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Improving qualification of PMSM electric drive systems based on adaptive fuzzy sliding control method

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ABSTRACT

In this paper, the authors present a solution to improve the precision in speed control for permanent magnet synchronous motors (PMSM) based on Fuzzy Adaptive Sliding Mode Controller (FASMC) to solve the nonlinear tracking problem with continuously switching topologies. The synthesis algorithm is meant to evaluate the operating performance of electric drive systems. The results is simulated and experimentally verified in the environment of Matlab-Simulink, cotrol Desk with dSPACE 1104 card, proving the applicability of the control algorithm, which not only works well in theory but also in practice for industrial traction drive systems.

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1. INTRODUCTION

For decades, PMSM are widely used in industrial electric drive systems. The drive provide high-quality speed adjustment applications such as electric vehicles, precise position control such as industrial robots, industrial machining machines, traction drive systems, military radar system, rocket control systems, etc. In addition, PMSM can be found in medication manufacturing, such as pill-pakcing machine in the pharmaceutical industry, equipment and machinery for supporting surgical operations in the field of medince, ect... because of its outstanding characteristics (wide and regularly stable working speed range: from very low speed to high speed, with a large moment/current ratio, less interference, stability with load, high performance, very high precision in position control). These PMSM motors are intended to replace the previous drive control systems (which have been using DC motors, causing errors at all times during speed control and position control), [1, 2]. In order to apply these given issues, an intelligent controller – Fuzzy Adaptive Sliding Mode Controller; is an efficient control method that has been widely applied to control for both linear and nonlinear systems [2]-[7].

In applications to precise control systems with various operating speed ranges such as traction systems in the machinery of pharmaceutical industry (pill-packing machine); and strict requirement in metalworking industry, in traction systems of military weapons etc., [5, 6], [8]-[10]. However, there exist some problems need to be solved to improve the quality of control. In [4, 6] and [11] - [13], the authors have only recommended fuzzy control methods for PMSM without considering system uncertainties and external disturbances. In [14]-[17] the authors have used adaptive sliding controller and adaptive backsteping controller, with evaluation of the nonlinear component base on the estimators with light power motors hence limiting its practical implementation with high power requirements. This paper have proposed the FASMC to handle mismatched uncertainties and disturbances and alleviate chattering to gain good performances in the close-loop system, [18]-[23].

The appropriate structure is designed in the paper to ensure quality in the controlled system. The control is constructed for achieving tracking response of drive sysems. In electrical drives, it is necessary to provide quality criteria such as: fast-acting in the control process, ensuring optimization of control law, non-sensitivity to uncertainties in the control process, [1, 15]. This is a multi-objective optimization control problem with many different solutions [1, 5, 9, 13, 21]. This paper presents a researche to improve the quality of precision control for PMSM applications in industrial applications; taking into account the nonlinear uncertainty, the kinematics of the actuator and the converters based on the adaptive fuzzy sliding control method, and experimenting with the dSPACE 1104 card to demonstrate the results, [3, 5, 8, 15, 24].

2. MATHEMATICAL MODEL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

The mathematical model of the three-phase PMSM is decribed as in [4]. By taking the rotor coordinates of PMSM as the reference coordinates, the systems dynamic is represented by the following equation, [4, 8, 10].

$$\begin{cases} \dot{\omega} = k_1 i_q - k_2\omega - k_3 M_L \\ \dot{i}_q = -k_4 i_q - k_5\omega + k_6 V_q - \omega i_d \\ \dot{i}_d = -k_4 i_d + k_6 V_d + \omega i_q \end{cases} \tag{1}$$

where M_L is the load torque, ω is the rotor angular speed, i_q and i_d are linearized d-axis and q-axis stator currents, V_q is q-axis voltage, R_s is stator resistance, V_d is d-axis voltage, and k_i, i = 1….6 are obtained as follows:

$$k_1 = \frac{3}{2}\frac{1}{J}\frac{p^2}{4}\lambda_m,\ k_2 = \frac{B}{J},\ k_3 = \frac{p}{2J},\ k_4 = \frac{R_s}{L_s},\ k_5 = \frac{\lambda_m}{L_s},\ k_6 = \frac{1}{L_s} \tag{2}$$

$$V_q = R_s i_q + L_q \dot{i}_q + \omega L_d i_d + \omega\lambda_m \tag{3}$$

$$V_d = R_s i_d + L_d \dot{i}_d - \omega L_s i_q \tag{4}$$

$$M_e = \frac{3}{2}\frac{p}{2}\left[\lambda_m i_q + (L_d - L_q) i_d i_q\right] \tag{5}$$

$$M_e = M_L + B\frac{2}{p}\omega + J\frac{2}{p}\dot{\omega} \tag{6}$$

where M_e is electromagnetic moment, p is number of pole pairs, R_s is stator resistance, L_d is the d-axis stator inductance and L_q is the q-axis stator inductance, L_s is stator inductance, J is rotor moment of inertia, B is viscous friction coefficient, is λ_m linkage magnetic flux and $\omega = \dot{\theta}$; Hence, a nonlinear control loop of linearization methodology is used to estimate the θ, the rotor speed ω which are the unmeasured components of the motor. Furthermore, the facilitate calculation on the d-q reference axis coordinate system of the motor can be obtained as [4]:

$$\begin{bmatrix} v_d^e \\ v_q^e \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + \sigma L_s p & -\sigma L_s \omega_e & \frac{L_m}{L_r} p & -\frac{L_m}{L_r}\omega_e \\ \sigma L_s \omega_e & R_s + \sigma L_s p & \frac{L_m}{L_r}\omega_e & \frac{L_m}{L_r} p \\ -L_m \frac{R_r}{L_r} & 0 & \frac{R_r}{L_r} + p & -\omega_{sl} \\ 0 & -L_m \frac{R_r}{L_r} & \omega_{sl} & \frac{R_r}{L_r} + p \end{bmatrix} \begin{bmatrix} i_d^e \\ i_q^e \\ \phi_d^e \\ \phi_q^e \end{bmatrix} \tag{7}$$

$$M_e = \frac{3}{2}\frac{n}{2}\frac{L_m}{L_r}(i_q^e \phi_d^e - i_d^e \phi_d^e) \tag{8}$$

In the FOC (Field Oriented Control) method, the magnetic flux is oriented completely along *d*-axis implying $\phi_q^e = 0$ and we get:

$$\phi_r^e = \phi_d^e \tag{9}$$

then the slip speed is represented as follows:

$$\omega_{sl} = \frac{L_m}{\phi_r^e}\left(\frac{R_r}{L_r}\right) i_q^e \tag{10}$$

The electromagnetic torque is obtained as in the following form:

$$M_e = \frac{3}{2}\frac{n}{2}\frac{L_m^2}{L_r} i_q^* i_d^* = K_t i_q^* \tag{11}$$

in which:

$$K_t = \frac{3}{2}\frac{n}{2}\frac{L_m^2}{L_r} i_d^* \tag{12}$$

The mathematical equation describing the mechanical part of the synchronous motor is written as follows:

$$J\dot{\omega}_r(t) + B\omega_r(t) = M_e + M_L \tag{13}$$

where J_r is rotor moment of inertia, B is viscous friction coefficient, M_L is load moment, by replacing (11) and (12) into (13), derivative of rotor speed $\dot{\omega}_r(t)$ is given as:

$$\dot{\omega}_r(t) = -\frac{B}{J_r}\omega_r(t) + \frac{Kt}{J_r} i_q^{*e} - \frac{M_L}{J_r} = B_p\omega_r + A_p i_q^{*e} + D_p M_L \tag{14}$$

in which, $B_p = -B/J_r < 0; A_p = K_t/J_r > 0; D_p = -1/J_r < 0$. In order to obtain a mathematical model that is suitable for control design, the nominal value of the motor parameters must be taken when ignoring influencing factors of nonlinear componentes and unaffected by any disturbances [13, 14, 17, 19]. Therefore, the kinematic model of the PMSM that given by (14) becomes:

$$\dot{\omega}_r(t) = \bar{B}\omega_r(t) + \bar{A} i_q^{*e} \tag{15}$$

where, $\bar{A} = \bar{K}_t/\bar{J}_r$ and $\bar{B} = -\bar{B}/J_r$ are the nominal values of A_p and B_p, respectively. Therefore, the computations of unmodel system in the equation (14) can be rewritten as:

$$\dot{\omega}_r(t) = (\bar{B} + \Delta B)\omega_r(t) + (\bar{A} + \Delta A) i_q^{*e} + D_p M_L + \delta = \bar{B}\omega_r(t) + \bar{A} i_q^{*e} + L(t) \tag{16}$$

where, $L(t) = \Delta B\omega_r(t) + A i_q^{*e} + D_p M_L + \delta$. In the equation (16), the unknown parameters are represented by ΔA and ΔB; characteristics for the system containing the uncertainty components including the variable parameter and the nolinear estimation error which are unmeasurable components. In addition, these parameters are the unchangeable depend on the dynamics of the system, so in order for simplicity of analysis, calculation and estimation of parameters in my research, the above parameters are assumed to be constant. Therefore, we write as δ. In the above question, $L(t)$ is the unknown components; however, it is limited by $|L(t)| < m$, where m is a positive constant.

3. STUDY OF FUZZY ADAPTIVE SLIDING MODE CONTROLLER FOR THE SYSTEM

3.1. The conventional Sliding mode controller

Sliding mode control offers many advantages in the synthesis of nonlinear contorl system [5, 8, 12], due to invariance to disturbances on the system and unknown components; the order of the system is decreased when the the system in on the sliding surface. We consider the change of speed adjustment error, $e(t) = \omega_r(t) - \omega_r^*(t)$, thus, in the sliding mode with the space state, $S(t)$ can be obtained as:

$$S(t) = h(Ce(t) + \dot{e}(t)) \tag{17}$$

in which, C and h are positive constants, substituting (16) into (17), with the first derivative of $S(t)$ taking the following form:

$$\dot{S}(t) = h\left(C\dot{e}(t) + \bar{B}\dot{\omega}_r(t) + \bar{A}u(t) + \dot{L}(t) - \ddot{\omega}_r^*(t)\right) \tag{18}$$

in which, $u(t) = i_q^e(t)$. Setting, $\dot{S}(t) = 0$ and $\dot{L}(t) = 0$, then the desired performance according to the system kinematics model (equivalent control) is defined as, [1, 4, 5, 9, 20].

$$u_{eq}(t) = -(\bar{A})^{-1}\left[(C + \bar{B})\dot{e}(t) + \bar{B}\dot{\omega}_r^*(t) - \ddot{\omega}_r^*(t)\right] \tag{19}$$

Then the reaching law $u_r(t)$ is designed as:

$$u_r(t) = -(\bar{A}h)^{-1} k(t)\,\mathrm{sign}(S(t)) \tag{20}$$

in which, $k(t) > 0$ and the "sign" function are defined as follows:

$$\mathrm{sign}(S(t)) = \begin{cases} 1, & if\ S(t) > 0 \\ -1, & if\ S(t) < 0 \end{cases} \tag{21}$$

Therefore, the performance of the controller is achieved when considering the utilization of digital controller and unmodeled actuator dynamics, which can be defined as following:

$$u(t) = u_{eq}(t) + u_r(t) \tag{22}$$

$$i_q = \frac{1}{\tau}\int_0^t u(t)dt \tag{23}$$

in which, τ is the integral positive constant. According to the designed control, a Control Lyapunov Function (CLF) candidate is chosen in the following form:

$$V(t) = \frac{1}{2}S^2(t) \tag{24}$$

The stability condition showing the stability can be obtained from the stability theorem of the Lyapunov function of, [1, 5, 8].

$$\dot{V}(t) = S(t).\dot{S}(t) \leq \eta\left|S(t)\right| \tag{25}$$

Where η is a positive constant. From (18), (19) and (22), (25), it can be rewritten as:

$$\begin{aligned} &\dot{V}(t) = S(t).\dot{S}(t) = -S(t)h\bar{A}u_r(t) + hS(t)\dot{L}(t) \\ &\dot{V}(t) \leq -k\left|S(t)\right| + h\left|S(t)\right|\left|\dot{L}(t)\right| \quad \Rightarrow \quad \dot{V}(t) \leq -\left|S(t)\right|(k(t) - hm) \end{aligned} \tag{26}$$

Compare equation (25) and (26) then consider $\left|\dot{L}(t)\right| < m$, the stability of the system is guaranteed according to the following equation:

$$k(t) \geq hm + \eta \tag{27}$$

In practical applications, we may experience undesirable phenomenon of oscillations having finite frequency and amplitude, which is known as 'chattering' especially when η is large recpectly. The phenomenon of chattering can be reduced by replacing the discontinuous function sign with a continuous function of approx $s/(\left|s\right| + \mu)$, in which, μ is a positive constant. Thus, by reaching $\mu \to 0$ the approximate controller characteristic which is approached to the original controller as well [5], [14]. The nonlinear state estimator is considered in this research such as: in rotor flux-based control, information about angular position of the rotor must be provided for conversion of the coordinate system. A nonlinear state observer to accurately estimate the position and speed of the motor with the influence of unmeasured component parameters in both low and high speed regions control. The design sequence of the nonlinear state observer has been carefully presented by the author in the [21]. This nonlinear state observer is used to calculate and estimate the rotor position (θ), rotor speed (ω), load torque component (M_L) and unmeasured component of the system (d1, d2), [25]-[27].

3.2. Fuzzy adaptive sliding mode controller designed

In this paper, we investigated the fuzzy adaptive sliding mode controller for the disturbance observer control tracking approach of the PMSM driven system. Field oriented control (FOC) improves dynamic response by adjusting both amplitude and phase of the control signals feedback to the PMSM. In FOC, stator field is continuously updated based on the position of the rotor field, since position and speed of the motor are estimated based on currents and voltages. thus, a nonlinear state estimator which is estimated accurately of the rotor is implemented as well. The block diagram of the FASMC system is shown in the Fig. 2, which in speed loop control, the stator current i_q^{*e} is represented as its output. The independent control of *Ids* and *Iqs* consisst of two PI regulators. The FOC algorithm usually generates voltage references that a PWM modulator transforms into gating signals for a voltage source inverter. In the present implementation, the rotor position measurement is derived from an angle sensor. Chattering can be eliminated by smoothing the control discontinuity to a limit close to the sliding surface when the "sign" function in (20) is replaced by the function "sat" which is defined as follows:

$$\text{sat}\left(\frac{S}{\psi}\right) = \begin{cases} \text{sign}(S), \text{ when } \left|S\right| > \left|\psi\right| \\ \dfrac{S}{\psi}, \text{ when } \left|S\right| \leq \left|\psi\right| \end{cases} \tag{28}$$

In which, ψ is defined as the thickness of the border layer on the sliding surface. Thus, the discontinuous component control is given by (20) becomes:

$$u_r(t) = -(\bar{A}h)^{-1}k(t)\text{sat}(S(t)/\psi) \tag{29}$$

Since the control is constant within a sampling interval, switching frequency can not exceed that of sampling, which lead to chattering as well. Therefore, the methods of chattering destructively can be developed such that the magnitude is decreased properly holding the establishment of sliding mode. Thus, when the mathematical model of the process does not exist, or exists but with uncertainties, Fuzzy is an alternative way to deal with the unknown process.

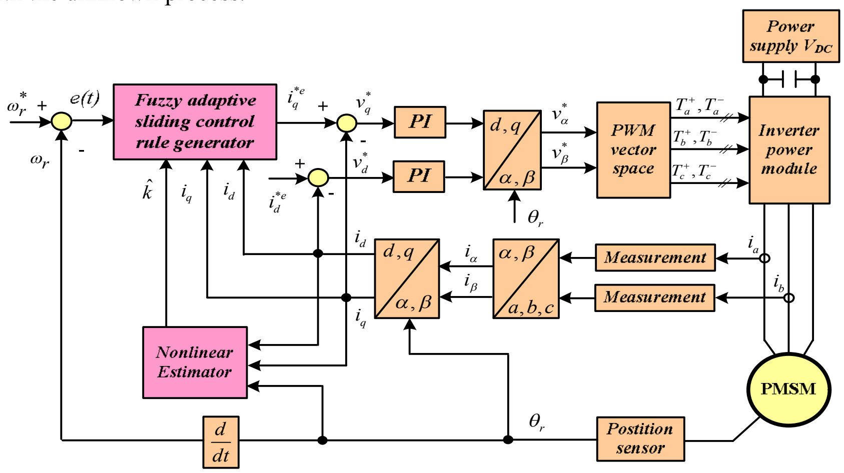


Figure 1. Block diagram of control structure of the drive system using PMSM based on the FASMC

In order to solve these problems, the sign function is replaced by the saturation function which reduce the nonlinear uncertainties. Thus, S(t) is changed to ΔS(t) which is the input variables and the output variable u_{TMTN} of FASMC algorithm is proposed as:

$$u_{TMTN} = TMTN(\mathrm{S}(t), \Delta\mathrm{S}(t)) \tag{30}$$

Then the reaching law and control law are defined as follows:

$$u_r(t) = -(\bar{A}h)^{-1} k(t) u_{TMTN} \tag{31}$$

$$u(t) = u_{eq} - (\bar{A}h)^{-1} k(t) u_{TMTN} \tag{32}$$

Because the plant is lack of an integral action, thus, we chooses a PT fuzzy controller. Additionally, refer to [8, 14], we can build the structure of the FASMC which is shown in the Fig.1.

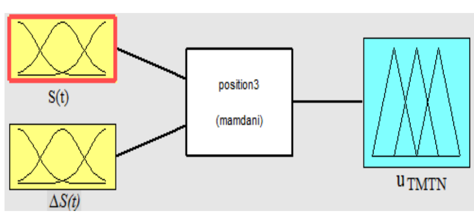


Figure 2. Fuzzy controller structure

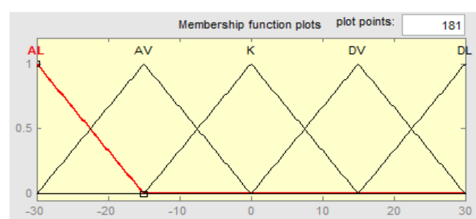


Figure 3. Membership function of Fuzzy controller input *S(t)*

The fuzzy controller consists of: two input linguistic variables which are error S(t), and the error derivative ΔS(t); one output linguistic variable U_{TMTN}. The FASMC structure is illustrated in Figure 2. The fuzzy rule table is set as in Table 1. Inputs and output relationship of the fuzzy controller is as shown in Fig.3, Fig.4, Fig.5 and Fig. 6 the relationship of the fuzzy controller. Then it is necessary to minimize the L(t) which is in (26). Hence, to estimate the k(t) given in Eq. (30) we using the corresponding adaptation law presented in [8].

$$\dot{k}(t) = \lambda_k \left|S(t)\right| \tag{33}$$

in which, λ_k is a positive constant. In fact, t *k(t)* is as an adaptive filter to minimize control errors.

$$\dot{k}(t) = \lambda_k \left|S(t)\right| \tag{33}$$

in which, λ_k is a positive constant. Consider the following Lyapunov candidate function (34), it can be an estimate of *k(t)*.

$$V(t) = \frac{1}{2} S(t)^2 + \frac{1}{2\lambda_k}(k(t) - k)^2 \tag{34}$$

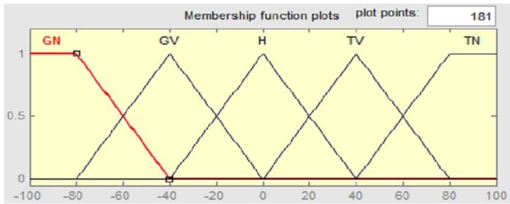


Figure 4. Membership function of Fuzzy controller input $\Delta S(t)$

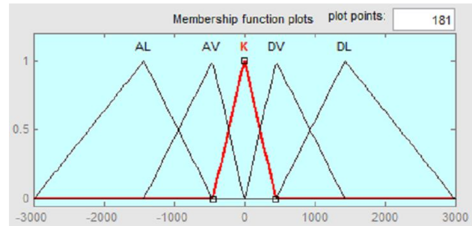


Figure 5. Membership function of fuzzy controller output u_{TMTN}

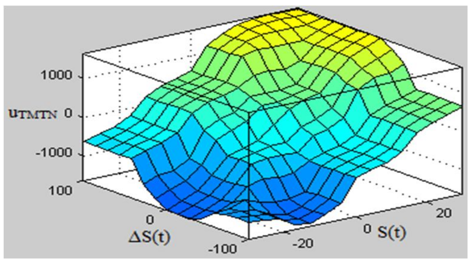


Figure 6. The relationship of the fuzzy controller

Table 1. The rule base of fuzzy controller

u_{TMTN}		$S(t)$				
		AL	AV	K	DV	DL
$\Delta S(t)$	GN	AL	AN	AV	K	DV
	GV	AL	AV	AV	K	DV
	H	AL	AV	K	DV	DL
	TV	AV	K	DV	DV	DL
	TN	AV	K	DV	DL	DL

substitute (18) and (34) for (25) to get $|S(t)| < \psi(t)$ as follows:

$$\dot{V}(t) = S(t)h\left(\bar{A}u_r(t) + \dot{L}(t)\right) + \frac{1}{\lambda_k}\left(k(t) - k\right)\dot{k}(t) = S(t)h\left(-\bar{A}k(t)(h\bar{A})^{-1}\operatorname{sgn}(S) + \dot{L}(t)\right) + \\ + \frac{1}{\lambda_k}\left(k(t) - k\right)\dot{k}(t) = -S(t)k(t)\operatorname{sgn}(S) + h\mathrm{S}(t)\dot{L}(t) + \frac{1}{\lambda_k}\left(k(t) - k\right)\dot{k}(t). \tag{35}$$

Substitute (33) for (35) and alter (25), we get:

$$\begin{aligned} \dot{V}(t) &\le \left|k(t) - k - k\right|\left|S(t)\right| + h\left|\dot{L}(t)\right|\left|S(t)\right| + \left|k(t) - k\right|\left|S(t)\right| \\ &< -\left|k(t) - k\right|\left|S(t)\right| - k\left|S(t)\right| + hm\left|S(t)\right| + \left|k(t) - k\right|\left|S(t)\right| \\ &< (-k + hm)\left|S(t)\right| \end{aligned} \tag{36}$$

Compare (25) and (36), we get:

$$\dot{V}(t) < (-k + hm)\left|S(t)\right| \le \eta\left|S(t)\right| \tag{37}$$

Therefore, the component k can be chosen so that the value of $-k + mh + \eta$ is still negative In other words, for the stable working process of the proposed adaptive fuzzy sliding controller, we choose $-k \ge +mh + \eta$. In this paper, by applying the proposed adaptive fuzzy sliding controller along with the designed fuzzy rules and the mentioned conditions, the system stability condition in (25) will be satisfy and thus the stability of the system is guaranteed. In practical, the factors of frictional moment, elasticity, clearance, etc. always exist in the electro-mechanical drive system including motor and working structure. This is a typical nonlinear component, traditional controllers have not been able to overcome their influence on the system working quality. By improving the quality of the FASMC, the effects of the nonlinear factors on the quality of the drive system have been resolved, [14, 15, 16]. The controller is synthesized for the proposed nonlinear quantity object; have made the system operate smoothly, overcome the nonlinearity well, especially always make the system stable globally asymptotically.

Parameters V_p, V_I are chosen based on Zeigler - Nichols experimental method. After choosing parameters V_p, V_I, we can calculate parameters V_p and d. However, due to experimental method, in order to improve control quality: short transient time and small overshoot since two parameters V_p and d need to be adjusted furtherly. Parameters is set: V_P = 0.01; d = 0.99 (with T = 0.002). The quality of the PI controller after calculating the selection, we obtain: K_P = 0.3; K_I = 0.0001. The PID-controller design process is considered in [1, 14, 17, 18, 19].

4. SIMULATION AND EXPERIMENTAL RESULTS

The Simulation and experimental results of FASMC are shown as following. The paramenters of PMSM is model: 1FK708-2AF71-1EA0 of Siemens, motor code YF C037579101001, including: Power P = 2.1 kW; rated speed 3000 rpm; voltage U = 315 V; rated current I = 4.4A; number of poles 2p = 8; static torque M_0 = 8.0 Nm; Rated torque M_{dm} = 6.8Nm; coefficient of viscous friction B = 0.0001 N.m.s / rad;

moment of inertia J = 14200 kgcm²; maximum allowable speed 6000 rpm; encoder AM 2048 S/R; The mass of the engine is 10.3 kg. Simulation results for the following cases.

Case 1: Simulation of evaluation the system's working ability when the speed changes with amplitude of 1000 rpm to -1000 rpm, the load moment changes in the form of a sinusoid, the load torque is 0.5Nm which shows in Fig.7~10.

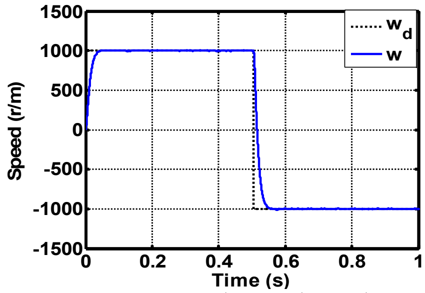


Figure 7. Response speed ω_d and actual speed ω of motor in case 1

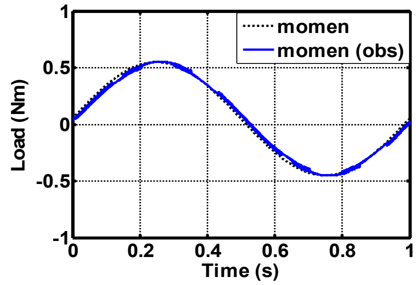


Figure 8. Response torque and estimated torque in case 1

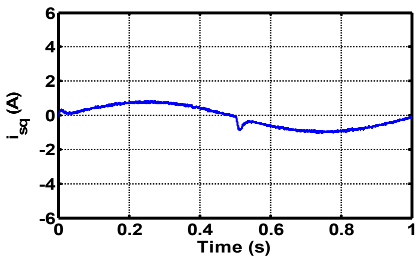


Figure 9. Current response iq in Case 1

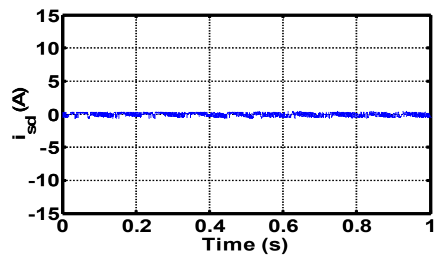


Figure 10. Current response i_d in case 1

Case 2: Simulation of evaluation the motor speed with amplitude of 50 rpm and speed of working structure is 0.5 rpm. The input is a unchanged load torque constant that shown in Fig.11~14:

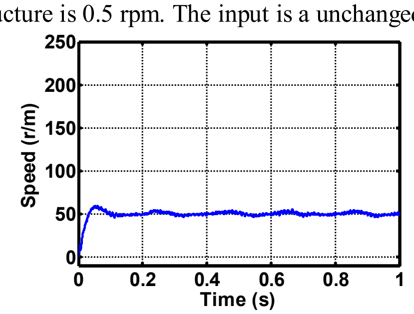


Figure 11. Response speed ω_d and actual speed ω of motor in case 2

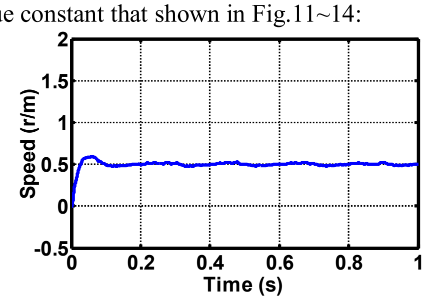


Figure 12. Response set speed ω_d and actual speed ω of the working mechanism case 2

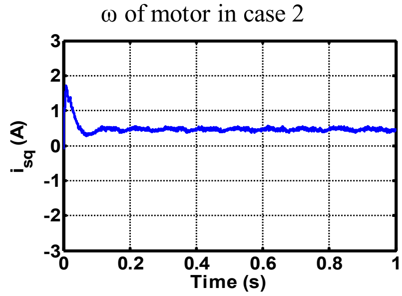


Figure 13. Current response i_q in case 2

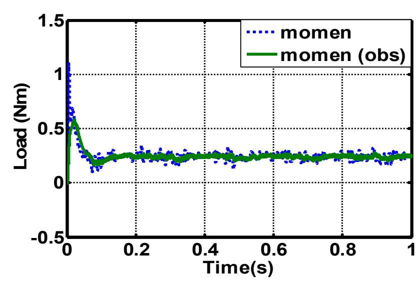


Figure 14. Response torque and estimated torque in case 2

Case 3: Simulation the system's response when the input angle changes according to the law of function Xv = V.t, (V = 1rad/s) constant load moment Mc = 0,5Nm that shown in Fig.15~18:

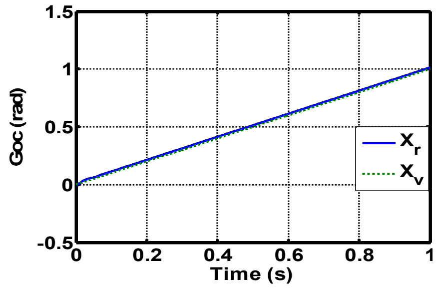


Figure 15. Controller input/output response in radian in case 3

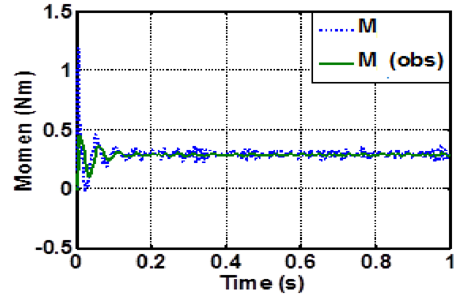


Figure 16. Controller input/output response in torque in case 3

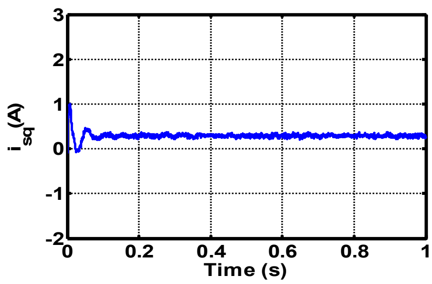


Figure 17. Current response iq in case 3

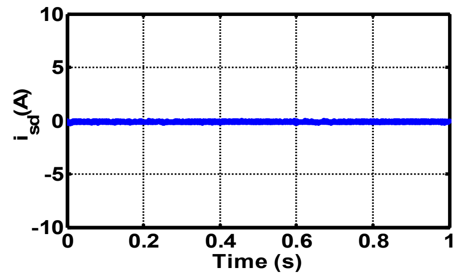
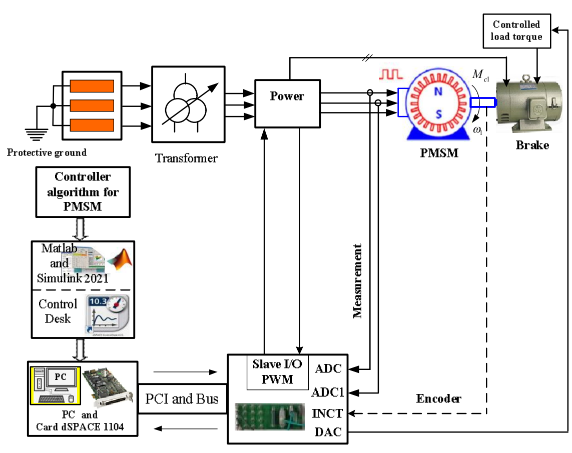
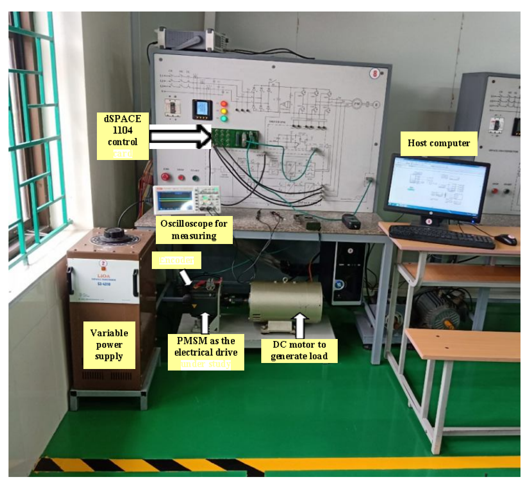


Figure 18. Current response id in case 3

The simulation results of some cases shows that the FASMC is proposed with the sustainability, stability of the control law against the effects of unknown parameters which will change the transition time, increase the fast response of the system. Moreover, in the transient mode, the aplication of proposed controller given a good performance response as well.

The experimental structure diagram as shown in figure 19a and the experimental system in real time is depicted in figure 19b: with its designed, built and simulated on Matlab simulinks 2021 and connected to the control board. dSPACE 1104 with a combination of graphical control desk software in controlling; observe system characteristics in real time. Combined with power electronics, and current measurement sensors connected to the dSPACE panel. PMSM motor parameters used in the experiment are the same as those used in simulations, encoder AM 2048 S/R, DC motor used to generate loads, symbol DOLIN - SH.198V with voltage U = 190V, I = 13.5A, n = 175 rpm.





a) b)

Figure 19. The overall system in experimental: a) Structure and control diagrams; b) The experimental table system using dSPACE 1104

Studying the process of changing low speed from 50 rad/s (478 rpm) to - 50 rad/s (-478 rpm, timing the conversion is 2.5s in the total response time of 5s, figure 20. The results show that the FASMC controller response is working well, the output is close to the input in the balance process, the current response value Id and Iq in figure 21 shows the correct working process of the system.

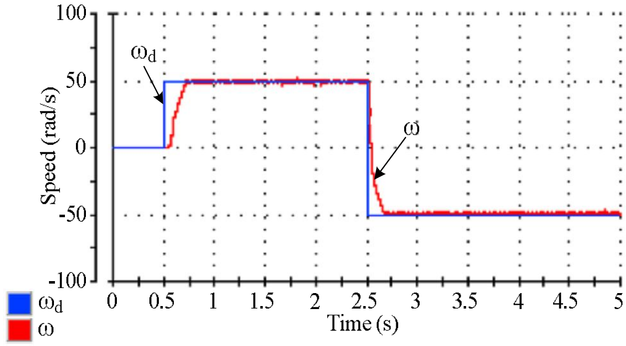


Figure 20. The experimental response by changing speed from 50 rad/s to -50 rad/s speed

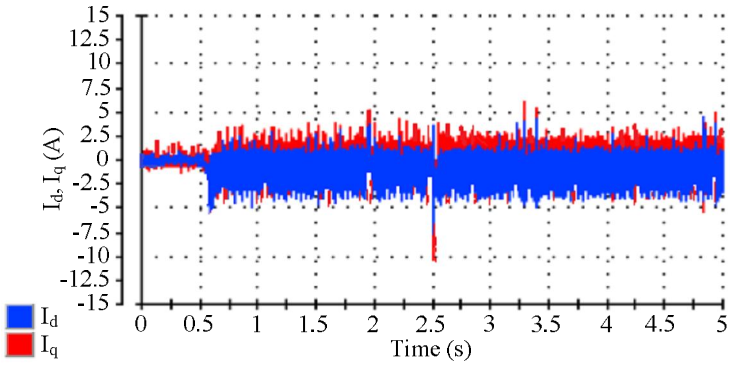


Figure 21. The experimental results with current values I_d and I_q

5. CONCLUSION

The traction drive system for control objects in industry and military needs very high reliability and accuracy; replacing old control systems is necessary and urgent in traction electric systems being used a lot in practice. The paper presented a new approach, researched and built an adaptive FASMC for industrial traction drive systems. The main advantage of this method is that the robust behavior of the system is guaranteed. The second advantage of the proposed FASMC is that the performance of the electric drive system in the sense of reducing chattering is improved. Theoretical research and simulation results show that the proposed FASMC algorithm for PMSM which achieves good quality and more stable operation. The results of simulation and experimental studies with the dSPACE 1104 card show that the above control algorithm achieves good quality and stable operation when compared to other research works, [15, 16, 27]. This study has proven the correctness of the FASMC algorithm which has ability to apply in practice to the traction electric drive systems.

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