Genetic Algorithm Tuned PI Controller on PMSM Direct Torque Control

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ABSTRACT

This paper presents the Direct Torque Control (DTC) strategy for the Permanent Magnets Synchronous Machine (PMSM) with tuning the PI controller by using genetic algorithms to ensure optimal performance it allows reducing the ripples of the torque and flux. A genetic algorithm is used to optimize the gains of the PI controller forgiven the reference of the torque. Simulation results verified the performance of the proposed approach. The simulations result of this technique is justified the minimization the ripples of switching in the inverter and reduces the harmonious of the torque and the stator current.

I. Introduction

Permanent Magnet Synchronous Machines (PMSMs) are widely used in many industrial production systems and attractive candidates for high-performance applications due to their high efficiency, high torque mass ratio, and ease to be controlled [1,2] PMSMs are mainly applied when the system requires fast torque response and best performance such as in the wind power industry, especially for direct-driven wind turbine applications, due to capability of multiple-pole design [3], and railway traction application, in order to achieve the PMSM start-up at standstill or at very low speeds [4]. Many studies have been developed to find out different solutions for reducing the complexity of Filed Oriented Control (FOC), several approaches are used, such as the Direct Torque Control (DTC) strategy that is insensitive to the motor parameters variation [5, 6]. The DTC was proposed by Takahashi and Depenbrock in the middle of the 1980s, for driving the induction motors [4,5]. the application of DTC to permanent magnet synchronous machines (PMSMs) was presented in the late 1990s [7]. The DTC control is based on an appropriate choice of voltage vector generated by the inverter. It has several advantages compared to other conventional techniques, such as a fast dynamic torque, robustness with respect to parameter variations, a simple control with low-cost computing efforts because it does not need the complex coordinate transformation, and the possibility to control the torque independently from the flux, the rotor position sensor is not required, reduced computations. [8,9,10,11,6]. The DTC, however; has the inherent problem of varying switching frequency with constant hysteresis bands, which is undesired for some applications [12]. This problem of the DTC control has generated some new research interests in the field of electrical drives. In particular, several techniques have been carried out to reduce the flux and torque ripples released by an inverter. A popular solution is to increase the number of available voltage vectors, following that idea, a multilevel inverter, and a discrete space vector modulation (DSVM) technique which divided each control period into three intervals, or using fairly low sampling frequencies [13]. Other researches have focused on Space Vector Modulation (SVM) to achieve constant switching frequency while obtaining the desired torque and stator flux in one control period by synthesizing a suitable voltage vector through SVM [7,14], or using the DTC-SVM with a sliding mode control [15]. On other hands, there exist a solution based on the technique of artificial intelligence such as Artificial Neural Network (ANN) in [14], Fuzzy Logic Controller (FLC) in [16], Particle Swarm Optimization (PSO) and Genetic Algorithms (GA). The controller PI is used to control the speed due to simple structure; however, tuning the accurate parameters of PI controller is a hard task, where these parameters are necessary to improve the performance of the DTC control. To enhance the issue of conventional PI parameter tuning techniques many research has been suggested as Particle Swarm Optimization (PSO) and Genetic Algorithms (GA). This work proposes to control the speed of a PI controller optimized by using the Genetic Algorithms (GA) to provide the performances of direct torque control. GA is general-purpose optimization techniques that use a direct analogy of natural evolution where stronger individuals would likely be the winners in a competing environment. Efficacy of GA as an optimization tool has already been observed in process control [14]. In this work, GA is used to optimize the motor's speed for minimized the ripple of the torque and the flux. This paper is organized as follows. In section II, PMSM is presented. Section III, describes the principle of DTC. In section IV, the implementation of a genetic algorithm (GA) is used in tuning the PI controller parameters of speed. In Section V, simulation results and discussion are presented. Conclusions are summed up in the last section;

II. PMSM Modeling

The continuous time model for PMSM in the d-q coordinate system can be described as:
Currents equations [14]:

$$\begin{cases} \dfrac{di_d}{dt} = \dfrac{1}{L_d}(u_d - R_s i_d + \omega\, L_d i_q) \\ \dfrac{di_q}{dt} = \dfrac{1}{L_q}(u_q - R_s i_q + \omega\, L_q i_d - \omega\, \varphi_f) \end{cases} \tag{1}$$

Stator flux equations:

$$\begin{aligned} \varphi_d &= L_d i_d + \varphi_f \\ \varphi_q &= L_q i_q \end{aligned} \tag{2}$$

Electromagnetic Torque equation:

$$T_{em} = \frac{3}{2} p\left[\left(\varphi_f i_q + (L_d - L_q)\right) i_d i_q\right] \tag{3}$$

The mechanical equation

$$J \frac{d}{dt}\Omega + f\Omega = T_{em} - T_r \tag{4}$$

where R_s is stator resistance, i_d *and* i_q *are* stator currents in d-q coordinate system , v_d *and* v_q *are* stator voltages in d and q axis-components, φ_d , φ_q are stator flux, ω is the angular speed, L_d and L_q are direct-axis, and quadrature-axis inductance, φ_f is permanents magnet flux, and Ω, C_r, f, and J are the speed, load torque, and friction coefficient, and moment of inertia respectively.

III. Principle of DTC

The block diagram of the classical DTC of a PMSM scheme is shown in Fig.1.The basic idea of DTC is to control the electromagnetic torque and the stator flux by selecting one of the voltage vectors generated by a VSI in order to maintain flux and torque within the limits of two hysteresis bands and the right selection of the voltages vector allows a decoupled control for both the flux and the torque without d-q coordinate transformation [15]. The estimated electromagnetic torque and the stator flux are compared with their desired values respectively shown in fig1. The stator flux and torque errors generated by hysteresis comparators are used to deliver the appropriate voltage vector based on the position of stator flux from switching table.

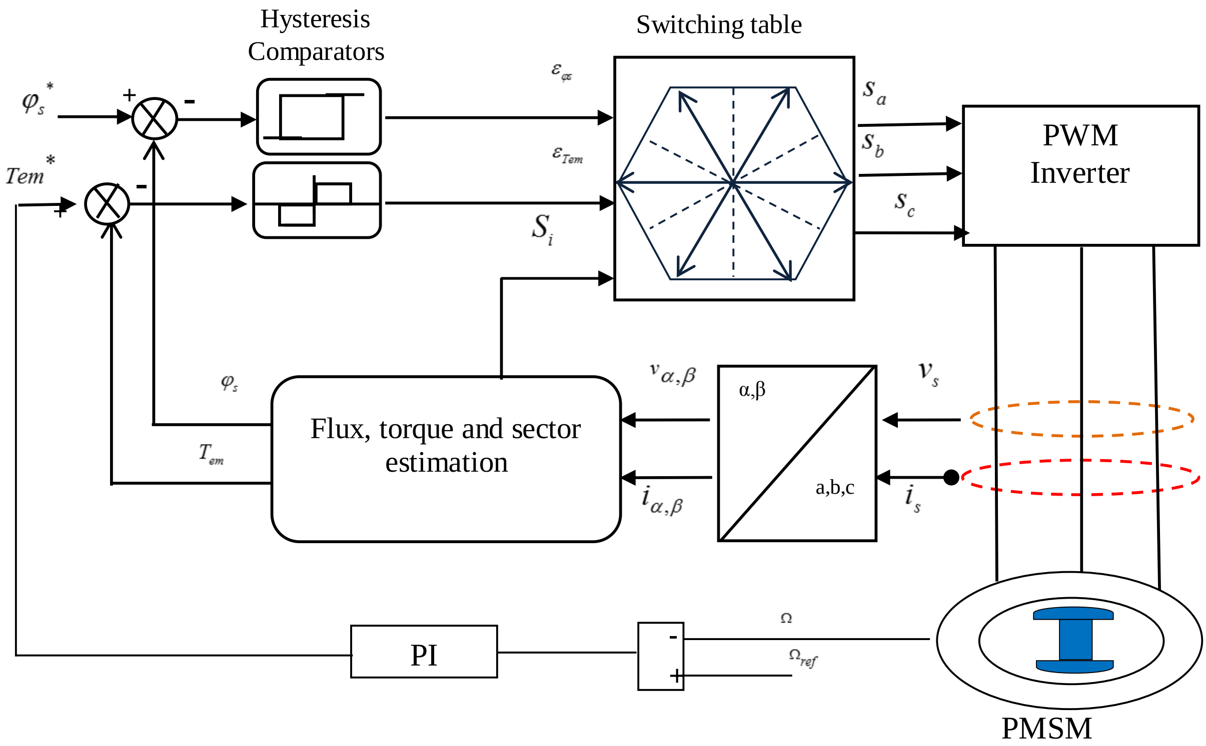

Fig.

Fig;1. The general structure of classic DTC

The voltage vector of the PWM inverter V_s can be defined by three inverter switching states S_1, S_2 and S_3 and the DC linkage V_{DC} as:

$$V_s = \sqrt{\frac{2}{3}} V_{DC} \left[S_1 + S_2 e^{j2\pi/3} + S_3 e^{j4\pi/3} \right] \tag{5}$$

The stator flux can be expressed as:

$$\varphi_s(t) = \int_0^t (\bar{V}_s - R_s \bar{I}_s) dt \tag{6}$$

The magnitude of stator flux linkage given by:

$$\varphi_s = \sqrt{(\varphi_{s\alpha})^2 + (\varphi_{s\beta})^2} \tag{7}$$

If the voltage drop across the stator resistance is neglected Eq.(6) yields:

$$\varphi_s(t) \approx \varphi_{s0} + \int_0^t V_s dt \tag{8}$$

With φ_{s0} is the initial value of the stator flux.

Eq. (8) could be written in the discrete form as follows:

$$\varphi_{sk+1} - \varphi_{sk} \approx V_{sk} T_s \tag{9}$$

Where T_s is the sampling time.
This relation means that if the sampling period is constant, the stator flux variation can be directly adjusted by the voltage vector applied to the machine. In the case of the PMSM, the stator flux changes even if we apply a zero voltage when magnets turn with the rotor. Consequently, the non-null voltage vectors are not used in the control of the flux.
The electromagnetic torque is proportional to the vectors of the stator flux and the rotor flux according to the following expression:

$$T_{em} = \frac{P}{L_d} \varphi_S . \varphi_f . \sin \gamma \tag{10}$$

With γ is the angle between φ_s and φ_f .
From this expression, if we maintain the flux constant we can directly control the torque by changing the angle.

The voltage space vector angle is represented in a frame on Fig. 3 and separated in 6 sectors with an index 'k' with k=1,2, 6. When the vector flux is in a sector ' k ', then the control of the flux and the torque is assured by selecting one of the four non-zero voltage vectors (V_1 to V_6) or one of the two zero vectors V_0 or V_7 [16,8]. The role of the selected voltage vector is presented in fig.3.

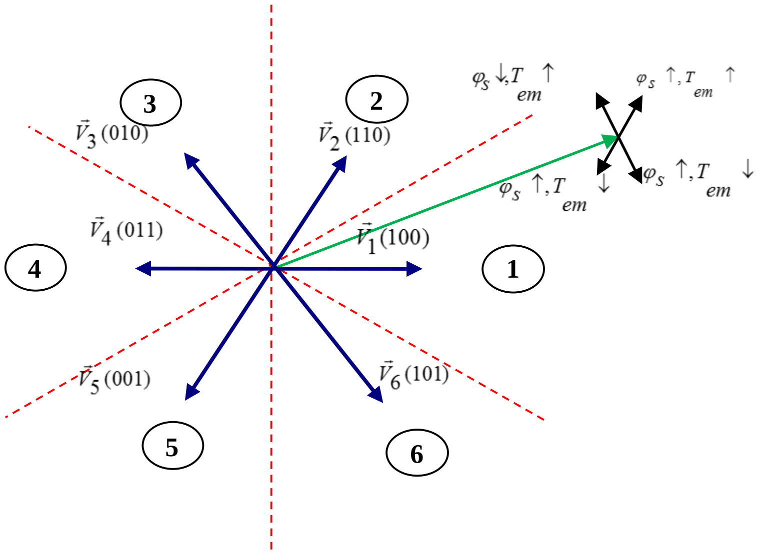

Fig. 2. The voltage space vector angle for flux and torque command

The selected voltage vector is depended with the both hysteresis controllers' outputs ($\varepsilon_{\varphi s}, \varepsilon_{Tem}$) and the sector ($S_i$) of the stator flux. Generally, the stator flux is located in one of the k^{th} sector. The selection of voltage vectors V_{k+1} and V_{k+2} should increase the torque and the vectors V_{k-1} and V_{k-2} should decrease it. In addition, the application of V_{k+1} and V_{k-1}should increase the stator flux, and V_{k+2} and V_{k-2} should decrease it. The application of the zero voltage (V_0, V_7) kept the torque in the hysteresis bands [14,17]. The switching table for all the different is shown by Table 1.

Table 1. Switching table of the classic DTC

$\varepsilon_{\varphi s}$	1			0		
ε_{Tem}	**1**	**0**	**-1**	**1**	**0**	**-1**
Sector 1	V_2	V_7	V_6	V_3	V_0	V_5
Sector 2	V_3	V_0	V_1	V_4	V_7	V_6
Sector 3	V_4	V_7	V_2	V_5	V_0	V_1
Sector 4	V_5	V_0	V_3	V_6	V_7	V_2
Sector 5	V_6	V_7	V_4	V_1	V_0	V_3
Sector 6	V_1	V_0	V_5	V_2	V_7	V_4

IV. PI Controller Tuning Using GA

Gienetic Algorithm (GA) is a stochastic optimization technique based on the mechanisms of natural selection. Compared with other optimization techniques GA is superior in avoiding local minima which is a common aspect of nonlinear systems. In addition, GA is a derivative-free optimization technique that makes it more attractive for applications that involve nonsmooth or noisy signals. Generally, GA consists of three main stages; selection, crossover and mutation [21].

- Selection stage: The target of this operation is to obtain a mating pool with the fittest individuals selected according to a probabilistic rule that allows these individuals to be mated into the new population.
- Crossover stage: this operation is used to generate new individuals or offsprings which acquire good features from their parents.
- Mutation stage: represent the last step of the GA that introduces a change in the offspring bit string to generate new chromosomes which may well solve the problem and at the same time avoid the population falling into a local optimal point.

The strategy of GA based on:

- Create initial population
- Evaluate fitness value for each chromosome.
- Perform selection, crossover and mutation process.
- Test the max generation or min performance index reached.

V. Results and Simulation

The simulations result of the proposed direct torque of the PMSM motor with the PI controller optimized by GA are presented in fig4.

Fig. 4-a. Show the rotor speed range of PMSM, the machine starts at t=0.22s from the value the reference (0) until t=0.25s achieves the value of speed (100rad/s) by slowly crossing, and follows the reference without errors in the both states transit and steady.

Fig. 4-b presented the electromagnetic torque, where the torque follows the reference value quickly without any errors, and the ripples torque are reduced into the comparison with the classical DTC.

Fig. -c illustrated the current, in this figure the current ripples are reduced but the commutation frequency is not controlled.

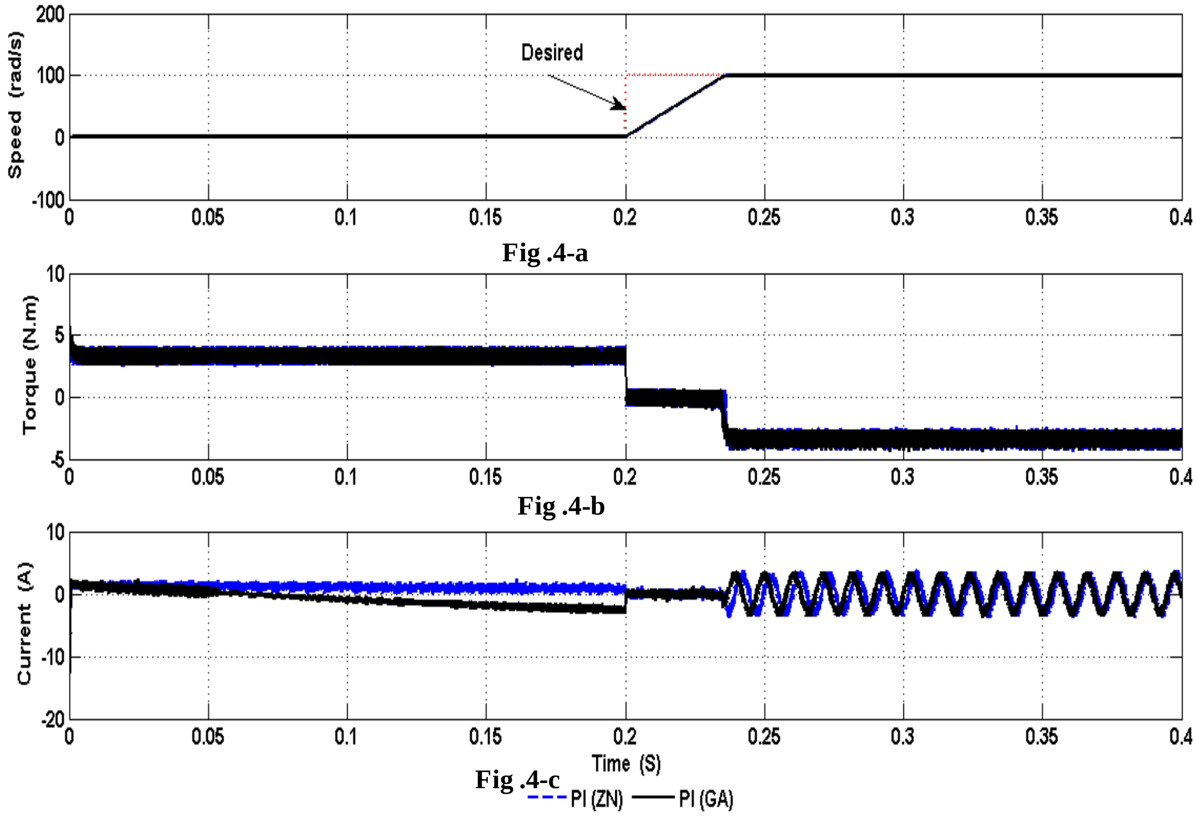

Fig.4 The results of the control DTC-GA

On the other hand, Table II, establishes the GA tuning PI speed controller, with the parameters. The GA method with the technique found the "optimum" gains is achieved the values Kp = 1.23129615, Ki = 0.73455084 and J=142.946447.

Table 2. The parameters of GA tuning PI speed controller

	GA			
	IAE	ISE	ITAE	ITSE
K_p	0.61544707	0.68335393	1.23129615	0.61544707
K_i	0.38069398	0.71847131	0.73455084	0.38069398
J	57946.5886	1205298.65	142.946447	66667.5722
Time (min)	23.75605	23.7602833	24.0023167	23.8325
OS (%)	0.04979467	0.04872401	0.07113588	0.04979467
ST (s)	9.80235721	9.80521777	9.77498048	9.80235721

From simulation results, we find the controller PI tuning parameters by using GA give the better performance for instance the torque and current ripples are reduced.

VI. Conclusion

In this paper, the strategy for the speed controller in DTC of PMSM motor is presented, PI controller tuned by a genetic algorithm, for reducing the ripple of the torque and current. The simulations result of this technique is justified the minimization the ripples of switching in the inverter and reduces the harmonious of the torque and the stator current.

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