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THE APPLICATION OF AN INTELLIGENT ADAPTIVE CONTROLLER FOR PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE USING NEURAL NETWORK

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ABSTRACT

Electrical motors are designed to operate with high performance and precision while a fast response is achieved by the intended control. Compared to traditional synchronous motors, permanent magnet synchronous motors have complicated mathematical and non-liner models when considering control design. Designing traditional control system becomes more difficult especially when dealing with the interactive parameters. Moreover, the neural network control systems have been a topic of interest since they can be implemented for non-liner and complicated systems without considering the mathematical model of the proposed system. In order to obtain a desired response, the design is achieved through procedure called training the network based on the model. Therefore, this paper presents an implementation of a neural network for a permanent magnet synchronous motors control where improvement of the performance of control is achieved and compared with conventional proportional-integral control. The Matlab/Simulink tool box is used to simulate the proposed system. Simulation results have shown that the suggested controller provides better response than traditional proportional-integral controller for the speed control for synchronous motor driver. In addition, the speed/torque of the selected permanent magnet synchronous motor can be controlled as a desired.

***Keywords**:*
An Intelligent Adaptive Controller.
Artificial Neural Network.
Proportional-Integral Controller.
Permanent Magnet Synchronous Motor Driver.

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1 INTRODUCTION

The most commonly used controller for a synchronous 3-phase motor drives are Proportional integral (PI) and Proportional-Integral-Derivative (PID) controller. However, they have some disadvantages including high starting overshoot, sensitivity to controller gains and sluggish response due to sudden load disturbance. Since the Permanent Magnet Synchronous Motors drive (PMSM) have complicated mathematical and non-liner models, therefore, designing traditional control system becomes more difficult especially when dealing with the interactive parameters. Although the PID controller has the advantage of simple structure and easy implementation, however, it unable to deal with nonlinear behaviour and it has sluggish speed response. For example in reference [1] the PMSM drive has been controlled using PI controller. However, the results show that the PI controller is sensitive to speed changes, load disturbances and parameters variation without continuous tuning of its gains. Simulation of the PMSM System using Fuzzy Self-Adjusting PID Controller is presented in [2]. Reference [3] presented Fuzzy and PID controller for speed control of the PMSM motor. The results show that there overshoot when using both the Fuzzy and PID. However, Fuzzy controller provides less overshoot and faster speed response than the PID controller. A PMSM drive based on Fuzzy/PID control is reported in [4]. Results show that the Fuzzy/PID adaptive control responds fastest than PID controller. However, Fuzzy adaptive controller has some overshoot of speed response. Reference [5] presented the detailed modelling using Fuzzy logic controller for the PMSM derives system using Matlab/Simulink. The performance of the proposed Fuzzy logic controller has been compared with that of the conventional PI and PID controllers. Engineers and researchers have recognized that the implementation of an Artificial Neural Network (ANN) as key factor in designing reliable and effective control systems in industrial applications. For example reference [6] introduced the use of neural model reference control method with the design of the inverted pendulum. In addition, it presented the limitation of PID control algorithm for inverted pendulum. The results proved that the performance of the original system had very big improvement, system stability, accuracy and rapidity. An adaptive controller using ANN for nonlinear time-varying system is presented in [7]. The simulation results conform the effectiveness of the proposed algorithm. Also, the results show that the presented controller is simple to implement and may be used for multivariable system. Reference [8] proposed a neural network controller for the speed loop of electric drive. The use of parallel neural network combined with sliding mode control in overhead crane control system is introduced in [9]. The paper applied the parallel processing capability of NNs and used SMC concepts to tune the free parameters. Results show that the proposed control can drive a crane efficiently and minimize the positioning error for the cart and load swing for the load. Moreover, the proposed method is confirmed the effectiveness of control based on NNs for solving other sway problems. From the above discussion, it can be seen that limited research has been done in designing an effective and reliable control for the PMSM drive, particularly using ANN. This paper has addressed this issue and presents a novel Intelligent Adaptive Controller (IAC) for the PMSM drive based on ANN. Moreover, the paper aims to compare the proposed IAC with the PI controller.

2 OVERALL BLOCK DIAGRAM

The Motor (PMSM) drive system compound of five main ingredients namely controller, d-q/abc, Pulse Width Modulation (PWM), abc/dq, and the PMSM as shown in Figure 1. Controller and model (PMSM) under study we will be discussed separately in next subsections.

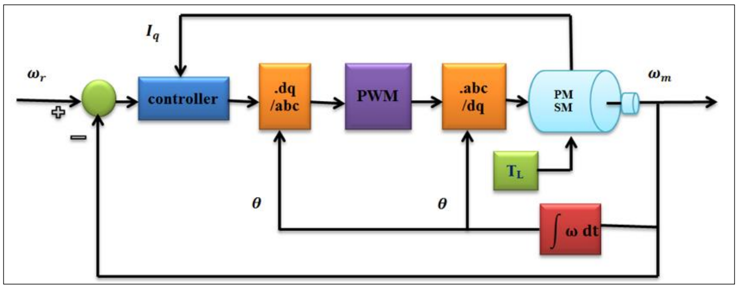

Figure 1: The permanent magnet synchronous motor drive system

2.1 Controller Modelling

Since this paper aims to compare the results that come out from the proposed IAC with, the results that come out from the PI controller therefore, both controllers will be described in following subsections.

2.1.1 The Intelligent Adaptive Controller

The proposed Intelligent Adaptive Controller (IAC) is created using Matlab/neural network toolbox as shown in Figure 2. The feed forward Multilayer Perceptron (MLP) neural network is used in this study in order to build the proposed IAC. It contains of input layer with one neuron; three hidden layers contain 10, 50 and 15 neurons respectively and one neuron in the output layer as shown in Figure 3. The used transfer function for hidden layers is 'tansig' and 'purelin' transfer function for the output layer. For the training process of the MLP, the maximum acceptable sum error is set at 0. In addition to that a number of iterations for the training of ANN model are set to 300 epochs (cycles). The training procedure is carried out until a maximum of 300 epochs or the maximum acceptable sum error is reached. In this study computer memory is sufficient for the training. The error (the difference between the reference and output of the PMSM) and the target (output signal of the PMSM) are used as input (data) to train the proposed neural network. In order to implement the ANN model the data is divided into three sets namely training, validation and testing sets. For the training phase of MLP model, 80% of the data are assigned as the training set, 10% for the validation set and the remaining 10% are employed for testing the performance of the network.

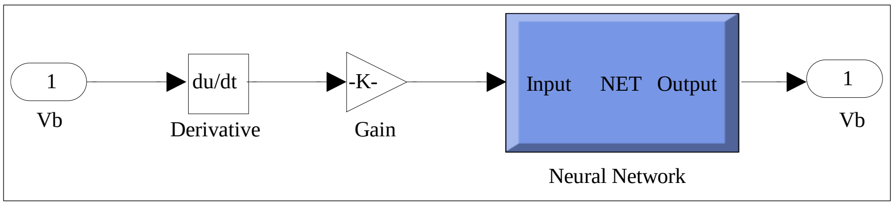

Figure 2: Structure of the IAC

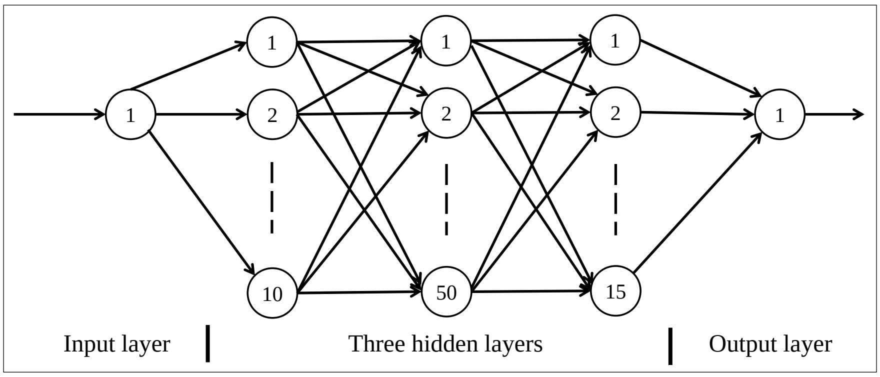

Figure 3: The used multilayer perceptron for the proposed controller

2.1.1.1 Mechanism of an Intelligent Adaptive Controller

A multilayer neural network is used in order to concept an intelligent controller for the PMSM drive as shown in Figure 3 and Figure 4. The adapted output of the neural network is fed into the PWM, where the signal is modulated and then passed into the converter block (abc/dq). In the abc/dq block the signal is changed from the abc into the dq. The output signal is then used for controlling the speed of the PMSM drive as shown in Figure 4.

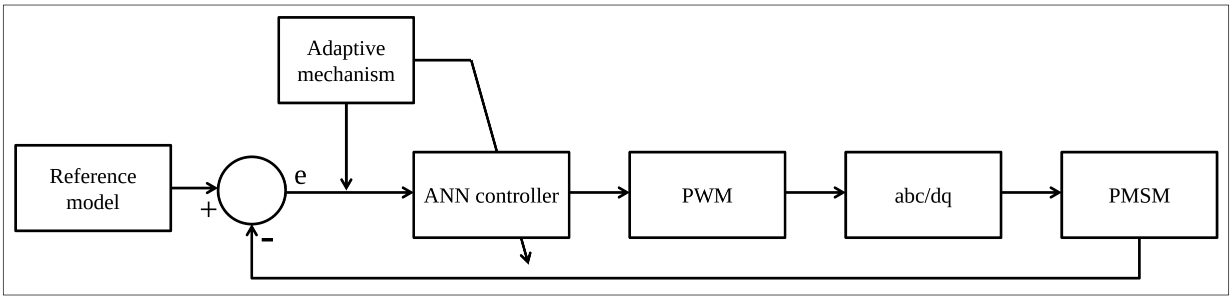

Figure 4: The mechanism of the intelligent adaptive control

2.1.2 Proportional-Integral Controller

PI or two-term controllers were used in this paper. Speed, current, and position were controlled by PI controller..

The Mathematical equations that represent the PI controller in time domain are:

$$u(t) = k_p[R(t) - Y(t)] + k_i \int_0^t [R(t) - Y(t)]dt \quad (1)$$

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt \quad (2)$$

Where:

$\boldsymbol{u(t)}$ - controllers output signal

$\boldsymbol{e(t)}$ - controllers input error signal

$\boldsymbol{k_p}$ - proportional control gain

$\boldsymbol{k_i}$ - integral control gain

2.2 Permanent Magnet Synchronous Motor d-q Modelling and Simulation

A mathematical model is needed for appropriate simulation of the PMSM in a rotor d-q reference frame and can be described by the following equation.

$$\lambda_q = L_q i_q \quad (3)$$

$$\lambda_d = L_d i_d + \lambda_m \quad (4)$$

$$V_q = R_s i_q + \omega_r \lambda_d + \rho \lambda_q \quad (5)$$

$$V_d = R_s i_d - \omega_r \lambda_q + \rho \lambda_d \quad (6)$$

$$\rho = \frac{d}{dt} \quad (7)$$

The developed torque motor is being given by :

$$T_e = T_L + B\omega_r + J\frac{d\omega_r}{dt} \quad (8)$$

$$T_e = K_t i_q + \frac{3}{2}\frac{P}{2}\left(L_d - L_q\right) i_d i_q \quad (9)$$

$$K_t = \frac{3}{2}\frac{P}{2}\lambda_m \quad (10)$$

$$\omega_r = \int \left(\frac{T_e - T_L - B\omega_r}{J}\right) dt \quad (11)$$

$$\omega_r = \frac{2\pi f}{P/2} \text{(rad/s)} \quad (12)$$

Where:

V_q – q-axis voltage
V_d – d-axis voltage
R_s – Stator resistance
i_q – q-axis current
i_d – d-axis current
L_d – Direct-axis inductance
L_q – Quadrature-axis inductance
λ_q – Flux linkage due q-axis
λ_d – Flux linkage due d-axis
λ_m – Permanent magnet flux

ω_r – Electrical speed
T_e – developed torque
T_L – Load torque
f - Frequency
λ – Flux linkage
B - Friction
J - Inertia
p – Pole pair

The above equations can be used in order to simulate the motor using Matlab / Simulink tool box as shown in the Figure 5.

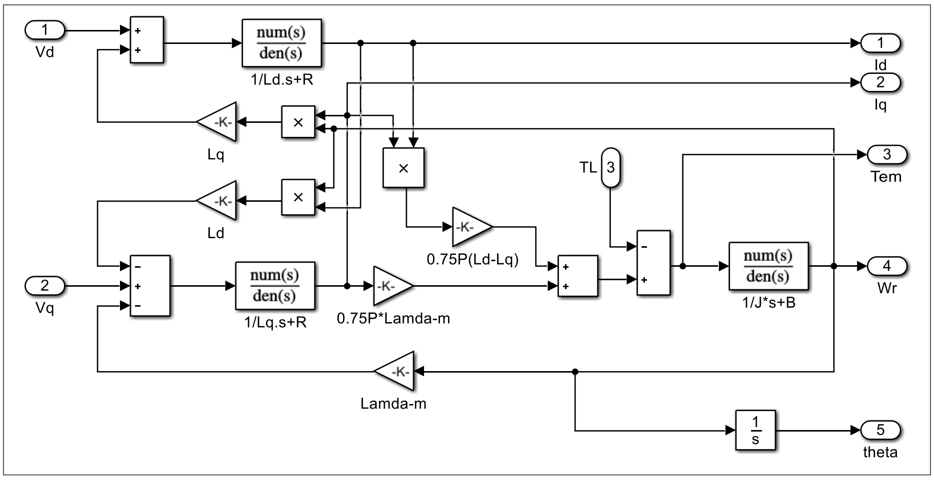

Figure 5: MATLAB simulation of d-q model of the PMSM

3 SIMULATION OF THE OVERALL SYSTEM

The Matlab/Simulink tool box is used to simulate the overall system. So system blocks are created of lower level blocks grouped into a single mask-able block as shown in Figure 6. In this paper, simulation of the PMSM drive has been done with the following speed and current controllers:

1. PI speed controller with PWM current controller.
2. An Intelligent Adaptive Controller (IAC) with PWM current controller.
3. The simulation parameters of the PMSM drive is shown in Table 1[10].

Table 1: The PMSM drive parameters

Parameters	Symbol	Value
Rated stator voltage	Vs	380 V
Load Torque	T_L	6.45N.m
Moment of inertia	J	0.015
Armature resistance	Ra	3.59 Ω
Per phase inductance	L Ph	0.0435 H
Rated Frequency	F	60Hz

Pole pairs	p	6
Nominal rotor speed	n_n	0 rpm)120125.6 rad/sec (
Permanent magnet flux	λ_m	0.545 Vs
Direct-axis inductance	L_d	0.036 H
Quadrature-axis inductance	L_q	0.051 H
constant	K_E	0.148 V.rad/s

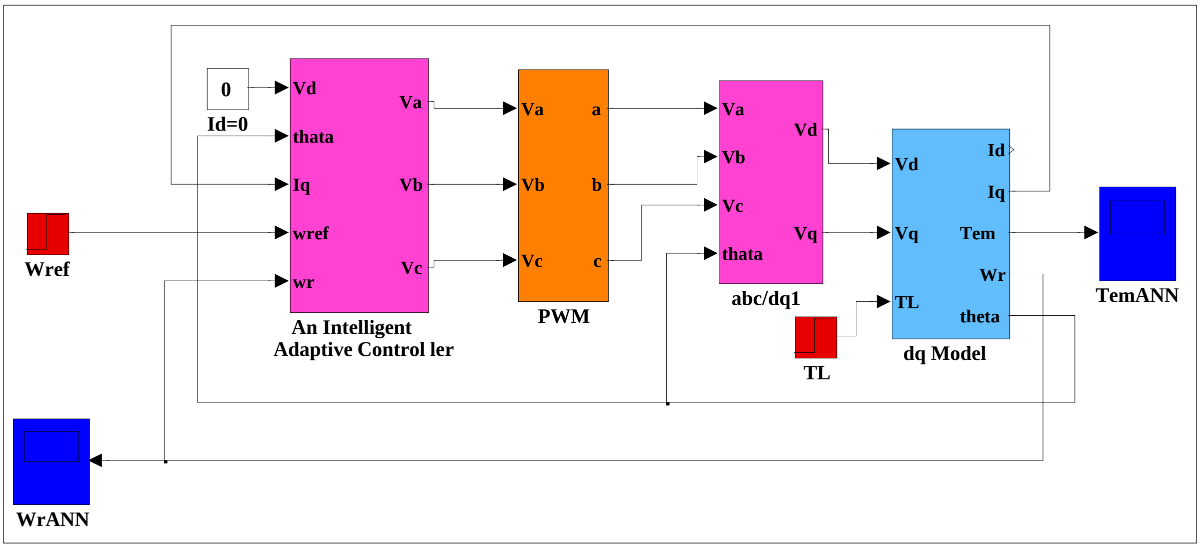

Figure 6: MATLAB/SIMULINK of the proposed PMSM drive system

4 SIMULATION RESULTS AND DISCUSSION

Results, which have been carried out using the proposed IAC based on ANN is compared with results that carried out with the conventional PI controller. Therefore, in order to test the system reliability, a step input signal with amplitude is applied to the both systems individually. The results of this study can be divided into:

4.1 The results that comes out using the proposed IAC.

Figure 7 shows the speed response of the IAC without load. From Figure 7, it clearly can be noticed that the IAC meets the desired requirement with a rise time of about 0.017 sec, settling time of about 0.125 sec and almost 0% steady state error. Moreover, it can be observed that the output of the IAC is acceptable and its response works very well.

A torque of 6.45N.m is applied to the PMSM driver in order to investigate the performance of the system using the proposed IAC. The speed response of the IAC is shown in Figure 8. From the Figure 8.it can be observed that the system behaviour faster than PI controller. It also, can be noticed that the rise time 0.016 sec and settling time 0.125 sec. In addition to that it can be seen that the torque affects the system instantly with steady state error 5.5%. Also, the IAC can overcome the nonlinear behaviour and it can drops the electric magnetic torque from 25 N.m to zero without load and from 20 N.m to zero with load torque 6.45 N.m as shown in Figure 9, and Figure 10.

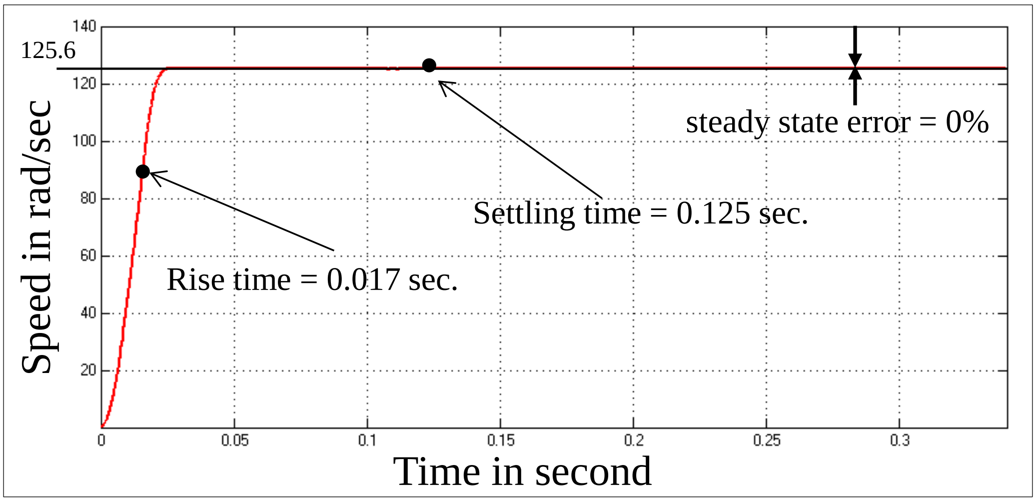

Figure 7: Speed response using IAC without load

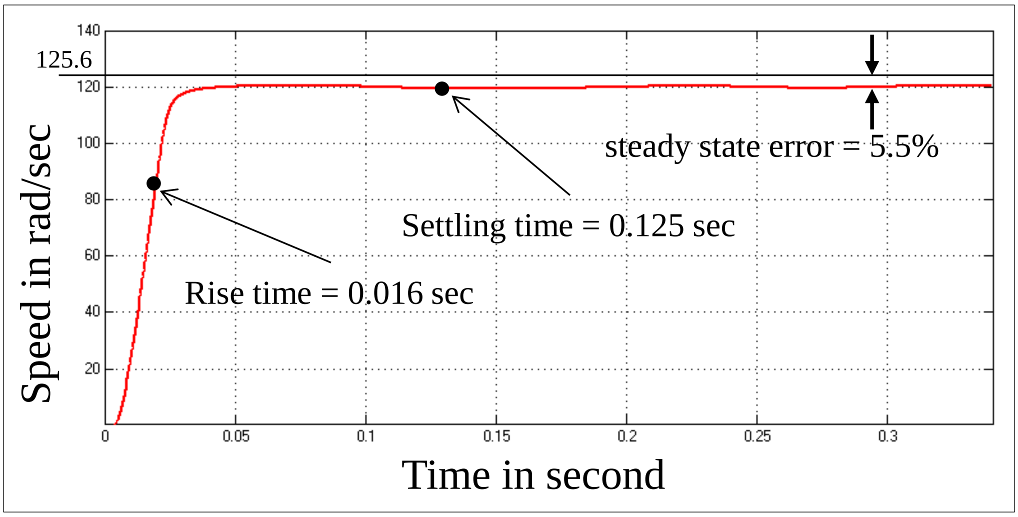

Figure 8: Speed response using IAC with load 6.45N.m

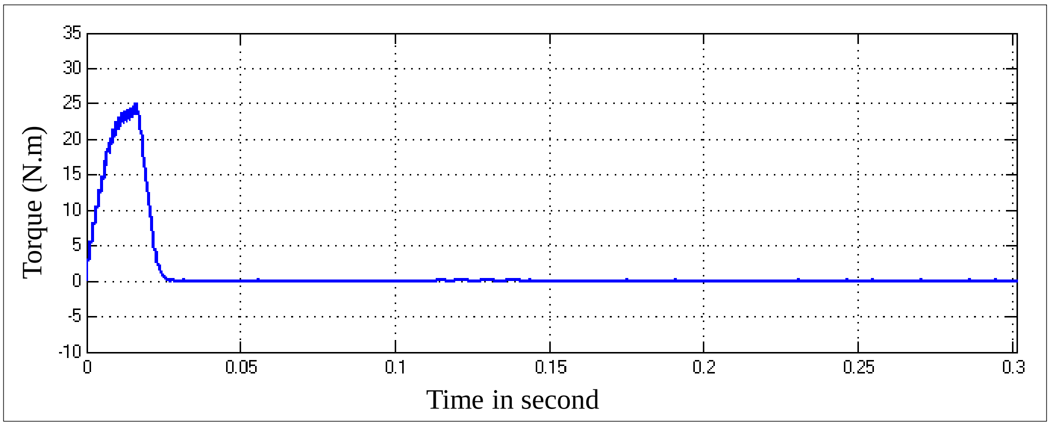

Figure 9: Obtained electromagnetic torque (N.m) using the proposed IAC without load

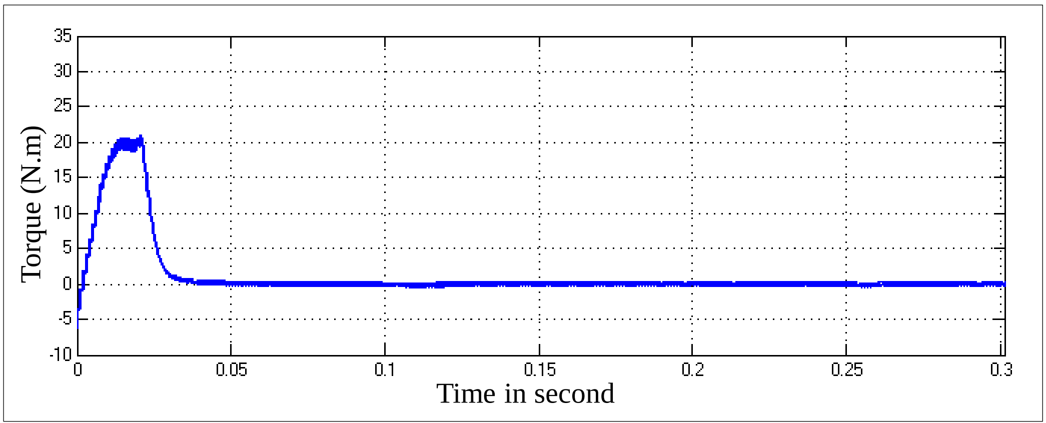

Figure 10: Obtained electromagnetic torque (N.m) using the proposed IAC with load 6.45N.m.

4.2 The results that comes out using the PI controller.

The responses of the PI-controller without load and with load 6.45 are shown in Figure 11 and Figure 12 respectively. From Figures it clearly can be observed that the speed response sluggish than the proposed IAC with 0% of overshoot, steady-state error 0%, rise time 0.034sec, and settling time 0.175sec, for the PI controller without load and 0% of overshoot, steady-state error 5%, rise time 0.036sec, and settling time 0.175sec, for the PI controller with load 6.45N.m. In addition to that it can be noticed that there is a non-linear behaviour has been accrued during the system run time. Finally, it clearly can be seen that the PI controller cannot overcome the nonlinear behaviour as shown in Figure 13 and Figure 14.

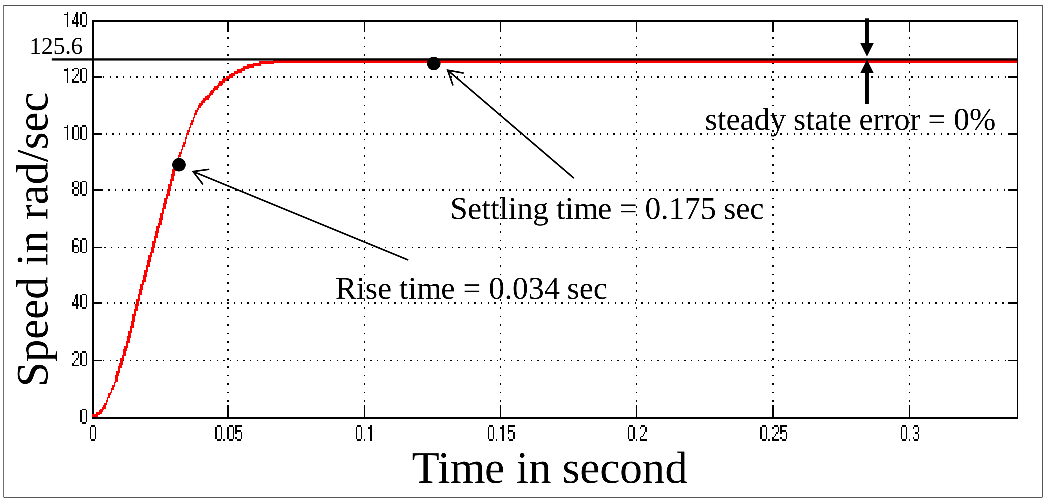

Figure 11: Speed response using the PI controller without load

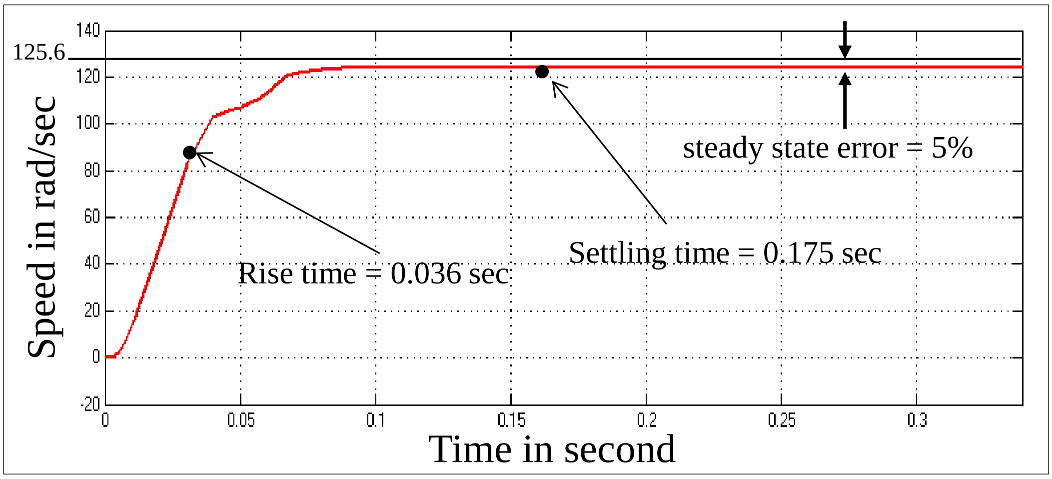

Figure 2: Speed response using the PI controller with load 6.45

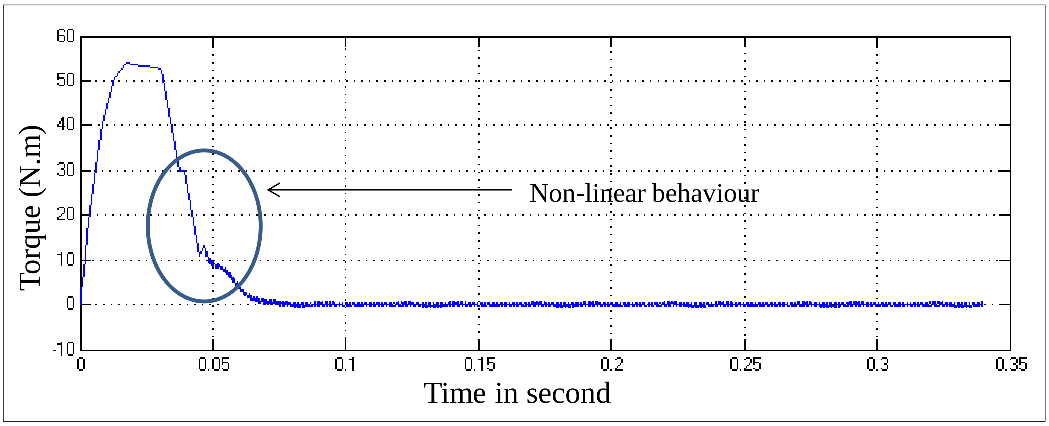

Figure 13: Obtained electromagnetic torque (N.m) using the PI controller without load.

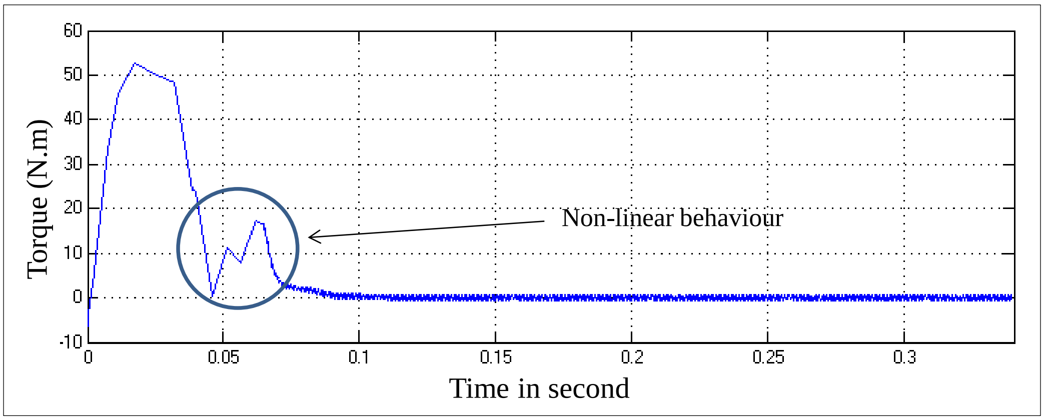

Figure 14: Obtained electromagnetic torque (N.m) using the PI controller with load 6.45N.m.

A comparison between two models of the proposed IAC and PI controller is shown is shown in table 2.

Table 2: presents the obtained results using both controllers

Type of controller	**PI without load**	**IAC without load**	**PI with load 6.45**	**IAC with load 6.45**
Overshoot (%)	zero	zero	zero	zero
Settling time (sec)	0.175	0.125	0.175	0.125
Rise time (sec)	0.034	0.017	0.036	0.016
Steady-state error (%)	0	0	5	5.5

5 CONCLUSION

From above discussion in section 4 it can be concluded that the proposed IAC using ANN has the advantages of the PI control, so it can get better control performance of the PMSM drive. In addition to that, the system which uses the IAC can run faster, smoothly and still it has perfect dynamic and static characteristics for a speed of 125.6 rad/sec (1200 rpm). Moreover, the IAC using ANN has less regulating time and it can successfully overcome the nonlinearity of the system compared to the traditional PI controller. Finally, even though the PI performed better in terms of the steady state error, however, it can't overcome the nonlinearity of the system..

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تطبيق التحكم التكييفي الذكي علي المحرك التزامني ذو المغناطيس الثابت باستخدام الشبكات العصبية

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الملخص

قد صممت المحركات الكهربائية لكي تعمل بأداء عالي ودقة عالية وتحقق الاستجابة السريعة بالتحكم المطلوب. مقارنة بالمحركات المتزامنة التقليدية فإن للمحركات المتزامنة ذات المغناطيس الدائم نماذج رياضية معقدة وغير خطية عند تصميم المتحكم ويصبح من الصعب جدا تصميم نظام تحكم تقليدي خاصة عند التعامل مع العناصر التفاعلية (interactive parameters). يولي الباحثون اهتماما لأنظمة التحكم بالشبكات العصبية حيث يمكن استخدامها للأنظمة المعقدة الغير خطية بدون معرفة النموذج الرياضي للنظام ويعتمد المتحكم في الشبكات العصبية على التدريب على هذا النموذج الرياضي للحصول على استجابة محسنة وتحقيق افضل اداء بعملية التجربة والخطاء. الفكرة الاساسية لهذه الورقة هي تصميم وانجاز وتنفيذ وحدة التحكم باستخدام الشبكات العصبية للتحكم في محرك تزامني ثلاثي الطور وتحسين اداءه ومقارنته بالمتحكم التقليدي (Proportional- Integral) ودراسة اداءه. وهذا يتم انجازه بمحاكاته ب MATLAB, SIMULINK, وكذلك (Neural Network)ومقارنته بالمتحكم التقليدي (Proportional-Integral) والحصول على نتائج مرضية يمكن الاعتماد عليها. بالإضافة الى ذلك فإن السرعة والعزم للمحرك التزامني ذو المغناطيس الدائم يمكن التحكم بهما كما ينبغي.

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الكلمات الدالة:
المتحكم التكييفي الذكي.
الشبكات العصبية المصطنعة.
المتحكم التكاملي – النسبي.
المحرك التزامني ذو المغناطيس الثابت.