Torque Ripple Minimization Of Switched Reluctance Machine Using Genetic Algorithm

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Abstract: - A major problem of Switched Reluctance Motors (SRM) is the Torque ripple, which causes undesirable acoustic noise and vibration. It is caused by saliency of the stator and rotor. In this paper, a novel method on the basis of Genetic Algorithm (GA) is proposed to reduce the torque dip, thereby reducing the associated torque ripple, with simultaneous increase in Torque using GA and the obtained result is compared with a standard 6/4 pole, 3 phase SRM. The optimization results are encouraging and co-verified using Finite Element Analysis (FEA).

Key-Words: - Torque dip, Torque Ripple Minimization, Switched Reluctance Machine (SRM), Genetic Algorithm (GA), Finite Element Analysis (FEA)

1 Introduction

Recently, the Switched Reluctance Motor (SRM) is widely applied for high-speed applications, because of its simple mechanical structure and development of power electronics. But a major disadvantage of SRM is the large torque ripple, which produces acoustic noise and vibrations. These are mainly produced by the nonlinear property of the inductance according to the current and rotor position. The torque pulsations in switched reluctance motors are relatively higher compared to sinusoidal machines, due to the doubly salient structure of the motor [2]. This torque ripple is particularly intolerable in servo or servo-type systems, where its presence is painfully felt by the user or harmfully reflected on the load. In general, there are two approaches for torque ripple reduction. One method is to improve the magnetic design of the motor, while the other is the sophisticated electronic control technique [2]. By means of effective design, it is possible to reduce the torque ripple by choosing appropriate stator and rotor pole arcs. The minimization of torque ripple through the electronic control approach may lead to reduction in the average torque. In this paper, flux linkage is maximized with inductance overlap ratio of two phases using genetic algorithm to minimize the torque ripple.

2 Basic SRM Model

Schematic diagram of a standard 3 phase Switched Reluctance Motor is shown in Fig.1 along with necessary specifications. It has a 4-poles rotor and 6-poles stator, which is modeled and simulated using FEA based CAD package for torque dip measurement [4].

Most CAD systems for numerical analysis of electromagnetic problems are based on the Finite Element Method (FEM). The amount of torque ripple expected from a particular motor can be evaluated from the torque dips in the T-θ characteristics. The three dimensional view of three phase SRM is shown in fig.2. The Descretized model of SRM and field distribution of the same is depicted in figures 3 and 4.

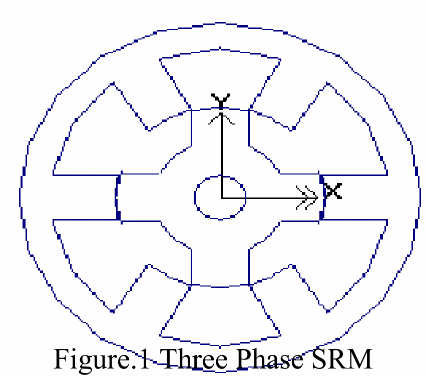

Figure.1 Three Phase SRM

Specifications in cm and degrees

- Rsh = 4.50
- R0 = 11.88
- R1 = 18.5
- Gap = 0.025
- R2 = 30.5
- R3 = 35.54
- βs = 28
- βr = 32
- Lstack = 50.8

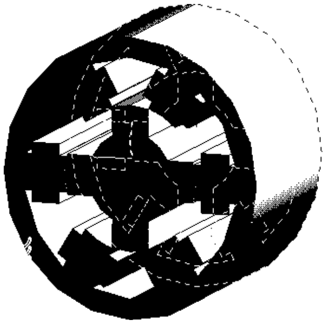

Figure 2 .3D View of the SRM

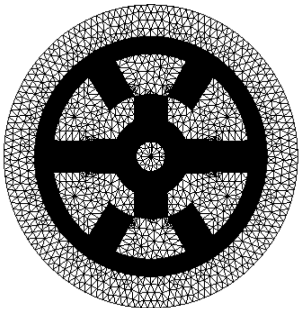

Figure 3. Descretized model of SRM

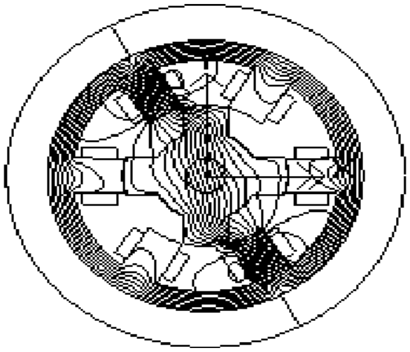

Figure 4. Flux distribution of standard SRM

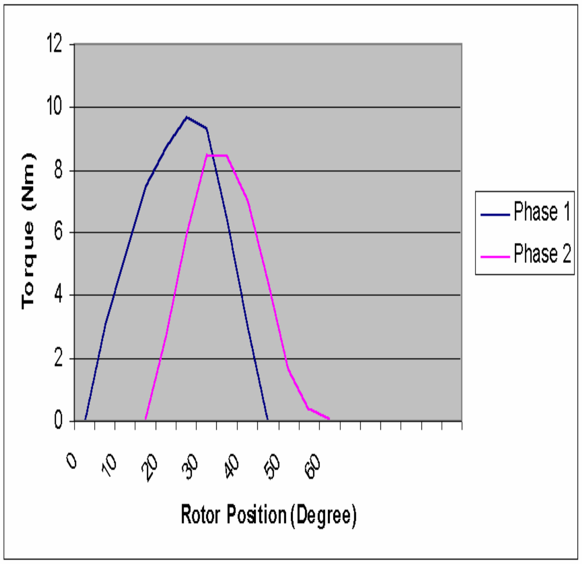

Figure 5. T-θ Characteristics of Standard 3 phase SRM

The Torque-Angle (T – θ) characteristics of a SRM depends on the stator-rotor pole overlap angle, pole geometry, material properties, number of poles and number of phases [2].

3 Torque ripple Minimization

In general, by means of splitting the stator poles and skewing the rotor poles, reduction in torque ripple is possible. However these methods reduce the obtained torque. Moreover, the minimization of torque ripple through the electronic control approach, may also lead to a reduction in the average torque. The majority of torque ripple occurs in the phase overlap region, where torque-producing responsibility is commutated from one phase to another. Torque ripple is defined as the difference between the maximum and minimum instantaneous torque expressed as a percentage of the average torque during steady state operation. Torque dip is the difference between the peak torque of a phase and the torque at an angle where two overlapping phases produce equal torque at equal levels of current [2]. The smaller the torque dip, the minimum is the torque ripple.

Genetic algorithm (GA) has computational procedures that mimic the natural process of evolution [7]. The main advantages of GA are as follows:

- They are adaptive, and learn from experience.
- They have intrinsic parallelism
- They are efficient for complex problems.

The objective of GA is to find an optimal solution to a multi-objective problem. Here, Flux linkage is maximized with inductance overlap ratio of two adjacent phases, to reduce the torque dip and improve the performance of a 3 phase SRM.

The Objective Function is defined as,

$$F = \text{Maximize}\ (\psi, K_L)$$

Where, ψ is the flux linkage given by,

$$\psi = L.i \qquad \ldots.\ (1)$$

The general expression for inductance of SRM as the function of rotor position θ, is given by [9],

$$L = \frac{2N_p^2\mu_0\, r_l l\alpha}{g} + L_u \qquad \ldots.\ (2)$$

Using the typical values of a 3 phase SRM,

$$L = [0.1143(\theta - \theta_x) + L_u]$$

Where, θ and θ_x depend on the rotor and stator pole arcs.

K_L is the inductance ratio and is given by

$$K_L = 1 - (\varepsilon / \min(\beta_r, \beta_s)) \qquad \ldots.\ (3)$$

Where, ε is the stroke angle.

From this, we can state that torque overlap can be increased by widening the stator and rotor poles. The higher the K_L, the lower will be the torque dip and higher will be the mean torque as well. The Constraint conditions are given by [4],

$$0 < \beta_r \leq \alpha_r;\ 0 < \beta_s < \alpha_s$$
$$\beta_r > \beta_s,\ 2\pi/N_r - \beta_r > \beta_s \qquad \ldots.\ (4)$$

where,

α_r = Rotor Pole Pitch
α_s = Stator Pole Pitch
β_r = Rotor Pole Arc
β_s = Stator Pole Arc

The equations have been framed in accordance with references [1] and [2].

GA Parameters

Number of Design variables	:	2
Number of Chromosomes	:	10
Cross over rate (in %)	:	60
Mutation rate (in %)	:	10
Maximum generation	:	10000

The design variables are Stator pole arc and Rotor pole arc. The main aim is to find the best values of stator and rotor pole arcs to get maximum inductance ratio. It is also possible to obtain the pole arcs values by trial and error method and then design the machine for each and every value, using FEA based CAD package. But it consumes a lot of time in modeling and simulation. Instead, if we apply intelligence technique, it is possible to achieve the best result within the minimal time period, which makes this technique very effective and this implies the need for GA. The constraints are called pole arc constraints, to achieve the maximum performance and maximum torque output with reduced ripple. By observing the Torque –Angle Characteristics of the proposed design, the maximum torque and the average torque were improved, in comparison with that of a standard machine.

4 Results

Parameters	Standard Model	Torque Ripple Minimized Model
β_r (deg)	32	35
β_s (deg)	28	30
K_L	0.4643	0.5
Torque dip (NM)	1.316345	0.016860

From the results, it has been observed that torque ripple is very minimum for the stator and rotor pole arc values of 30 and 35 degrees respectively. This paper suggests this proposed design for direct drive applications, which requires higher average torque at low speed with reduced ripple. Estimation of copper losses at all speeds is complicated by the fact that the current waveform in the SRM is not sinusoidal. The waveform is dependent on operating conditions, particularly the excitation current, speed and the switching strategy. But for low speed operation, it can be controlled by minimizing the ripple and shaping the current waveform. Moreover, when the rotor is at or near the aligned position, the flux is generally higher and the bulging of flux outside the core depends on the flux level in the laminations near the ends of the stack. Therefore, the factor that accounts for the axial fringing in the end region is calculated using [1], and there is not much deviation in this factor for the standard and proposed model.

5 Validation of Results

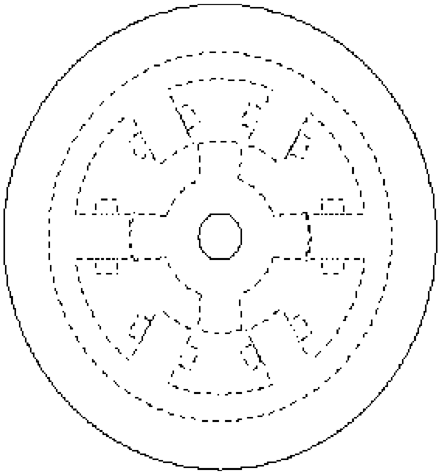

Figure 6. Torque ripple minimized Model

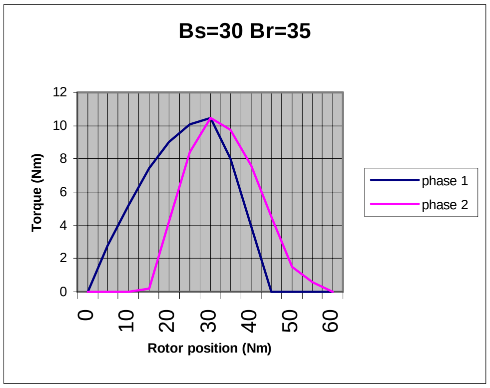

Figure 7. T-θ characteristics of proposed design values

6 Conclusion

In this design methodology, Rotor pole arc, Stator pole arc of SRM are taken as design variables. Based on the Genetic Algorithm, an improvement in performance has been effected, by way of increase in Torque and reducing the torque dip, thereby minimization of torque ripple of SRM has been accomplished. The obtained design values are modeled again using FEA based CAD package for verification and the results are cross-checked. By means of maximizing the flux linkage, we can notice an improvement in torque throughput and by maximizing the inductance ratio, the model corresponding to βs = 30° and βr = 35° has 98.72% lesser torque dip, which is a quite significant optimization result when compared to the recent work, reported in [8].

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