Novel Method for Design and Control Strategy of Switched Reluctance Motor

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Abstract— A SRM has several features, including high reliability, simple construction, inherent fault tolerance, low manufacturing cost and possible operation in high temperature make it more attractive for industries and electric vehicle applications. However main drawbacks of SRM are high acoustic noise level, large torque ripple and vibrations. This paper proposed 8/6 pole, 4 phase SRM and new control strategy to improve torque sharing mechanism during phase commutation period and also very low torque ripple and low level of vibration with flexible control. Finally simulation results and developed MATLAB/SIMULINK based model is presented.

Key words: SRM, Switched Reluctance Motor

I. Introduction

Switched reluctance motor (SRM) has robust and simple construction, inherent fault tolerance capability and flexible control due to this tremendous advantages it attracts various technical appliances and industries and it becomes more popular than other motors. This motor has some drawbacks like torque ripples, vibration, high acoustic noise which are responsible for fault tolerances it means SRM is not fault free motor and this type of fault occurs at low speed. This paper present strategy to overcome above mentioned fault and to minimize the faults fast and accurate identification is important. Real time control of SRM is governed by the accurate rotor position signals. Which is sensed by the different sensors (Optical encoder, magnetic, mechanical position, Hall sensors)[1][2]

For the high speed application SRM has robust rotor and simple structure is most important. When rotor rotates at high speed the centrifugal force is also high. SRM can easily compete other motor types because of his simple and robust structure. The output of SRM is mainly dependent on the phase current and nonlinear inductance slope. At aligned position inductance is maximum, when negative and positive torque region are mechanically near. Due to lack of magnets or conductors on the rotor, high speed can easily achieved as compared to the other motors.[3]

The main propulsion of this paper is to make a controller which will reduce a torque ripple of the motor to an acceptable industrial level. Concentrate magnetic flux and double saliency these are two factors which is responsible to develop a torque ripples and high acoustic noise level. The vibrations, torque ripples and high acoustic noise are mainly high when motor runs at low speed.

II. Mathematical Modeling

Consideration of elementary reluctance machines are used for the derivations of basic torque equations of SRM. The rotor freely rotates as the excited winding is wound on the stator side.

The flux linkage is,

$$\psi = L(\theta)i$$

The torque expression

$$T_e = \left[\frac{\partial W'}{\partial \theta}\right]_{i=constant}$$

Where, W'= co-energy

It can also be defined as the definite integral

$$W' = \int_0^{i_1} \lambda\,(\theta, i)di$$

At any positions if we considered the co-energy, it can be defined as area above the magnetization curve.

So, torque equation become

$$T_e = \int_0^{i_1} \frac{\partial\lambda(\theta, i)}{\partial\theta}di$$

The instantaneous torque can be visualized graphically for this kind of equation $\frac{\Delta\omega_m}{\Delta\theta}$ where $\Delta\omega_m$ is involved at constant stator current because move through infinite terminal displacement$\Delta\theta$.

During some displacement changes occur,

- Exchange of energy with power supply.
- Also change in stored field energy.
- Change in co-energy is exactly equal to mechanical work done.

This can be proved as, Constant current in a displacement$\Delta\theta$, Exchange the energy with supply energy is$\Delta W_e = P_{ABCD}$. The change in stored field energy $\Delta W_f = P_{OBC} - P_{OAD}$ and mechanical work done is,

$$\Delta W_m = T_e\Delta\theta$$
$$\Delta W_m = \Delta W_e - \Delta W_f$$
$$\Delta W_m = P_{ABCD} - (P_{OBC} - P_{OAD})$$
$$\Delta W_m = P_{ABCD} - P_{OBC} + P_{OAD}$$
$$\Delta W_m = P_{OAB}$$
$$\Delta W_m = \Delta W'$$

We find that all of the energy is not converted into mechanical work and some kind of energy is stored in magnetic field. The energy which stored in magnetic field is useful it can't be wasted. The magnetization curve can be straight line if magnetic saturation doesn't occur.

The instantaneous torque,

$$T_e = \frac{1}{2}i^2\frac{dL}{dt}$$

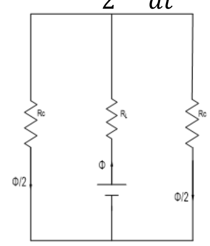

Fig. 1: Magnetic circuit for SRM

III. VALID ROTOR AND STATOR POLE ANGLE SELECTION

In design process of SRM Selection of Rotor and Stator pole angle plays a vital role. Normally in standard design process the rotor pole arc angleβ_r is greater than stator pole arc angleβ_s.

1) The rotor pole arc angle β_r is greater than stator pole arc angle $\beta_{s\ i.e.}\beta_r>\beta_s$.
2) The stator pole arc angle β_s is greater than effective torque zone, but effective torque zone is lesser than stroke angle.

$$\varepsilon = \frac{2\pi}{\frac{Ns}{2}Nr}$$

In 8/6 machine the stroke angle is,

$$\varepsilon = \frac{2\pi}{\frac{8}{2}6} = 0.2612\ rad = 15°$$

Machine may not start at some position if,

$$\varepsilon > \beta s$$

To better understand this phenomenon the inductance profile of SRM shown in fig.2.2

As per the given figure if the stator and rotor pole does not overlap each other. If this condition occurs then the phase inductance remains constant at the aligned value Lu. The existence of the region if from 0-$\theta_{1,}$ where 0 is considered to be fully unaligned position. From fig 2.1(a) it can be analyzed that fully unaligned position and also the rotor has to traverse an angle $\theta_1 = \frac{\pi}{Nr} - \frac{\beta s}{2} - \frac{\beta r}{2}$ fir the necessity condition i.e. tip of the rotor pole come to under the stator pole i.e. it should be placed one after the other and there should be no overlap. As the position changes so accordingly the position of $\theta_{1\ \text{and}}\ \theta_2$ changes so from position θ_1 to position θ_2 there is overlapping of stator and rotor pole to some extend. In the above condition there is no overlapping so in this rotor traverse the region and inductance value rises.

After the observing the fig.2.1(b) i.e. $\theta_2 - \theta_1 = \beta s$ is the observed angle. Of the rotor changes its position and reaches the position $\theta_2$then the overlapping occursdue to overlapping inductance value at position $\theta_2$is equal to the maximum value La. If the position changes from θ_2 to θ_3 then there would bea complete overlap of rotor and stator pole as shown ion fig 2.1(c). due to this inductance value stag constant (stable) at per the maximum value of La. Changing in position θ_3 to position θ_4 the change in angle has been observed that i.e. $\theta_3 - \theta_2 = \beta r - \beta s$due to this there would be a change in rotor and stator pole. So there would be overlapping to some extent and also steady decrease in inductance value as the rotor traverse this region. From fig 2.1(d) the considered angle is$\theta_4 - \theta_3 = \beta s$, so in this condition rotor reaches position θ_4 and pole are unaligned. At this position θ_4 the inductance value is approximately equal to minimum value Lu. So for reaching the fully unaligned position, rotor has to traverse an angle of$\theta_5 - \theta_4 = \frac{\pi}{Nr} - \frac{\beta s}{2} - \frac{\beta r}{2}$as per the fig 2.1(e).

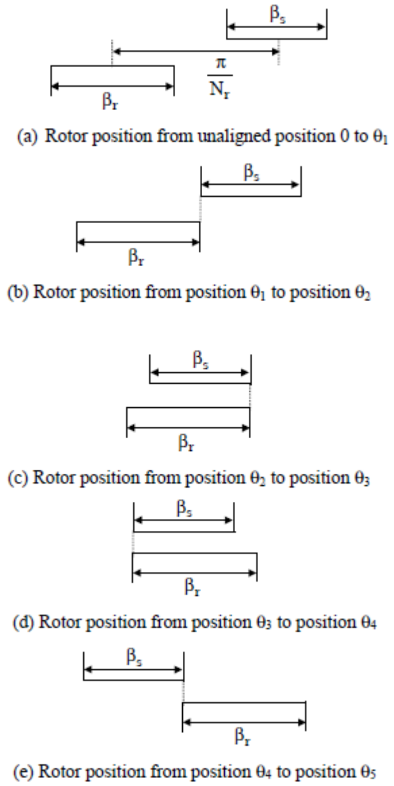

Fig. 2.1: Schematic representing the traverse of rotor

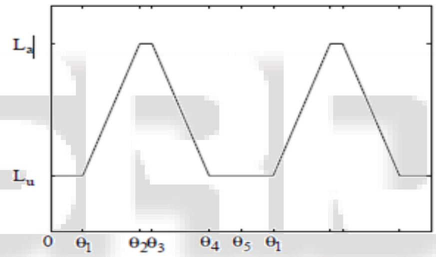

Fig. 2.2: Ideal inductance vs. rotor position profile

IV. DESIGN PROCESS OF SRM

The outer diameter of the stator automatically fixes by the frame size:

$$Do = (\text{Frame Size} - 3)*2$$

- Polenumbers, outer diameter D_o, and preliminary pole arcs are fixed. Only changing the entire frame size the D_o can change.
- As per the requirement of torqueshaft diameter D_{sh} can also be selected.
- Assuming that B_{max} is assumed to be equal tothe stator pole flux density B_s

The area of stator pole can be written as,

$$A_s = \frac{D}{2}L\beta_s$$

The Product of the stack length and back iron thickness C is equal to area of yoke.

$$A_y = CL$$

The height of stator and rotor pole can be calculated as,

$$h_s = \frac{Do}{2} - C - \frac{D}{2}$$

and

$$h_r = \frac{D}{2} - g - \frac{Dsh}{2} - \frac{Arc}{L}$$

The area of rotor pole can be written as

$$A_r = \left(\frac{D}{2} - 2\right) L\beta_s$$

V. MATLAB/SIMULINK MODEL AND RESULTS

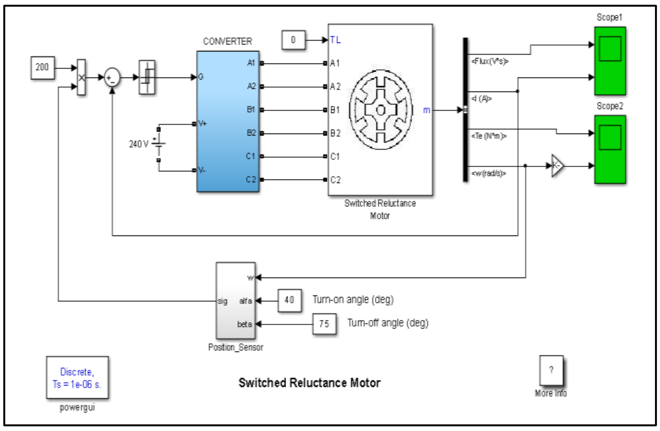

Fig. 3.1: 6/4 Switched Reluctance Motor

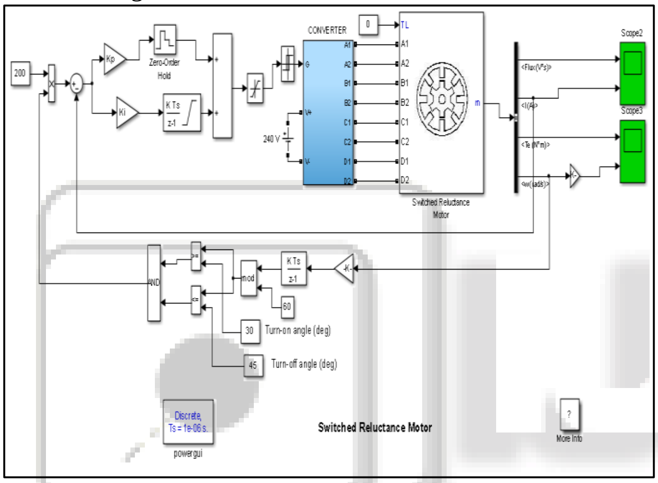

Fig. 3.2: 8/6 Switched Reluctance Motor

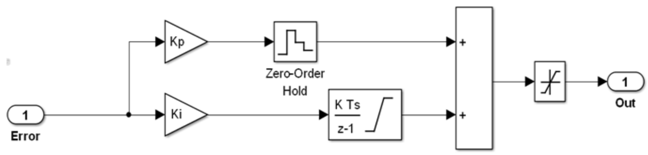

Fig. 3.3: PI controller

Fig.3.1 shows MATLAB/SIMULINK model of 6/4 SRM and Fig.3.2 shows the MATLAB/SIMULINK model of 8/6 SRM with PI controller. In this PI controller is used for increase the speed of the response and accuracy, eliminate the steady state error and also develop required torque command. Where Kp and Ki values are taken from the trial and error method. Position sensor is used to detect rotor position and give signal to the controller. Converter consists four blocks for four phases, each block have two IGBT and two diodes are used.

VI. SIMULATION RESULTS

Results for 6/4 and 8/6 SRM is shown in Fig.4-9. From below results the torque ripple in 8/6 SRM is less than 6/4 SRM.

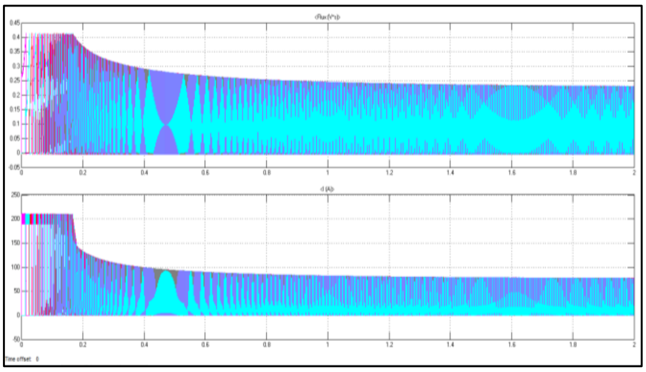

Fig. 4: Torque and Flux Linkage

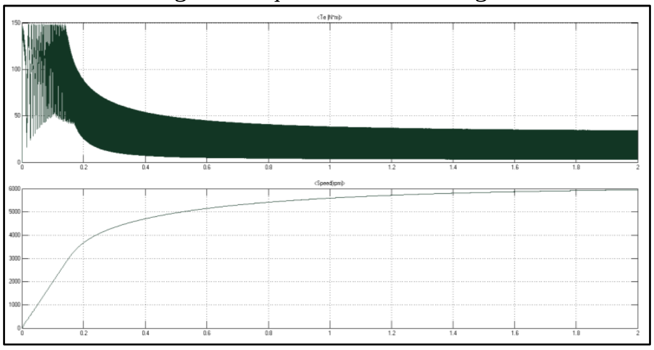

Fig. 5: Current and speed

From fig.6 it is seen that at the time of starting torque is high but after time t=0.2 it get stable. Similarly in fig.7 and 8 same thing is happens with flux linkage and current but time to get stable is less i.e. t=0.2 and t=0.25 respectively.

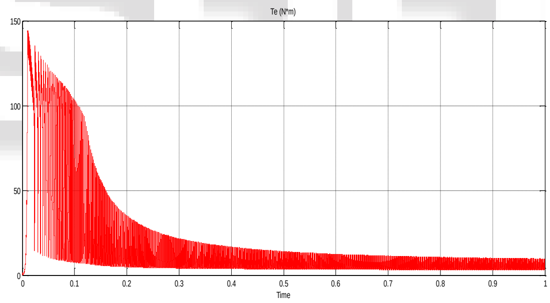

Fig. 6: Electromagnetic Torque

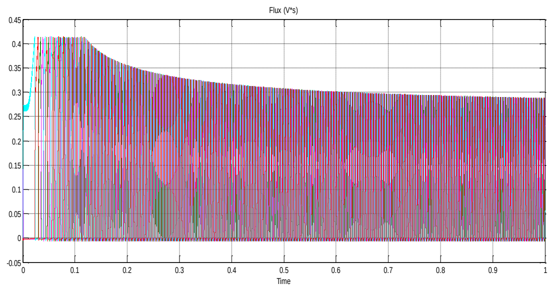

Fig. 7: Flux linkage

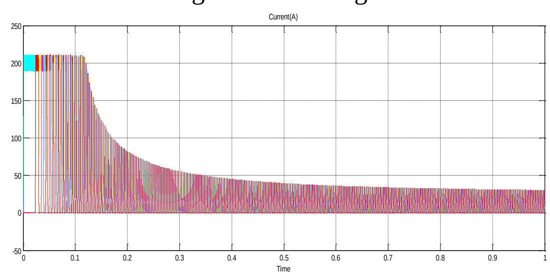

Fig. 8: Current(A)

Fig. 9 shows that at starting motor speed get increased and after 0.6 speeds gets constant. If we apply any load the speed will change as per load requirement

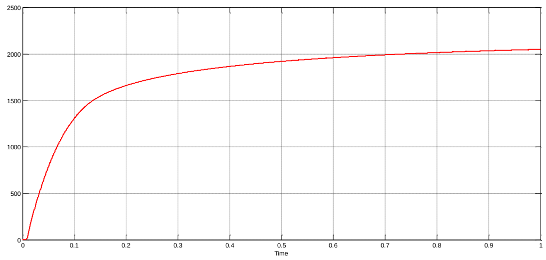

Fig. 9: Speed (RPM)

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