Fuzzy logic control of a switched reluctance motor

CONFERENCE PAPER · AUGUST 1997
DOI: 10.1109/ISIE.1997.649009 · Source: IEEE Xplore

5 AUTHORS, INCLUDING:

Walter Suemitsu
Federal University of Rio de Janeiro
56 PUBLICATIONS  255 CITATIONS

P. J. Costa Branco
Universidade de Lisboa, Instituto Superior Té...
115 PUBLICATIONS  848 CITATIONS

J. A. Dente
Technical University of Lisbon
98 PUBLICATIONS  498 CITATIONS

Available from: P. J. Costa Branco
Retrieved on: 01 October 2015
FUZZY LOGIC CONTROL OF A SWITCHED RELUCTANCE MOTOR

M.G.Rodrigues*  W. I. Suemitsu*  P.Branco**  J.A.Dente**  L.G.B.Rolim***

* COPPE/UFRJ-Federal University of Rio de Janeiro
  p.o.box.60504 Rio de Janeiro RJ Brazil
  Fax: 55-21-290-6626
  e-mail:suemitsu@coe.ufrj.br

** Instituto Superior Técnico
  CAUTL/Laboratório de Mecatrônica (http://macdente.ist.utl.pt)
  Av. Rovisco Pais, 1096 Lisboa Codex, Portugal
  E-mail:pbranco@alfa.ist.utl.pt

***TU Berlin - Institut für Electrische Maschinen
  Sekr. EM4, Einsteinufer 11, 10587 Berlin, Deutchland
  Fax:+49 30 314 21133 e-mail: eee10000@ufrj.bitnet

Abstract
This paper presents the use of fuzzy logic control (FLC) for switched reluctance motor (SRM) speed. The FLC performs a PI-like control strategy, giving the current reference variation based on speed error and its change. The performance of the drive system was evaluated through digital simulations through the toolbox Simulink of Matlab program.

1. INTRODUCTION

The switched reluctance motor (SRM) has becoming an attractive alternative in variable speed drives, due to its advantages such as structural simplicity, high reliability and low cost [1,2]. Many papers have been written about SRM concerning design and control [3]. An important characteristic of the SRM is that the inductance of the magnetic circuit is a nonlinear function of the phase current and rotor position. So, for the control and optimization of this drive, a precise magnetic model is necessary. To obtain this model is not an easy task, because the magnetic circuit operates at varying levels of saturation under operating conditions [4]. Further, the nonlinear characteristic of this plant represents a challenge to classical control. To overcome this drawback, some alternatives have been suggested in [5], using fuzzy and neuronal systems.

This paper proposes to control SR drives using fuzzy logic control (FLC), which is mainly applied to complex plants, where it is difficult to obtain accurate mathematical model or when the model is severely nonlinear. FLC has the ability to handle numeric and linguistic knowledge simultaneously [6].

In this paper we present a study by simulation of the use of a FLC for SR drive. The SRM simulated has a structure of six poles on the stator and four on the rotor and power of 1 HP. The nonlinear model of this motor was simulated with the Matlab Simulink package and two tables were used to represent the nonlinearities: \( I(\theta, \lambda) \), current in function of rotor position and flux, and \( \tau(\theta, I) \), torque in function of rotor position and current. The objective of the FLC is to present a good performance, even if the two tables for a given motor were not accurately determined.

The proposed control can be divided in two parts. The first employs FLC and will generate current reference variations, based on speed error and its change. The second one has the function of selecting the phase that should be fed to optimize the torque, based on rotor position.

2. MOTOR

In a Switched reluctance motor, both stator and rotor have different magnetic reluctance along various radial axis. Fig. 1 shows the controlled SRM, which has six poles on the stator and four on the rotor.

Fig. 1 - SRM with 6 poles on the stator and 4 poles on the rotor.
SRM electromechanical model can be represented by the following equations:

\[ V = RI + \frac{d\lambda}{dt} \]  
\[ \tau_e = \frac{d}{d\theta} \int_0^\theta \lambda \, d\theta \]  
\[ \tau = \tau_e - \tau_L = J \frac{d\omega}{dt} \]

where \( V \) is the stator voltage, \( R \) resistance in the winding, \( \lambda \) leakage magnetic flux, \( \tau_e \) electromechanical torque, \( \tau_L \) load torque, \( \theta \) rotor position, \( \omega \) speed, \( J \) momentum of inertia.

3. MOTOR SIMULATION

Matlab Simulink package was used to simulate the SRM. This choice was taken because this software has a good performance and satisfies all features required. Simulation was based on equations 1, 3 and the tables of torque in function of angle and current, \( \tau(\theta,I) \), and current in function of angle and flux linkage, \( I(\theta,\lambda) \). These tables, extracted from the numeric data of the motor design by a finite elements program [7], were used to avoid the time consuming due to partial derivatives equations solution.

See, in Fig. 2, the block diagram used.

4. CONTROL

The knowledge of rotor position is essential for the speed control of a SRM drive, since with the rotor position, we can determine which phase should be supplied, to provide positive or negative torque. Moreover, another feature affects torque control: current reference for hysteresis control. Thus, the control can be divided in two parts:

- Current reference settling.
- Choice of the phase to be fed.

Fig. 2 - Block diagram of the simulation

Fig. 3 - Block diagram of the SRM control
4.1 CURRENT REFERENCE SETTLING

In this part, we determine current reference for the three phases currents hysteresis control. The FLC generates current reference changes ($\Delta I_{ref}$), based on speed error ($e_\omega = \omega_{ref} - \omega_{actual}$) and its change ($ce_\omega = e_\omega(k+1) - e_\omega(k)$). $\Delta I_{ref}$ is integrated to achieve current reference.

We will show how the limits for the universes of the antecedents and consequents were initially settled.

The $e_\omega$ has its minimal value when the motor speed has nominal value, +180 rad/s, and is inverted to -180 rad/s. So, we have $e_\omega = \omega_{ref} - \omega = (-180) - (+180) = -360$ rad/s. The maximum value, +360, is obtained in the opposite situation.

The maximum torque obtained with the motor nominal current (5 A) is 1.2 Nm, thus which we can calculate the maximum absolute value for $ce_\omega$:

$$ce_\omega = e_\omega(k) - e_\omega(k-1) = (\omega_{ref} - \omega(k)) - (\omega_{ref} - \omega(k-1)) = -\Delta \omega$$

$$J \frac{\Delta \omega}{\Delta t} = \tau \Rightarrow \Delta \omega = \frac{\Delta t}{J} \tau$$

$$|ce_\omega| = \frac{\Delta t}{J} \tau = \frac{2 \cdot 10^{-3}}{1.3 \cdot 10^{-3}} \cdot 1.2 = 19$$

where $\Delta t$ is the interruption time.

The maximum absolute value for the $\Delta I_{ref}$ universe was obtained by trial and error.

So, the initial limits for the universe of the antecedents ($e_\omega$, $ce_\omega$) and consequent ($\Delta I_{ref}$) were the following:

- $e_\omega$: -360 a +360 rad/s
- $ce_\omega$: -19 a +19 rad/s/s
- $\Delta I_{ref}$: -1 a +1 A

After some manual changes in these limits to optimize the speed control, we got the following values:

- $e_\omega$: -180 to +180 rad/s
- $ce_\omega$: -19 to +19 rad/s/s
- $\Delta I_{ref}$: -0.7 to +0.7 A

Both antecedents and consequent linguistic variables are represented by seven triangular membership functions as shown in Fig. 4.

Some simulation results are presented on Fig. 5, which shows this control performance when there is a change in load and in speed reference. At first, 0.1 Nm load is applied to this motor. At 0.27s, load is increased to 1 Nm, requiring higher torque. At 0.61 s, speed reference is decreased to 80 rad/s and in consequence current decreases for desacceleration.

![Fig. 4 - Linguistic rules for current reference determination. (a) speed error. (b) change of speed error. (c) change of current reference.](image)

![Fig. 5 - Simulation results. (a) speed x time. (b) current reference x time.](image)
4.2 CHOICE OF THE PHASE TO BE FED

This part of the control determines which phase should be fed. Its inputs are rotor position, and speed.

Consider a phase ideal inductance profile shown in figure 6. If $\omega > 0$ and $\theta \in$ interval 1, feed the corresponding phase. The presence of current in this increasing inductance region will produce positive torque. If $\omega > 0$, current should produce electrical torque, $\tau_e$, higher than load one, $\tau_{load}$ to accelerate. If $\omega < 0$, $\tau_e$ should be lower than $\tau_{load}$ for deceleration. Current reference value (electrical torque) and so acceleration or deceleration is established by the first part of the control.

It is also possible to decelerate the motor feeding the phase with decreasing inductance. However, it would cause overshoot. Fig. 7 shows speed change from 180 to 80 rad/s, feeding and not feeding the decreasing inductance phase.

The converter capacitor voltage will disenergize the phase to avoid production of negative torque.

If $\omega > 0$, $\theta \in$ interval 2 and there be current in this phase, the source will not supply the phase.

In Fig. 9, we show the control performance.
5. CONCLUSIONS

To get dynamics performance predictions of SRM’s, including its control, a simulating model has been shown in this paper. The nonlinear modeling has been represented by look-up tables to obtain torque and current.

A control has been developed for the switched reluctance motor speed. This control has two parts. Part 1 determines the reference current, and so electromechanical torque. Part 2 chooses which phase should be fed, based on \( \theta \) and speed, and is responsible for imposing speed direction.

It was shown that inverting speed direction by energizing the phase with decreasing inductance to desaccelerate the motor provided speed overshoot, while the use of load torque on desacceleration made the speed response more smooth.

The FLC has demonstrated a good accuracy and has performed well for the speed control of the SRM, surpassing its nonlinearities.

6. REFERENCES


