ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING

YEAR : 2010 (1197 - 1200)
VOLUME : 10
NUMBER : 1

IMPLEMENTATION OF DYNAMIC ANALYSIS OF SRM WITH MODIFIED POLE GEOMETRY

Yusuf OZOGLU
Istanbul University, Vocational School of High Tech, 34850, Istanbul, Turkey,
yozoglu@gmail.com

ABSTRACT

One solution to the high torque ripple problem of the switched reluctance motor is to modify its pole geometry. To show how much this solution is effective, static field analyses are usually contended with. However, dynamic analyses of SRM are to be made to get a real model of SRM. In this study, dynamic analysis of conventional SRM and the modified SRM are made and their performance parameters are compared with each other. The comparison shows an improvement of 23.6 % in torque ripple and 18 % in efficiency which is in agreement with the results of static analysis.

Keywords- *Torque Ripple, Switched Reluctance Motor, Pole Geometry*

1. INTRODUCTION

Switched reluctance motor (SRM) has a high torque/mass ratio and is commonly used in variable speed applications, but it has some drawbacks such as high torque ripple, acoustic noise and the need of a sensor to determine the rotor position. To reduce the torque ripple, various methods have been suggested in the literature. These methods can be divided into two main categories: the first, those which suggest the modifications in the pole geometry [1-2] and the second, those which offer new driver circuits and control methods [3-4]. In the first category, a new SRM model with modified stator and rotor pole geometry has been offered. This investigating has been realized using Finite Element Method (FEM) under the static conditions [5].

Previous study of new SRM model with modified stator and rotor pole geometry has been based on static field analysis. It is an essential point of investigation whether or not this new model keeps the same advantages over the conventional SRM even under the dynamic working conditions. This study basically covers this investigation and extends the knowledge obtained from the static field analysis. It starts with the development of the dynamic models of both kinds of motor together with their driver circuits, and provides an overall description of the dynamic behaviour of the motors. No control method is applied to driver circuit in the dynamic study so that the results of static and dynamic studies can be compared with each other.

2. DYNAMIC MODEL OF SRM

SRM is used in this study is a three-phase motor with 6/4 pole construction, 500W, 24 V, 11 A, β_s/β_r 30/32 degree and an air gap of 0.228 mm [6]. Although these characteristics belong to conventional SRM, they are also valid for the modified SRM, the only difference between them is that the modified SRM has a different stator and rotor pole shape. The detail of both stator and rotor pole parameters and how the pole geometries have been obtained is given in previous study [5]. From now on, the SRM with conventional pole construction will be called as

Received Date : 19.05.2009
Accepted Date: 26.11.2009

SRM-I and SRM with modified pole geometry as SRM-II, for ease of reference. Subscript 1 and 2 will be used for SRM-I and SRM-II respectively.

The dynamic model of SRM consists of three parts: data obtained from FEM, equivalent model of SRM and the driver circuit. Data obtained from FEM are generally used in the dynamic model by employing two different methods: In the first method, equations representing inductance, flux and torque characteristics of SRM are obtained. This method is known as "curve fitting method". In the second method, inductance, flux and torque data are put into look-up tables. As the first method is difficult, the second one has been preferred in this study. Inductance, flux and torque data obtained from FEM by static field analysis are entered into look-up tables. The equivalent model of SRM has been generated using voltage, flux and torque equations.

$$V = R \cdot i + \frac{d\lambda(\theta,i)}{dt} \qquad \textbf{(1)}$$

$$\lambda(\theta,i) = L(\theta,i) \cdot i \qquad \textbf{(2)}$$

L(θ,i) in Eq.2 is taken from the FEM data in the look-up table. The current expression obtained from Eq.2 and θ values obtained from mechanical circuit of the motor are used as inputs in the T(θ,i) look-up tables and dynamic torque characteristics are obtained accordingly.

In generating dynamic model of SRM Matlab-Simulink has been used. In the dynamic model, voltage is applied to phase windings with a delay angle θ_i=2.5 and turn-off angle θ_c=10° for a dwell angle Δθ=32.5°.

Then, the state equations for C-dump driver can be written as follows:

$$\frac{dV_{cd}}{dt} = \frac{\left(i - u_g i_d\right)}{C_d} \qquad \textbf{(3)}$$

$$\frac{di_d}{dt} = \frac{\left(u_g V_{cd} - V_{dc} - R_d i_d\right)}{L_d} \qquad \textbf{(4)}$$

As it is seen, the dynamic model generated for SRM dynamic analysis incorporates also C-dump driver circuit. When the state equations for C-dump driver circuit are solved, C-dump voltage (V_{cd}) and current (i_d) become the input variables of the dynamic model of SRM.

Dynamic parameters of these SRM models are J=189·10-6 Kg·m2, B=0.1·10-3 Nm·s/rad, K=5·10-3 Nm·s/rad, R=0.111 Ω, V_{dc}=24 V, R_d=2.67 Ω, L_d=193 mH, C_d=370 μF, f_s=10 kHz d=0.5, V_{cd}=2V_{dc}.

Circuit parameters used in the dynamic analysis are entirely the same for SRM I and SRM II to enable a comparison between them.

3. COMPARISON OF DYNAMIC CHARACTERISTICS

In this section, the performance characteristics obtained from dynamic analysis of SRM-I and SRM-II are given in a comparative form.

3-phase inductance waveforms for SRM-I and SRM-II are given in Fig.1 which shows that the lowest value of the phase inductance is 0.5 mH and the highest value 5.9 mH. In Fig.1 the variation of the slope in the increased portion of the inductance waveform for SRM-II resulting from the suggested pole construction inhibits high oscillation of the phase current.

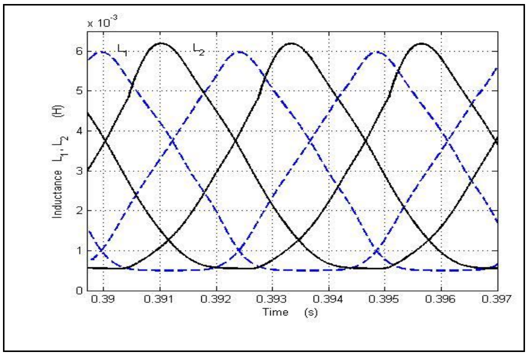

Fig. 1 3-phase Inductance Waveforms

Current curves for SRM-I and SRM-II are given in Fig.2. When the current waveforms are examined, i_{max}, i_{min} and Δi values are 14.5 A, 8 A and 6.5 A for SRM-I and 10.5 A, 7.6 A and 2.9 A for SRM-II. This shows that current variation for SRM-I have sharp rises and falls, whereas this variation is moderate for SRM-II.

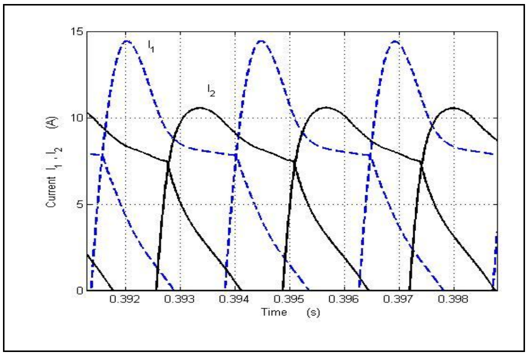

Fig. 2 3-phase Current Waveforms

It is noticed that phase transistors of the SRM-II currents are softer than SRM-II currents.

In Fig.3, total 3-phase torques produced by SRM-I and SRM-II are given as T_1 and T_2 respectively. Important parameters read from Fig.3 are given in detail in Table 1.

Variations in the torque ripples are the same as the variations in the current: they are high for SRM-I, whereas they are low for SRM-II. Moreover, both waveforms have the same average values.

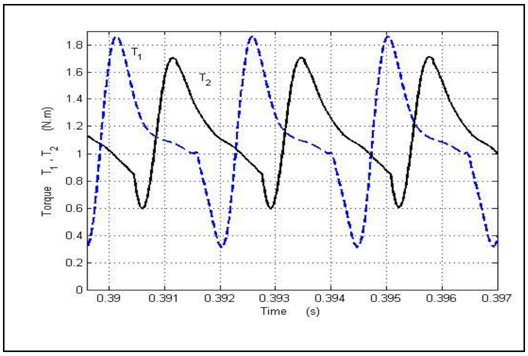

Fig. 3 Torque Waveforms

Table 1 shows that torque ripple values obtained from the dynamic analysis are 71.4 % for SRM-I and 47.8 % for SRM-II, so torque ripple in SRM-II has been improved by 23.6 % in comparison with SRM-I.

Table 1 Obtained Torque Values from Fig.5

Quantity	***SRM-I***	***SRM-II***
T_{max}	*1.86 Nm*	*1.70 Nm*
T_{min}	*0.31 Nm*	*0.60 Nm*
T_{avg}	*1.07 Nm*	*1.00 Nm*
$\%T_{ripple}$	*71.4 %*	*47.8 %*
ΔT_{ripple}	*-23.6 %*	

The figure of improvement was obtained as 24.1 % in the static analysis. So, the improvements obtained from the static and dynamic analysis are almost the same (24.1% vs. 23.6%); in other words the results of both analysis greatly support each other.

Table 2 Obtained Power and Efficiency Values

Quantity	***SRM-I***	***SRM-II***
P_s	*300 W*	*275 W*
P_m	*223 W*	*252 W*
η	*73 %*	*92 %*
$\Delta\eta$	*18 %*	

Table 2 provides a comparison of efficiency values for SRM-I and SRM-II. As can be seen, SRM-I gets 300W from the supply and delivers 223W, so efficiency is 73%. For SRM-II, these figures are 275W, 252W and 92%. The improvement in efficiency of SRM-II is 18% which is a significant increase.

4. CONCLUSION

In this study dynamic analysis of SRM with conventional pole shape (SRM-I) and SRM with modified pole shape (SRM-II), both incorporate driver circuits, have been made and 23.6% improvement in torque ripple and 18% improvement in efficiency have been achieved. These figures of improvement are in agreement with the results of the static analysis.

REFERENCES

[1] Moallem, M., Ong, C.M., and Unnewehr, L.E.: Effect of Rotor Profiles on the Torque of a Switched Reluctance Motor, IEEE Trans. on Ind. App., Vol. 28, No. 2, 1992, pp 364-369.
[2] Ohdachi, Y., Kawase, Y., Miura, Y., Hayashi, Y.,. Optimum Design of Switched Reluctance Motors using Finite Element Analysis, IEEE Trans. on Magnetics., Vol. 33, No. 2, 1997 pp 2033-2036.
[3] Rochford, C., Kavanagh, R.C., Egan, M.G., and Murphy, J.M.D., Development of Smooth Torque in Switched Reluctance Motors Using Self-Learning Techniques, European Power Electronics, pp 14-19, 1993.
[4] Derdiyok A., Inanc N., Ozbulur, V., Ozoglu Y., Optimal Phase Current Profiling of SRM by Fuzzy Logic Controller to Minimize Torque Ripple, 12th IEEE-ISIC 97 Conf., Istanbul, TURKEY, pp.77-82, 1997.
[5] Yusuf Ozoglu, Muhammed Garip, Erkan Mese, Torque Ripple Reduction in Switched Reluctance Motors by Pole Tip Shapings, 10th International Power Electronics and Motion Control, EPE-PEMC 2002, Cavtat & Dubrovnic, Croatia, September, 9-11 2002.
[6] Miller, T. J. E., 1993. Switched Reluctance Motors and Their Control. Oxford University Press, Oxford.

BIOGRAPHY

Yusuf Ozoglu was born in Urgup, Turkey in 1967. He received the B.Sc., M.Sc. and Ph.D. degrees in Electrical Engineering from Istanbul Technical University, in 1989,1995,1999 respectively. In 1991, he joined the Control Technology Program of Vocational School of High Tech in Istanbul University as a Research Ass. Since 1991, he is working at the same program in Istanbul University as an Instructor and Lecturer. His research interests are in the areas of electrical machines, their designs and controls.