Robust Speed Control of a Three Phase Induction Motor Using Support Vector Regression

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Abstract-The Three Phase Induction Motor (TIM) is one of the most widely used motors due to its low price, robustness, low maintenance cost, and high efficiency. In this paper, a Support Vector Regression (SVR) based controller for TIM speed control using Indirect Vector Control (IVC) is presented. The IVC method is more frequently used because it enables better speed control of the TIM with higher dynamic performance. Artificial Neural Network (ANN) controllers have been widely used for TIM speed control for several reasons such as their ability to successfully train without prior knowledge of the mathematical model, their learning ability, and their fast implementation speed. The SVR-based controller overcomes the drawbacks of the ANN-based controller, i.e. its low accuracy, overfitting, and poor generalization ability. The speed response under the proposed controller is faster in terms of rising and settling time. The dynamic speed response of the proposed controller is also superior to that of the ANN-PI controller. The performance of the proposed controller was compared for TIM speed control with an ANN-PI controller via simulations in SIMULINK.

Keywords- three-phase induction motor; indirect vector control; ANN controller; SVR controller

I. INTRODUCTION

Its simple structure, inexpensive, and good robustness have made the Three-phase Induction Motor (TIM) a most attractive choice [1, 2] for industrial applications. In high performance speed control of the TIM, the Indirect Vector Control (IVC) method is extensively used. The IVC method of speed control has been preferred due to its good dynamic performance [3, 4]. ANN research has been increasing fast since the '80s [5]. ANN-based controllers are widely used for the speed control of the TIM. The ANNs have the capability to map non-linear dependencies in the data without using any preconceptions. Their ability to successfully train without prior knowledge of the mathematical model and load variations are their main advantages [6, 7]. However, ANN controllers have some drawbacks such as: low accuracy, poor generalization ability, and overfitting [8]. A Support Vector Regression (SVR) -based controller can overcome the drawbacks of the ANN controller with superior generalization ability. It has high accuracy and good performance despite the small training samples [9, 10].

Recently, the SVR technique has been applied in the field of electrical engineering. M. Pellegrini proposed a technique based on SVR for short-term load forecasting in smart grids and concluded that the SVR can predict load demand more accurately than the ANN [11]. Authors in [12] proposed an SVR model for predicting the electricity consumption and concluded that the proposed model predicts the electricity consumption with higher accuracy than the ANN model. Authors in [13] proposed an SVR based dynamic behavioral model for RF power amplifiers. The obtained results show that the SVR model gives an improved performance and predicts the behavior of power amplifier more accurately than the ANN model. Authors in [14] presented solar power forecasting using SVR and ANN and concluded that the best solar power forecast is obtained with the SVR model. Authors in [15] developed an SVR model for the prediction of light energy consumption. The obtained results showed that the proposed model outperformed the ANN model [15]. Authors in [16] presented an SVR-based behavioral model for RF power transistors. The obtained results suggested that the SVR based approach is more efficient and overcomes the overfitting issue of the ANN-based approach. The reason for choosing SVR over ANNs is that it is based on the structural risk minimization principle that minimizes the generalization errors, rather than minimizing the errors on the training data as is the case of the ANNs [17].

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II. THE PROPOSED FRAMEWORK

Different controllers have been developed to control the speed of TIM as PI [18, 19], Fuzzy-PI [20-22], ANNs [23-25], ANN-PI [26], Fuzzy-Neuro [27, 28] and Support Vector Machine (SVM) [29]. This paper presents a new PI-SVR controller technique for speed tracking of TIM based on IVC. For the first time, the SVR-PI controller is successfully developed and implemented for TIM speed control using the IVC. Here, the Radial Basis Function (RBF) is used as the kernel function. The proposed controller approach has the advantages of having very fast response, superior dynamic performance, and higher stability. Figure 1 depicts the block diagram of the suggested framework. An Insulated-Gate Bipolar Transistor (IGBT) inverter converts the DC voltage to AC voltage and variable frequency. The TIM is fed by the PWM inverter. The TIM provides feedback signals to the SVR-PI controller. The speed control approach employed here is IVC, which is a dynamic and reliable control method.

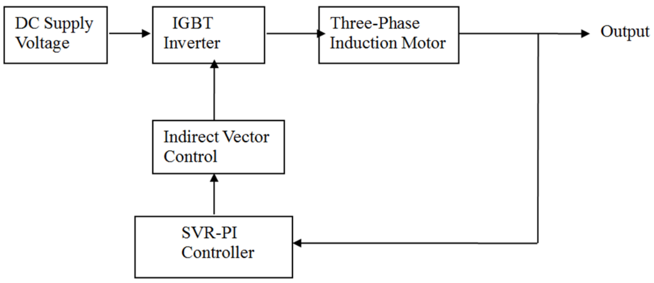

Fig. 1. Block diagram of the proposed framework.

III. THE ARTIFICIAL NEURAL NETWORK CONTROLLER

An ANN-PI controller was developed for TIM speed control. Figure 2 depicts the SIMULINK model of the ANN-PI controller.

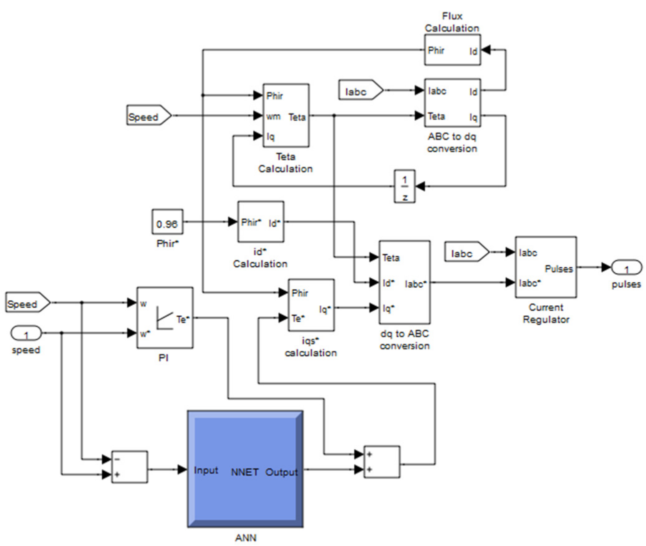

Fig. 2. The ANN-PI TIM controller.

Figure 3 depicts the construction of the developed ANN controller. The hidden layer uses a logarithmic sigmoid activation function and the output uses a linear activation function.

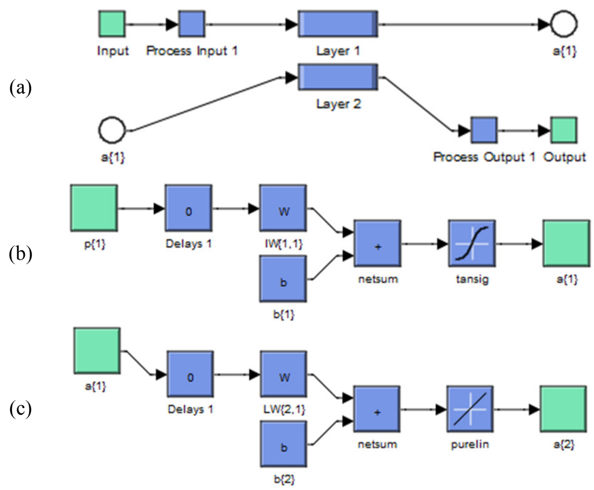

Fig. 3. The ANN controller developed in SIMULINK. (a) Internal layers, (b) weight and bias of the first layer, (c) weight and bias of the second layer.

IV. SUPPORT VECTOR MACHINE FOR REGRESSION

SVM is a machine learning technique that can be used for classification and regression analysis. When SVM is used for regression analysis, it is termed as SVR [30-32]. SVR is considered as a non-parametric technique because it depends on kernel functions. In linear epsilon-intensive SVR (ε-SVR), the training data set comprises of the observed response values and the predictor variables. The aim is to determine a function $f(x)$ that deviates from y_n by no more than ε for each training point x and simultaneously is as even as possible [33]. Here, the RBF used as the kernel function. This paper for the first time presents a modern performing SVR-PI controller. The trained SVR calculates the output according to the reference constant speed. Then the output of the trained SVR is added to the PI output. It makes the TIM speed response faster and stable. Table I shows the epsilon, sigma and C parameters for SVR. Epsilon denotes the epsilon-insensitive loss function, sigma is the RBF kernel, and C is the upper limit of double problem variable alpha. Figure 4 depicts the simulation in SIMULINK of the SVR-PI controller.

TABLE I. SVR PARAMETERS

Parameters	ε	σ	C
Values	10^{-6}	0.6	10^4

V. RESULTS AND DISCUSSION

The TIM was built using the asynchronous machine block in SIMULINK. The complete simulation in SIMULINK of the TIM speed control using IVC is shown in Figure 5. The three-phase induction motor is fed by the three-phase inverter that is built using a universal bridge block. The TIM drives a mechanical load characterized by inertia, friction coefficient, and load torque. The speed control loop produces the quadrature-axis current reference that controls the TIM speed using the SVR based controller. Originally, the three phase induction motor is at standstill without load. Then the load is increased from 0 to 200Nm. Simulations were carried out on both controllers. The simulated results of the SVR controller were compared with the results of the ANN controller. Table II summarizes the simulation results of the ANN-PI and SVR-PI controllers.

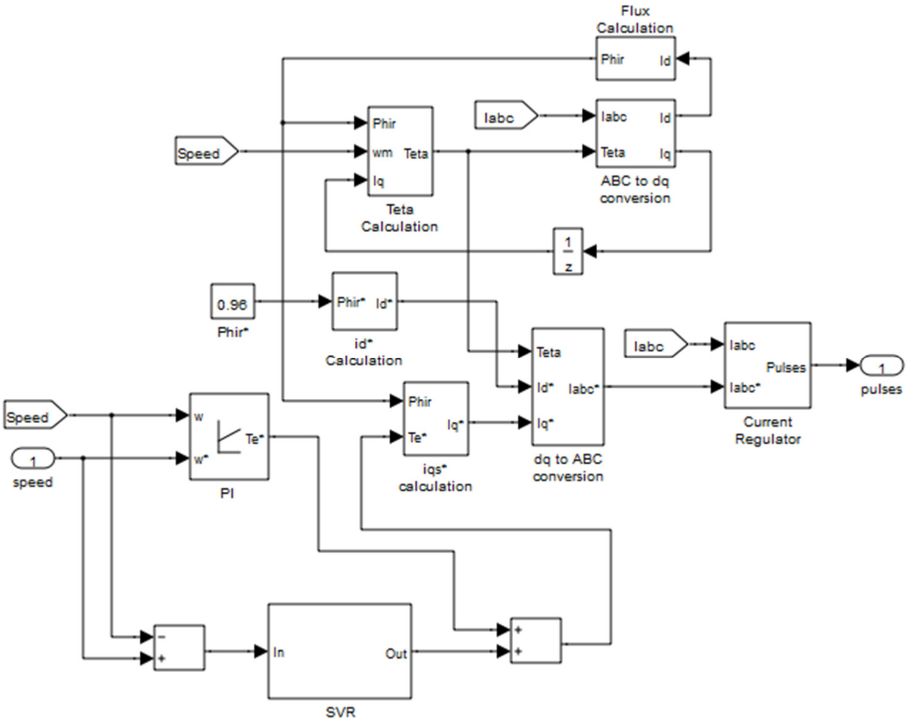

Fig. 4. The three-phase induction motor controller using SVR-PI.

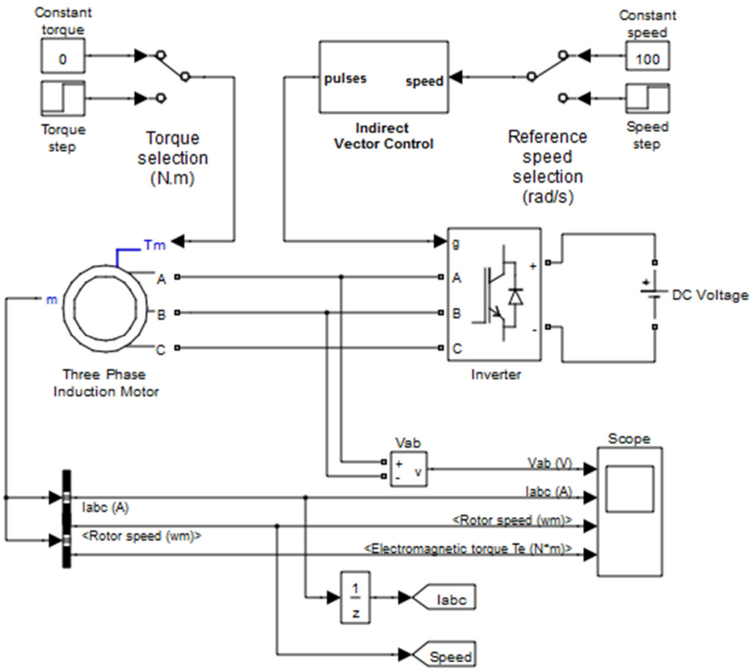

Fig. 5. The complete simulation in SIMULINK of the IVC based TIM speed controller.

TABLE II. PERFORMANCE ANALYSIS

Load (Nm)	**Controller**	**Settling time (s)**	**Overshoot (%)**	**Rise time (s)**
0	ANN-PI	0.567	0	0.508
	SVR-PI	0.408	0	0.367
50	ANN-PI	0.684	0	0.613
	SVR-PI	0.475	0	0.417
100	ANN-PI	0.861	0	0.772
	SVR-PI	0.541	0	0.487
150	ANN-PI	1.161	0	1.041
	SVR-PI	0.647	0	0.581
200	ANN-PI	1.782	0	1.596
	SVR-PI	0.810	0	0.718

Figure 6 shows that the SVR-PI controller has better performance than the ANN-PI controller. The settling time and rise time of SVR-PI controller are smaller than the ANN-PI controller's.

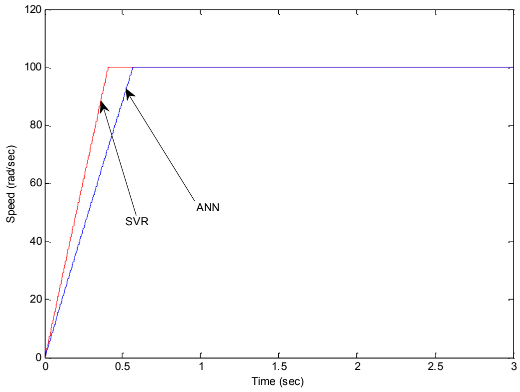

Fig. 6. No load response of the TIM.

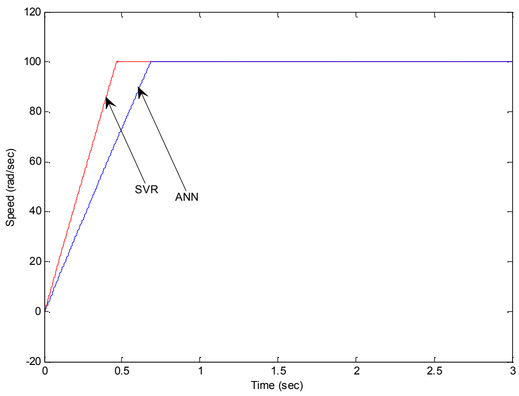

Fig. 7. Speed response of the TIM at 50Nm load.

Figure 7 shows that the SVR controller gives better settling time and faster response than the ANN-PI controller. As shown in Figure 8, the motor reaches the reference speed faster when using the SVR-PI controller. When we use the ANN controller for a load of 150Nm, it will increase rise time and settling time. On the other hand, as illustrated in Figure 9, the proposed controller performs better with less settling and rise time.

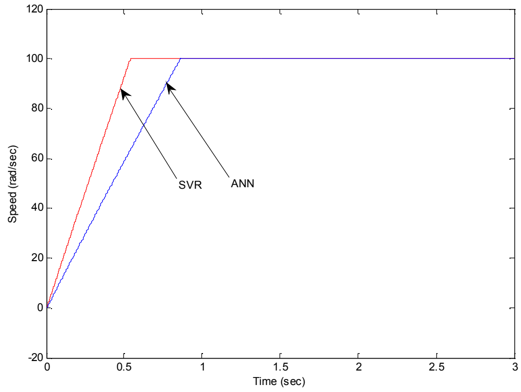

Fig. 8. Speed response of the TIM at 100Nm load.

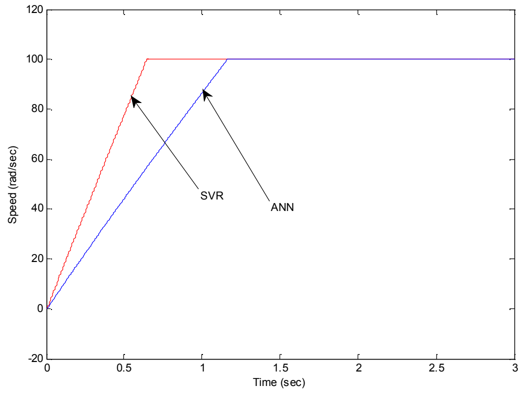

Fig. 9. Speed response of the TIM at 150Nm load.

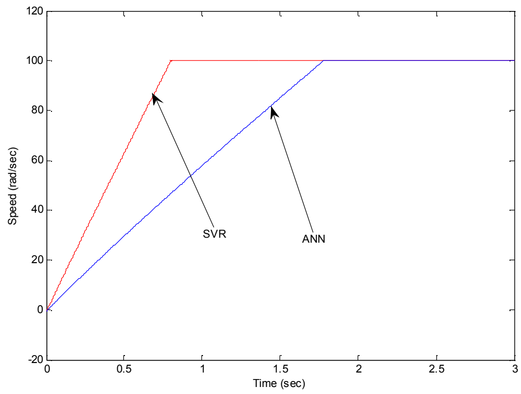

Fig. 10. Speed response of the TIM at 200Nm load.

We used the ANN controller for a large load of 200Nm as shown in Figure 10. We see that the system suffers from high settling time of 1.782s and high rise time of 1.596s, while the SVR controller takes only 0.810s to stabilize and has a rise time of 0.718s. To study the TIM dynamic performance, a step change in load torque and a step change in reference speed are employed. Figures 11 and 12 show the dynamic response of the TIM. Due to the huge increase in load, the ANN controller does not settle down at a required initial and final speed steps. The SVR controller settles down at the initial and final reference speed step of 100rad/s and 160rad/s without undershoot and with small settling and rise times. These results indicate that the SVR controller gives a robust and superior dynamic performance.

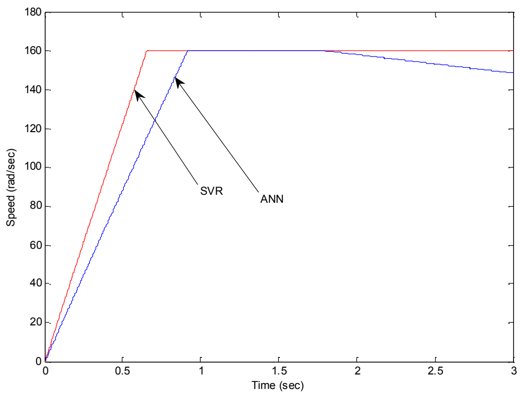

Fig. 11. Dynamic speed response of the TIM with the final speed reference at 160rad/s at t=0.4s and a 300Nm load at t=1.6s with SVR and ANN controllers.

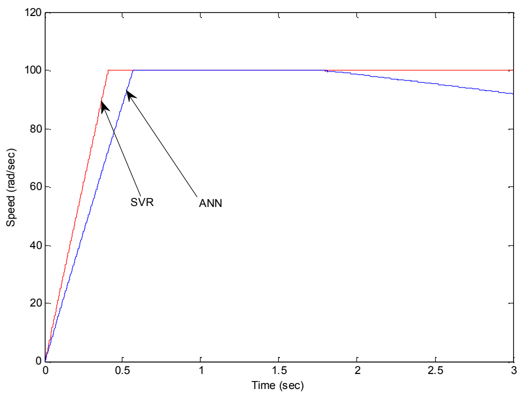

Fig. 12. Dynamic speed response of the TIM with the initial speed reference at 100rad/s at t=0.4s and a 300Nm load at t=1.6s with SVR and ANN controllers.

VI. CONCLUSION

This paper presents for the first time the use of SVR with PI controller for TIM speed control using IVC. This method combines the advantages of the SVR technique and the conventional PI controller to further improve the TIM speed response. The IVC is widely used for speed control due to its simple configuration. The controller was successfully developed and simulated in MATLAB/SIMULINK. The ANN controller offer no % OS due to its self-learning ability. The proposed controller was tested at different load torque values and had less rise time and faster settling time than the ANN controller. The simulation results suggested that the SVR controller is generally more effective and performs faster. The proposed controller improves greatly the dynamic performance. On the other hand, the dynamic performance of the ANN controller is poor.

APPENDIX

TIM Electrical Parameters

3 Phases, Poles = 4, P = 50hp, Ns=1800rpm
Voltage = 460V, F = 60Hz
R_s = 0.087Ω, R_r = 0.227Ω
L_s = 0.8mH, L_r = 0.8mH
L_m = 34.7Mh
J = 1.662Kg-m^2

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