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Analysis of Performance of PSO Based Fuzzy Controller for 4 Phase SRM Motor

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Abstract

Background: The Switched Reluctance Motor (SRM) is considered to be effective for variable speed applications with high power density. A controller is designed for reduction of torque ripples and for speed control. **Methods:** This paper presents a PSO based fuzzy controller for the switched reluctance motors (SRM). **Results:** The dynamic response of the SRM with the proposed controller is studied and the effectiveness of the proposed controller is compared with that of the fuzzy PI controller. **Applications:** Hybrid electric vehicles, aircraft starter/generator systems, washing machines, automotive applications etc.

Keywords: Fuzzy PI Controller, PSO, SRM

1. Introduction

SRM has been increasingly used in variable speed drives[1–4]. The introduction of optimization technique has brought a new era in the industrial drive.

A Fuzzy Logic Controller [FLC][13–17] chooses the switching states based on a set of fuzzy variables. Here, the design of FLC has also been tackled with Particle Swarm Optimization (PSO).

The phases of PSO optimized Fuzzy controller are realized with the help of standard procedures of the Fuzzy Logic Toolbox of the MATLAB/SIMULINK software.

In the present work, the performance of proposed controller is compared with fuzzy PI controller under load and no load conditions and is efficiency is proved. In this paper Section 2 reviews the SRM model. Section 3 discusses the fuzzy logic PI controller implementation. Section 4 describes about the PSO system, section 5 deals with PSO optimized fuzzy controller and the results are presented in section 6.

2. SRM Model

The switched reluctance motor with passive rotor has a simple construction, but the solution of its mathematical model is relatively difficult due to its dominant non-linear behavior.

The mathematical model comes from the equivalent circuit for one phase as shown in Figure 1.

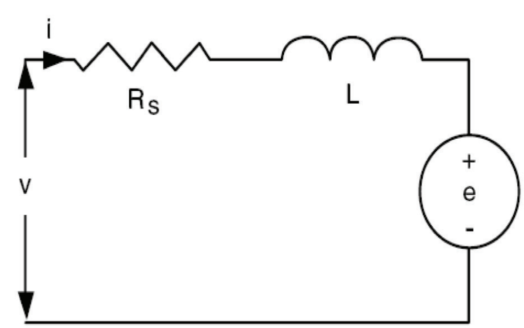

Figure 1. Single-phase equivalent circuit of the SRM.

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The applied voltage to a phase is equal to the sum of the resistive voltage drop and the rate of the flux linkages and is given as:

$$V = RSi + \frac{d\lambda(\theta,i)}{dt} \tag{1}$$

where

Rs is the resistance per phase, and λ the flux linkage per phase given by:

$$\lambda = L(\theta,i)i \tag{2}$$

Where

L is the inductance dependent on the rotor position and phase current. Then, the phase voltage is:

$$\begin{aligned} V &= RSi + \frac{d\{L(\theta,i)i\}}{dt} \\ &= RSi + L(\theta,i)\frac{di}{dt} + i\frac{d\theta}{dt}\frac{dL(\theta,i)i}{d\theta} \end{aligned} \tag{3}$$

$$V = RSi + L(\theta,i)\frac{di}{dt} + \frac{dL(\theta,i)}{d\theta}\omega m i \tag{4}$$

The induced emf (e), is expressed as:

$$e = \frac{dL(\theta,i)}{d\theta}\omega m i = Kb\omega m i \tag{5}$$

In terms of torque (T), it can be expressed as

$$T - TL = J\frac{d\omega}{dt} + B\omega \tag{6}$$

2.1 SRM Speed Control

In Figure 2, the block diagram of the speed control of SRM is shown.

Reference speed ω^* is compared with the rotor speed (ω). Then error signal (w_e) is fed to the speed controller. Each phase winding current is sensed at the output of the converter and compared with its reference in the current controller[2]. The current controller then decides the switching (on/off). Winding excitation is controlled by controller through converter and motor drives the load torque at the reference speed.

Here, PSO based fuzzy controller is used as a speed controller.

3. Controller Design

3.1 PI Controller

PI control uses a low-pass filter on the command signal to remove overshoot, which is present in open loop. A proportional controller reduces error but does not eliminate it (unless the process has naturally integrating properties), i.e. an offset between the actual and desired value will normally exist. Therefore, a PI controller does not meet the requirements of the robust performance[5].

3.2 Fuzzy Controller

The fuzzy controller is composed of the following four elements:

- Rule-base (a set of if-then rules).
- Fuzzy inference engine.
- Fuzzification interface.
- Defuzzification interface.

3.3 Design of Fuzzy PI Controller

The basic block diagram of a PI type FLC for SRM speed control is shown in Figure 3[6]. It is known that a FLC consists of the fuzzification process, the knowledge base and the defuzzification process.

It is defined as,

$e(k) = r(k) - y(k)$ and

$\Delta e(k) = e(k) - e(k-1)$

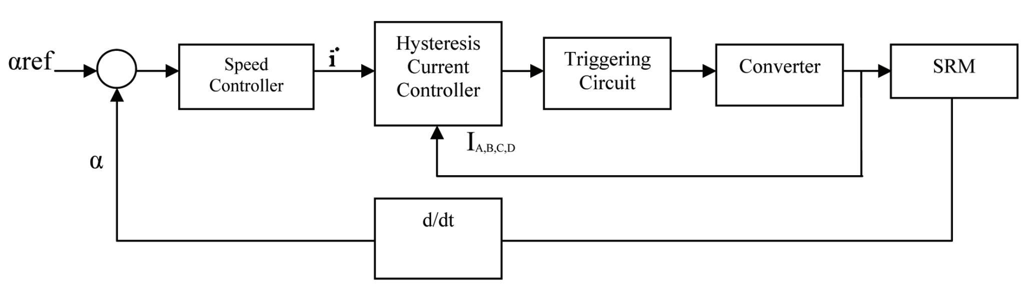

Figure 2. SRM speed control block diagram.

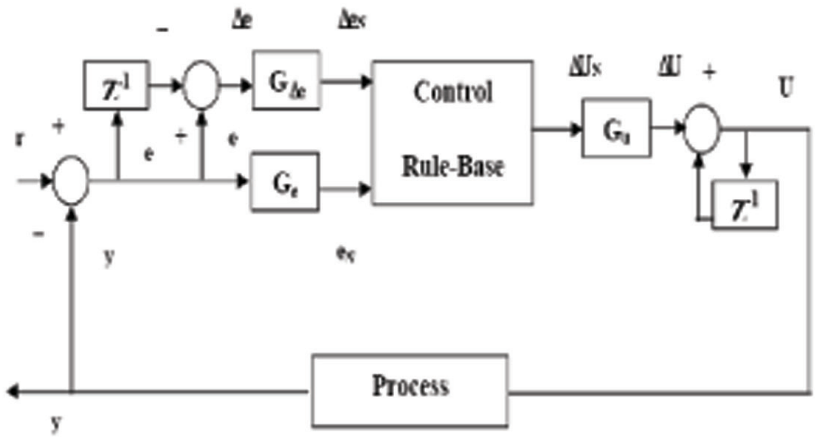

Figure 3. Block diagram of Fuzzy PI Controller.

Where,
e(k) = error
Δe(k) = change of error
r = applied set point input
y = plant output indices

Where k and k^{-1} indicate the present state and the previous state of the system. The output of the FLC is the incremental change in the control signal Δu(k)[6].

The input and output variables of fuzzy PI controller[6,11] can be defined as

$$E(k) = e(k).Ge \tag{7}$$

$$CE(k) = ce(k).Gce \tag{8}$$

$$CE(k) = ce(k).Gce \tag{9}$$

where e(k) is the error between reference speed and rotor speed, ce(k) is the change of error in speed, I(k) is the output of the fuzzy logic controller, and Ge, Gce and GΔi are scaling factors.

The actual value of the controller output is

$$u(k) = u(k-1) + \Delta u(k) \tag{10}$$

where u(k) is the controller output, u(k-1) the (k-1) th instant controller output and Δu(k) the incremental change in controller output.

Figure 4 indicates the membership functions are triangle ones having linguistic labels of,

NB (Negative Large),
NM (Negative Medium),

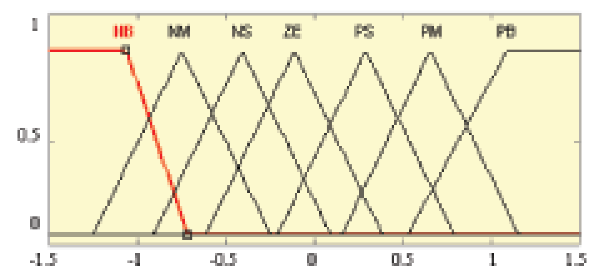

Figure 4. (a) Membership Functions for e.

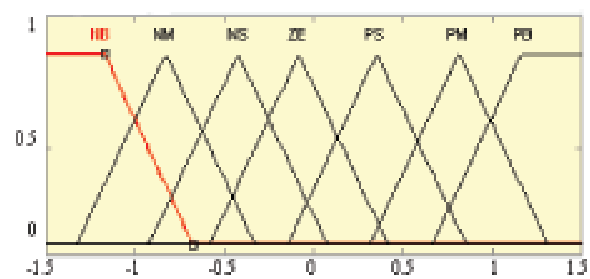

Figure 4. (b) Membership Functions for Δe.

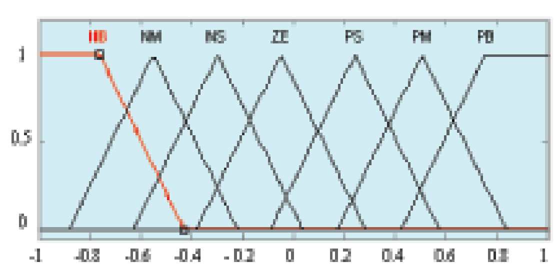

Figure 4. (c) Membership Functions for Δu.

NS (Negative Small),
ZE (Zero),
PS (Positive Small),
PM (Positive Medium) and
PB (Positive Large)

The rule base consists of 49 IF-THEN rules[7]. The defuzzification operation is done by center of gravity method.

After designing a fuzzy PI controller, fuzzy PI controller is optimized using PSO.

4. Particle Swarm Optimization

It is a population-based optimization tool, which could be implemented and applied easily to solve various function optimization problems. The main strength of PSO[8] is its fast convergence than the other global optimization algorithms. PSO utilizes a population of candidate solutions to evolve an optimal or near-optimal solution to a problem.

5. Algorithm for Fuzzy Model Identification through PSO

The problem of fuzzy model identification includes the following issues:

- Selecting the type of fuzzy model.
- Selecting the input and output variables for the model.
- Identifying the structure of the fuzzy model, which includes determination of the number and types of membership functions for the input and output variables and the number of fuzzy rules.
- Identifying the parameters of antecedent and consequent membership functions.
- Identifying the consequent parameters of the fuzzy rule base.

The objective of optimization problem is to look for the values of the variables being optimized, which satisfy the defined constraints, which maximizes or minimizes the fitness function. The Mean Square Error (MSE) defined in the following equation is used as the fitness function for rating the fuzzy model.

$$\text{MSE}=(y(k)-\overline{y(k)})^2 \qquad (11)$$

where,

$y(k)$ is the desired output,
$\tilde{y}(k)$ is the actual output of the model and

PSO Algorithm

Step 1 : Define fitness function.

Step 2 : Initialize the particles of the population according to the limits. Initialize parameters W_{max}, W_{min}, C_1, C_2 and $iter_{max}$.

Step 3 : Generate the initial population of N particles with random positions and velocities.

Step 4 : Calculate the fitness and evaluate the fitness values of current particle using the objective function of MSE, given in equation (3.12).

$$\text{MSE}=(y(k)-\overline{y(k)})^2$$

Step 5 : Compare the fitness value of each particle with its pbest. If the current value is better than pbest, then set pbest value to the current value.

Step 6[11,9] : Compare the fitness value of each particle with its gbest. If the current value is better than gbest, then set gbest value to the current value.

Step 7 : The member velocity V of each individual in the population is updated according to the velocity update equation, given below

$$\begin{aligned} V_i^{(t+1)} &= w \text{ x } V_i^{(t)} + c_1 \text{ x } r_1 \text{ x} \left(pbest_i - x_i^{(t)}\right) \\ &\quad + c_2 \text{ x } r_2 \text{ x} \left(gbest - x_i^{(t)}\right) \end{aligned} \qquad (12)$$

$V_i^{(t+1)}$ is the new velocity of the i^{th} patticle.
$V_i^{(t)}$ current velocity of the i^{th} patticle.
W is the weight factor
r_1 and r_2 are random two numbers between the range (0,1).
c_1, c_2 are learning factors. Usually $c_1 = c_2 = 2$.
$x_i^{(t)}$ is the current position of the i^{th} particle.

Step 8 : The position of each individual is modified according to the position update equation, as follows

New position = old position + updated velocity (13)

Step 9 : If the number of iterations reaches the maximum, then go to Step 10. Otherwise, go to Step 4.

Step 8 : The particle that generates the latest gbest is the solution of the problem.

Step 9 : Stop.

6. Results and Discussion

6.1 Under No-load Condition

The system was operated at a reference speed of 120 rad/s when the motor shaft is under no load. The performance of fuzzy PI controller is compared with the PSO based Fuzzy logic controller in terms of the rise time (tr0), settling time (ts0), Overshoot (Os) is shown in Table 1[9–11].

6.2 Under Load Condition

The system was operated after the motor was loaded with 10% of the nominal load. The performance of fuzzy PI controller is compared with the PSO based Fuzzy logic controller in terms of the Rise Time (tr0), Settling Time (ts0), Overshoot (Os) is shown in Table 2[12].

Figure 5 illustrates the comparative study of speed response of 4 phase SRM motor using fuzzy PI controller and PSO optimized fuzzy controller under both load and unloads condition at 120 rad/s.

7. Conclusion

A PSO based fuzzy controller for the speed controller system has been successfully developed to control the speed of a SRM motor. A comparison of the performance has been done for the proposed system with other existing controllers of various types. It has been found that the speed regulation by the proposed PSO based Fuzzy controller is superior to the other controllers. In future the same can be analyzed using robust controller using model predictive controller.

Table 1. No-load condition

Type of control	Speed =120 rpm		
	tro (s)	tso (s)	Os (rad/s)
PSO based Fuzzy Logic Controller	0.024	0.024	No overshoot
Fuzzy PI Controller	0.026	0.026	No overshoot
Fuzzy Logic Controller	0.0812	0.0812	No overshoot
Conventional PI Controller	0.0905	0.0905	overshoot

Table 2. Load condition

Type of control	Speed =120 rpm		
	tro (s)	tso (s)	Os (rad/s)
PSO based Fuzzy Logic Controller	0.026	0.026	No overshoot
Fuzzy PI Controller	0.028	0.028	No overshoot
Fuzzy Logic Controller	0.0899	0.0899	No overshoot
Conventional PI Controller	0.1996	0.1996	overshoot

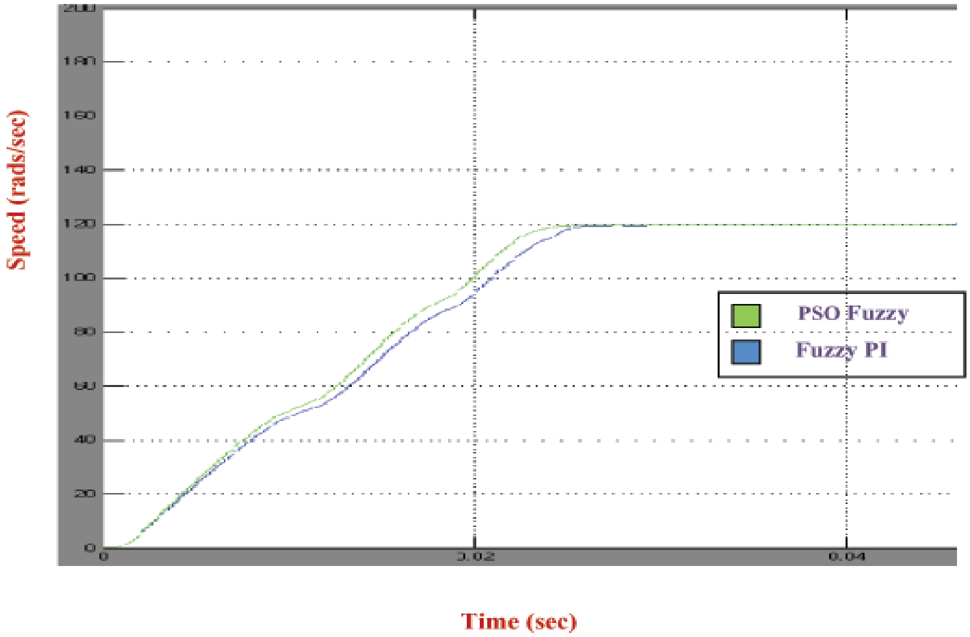

Figure 5. (a) The speed responses of SRM using FLC PI and PSO based fuzzy controllers under no-load condition.

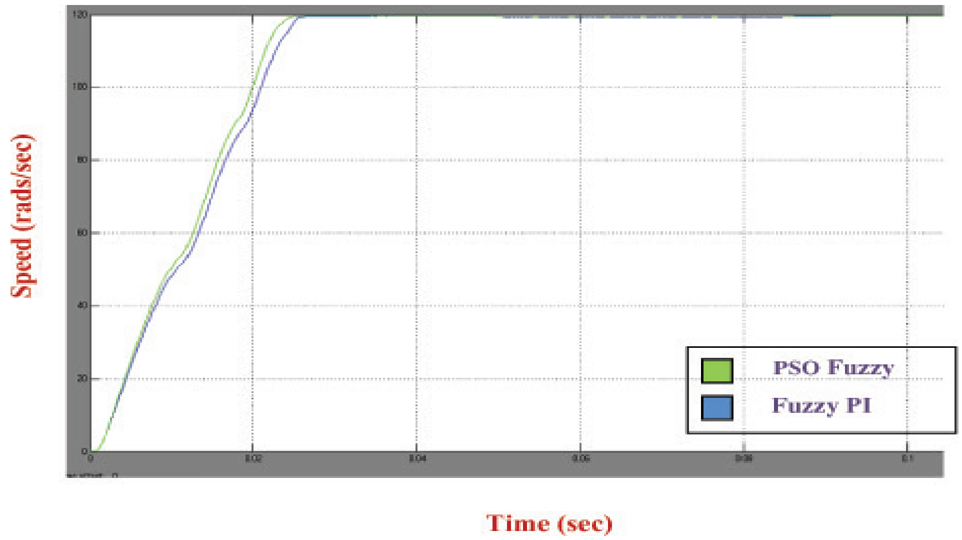

Figure 5. (b) The speed responses of SRM using FLC PI and PSO based fuzzy controllers under load condition.

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