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A LOW COST BI-STATE REFERENCE CURRENT CONTROLLER FOR SWITCHED RELUCTANCE MOTOR

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ABSTRACT- The modern trend in motor drive application is to drive the motor with very good performance. But it leads to complex control. It also makes the system bulky and expensive. A simple current control technique is explained in this paper which can be realized very cheaply. Here the motor is considered as a digital system with two input states. Switching between these two states, the speed is maintained. This method has a wide speed range and is not at all sensitive to motor parameters. It is very reliable, simple, and low cost and does not require any look up tables.

Key words - Switched Reluctance Motor (SRM),Reference Current Control, Bi-state Hysteresis Control

I. INTRODUCTION

The switched reluctance motor has a very simple construction and is very reliable. The motor does not have any winding in the rotor making it robust in nature. There are no permanent magnets in the structure and can be used at high temperatures. Despite of these, the design and implementation of the controller for the switched reluctance motor continued to be a challenge for the engineers. This is due to the non-linear nature of the motor. The nonlinearity in the motor causes a lot of control issues during the motor operation from zero to rated speed. The conventional methodologies used for the control of switched reluctance motor are angle control, pulse width modulation control, chopped current control, PI or other linear controls. The studies were done on these methods to provide satisfactory performance of the drive. The turn-off angle plays an important role in the control of SRM since if the current is notturnoff in the negative slope of inductance profile, negative torque is produced. Fixed turn-off angle control method holds good only for low speed operations. For high speed operations, both the turnon and turn-off angles are regulated to control the output torque and speed of the rotor. In fixed PWM control, the duty ratio of the PWM is regulated keeping the turn-on and turn-off angles constant. Switching frequency remains constant throughout the operation. The variable angle PWM control method has a low peak value of phase current, high efficiency and fixed switching frequency

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value over the low speed range. Different methods have been presented to implement non-linear control techniques for SRM drives or linearize the SRM motor equations [6], [7]. To improve the real-time control performance, several digital signal processors (DSP) and Field Programmable Gate Array (FPGA) boards have been used for SRM drives. However, such digital processors increase the system cost. A simple current control technique is explained in this thesis, which can be realized very cheaply. Here the motor is considered as a digital system with two input states. High state represents high amplitude current and low state represents low amplitude current. Switching between these two states, the speed .is maintained. The paper is organized as follows. In sect.the mathematical model of switched reluctance motor is described. In sect. III, the fundamentals of hysteresis control for SRM drives is discussed. Sect. IV deals with the details of the bi-state control technique proposed in this paper. The simulation results and its analysis are given in sect.V.

II.SWITCHED RELUCTANCE MOTOR MODEL

The modeling is done based on the following assumptions: 1) The motor is will not go to saturation. 2) The inductance profile of the motor is linear. 3) Stator resistances of all windings are equal. 4) Iron Losses are negligible. The model consists of four phases in stator and three phases in rotor. The voltage equation of each phase of the switched reluctance motor is given by

$$v = iR + \frac{d\lambda}{dt} \quad (1)$$

where Vdc is the DC bus voltage, R is the phase resistance, i is the instantaneous current flowing through the phase winding and λ is the flux linkage per phase. Flux linkage λ can be expressed as the product of instantaneous current, i and the inductance per phase L

$$\lambda = i \times L \quad (2)$$

Now, the voltage equation becomes,

$$v = iR + \frac{d(i \times L)}{dt} \quad (3)$$

$$v = iR + L\frac{\partial i}{\partial t} + i\omega\frac{\partial L}{\partial \theta} \quad (4)$$

where ω is the speed of the rotor in radians per second. The last term of (6) can be replaced by eb,

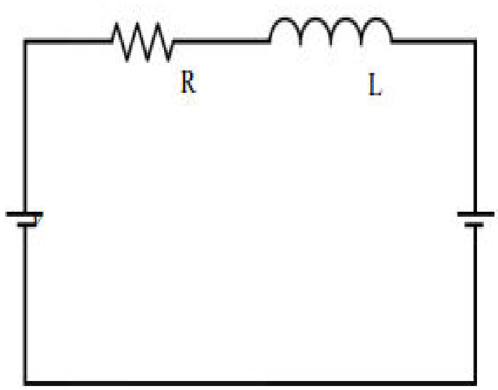

Fig. 1. The equivalent circuit per phase of SRM

The instantaneous electrical torque equation per phase of SRM is given by

$$T_e = \frac{dW}{d\theta} \quad (5)$$

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where W is the co-energy which can be expressed as

$$W = \frac{1}{2} i^2 L \qquad (6)$$

Substituting (6) in (5)

$$T_e = \frac{1}{2} i^2 \frac{dL}{d\theta} \qquad (7)$$

The instantaneous output torque of a four phase SRM is expressed as follows:

$$T_e = \sum_{i=1}^{4} \frac{1}{2} i^2 \frac{dL_i}{d\theta_i} \qquad (8)$$

Note that ∂L / ∂θ is the slope of the inductance at different rotor positions. θon and θoff are the turn-on and turn-off angles for each phase. The average torque is defined as:

$$T_e = \frac{2\omega}{\pi} \int_{t_{on}}^{t_{off}} \sum_{i=1}^{4} \frac{1}{2} i^2 \frac{\partial L_i}{\partial \theta_i} dt \qquad (9)$$

The torque equation of SRM is given by

$$T - T_L = J \frac{d\omega}{dt} + B\omega \qquad (10)$$

where TL is the load torque in Nm, J is the moment of inertia in kgm2 , and B is the friction coefficient in Nms.

III. FUNDAMENTALS OF HYSTERESIS CONTROL From (9), it is clear that the torque of the SRM depends on turn-on, turn-off and the square of the instantaneous current. Also, for running the motor in positive torque region, the current should be turned on only during the positive slope of inductance profile. When current is applied in negative slope of inductance profile, negative torque will be produced. In all other cases, torque produced is zero. The conduction period of a single phase should not exceed π since the current may become continuous in each phase and will cause the same effect as mentioned above. Also, to keep a constant torque during the on period of a phase, we should maintain the current at a constant value. The switches connected to that phase must be properly turned on and off, so that the current is maintained at pre-defined value. This process is known as Hysteresis control. Fig. 2 shows the SRM phase current under regular hysteresis control. θon and θoff are the turn-on and turn-off angles for each phase

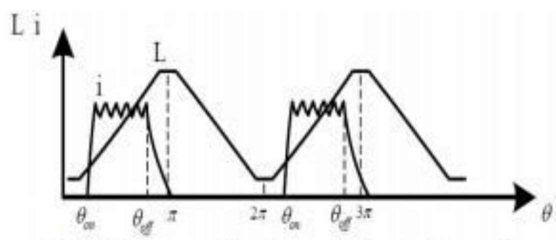

Fig. 2. Phase current for the regular hysteresis control.

IV. BI-STATE HYSTERESIS CONTROL FOR SRM Fig. 3 is the block diagram of the proposed bi-state control system for a 4-phase 8/6 SRM. The controller follows a simple logic: 1) If motor speed is less than the reference speed, input of the hysteresis controller is set to the high state which increases the speed. 2) If motor speed is greater than the reference speed, input of the hysteresis controller is set to the low state which decreases the speed. The logic of bi-state hysteresis controller is explained below. The speed of the motor is checked before each phase is excited. If the actual speed of the motor is less than the reference speed, the bi-state hysteresis controller will switch to high state. ie, the reference current is set at a high magnitude. So the hysteresis controller takes this high

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magnitude current as reference current and maintains the motor current at that value. And if the actual speed of the motor is greater than the reference speed, the bi-state hysteresis controller will switch to low state. ie, the reference current is set at a low magnitude. So the hysteresis controller takes this high magnitude current as reference current and maintains the motor current at that value. The bi-state hysteresis controller switches between these two states appropriately so that the speed is maintained constant at the reference speed.

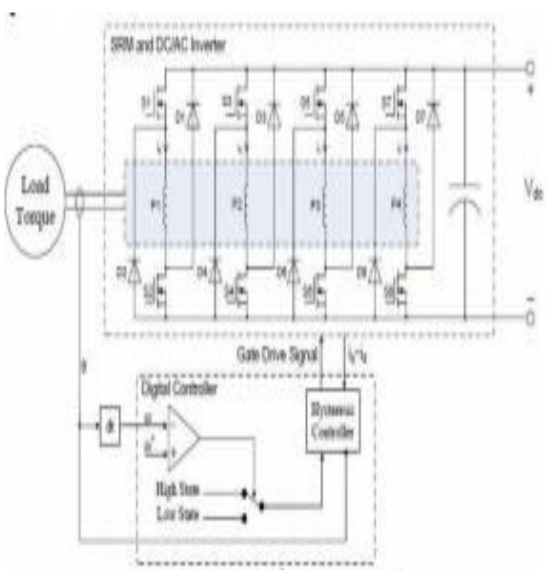

Fig. 3. Block diagram for reference current control

Reference current control In the reference current control mode, the conduction angle of the current pulse is kept constant. The turnon and turn-off angles are fixed at particular values of the positive slope of inductance profile. High and low states indicate two different reference currents here. At steady state, the torque equation (10) becomes:

$$T - T_L = B\omega_{ss} \quad (11)$$

where ω_{ss} is the steady state speed.

Now, load torque,

$$T_L = B\omega^* + T \quad (12)$$

If only one phase is conducting at a time, (8) could be written as

$$T = \frac{1}{2} i^2 \frac{dL}{d\theta} \quad (13)$$

The reference currents to the motor are determined from the minimum and maximum load torque that will be applied on the motor. Let the minimum load torque applied be Tmin and maximum load torque applied be Tmax. The equations for Tmax and Tmin at constant reference speed ω* can be given as

$$T_{min} = B\omega^* + \frac{1}{2} L I_L^2 \quad (14)$$

$$T_{max} = B\omega^* + \frac{1}{2} L I_H^2 \quad (15)$$

Deducting the torque equations (14) and (15), the low state reference current and high state reference currents can be obtained.

$$I_L < \sqrt{\frac{2}{\partial L / \partial \theta}(T_{min} + B\omega^*)} \quad (16)$$

By choosing the proper reference current and switching between them, the speed of the motor could be regulated at a certain value. Idealized bi-state reference current control waveforms are shown in Fig. 4.

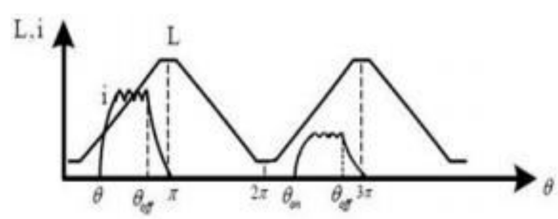

Fig. 4. Phase current for the reference current control.

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V. SIMULATION AND RESULTS

A 4-phase 8/6 SRM is simulated in MATLAB/Simulink. The simulation result of the bistate reference current control scheme is shown in the Fig. 5. High state reference current is set at 7 A and low state reference current is set at 3 A. Conduction angle is set 105°-150° for both of them. Speed sampling frequency is 1 kHz. The reference position of the conduction angle is the rotor position when it isfully aligned with the stator poles. It shows that the proposed reference current control technique could maintain the motor speed at the reference value.

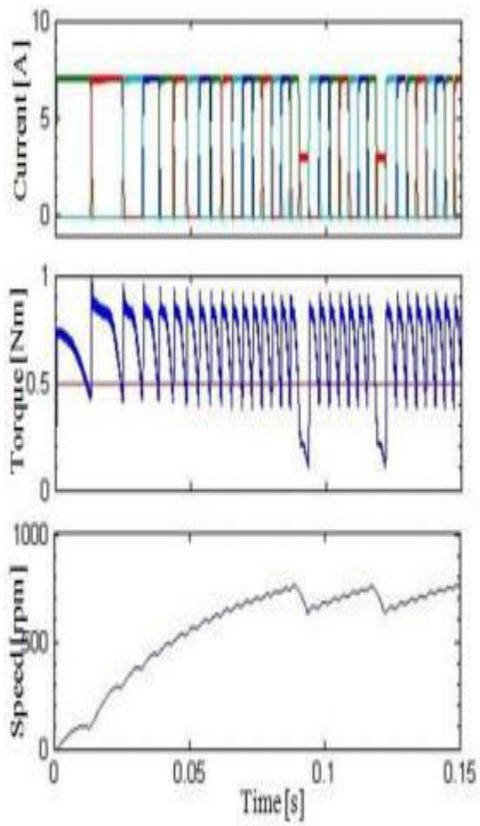

Fig. 5. Simulation results with high state and low state reference currents 7A and 3A. Conduction period is 105°-150°. Load torque is 0.5 Nm. Command speed is 750 rpm.

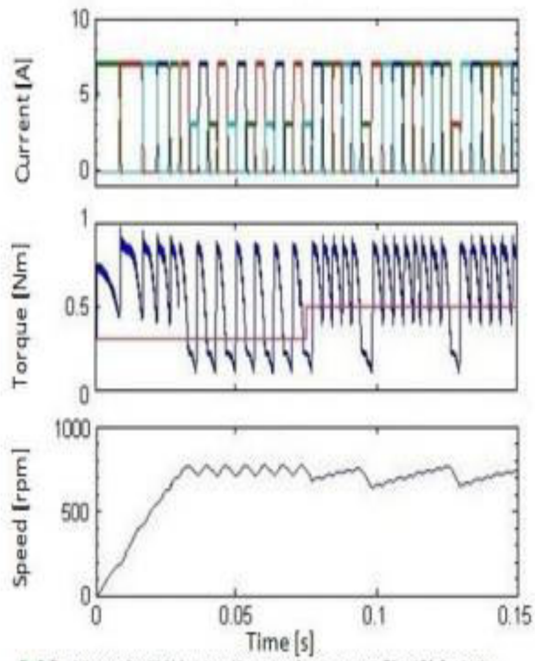

Fig.5. Simulation results with high state and low state reference currents 7A and 3A. Conduction period is 105°-150°. Load torque is changed from 0.3Nm to 0.5 Nm at 0.075s. Command speed is 750 rpm.

CONCLUSION

Speed control of switched reluctance motor using the reference current control is simulated in MATLAB/SIMULINK environment. The method proposed in this work is simple, reliable and easy to implement. It avoids the use complex controller circuit. The low and high speed performance of the drive is found to be good. But in the very high speed range, ripples are present in the speed response. This is due to the improper commutation of switches at that speed. The closed loop control is simulated and the commutation logic is found to be practically feasible. It can be possible to implement this method in various low cost house hold and industrial applications.

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