Delta Converter Modification in SR Machine

Seyed Borhan azimi
AmirKabir Univ. of Technology

Hassan Ghafoori Fard
AmirKabir Univ. of Technology

Amin Hassan Yazdavar
AmirKabir Univ. of Technology

Abstract: In this paper, overall comparison between two suitable converters for switched reluctance motors, one, new invented delta and the other, well-famous asymmetric bridge converter is performed. Defects of both converters in current control at high speeds are presented. Also, a modification in delta converter structure is carried out to improve its performance under usage of hystresis controller. Prevention from bus over voltage at energy recovery is another advantage of modified delta converter. Finally, simulations of both converters in supplying energy requirement of a SR motor are presented.

Keywords: Delta, AHB, Inverter, SRM

1. Introduction

Novel inverter configurations, based on the three-phase bridge, have been demonstrated to work very effectively with both short pitched winding [4] and fully pitched winding machines [5]. Conversion process from AHB converter to Delta converter is presented in [2]. Fig. 2 shows delta inverter used to produce unipolar currents in a three-phase SR machine. Diodes are placed in series with each phase to force the phase currents to be unipolar. As all three phases are now connected together, the phases cannot be independently controlled. i.e. the sum of the voltages applied to the windings must be zero (Va + Vb + Vc = 0) and the sum of the line currents must be zero.

Three additional diodes are required with the delta circuit to prevent the phases current from becoming bipolar. It should be noted that these diodes do not see any large di/dt and do not contribute to turn on losses in the active devices due to stored charge effects. They can therefore be of a standard recovery type and are low cost.

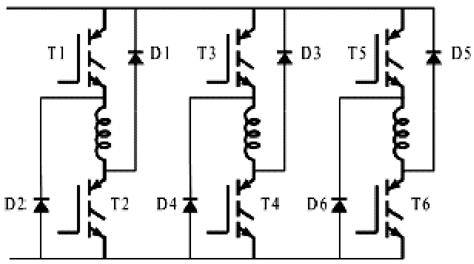


Fig. 1: Asymmetric half bridge converter

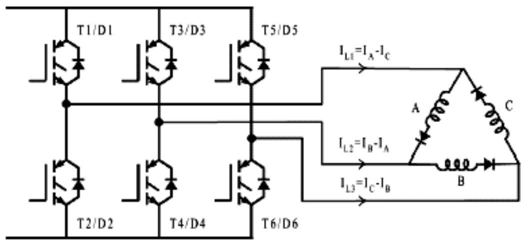


Fig. 2: Delta converter

2. Comparison of AHB and Delta converters

Some of advantages of DID inverter (delta inverter with diode) to AHB inverters (asymmetric half bridge) are described below:

Ability of implementation using intelligent power modules (IPM).Using IPM, in comparison with discrete switches, simplifies drive implementation because of its internal protection against over voltage, over current and over temperature and so brings to reduce inverter and heat sink size.

Also, using delta configuration, because of its likeness to induction motor and BLDC motor inverters, causes to use this configuration for drive other type of motors only by changing software of drive. Loss in the delta inverter is also more less with comparison to AHB inverter and so start torque in delta is more than AHB [2-4].

3. Operation of SR machine in brake mode using AHB inverter

The SRM as generator is the dual of the machine as a motor [5, 6]. In fact the machine phase current waveforms during generating are simply the mirror images, around the aligned rotor position, of the phase currents during motoring [5, 6]. Current waveform in a typical SR machine shows in Fig. 3:

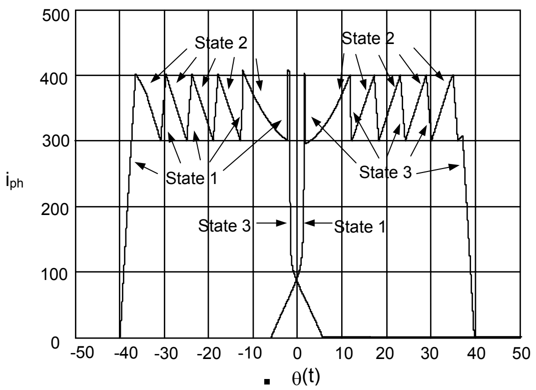


Fig. 3: Simulated phase current for low speed motoring and generating with converter states labelled.

To obtain generating action with the SRM, the phase current must activate in negative torque region. In this case, because of inductance decrease and increase of negative EMF, phase current increases and generation occurs. Operation of an AHB inverter to drive a SR machine is summarized in table 1:

Table 1: Summary of SRM duality between motoring and generating.

Motoring	Generating
Both switches on - Current increases	Both switches off - Current decreases
One switch on, one switch off - Current decreases	One switch on, one switch off - Current increases
Both switches off - Current decreases	Both switches on - Current increases
Current starts before pole overlap, before alignment	Current ends after pole overlap, after alignment
Current ends after alignment	Current begins before alignment

Practically, hysteresis method is used to control the current in motoring and generating mode. In this way, by switching the switches, current retains between two specified values. This method do not encounter to any problem in motoring and low speed generating modes, but in high speed generating mode, while we want to apply a large braking force using high controlled current, this method can not control the current and high current will hurt to motor and power electronic components.

4. Analyze of operation

In the braking mode, every phase that is in the negative torque region, acts as a current source [7], and its current can be obtained by solving equation. 1-4:

$$V_{phase} = R_{Ph}i + \frac{d\psi}{dt} = R_{Ph}i + L(i,\theta)\frac{di}{dt} + i\omega\frac{dL}{d\theta} \quad (1)$$

$$V_{bus} = V_{DC} + \frac{1}{C}\int i_R dt \quad (2)$$

$$V_{phase} = V_{bus} \qquad \text{Stage 1} \quad (3)$$

$$V_{phase} = -V_{bus} \qquad \text{Stage 2} \quad (4)$$

Because the term $\frac{dL}{d\theta}$ is negative in the generating region, so by increasing the velocity, the term $i\omega\frac{dL}{d\theta}$ will add to V_{phase} and causes to current increase (stage 1). If we cut-off switches, reverse voltage will connect to phase and causes to small reduce in current (Stage 2). This reduction causes to $L\frac{di}{dt}$ be negative. Now if phase voltage is less than bus voltage, current decrement will continue, but if phase voltage is more than bus voltage, like in high speed, current will increase (Fig. 7, 8) until bus voltage riches the phase voltage because of charging capacitors, and then current will decrease (stage 3).

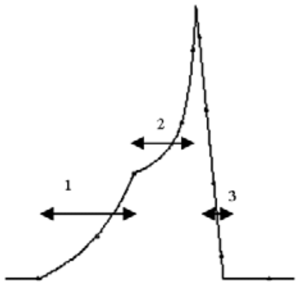


Fig. 4: phase current waveform in high speed, braking mode and its change stages.

5. Operation of SR machine in brake mode using Delta inverter

In the case of use delta inverter to drive SR machine, we have an operation like AHB configuration, but in the delta configuration, phases are not independent, thus a few current will flow in other phases. To study currents more accurately, strictly mathematical simulation and concurrent solving of three phase equation is needed, but briefly express for this configuration is like AHB configuration. In the first stage, both switches are on and current will increase, and when switches are off, phase is inversely connected to dc bus using freewheeling diodes. Now when bus voltage is less than phase voltage, current will increase and when bus voltage reaches to phase voltage, current will decrease, but here amount of current will circulate in other phases.

6. Proposed method

In the Fig. 5, a modified structure is proposed to eliminate the problem of Delta converter in the braking mode of SR machine.

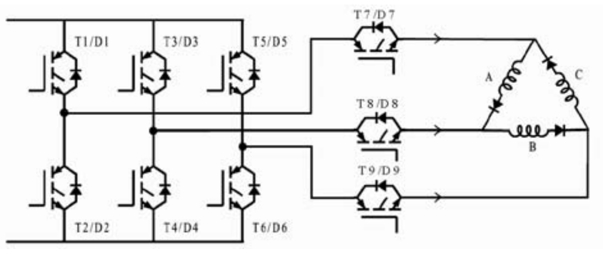


Fig. 5: modified delta converter

In this method, hysteresis controller of every phase fully controls the current of phase by controlling the IGBT T7-T9 in addition to three phase bridge controlling. For example, to decrease the current in phase A, T1, T4 and T7 will turn off simultaneously. Operation method briefly described below:

By disconnecting the input head of phase from bridge, other phases will provide the first phase's current and phase voltage will be equal to sum of other phase voltage, and thus the current will decrease in the phase.

7. Computer simulation

Simulation of SR machine and its drive and controller circuits is performed using Spice for assurance of safe operation of proposed method. Therefore a SR machine model with below specification is used:

Power:	4 KW
Vbus:	510 V
Speed:	1600, 5000 RPM
$I_{hysteresis}$:	10A, 20A

As shown in Fig. 6, by setting the hysteresis controller's reference current on 10A, current will decrease and is controllable. But by setting the hysteresis controller's current on 20A, phase voltage exceeds the bus voltage and causes to current increase (Fig. 7) whereas in lower speeds of 1600 RPM, it is possible to control current around 20A.

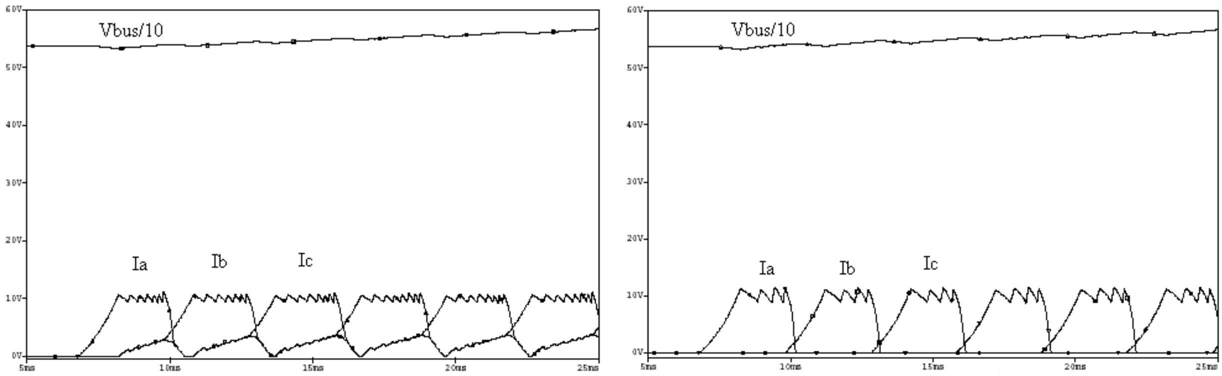
Also bus voltage increase caused by phase regeneration current, which leads to fault in power devices, is shown in Figures too. In the Fig. 8, simulation response is shown for 5000 RPM. Here, aligning the phase in the motoring region causes to current reduction. In the Fig. 9 effect of inverter improvement on phase current and voltage is presented. It is clear that current is fully controllable and so bus voltage has not sensible increase. It is because of regeneration current flows in other phases instead of bus capacitors. Thus, need to circuits to prevent the bus over voltage is resolved and delta converter modification cost is recoverable by this method.

8. Conclusion

As respect to the computer simulations, we understand that in high speed operation of SR machine in the brake mode in both Delta and AHB converters, the phase current is not controllable and it may cause to fault in machine or power electronic devices.

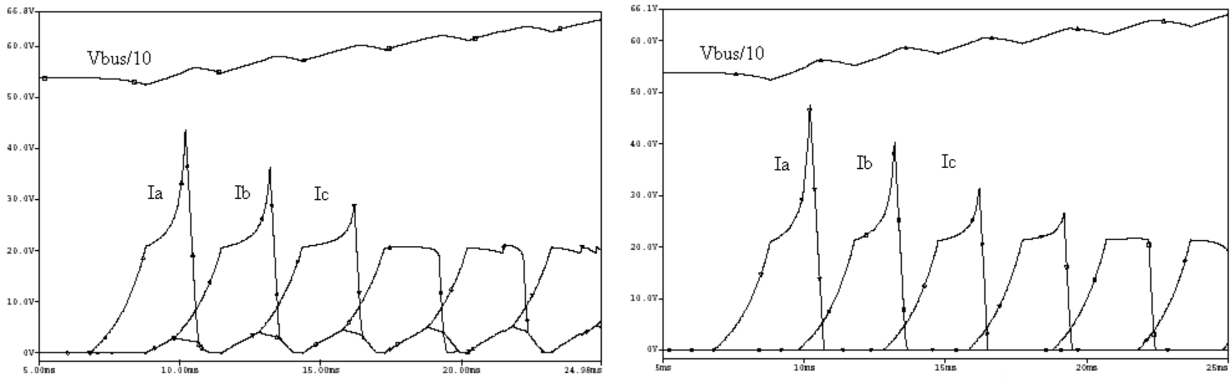
Modified structure of Delta converter, in addition to resolving above problem, prevents bus over voltage in the regeneration mode, and transfers the current to the other phases and eliminates need to circuits like the Dynamic brake or regenerative brake.

9. Simulation Figures



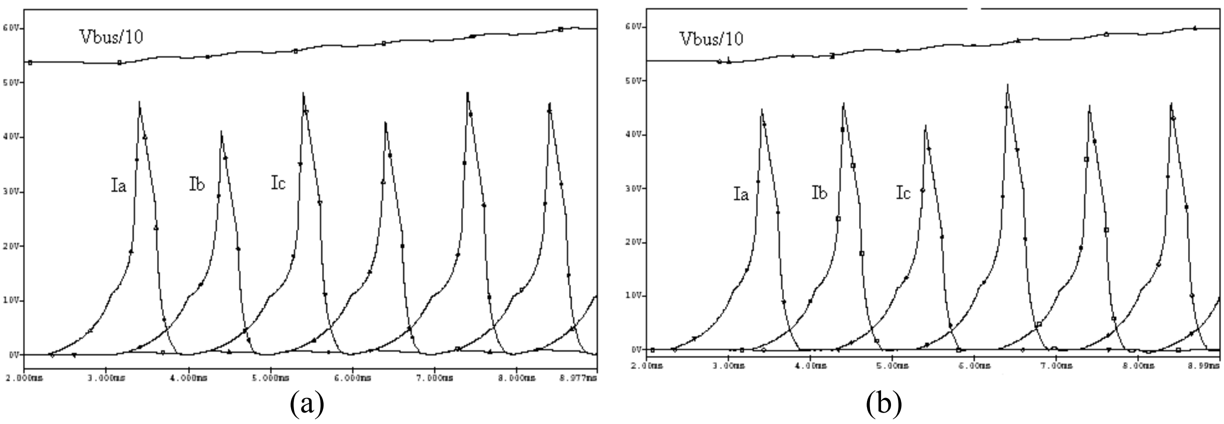
(a) (b)

Fig. 6: Current in 1600 RPM by setting the current controller on 10A in (a) Delta (b) AHB



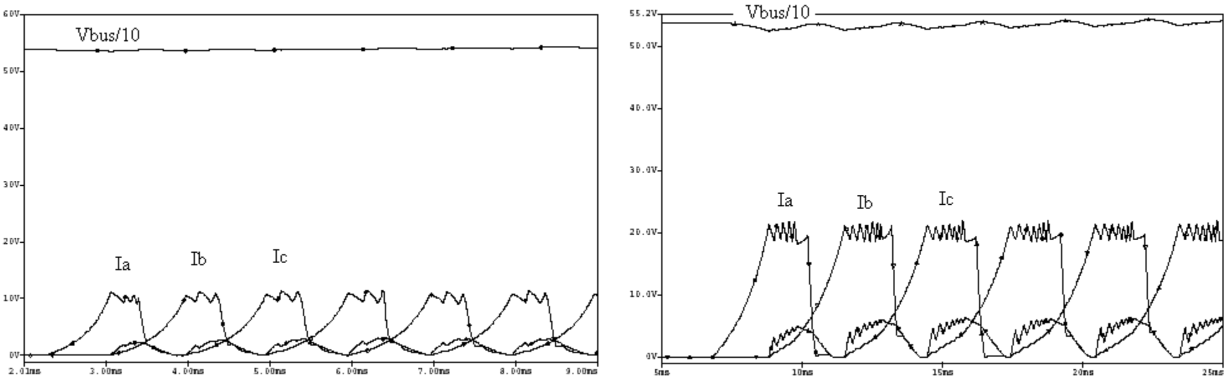
(a) (b)

Fig. 7: Current in 1600 RPM by setting the current controller on 20A in (a) Delta (b) AHB



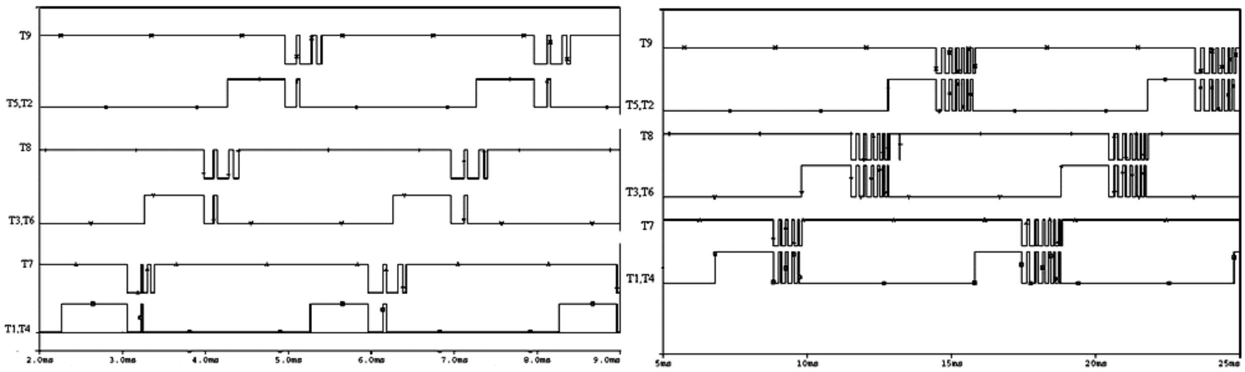
(a) (b)

Fig. 8: Current in 5000 RPM by setting the current controller on 10A in (a) Delta (b) AHB



(a) (b)

Fig. 9: Current in the modified delta converter in (a)5000 RPM ,10A (b) 1600RPM , 20A



(a) (b)

Fig. 10: IGBT's gate pulses in modified delta converter

10. References

[1] A.C. Clothier, B.C. Mecrow, *"Operation of Switched Reluctance Machines from Three Phase Bridge Inverters"*, EMD, Cambridge, Sept. 1997

[2] B.C. Mecrow, A.C. Clothier, P.G. Barrass, C. Weiner, *"Drive Configurations for Fully Pitched Winding Switched Reluctance Machines"*, Industrial Applications Society,Oct. 1998.

[3] A.C. Clothier, B.C. Mecrow*," Inverter Topologies and Current Sensing Methods for Short Pitched and Fully Pitched Winding SR Motors"*, IEEE, 1999, 0-7803-5160-6/99

[4] A.C. Clothier, B.C. Mecrow, " *The Use Of Three Phase Bridge Inverter With Switched Reluctance Drives",* Conference Publication IEE 1997, No. 444

[5] A. V. Radun, J. A. Rulison, and P. Sanza,., *"Switched reluctance starter/generator,"* Trans. SAE, J. Aerosp., v 101, n Sect 1, 1992, p 1771.

[6] A. V. Radun, *"Generating with the switched reluctance motor,"* Proceedings of the Ninth Annual Applied Power Electronics Conference and Exposition, Vol 1 pg. 41, 1994.

[7] A.V. Radun, and Y. Q. Xiang, *"Switched reluctance starter/generator system modeling results,"* Trans. SAE, J. Aerosp., vol. 104, sec. 1, pp. 257-266, 1995.