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Speed Observer Based on ICA Trained Neural Network in DTC drive of IPMSM

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Abstract
In this paper a speed observer based on Imperialist Competitive Algorithm (ICA) trained artificial neural network is presented. The proposed speed observer is used in sensorless Direct Torque Control (DTC) IPMSM drive scheme. A multilayer perception is trained using imperialist competitive algorithm to estimate the rotor speed. Due to artificial neural network characteristics the proposed speed observer works in wide range speed as opposed to previous observers that doesn't works low speed or high speeds. Since neural network is trained with ICA, optimum weights of neural network are obtained. Simulation results on different conditions show the good performance of proposed speed observer.

1- Introduction

Permanent magnet synchronous machines (PMSMs) are widely used in many industrial applications, thanks to their compact size, high efficiency, high power density, large torque to inertia ratio and absence of rotor losses [1]- [4]. These advantages make them good candidates for high-performance applications, such as electric vehicles, wind turbines and robotics [2]. Recently, sensorless PMSM drives have received increasing interest for industrial applications where there are limitations on the use of a position sensor. Furthermore, sensorless control for motor drives reduces susceptibility to noise and vibration, cost, size and maintenance while increasing the overall system's reliability and robustness when used properly.

Over the years, researchers attempted various estimation techniques. The rotor flux linkage estimation method [5], Extended Klaman filters (EKF) [6], [7], Model-based observers [8], [9] and model reference adaptive system (MRAS) observer [10] are the main estimation techniques that presented in literature. Each one of these techniques suffers from some defects such poor precision at low speed, dependency on parameters, and requirement to proper initialization, instability, etc.

On another aspect, artificial neural networks (ANNs) and fuzzy logic systems (FLSs) have been known as powerful tools capable of providing robust approximation for mathematically ill-defined systems that may be subjected to structured and unstructured uncertainties. The universal approximation theorem has been the main driving force of such methods as it shows that they are theoretically capable of uniformly approximating any continuous real function to

any degree of accuracy. Various ANNs and FLSs have been proposed for speed and position estimation and control of a PMSM, which have led to a satisfactory performance [11], [12].
Direct torque control (DTC) method is selected thanks to it is various advantages such as the elimination of coordinate transformation, lesser parameter dependence, and faster dynamic response in comparison with FOC method [1].
In this paper, we present a neural network based observer to estimate the IPMSM rotor speed. Imperialist competitive algorithm is used to calculate the optimum neural network weights. Simulation results for different condition are presented for validation of proposed speed observer.

2- IPMSM MODELING

The IPMSM dynamic mathematical model in the d-q axes rotational reference frame can be described by the following equations:

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - \omega L_d i_q \quad (1)$$

$$v_q = R_s i_d + L_q \frac{di_q}{dt} - \omega L_d i_d + \omega \lambda_f \quad (2)$$

$$T = \frac{3}{2} P\left[\lambda_f i_q + \left(L_d - L_q\right) i_d i_q\right] \quad (3)$$

The mechanical equations of motion can be expressed by:

$$\frac{d}{dt}\omega_{re} = \frac{1}{J}(T - F\omega - T_L) \quad (4)$$

$$\frac{d}{dt}\theta = \rho\omega \quad (5)$$

Where:

v_d,v_q voltage in d-q axes
i_d, i_q current in d-q axes
L_d, L_q inductance in d-q axes
R_s stator winding resistance
ρ number of pole pairs
λ_f flux linkage
T motor torque
T_L load torque
J rotor and load inertia
F friction coefficient
θ rotor angular position
ω rotor angular velocity

The model of the PMSM is developed using

MATLAB SIMULINK.

3- Imperialist Competitive Algorithm

Imperialist Competitive Algorithm (ICA) is a novel global search heuristic that uses imperialism and imperialistic competition process as a source of inspiration. This algorithm considers the imperialism as a level of human's social evolution and by mathematically modeling this complicated political and historical process, harnesses it as tool for evolutionary optimization. Since its inception this novel method has been widely adopted by researchers to solve different optimization tasks. This method is used to design optimal layout for factories, adaptive antenna arrays, intelligent recommender systems, optimal controller for industrial and chemical possesses [13]. Figure 2 shows the flowchart of the ICA.

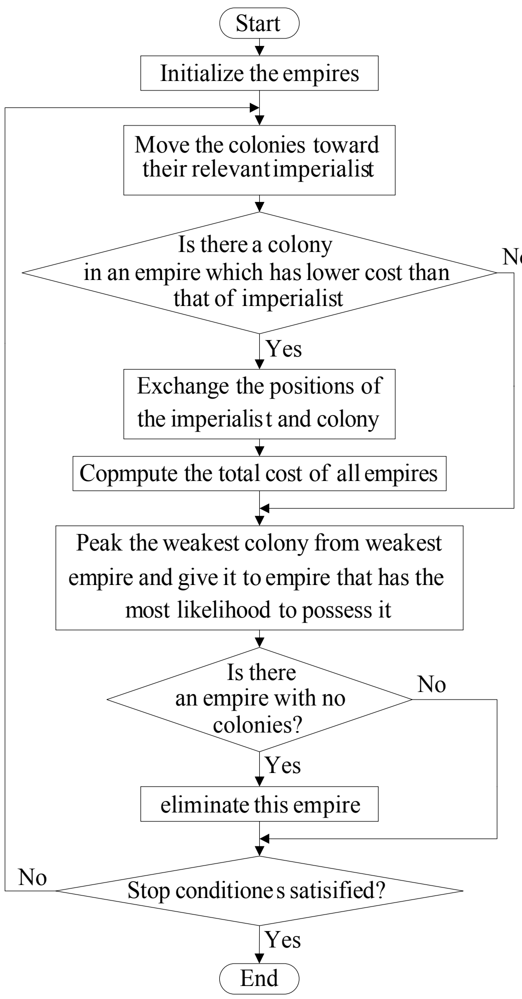

Fig.1 Flowchart of the ICA

More detailed information and mathematical formula of imperialist competitive algorithm was presented in [13] and [14].
One of the most important parts of the Evolutionary algorithms is cost or fitness functions. In this paper cost function is defined as below:

Cost= Mse (Net Out, Train Data) (6)

Mse: Mean squared error

4- Neural Network Observer

ANN shown in Fig. 2 is a multilayer feed-forward artificial neural network used for ANN based observer in the proposed work.

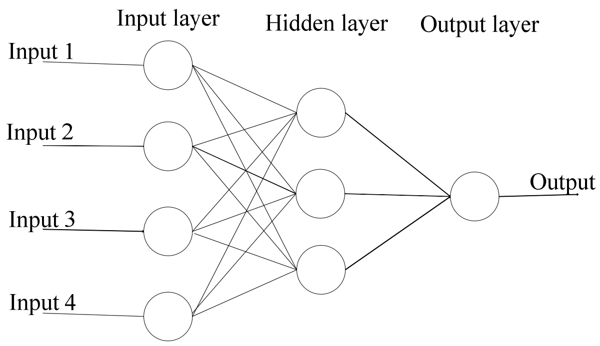

Fig.2 Multilayer feed-forward artificial neural network with one hidden layer.

There is an input layer, an output layer, and between the input and output layers there are hidden layers. In this work two hidden layers are used. In all layers there are nodes as shown in this figure there are four nodes in input layer. The numbers of nodes are same as input signals. There could be any number of hidden nodes. Finally in the output layer there is only one output node, since there is only a single output signal in ANN based observer. The input signals are direct inputs to the input nodes. All the nodes of a specific layer are connected by weights are denoted by w, and represent the strength of the connection (e.g. zero weight would mean that there is no connection). The input nodes transmit the input signal directly to the nodes in the first hidden layer as shown in Fig. 2 and the input nodes do not perform any processing.
Error Back-Propagation (BP) algorithm is educed from Gradient based methods. BP algorithms are fast but they trapped in local minimums. ICA is find the global minimum and also ICA is capable to every structure of network this means ICA unlike the gradient based method doesn't depend on network structure, however ICA it isn't fast.

5- SIMULATION RESULTS

Simulation is carried out in MATLAB/SIMULINK to study the proposed observer's performance. IPMSM parameters are summarized in Table.1 [2]. Fig.3 shows the typical DTC drive scheme. DTC drive is applied to IPMSM and required data is stored in MATLA workspace. Required data are line – line motor voltage and current as network input and motor speed as an output of network. ICA is applied to obtain optimum neural network weights (network training). To show the performance of neural network based speed observer, wide range of speed with big step changes is considered.

Table.1 Motor's Parameters

Parameter	Values
Nominal power (kW)	$P_n = 24$
Nominal torque (N.m)	$\tau_n = 416$
Nominal speed (RPM)	$w_n = 600$
Inductance in d-axis (H)	$Ld = 15.9*10^{-3}$
Inductance in q-axis (H)	$Lq = 24.88*10^{-3}$
Armature winding resistance (Ω)	$R = 361.45*10^{-3}$
Flux linkage (Wb)	$\lambda = 1.6504$
Rotor and load inertia (kg·m2)	J =1
Friction coefficient (N.m)	F =2
Number of pole pairs	p =5

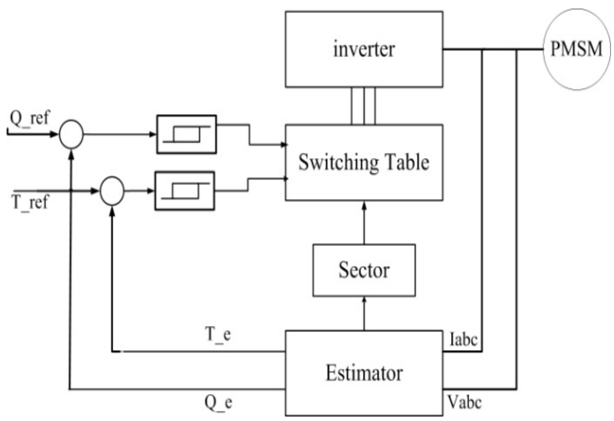

Fig.3 Block diagram of a typical DTC

In first scenario speed reference include decreasing and increasing big step change to show the precision of proposed observer. Fig.4 shows the first considered speed reference and Fig.5 shows the speed error cure.
Error is difference between speed reference and observer speed.

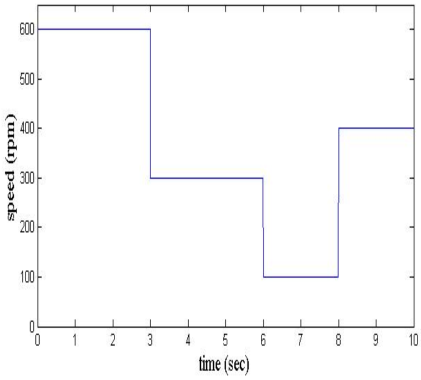

Fig.4. First considered speed reference

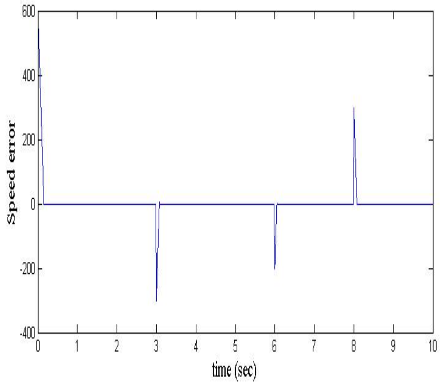

Fig.5. speed error in first scenario

In the second scenario as shown in Fig.6 speed is decreased to 4 percent of nominal speed (25 rpm) to show the performance of proposed observer in low speed condition. Motor speed is decreased from 400 rpm to 25 rpm in three steps that illustrated with numbers 1, 2, and 3 in Fig.6. Figures 7 to 9 obtained by zooming in steps changing points of Fig.6 to comparison of observer output in different speeds.
Simulation results in second scenario shows that the undershot in increased by decreasing speed (from 4 percent in point number 1 to near 7 percent in point number 3) but observer has fast respond dynamic. In appendix A output of observer, when 200 (N.m) load torque is applied at the moment of fours second, is presented

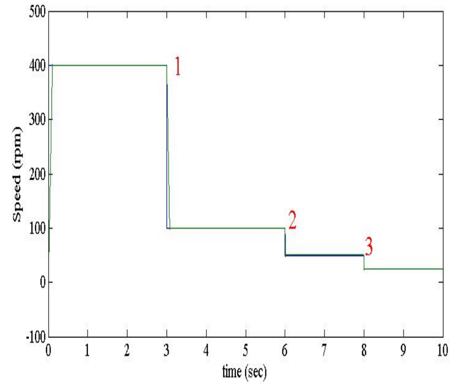

Fig.6. Second scenario's speed reference

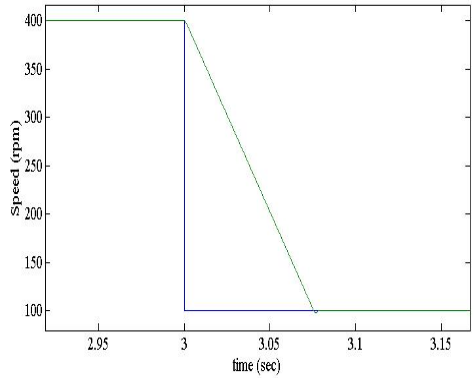

Fig.7. Zoomed in first changing point

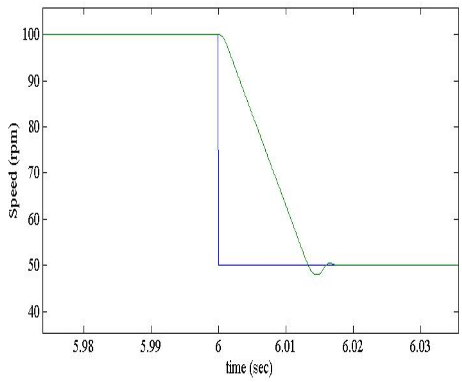

Fig.8. Zoomed in second changing point

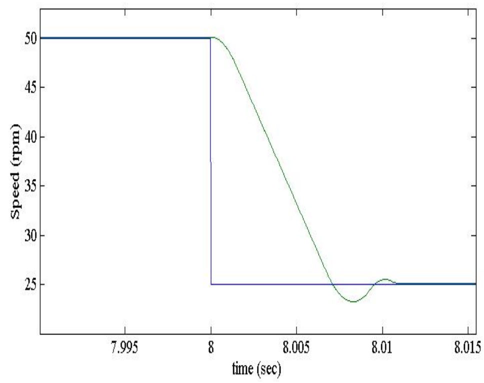

Fig.9. Zoomed in third changing point

6- CONCLUSION

In this paper a neural network based speed observer is presented. Proposed observer is fast with good precision. As opposed to conventional observers was presented in literature, that have problem in high or low speeds, this observer because of using artificial intelligence characteristics, works in wide range of speed as shown in simulation results.

Furthermore reaching to the global minimum is guaranteed by using evolutionary algorithms like ICA in neural network training problems.

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Appendix A

Performance of the observer in load disturbance is also important. So 200 (N.m) is applied at the moment of 4th second and the result is presented in Fig.10

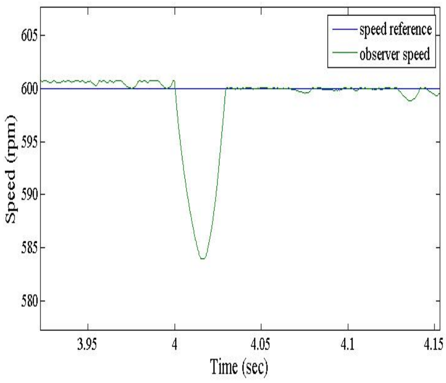

Fig.10. observer speed in load disturbance

As shown in Fig.10 proposed observer have good performance in scenario also.