Control of Torque Ripple for SRM Using Intelligent System

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Abstract:- In this paper modelling and analysis of the SRM torque characteristics including torque ripples are described. Optimal control strategy based on genetic algorithm (GA) to minimize torque ripple is proposed. The optimization criteria depend on choosing the exact current profile based on the optimal excitation parameters which govern the torque shape. The model and control are carried out on high range three phase SRM of 60 KW and 121 Nm where torque ripples is considerable. The results are presented to indicate the performance of the drive system using this technique .

Key-Words:- SRM, Torque ripple, Torque modelling, Intelligent control

1. Introduction

The smooth production of electromagnetic torque is a desirable characteristic of any motor. While smooth torque production has been achieved in dc and ac induction and synchronous machines, it has not, historically, been achieved by switched reluctance motors. Smooth torque production is a necessary, but not sufficient, requirement in order to achieve servo grade performance from a motor. Another necessary condition is dynamic torque control [1].

Switched Reluctance Motor (SRM) is an electric motor in which torque is produced by reluctance variation. Its simple and stiff structure makes it easy to mass-produce. But because of its saliency and pulse shape voltage applied to stator winding it has comparable large torque ripple. The torque ripple remains one of the main problems linked to the use of switched reluctance motor. In order to use these drives in low speed application, we have imagined a current control, with optimized waveforms allowing torque ripple minimization [2]. We have to take into account motor parameters and converter voltage limitations [3]. In this work modelling and analysis of the SRM dynamic torque characteristics including torque ripples is described. An optimal control strategy based on genetic algorithm (GA) to minimize torque ripple is also proposed on this work. The algorithm is carried out on a three phase SRM machine with6/4 poles.

2. SRM Torque Characteristics:

The calculation of the magnetic energy is directly linked to the knowing of the electromagnetic characteristic of the machine. So static torque characteristics can be computed based on obtaining magnetic energy. The torque T_j produced by phase j is determined by differentiating the coenergy function W_j with respect to rotor position θ [4].

$$T_j(\theta, i_j) = \frac{\partial W_j(\theta, i_j)}{\partial \theta} \qquad (1)$$

The instantaneous torque for phase *j*, produced by a SRM with independent phases during both saturated and unsaturated magnetic operation, can be determined according to equation (1).

The torque and stored field energy in an SRM can be expressed as a function of rotor position and flux linkage as follows. Assuming the current in the machine, as well as the stored magnetic energy and the electrical energy, are functions of flux linkage and position.

This is the coenergy analysis given in [5]. From this analysis the following form is given by:

$$W_j(\theta, i_j) = \int_0^{i_j} \psi_j(\theta, i_j) di_j \qquad (2)$$

$$T_j(\theta,i)=\int_0^i \frac{\partial\psi(\theta,i_j)}{\partial\theta}di_j \qquad (3)$$

Equation (3) gives the desired expression for instantaneous torque in terms of the differential change in stored energy with respect to position, evaluated at a constant flux linkage. Fig. 3 shows the differential stored field energy between two rotor positions as the change in stored field energy with a constant flux linkage.

The average torque is equal to the area enclosed by this change in stored field energy divided by the change in rotor position. The instantaneous torque is the differential area divided by the change in rotor position as the change in rotor positions tends towards zero.

From the above analysis, we get the average torque equation of the switched reluctance motor

$$T_a = \frac{1}{\theta_c}\int_{\theta_a}^{\theta_u} T_j(\theta,i)d\theta \qquad (4)$$

$$T_a = K(w_a - w_u) \qquad (5)$$

Where w_a and w_u are the co-energies, when the rotor is at the aligned and unaligned position, respectively.

We can get the well known simplified average torque equation of the switched reluctance motor by defining the phase inductance given in the following equation.

$$L_j(i_j,\theta) = \frac{\partial\psi_j(i_j,\theta)}{\partial i_j} \qquad (6)$$

$$T_a = \tfrac{1}{2} i^T \frac{\partial L}{\partial\theta} i \qquad (7)$$

Our analysis for determining the torque ripple formula is based on the assumption of a constant load torque equal to the average torque given in equation (6) developed by the motor and the rotor runs at steady state with average speed ω. Any fluctuations above or below average speed ω are due to torque ripple which has period T= ϕ/ω and given by the difference between the instantaneous torque in equation (1) and average torque in equation (6). This is given by the following equation.

$$T_r = T(\theta,i) - T_a \qquad (8)$$

The torque ripple T_r is function of current, which is consequently function of excitation parameters. So by choosing the exact current profile based on the optimal excitation parameters using GA technique, the torque ripple will be reduced and optimum torque profile is obtained. Equation (7) will be our fitness function in the optimization technique based on GA.

Figure 1 shows a graph of the output torque with minimum torque ripple. We see that the torque ripple is minimized due to control in the current profile. The output torque waveform given here has a trapezoidal shape and affected by turn on and turn off angles.

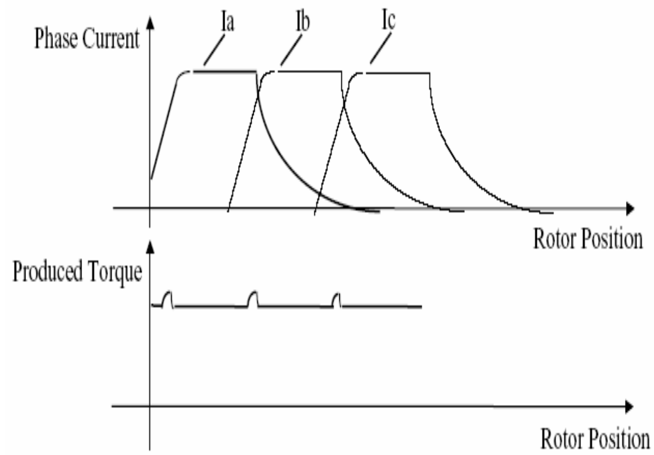

Fig. 1 Output torque with minimum torque ripple

3. Influence of the Excitation Parameters in the Output Torque

Theoretically, for given current amplitude the maximum gross output torque is reached by instantaneously turning on each phase at the beginning of its corresponding rising inductance slope and by instantaneously turning off each phase at the end of the rising inductance slope. As the dc supply voltage is limited, turn on time at θ_{on} and turn off time at θ_{off} is not negligible. At higher running speeds, each of these events easily exceeds more than 15^0. When keeping these parameters unconsidered, a high degradation of the gross output torque will result [7]. Additionally, both the torque ripple and the acoustic noise will considerably increase. A common figure of merit for torque smoothness is the ratio of the peak-to-peak ripple to the average torque, often expressed as percentage. However, the nature of torque production in SRM motors, and the various current profiles that can be employed, gives rise to torque ripple waveshapes that may not be adequately characterized by a peak-to-average ratio. We define the torque ripple as the differences of waveshape while remaining independent of the speed regulation and computing it at constant speed. The torque ripple can be minimized by controlling the current profile i.e excitation parameters.

4. Optimal Excitation Algorithm Using GA

Genetic algorithms (GA) are stochastic search methods that mimic the metaphor of natural biological evolution. Genetic algorithms operate on a population of potential solutions applying the principle of survival of the fittest to produce better and better approximations to a solution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from other process, just as in natural adaptation. GA provides a powerful mechanism for searching through a large solution space for global optimal solutions. In our case, we are searching for optimal excitation parameters to reduce the toque ripples of the drive system.

4.1 The Procedure Used in the Genetic Algorithm.

The profile selection process based on optimum torque operation is carried out by selecting the excitation parameters θ_{on} , θ_{off} , and I_{ch} (No of chop), using the GA procedures described in [8]. Figure 3 shows the flow chart of the GA procedure to carry out the optimum parameters. The Excitation parameters have an influence on the output torque production as explained in the previous section. For this purpose, the initial values of the excitation parameters are generated randomly, and this form the initial individuals of a population. The GA is then used to obtain the individuals of the final population by performing a population-based optimization. The GA requires the use of fitness and this is chosen to be the torque ripple defined by equation (3,7). So to optimize the torque waveshape we need to minimize the torque ripple. The fitness function is given by:

$$f = 1/\tau_r \qquad (9)$$

The goal of the GA is then to maximize the fitness function, i.e minimize torque ripple in equation 8, and after a suitable number of generations, the optimal parameters (corresponding to the highest fitness value) are obtained. The following flow chart shown in figure 2 is describing the procedure of GA to obtain the optimum parameters. In this flow chart the role of the search is broken into two separate problems:

- Producing a current profile with the correct no of chops without regard for torque output.
- Correcting the torque output of the current waveform which has the correct no of chops.

Since all possible current profiles which meet the operating point requirements will be optimized, there is no loss in generality by starting with one chop and increasing the number of chops sequentially in each step until a global optimum can be determined.

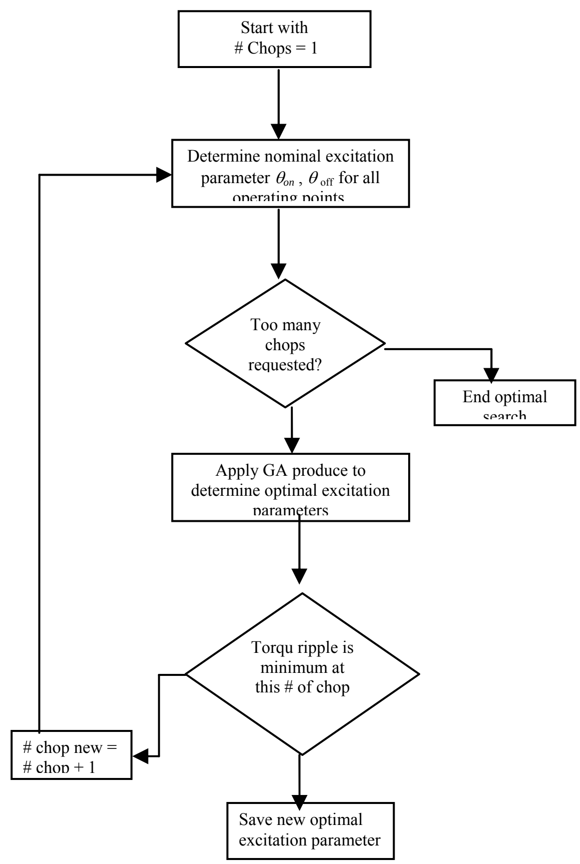

Fig. 2 Flow chart of the GA steps

5. Results and Discussion:

The application of GA promises a high computation rate provided by the massive parallelism, a great degree of robustness, or fault tolerance due to the distributed representation, and the ability of generalization to improve the performance. Also it cooperates with the nonlinearities of the drive system.

Figures 3-5 illustrate the excitation parameters (θ_{on}, θ_{off}, I_{ch}) versus rotor speed at different operating torque obtained from the GA and analytically. In order to evaluate the control model, the performance of the drive system under optimal excitation parameters using GA technique is examined. The control model is carried out on high range three phase SRM of 60 KW and 121 Nm where torque ripples is considerable. Figure 6 shows the optimal output torque waveform based on the excitation parameters obtained from GA technique. It is clear that the torque waveform has a trapezoidal shape which leads to ripple reduction.

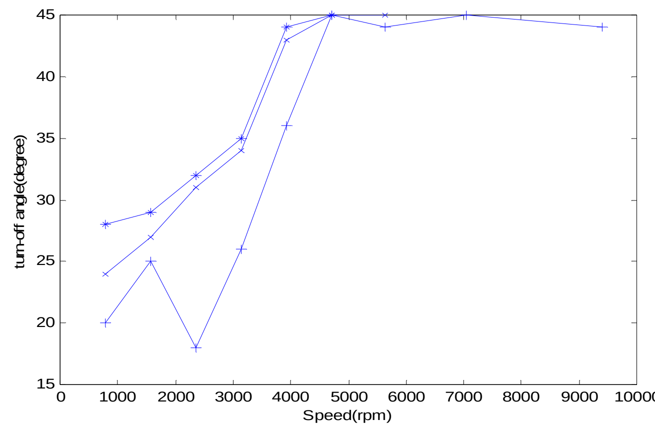

Fig. 4a Optimum chop current Vs speed at torque T(*)=121.9 Nm, T(x)=101.6 Nm, T(+)=61.0 Nm (GA results)

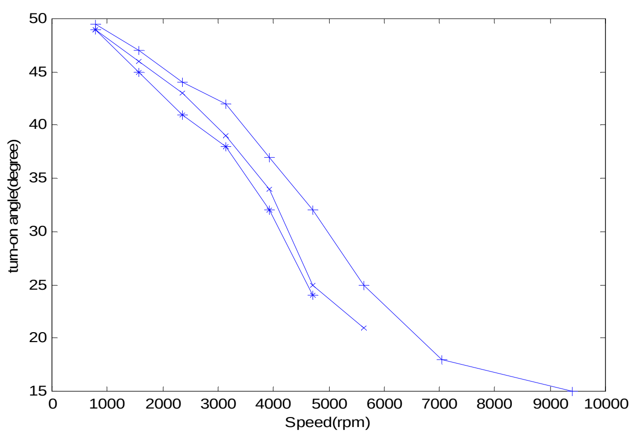

Fig. 3a Optimum turn-on angle Vs speed at torque T(*)=121.9 Nm, T(x)=101.6 Nm, T(+)=61.0 Nm (GA results)

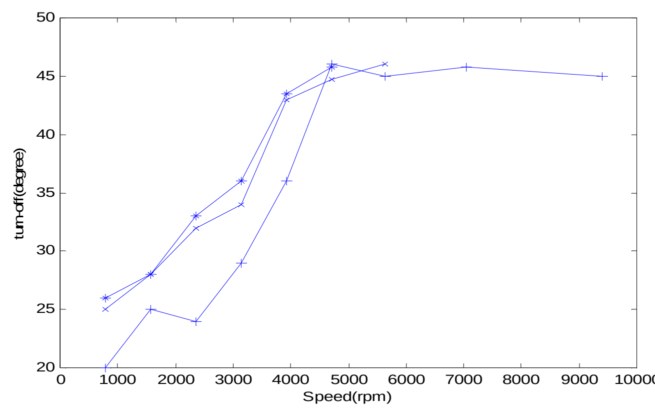

Fig. 4b Optimum turn-on angle Vs speed at torque T(*)=121.9 Nm, T(x)=101.6 Nm, T(+)=61.0 Nm (Analytical)

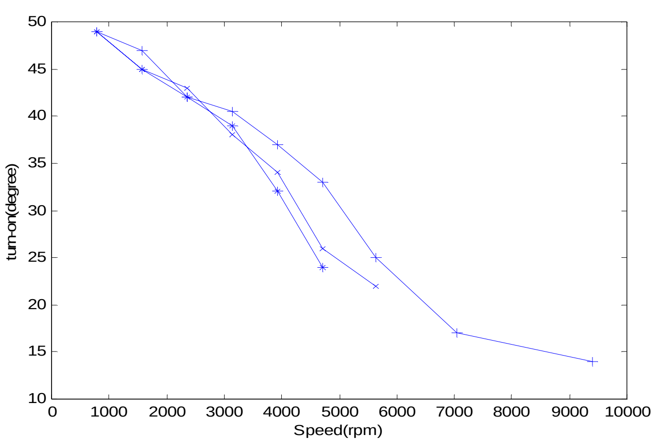

Fig. 3b Optimum turn-on angle Vs speed at torque T(*)=121.9 Nm, T(x)=101.6 Nm, T(+)=61.0 Nm (Analytical)

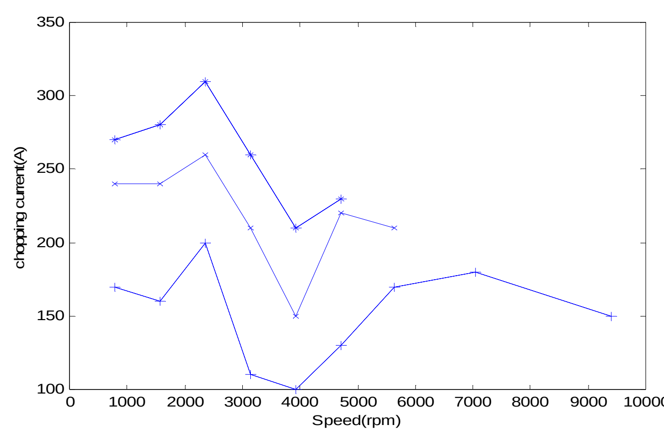

Fig. 5a Optimum chop current Vs speed at torque T(*)=121.9 Nm, T(x)=101.6 Nm, T(+)=61.0 Nm (GA results)

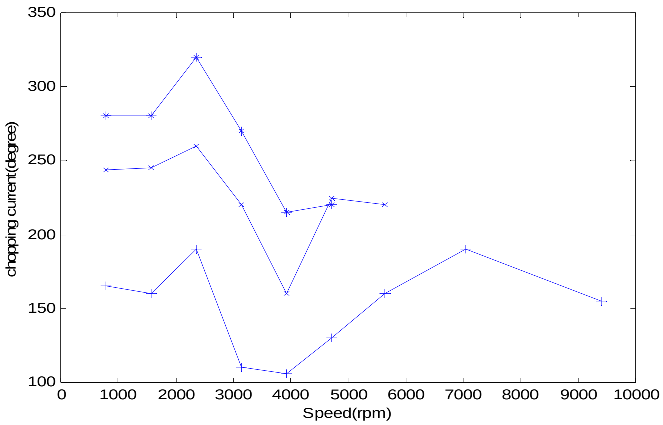

Fig.5b Optimum chop current Vs speed at torque T(*)=121.9 Nm, T(x)=101.6 Nm, T(+)=61.0 Nm (Analytical)

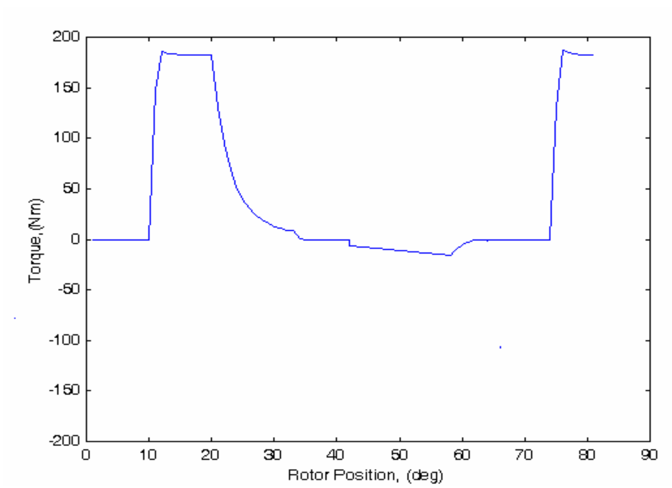

Fig. 6 Optimum output torque at desired excitation parameters

6. Conclusion

In this paper an intelligent technique based on GA is used to solve the problem of determining the optimal excitation parameters for the desired output torque with minimum torque ripple. A genetic algorithm is a straightforward computerized search method based on the ideas of genetics and natural selection. GA provides a powerful mechanism for searching through a large solution space for global optimal solutions. The GA is concerned with finding the excitation parameters (θ_{on}, θ_{off}, and I_{ch}) such that the optimum output torque is produced with the constraint of the current waveform profile.

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