Control of Permanent Magnet Synchronous Motor Using the Passive Feedback Control Method

M. Messadi, A. Mellit
LER laboratory, Jijel University,
Jijel, Algeria
Messadi manel@gmail.com

***Abstract*—In this paper the tracking control of Permanent Magnet Synchronous Motor (PMSM) system is investigated, with only one input via the passive feedback control method. Based on the property of the passive system, the essential conditions for which the PMSM system could track any path desired is also studied. Some Simulation results clearly show performance of proposed passive feedback controller.**

Keywords: PMSM; Passive control ; Lyapunov theory

I. Introduction

As results of the progress in power electronics, software engineering, and materials, the PMSM, based on modern rare earth variety, becomes serious competitor to the induction motor and conventional wound rotor synchronous motor .A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. Thanks to its significant benefits like their high efficiency, high speed, high power density and large torque of inertia ratio, the PMSMs are frequently used in high performance servo application

For industrial applications, such as high performance motor drives, accurate motor speed control is required in which regardless of sudden load changes and parameter variations, this is why, the control system must be design very carefully as it required to ensure the optimum speed operation under the environmental variations, load variations and structural perturbations. Many control strategies have been studied extensively in attempts to provide accurate control capability , taking as an example , in [1] Guney and al have designed a fuzzy logic controller to obtain the desired output torque, stator phase current and stator flux of permanent magnet synchronous motor (PMSM) , in [2] Hyung-Tae Moon and al, have presented a new predictive current controller for a permanent magnet synchronous motor (PMSM) considering delays, in [3] J.Zhou and al, have presented a nonlinear adaptive speed controller for a permanent magnet synchronous motor based on a newly developed adaptive backstepping approach (PMSM), and still many researchers who are interested in the control of this type of motor [4-5] .

In this study, the passive feedback control method is studied on a permanent magnet synchronous motor system. Based on the passivity concept, there is only one control state needed, instead of the three states. Simulation results are presented to show the effectiveness of the proposed controller.

II. PMSM Modeling

The mathematical model of a PMSM in a synchronous d-q frame can be described as follows [6]:

$$
\begin{aligned}
v_d &= Ri_d + \frac{d\phi_d}{dt} - \omega\phi_q \\
v_q &= Ri_q + \frac{d\phi_q}{dt} + \omega\phi_d \\
\phi_d &= L_d i_d + \phi_m \\
\phi_q &= L_q i_q
\end{aligned}
\tag{1}
$$

The electric torque is given by :

$$T_e = \frac{3}{2} p[\phi_m i_q - (L_q - L_d) i_d i_q] \tag{2}$$

And the equation for the motor dynamics is :

$$T_e = T_L + B\omega_r + j\frac{d\omega_r}{dt} \tag{3}$$

the nonlinear state equations are given as :

$$
\begin{aligned}
\frac{di_d}{dt} &= \frac{v_d}{L_d} - \frac{R}{L_d} i_d + \omega_r p \frac{L_q}{L_d} i_q \\
\frac{di_q}{dt} &= \frac{v_q}{L_q} - \frac{R}{L_q} i_q - \omega_r p \frac{L_d}{L_q} i_d - \omega_r p \frac{\phi_m}{L_q} \\
\frac{d\omega_r}{dt} &= \frac{3p\phi_m}{2J} i_q + \frac{3p}{2J}(L_q - L_d) i_d i_q - \frac{B}{J}\omega_r - \frac{1}{J} T_L
\end{aligned}
\tag{4}
$$

Where:

v_d, v_q	Stator d and q axes voltages.
i_d, i_q	Stator d and q axes currents.
ϕ_d, ϕ_q	Stator d and q axes flux linkages.
ϕ_m	Flux created by rotor magnets.
R	Stator resistance.
L_d, L_q	Stator d and q axes inductances.
T_e, T_L	Electromagnetic and load torques.

J Moment of inertia.
B Viscous of poles pairs.
p Number of poles pairs.
ω_r Rotor speed in angular frequency

III. CONTROL OF THE PMSM WITH THE PASSIVE FEEDBACK CONTROL METHOD

Consider a nonlinear system described by the following equations [7-10]:

$$\begin{aligned} \dot{x} &= f(x) + g(x)u \\ y &= h(x) \end{aligned} \tag{5}$$

where: $x \in X$ is the state variable, $f(x)$ and $g(x)$ are smooth vector fields, $u(t) \in U$ is the input, $f(0) = 0$ and $h(x)$ is a smooth mapping.

System (5) is passive if :

1. $f(x)$ and $g(x)$ exist and they are smooth vector fields;
2. For any $t \geq 0$, there is a real value β that satisfies the inequality:

$$\int_0^t u^T y(\tau) d\tau \geq \beta \tag{6}$$

System (5) can be represented in the form:

$$\begin{aligned} \dot{z} &= f_0(z) + g(z,y)y \\ \dot{y} &= l(z,y) + k(z,y)u \end{aligned} \tag{7}$$

If the system (5) is of a minimum phase, the system (7) will be equivalent to a passive system and it could be asymptotically stabilized at the desired or equilibrium points through the local feedback controller as follows:

$$u = k(z,y)^{-1}\left[-l(z,y) - \frac{\partial W(z)}{\partial z} g(z) - \gamma y + \eta\right] \tag{8}$$

where $W(z)$ is the Lyapunov function of $f_0(z)$, γ is a positive real value and η is an external signal which is connected to the reference input.

Let: $z = [z_1, z_2]^T = [i_q, w_r]^T$ and $y = i_d$, $u = v_d$; so the system (4) can be rewritten into the following form:

$$\begin{aligned} \frac{dy}{dt} &= \frac{u}{L_d} - \frac{R}{L_d} y + z_2 p \frac{L_q}{L_d} z_1 \\ \frac{dz_1}{dt} &= \frac{v_q}{L_q} - \frac{R}{L_q} z_1 - z_2 p \frac{L_d}{L_q} y - z_2 p \frac{\phi_m}{L_q} \\ \frac{dz_2}{dt} &= \frac{3p\phi_m}{2J} z_1 + \frac{3p}{2J}(L_q - L_d) y z_1 - \frac{B}{J} z_2 - \frac{1}{J} T_L \end{aligned} \tag{9}$$

with:

$$f_0(z) = \left[\frac{v_q}{L_q} - \frac{R}{L_q} z_1 - z_2 p \frac{\phi_m}{L_q}, \frac{3p\phi_m}{2J} z_1 - \frac{B}{J} z_2 - \frac{1}{J} T_L\right]^T$$

$$\mathrm{g}(z) = \left[-z_2 p \frac{L_d}{L_q}, \frac{3p}{2J}(L_q - L_d) z_1\right]^T \quad k(z,y) = \frac{1}{L_d}$$

$$l(z,y) = -\frac{R}{L_d} y + z_2 p \frac{L_q}{L_d} z_1, \tag{10}$$

Our aim is to design a smooth control (8) for the PMSM motor system to make the closed-loop system passive. In order to achieve this result, we choose a storage function candidate:

$$V(z,y) = W(z) + \frac{1}{2} y^2 \tag{11}$$

where $W(z)$ is a Lyapunov function , with $W(0) = 0$,

$$W(z) = \frac{1}{2}(z_1^2 + z_2^2) \tag{12}$$

when y = 0, and differentiating the following equation is obtained:

$$\begin{aligned} \dot{W}(z) = z_1\dot{z}_1 + z_2\dot{z}_2 = \frac{z_1 v_q}{L_q} - \frac{R}{L_q} z^2{}_1 - z_1 z_2 p \frac{\phi_m}{L_q} + \\ \frac{3p\phi_m}{2J} z_2 z_1 - \frac{B}{J} z^2{}_2 - \frac{1}{J} z_2 T_L \end{aligned} \tag{13}$$

Form (10) , $\dot{W}(z) < 0$

Thus the zero dynamics of (13) is Lyapunov stable. The derivative of $V(z, y)$ along the trajectory of the system (11) is:

$$\begin{aligned} \frac{d}{dt} V(z,y) &= \frac{\partial}{\partial z} W(z)\dot{z} + y\dot{y} \\ &= \frac{\partial}{\partial z} W(z) f_0(z) + \frac{\partial}{\partial z} W(z) g(z,y) y \\ &\quad + y l(z,y) + y k(z,y) u \end{aligned} \tag{14}$$

The system (12) is of minimum phase:

$$\frac{d}{dt} W(z) f_0(z) \leq 0 \tag{15}$$

The equation (12) becomes:

$$\frac{d}{dt} V(z,y) \leq \frac{\partial}{\partial z} W(z) g(z,y) y + (l(z,y) + k(z,y)u) y \tag{16}$$

If we select the feedback control (8) of the following form and consider equation (10) we obtain:

$$\begin{aligned} u &= k\ (z,y)^{-1}[-l^T(z,y) - \frac{\partial W(z)}{\partial z} g(z,y) - \gamma y + \eta] \\ &= L_d \begin{pmatrix} + \frac{R}{L_d} y - z_2 p \frac{L_q}{L_d} z_1 + z_1 z_2 p \frac{L_d}{L_q} \\ - \frac{3p}{2J}(L_q - L_d) z_2 z_1 - \gamma y + \eta \end{pmatrix} \end{aligned} \tag{17}$$

Where γ is a positive constant and η is an external signal which is connected with the reference input. The inequality (16) can be rewritten as:

$$\frac{d}{dt}V(z,y) \leq -\gamma y^2 + \eta y \tag{18}$$

Integrating both terms of (16)

$$V(z,y) - V(z_0,y_0) \leq \int_0^t -(\gamma)y(\tau)^2 d\tau + \int_0^t \eta(\tau)y(\tau)d\tau \tag{19}$$

$V(z,y) \geq 0$ and $\rho = V(z_0,y_0)$

$$\int_0^t \eta(\tau)y(\tau)d\tau + \rho \geq V(z,y) + \int_0^t \gamma y^2(\tau)d\tau \geq \int_0^t \gamma\ y^2(\tau)d\tau \tag{20}$$

The result satisfies the passivity definition (6). Under the feedback control, the system (12) is transformed so that it is output strictly passive.
To force the system to follow the desired path, we just put the equation (9) equal to 0 and calculate the value of η .

IV. SIMULATION RESULT

The performance of proposed passive feedback control strategy is evaluated with the simulation study using MATLAB and the fourth-order Runge–Kutta algorithm with the initial condition vector $(i_{q0}, i_{d0}, \omega_{r0}) = (5,1,20)$, a time step of 0.001 and fixing the parameter value γ =20 and Table I shows PMSM parameters.

TABLE I: PARAMETER VALUES OF PMSM USED IN SIMULATION.

Number of pole pairs P	2
Armature resistance R	3 Ω
Magnet flux linkage ϕ_m	0.167 *web*
d-axis inductance L_d	7 $m\Omega$
d-axis inductance L_q	7 $m\Omega$
Moment inertia J	0.134 10^{-3} kgm^2

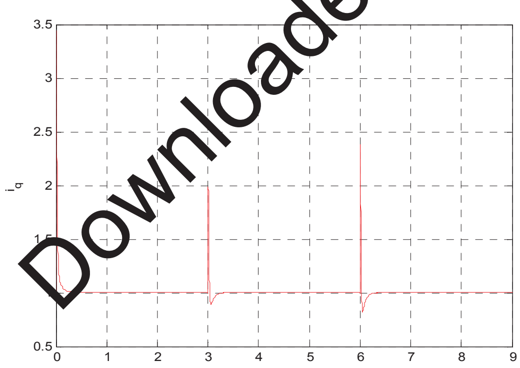

Fig 1: q-axes current.

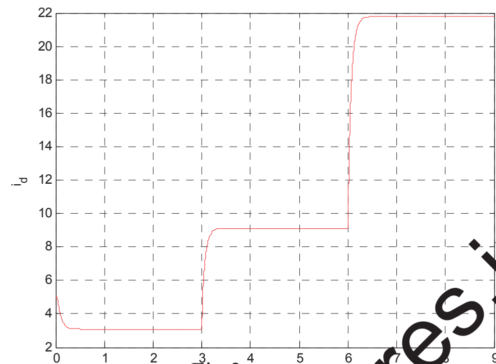

Fig 2: q-axes current.

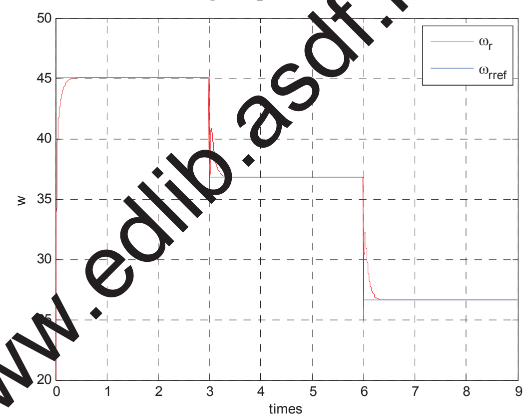

Fig 3: angular speed of the rotor and its reference.

The Figures 1 and 2 show respectively the evaluation of the current in the d-q axes.
From Figure 3, we can easily see that the passive feedback controller applied in this paper achieved excellent control effect, the angular speed of the rotor can quickly and accurately tracks the desired reference.

V. CONCLUSION

In this study, control functions have been designed via the passive control method for control of a permanent magnet synchronous motor (PMSM) system. Although the controller has been applied only on one state of the system, but he was able to stabilize the PMSM system in any position and fair follow any path she desired.
Some simulation results have been provided to verify The effectiveness of the proposed control method.

VI. REFERENCE

[1] Guney, Oguz, Y. ; Serteller, F:' I Dynamic behaviour model of permanent magnet synchronous motor fed by PWM inverter and fuzzy logic controller for stator phase current, flux and torque control of PMSM" Electric Machines and Drives Conference,IEMDC 2001

[2] Hyung-Tae Moon, Hyun-Soo Kim, Myung-Joong Youn "A discrete-time predictive current control for PMSM" Power Electronics, IEEE Transactions ,Vol 18 , Issue 1,2003 .

[3] J. Zhou, Y. Wang "Adaptive backstepping speed controller design for a permanent magnet synchronous motor" IEE Proceedings - Electric Power Applications, Vol 149, Issue 2, pp 165 – 172 , 2002.

[4] Shihua Li , Huixian Liu , Shihong Ding , "A speed control for a PMSM using finite-time feedback control and disturbance compensation" Transactions of the institute of measurement and control, vol. 32 no.2, pp 170-187, 2010.

[5] Z.Qiao, T.Shi ; Y.Wang ; Y.Yan "New Sliding-Mode Observer for Position Sensorless Control of Permanent-Magnet Synchronous Motor" Industrial Electronics, IEEE Transactions, Vol 60 , Issue 2, pp 710-7019, 2013

[6] M.Ouassaid, M.Cherkaoui, A.Nejmi, and M.Maaroufi, "Nonlinear Torque Control for PMSM: A Lyapunov Technique Approach" World Academy of Science, Engineering and Technology, pp 708-711, 2007.

[7] F. Wang and C. Liu, "synchronization of unified chaotic system based on passive control" Physica D Nonlinear Phenomena, Vol 225, Issue 1, pp. 55-60, 2007.

[8] K.Kemih, "Control of nuclear spin generator system based on passive control" , Chaos Solutions & Fractals Vol. 41, no. 4, pp 1897-1901 , 2009.

[9] K. Kemih, M. Benslama, S. Filali et al, "Synchronization of chen system based on passivity technique for CDMA underwater communication", International Journal Of Innovative Computing Information And Control, vol. 3, no. 5, pp. 1301-1308, 2007.

[10] K. Kemih, H. Bouraoui, M. Ghanes, R. Remmouche, A. Senouci "Tracking control of the new hyperchaotic 5D system with one input via passive controller" International Journal of Modelling, Identification and Control, vol 17, no.3/2012 ,pp. 206-211, 2012.