SIMULATION OF SWITCHED RELUCTANCE MOTOR BACK-EMF COMPENSATION

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Abstract- At high speed, the reluctance machine back-emf is significant, often exceeding the DC bus voltage when the current is actually forced to decrease during the rising inductance region. For sufficient current build up, it is necessary to advance the phase turn-on angle substantially, even up to the point where the rotor is still in the falling inductance region of the previous pole overlap. In this paper, a new method has been developped to compensate the back-emf at the rated speed of a 4-phase, 6-pole switched reluctance machine without being penalized by a negative torque. The simulation results show better dynamic performances using the new method over the previous, which have been presented before.

I. INTRODUCTION

The switched reluctance machine torque is known by its unidirectional-pulsed nature. Therefore, in the applications where the constraint on the torque ripple is important, it is necessary to optimize the power supply to maximize the average torque per ampere and this is achived by careful control of winding currents as a function of a shaft position. Then, if the actual phase currents are made to track the reference currents perfectly, and these reference currents are computed from a reliable model, the torque ripple will be minimized.

The most important problem of the variable reluctance motor current control, is that at high speeds the reluctance motor back-emf exceedes the DC voltage, when the current decreases in the rising inductance region. Any small changes in the machine current tracking, will be translated by important ripples in the motor torque. To overcome this drawback, the turn-on angle of the phase current pulse advancements are necessary at high speeds so that the current can rise to the desired reference level (current maximum value), befor the rising inductance region begins. Since the turn-on angle computation is a fonction of the speed, then for a sufficient current buildup, it is advanced even up to the point where the rotor is still in the falling inductance region of the previous pole overlap [1], which produces a negative torque. In this paper we will introduce a new method of turn-on angle computation to compensate the back-emf at high speeds, and applied to a model of machine inductance behaviour approximated to the real one [4].

The first part of the paper deals with the current control and the computation of the turn-on angle by the conventional and the new method, with the complete control scheme of the variable reluctance machine drive system, while the second part is related to a comparative study of simulation results of both methods showing the advantages of the new mehod over the conventional one, and finally a conclusion of this study has been presented.

II. CURRENT CONTROL

Figure 1 shows the supply stroke of the machine phase divided into four intervales [2]:

-the first interval extends from the angle θ_{on} to θ_{im}. At θ_{on}, the voltage generator is fully applied across the phase to establish a current into it.

-the second interval extends from the angle θ_{im} to the angle θ_{off}, which correponds the period of the increasing inductance. During this interval, the current is regulated at the demanded level (i_m) by chopping the voltage generator.

-the third interval extends from the angle θ_{off} to the angle θ_e. At θ_{off}, the voltage generator is fully inverted across the phase to remove the current quickly; because of the phase inductance, the current does not extinguish immediately but it does so at θ_e. If θ_e lies in the region of the decreasing inductance, a negative instantaneous torque arises.

-the last interval extends from θ_e to the successive on angle. During this interval, the phase is open and no current flows into it.

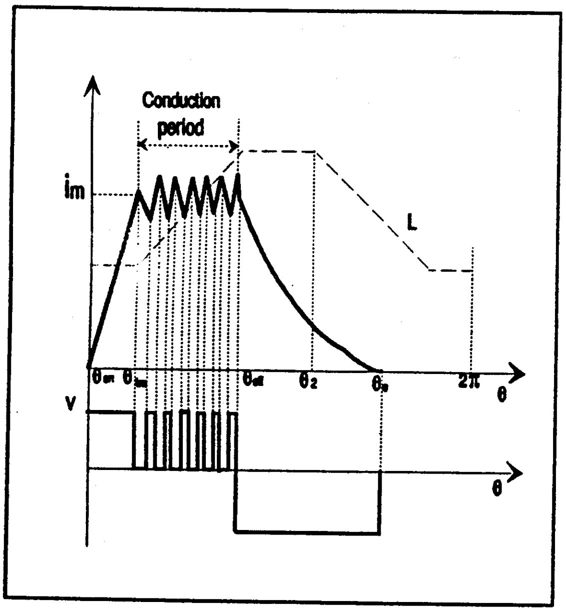

Figure1. Profiles of phase current, voltage and inductance of the variable reluctance machine current control.

In this work, the period of conduction has been controlled using the hysteresis [3], [5] current control technique PWM at a fixed frequency of 10kHz. The turn-on angle is calculated in terms of speed in ordre to regulate the current at different motor speeds, in particular at high speeds. Before introducing the new method of the machine back-emf compensation, the conventional method applied to the ideal trapezoidal inductance will be presented first.

II.1 Conventional method

In this method, the inductance is considered as an ideal trapezoidal waveforme, and the turn-on angle is regulated so that the current can rise to the desired reference level "i_m" before the rising inductance region begins (figure 1).

Starting from the voltage phase equation and neglecting the phase resistance, the turn-on angle θ_{on} is chosen for the current to reach the desired level i_m at $\theta = \theta_{im}$.

$$V_n = L\frac{di}{dt} + i\Omega\frac{dL}{d\theta} \tag{1}$$

In this method the current reaches at its maximum value in the position of unalignment, i.e., dl/dθ=0. Then the equation (1) will be:

$$V_n = L\omega\frac{\Delta i}{\Delta\theta} \tag{2}$$

supposing that $\Delta\theta$ is the interval for the current to rise from zero at θ_{on} and reaches the desired level (maximum value) at θ_{im}. then:

$$\Delta i = i_m \tag{3}$$

$$\Delta\theta = \theta_{im} - \theta_{on} \tag{4}$$

$$\theta_{on} = \theta_{im} - \frac{(L_{im}\ \omega\ i_n}{V} \tag{5}$$

where

ω	:motor speed (NR Ω),
NR	:number of rotor poles,
Vn	:rated phase voltage,
θ_{on}	:turn-on angle,
θ_{im}	:corresponding angle at the maximum value of the current,
L_{im}	:inductance corresponding to the maximum vde of the phase current. In this model, L_{im} equal to the minimum inductance of the machine (inductance of the unaligned position).

II.2 New method applied to the approximated model of inductance

As we said before, the motor back-emf is significant, often exceeding the dc voltage when the current is actually forced to decrease during the rising inductance region. The solution of the turn-on angle advancement by the conventional method has an important drawback; at high speeds the turn-on angle has to be advanced even to the point where the rotor is still in the falling inductance region of the previous pole overlap. In many cases this advancement reaches to 100°, which produces a negative instantaneous torque arises from θ_2 to θ_e which decreases the average torque of the variable reluctance machine. The proposed solution is to take the back-emf of the machine into consideration to avoid this negative instantaneous phase torque (figure 2).

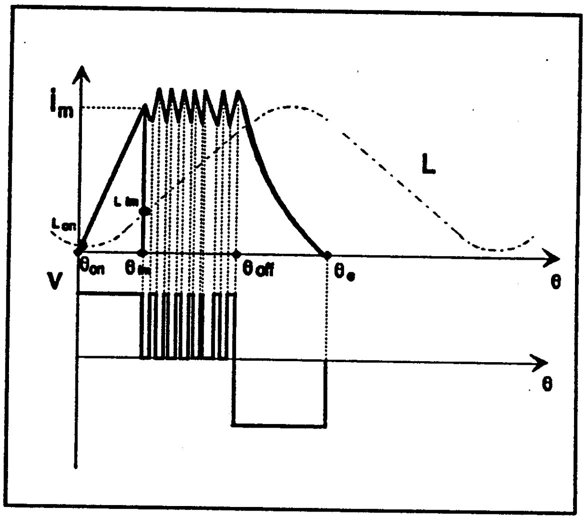

Figure2. Profiles of phase current, voltage and inductance of the variable reluctance machine current control using the new method of the back-emf compensation.

The values of inductances corresponding to θ_{on} and θ_{im} must be included in the computation of θ_{on}. Starting from the equation (1), the turn-on angle can be calculated in this methode, as follows:

$$V_n = L\Omega\frac{di}{d\theta} + i\Omega\frac{dL}{d\theta} \tag{6}$$

supposing that ΔL is the variation in the inductantance during the interval $\Delta\theta$, then:

$$V_n = L\Omega\frac{\Delta i}{\Delta\theta} + i\Omega\frac{\Delta L}{\Delta\theta} \tag{7}$$

$$\Delta L = L_{im} - L_{on} \tag{8}$$

from the equations (3), (4), (7), (8) the turn-on angle will be:

$$\theta_{on} = \theta_{im} - \frac{L_{im} - \omega i_m + \omega i_m (L_{im} - L_{on})}{V_n} \tag{9}$$

where

L_{im} :inductance value corresponding to θ_{im}.

L_{on} :inductance value corresponding to θ_{on}.

II.3 Control scheme

The complete system together with the current controller and the commutation control circuit has been simulated using the ATP (Alternative Transients Programs). It has been simulated in the two cases, the case of the conventional model and that of the new one so as to be able to show the advantages of the new model over the conventional one. Figure 3 shows the control scheme of the complete drive system of the switched reluctance motor using the new commutation control circuit.

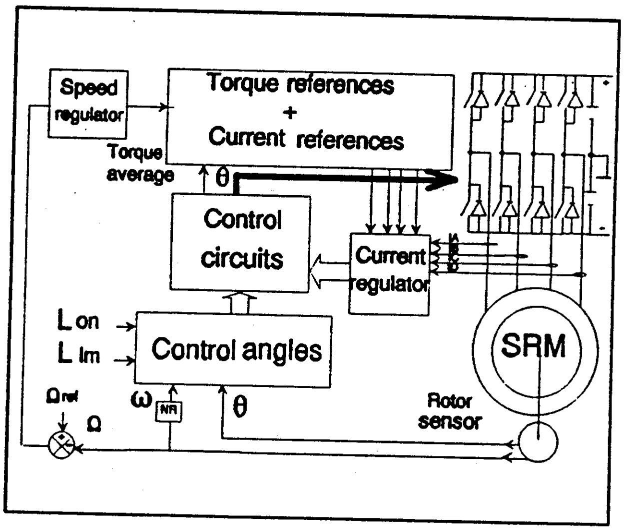

Figure 3. Control scheme of the switched reluctance motor drive system.

III. SIMULATION RESULTS

The system has been operated at the rated speed (1900 rev/min). Figure 4 shows the dynamic responses of the phase current in case of using the conventional method of the advancement of the turn on-angle, while figure 5 shows the same dynamic reponses in the case of the regulation based on our new model. Comparing the current regulation in the two dynamic reponses of current (figures 4 and 5) of the two methods, one can find that the new regulation allows accurate current tracking, and therefore reduced torque ripple over a wide range of operating speeds up to the rated one.

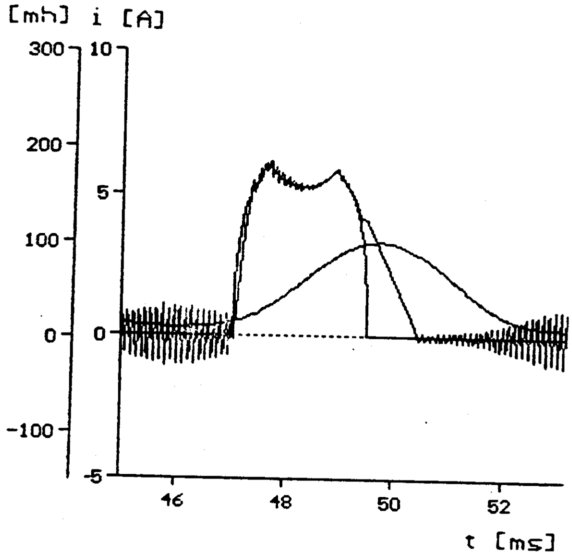

Figure 4. Dynamic response of motor current using the conventional method.

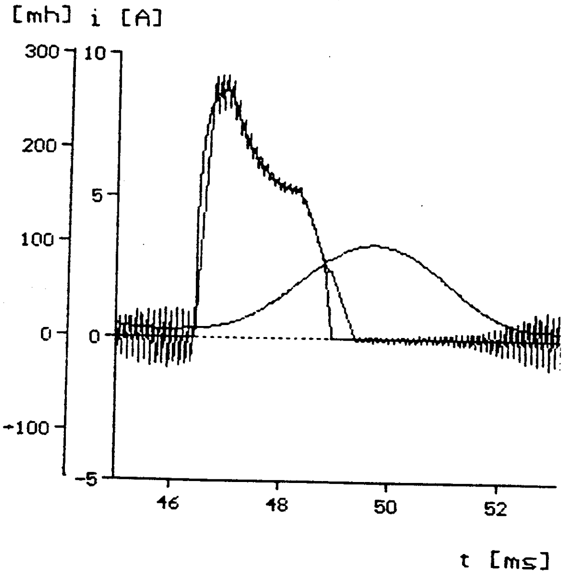

Figure 5. Dynamic response of motor current using the new method.

IV. CONCLUSION

As the real behaviour of the switched reluctance motor inductance is not an ideal trapezoid, the turn-on angle has been calculated using a variable inductance model approximated to the real behaviour, taking into consideration the back-emf. This improvement has been made to avoid the apparition of the negative torque which decreases the maximum average torque and increases its peak to peak fluctuations. The complete model has been used to simulate a switched reluctance motor drive using ATP.

V. REFERENCES

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