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Simulation and Analysis of 5 Phase SRM Converter

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Abstract - *In this paper SRM motor modelling for five phase 10/8 switched reluctance motor (SRM) drive is presented. This paper also presents computation of Turn ON and Turn OFF angle based on linear model. A simulation running the Five phase SRM model with power converter using two IGBT's and two diodes for each phase is performed and the parameters of the motor such as motor flux of each phase, armature current, torque and motor speed were analysed and recorded.*

Key Words: SR Motor, SRM Controller, Multi-Phase , Position Sensor, Electric Vehicle.

1. INTRODUCTION

switched Reluctance Motor (SRM) drives are gaining interest in various applications due to their simple and rigid structure, four quadrant operation and extended speed constant power range. SRM shows crucial attributes to applications where light weight, high temperature adaptability, fault tolerance capability are strongly required. It has doubly salient pole arrangement and is highly effective for electromagnetic energy conversion. Both rotor and stator are made up of ferromagnetic material and by controlling sequence of supply we can easily change direction of rotation of the motor. For SRM close loop control is essential to optimise the switching angles of the applied coil voltage. SRM is highly used in industrial application as well as electric vehicles due to its high rating (Upto 75 KW) and higher overall efficiency. SRM is available from 3 phase (6/4 poles) to higher phases. In this paper we have simulated a five phase (10/8 poles) S RM with a phase converter.

In last decade many industries mainly focused on improvement and modification in control and design of SRM in order to improve its efficiency and life. SRM is now fully developed to prove it's self in the market as compared to Induction and brushless permanent magnet motor and SRM now preferred in advancement have high number of modern applications.

2. BASIC PRINCIPLE AND MODELLING OF SRM DRIVES

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SRM works as the same basic principle as that of a variable reluctance stepper motor. The switched reluctance motor (SRM) is an electric motor in which torque is produced by the tendency of its moveable part to move to a position where the inductance of the excited winding is maximized. SRM is a type of synchronous machine. It has wound field coils for its stator windings and has no coils or magnets on its rotor. Both the stator and rotor have salient poles, hence, the machine is a doubly salient, singly excited machine.

2.1 Principle of Operation

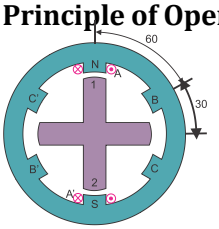

Figure -1: (a)

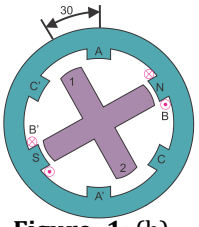

Figure -1: (b)

With phase A excited and rotor position as shown, the flux linkages are maximized with phase A

With phase winding A de-energized and phase B energized the rotor moves counter clockwise.

In SRM variation of reluctance in air gap produces the torque. Mathematically, stored energy in an inductor is LI2/2. By differentiating this energy with respect to position we get the value of Torque.

$T=0.5I^2dL/d\theta$

where,

I : the instantaneous value of exciting current

L : the self inductance of the phase winding.

As the torque is proportional to square of the phase current, the torque is independent of the current direction.

The sign of torque is dependent upon the variation of inductance with rotor position θ.

Equation of voltage for single phase

$V = e + Ri$

i.e. $e = V - Ri$

Where,

i - Current

R- Resistance

V- Terminal voltage

e- Back EMF

Faradays law is rate of change of flux linkage(ψ)

For back EMF,

$$e = \frac{\partial \psi}{\partial t}$$

The area covered by 'W' is in the electrical energy converted to mechanical energy or vice versa.

Average torque,

$$Te(avg) = \frac{SW}{2\pi}$$

Where,

S – Number of stroke per revolution

Nr – Number of rotor pole

Φ – Number of phase

S = NrΦ

Assuming that the phase current is flat-topped during the phase conduction period and the phase winding resistance is negligible, the voltage equation for one

phase can be given as,

V = I[La – Lu]/dt

where La and Lu are the inductances in the aligned and unaligned positions, respectively. dt is the time taken for the rotor to move from the unaligned to aligned position.

The consideration of elementary reluctance machine is used for the derivation of basic torque equation of SRM.

The carries only one winding of the stator as machine is single phase excited. The rotor freely rotates as the excited winding is wound on the stator. The flux linkage is,

ψ= L(θ)i.

We find that all of the energy is not converted into mechanical work and some kind of energy is stored in magnetic field. This energy which stored in magnetic field is useful it can't be wasted.

For Five phase SRM having 10 Stator Pole and eight rotor poles.

Stator pole pitch equal to 360/10=360, and

Rotor pole pitch = 360/8 = 450.

Circular Structure in Linear Fashion									
Stator Pole Position									
A	*B*	*C*	*D*	*E*	*A'*	*B'*	*C'*	*D'*	*E'*
0°	36°	72°	108°	144°	180°	216°	252°	288°	324°
Rotor Pole Position									
9°	54°	99°	144°	189°	234°	279°	324°		

The excitation sequence of phase winding is to be repeated after every electrical cycle.

The mechanical angle over one electrical cycle for the five phase SRM is given as,

$$\alpha = \frac{360^\circ}{P_r} = 45^\circ$$

Where, Pr is the number of rotor poles.

$$L_u = 0.064e^{\frac{(\theta - 4.231)}{0.7927}}.$$

Where, Lu is unaligned inductance.

$$V_{DC}\frac{\theta_{off} - \theta_{on}}{\omega} = V_{DC}\frac{\theta_Z - \theta_{off}}{\omega},$$

$$\theta_{off} = \frac{\theta_Z + \theta_{on}}{2}.$$

Θon= α/2=45/2=22.50

Θoff= (Θon+ α)/2=33.750

Where,

Θoff is Switch OFF Angle, and

Θon is Switch ON Angle.

3. FIVE PHASE SRM CONVERTER

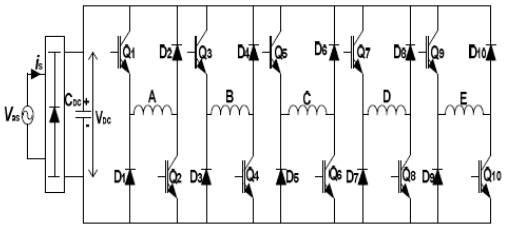

Figure -2: Block Diagram of 5 phase SRM converter

Figure2 shows the five phase SRM Converter all phases of five phase SRM are connected across same DC bus bar. The phase A is energised by turning on both the switches Q1 & Q2 simultaneously and current will start flowing through phase

A. After some specific Turn ON time switches Q1 & Q2 are turned OFF simultaneously. The energy stored in the motor winding of phase A will keep the current in the same direction until its value become zero. Hence diode D1 & D2 will become forward biased that will decrease the current rapidly. Similarly four phase B devices Q3 & Q4 and diodes D3 & D4 are used and in same pattern the operation takes place for phase C, D and E.

4.SIMULATION AND RESULTS

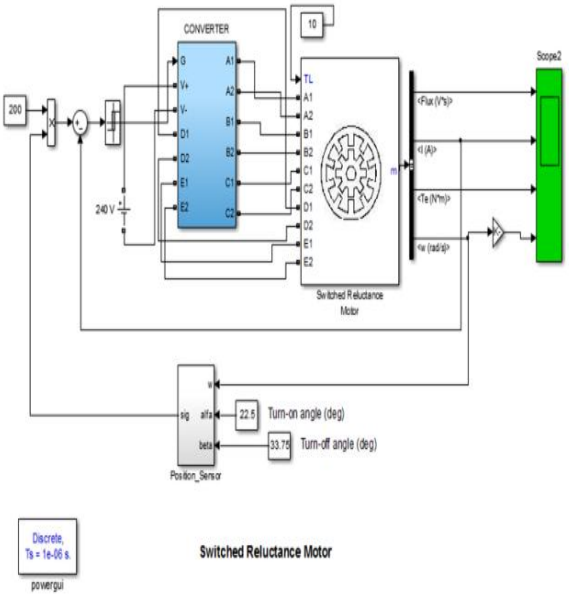

Figure -3(a): Matlab Simulation Model

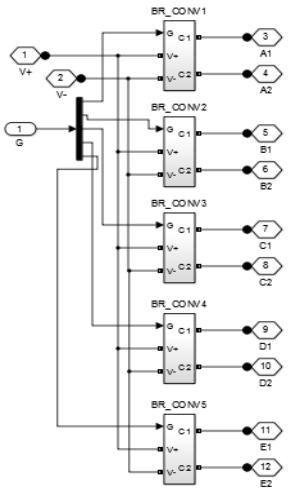

Figure-3(b). Converter Circuit Model

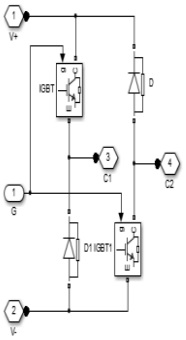

Figure-3(c). Per Phase Converter model

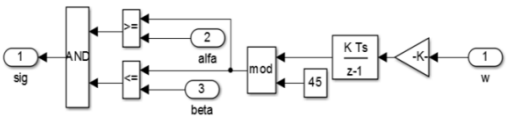

Figure -3 (d): Position Sensor

Parameters of SRM Drive used in simulation		
Parameters	Value	Unit
Stator Resistance	0.05	ohm
Inertia	0.05	Kg-m2
Friction	0.02	N-m-s
Initial Speed	0	rad/sec
Initial Position	0	rad
Stator Pole	10	
Rotor Pole	8	
Input DC Voltage	240	volt

The motor load torque was set to 10 N-m.

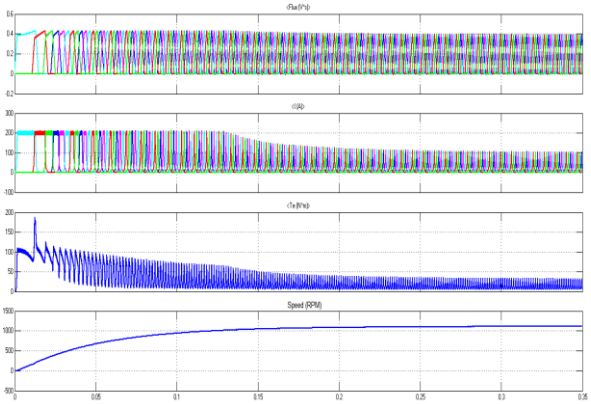

Figure -4(a) Matlab Simulation Result

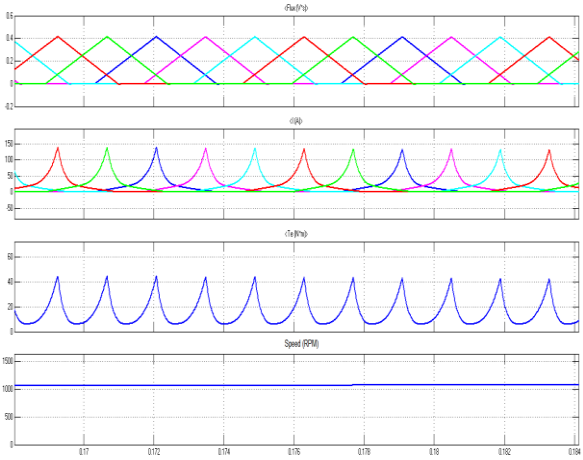

Figure -4 (b). Zoomed Simulation Result

5.CONCLUSION

The five phase SRM drive is studied. The SRM converter is analysed and waveforms of flux of each phase, phase currents, torque and speed were recorded. It is observed that the motor draws a ripple current and the torque developed by the motor contains the ripples as per current phase. The speed of the motor settles at 1100 rpm. The flux of each phase is triangular in nature with 72 degree phase shift.

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