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Sensorless Speed Control of Induction Motors with Artificial Neural Networks

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ABSTRACT

As Induction Motors (IM) are widely used in industrial areas, the control problem of these motors at different speeds has occurred. In this study, sensorless speed control of IM was performed with Artificial Neural Networks (ANN). Frequency-controlled scalar control method was utilized to control IM. Speed and torque data have been entered to ANN. Here, ANN provided to achieve the desired speed of the motor by estimating frequency. The results of the study conducted based on Matlab/Simulink examined and presented. According to the results of the study, it has been shown that the proposed method can be used in practical applications.

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1. Introduction

IMs are often used in industrial areas due to advantages such as simple structure, low cost, low maintenance requirements and higher efficiency [1]. However, the control of these motors is extremely difficult because of the changes in parameters (such as load torque, time-dependent parameter change). Therefore, there is a need for high-performance control systems [2]. Scalar, vector, P, PI, PID methods are used in the control of IMs [2]-[5]. It is observed that scalar control is preferred among these methods due to the simple structure and easy to implement [6], [7]. Controllers used to improve the control performance, such as P, PI and PID are adversely affected by changes of system parameters [8]. In this context, the sensor control methods have been applied to improve the control performance. Motors' sensor control is performed with the help of encoders in the motor shaft. Encoders are not preferred because of the negative effects of motor vibration and high cost. For this reason, sensorless control is been used frequently in recent years [9]. It is seen that researchers are using intelligent control methods nowadays to improve the performance of the control systems [10], [11]. ANN one of these intelligent methods is used to solve many nonlinear problems. ANN also offers solutions in many areas such as predicting, modeling, classification and learning [12]-[15]. The aim of this study is to develop an intelligent and sensorless control method for IM. Therefore, a sensorless speed control with ANN has been proposed for speed control of IM.

2. Materials and Methods

In this study, Matlab/Simulink simulation was carried out primarily by using known mathematical expression of IM [16]. In this context, idle and load test results of the motor were obtained with scalar control simulation by using scalar control mathematical expressions given in Equation 1 [2].

$$V_a = V_m Sin(\theta)$$
$$V_a = V_m Sin(\theta - 2\pi / 3) \quad (1)$$
$$V_a = V_m Sin(\theta + 2\pi / 3)$$

Part of test results obtained while idle and load is given in Table 1. When Table 1 is examined, it is understood that the motor speed error has occurred as torque increases and this error decreases as motor speed increases. In addition, it is understood that the motor idle speed was equal to the reference speed. This study will be to reduce the speed loss when IM runs at load. In the proposed study, frequency estimation will be carried out by ANN to reduce this error. In this sense, Torque and Speed information will be entered into ANN input. In the ANN output, the required frequency will be estimated to obtain the reference speed. For example, the motor has an obligation to operate at 750 rpm with a torque of 0.5 Nm. However, obtained motor speed is 742.7 rpm. 750 rpm and 25 Hz were applied to the motor. The frequency obtained from the motor was about 24.76 Hz. Because the frequency difference was about 0.24 Hz, motor will have reached the desired speed if 25.24 Hz is obtained from the ANN output. 63 test results obtained from scalar control simulation are recorded for this study and used for ANN training. 80% of these data were used for ANN training and 20% is reserved for ANN test.

ANN was trained with values of 0-0.5-1 Nm torque and between 300 rpm and 1500 rpm speed. While creating the ANN structure, Feed-forward Back-propagation Learning Algorithm that is commonly used in solving these kinds of problems was used. ANN's learning methodology is Supervised Learning because it made an estimate of the output from the input data [2].

Table 1. Test results of scalar control

Ref. Torque (Nm)	Ref. Speed (rpm)	Obtained Speed (rpm)	Speed Error (%)	Motor Current (A)
0	300	300	0.00%	1.638
0	450	450	0.00%	1.67
0	750	750	0.00%	1.67
0	1050	1050	0.00%	1.698
0	1500	1500	0.00%	1.705
0.5	300	292	2.67%	1.604
0.5	450	442.5	1.67%	1.65
0.5	750	742.7	0.97%	1.68
0.5	1050	1043	0.67%	1.695
0.5	1500	1493	0.47%	1.706
1	300	283.1	5.63%	1.592
1	450	434.4	3.47%	1.652

1	750	735.2	1.97%	1.694
1	1050	1035	1.43%	1.712
1	1500	1486	0.93%	1.727

In the literature, it is understood that the normalization of ANN input makes a positive contribution to the results. In this regard, the D_Min_Max Normalization Method which is commonly used in applications is preferred in this study [10]. Matlab/nntool box was used in ANN training [15]. Here, results obtained by using both Tansig and Logsig functions that are used as the activation function were compared. Because of producing the best results for this study, Logsig activation function was preferred. ANN structure used in this study is shown in Fig. 1. Mathematical expressions used in the ANN structure are given Equation 2, 3, 4 respectively [2].

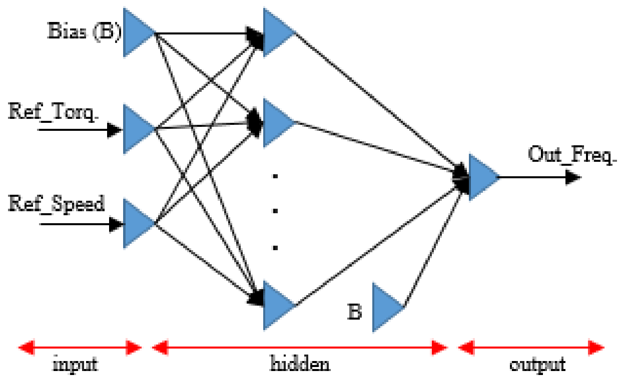


Figure 1. ANN structure

The D_Min_Max normalization Equation used for inputs:

$$X = 0.8 * \frac{X_i - X_{min}}{X_{max} - X_{min}} + 0.1 \tag{2}$$

Here; $\boldsymbol{X}$, $\boldsymbol{X_i}$, $\boldsymbol{X_{max}}$ and $\boldsymbol{X_{min}}$ indicate normalized data, input value, the greatest value in the input set and the smallest value in the input set respectively.
Sum Function is the section to calculate the net inflow to the cell and indicated by Equation 3.

$$net = \sum_{i=1}^{n} (w_{ij} x_i + B_j) \tag{3}$$

Weights ($\boldsymbol{w}$) are the coefficients that determine the effect of received information in the ANN. $\boldsymbol{B}$ is the bias. The activation function performs a curvilinear match between input and output information. Therefore, it is an important factor for the performance of the network.

$$f(net) = \frac{1}{1 + e^{-net}} \tag{4}$$

The block diagram of the study made by these processes was shown in Fig. 2.

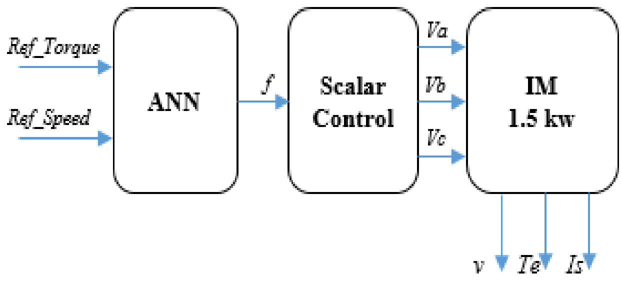


Figure 2. The block diagram of the study

3. Simulink Results

Obtained result graphs are shown in Fig. 3 when the input of 0.5 nm and 750 rpm is entered in ANN. The motor's speed error is 7.3 rpm at Fig. 3*a*, while this error is 0.6 rpm at Fig. 3*b*. Error percentage is 0.97% in scalar control, 0.8% in this study. Some of the results obtained from the study carried out are given in Table 2.

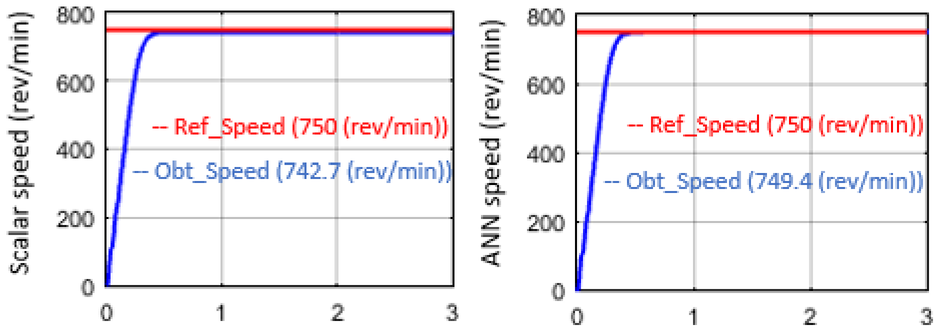


Figure 3. Sample speed graph, (a) Sensorless scaler speed control, (b) Sensorless scaler speed control with ANN

Table 2. The data obtained from the study

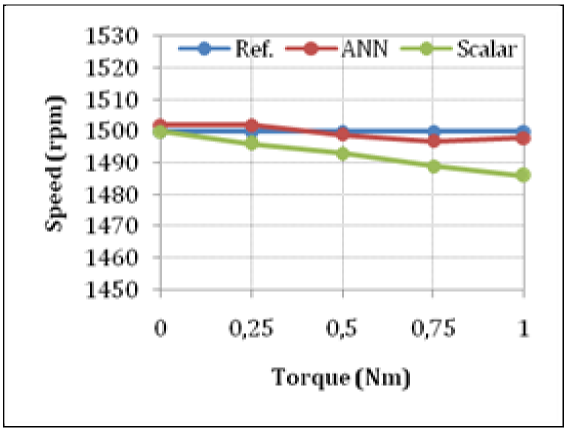
Ref. Torque (*Nm*)	Ref. Speed (*rpm*)	ANN Speed (*rpm*)	Scalar Speed (*rpm*)	ANN Error (*%*)	Scalar Error (*%*)
1	1500	1498	1486	0.13%	0.93%
0.75	1500	1497	1489	0.20%	0.73%
0.5	1500	1499	1493	0.07%	0.47%
0.25	1500	1502	1496	-0.13%	0.27%
0	1500	1502	1500	-0.13%	0.00%
1	1000	998.9	985.6	0.11%	1.44%
0.75	1000	997.4	989.3	0.26%	1.07%
0.5	1000	999.2	993	0.08%	0.70%
0.25	1000	1002	996.6	-0.20%	0.34%
0	1000	1002	1000	-0.20%	0.00%
1	500	498.8	484.6	0.24%	3.08%
0.75	500	498.6	488.7	0.28%	2.26%
0.5	500	500.1	492.6	-0.02%	1.48%
0.25	500	502.1	496.3	-0.42%	0.74%

0	500	502.2	500	-0.44%	0.00%
0.6	825	823.4	816.3	0.19%	1.05%
0.85	825	822.8	812.6	0.27%	1.50%
0.9	951	948.7	937.9	0.24%	1.38%
0.9	1245	1242	1232	0.24%	1.04%
0.55	150	148.5	138.5	1.00%	7.67%

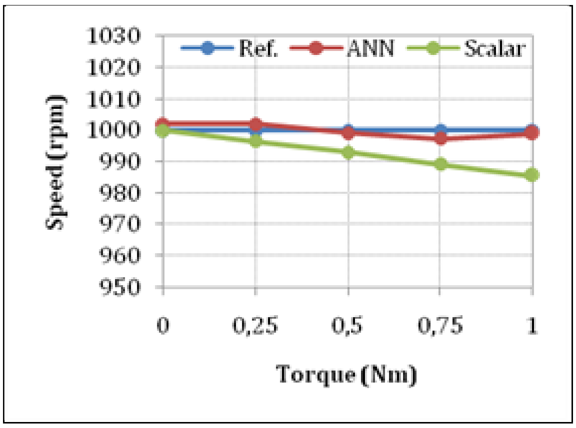
When Table 2 was examined;

- For 1500 rpm: All torque values applied to the motor the proposed method has been successful by making less speed errors. Negative % values in the table indicate obtained more speed from the desired speed. For example, the motor was asked to return 1500 rpm at 0.25 Nm. Speed obtained by ANN is 1502 rpm and speed obtained by Scalar is 1496 rpm. ANN speed error percentage is –0.13%, Scalar speed error percentage is 0.27%. This means that the ANN has reached the nearest result with an error percentage of 0.13%.
- Similar expressions can be used for a speed of 500 rpm and 1000 rpm in Table 2.

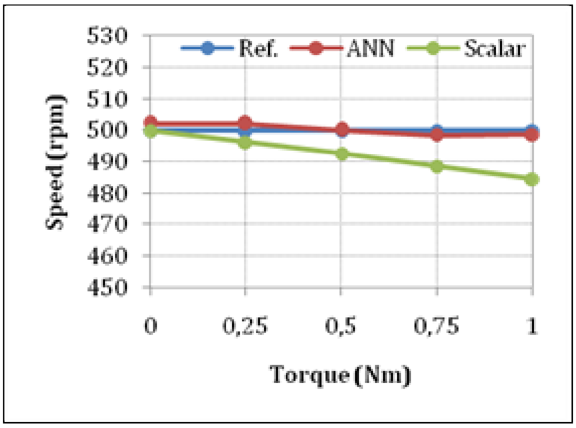
- In the last section of the table, the results obtained by entering very different values from ANN training values were given. For example, the speed error percentage of the proposed method is 0.27% for 825 rpm and 0.85 Nm.



(a)



(b)



(c)

Figure 4. Graphics obtained at different loads and speeds

- These values show that speed error in the proposed method is between about 0.1% and 0.4%. In contrast, it is understood that speed error of Scalar method is between approximately 0% and 3%.

Results in the last line of Table 2 and Fig. 4a, 4b, 4c show the performance of the proposed method at very low speed.

4. Conclusion

In this study, sensorless speed control of IM was performed with Artificial Neural Networks (ANN). Percentages in speed errors indicate the success of the proposed method. The proposed method may be applied to industrial applications by performing real-time implementations. Furthermore, besides this study, it is understood that a study can be made at very low speeds (0-5 Hz).

Appendix

Motor parameters are shown in Table 3 as below.

Table 3. Motor parameters

Induction Motor Parameters		
Stator Resistance (*Rs*)	4.85	Ohms
Stator Inductance (*Ls*)	0.274	Henry
Rotor Resistance (*Rr*)	3.81	Ohms
Rotor Inductance (*Lr*)	0.274	Henry
Mutual Inductance (*Lm*)	0.258	Henry
Rotor Inertia (*J*)	0.031	Kg.m2
Number of Poles (*p*)	4	
Output Power (*Pout*)	1.5	kW

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