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Dynamic Testing & Simulation of 4 KW (5.5 Hp) Switched Reluctance Motor using PSpice

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Abstract
In this paper, the requirement of mechanical model of SR Motor for determination of dynamic characteristic is presented. The PSpice is circuit oriented software package and it is believed that no direct mechanical models are available. Therefore electrical equivalent of mechanical sub systems were used for determination of dynamic characteristics. The variable inductor model is also proposed using voltage controlled component.

Keywords: *Switched Reluctance Motor, Dynamic Characteristics, Torque*

1. Introduction

In this paper, the method of modeling the mechanical portion of the Switched Reluctance Motor is presented for determination of Dynamic Characteristics. A PSpice software is used for the determination of dynamic characteristics. The main drawback of the Pspice program is that the Pspice is developed for electronic circuit design and their analysis. Due to SR Motor distinguishing characteristics (its geometry and the magnetic saturation), it is believed that no direct mechanical simulation models are available for the study of static and dynamic behavior of Switched Reluctance Motor.

Switched Reluctance Motor (SRM) is the simple electric machine having salient rotor and stator poles. There is no winding on the rotor, and two diametrically opposite stator winding on stator. The torque is produced by the tendency for magnetic circuit to adopt minimum configuration of reluctance. This is achieved by maximizing inductance in synchronous with rotor position [1].

A Switched Reluctance Motor is a closed loop control system and its torque is controlled by suitable commutation strategy which is synchronized with knowledge of rotor position (Rotor Speed and Rotor Angle).The production of torque is independent of current flowing through the phase winding of SRM [2].

2. Relation of Torque, Rotor Speed and Rotor Angle

The most important relation between torque, speed and position can be derived as follows equation. By observing equation (5), (7) and (2), we can now model the speed as a current flowing through the capacitor, torque as a voltage across the capacitor with moment of inertia $2\pi \times J$. The rotor angle will be the proportional voltage at the node; therefore it is assumed that 1 volt correspondence to 1 radian. In switched reluctance motor the torque is proportional to the square of the current flowing through winding therefore the torque is unipolar [3] Figure (1) shows equivalent circuit of above equations [6].

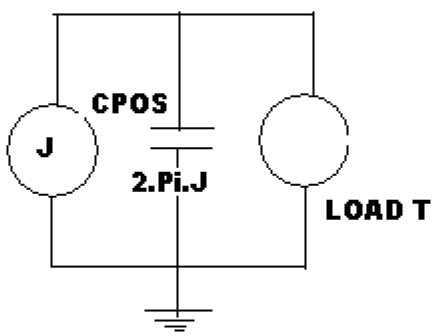

Fig. (1). Rotor Motion Circuit

The following Table gives conversion of mechanical part in to equivalent electrical parameters.

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Table 1. Conversion of mechanical part

Sr. No	Parameter	Mechanical System	Electrical System
1	Moment of Inertia	Inertia (J)	Capacitor
2	Torque	T	Voltage/Current
3	Rotor Angle	Angle of Rotation	Voltage Across 'C'
4	Rotor Speed	Speed of Rotor	Current through 'C'

$$T = J.\frac{d\theta}{dt} \qquad (1)$$

Where

$w = \frac{d\theta}{dt}$ and $w = 2\pi f_s$ Therefore

$F_s = S = \text{Speed} = \frac{w}{2\pi}$ becomes

$$S = \frac{d\theta}{dt} \times \frac{1}{2\pi} \qquad (2)$$

where S is the rotor speed (Re v / Sec)

$$T_{Total} = J \times \frac{d}{dt}(\frac{d\theta}{dt}) = J \times \frac{d^2\theta}{dt^2} \qquad (3)$$

$$\therefore T_{Total} = T(\theta, i) = \sum_{k=1}^{ph} T(\theta,i) - T_L$$

$$\frac{dw}{dt} = \frac{1}{J}\sum_{k=1}^{ph} T(\theta,i)\text{-}T_L \qquad (4)$$

Equation (3) can be written as

$$T_{Total} = 2\pi \times J \times \frac{dS}{dt} \qquad (5)$$

For modeling the torque and speed , we can consider

$V = \frac{1}{C}\int i \times dt$ and can be written as (6)

$$i = C \times \frac{dv}{dt} \qquad (7)$$

3. Modeling Mechanical Losses

The mechanical losses observed such as damping losses, Frictional losses in SR Motor. The eddy current also contributes the above during production of torque. The torque due to damping effect is the product of 2π, damping, eddy current losses and the rotor speed as well. The damping factor of the rotor is taken from 0.1 to 0.4. The friction losses are taken depending upon type of machine used. The values are used by simple function of parameter passing through sub circuit of the PSpice program.[4]

4. Modeling Stator Winding of SR Motor

SR Motor consists of salient pole stator with two diametrically opposite winding on it. Following are the parameters to be considered for simulation,

i. Phase/winding inductance (mH)
ii. Phase/winding Resistance (Ohm)
iii. Phase/winding Capacitance(F)
iv. Mutual Inductance of the winding. (mH)
v. Back EMF of the winding
vi. Torque producing current Itq(mA)

The actual values of point (i) to (iv) can be directly used in Pspice with .PARAM command and (v) and (vi) requires analog behavioral modeling of Pspice software.

5. Modeling Variable Inductor

The inductance of the phase winding varies according to variation of rotor position or angle from unaligned to aligned position of rotor and stator. Therefore the variation of inductance can be simulated using “ZX” sub circuit as a voltage controlled impedance or inductance. In this case current flowing through the pseudo-component is mirrored directly to reference component which is either inductor or resistor. The resulting voltage is then mirrored to output terminals multiplied by the controlling voltage. As a result the voltage at output terminals is proportional to voltage across the reference component and control voltage [5].

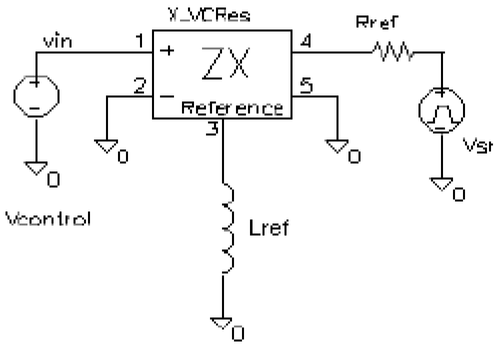

Fig.2. Modeling Variable Inductor

Pspice Program developed for simulation of variable inductance with rotor position is listed below

```
*Variable Inductor Circuit for SR Motor
R1 1 2 50ohm
RO 2 3 10 ohm
X1 VIN 0 Rref 3 0 ZX
Lref Rref 0 10mH
.PARAM ControlVoltage=0.5, 2, 0.5
Vcontrol Vin 0 dc 0.5
Vsrc 1 0 PULSE(0V, 1V, 0.5MS, 1US, 1US, 0.5MS, 4MS)
.TRAN 0.1m 4m 0 0.01m
.probe
*Sub Circuit for Zx Component
.subckt ZX 1 2 3 4 5
eout   4 6 poly(2) (1,2) (3,0) 0 0 0 0 1
fcopy  0 3 vsense 1
rin    1 2 1G
vsense 6 5 0
.ends
.end
```

6. Simulation of Q-Factor SR Motor Winding

The Pspice program is developed to analyze the quality factor of an inductor circuit of stator phase. The Stator circuit is compared with the R-L-C circuit where resistance ‘R’ is the winding resistance, ‘L’ is the inductance of winding and c is the capacitance of the Pspice Program for simulation of variable Q- is listed below [6]

```
*VARIABLE Q FOR SR MOTOR CIRCUIT
L1 1 2 10mH
C2 2 3 1uF
X1 VIN 0 Rref 3 0 ZX
Rref Rref 0 40E
.PARAM ControlVoltage=0.5, 2, 0.5
Vcontrol Vin 0 dc 0.5
Vsrc 1 0 PULSE (0V, 1V, 0.5MS, 1US, 1US, 0.5MS, 4MS)
.TRAN 0.1m 4m 0 0.01m
.probe
*SUB CIRCUIT ZX
.subckt ZX 1 2 3 4 5
eout   4 6 poly(2) (1,2) (3,0) 0 0 0 0 1
fcopy  0 3 vsense 1
rin    1 2 1G
vsense 6 5 0
.ends
.end
```

7. Simulation Results

The winding of SR Motor – variation of Q is observed as input changes sinusoidal function. This can be seen in fig.3. Output waveform during variation of rotor position and Inductance can be seen in fig.4. In simulation process, 'θ' (Rotor angle) is varied in three steps of equivalent DC voltage at in put of Zx sub-system. The variation of inductance with change in rotor position is observed in fig. 5. Fig. 6 shows conversion of angles into equivalent radian required to estimate rotor position.

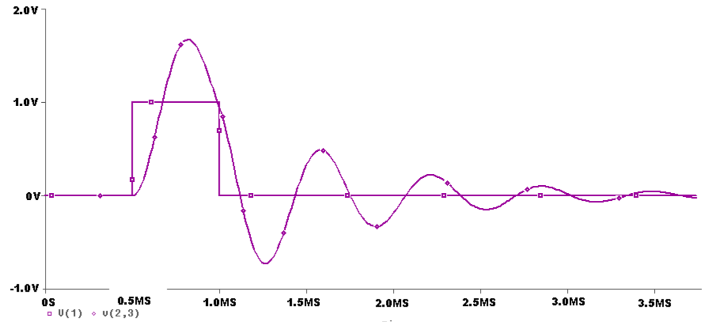

Fig.3. Output waveform during variation of rotor position with variation og Q of stator winding.

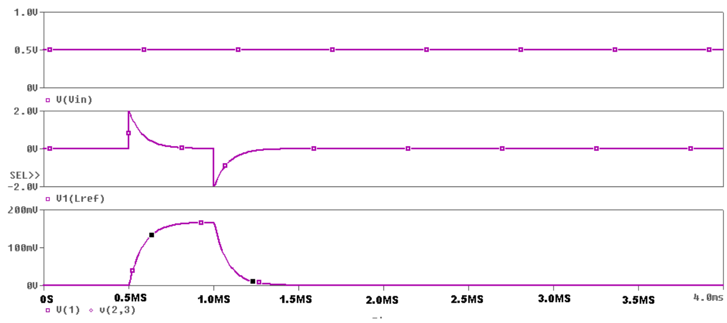

Fig.4 Output waveform during variation of rotor position and Inductance.

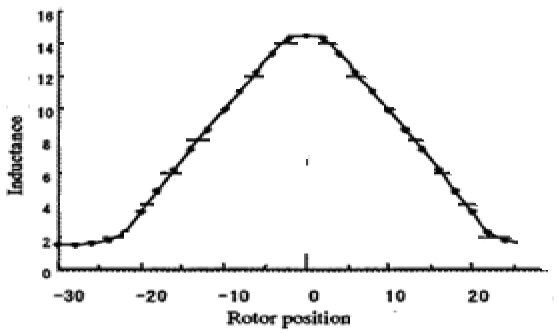

Fig.5 Output waveform during variation of inductance with rotor position

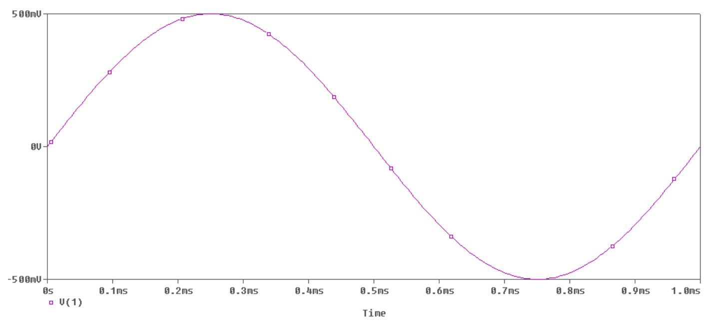

Fig. 6. Rotor Position

8. Conclusion

A Pspice simulation method is used to study the basic requirement for analysis of dynamic characteristics of SR Motor. Mechanical sub-systems are studied and implemented in the main program of simulation. The variable inductor model is also proposed using voltage controlled component. As a future work, actual models of mechanical systems are to be simulated for determination of dynamic characteristics of SR Motor.

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