Optimized DTC by Genetic Speed Controller and Inverter Based Neural Networks SVM for PMSM

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ABSTRACT: *A optimized speed controller for permanent magnet synchronous motor (PMSM) is investigated in this paper, in which genetic algorithm (GA), direct torque control (DTC) concept, and neural networks space vector modulation (NNSVM) are integrated to achieve high performance for speed and torque responses. A GA is integrated to optimize the proportional integral (PI) controller. While NNSVM is contributed to reduce more the ripples of mechanical speed and torque of PMSM, like that combination elements of artificial intelligence, proposed control reacts as, ensemble of intelligent human is gathered to solve a mathematical or physical problem in a little time than one of them. Simulation results show that the proposed controller provides high-performance dynamic characteristics and is robust with regard to plant parameter variations. Furthermore, comparing with the other controller, the harmonic ripples is much reduced by the proposed controller.*

Keywords: Magnet Synchronous Motor, Direct Torque Control, Space Vector Modulation

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1. Introduction

In the past, discontinuous current (DC) motors were used extensively in areas where variable speed operation was required, since their flux and torque could be controlled easily by the field and armature current. However, DC motors have certain disadvantages, which are due to the existence of the commutator and the brushes, that is, they require periodic maintenance, and they have limited commutator capability under high-speed, high-voltage operational conditions. These problems can be overcome by the combination of rapid development of semiconductors, microprocessors and control technology of alternative current (AC) motor. Now PMSM has become a leading in the industrials applications because it has simple and rugged structure, high maintainability and economy, it is also robust and immune to heavy overloading, etc [1]. Its small dimension compared with DC motors allows PMSM motor to be used widely in industrials applications.

Direct torque control method is one of the newest control systems for PMSM based on vector control of electric motors [2]. This method was invented originally for induction motor (IM) by Takahashi [3] and Depenbrock [4] in 1986 and 1988 respectively, and then a lot of improvements over their proposed method have been made by other researchers for PMSM. The DTC of a PMSM motor involves the direct and independent control of the flux linkage and electromagnetic torque, by applying optimum current or voltage switching vectors to the converter.

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, genetic algorithm and expert system, has exhibited particular superiorities and used widely in electrical drives [5], [6]. [7] implemented a neural-network based space-vector PWM controller for three-level voltage fed inverter induction motor drive, where [8] presents excitation control of synchronous machine using polynomial neural networks. A single neuron PID controller based PMSM DTC drive system fed by fault tolerant 4-switch 3-phase inverter is treated in [9], while [10] presents a neuro-fuzzy controller for speed control of a permanent magnet synchronous motor drive. Others studies have suggested the application of the techniques of artificial intelligence (AI) to control speed loop of AC motors as ones of them PMSM [11], [12].

This paper proposes optimized DTC with genetic controller for PMSM fed by neural networks SVM. In order to prove the superiority of the proposed GA controller with neuro selector, its performances are compared to those obtained by a conventional PI [4]. The proposed method based PMSM drive is found to be more robust as compared to the conventional PI based drive and hence found suitable for high performance industrial applications. The contents of this paper are organized as follows. In section II, analytic model of PMSM is developed, in section III the proposed method control of PMSM is implemented, the principal of neuro selector and GA controller are treated in sections IV and V respectively, motor parameters and comparisons between simulation results are given and show the validity and the limits of the proposed method in sections VI. Finely section VII concludes the paper.

2. Mathematical Model of PMSM

By developing the coupled three-phase mathematical model of PMSM, the (*dq*) axis of current, voltage and flux will be obtained from two transformations. The first part transfers the three phases (*abc*) to two phases ($\alpha\beta$). The second part is the quantities at stationary to rotational frame (*dq*). Electromechanical behavior of the PMSM in the (*dq*) frame is as follows [13], [14]:

$$V_d = Ri_d - \omega_r \lambda_q + \frac{d\lambda_d}{dt}, \tag{1}$$

$$V_d = Ri_q + \omega_r \lambda_d + \frac{d\lambda_q}{dt}, \tag{2}$$

$$\lambda_d = L_d i_d + \lambda_m, \tag{3}$$

$$\lambda_q = L_q i_q, \tag{4}$$

$$T_e = \frac{3}{2}(\lambda_m i_q + (L_d - L_q)\, i_d i_q), \tag{5}$$

$$\frac{d\omega_r}{dt} = \frac{p}{J}(T_e - B\omega_r - T_m), \tag{6}$$

$$\omega_r = p\omega_m \tag{7}$$

Where R represents resistance, θ represents the rotor position, V_d and V_q represent stator voltage at rotational reference frame, i_d and i_q represent direct and quadrature stator currents, ω_r and ω_m represent electrical and mechanical rotor speed, λ_d and λ_q represent stator flux at rotational reference frame, λ_m represents stator flux linkages due to the permanent magnet, T_e represents electrical torque, p represents the number of pole pairs, J represents rotor inertia, B represents friction T_m represents mechanical load torque,and L_d, L_q represent stator inductance.

3. Proposed DTC With Soft-Computing

Based on the theoretical statements and GA controller with neuro SVM selector, the intelligent control structure of a PMSM drive system with DTC shall now be looked at in some more detail in Figure 1.

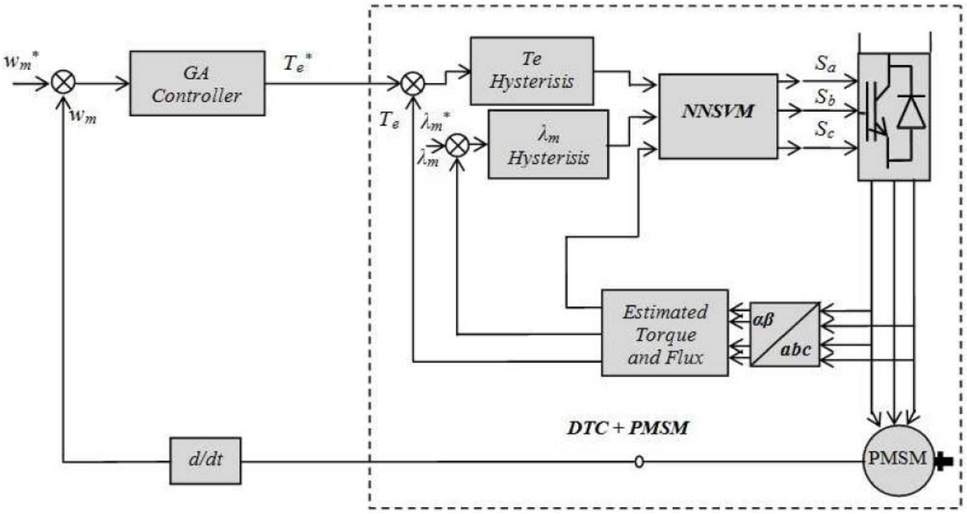


Figure 1. Block diagram of the optimized DTC with genetic controller and NNSVM for PMSM

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 output of this is considered to be the reference torque. Then the neuro selector calculates the S_a, S_b and S_c from the outputs of hysteresis comparators H_T, H_λ and the sector S. After processing the well known of inverter, the stator voltage is finally applied on the motor terminals with respect to amplitude and phase.

4. Neural Networks 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. The neural network selector inputs proposed are the position of stator flux vector represented by the number of the corresponding sector, the error between its estimated value and the reference value and the difference between the estimated electromagnetic torque and the torque reference that is to say three neurons of the input layer Fig. 4, [15]. Using a general flowchart for neural networks with backpropagation (BP) training algorithm, and after several tests the architecture 3-17-3 with tansig hidden layer and purelin output layer is established to illustrate the neural network voltage selector Figure 4.

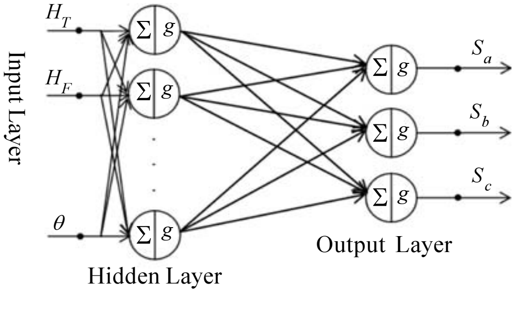


Figure 2. Architecture of NNSVM

5. Genetic Algorithm

Genetic algorithms are collections of modeling, search, and optimization methods inspired by evolutionary biology. GA are based on an analogy to the genetic code in our own deoxyribonucleic acid (DNA) structure, where its coded chromosome is composed of many genes [12], [16], [17]. 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. GA is a search mechanism based on the principle of natural selection and population genetics that are transformed by three genetic operators: selection, crossover and mutation. Each string (chromosome) is a possible solution to the problem being optimized and each bit (or group of bits) represents a value or some variable of the problem (gene). The general flowchart of GA is shown in Figure 3.

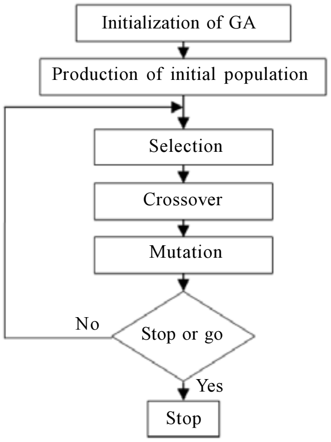


Figure 3. Genetic algorithm flowchart

The fitness of each individual is calculated with the expression in Equation (8), [18].

$$fitness = \frac{1}{MO + ST + 1} \tag{8}$$

MO represents the overshot and *ST* is the settling time. In this paper we are using the genetic optimization with the parameters presented in the Table 1.

Parameter	Value
Crossover probability	0,85
Mutation probability	0,001
Generation number Population	100
Population	80
Chromosome length	24 bit

Table 1. GA Paremeters

4. Simulations

4.1 Motor parameters

Table 2. presents the parameters of PMSM.

Features	Values	Units
Stator resistance	1.4	Ω
d-axis inductance	6.6	$m\,H$
q-axis inductance	5.8	$m\,H$
Magnetic flux constant	0.1546	Wb
Friction coefficient	0.00038	$N.m.rad^{-1}s^{-1}$
Motor inertia	0.00176	$Kg.m^2$

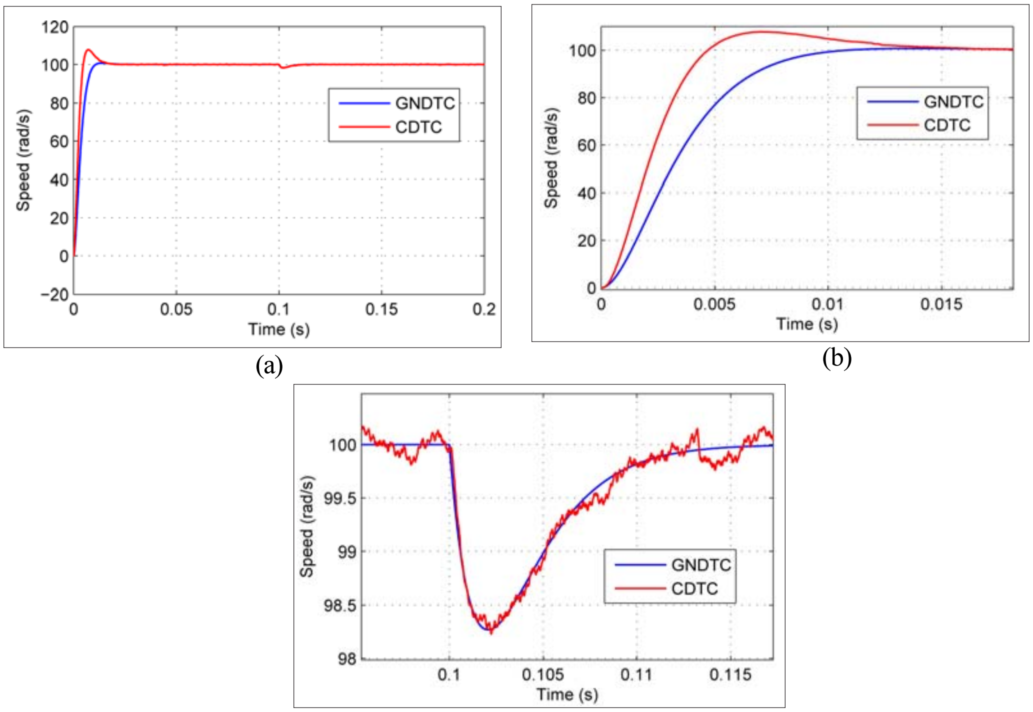
Table 2. Parmeters of PMSM

4.2 Results and discussion

The optimized DTC with GA speed controller for PMSM fed by inverter based NNSVM is done using Matlab/Simulink. Results are discussed and compared with classical DTC. Figure 4-a,b,c illustrate the simulation results of mechanical speed, while Figure 5 and Figure 6 represent the simulation of flux and torque, where a reference speed equal to +100 rad /s and stator flux equal to 0.3128 Wb.

It is noted that the classical DTC presents a large overshoot speed with harmonic ripples, and we can see that the proposed DTC has a high dynamic without overshoot, start-up, the response time is reduced compared to the classical DTC and the harmonic ripples is reduced also, as showed the zooms in Figure 4-b,c.

At the moment $t = 0.1$s we have applied load torque (T_m = 4N.m) to PMSM, the results of simulation are satisfactory and the robustness of this optimized genetic neural networks DTC is guaranteed more than the conventional DTC. Figure 4-c, shows zoom of speed response where the load torque applied.



(a) (b)

(c)

Figure 4. Simulated speed, responses of the PMSM drive with classical and optimized controllers for a +100 rad/s speed reference with fixed charge 4N.m

Figure 5 point the difference between proposed and classical direct torque control (CDTC) control, where oscillations of CDTC are remarkable compared to genetic neural direct torque control (GNDTC) flux response in alpha-beta space.

Figure 6 show torque response in this case for the PI controller and GNDTC. As seen from the figures, overshoot and oscillation exist in the torque curves for PI controller more and more than this presented from GNDTC. Finally we can say that the simulation results indicated by the proposed GNDTC is less sensitive to the parameter variations and external load disturbances than its of the conventional PI controller.

7. Conclusion

In this paper, an optimized genetic neural networks DTC for PMSM drive system is presented. A three layer NN is used to adjust input and output parameters of SVM. Simulation results indicate that the proposed controller is reliable, effective in the speed control of the PMSM with various working conditions. The results also show that the optimized genetic neural control is able to tract the reference speed closely with almost no overshoots and oscillations.

Our future research work is to develop and improve other intelligent techniques such as the fusion of neural network with fuzzy

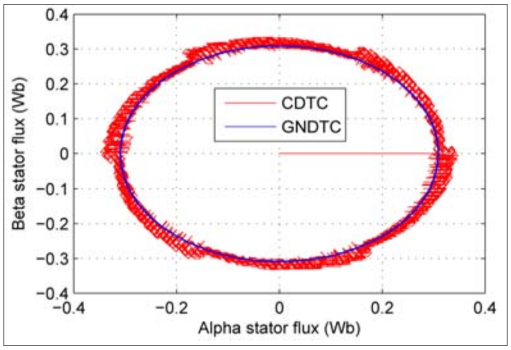


Figure 5. Simulated flux in Alpha-Beta space

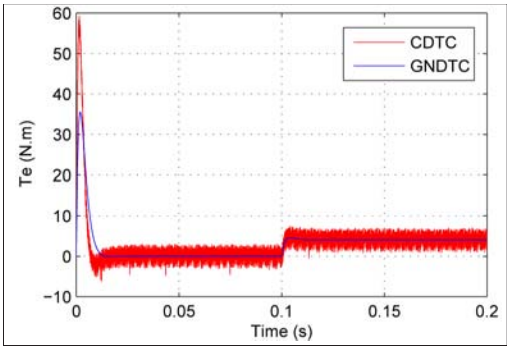


Figure 6. Response simulation of electrical torque

logic by using the genetic algorithms to reduce more the speed ripple of the PMSM. We will work also about other algorithm to train the neural network.

References

[1] Peter Vas. (1998). *Sensorless Vector and Direct Torque Control*, Oxford university press.

[2] Lamchich, M. T. (2011). *Torque Control*, Janeza Trdine 9, 51000 Rijeka, Croatia.

[3] Hasanien, H. M. (2010). Torque ripple minimization of permanent magnet synchronous motor using digital observer controller, *Energ. Convers. Manag.*, 51, 98-104.

[4] Maiti, S., Chakraborty, C., Sengupta, S. (2009). Simulation studies on model reference adaptive controller based speed estimation technique for the vector controlled permanent magnet synchronous motor drive, *Simul. Model. Pract. Th.*, 17, 585-596.

[5] Hazzabl, A., Bousserhanel, K., Sicard, P. (2006). Fuzzy Soft-Switching Law of an Adaptive Sliding Mode Controller for Induction Motor Speed Control, *In*: *Proc. IEEE ISIE*, July, 1, 9-12.

[6] Bouafia, A., Krim, F., Gaubert, J. P. (2009). Fuzzy-Logic-Based Switching State Selection for Direct Power Control of Three-Phase PWM Rectifier, *IEEE Tans. Ind. Electronics*, 56, 1984-1992, Jun.

[7] Mondal, S. K., Pinto, J. O. P., Bimal K. Bose. (2002). A Neural-Network-Based Space-Vector PWM Controller for a Three-Level Voltage-Fed Inverter Induction Motor Drive, *IEEE Tans. Ind. Appl.*, 38, 660-669, May/Jun.

[8] Karnavas, Y. L., Papadopoulos, D. P. (2004). Excitation control of synchronous machine using polynomial neural networks, *Journal of Electrical Engineering*, 55, 169-179.

[9] Sun, D., Meng, J. (2006). A Single Neuron PID Controller Based PMSM DTC Drive System Fed by Fault Tolerant 4-Switch 3-Phase Inverter, *In*: *Proc. Ind. Electr. and Applicat.*, p. 1-5.

[10] Elmas, C., Ustun, O., Sayan, H. H. (2008). A neuro-fuzzy controller for speed control of a permanent magnet synchronous motor drive, *Expert Sys. Appl.*, p. 657-664.

[11] KC, N., Murray-Smith, L.Y., DJ, KC, S. (1995). Genetic algorithms applied to fuzzy sliding mode controller design, *In*: *Proc. first IEE/IEEE Intl. Conf on Genetic Algorithms in Eng. Syst.*, p. 220-225.

[12] Dahidah, M., Agelidis Vassilios, G., Rao Machavaram, V. (2008). Hybrid genetic algorithm approach for selective harmonic control, *Energy Convers Manage.*, 49, 131-42.

[13] El Janati El Idrissi, A., Zahid, N. (2011). GA speed and dq currents control of PMSM with vector control based space vector modulation using matlab/simulink, *Journal of Theoretical and Applied Information Technology*, 30, 1-9.

[14] El Janati El Idrissi, A., Zahid, N., Jedra, M. (2012). Neuro direct torque control of permanent magnet synchronous motor with genetic algorithm speed controller, *Journal of Theoretical and Applied Information Technology*, 35, 1-6.

[15] Bimal K. Bose. (2002). *Modern Power Electronics and AC Drives*, Prentice Hall PTR, Upper Saddle River, NJ 07458.

[16] Goldberg DE. (1989). *Genetic algorithms in search, optimization, and machine learning*, Reading, MA: Addison-Wesley.

[17] Haupt, R. L., Haupt, S. E. (2004). *Practical Genetic Algorithms*, A. John WILEY&SONS, INC. Publication.

[18] Vakkas, S., Metin Demirtas, U. (2009). Modeling and control of V/f controlled induction motor using genetic-ANFIS algorithm, *Energ. Convers. Manag.,* 50, 786-791.