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A Novel Six Layered Switched Reluctance Motor with IGBT Controller Design for Torque Improvement and Torque Ripple Reduction

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Abstract

Apart from the valuable feature in the switched reluctance motor, it has some remarkable annoyance like high torque ripple and high acoustic noise. There are several publications and papers that discussed about the disadvantage and giving more ideas to mitigate crisis but giving partial solution to the problem of SRM. This paper provides a new type of approach of changing both the controller for switching device and mechanical magnetic design of the rotor. Generally there are two types of torque ripple occurred in SRM they are high frequency torque ripple and low frequency torque ripple. High frequency torque ripple can be trim down by switching control of stator and low frequency torque ripple can be reduced by changing mechanical structure. The proposed 8X8 SRM consists of IGBT controller with six layer structured rotor. Each layer in six layered rotor work complementary way and helps to another layer produces high torque and fast switching of IGBT helps in reducing torque ripple to a negligible level.

Keywords: Switched reluctance motor, Torque ripple, Layered rotor structure, IGBT controller.

INTRODUCTION

Switched reluctance motor consigns an imperative role in many industrial appliances and also in domestic appliances. It's an effective machine with simple construction, boosted performance, better reliability, low price, better efficiency and lower volume. Instant torque, high energy density and low rotor inertia makes the motor an intensify machine [1]. Torque repulsion and acoustic noise are two main drawbacks in the switched reluctance motor which are caused due to non linearity nature of torque production mechanism [7]. Torque ripple and acoustic noise are to be disregard to acquire an effective functioning drive [3, 5]. In common two fronts have been taken to mitigate the problem by refining magnetic design of the motor and improve magnetic control with proper switching control [6,8]. During the commutation of a phase, radial magnetic attraction and harmonic current are responsible for torque ripple [2,4]. A multi level switching scheme can be used for the reduction of radial attraction and an improved rotor design to reduce the harmonic current loss was introduced in this work [15].

Various control methods have been suggested to minimize the torque ripple, if a converter has short commutation ability for phase current the ripple will be reduced considerably [9,16]. The paper employs an powerful power conductor switching circuit using IGBT converter. IGBT converter has the capability to produce quick phase current commutation and reduces phase current overlapping results in uniform phase current [13]. Instant switching capability and uniform phase current produced by IGBT effectively maneuver the flux density angular velocity and thoroughly reduces the torque ripple [14]. This paper also implies a refined magnetic rotor design to suppress the torque ripple and acoustic noise [10, 12]. High frequency torque ripple was mitigated by controller section and low frequency torque ripple was suppressed by changing the structure and providing uniform magnetization [17,18]. The collective implementation of effective controller and rotor design variation thoroughly reduces the torque ripple and acoustic noise present in the machine [11,19].

CONVERTER DESIGN

Figure.1 shows the proposed converter design has half bridged IGBT controller and SCRs for closed loop control scheme that replaces the asymmetric power converters used in the SRM. The phase windings of SRM are connected to power semiconductor switching circuit which is energized by a DC supply.

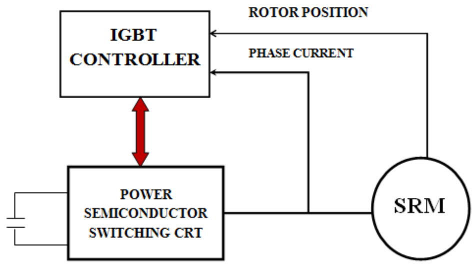

Figure 1. Block diagram of converter with IGBT CONTROLLER circuit

Rotor position sensor fitted to the shat of the SRM provides information to the IGBT controller about the position of the rotor from its reference axis. IGBT has high speed switching capability and low saturation voltage that helps the controller to activate the desired phase windings using power semiconductor switching circuit at instant. The phase current in overlapping region i.e incoming phase and outgoing phase are controlled effectively and nonlinear torque liable for torque ripple is also controlled. Torque characteristics are depending on the relationship between flux linkage and rotor position as a function of current it is worthwhile to conceptualize the control possibilities and limitation of the motor drive. Relationship between flux linkage and rotor position is shown in Figure 2.

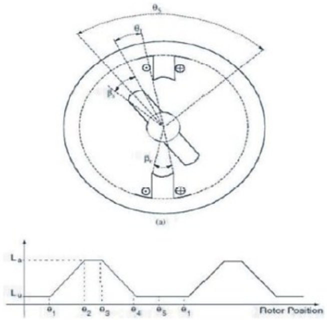

Figure 2. Relationship between flux linkage and rotor position.

Torque developed by SRM is given by Equation.1

$$T(\theta) = \frac{1}{2} i^2 \frac{dL(\theta)}{d\theta} \quad \text{Nm} \tag{1}$$

The instant switching and effective characteristics of IGBT effectively manipulates the flux, phase current angular velocity of the motor for the minimization of torque ripples. IGBT controller controls the switching of phase in stator to reduce torque ripple to a better extent. This paper concentrates on the controller and also design of machine, a novel six layered rotor is used for minimizing the torque ripple to negligible level. Each layer works exactly in a complementary way and helps to another layer in an accurate method to give a suitable torque output. Low frequency torque ripple cannot be controlled by the switching devices because of its high torque pitch and angular overlapping of phases, so the only way for controlling is by changing the shape of rotor or stator.

The proposed 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. 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. 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 in Figure.3

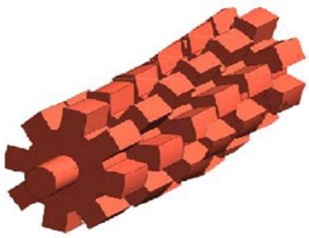

Figure 3. Six layered rotor design

If one layer of stator is active or energized, all the layers of rotor are coming to the position as shown in Figure.4 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.

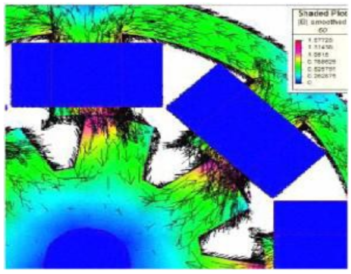

Figure 4. Unaligned position of rotor structure

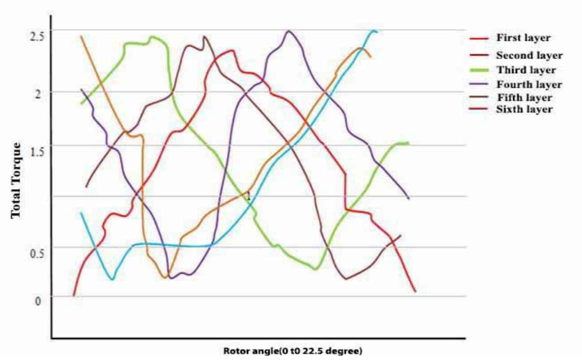

Figure 5(a). Torque produced on individual layer

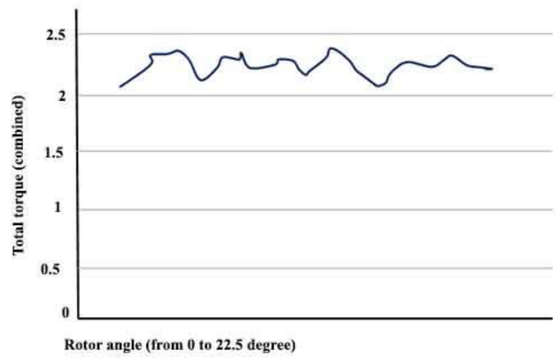

Figure 5(b). Maximum torque output

The phase 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 Figure.5 (a) and 5(b).

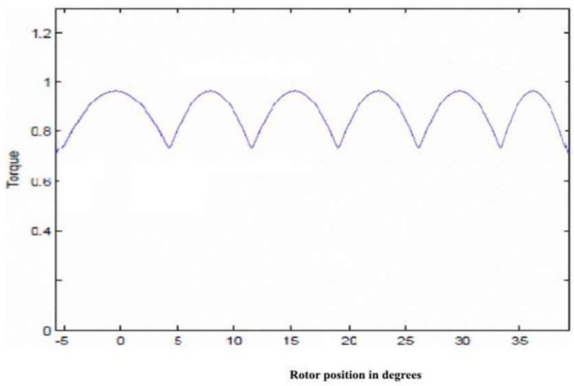

Figure 6. Output torque

From the Figure.6 angle period of torque ripple is found at 5.265°. The ripple angle is considered for positioning the rotor layer.

If the system is considered to be linear then the inductance equation of first layer is given by Equation.2

$$L_{1s}(\theta) = L_0 + L_1 \sin(8\theta) \quad (2)$$

Where

$L_{1S}(\theta)$ is inductance versus rotor position

L_0 is the minimum value of the inductance at unaligned position

L_1 is a constant value

So Torque value of first layer is given by Equation .3

$$T_{1s}(\theta) = \frac{1}{2} i^2 \frac{dL_{1s}(\theta)}{d\theta} \quad (3)$$

Substituting equation (2) in equation (1) and keeping the current as 1 ampere

Torque equation of first layer is derived as Equation.4

$$T_{1s}(\theta) = 6L_1 \cos 8(\theta) \quad (4)$$

By referring the previous analysis torque equation for the other layers can be derived as

$$T_{2s}(\theta) = L_1 \cos\big(8(\theta + 7.5)\big)\ , for\ 2nd\ layer \quad (5)$$

$$T_{3s}(\theta) = 6L_1 \cos\big(8(\theta + 15)\big)\ , for\ 3rd\ layer \quad (6)$$

$$T_{4s}(\theta) = 6L_1 \cos\big(8(\theta + 22.5)\big)\ ,\ for\ 4th\ layer \quad (7)$$

$$T_{5s}(\theta) = 6L_1 \cos\big(8(\theta + 30)\big),\ for\ 5th\ layer \quad (8)$$

$$T_{6s}(\theta) = 6L_1 \cos\big(8(\theta + 37.5)\big)\ ,\ \ for\ 6th\ layer \quad (9)$$

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

$$10T_s(\theta) = \begin{cases} 6L_1 \cos(8\theta) & -5.625 < \theta < 5.625 \\ 6L_1 \cos\big(8(\theta - 7.5)\big) & 5.625 < \theta < 13.125 \\ 6L_1 \cos\big(8(\theta - 15)\big) & 13.125 < \theta < 20.625 \\ 6L_1 \cos\big(8(\theta - 22.5)\big) & 20.625 < \theta < 28.125 \\ 6L_1 \cos\big(8(\theta - 30)\big) & 28.125 < \theta < 35.625 \\ 6L_1 \cos\big(8(\theta - 37.5)\big) & 35.625 < \theta < 43.125 \end{cases} \quad (10)$$

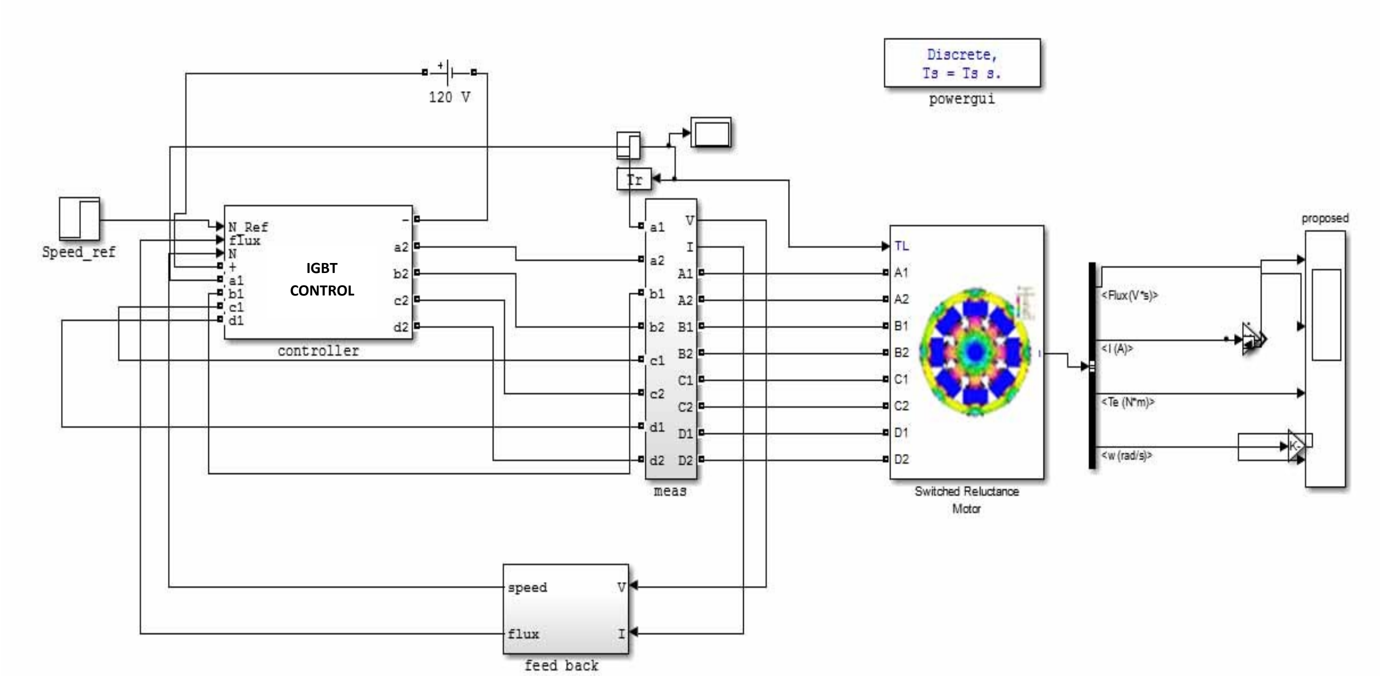

Figure 7. Simulation diagram of 8X8 six layered SRM with IGBT controller

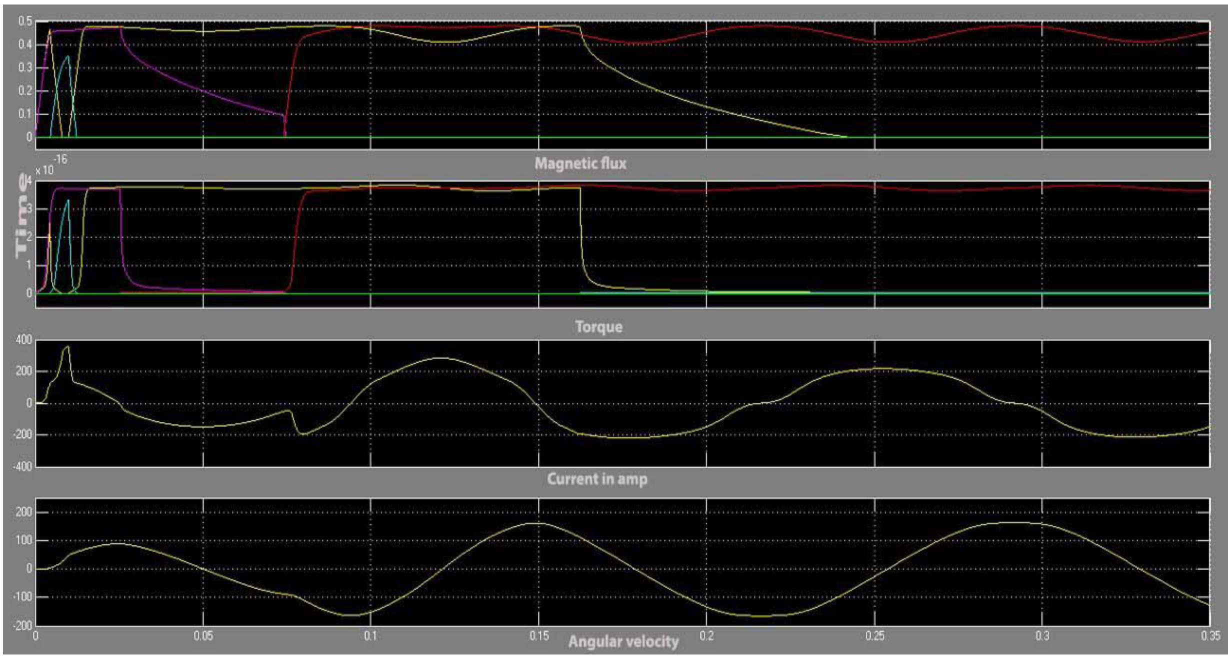

Figure 8. Simulation result of proposed IGBT controller with six layered rotor structured SRM

The Figure.8 depicts simulation result of proposed IGBT controller with six layered rotor structured SRM. From the output wave form it is found that performance of the drive has improved. Fast switching of IGBT in each layer of rotor produces linear variation of flux results in reduction of unwanted ripples and angular velocity is also seems to be constant. The proposed control method considerably mitigates the torque ripple to a negligible level which helps the machine to run effectively.

CONCLUSION

SRM drive exhibits typical characteristics like vibration and torque ripple which are lessen by applying a special control strategy and making structure variation that results in sinking unwanted ripple in torque production. This paper presents a special IGBT controlled switching circuit with a novel six layered rotor structure is proposed and it give an effective result of mitigating the torque ripple to a greater extent and helps in effective working of the machine. The travelling path of magnetic flux is also reduced also improves the output torque, high ripple reduction and very low acoustic noise. The effectiveness of controller with six layered rotor is verified and proved in simulation results.

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