IMPLEMENTATION OF NEURAL NETWORK IN ENERGY SAVING OF INDUCTION MOTOR DRIVES WITH INDIRECT VECTOR CONTROL

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ABSTRACT

Induction motors are extensively used in industrial and household appliances consume about 54% of the total consumed electrical energy. The need for energy conservation is increasing the requirements for saving the electrical energy. It is therefore important to optimize the efficiency of motor drive systems if significant energy savings are to be obtained. This paper proposes a new control scheme based on artificial neural networks taking advantage of Nola theory which states that at a certain torque and speed operating point there exist only one set of voltage amplitude and frequency that operates the machine at optimum efficiency

Keywords: Energy *saving, artificial neural network, and induction motor drive*

1. INTRODUCTION

The efficiency of Induction Motor when operate at rated speed and load torque is high. Unfortunately for variable load operation the application of the motor at rated flux will cause the iron losses to increase excessively, hence its efficiency will reduce dramatically. In order to reduce the iron losses the flux level should be set lower than rated flux, but this will increase the copper loss. Therefore, to optimize the efficiency of the induction motor drive system at partial load, it is essential to obtain the flux level that minimizes the total motor losses.

In air conditioning system, the induction motors are oftenly used to drive a compressor at constant speed operation. However, because the typical load profile of this load is that the load torque varies with speed, therefore implementation of a variable speed drive for it is potential to increase energy saving**.** Because of their easy implementation and low cost, indirect field oriented induction machine drives are finding numerous industrial applications. Most of the industrials motors are used today are in fact induction motors. Induction motors have been used in the past mainly in applications requiring a constant speed because conventional methods of their speed control have either been expensive or highly inefficient. Various methods have been designed to achieve the best performance of the motor and the approaches used can be classified into three different types. The first, so called “loss model controller”. The second type, named “search controller”.

2. FIELD ORIENTED CONTROL SCHEME

In this system, the flux coordinates reference frame is locked to the rotor flux vector rotating at the stator frequency as shown in Fig. 2. This results in a decoupling of the variables so that flux and torque can be separately controlled by stator direct-axis current and quadrature-axis current respectively.

The vector control is applicable to both induction and synchronous motor drive, It is also known as decoupling, orthogonal or trans-vector control. The designed control algorithm is divided in two parts: one part whose task is to translate the motor from one operating. The FOC block used here gets the value of the flux and voltage frequency ratio to give gating pulses to the inverter which controls the voltage being fed to the induction motor and hence the efficiency optimization is obtained to achieve the task of energy saving. The feedback is again send to the speed controller for the optimization purpose. Point to another through the adequate optimal trajectory and the other which is in charge of keeping the motor at a maximum efficiency operating point in the steady state for a given speed and torque. The first part acts when a modification in the reference speed is produced. Its function consists of determining the necessary optimal trajectory, starting from the present state of the motor and the aimed speed, creating the adequate reference signals and . Once the desired speed is reached, the motor changes into steady state with minimum stator current for the new load torque. From this moment, the second algorithm acts. The search for the maximum efficiency operating point is based on and consists of an iterative algorithm, which applies small increments to the reference signal while reference signal is in charge of maintaining the required torque and speed. A step followed by a decrease in the consumed active electric power means that it acts in the correct direction and must be repeated. Otherwise, a successive step will be reversed. A special algorithm that selects the most convenient state of the three-phase inverter among the eight possible ones achieves the closeness of the stator current space vector to its reference signal in both transient and steady states. In this way, the inverter, in spite of being a voltage-source one, acts as a current source that permits us to ignore the voltage equations of the motor model as mentioned.

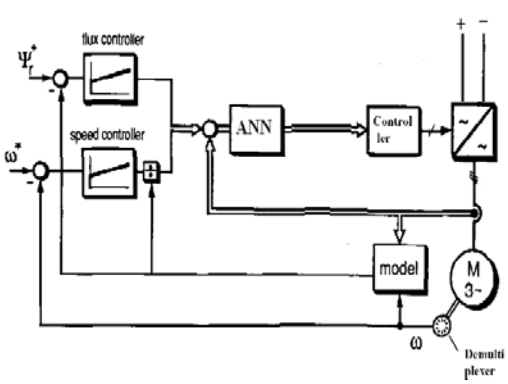

Fig. 1. Block diagram of FOC scheme

3. ARTIFICIAL NEURAL NETWORK MODEL

The outputs are the operating speed and torque of the artificial neural networks is valuable on several counts including their adaptability, non-linearity, and generalization capabilities. Recent development in the ANN technology has made it possible to train an ANN to represent a variety of complicated nonlinear systems. The ANN is the simulation of human brain nervous system and is constructed of artificial neurons and their interconnections.

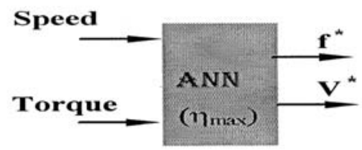

Fig. 2. Neural network system to calculate commanded voltage and frequency

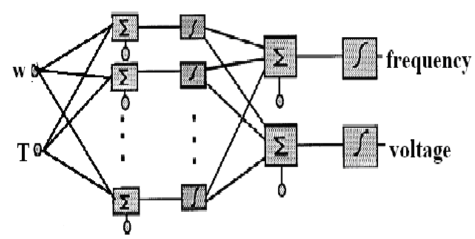

Fig. 3. ANN with separate hidden layers for speed and torque estimation

Like the human brain the ANN can be trained to solve the lost complex non-linear problems with variable parameters. The ANN has been successfully applied to identify and control the currents of an induction machine. There have been several applications of ANN in AC drive systems such as adaptive flux control, current control, speed control, and field-oriented control. It is expected that ANN as an artificial intelligence tool will guide to new modern techniques in power electronics and motion control systems. As mentioned earlier speed and torque estimation two other applications for the ANN in motion control that is proposed, Moreover, this paper introduces a new neural network approach to control the induction machines without a mechanical speed sensor while maintaining maximum efficiency.

Artificial neural network is a system of interconnecting neurons in a network working together to produce an output function. The output of a neural network relies on the cooperation of the individual neurons within the network to operate. Processing of information by neural networks is often done in parallel rather than in series (or sequentially). Since it relies on its member neurons collectively to perform its function, a unique property of a neural network is that it can still perform its overall function even if some of the neurons are not functioning. That is, they are very robust to error or failure. Neuron is a fundamental processing component of a neural network.

Once the network is structured, network is ready to trained. For this initial weights are chosen

randomly [7]. Here, neural network is used for the compute the appropriate set of voltage and frequency to achieve the maximum efficiency for any value of operating torque and motor speed. NN have the two inputs, motor torque and speed and have two outputs, optimum voltage and frequency.

The two layer feed forward structure of NN model is used in this paper. It has two hidden layers; one is of tan-sigmoidal function. Since the optimum voltage and frequency are highly non-linear function of motor speed and load torque so we preferred the tan-sigmoidal function and other is of pure linear function. The two inputs of NN model is firstly feed to the layer of tan-simoidal function and output of this layer is broadcast to the layer of linear neurons.

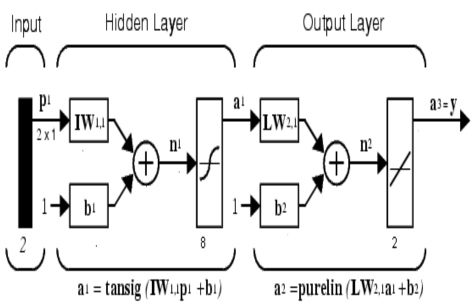

Fig. 4. Neural network model

The back-propagation training algorithm is used for this network. The training is automated with Matlab Simulation program developed for this purpose, which train the network using the back propagation method. At the end of training of network the value of weight and bias are set [8]. . These calculations are easily done offline, but have a precise knowledge of the equivalent circuit parameters and the operating point limits. The torque and speed should vary with in a practical limit corresponding the value of voltage and frequency is calculated and saved in a data file in matrix form [7].

4. DESCRIPTION OF THE CONTROL SYSTEM

A simple open loop torque control scheme of an induction machine is shown. The commanded voltage and frequency of the system that could give maximum efficiency for a given torque T* are obtained using the 'V and f Calculator' which uses the machine model. This model requires the speed of the machine which in turn is obtained from a 'Speed Estimator'. Both these blocks need the model of the machine whose rotor and stator resistances could change with temperature under nominal flux condition. As it is not practical to measure the temperature of the machine windings, a machine model has been proposed as a function of the case temperature. This model is found to give accurate results for the speed and torque estimation also has been successful. The speed estimation in this scheme is done by solving the proposed machine model in real time. In order to reduce the calculation time between the sampling interval get the commanded voltage and frequency for the given torque and speed. For the present work the artificial neural network ANN is used to perform the functions of the above mentioned blocks. The inputs for ANN are the magnitude of torque and speed, the DC input power to the inverter. The neural network ANN gets the operating speed and torque, of the induction machine to give the commanded value of stator voltage and frequency such that the efficiency of the machine is maximized. The network inputs and outputs for estimation of speed and torque of the machine are taken from its electrical magnitudes.

The data required to train ANN obtained by simulating the torque dependent machine model at different speed and load conditions. This calculates the commanded voltage and frequency at a certain temperature for different operating points of the torque-speed envelope. To achieve maximum efficiency at each point of the torque-speed envelope, the total loss of the induction machine and inverter is calculated and minimized. The maximum torque depends on the current limit and the maximum value of the air-gap flux at low speeds and voltage limit at high speeds. At low speeds, a higher value of torque may be obtained, if the air-gap flux value and the current of the machine are allowed to be more than the rated value. At low speeds a high starting torque is required and therefore the value of the air-gap flux limit is increased. However, this leads to a higher torque per amp values, because the machine enters the saturation region. This does not cause over heating of the machine with an assumption that the prolonged running of the machine in between stating operation is sufficiently long to cool the machine. Sensor-less open-loop and closed-loop control of an induction machine using neural network systems are shown.

The machine case temperature, DC input power, and a phase current are the only required inputs, because voltage and frequency are commanded by the controller. However, if the switching devices of the inverter have a dead-band of more than a few micro-seconds, it would be necessary to measure the voltage, especially at low speeds.

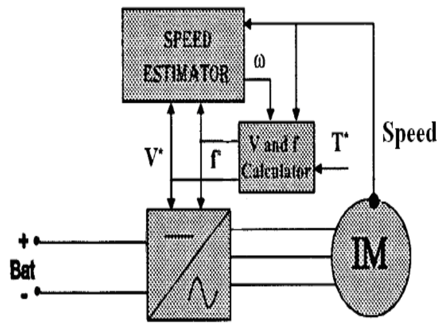

Fig. 5. Open-loop control of an induction machine using induction machine model.

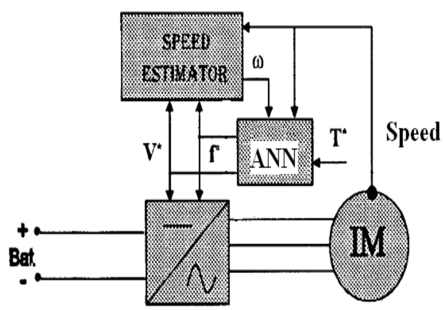

Fig. 6. Open-loop control of an induction machine using neural network system.

Table 1
Parameters of the neural network model

Input	ω_m, T_e
Output	f_{op}, V_{op}
Maximum input value	ω_{max} = 1(p.u.) T_{max} = 1.5(p.u.)
Minimum input value	ω_{min} = 0(p.u.) T_{min} = 0(p.u.)
Maximum output value	f_{max} = 1(p.u) V_{max} = 1(p.u.)
Minimum output value	f_{min} = 0(p.u) V_{min} = 0(p.u.)
Functions	Tansigmoidal + Linear
Hidden nodes	8
Number of samples	7104
Epochs	76
Mean square error	$1\text{x}10^{-4}$

5. SIMULATION AND RESULTS

Figure 5, and 6 shows the model consisting of two networks, one is the network of the machine in which optimization techniques with ANN is used and in the other one the circuit model without ANN is used. The model is used to run for different values of torque and speed. Parameters of neural network model are shown in table 1.

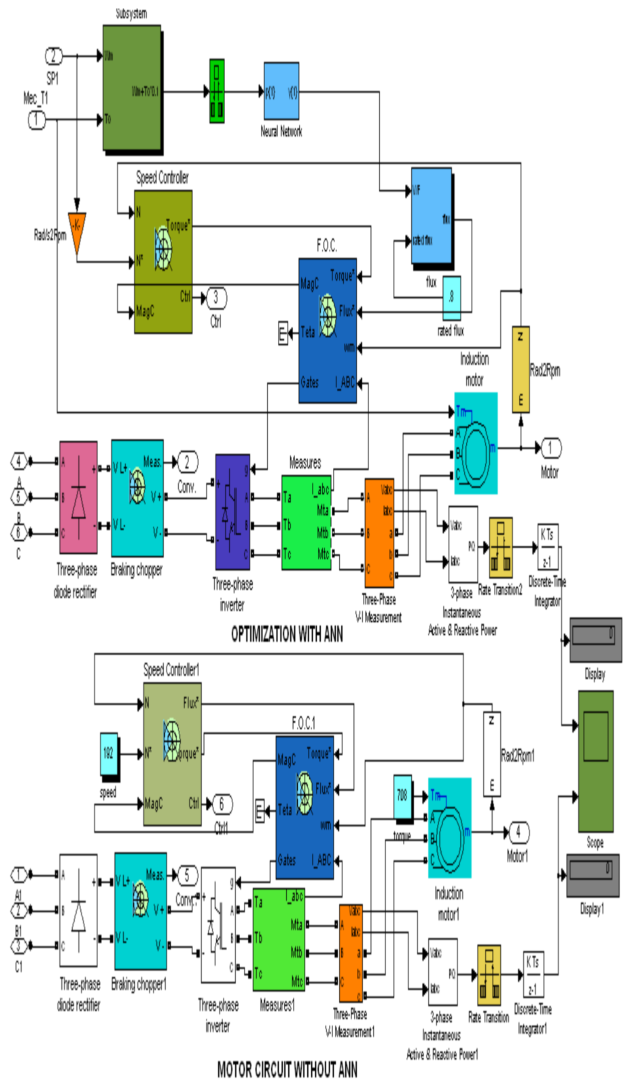

Fig. 7. Simulink Model for Energy Saving in FOC Induction Motor Drive using ANN

The simulation diagram for energy saving in Field Oriented Control Induction Motor Drive is as shown in Fig. 7. The drive model consists of induction motor, the load, the source and the proposed ANN model. This model contains the input power supply connected with the field oriented control block.

This block diagram shows the field oriented control with artificial neural network and without artificial neural network. The speed and torque are being taken as the inputs which are converted into one signal and then being fed to the ANN block which uses these values for the optimization purpose. There are individual displays provided for the circuits of with and without ANN which displays the values of both the circuit during the running state. The two outputs are then connected to the scope which is shown as dark green coloured. This scope shows both the outputs at the same time, they can be compared during the simulation. These are two yellow coloured graphs. The two simouts are also provided for storing the outputs of the two circuits. It is found that this circuit optimizes the efficiency and hence the energy is saved up to 27% than without using the ANN.

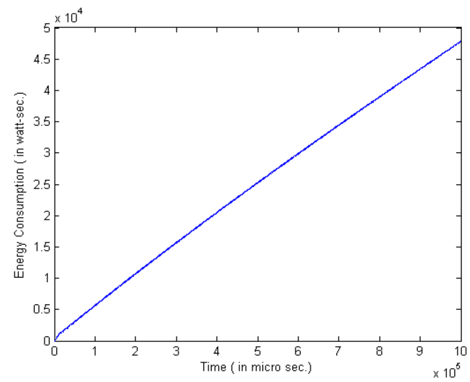

Fig. 8 Energy-Time Curve without ANN

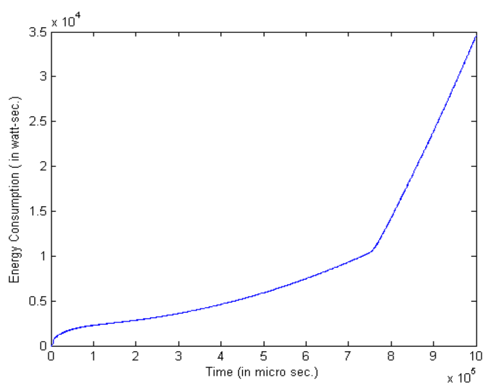

Fig. 9Energy-Time Curve with ANN

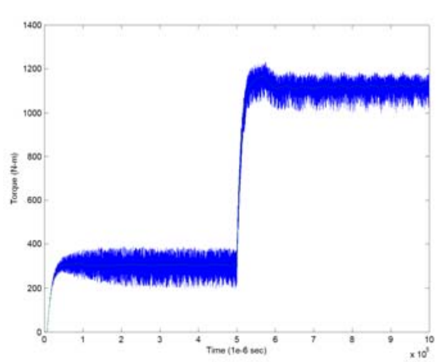

Fig. 10. Figure showing the variations in torque with time

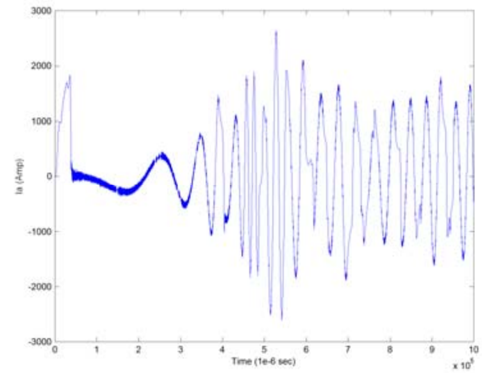

Fig. 11. Variations of phase current Ia with time

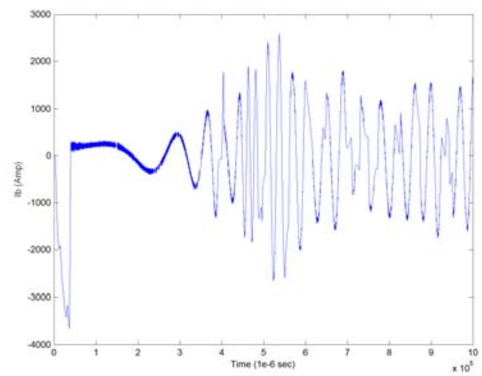

Fig. 12. Variations of phase current Ib with time

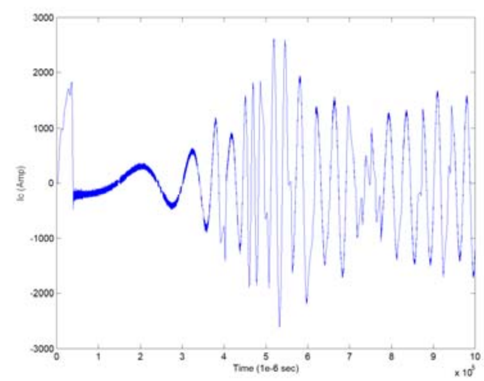

Fig. 13. Variations of phase current Ic with time

6. CONCLUSION

This paper has presented an ANN-based scheme for induction motor drive leading to energy saving. The proposed scheme uses information on speed and torque of the motor to generate the appropriate voltage amplitude and frequency that save the energy. An ANN model has been configured and trained on a set of data generated, based on the motor equivalent circuit, using a Matlab computer program. The model uses two hidden neuron layers. The numbers of hidden neurons are eight and linear layers, respectively. The trained model was validated by simulation using a typical induction motor drive model implemented with Matlab/Simulink. A comparison of the two waveforms of different circuits one is with ANN block and another is without ANN has shown a very good concordance between the two results.

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