An IGBT Controller Based Torque Ripple Reduction Strategy In Switched Reluctance Motor

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Abstract: This paper presents a typical model for the minimization of torque ripple in switched reluctance motor. The SRM motor drive have received a considerable awareness among the researchers due to it sturdy and robust construction. Also it has neither permanent magnets nor any winding. The SRM motor exhibits the peculiar problem of torque ripple, vibration and noise due to the periodic excitation of stator phase and the control strategy derived from the converters. Torque ripple is essentially unbearable in servo system, because its occurrence will affect the load characteristics. Many attempts were made by changing the design parameters and control strategies to minimize the torque ripples. In this paper an optimized IGBT controller is modeled to minimize the torque ripple by manipulating the phase current. The optimized current profiles produced by this methodology helps in reducing the torque ripple. Here SRM drive simulation using the proposed controller is presented and the results are compared with other methods. The result validates that the methodology effectively minimizes the torque ripple of SRM drive.

Key words: SRMotor • Torque ripple IGBT Controller

INTRODUCTION

In the recent past, switched reluctance motor have received attention among the researchers because of its simplicity, robustness, high efficiency and absence of rotor windings [1]. The reliable characteristics of SRM enable its usage in coal mining, fans, pumps and electrical vehicles etc. the production cost of SRM is also low because of its simple and elegant construction [2]. It can be operated at high speed without any mechanical problem. In SRM winding are placed in the stator whereas the rotor is made up of only with steel lamination or permanent magnets. Both stator and rotor has been designed with salient poles [3]. The diametrical opposite poles are connected in series to make it as a single phase. As soon as the stator pair is energized the nearby rotor pole is attracted linear the position when the magnetic path has low reluctance [4]. Hence the motion is created and torque has been developed in either direction of rotation. Even though the machine exhibits some troublesome characteristics like vibration, torque ripple and acoustics noise [5]. The prime cause for torque ripple is due to continuity in the generated torque. The presence of ripple in torque will be reflected on the load. This can be mitigated to a large extent by overlapping the phase currents [6].

There are two ways for minimizing the torque ripple: one method is by improving the performance of magnetic design of motor while the other is by introducing the advanced electronic control technologies [7]. Hence the converter used for SRM drives needs unique control for each phase for reducing the torque ripple by phase current overlapping.

Researcher has more significant contribution over the year to bypass the problems. Various control methods have been suggested to minimize the torque ripple where direct instantaneous torque control has been employed to synchronous motor [8].

A motor drive hardware executed by a three phase AC power module seems to be more simple and flexible which describes the dynamic analysis of SRM with conventional and modified pole shape exploits the driver circuit which improves the efficiency and reduce the torque ripple.
An asymmetric converter is used as switching circuit to reduce the phase current overlapping which is directly proportional to torque ripple [9]. The main drawback of this converter is wastage of phase inductor energy wasted by resistance which produces long commutation gap. If the converter used has short commutation ability for phase current then the ripple will be reduced considerably [6].

This paper employs a power conductor switching circuit using IGBT converter, which has a tendency to produce quick phase current commutation and reduces phase current overlapping which results a uniform phase current. This uniform phase current and instant switching of IGBT effectively manipulates the flux density, angular velocity and thoroughly reducing torque ripples.

**Torque Ripple in Srm:** In SRM when one phase of the stator is initiated and other is commutated even after commutation of a phase the current flow is seen in two phases, the sum of air gap torque contributed by outgoing and the incoming phase need not to be constant since the current is only controlled in the incoming phase and not controlled in the outgoing phase. The resultant torque usually has a culvert during the interval known as commutation interval or overlap interval that produces the torque ripple [10]. The nonlinear current produced due to change of inductance in the overlap region is responsible for the nonlinear torque in SRM [11]. The change of inductance in the overlap region prior to the overlap of stator and rotor teeth is not constant due to fringing flux. In multi teeth design the fringing flux effects are more significant. To attenuate/reduce/mitigate the fringing flux effect the ratio between the tooth with and air gap has to be maintained in large otherwise a fast switching device is used with convenient controller. In direct drive application torque ripple is found to be intolerable fact. In this the electronic approach is based on optimizing the control parameters, which includes the supply voltage, turn on and turn off angles and current level [11]. Torque ripples is of two parts; high frequency torque ripple and low frequency torque ripple. The low frequency torque ripple is produced because of the difference between the peak torque and angle where the overlapping phases produce equal torque at equal level of current. This high frequency torque is reduced using switching strategy and converted circuit. Generally torque ripple minimization is done by nonlinearity functions of phase current and rotor position which is done by fixing a suitable controller for phase switching [12] and [13].

**Converter Design:** To design a new converter consisting of half bridge IGBT module and SCRs for closed loop control of SRM is proposed. The proposed converter topology replacing the conventional asymmetric bridge converter in SRM drives.

The various phase windings of SRM are connected to power semiconductor switching circuits which are energized by a DC supply. The rotor position sensor mounted on the shaft of the SRM provides signal to the IGBT controller about the position of the rotor with reference to the reference axis. Due to hybrid combination capacity of of the IGBT controller the information of position sensor, reference speed signal, phase current are feedback. The high speed switching characteristics and low saturation voltage of IGBT helps the controller to switch the desired phase winding of the power semiconductor switching device.

**Rotor Position Nonlinear Analysis:** Torque characteristics are dependent on the relationship between flux linkage and rotor position as a function of current, it is worthwhile to conceptualize the control possibilities and limitation of the motor drive. A typical inductance VS rotor position is shown in Fig. 1. The inductance corresponds to that of a stator phase coil of switched reluctance motor by neglecting the fringe effect and saturation.

The various angles are derived as

\[ \theta_1 = \frac{1}{2} \left( \frac{2\pi}{R'} - (\beta_s + \beta_r) \right) \]

\[ \theta_2 = \theta_1 + \beta_s \]

\[ \theta_3 = \theta_2 + (\beta_r - \beta_2) \]

\[ \theta_4 = \theta_3 + \beta_s \]

\[ \theta_5 = \theta_4 + \theta_1 = \frac{2\pi}{R'} \]
Voltage and Torque Equation of SR: Basic voltage equation of SRM is given by

\[ V = Ri + \frac{d\lambda}{dt}[\lambda = Li] \]  

where

- \( V \) – input voltage
- \( I \) – current through the phase winding
- \( R \) – resistance of the phase winding
- \( \lambda \) – flux linkages=Li

\[ \frac{d\lambda}{dt} = \frac{d(Li)}{dt} \]

\[ \frac{\partial \lambda}{\partial t} = L \frac{\partial i}{\partial t} + i \frac{\partial L}{\partial t} \]

\[ L = \frac{\partial i}{\partial t} + i \frac{\partial L}{\partial \theta} \]

\[ L = \frac{\partial i}{\partial t} + i \omega \frac{\partial L}{\partial \theta} \]

Where \( \frac{\partial \lambda}{\partial t} \)

\[ V = iR + L \frac{\partial i}{\partial t} + i \omega \frac{\partial L}{\partial \theta} \]  

(2)

\[ V = Ri + L \frac{\partial i}{\partial \theta} + e \]

It is the voltage equation of SRM.

where

- \( L \) - incremental inductance

Type equation here

\( R \) - resistive drop

\[ L \frac{\partial i}{\partial t} \rightarrow \text{emf due to incremental inductance} \]

\[ i \frac{\partial L}{\partial \theta} \rightarrow e = \text{self emf depends on current, speed and rate of change of inductance with rotor angle.} \]

From the voltage equation, easily we can draw the equivalent circuit for one phase of SRM. Thus the equivalent circuit of SRM consists of each phase, a resistance, an incremental inductance and self emf.

\[ L \frac{\partial i}{\partial t} \text{emf due to incremental inductance is zero.} \]

During the flat top period, emf ‘e’ is constant.

At some instant the inductance is constant, ‘e’ will be zero and \( L \frac{\partial i}{\partial t} \) will be a constant.

Thus the equivalent circuit of SRM changes from being mainly on inductance and emf.

Multiply equation (1) by current ‘I’ on both sides, we get

\[ Vi = (Ri + L \frac{\partial i}{\partial t} + i \omega \frac{\partial L}{\partial \theta}) I \]

\[ i^2 R + Li \frac{\partial i}{\partial t} + i^2 \omega \frac{\partial L}{\partial \theta} \]

This equation is power equation of the SRM.

where

- \( Vi = \) electrical power supplied in watts
- \( i^2 R = \) resistive loss
- \( Li \frac{\partial i}{\partial t} = \) power associated with incremental inductance
- \( i^2 \omega \frac{\partial L}{\partial \theta} = ei = \) power due to self emf.

- Power associated with change in stored energy
- Power converted into mechanical stored energy in the magnetic field.
\[ W_s = \frac{1}{2} L i^2 \]

Power associated with change in stored energy \[ \frac{dW_{st}}{dt} = \frac{1}{2} L (2i) \frac{\partial i}{\partial t} + \frac{1}{2} i^2 \frac{\partial L}{\partial t} \] (4)

Power converted into mechanical \[ P_m = V_i - i^2 R - \frac{dW_{st}}{dt} \] (5)

Substitute equations(2) and (3) in equation (4), we get

\[ P_m = i R + L i \frac{\partial L}{\partial i} + i^2 \frac{\partial L}{\partial \theta} - i^2 R - L i \frac{\partial L}{\partial t} - \frac{1}{2} i^2 \frac{\partial L}{\partial \theta} \]

\[ P_m = \frac{1}{2} i^2 \frac{\partial L}{\partial \theta} \]

\[ P_m = \omega T \]

Torque developed by an SRM

\[ T = \frac{p_m}{\omega} \]

\[ = \frac{1}{2} i^2 \omega \frac{\partial L}{\partial \theta} \]

\[ = \frac{1}{2} \frac{\partial L}{\partial \theta} \omega \]

\[ T = \frac{1}{2} i^2 \frac{\partial L}{\partial \theta} N - m \] (6)

Fig. 3: Simulation Block diagram of Torque ripple SRMotor Drive
RESULTS AND DISCUSSIONS

In order to evaluate the performance of the proposed SRM drive, it has been subjected to computer simulation by MATLAB software. The simulation results of the proposed converter have been compared to the result of a SRM drive which employs a regular asymmetric converter.

The simulation results of a asymmetric converter is graphically represented in Fig. 4. Here the flux linkages, phase current, torque and angular velocity are taken into consideration for the analysis. From the graph it is observed that this converter causes more ripples in torque. This is because the excessive variation in flux density makes the phase current to be non linear which results in immoderate torque.

![Fig. 4: Minimization of torque ripples in SRM by using asymmetric converter](image)

![Fig. 5: Minimization of torque ripples in SRM by using proposed IGBT converter](image)
Fig. 4: Comparison of minimization of torque ripples in SRM by using asymmetric converter and proposed converter

The Fig. 5. depicts the simulation result of proposed IGBT based controller. From the out waveform it is found that the performance of the drive has been improved. This is due to the fact that the linear variation of flux produces the uniform phase current and hence the torque obtained by the drive curtails the unwanted ripples. The angular velocity also seems to be constant. The torque ripple of the proposed control scheme is much reduced than the conventional asymmetric converter. The result demonstrates that the IGBT based converter improves the performance of the drive by reducing the torque ripple.

CONCLUSION

The SRM drive exhibits a typical vibration, torque ripple and noise characteristics. Hence when operating at generated speed and normal situation it has a precise processing time to execute their control instructions. Some of these parameters prevent the execution of switched control technique in motor phase windings. In this paper a simple approach of IGBT based controller has been suggested for power semiconductor switching circuit, which is responsible for energizing the stator. The instant switching and effective characteristics of IGBT effectively manipulates the flux, phase current angular velocity of the motor for the minimization of torque ripples. From the experimental results obtained it is found that the proposed methodology performs well in reducing the torque ripples. In order to validate the outcomes it has been compared with that of a conventional asymmetric converter hence the proposed method can be well suited for practical applications of SRM drive which can pave a simple way for the industrial applications.

REFERENCES


