

Control Strategy of Switched Reluctance Motor

Vallala Krishna

M.tech Scholar, EEE
VNR VJIET
Hyderabad, India

E. Shiva Prasad

Assistant Professor
Dept of EEE, VNR VJIET
Hyderabad, India

Abstract—This paper discuss about the mathematical modeling and simulation of switched reluctance motor(SRM) and working principle. The torque sharing function method is proposed for the controlling of torque in switched reluctance motor. This method provides the maximum speed of torque ripple operation. Due to increasing phase inductance in outgoing phase during the commutation region, reference current tracking can be deteriorated especially when the speed increased. Torque error for outgoing phase can cause increasing the resultant motor torque while it would be negative for incoming phase and yields reducing the motor torque. This yields to build up motor efficiency compared than the conventional receding turn-on and turn-off angles. In addition to this Simulink model of SRM is designed and tested through MATLAB/Simulink software. The parameters like current, torque and speed are represented graphically.

Keywords—Switched reluctance motor, Torque control, high speed operation.

I. INTRODUCTION

The switched reluctance motor are mainly used in electric vehicles, vaccum cleaners, washing machines, servo type and variable speed applications. The SRM has rugged structure with the most robust and reliable constructions[1] therefore it can be suitable for vibrating and high temperature zone. Switched reluctance motor is a double salient motor with no winding on rotor. The torque produced by switched reluctance motor is not dependent of phase currents polarity. Therefore the less number of semiconductor switches are used in the power converters. In addition to this the loss occurred in the SRM motor is from the stator only. Hence it can be cooled easily[2]. The main drawback in switched reluctance applications is high torque-ripple compared than other ac type machines [1]. The switched reluctance motor is high torque and high reliability.

II. CONSTRUCTION AND WORKING PRINCIPLE OF MOTOR

The switched reluctance motor is working on the principle of minimum reluctance, which is a physical law of minimum energy, i.e., a movable mechanical system subject to a

magnetic field tends to find the position where the energy stored in the magnetic field is minimum. At this position, the reluctance of magnetic circuit is also minimum, and the inductance seems by the electrical circuit is maximum [8]. The figure [1] shows the cross sectional view of a switched reluctance motor.

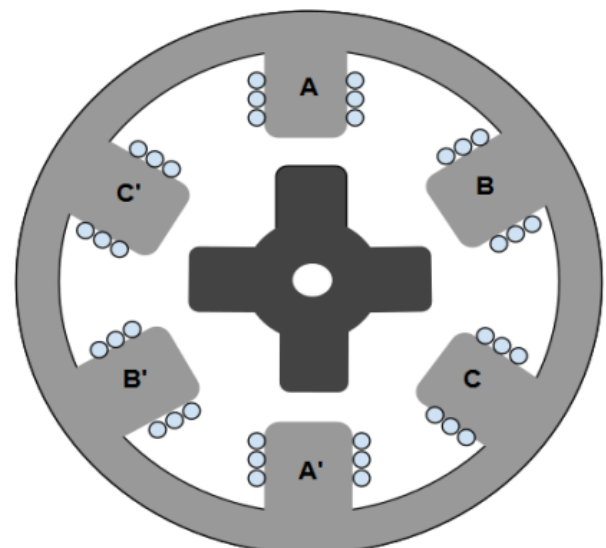


Figure 1: 6/4 three phase switched reluctance motor

From figure[1] we can see the 6/4 pole arrangement. This shows the stator and rotor poles of switched reluctance motor. Three phase supply is given to the SRM. Basically in electrical machines the switched reluctance motor is the simplest one when compare with the other electrical machines.

In construction of motor, there is no winding or permanent magnet or conductors on the rotor. The rotor consists of steel lamination stacked on a shaft. In addition to this the cost of the motor is low due to the simple mechanical construction. The SRM is electric motor, in this motor torque is produced through the movable part to the position where the inductance of the excited winding is maximized. This torque is said to be reluctance torque, since it can be said that, it is out of tendency to decrease the reluctance to minimum. On the basis of torque production the electrical machines are classified into two types; the one way of torque production is

due to the electromagnet and the other way of torque production is due to variable reluctance.

In switched reluctance motor the torque is produced due to variable reluctance, hence it is called as switched reluctance motor. The undesired torque ripples is caused by the high saturated nature of magnetic characterization. The motor drive performance especially used in high industrial applications. In order to reduce the torque ripples many research have been done and torque control techniques are introduced. Even after design parameters are taking into consideration to produce the constant torque and minimizing the torque ripple, control techniques have been more considered to control the motor torque in conventional switched reluctance motors. One of the most important approaches is to coordinate incoming and outgoing phase torque so that the resultant torque remains constant during the commutation between the phases. Torque Sharing Function (TSF) is a well known technique for torque control in alternative in which reference torques for individual phases defined assuming the total torque stays at constant level. Some of the torque sharing functions such as linear, cosine, cubic and exponential types[7]. The most drawbacks of torque sharing function method in industrial applications is the limitation of maximum speed with acceptable torque ripples. Effective and peak phase currents, power loss and voltage requirements during the commutation would be some possible secondary objective functions to make an optimal TSF.

III. MATHEMATICAL MODEL OF SWITCHED RELUCTANCE MOTOR

$$V = R_s I + \frac{d\psi\{\theta, I\}}{dt} \quad (1)$$

R_s = Resistance / phase

ψ = flux linkage / phase

$$\psi = L\{\theta, I\}I \quad (2)$$

L = Mutual inductance

$$V = R_s I + \frac{d\{L(\theta, I)I\}}{dt} \quad (3)$$

$$V = R_s I + L\{\theta, I\} \frac{dI}{dt} + I \frac{d\theta}{dt} \frac{dL\{L(\theta, I)\}}{d\theta} \quad (4)$$

$$V = R_s I + L\{\theta, I\} \frac{dI}{dt} + \frac{dL(\theta, I)}{d\theta} \omega_m I \quad (5)$$

$$e = \frac{dL(\theta, I)}{d\theta} \omega_m I = K_b \omega_m I \quad (6)$$

$$K_b = \frac{dL(\theta, I)}{d\theta} \quad (7)$$

Instantaneous input power is the sum of winding resistance loss, rate of change of field energy and air gap power. Therefore the instantaneous input power can be given as,

$$P_i = VI = R_s I^2 + I^2 \frac{dL(\theta, I)}{d\theta} + L\{\theta, I\} I \frac{dI}{dt} \quad (8)$$

$$\text{Time, } t = \frac{\theta}{\omega_m} \quad (9)$$

Air gap power equations,

$$P_a = \frac{1}{2} I^2 \frac{dL(\theta, I)}{d\theta} \quad (10)$$

$$P_a = \frac{1}{2} I^2 \frac{dL(\theta, I)}{d\theta} \frac{d\theta}{dt} \quad (11)$$

$$P_a = \frac{1}{2} I^2 \frac{dL(\theta, I)}{d\theta} \omega_m \quad (12)$$

$$P_a = \omega_m T_e \quad (13)$$

By equating the equations 12 and 13 we get torque $\{T_e\}$

$$T_e = \frac{1}{2} I^2 \frac{dL(\theta, I)}{d\theta} \quad (14)$$

The numerical and analytical modeling of switched reluctance machine has been explained clearly by Zhang zhihui[9].

Table.I Specifications of the 6/4 switched reluctance motor

S.NO	PARAMETERS	VALUES
1	Stator poles	6
2	Rotor poles	4
3	Frequency	50Hz
4	Phases	3
5	Supply voltage	240 volts
6	Firing angle	45 deg
7	Reference speed	2500
8	Friction	0.01 N-m
9	Stator resistance	0.01 ohms/phase
10	Moment of inertia	0.0082 Kg-m/sec

IV. DESCRIPTION OF TORQUE SHARING FUNCTION TOPOLOGY

Relationship with rotor position and phase current in SRM. The rotor position of θ can be calculated as the torque produced;

$$T_{e,k} = \frac{\partial \int \lambda_k(i_k, \theta) di_k}{\partial \theta} \quad \text{for } k = 1, 2, \dots, n$$

Where n is the number of phases.

Generally, non-linear characteristics between flux and phase current. Therefore it is not possible to calculate the single formulae for exact phase torque as in the functions of rotor position and phase current. The phase torque obtained from the relationship of phase current and flux.

$$T_{e,k} = \frac{1}{2} \frac{\partial L(\theta, i_k)}{\partial \theta} \cdot i_k^2$$

Torque sharing function to be considered for switched reluctance motor in both industrial and research applications. Generally, there are two regions for conduction period of each phase. One region is single phase conduction and the other is two phase conduction. Fig.2 shows the Basic block diagram using Torque sharing function for a three phase switched reluctance motor. The individual phase torques through the TSF functions are obtained from the input reference torque. Torque to current gives the phase reference currents at rotor position and to get the desired currents the PWM block is applied.

We obtained a equation for torque ripple factor is given below,

$$T.R\% = \frac{T_{max} - T_{min}}{T_{avg}} * 100$$

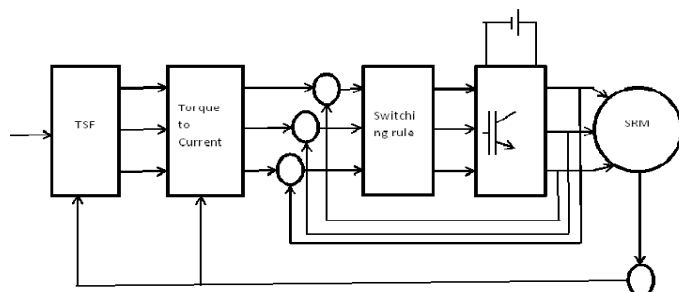


Fig. 2 Basic block diagram using Torque sharing function

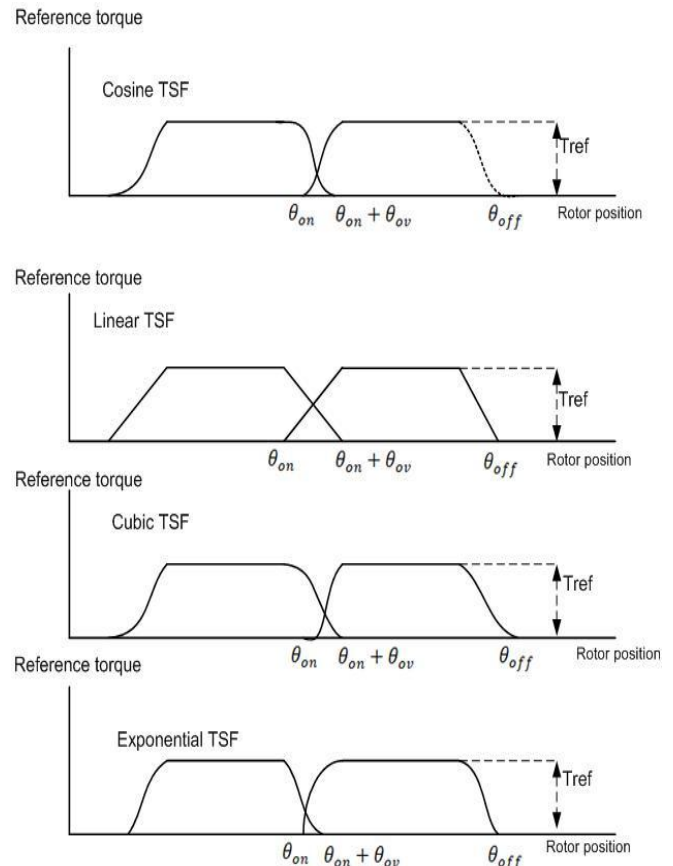


Fig. 3 Conventional TSF profiles: Cosine, linear, cubic, exponential

V. SIMULATION MODEL OF SWITCHED RELUCTANCE MOTOR

The simulation of a 6/4 switched reluctance motor is done on the MATLAB has clearly presented by F Soares and C Branco [10]. In the MATLAB simulation of switched reluctance motor specifications are given as; no. of stator poles = 6, no. of rotor poles = 4, Frequency = 50Hz, Number of phases = 3, DC supply voltage(V_{dc}) = 240 volts, Turn on angle = 45° , Turn off angle = 75° respectively.

Reference current = 200 amps, Hysteresis band = +10, -10. Aligned inductance = 20 milli Henry, Friction = 0.01 newton per meters, Unaligned inductance = 0.7 milli Henry, Stator resistance = 0.01 ohms per phase, Moment of inertia = 0.0082 Kg-m/sec.

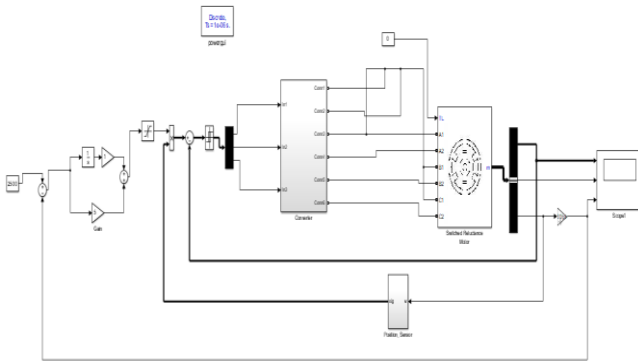


Fig. 4 Simulink model of switched reluctance motor in MATLAB

VI. SIMULATION RESULTS

i. Current

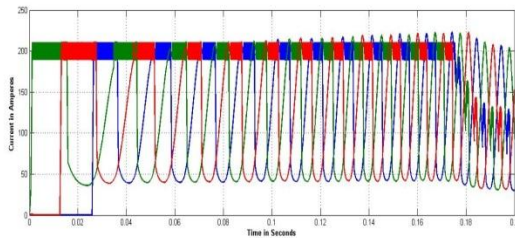


Fig. 5 Current vs. time

ii. Torque

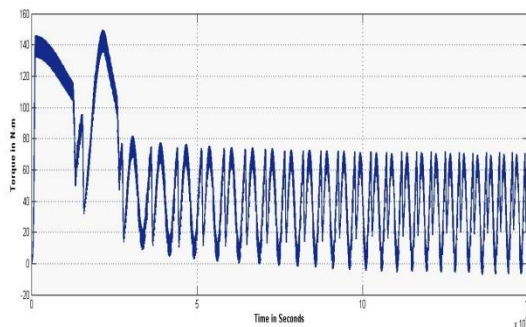


Fig. 6 Torque vs. time

iii. Speed

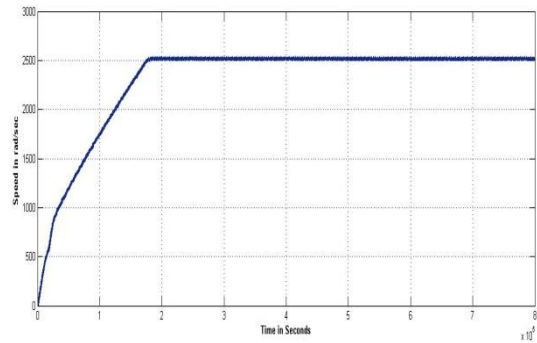


Fig. 7 Speed vs. time

In this we observed that the torque is directly proportional to the square of the current, the torque of the switched reluctance motor depends on $\frac{dL}{d\theta}$ value, and is independent of current direction. But this torque contains noise and harmonics. Turn on and turn off angles are given so that the rated speed without negative phase torque was obtained.

VII. CONCLUSION

In this we observed that the potential of switched reluctance motor is highly greater in motion control. At the same time it gives the high performance in harsh conditions like dusty environment and high temperature. The motor is designed in MATLAB software. The proposed scheme considered for voltage saturation of SRM converter. The incoming phase torque control failed to operate properly in mid-high speed region because of low capability of torque production at the starting of incoming phase. This yields ripples on the resultant motor torque.

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