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A New Design Approach for Torque Improvement and Torque Ripple Reduction in a Switched Reluctance Motor

Muruganantham.S[1], Ashokkumar.R[2]
[1](Assistant Professor, Dept. of Electrical Engineering, Annamalai University, Tamilnadu, India)
[2](Professor, Dept. of Electrical Engineering, Annamalai University, Tamilnadu, India)

Abstract: *High torque ripple and high acoustic noise are the major disadvantages of Switched Reluctance Motor (SRM). SRM has valuable features like low cost, reduced maintenance requirements, fault tolerance, high efficiency, rugged behavior and large torque output over a very wide speed range the researcher giving more concentration to this device, there are several publications which gives full or partial solution to the problems of SRM. This paper proposes a simple new structured stator and rotor design for SRM to increase the torque and reduce the torque ripple considerably. The proposed 8X8 motor Consists of six layered magnetically independent stator and rotor sets .Each layer works exactly in a complementary way and helps to another layer in an accurate method to give a suitable torque output. Based on special switching method at a time one layer produces torque and the remaining layers doesn't produces torque and it continues periodically with six layers which results in high torque and less ripple, low noise and vibration. This proposed method with six layered rotor and stator with special switching method works complementary to each other and hence produces high torque with less torque ripple and noise.*

Keywords: *switched reluctance motor, SRM, torque ripple, high torque, acoustic noise***.**

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I. Introduction

A lower cost and higher efficiency brushless motor drive has intensified with the advent of variable-speed applications in home appliances and power tools. While a variable-speed motor drive may become acceptable in some appliances, the industry predominantly moves away from brush- and commutator-based machines for reasons of reliability, safety, longevity, and acoustic noise [1]. Hence, the search for a simpler and lower cost brushless motor drive has intensified with the prospective oncoming variable-speed applications. One of the possible electrical machines in low cost and variable-speed drives is the switched reluctance motor (SRM)[2][4]. A reluctance motor consists of a winding less rotor made of soft iron, and is free to rotate between magnetic excited stator. Torque is produced by the tendency of the rotor to align itself with the stator magnetic field. SRM has serious disadvantage of large torque ripple due to its geometric characteristic; there are two approaches to reduce torque ripple. One of these methods is to modify magnetic design and to change the shape of rotor and stator and the other method is based on switching control [7][10]. Generally there are two types of torque ripple; high frequency torque ripple and low frequency torque ripple. High frequency torque ripple doesn't produce much problem and it will be controlled by electronic switching [1][3]. But the low frequency torque ripple produced because of the difference between the peak torque and the angle where two overlapping phases are highly considerable and cannot be controlled by switching methods [5][6]. So overlapping phase angles are considered, this is done only by altering the shape of stator and rotor. In this study a new mechanical construction is proposed and simulated [9]. The paper presents a new approach of six layered stator and rotor [7][11]. The six layers of rotor are positioned in different angles and the performances of each layer are considered and the torque produced on the layers is plotted. The proposed 8X8 motor Consists of six layered magnetically independent stator and rotor sets. Each layer works exactly in a complementary way and helps to another layer in an accurate method to give a suitable torque output. Based on special switching method at a time one layer produces torque and the remaining layers doesn't produces torque and it continues periodically with six layers which results in high torque and less ripple, low noise and vibration.

II. Proposed SRM Design

The proposed 8X8 SRM consists of six layered magnetically dependent stator and rotor sets, where each stator set includes salient poles with windings wrapped around them and the rotor comprises of eight salient pole made of soft iron as it is shown in Fig.1a. and Fig 1b.The angle of stator and rotor pole arc is 22.5°, air gap of 0.25mm, stator core outer diameter and inner diameter are 72 mm and 62mm and rotor core outer diameter and shaft diameter are 41.5 mm and 20 mm respectively. Each layer of motor is a single phase motor so eight pole coil windings are connected in series; number of turns in each pole is 100. each layer of the eight coils are switched as shown in Fig. 2 all of the eight poles are on and the magnetic field flow through all of the poles, and the direction of magnetic field in each stator pole as one among is positive and negative. The magnetic flux produced by the coils travels through the guide and the motor shaft to the rotor and then to the stator poles, and finally closes itself through the motor housing [7]. Therefore, four of both stator and rotor poles are magnetically north and the other set is magnetically south.

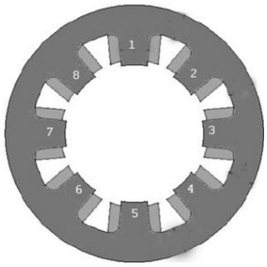

Fig 1a. Stator shape

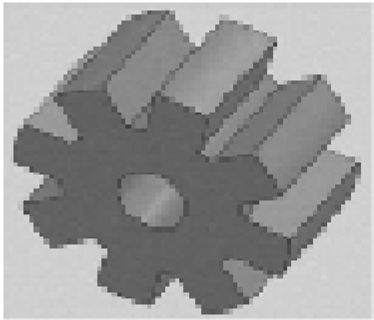

Fig 1b. Rotor shape

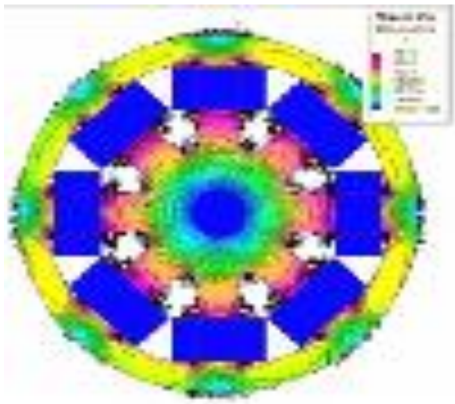

Fig.2 Poles are active in first layer

Specification of motor is given in the table:

Stator core outer diameter	72mm
Stator core inner diameter	62mm
Stator pole arc & Rotor pole arc	22.5°
Air gap	0.25mm
Rotor core outer diameter	41.5mm
Rotor shaft diameter	10mm
Each module thickness	20mm
Number of tums per pole	100

The field analysis has been performed using a Magnet CAD package [12] which is based on the variation energy minimization technique to solve for the magnetic vector potential. The partial differential equation for the magnetic
Vector potential is given by:

$$-\frac{\partial}{\partial x}\left(\gamma\frac{\partial A}{\partial x}\right)-\frac{\partial}{\partial y}\left(\gamma\frac{\partial A}{\partial y}\right)-\frac{\partial}{\partial z}\left(\gamma\frac{\partial A}{\partial z}\right)=J \qquad (1)$$

Where, A is the magnetic vector potential. In the variation method (Ritz) the solution to (1) obtained by minimizing the following functional:

$$F(A)=\frac{1}{2}\iiint\left[\gamma\left(\frac{\partial A}{\partial x}\right)^2+\gamma\left(\frac{\partial A}{\partial y}\right)^2+\gamma\left(\frac{\partial A}{\partial z}\right)^2\right]d\Omega-\iiint \mathrm{J}A\,d\Omega \qquad (2)$$

Where Ω is the problem region of integration. The stator and rotor cores are made up of M-27 non- oriented silicon steel laminations with the following static B-H curve shown in Fig. 3.

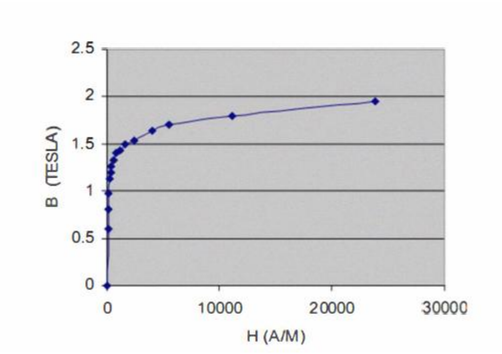

Fig.3 Magnetization Curve.

First one of the layer is simulated torque characteristics was examined [8]. It produces high torque but without suitable ripple reduction. It has been simulated for 100 point in magnet software that start from unaligned to align that is shown in Fig. 4a, Fig. 4b and Fig. 4c.

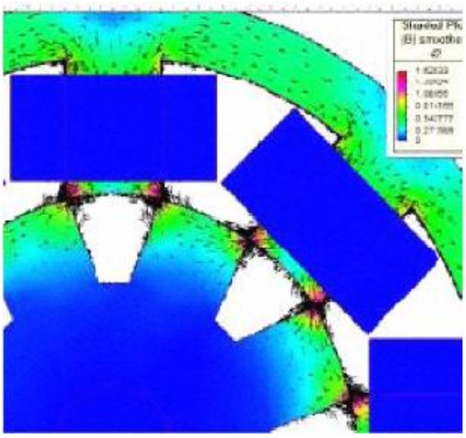

Fig.4a. Unaligned position

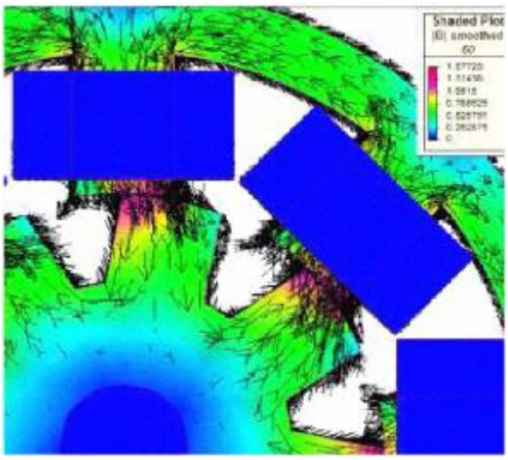

Fig.4b. Half aligned position

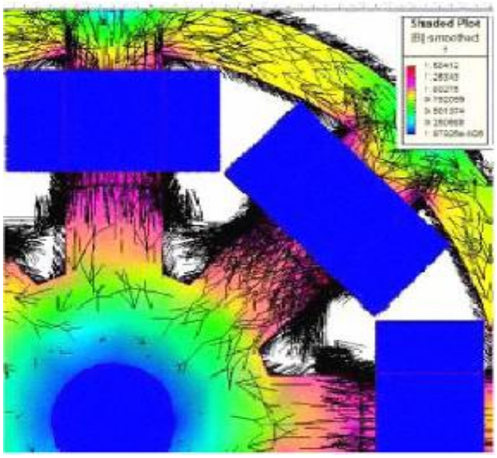

Fig 4c. Fully aligned position

The important point is that this torque value which is obtain for a single layer is shown the torque characteristic while it stick to all of the five other layers. Fig. 4a. is shown unaligned condition for the motor that torque is about zero, Fig. 4b. is shows a half aligned position, Fig.4c. is portrayed aligned position of this motor and finally Fig. 5 illustrated the torque characteristic from aligned position to next aligned position which will be after 22.5 rotations. As it is obvious in Fig. 5 the maximum torque is about 2.38 NM, but it has so big ripple that its torque amplitude reaches to zero. Therefore each rotor will be active in a specific situation so that it always utilizes the maximum torque and don't Permit torque characteristic to descend to low magnitude. For example each layer will be turn on in the half aligned position as it is shown in Fig. 4b. and will turn off exactly in aligned position and forthwith the next layer which has reached to half aligned position will turn on.

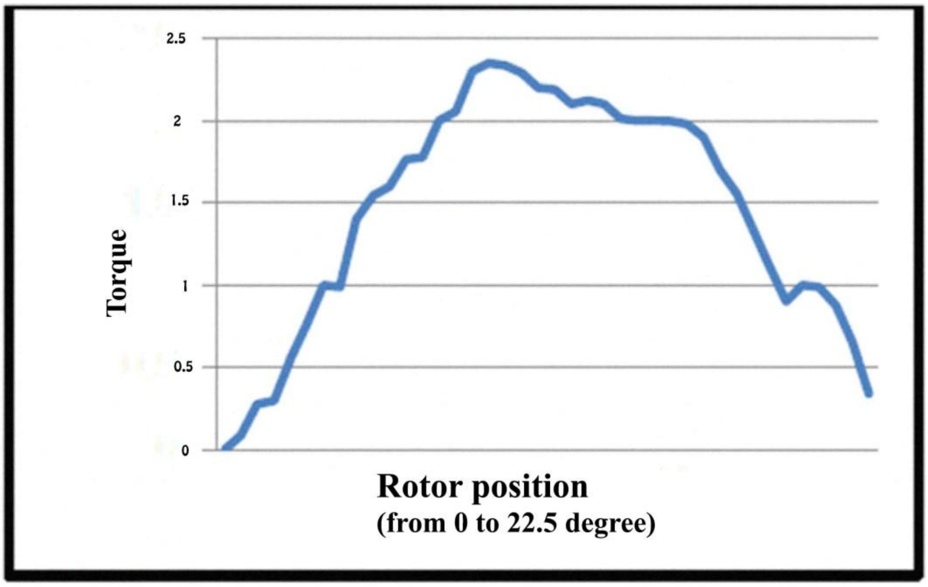

Fig.5. Torque characteristics

III. Rotor Design

There are six layers that each rotor section from one layer to the next one has a 7.5° angular shift in position. So when layers work complementary six layers generate a high torque that its ripple has been decreased. In order to get a better view of the motor configuration, the motor assembly without stators and house is shown Fig.6. If one layer of stator is active or energized, all the layers of rotor are coming to the position as shown in Fig 4b. that is half aligned position and it is remained in the position until the output torque is maximum in torque characteristics and then change to full aligned position. After that the next layer is turned on and the method is repeated. In this way the maximum torque was obtained with considerable minimum torque ripple.

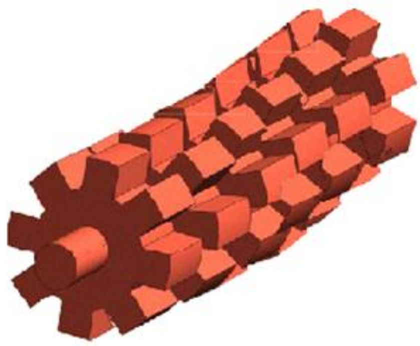

Fig.6 six layer rotor design

The torque characteristics of six layers are presented individually and shown in Fig.7

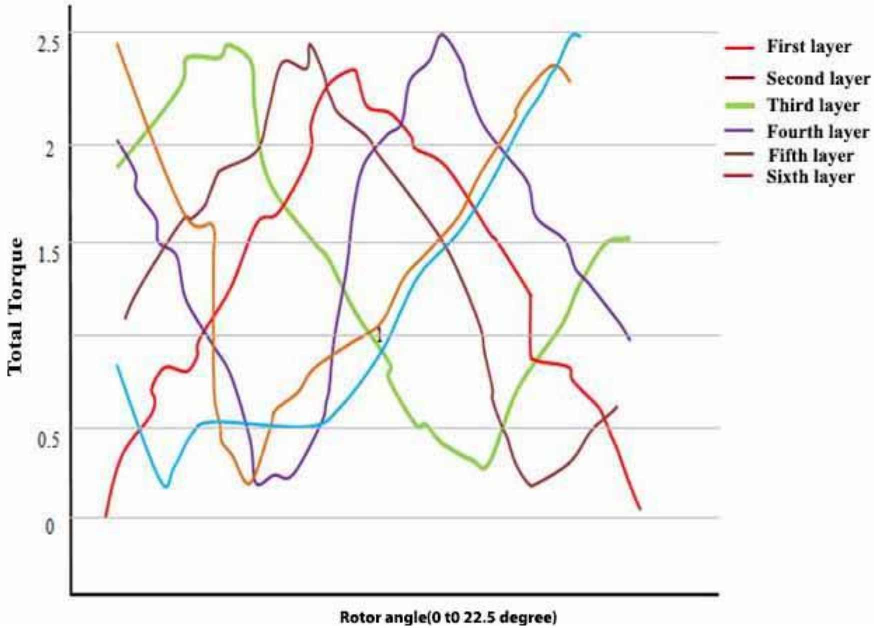

Fig.7 Torque characteristics of six layers are presented individually

But, based on special drive system it doesn't allow to all of the coils of layers to be stayed on all the time. And that coil which has produced the maximum torque will be active and once, next layer starts to produce its maximum output torque, it will be on and previous layer is turn off. Based on this states and the special method in switching the output torque will be same. Hence the maximum output torque produced from 0° to 22.5° is shown in Fig.8

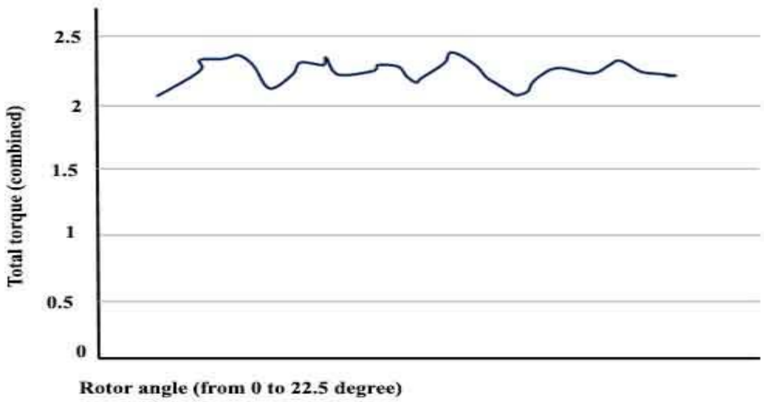

Fig.8 Maximum output torque produced from different layers of rotor.

From the Fig.8 the angle period of final ripple is found as 5.625°. The value of ripple angle is considered for positioning the rotor layer.
Inductance equation for the first layer by assuming the system is linear is given by equation (3),

$$L_{1s}(\theta) = L_0 + L_1 \sin(8\theta) \tag{3}$$

Which L_{1S} (θ) is inductance versus rotor position, L_0 is the minimum value of the inductance, unaligned position, L_1 is a constant value. And the torque value can be expressed as equation (4).

$$T_{1s}(\theta) = \frac{1}{2} i^2 \frac{dL_{1s}(\theta)}{d\theta} \tag{4}$$

And with substituting equation (4) with equation (3) and setting the current 1 Ampere , it can be rewritten as following equation.

$$T_{1s}(\theta) = 6L_1 cos(8\theta) \tag{5}$$

Regardless of the constant value of $4L_l$ the $T_{1S}(\theta)$ can be shown in the Fig. 9

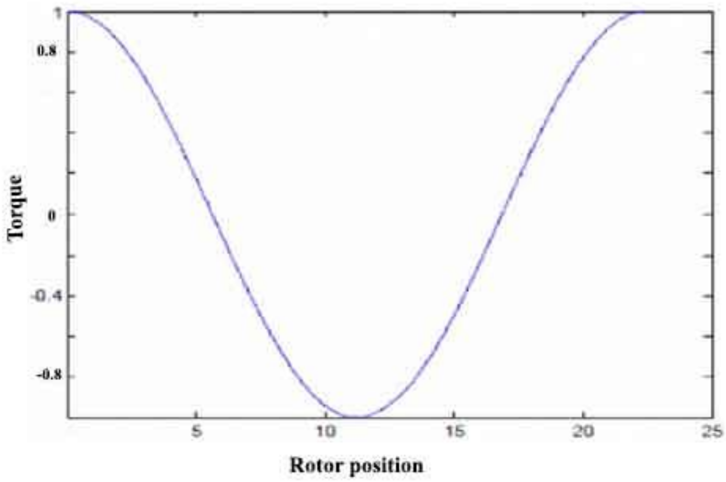

Fig.9 Torque verses Rotor Position

Five other torque values are given by referring the previous analysis

$$T_{2s}(\theta) = 6L_1 \cos(8(\theta + 7.5)) \;\; for\ second\ layer \tag{6}$$
$$T_{3s}(\theta) = 6L_1 \cos(8(\theta + 15)) \;\; for\ third\ layer \tag{7}$$
$$T_{4s}(\theta) = 6L_1 \cos(8(\theta + 22.5)) \;\; for\ fourth\ layer \tag{8}$$
$$T_{5s}(\theta) = 6L_1 \cos(8(\theta + 30)) \;\; for\ fifth\ layer \tag{9}$$
$$T_{6s}(\theta) = 6L_1 \cos(8(\theta + 37.5)) \;\; for\ sixth\ layer \tag{10}$$

On considering the final torque ripple angle period 5.625, the output torque produced for a period of 45° is given by the following function

$$T_s(\theta) = \begin{cases} 6L_1 \cos(8\theta) & -5.625 < \theta < 5.625 \\ 6L_1 \cos(8(\theta - 7.5)) & 5.625 < \theta < 13.125 \\ 6L_1 \cos(8(\theta - 15)) & 13.125 < \theta < 20.625 \\ 6L_1 \cos(8(\theta - 22.5)) & 20.625 < \theta < 28.125 \\ 6L_1 \cos(8(\theta - 30)) & 28.125 < \theta < 35.625 \\ 6L_1 \cos(8(\theta - 37.5)) & 35.625 < \theta < 43.125 \end{cases} \tag{11}$$

The output torque characteristics for rotor position between -5.625° to 39.375 ° is shown in Fig.10

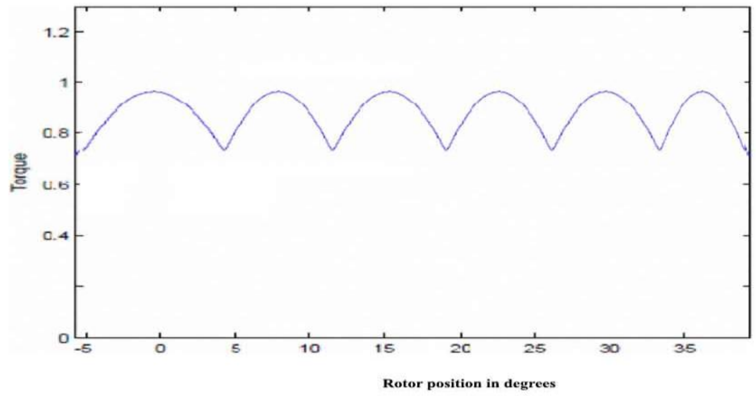

Fig.10 Output torque.

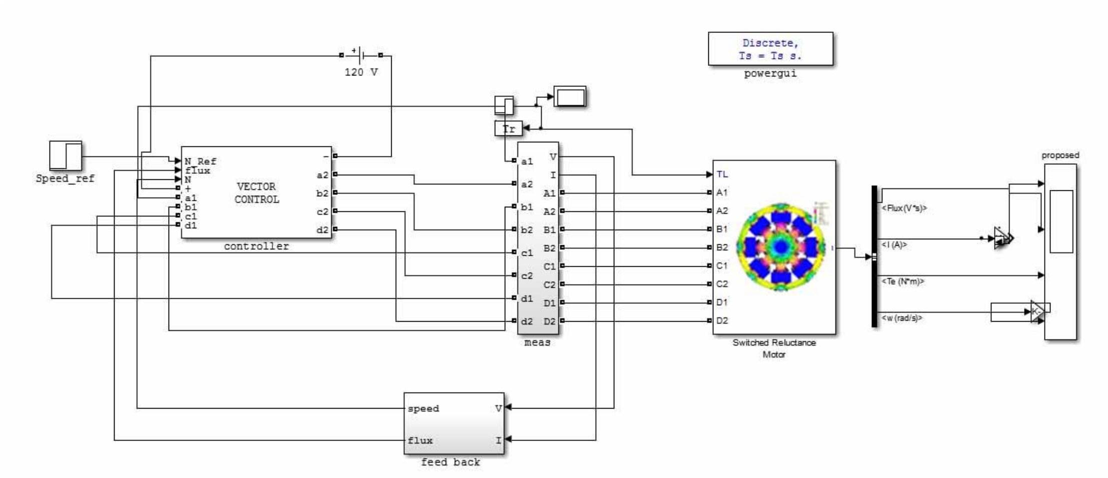

Fig.11 Simulation block diagram of six layered 8X8 SRM.

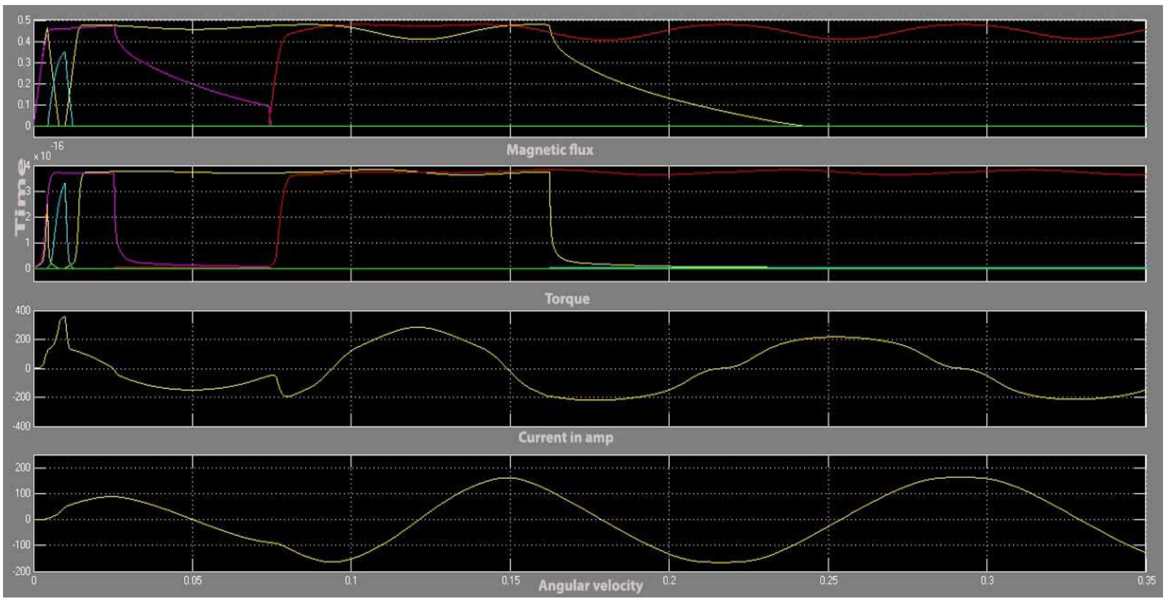

Fig.12 simulation result of six layered 8X8 SRM

IV. Conclusion

In this paper a novel six layered 8X8 switched reluctance motor was introduced by altering the rotor layer position angle. From this new structure the torque ripple was considerably reduced to high extent. This constructional structure change considerably reduces the low frequency torque ripple which effects in reduction of vibration, torque ripple and acoustic noise. With this setup the output torque is also improved to the great extent by energizing the 8 poles of motor at the same time with suitable special switching devices. The travelling path of magnetic flux is also reduced which results in improved output torque, high ripple reduction and low acoustic noise. All the above claims have been verified and proved in simulation results are shown in Fig.11 and Fig.12.

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