the result to be a function of rotor flux we can approximate the total losses as shown below:

$$P_{total-losses} \approx \left(\frac{R_s}{L_m^2} + a P_{core} \right) \lambda_r^2 + b \frac{T_e^2}{\lambda_r^2} \left(\frac{R_s}{K_r^2} + R_r \right) + \tag{12}$$

$$+ K_w {\omega_r}^2$$

The total losses are mainly a function of three parameters $(\lambda_r, \omega_r, T_l)$ if the effect of parameter changes due to temperature and magnetic saturation is omitted. The efficiency of the induction motor can be calculated as follows:

$$\eta = \frac{P_{out}}{(P_{out} + \sum Losses)} \tag{13}$$

Thus, decreasing the losses in the Induction motor, to increase the efficiency is the most important aim for researches. The neural network is used with the loss model control strategy because it achieves a fast and good response in finding the optimum value of flux which achieves the maximum efficiency.

III. EFFICIENT CONTROL SYSTEM FOR IM BASED ON NEURAL NETWORK

It is evident that for low work condition and if the magnitude of the rotor flux is decreased the losses also will be decreases. So at low values of torque, we need to decrease the flux to a value that achieves minimum losses. The speed of computing the optimum value of flux for a given speed and torque values is very important.

The block diagram for the IM control system is shown in Figure 2 including the ANN controller with field oriented control, The ANN block is used to calculate the optimum flux value which achieves the minimum losses calculated by Equation (17), and this net has three layers. NN has been trained with the following structure: one input layer with 2-inputs (speed, torque), first hidden layer (3-neurons), second hidden layer (5-neurons) and one output layer (1-neuron).

For every fixed value of $T_e(i), \omega_r(i)$ in Equation (13) there is ${\lambda_r}^{*opt}(i)$ value where the minimum losses is achieved, these values can be presented in Equation (14):

$$\left\{ P_{total-losses} \left(\lambda_r^{*opt}(i) \right) = P_{\min}(i) \right\}_{| \omega_r(i), T_e(i)} \tag{14}$$

This vector of $\lambda_r^{*opt}(i)$ values is used to train the neural network by using a limited length about 63 values. To train the network it is necessary to have enough sets of input-output patterns, we achieved that by a 63 patterns. Figure 4 shows the built net with 4-layers with a set of $N = 63$ samples for X, Y. The input layer has tow inputs [speed; torque], the first hidden layer has 3 neurons, and the second hidden layer has 5 neurons, and one output layer which is the optimum value of the flux.

Testing the net for a 63 set of input/output patterns where input=[speed; torque], the output will be the optimum flux value achieve minimum losses as shown in Figure 5. We reach a mean squared error $\leq 10^{-6}$, as shown in Figure 5. The generated net which is generated by Matlabe/Simulink will be used within the model representing the block diagram shown in Figure 3.

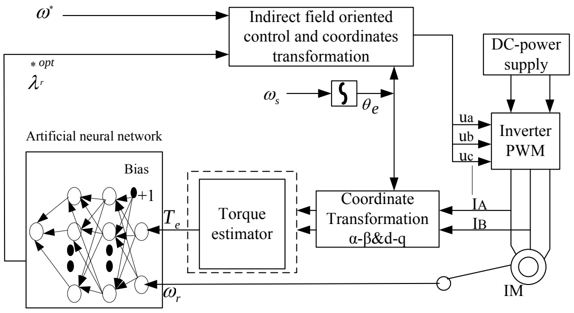

Figure 2. Induction motor control with ANN

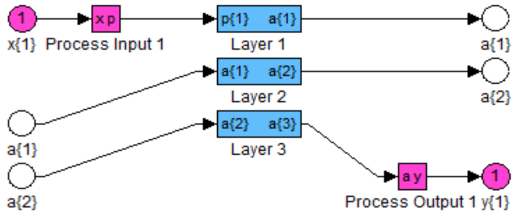

Figure 3. Network structure

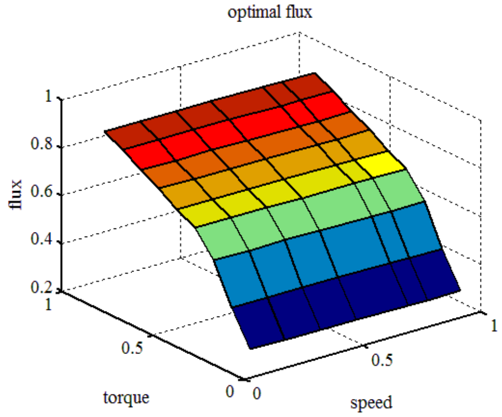

Figure 4. Optimum flux with ANN response input

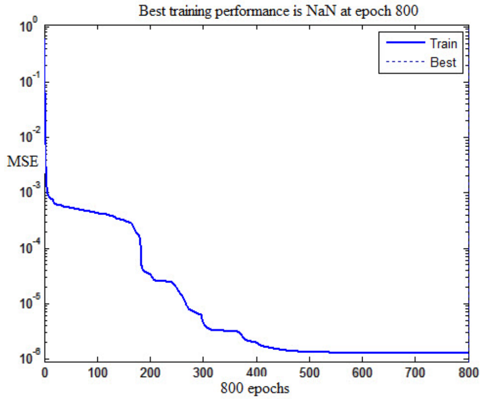

Figure 5. ANN-mean squared error

IV. SIMULATION RESULTS

Depending on approaches described above, induction motor control system is modeled by Matlab/Simulink file. The simulation results will be derived with and without the ANN. Test-1: It was seen that for a response to speed equals to 100 rpm at low load torque 0.6 N.m, the NN quickly reached the optimum flux value and the losses are decreased and consequently the efficiency is improved when using ANN than that without using ANN, where we using rated flux value equal to (0.9 pu) (Figures 6-10).

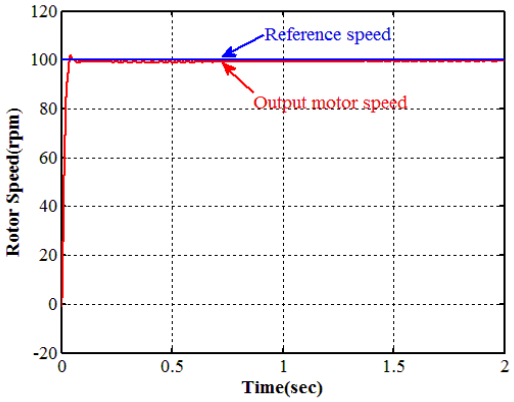

Figure 6. Rotor speed reference versus output

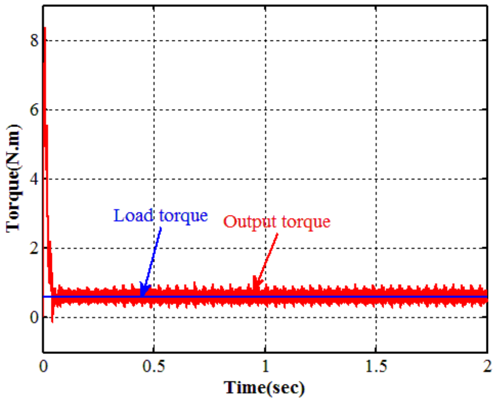

Figure 7. Load torque load versus output

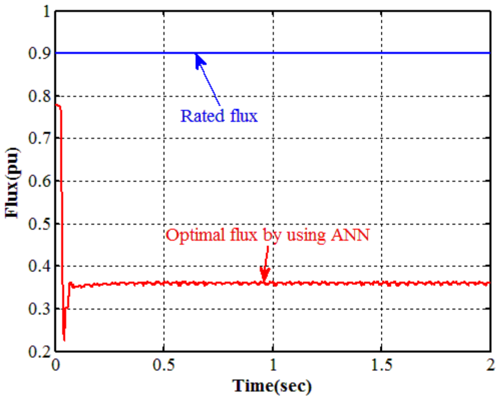

Figure 8. Rotor flux rated versus ANN-output

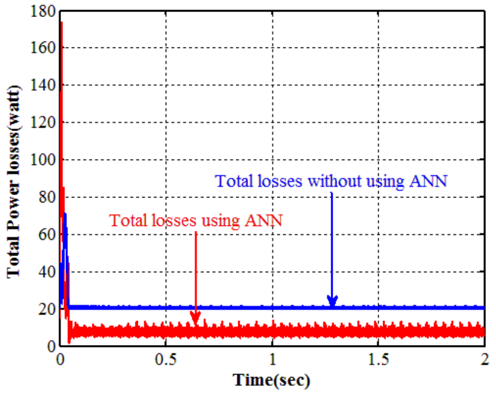

Figure 9. Losses with and without using ANN

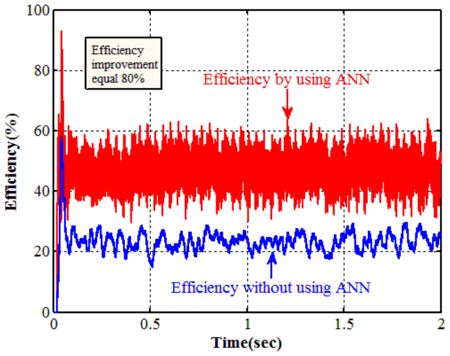

Figure 10. Efficiency with and without using ANN

Test-2: For a speed response equals to 100 rpm it was seen that for a varying load torque (0.3, 1.5, 0.6 N.m), the NN quickly reached the optimum flux values and losses are decreased and consequently efficiency is improved by using ANN than that without using ANN, where using rated flux value equal to (0.9 pu) (Figures 11-15).

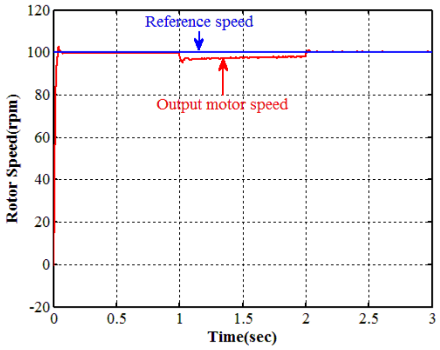

Figure 11. Rotor speed reference versus output

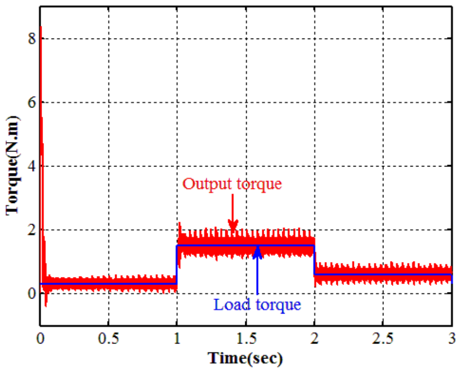

Figure 12. Torque load versus output

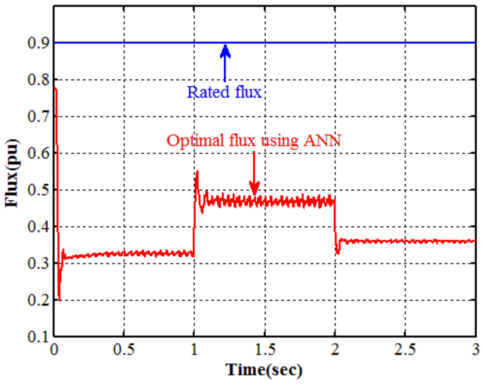

Figure 13. Rotor flux rated versus ANN-output

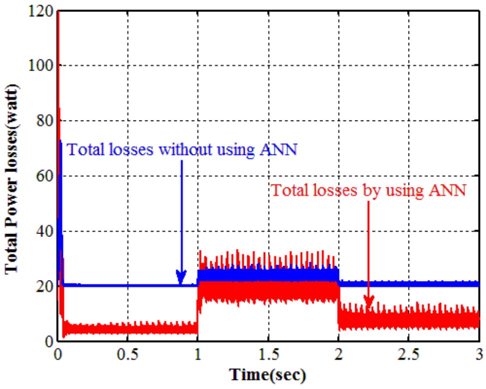

Figure 14. Losses with and without using ANN

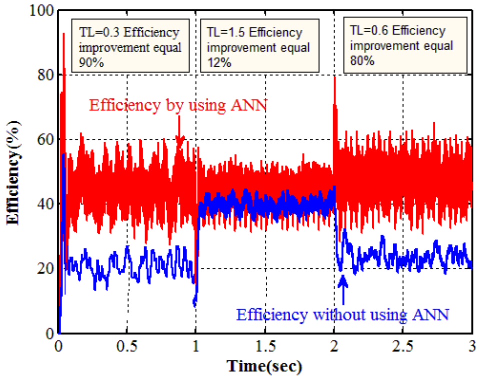

Figure 15. Efficiency (with and without using ANN)

V. CONCLUSIONS

A study of using loss model control method that depends on neural network algorithm with vector control for efficiency improvement in induction motor was presented. A neural network based optimal rotor flux estimator has been designed. A 3-5-1 feed-forward neural network with 2 inputs (Estimated torque and actual speed) has been designed and trained by Levenberg-Marquardt back-propagation method to estimate optimal rotor flux for different conditions of torque and speed.

Testing the system with and without using the NN for different work condition was done. A better efficiency improvement in the drive system was achieved for the worst work case when the motor works at minimum load torque where the iron losses increase. This is done in a very short interval time, while maintaining a good performance of the induction motor drive. This work can be better improved by entering the effect of deviation in the parameters due to temperature and saturation like mutual inductance and rotor resistance. The induction motor is squirrel cage rotor and the parameters used in simulation are given in the Table 1.

Table 1. Induction motor parameters

Type	IM Parameters
Rated Power	1880VA
Rated Voltage	380V
Rated current	4.9A
Rated frequency	50 Hz
Rated speed	1395 rpm
Number of poles	4
Stator Resistance	3.83 Ω
Rotor Inductance	0.023 H
Stator Inductance	0.023 H

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BIOGRAPHIES

Asghar Taheri was born in Zanjan, Iran, in 1977. He received the B.Sc. and Ph.D. degrees all in Electronics Engineering from the Amirkabir University of Technology (Tehran, Iran) and Iran University of Science and Technology (Tehran, Iran), in 1999 and 2011, respectively. He has been a member of the faculty at the University of Zanjan (Zanjan, Iran) since 2010 where he is currently an Assistant Professor. His current research interests include DSP and FPGA based system designs, motor drives and control, multiphase machine drives and control, power electronic systems design, process control, hardware in the loop, and computer-aided control.

Hassan Al-Jallad was born in Lattakia, Syria, in 1971. He received the B.Sc. degree from Aleppo University, Aleppo, Syria in the field of Electronics Engineering in 1996 and M.Sc. degree from Iran also in the field of Electronics Engineering in 2011. His research interests are in industrial production, engineering domain and power electronic engineering.