A non-linear backstepping control of Permanent Magnet Synchronous Motor (PMSM)

Ben Achour *Hafid*[1], Ziani *Said*[2], El Hassouani *Youssef*[1]

[1]Department of Physic, Faculty of Science and Technology Errachidia, Moulay Ismail University, BP-509 Boutalamine Errachidia 52 000, Morocco
[2]Laboratory of Networks, computer Science, Telecommunication, Multimedia (RITM), Department of Electrical Engineering, High School of Technology ESTC, Hassan II University, Casablanca, Morocco

Abstract. in the industry, the permanent magnet synchronous motors are one of the most widely used motors and have superior performance compared to the other types of motors. The principal objective of this paper is to ameliorate the performance of PMSMs by implementing a robust non-linear backstepping control. The first part deals with the vector control of mechanical sensors using PI controller. In the second part, we shed the light on the non-linear backstepping control, using Lyapunov function, of PMSM from the point of view of stability and robustness. The results are validated by MALTAB/SIMULINK. The results obtained show the good stability and good dynamic of PMSM's control by backstepping controller, also the PI is very sensitive to parameter's machine variation compared with the backstepping controller.

1 Introduction

Due to its simplicity and performance, the permanent magnet synchronous machine among the most used machines in different fields and industry. For this reason, the current scientific research converges on the control of the asynchronous machine. The classical PI controller is the most used technique because it is applicable and simple to implement, but this technique is not satisfactory because of the non-linearity of the PMSM [1]. This is why we have decided to develop different non-linear techniques more advanced that ensures the stability and robustness of the system. Among these methods we quote backstepping, artificial intelligent and sliding mode control [2, 3, 4].
The present work highlighted the application of the PI controller and the backstepping control to PMSM. The latter controller presents a promising alternative to control methods for nonlinear systems, to ensure the control by the backstepping, it is necessary to combine the choice of the function of Lyapunov with that of the control laws [5]. this allows us to guarantee the global stability of the system at any time, and thus to ensure a good regulation and setpoint tracking [6].

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

2 Mathematical model of PMSM

The mathematical model of the Permanent Magnet Synchronous Motor in the d-q reference frame is described as the next form [7].

$$\begin{cases} \frac{d_{id}}{dt} = -\frac{R_s}{L_d} i_d + p\frac{L_q}{L_d}\Omega i_q + \frac{v_d}{L_d} \\ \frac{d_{iq}}{dt} = -\frac{R_s}{L_q} i_q - p\frac{L_d}{L_q}\Omega i_d - p\frac{\Omega\varphi_f}{L_q} + \frac{v_q}{L_q} \\ \frac{d\Omega}{dt} = \frac{p}{J}\left(L_d - L_q\right) i_d i_q - \frac{f}{J}\Omega + \frac{P}{J}\varphi_f i_q - \frac{C_r}{J} \end{cases} \tag{1}$$

Where : L_d,L_q: direct, quadrature axis self-inductance (H); R_s : Stator resistance (Ω); φ_f : Mutual flux due to permanent magnetic (Wb); Ω : Angle speed (rad/s); θ : the position of the rotor; J : inertia moment (kg.m2); i_d,i_q: direct, quadrature axis currents (A); f : damping constant (N/rad/s; C_r: load torque (N.m);); p : Number of pole pairs.

3 The PMSM's field-oriented control

We get the PMSM with a surface mounted PMSM, L_d=L_q, in the field vector control we set the i_d current to zero in order to have an optimal linearization of the torque, so:

$$i_d=0 \quad ; \quad i_q=i_s \quad ; \varphi_d = \varphi_f \tag{2}$$

The electromagnetic torque is given by the follows form:

$$C_e = \frac{3}{2}\varphi_f i_q = K_f i_q \tag{3}$$

4 The PMSM's PI controller law

The law of the PI controller is:

$$u(t) = K_p e(t) + K_i \int e(t) \tag{4}$$

We can define the regulator parameters for i_d and i_q by

$$k_{id} = \frac{{R_s}^2}{L_d} ; k_{pd} = k_{id}.T_{ds} \tag{5}$$

$$k_{iq} = \frac{{R_s}^2}{L_q} ; k_{pq} = k_{iq}.T_{qs} \tag{6}$$

For the speed we have:

$$K_i = J{\omega_0}^2 ; K_p = 2J\omega_0 - f \tag{7}$$

5 Backstepping design

5.1 i_d current control

The control law of backstepping for i_d current is:

$$v_{d,ref} = L_d\left[k_d e_d + i_{d,ref} + \frac{R_s}{L_d} i_d - p\frac{L_q}{L_d}\Omega i_q\right] \tag{8}$$

5.2 Speed control

The control law of backstepping for the speed current is:

$$i_{q,ref} = \frac{J}{p\varphi_f}\left[\dot{\Omega}^* + \frac{C_r}{J} + \frac{f}{J}\Omega + K_\Omega e_\Omega\right] \tag{9}$$

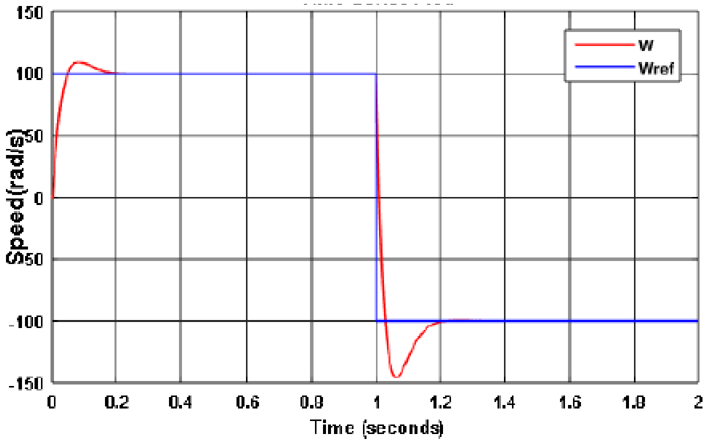
5.3 i_q current Control

The control law of backstepping for i_q current is:

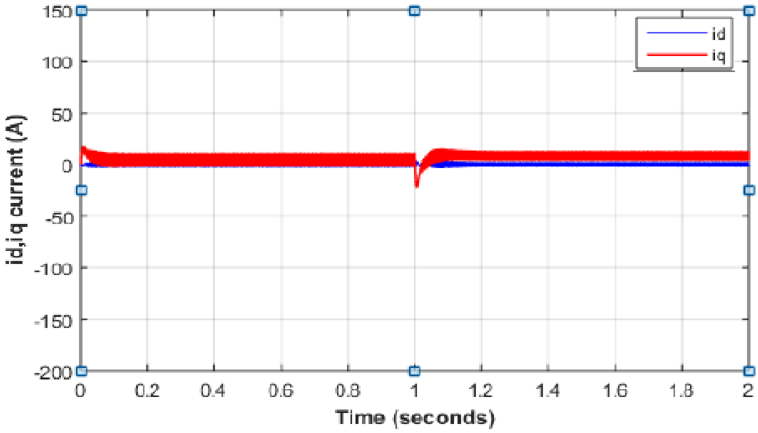
$$v_{q,ref} = L_q\left[K_q e_q + \dot{\iota}_{q,ref} + \frac{R_s}{L_q} i_q + \frac{p\Omega}{L_q}\left(L_d i_d + \frac{\varphi_f}{L_q}\right)\right] \tag{10}$$

6 Simulation results

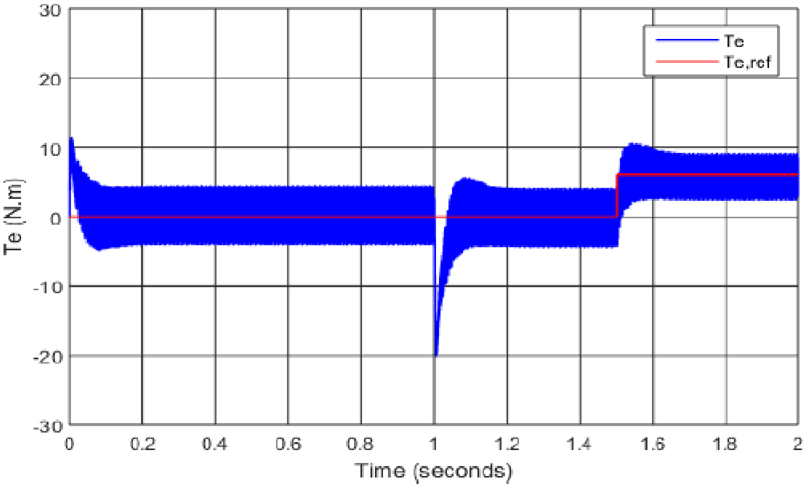
The figures 1.a, 1.b and 1.c represent the results of PI controller of PMSM, since the figure 2.a, 2.b and 2.c show the those of backstepping controller.



(a)

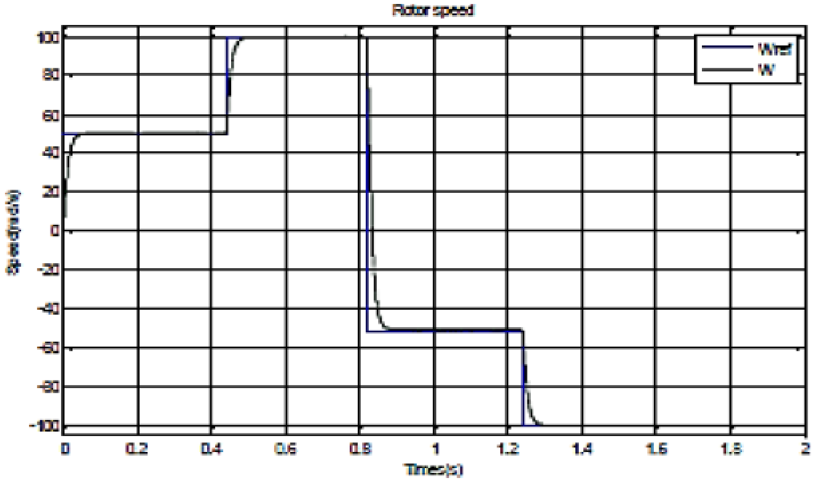


(b)

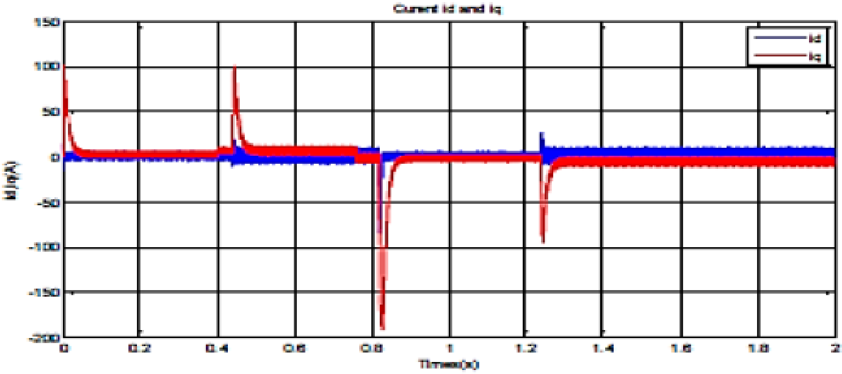


(c)

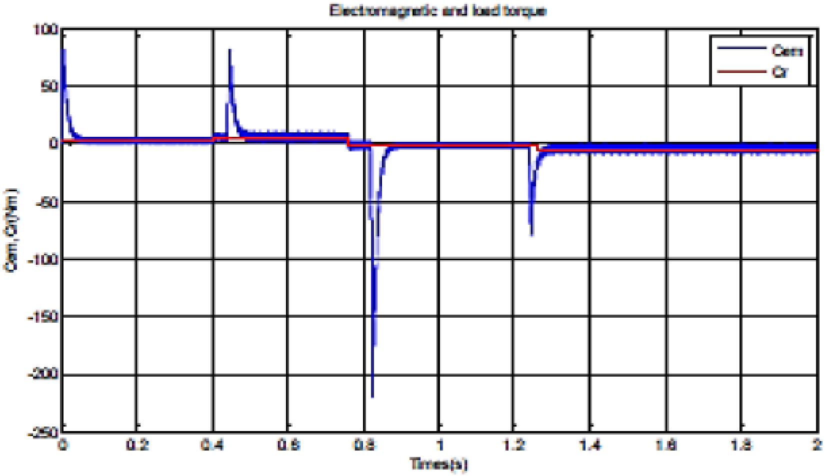
Fig. 1. (a) the speed, (b) id,iq currents and (c) torque with speed inversion at 1s and load torque at 1.5s.



(a)



(b)



(c)

Fig. 1. (a) the speed, (b) id,iq currents and (c) torque with speed inversion and load torque variation.

7 Discussion

The figure 1.a shows that an overshoot in speed tracking for PMSM's PI controller. when we applied the load, the speed decreased, and we observe a high value for id current. The electromechanically torque compensates the applied load with an exceed value of the torque (1.c). For the speed inversion the figure (1.b) shows that in the moment of the inversion of speed the iq current and the torque make a high drop. When the parameter's machine varies effects on the iq current and on the torque.

The figure 2 (a, b et c) illustrate that for the backstepping controller, the speed reaches the speed tracking with a fast response time and without the exceeding, the same when we inverse the speed. The backstepping controller assure a good speed dynamics and disturbance's rejection. an instantaneous increase in the torque to compensate for the load applied at that moment. The id and iq currents stator's characteristics at the start-up the machine lead to a high current afterwards then we observe a decrease as the machine has the normal operating regime. The decoupling that we introduce in this controller technique (id=0) applied of PMSM illustrated by the iq and id currents.

8 Conclusion

In this work we present the PMSM's vector control based by the classical PI controller. The analysis of the robustness of this controller shows that is not robust to the parameter's machine variation and to disturbances. To have a satisfactory result for PI controller, it is necessary to ensure the elimination of disturbances and the variation of the machine parameters.

The Backstepping controller, is a nonlinear controller that current research is converging on. It based on a recent methodology using the Lyapunov function, proposed in this paper to improve the PMSM's control. According the results obtained we conclude that this controller has a good robustness to parameter's variation and disturbances compared with a PI controller. The synthesis of this nonlinear controller led to the globally asymptotically stability.

References

1. Hafid Ben Achour, Said Ziani, Youssef Chaou, Youssef El Hassouani, Abdelkarim Daoudia, "Permanent Magnet Synchronous Motor PMSM Control by Combining Vector and PI Controller," WSEAS Transactions on Systems and Control, vol. 17, pp. 244-249, 2022
2. Youssef Chaou, Said Ziani, Hafid Ben Achour, Abdelkarim Daoudia, "Nonlinear Control of the Permanent Magnet Synchronous Motor PMSM using Backstepping Method," WSEAS Transactions on Systems and Control, vol. 17, pp. 56-61, 2022
3. L. Weijie, L. Dongliang, W. Qiuxuan and Z. Xiaodan, "On Sliding Mode Control of Permanent Magnet Synchronous Motor," The 26th Chinese Control and Decision Conference (2014 CCDC), Changsha, China, 2014, pp. 4555-4559, doi: 10.1109/CCDC.2014.6852985.
4. Huixian, L.; Shihua, L. Speed Control for PMSM Servo System Using Predictive Functional Control and Extended State Observer. IEEE Trans. Ind. Electron. 2012, 59, 1171–1183.
5. J. W. Lau, "Adaptive backstepping based nonlinear control of an interior permanent magnet synchronous motor drive," 2005.
6. J. Zhou and Y. Wang, "Real-time nonlinear adaptive backstepping speed control for a PM synchronous motor," Control Engineering Practice, vol. 13, pp. 1259-1269, 2005.
7. K. B. Bimal, Modern Power Electronics and AC Drives, Beijing: Machine Press, 2006.