

Speed control of Switched Reluctance Motor using Fuzzy Logic Controller

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October 12, 2018

Abstract

Due to its simple structure and its reliability Switched Reluctance Motor (SRM) is becoming very popular. Usually, typical PI controller is used to regulate the speed of SRM. However, PI controller cannot regulate SRM under sudden changes of load. In this paper, a Fuzzy Logic Controller (FLC) is designed to control the speed of SRM drive. The performance of SRM with FLC is analyzed in Matlab/Simulink platform. To prove the superiority of FLC, its performance is compared with typical PI controller.

Key Words:: Switched Reluctance Motor; PI Controller; Fuzzy Logic Controller.

1 Introduction

The Switched Reluctance Motor (SRM) consists of salient poles on both stator and rotor. Thus it is called as double salient pole machine with no winding or permanent magnets on the rotor. In SRM

stator poles are greater than rotor poles. Because of winding free rotor, SRM offers a low inertia, gives a good performance. It is also cheaper in cost and has high efficiency. Due to these features, it is used in industrial applications, but SRM suffers from high torque ripples and possesses a non-linear magnetism. These drawbacks limit the SRM in many applications where the smooth response of the motor is required. Because of non-linear magnetic structure, conventional control schemes are inadequate to regulate the speed of SRM. Consequently, non-linear controllers are required to control SRM drive. Many controllers are discussed in literature [5-6]. In [4], a controller is designed based on feedback, to enhance the performance of SRM. A sliding mode controller is also developed in [6] to achieve the smooth control of SRM under sudden changes of load. But, it has ripples in speed because of its control unit which required high switching frequency. Fuzzy controllers are currently trending in engineering fields. These are intelligent and robust controllers, it accepts uncertainties in its inputs. Fuzzy logic controllers are used effectively. In which the system is not completely described by using mathematical modelling. Fuzzy logic controller gives better performance than PI controller under transient conditions. In this paper, FLC is designed to get the smooth speed control of SRM under variable speed with constant load conditions.

2 MATHEMATICAL MODELLING OF SRM

The equivalent circuit of SRM is depicted in Fig. 1 for a single phase which consists of resistance and inductance. For modelling of SRM, neglect the magnetic saturation effect, leakage flux and mutual coupling between phase windings. The mathematical modelling of SRM consists of different kinds of electrical equations.

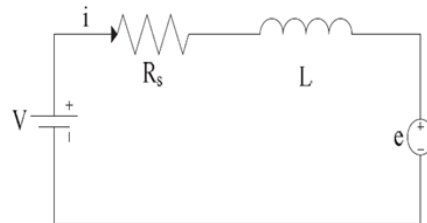


Fig. 1 Equivalent circuit of SRM

The equation for a phase voltage is expressed as

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

Where R denotes phase resistance, λ denotes flux linkage for each phase which is expressed as

$$\lambda = L(\theta, i) \quad (2)$$

Where L is phase inductance which function of rotor position ' θ ' and phase current ' i '

From equations (1) and (2)

$$V = R i + L(\theta, i) \frac{di}{dt} + \frac{dL(\theta, i)}{dt} i \omega_m \quad (3)$$

where ω_m denotes angular velocity of SRM

The emf induced in motor is

$$e = \frac{dL(\theta, i)}{d\theta} i \omega_m = i \omega_m K_b \quad (4)$$

The generated torque per phase is

$$T_e(\theta, i) = \sum_{phases} \frac{1}{2} i^2 \frac{dL(\theta, i)}{d\theta} \quad (5)$$

The total generated torque of motor is expressed as

$$T_e(\theta, i) = \sum_{phases} \frac{1}{2} i^2 \frac{dL(\theta, i)}{d\theta} \quad (6)$$

The equation (6) substitute in the mechanical equation and expressed as follows

$$T_e - T_l = J_m \frac{d\omega_m}{dt} + B_m \omega_m \quad (7)$$

Where B_m is friction coefficient, J_m is moment of inertia, T_l is load torque.

3 SPEED CONTROL OF SRM

For speed regulation of SRM, the fundamental block diagram is shown in Fig. 2. In this control scheme, the difference between reference speed and actual speed is given to speed controller. The reference current generator produces reference currents which are based on rotor position. The difference between reference currents and actual currents are given as input to Hysteresis current controller. This controller gives the control signals to the asymmetric bridge converter which is supplied to the SRM.

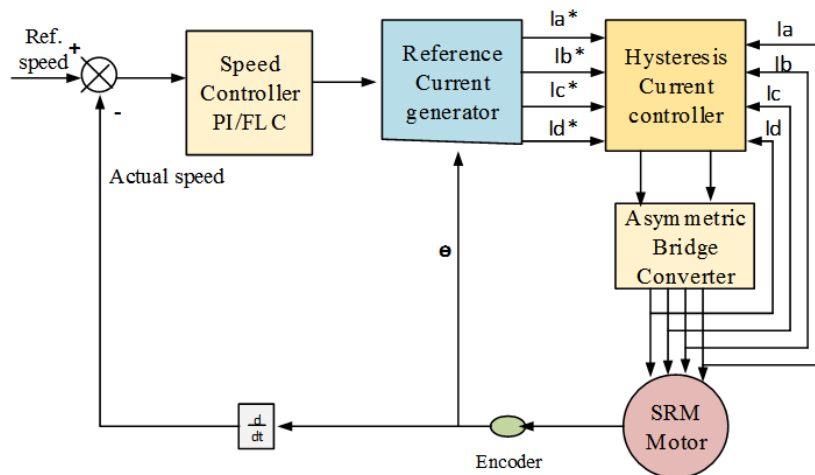


Fig. 2 Speed control of SRM drive

A. Fuzzy Logic Controller

The main feature of Fuzzy Logic controller is that it does not require any mathematical model of the system. The design of FLC is mainly based on experts experience. Fig. 3 shows the elementary arrangement of FLC.

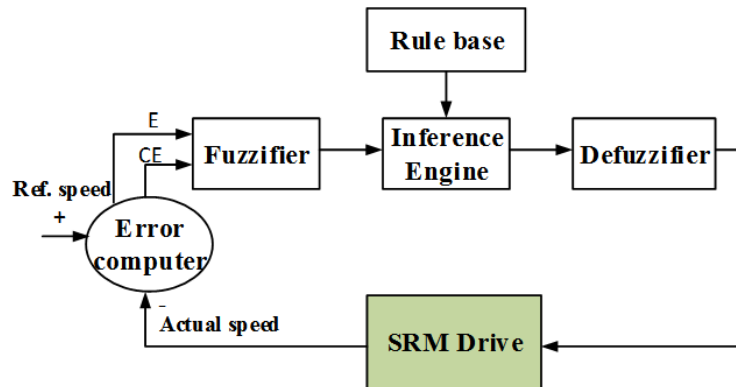


Fig. 3. FLC basic structure

In this speed control scheme, two inputs are given to FLC one is speed error (E), second one is change in speed error (CE). The output of FLC is expressed as

$$u(k) = F[E(k) - CE(k)]$$

There are mainly three steps are following for designing of FLC such as fuzzification, rule base and defuzzification. Firstly, the crisp inputs are converted into linguistic variables which is known as Fuzzification. Secondly, delineating the rules which are depicted in table 1. There are seven membership functions which are named as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive medium (PM), Positive Big (PB).

Table I. FLC Rules

Error	Change in error						
	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

The rule base of FLC produces the desired output in terms of linguistic variables. The final step in FLC design is changing the linguistic variables into crisp output which is labeled as Defuzzification. The membership functions for error, change in error of motor speed and output of SRM is depicted in Fig. 4.

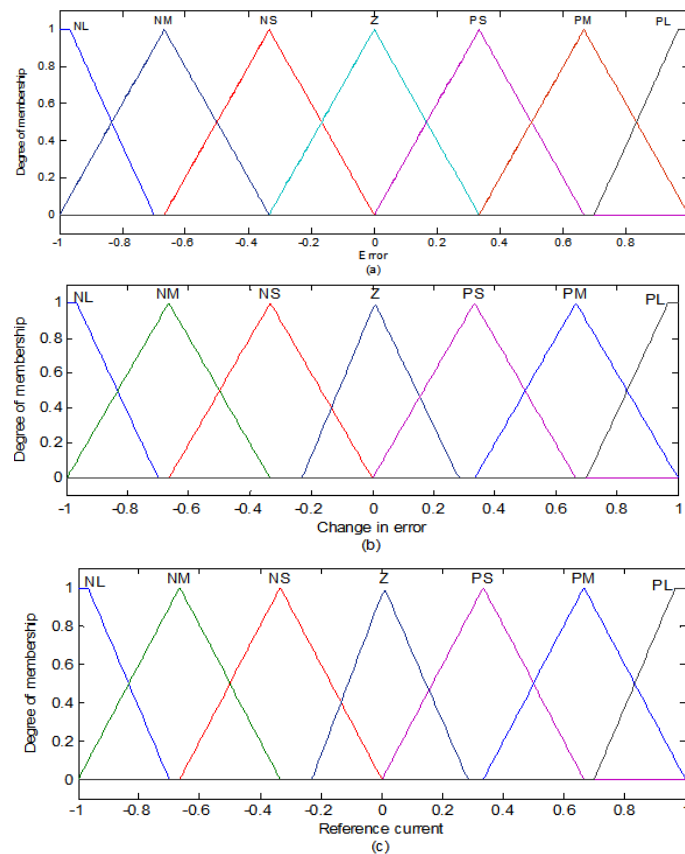


Fig. 4. Membership functions

4 RESULTS AND ANALYSIS

To validate the superiority of FLC for speed control of SRM, the simulation results are carried out in Matlab/Simulink environment.. The Simulink diagram of SRM for speed regulation is depicted in Fig. 5. The parameters of SRM drive are shown in Table II.

Table II. SRM motor parameters

Voltage	48V
Phase Resistance	0.5Ω
Inertia	0.005Kg.m.m
Friction	0.0001N.m.s
Unaligned inductance	$0.67\text{e-}3$ H
Aligned inductance	$23.6\text{e-}3$ H
Maximum current	30 A
Maximum flux linkages	0.486/5

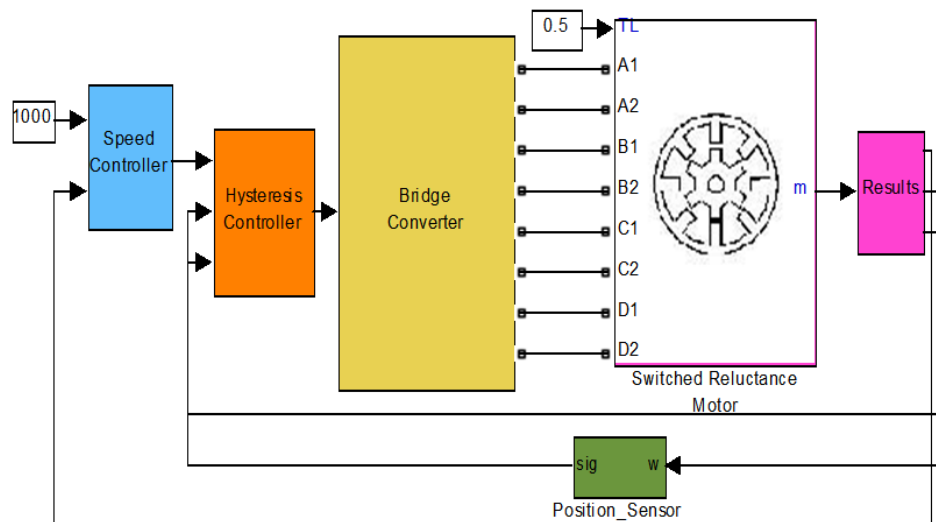
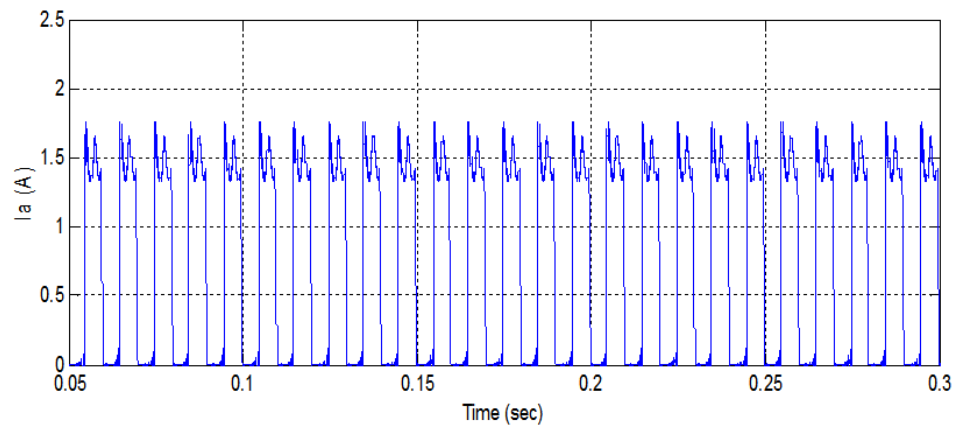
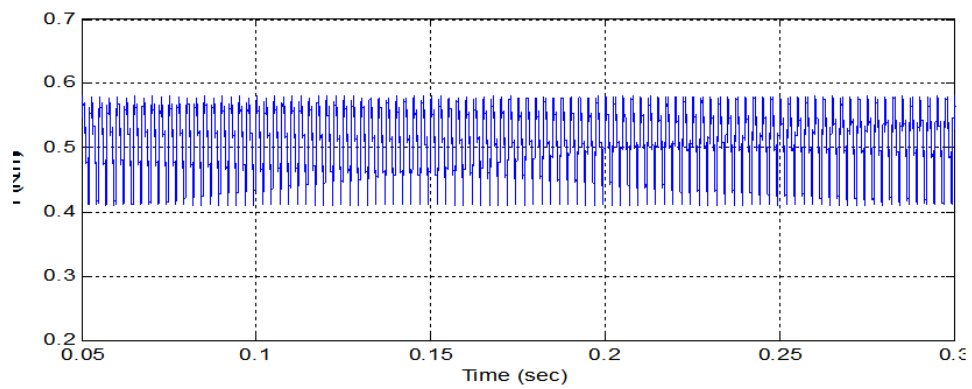


Fig. 5. Matlab/Simulink model of SRM for speed control

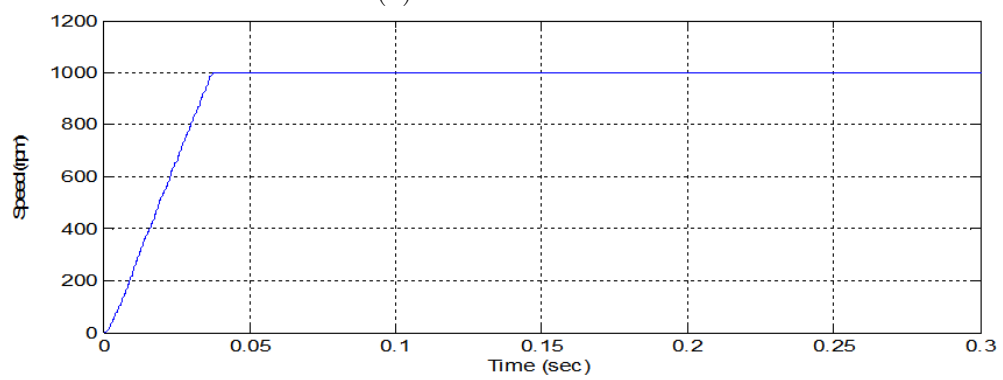
The performance of SRM drive with typical PI controller is shown in Fig. 6. The phase current of A phase is depicted in Fig. 6(a). The torque response of the SRM is depicted in Fig. 6(b). The speed response of SRM drive is depicted in Fig. 6(c). From Fig. 6(c), it is observed that SRM attains its reference speed with a higher settling time. To overcome these drawbacks associated with typical PI controller, FLC is best choice for controlling the speed of SRM drive.



(a)

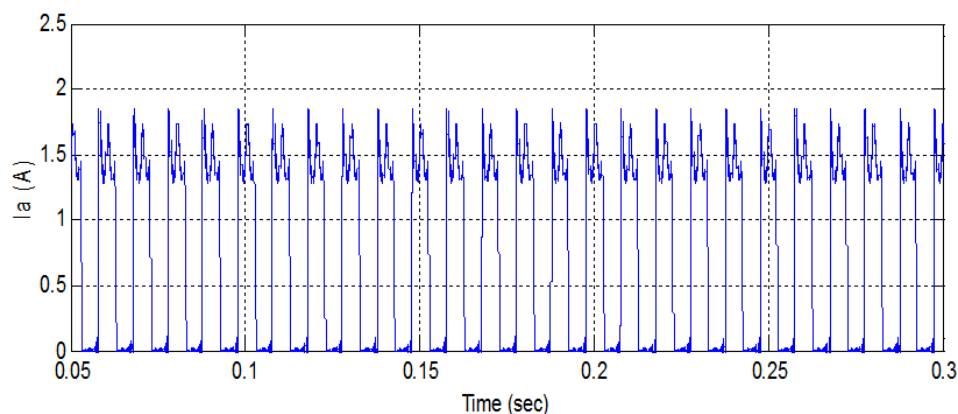


(b)

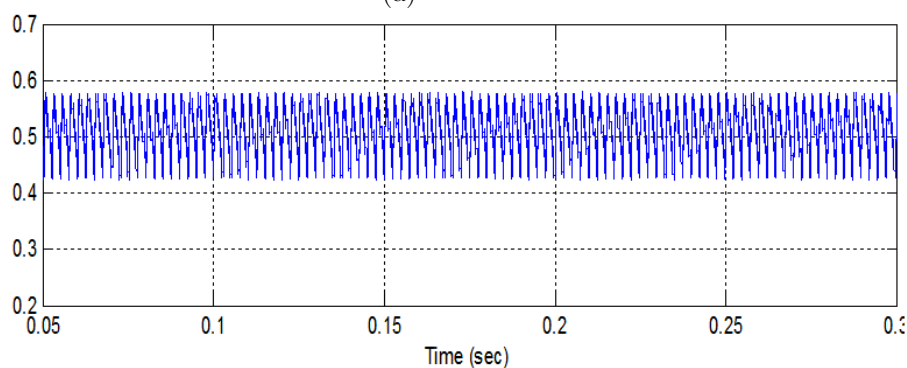


(c)

Fig. 6. Performance of SRM PI controller at of 0.5 Nm with a reference speed of 1000 rpm (a) Phase A current (b) Torque (c) Speed response Fig. 7 shows the performance of SRM drive with proposed fuzzy logic controller when the SRM is running at a speed of 1000 rpm with a load torque of 0.5 Nm. Fig. 7(a) depicts the waveform of phase A current. The load torque of SRM is depicted in Fig. 7(b). The speed waveform of SRM with FLC is depicted in Fig. 7(c). From this Fig. 7(c), it is noticed that the speed response of SRM has improved with less settling time.



(a)



(b)

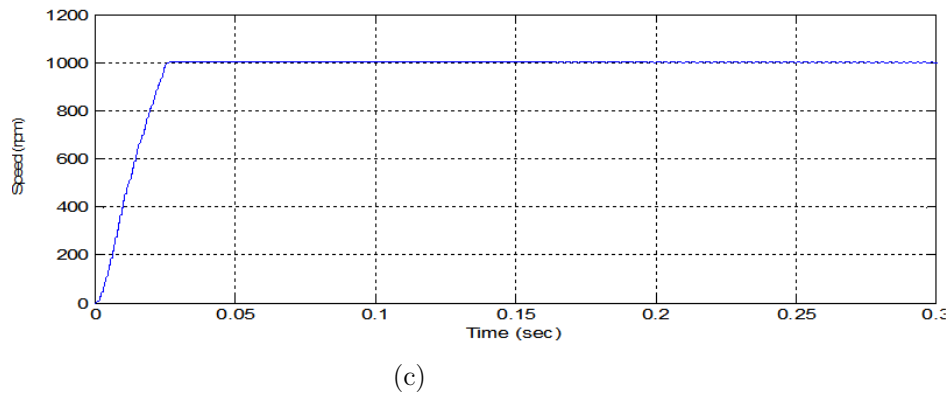


Fig. 7. Performance of SRM Fuzzy Logic Controller at of 0.5 Nm with a reference speed of 1000 rpm (a) Phase A current (b) Torque (c) Speed response

Fig. 8 depicts the performance of FLC is compared with traditional PI controller. From this figure, it is noticed that the SRM has attains the reference speed of 1000 rpm with the less settling time with enhanced response. The performance comparison between PI and FLC in terms of rise time, settling time and steady state error are illustrated in Table III. From this table, it is observed that the speed response of SRM with typical PI controller has large settling time under variable speed with constant load conditions. With FLC SRM drive has improved response with less settling time.

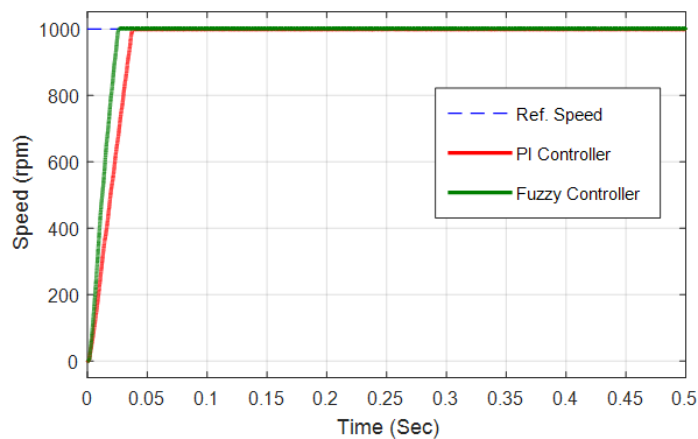


Fig. 8. Performance Evaluation of PI and FLC with SRM

Table III. Assessment of PI and FLC under different speeds

Parameters	At 1000 rpm with 0.5 Nm		At 500 rpm with 0.5 Nm	
	PI	Fuzzy	PI	Fuzzy
Rise Time (sec)	0.033	0.022	0.018	0.011
Settling Time (sec)	0.039	0.026	0.02	0.013
Steady state error (rpm)	0	3	0	1

5 Conclusion

In this paper, Performance of the switched reluctance motor has simulated and studied with typical PI and Fuzzy Logic Controller. From the simulation results obtained, it showed that FLC can improves the speed response of SRM drive with less settling time as compared to typical PI controller. Finally, it is proven that FLC is suitable for SRM drive to achieve the smooth speed response over a wide range of speeds.

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