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NEURO-GENETIC INPUT-OUTPUT LINEARIZATION CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

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ABSTRACT

By rapid development of semiconductor and commands strategies as vector control (VC), direct torque control (DTC) and input-output linearization (IOL) a permanent magnet synchronous motors (PMSM) have gained variety industrial applications. This paper combines the application of neuro-genetic (NG) with input-output linearization techniques to control the PMSM. The use of a genetic algorithm is particularly appropriate to find the optimal values of placing pole. The neuro space vector modulation is also used to prove more the performance of soft computing. A comparative study between intelligent VC with a proposed approach shows that not only these techniques has been improved but also IOL control reduces speed, flux and stator current ripples.

Keywords: *Permanent Magnet Synchronous Motor, Inputs-Outputs Linearization, Neuro Space Vector Modulation, Genetic Algorithm.*

1. INTRODUCTION

Permanent magnet synchronous motor (PMSM) is widely used in high performance servo applications due to their high efficiency, high power density, and large torque to inertia ratio [1], [2]. However, PMSM are nonlinear multivariable dynamic systems and, without speed sensors and under load and parameter perturbations, it is difficult to control their speed with high precision, using conventional control strategies.

The IOL control has been the advantage of being able to commands separately the currents, speed and the torque. With this technique, the model of motor is decomposed in two linear subsystems, mono independent variable. Each subsystem represents an independent loop control of a given variable. The dynamic of linearized systems is chosen an optimal imposition of the poles. But we not find usually, good parameters, of placing pole. However, intelligent control techniques as genetic algorithm can resolve this problem easily [3][4].

Recently, intelligent control, acts better than conventional adaptive controls. Artificial intelligent (AI) which is generally regarded as the aggregation of fuzzy logic control, neural network control, expert system and genetic algorithm, has exhibited particular superiorities and used widely in electrical drives [5][6].

GA is based on an analogy to the genetic code in our own deoxyribonucleic acid (DNA) structure, where its coded chromosome is composed of many genes [7][8]. GA approach involves a population of individuals represented by strings of characters or digits. Each string is, however, coded with a search point in the hyper search-space. From the evolutionary theory, only the most suited individuals in the population are likely to survive and generate offspring that passes their genetic material to the next generation [9].

This paper proposes IOL control of PMSM with GA speed controller

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simulations. The performance of this method investigated with different PMSM parameters in simulation. In order to prove the superiority of the proposed GA controller with neuro space vector modulation (NSVM), its performances are compared to those obtained by a genetic vector control [12]. The proposed method based PMSM drive is found also robust as compared to the conventional IOL based drive and it has the same result as genetic vector control, hence found suitable for high performance industrial applications.

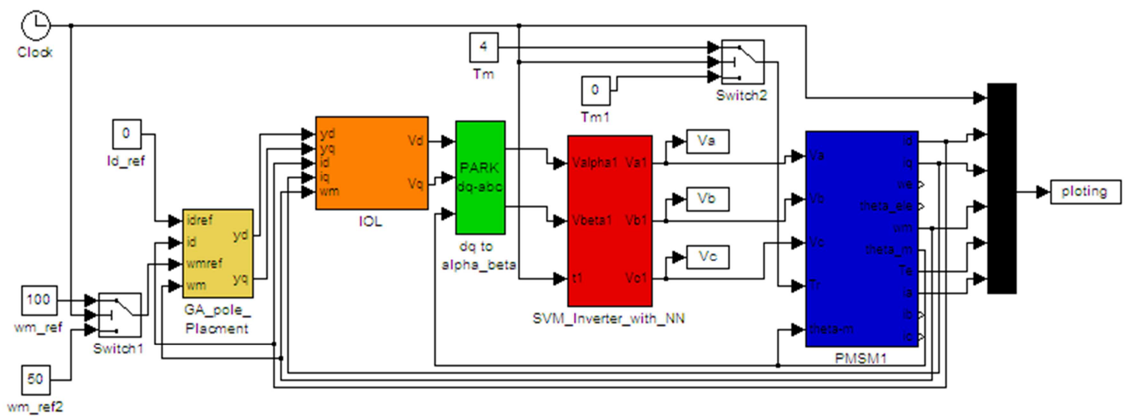
The contents of this paper are organized as follows. In section 2, the proposed method control of PMSM is implemented, analytic model of PMSM is developed in section 3, the principal of IOL and placing pole are detailed in section 4 and 5, GA and neuro selector are treated in sections 6 and 7, motor parameters and comparisons between simulation results are given and show the validity and the limits of the proposed method in sections 8. Finely section 9 concludes the paper.

The simulation method is designed with C Mex Files under Matlab/Simulink software.

2. PROPOSED METHOD CONTROL OF PMSM

Based on the theoretical statements and GA controller with NSVM, the intelligent control structure of a PMSM drive system with IOL control shall now be looked at in some more detail in figure 1. The rotor speed ω_m is compared with the reference speed. The resulting error is processed in the GA speed controller for each sampling interval.

The neuro selector calculates the S_a, S_b and S_c from U_α, U_β outputs of input-output linearization block and time t. After processing the well known of inverter, the stator voltage is finally applied on the motor terminals with respect to amplitude and phase.



SIMULATION SCHEME OF INPUT-OUTPUT FEEDBACK LINEARIZATION CONTROL

3. MATHEMATICAL MODEL OF PMSM

By developing the coupled three-phase mathematical model of PMSM, the (dq) axis current, voltage and flux will be obtained from two transformations. The first part transfers the three phases (abc) to two phases (αβ) .The second part is the quantities at stationary to rotational frame (dq).

Then electromechanical behavior of the PMSM in the (dq) frame is expressed with the following equations [12]:

$$U_d = Ri_d - \omega_r \lambda_q + \frac{d\lambda_d}{dt}$$

(1) $$U_q = Ri_q + \omega_r \lambda_d + \frac{d\lambda_q}{dt}$$

(2) $$\lambda_d = L_d i_d + \lambda_m$$

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

(4) $$T_e = \frac{3}{2} p\left(\lambda_m i_q + \left(L_d - L_q\right) i_d i_q\right)$$

(5) $$\frac{d\omega_r}{dt} = \frac{p}{J}\left(T_e - B\omega_r - T_m\right)$$

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(6) $\omega_r = p\omega_m$

(7)

Where

U_d :	Direct -axis stator voltages;
U_q :	Quadrature -axis stator voltage;
i_d :	Direct -axis stator current;
i_q :	Quadrature- axis stator current;
L_d :	Direct- axis stator inductance;
L_q :	Quadrature- axis stator inductance;
λ_d :	Direct-axis stator flux;
λ_q :	Quadrature-axis stator flux;
p :	Number of poles;
R :	Stator resistance;
λ_m :	Rotor magnet flux linkage;
ω_m :	Electrical rotor speed;
ω_r :	Mechanical rotor speed;
f :	Viscous friction coefficient;
T_m :	Load torque;
T_e :	Load torque;
J :	Moment of Inertia.

4. PRINCIPLE OF INPUT-OUTPUT LINEARIZATION

The concept of input-output linearization is now very known. Several references which describe the manner of applying it are now available [3][4]. We will show how to obtain a linear relation between the output y and a new input v, by carrying out a good choice of the linearizing law.

The condition of linearization that allows to checking if a nonlinear system admits input-output linearization is the order of the system degree. We deriving i_d and ω_m by the time, until the reveal of the U_d and/or U_q we obtain:

$$\dot{y}_1 = L_f h_1(x) + L_{g1} h_1(x) U_d + L_{g2} h_1(x) U_q = \frac{\partial h_1}{\partial x}.f(x) + \frac{\partial h_1}{\partial x}.g_1(x).U_d + \frac{\partial h_1}{\partial x}.g_2(x).U_q$$

(8)

$$= -\frac{R}{L_d} i_d + \frac{L_q}{L_d} p\omega_r i_q + \frac{1}{L_d} U_d$$

Then, the relative degree of y_1 is $r_1 = 1$.

$$\dot{y}_2 = \frac{3p}{2J}\left(\varphi_v i_q + \left(L_d - L_q\right)\right) i_d i_q - \frac{f}{J}\omega_r$$

(9)

We see that the derivative of the second output $y_2 = \omega_m$ does not utilize the input U_d and U_q Thus it is necessary to derive another time this output.

$$\ddot{y}_2 = L_f^2 h_2(x) + L_{g1}\left(L_f h_2(x)\right).U_d + L_{g2}\left(L_f h_2(x)\right).U_q$$
$$= \Lambda\left(L_d - L_q\right) i_q f_1(x) + \Lambda\left(\varphi_v + \left(L_d - L_q\right) i_d\right) f_2(x) - \frac{f}{J} f_3(x) + \frac{\Lambda\left(L_d - L_q\right)}{L_d} i_q U_d + \frac{\Lambda\left(\varphi_v + \left(L_d - L_q\right) i_d\right)}{L_d} U_q$$

(10)

With:

$$\Lambda = \frac{3p}{2J}$$

(11)

Then the relative degree of y_2 is $r_2 = 2$. The relative degree of the system is: $r_1 + r_2 = 3$ However, the system is exactly linearizable $r = n = 3$, or n is the order of the PMSM system.

With:

$$f(x) = \begin{bmatrix} f_1(x) \\ f_2(x) \\ f_3(x) \end{bmatrix} = \begin{bmatrix} -\frac{R}{L_d} i_d + \frac{L_q}{L_d} p\omega_r i_q \\ -\frac{R}{L_q} i_q + \frac{L_d}{L_q} p\omega_r i_d - \frac{\varphi_v}{L_q} p\omega_r \\ \frac{3p}{2J}\left(\varphi_v i_q + \left(L_d - L_q\right)\right) i_d i_q - \frac{f}{J}\omega_r \end{bmatrix}$$

(12)

And

$$g_1(x) = \begin{bmatrix} \frac{1}{L_d} \\ 0 \\ 0 \end{bmatrix}, \quad g_2(x) = \begin{bmatrix} 0 \\ \frac{1}{L_q} \\ 0 \end{bmatrix}$$

(13)

Finally, the relation input-output of the model is given by the following expression:

$$[\dot{y}_1 \;\; \ddot{y}_2]^T = \boldsymbol{\xi}(x) + D(x).U$$

(14)

Where:

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$$\xi(x) = \begin{bmatrix} L_f h_1(x) \\ L_f^2 h_2(x) \end{bmatrix} = \begin{bmatrix} -\frac{R}{L_d} i_d + \frac{L_q}{L_d} p\omega_r i_q \\ \Lambda(L_d - L_q) i_q f_1(x) + \Lambda(\varphi_v + (L_d - L_q) i_d) f_2(x) - \frac{f}{J} f_3(x) \end{bmatrix}$$

And

$$D(x) = \begin{bmatrix} \frac{1}{L_d} & 0 \\ \frac{\Lambda(L_d - L_q)}{L_d} . i_q & \frac{\Lambda(\varphi_v + (L_d - L_q).i_d)}{L_q} \end{bmatrix}$$

(16)

If the determinant of the matrix $D(x)$ is non null, the NL input output control is defined by a relation who connects the new internal inputs v_1 and v_2 with physical inputs U_d and U_q as follow:

$$\begin{bmatrix} U_d \\ U_q \end{bmatrix} = D(x)^{-1} \left(\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} - \xi(x) \right)$$

(17)

5. PLACING POLE

To impose the static mode and a dynamics on the error, the internal inputs are calculated by the following expression [15].

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} k_d.(i_{dref} - i_d) \\ \ddot{\omega}_{ref} + k_{w2}(\dot{\omega}_{ref} - \omega_r) + k_{w2}(\omega_{ref} - \omega_r) \end{bmatrix}$$

(18)

But if the imposed trajectory is a level (constant), then

$\dot{\omega}_{ref} = \ddot{\omega}_{ref} = 0$ and the expression (18) becomes:

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} k_d.(i_{dref} - i_d) \\ -k_{w1}.\dot{\omega}_r + k_{w2}(\omega_{ref} - \omega_r) \end{bmatrix}$$

(19)

In closed loop, the tracking error is:

$$\begin{cases} e_{id} = i_{dref} - i_d \\ e_\omega = \omega_{ref} - \omega_r \end{cases}$$

(20)

With: e_ω, e_{i_d}, are the errors of reference trajectories. By passing in the plan of Laplace, the system (19) becomes:

$$\begin{cases} s + k_d = 0 \\ s^2 + k_{\omega 1}.s + k_{\omega 2} = 0 \end{cases}$$

(21)

Finally we find the values of k_d, $k_{\omega 1}$ and $k_{\omega 2}$, by resolving the system (21). But we not find exact values, because this method is based on mathematical equation. However we use genetic algorithm to optimize k_d, $k_{\omega 1}$ and $k_{\omega 2}$.

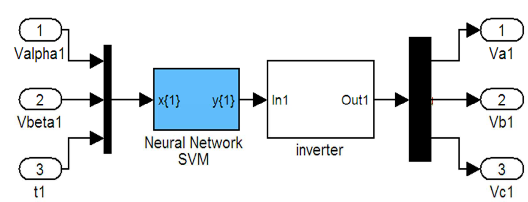
6. NEURO SPACE VECTOR MODULATION

The Neural network (NN) is the most generic form of Artificial Intelligence (AI) for emulating the human thinking process, is particularly suitable for solving many important problems as SVM. The NN uses a dense inter connection of computing nodes to approximate nonlinear function [13].

Using a general flowchart for neural network and the parameters presented in table 2.

Parameters	Value
Training Algorithm	Backpropagation
Input layer	3 neurons
Hidden layer	15 tansig neuron
Output layer	3 purelin neuron

The neural network voltage selector is illustrated by figure 2.



NEURAL NETWORK VOLTAGE SELECTOR

7. GENETIC ALGORITHM

Figure 3 shows the flowchart of GA [12]. In order to design a placing pole controller with the system (21) a genetic algorithm is employed to optimize K_d, $K_{\omega 1}$ and $K_{\omega 2}$, of control process. The configuration of genetic algorithm parameters used in this paper is given in Table 1.

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Table 1. GA Parameters.

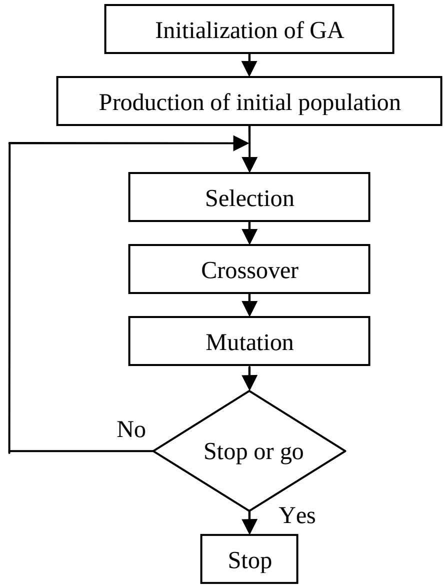
Parameters	Value
Crossover probability	0,95
Mutation probability	0,001
Generation number Population	100
Population	80
Chromosome length	24 bit

The fitness function of each individual of this study is expressed by the equation (10):

$$fitness = 1/(MO + 2 * ST + 1) \quad (10)$$

Where:

MO: represents the overshot and;
ST: represents the settling time.



GA FLOWCHART

8. PARAMETERS OF PMSM AND SIMULATION RESULT

The following table represents the parameters of PMSM:

Table 2. Parameters of PMSM

Parameter	**Value**	**Unit**
Stator resistance. R	1.4	Ω
d-axis inductance.	6.6	mH
q-axis inductance.	5.8	mH
Magnetic flux constant	0.1546	Wb
Friction coefficient.	0.00038	$N \cdot m \cdot rad^{-1} \cdot s^{-1}$
Motor inertia.	0.00176	$Kg \cdot m^2$

The neuro genetic NG-IOL control of PMSM is done using Matlab/Simulink. And results are discussed and compared with classical IOL and genetic vector control [12].

Figure 4 illustrates the simulation results of technical command, where a reference speed equal to (+100,-50rad /s) and stator current $i_d = 0A$. It is noted that the proposed IOL has a high dynamic without overshoot, start-up, the response time are reduced as in [12] with genetic vector control and the harmonic ripples is reduced also compared to classical control that presents large harmonic ripples.

At the moment t=0.5s we have applied 4N.m load torque to PMSM, the results of simulation are satisfactory and the robustness of this Neuro GA IOL is guaranteed as genetic vector control. We always see that the control suggested more powerful than the classical method

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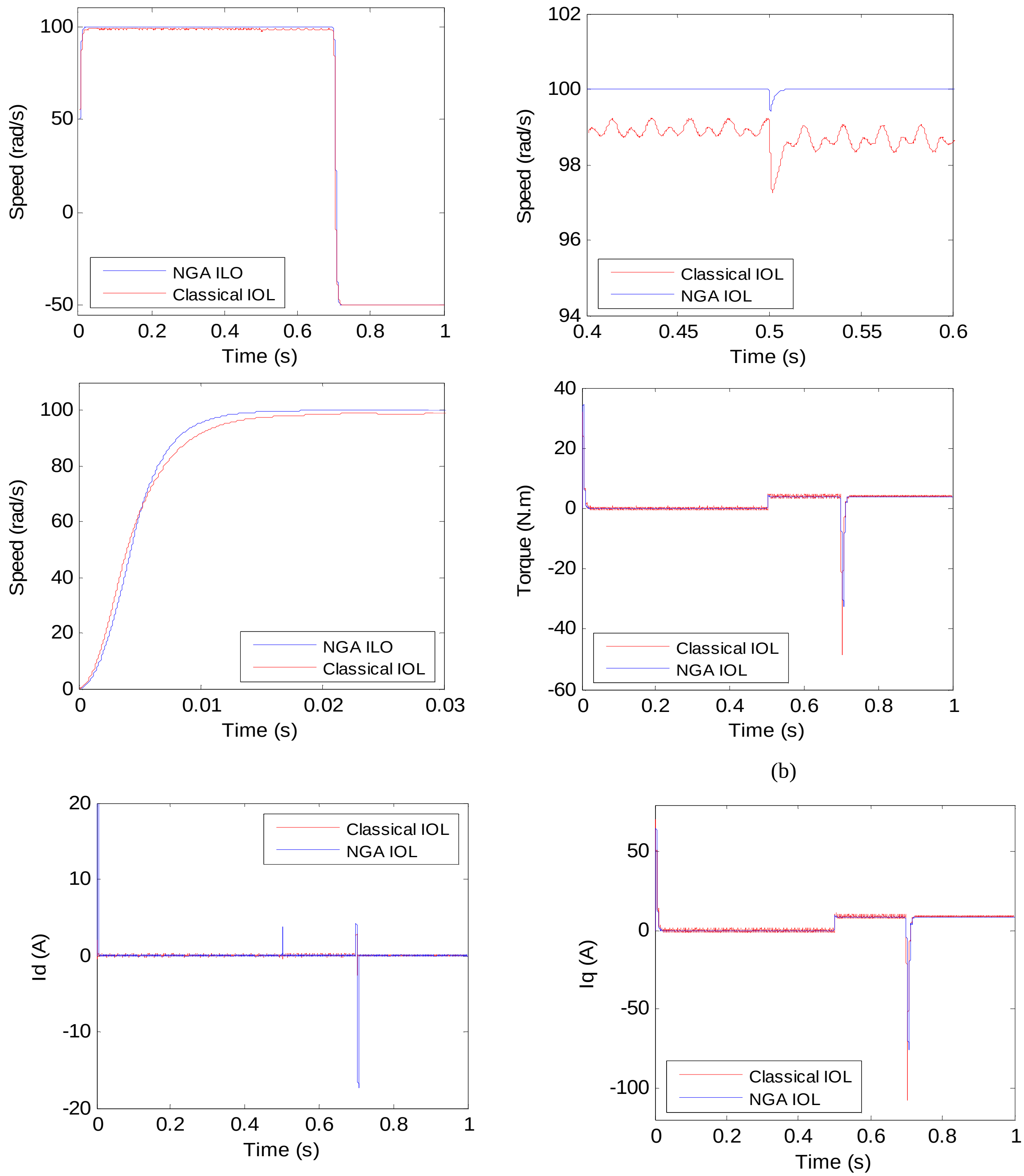

Figures (a) (b) (c) (d) (e) (f)

***SIMULATED* SPEED, TORQUE AND (DQ) CURRENTS RESPONSES OF THE *PMSM* DRIVE WITH *NEURO GA IOL* AND *CLASSICAL IOL* FOR A +100,-50 SPEED REFERENCE WITH A FIXED CHARGE OF *4N*.M:**

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The figures below (4-e and f) shows clearly that the evolution of d-q axis currents in the presence of a disturbance load torque flow the desired value without oscillation ripples present a little pike when we reverse the sense of rotation.

9. CONCLUSIONS

A method of input-output linearization control genetic placing pole and neural space vector modulation has been proposed and used for the control of a PMSM.

The simulation results shown with Matlab/Simulink® in this proposed study prove the superiority of soft computing to control non linear systems. In contrast to classical control we show that the soft computing control is designed without mathematical model. The NGA IOL technique gives better performances in elimination of the stator current harmonics and reduction of the torque ripple while maintaining the other characteristic of the system.

The future work will develop a sensorless input output linearizing control with observer which will eliminate speed sensor.

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