1st International Conference on Power Engineering, Computing and CONtrol, PECCON-2017, 2-4 March 2017, VIT University, Chennai Campus

Experimental Comparison of a 70 Watt Switched Reluctance Machine with Different Types of Converter Topologies

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Abstract

Two Power Converters namely (Asymmetric Bridge Converter and R-Dump Converter) that are suitable for a 70 W Switched Reluctance Motor (SRM) drive are experimentally compared with each other. The developed drive system is approached based on a Fan application. Hence, the total volume of the package is of paramount importance in the design of both motor as well as converter design. Careful design of the motor is initially studied and the performance of the motor is predetermined through FEA...As the Converter choice depends on the motor design, converter analysis and selection are done based on that. Later the converter testing is done along with the motor and the performance parameters such as volume, mass, cost, efficiency are determined.

Keywords: Power Converters;

1. Introduction

The switched reluctance motor(SRM) drive has excellent features like high robustness level, simple structure, low cost. It has windings only on the stator, no windings or permanent magnets on rotor and hence torque per volume is more comparable to Induction Motor(IM) [1] [2]. The overall efficiency of the SRM drive depends on

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both the machine and power converter and it is important to design an efficient and compact converter to match the particular application [2]. The power converter is needed for a SRM to have continuous torque production capability. Various types of power converters had been developed for SRM in the past [3]. One of the most suitable converter for high speed application is the asymmetric bridge converter (ABC) [4]. It comprises of two switches and two diodes per phase and will control the motor phases independently. For high performance drive applications where space requirement is highly precise, R-Dump converters are preferred when compared to ABC [5]. Unlike the ABC, it uses only one switch and one diode per phase which proves to be an advantage. However, the selection of the particular converter for high efficiency, reduced volume and reduced harmonics depends on the requirements of specific application. This paper experimentally compares the pros and cons of ABC and R-Dump converters for a 70 Watt two phase SRM. Chapter 2 deals with the design and Finite Element Analysis (FEA) of the 70 Watt SRM. Chapters 3 and 4 details on the simulation and hardware development of ABC and R-Dump Converters respectively. Chapter 5 provides hardware implementation with the motor and comparison of the results obtained.

Nomenclature

SRM   switched reluctance motor
ABC   asymmetric bridge converter
FEA   finite element analysis

2. Design and FEA of 70 W SRM

2.1 Analytical Design

This chapter discusses the analytical design and design verification using Finite Element Analysis (FEA). The specifications of the machine are shown in Table 1. The detailed dimensions of the SRM are shown in Table 2.

Table 1. Specifications of the SRM.

parameters	Ratings	Units
Output power	70	W
Supply voltage	230	Vac
Rated speed	1500	rpm
Maximum speed	3500	rpm
Number of phases	2	
Number of stator poles	8	
Number of rotor poles	4	
Torque at 1000 rpm	0.445	Nm
Torque at 3500 rpm	0.2	Nm

Table 2. Detailed dimensions of the SRM.

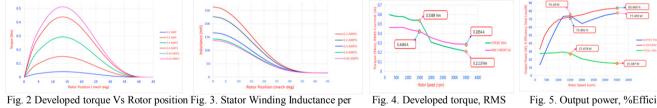| Parameters	Specifications	Units
Stator outer diameter	71	mm
Stack length	23	mm
Stator inner diameter	45	mm
Shaft diameter	12	mm
Stator pole arc	22	deg (mech)
Rotor pole arc	23	deg (mech)
Stator back iron depth	6	mm
Rotor back iron depth	5.4	mm
Air gap length	0.5	mm

2.2 Finite Element Analysis and Results

In order to reduce time consumption and to make the design more accurate to the real time situations, it is necessary to take up Finite Element Analysis (FEA). FEA provides an opportunity to verify and optimize the designed motor before fabricating the machine. In FEA, through proper meshing, the designed model is split into huge number of nodes with element size as small as 0.1 mm and then the motion fields are evaluated at each node. The 2-D and 3-D FEA of the designed SRM is shown in Fig. 1.

Fig. 1. (a) 2-D FEA model of the SRM;(b) 3-D FEA model of SRM.

During static analysis the Torque and Inductance profile for one phase are obtained. Fig. 2. Shows the torque developed by the motor as a function of rotor position (mech deg) for different currents. The peak torque developed is 0.5117 Nm and the average torque is 0.4935 Nm at the rated current of 0.42 A. Fig. 4. Shows the inductance profile for different currents. The aligned inductance is 137.74 mH and the unaligned inductance is 15.819 mH. Transient analysis is performed over a range of speeds for estimating the motor performance. The parameters studied are the developed electromagnetic torque, output power, RMS current, percentage efficiency and losses. Fig. 5. depicts the developed electromagnetic torque and RMS current as a function of rotor speed. It is evident that at the base speed of 1500 rpm, the motor torque is 0.5389 Nm for RMS current of 0.4484 Amps for which the turn on advance angle is 2.769 deg (mech) and turn off advance angle is 4.197 deg (mech). At higher speeds, the advance angles are increased to get the required torque. At maximum speed of 3500 rpm, the turn on advance angle is 7.149 deg (mech) and turn off advance angle is 6.366 deg (mech).

| Fig. 2 Developed torque Vs Rotor position for different currents | Fig. 3. Stator Winding Inductance per phase Vs Rotor position for different currents | Fig. 4. Developed torque, RMS Current Vs Rotor Speed. | Fig. 5. Output power, %Efficiency and total loss Vs Rotor Speed. |

Fig. 5. shows the output power, percentage efficiency and losses as a function of rotor speed. It is inferred that at base speed the output power is 74.26 W with 72.8% efficiency. As the speed increases the loss decreases to 15.387 W, the current decreases at higher speeds because of increase in back emf which is greater than the supply voltage due to which the losses decrease and efficiency increases to 83.665 %.
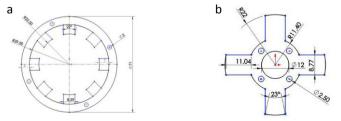
Fig. 6. a) CAD model of stator;b) CAD model of rotor

2.3 Prototype development of two phase SRM

The stator and rotor are manufactured according to the dimensions using non – oriented silicon steel (M47-26 Gauge). During fabrication of the motor, steel laminations are stacked to the total length of 23mm using screws to hold the laminations together. The CAD model of one lamination (0.47mm thickness) for both the stator and rotor with screw dimensions is depicted in Fig. 6. The screws inserted in the stator and rotor are of 1.5 mm diameter and keying inserted for the rotor is of 0.5 mm diameter. The shaft is carved out of mild steel which is of 12 mm diameter and then fitted to the rotor. The windings are wound according to the number of turns determined during the magnetic circuit analysis using suitable wire gauge.

3 Simulation and prototype of ABC
3.1 Specifications of converter
This chapter deals with the working, simulation and prototyping of ABC. The converter is designed for a 70 W 2 phase SRM and the specifications are given in Table-3.

Table 3. Specifications of ABC and R-Dump Converter

Parameters	Ratings	Units
Input Voltage	230	Vac
Efficiency	80(max)	%
Output Current	0.42	A

3.2. Working of ABC

The asymmetric bridge converter is one of the SRM converter topology with two switches and two diodes per phase as shown in Fig. 7.

Fig. 7. Asymmetric Bridge Converter

3.2.1 Simulation Results of ABC
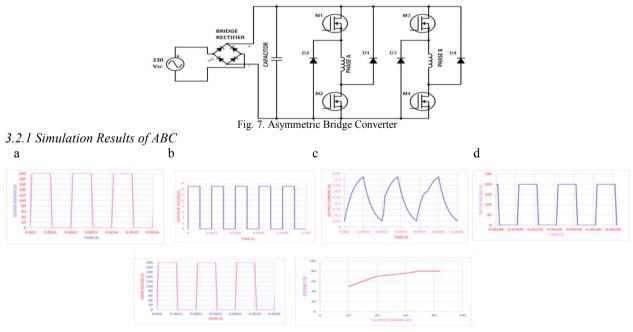
a   b   c   d

Fig. 8. Simulation results at rated load for one phase.

The simulation is performed on the converter from no load to full load and results at rated load for one phase is shown in Fig. 8. The switching topology used here is soft switching i.e.., the triggering pulse is applied to the upper switch and the commutation pulse is applied to the lower switch. The gate pulse voltage of 15 V is given to trigger the mosfet is shown in Fig. 8(b). The voltage across the phase windings obtained is 200 V, as soft switching is adopteed the possitive voltage is obtained as shown in Fig. 8(a). The output current from the load is 0.42 A(peak currrent), which will rise until the switch is in turn on position and the demagnetizes until the next phase turns on, which is depicted in Fig. 8(c). The voltage across the switch shown in Fig. 8(d). represents that when the voltage across phase is maximum, the switch voltage is minimum.The dioge voltage shown in Fig. 8(e). is exactly inverse of the switch voltage.From Fig. 8(f). it can be inferred that output power of the converter decreases as the efficiency increases, this is due to the switching loss of the mosfet and inductive loss. The efficiency of the converter at required output power is 80 %.

3.3 Prototype Development of ABC

3.3.1 Layout of the circuit

The hardware images of the whole converter are shown in Fig. 9. in which a 230V$_{ac}$ is rectified by using a bridge rectifier module and given as input to the converter and the output of the converter is given as input to SRM. The controller and driver circuit are provided with a dc supply of 15V. The IC chosen for controller board is PIC18F4431, because the ports for generating PWM for different duty cycles are more when compared with other PIC families. An IR2110 driver IC which can drive both high side and low side mosfets is used. The switches used in the main board are IRFP-250N as per the requirement of voltage and current capacity as 200V and 30A ranges, which are enough to drive the motor. The diodes chosen in main board is RHRP-8120, because it is a hyper fast diode with soft recovery characteristics.

S.no	Components	Part Number	ratings
1	Voltage regulator	7805	5 V
2	Voltage regulator	7815	15 V
3	Diode	1N4007	1000 V
4	IR2110 (gate driver)		
5	Resistor		1 kΩ, 10 W
6	Capacitor		22uf, 50 V
7	Capacitor		22uf, 400 V
8	Bug strips		

Fig. 9. Image of the ABC converter hardware

4. Simulation and Prototype of R-Dump Converter

This chapter discusses about the working, simulation and prototype of the converter. The converter is designed for the 70 W SRM and its specifications are given in table-3.

4.2 Working and Simulation of R-Dump Converter

4.2.1 Working of R-Dump Converter

The R-Dump Converter is one of the SRM converter topologies comprising of one switch and one diode per phase as shown in Fig. 10. During turn on mode the phase windings of the machine gets energized and during turn off mode the current free wheels through the diode and charges capacitor. The energy stored in the phase winding will get dissipated through the resistor and is not fed back to the supply. The current will take more time to

reach to zero when compared with recharging of the source. Due to the cause that the energy is dissipated by the resistor, the overall efficiency of motor drive is reduced. The selection of R value determines the switch voltage. If higher value of R is chosen, then voltage drop across the winding increases and the low value of R increases the fall time of current.
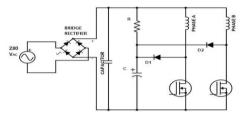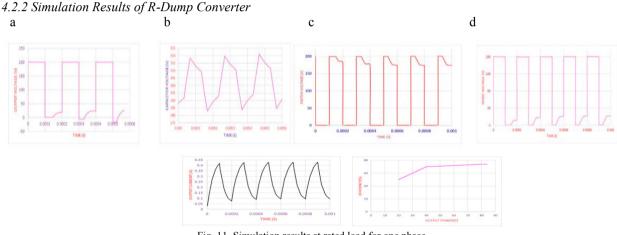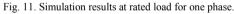

Fig. 10. R-Dump Converter

4.2.2 Simulation Results of R-Dump Converter

a   b   c   d

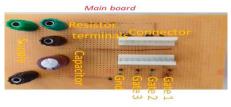Fig. 11. Simulation results at rated load for one phase.

The waveforms obtained at rated load are depicted in Fig. 11. The output power decreases as the efficiency increases, this is due to the switching loss of the mosfet and inductive loss. The efficiency of the converter at required output power is 74 %as shown in Fig. 11(f). The voltage across the phase windings is 200 V, as the switching technique chosen, the voltage goes to the negative side as shown in Fig. 11(a). The output current from the phase windings is 0.42A (peak current), which magnetizes until switch is in turn on and demagnetizes when switch turns off as shown in Fig. 11(c). The switch voltage is 200 V, which shows that it reaches to the same as output voltage as shown in Fig. 11(d). The diode voltage shown in Fig. 11(e). is a mirror image of switch voltage. The capacitor voltage will charge up to a maximum of 320 V at the rated load as shown in Fig. 11(b).

4.3 Prototype and Development of R-Dump converter

4.3.1 Board of the R-Dump Circuit

Fig.12. shows the R-Dump converter hardware circuit. Since the same controller and driver are being used for this converter. An additional resistor and capacitor are added as shown in circuit diagram, in Fig. 9.
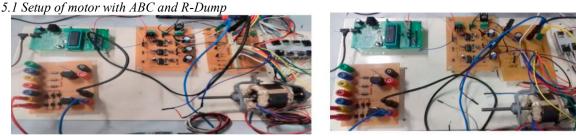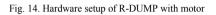
5. Hardware implementation and testing of SRM drive

5.1 Setup of motor with ABC and R-Dump

Fig. 13. Hardware setup of ABC with motor

Fig. 14. Hardware setup of R-DUMP with motor

The driver output pulses are given as input to the converter and the power supply to the converter will be given through a bridge rectifier circuit, which will supply the voltage of 200V to the power converter. The converter output is given to the motor phase windings of two phases respectively.

5.1.1 Hardware results of ABC and R-Dump

The testing of ABC is performed and corresponding waveforms are taken at different load conditions as shown in fig. 13. The above figure infers that when an external load resistance with 200V DC supply and PWM pulses applied to the converter, the voltage obtained across high side is72V and low side switch is 12.4V and the current at the load is 0.42A which can be inferred from figure 15. The switching frequency obtained is 4.95kHz, for a duty ratio of 50%. The microcontroller and driver board is given a supply of 15 V and the driver output pulses are given as input to the converter.

The testing of R-DUMP is performed to the external load of 70W with 200V DC supply and 5KHz gate pulses to the converter, the voltage obtained across the phase-1 and phase-2 winding is 72.0V and 12.4V respectively and current drawn is around 0.42A which can be inferred from figure
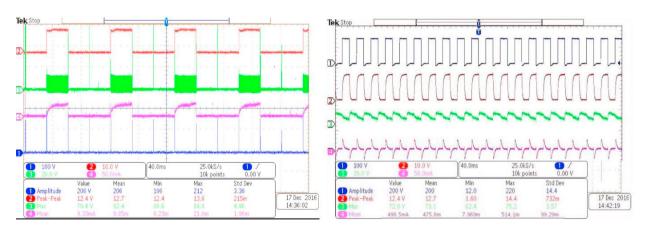

Fig. 15. Hardware results for ABC

Fig. 16. Hardware results of R-Dump

5.3 Comparison of ABC and R-Dump Converters

From the below figure, it can be inferred that bar-1 shows that the efficiency of ABC is 80 % and R-Dump is 75 %. So, by comparing two power converters based on efficiency perspect, ABC is better than R-Dump, but complexity of circuit will be more. Due to the effect of the dissipative element resistor, the energy stored will be dissipated across the phase windings, so it will leads to reduction in efficiency for R-Dump, but for low speed applications, where efficiency is not required, there these converters are widely adopted.
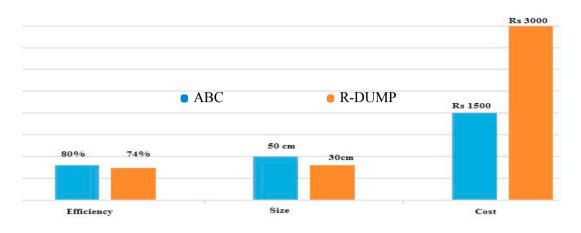
Fig. 17. Bar diagram for ABC and R-Dump

The above figure, bar-2 shows that size required for ABC is larger compared to R-Dump converter package this is due to the number of switches that are being used in the ABC are twice that of the R-Dump converter for each phase as a result of this when it comes to a 3-phase circuit package the size of ABC is more when compared to that of the R-Dump converter.The above figure, bar-3 shows the overall cost of the converter even though the size of ABC is more than the R-dump converter which expects that the ABC is more cost than R-Dump but in contary to that condition the cost of R-Dump is more than the ABC. This is due to the "resistance" value that is being used for the R-Dump converter.

6. Conclusion

The operation, modelling, simulation, analysis, design and prototype testing of ABC and R-Dump converter has been performed with SRM. It can be concluded that

- ABC is 6% more efficient and its size is 20% more than that of the R-Dump converter.
- R-Dump converter is costlier than ABC by 50%.
- ABC has higher power handling capability than R-Dump.
- The losses in ABC are mainly switching losses while in R-dump resistive loss is more.
- Thus it can be stated that ABC is applicable for Higher power ratings, while R-Dump is suited for low power applications.

REFERENCES:

[1] P. J. Lawrenson, J. M. Stephenson, P. T. Blenkinsop, J. Corda, and N. N. Fulton, "Variable-speed switched reluctance motors," *Proc. Inst. Elect. Eng.*, vol. 123, pt. B, no. 4, pp. 253–265, 1980.
[2] T. J. E. Miller, *Switched Reluctance Motors and Their Control*. Hillsboro, OH: Magna Physics, 1993.
[3] R. Krishnan, *Switched Reluctance Motor Drives*. Boca Raton, FL: CRC Press, 2001.
[4] R. Krishnan and P. N. Materu, "Design of a single-switch-per-phase converter for switched reluctance motor drives," *IEEE Trans. Ind. Electron.*, vol. 37, no. 6, pp. 469–476, Dec. 1990.
[5] Mike Barnes and Charles Pollock, "Power electronic converters for switched reluctance drives", *IEEE Trans. On Power Electronics ...,* vol. 13, no. 6, Nov. 1998.
[6] T.J.E. Miller, *et al*., "Microcomputer Control of Switched Reluctance Motor", *IEEE Trans. Ind. Applns*, vol. IA-22, Jul/Aug. 1986.
[7] C. Laudensack, *et al*., "Investigation of Different Parameters on the Performance of Switched Reluctance Machines", 19th International Conference on Electrical Machines - ICEM 2010, Rome.
[8] Gungor BAL, Durmus UYGUN, "An approach to obtain an advisable ratio between stator and rotor tooth widths in switched reluctance motors for higher torque and smoother output power profile", Gazi University Journal of Science.