Voltage controlled induction motor drive using artificial neural network

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This paper presents a novel artificial neural network-based AC voltage controller in which the appropriate thyristors-firing angles are generated for any given operating conditions. An ANN model was designed for that purpose. The results obtained are very satisfactory and promising. The advantage of such a controller is its simplicity and high accuracy compared to conventional mathematical calculation of the firing angle, which is a very complex and time consuming task.

تعتبر تقنية التحكم فى جهد المنبع للمحرك التأثيرى بإستخدام نبائط القدرة من أكثر الطرق شيوعا للتحكم فى سرعة دوران المحرك وأيضا للتحكم فى قيمة تيار المحرك عند بدء الحركة. ويعتبر تعيين زاوية الإشعال لنبائط القدرة المطلوبة عند حمل وسرعة محددين بالطرق الرياضية التقليدية من أكبر المشاكل المصاحبة لهذه التقنية وذلك لأن المحكم يعتبران نظاما غير خطى. ويقدم هذا البحث طريقة جديده تعتمد على إستخدام الشبكات العصبية الاصطناعية لتحديد زاوية الإشعال لنبائط القدرة المطلوبة عند قيم محددة من سرعة المحرك وعزم الحمل. وقد تم محاكاة النظام المقترح بنموذج رقمى وتمت عملية التدريب والإختيارللشبكة العصبية الصناعية وكانت النتائج متطابقة. هذا وقد أعطى البحث نتائج مرضية وواعدة للنظام المقترح وتبين من البحث سهولة الطريقة المقترحة ودقتها العالية مقارنة بالطرق الرياضية التقليدية.

Keywords: AC voltage controller, Induction motor, ANN, Soft starter

1. Introduction

AC voltage controllers are increasingly used to control the speed of three-phase induction motors, especially in low power applications with variable load torques such as fans, blowers, compressors and centrifugal pumps [1-2]. Apart from providing speed control, voltage controllers may be used to achieve soft starting for large squirrel-cage induction motors [2]. Both motor speed control and soft starting can be done by appropriate adjustment of the motor terminal voltage. However, adjusting the voltage for a given operating condition of speed and torque is not a simple task. To adjust the voltage, the firing angle α of the thyristors must be calculated for each operating condition. This firing angle is a non-linear function of the motor speed and torque and it is quite difficult to find the exact value of α for any motor speed and torque. Some methods of closed loop control of AC voltage regulators have been developed and applied, which requires a speed sensor [2]. In [3] the authors have proposed a method of optimal soft starting without a speed sensor but it requires sensing of the thyristors voltages.

This paper proposes an ANN based selection of the thyristors firing angles of a voltage-controlled induction motor drive. The controller operates in open loop and does not require any speed or voltage sensing. This controller is simple and has high accuracy compared to conventional mathematical calculation of the firing angle.

2. AC voltage controller

Fig. 1 shows a typical configuration of a symmetrical voltage controller in which the voltage is adjusted through the setting of the thyristors firing angle α. The six thyristors in fig. 1 are fired according to the sequence shown in fig. 2. Note that at least two thyristors must conduct simultaneously to allow current flow through the load. It should be noted that the firing angle α is measured from the zero crossing of phase A voltage.

A voltage controlled three-phase induction motor was modeled and simulated using the two-phase time-invariant representation of the induction machine with respect to orthogonal

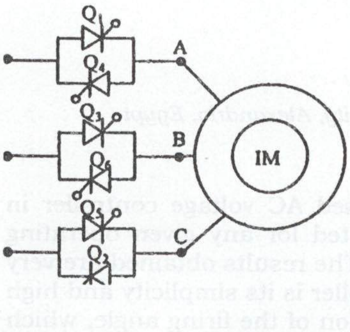

Fig. 1. Symmetrical AC voltage controller.

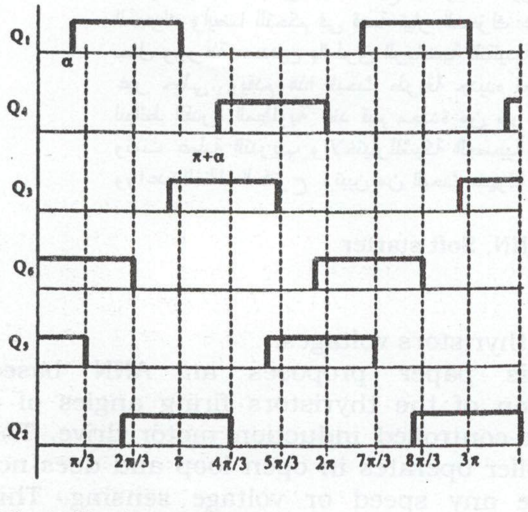

Fig. 2. Thyristors firing logic.

stationary axes. All power electronics switches were modeled according to their operating characteristics. A computer program written in Pascal was developed and tested in previous work [4]. The program was used for predicting the performance of the voltage controller and has given satisfactory results. The program is run several times with fixed firing angle and varying load torque. The steady state value of the speed is calculated after each run. The same procedure is repeated for different values of firing angle. Fig. 3 shows the electric torque versus speed characteristics obtained for different values of thyristors firing angle. Note that for small values of α, from 0° up to 30° the speed torque characteristics are very similar.

This can be explained by the fact that for values of the firing angle smaller or equal to the load impedance angle (α≤ϕ), there is a continuous conduction. Thus, changing the firing angle within that limit will have no effect on the voltage applied to the motor; hence, the torque and speed values are kept unchanged.

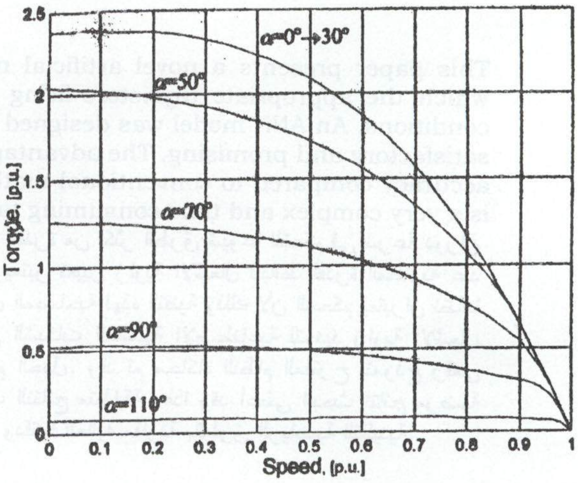

Fig. 3. Torque-speed characteristics for different values of the thyristors firing angle.

The system parameters used in the simulation are the same as those quoted in [5]: viz. 1/3 hp, 4 pole, 50 Hz, 220V, star-connected, squirrel-cage induction motor. The motor parameters in per unit using the rated voltage as a base voltage and the rated apparent input power of 375 watts as base power are:

R_s = 0.0566 p.u. R_r=0.1252 p.u

L_s=L_r= 1.0318 p.u. M=0.969 p.u.

Moment of inertia (J) =203 p.u.

3. Artificial neural network

The neural network model to be used for the calculation of the appropriate thyristor firing angle (α) as a function of the motor speed (ω_m) and electric torque (T_e) has two inputs (ω_m, T_e) and one output (α). Since the angle α is a nonlinear function of the ω_m and T_e, then the tansigmoidal function is most appropriate to model it. The tansigmoidal function is given by (1).

$$f(n) = \frac{2}{1+e^{-2n}} - 1 \ . \qquad (1)$$

The typical two-layer architecture used for the firing angle calculation is shown in fig. 4.

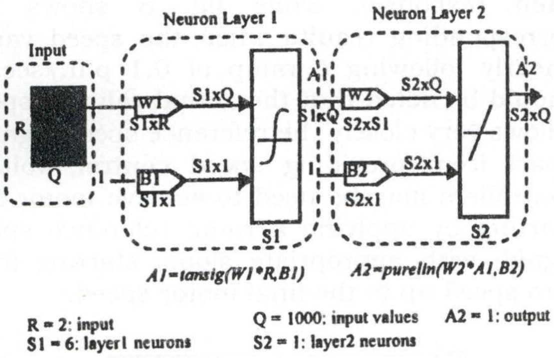

Fig. 4. Block diagram of ANN model.

It has a hidden layer of tansigmoidal neuron, which receives inputs (in this case the speed and the torque) directly, then broadcast their outputs to a layer of linear neurons, which compute the network output (in this case the firing angle). This architecture has been proven capable of approximating any function with finite number of discontinuity with arbitrary accuracy [6]. If an input set of data corresponds to a definite speed and torque pattern, the network can be trained to give a correspondingly desired firing angle pattern at the output. The network has the capability to learn. The back-propagation-training algorithm is most commonly used for feed forward neural networks. The training is automated with Matlab simulation program that uses a certain number of input-output example patterns. The example patterns can be derived by experiments or by simulations. In our case the patterns were derived by simulation using the computer program mentioned in section II (fig. 3). The generated data is used to train the neural network. At the end of the training process (when the target mean squared error is reached), the model obtained consists of the weight and the bias vectors. Table 1 summarizes the parameters of the ANN model and the results of the training. The obtained weight and bias vectors are saved in a file that will be used during the simulation of the induction motor drive system.

Table 1
Parameters of the neural network model

Input	ω_m (normalized, p.u)
	T_e (normalized, p.u)
Output	α
Maximum input value	$\omega_{max} = 1$ (p.u) $T_{max} = 2.4$ (p.u)
Minimum input value	$\omega_{min} = 0$ (p.u) $T_{min} = 0$ (p.u)
Maximum output value	$\alpha_{max} = 1.92$ (rad)
Minimum output value	$\alpha_{min} = 0.5934$ (rad)
Functions	Tansigmoidal + Linear
Hidden nodes	6
Number of samples	1000
Iterations (Epochs)	10170
Mean squared error	6.57×10^{-5}

To check the accuracy of the designed ANN model, the actual values of the firing angle obtained by simulation were compared to those values obtained by ANN (see fig. 5).

Note that the samples used for this comparison are different from the samples used for the training of the ANN model. The newly generated sets of speed and torque patterns are input to the Matlab neural net model and the corresponding pattern of firing angle is calculated systematically. According to fig. 5, it is noticed that there is a very good fitting between both ANN and actual results, which proves that the designed ANN model is very precise.

4. Simulation

4.1. Procedure

The ANN model was implemented by software and incorporated in the drive system program as shown in fig. 6. The weight and biases used are those obtained from the trained network in table 1. The load was considered as a pump or a fan with the following torque-speed charact-eristic:

$$T_L = k\omega_m^2 \text{ N.m}, \qquad (2)$$

where $k=1.7$ N.m.s^2/rad^2 (constant).
The input to the program is the reference speed ω_{ref}. Based on the setting of the initial

conditions, the program can simulate any operating condition of the system such as starting, braking, or speed control. The reference torque is calculated based on the reference speed and load characteristic (2). Both the reference speed and torque are inputs to the ANN model, which produces the corresponding firing angle. A triggering logic module generates pulses to the six thyristors according to the firing pattern in fig. 2.

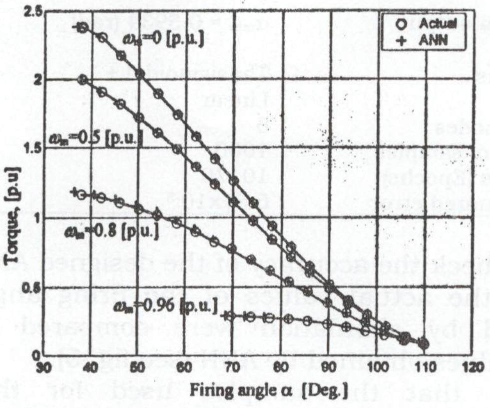

Fig. 5. Comparison between actual and ANN results.

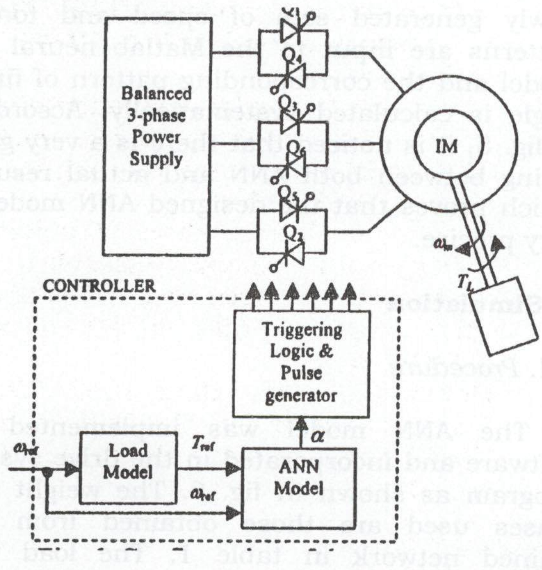

Fig. 6. Configuration of the proposed control system.

The outputs of the program are:

- instantaneous values of the line currents and voltages,
- instantaneous values of the motor electric torque and speed, and
- average value of the motor electric torque.

4.2. Results

The designed ANN-based voltage controller was tested for motor speed control by varying the reference speed signal from 0.4 to 0.7 then back to 0.4 p.u. Fig. 7 shows the simulation results when the variation occurs suddenly (step response), while fig. 8 shows the corresponding results when the speed varies linearly following a ramp of 0.1 p.u./sec. It should be noted that the actual value of speed follows very closely the reference speed signal. Apart from providing speed control, voltage controllers may be used to achieve motor soft starting by applying a ramp reference speed signal, with appropriate slope, starting from zero speed up to the final motor speed.

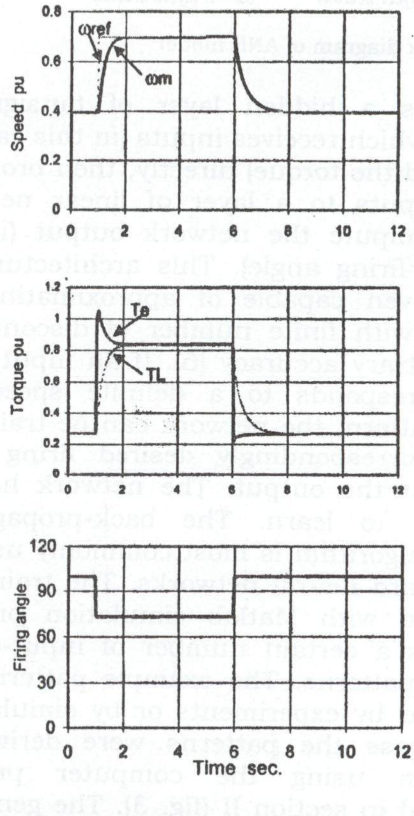

Fig. 7. Step response simulation results.

5. Conclusions

In this paper a novel method of controlling a voltage controlled induction motor drive using artificial neural networks has been introduced. The method depends on training a two-layer ANN model on a set of data generated by a simulation program. The generated data are the speed and torque patterns as an input and their corresponding firing angle patterns as an output of the ANN model. The ANN model was trained successfully and the results of comparison

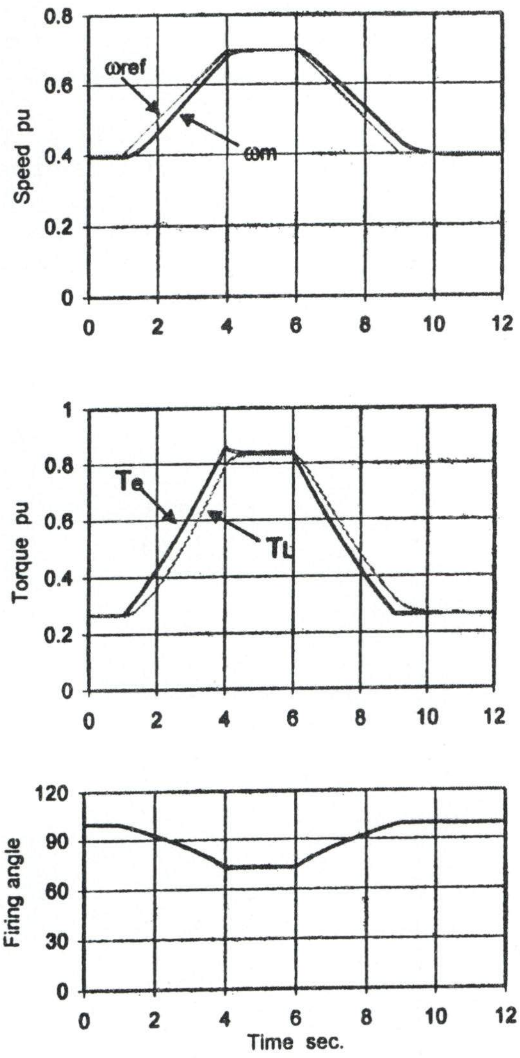

Fig. 8. Ramp response simulation results.

between the actual data and the ANN calculated data were very satisfactory. To validate the effectiveness of the proposed voltage control scheme, an induction motor fan drive system, fed by the proposed voltage controller, was implemented by a software program. Simulations were carried out for different operating conditions and the results were very satisfactory. Thus, the ANN approach has resolved the problem of the complexity of the online determination of the appropriate thyristor firing angle for any operating condition. It is also important to note that the controller operates in open loop and does not require any speed, voltage, or current sensing. The proposed voltage controller is designed to meet the industrial requirements of compressors, blowers, fans, pumps, mixers, crushers and grinders, etc.

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