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Research Article

Etude comparative between twosliding mode controllerstructure of five phase permanent magnet synchronous motor

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Abstract – Five phase permanent magnet synchronous machines' sliding mode controller is presented in this paper. This control is a nonlinear control technique that modifies a nonlinear system's dynamics by delivering a discontinuous control signal that compels the system to "slide" through a cross-section of the system's typical behavior along the surface S(x). Sliding mode controller (SMC) stability employing Lyapunov stability criteria and the selection of sliding surface S (x). Using (SMC) for simple surface S(x) and surface contain integral error, that is the paper's major goal. The simulation findings show that the sliding mode controller of five PMSMs works best for surfaces that contain integrals because they have a faster dynamic response and better perturbation rejection than surfaces without integrals.

Keywords – Five Phase Permanent Magnet Synchronous Motor, Sliding Mode Controller, Sliding Surface S(X).

I. Introduction

The permanent magnets synchronous motor have developed to give much more, including low inertia, high mass torque, and minimal rotor losses, they continue to be a strong candidate for variable speed drives. Due to their many advantages, such as fault tolerant capability, higher torque density, less noise characteristics, and control almost identical to three-phase machines, multiphase machines are being used more and more in industrial certain applications, such as electric vehicles, wind or marine current turbines, and ship propulsion.The development of the sliding mode controller, which is used to control the five-phase permanent machine, is a result of the significant advancements made in the field of controlling these machines. Unlike traditional controls,The SMC control is unaffected by changes in parameters, disturbances, and system nonlinearity, and it depends on variable structure control for simple construction. It is renowned for its dependability, stability, simplicity, and quick response time in comparison to its immunity to changes in internal and external parameters. The sliding mode controller's basic operating principle is to select a switching surface and slide the system's trajectory in that direction. The system is then rebuilt in a reduced form that is stable, and the control is determined by a low-order and discrete Lyaponov function to remove chattering.The choice of surface has a significant impact on how the system behaves, particularly in terms of response time, reducing overshoot, and system stability.

II. Modelling of five PMSM

a) Electrical equations in the reference abcde:

The electrical equations (a, b, c, d, and e) that regulate a five-phase permanent magnet synchronous machine's operation assume the following form in a fixed reference connected to the stator.[1]

$$[V_s]=[R_s][I_s]+\left[\frac{d\varphi_s}{dt}\right] \quad (1)$$

The rotor of five phases PMSM Consists of permanent magnet only, designed by constant flux φ_m .

V_s, R_s, I_s, φ_s are the stator voltage, resistance ,current , flux linkages matrices with :

$$[V_s]=[V_a,V_b,V_c,V_d,V_e]^T$$

$$[I_s]=[I_a,I_b,I_c,I_d,I_e]^T$$

$$[R_s]=diag[R_s,R_s,R_s,R_s,R_s]$$

The references associated to the stator are written using the totalized fluxes $[\varphi_s]$ of the phases as the following matrix:

$$[\varphi_s]=[L_{ss}][I_s]+[\varphi_{sr}] \quad (2)$$

$[\varphi_{sr}]$ Is mutual flux stator-magnet inductances corresponds of mutual stator-magnet inductance $[L_{sr}]$ expressed by:

$$[L_{sr}]=\varphi_m\begin{pmatrix}\cos(\theta_r)\\ \cos(\theta_r-2\pi/5)\\ \cos(\theta_r-4\pi/5)\\ \cos(\theta_r+4\pi/5)\\ \cos(\theta_r+2\pi/5)\end{pmatrix} \quad (3)$$

$[L_{ss}]$ Is the stator inductance matrix expressed by:

$$[L_{ss}]=\begin{bmatrix}L_{sa}M_{ab}M_{ac}M_{ad}M_{ae}\\ M_{ba}L_{sb}M_{bc}M_{bd}M_{be}\\ M_{ca}M_{cb}L_{sc}M_{cd}M_{ce}\\ M_{da}M_{db}M_{dc}L_{sd}M_{de}\\ M_{ea}M_{eb}M_{ec}M_{ed}L_{se}\end{bmatrix} \quad (4)$$

The nonlinearity of the synchronous motor with magnets model, which results from the connection between the stator and rotor:[1]. is discernible from the flow equations.In order to resolve this issue, we will make use of mathematical transformations (Park and Clark), which allow us to model the system and employ differential equations with constant coefficients to explain the behaviour of the motor.

b) Electrical equations in the reference dqxy:

To simplify the machine model an arbitrary transformation is introduced which transforms the phase variables of five phase motor into a reference frame rotating at an arbitrary angular velocity. The transformation matrix:

(5)

Where:

$$[V_{qdxy0}]=[V_q,V_d,V_x,V_y,V_0]^T \text{ And,}$$

$$[I_{qdxy0}]=[I_q,I_d,I_x,I_y,I_0]^T$$

$$[I_{qdxy0}]=[K][I_{abcde}] \text{ And } [V_{qdxy0}]=[K][V_{abcde}] \quad (6)$$

The homopolar terms V_0 and I_0 are null in all the expressions preceding. In the opposite case to determine the values of $[V_{adcde}]$ and $[I_{adcde}]$ from inverse park matrix such that:

$$[V_{adcde}]=[K]^{-1}[V_{qdxy0}] \quad (7)$$

The flux expression in frame dqxy is:

$$[\varphi_{qdxyo}]=[L_{qdxy0}][I_{qdxyo}]+[\varphi_m] \quad (8)$$

Where:

$$[\varphi_m]=[\varphi_m,0,0,0,0]$$

and

$$[L_{qdxy0}]=diag[L_q \quad L_d \quad L_{ls} \quad L_{ls} \quad L_{ls}]$$

$$L_q=L_{ls}+L_m$$
$$L_d=L_{ls}+L_m$$

L_{ls} is the stator windings self-leakage inductance and Lm :mutual inductance of stator windings.

The five-phase PMSM model in the dqxy coordinates with third harmonic system is shown as:[2][3]

$$\begin{aligned}V_d&=R_sI_d+L_d\frac{dI_d}{dt}-L_qwI_q\\ V_q&=R_sI_q+L_q\frac{dI_q}{dt}+L_dwId+w\Phi_m\\ V_x&=R_sL_x+L_x\frac{dI_x}{dx}-3L_ywI_y\\ V_y&=R_sL_y+L_y\frac{dI_y}{dx}+3L_xwI_x\end{aligned} \quad (9)$$

The electromagnetic torque is given by*:*

$$T_e = \frac{5}{2} p(\Phi_m + (L_d - L_q) I_d) I_q \quad (10)$$

T_e = 5/2 [$\psi sdisq - \psi s$]

Where Φ_m is the maximum of permanent magnet flux linkage , and p is the number of pole pairs.

c) - The mechanical dynamic equation:

The equation of mechanical dynamic for five PMSM is expressed by: [4]

$$J \frac{dw_r}{dt} = T_e - T_l - fw_r \quad (11)$$

Where f is the viscous friction coefficient; TL is the load torque and wr is the rotor speed and J is the rotor moment of inertia.The five-phase permanent magnet's power supply A synchronous motor requires an inverter to convert one or more continuous sources into sinusoidal waveform sources. It contains additional static voltage or current converters (semiconductors) with anti-parallel connected diodes that are primed by signals from devices to produce the sinusoidal output .

III. DESIGN OF SLIDING MODE CONTROL

The sliding mode controller stands for robustness, precision, ease of implementation and tuning.SMC is benefited from the dynamic behavior of the system adapted by each selection of slide functions, also its closed loop response becomes completely insensitive to a certain uncertainty.

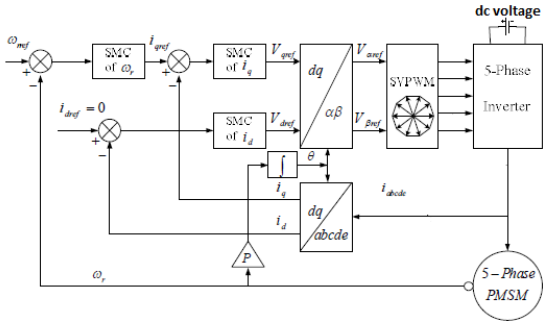

Fig 1: Blok diagram of SMC of five PM SM.

The design of sliding mode controllers takes stability and good performance into account methodically. There are three basic stages to this process:

III. SELECT OF SLIDING SURFACE:

Typically, the choice of the number of sliding surfaces is equal to the dimension of the control vector u(t). In order to ensure the convergence of a state variable x towards its reference value x ref several works propose the following general form:

$$S(x) = (\frac{\partial}{\partial t} + Kx)^{r-1} e(x) \quad (12)$$

with:

e(x) :the difference or error of the variable to be adjusted: $e(x) = x_{ref}(t) - x(t)$. (13)

K_x: A positive constant that interprets the bandwidth of desired control.

r : Relative degree, equal to the number of times the output must be derived till the command appear.

IV. IDENTIFIE THE CONDITIONS OF EXISTENCE AND CONVERGENCE:

The existence condition realized by replace the system in reduced form it must be stable by S(x)=0.

The convergence or attractiveness conditions are the criteria that allow different dynamics of the system to converge towards the sliding surfaces realized by the followingcondition:

$$S(x)\dot{S}(x) < 0 \quad (14)$$

Also can be use the lyabonov condition in which building a function V(x) realized the condition: $V(x)\dot{V}(x) < 0$ (15).

The control Un which ensure the condition of convergence and fulfills the condition of convergence: $U_n = K_x \operatorname{sgn}(S(x))$

V. Determination the global control:

The general form of command is: $U = U_{eq} + U_n$,

For this action determine the command U_{eq} valid onthe sliding surface by : $\dot{S}(x) = 0$,The control U_n which ensures the commutation and allows to bring the system back to the sliding surface is generally in the form $U_n = K_x \operatorname{sgn}(S(x))$.

VI. Sliding mode control of five PMSM

Designing a sliding mode control (SMC) structure for a five Phase Permanent Magnet Synchronous Motor (PMSM) involves creating a control system that can ensure the motor's stability and precise performance. [5]

In this section discusses the application of sliding mode control of Five PMSM for two different structure of sliding surface,the first has a simple structure S(x)=e(x) ,the second represent a sliding surface with its integral s(x)= e(x) +Ki ∫ e(x).[6][7]

The signum function is often employed as a control law in sliding mode control systems. It generates a discontinuous control signal that helps guide the system's state towards the sliding surface and then keeps it there. While chattering suppression is one of the primary motivations for using the signum function. [8]

The structure of sliding mode control depend the model of machine formed in dq frame and sliding surface or reaching law.the two method are explained in the following part: [9]

1- SMC of simple structure of surface

S(x) =e(x), so r=1:

$$S(x) = e(x) = x_{ref} - x \Rightarrow \dot{S}(x) = \dot{x}_{ref} - \dot{x}$$

then

$$\dot{S}(w) = \dot{w}r_{ref} - \dot{w}r,$$

$$\dot{S}(Iq) = \dot{I}q_{ref} - \dot{I}q,$$

$$\dot{S}(Id) = \dot{I}d_{ref} - \dot{I}d,$$

$$\dot{S}(Ix) = \dot{I}x_{ref} - \dot{I}x,$$

$$\dot{S}(Iy) = \dot{I}y_{ref} - \dot{I}y,$$

On sliding mode condition: $S(x) = 0 \Rightarrow \dot{S}(x) = 0$

$$For\ \dot{S}(wr) = 0$$

$$\dot{I}q_{ref} = \frac{2}{5}\left[\frac{J\,\dot{w}r_{ref} + Tl + fwr}{p((Ld - Lq) + \Phi_m)}\right]$$

$$Iq_n = K_w \operatorname{sgn}(S(wr).then$$

$$Iq = \frac{2}{5}\left[\frac{J\,\dot{w}r_{ref} + Tl + fwr}{p((Ld - Lq) + \Phi_m)}\right] + K_w \operatorname{sgn}(S(wr))$$

$$For\ \dot{S}(Iq) = 0 \Rightarrow \dot{I}q_{ref} - \dot{I}q = 0.$$

$$\dot{I}q_{ref} - \frac{1}{Lq}(Vq - RsIq - LdwLd - w\Phi_m) = 0 \Rightarrow$$

$$Vq = Lq\,\dot{I}q_{ref} + RsId + LdwId + w\Phi_m.$$

$$U = Ueq + Un.$$

$$Vq = Lq\,\dot{I}q_{ref} + RsId + LdwId + w\Phi_m + K_{iq} \operatorname{sgn}(S(Iq)).$$

In the same way can be determine Vd,Vx,Vy.[6]

$$Vd = Ld\,\dot{I}d_{ref} + RsId - LqwIq + K_{id} \operatorname{sgn}(S(Id)).$$

$$Vx = Lx\,\dot{I}x_{ref} + RsIx - 3wIyLy + K_{id} \operatorname{sgn}(S(Ix)).$$

$$Vy = Ly\,\dot{I}y_{ref} + RsIy - 3wIxLx + K_{id} \operatorname{sgn}(S(Iy)).$$

In order to set the positive constants of sign $K_w, K_{iq} K_{id}, K_{ix}, K_{iy}$ requires resolve thefollowing condition: $\dot{S}(x) = 0$ and $S(x)\dot{S}(x) < 0$.

SMC OF STRUCTURE WITH INTEGRAL OF SURFACE FOR S(X) =E(X) +Ki ∫ e(x):

The derivate of sliding surface as a following:

$$\dot{S}(x) = \dot{e}(x) + k_i e(x) = \dot{x}_{ref} - \dot{x} + k_i e(x)$$

The control expressions are determined by the same procedures of course by the cancellation of the drift of the surfaces; but in this time we find two positive constants in each relation:[10]

$$Iq = \frac{2}{5}\left[\frac{J\,\dot{wr}_{ref} + Tl + fwr}{p\left(\left(Ld - Lq\right) + \Phi_m\right)}\right] + K_w\,\mathrm{sgn}(S(wr))$$

$$Vq = Lq\,\dot{Iq}_{ref} + RsId + LdwId + w\Phi_m + K_{1iq}e(Iq) + K_{2iq}\,\mathrm{sgn}(S(Iq)).$$

$$Vd = Ld\,\dot{Id}_{ref} + RsId - LqwIq + K_{1_{id}}e(Id) + K_{2_{id}}\,\mathrm{sgn}(S(Id)).$$

$$Vx = Lx\,\dot{Ix}_{ref} + RsIx - 3wIyLy + K_{1ix}e(Ix) + K_{2_{ix}}\,\mathrm{sgn}(S(Ix)).$$

$$Vy = Ly\,\dot{Iy}_{ref} + RsIy - 3wIxLx + K_{1_{iy}}e(Iy) + K_{2iy}\,\mathrm{sgn}(S(Iy)).$$

VII. RESULTS

In this paper the sliding mode controller of five PMSM has been simulated using a Matlab/Simulink program, and the result obtained at in same conditions, the speed variation applied from 200rad/s to -100rad/s(changed at t=0.3s). also the resistant torque Tl=15 N.m Applied in t=0.2s.

Note: the results without resistant torque is same an exception the notch at T=0.2s.

a)-Results of S(x)=e(x),and Tl=15n.m .

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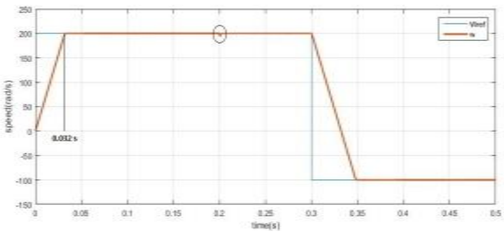

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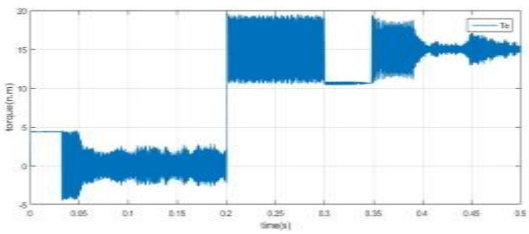

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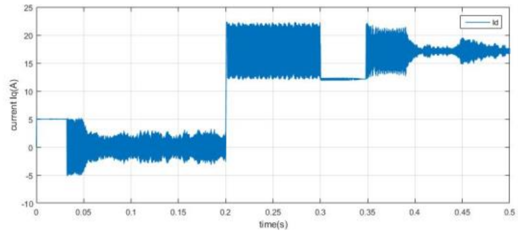

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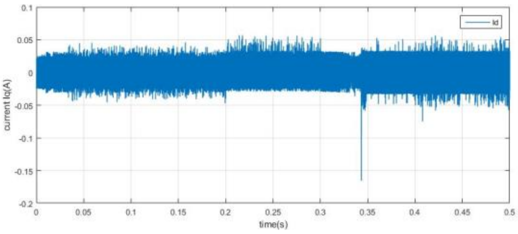
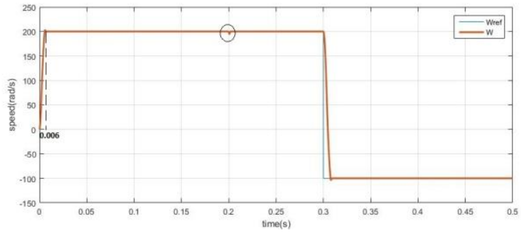


d)

b-results of S(x)=e(x)+k∫e(x),and Tl=15n.m :



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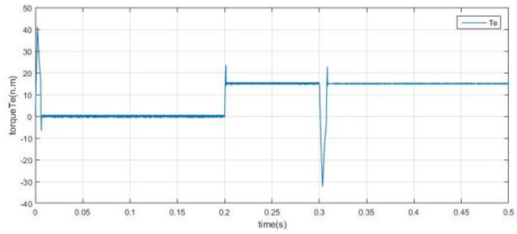

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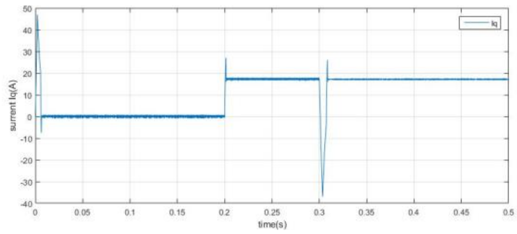

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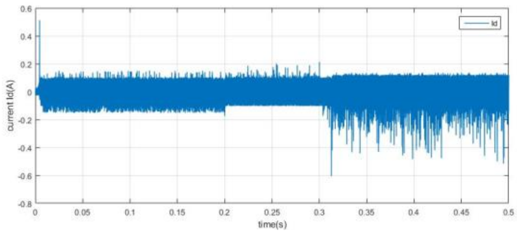

h)

Table 1. SMC of Five PMSM parameters

Parameters of	**S(x) =e(x)**	**S(x)=e(x)+k∫e(x)**

S(W)	K_W=5	$K1_w$=0.2,$K2_w$=20
S(Iq)	K_{iIq}=7000	$K1_{Iq}$=0.2,$K2_{Iq}$=400
S(Id)	K_{Id}=5000	$K1_{Id}$=0.2,$K2_{Id}$=400
S(Ix)	K_{Ix}=5000	$K1_{Ix}$=0.2,$K2_{Ix}$=400
S(Iy)	K_{Iy}=7000	$K1_{Iy}$=0.2,$K2_{Iy}$=400

VIII. DISCUSSION

The system response time in the first structure of S(x) =e(x) equal a 0.032s,but in the secondwhen S(x) =e(x) + k∫e(x)equal to 0.006s; so the second has afast response (. Show in fig (a,a) and fig (b,a)).

Also fig(a,b)and(a,c) and (a,d) illustrate that the couple form Te and the current Iq are very precise(thin waveform in S(x)=e(x)+ k∫e(x)) contrary in the case of fig(b,b)and (b,c),(b,d)are thick S (x)= e(x).That designe the chattering rejection in two cases. Then the integral surface is a better solution of the chattering problem.

- both signals are totally tracks the reference speed value during the transient and steady states even that there is a disturbance indicates that the robustness and affability the sliding mode controller.

IX. CONCLUSION

The sliding mode controller (SMC) of a five-phase permanent magnet synchronous motor is examined in this work (PMSM). The results obtained with speed variations and resistive torque demonstrate the robustness, high precision, and stability of this non-linear control, which are significant benefits of SMC. This controller is unavoidably implemented by a lyaponov law and the selection of a sliding surface; the results show that adding an integral improved chattering rejection and sped up the speed response of the system.ACKNOWLEDGMENT

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