# A NOVEL METHOD FOR SPEED CONTROL OF SWITCHED RELUCTANCE MOTOR BY FUZZY PI CONTROLLER

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**Abstract: This paper presents a speed control of switched reluctance motor using fuzzy PI controller . Depending on the non linear model of the SRM with negligible mutual inductances and the torque depending on the rotor position of the motor, the subsystems are modeled using MATLAB/SIMULINK . The fuzzyPI controller is robust to sudden changes in reference speed and shows its effect on transient response and decreases the steady state error. This paper provides a better control on the speed of the SRM when compared with conventional PI controller.**

**Keywords: switched reluctance motor, current control, fuzzy PI controller**

## I. INTRODUCTION

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. In speed control of SRM , it consists of switched reluctance motor, converter and a controller**.**

## II. MATHEMATICAL REPRESENTATION 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

$$U_k=R_k i_k + d£_k(\theta,i_k)/dt \quad K=1,2,\ldots..p \qquad (1)$$

Where $£_k$ is the flux linkages, $U_k$ is the terminal voltage of phase k, $R_k$ is the phase winding resistance,$i_k$ 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

$$£_{k=} £_k(\theta,i_k)=L_k(\theta,i_k),i_k \quad K=1,2,\ldots..p \qquad (2)$$

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

$L_k(\theta,i_k)$ is given by fourier series expression and it is given by:

$$L_k(\theta,i_k)=L_0(i_k)+L_1(i_k)\cos(N_r\theta+\pi) +\sum L_n(ik)\cos(N_r\theta+n\pi) \quad n=2,3,\ldots.N \qquad (3)$$

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

$$L_k(\theta,i_k)=L_0(i_k)+L_1(i_k)\cos(N_r\theta+\pi) \qquad (4)$$

Where

$$L_0(i_k) = \frac{L_{kmax}(i_k) + L_{kmin}(i_k)}{2}$$

$$L0(i_k) = \frac{L_{kmax}(i_k) +L_{kmin}(i_k)}{2} \qquad (5)$$

Where $L_{kmax}(i_k)$ is the aligned position inductance [2,3,4,5] and $L_{kmin}(i_k)$ is the unaligned position inductance and is assumed to be constant.

$$L_{kmax}(i_k) = \sum a_n i_k^n \quad n=0,1,2,3$$

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

$$T_K = -\frac{N_r i_k^2}{4}\left[\sum_{n=0}^{3}\frac{2a_n}{n+2} - L_{kmin}(i_k)\right]\sin(N_r\theta) \qquad (6)$$

The dynamic equation can be expressed as

$$\omega = \frac{d\theta}{dt} \qquad (7)$$

and

$$T_e = J\frac{d2\theta}{dt2} + D\frac{d\theta}{dt} + T_L \qquad (8)$$

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

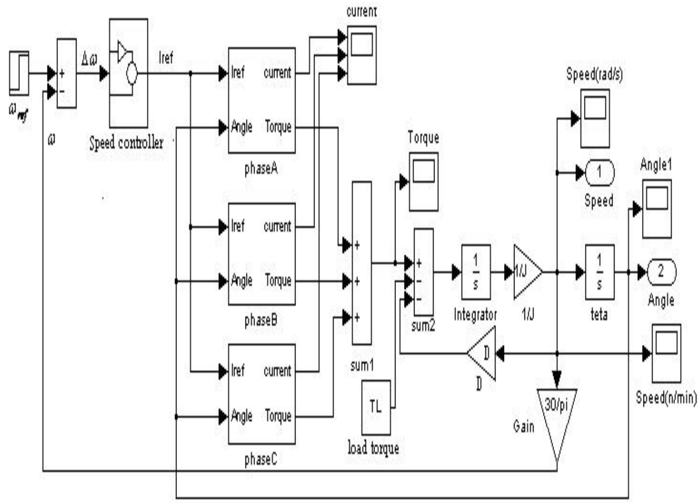



Fig 2. Simulation model of switched reluctance motor

## III. DYNAMIC MODELLING OF THE SWITCHED RELUCTANCE MOTOR USING MATLAB/SIMULINK

On basis of nonlinear model of SRM ,dynamic model of SRM for the speed controller is developed with the help of MATLAB/SIMULINK. The schematic diagram for the speed control of SRM is as shown in fig.:1:

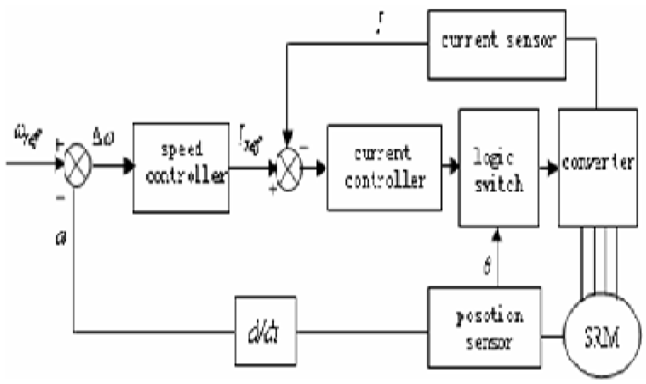



**Fig:closed loop control of SRM drive system**

It consists of position sensor to sense the Rotor position . The derivative of rotor position gives the rotor speed . Then, the reference speed ω*ref is* compared with the rotor speed ω and the difference of them is speedd error. Now 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 to determine the 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.

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

### A. MOTOR PHASE WINDING BLOCK

Motor phase winding block is the important part of the whole system simulation. It shows the existing properties of SRM. In this, all three phases are assumed to be identical, therefore the modelling procedure of them are almost same, though have a little difference in their modulo block. Detailed implementation .The function of modulo block is to work out the angle of
rotor position angle relative to reference zero angle in a electric cycle. For a 3-phase 6/4 SRM, the phase inductance has a periodicity of *90* degrees. Therefore, it is convenient to transform the rotor position angle coming from the mechanical equation to 90 degrees. Hence , this modulo is realized by virtue of rem function.

**SWITCH RELATIONS OF 3-PHASEWINDINGS**

| Position angle | switching on phases |
|---|---|
| 0 ~ 10 | C, A |
| 10 ~ 30 | A |
| 30~ 40 | A B |
| 40 ~ 6o | B |
| 60 ~ 70 | B ,C |
| 70 ~ 90 | C |

The simulation model for the phase of the SRM is shown in fig.3. The inputs to the current calculation block is rotor position angle and phase current where output is phase current. Using equations(2),(3)(4)(5), we calculate the phase current by using MATLAB function compiler. The torque calculation block consists of phase current and rotor position angle as inputs with torque as it output. The torque of each phase is obtained by using equations(6)(7)(8). The total torque is the sum of individual phase torques .

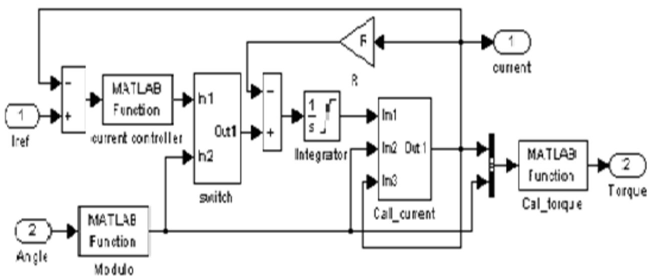
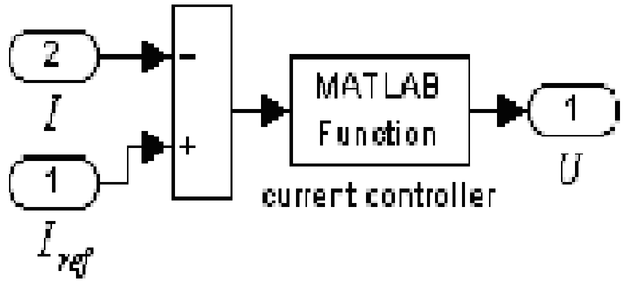



Fig. 3: A phase block of Switched Reluctance Motor

### B. CURRENT CONTROL BLOCK

Current control is achieved with current switching control of the converter. In this,the current error is computed from which the switching is generated depending on its relationship to the current breadth. The reference current *I ref* will be compared to the motor phase current *I* .It is assumed that the power devices in the converter are ideal , hence their voltage drops and switching times are neglected




## IV. SPEED CONTROLLER BLOCK

The fuzzy logic controller is robust to sudden changes in reference speed, but has a significant study on steady state error. The fuzzy logic controller reduces the steady state error. The inputs to fuzzy logic controller are Speed error and change in speed error.

The output variables are $K_p$ and $k_i$ 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 asfollows. 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 as follows:

| $\Delta e_N$ / $e_N$ | 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 |

The fuzzy pi controller for the switched reluctance motor can be designed using fuzzy logic toolbox in MAT LAB. The conventional PI controller is also designes using MATLAB/SIMULINK. The simulation results of speed for both conventional PI controller and fuzzy PI controller are obtained with load disturbance of 5N.m at 0.1sec.

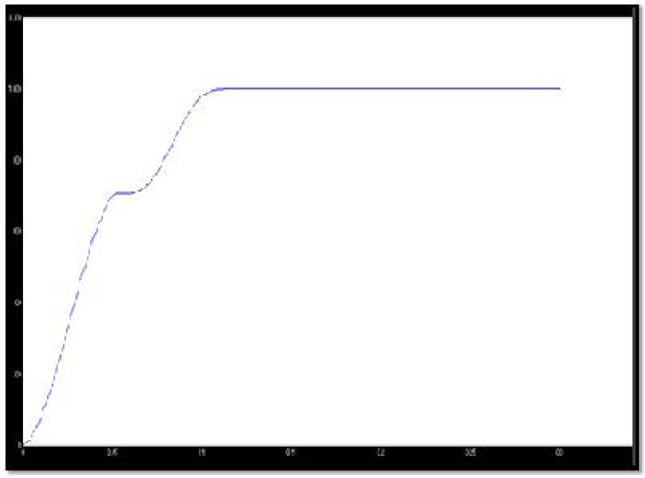


Fig. 6 simulation result of speed for conventional PI controller with reference speed of 1000RPM

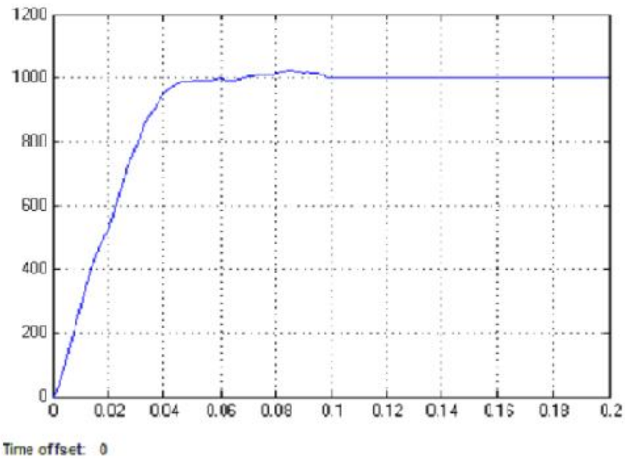



Fig .7 simulation result of speed for fuzzy PI controller with reference speed of 1000RPM

## V. CONCLUSIONS

In this paper, the speed control for the switched reluctance motor using effective dynamic modelling of the SRM is given. This model consists of number of subsystems and hence can be modified easily. The fuzzy PI controller shows its effect on the transient state of the SRM and steady state error is reduced.

## VI. 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, $L_{min}$=22$e^{-3}$H, $a_1$=4.95, $a_2$= -1.3, $a_3$=0.16, J=0.08 kg.$m^2$, D=0.0183.

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