

Torque ripple reduction of switched reluctance motor drives below the base speed using commutation angles control

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ABSTRACT : This paper mockles the problem of high torque ripple in current controlled switched reluctance motor (SRM) drives. Torque ripple reduction below the base speed of the motor is studied through adjustment of both turn-on and turnoff angles. A multi objective optimization function is used to determine the proper turn-off angle in each operation point. Based on a proposed approach on intersecting of the consecutive phase currents, the turn-on angle is properly adjusted. The proposed method is quite easy to implement and does not need the exact parameters of the motor to run. Simulations and comparisons are also presented to validate the proposed control scheme. High speed drive systems are much interested in the industrial application such as blower, compressor, pump and spindle due to the compact size and high efficiency. In recent, the demands of high speed drives are much increased due to the mechanical advantages of high speed system. SRMs (Switched Reluctance Motors) have simple structure and inherent mechanical strength without rotor winding and permanent magnet.

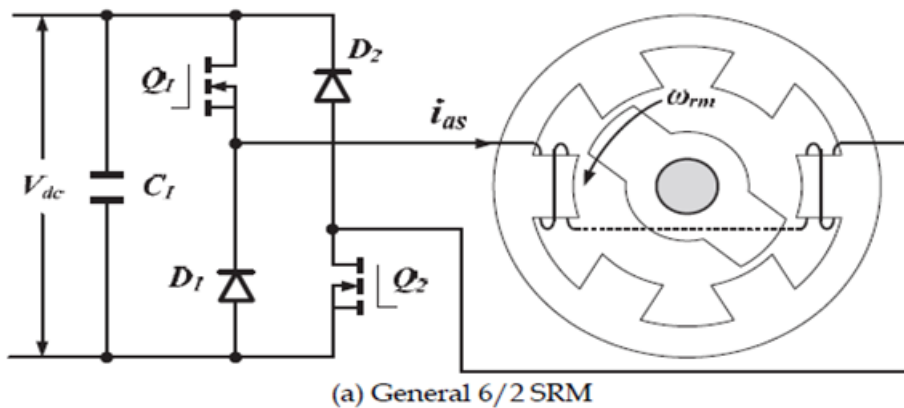
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I. INTRODUCTION

The mechanical structure of a switched reluctance motor is suitable for harsh environments such as high temperature and high speed applications. Although SRMs have many advantages for the high speed applications, high torque ripple is still main problem to be applied to a high speed drives. SRM (Switched Reluctance Motor) has been researched in last 150 years. However, significant amount of attention to this motor type was given in last few decades thank to the development of microcontrollers, power semiconductors and CAD technology. But compared with other motor, SRM cannot be operated without inverter. Therefore, it is suitable for variable speed application because inverter is essential. SRM is a doubly salient machine because both the stator and rotor have salient poles. Flux is created by concentrated stator winding only. There are no permanent magnets, commutators, and windings in rotor side. So, SRM has simple and robust rotor structure that is very important in high speed application because centrifugal force is very high when rotor rotates at high speed. Due to a simple structure at the stator and the rotor, SRM can compete with other types of motor. The SRM is an electric machine that converts the reluctance torque into mechanical power.

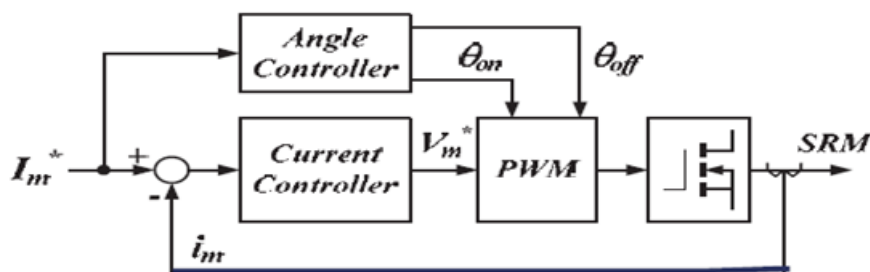
In the SRM, both the stator and rotor have a structure of salient-pole, which contributes to produce a high output torque. The torque is produces by the alignment tendency of poles. The rotor will shift to a position where reluctance is to be minimized and thus the inductance of the excited winding is maximized. The SRM has a doubly salient structure, but there are no windings or permanent magnets on the rotor. The rotor is basically a piece of steel (and laminations) shaped to form salient poles. So it is the only motor type with salient poles in both the rotor and stator. As a result of its inherent simplicity, the SRM promises a reliable and a low-cost variable-speed drive and will undoubtedly take the place of many drives now using the cage induction, PM and DC machines in the short future. The number of poles on the SRM's stator is usually unequal to the number of the rotor to avoid the possibility of the rotor being in a state where it cannot produce initial torque, which occurs when all the rotor poles are aligned with the stator poles. Constructions of SRM with no magnets or windings on the rotor also bring some disadvantage in SRM. Since there is only a single excitation source and but also magnetic saturation, the power density of reluctance motor is lower than PM motor. The construction of SRM is shown in Fig. 4. The dependence on magnetic saturation for torque production, coupled with the effects of fringing fields, and the classical fundamental square wave excitation result in nonlinear control characteristics for the reluctance motor.

II. FUNCTIONAL UNITS



In order to overcome the inherent torque dead-band, asymmetric SRMs are investigated. These types have wide positive torque region with a short negative torque region, and are useful in an unidirectional application such as blowers and fans. For the single phase SRM, hybrid type using permanent magnet is researched. The inserted permanent magnet can produce cogging torque during torque dead-band. However, the torque of the inserted PM poles cannot be controlled, so it has high torque ripple but smaller than a conventional single-phase SRM.

To reduce the torque ripple of stepper region, optimization design process can be adopted. From these research results, the inherent torque dead-band can be reduced. The other is from the non-linear characteristics of inductance and un-constant torque by the constant current due to the saturation effect. Although the output torque is proportional to the inductance gradient, the inductance gradient is not constant. The inductance has non-linear according to rotor position due to the saturation effect.



III. FILTER DESIGN

The selection of LC component present in the filter plays a major role in the performance of the drive. The charging and discharging of the capacitor improves the quality of the voltage given to the motor.

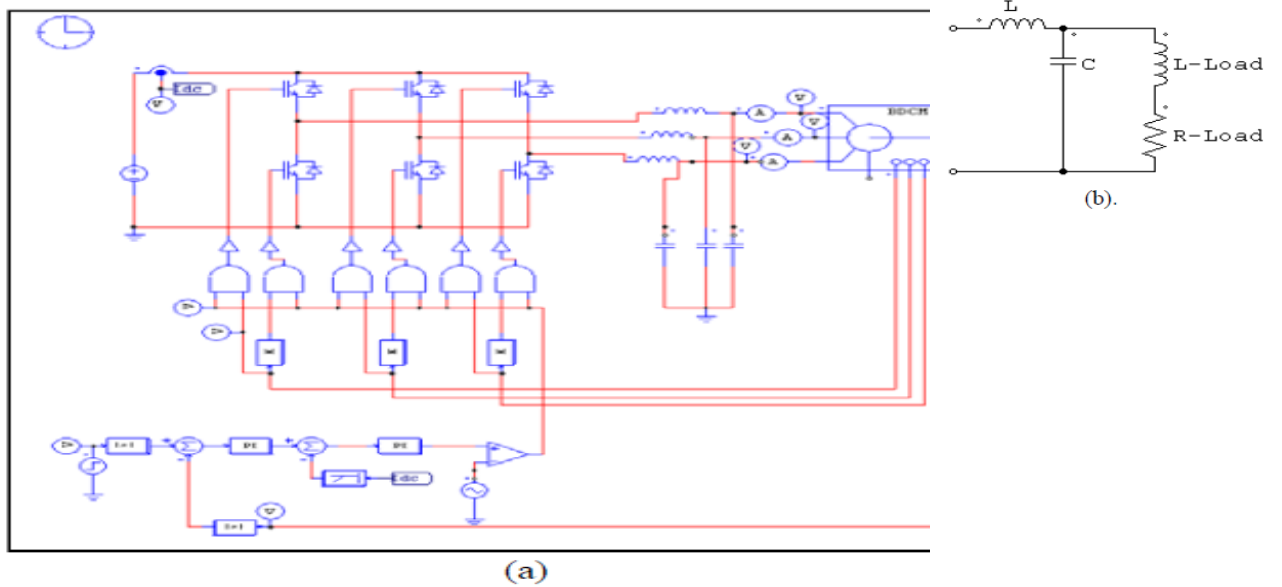


Figure 2 (a) Circuit for simulation analysis, (b) equivalent LC filter for one phase

Now the peak inductor current,

$$I_{\text{peak}} = \frac{2V_m}{Z_{\text{min}}} \dots\dots\dots(1)$$

Where Z_{min} is the minimum value of load impedance, V_m is the peak magnitude of the phase voltage. The capacitance of the filter is

$$C = \frac{V_m}{2Z_{\text{min}} f_{\text{sw}} \Delta V} \dots\dots\dots(2)$$

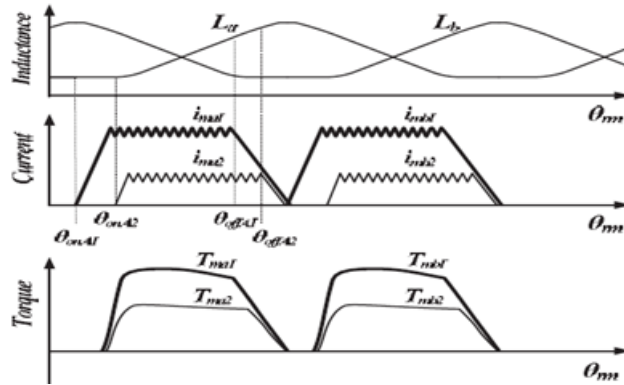
ΔV is the ripple voltage at the input of the filter f_{sw} is the switching frequency of the inverter power devices, that is equal to the ripple frequency. t_{on} and t_{off} are the on time and off time of the power devices.

$$t_{\text{on}} + t_{\text{off}} = \frac{1}{f_{\text{sw}}} \dots\dots\dots(3)$$

The value of the inductance is calculated as

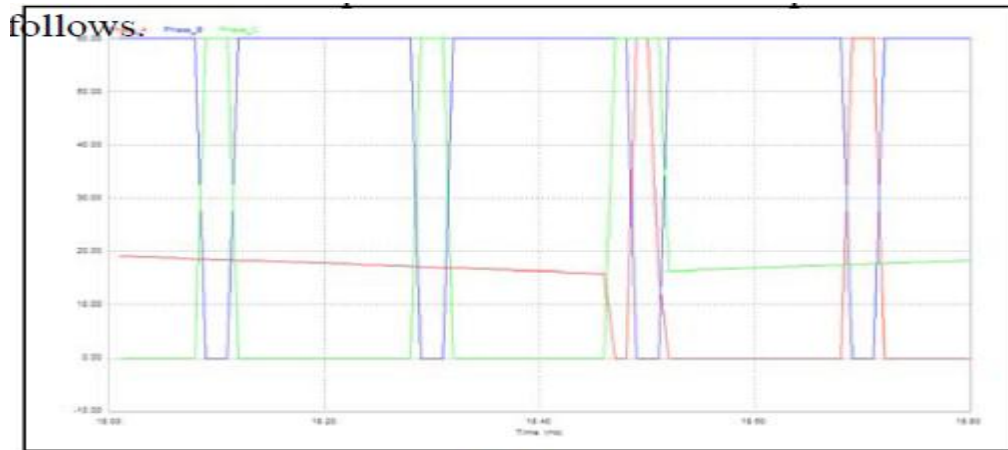
$$L = \frac{V_s - V_o}{I_{\text{peak}}} \times t_{\text{on}} \dots\dots\dots(4)$$

V_s is the source Voltage of the filter and V_o is load voltage.



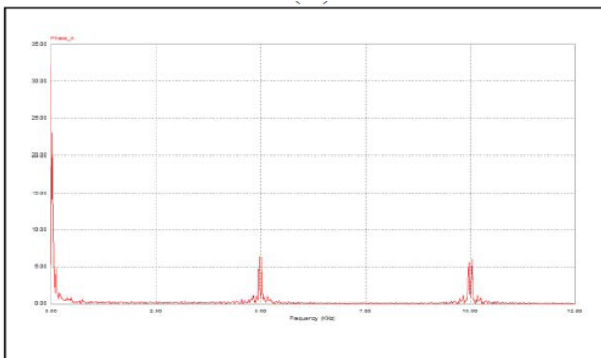
IV. SIMULATION AND EXPERIMENTAL RESULTS

Various simulations are done using simulation software for the converter circuit presented in Fig 2. The

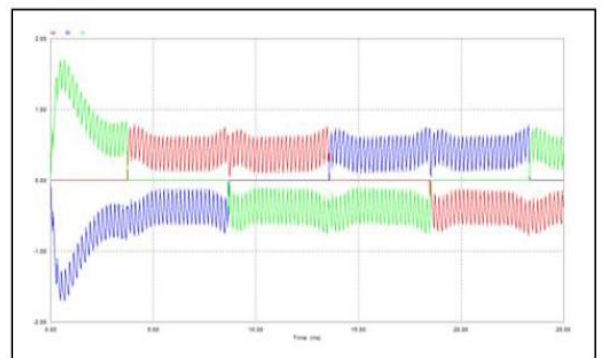


(3a)

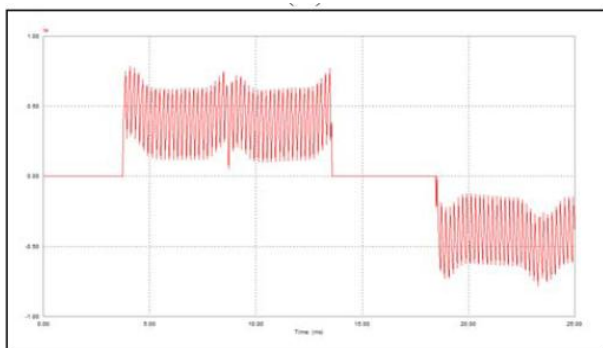
simulation values are set based on the sample calculation and simulated results for the drive circuit is compared for the system with filter and without filter. In this paper, simulated and experimental results are presented as follows.



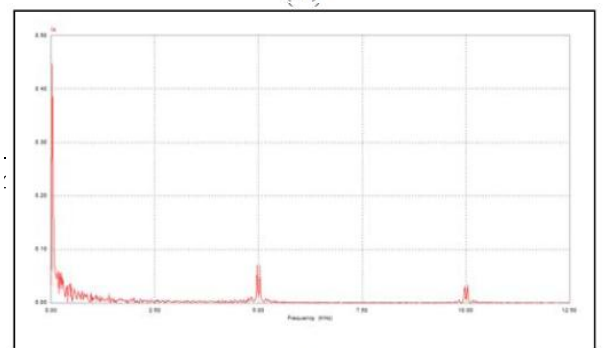
(3b)



(3c)



(3d)



(3e)

Figure 3. Current and Voltage analysis without filter (3a) Three phase magnified voltage input to motor. (3b) the FFT analysis for Phase -A voltage. (3c) the three phase current simulate waveform. (3d) magnified phase current for phase-A. (3e) the FFT analysis for line current in Phase –A.

Fig 3. (a) shows the magnified voltage of the motor input voltage at the time of commutation. The three phase voltages at any particular instant is shown in 3 colored waveform. Fig. (3b) shows the harmonics present in the phase-A of the voltage to the motor. The harmonics are present in the switching frequency of the power devices and the multiples of switching frequencies. Fig. (3c) shows the combined waveform for the three phase current input to the motor. The magnitude at the starting is higher. Fig. (3d) shows the magnified line current (Ia) (e) shows the FFT analysis of the harmonics presents in the line current (Ia). At 5 KHz and 10 KHz the harmonics component is around 30%. The line current varies abruptly during commutation. This causes the jerk in the motor due to sudden variation of torque. For higher speed of operation this jerk causes vibration and acoustic noise.

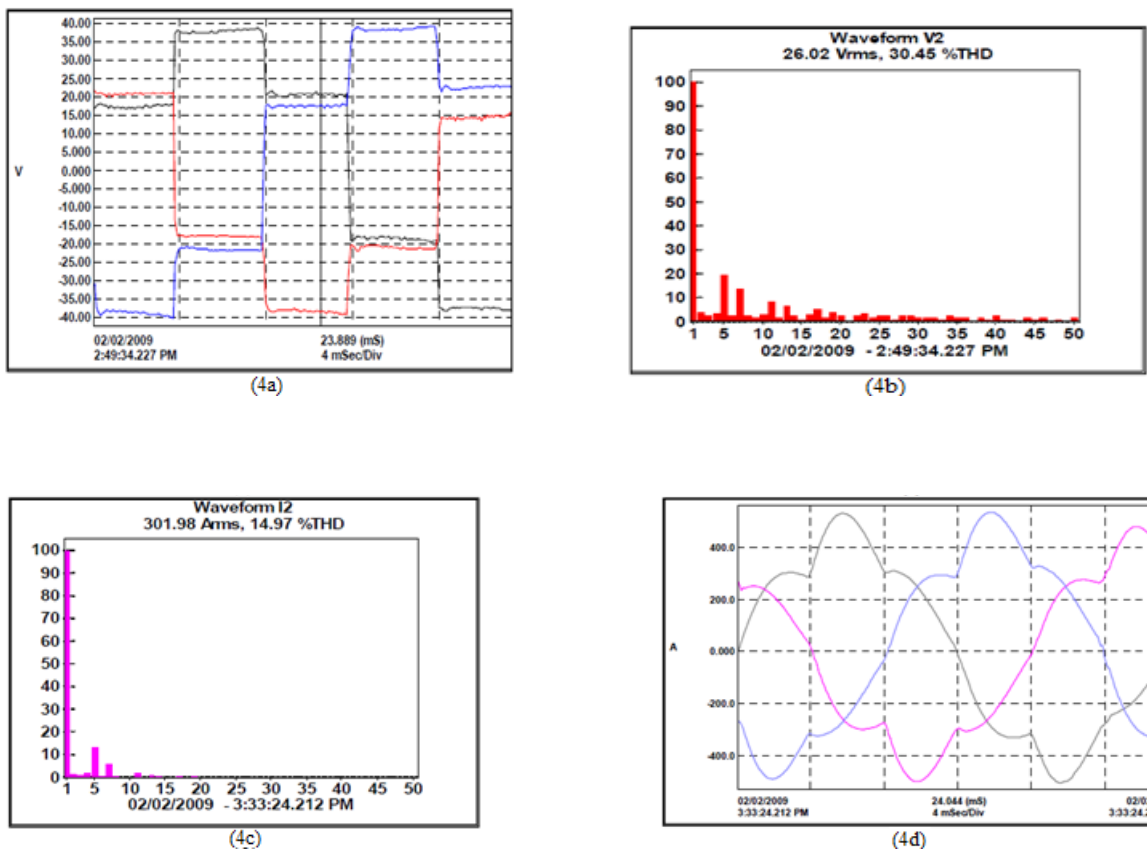


Figure. 4. Experimental result of harmonics analysis for phase voltage and line current with filter. (a) Phase voltages of the motor with filter (b) harmonic analysis for the voltage. (c) harmonic analysis for line current. (X axis –Harmonic order, Y axis- Magnitude in Percentage of fundamental) (d) Phase currents of the motor.

V. CONCLUSION

The reasons of the torque ripple in SRM are the inherent torque dead-zone from the design scheme, non-linear torque characteristics and the negative torque in a high speed region. The inherent torque dead-zone can be removed by the design approach in two-phase SRM and Hybrid single-phase SRM. This torque ripple source cannot be removed by the control approach due to the inherent torque production mechanism of SRM. Various torque control approaches can reduce the torque ripple from the non-linear torque characteristics of SRM. DTC and TSF method are good choice to improve the torque control performance although they require a complex torque data of the practical motor. However, the performance of the current controller is much decreased. So, the conventional torque control scheme has torque ripple due to the current error and tail current. In order to reduce the tail current and current error in a high speed region, advance converter topologies which can supply additional boost voltage to increase the current control performance are introduced. These converters can reduce the current error in the torque control scheme, and it can improve the torque control performance in the high speed region. The negative torque from the tail current during the high speed can be compensated by the simple compensation technology. The detailed control scheme to compensate the negative torque is presented. The simulation and experimental results show the effectiveness the advanced converter topologies and torque compensation technology.

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