APPLICATION OF FUZZY LOGIC IN CONTROL OF SWITCHED RELUCTANCE MOTOR

P. Brandstetter, R. Hrbac, M. Polak, L. Stepanec

VŠB – Technical University of Ostrava
Department of Power Electronics and Electrical Drives
17. listopadu 15, 708 33 Ostrava-Poruba, Czech Republic
e-mail: pavel.brandstetter@vsb.cz, roman.hrbac.fei@vsb.cz, martin.polak.fei@vsb.cz, stepanec@unicontrols.cz

Summary The flux linkage of switched reluctance motor (SRM) depends on the stator current and position between the rotor and stator poles. The fact determines that during control of SRM current with the help of classical PI controllers in a wide regulation range unsatisfied results occur. The main reasons of the mentioned situation are big changes of the stator inductance depending on the stator current and rotor position. In a switched reluctance motor the stator phase inductance is a non-linear function of the stator phase current and rotor position. Fuzzy controller and fuzzy logic are generally non-linear systems; hence they can provide better performance in this case. Fuzzy controller is mostly presented as a direct fuzzy controller or as a system, which realizes continued changing parameters of other controller, so-called fuzzy supervisor. Referring to the usage of fuzzy logic as a supervisor of conventional PI controller in control of SRM possible improvement occurs.

1. INTRODUCTION

Electrical drives with switched reluctance motors (SRM), which are characterised especially by their simple construction, low price and high efficiency, also belong to the group of A.C. electrical drives. In spite of the mentioned advantages of switched reluctance motors, and the rapidly developing semiconductor and micro-processor technique, the number of commercially produced products is still very low, and to this day there is no universal way of design of electrical drive with switched reluctance motor and its control for a wider area of applications. At present many scientist workplaces try to develop mentioned universal design way of SRM drives.

Using fuzzy logic as so-called „supervisor" for SRM control is possible for better control like a superior control for change of the PI regulator parameters. In the case of SRM, system is nonlinear for view of inductance varying on turning motor. In the present, SRM are developed for their positive features and parameters. In the past, SRM using was not possible because of the power electronic components and sufficiently fast control systems. Their main advantages are:

- simplicity and robustness
- high torque overload capacity
- high efficiency over wide speed-range
- low machine inertia
- decreased maintenance requirements

High efficiency of SRM results to use this motor in application of the runabout with battery source. Brushless construction allowed using in explosive environments. One of troubles of the control is strongly nonlinear motor model. For example, in Fig. 1 is waveform of the stator inductance in one phase for situation when motor is run. For simplicity, in figure is show idealized waveforms of the stator inductance in one phase, which is more nonlinear in reality [1].

The flux linkage depends on the parameters like e.g., current amplitude and rotor pole piece position compared with stator position. These assumptions give unsatisfactory results during the current control with conventional PI regulators in wide range of the control, the main reason is high change of the inductance with position rotor compared with stator changing and current amplitude. Regulation range for the compliance of the prosperous waveforms is close.

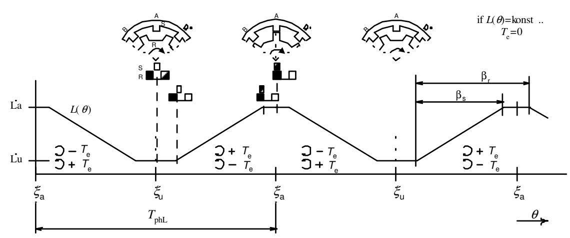

Fig. 1. Idealized waveform of stator inductance in one phase of SRM

Fuzzy regulator and fuzzy logic is nonlinear system, this fact is able to produce innovation of nonlinear system control. The most often the fuzzy regulator is in literature so-called direct fuzzy regulator or like an instrument for the continuous parameters change of another regulator, so-called fuzzy supervisor. In this part, fuzzy logic is used for gain and time constant parameters adaptation of conventional current PI - controller.

2. CONTROL STRUCTURE OF SRM

The torque in the SRM is produced by pulses of phase current synchronized with the rotor position. The timing and control of these current pulses are controlled by the drive circuit. Usually there are also outer feedback loops for controlling speed or shaft position, as shown in Fig. 2. The outer loops are generally similar to those used in other types of motor drive, but the inner torque loop is specific to the switched reluctance machine.

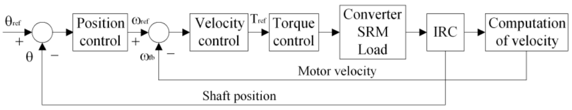

Fig. 2. Block diagram of SRM control loops

The torque demand signal generated by the outer control loops is translated into individual current reference signals for each phase. Usually there is no torque sensor and therefore the torque control loop is not a closed loop. Consequently, if smooth torque is required, any variation in the torque/current or torque/position relationships must be compensated in the feedforward torque control algorithm. This implies that the torque control algorithm must incorporate some kind of 'motor model'. Unlike the d.c. or brushless d.c. motor drive, the switched reluctance motor drive cannot be characterized by a simple torque constant *kT*. This in turn implies that the drive controller must be specifically programmed for a particular motor, and possibly also for a particular application. It also implies that one cannot take a switched reluctance motor from one source and connect it to a drive from another source, even when the voltage and current ratings are matched. The control of the SRM can be described like the control in the range of low and high speed. At lower speeds the torque is limited only by the current, which is regulated either by voltage-PWM, or instantaneous current regulation. As the speed increases the back-EMF increases to a level at which there is insufficient voltage available to regulate the current; the torque can then be controlled only by the timing of the current pulses. This control mode is called ‚single-pulse mode' or ‚firing angle control', since the firing angles alone are controlled to produce the desired torque. Many applications require a combination of the high-speed and low-speed control modes. Even at lower speeds with voltage-PWM or current regulation, the firing angles are typically scheduled with speed to optimise performance [1].

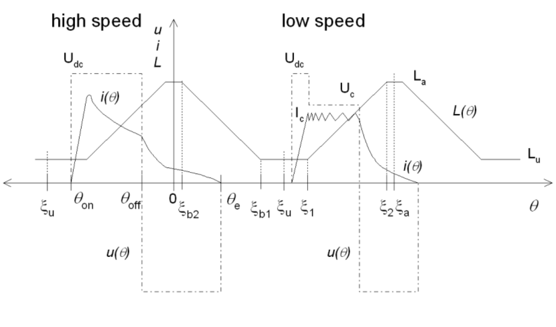

Fig. 3. High speed and low speed range, voltage, current and stator inductance courses

Figure 3 shows typical waveforms of voltage and current for the switched reluctance motor, which is fed from the constant voltage source during one working cycle in motoring regime. The current is not represented by square pulses in this case, but its waveform depends on phase voltage. Time of current conduction in one phase during a period consists of two intervals, which are different in phase voltage polarity. The energy from the source is supplied in the interval $\theta_c = (\theta_{off} - \theta_{on})$, energy is returned to the source over zero diode in the interval $(\theta_{off} - \theta_e)$. Interval $(\theta_e - \theta_{on})$ is the current conduction angle [2].

Figure 4 shows a speed control structure. Speed controller output is reference current i_{ref}, which is restricted to maximal value and to the current controller enter his absolute value at the beginning of each working motor cycle. To the block BRS enter in the desired speed of rotation Ω_{mref}, the speed of rotor rotation Ω_{mfb} from the block of speed calculation BVR and the speed controller output i_{ref}. Desired and actual speed is compared in the first step. If signs of both speeds are various then there are determined switching angle for braking motor operation and the motor is braking with commutation phase sequence destined for direction of rotation according by real speed Ω_{mfb}. After crossing the zero, the motor works with switching phases in sequence destined for rotation direction according to desired speed, and switching angles are determined according to sign of speed controller output i_{ref} for braking or motoring regime.

The pulse signals from output position sensor IRC are evaluated in block of evaluation position BVP. Block of switch logic BSL interlock in dependence on motor operation, operating angles and rotor position, conduction times of individual phases with closure time of appropriate switching devices, which is determined by current controller in individual phases.

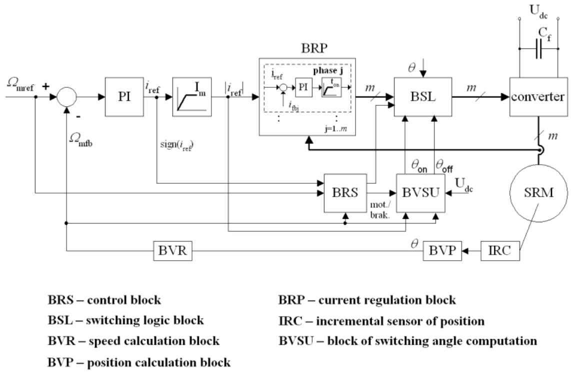

Fig. 4. Block diagram of SRM speed control with current controller

Fig. 5 shows a simulation diagram in *Matlab-Simulink*. In the simulation is thought SRM 8/6 making use for modeling a non-linearity so-called look-up table with "cubic-spline" interpolation,

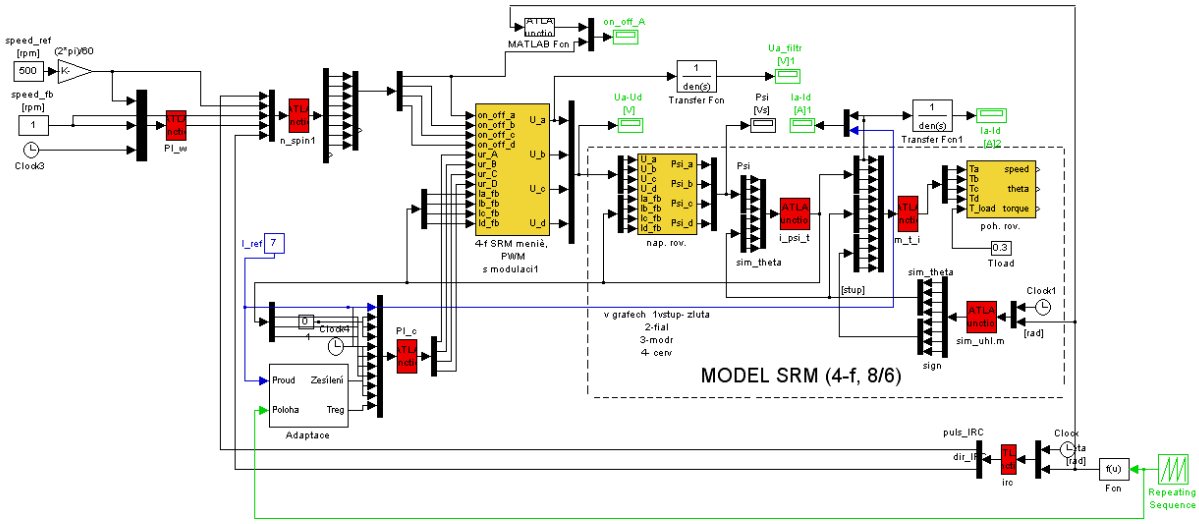

Fig. 5. SRM control structure in Matlab-Simulink

which relatively truly matches a nonlinear system. The fuzzy supervisor makes the parameter change on the basis of input current and mutual position of rotor and stator pole. This is control method of SRM with current controller. There are also included blocks in the regulation structure for determination the conduction of individual motor phases [1], [3].

3. FUZZY SUPERVISOR FOR PARAMETER ADAPTATION OF THE CONTROLLER

It is good to remind for introduction that the general supervisor was developed for the change of parameters of PID controller. The fuzzy supervisor was used for the creating PID controller with nonlinear setting of parameters K, T_I, a T_D for the reducing overshoot or acceleration of transient effect. In this case the fuzzy supervisor evaluates values of input. The value of current PI controller parameters is changed according to set the rule base and function of pertinence in every step. The rule of fuzzy supervisor may be in form:

IF *current* is *small* AND *position* is *high* THEN *output* is *small* (1)

The same results can be obtained, if you use the fuzzy PI controller with nonlinear setting. Until you know the setting of PI controller parameters for an environment of the operating points in which regulation system is. It can be selected the correct setting of controller parameters with help of fuzzy supervisor. There is not to think only one complexion fuzzy PI controller due to rising severity in these simulation cases and from practical overview. The fuzzy controller is with two inputs and division 'universe' on 7 functions to needs 49 rules. When you have the same number of division universe and you want to rise up the number of inputs for good description of nonlinear system with 4 inputs then the number of rule rise up to 2401. On this account it is important to combine more fuzzy structures with inputs less than one fuzzy system with huge number of rule [4].

We can describe fuzzy system by next equation:

$$\text{output} = D\{\text{ interference } \{F(\text{input\_current}), F(\text{input\_position})\}\} \quad (2)$$

where F is representing fuzzification, D defuzzification.

It was selected the variation which is observing the same PI controller which is using superior adaptation fuzzy controller for the change of parameters. The inner structure of adaptation block from Fig. 5, we can see in Fig. 6. It is clear, that adaptation is performed in certain range of input values which have the influence for motion of SRM. The outputs of block are signals corresponding to gain and time constant for classical PI controller.

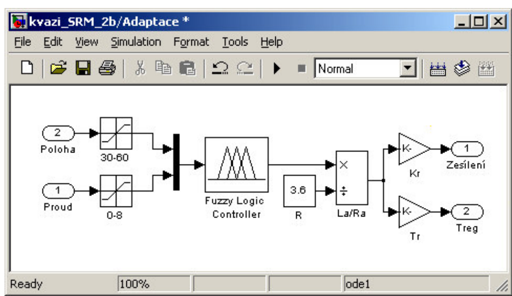

Fig. 6. Scheme of adaptation fuzzy controller for parameters setting

The realized fuzzy supervisor is equivalent to fuzzy controller which has two inputs and one output too. We can set its nonlinear behave with the aid of rule base. It is expert system, where the rule base entry is on the foundation of knowledge and experience of an expert with system. The control surface is result of designed fuzzy system. The control surface is in Fig. 7. This surface determines the response of output on input values change and than the surface is more easily implemented as table form in microprocessor control system [5].

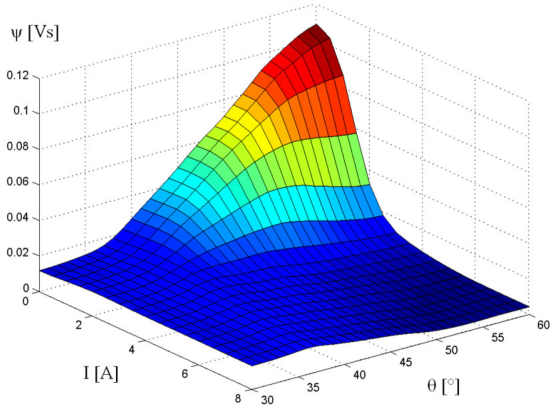

Fig. 7. Characteristic area of adaptive fuzzy controller

4. SIMULATION RESULTS

Designed adaptation controller for parameters setting was verified on described mathematic model. The courses introduced below in figures are achieved for changing applied current value from 0.5A to 6A. There are showed the phase current courses with corresponding logic signal value which corresponds to leading specific phase applied time.

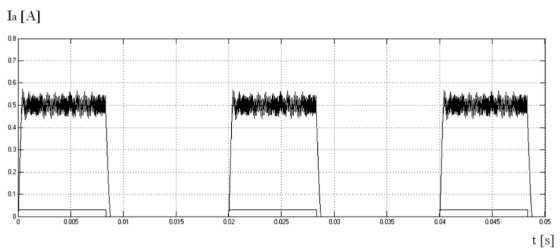

Fig. 8. Phase current I_a time courses with I_{ref} = 0,5A

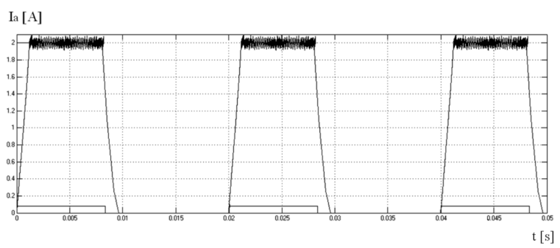

Fig. 9. Phase current I_a time courses with I_{ref} = 2A

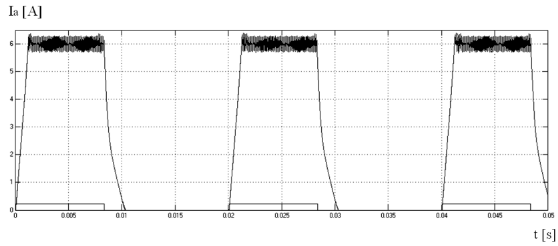

Fig. 10. Phase current I_a time courses with I_{ref} = 6A

5. CONCLUSION

The result of designed system of current control with classic PI controller, which is observed by fuzzy supervisor, is improved current courses during changing system parameters. The main output of designed fuzzy supervisor for simple review of system non-linearity is so-called control area which determines non-linearity of the system. Current control independence during changing system parameters is shown in figures 8, 9 and 10 of current courses. The independence is given by the change of the PI controller parameters. As it was mentioned before, the main advantage of fuzzy control is a possibility to create for the drive suitable control on basic rules. We can achieve better control results because of the fuzzy systems non-linearity. It is confirmed by these simulation results.

The similar behaviour can be achieved also e.g. by using two-valued control. The used method is more suitable just in case, when EMC shielding must be used. This is mostly a problem for two-valued control because of unknown frequency.

Acknowledgement

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