

A New approach for minimization of torque ripple in 8/6 switched reluctance motor

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Abstract - Switched Reluctance Motor (SRM) has become popular in various industries because of increasing cost of permanent magnet as it has concentrated winding on each and every pole also it has salient structure therefore SRM is a low cost extremely robust variable speed motor. In this paper new method is introduced to minimize torque ripple and improve the accuracy.

Key Words: Switched reluctance motor, Torque ripple, Key word3, etc (Minimum 5 to 8 key words)...

1. INTRODUCTION

Now a days switched reluctance motor (SRM) has great demand in fields living, industry and transportation because of its high efficiency and accuracy. So there should be modification of size and weight, torque and Efficiency of motors is required. AC motor has achieved the same controllability as a conventional DC Motor due to the advancement and modification in power electronics technology. Major advancement have taken place viz induction motor and permanent magnet synchronous motor have received practical application due to simple and robust structure and maintenance free. SRM also expected low cost extremely robust and it has application in Hybrid electric vehicle and electric vehicle. For low cost variable speed applications the two SRM which is single phase with a two switch based asymmetric converter and two phases with two switch based split supply converter are found to be competitive. There are many applications of this drive i. e. Reduction in cost and component which would be highly appealing for Industry. It is also necessity to meet highly cost sensitive and high volume application. The new converters are more modified than original converter. They can recover the energy from main winding and it is Utilized instead of returning to the source. The motor and source causes extra losses due to the energy circulation. It can also reduce the life time as well as there can be need of larger DC link capacitor. DC bus or an AC line can not help SRMs to run just like the brushless DC Motor and normal induction motor. To control the SRM and produce a torque saliency of stator and rotor is important. Industry acceptance of SRM is slow due to the combinations of pursuit difficulty of SRM. They cannot be

easily available in market to operate with traditional AC and DC machines. [1]

SRM is rarely found in the factory but it is more popular due to their reliability and modification in electric machine technology. Very few practitioners are successful with SRM while others are complaining about there in correction. It is the machine, tendency of moveable part produces torque and it is moved where the inductance of excited winding is maximized. The SRM has both stator and rotor has salient poles and it operates like variable reluctance stepper motor. The main part of this motor is electronic drive and controller by which it cannot work. SRM is given its name because of switching which use in controller. [2]

2. PRINCIPLE OF OPERATION

Both stator and rotor of switched reluctance motor (SRM) have salient poles. There are no coils and magnets in rotor side. The stator of SRM has simple concentric winding. In SRM there are different combinations like 6:4, 8:6, 12:8, 16:12 etc. The structure of 8:6 SRM shows in figure (1). The current reluctance has minimum value when rotor of an SRM is in aligned position with respect to fixed phase. The current reluctance has maximum value when the rotor of SRM is in unaligned position with respect to the fixed phase. The maximum stator and rotor poles number causes less torque ripple. To achieve lower switching frequency and higher starting torque of power converter the combinations should be the number of stator poles are more than rotor poles by two. The rotor pole pair is get attracted towards stator pole pair where the value of reluctance is very less in magnetic path. The phase winding energized the stator pole pair. The direction of rotation can be achieved in either direction by energizing the consecutive stator phase in sequence. Assuming only one switched ON (exited) initially. The above explanation gives direction of the rotor clockwise to nearest aligned position. I is the current in the phase A When it is switched ON the rotor comes to aligned position then phase D is switched ON. Similarly when rotor comes to unaligned position then phase C is switched ON and rotor continues to rotate in clockwise direction.

If excitation sequence frequency stator phase is varied the speed of SRM drive is changed the fundament switching frequency can be expresses follows,

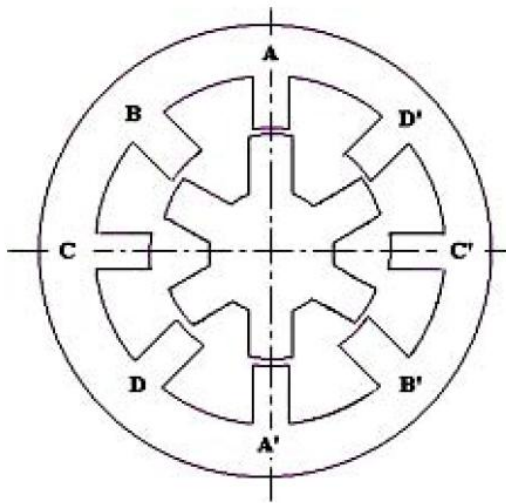


Fig -1: 8/6 SRM

$$f = N_r \omega_r$$

Where,

N_r = Number of rotor poles.

ω_r = Angular rotor speed.

The rotor tends to move by the torque when stator winding has current flowing through it. Rotor rotates in such direction to increase the inductance. It will continue to rotate until the maximum inductance is achieved. When there is no residual magnetization in steel, the current has unipolar direction. The nearest aligned position determine the direction of the torque. When the rotor is in between unaligned and aligned position in forward direction produces motoring torque (positive torque). For motoring mode it is important to make stator phase turn off before the region where increasing inductance ends. In this case, current falls to zero and produces no negative torque.

3. MATHEMATICAL MODELING

The consideration of elementary reluctance machine is used for the derivation of basic torque equation of SRM. The carries only one winding of the stator as machine is single phase excited. The rotor freely rotates as the excited winding is wound on the stator.

The flux linkage is,

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

The general torque expression

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

Where, W' = co-energy

If we considered the co-energy at any position, it can be defined as area below the magnetization curve. It can also be defined as the definite integral

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

So, torque equation becomes

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

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 $\Delta \theta$, the energy exchange with supply energy is $\Delta W_s = P_{ABCD}$. The change in stored field energy $\Delta W_f = P_{OBC} - P_{OAD}$ and mechanical work done is,

$$\begin{aligned} \Delta W_m &= T_e \Delta \theta \\ \Delta W_m &= \Delta W_s - \Delta W_f \\ \Delta W_m &= P_{ABCD} - (P_{OBC} - P_{OAD}) \\ \Delta W_m &= P_{ABCD} - P_{OBC} + P_{OAD} \\ \Delta W_m &= P_{OAB} \\ \Delta W_m &= \Delta W' \end{aligned}$$

We find that all of the energy is not converted into mechanical work and some kind of energy is stored in magnetic field. This 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,

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

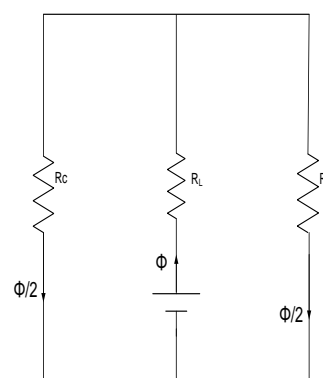


Fig -2: Magnetic circuit for SRM

4. TORQUE GENERATIONS AND IT'S OUTPUTS

The equation of SRM is case of electromechanical energy conversion are given by,

Equation of voltage for single phase

$$V = e + R_i$$

i. e. $e = v - R_i$

Where,

i - Current

R- Resistance

v- Terminal voltage

e- Back EMF

Faradays low is rate of change of flux linkage(ψ)

For back EMF,

$$e = \frac{\partial \psi}{\partial t}$$

$$\text{i.e. } \frac{\partial \psi}{\partial t} = (v - R_i)$$

For constant speed,

$$e = \frac{\partial \psi}{\partial t} = \omega_m \frac{\partial \psi}{\partial \theta}$$

Where,

ω_r - Angular Velocity

ψ - Flux Linkage

In SRM both stator and rotor have salient poles. The relation in between current and flux linkage is non linear due to magnetic saturation and it is also depends on rotor position. Consider moment that there is no mutual coupling in between phase.

We can write $\psi (i, \theta)$ and it represented set of curve of ψ verses i with θ as parameter which shown in figure 3

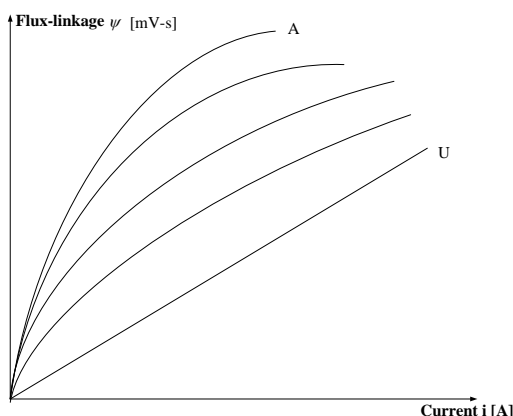


Fig -3: Magnetization Curves

In figure 3 showing flux linkage ψ as a function of phase current i at different rotor position θ and U is for unaligned and A for aligned.

The area covered by 'W' is in the electrical energy converted to mechanical energy or vice versa.

Average torque,

$$T_{e(avg)} = \frac{5W}{2\pi}$$

Where,

S - Number of stroke per revolution

N_r - Number of rotor pole

Φ - Number of phase

$$S = N_r \Phi$$

It is noted that by increasing number of rotor pole output of torque also get increased as per phases given. All machines (3,4,5 phases SRM) is having approximately same copper loss along with same dimensions. As this motor having high number of phases then it develops positive torque producing zone simultaneously with two phases. Hence we can excite two phases at the same time.

Table -1: Motor Data

Parameters	Values
Number of stator poles(N_s)	8
Number of rotor poles(N_r)	6
Number of phases(Φ)	4
Angel of stator pole(β_s)	25
Angel of rotor pole(β_r)	27
Frequency(F)	50 Hz
Voltage (V)	240

5. 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.

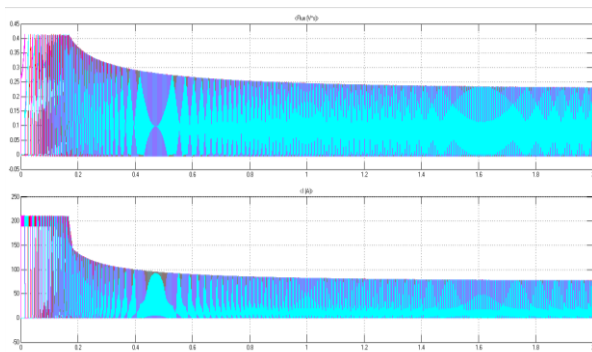


Fig -4: Torque and Flux Linkage

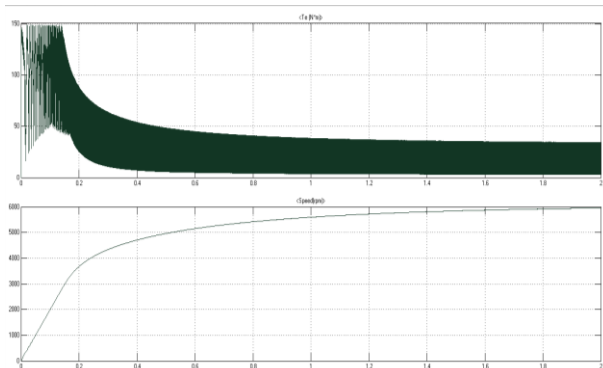


Fig -5: Current and speed

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.

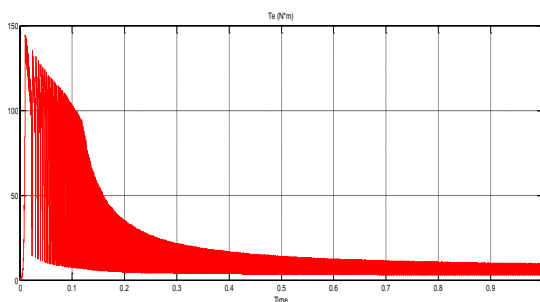


Fig -6: Electromagnetic Torque

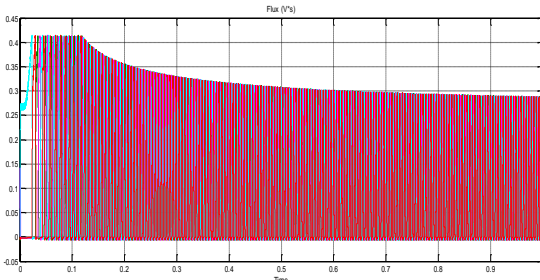


Fig -7: Flux linkage

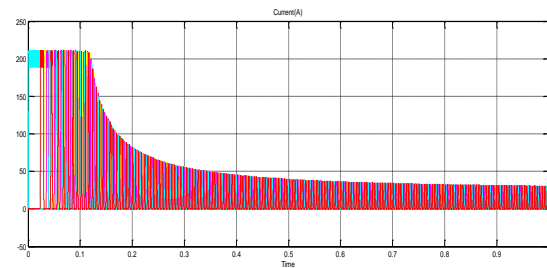


Fig -8: Current(A)

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

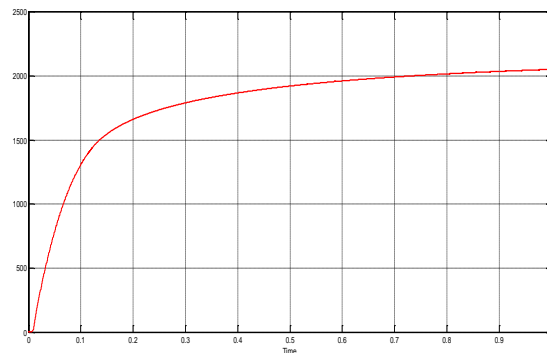


Fig -9: Speed (RPM)

6. CONCLUSIONS

In last decade many industries mainly focused on improvement and modification in control and design of SRM in order to improve its efficiency and life. SRM is now fully developed to prove it's self in the market as compared to Induction and brushless permanent magnet motor SRM have less number of applications.

In this paper the mathematical design theory of SRM is too simple but in real practice it is difficult to implement. Computers methods are also required for simple design calculation. Natural architecture is not recommended by this mathematical calculation or mathematical modeling for the innermost feed forward control. The combination of computation including mechanical, electromagnetic and electric design , laboratory testing and suitable investment plays a vital role in development of successful design of SRM.

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