Abstract—This paper proposes an effective adaptation learning algorithm based on artificial neural networks for speed control of an induction motor assumed to operate in a high-performance drives environment. The structure scheme consists of a neural network controller and an algorithm for changing the NN weights in order that the motor speed can accurately track of the reference command. This paper also makes uses a very realistic and practical scheme to estimate and adaptively learn the noise content in the speed load torque characteristic of the motor. The availability of the proposed controller is verified by through a laboratory implementation and under computation simulations with Matlab-software. The process is also tested for the tracking property using different types of reference signals. The performance and robustness of the proposed control scheme have evaluated under a variety of operating conditions of the induction motor drives. The obtained results demonstrate the effectiveness of the proposed control scheme system performances, both in steady state error in speed and dynamic conditions, was found to be excellent and those is not overshoot.

Keywords—Electric drive, Induction motor, speed control, Adaptive control, neural network, High Performance.

I. INTRODUCTION

AC induction motors are very popular in variable speed drives. They are simple rugged, inexpensive and available at all power ratings. Progress in the field of power electronics and microelectronics enables the application of induction motors for high performance drives, where traditionally only DC motors were applied [1]. Thanks to sophisticated control methods, AC induction drives, where sophisticated control methods, AC induction drives offer the same control capabilities as high performance four quadrant DC drives. The induction motors it is desirable to control the flux and torque separately in order to have the same performances as those of DC motors. One way of doing this is by using the field oriented control [2]. This method assures the decoupling of flux and torque. The Vector-controlled induction motors with a conventional PI speed controller is used extensively in industry [3], because the conventional PI controller is easily implemented. Many theories for the non linear system control have been proposed to solve the problems of the conventional control method.

One of the most noticeable control theories is the method using the Adaptive Neural Network [4]. Adaptive Neural Network can approximate linear or non linear functions through learning. Compared with existing control method, it does not require complex mathematical calculation or models needed for obtaining system parameters and it can success fully control non linear system. In the following section, we explain a vector control of the induction motor in section II; section III describes the structure of the proposed neural control scheme. The obtain simulation results are shown discussion in section IV. Finally, conclusion is made in section V.

II. VECTOR CONTROL OF THE INDUCTION MOTOR

A. Differential Equations of the Induction Motor

Up to now the space vector method presented by Fig. 1 has been used to describe the induction motor mathematical model, based on the vector method. [5]

where s,r denote stator and rotor. a,b,c are the phase system axis. d and q denote direct and quadrantal components of the vectors with respect to the fixed stator reference d,q. Thus the
slip angle $\theta_s$ can be calculated as the time integral of the slip angle velocity $\omega_s$, by adding the rotor angle $\theta_r$ to the slip angle the rotor flux position $\theta_m$, many be calculated:

$$\theta_s = \theta_r + \theta_m \quad (1)$$

The mathematical model of induction motor applied in the paper, has been obtained after the transformation of the stator and the rotor phase equations into two, rotating with synchronous velocity $\omega_s$ orthogonal axes.

$$\begin{align*}
\frac{d}{dt} i_d &= \frac{1}{\sigma L_s} \left[ -\left( R_s + \frac{M^2 R}{L_r} \right) i_d + \omega_r \cdot \sigma L_s i_q + \frac{M R}{L_r} \psi_{sd} + M \omega_r \cdot \psi_{rq} + u_d \right] \\
\frac{d}{dt} i_q &= \frac{1}{\sigma L_s} \left[ -\omega_r \cdot \sigma L_s i_d - \left( R_s + \frac{M^2}{L_r T_r} \right) i_q + \frac{M}{L_r} \omega_r \cdot \psi_{sd} + \frac{M}{L_r} \psi_{rq} + u_q \right] \\
\frac{d}{dt} \psi_{rd} &= \frac{M R}{L_r} i_d - \frac{R_s}{L_r} \psi_{rd} + (\omega_r - \omega_s) \cdot \psi_{rq} \\
\frac{d}{dt} \psi_{rq} &= \frac{M R}{L_r} i_q - (\omega_r - \omega_s) \cdot \psi_{rd} - \frac{R_s}{L_r} \psi_{rq} \quad (3)
\end{align*}$$

where $i, u, \psi$ denote current, voltage and flux linkage respectively. Subscripts $r$ and $s$ stand for rotor and stator. $\omega_r$ is the rotor speed, $\sigma$, $L$ and $R$ are the auto-inductances and resistances, $M$ is the mutual inductance. $\sigma$ constant coefficient. The motor load system can be described by a fundamental torque equation (4):

$$T = T_l + J \frac{d\Omega_m}{dt} + \beta \Omega_m \left( \psi_{rd} i_d - \psi_{rq} i_q \right) \quad (4)$$

where $T$ the instantaneous value of the developed motor torque. $T_l$ the instantaneous value of the load torques. $\Omega_m$ rotor speed of the motor shaft. $J$ the moment of inertia of the motor load system. $F$ the coefficient of friction the number of pair poles.

B. Indirect Vector Control of an Induction Motor

Based on reference frame theory, the induction motor drive can be controlled like a separately exited dc machine by field oriented control method [1], which can be design in tow basic ways by direct or indirect method. The choice between these two methods is not obvious because each method has its distinctive advantages and disadvantages. As a result a great research effort has been made to improve both direct and indirect field oriented controllers by design of complicated hardware and software to compensate non-ideal machine behaviour such as parameter variations due to temperature changes, rotor deep bar effects and magnetic saturation. The bloc diagram shown in Fig. 2, depicts the general structure of the indirect field oriented control with speed control motor drive.

![Fig. 2 Indirect field oriented induction motor drive](image)

This scheme includes induction motor, pulse with modulated (PWM) inverter, indirect field oriented control (IFOC) and speed controller. In this approach the flux angle $\theta_r$ is not measured directly, but is estimated from the equivalent circuit model and from measurements of the rotor speed, stator currents, and the voltages $u_d, u_q$.

C. PI Speed Controller

The dynamic model of speed induction motor drive is significantly simplified, and can be reasonably represented by the bloc diagram shown in Fig. 3.

![Fig. 3 Bloc diagram of speed system controller](image)

By using the Laplace transformation, the transfer function for (4) is equation (5):

$$\omega_m(s) = \frac{\frac{n_p}{s} \left( T - T_l \right)}{J s + F} \quad (5)$$

The classic numerical PI (Proportional and Integral) regulator is well suited to regulating the torque, to the desired values as it is able to reach constant reference, by correctly both the P term ($K_p$) and I term ($K_i$) winches are respectively responsible for error e sensibility and for the steady state error. If $T_l = 0$, the transfer function is as following (6):

$$G(s) = \frac{n_p \left( K_p s + K_i \right)}{J s^2 + \left( f + K_p n_p \right) s + K_i n_p} \quad (6)$$

where
The expressions for $K_p$ and $K_i$ of the regulator is calculated by Imposeion of poles complexes combined with real part negative $S_{1,2} = \rho(-1 \pm j)$. 

\[
\begin{align*}
K_p &= \frac{2\rho j - f}{n_p} \\
K_i &= \frac{2\rho^2}{n_p}
\end{align*}
\]  

where $\rho$ It is a positive constant.

The proposed indirect vector control has several advantages over conventional one as are its independence of the motor model parameters and simple microcomputer implementation. The effects of stator resistance $R_s$ variations in the calculation of slip frequency and transformation angle is compensated by motion controller. The nonlinearities caused by magnetic saturation can be compensated by the inverse magnetizing characteristic.

III. CONTROL SYSTEM BASED ARTIFICIAL NEURAL NETWORK

A. Adaptive Neural Networks

A general architecture graph of Multilayer Perceptron (MLP) is shown in Fig. 4. This network which can be multiplexed for each output of the controller has been found to possess acceptable performance in many industrial applications. The feed-forward topology shown in the network of Fig. 4 offers the advantage of simplicity and ease programming. Such a neural network contains three layer, hidden layers and output layer. Each layer is composed of several neurons. The number of the neurons in the output and layers depends on the number of the selected input and output variables. The number of hidden layers and the number of neurons in each depend on the system dynamic and the desired degree of accuracy.

The block-diagram in Fig. 5 shows the model of a neuron, which performs two functions. The fist is to sum all the inputs from the upper layer based on their weighting factors in equation (9). The second is to process this sum by a nonlinear sigmoid function in equation (10).

\[
E = \frac{1}{2} \sum_j e_j^2(k) = \frac{1}{2} \sum_j [y_j^* - y_j(k)]^2
\]

where $y_j(k)$ is the output of neuron $j$ and $y_j^*(k)$ is the desired pattern for that neuron. Let $\eta_j(k)$ denote the learning
rate parameter assigned to synaptic weight $w_p(k)$ at iteration number $k$. Minimizing equation (12) leads to a sequence of update of weight vector. The weights of the interconnections between two adjacent layers can be update based on the following formula:

$$w_p(k+1) = w_p(k) - \eta_p(k+1) \frac{\partial E(k,\omega)}{\partial w_p(k)} + \alpha \Delta w_p(k)$$ (12)

$\alpha$ is the momentum gain, is susceptible to local minima and needs additional computation for gradient evaluation, and $\Delta w_p(k)$ is weight change based on gradient of the cost function $E_{k,w}$ and $k$ is the iteration number.

C. Adaptation Learning Control Scheme

The proposed adaptive neural network controller is shown in Fig. 6 where as the structure of the neural network used is featured in Fig. 7. In off line training the targets are provided by an existing controller, the neural network adjusts its weights until output from the ANN is similar to the controller.

The four input signals ($e(k)$, $e(k-1)$, $isq(k-1)$, $w_r(k-1)$) and the torque ($T(k)$) output are exported to the MATLAB Workspace. The following MATLAB code trains the Neural Network. The first section of code generates the ‘cell array’. The cell array combines the 4 different inputs into 1 input vector. The Feed-forward network has 10 neurons in the two layers Fig. 7. The activation function in the two layers is tan-sigmoid and the output layer is a linear function.

Where the training is finished, the weights are set Fig. 8, and a Simulink ANN is generated. The network is placed in the existing PI controller Fig. 9, in the block diagram of indirect oriented Field vector controller.

IV. RESULTS AND DISCUSSION

The vector controller induction motor drive using artificial neural network was simulated through Matlab-Software with Simulink Toolboxes. The simulation phase was very important to verify correctness of theoretical assumptions and to find behaviour of the drive. The parameters values of the system under study are summarized in Table I.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>RATING OF TESTED INDUCTION MOTOR</th>
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<tbody>
<tr>
<td>Rated values</td>
<td>Power</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Voltage ΔY</td>
<td>220/380 V</td>
</tr>
<tr>
<td>Current ΔY</td>
<td>220/380 V</td>
</tr>
<tr>
<td>Motor Speed</td>
<td>1420 rpm</td>
</tr>
<tr>
<td>pole pair (p)</td>
<td>2</td>
</tr>
<tr>
<td>Rated parameters</td>
<td>$R_s$</td>
</tr>
<tr>
<td></td>
<td>$R_r$</td>
</tr>
<tr>
<td></td>
<td>$L_s$</td>
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<td>$L_r$</td>
</tr>
</tbody>
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The proportional and derivative parameters of the proposed control scheme are $K_p=0.58$ and $K_i=11.19$. Several test cases were considered in order to evaluate the performances under a variety of operating conditions. For the robustness of the proposed control scheme, we assure that the parameters of rotor resistance $R_r$ and load inertia $J$ have been perturbed from their nominal values Figs. 10, 11. The parameters of the stator resistance, inductance and viscous friction change their nominal values. It is evident that the speed response of the proposed control scheme is not significantly affected by this variation. One can see from these all figures the results were very successful and the obtained results confirm the validity of the proposed control scheme.

The Fig. 12 shows the behaviour of the system to screw of resistant torque $T_l=10 \text{ N.m}$, his disturbance can be seen at $t=0.5 \text{ s}$ and $t=2 \text{ s}$, in maintaining the constant speed control $\omega_0=150\text{rad/s}$ and $\omega_0=-150\text{rad/s}$ at $t=1.5 \text{ s}$. Fig. 13 shows the results by Reference without filter, the results were very successful and the obtained results confirm the validity of the proposed controller. To demonstrate the robustness of the proposed controller, Fig. 14 displays the results of speed control using neural controller with stochastic lead change, the neural controller reduces both the overshoot and extent of oscillation under the same separating condition.

### Table

<table>
<thead>
<tr>
<th>M</th>
<th>0.258</th>
</tr>
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<tbody>
<tr>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Constants</td>
<td>J</td>
</tr>
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<td></td>
<td>f</td>
</tr>
</tbody>
</table>

**Fig. 10** Results of speed evolution after resistance changes

**Fig. 11** Results of speed evolution after inertia load changes

**Fig. 12** Speed control system using neural controller and PI controller
real-time under load conditions by applying a load torque to linear characteristics.


In this paper, we have designed and implemented the neural network controller NNC, for accurate speed control of an induction motor. Comparing PI-type control method, simulation results are provided to illustrate the performance and the effectiveness of the proposes control scheme, even in the presence of much strong mechanical friction and other non-linear characteristics.

The success of the designed controller is demonstrated in real-time under load conditions by applying a load torque to the shaft of the motor. The results show that the controller could compensate for this kind of disturbances. The plant is also tested for the tracking property using different types of reference signals. Satisfactory performance was observed for most reference tracks and the results demonstrated the effectiveness of the proposed structure and the proposed control scheme it is believed will constitute a major step in the evolution of intelligent control of complex mechatronic systems.

REFERENCES


Soufyan Chekroun was born in Tlemcen, Algeria, in 1983. He received his B.S degree in Electrical Engineering from the University of Sciences and Technology of Oran in 1982, respectively. Following graduation, he joined the Institute of Electrical and Electronic Engineers (ENSEM) of Oran-Algeria. His current research interests include artificial intelligence. Actually he is associate Professor at the department of Electrical Engineering (ENSEM) of Oran-Algeria. He has authored more than 45 technical papers published in international journals and conferences proceedings. He authored a book on automatic Control, which was recently published and regularly gives tutorials and industrial courses on these subjects.

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