IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 11, Issue 1 Ver. I (Jan – Feb. 2016), PP 30-35
www.iosrjournals.org

Investigations of Fuzzy Logic Controller for Sensorless Switched Reluctance Motor Drive

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Abstract: *The proposed work is Investigations of Fuzzy Logic Controller for Sensor less Switched Reluctance Motor Drive. The switched reluctance motor is highly nonlinear in nature. But SRM has no rotor windings makes the drive cheaper. The input for the controller is phasor current and voltage and the output of the controller is rotor position estimation. By effective design of controller with the help of fuzzy logic algorithm can able to derive the system with minimum steady state error, good dynamic response and robust in nature. The SRM drive performance is validated with the help of numerical simulation of 8/6 SRM drive using Matlab/simulink.*

Keywords: *Fuzzy logic controller, SRM, steady state error, dynamic response.*

I. Introduction

The Switched Reluctance Motor (SRM) is a doubly salient machine with rotor has no winding. The stator windings of opposite poles are connected in series to one phase of the supply. When the stator is sequentially excited the rotor gets attracted and aligned with the respective poles. Due to continuous excitation of the phase rotor gets rotated with the reasonable torque ripple.

This paper [1] discusses robust control of SRM in robotic application by considering a mathematical model of SRM with unmodeled dynamics is proposed. Compared with normal controller, the proposed controller overcomes the influence of model uncertainties on system performance. The stability of the system is proven by using Lyapunov function. The proposed [2] system determines the magnetic characteristics of the SRM as the functions of the rotor position and winding current. The measurement system provides the way for the engineers to concentrate more on parameter variation instead of handling the problem of system configuration and accuracy. This paper [3] presents a novel voltage control servo hydraulic press driven directly by SRM .Online adaptive tuning fuzzy PID controller proves that the performance has higher control precision compared with conventional PID controller in the servo control application. The robust operation of a fuzzy based angle estimator algorithm for the position of SRM drives is described using theoretical and experimental analysis. From the result it proves that due to noisy and common error conditions fuzzy based algorithm performs highly efficient when compared to non fuzzy based algorithm. Hence, it was confirmed that the average and maximum position estimation errors of the fuzzy logic based estimation scheme due to feedback signal error were low compared to the non fuzzy estimation methods [4, 5].The paper [6] proposed the multi objective optimization function for the reduction of the torque ripple in the SRM drive below the base speed. By adjusting both turn on and turn off angle alone the parameters of the controller has been determined. The proposed work [7] to minimize the torque ripple of the drive with the help of PI and Fuzzy logic controller under three different strategies. In this paper [8,9], author proposed the PI controller and PI-Fuzzy based controller to the SRM drive .The performance of the system under steady state, dynamic response and robustness is comparatively analyzed and proven that PI-Fuzzy based controller is the best.

II. SRM Structure

A prototype of SRM considered has 8/6 poles with detailed parameters shown in table-.

The figure shows an idealized profile of an SR motor. The phase inductance is maximum when the rotor pole is aligned with the stator pole and is minimum when the rotor pole is aligned with the inter polar axis of the stator [11, 12]

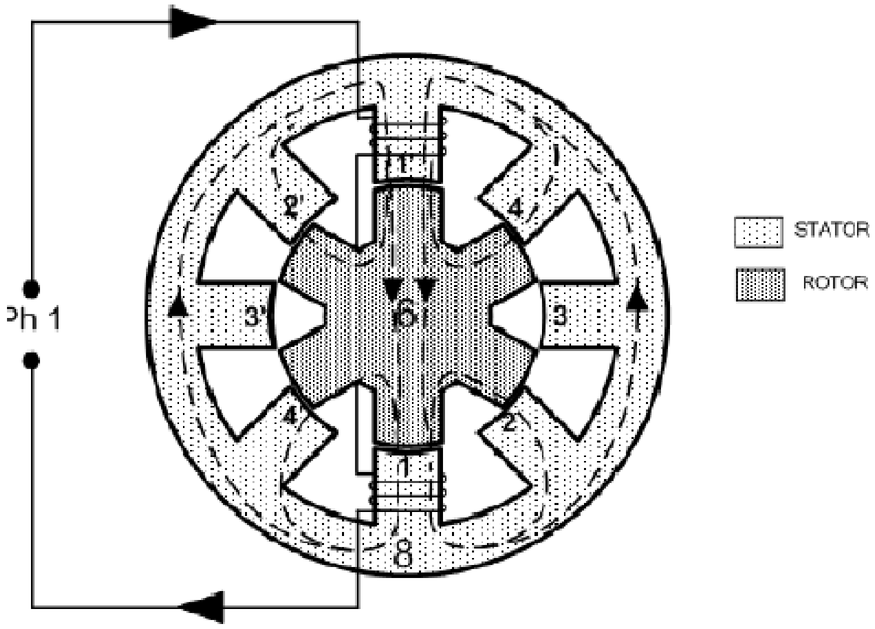

Fig 1. 8/6 Switched Reluctance Motor Structure.

$$L(\theta) = \begin{cases} L_{\min} & \theta_0 \le \theta \prec \theta_1 \,, \\ L_{\min} + p\theta & \theta_1 \le \theta \prec \theta_2 \,, \\ L_{\max} & \theta_2 \le \theta \prec \theta_3 \,, \\ L_{\max} - p(\theta - \beta_r) & \theta_3 \le \theta \prec \theta_4 \,, \\ L_{\min} & \theta_4 \le \theta \prec \theta_5 \,. \end{cases} \qquad (1)$$

L (θ) –inductance variation over one rotor pole pitch,
L_{min} –unaligned inductance (H),
L_{max} –aligned inductance (H),
β_s –stator pole arc (rad),
β_r –rotor pole arc (rad),

$$\beta_r > \beta_s \text{ and } p = \frac{L_{max} - L_{min}}{\beta_s} .$$

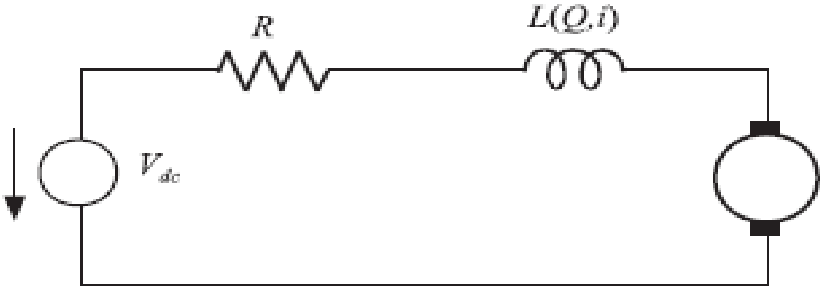

Fig 2. Equivalent circuit for SRM Drive

V	is the voltage applied to the phase,
R	is the phase resistance,
Ri(t)	is the resistive voltage drop,

is the static voltage,

is the speed voltage.

$$\psi_k(\theta_r, i_k) = L_{kk}(\theta_r, i_k) \times i_k \qquad k = 1,2,3,4 \qquad (2)$$

$Ai(x1)$ and $Ai(x2)$ The instantaneous torque (T) produced in the SRM is given by the formula,

$$T_d = \frac{1}{2} i^2 \frac{dL}{d\theta} \; . \qquad (3)$$

From the above non linear equation (3), it is understood that motoring torque can be obtained only when the phase current is switched on at rising period of time and breaking torque can be obtained only when the phasor current is switched off at falling period of time. To get optimal speed control, switching of phase current must be done at appropriate rotor position. So rotor position

$$T_e = J_m \omega_r + B_m \omega_r + T_L \qquad (4)$$

The above equation (4) represents the electromagnetic torque developed in the SRM drive

III. Fuzzy logic controller algorithm

The function of fuzzy logic controller is explained with the help of normalization, Fuzzification, Rule base an inference engine, Defuzzification, Denormalization.

1. Normalization:

Normalization performs the scale transformation, which maps the physical values of the speed (input) variable in to a normalized universe of discourse.

2. Fuzzification:

The process of converting numerical measurements to grades of membership of fuzzy set members is called Fuzzification. Fuzzy controllers use different membership function for different applications.

3.Rule base:

Basically a rule base is a linguistic controller, which contains rules in the IF THEN format. In this research the fuzzy parameters of e-error, ce- change in error, GE, GCE→Scaling factor

4. Inference engine:

According to rule base, if error at Iref side is very low (VL) then the change in error at very low (VL) side gives the output as M (Medium speed). For each rule, the inference engine looks up the membership values in the condition of the rule. As the fuzzy logic controller receives input, the rule base is evaluated.

5. Defuzzification

The RSS (Root Sum Square) method was chosen to include all contributing rules, since there are few member functions associated with the inputs and outputs.

6. Denormalization

The crisp output of the fuzzy logic controller is normally in the range of 0 to 1. In order to get the desired pulse width, it is required to multiply the crisp output by 0XFFFF (maximum pulse width =65535).

IV. Fuzzy Controller Implementation:

The universe of discourse of each input and output are divided

$$u^{crisp} = \frac{\sum_{i=1}^{R} b_i \mu_i}{\sum_{i=1}^{R} \mu_i} \qquad (9)$$

into equal intervals. The membership functions are introduced to characterize each interval. The universe of discourse selection depends on the input and output parameter needed for the particular performance of the u^{crisp} SRM drive. The values of these parameters are tuned during simulation to obtain a good

$$E(k) = e(k)GE(k) \qquad (6)$$

$$CE(k) = ce(k)GCE(k) \qquad (7)$$

$$ce = e(k-1) - e(k) \qquad (8)$$

performance of the drive. In this kind of Fuzzy controllers 50% of overlap have been chosen for the input error (e), change error(ce) and output(Iref) . The linguistic description of input and output functions are VL(Very Low), L(Low), M(Medium), H(High), VH(Very High).
For two input fuzzy system,

$$\mu A_1(x1) \cap A_2(x2) = \min\{\mu A_i(x1), \mu A_i(x2)\} \qquad (5)$$

Where are input fuzzy sets. The rule base of the direct fuzzy controller relates the premise (E and CE) to consequent Iref.

E and CE --- error and change in error.
GE and GCE --- scaling factor.
K --- Sampling instants.

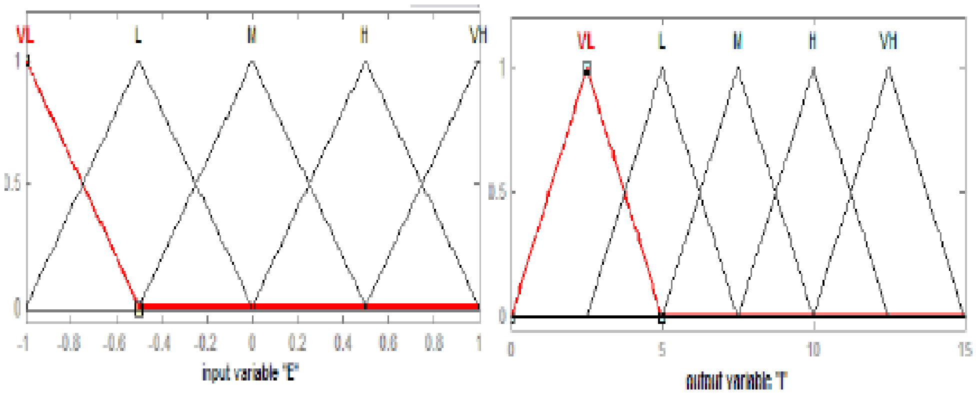

Fig 3. Supervisory Fuzzy Controller Membership function

Defuzzification is given by,
Where – output of the fuzzy controller
-- centre of membership function of the consequent of the Ith rule.

--membership value for the Ith rule 0s premise

R -- total number of fuzzy rules

		CE				
	Iref	*VL*	*L*	*M*	*H*	*VH*
e	*VL*	M	M	L	L	L
	L	M	L	L	L	H
	M	L	L	H	H	H
	H	L	H	VH	H	VH
	VH	H	VH	VH	VH	VH

Table 1. Fuzzy rule base for direct Fuzzy controller

V. Numerical results

To check the feasibility and robustness of the designed controller the simulation was performed in 8/6 SKM drive using Matlab/simulation.

Phase	4
Stator pole number	8
Rotor pole number	6
Rated voltage	230V
Rated current	10A
Rated speed	4000 rpm
Rated load	0.75 kw
Moment of inertia(Jm)	0.005 kg-m^3
Viscous friction coefficient(Bm)	0.005 Nm/(rad/s)
Stator resistance (R_k)	50 m-ohm

Table 2. Specifications of SRM

Fig 4. Simulation results at 200 rad/sec

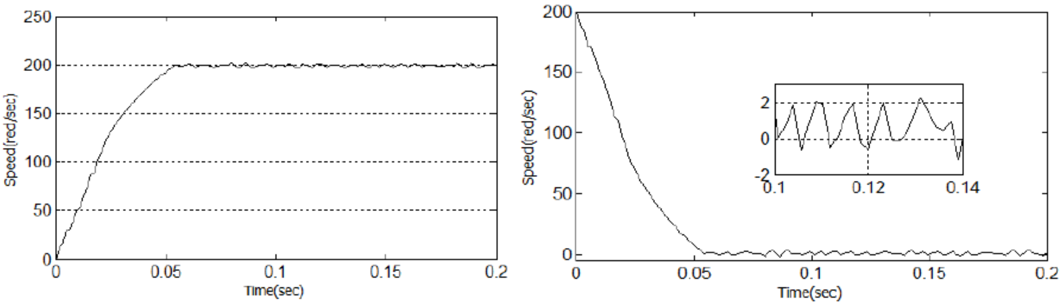

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Fig.5.Simulation results at different set point conditions at 0.2 s (100-180 rad/sec), 0.4s (180-200 rad/sec)

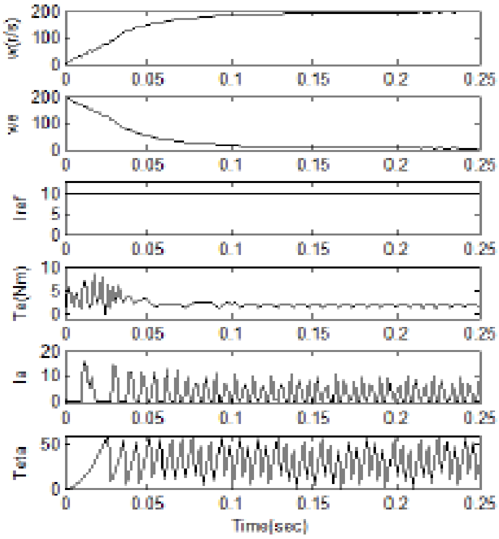
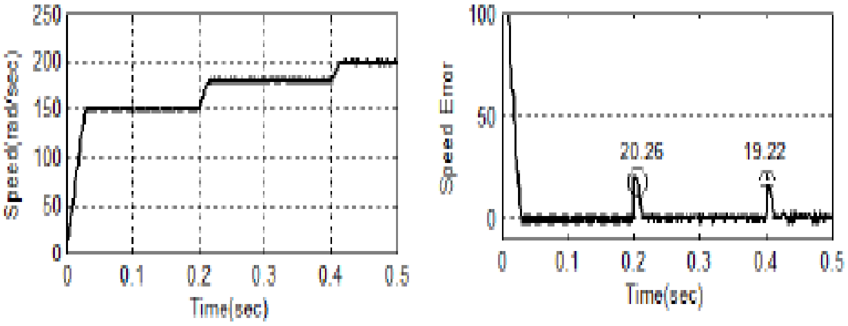


Fig 6. Simulation results under Full Load Condition



To test the system first it was operated at 200 rad/sec with external load TL=1Nm, to observe the steady state performance of the controller Fig4. Next it was test by different constant speed (150, 180 and 200 rad/sec) at different times to observe the dynamic response of the drive Fig.5. Finally the test was performed with external load of TL=1.9 Nm to observe the controller performance at the full load condition Fig.6.

From the simulation results of three conditions we finalized the performance of the fuzzy controller for the SRM device. During the first test performance, the steady state error occurrence in these for the measurable time period of 0.1 to 0.14 sec. the second test performance of the controller at different set speed was observed in the simulation, in the simulation result, it clearly explains the overshoot error of the speed at 0.2 sec and 0.4 sec as 20.26 rad/sec and 19.22 rad/sec respectively Fig.4. Finally the test was performed with full load conditions, in that simulation of the particular load condition reaches the steady state only after some period of time with online fine tuning. The online fine tuning of the controller takes some time to produce the nearing output.

VI. Conclusion

The proposed fuzzy controller based drive was simulated with the help of 8/6 SRM drive. The design controller was tested by three kind of testing method to observe the response of the controller under steady state, dynamic response and effectiveness under robust condition. The proposed controller validates the result that the device can be operated with some errors of appreciable one at all condition of constraints. The future scope of the paper is needed to design a controller of hybrid to overcome the error even under the testing of worst conditions.

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