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Control of Switched Reluctance Motor Using Dynamic Braking

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--ABSTRACT--
In this paper, switched reluctance motor employing two phase excitation is implemented. Switched reluctance motors are much suitable for high speed applications, whereas while running at high speeds braking may become difficult, because the regeneration energy may increase the voltage of a dc-link to a certain level if a diode rectifier bridge is used for ac–dc conversion. The relationship between the regeneration energy and the dc-link voltage and proposes an electric braking scheme employing two-phase excitations.

INDEX TERMS: *dc link voltage, dynamic braking, switched reluctance motor*

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I. INTRODUCTION

Switched reluctance motor (SRM) drives use a cascaded ac-to-dc and dc-to-dc converter topology for power conversions. For low cost variable speed SRM drive applications, for example, in home appliances, a diode rectifier to supply ac power from the utility to the dc link is the most cost-effective solution. However, this prohibits dc-link energy from returning to the utility. Motor braking energy may be dissipated with a chopper-controlled braking resistor across the dc link or an electromechanical brake or as heat in the motor windings [1], [2]. Most of them assumed an actively controlled ac-to-dc converter or large energy storage in the dc link, dealing with the control strategy of restoring braking energy back to the dc link. Since torque is related to the phase current, turn-on angle, and turnoff angle, these parameters are investigated to improve the braking operation. The performance of switched reluctance motor depends upon the control applied. Figure 1 shows the parts of a switched reluctance drive. Three main parts are classified as: the motor, which can have various topologies the power electronic converter and the controller [3]. The drive system, comprising signal processing, motor and power converter must be designed as a whole for a particular application. The dc supply is given to the converter and also Switched Reluctance Motor is coupled with a converter. The rotor position and the phase current are sensed and fed back to the controller.

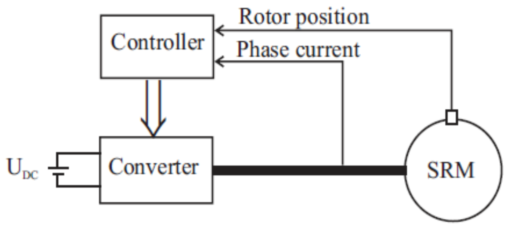

Figure 1 Simple Block Diagram of Switched Reluctance Motor

II. OPERATING FUNDAMENTALS

While considering switched reluctance motors, the number of stator poles is higher than the number of rotor poles, which prevents the poles from all aligning a position which cannot generate torque and also reduces torque ripple. The stator of switched reluctance motor is made up of silicon steel stampings with inward projected poles. The number of poles of the stator can be either in an even number or an odd number. Most of the motors have even number of stator poles. All the poles carry field coils or stator windings. The field coils of opposite poles are connected in series such that mmfs are additive and they are called"phase windings". Phase windings are connected to the terminals of the motor [4]. The rotor is also made up of silicon steel stampings with outward projected poles.

The rotor position sensor is adapted on rotor shaft. From rotor position sensor signal the turning on and off operation of the various devices of power semiconductor switching can be performed. Numbers of poles of the rotor are different from the number of stator poles. The direction of rotor torque will reduce reluctance, when a stator pole is energized. Thus the rotor pole is in alignment which is pulled from the unaligned position with the stator field (a position of less reluctance). In order to strengthen the rotation, in advance to the rotor poles the stator field must be rotated, thus constantly "pulling" the rotor. Some motor variants will run on 3-phase AC power. Electronic commutation gives significant control advantages for smooth operation motor starting and speed control (low torque ripple) because switched reluctance type are the most modern design[9].By using torque control techniques, in a motor design through magnetic circuit torque ripple minimization can be done. Compared to rotating field machines, switched reluctance machine torque control is not based on model reference control theory, such as field oriented control, but it can be obtained by setting control variables with reference to the calculated functions [8]. Low torque ripple, noise reduction and increase in the efficiency can be achieved by controlling the torque of the motor.

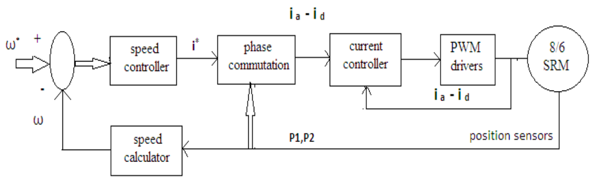

Figure 2 Block diagram of switched reluctance motor

The phase inductance varies with θ due to the doubly salient pole structures. Positive torque is generated when current is applied in the ascending-inductance region. Conversely, negative torque is produced when current is applied in the Descending - inductance region [5].Figure 2 shows a control block diagram of the SRM. The outer loop is a motor speed controller. It reads rotor angular position sensors and calculates motor speed for feedback control. The speed controller output is treated as the phase current command *i*. If the current command is positive, the ascending-inductance region of the active phase is energized to produce a positive torque [7]. Otherwise, the descending-inductance region of the active phase is energized to produce a negative torque. Each phase is energized for 15 mechanical degrees. Phase commutation is initiated by rotor angle position sensors. Two photo interrupter sensors are used for commutation angle sensing. Commutation signals are aligned with the unaligned position of the incoming active phase. At the unaligned position, the inductance of the incoming phase is at its minimum value. After the commutation signal is detected, a timer is enabled to delay for a predetermined time that is inversely proportional to the motor speed. The incoming phase switches are then turned on to establish the requested current.

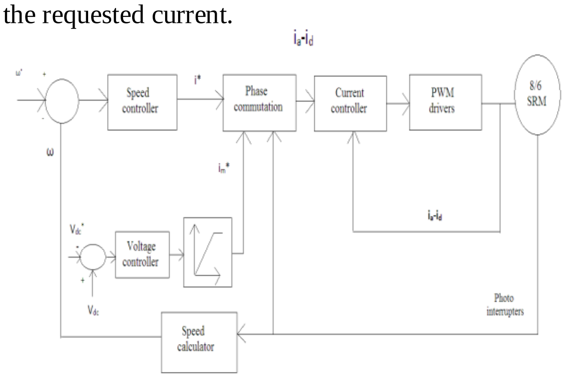

Figure 3 control Block Diagram

Figure 3 shows a control block diagram of the SRM. The outer loop is a motor speed controller. It reads rotor angular position sensors and calculates motor speed for feedback control. The speed controller output is treated as the phase current command *I**. If the current command is positive, the ascending-inductance region of the active phase is energized to produce a positive torque. Otherwise, the descending-inductance region of the active phase is energized to produce a negative torque. Each phase is energized for 15 mechanical degrees. Phase commutation is initiated by rotor angle position sensors. Two photo interrupter sensors are used for commutation angle sensing. Commutation signals are aligned with the unaligned position of the incoming active phase [10]. At the unaligned position, the inductance of the incoming phase is at its minimum value. After the commutation signal is detected, a timer is enabled to delay for a predetermined time that is inversely proportional to the motor speed. The incoming phase switches are then turned on to establish the requested current. Both the upper and lower switches are turned on/off simultaneously for current regulation.

The motor phase voltage can be expressed as

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

III. STATIC TORQUE PRODUCTION

Consider the primitive reluctance motor, when current is passed through the phase winding the rotor tends to align with the stator poles that is, it produces a torque that inclines the rotor to a minimum-reluctance position[11].

The most general expression for the instantaneous torque is

$$T = [\partial W' / \partial \theta]_{i=constant} \qquad (2)$$

Where *W'* is the co energy defined as

$$W' = \int_0^i i \, d\psi \qquad (3)$$

An equivalent expression is

$$T = -[\partial w_f / \partial \theta]_{\Psi=constant} \qquad (4)$$

Where W_f is the stored field energy defined as

$$W_f = -\int_0^\psi i \, d\psi \qquad (5)$$

If magnetic saturation is negligible, then the relationship between flux-linkage and current at the instantaneous rotor position 6 is a straight line whose slope is the instantaneous inductance *L*.

$$\psi = Li \qquad (6)$$

and

$$W' = W_f = \frac{1}{2} L i^2 J \qquad (7)$$

therefore

$$T_e = \frac{1}{2} i^2 dL / d\theta \qquad (8)$$

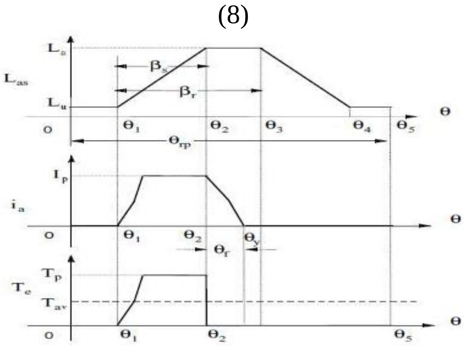

Figure 4 Effect of rotor pole arc greater than the stator pole arc on torque generation

The variation of current and torque in switched reluctance motor is shown in the figure 4. The changes in waveform are calculated using θ values. The rise and fall in the waveform denotes the stator and rotor characteristics. The switched reluctance motor flux changes are denoted in the waveform [12].

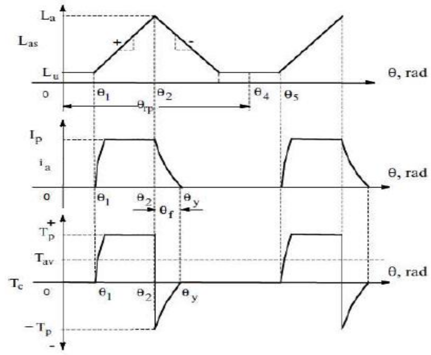

Figure 5 Effect of equal stator and rotor pole arcs on torque generation.

Figure 5 shows the stator and rotor torque generation. It shows the changes with flux values.

Core Losses

Core losses can be modeled as

$$P_n = [c_h f B_m{}^{\alpha} + c_e f^2 B^2{}_m] \quad (9)$$

f is the excitation frequency,
c_h and c_e are the coefficients for hysteresis and eddy current losses,
B_m is the flux density,
And α is a constant for the hysteresis loss

Conduction Losses

Because only one inverter leg is excited at any instant, the conduction losses of the power switches can be shown to be

$$P_{sw} = 2(\frac{1}{2} i \frac{t_{on}}{T_s} + \frac{1}{2} i \frac{t_{off}}{T_s} + \frac{i * t_{rr} + Q_{rr}}{T_s}) V_{dc} \quad (10)$$

Where t_{on} and t_{off} are the turn-on and the turnoff time,
Trr and Q_{rr} are the reverse recovery time and charge to be removed for the anti parallel diode.

DC-Link Voltage

Let the net power returning to the dc link be *p*dc. Then, from the power balance

$$p_{dc} = p_m - p_{loss} = p_m - (p_c + p_n + p_{con} + p_{sw}) \quad (11)$$

Where ploss = p_c+ p_n + p_{con} + p_{sw}.

If the dc link is modeled as a pure capacitor *C*, then

$$p_{dc} = V_{dc} * C \frac{dV_{dc}}{dt} \quad (12)$$

IV. SIMULTION STUDIES

MATLAB is a termed as a high performance language for technical computing purposes. It supports automatic code generation, system level design, simulation and also integrates computation, visualization, programming, verification of embedded systems and continuous test where problems and the corresponding solution can be expressed in simple mathematical notation. MATLAB is the tool of choice for analysis and development high-productivity research. By using these type of high productivity tools in our application it is very easy to identify the errors and troubleshoot effectively. Math works offers technologies and tools for model based design which includes design complex, signal processing, communications, video processing, multi domain and cyber physical system applications.

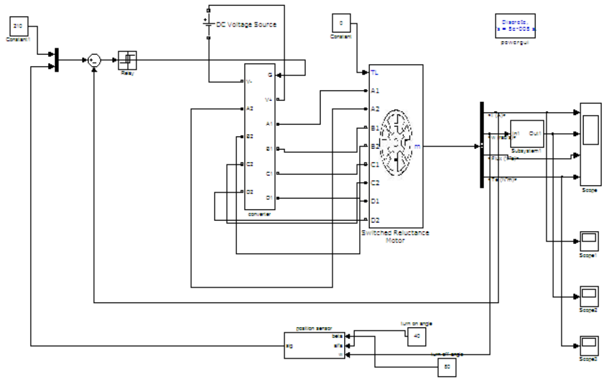

Figure 6 Simulink block of converter and position sensor the actual speed is compared with the constant and an error is sensed the converter and then corresponding gate signal is given to the converter. The various phases are excited and also the rotor is aligned to the corresponding commutation degrees.

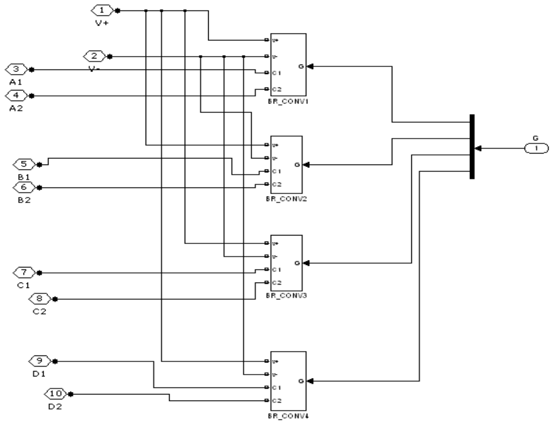

Figure 7 Simulink block of converter

The simulation block of the converter is shown in the figure 7 corresponding each phase excitation is shown and also rotor is aligned to the corresponding phase excitation.

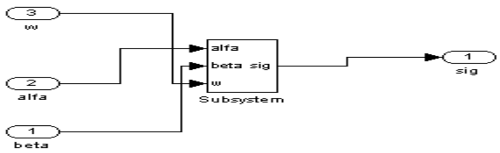

Figure 8 Simulink block of position sensor

Figure 8 shows the position sensor block of an switched reluctance motor.The corresponding turn on and turn off angle, position sensing are given as input. The reference speed is compared with actual speed and error signal is generated then required gate pulse is given to the converter.

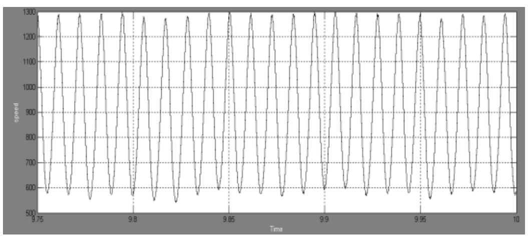

Figure 9 Output waveform of speed

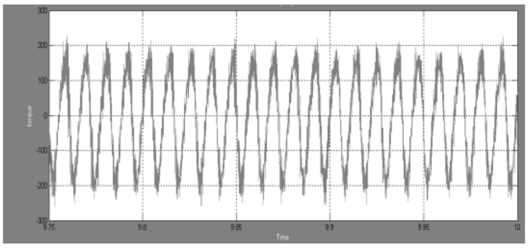

Figure 10 Output waveform of torque

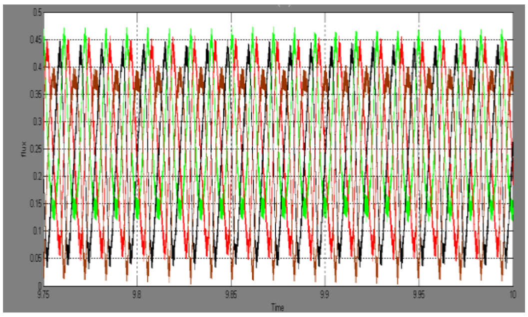

Figure 11 Output waveform of flux

V. CONCLUSION

An electric braking scheme for an SRM using multiple- phase excitations is shown. In addition to the active phase, a second phase prior to the active phase is also excited to dissipate excessive rotor kinetic energy so that the dc link voltage is restricted to a safe range. The second-phase current can be controlled with open-loop or closed-loop control schemes. The open-loop scheme requires the pre calculation of the magnitude and time duration of the second-phase current as a function of the deceleration rate, but no additional hardware is needed. The closed-loop scheme requires a dc-link voltage sensor. However, open loop control is shown to have better responses when a higher deceleration rate is requested. The proposed scheme can be used in low-cost variable-speed drives where rectifiers are used to convert ac to dc power source. Four phase excitation can be implemented.

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