Soft-Modeling of Switched Reluctance Motor Using MATLAB/Simulink software

K.S Krikor, **M.Daood** **Qussay.S.Taufeeq**
University of Technology , Baghdad

Abstract

Analysis is the main step for the most engineers and researchers in study the behavior of over all system or each plant of the system separately; this must be made before any enhancing treatment. In other words, the validity of any model is verified by various simulation results, in order to specify which control strategies can be used. In this paper plant of three phases Switched Reluctance Motor (SRM) had been presented depending on direct blocks solution for the dynamic and mechanical load equations of (SRM) using ***Matlab / Simulink*** software blocks building. The output of (SRM) and mechanical load parameters (current, flux, torque and speed) had been observed to fulfill the main task of this paper.

***Index Terms* - Modeling, performance analysis, simulation, switched reluctance motor, turn -off angle.**

الخلاصة:

التحليل الخطوةُ الرئيسيةُ لأكثر المهندسين والباحثين لدِراسَة السلوكِ لأكثر الانظمة أَو كُلّ محططات النظامِ مُنفصلاً؛ هذه يجب أنْ تُعَملَ قبل أيّ تَحسين او معالجةِ. بكلمة أخرى، صلاحية أيّ نموذج تحَقَّقُ بنَتائِجِ المحاكاةِ المُخْتَلِفةِ، لكي تحدّدَ أَيّ ستراتيجيات لسيطرةِ يُمْكِنُ أَنْ تُستَعملَ. في هذه الورقةِ مِنْ ثلاث وجوه او مراحلِ نَقلتْ محرك نقل التردّدِ (SRM) قَدْ قُدّمتْ بالإعتِماد على حَلِّ الكُتَلِ المباشرِ لمعادلاتِ الحملِ الديناميةِ والميكانيكيةِ (SRM) بإستعمال Matlab / Simulink برامجَ لكتل البناء. ناتج بارامترات (SRM)و حملِ ميكانيكيةِ (تيار وجريان وعزم لّي وسرعة) كَانتْ قَدْ لوحظتْ لإنْجاز المهمّةِ الرئيسيةِ هذه الورقةِ.

I-Introduction

The Switched Reluctance Motor (SRM) is a doubly salient machine with independent phase winding on the stator and solid laminated rotor. The stator winding on diametrically opposite poles are connected in series to form one phase of the motor Figure(1) shows a three phase 6/4 switched reluctance motor [BPRAOS8 1997]. When the stator phase is energized the rotor is moving relative to the stator in order to minimize the reluctance of the magnetic path. So by energizing consecutive phases in succession it is possible to develop constant torque in either direction of rotation.

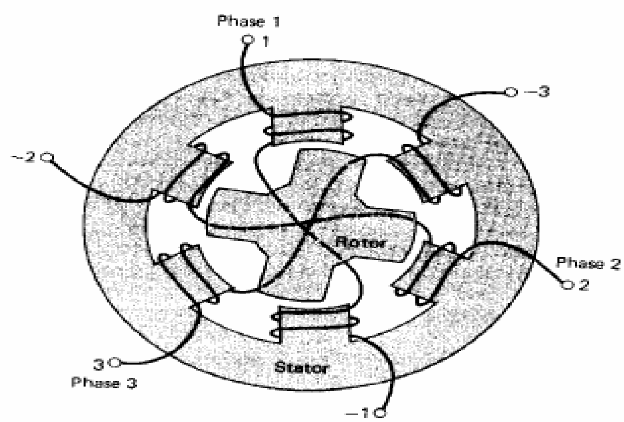


Figure (1) Stator and rotor configuration of three-phase 6/4 SRM

A well designed SR motor will minimize the core losses, offer a good starting capability and also minimize the unwanted effects due to varying flux distribution and saturation. The choice of the number of phases is open but increasing the number of phases would increase the number of power devices needed for power converter.
Moreover, higher number of poles will decrease the maximum inductance ratio obtainable for a good torque per ampere. The good practical design commonly limits the pole ratio to (6/4) in most application of motors. In this paper we apply direct blocks plant building depending on the previous feature and the structural for solving dynamic of SR motor structure.

II-Basic principle of operation

The phase voltage equation in switched reluctance motor can be written as:

$$V = R * i(t) + \frac{d\varphi(t)}{dt} \qquad \text{....... (1)}$$

Where V is the DC voltage, $i(t)$ is the instantaneous phase current, R is the phase resistance and $\varphi(t)$ is the flux linkage with the phase coil. Ignoring stator resistance, equation (1) can be rewritten as:

$$V = L(\theta)\frac{di}{dt} + i * \frac{dl(\theta)}{d\theta} * \omega \qquad \text{......(2)}$$

Where ω is the rotor velocity, θ is the rotor angular potion, $l(\theta)$ is the instantaneous phase inductance. The rate of flow of energy can be obtained by multiplying the voltage with current and can be written as:

$$V * i = i * L(\theta)\frac{di}{dt} + i^2 * \frac{dl(\theta)}{d\theta} * \omega \qquad \text{.....(3)}$$

or

$$P = \frac{d}{dt}(\frac{1}{2} l * i^2) + \frac{1}{2} * i^2 * \frac{dl}{d\theta} * \omega \qquad \text{.....(4)}$$

or

$$P = P_c + P_m \qquad \text{......(5)}$$

The first term of equation (5) (P_c) is the rate of increase in the stored magnetic field energy while the second term (P_m) is the mechanical output, which can be expressed as:

$$P_m = \frac{1}{2} i^2 * \frac{dl}{d\theta} * \omega = \omega * T(\theta, i) \qquad \text{.....(6)}$$

Then the instantaneous torque can be written as:

$$T(\theta, i) = \frac{P_m}{\omega} = \frac{1}{2} i^2 * \frac{dl}{d\theta} \qquad \text{.......(7)}$$

Figure (2) shows the idealized inductance profile of an SR motor [Mohammed 1998]. In order to obtain the motoring torque, phase current is switched on during the rising period of phase inductance. Generating operation or braking torque can be obtained by switching phase current during the decreasing period of phase inductance [BPRAOS8 1997].

It is obvious from figure (2) that in order to obtain optimum performance, switching must be done accurately for each phase. This is why the rotor position information is always estimated to operate the SR motor drive. Rotor position information is fed back to the controller to determine accurately the phase commutation sequence and instants.

III- Dynamic Model of SRM

In order to express the dynamic model of SRM, we apply Newton's law to the rotor and Kirchhoff's law to the stator, to yield the stator space model:

$$\frac{d\theta}{dt} = \omega \qquad \text{........(8)}$$

$$\frac{d\omega}{dt} = \frac{1}{J}(Te - Tl - B\omega) \qquad \text{.......(9)}$$

Where θ is the rotor position, ω is the rotor angular velocity, Te is the electromagnetic torque, Tl is the load torque, J is the rotor and load inertia and B is the damping factor [Erkan 2000].

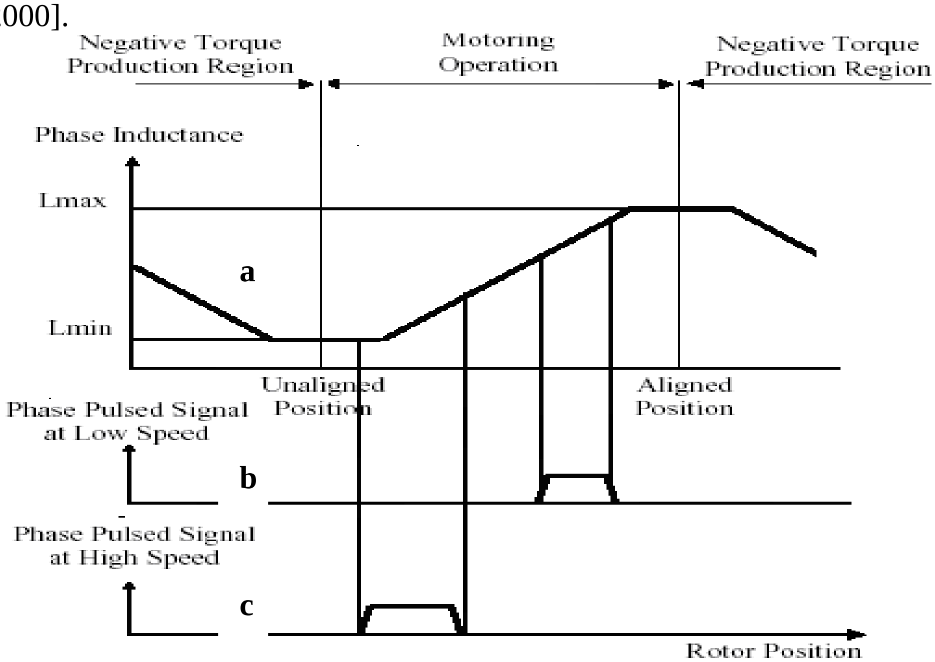


Figure (2) Inductance profile of SR motor, a-Variation of inductance with rotor position, b- Phase current at low speed, c- Phase current at high speed.

VI-Software blocks plant building

Depending on the main basic concepts and equations of the SRM operation aiding with dynamic effects of the load which are explained previously [Wilbert 2007]. The idea of the soft-modeling is consist of two main structures; (a) the first one is consist of mechanical equations representation which had been solved as shown following figure [BPRAOS8 1997].

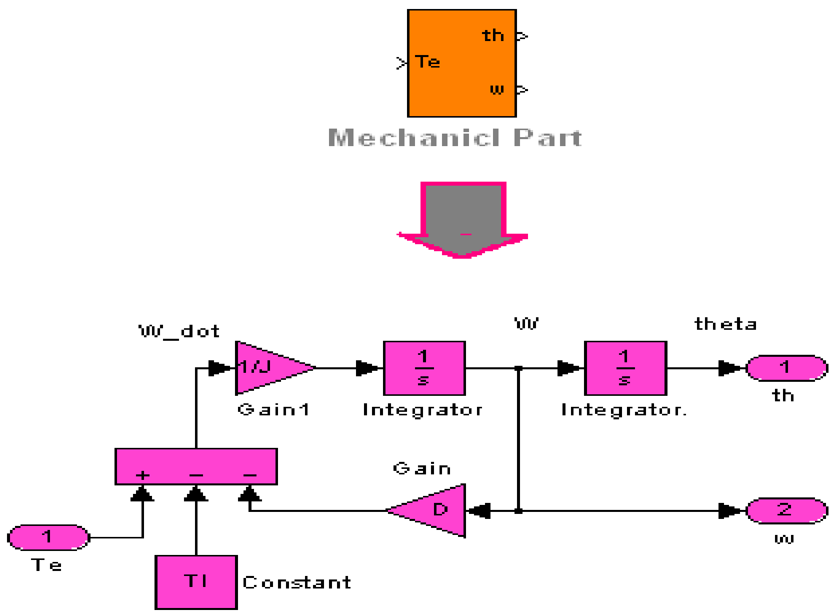


Figure (3) Structure containing the mechanical equation

The program depends mainly on the relation position behavior and taking up all electromechanical constrains. Furthermore, figure (3) represent the direct solving for mechanical equations (9) which are used for position sensing driving process. (b) The second one, consist of the relationships between the position parameter (θ), inductance (L) and inductance derivative (dL), these relations had been built as m-file subroutines program using S-function properties for each phase separately [Barambnes 2001];as shown in figure (4).

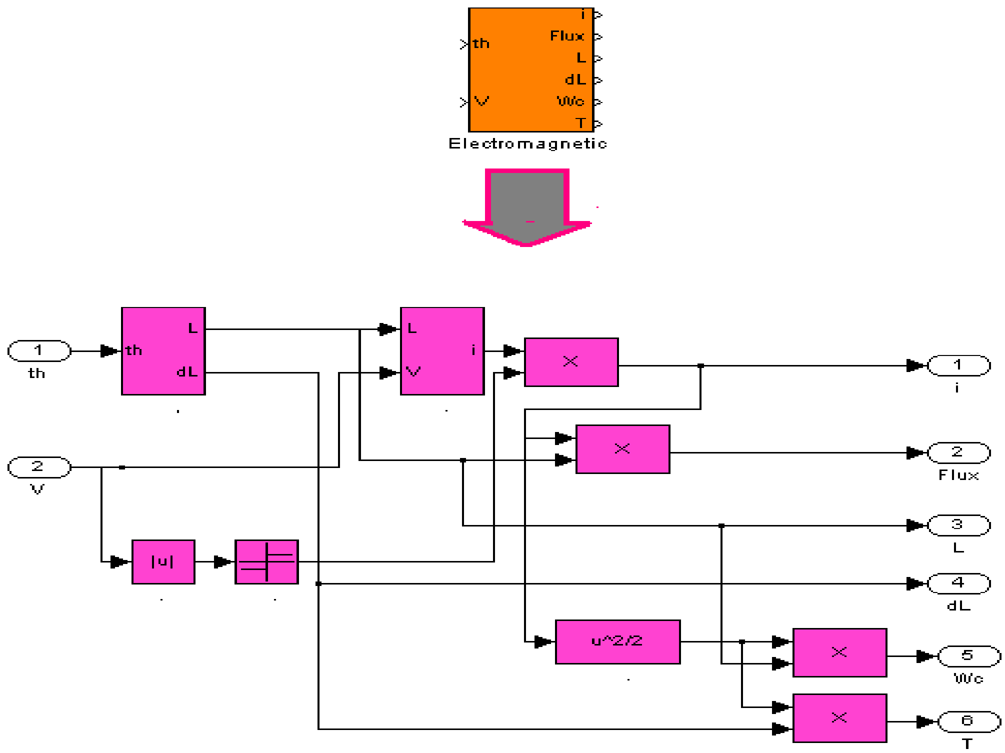


Figure (4) Structure to obtaining the motor parameters in one phase

Integration of subsystems and function for the major elements of each phase had been made in order to get the three-phase 6/4 plant as a final task of our procedure. This is shown as in figure (5); where, for each phase a condition of the rotor position of the motor had been derived, figure (6) shows the specified phase condition [Alexander 2007].

Integrated model 3-phase SRM shown in figure (5) which can be used as a 6/4 three phase SRM plant in any control system, which finally yield the major task of this paper.

In addition to the SRM plant building, some analysis had been taken up to show the validity of our representation, where a modulated three-phase voltage source had been used depending on the rotor position and currents. Using the simple controlled system shown in figure (7), the main time responses of the three-phase SRM such as (I,φ, L,dl,T,ω) can be obtained in the form shown in figures (8-13) respectively. The fact that each SRM uses the same lamination, and only the number of turns, wire thickness, and motor length are changed, makes the task of customizing the equations for each motor easier. If the number of turns in an SRM is doubled, then to maintain the same flux density (B) at a particular rotor position and operating point, the phase current is approximately doubled and the voltage is halved. If the SRM length is halved, then to maintain the same flux density at a particular rotor position and speed, the phase current is approximately the same, the torque is halved and the voltage is halved. Therefore, if we mathematically rescale the torque versus current curves for each SRM (shown in Figure 4) to fit the torque versus current curve of the prototype SRM, we can use the torque and current rescaling factors to re-scale the prototype equations (3), (4), and (5) for each SRM [Wu 2002].

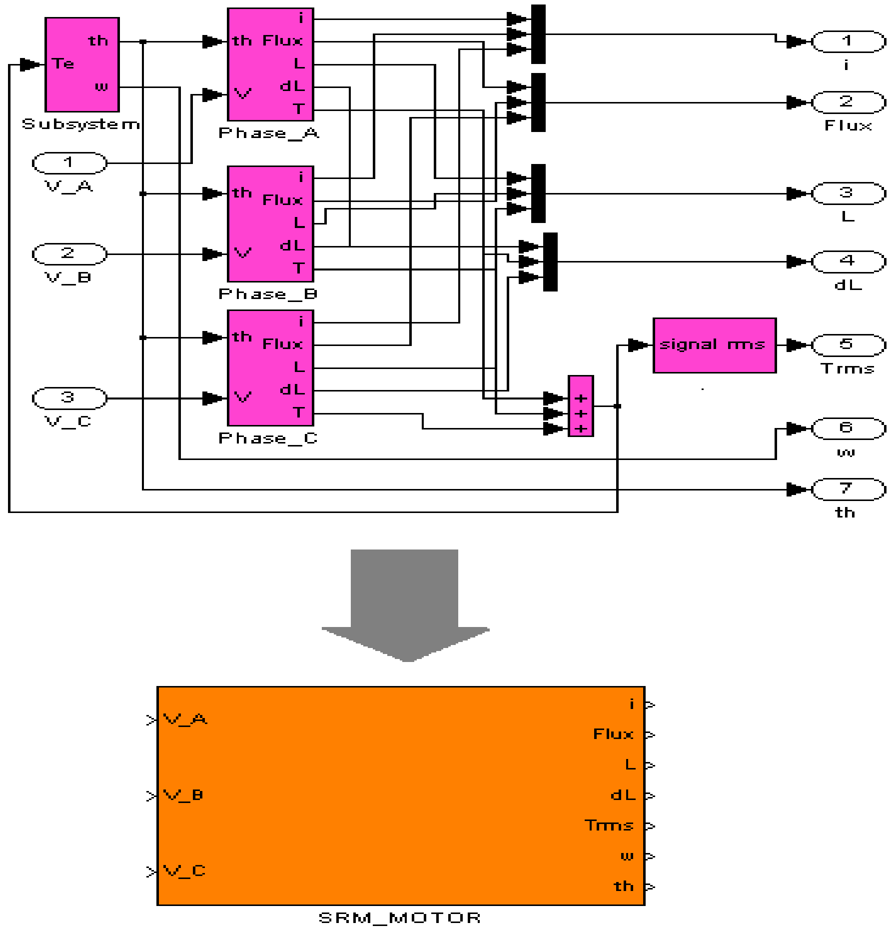


Figure (5) Building the three phase SRM control system

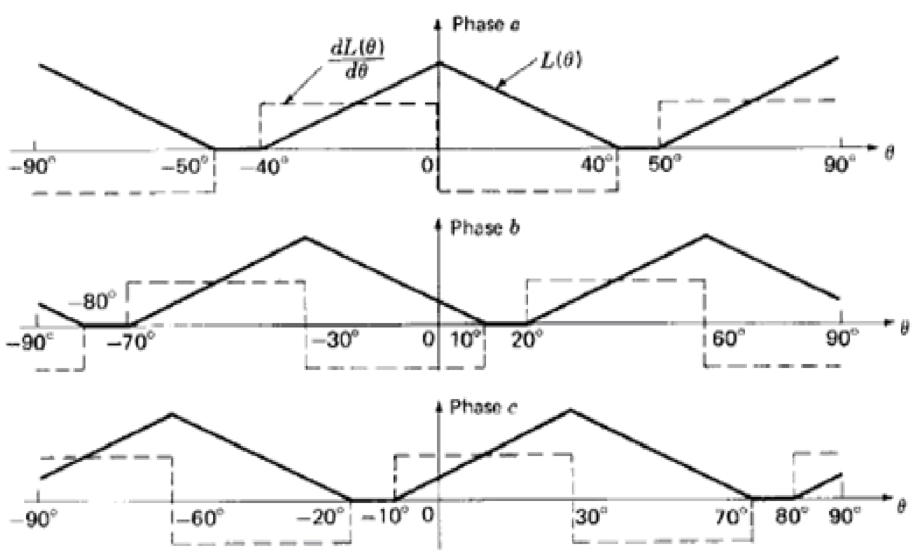
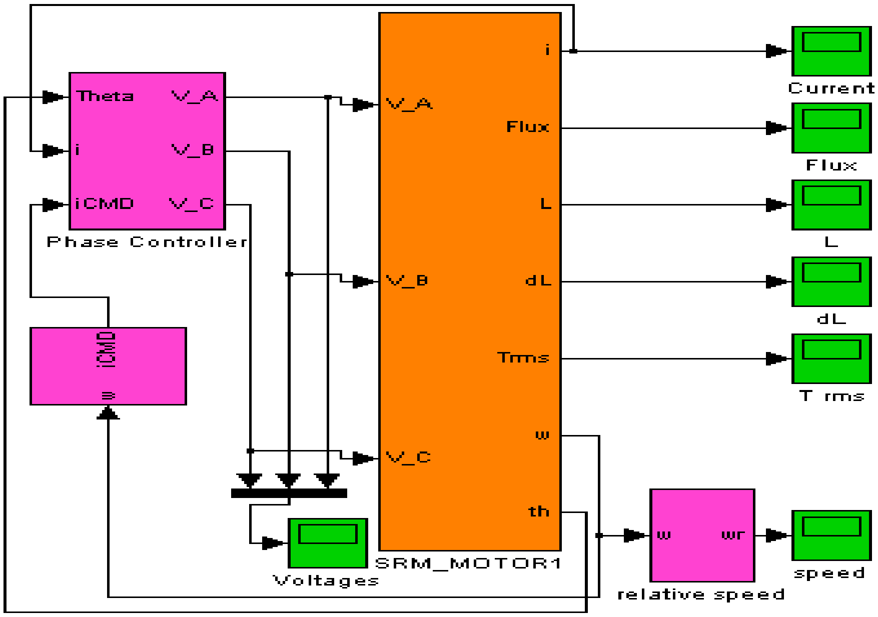


Figure (6) Process of SRM drive with 40 deg. phase shift



Figure(7) Main SRM system using the controller

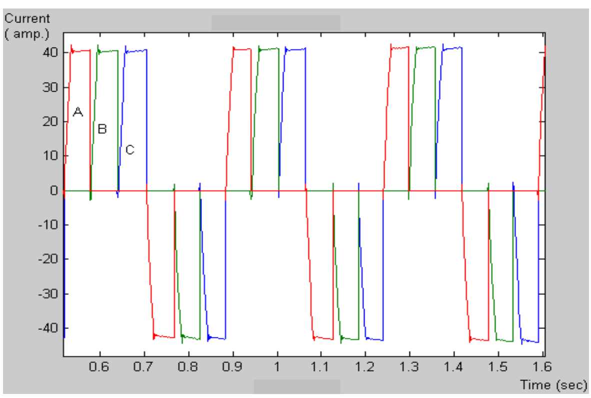


Figure (8) The current produced when using the controller

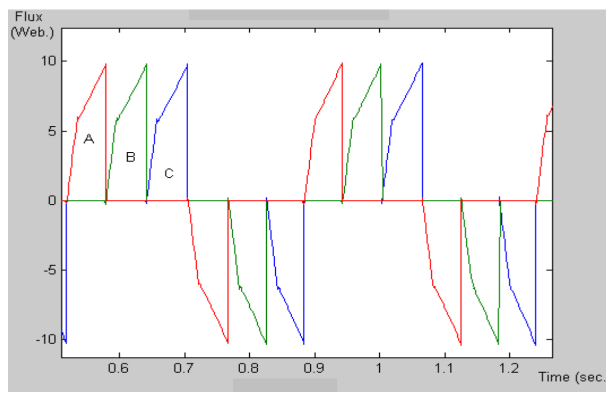


Figure (9) The flux behavior when using the controller

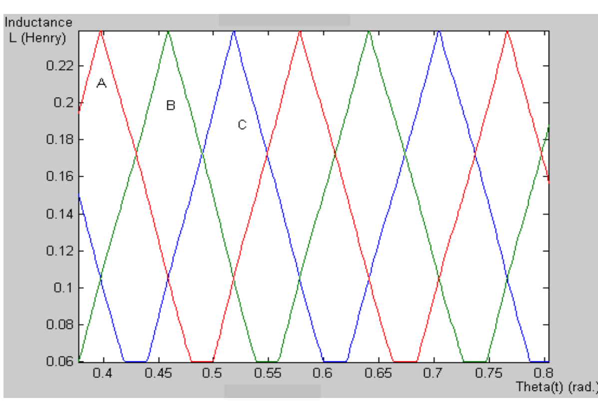


Figure (10) The produced inductance when using

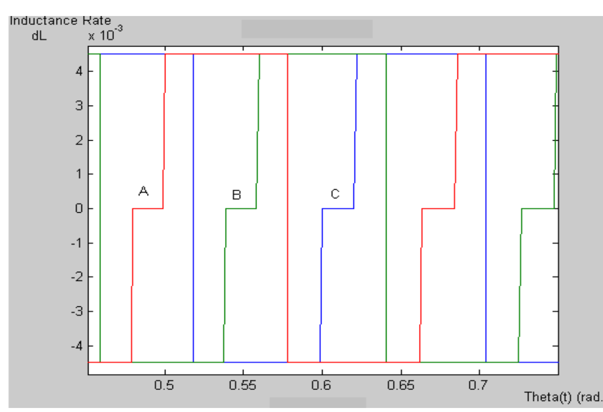


Figure (11) The inductance rate when using the controller

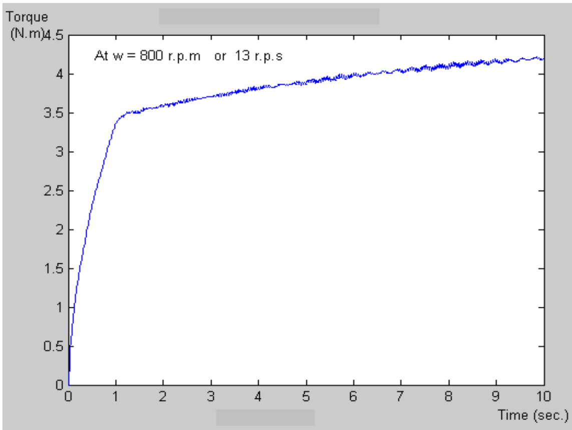


Figure (12) The total torque when using the controller

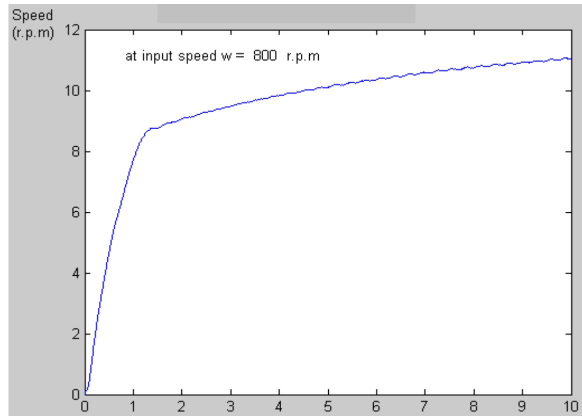


Figure (13) The speed curve when using the controller

The coupling between drive model and analysis is represented in figure (8). The input parameters for the FE-analysis are the applied phase voltages, the switch resistance values (*RON* or *ROFF*) and the rotor speed. The output parameters of the analysis are the phase currents, the coil voltages and the instantaneous electromagnetic torque in the air gap. At every time-step (ts = 2.10-5 s), data is exchanged between the drive model and the analysis. This method has the great advantage that a complex drive model in Matlab/Simulink can be used in combination with accurate flux linkage calculation, taking into account the mutual coupling between adjacent phases. The disadvantage of this method is the rather high

Calculation time, caused by the high amount of elements in the thin air gap. Figure (9) shows the simulation results of coil voltage, phase current and electromagnetic torque production for a reference current of 7.5 A and a rotor speed of 800 rad/s. The results clearly show that, besides the normal ON, OFF and chopping voltage of phase A, an extra induced voltage occurs, due to the excitation of adjacent phases C and B. Conform the flux distribution of Figure (10), this voltage is induced in phase A when phase B or D is activated together with phase C (see Figure (11)). Due to time constraints it was not possible to mount each SRM on a loading rig to verify its performance. The final SRMs were assembled in both cars, and a technique had to be developed to commission and test the individual systems. The ICE, disc brakes, and motoring and generating capabilities of the SRMs were all utilized to make the car its own loading rig for testing the individual systems. The r.m.s current of the three phases were measured and averaged to give an estimate of the SRM torque at a particular steady state load point to confirm our set of motor equations. Most of the measured operating points fell within our targeted torque accuracy of 10%. In driving trials, the response and stability of the control system was as a driver would expect. Also, in most cases the transition from one commutation state to the next was undetectable to the driver.

V-Conclusion

MATLAB/Simulink structural blocks building provides an easy and powerful method to simulate and solve any represented mathematical model. Masking properties had been used to produce fast accessing program operation related to direct values of the modeled SRM plant. SRM plant can be used now to be involved in any control systems that is the interested feature with these types of motors. A new powerful SRM plant modeling is now available. Experimental results demonstrate the good behavior of the double converter and the DC chopper, in the nominal current situation.

It is seen that the drive operates satisfactorily for the proposed fixed turn-off angle control and therefore this simple scheme should be preferred to variable turn-off angle control that requires high speed signal processing. Since full-load start is the most rigorous starting condition, the optimum turn-off angle corresponding to a particular fixed turn-on angle should be determined for this condition and then used for all other loads, so as to ensure optimum performance of SRM drive for all loads. It is seen that the drive operates satisfactorily for the proposed fixed turn-off angle control and therefore this simple scheme should be preferred to variable turn-off angle control that requires high speed signal processing. The performance of the drive with lower values of fixed turn-on angles is under study to determine an optimum pair of fixed turn-on angle and turn-off angle for SRM drive and results of the study would be reported soon. MATLAB Simulink to Flux coupling technology provides an interactive and easy to use solution to real-world problems that combine both electromagnetic and control systems.. The use of full co-simulation offers much improved power and accuracy compared to tradition look up table transfer between programs.

VI- References

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