Fuzzy Logic Controller Design for Switched Reluctance Motor

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Abstract: ***The switched reluctance motor rugged in construction therefore it can be suitable for vibrating and high temperature zone. But the main drawback of switched reluctance motor is large torque ripple. This produces vibration and noise in the motor. Therefore in order to overcome that problem the fuzzy logic controller is implemented. Due to the fuzzy logic controller output torque of the switched reluctance motor can be regulated within the hysteresis band. This paper describes the mathematical model of SRM motor and fuzzy logic control technique. In addition to this the simulink model of switched reluctance motor with fuzzy control technique is designed and tested through MATLAB/Simulink software. The parameters like speed and torque are represented graphically.***

Keywords: Fuzzy Logic Control, SRM Motor, FLC Controller and Switched Reluctance Motor

1. Introduction

The switched reluctance motor rugged in construction therefore it can be suitable for vibrating and high temperature zone. The torque produced by the switched reluctance motor is not dependent of phase currents polarity. Therefore the less number of semiconductor switches are used in the power converters. In addition to this the loss occurred in the SRM motor is from the stator only. Hence it can be cooled easily.

The switched reluctance motor are mainly used in electric vehicles, vacuums cleaner, washing machine, servo type and variable speed applications. The switched reluctance motor simulink model consists of three main blocks. They are position sensor block, converter block and switched reluctance block. The position sensor block consists of a position sensor which is linked to the rotor of switched reluctance motor. Hence the turn-on and turn-off angles of the switched reluctance motor phases can be measured accurately. To control the developed torque switching angles are used. At the same time the measured current and reference current are compared to generate drive signal for insulated gate bipolar transistor. Hence the hysteresis controller controls the currents independently. The converter block consists of three legs and each leg consists of two insulated gate bipolar transistor and two FW diodes. R Krishnan has presented the detailed switched reluctance motor drive modeling, simulation, analysis, design and applications [1].

2. Construction and Operating Principle of Switched Reluctance Motor

Actually in electrical machines the switched reluctance motor is the simplest one when compare to other electrical machines. Construction wise there is no permanent magnet or conductors in the rotor of switched reluctance motor. The rotor of switched reluctance motor consists of steel lamination stacked on to a shaft. In addition to this the cost of motor is low due to simple mechanical construction. T. J. E. Miller has explained the Switched Reluctance Motors and their Control techniques [2].

The Figure [1] shows the cross sectional view of a switched reluctance motor. From figure [1] we can see the 6/4 pole arrangement. That is the stator and rotor poles of switched reluctance motor. Three phase supply is given to the 6/4 switched reluctance.

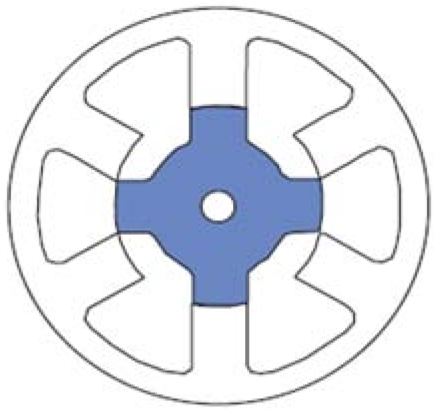

Figure 1: 6/4 Three phase SRM motor

On the basis of torque production the electrical machine are classified in to two types. Therefore the one way of torque production is due to electromagnet and the other way of torque production is due to variable reluctance. In switched reluctance motor the torque is produced due to variable reluctance. Hence it is known as switched reluctance motor.

The main principle of SRM motor is to give rise to minimum magnetic reluctance in order to form a stable equilibrium position in electromagnetic system. The nearest rotor poles are attached towards each other. At the time two diametrically opposite poles are excited to produce torque. But de-energize takes place when two rotor poles gets aligned with the stator pole. Now the adjacent stator pole gets energized to attract another pair of rotor poles. The aligned position is nothing but when the rotor poles and the stator poles get aligned in a certain position. At this time the la reaches maximum value. So as reluctance reaches minimum value. Once the L_a value decreases gradually then the rotor poles move away from its aligned position and reluctance value reaches minimum value. Since the L_a value decreases gradually the rotor poles moves away from its aligned position. At a certain point the rotor poles moves to a complete unaligned position from stator poles. At that moment phase inductance value reaches minimum value L_u and reluctance reaches maximum value.

3. Block Diagram of Fuzzy Logic Controller and Its Working

The approximate information, approximately reasoning and uncertainty to generate decision are called fuzzy set theory. Actually for selecting fuzzy logic controller there are two main reasons like Modelling can be developed for non-linear system and it has adaptive characteristics.

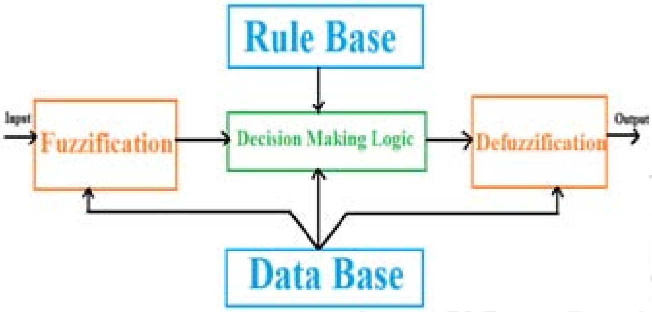

Figure 2: Block diagram of FLC

The figure [2] shows the fuzzy logic controller configuration. In defining operating characteristic of a system is simple in fuzzy logic. Hence it becomes feasible. But in case of traditional method it to too complex for complex mathematical equation. Hence it becomes infeasible.

A. Fuzzification

Fuzzification is nothing but the process of mapping the fuzzy membership function with multiple measured crisp inputs. At the same time it converts input data in to suitable value .Hence this suitable value is considered as a label of fuzzy sets. Fuzzification performs a scale mapping also. In scale mapping transfer of input variables to corresponding universe of discourse takes place. The fuzzy membership functions in the form of trapezoidal, triangle and bell membership functions are shown in figure [3].

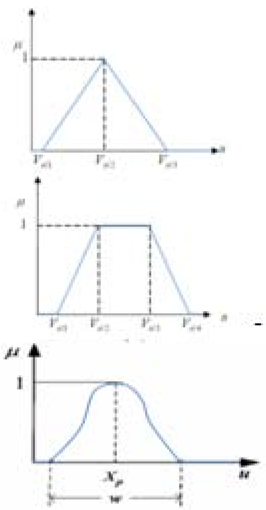

Figure 3: Triangle (a), Trapezoidal (b) and Bell membership function (c)

$$\mu(u_i)=\begin{cases}\dfrac{u_i-V_{a/1}}{V_{a/2}-V_{a/1}}, & V_{a/1}\le u_i\le V_{a/1}\\ \dfrac{V_{a/3}-u_i}{V_{a/3}-V_{a/2}}, & V_{a/2}\le u_i\le V_{a/2}\\ 0, & Otherwise\end{cases}\rightarrow Equation\{a\}$$

$$\mu(u_i)=\begin{cases}\dfrac{u_i-V_{a/1}}{V_{a/2}-V_{a/1}} & V_{a/1}\le u_i\le V_{a/2}\\ 1 & V_{a/2}\le u_i\le V_{a/3}\\ \dfrac{V_{a/4}-u_i}{V_{a/4}-V_{a/3}} & V_{a/3}\le u_i\le V_{a/4}\\ 0 & Otherwise\end{cases}\rightarrow Equation\{b\}$$

$$\mu(u_i)=\frac{1}{\left\{1+\left\{\dfrac{|u_i-X_p|}{w}\right\}^{2m}\right\}}\rightarrow Equation\{c\}$$

The above equations a, b and c represents triangle membership function, trapezoidal membership function and bell membership function respectively.

The limits $[V_{a/1}, V_{a/2}, V_{a/3}]$ represent triangle membership function.

The limits $[V_{a/1}, V_{a/2}, V_{a/3}, V_{a/4}]$ represent trapezoidal membership function.

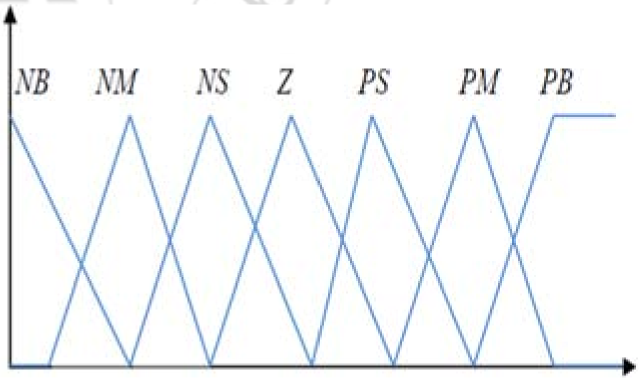

Figure 4: Seven level fuzzy membership functions

B. Fuzzy Inference

Fuzzy inference is nothing but by using fuzzy logic there is a process of mapping the given input to the output and on the basis of this mapping decision are made or pattern discerned.

C. Defuzzification

The outputs of the interference mechanism are the output variables. The fuzzy logic controller converts internal fuzzy output variables in to crisp values. so that system can use these variables. Hence it is called as defuzzification.

4. FLC Speed Control Algorithm

Step 1: The Switched reluctance motor speed signal is sampled.
Step 2: Calculate speed error and change in speed error.
Step 3: Determine fuzzy sets for speed error.
Step 4: Determine membership for speed error.
Step 5: Determine fuzzy sets for change in speed error.
Step 6: Determine membership for change in speed error.
Step 7: Finding control action as per fuzzy rule and Calculate Δ_{iqs}.
Step 8: Sending control command to the system after calculation of Δ_{iqs}.

Input and output variables of fuzzy membership function are selected as follows,
PB-Positive Big
PM-Positive Medium
PS-Positive Small
NB-Negative Big
NM-Negative Medium
NS-Negative Small
Z-Zero

In Input variables the value of speed error is $-1 \le \omega_e \le +1$ and value of change in speed error is $-1 \le \omega_{ce} \le +1$. In output variables the value of change in torque reference current $-1 \le \Delta_{iqs} \le +1$. The triangular shaped function is chosen as membership functions Because of the best control performance and simplicity.

Table 1: Rule based table

E/CE	NB	NM	NS	ZO	PS	PS	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

5. Mathematical Model of Switched Reluctance Motor

The numerical and analytical modeling of switched reluctance machine has been explained clearly by Zhang zhihui and Somesan Liviu [3-4]. A New Torque and Flux Control Method for Switched Reluctance Motor Drives have been developed by A. D. Cheok [5]. S Mir designed the Torque Ripple Minimization in Switched Reluctance Motors Using Adaptive Fuzzy Control model [6].

Mathematical equations for switched reluctance motor:

$$V = R_s I + \frac{d\psi\{\theta, I\}}{dt} \rightarrow Equation\{1\}$$

R_s=Resistance / phase
ψ = flux linkage / phase

$$\psi = L\{\theta, I\} I \rightarrow Equation\{2\}$$

L=Mutual inductance {depends on rotor position and phase current}
Phase Voltage equations,

$$V = R_s I + \frac{d\{L(\theta, I)I\}}{dt} \rightarrow Equation\{3\}$$

$$V = R_s I + L\{\theta, I\}\frac{dI}{dt} + I\frac{d\theta}{dt}\frac{d_L\{L(\theta, I)\}}{d\theta} \rightarrow Equation\{4\}$$

$$V = R_s I + L\{\theta, I\}\frac{dI}{dt} + \frac{d_L(\theta, I)}{d\theta}\omega_m I \rightarrow Equation\{5\}$$

$$e = \frac{d_L(\theta, I)}{d\theta}\omega_m I = K_b \omega_m I \rightarrow Equation\{6\}$$

$$K_b = \frac{d_L(\theta, I)}{d\theta} \rightarrow Equation\{7\}$$

Instantaneous input power is the sum of winding resistance loss, rate of change of field energy and air gap power. Therefore the instantaneous input power can be written as,

$$P_I = VI = R_s I^2 + I^2\frac{dL\{\theta, I\}}{dt} + L\{\theta, I\} I \frac{dI}{dt} \rightarrow Equation\{8\}$$

$$\text{Time}, t = \frac{\theta}{\omega_m} \rightarrow Equation\{9\}$$

Air gap power equations,

$$P_a = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{dt} \rightarrow Equation\{10\}$$

$$P_a = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{d\theta}\frac{d\theta}{dt} \rightarrow Equation\{11\}$$

$$P_a = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{d\theta}\omega_m \rightarrow Equation\{12\}$$

$$P_a = \omega_m T_e \rightarrow Equation\{13\}$$

By equating the equations 12 and 13 we get torque $\{T_e\}$,

$$T_e = \frac{1}{2} I^2 \frac{dL\{\theta, I\}}{d\theta} \rightarrow Equation\{14\}$$

Mathematical equations for direct torque control technique:

$$T_e = \frac{3}{2}\left\{\frac{P}{2}\right\}\frac{L_m}{L_s{}'L_r}\overline{\psi_s} * \overline{\psi_r} \rightarrow Equation\{15\}$$

$$T_e = \frac{3}{2}\left\{\frac{P}{2}\right\}\frac{L_m}{L_s{}'L_r}\psi_s \psi_r \sin\gamma \rightarrow Equation\{16\}$$

The stator flux assessment is done on the basis of stator voltage model and current model. The equation 17, 18 and 19 represents stator voltage equations. In case of current model equation 20 and 21 are used.

$$\psi_{ds}{}^s = \int\{V_{ds}{}^s - i_{ds}{}^s R_s\}dt \rightarrow Equation\{17\}$$

$$\psi_{qs}{}^s = \int\{V_{qs}{}^s - i_{qs}{}^s R_s\}dt \rightarrow Equation\{18\}$$

$$\psi_s = \sqrt{\psi^s{}_{ds}{}^2 + \psi^s{}_{qs}{}^2} \rightarrow Equation\{19\}$$

$$\frac{d}{dt}\overline{\psi_r} = \left\{\frac{\{L_m i_s - \psi_r\}}{T_r} - \omega_r \psi_r\right\} \rightarrow Equation\{20\}$$

$$\overline{\psi_s} = \left\{\frac{L_m}{L_r}\psi_r + \sigma L_s i_s\right\} \rightarrow Equation\{21\}$$

6. Simulation Model of Switched Reluctance Motor With Fuzzy Logic Control

In the MATLAB simulation of switched reluctance motor the following specification are used: Number of phases = 3, Number of stator and rotor poles = 6/4, Frequency [F] = 50 Hz, DC supply voltage [Vdc] = 120 volts, Stator resistance [Rr] = 0.01 ohms/phase, Moment of inertia [J] = 0.0082 Kg-m/sec, Unaligned inductance = 0.7 m H, Aligned Inductance = 20 m H. The simulation of a 6/4 switched reluctance motor based on MATLAB/Simulink environment has clearly presented by F Soares and C Branco [7].

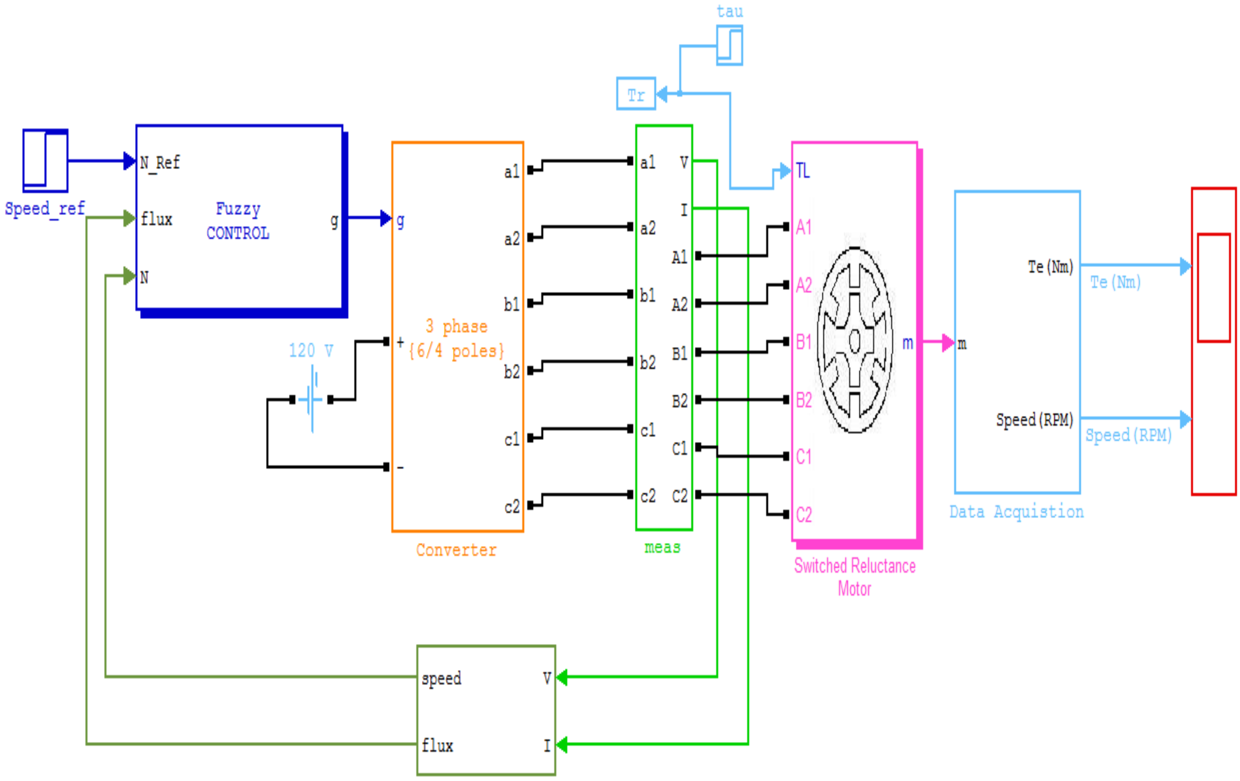

Figure 5: MATLAB simulink model of switched reluctance motor with FLC technique

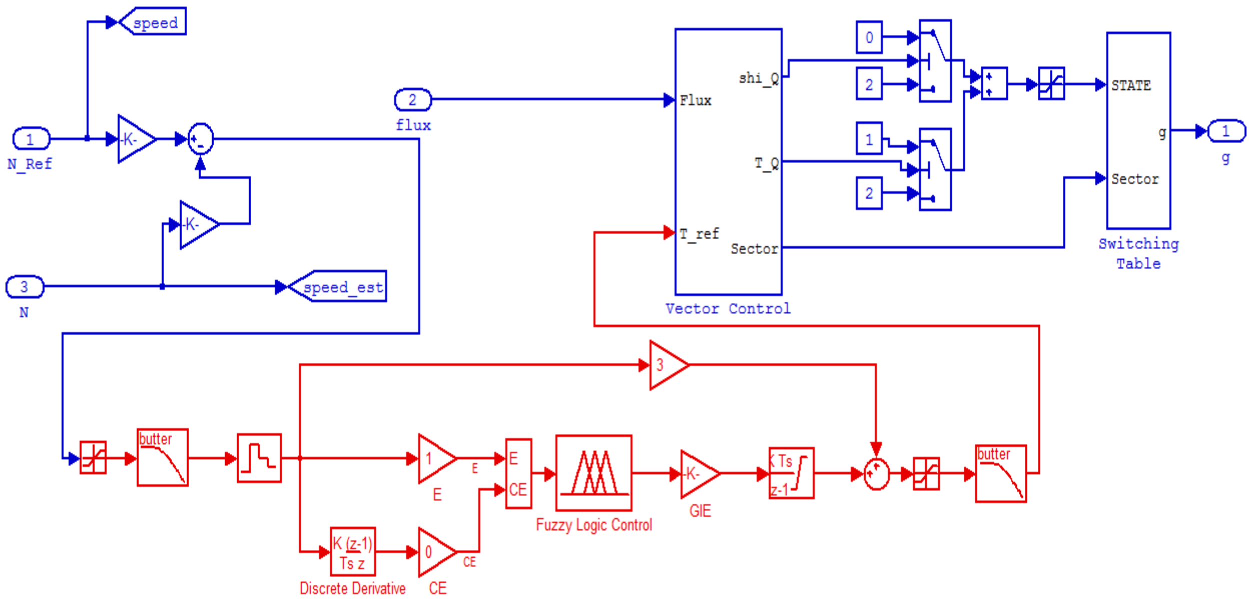

Figure 6: MATLAB simulink subsystem model of fuzzy logic control block

7. Simulation Results

[A] Torque

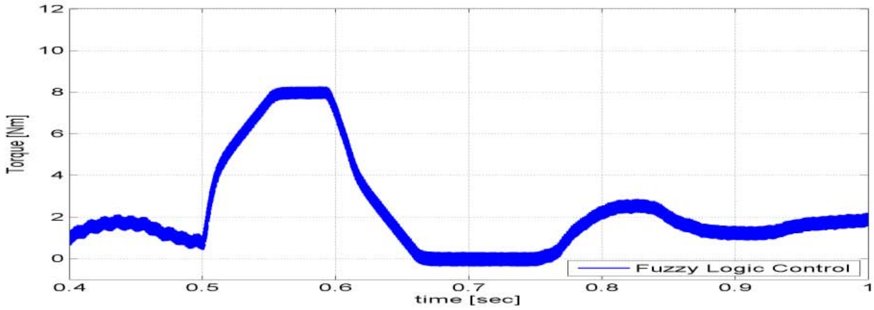

Figure 7: Torque in Newton-Meter

[B] Speed

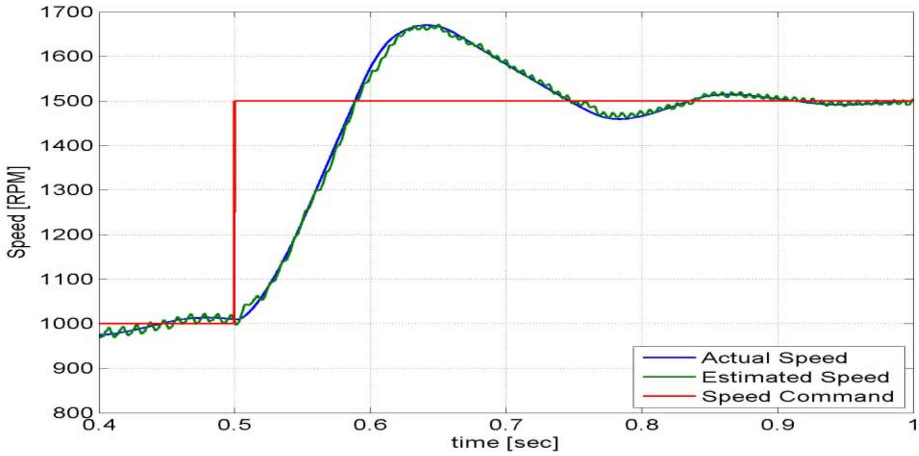

Figure 8: Speed in Revolution per Minutes

8. Conclusion

The switched reluctance motor gives high performance in harsh conditions like dusty environment and high temperature. In this research paper switched reluctance motor model with fuzzy Logic controller is designed through MATLAB software and also tested successfully by presenting the torque and speed values graphically. The potential of switched reluctance motor is highly greater particularly in motion control.

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