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BEYNƏLXALQ ELMİ ARAŞDIRMALAR JURNALI

FAMOUS AZERBAIJANI SCIENTISTS

Prof. Aida Imanguliyeva (1939-1992)

Aida Nasir gizi Imanguliyeva was born on October 10, 1939 in Baku in an intelligent family. Her father- well-known journalist, pedagogue, Honoured Worker of Science-Nasir Imanguliyev was one of the founders of Azerbaijani press, editor of "Baki" and "Baku" newspapers for a long time.

In 1957, Aida Imanguliyeva graduated from school No. 132 of Baku with gold medal. In 1957, she entered Azerbaijan State University. In 1962, after graduation from Arabic philosophy of Oriental Studies faculty of the university she became postgraduate student of "Eastern nations and the history of literature" cathedra of the same university.

Then, she studied at "Nations of Asia" institute of the former Academy of Sciences of the USSR.

In 1996, after defence of dissertation, Aida Imanguliyeva began to work at the Institute of Oriental Studies of the Academy of Sciences of Azerbaijan-junior researcher (1966), senior researcher (1973), head of Arabic philology department (1976), deputy director for research works (1988). From 1991 to the end of her life she worked as a director of Oriental Studies Institute of the Academy of Sciences of Azerbaijan.

In 1989, after successful defence of doctoral dissertation in Tbilisi, Aida Imanguliyeva became the first woman-doctor of oriental studies and soon she was given professor's degree of this very speciality.

Aida Imanguliyeva is the author of 3 monographs ("Michail Nuayme and Association of pens", M. 1975, "Gubran Khalil Gubran", B. 1975, "Coryphaei of new Arabic literature", B. 1991), more than 70 research papers written about Eastern literature. She was the member, deputy chairman and chairman of Defence Union by the profile of "Literature of Asian and African countries" operating at the Institute of Oriental Studies of the Academy of Sciences of Azerbaijan.

Professor A. Imanguliyeva presented oriental studies of Azerbaijan in countries of the Middle East and in other foreign countries (Moscow, Kiev, Poltava, Saint Petersburg, Galle and etc.).

In the sphere of scientific-organizational activities Aida Imanguliyeva gave great consideration to training of highly specialized personnel of Arabists.

In the department of "Arabic philology", which she managed, more than 10 Candidate's dissertations were defended under her guidance during the short period of time.

A. Imanguliyeva was the member of presidium of the All-Union Society of Orientalists, the All-Union Coordination Council of Eastern Literature's research and the Union of Writers.

For many years she was engaged in pedagogical activity, delivered lectures on Arabic philology in ASU.

Aida Imanguliyeva died on September 19, 1992.

For the perpetuation of memory of the famous scientist-Arabist Aida Imanguliyeva, one of high-achiever students of oriental studies faculty of BSU was given the scholarship named after her.

The nation's future success lies with science and education!

Heydar Aliyev
National Leader of Azerbaijan

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2nd PART

HUMANITIES AND SOCIAL SCIENCES

NEURAL NETWORK TECHNIQUE FOR DIRECT TORQUE CONTROL OF INDUCTION MOTOR USED IN ELECTRICALLY DRIVEN MARINE PROPELLER

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ABSTRACT

In the electric propulsion system, induction motor is used to drive the marine propeller. The control of induction motor is very complex and totally difference compared with in industries. This control is affected by ocean surface waves, ocean current, wind, weather and also ship motions such as yaw, pitch and rolls. In this paper, a neural network (NN) controller is designed to control the speed of direct torque controlled induction motor. NN is a machine like human brain with basic properties of learning capability and generalization. This network requires a lot of training to understand the characteristic of nonlinear dynamic system mapping. NN controller is trained using the input and output data of PI controller under normal and disturbance conditions. To examine the robustness of NN controller, the induction motor is used for electric propulsion system. In this system, load torque applied to the induction motor depends on rotor speed of propeller and also speed of induction motor depends on torque output of propeller. Simulation results of the designed NN controller show that the induction motor rapidly achieves the speed reference, without overshoot and small steady state error. And also, load disturbance is rapidly rejected.

Key words: Induction Motor, Direct Torque Control, Neural Network, electric propulsion system.

1. INTRODUCTION

Recently, electrical energy is applied to many transportation systems particularly in marine transportation system. One of them is electric propulsion system. In this system, electric motor is used to drive the marine propeller to produce the ship propulsion. The electric motor is the most commonly used in propulsion system to convert an electrical power to mechanical power because it can be directly connected to the electric network. In the propulsion system, electric motor is directly coupled with the ship propeller [1-5]. The most popular electric motors is the squirrel cage induction motor because it has many advantages such as simple in construction, reliable, inexpensive, high efficiency and free maintenance. However, induction motor is difficult to maintain a constant speed whenever the load is changed. There are several methods to solve such kind of problem. One of the popular methods to solve the problem is field oriented control (FOC) or vector control method. In FOC method, the magnetic flux and torque are easily controlled by the excitation and load current. By this way, the induction motor can be operated as a separately dc motor [6-7]. However, the FOC method has the complexity control system because it requires current controller, coordinate transformation and current regulator. Recently, the new control method well known as direct torque control (DTC) is introduced with different method to control the magnetic flux and torque of the induction motor. In this method, the magnetic flux and torque are directly controlled by using a voltage vector of the inverter [7-11].

In the real practice, variable speed of induction motor drive is equipped with a speed controller. Most popular of the speed controller use conventional PI controller because of their simple structure and offers a satisfactory performance for wide range operation. However, conventional PI controller cannot provide the desired control performance whenever plant parameter is changed or due the nonlinear operation. The nonlinearities or changing plant parameters are occurred whenever a variable speed drive system is fed by an induction motor [12-14]. Many strategies have been proposed by many researchers to solve the drawback of the PI controller by using artificial intelligence (AI) methods such as fuzzy logic, neural network and genetic algorithm. In addition, AI methods are very promising for the identification and control nonlinear dynamic system without requirement to acknowledge the internal system behavior [14-18].

This paper presents the usage of AI methods particularly neural network in the speed control of induction motor. To examine the robustness of this method, the induction motor is used for electric propulsion system because its complexity for the speed and torque through a MATLAB/Simulink. Load torque of electric propulsion system depend on rotor speed and pitch angle of the propeller and also speed of induction motor depend on torque output of the propeller.

2. PROPOSED NEURAL NETWORK SPEED CONTROL OF INDUCTION MOTOR

2.1. DTC Method Strategy

The block diagram of speed control of induction motor based on DTC method is presented in Figure 1. The DTC method is introduced by Takahashi and Noguchi [10]. The DTC of induction motor is based on the directly determination of command sequence applied to the switches of voltage source inverter fed induction motor. The command stator flux (ψ_s) and electromagnetic torque (T_e) magnitude are compared with the respective estimated value. Resulted errors of T_e and ψ_s respectively are processed in hysteresis controllers. Two output hysteresis controllers (S_ψ,S_T) and stator flux position (θ_e) in space vector are used to determine one of eight switching combinations in voltage source inverter, two zero voltage vectors and six voltage vectors shown in Figure 2. This determination is used to maintain torque and flux error inside the hysteresis band.

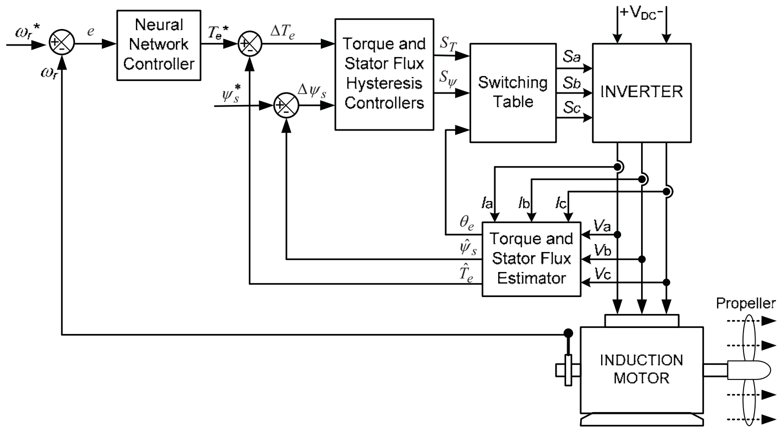

Fig. 1. *Block diagram of DTC with speed control*

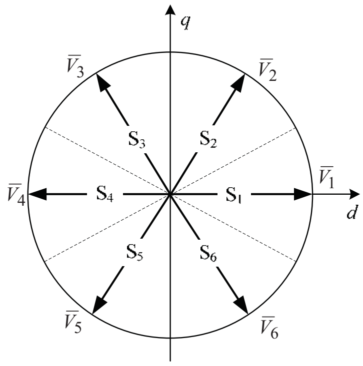

Fig. 2. *Inverter output voltage vectors and stator flux sectors*

The basic principle of DTC method can be described from electromagnetic torque equation in the stationary reference frame as given by equation (1).

$$T_e = \frac{3}{2}\frac{p}{2}\frac{M}{(\sigma L_r L_s)}|\overline{\psi}_s||\overline{\psi}_r|\sin\theta_e \quad (1)$$

Equation (1) shows that the electromagnetic torque (T_e) depends on the stator flux (ψ_s), rotor flux vectors (ψ_r) and their relative position (θ_e). The rotor flux changes slowly if it is compared to the stator flux because the rotor time constant of induction motor (σ) is very large. During a short transient, the rotor flux almost unchanged. Thus, rapid change of electromagnetic torque can be produced by rotating the stator flux in the required direction, which is determined by the torque command. Whereas, the stator flux can be obtained from Equation (2) and if the stator resistance (R_s) is neglected, the stator flux can be expressed in Equation (3).

$$\overline{\psi}_s = \int_0^t \left(\overline{V}_s - R_s \overline{I}_s\right) dt \quad (2)$$

$$\overline{\psi}_s = \int_0^t \left(\overline{V}_s\right) dt \quad (3)$$

The voltage vector is still constant during one period of sampling T_s. The stator flux of induction motor can be expressed in Equation (4).

$$\overline{\psi}_s(k) = \overline{\psi}_s(k-1) + \overline{V}_s T_s \quad (4)$$

or

$$\Delta\overline{\psi}_s = \overline{V}_s T_s \quad (5)$$

Equation (5) shows that the stator flux can be increased or decreased by applying suitable stator voltage vector. Stator flux error consists of the radial and tangential of components shown in Figure 3. The radial component (ψ_{st}) states the torque action and tangential component (ψ_{sf}) states the flux action. If the position of stator flux is known, both flux and torque can be controlled by selecting the suitable inverter voltage vectors. The inverter voltage vectors are selected by using DTC algorithms based on the torque and flux hysteresis controller status and stator flux position sector which is denoted by S_i (i = 1,2,3,…6). The switching combinations of switch device of inverter can be obtained from the output of switching table. Table 1 and Table 2 show the logic control of the flux and torque hysteresis controllers and switching table of inverter, respectively.

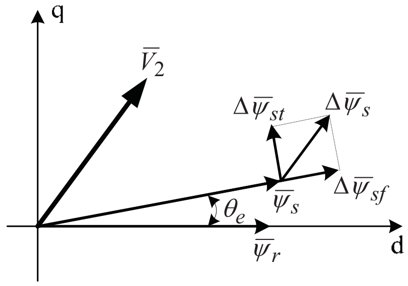

Fig. 3. *Components of the stator flux error when applying the voltage vector V_2*

Table 1. Logic control of flux and torque hysteresis controllers

Conditions of Flux	S_ψ
$\lvert\psi_s\rvert \le \lvert\psi_s^*\rvert - \lvert\Delta\psi_s\rvert$	1
$\lvert\psi_s\rvert \ge \lvert\psi_s^*\rvert + \lvert\Delta\psi_s\rvert$	0
Conditions of Torque	S_T
$\lvert Te\rvert \le \lvert Te^*\rvert - \lvert\Delta Te\rvert$	1
$\lvert Te\rvert = \lvert Te^*\rvert$	0
$\lvert Te\rvert \ge \lvert Te^*\rvert + \lvert\Delta Te\rvert$	-1

Table 2. Switching table of voltage source inverter

S_ψ	S_T	Stator Flux Sectors					
		S_1	S_2	S_3	S_4	S_5	S_6
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

2.2. Neural Network Controller Design

A neural network (NN) is a machine like human brain with properties of learning capability and generalization. It requires a lot of training to understand the model of plant. The basic property of this network is capability to learn the characteristic of nonlinear dynamic system mappings. The neural network consists of three layers, an input layer, one or more hidden layers and an output layer. Neurons of hidden and output layers have an activation functions. The knowledge of NN can be achieved through a learning algorithm process [11,14-17].

Learning term of NN is a regulation process of weights connection between nodes by particular method to obtained desired weights. Learning process must be performed to guarantee the error between the desired output (target) and the output of the network according to an error goal. If connection weights are not able to produce desired output, weights will be regulated by particular method through continuous training. By this way, weights will have a new and better composition. By this new weight composition, the differences between neural network output and desired output will be small. Hence, the output of neural network will be equal with the desired output. After neural network is trained, the neural network is ready to be validated and used. Validating process is said success if neural network can receive input and obtain output according to output target.

The structure of NN controller selected in this paper is shown in Figure 4. The NN controller consists of two neurons in the input layer, ten neurons in the hidden layer and a neuron in the output layer. Two inputs and one output of the controller are the speed error *e(k)*, the previous speed error *e(k-1)* and electromagnetic torque reference T_e*, respectively. The activation functions of the hidden and output neurons are logarithmic sigmoid and linear, respectively. The learning of NN controller is done using the Levenberg-Marquardt back-propagation algorithm.

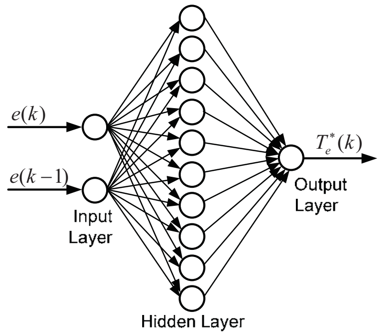

Fig. 4. *Neural network controller structure*

The learning process of NN controller is shown in Figure 5. The data training is taken from the input and output values of the PI controller by simulating it under normal and disturbance conditions. The previous speed error *e(k-1)* is obtained by delaying the speed error *e(k)*. The electromagnetic torque from PI controller and the electromagnetic torque from NN controller are compared to obtain desired error goal.

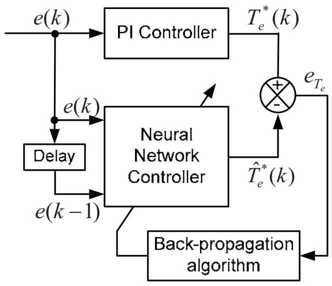

Fig. 5. *Learning process of NN controller*

2.3. Load Torque Model of Electric Propulsion

The electric energy generated by the power plant is utilized to propel the marine vehicle. It must be utilized to rotate a shaft connected between induction motor and propeller. The rotation force is required to turn the shaft is simply torque. Typically for induction motor, power and available torque are provided by the torque of propeller [1-3]. In the electric propulsion system, load torque has a specific characteristic. Load torque obtained by the propeller depends on its rotor speed and pitch angle. The torque of propeller (T_P) can be modeled as given by Equation (6) [19,20].

$$T_P = \alpha_1 \omega_P + \alpha_2 \omega_P^2 \tag{6}$$

where, α_1 and α_2 are the aerodynamic torque coefficients and ω_P is the rotor speed of propeller. The value of aerodynamic torque coefficients depend on the propeller pitch angle. Figure 6 shows the load characteristics for an induction motor with load curves for a full pitch propeller.

3. SIMULATION RESULTS AND DISCUSSIONS

Some simulation results are shown to clarify the effectiveness of the proposed control scheme and compared with conventional PI controller using MATLAB/Simulink. A block diagram of simulation model system is shown in Figure 7. Load torque applied to the induction motor is taken from electric propulsion system which depended on rotation speed and pitch angle of the propeller. The induction motor used for the simulations have the following parameters: rated voltage of 380 V, 4 poles, 50 Hz, nominal rotor speed of 150.8 rad/s, nominal stator flux of 1.74 Wb, stator resistance of 1.7 Ω, rotor resistance of 1.34 Ω, stator inductance 459.2 mH, rotor inductance of 457 mH, mutual inductance of 442.5 mH, inertia moment of 0.025 Kg.m^2, and friction coefficient of 1e^{-5} Kg.m^2/s. The simulation strategies are done in the operating conditions of normal and load disturbance.

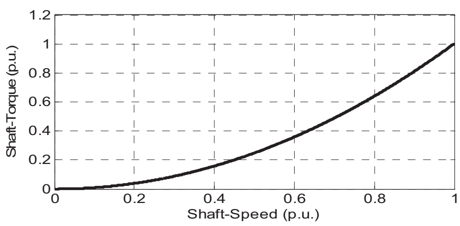

Fig. 6. *Speed-torque characteristic of full pitch propeller*

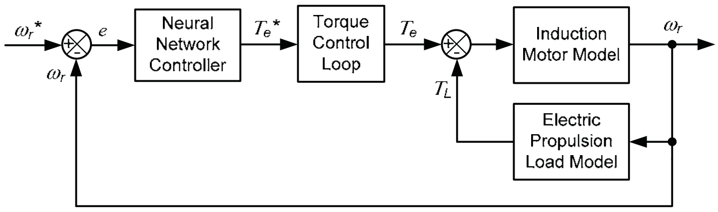

Fig. 7. *Block diagram of simulation model system.*

Comparison of speed response between conventional PI and NN controllers for speed reference of 50 rad/s are shown in Figure 8. Figure 8 shows that PI controller provide settling time of 0.07 s, no overshoot, steady state error of 0.001 rad/s, whereas NN controller provide settling time of 0.042 s, steady state error of 0.002 rad/s and no overshoot. From their simulation results see that NN controller give the good improvement of performance system compared to PI controller. Figure 9 shows the load torque applied to the system for both controllers. From figure 9 see that the load torques for both controllers depend on the speed of the propeller.

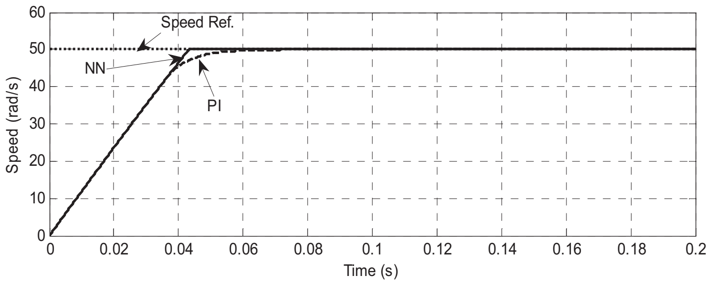

Fig. 8. *Speed responses for normal condition*

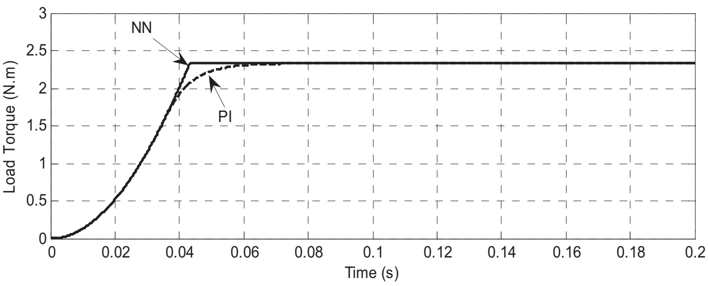

Fig. 9. *Load torques for normal condition*

Comparison of electromagnetic torque response between PI and NN controllers are shown in Figure 10. In this figure, NN controller needs the greater electromagnetic torque than PI controller. This electromagnetic torque is used by NN controller to rapidly achieve the speed reference.

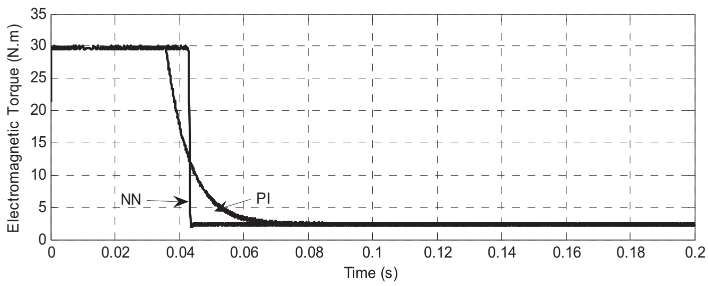

Fig. 10. *Electromagnetic torque responses for normal condition*

For disturbance conditions, the load of induction motor suddenly changes 0.2 N.m and -0.2 N.m at t = 0.16 s and t = 0.26 s. And also returns again at t = 0.20 s and t = 0.30 s as shown in Figure 11. Influence of load changing on the speed and electromagnetic torque of induction motor are shown in Figure 12 and Figure 13. Load changing causes the increasing and decreasing of induction motor speed and electromagnetic torque. Simulation results show that the increasing and decreasing of induction motor speed for PI controller are 0.057 rad/s from 50.001 to 50.058 rad/s and -0.057 rad/s from 50.001 to 49.944 rad/s. The increasing and decreasing of electromagnetic torque for NN controller are 0.002 rad/s from 49.997 to 49.999 rad/s and -0.002 rad/s from 49.997 to 49.995 rad/s. Hence, NN controller provides best disturbance rejection than PI controller.

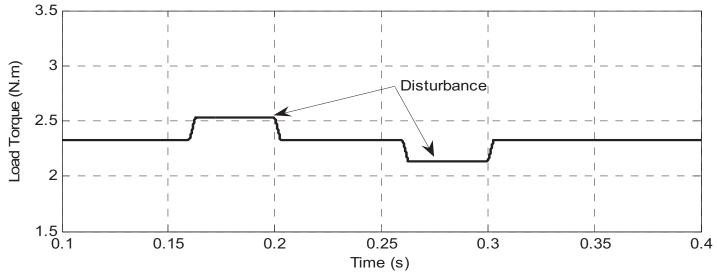

Fig. 11. Load torque for disturbance condition

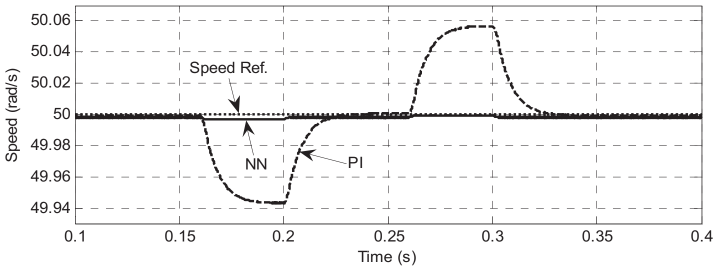

Fig. 12. Speed responses for disturbance condition

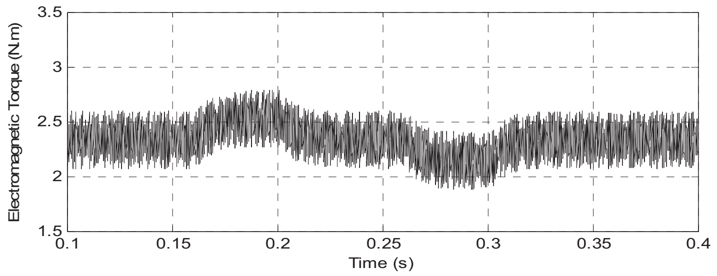

Fig. 13. Electromagnetic torque for disturbance condition

4. CONCLUSION

Speed control of direct torque controlled induction motor drives for electrically driven marine propeller has been presented. Neural network technique is used as speed controller of induction motor drives. It doesn't require the accuracy of induction motor and drive model, but only requires the input and output mapping of PI controller under normal and disturbance conditions for learning process of the neural network. Load torque applied to the induction motor uses the electric propulsion system which depends on the rotor speed of the induction motor directly connected to the propeller. Simulation results show that the designed neural network controller is better than conventional PI controller. It provides a good dynamic performance of induction motor with a rapid settling time, no overshoot, small steady state error and rejection of load disturbance.

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