VOL. X,NO.X,XXXXXXXX ISSN 1819-6608
ARPNJournal of Engineering and Applied Sciences

www.arpnjournals.com

THE IMPLEMENTATION OF PERMANENT MAGNET SYNCHRONOUS MOTOR SPEED TRACKING BASED ON ONLINEARTIFICIAL NEURAL NETWORK

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ABSTRACT
This paper deals with the performance analysis of the field oriented control for a permanent magnet synchronous drive system with an artificial neural network proportional-integral-derivative for speed control in closed loop operation. Space vector pulse width modulation is used to generate the required stator voltage. The space vector pulse width modulation has the character of wide linear range, little higher harmonic and easy digital realization. The field oriented control theory and space vector pulse width modulation technique make the permanent magnet synchronous motor can achieve the performance as well as a direct current motor. Therefore an online and offline learning of artificial neural network algorithm is derived. The controller is designed to tracks variations of speed references and stabilizes the output for both systems. The effectiveness of the proposed method is verified by develop the system in MATLAB-simulink program and experimental by using Digital Signal Processing boardand interfacing DAQ with LabView software in order to recorded the result. The results show that the proposed online learning artificial neural network controller produce significant improvement control performance for controlling speed reference variations condition compared to offline learning artificial neural network system. It can conclude that by using proposed controller, the settling time and speed achieving can be improved significantly.

Key words: Permanent Magnet Synchronous Motor • Online Neural Network • Field Oriented Control •

INTRODUCTION
The earliest power systems were d.c systems, but by the 1980s a.c power system were clearly winning out over d.c systems. Despite this fact, there were several reasons for the continued popularity of dc motors such as in which wide variations in speed are needed. For dc system, the flux and torque can be controlled separately by means of controlling the field and the armature currents respectively. In some applications today, d.c electric motors are replaced by combining an a.c electric motor with an electronic speed controllerbecause it is a more economical and less expensive solution. Moreover, d.c electric motors have many moving parts that are expensive to replace, and d.c electric motor repair is usually more expensive than using a new a.c electric motor with an electronic controller. By these reason, Permanent magnet synchronous motors (PMSM) has been selected.

PMSM are widely used in low and mid power applications such as computer peripheral equipment, robotics, adjustable speed drives and electric vehicles. Permanent magnet synchronous motor has the characteristics of high power density, free maintenances and high efficiency, which has been widespread application in the various electric drives applications (E. S. Sergaki et al. 2008).

Since 1988, Pillay, P and Krishnan, R. has been presented about PM motor drives and classified them into two types such as permanent magnet synchronous motor drives (PMSM) and brushless dc motor (BDCM) drives (P. Pragasen& R. Krishnan 1989). The PMSM has a sinusoidal back emf and fed with sinusoidal stator currents while the BDCM has a trapezoidal back emf and fed with direct currents. The PMSM is very similar to the wound rotor synchronous machine except that the PMSM that is used for servo applications tends not to have any damper windings and excitation is provided by a permanent magnet instead of a field winding. The PM motor family incorporates two designs: internal rotor and external rotor. Both designs are industrially rated and adopted in critical applications such as elevator winches and wind power generators. However, the main drawbacks that make a.c. motor retreats from industry were the control between flux and torque are inherent coupling but this problem was amended by the exits of electronic control.

So, Field Oriented Control (FOC) technique has been chosen for this system.FOC also known as decoupling or vector control, came into the field of ac drives research in the late 1960s and was developed prominently in the 1980s to meet the challenges of oscillating flux and torque response in inverter fed induction and synchronous motor drive.In FOC, motor stator currents & voltages are manipulated in the direct-quadrature (d-q) reference frame of the rotor and it's a control procedure for operating the motor that results in fast dynamic response and energy efficient operation at all speeds.

There are two methods to achieve zero steady state error: switching and integration. To eliminate steady state error, a Proportional and Integral (PI) controller should be employed (L.K. Wong et al. 1998). Other than that by using Proportional-Integral-Derivatives (PID) controller exact dq axis reactance parameters can be obtained. Moreover, to step change of command speed, parameter variations and load disturbances is very sensitive. Since it is slightly simple to implement, PI and PID controller become most widely used for PMSM. So, a real time self-automated hardware implementation of PID controller is desired (MohdMarufuzzaman et al. 2010).

ISSN 1819-6608
ARPNJournal of Engineering and Applied Sciences

While, the artificial neural networks (ANN) are best suited for solving the problems that are nonlinear in nature. In ANN we can use parallel processing methods to solve some real-world problems where it is difficult to define a conventional algorithms. The ability of ANN to learn large classes of nonlinear functions is well known (Yang Yi et al. 2003)(K.S. Narenda&K. Parthasarathy 1990). It can be trained to emulate the unknown nonlinear plant dynamics by presenting a suitable set of input/output patterns generated by the plant (JiangWeidong et al. 2009). Once system dynamics has been identified by using an ANN, many conventional control techniques can be applied to achieve the desired objective.

In this paper, a model of ANN closed-loop PMSM control system that is controlled by SVPWM are develops for speed performance in FOC PMSM drive.Therefore an online and offline training of ANN algorithm is derived. The controller is designed to tracks variations of speed references and stabilizes the output for both systems. The effectiveness of the proposed method is verified by develop the system in MATLAB-simulink program and experimental by using Digital Signal Processing board.

FIELD ORIENTED CONTROL

Dynamic Modeling of PMSM

PMSM is essentially a three phase AC motor with sinusoidal back EMF driven by a DC source, which is converted to three-phase alternating currents supplying to the three stator windings of PMSM. The mathematic model of PMSM i_{dq} synchronous rotating reference frame can be obtained from synchronous machine model. Due to the constant field produced by permanent magnets, the field variation is zero. It is also assumed that saturation and losses of core are negligible, the induced emf is sinusoidal and there is no damper winding on rotor. Using these assumptions, the voltage equations can write as follow:

$$v_d = R_s i_d + L_d \frac{d}{dt} i_d - L_q \omega_e \frac{d}{dt} i_q \quad (1)$$

$$v_q = R_s i_q + L_q \frac{d}{dt} i_q - L_d \omega_e \frac{d}{dt} i_d + \omega_e \lambda_{PM} \quad (2)$$

The produced torque of the machine can be presented as follow:

$$T_e = \frac{3}{2} P[\lambda_{PM} i_q + (L_d - L_q) i_d i_q] \quad (3)$$

While, the maximum speed can be identified from the relationship:

$$T_e = T_L + K_f \omega_m + J \frac{d}{dt} \omega_m \quad (4)$$

The update frequency of the control loops must be high enough and the SVPWM should be properly configured to ensure sinusoidal currents applied to the stator windings.

The parameters for the PMSM are given as Table 1.

Table 1: Parameters of PMSM

Motor Parameter	Value
Frequency, f	50 Hz
Pole, p	4
Stator Resistance, R_s	2.875Ω
d-axis Inductances, L_d	0.0085H
q-axis Inductances, L_q	0.0085H
Moment of Inertia , J	0.0008kgm²
PM Flux Linkage,λ_{PM}	0.175Wb
Friction Coefficient, K_f	0.00038818

PMSM Drive System

The operation of PMSM drive system is based on the measure of two phase currents and of the motor position. The rotor position feedback is necessary to generate the reference speed. In this case, incremental encoder (2500 pulse per revolution)has been attached. The measured phase currents$\boldsymbol{i_a}$ and $\boldsymbol{i_b}$ are transformed into the stator reference frame components $\boldsymbol{i_{alpha}}$ and $\boldsymbol{i_{beta}}$. Then, based on the position information, these components are transformed into the rotor frame direct and quadrature components $\boldsymbol{i_d}$ and $\boldsymbol{i_q}$. The speed and current controllers are PID discrete controllers. The inverse coordinates transformation is used for the computation of the phase voltages references, $\boldsymbol{V_a}$, $\boldsymbol{V_b}$ and $\boldsymbol{V_c}$, applied to the inverter, starting from the values of voltage references computed in the d and q reference frame ($\boldsymbol{V_d}$, $\boldsymbol{V_q}$). Thus, the 6 full-compare SVPWM outputs of the DSP controller are directly driven by the program, based on these reference voltages. The code is developed only in C language, both for the main structure of the application and for the time-critical parts (as controllers, coordinates transformation, etc) The direct current component reference $\boldsymbol{i_d}$is set to 0 because of the case corresponding to the motion of the motor in the normal speed range, without considering a possible field weakening operation.Figure 1 is the diagram of current control loop using FOC technology based on proposed ANN speed controller.

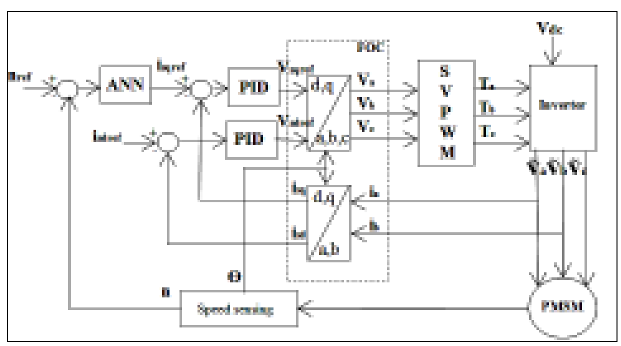

Figure 1: PMSM drive system with ANN controller

Proposed ANNController Structure

To design the neural network control some information about the plant is required. Basically, the numbers of input and output neuron at each layer are equal to the number of input and output signals of the system respectively. Further the number of hidden layers and the total neurons is depended on the complexity of the system and the required training accuracy. To implement search efficiency optimal control of PMSM drive, a multilayer

ISSN 1819-6608
ARPNJournal of Engineering and Applied Sciences

perceptron neural network control is developed. Based on the type of the task to be performed, the structure of the proposed ANN speed controller is shown in Figure 2 (NooradzianieMuhd. Zin et al. 2013)

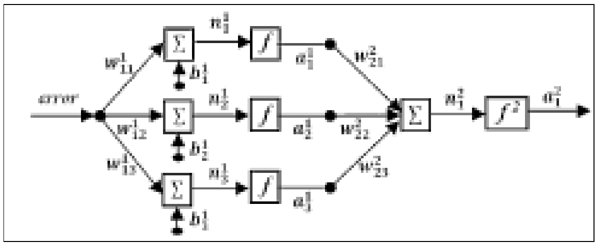

Figure 2: Block diagram of ANN controller for PMSM drive system.

The controller consists of input layer, hidden layer and output layer. Based on number of the neuron in the layers, the ANN is defined as a 1-3-1 network structure. The first neuron of the output layer is used as a torque reference signal ($a^2_1 = m_j$). The connections weight parameter between j^{th} and i^{th} neuron at m^{th} layer is given by w^m_{ij}, while bias parameter of this layer at i^{th} neuron is given by b^m_i. Transfer function of the network at i^{th} neuron in m^{th} layer and output function of neuron at m^{th}layer is defined by:

$$n_i^m = \sum_{j=1}^{S^{m-1}} w_{ij}^m a_j^{m-1} + b_i^m \quad (5)$$

The output function of neuron at m^{th}layer is given by:

$$a_i^m = f^m(n_i^m) \quad (6)$$

Where $f$is activation function of the neuron. In this design the activation function of the output layer is unity and for the hidden layer is a tangent hyperbolic function given by:

$$f^m(n_i^m) = \frac{2}{1+e^{-2n_i^m}} - 1 \quad (7)$$

Updating of the connection weight and bias parameters are given by:

$$w_{ij}^m(k+1) = w_{ij}^m(k) - \alpha \frac{\partial F(k)}{\partial w_{ij}^m} \quad (8)$$

$$b_i^m(k+1) = b_i^m(k) - \alpha \frac{\partial F(k)}{\partial b_i^m} \quad (9)$$

where$k$ is sampling time, α is learning rate, and F performance index function of the network.

Online Scheme of the Proposed ANN

After the neural network architecture is modelled, the next stage defines the learning model to update network parameters. By this learning capability, it makes the ANN suitable to be implemented for the system with motor parameters which are difficult to define and vary against with environment. The training process minimizes the error output of the network through an optimization method. Generally, in learning mode of the neural network controller a sufficient training data input-output mapping data of a plant is required. Since the motor parameters of the PMSM drive vary with temperature and magnetic saturation, the online learning Back propagation algorithm is developed. Based on first order optimization scheme, updating of the network parameters are determined. The performance index sum of square error is given by:

$$F(k) = \frac{1}{2}\sum_i e_i^2(k) \quad (10)$$

$$e_i(k) = t_i(k) - a_i(k) \quad (11)$$

where:t_i is target signal

a_i output signal on last layer.

The gradient descent of the performance index against to the connection weight is given by:

$$\frac{\partial F}{\partial w_{ij}^m} = \frac{\partial F}{\partial n_i^m}\frac{\partial n_i^m}{\partial w_{ij}^m} \quad (12)$$

The sensitivity parameter of the network is defined as:

$$s_i^m = \frac{\partial F}{\partial n_i^m} \quad (13)$$

$$s_i^m = \frac{\partial F}{\partial a_i^m}\frac{\partial a_i^m}{\partial n_i^m} \quad (14)$$

Gradient the transfer function again to the connection weight parameter is given by:

$$\frac{\partial n_i^m}{\partial w_{ij}^m} = a_i^{m-1} \quad (15)$$

From substitution equation (13) and (15) into (8) the updating connection parameter is given by:

$$w_{ij}^{m-1}(k+1) = w_i^{m-i}(k) - \alpha s_i^m(k) a_i^{m-1}(k) \quad (16)$$

With the same technique the updating bias parameter is given by:

$$b_i^{m-1}(k+1) = b_i^{m-i}(k) - \alpha s_i^m(k) \quad (17)$$

RESULTS AND DISCUSSION

The proposed model has been developed by Matlab/Simulink. The simulation block diagram for the proposed PMSM drives system with ANN is shown in Figure 3. The simulation block diagram has been created in order to download all the proposed system into DSP board.

For the experimental set up, all the main circuit including of 3 inputs 6 outputs gate driver, inverter and current sensor (model: ACS756KCA-050B-PFF-T) has been built. All the connection between PMSM and all the circuit has been connected as shown in Figure 4. The

ISSN 1819-6608
ARPNJournal of Engineering and Applied Sciences

hardware is interfacing with system by using TMS320F28335 DSP controller that the program will be downloaded. While, the PMSM equipped with 500-line quadrature incremental encoder (2500 pulse per revolution) is used.Results for each testing wererecorded by interfacing data acquisition (DAQ)with LabView software.

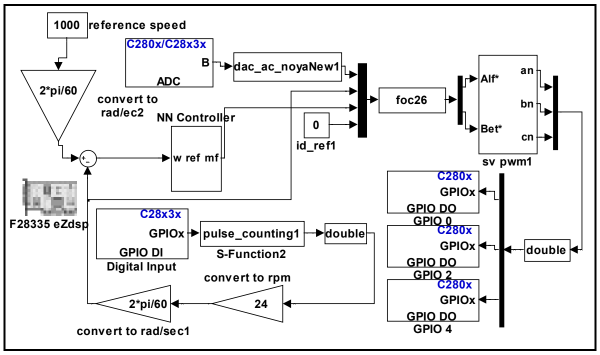

Figure 3: The simulink block diagram of the proposed PMSM drive system with ANN.

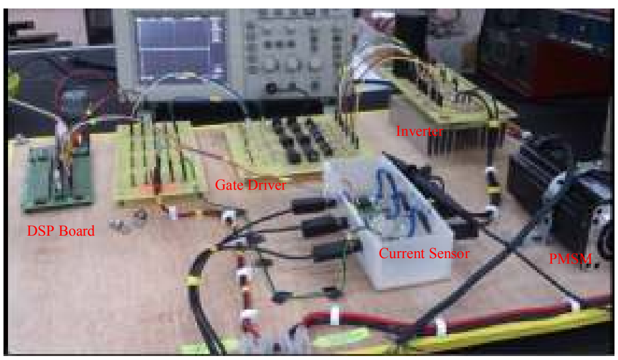

Figure 4: Experimental setup for proposed PMSM drive system with ANN

In order to verify the validity of the proposed PMSM drive system with ANN, both online and offline ANN system has been testfor a variety of speed. Different operating speed is tested, which is constant speed reference 1000rpm, step up speed reference is varying from 400rpm to 900rpm and step down speed reference is varying from 900rpm to 600rpm for both systems. All the results are shown in Figure 5 to Figure 10.

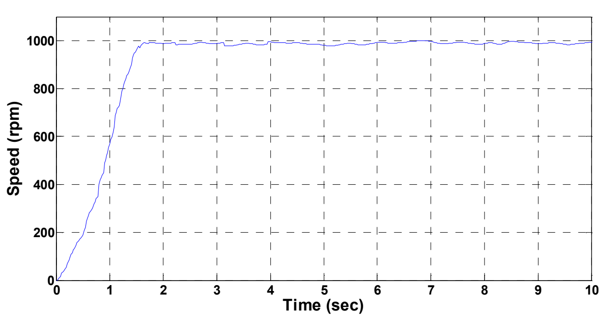

Figure 5: PMSM drive system with online ANN for constant speed reference 1000rpm

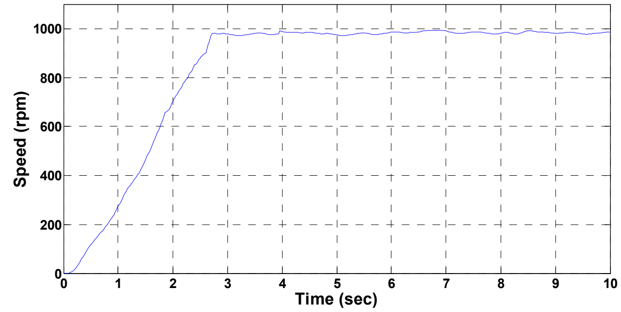

Figure 6: PMSM drive system with offline ANN for constant speed reference 1000rpm

From the resultsin Figure 5 and Figure 6, it shows that by using an online ANN speed controller produced a better start-up performance compare to the offline ANN speed controller where the settling time more faster than offline speed controller in achieving desired output speed. The settling time for online ANN speed controller is 1.6sec while 2.74sec of settling time for offline ANN speed controller. Moreover in speed achieving for both system, an online ANN speed controller achieved 990rpm from the 1000rpm speed reference while offline ANN speed controller achieved 980rpm from the 1000rpm speed reference.Based on result from figure 5 and Figure 6, thedifferencepercentage for settling time between offline ANN and online ANN is 52.54% improved. Meanwhile, the rpmpercentage is 1.02% improved.

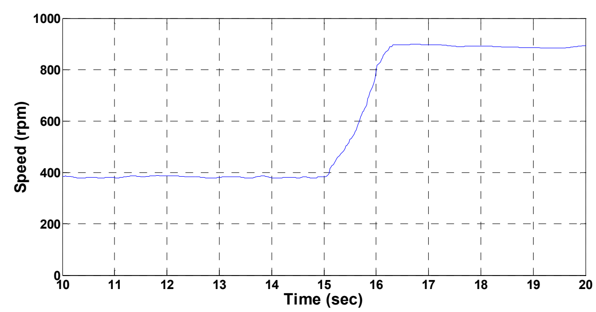

Figure 7: PMSM drive system with online ANN for step up response from 400rpm to 900rpm

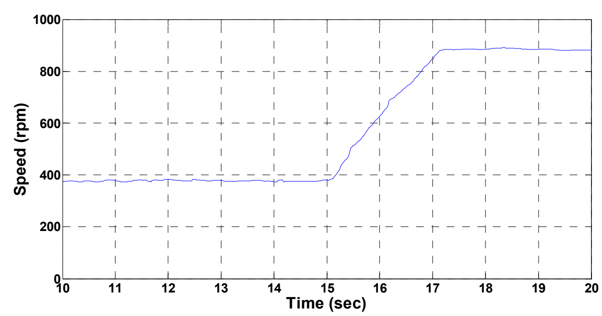

Figure 8: PMSM drive system with offline ANN for step up response from 400rpm to 900rpm

Refer to the Figure 7 and Figure 8, it is also shows that by using an online ANN speed controller produced a better step up performance compared to the offline ANN speed controller where the settling time more faster than offline speed controller in achieving desired output speed. Their settling time is1.32sec and 2.14sec respectively. It is also same in speed achieving performance which is an online ANN speed controller achieved 390rpm and 890rpm from the speed reference 400rpm and 900rpm compared to offline ANN speed controller which is reduced 10rpm respectively from online ANN speed controller in speed achieving. Difference percentage between offline ANN and online ANN for the result of settling time is 47.4% improved and speed is 2.6% improved for 400rpm reference speedand 1.13% improved for 900rpm reference speed. An online ANN can adapt variety condition because of their system always update the parameter even though one of the parameter during testing such as changing of temperature. In other words the weight and bias is updated together with the testing process.

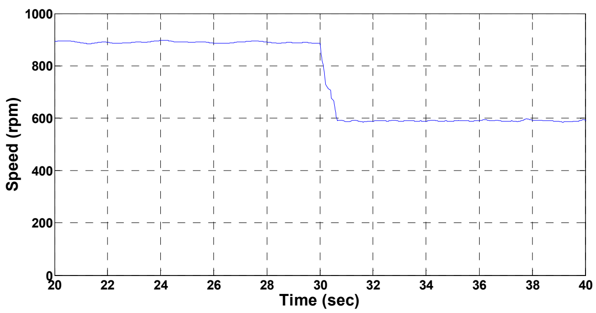

Figure 9: PMSM drive system with online ANN for step down response from 900rpm to 600rpm

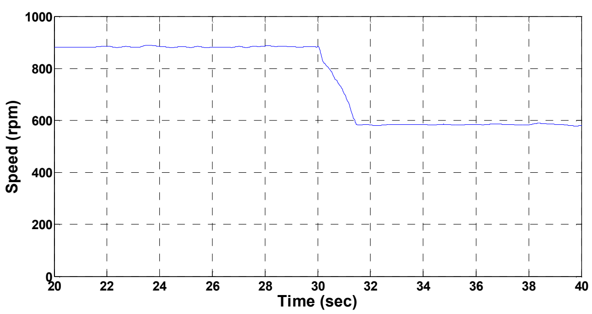

Figure 10: PMSM drive system with offline ANN for step down response from 900rpm to 600rpm

While, by referring to the Figure 9 and Figure 10, it is also shows that by using an online ANN speed controller produced a better step down performance compared to the offline ANN speed controller where the settling time more faster than offline speed controller in achieving desired output speed. Their settling time is 0.66sec and 1.46sec respectively. It is also same in speed achieving performance which is an online ANN speed controller achieved 890rpm and 590rpm from the speed reference 900rpm and 600rpm compared to offline ANN speed controller which is reduced 10rpm and 5rpm respectively from online ANN speed controller in speed achieving.Difference percentage between offline ANN and online ANN for the result of settling time is 75.47% improved and speed is 1.13% improved for 900rpm reference speed and 0.85% improved for 600rpm reference speed.

So, for the result difference percentage for constant speed 1000rpm, step up response and step down response can be conclude that by using online ANN will be 1.35% improved in average for speed achieving. While, 58.47% improved in average for settling time.

CONCLUSION

This paper has presented the modelling and hardware implementation of the field oriented control for PMSM drive system using online and offline neural network controller. The effectiveness of the proposed method is verified by develop the system in MATLAB-simulink program and experimental by using Digital Signal Processing board and interfacing DAQ with LabView software in order to recorded the result . The results show that the proposed an online ANN controller produce significant improvement control performance for controlling speed reference variations condition compared to offline ANN system especially for settling time which is 58.47% improved in average While 1.35% improved in average for speed achieving. It can conclude that by using proposed controller, the settling time and speed achieving can be improved significantly.

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