MODELING LINEAR 6/4 SWITCHED RELUCTANCE MOTOR USING MATLAB SIMULINK

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"I hereby verify that this paper work is done on my own except for the references I made which I stated the source clearly on the specified section"

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For my beloved father and mother.

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Syukur Alhamdulillah, thank God because I complete my PSM project and finish my report before my due date.

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Abstract

This paper describes details on Matlab Simulink environment on modeling 6/4 Switched Reluctance Motor concentrating on linear model by obeying all of its characteristics and requirements that being discussed in detail. All simulations are completely documented through this paper including its block model according to equation derive from theory and the result are compare between simulation and theoretical result.

Abstrak

Projek ini menjelaskan secara terperinci tentang Matlab Simulink untuk memodelkan 6/4 Switched Reluctance Motor memfokuskan model linear dengan mematuhi cirri-ciri dan spesifikasinya. Kesemua simulasi didokumentasikan dengan lengkapnya dalam tesis ini termasuklah model blok berdasarkan terbitan persamaan dalam teori dan ianya dibandingkan antara simulasi dan teori.

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CHAPTER 1

INTRODUCTION

Switched Reluctance Motor (SRM) has been well known in electrical machines application through out the world. History recorded SRM was built and used to propel a locomotive on the Glasgow-Edinburgh railway near Falkirk by Davidson in Scotland in 1838 [1]. The stepper motor that includes some of the features of the modern switched reluctance motor was invented and patented in the 1920's by C.L. Walker. In 1969, S.A. Nasar introduced the basic concepts of the modern day SRM [2]. During 1971 and 1972, Bedford and Hoft patents many of the essential features of the modern SRM along its electronic commutation synchronized with the rotor position, rotor geometry as the circuit topology of the power electronic controller [3].

In Europe, Byrne and Lawrenson realized the commercial use of the SRM and since then there have been massive development in both control and design of SRM because of the rapid exploitation and technical development in early 80's[4].

In the United States, the first application used that history recorded was the Hewlett-Packard servo drive used in the Draftmaster computer plotter. The Hewlett

Packard motors are controlled by a special integrated circuit, HCTL1100 which incorporates many advanced features[5].

Now days, SRM is widely used because it offers good performance at very low cost in many applications and it is easily operated in the field weakening region to allow further reductions in the cost of the electronics.

CHAPTER 2

LITERATURE REVIEW

2.1 Definitions

A 6/4 Switched Reluctance Motor is a 3 phase electric motor which contains 6 stator and 4 rotor and each phase comprises two coils wound on opposites poles and connected so that their fluxes are additive where so that its torque is produced by tendency of its rotor to move to a position which the inductance exist because of the excited winding is maximized.

2.2 Energy conversion principles of the Switched Reluctance Motor

The energy conversion principles of the switched reluctance motor are view in aspects of its magnetization curves which include the analysis of the 3 most important positions analyzed in SRM which are aligned position, unaligned position and intermediate rotor position. Instantaneous torque and average torque are also other aspects analyzed in this sub topic.

2.2.1.1 Aligned position

The aligned position as shown in Fig 2.0(a), shows that when a pair of rotor exactly in line with a pair of stator. During this position, there is no torque occur because rotor is at the position of maximum inductance. Maximum inductance phenomena happen because of the magnetic reluctance of the flux path is at its lowest when the current flow. However when the rotor moves in either direction, it will produce a restoring torque that tries to maintain the position to achieve maximum inductance.

Figure 2.0(a) : Aligned position

2.2.1.2 Unaligned position

The unaligned position as shown in Fig 2.0(b), the rotor poles are not in line with the stator poles and minimum phase inductance exist because of magnetic reluctance of the flux path is at its highest. There is no torque occur during this position unless the rotor is moved in either direction, attracting it to the second phase being excited.

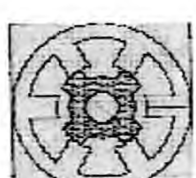

Figure 2.0(b): Unaligned position

2.2.1.3 Intermediate rotor position

The intermediate rotor position as shown in Fig. 2.0(c), the position of rotor poles is between the position of aligned and unaligned. Fig. 2.1 shows the magnetization curve of all three positions where unaligned magnetization curve is not as susceptible to saturation as is the aligned curve and magnetization curve for intermediate position is between aligned and unaligned curve.

Figure 2.0(c): Intermediate rotor position

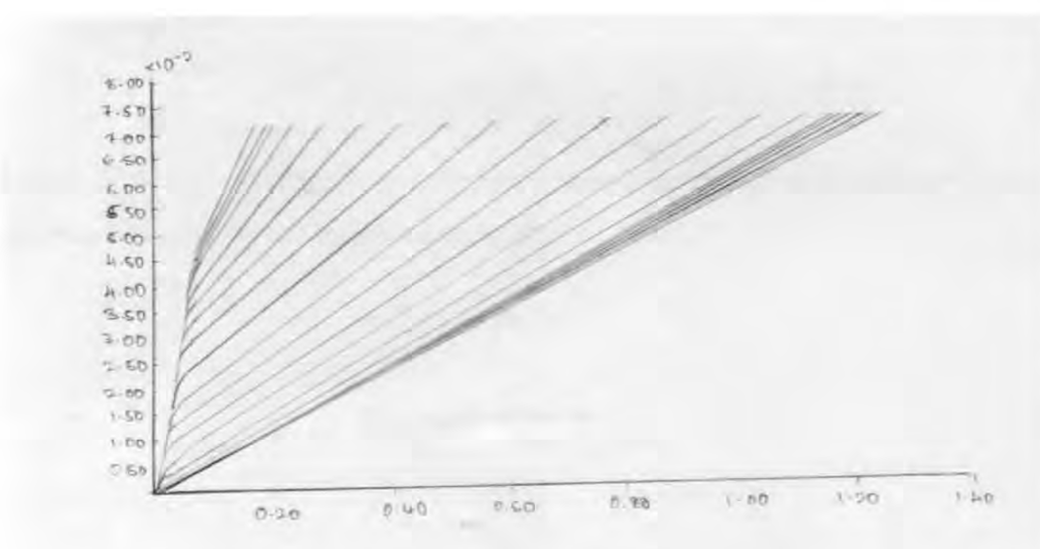

Figure 2.1: Magnetization curve

Between the unaligned position and the start of overlap, the magnetization curve do not change very rapidly. When it start to overlap, the curve begin to increase and in the last few degrees before alignment, there is another changes happen to the curves.

2.2.2 Instantaneous torque

When current flows in a phase, torque that exists tends to move the rotor in a direction as to increase the inductance so it will reach the maximum inductance position. The torque direction is always towards the nearest maximum inductance position. When the rotor position is between the aligned and the next aligned position in forward direction or in other words in the direction of rising inductance, positive torque (motoring torque) can be produced. Negative torque or generating torque is produced when the current flow at position where the rotor is in inductance decreasing direction.

General expression for the torque produced by one phase at any rotor position is

$$T = \left[\frac{\partial W'}{\partial \theta} \right]_{i=const.} \qquad (2.1)$$

where W' is the coenergy that is the area below magnetization curve shown in Fig. 2.2 and can be derive by the formula below;

$$W' = \int_0^{i_1} \psi di \qquad (2.2)$$

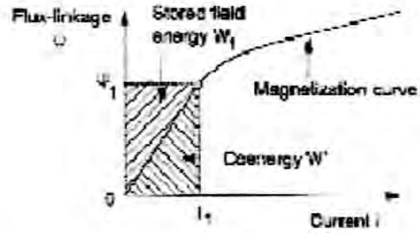

Figure 2.2 : Definition of coenergy W' and stored filed energy W_f

Referring to Fig. 2.2, instantaneous torque can be visualized by the work ΔW_m divided by $\Delta\theta$ which is ΔW_m evolving during at constant current as rotor moving through an infinitesimal displacement $\Delta\theta$. There is an exchange of energy with the supply and stored field energy during the displacement as illustrated in Figure 2.3.

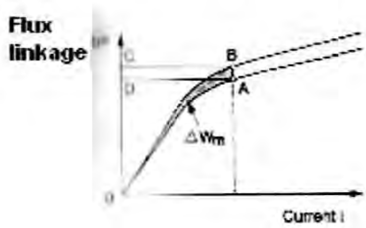

Figure 2.3 : Instantaneous torque from the rate of change of coenergy at constant current.

During the displacement, the constant current constraint ensures the mechanical work done is exactly equal to the change in coenergy and as prove as calculation and explanation below;-

In a displacement $\Delta\theta$ from A to B at constant current referring to Figure 2.3, the energy exchanged with the supply is

$$\Delta W_e = ABCD \quad (2.3)$$

The change in store field energy is

$$\Delta W_f = OBC - OAD \quad (2.4)$$

The mechanical work done

$$\begin{aligned}\Delta W_m &= T\Delta\theta \\ &= \Delta W_e - \Delta W_f \\ &= ABCD - (OBC - OAD) \\ &= (ABCD + OAD) - OBC \\ &= OAB\end{aligned}$$

Some of the energy obtained from the supply is converted to mechanical work and some of it is stored in the magnetic field. The energy stored in magnetic field is not available during the motion from A to B.

For ideally saturable magnetization curve and infinite unsaturated aligned inductance, changes that happen in stored field energy would be negligible as the rotor moves. All of the energy obtained form the supply would be converted into mechanical work instantaneously. The ideal curves is as shown in Figure 2.4 could only happen if the current is constant, flux linkage of a phase winding has a triangular or trapezoidal waveform in a machine as the rotor rotates as constant speed will allow a square wave induced EMF to rise.

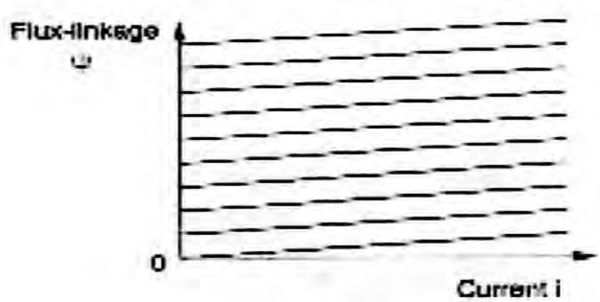

Figure 2.4 : Ideally-saturable magnetization curve

In the actual switched reluctance motor, the magnetization curves are nowhere near ideal and the aligned inductance is not infinite. In a motor without magnetic saturation, the magnetization curves would be straight lines and at any position the coenergy and the stored magnetic energy are equal and given by

$$W_f = W' = \frac{1}{2} L i^2 \qquad (2.5)$$

In real switched reluctance motor, the instantaneous torque reduces to

$$T = \frac{1}{2} i^2 \frac{dL}{d\theta} \qquad (2.6)$$

During overlap, $\frac{dL}{d\theta}$ = constant and therefore the torque is constant if the current is held constant during overlap as refer to Figure 2.5.

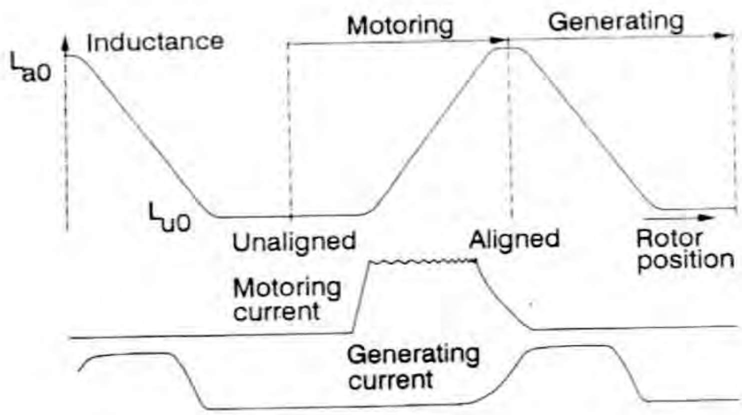

Figure 2.5 : Inductance vs. rotor position in non saturable motor

2.2.3 Average Torque

Average torque can be derived by integrating equation 1 but it is more illuminating by deriving it from areas on the energy conversion diagram which is done in three stages as shown in Figure 2.6

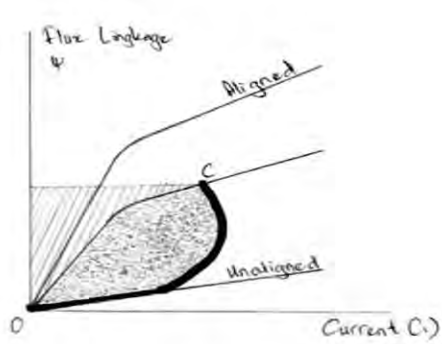

Figure 2.6 (a) : Transistor Conduction Period

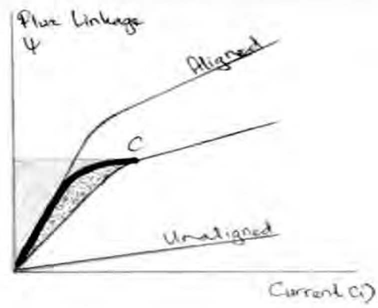

Figure 2.6 (b) : Diode Conduction Period

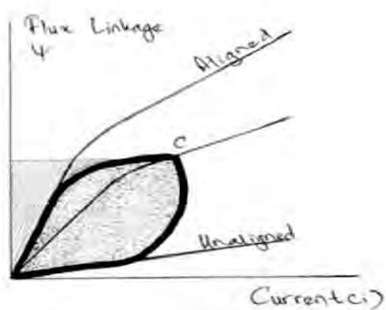

Figure 2.6 (c) : Entire Loop

Imagine that the motor is rotating at essentially constant speed and voltage is applied to phase 1 at or near the unaligned position θ_u and the flux linkage ψ increases referring to equation

$$\psi = \int (V_s - Ri)dt = \frac{1}{\omega}\int (V_S - Ri)d\theta \qquad (2.7)$$

Figure 2.6(a) shows the magnetization curves for the aligned and unaligned position together with the commutation angle θ_C when the supply voltage V_S is constant and the phase resistance R is small resulting ψ increases linearly with rotor position. At first, inductance around the unaligned position remains low and nearly constant while current rises linearly. Inductance increases and a back e.m.f. builds up as