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Original article

Nonlinear adaptive observer for sensorless passive control of permanent magnet synchronous motor

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A B S T R A C T

This paper presents an adaptive nonlinear observer for sensorless passivity based control applied to permanent magnet synchronous motor. The passivity based control approach is applied to a complex and coupled nonlinear mathematical model of permanent magnet synchronous motor without any approximation or cancellation of nonlinearities.

A nonlinear adaptive observer is proposed to estimate the mechanical speed and the unmeasured load torque (unknown disturbance) that has an effect on the control performance; therefore, those estimated states are then used to improve the performance of the passivity based control for permanent magnet synchronous motor.

The performance of the proposed controller-observer have been tested using MATLAB/SIMULINK, where those Simulation results show a perfect tracking of the mechanical speed and load torque.

1. Introduction

The permanent magnet synchronous motor has been widely used for industrial applications due to its simplicity, robustness and low cost; however, the permanent magnet synchronous motor (PMSM) is described by a nonlinear coupled and complex mathematical model; which is a challenging task for control engineering.

Many control techniques have been studied and applied to drive the permanent magnet synchronous machine, such as: Feedback linearization control, sliding mode control, adaptive control, backstepping control, passivity based control…

The passivity based control term was introduced in (Ortega & Spong, 1988), which was inspired from three proposed control laws that are applied to a robot manipulator (Paden & Panja, 1988; Slotine & Li, 1991; Takegaki & Arimoto, 1981). The passivity based control (PBC) was applied to dynamical systems that could be modeled using Euler-Lagrange, such as permanent magnet synchronous motor (PMSM) in (Romeo, Antonio, Per, & Hebertt, 1998). Hence the passivity based control technique has been used to enhance the performance of the permanent magnet synchronous motor such as: passivity based voltage control (PBVC) (Achour, 2011), passivity based current control PBCC (Achour, Mendil, Bacha, & Munteanu, 2009), passivity based control with flux orientation (Belabbes, et al., 2009) and interconnection and damping assignment passivity (IDA-passivity) (Khanchoul, et al., 2014; Petrovic, Ortega, & Stankovic, 2001). Therefore, different strategies of the passivity based control combined with other control techniques have been applied to drive the PMSM such as: integral action control (Zhuang & Huang, 2017), sliding mode control (Yang et al., 2018), backstepping control (Belabbes & Larbaoui, 2015), adaptive control (Liu et al., 2014) and Fuzzy sliding mode (Shen & Ji, 2007).

In this work, the passivity based voltage control is applied to drive the PMSM, the PBC is based on the energy that links the input and output of the system. In order to construct such controller the model of the system should be modeled using Euler Lagrange method.

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The contribution in this work is based on the following two points:

- The passivity based control of the permanent synchronous motor is affected by the variation of the unknown and unmeasured load torque (input disturbance); therefore, the load torque has to be estimated to hence the performance of the motor.
- The unmeasured machine states as well as the parametric variation have a direct influence on the control performance.

A nonlinear adaptive observer is proposed to overcome the aforementioned points, which is used to estimate the unmeasured mechanical speed and the load torque of the PMSM.

2. PMSM modelling

Euler Lagrange method is used to construct the passivity based controller for permanent magnet synchronous motor.

2.1. Euler-Lagrange model of PMSM

The Lagrangian function is given by (Dong-lian, Jia-jun, & Guang-zhou, 2005):

$$L(q_m, \dot{q}_m, \dot{q}_e) = \underbrace{\frac{1}{2}\dot{q}_e^T D_e(pq_m)\dot{q}_e \varphi_f^T(pq_m)\dot{q}_m}_{\text{electrical co - energy}} + \underbrace{\frac{1}{2}D_m\dot{q}_m^2}_{\text{mechanical co - energy}} \quad (1)$$

The equations of motion of the machine are obtained by applying the Euler-Lagrange method (Achour, 2009; Mansouri, et al., 2004; Mocanu & Onea, 2018):

$$D_e(pq_m)\ddot{q}_e + W_1(pq_m)p\dot{q}_m\dot{q}_e + W_2(pq_m)p\dot{q}_m + R_e\dot{q}_e = M_e.U \quad (2)$$

$$D_m\ddot{q}_m + R_m\dot{q}_m = \tau - \tau_l \quad (3)$$

$$\tau = \frac{1}{2}\dot{q}_e^T W_1(pq_m)\dot{q}_e + W_2^T(pq_m)\dot{q}_e \quad (4)$$

where:

- $\dot{q}_m$ the mechanical speed
- q_m the rotor position
- $\dot{q}_e$ currents vector
- p the number of poles pairs
- $R_e = \mathrm{diag}\{R_s, R_s\}$
- $U = [U_\alpha U_\beta]^T$
- $D_e = \mathrm{diag}\{L_d, L_q\}$
- L_d: Longitudinal inductance
- L_q : Cross inductance
- R_s: Stator resistor.
- D_m moment of inertia
- R_m friction coefficient
- τ electromagnetic torque
- τ_l load torque
- $W_1(pq_m) = \frac{\partial D_e(pq_m)}{\partial(pq_m)}$
- $W_2(pq_m) = \frac{\partial\varphi_f(pq_m)}{\partial(pq_m)} = \phi_f\begin{bmatrix} -\sin(pq_m) \\ \cos(pq_m)\end{bmatrix}$
- ϕ_f : Flux of the permanent magnets

Since the PMSM has a smooth poles ($L_d = L_q$) then $D_e(pq_m)$ is a diagonal matrix with a constant elements, and therefore $W_1(pq_m) = 0$

Thus the differential equations that describe the smooth poles PMSM in αβ reference frame are given by (Achour, 2009; Dong-lian et al., 2005):

$$L_d\ddot{q}_\alpha - \phi_f\sin(pq_m)p\dot{q}_m + R_s\dot{q}_\alpha = U_\alpha \quad (5)$$

$$L_q\ddot{q}_\beta + \phi_f\cos(pq_m)p\dot{q}_m + R_s\dot{q}_\beta = U_\beta \quad (6)$$

$$-\tau_l = D_m\ddot{q}_m + R_m\dot{q}_m + p\phi_f\sin(pq_m)\dot{q}_\alpha - p\phi_f\cos(pq_m)\dot{q}_\beta \quad (7)$$

The smooth poles PMSM model can be represented in state space as follows (Khanchoul et al., 2014; Ramírez-Leyva, et al., 2013):

$$\begin{cases} x = Ax + F(x,y,u) + B\,\tau_l \\ Y = Cx \end{cases} \quad (8)$$

where:

$$x = \begin{bmatrix} \dot{q}_\alpha & \dot{q}_\beta & \dot{q}_m \end{bmatrix}^T$$

$$A = \begin{bmatrix} \frac{-R_s}{L_s} & 0 & 0 \\ 0 & \frac{-R_s}{L_s} & \frac{p\varnothing_f}{L_s} \\ 0 & \frac{p\varnothing_f}{D_m} & \frac{-R_m}{D_m} \end{bmatrix}$$

$$F(x,y,u) = \begin{bmatrix} p\Omega\dot{q}_\alpha + \frac{U_\alpha}{L_s} \\ -p\Omega\dot{q}_\beta + \frac{U_\beta}{L_s} \\ 0 \end{bmatrix}; B = \begin{bmatrix} 0 \\ 0 \\ \frac{-1}{D_m} \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}; y = \begin{bmatrix} \dot{q}_\alpha \\ \dot{q}_\beta \end{bmatrix}; u = \begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix}$$

2.2. Forces factorization

The model of the PMSM can be written in a compact form as (Mellah et al., 2011):

$$D(q)\ddot{q} + W(q,\dot{q}) + R\dot{q} = MU_{\alpha\beta} + \xi \quad (9)$$

where:

$$D(q) = \mathrm{diag}\{D_e, D_m\},\ R = \mathrm{diag}\{R_e, R_m\}$$

$$\xi = [0, 0, -\tau_l]^T;\ M = [I_2, 0_{2*1}]^T$$

Rewriting the matrix Was product of a matrix C with $\dot{q}$ vector yields:

$$C = \begin{bmatrix} \frac{1}{2}W_1 p\dot{q}_m & \frac{1}{2}W_1\dot{q}_e + W_2 \\ -\left(\frac{1}{2}\dot{q}_e{}^T W_1 + W_2^T\right) & 0_{1*1} \end{bmatrix} \quad (10)$$

Hence, Eq. (9) will be written in compact form as:

$$D(q)\ddot{q} + C(q,\dot{q})\dot{q} + R\dot{q} = MU_{\alpha\beta} + \xi \quad (11)$$

2.3. Passivity of PMSM in open loop:

The Hamiltonian (total energy) of the PMSM is (Achour, 2011; Mocanu & Onea, 2018):

$$H = \frac{1}{2}\dot{q}_e{}^T D_e(pq_m)\dot{q}_e + \varphi_f{}^T(pq_m)\dot{q}_e + \frac{1}{2}D_m\dot{q}_m{}^2 \quad (12)$$

The Hamiltonian derivative is given by:

$$\dot{H} = -\dot{q}^T R\dot{q} + \frac{d}{dt}\left(\varphi_f^T(pq_m)\dot{q}_e\right) + y^T v \quad (13)$$

By the integration of Eq. (13) on the interval $[O;T]$ we get:

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$$\underbrace{H(T)-H(0)}_{stored\ energy}=\underbrace{\int_0^T y^T v\,d\sigma+\left[\varphi_f^T(\mathrm{pq_m})\,\dot{q}_e\right]_0^T}_{supplied\ energy}-\underbrace{\int_0^T \dot{q}^T R\dot{q}\,d\sigma}_{dissipated\ energy}$$

Note that $H(T)\geq 0$and $H(0)$ initial stored energy hence:

$$\int_O^T y^T v\,d\sigma \geqslant \lambda_{min}\{R\}\int_0^T \parallel \dot{q}^2 \parallel-\left(H(0)+\ \left[\varphi_f^T(\mathrm{pq_m})\dot{q}_e\right]_0^T\right) \tag{15}$$

where: $\begin{cases}\alpha=\lambda_{min}\{R\}\\ \beta=-\left(H(0)+\left[\varphi_f^T(\mathrm{pq_m})\dot{q}_e\right]_0^T\right)\end{cases}$

Therefore the PMSM is passive in the open loop (Achour, 2011).

2.4. Problem formulation

In order to perform a nonlinear sensorless control of the PMSM, a nonlinear passivity based controller is applied to control the speed and the torque of the PMSM; then the closed loop system must give:

- $\lim\limits_{t\to+\infty}(\tau-\tau^*)=0$
- $\lim\limits_{t\to+\infty}\dot{q_m}=\dot{q_m}^*$ or $\lim\limits_{t\to+\infty}q_m=q_m{}^*$

A nonlinear adaptive observer is used to estimate the mechanical speed and the load torque using the measured states (stator currents).

2.5. Passivity based control design

The first synthesis step is to determine the desired dynamic. According to the Eq. (2) the following dynamics is proposed (Achour, 2011; Benfriha, 2014):

$$\begin{aligned}U^*_{\alpha\beta}&=D_e(\mathrm{pq_m})\ddot{q_e}^*\\&+\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m\right)\dot{q_e}^*+\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m+R_e\right)\dot{q_e}^*+W_2(\mathrm{pq_m})\mathrm{p}\dot{q}_m\end{aligned} \tag{16}$$

where $\dot{q_e}^*$ is the vector of the desired currents.

The dynamic equation of the error is calculated by subtracting (16) from (2), after calculation we obtain:

$$\begin{aligned}U_{\alpha\beta}-U^*_{\alpha\beta}=D_e(\mathrm{pq_m})\dot{e}_e+\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m\right)e_e\\+\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m+R_e\right)e_e\end{aligned} \tag{17}$$

$e_e=\dot{q_e}-\dot{q_e}^*$ is the error vector of the currents.

To ensure the convergence of the tracking error, the following quadratic function is considered (Belabbes & Larbaoui, 2015; Benfriha 2014):

$$V_e(e_e)=\frac{1}{2}{e_e}^T D_e(\mathrm{pq_m})e_e \tag{18}$$

The derivative of Eq. (18) is given by:

$$\dot{V}_e(e_e)=-{e_e}^T\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m+R_e\right)e_e+{e_e}^T(U_{\alpha\beta}-U_{\alpha\beta}{}^*) \tag{19}$$

Choosing:

$$U_{\alpha\beta}=U_{\alpha\beta}{}^* \tag{20}$$

The expression of $\dot{V}_e(e_e)$ will be reduced to:

$$\dot{V}_e(e_e)=-{e_e}^T\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m+R_e\right)e_e \tag{21}$$

2.6. Damping injection

A damping term K_e is inserted into the controller that ensure the negativeness of Eq. (21), therefore Eq. (20) will be:

$$U_{\alpha\beta}=U_{\alpha\beta}{}^*-K_e e_e \tag{22}$$

Therefore, Eq. (17) becomes:

$$\begin{aligned}&D_e(\mathrm{pq_m})\dot{e}_e+\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m\right)e_e\\&+\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m+R_e+K_e\right)e_e=0\end{aligned} \tag{23}$$

Choosing the same quadratic function V_e of Eq. (18), the derivative of V_e is given by:

$$\dot{V}_e(e_e)=-{e_e}^T\left(\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m+R_e+K_e\right)e_e \tag{24}$$

The function $\dot{V}_e$ is negative if:

$$K_e={K_e}^T>-R_e-\frac{1}{2}W_1(\mathrm{pq_m})\mathrm{p}\dot{q}_m \tag{25}$$

This condition can be satisfied if we choose (Achour, 2011):

$$K_e=\frac{1}{2}W_1(pq_m)p\dot{q}_m+k_eI_2\ \ k_e>R_e \tag{26}$$

2.7. Desired currents

The PMSM is working at a maximum torque if the desired current i_d^* is zero, then the torque equation is written as follows (Sanjuan, et al., 2018):

$$\tau^*=p\phi_f\dot{q}_q^* \tag{27}$$

Desired currents in the *dq* frame are given by:

$$\begin{cases}\dot{q}_d^*=0\\ \dot{q}_q^*=\frac{\tau^*}{p\phi_f}\end{cases} \tag{28}$$

Hence, the desired current vector in the $\alpha\beta$refrence frame is given by:

$$\dot{q_e}^*=\frac{\tau^*}{p\phi_f}\begin{bmatrix}-\sin(pq_m)\\ \cos(pq_m)\end{bmatrix} \tag{29}$$

2.8. Desired torque

The desired torque proposed in (Achour, 2011; Belabbes & Larbaoui, 2015) is given by the following equations:

$$\tau^*(\dot{q_e}^*,\mathrm{pq_m})=D_m\ddot{q_m}^*-z+\tau_l \tag{30}$$

$$\dot{z}=-az+b(\dot{q_m}-\dot{q_m}^*)\ a,b>0 \tag{31}$$

The parameters (a,b) are chosen to ensure the stability and improve the system performance.

Note: In practice the load torque is not a measured quantity, therefore the proposed adaptive observer is used to estimate the load torque.

2.9. Passivity of PMSM in closed loop

Let us consider the quadratic function (Achour, 2011):

$$H_{CL}=\frac{1}{2}\dot{q_e}^T D_e(\mathrm{pq_m})\dot{q_e} \tag{32}$$

The derivative of Eq. (32) is given by:

$$\dot{H}_{CL} = -\dot{q}_e{}^T v + \dot{q}_e{}^T (R_e + K_e I_2)\dot{q}_e \tag{33}$$

Following the same steps in Section 2.3, we get the following dissipation inequality:

$$\int_0^{T_C} \dot{q}_e^T v\, d\sigma \geqslant \lambda_{\min}\{R_e\} + K_e I_2 \int_0^{T_C} \| \dot{q}_e \|^2 d\sigma - H_C(0) \tag{34}$$

Taking: $\begin{cases} \alpha_C = \lambda_{\min}\{R\} + K_e I_2 \\ \beta_C = -H_C(0) \end{cases}$

Therefore the PMSM is passive in the closed loop.

3. Adaptive observer synthesis:

3.1. Adaptive observer structure

Based on the model of Eq. (8) a nonlinear adaptive observer is proposed to estimate the mechanical speed and the load torque of the PMSM as follow (Boufadene, et al., 2016; Hamida, et al., 2013):

$$\begin{cases} \dot{\hat{x}} = A\hat{x} + F(\hat{x}, y, u) + B\hat{\tau}_l + L(Y - C\hat{x}) \\ \dot{\hat{\tau}}_l = \gamma B^T Pe \\ y = Cx \end{cases} \tag{35}$$

With the following assumptions are holds (Boufadene, et al., 2018; Mohamed, et al., 2017):

- Assumption1: The pair (A,C) Matrix are observable
- Assumption2: The signals y and u are measurable
- Assumption3: The unknown disturbance τ_l is bounded($\dot{\tau}_l = 0$)
- Assumption4: the observer gain matrix L is chosen so that $A_c = A - LC$ is Hurwitz, Such that P, Q are positive matrix that satisfy Lyapunov function:

$$A_c{}^T P + PA_c = -Q$$

where:

$e = x - \hat{x}$

γ is an adjustable gain of adaptation.

3.2. Observer stability analysis

Let us consider the following Lyapunov positive function:

$$V = \frac{e^T Pe}{2} + \frac{\tilde{\tau}_l \ \tilde{\tau}_l^T}{2\gamma} \tag{36}$$

with: $\tilde{\tau}_l = \tau_l - \hat{\tau}_l$

The derivative of V is given by:

$$\dot{V} = \frac{\dot{e}^T Pe}{2} + \frac{e^T P\dot{e}}{2} + \frac{\dot{\tilde{\tau}}_l \ \tilde{\tau}_l^T}{2\gamma} + \frac{\tilde{\tau}_l \ \dot{\tilde{\tau}}_l{}^T}{2\gamma} \tag{37}$$

Replacing $\dot{e}$ by its expression ($\dot{e} = A_c e + B\,\tilde{\tau}_l$) we get:

$$\dot{V} = \frac{(A_c e + B\,\tilde{\tau}_l)^T Pe}{2} + \frac{e^T P(A_c e + B\,\tilde{\tau}_l)}{2} + \frac{\dot{\tilde{\tau}}_l \tilde{\tau}_l^T}{2\gamma} + \frac{\tilde{\tau}_l \dot{\tilde{\tau}}_l^T}{2\gamma} \tag{38}$$

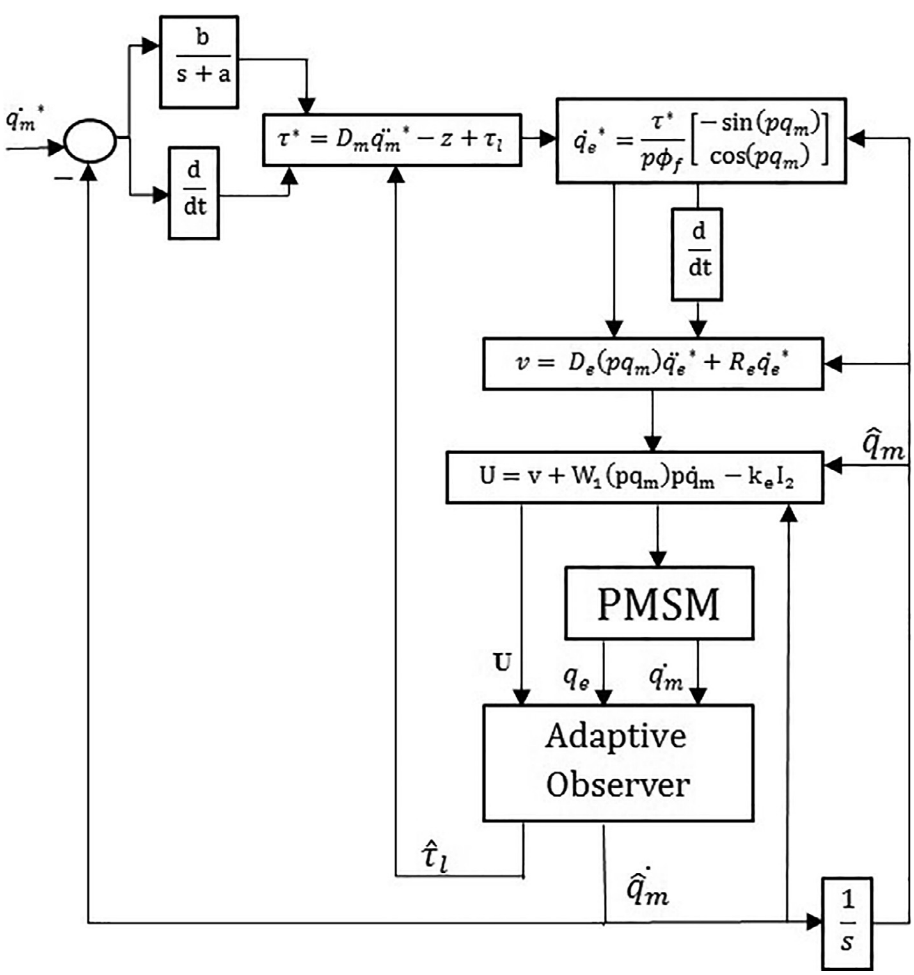

Fig. 1. Simulation block of BPC of PMSM associated to nonlinear adaptive observer.

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$$\dot{V} = \frac{e^T P A_c e}{2} + \frac{e^T P B \tilde{\tau}_l}{2} + \frac{e^T A_c^T P e}{2} + \frac{\tilde{\tau}_l^T B^T P e}{2} + \frac{\dot{\tilde{\tau}}_l \tilde{\tau}_l^T}{2\gamma} + \frac{\tilde{\tau}_l \dot{\tilde{\tau}}_l^T}{2\gamma} \tag{39}$$

$$\dot{V} = \frac{e^T \left(A_c^T P + P A_c\right) e}{2} + \frac{e^T P B \tilde{\tau}_l}{2} + \frac{\tilde{\tau}_l^T B^T P e}{2} + \frac{\dot{\tilde{\tau}}_l \tilde{\tau}_l^T}{2\gamma} + \frac{\tilde{\tau}_l \dot{\tilde{\tau}}_l^T}{2\gamma} \tag{40}$$

Using the expression of the Lyapunov function we obtain:

$$\dot{V} = \frac{-1}{2} e^T Q e + \frac{e^T P B \tilde{\tau}_l}{2} + \frac{\tilde{\tau}_l^T B^T P e}{2} + \frac{\dot{\tilde{\tau}}_l \tilde{\tau}_l^T}{2\gamma} \quad + \frac{\tilde{\tau}_l \dot{\tilde{\tau}}_l^T}{2\gamma} \tag{41}$$

Note that $\dot{\tau}_l = 0$ and $\dot{\tilde{\tau}}_l = \gamma B^T P e$, then the Eq. (41) will be simplified to:

$$\dot{V} = \frac{-1}{2} e^T Q e \tag{42}$$

$$\dot{V} < 0$$

Therefore the proposed adaptive observer is stable in Lyapunov sense (see Fig. 1).

4. Simulation results

In order to conclude on the performance of the use of the passivity based control via adaptive observer, let's introduce the simulations performed on a PMSM powered by a PWN inverter using MATLAB/SIMULINK.

The PMSM's parameters are given in the table below (see Table 1):

Table 1
PMSM parameters (Amrous, 2009).

Rated power	Pn	2 KW
Phase resistance	Rs	1 Ω
Longitudinal inductance	Ld	3.2 mH
Cross inductance	Lq	3.2 mH
Number of pole pairs	p	3
Flux of the permanent magnets	$\varnothing_f$	0.13 Wb
Moment of inertia	D_m	6.10^{-4} Kg.m2
Friction coefficient	R_m	$9.5{*}10^{-5}$ N.m/rd/s

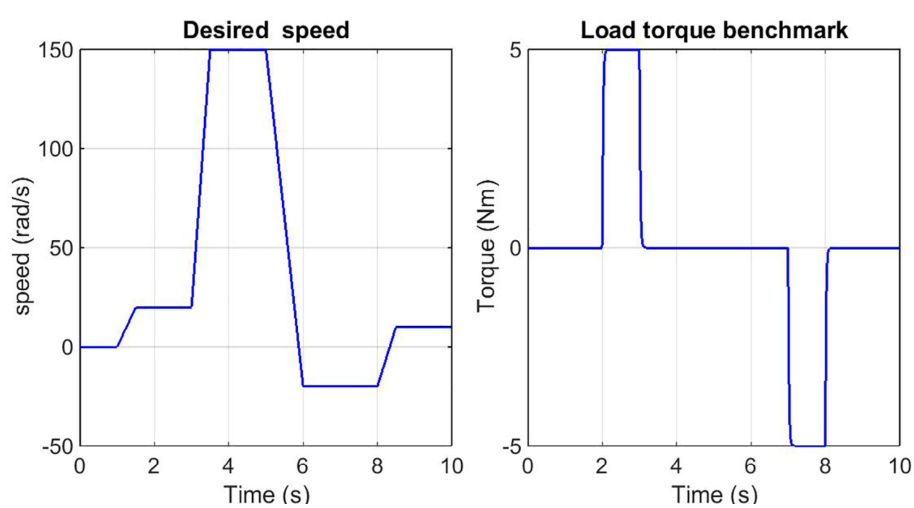

Fig. 2. Speed benchmark and load torque benchmark.

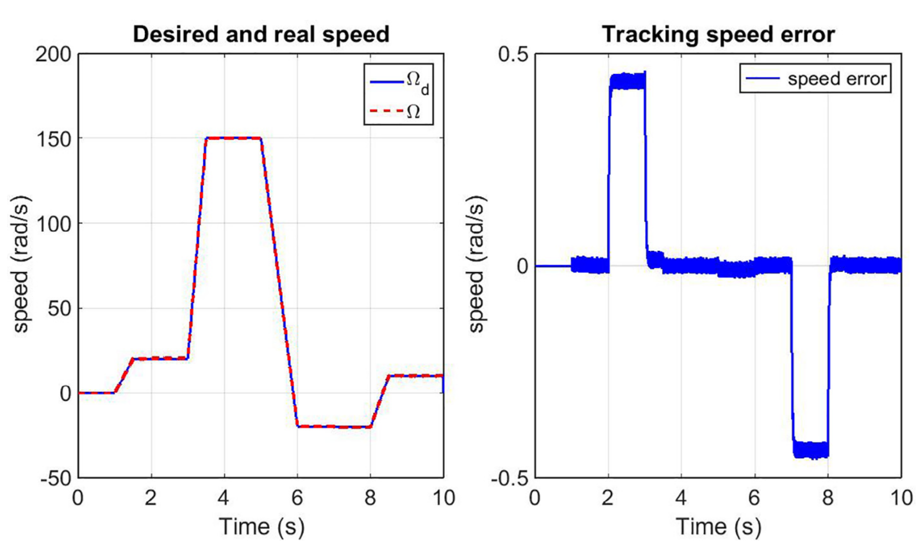

Fig. 3. Tracking Speed.

4.1. Robustness test

To highlight the importance of passivity-based control associated with an adaptive observer, the following robustness tests were carried out:

Test 1:

- variation −50% of stator resistanceR_s
- variation −50% of stator inductance L_s
- variation −20% of the flux of magnets $\varnothing_f$

Test 2:

- variation + 50% of stator resistanceR_s
- variation + 50% of stator inductance L_s
- variation + 20% of the flux of magnets $\varnothing_f$
- variation + 200% of moment of inertia D_m

5. Results discussion

Fig. 2 shows the input load torque, and the mechanical speed that were applied to the PMSM, where the speed benchmark is used to test the performance of the proposed control method for several speed profiles; low speed zone ([0 s 3 s], [6 s 10 s]), the instant of reversal of the motor rotation direction (6 s), the speed benchmark also allows to test the period that the speed increases (upward) or decreases (downward) and also when the speed is constant.

The performances were established from the simulation of the following operating modes: start without load followed by an application of a positive load torque of Cr = 5 Nm between 2 s and 3 s, and another application of a negative load torque of Cr = −5 NM between 7 s and 8 s (Fig. 2).

The results (Fig. 3) show that the tracking speed error is zero when the speed is constant, however the appearance of a very small error in the tracking speed when the speed varies (upward or downward); it is noted also that the tracking speed error is corresponding to 0.45 rad/s during the period of application of the positive load and −0.45 rad/s during the period of the application of negative load.

According to the results in Fig. 3 we notice that the real speed follows perfectly its reference.

A small chattering occurs in the simulation results due to the use of the PWM inverter which is similar to the case in [20], where a low pass filter is proposed to minimize it.

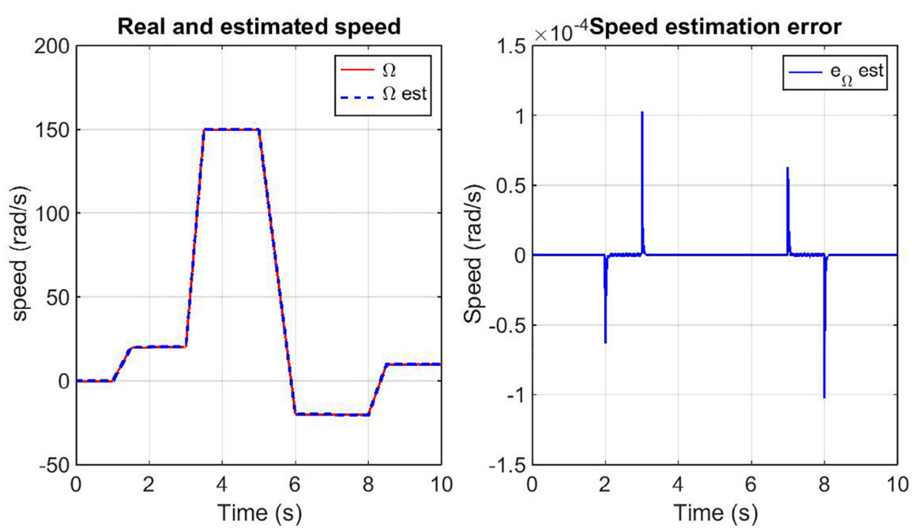

Fig. 4. Speed estimation.

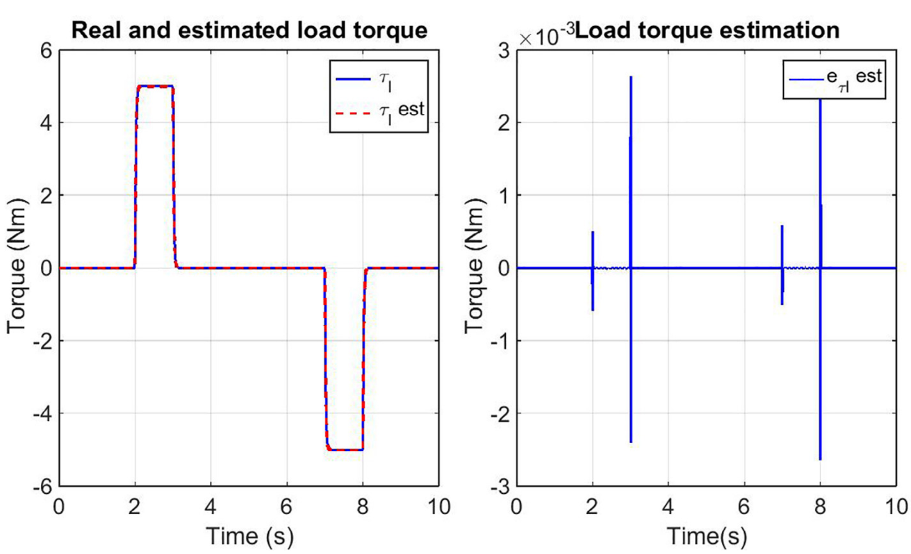

Fig. 5. Load torque estimation.

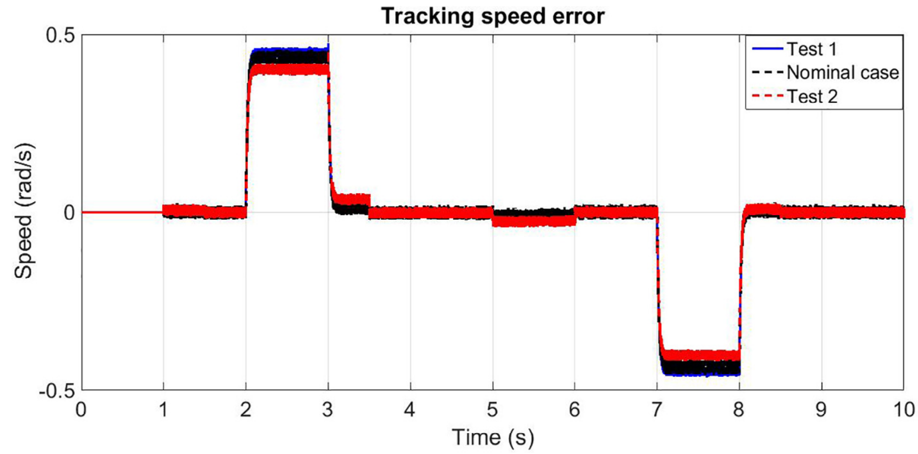

Fig. 6. Tracking speed error (robustness test).

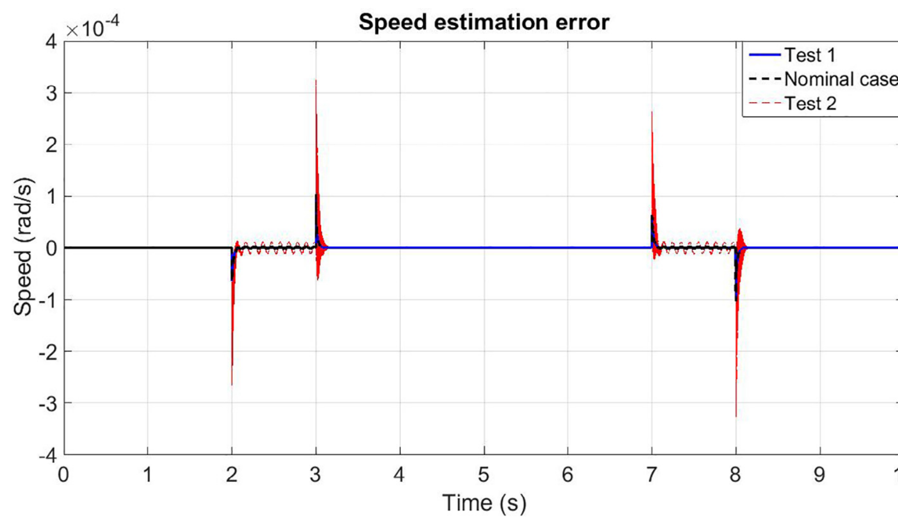

Fig. 7. Speed estimation error (robustness test).

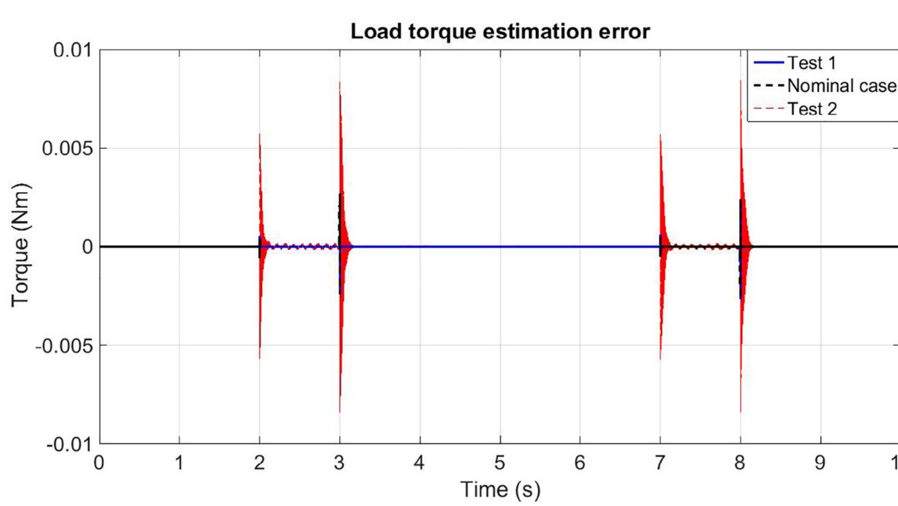

Fig. 8. Load torque estimation error (robustness test).

The results of the estimation of the speed and the load torque (Figs. 4 and 5) show the appearance of some peaks corresponding to the instants of the application and the cancellation of the load torque. Moreover, small oscillations corresponding to the periods of application of the load torque has been appeared.

Figs. 3–5 show the effectiveness and performance of the passivity based control via an adaptive observer. It gives good performance vis-a-vis the desired speed, the application and the cancellation of the load torque, the reversal of direction of motor rotation and also in the zone of low speed.

Figs. 6–8 show the simulation results with simultaneous variation of motor parameters, it is noted that the speed tracking error slightly increases especially in the period of the application of the load torque, moreover the oscillation in the speed estimation error corresponding to the period of the application of the load torque is a bit important than that in the normal case.

The response to the desired speed is carried out with a rejection of fast disturbance, otherwise the system is insensitive to parametric variations, and so it is robust.

6. Conclusion

In this paper a nonlinear passive control based adaptive observer is applied to drive the permanent magnet synchronous motor; the damping coefficient injected into the controller makes the system more stable and gives better performance.

Simulation results show the performance of the proposed controller-observer against several speed profiles, load torque variations, and parameters uncertainties.

Some perspectives of this work can also be oriented towards: the real-time implementation of the proposed method in the real PMSM using a real environment based on microcontroller board (dspace card), the use of new algorithms for chattering elimination and the optimization of the gains of the proposed controller-observer using genetic algorithms, neural network or fuzzy logic.

Declaration of Competing Interest

There is no conflict of interest between authors or other.

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