스위치드 리럭턴스 전동기 구동시스템의 최대효율 운전

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Maximum Efficiency Operation of SRM Drive System

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Abstract - The present paper investigates the optimal operation of a switched reluctance motor such that overall drive efficiency is maximized under a variable supply voltage. The operation under a variable supply voltage exhibits the improved drive efficiency in the full range of operating torque and speed, and exhibits the expanded range of operating torque and speed. Furthermore a variable supply voltage may be utilized in reducing torque ripple.

1. Introduction

One of some particular advantages is that SRM can be operated over a wide range of operating torque and speed with high drive efficiency. Some work has been presented on maximizing efficiencies of switched reluctance motor drives.[1,2] The previous work for maximizing the drive efficiency was performed the constraint of a fixed supply voltage. The present paper investigates the maximum efficiency operation of SRM in the case such that the supply voltage is variable.[3] A methodology is developed to perform an optimization such that the drive efficiency is maximized subject to the constraints of a given speed and time-average torque, and physical limits imposed on a SRM drive. Fig. 1 shows the maximum developed torques of the SRM in the variation of supply voltage. The operation under a variable voltage supplies two advantages, the improved efficiency and the expanded range of operating torque and speed. Furthermore the variable voltage may be utilized in reducing torque ripple.

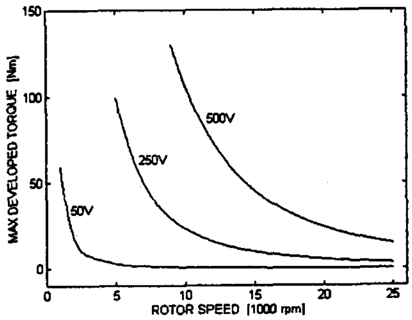


Fig. 1 Maximum developed torque

2. SRM Drive Model

SRM is an electromechanical device that is magnetically decoupled because the mutual flux can be neglected. However, SRM generally operates in the magnetically saturated region because the saturation gives several benefits to its performance. The voltage equation which describes a nonlinear SRM may be written as

$$v_i = r\,i + \frac{d\lambda}{dt} \qquad (1)$$

The linkage flux is a nonlinear function of winding current and rotor position. Fig. 2 shows the curves of linkage flux of the SRM considered in this paper. The SRM has 6/4 poles, 3 phase bifilar-windings. The nominal power and speed are 60KW and 4700rpm.

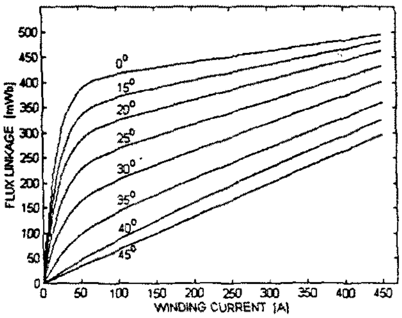


Fig. 2 Linkage flux curves

The instantaneous torque produced by one phase during both saturated and unsaturated magnetic operation can be determined according to

$$T_i = \frac{\partial W'}{\partial \theta} = \frac{\partial}{\partial \theta} \int_0^i \lambda(i', \theta)\, di' \qquad (3)$$

The inverter excites SRM as commended by the excitation algorithm. The inverter shown in Fig. 3 is considered as the per phase drive circuit of the SRM. All the losses dissipated in the motor and inverter should be analysed to evaluate the drive efficiency in obtaining the optimal excitation. The losses are analytically approximated as follows. Snubber losses arise from discharging the stored energy of a snubbing capacitor, and these are classified as three cases; GTO conduction, secondary conduction and phase reset.

$$P_{s_1} = \frac{1}{2} C_s V_o^2 f_s \qquad (4)$$

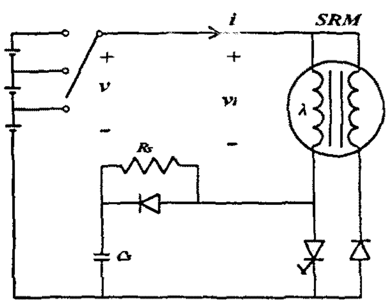


Fig. 3 Per phase drive circuit of SRM

$$P_{s_2} = R_s L_l C_s I_o^2 f_s \left(\frac{s_1 s_2}{s_1 - s_2}\right)^2 \left\{ \frac{1}{2s_1}(e^{2s_1 t} - 1) - \frac{2}{s_1 + s_2}(e^{(s_1+s_2)t} - 1) + \frac{1}{2s_2}(e^{2s_2 t} - 1) \right\} \qquad (5)$$

where $s_{1,2} = -\frac{R_s}{2L_l} \pm \sqrt{\left(\frac{R_s}{2L_l}\right)^2 - \frac{1}{L_l C_s}}$

$$P_{s_3} = \frac{R_s C_s V_s^2 f_s}{4 L_m \beta^2} \left\{ 2 e^{2\alpha t} \sin\beta t\, (\alpha \sin\beta t - \beta \cos\beta t) + \frac{\beta^2}{\alpha}(e^{2\alpha t} - 1) \right\} \qquad (6)$$

where $\alpha = -\frac{R_s}{2L_m}$, $\beta = \sqrt{\frac{1}{L_m C_s} - \left(\frac{R_s}{2L_m}\right)^2}$

Switching loss is the loss dissipated in the GTO during turnoff transition.

$$P_{sw} = \left(\frac{2 C_s V_s^2}{I_o} + \pi V_s \sqrt{L_l C_s} + L_l I_o \right) I' f_s \qquad (7)$$

where $I' = -2.7232 + 0.1594\, I_o + 0.000381\, I_o^2$

Conduction loss occurs in both the GTO and freewheeling diode due to the voltage drops while conducting.

$$P_c = f_s \left(\int V_G\, i_1\, dt + \int V_D\, i_2\, dt \right) \qquad (8)$$

Motor loss is the loss dissipated in the windings while conducting.

$$P_m = f_s \left(\int R_1\, i_1^2\, dt + \int R_2\, i_2^2\, dt \right) \qquad (9)$$

3. Optimal Operation

The excitation in a SRM drive is designed to produce the required drive output of speed and torque while satisfying some performance measure. In the present paper, that performance measure is the maximum drive efficiency. Therefore the maximum efficiency operation can only be determined by examination of all excitations that meet the torque and speed requirements. The optimization problem may be written as

$$\begin{aligned}
\textit{maximize} \quad & \eta(\theta_{on}, \theta_{off}, v) \\
\textit{subject to} \quad & T_{ave}(\theta_{on}, \theta_{off}, v) = T_o \ (constant) \\
& \frac{d\theta}{dt} = \omega_o \ (constant) \\
& i(\theta_{on}, \theta_{off}, v) < I_{max} \\
& 0^\circ < \theta_{on} < 90^\circ \\
& \theta_{on} < \theta_{off} < \theta_{on} + 45^\circ \\
& v < V_{max}
\end{aligned}$$

4. Results and Discussion

Fig. 4 shows the instantaneous torque obtained from the maximum efficiency operation at the operating point of torque 120Nm and speed 1000rpm under the supply voltage 250V. The maximum efficiency is 60% which is obtained from the chopping-mode excitation. Fig. 5 show the instantaneous torque obtained from the maximum efficiency operation at the same operating point under the supply voltage 100V. The maximum efficiency is 68% which is obtained from the switching-mode excitation. If the supply voltage is well selected, the drive efficiency is improved, and the torque ripple is reduced as shown in the figures. Fig. 6 shows the optimal supply voltage and the maximum drive efficiency found in the full range of operating torque and speed through the maximum efficiency operation algorithm.

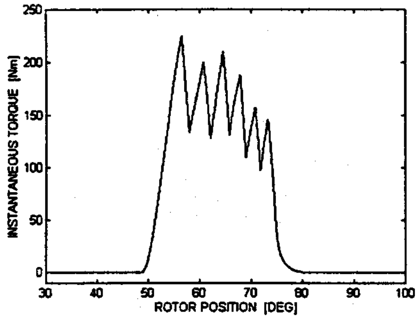


Fig. 4 Instantaneous torque in the chopping-mode excitation

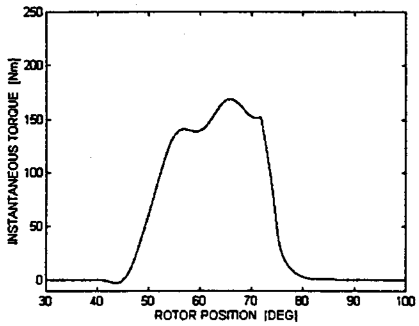
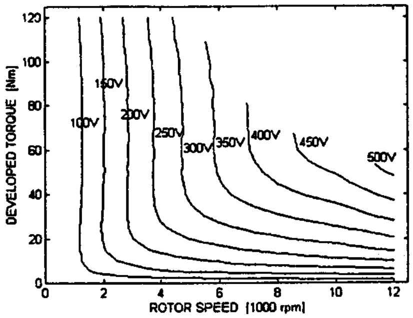
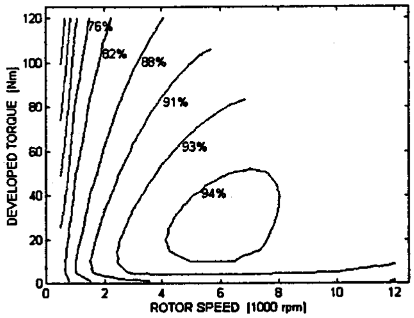


Fig. 5 Instantaneous torque in the switching-mode excitation



(a)



(b)

Fig. 6 Maximum efficiency operation (a)Optimal voltage (b)Maximum efficiency

5. Conclusions

This paper investigates the maximum efficiency operation of SRM under a variable supply voltage. If the supply voltage is well selected, the drive efficiency is improved, and the torque ripple is reduced as shown in the results. The optimal operation presented in this paper may be applied to any other SRM drive.

[References]

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