Design and Simulation of Converter with Improved Performance for Switched Reluctance Motor

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***Abstract*- In this paper a new converter is proposed after analyzing the merits and demerits of all conventional converters for switched Reluctance Motor (SRM). The proposed converter uses only one switch per phase and phase inductance energy is sent back to the source. Overlapping of phase currents and faster phase current commutation of this proposed converter reduces the negative torque and torque ripples which is the main drawback of switched reluctance motor drives. Design calculations for the converter is performed. Simulation of the SRM along with the asymmetric bridge converter and proposed converters are completed using MATLAB Simulink and the results are analyzed and compared. The simulation results are presented and it shows that the new converter performs the phase current commutation faster than the asymmetric Bridge converter which in turn reduces the torque ripples.**

Index Terms- Switched Reluctance Motor, fast commutation, Asymmetric converter.

I. INTRODUCTION

The Switched Reluctance Motor (SRM) drive is receiving increasing attention from industries for adjustable speed drive applications. Switched Reluctance Motor (SRM) drives are extremely rugged construction, fault-tolerant capabilities, high torque to weight ratio and simple construction as compared to other AC or DC motor drive systems.
The switched reluctance motor (SRM) is a 'doubly-salient and singly excited' machine. The SRM has inherent mechanical strength without rotor winding and permanent magnet. Major drawbacks of the SRM are acoustic noise and the torque ripples. The torque ripples in the SRM are arises, due to the phase current commutation. Therefore the proposed converter of SRM is designed such that it has faster phase current commutation.

Commonly used converters for SRM includes R-dump converter, C-dump converter, Asymmetric bridge converter. In R-dump converter the stored phase inductance energy is wasted by dissipating through a resistor. The advantage of this converter is it uses only one switch per phase which results in smaller size and lower cost. In C-dump converter the phase inductance energy is stored in capacitor but the drawback with this converter is number of switch used per phase is increased. In asymmetric converter torque ripple is reduced to greater extent but the number of switches and diodes used for freewheeling is increased thus increasing the complexity of the circuit.
The proposed converter uses only one switch per phase and stored phase inductance energy is sent back to the source. Overlapping of phase currents and faster phase current commutation of this proposed converter reduces the negative torque and torque ripples which is the main drawback of switched reluctance motor drives. Regarding the number of switches used this converter is similar to r dump converter and it function like c dump converter since the phase inductance energy is recovered and sent back to the source.

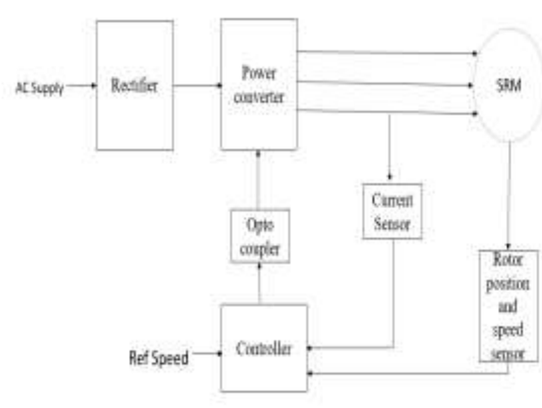
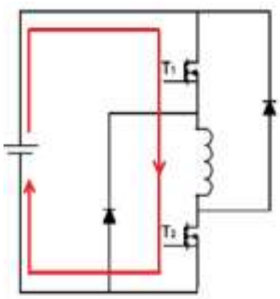


Fig 1 Block diagram of converter for SRM

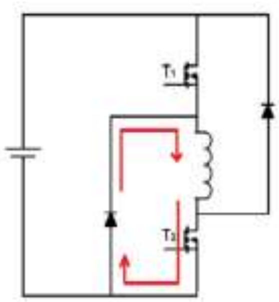
II. CONVERTER SELECTION

A. Asymmetric converter

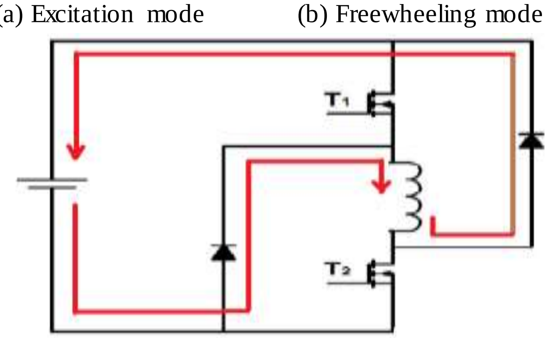
The most widely used converter for Switched Reluctance Motor is the asymmetric bridge rectifier. In this, the winding is connected between the two switches.Fig.2 shows the asymmetric bridge rectifier, which is most widely used for Switched Reluctance Motor. In this design, each phase winding uses two switches. The switch S2 is in charge of commutation, while the switch S1 is used to perform the PWM switching control. The switch S2 is in charge of commutation, while the switch S1 is used to perform the PWM switching control. In asymmetric half bridge design each phase can be controlled independently. From the current controlled PWM switching control, there are three modes of operation. They are, Excitation mode, Freewheeling mode and de-energization modes are shown in the Fig.2.



(a) Excitation mode



(b) Freewheeling mode



(c) De-energization mode

Fig 2 Operating modes of asymmetric converter

B. Proposed converter

The figure 3 shows the per phase structure of the proposed SRM drive topology. The various operating modes of the proposed converter are

i. Magnetization mode

ii.Demagnetization mode

iii. Overlap of two phases

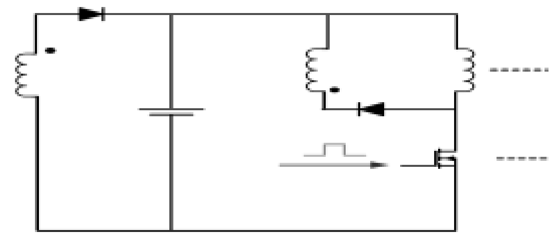
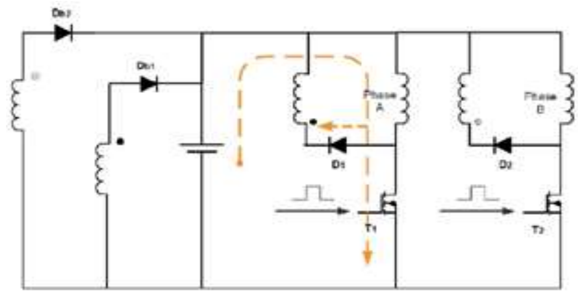
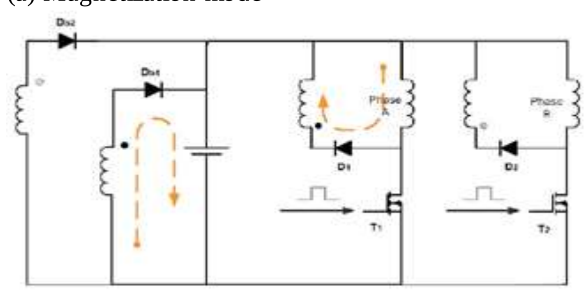


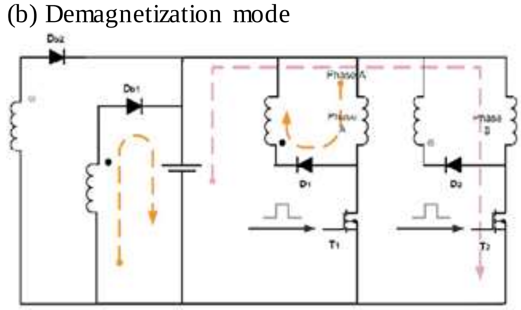
Fig 3 Circuit diagram of per phase of the proposed converter



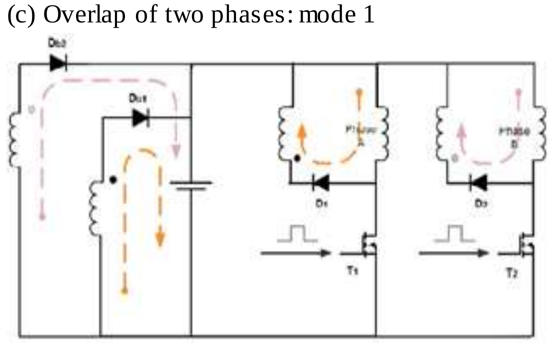
(a) Magnetization mode



(b) Demagnetization mode



(c) Overlap of two phases: mode 1



(d) Overlap of two phases: mode 2

Fig 4 Operating modes of proposed converter

Magnetization mode

In the magnetization mode (Fig.4 (a)), the switch T1 turns on in order to magnetize phase ‘a’. AS T1 turns on, the energy is transferred from the source to phase winding and the current in phase inductance increases. Also, in this mode if the magnetizing inductance of coupled inductors is not reset yet, diode D1 would conduct the magnetizing inductance current of the coupled inductors and the input voltage would reset this inductor. When the magnetizing inductance of coupled inductors is reset, Diode D1 turns off.

Demagnetization mode

When the phase current reaches the reference, T1 is turned off and demagnetization Starts. In this mode (Fig. 4(b)) the voltage across phase winding is reversed, diode D1 Turns on in this mode. When D1 turns on, Db1 turns on and a negative voltage is placed across the phase winding in proportion to the coupling ratio which accelerates phase current commutation.

Table.1 Comparison of various converters for SRM drive

Converter	R-Dump	C-Dump	Asymmetric	Proposed
No.of phases	3	3	3	3
No.of switches	3	4	6	3
Energy	Dissipate	Recovered	Recovered	Recovered
commutation	Not fast enough	Not fast enough	Not fast enough	Fast
Negative torque	High	<R-dump	Moderate	Reduced
Efficiency	Low	> R-dump	High	High
Applications	Low speed	Low speed	Low and Medium speed	Medium and high speed

Overlap of Two Phases

Fig.4 (c) and Fig.4 (d) Show two overlapping modes of stator phase currents. In the First mode, the phase inductance ‘a’ is being demagnetized and phase ‘b’ is being magnetized. In the second mode, both ‘a’ and ‘phases are being demagnetized. As it can be observed, this converter has the ability to separately control phase currents. Also, It is important to notice that the snubber circuit of each switch will absorb the Voltage spikes across the switches that, otherwise would occur due to leakage inductance of coupled inductors

III. DESIGN CONSIDERATION

For designing this converter, the coupled inductors ratio has to be determined considering the performing speed of the drive. If the phase current does not reach zero fast enough during the commutation, the phase current continues to exist in the negative torque production area and the phase torque becomes negative. This negative torque will cause large ripples in the torque generated by the motor. This is especially important at higher speeds, because higher speed requires faster commutation. So, each SRM drive can function to an extent of speed with regard to its converters structure. The maximum SRM drive speed depends on the type of converter used and is illustrated by the following equation.

$T_f = \tau_a \ln [1+(R_s I_p)/V_c]$ (1)

Where,

T_f is the time needed for the current to reach from reference value to zero.

τ_a is the electrical time constant of machine phases.

R_s is the resistance of each phase winding.

V_c is the reverse voltage applied to the phase inductance during commutation.

The electrical time constant equation of the machine is as follows.

$\tau_a = L_a/R_s$ (2)

The phase inductance at the current commutation area equals to aligned inductance, thus L and τ would take an “a” subscript.

Current drop angle at speed ω is calculated as follows.

$\theta_f = \omega_m T_f = [\omega_m T_a] \ln [1+(R_s I_p)/V_c]$ (3)

As it can be observed from (3), when speed increases, θ_f becomes larger resulting in a larger negative torque and, consequently, more torque ripples. Therefore, it is needed to look for a way to reduce θ_f at higher speeds. As it can be observed from (3), commutation can be carried out faster by increasing V_c. In the proposed converter, the reverse voltage across the phase winding can be increased for faster commutation purposes by increasing the coupled inductors L1 and L2 turns ratio. Also it is important to notice that V_c is constant in most of the converters introduced so far. But, in this converter, V_c can be designed by changing the coupled inductor turns ratio considering the maximum SRM drive functioning speed.

IV. SIMULATION RESULTS

The simulation results of the SRM drive using the proposed converter is compared with SRM drive that use asymmetric converter.

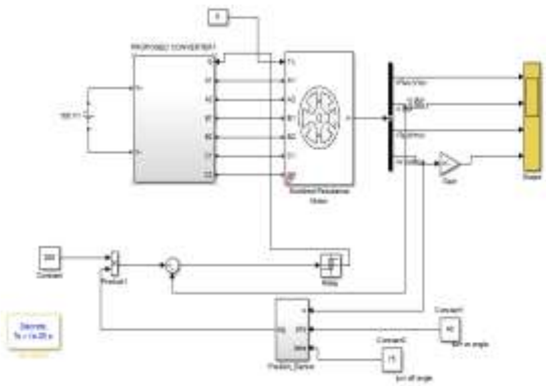


Fig.5 Simulink model of proposed converter

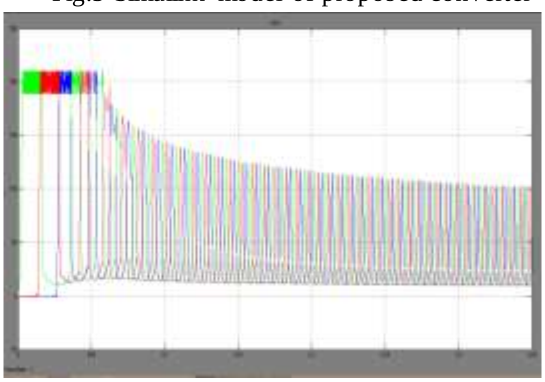


Fig.6 Phase current waveform of asymmetric converter

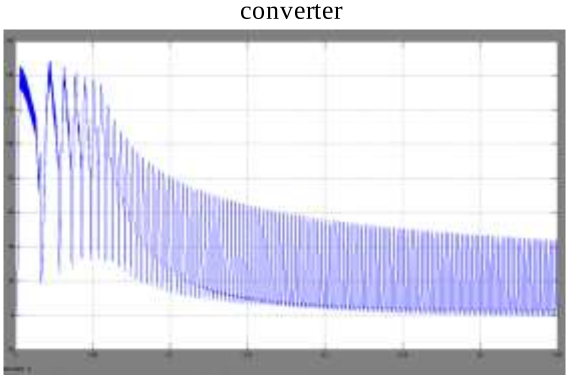


Fig.7 Torque characteristics of proposed converter

In asymmetric converter as explained before, the angle θ_f becomes larger as speed increases. Consequently, causes more torque ripples.by increasing the coupled in inductor turns ratio in proposed converter torque ripples are reduced.

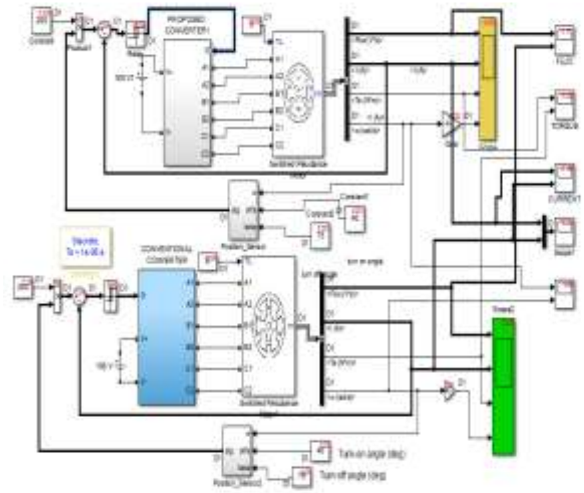


Fig.8 Simulink model for comparison of asymmetric converter and proposed converter

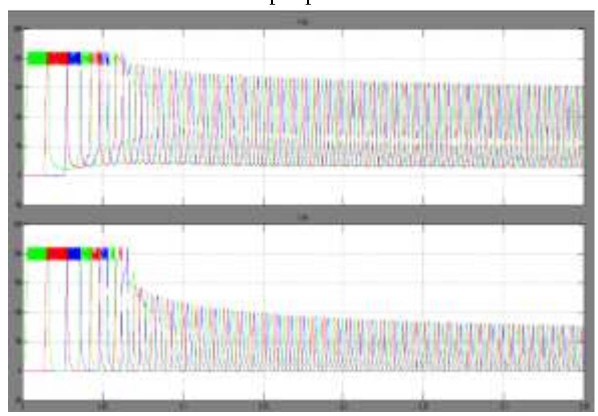


Fig 9 Comparison of current waveform

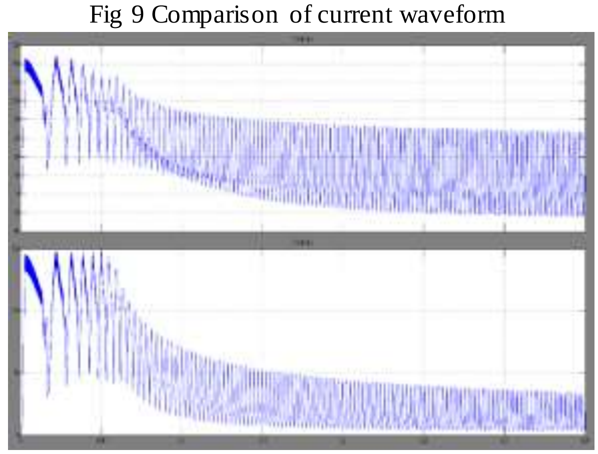


Fig 10 Comparison of torque waveform

For simulation purposes coupling ratio is selected 3:4.Figure 9 shows the comparison of SRM phase currents that are driven by a regular asymmetric converter and proposed converter at 2500 rpm. Comparing the phase current waveforms of Asymmetric converter and proposed converter, the commutation time has considerably decreased which improves the commutation process with high speed making it as an excellent drive for Switched Reluctance Motor

V. CONCLUSION

Thus the new drive for Switched Reluctance Motor is proposed and introduced. The proposed converter is designed, analyzed and its operating modes are discussed. The proposed converter only uses one switch for each motor phase. The proposed converter's operation is simple with a minimum number of switches (one switch per phase) and it is performing phase current commutation quickly. Simulation of asymmetric and proposed converter using MATLAB Simulink was completed and the results are presented.

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