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SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR USING A FUZZY ADAPTIVE CONTROLLER

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***Abstract** : In this paper the speed control of a switched reluctance motor using fuzzy adaptive design is proposed. First, a fuzzy adaptive design for speed control of SRM is descriped. Finally, the fuzzy adaptive controller is investigated. The effectiveness of the proposed control scheme is verified by numerical simulation. Digital simulation results shows that the designed adaptive fuzzy speed controller realises a good dynamic behaviour of the motor, a perfect speed tracking with no overshoot and a good rejection of impact loads disturbance.*

1. Introduction

Switched reluctance motors (SRMs) can be applied in many industrial applications due to their cost advantages and ruggedness. The switched reluctance motor is simple to construct. It is not only features a salient pole stator with concentrated coils, which allows earlier winding and shorter end turns than other types of motors, but also features a salient pole rotor, which has no conductors or magnets and is thus the simplest of all electric machine rotors. Simplicity makes the SRM inexpensive and reliable, and together with its high speed capacity and high torque to inertia ratio, makes it a superior choice in different applications [1, 2].

Fuzzy controllers can be easily combined with traditional controllers thus making various combinations of complex or so-called hybrid fuzzy control schemes [3]. The usage of a fuzzy controller in parallel with a PI controller has been adopted as a standard industry solution. By adding a nonlinear component to the existing PI controller, a new controller can cope much better with process nonlinearities in a certain range around the operating point. We show that in a selected servo control application, design of such a controller can ensure high robustness to moderate parameter variations and fair robustness to large parameter variations.

In the complex fuzzy control systems, we can count all forms of fuzzy controllers combined with conventional nonlinear controllers, as well as all combinations of fuzzy control algorithms and other intelligent control techniques [4]. In this paper, we shall focus an adaptive fuzzy control structures, which are, due to their simplicity and effectiveness, attractive for implementation in control system. Since the year 1951 when Draper and Li introduced an adaptive control system, which searched for the optimal operating point of an internal combustion engine, different adaptive control methods have been developed [3, 5], some of them focused on adapting parameters (so-called parameter adaptation) and some of them on adapting signals (so-called signal adaptation). In order to maintain a uniform dynamic performance of the control system, we need to set a control goal in the form of a desired control quality criterion. Then we need to gather information from the control system, for assessment of the achieved control quality. Based on a difference between them, a decision about necessary changes, either in feedback controller parameters or in adaptation signal is made. An adaptation law contained in the adaptation algorithm defines how parameters or signal will be changed. All these functions together form an adaptation mechanism. While planning to solve a control problem by using an adaptation mechanism, we should keep in mind real system characteristics, especially the imposed limits on key system variables, type of implementation, and the width of operating range.

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The organization of this paper is as follows: in section 2, the diagram of the speed control of SRM drive is presented; in section 3, the proposed fuzzy adaptive and used to control the speed of the switched reluctance motor. Simulation results are given to show the effectiveness of this controller. Conclusions are summarized in the last section.

2. SRM Model

2.1. 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, 5]. A cross-sectional view is presented in figure 1.

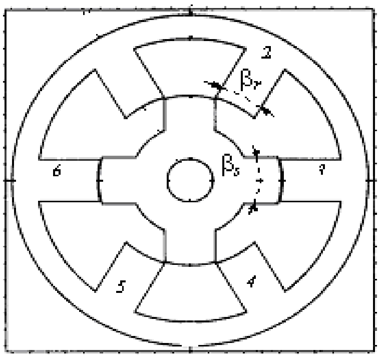


Figure. 1 Switched reluctance motor

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, 6].

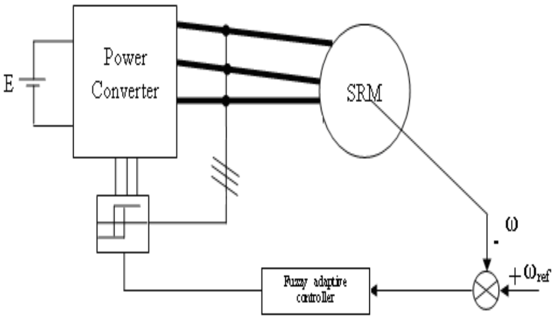


Figure. 2 Control of SRM

2.2. 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 θ).

The mathematical model from the equivalent circuit is [1, 2, 7]:

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

With $j = 1,2....3$

Then we can write:

$$V_j = RI_j + \frac{d\Psi_j(i,\theta)}{di}\frac{di}{dt} + \frac{d\Psi_j(i,\theta)}{d\theta}\omega \qquad j = 1,2....3 \quad (2)$$

In which: $\omega = \dfrac{d\theta}{dt}$

The motion equation is:

$$J\frac{d\omega}{dt} = T_e - T_l - f\omega \qquad (3)$$

$$T_{phase} = \frac{1}{2}\frac{dL(\theta,i)}{d\theta}i^2 \qquad (4)$$

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

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

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, $L(\theta,i)$ - the instantaneous inductance and T_e is the total torque.

3. SRM Fuzzy Adaptive Speed Controller

3.1. Fuzzy Adaptive Principle

Adaptive control has an important role in modern control systems. During operation, many controlled processes experience abrupt or continuous parameter variations, varying external conditions and, in some occasions, alternations of operating modes. For example, continuous changes of inertial moments and gravity-dependent loads are affecting robot joint servo control loops. Control of mass flow in plastic extruders must deal with a gradual change of material density, temperature, and viscosity as well as varying homogeneity of the material. The fuzzy adaptive are represented with a general structure shown in figure 3 [8, 9, 10, 11, 12].

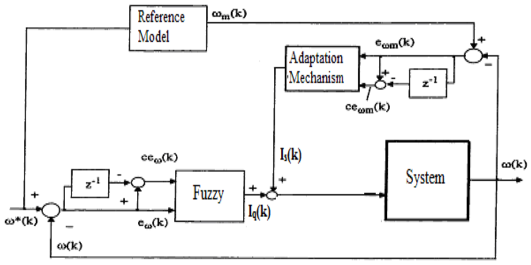


Figure.3 Fuzzy model reference learning controller structure

3.2. Fuzzy Adaptive Controller

The goal of a model reference adaptive fuzzy controller design is to find a controller capable to keep a difference (i.e., a tracking error) between the reference model and the process as small as possible. This goal can be accomplished in several possible ways, as shown in figure 4 [13, 14].

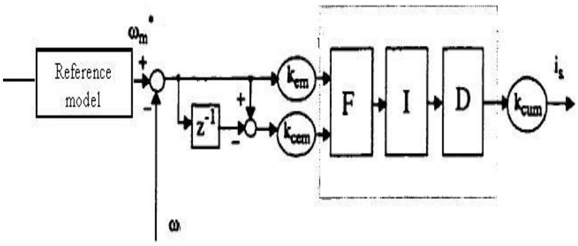


Figure.4 structure of adaptation mechanism

The output of the model of reference ω_m^* is compare with the response of the system in order to produce a signal of correction to reduce the difference. There are two signals which input the block of adaptation of fuzzy logic (fig. 4): Error between the output of the model of reference and speed of the motor, and the derivate of this error which can be giving has the moment K come follows:

$$e(k) = \omega_m(k) - \omega(k) \qquad (6)$$

$$de(k) = e_{\omega_m}(k) - e_{\omega}(k-1) \qquad (7)$$

These sizes of input are treated by the system of adaptation by using the rules of fuzzy logic to produce a signal of adaptation $I_s(k)$ which is addition has the output of the direct RLF.

$$I(k) = I_s(k) + I_q(k) \qquad (8)$$

With $I_q(k)$ is the output of fuzzy logic controller.

Table 1 shows the rules base. The rows represent the rate of the error change $ce_{\omega m}$ and the columns represent the error $e_{\omega m}$.

Table 1. Rules Base for speed control.

$ce_{\omega m}$	$e_{\omega m}$						
	-3	-2	-1	0	1	2	3
-3	-3	-3	-3	-3	-2	-1	0
-2	-3	-3	-3	-2	-1	0	1
-1	-3	-3	-2	-1	0	1	2
0	-3	-2	-1	0	1	2	3
1	-2	-1	0	1	2	3	3
2	-1	0	1	2	3	3	3
3	0	1	2	3	3	3	3

The fuzzy controller combines with the fuzzy adaptive controller as shown in figure. 4. Instead of using two variables for setting up fuzzy rule base on the fuzzy adaptive controller.

Corresponding membership functions are depicted in figures 5 and 6, respectively.

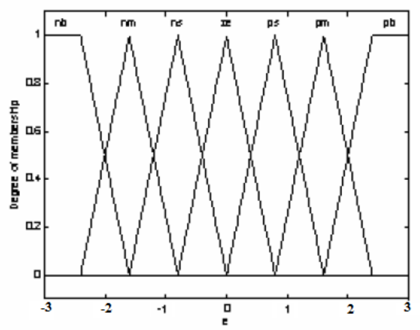


Figure. 5. – Membership functions attributed to *e*.

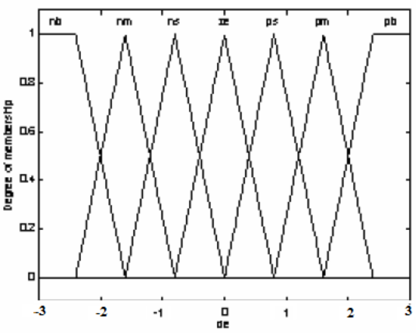
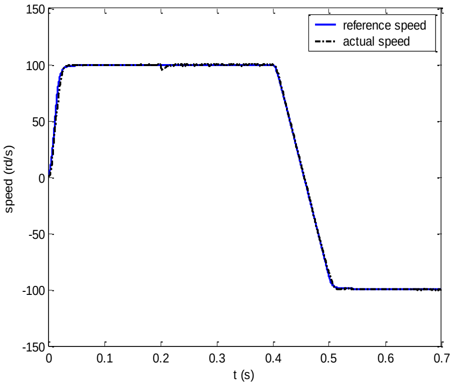


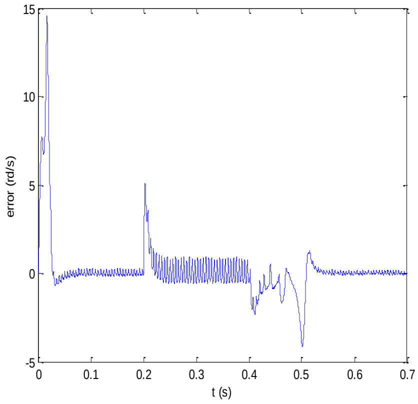
Figure. 6. – Membership functions attributed to d*e*.

4. Simulation Results

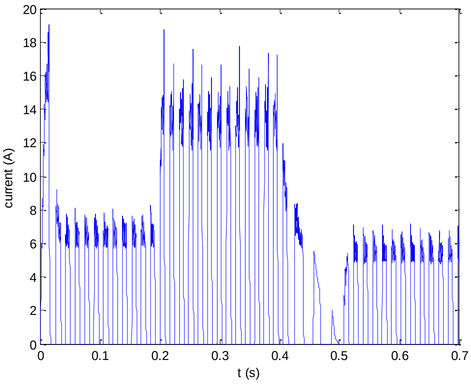
The simulation of the starting mode without load is done. A simulation test was achieved for two speed reference signals, respectively: +100 and -100 rad/s. These results have been obtained with a load of $T_r = 1{,}5\,\text{Nm}$ applied at $t = 0{,}2\,\text{s}$. The simulation is realized using the SIMULINK software in MATLAB environment. The fuzzy adaptive controller uses 7×7 rule base. These transient responses of the proposed fuzzy adaptive control systems do not exhibit any overshoots; that is, the outputs never exceed their final values during the transients.



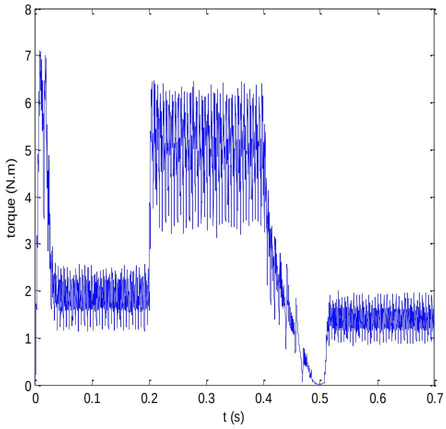
a)



b)



c)



d)

Figure.7 Response of System, a) Speed, b) Tracking Error of Speed, c) Current and d) Torque.

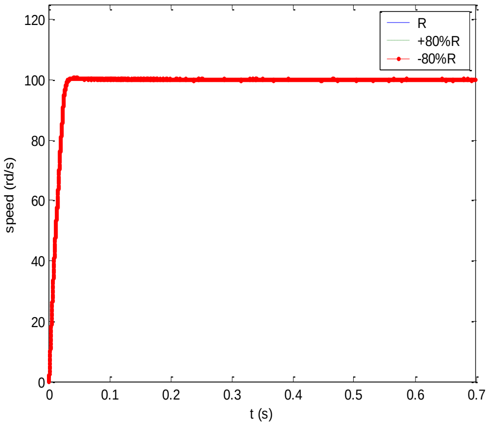
5. Robustness

In order to test the robustness of the proposed control, we have studied the speed performances. Two cases are considered:

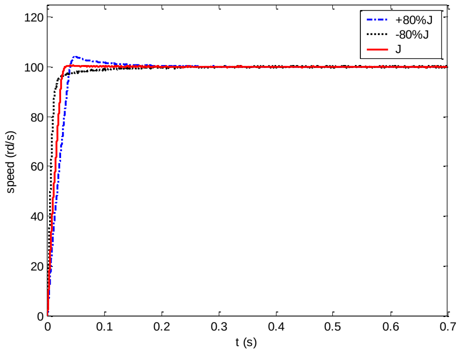
1. Inertia variation,
2. Stator resistance variation.

The figure 8 shows the tests of the robustness: a) The robustness tests concerning the variation of the resistances, b) the robustness tests in relation to inertia variations

Figure 8 shows the parameter variation does not allocate performances of proposed control. The position response is insensitive to parameter variations of the machine, without overshoot and without static error. The other performances are maintained



a) For Different Values of Stator Resistance



b) For Different Values of moment of inertia:
Figure. 8 Test of The Robustness

6. Conclusion

The paper presents a new approach to robust speed control for switched reluctance motor. It develops a simple robust controller to deal with parameters uncertain and external disturbances and takes full account of system noise, digital implementation and integral control. The control strategy is based on adaptive fuzzy approaches.

The simulation study clearly indicates the superior performance of adaptive fuzzy control, because it is inherently adaptive in nature. It appears from the response properties that it has a high performance in presence of the plant parameters uncertain and load disturbances. It is used to control system with unknown model. The control of speed by adaptive fuzzy gives fast dynamic response without overshoot and zero steady-state error.

7. Appendix

Phase number 3; Number of stator poles 6; 30° pole arc; Number of rotor poles 4; 30° pole arc; Maximum inductance 60 mH (unsaturated); Minimum inductance 8 mH; Phase resistance R=1,3Ω ; Moment of inertia J=0,0013Kg.m^2 ; Friction f=0,0183Nm/s; Inverter voltage V=150 V.

8. References

[1] Miller TJE. Switched Reluctance Motors and Their Control. Oxford: Oxford University Press; 1993.

[2] Krishnan R., Switched Reluctance Motor Drives Modeling, Simulation, Analysis, Design and Applications. London: CRC Press; 2001

[3] Mendel J.M., Fuzzy Logic Systems for Engineering: Tutorial, Proceedings of the IEEE, vol. 83, no. 3, March 1995.

[4] Cirstea M.N., Dinu A., Khor J.G., McCormik M., Neural and Fuzzy logic control of Drives and Powers Systems, Newnes, Oxford 2002.

[5] Wang. L. X, Adaptive Fuzzy Systems and Control, Design and stability analysis, PTR Prentice Hall: Englewood cliffs, New Jersey, 1994

[6] Soares F. and Costa Branco P.J., 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.

[7] Simões M.G., Suemitsu W.I., Costa Branco P.J., Dente J.A. et Rolim L.G., Fuzzy Logic Control for a Switched Reluctance Motor, IEEE International Symposium on Industrial Electronics (ISIE'97), Vol.2, pp. 527-531, June 1997.

[8] Rodrigues M., Costa Branco P.J. and Suemitsu W.I., Fuzzy Logic Torque Ripple Reduction by Angle Compensation for a Switched Reluctance Motor, IEEE transactions Vol. 48 pp711-714, June 2001.

[9] Reay D.S., Moud M.M., Green T.C., Williams B.W., Switched Reluctance Motor Control Via Fuzzy Adaptive Systems, IEEE Control Systems, June 1995.

[10] Bühler H., Réglage par Logique Floue, Presse Polytechnique et Universitaires Romandes, Lausane 1994.

[11] Lee C.C., Fuzzy Logic in Control Systems: Fuzzy Logic Controller -Part I & II, IEEE Transactions on System, Man and Cybernetics, v01.20, n.2, pp.404-435, 1990.

[12] Mendel. J. M, Fuzzy Logic Systems for Engineering. A tutorial, Proc. IEEE, vol, 83, N. 3, pp. 345-377, March 1995

[13] Kovacic. Z et al, Fuzzy Rule Based Model Reference Adaptive Control of Permanent Magnet Synchronous Motor drive, IEEE/IECON 93, pp. 207-212

[14] Landau Y. D, Adaptive Control the Model Reference Approach, Marcel Dekker, Inc, control and systems theory, vol. 8, 1979.

Biographies

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