

Speed Control of Switched Reluctance Motor Using Fuzzy Sliding Mode

Ahmed TAHOUR¹, Hamza ABID², Abdel Ghani AISSAOUI³

¹University of Bechar, 08000, Algeria

²AML Laboratory, University of Sidi Bel Abbes, 22000, Algeria

³IRECOM Laboratory, University of Sidi Bel Abbes, 22000, Algeria,

Corresponding author e-mail: tahourahmed@yahoo.fr

Abstract—In this paper, a fuzzy logic controller (FLC) is designed, based on the similarity between the FLC and the sliding mode control (SMC), for a class of nonlinear system to tackle the nonlinear control problems with modelling uncertainties, plant parameters variations and external disturbances. The proposed scheme gives fast dynamic response with no overshoot and zero steady-state error. To show the validity and the effectiveness of the control method, simulations are performed for the speed control of a switched reluctance motor. The simulation results show that the controller designed is more effective than the conventional sliding mode controller in enhancing the robustness of control systems with high accuracy.

Index Terms—switched reluctance motor, sliding mode control, fuzzy logic and speed control.

I. INTRODUCTION

Sliding mode control (SMC) systems or variable structure control systems have been studied extensively to tackle problems of the nonlinear dynamic control systems with modeling uncertainties, time varying parameter fluctuation, and external disturbances [3, 4].

The main disadvantage of this approach is the high switching frequency of the control action or chattering that VSC system exhibit. Chattering is undesirable since it can excite the unmodeled high frequency dynamics in the nonlinear system control. Introducing a boundary layer is one of the most common techniques used, with the cost of an important degradation in tracking performance [4, 8]. Recently, the synthesis algorithms of modern control theory and artificial intelligent (AI) have been studied to upgrade the performance of SMC. In this paper, a methodology of FLC based on SMC is presented. The fuzzy sliding mode control (FSMC) takes the features of both SMC and FLC to overcome the disadvantage of chattering and enhance the robustness of the controllers. The motivation of this study is to design an FSMC control scheme in order to control the speed of switched reluctance motor. The organization of this paper is as follows: first, the model of SRM is presented; next, the modified sliding-mode controllers (SMC) are described and its stability is guaranteed by Lyapunov theory. In section 5, we show how an FC works like a modified SMC. A rigorous simulation is carried out for the system under study, and finally conclusions are summarized in the last section.

II. SRM MODEL

A. Description of the system

In a switched reluctance machine, only the stator presents windings, while the rotor is made of steel laminations without conductors or permanent magnets. This very simple structure reduces greatly its cost. Motivated by this mechanical simplicity together with the recent advances in the power electronics components, much research has being developed in the last decade.

The switched reluctance machine motion is produced because of the variable reluctance in the air gap between the rotor and the stator. When a stator winding is energized, producing a single magnetic field, reluctance torque is produced by the tendency of the rotor to move to its minimum reluctance position [1, 2, 7].

A cross-sectional view is presented in figure 1.

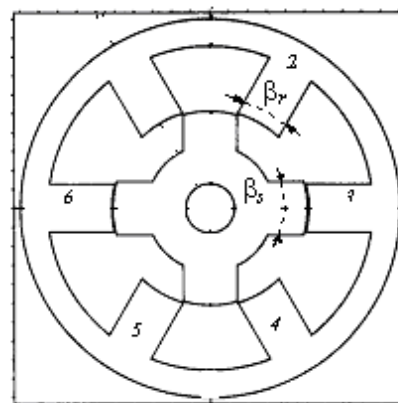


Figure 1. Switched reluctance motor.

The schematic diagram of the speed control system under study is shown in figure 2. The power circuit consists with the H-bridge asymmetric type converter whose output is connected to the stator of the switched reluctance machine. Each phase has two IGBTs and two diodes. The parameters of the switched reluctance motor are given in the Appendix [2, 7].

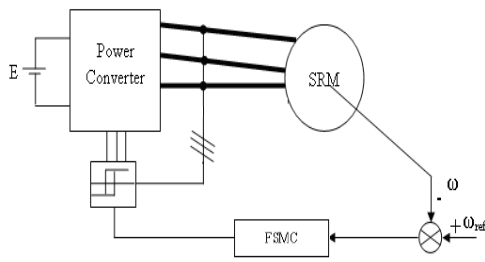


Figure 2. Control of SRM.

B. Machine equation

The switched reluctance motor has a simple construction, but the solution of its mathematical models is relatively difficult due to its dominant non-linear behaviour. The flux linkage is a function of two variables, the current I and the rotor position (angle q).

The mathematical model from the equivalent circuit is [1, 2]:

$$V_j = RI_j + \frac{d\Psi_j(i, q)}{dt} \quad (1)$$

With $j = 1, 2, \dots, 3$

Then we can write:

$$V_j = RI_j + \frac{d\Psi_j(i, q)}{di} \frac{di}{dt} + \frac{d\Psi_j(i, q)}{dq} w \quad j=1, 2, 3 \quad (2)$$

In which: $w = \frac{dq}{dt}$

The motion equation is:

$$J \frac{dw}{dt} = T_e - T_l - fw \quad (3)$$

$$T_e = \frac{1}{2} \frac{dL(q, i)}{dq} i^2 \quad (4)$$

The average torque can be written as the superposition of the torque of the individual motor phases:

$$T_e = \sum_{phase=1}^n T_{phase} \quad (5)$$

Where V - the terminal voltage, I - the phase current, R - the phase winding resistance, Ψ - the flux linked by the winding, J - the moment of inertia, f - the friction, $L(q, i)$ - the instantaneous inductance and T_e is the total torque.

III. SLIDING MODE CONTROL

Sliding modes is phenomenon may appear in a dynamic system governed by ordinary differential equations with discontinuous right-hand sides. It may happen that the control as a function of the system state switches at high frequency, this motion is called sliding mode. It may be enforced in the simplest tracking relay system with the state variable $x(t)$ [3, 4, 6, 11]:

$$\frac{\partial x}{\partial t} = f(x) + u \quad (6)$$

With the bounded function $f(x)$
 $|f(x)| < f_0$ f_0 constant and the control as a relay

function of the tracking error $e = r(t) - \frac{\partial x}{\partial t}$ $r(t)$ is the reference input and u is given by :

$$u = \begin{cases} u_0 & \text{if } e > 0 \\ -u_0 & \text{if } e < 0 \end{cases} \quad (7)$$

or $u = u_0 \text{sign}(e)$ $u_0 = \text{const}$

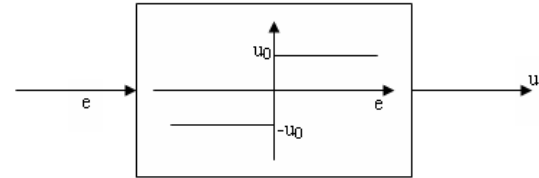


Figure 3. relay control.

The values of e and $\frac{\partial e}{\partial t} = \dot{e} = \dot{r} - f(x) - u_0 \text{sign}(e)$

have different signs if $u_0 > f_0 + \left| \dot{r} \right|$.

IV. SPEED CONTROL

The speed error is defined by [8, 9]:

$$e = w_{ref} - w \quad (8)$$

from the equation (8) and (3), we can be obtains

$$\dot{S} = w_{ref} - \frac{f}{J} w + \frac{K_t}{J} I - \frac{C_r}{J} \quad (9)$$

The current of control is given by

$$I = I_{eq} + I_s \quad (10)$$

$$I_s = K_w \text{sign}(s(w)) \quad (11)$$

K_w positive constant.

The current control I_{eq} is defined by:

$$I_{eq} = \left(\frac{J}{k_t} \right) (\dot{w}_{ref} + \left(\frac{f}{J} \right) w + \frac{T_l}{J}) \quad (12)$$

V. FUZZY SLIDING MODE CONTROL

The disadvantage of sliding mode controllers is that the discontinuous control signal produces chattering dynamics; chatter is aggravated by small time delays in the system. In order to eliminate the chattering phenomenon, different schemes have been proposed in the literature [12, 13]. In this section, a Fuzzy-Sliding mode controller is developed, in which a fuzzy inference mechanism is used to generate the equivalent control law parameters. The proposed fuzzy-sliding mode controller scheme for SRM speed control is shown in Fig. 5. The fuzzy logic controllers replace the inequalities given in (11) which determine the parameters of the equivalent control action. We follow the development established in [12] and show that a particular fuzzy controller is an extension of an SMC with a boundary layer [12, 13]. Suppose the fuzzy controller in this article is constructed from the following

IFTHEN rules:

Rule1: if s is NB, then u is Bigger

.

.

.

Rule (i): if s is F_s^i , then u is F_u^i

Here NB is negative big, NM is negative medium, ZR is zero, PB is positive big and PM is positive medium. NB, NM, ..., SMALL, SMALLER are labels of fuzzy sets and their corresponding membership functions are depicted in figures 3 and 4, respectively.

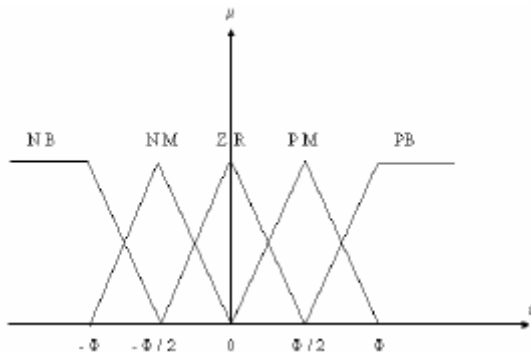


Figure 3. Membership function for inputs.

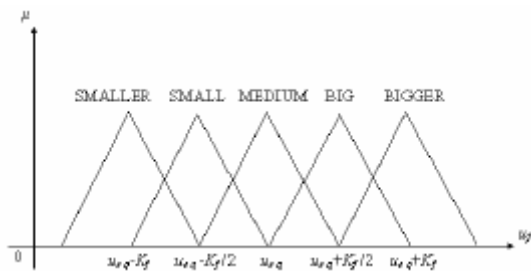


Figure 4. Membership function for output u .

In this paper, the triangular membership function, the max-min reasoning method, and the center of gravity defuzzification method are used, as those methods are most frequently used in many literatures [13, 14].

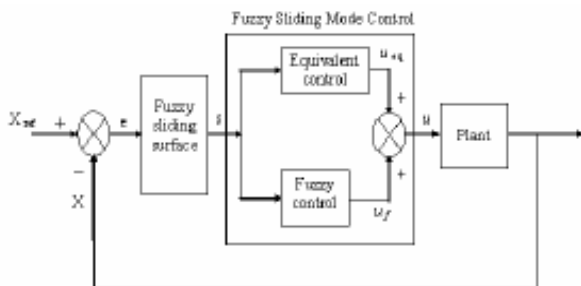


Figure 5. The bloc diagram of the fuzzy sliding mode control (FSMC).

VI. SIMULATION AND RESULTS

In order to validate the control strategies as discussed above, digital simulation studies were made the system

described in figure 1. The speed and currents loops of the drive were also designed and simulated respectively with fuzzy sliding mode control and sliding mode control. The feedback control algorithms were iterated until best simulation results were obtained.

The simulation of the starting mode without load is done, followed by speed reference $w_{re} = 150 \text{ rd/s}$ to $w_{re} = 100 \text{ rd/s}$ at 0,5s. The simulation is realized using the SIMULINK software in MATLAB environment.

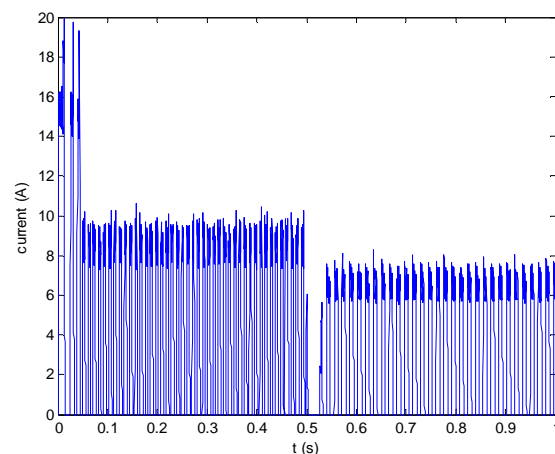
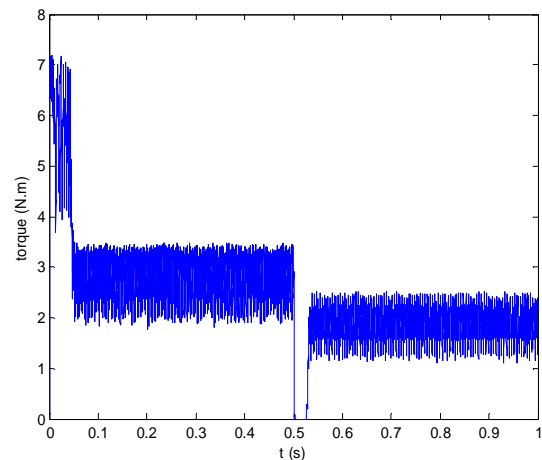
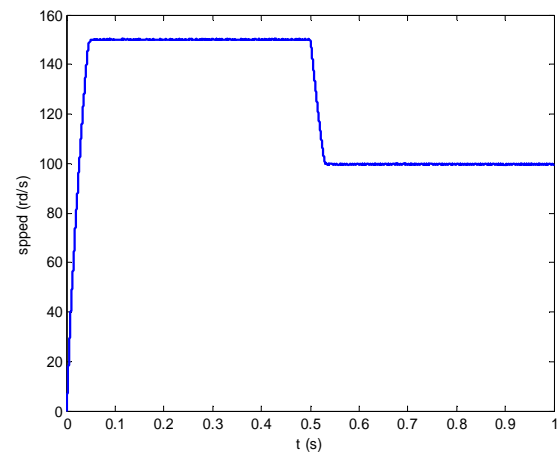
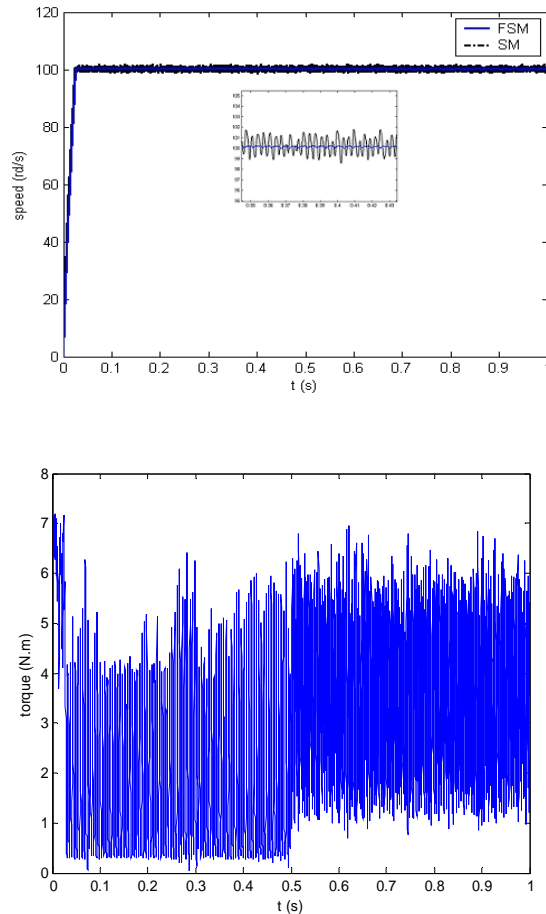
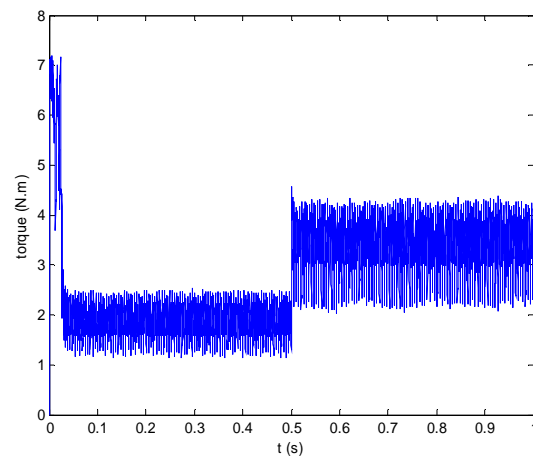


Figure 6. Simulation results of speed controller.

Figure 6 shows the performances of the fuzzy sliding mode controller. The control presents the best performances, to achieve tracking of the desired trajectory. The fuzzy sliding mode controller rejects the load disturbance rapidly with no overshoot and with a negligible steady state error. The simulation results show that the proposed controller is superior to SMC in eliminating chattering phenomena that appears in speed trajectory and in torque oscillation (figure 7).



1- Sliding mode control



2- Fuzzy sliding mode control.

Figure 7. Control of SRM speed by.

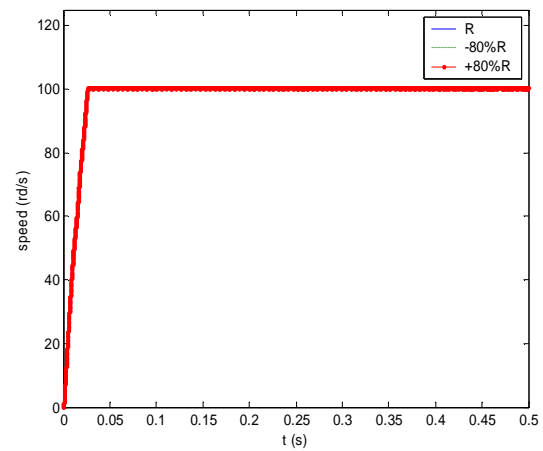
VII. ROBUSTNESS TESTS

In order to test the robustness of the used method we have studied the effect of the parameters uncertainties on the performances of the speed control. To show the effect of the parameters uncertainties, we have simulated the system with different values of the parameter considered and compared to nominal value (real value).

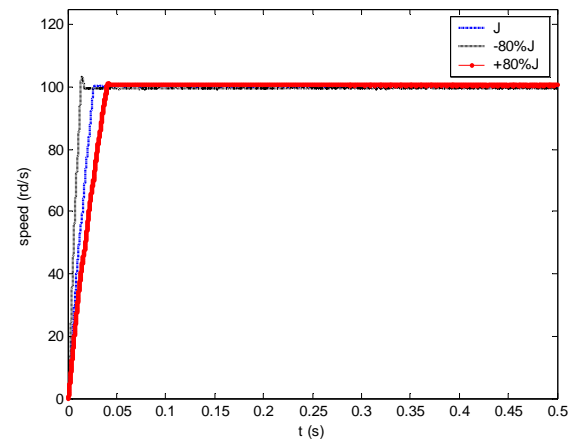
Two cases are considered:

- The moment of inertia.
- The stator resistances.

To illustrate the performances of control, we have simulated the starting mode of the motor without load; in presence of the variation of parameters considered (the moment of inertia, the stator resistances) with speed step of 100 rd/s .



a) Different values of resistance of stator



b) Different values of moment of inertia

Figure 8. Test of robustness.

Figure (8.a) shows the tests of robustness realized with fuzzy sliding mode control for different values of the moment of inertia.

Figure (8.b) shows the tests of robustness realized with fuzzy sliding mode control for different values of stator

resistances.

For the robustness of control, a decrease or increase of the moment of inertia J or the resistances doesn't have any effects on the performances of the technique used (figure 8.a and 8.b). An increase of the moment of inertia gives best performances, but it presents a slow dynamic response (figure 8). The proposed control gives to our controller a great place towards the control of the system with unknown parameters.

VIII. CONCLUSION

In this paper, we designed a sliding mode like FLC based on the similarity between the FLC and the sliding mode control. The proposed method permits us to use more formalized engineering type of knowledge to construct the FLC with fast self tuning the dead zone parameters (boundary layer thickness) under parameter variations in the controlled system. The different simulation results obtained show the high robustness of the controller in presence of the parameters variation as the resistances, the moment of inertia or the load. The control of speed gives fast dynamic response. The decoupling, stability and convergence to equilibrium point are verified.

REFERENCE

- [1] MILLER, T.J.E. Brushless -permanent-magnetic and reluctance motor drives. Oxford science publication 1989.
- [2] Krishnan R. Switched reluctance motor drives modeling, simulation, analysis, design and applications. London: CRC Press; 2001.
- [3] V.Utkin, J.Guldner, J.Shi, Sliding mode control in electromechanical systems, Ed Taylor and Francis 1999.
- [4] V. I. Utkin, Sliding mode control design principles and applications to electric drives, IEEE Trans. Industrial Electronics, Vol. 40, No. 1, February 1993
- [5] S. K. Panda and P. K. Dash, Application of nonlinear control to switched reluctance motors: A feedback linearization approach, Proc.Inst. Elect. Eng., vol. 143, pt. B, no. 5, pp. 371–379, 1996.
- [6] W. Perruquetti, J.P.Barbot, Sliding Mode Control In Engineering, Ed Marcel Dekker, 2002
- [7] F. Soares and P.J. Costa Branco, Simulation of a 6/4 Switched Reluctance Motor Based on Matlab/Simulink Environment, aerospace and electronic system. IEEE transactions, Vol 37 pp989-1009, July 2001.
- [8] Tzu-Shien Chuang and Charles Pollock, Robust Speed Control of a Switched Reluctance Vector Drive Using Variable Structure Approach, IEEE Transactions On Industrial Electronics, Vol. 44, No. 6, DECEMBER 1997 pp.800.808
- [9] I. Husain, S. Sodhi and M. Ehsani A sliding mode observer based controller for switched reluctance motor drives conference record of IEEE-IAS annual meeting, Denver, CO, pp 635-643, 1994.
- [10] Slotine J. J. E., Li W., Applied nonlinear control Prentice Hall, USA, 1998.
- [11] Buhler H., Réglage par mode de glissement, Presses polytechniques romandes, Lausanne, 1986.
- [12] Ji Chang Lo, Ya Hui Kuo, Decoupled fuzzy sliding mode control, IEEE Trans. on Fuzzy Systems, vol. 6, N°3, August 1998.
- [13] Kim W., Lee J. J., Design of a fuzzy controller with fuzzy sliding surface. Fuzzy Sets Syst., vol. 71, 1995, 359–367.
- [14] Hwang G. C. , Lin S. C., A stability approach to fuzzy control design for non linear systems. Fuzzy Sets Syst., vol. 48, 1992, 279–287.