International Journal of Latest Trends in Engineering and Technology
Vol.(10)Issue(2), pp.287-293
DOI: http://dx.doi.org/10.21172/1.102.47
e-ISSN:2278-621X

SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR BY FUZZY PI CURRENT CONTROLLER AND STATE SPACE MODELLING OF SWITCHED RELUCATNCE MOTOR

Ms.Sri Lakshmi Davuluri[1], Mr.K Trinadh Babu[2]

Abstract- The electric traction motor is a crucial component as it impacts the vehicle's performance. As the cost of batteries related to range requirements urges for a highly efficient but cost effective plays the important role. Several options for electric traction motors were investigated, namely permanent magnet motors, inductance motors and switched reluctance motors (SRM). Switched reluctance motors have found broad applications in automatic industry such as in electro- magnetic brakes. Due to their inherent simplicity, ruggedness and low cost, SRM posse's strong competition in many adjustable speed and servo type applications. These applications require position sensor control and torque ripple. Many experimental researches are done on switched reluctance motor for reducing steady state error.

In this paper, a new approach for reducing steady state error and transient response time for switched reluctance method is proposed by controlling the speed by using fuzzy PI controller. Fuzzy PI controller takes the action during transient response to get faster steady response. Later, a state space modeling of switched reluctance motor is ensured to support our result by taking an appropriate model for SRM consisting of non linear inductance and resistor.

Keywords – switched reluctance motor, rotor position control, fuzzy PI controller, state space modeling.

1. INTRODUCTION

On the basis of production of torque, electrical machines are classified into (i) electro-magnetically machines like dc and induction motor, torque is produced by the interaction of two magnetic fields and (ii) by variable reluctance machines like switched reluctance motor, torque is produced by variable reluctance in the air gap between stator and rotor. Switched reluctance motor is the simplest of all electrical machines. Only the stator has windings. The rotor contains no conductors or permanent magnets. It consists simply of steel laminations stacked onto a shaft. It is because of this simple mechanical construction that SRM is of low cost, which in turn has motivated a large amount of research on SRMs in the last decade. The state variable approach is the powerful technique and modern approach for the analysis and design of control systems. In this technique, no need to represent the physical quantities of system. SRM is a non linear system; hence to state stability and response of the system, state variable method is used. SRM is a non linear model consisting of uncertain parameters like inductance which depends on rotor position and phase current. So there is necessity of controller drive. A approach is proposed by fuzzy logic controller which does not require complex computations. In speed control of SRM, it consists of switched reluctance motor, converter and a controller.

2. PROPOSED MODEL

2.1 Mathematical reperesntation of SRM phase:

The equivalent circuit for the SRM can be derived neglecting the mutual inductance between the phases a. 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 by

$$Uk=Rkik + d\pounds k(\theta,ik)/dt \quad K=1,2,\ldots..p \qquad (1)$$

Where £k is the flux linkages, Uk is the terminal voltage of phase k, Rk is the phase winding resistance, ik is the phase current and θ is the rotor angle.

Flux linkage s depends upon the inductance and electric current in electromagnetic circuit of a SRM phase and given by

$$\pounds k= \pounds k(\theta,ik)=Lk(\theta,ik),ik \quad K=1,2,\ldots..p \qquad (2)$$

Where Lk is the inductance of the phase k, given in literature[1,2,3,4,5,6,7,8].

$Lk(\theta,ik)$ is given by Fourier series expression and it is given by:

$$Lk(\theta,ik)=L0(ik)+L1(ik)\cos(Nr\theta+\pi) +\sum Ln(ik)\cos(Nr\theta+n\pi)$$
$$n=2,3,\ldots.N \qquad (3)$$

where Nr is the number of rotor poles. Now, if two first two terms are considered then the above equation becomes

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[1] M.E,Asst Professor, Department of Electrical and Electronics Engineering, Anil Neerukonda Institute of Technology & Sciences, Visakhapatnam, Andhra Pradesh, India

[2] M,E,Asst Professor, Department of Electrical and Electronics Engineering, Anil Neerukonda Institute of Technology &Sciences, Visakhapatnam, Andhra Pradesh, India

$Lk(\theta,ik)=L0(ik)+L1(ik)\cos(Nr\theta+\pi)$ (4)

Where

$$L0(ik) = \frac{Lkmax(ik) + Lkmin(ik)}{2}$$

$$L0(ik) = \frac{Lkmax(ik) +L\ kmin(ik)}{2}$$ (5)

Where Lkmax(ik) is the aligned position inductance [2,3,4,5] and Lkmin(ik) is the unaligned position inductance and is assumed to be constant.

$Lkmax(ik) = \sum anikn \quad n=0,1,2,3$

The phase torque[3,4,8] is given by

$$= - \left[\quad (\quad) \right]$$ (6)

The dynamic equation can be expressed as

(7)

and

$$= J \quad + D \quad +$$ (8)

Where Te is electromagnetic torque, TL is load torque, ω is angular velocity, J and D are moment of inertia and coefficient of friction respectively.

2.2 Dynamic modelling of the SRM using MATLAB/SIMULINK

Using non linear model of SRM, a dynamic model of SRM for the speed controller is proposed with the help of MATLAB/SIMULINK. The schematic diagram for the speed control of SRM is as shown in fig.:1

A position sensor is used to sense the Rotor position . The derivative of rotor position gives the rotor speed. A reference speed ωref is compared with the rotor speed ω and the difference gives the speed error.Speed error is processed through a fuzzy proportional plus integral logic controller to obtain the reference current Iref . The reference current Iref is compared with the motor currents and the errors are used for switching of the phases of the Switched reluctance motor. Then, the voltages are applied to respective windings based on their position obtained from position sensor.

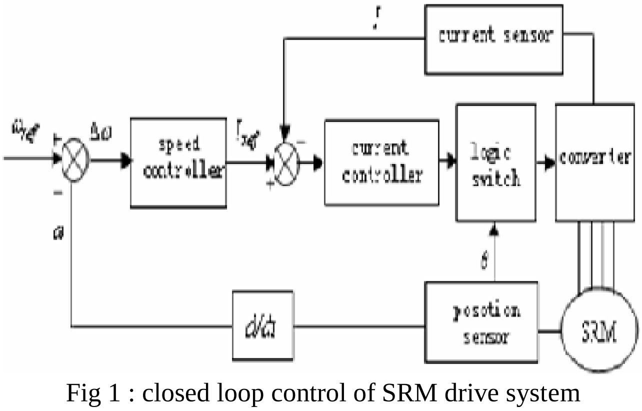


Fig 1 : closed loop control of SRM drive system

The complete model is divided into number of independent blocks, namely, phase winding block, speed controller block, current control block etc for the easy analysis. The whole simulation model of the switched reluctance motor is shown in fig.2

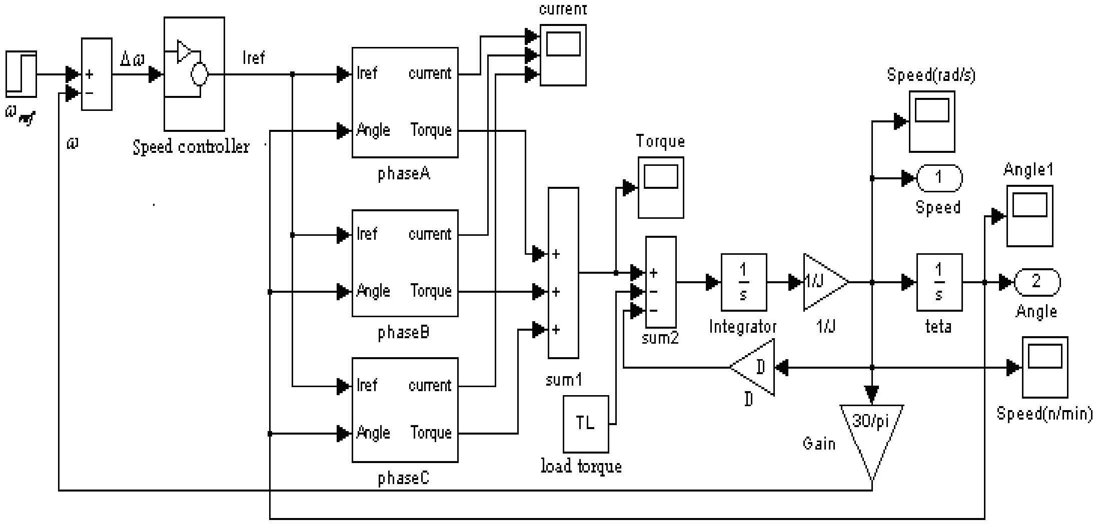


Fig 2: Simulation model of switched reluctance motor

2.3 Motor phase winding block:

An important block in this analysis is motor phase winding which show the properties of SRM. For easy analysis, three phases are considered to be identical though having little differences in their modulo block. Modulo block works out the angle of rotor position angle relative to reference zero angle in an electric cycle and switches the motor phase winding. For a 3-phase 6/4 SRM, the phase inductance has a periodicity of 90 degrees. So, rotor position angle coming from the mechanical equation is converted to 90 degrees. Hence, modulo is defined by using rem function. The switching relations of phases is given in table 1

Position angle	Switching on phases
0 ~ 10	C, A
10 ~ 30	A
30 ~ 40	A, B
40 ~ 60	B
60 ~ 70	B, C
70 ~ 90	C

Table 1

The simulation model for SRM phase winding is as shown in fig 3. Current calculation block has two inputs namely, rotor position angle and current controller output with phase current has its output. Using MATLAB function compiler, phase current is obtained from equations(2),(3)(4)(5) The torque for each phase is calculated from equations(6)(7)(8) with phase current and rotor position angle as inputs and torque as its output. The total torque is the sum of individual phase torques.

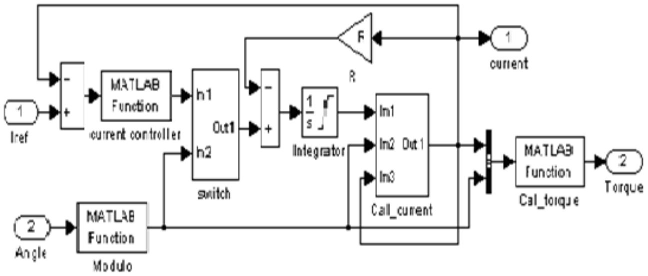
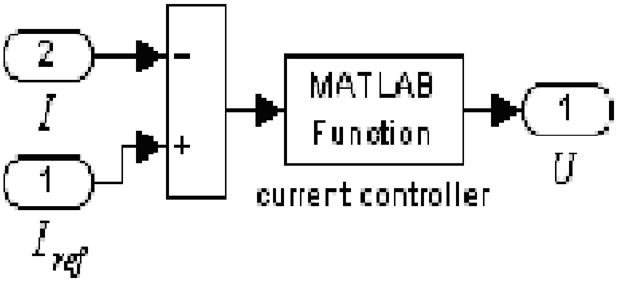


Fig. 3: A phase block of Switched Reluctance Motor

2.4. Current control block

By converter current switching control, current control is obtained. From current breadth relationship, current error is generated for switching. The motor phase current is compared with reference current I ref. the power devices of converter are considered to be ideal , so voltage drops and switching times are neglected



e Speed controller block

For any sudden speed changes the fuzzy logic controller is robust andhas a significant effect on steady state error. The fuzzy logic controllers decreases the steady state error,hence stability improves.The inputs to fuzzy logic controller are Speed error and change in speed error.

The output variables are Kp and ki of the PI controller. Hence the current is calculated using this values. Depending on the range of speed eror and precision of regulating speed , we deal with the input variables and the Madani method is used and COA method of defuzzification is used. The linguistic variables of the input and output fuzzy regions are negative larg(NL), negative medium(NM),

negative small(NS), zero(ZE), positive small(PS), positive medium(PM), positive large(PL).

These rules are taken a sfollows. If error and change in error is negative then output is negative. If error and change in error is positive then output is positive. If error is negative and change in error is positive then output us negative. The fuzzy rules for the fuzzy PI controller are shown in table 2

Δe_N e_N	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NL	NM	Z
NM	NL	NL	NL	NL	NM	Z	PS
NS	NL	NL	NM	NM	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

3. STATE SPACE MODELLING OF SWITCHED RELUCTANCE MOTOR

Analysis of switched reluctance motor is studied by considering a non linear inductance L and a resistance R which is an inductance based model [3] since, flux linkages and phase inductance changes with rotor position and the phase current.

The basic inductance model of SRM is shown in fig 5. It consists of only a resistance and non linear inductance. The model is good enough for SRM at standstill or under low currents.

Under high loads, the losses become significant. There are no windings on rotor. But, similar to synchronous machine there will be circulating current flowing body so damper windings is added to the basic model [13] shown in fig. 6. Now, the damper windings with damping resistance Rd and damper inductance Ld1 is added to basic model.

Let I be the total current, i1 be the magnetizing current and id1 be the damper winding current. Let V be the supply voltage, i2 and i3 be the loop currents.

By applying loop analysis for the fig. 5, the loop equations are as follows

$V = R\ i2 + L$ (9)

$R\ i3 + Ld1 - L =$ (10)

By solving equations (9) and (10), the equation for magnetizing current and damper current is obtained as follows

$= i1\ id1$ (11)

$= i1 \quad id1\ id1$ (12)

If X is the set of state variables which describes the system state at any time, U be the input variable and Y be the output variable, then the state representation of a system is given by

$=AX + BU$ (13)

$Y = CX + DU$ (14)

$$\left(\quad \right) = \left(\qquad \qquad \right) \left(\quad \right) + \left(\quad \right) V \qquad (15)$$

i=i1+id1 (16)

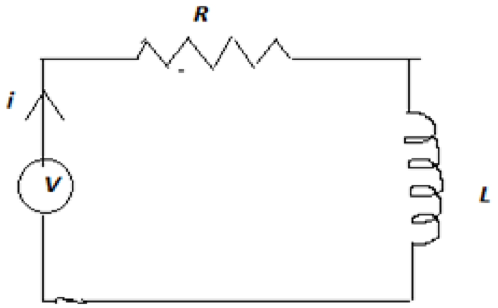
where A = , B = C = [1 1]

The transfer function of a switched reluctance motor is given by

G(S) = C(SI - A)-1 B

Substituting the matrix A, B and C in above equation, the transfer function is obtained as follows

Transfer function G(S) =



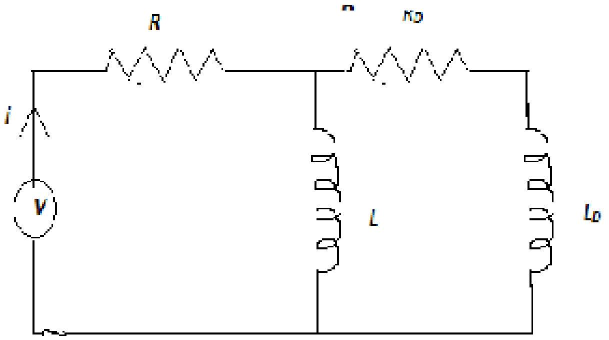


Fig5. basic inductance model fig 6 SRM under high loads

4. SIMULATION RESULT

Figure shows the simulation result of rotor position in degrees due to inductance with respect to

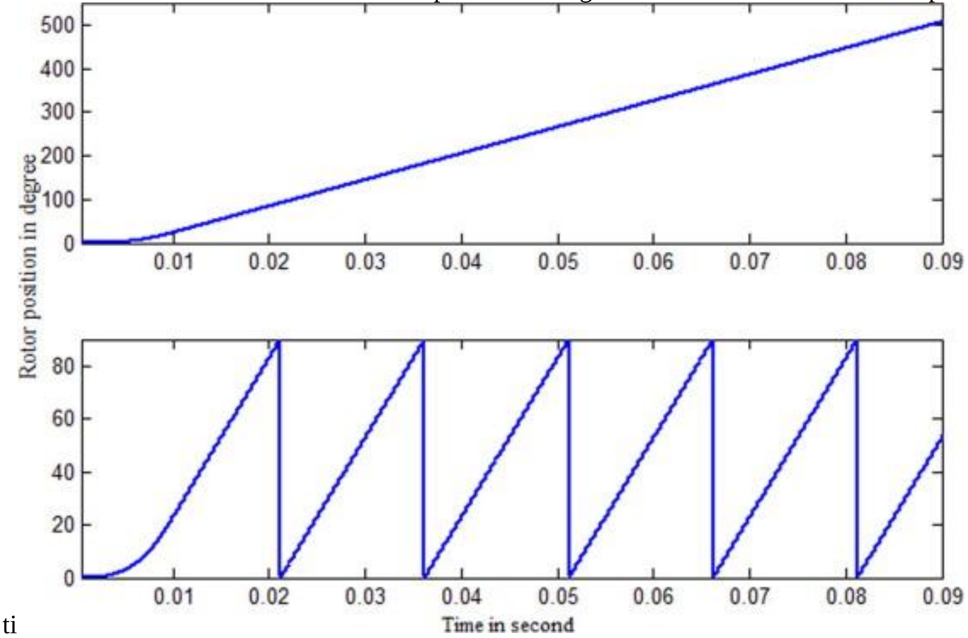


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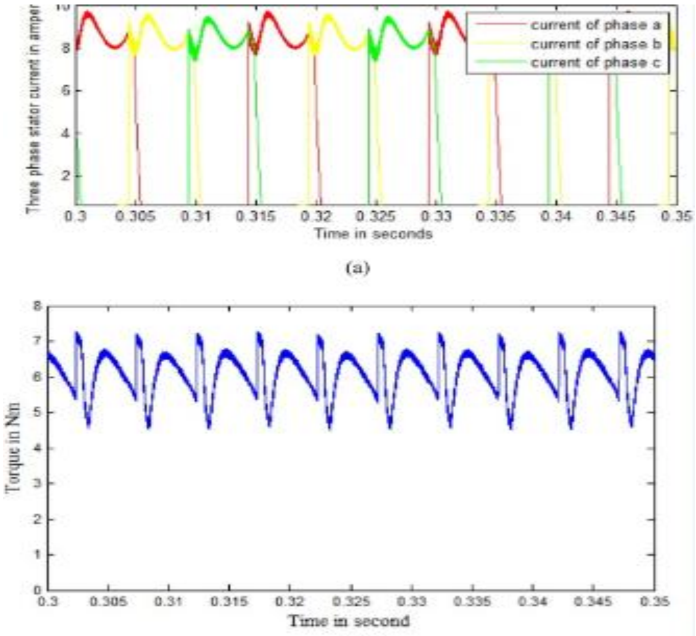
Figure shows the simulation result of three phase currennts



(a)

(b)

Figure shows the simulation result of speed for fuzzy PI controller with reference speed of 1000RPM.

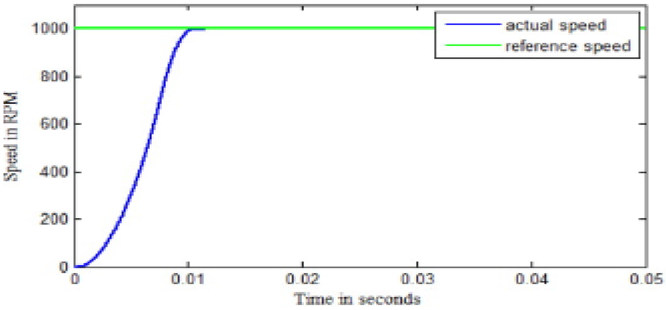
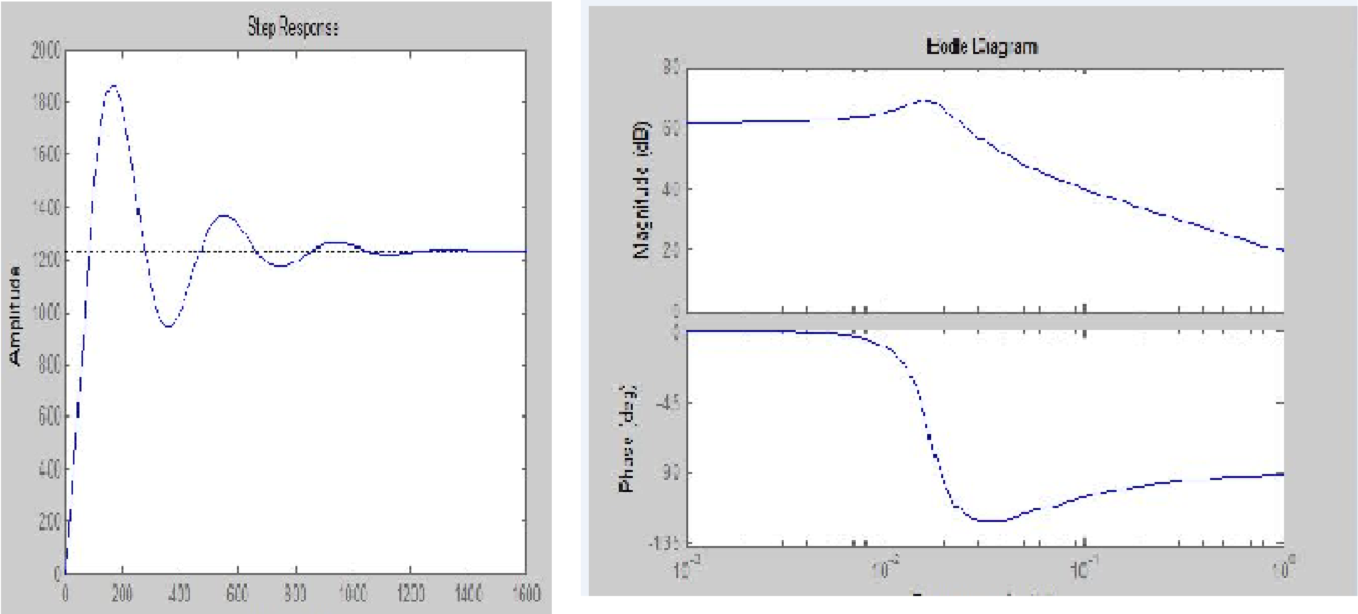


Figure shows the step response and bode plot when R=0.075Ω and L=0.1H Rd = 0.05Ω and Ld = 0.001H



5. CONCLUSIONS

An effective dynamic model for simulating the speed performance of SRM has been introduced in this paper. This model is the generalized model and consists of several sub systems. Hence, it can be modified and can be applied with other number of phases. The simulation results show the decrease of the steady state error which is nearly equalto zero and hence the stability is improved by using fuzzy PI controller when compared to conventional PI controller. The fuzzy PI controller has also effects the transient response so that steady state is reached quicker. The model is also ideal tool to validate the performance of different algorithms for any applications. From step response of SRM, it is observed that higher the values of damper winding inductance, the oscillations can be considerably reduced and quicker response is obtained. From bode plots; it is observed that the appropriate model is stable system.

appendix

Number of stator poles=6, number of rotor poles=4, number of phases=3, reference speed=1000RPM, DC link voltage= 120V, R=0.075Ω, Lmin=22e-3H, a1=4.95, a2= -1.3, a3=0.16, J=0.08 kg.m2, D=0.0183.

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