A New energy source discovered we will bill at 4 cents a kilowatt to suppliers and customers

We will replace Nuclear power plants Now cost 10 Million dollars total cost for one to show ...

Quantum Motors Corporation

1st step is Cooling towers ready now

this is ready now as 2nd step

Look at page 3

Thanks Reginald Garcia Inventor May10, 2022

Performance Analysis of a Bifilar Wound Switched Reluctance Motor

ABSTRACT

The switched reluctance machines (SRMs) have gained much attention in various applications due to their outstanding characteristics including fault-tolerant nature, simple and robust structure, and low manufacturing cost. Bifilar wound switched reluctance machine (BSRM) has been studied to add more improvements in the existing conventional design topology. In this paper, the study of BSRM having the same design and specification as a conventional SRM is studied. The study on the selection of winding turns on both primary and secondary for BSRM is presented. This paper also presents the motor and converter efficiencies of the designed BSRM in comparison with the conventional SRM.

INTRODUCTION

Over the past couple of decades, the switched reluctance machines (SRMs) have gained popularity mostly due to their simple structure and low cost. Having no permanent magnets or windings on the rotor is the most significant advantage of the SRMs when compared to other motor topologies. Therefore, based on specific targeted applications and requirements, several drive circuit topologies for SRM have been developed. Several studies in [1-6] present different drive circuit topologies such as C-dump topologies, two switch- per-pole drive circuits, resonant drive circuits, etc. to drive the SRMs. Each of these topologies has its benefits as well as some negative aspect.

Bifilar wound switched reluctance machines (BSRMs) are also studied to use the potential advantage of the SRM and require a different drive circuit topology given the nature of the machine. Bifilar converter to improve the performance of the machine, cost-effectiveness of the drive, and stress on the power devices are studied [6 and 7]. Also, bifilar wound AC motors are investigated for different applications in [8 and 9], where the benefit of using bifilar wound connection to simplify the design of the inverter with the use of only low side power devices are discussed.

The voltage supplied the phase of an SRM is given by (1)

$$V = iR + \frac{d\lambda}{dt} \quad (1) \qquad\qquad V = \frac{Ldi}{dt} + \frac{idL}{d\theta} \cdot \frac{d\theta}{dt} \quad (2)$$

where, V is the phase voltage, R is the winding resistance, i is the phase current, and λ is the flux linkage of the winding. Considering a linear magnetic circuit and neglecting the winding resistance, equation (1) can be written in terms of inductance L as (2). The output power of the SRM is given by (3) which infers that it is partially stored in a magnetic circuit of the motor and part of it is used to provide mechanical rotation of the rotor. The use of bifilar winding topology implies appropriately in this scenario where the stored magnetic energy from the motor winding is transferred back to the power supply which helps in high-speed operation.

$$Vi = \frac{d}{dt}\left(\frac{1}{2}Li^2\right) + \frac{i^2}{2}\frac{dL}{d\theta}\,\omega \quad (3)$$

The BSRM consists of two separate windings wound together on each stator pole for maximum magnetic coupling. The primary winding is used for magnetization while the secondary winding (bifilar winding) for demagnetization making this configuration the same as a transformer.

Therefore, the peak current of the secondary winding depends on the turns ratio which is a ratio of primary turns (N_1) over secondary turns (N_2). This configuration allows having only one transistor and diode per phase to drive the BSRM. This paper analyses the effect of the turn ratio on the peak current and the duration of the demagnetization of the secondary current. With the proper selection of the N_1 and N_2, the performance of the BSRM is analyzed. This paper also investigates the losses in the switch and the diode to compare the efficiency of the bifilar converter with the conventional asymmetric half-bridge converter.

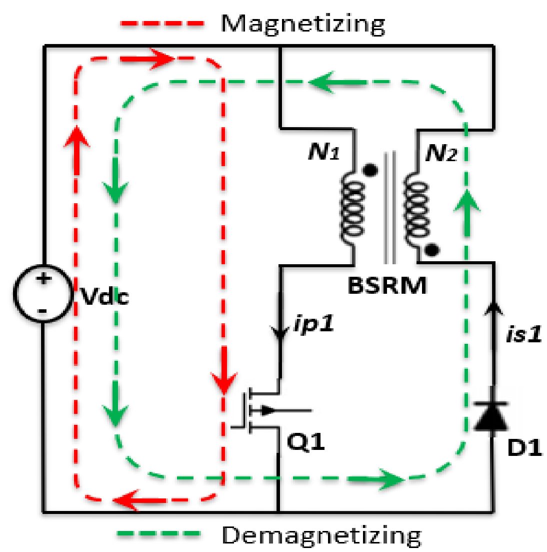

Figure 1: Bifilar winding converter.

BIFILAR CONVERTER AND PERFORMANCE OF THE BSRM

The bifilar converter for a single phase is shown in figure 1. A current flows into the primary winding when the switching transistor Q1 is turned ON hence it gets magnetized. When the transistor is turned OFF the primary winding must demagnetize which could be done using the secondary winding if the diode D1 is forward biased. As to maintain the constant flux linkages, the secondary winding due to its polarity causes the diode to forward bias. This results in the current flow in the secondary winding which circulates through the power supply transferring the energy from the motor winding to the source. However, the sudden drop of the current in the primary winding when the switch OFF causes a high level of stress on the switch and thus increases the voltage requirement of the switch [10]. Also, due to the bifilar winding, the leakage inductance is also the main concern of this topology. Several studies in [5-7] present a solution to these problems and are not part of this study.

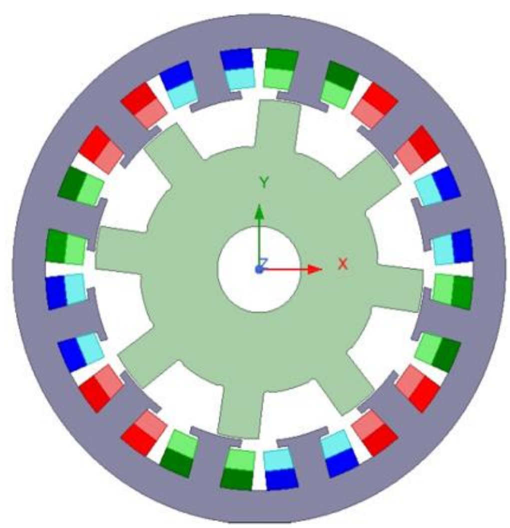

Figure 2: BSRM model.

The conventional SRM is designed for a specific application with the specification given in table I. Maintaining the same geometric features as the conventionally wound SRM, a second machine is wound with the addition of a bifilar winding to each pole of the stator. Figure 2 shows the model of the BSRM. Selection of the number of turns on the primary and the secondary is a crucial step in designing the BSRM as it determines the overall performance of the motor as well as the converter. The selection of the primary turns is not any different than the conventional SRM as it is the main winding that produces the torque. The primary turns are selected such that the machine produces the required power at base speed with the primary phase current almost in a single pulse

TABLE I. MACHINE SPECIFICATION

Parameters	Value
Rated Power	4.5 kW
Rated Speed	2000 rpm
DC Voltage	100 V
No. of Phase	3
Stator Poles	12
Rotor Poles	8

operation. Also, the current density is another factor in this selection. Since the base speed is 2000 rpm and the required power is 4.5 kW, it was found that turns provided the desired results with a current density of 10 A/mm^2.

The secondary winding turns are critical and require further analysis to see their effect both on the motor and converter performance. There are two aspects to this analysis: first, the overshoot, and second, the time it takes to demagnetize the secondary winding. The overshoot or spike in the secondary phase current is dependent on the turns ratio $\frac{N1}{N2}$. The turns ratio higher than 1.0 results in an overshoot in the secondary phase current when the switch is turned OFF. That implies that N_2 should not be much less than N_1 to tackle this issue. However, turns ratio of unity or close raises another issue which is the duration it takes to finally demagnetize the secondary winding before the next electrical cycle. Turns ratio closer to 1.0 increases the duration of demagnetization which requires a higher turn-off switching angle.

Figure 3 shows the effect of a higher turns ratio on the overshoot where it can be seen that the primary phase current is around 80 A peak while the secondary current has an around 140 A of a peak. Figure 4 shows the effect of N_2 very similar to N_1 resulting in the longer conduction period of the phase and taking a long time for the secondary current to demagnetize completely. Hence, it is important to find a suitable combination of the turns for a particular application. It was found that turns in secondary winding gave overall satisfactory results in terms of having moderate overshoot as well as quicker demagnetization. Figure 5(a) and 5(b) shows the torque and phase currents using turns on primary and turns on secondary winding at 2000 rpm and average torque of 22 Nm.

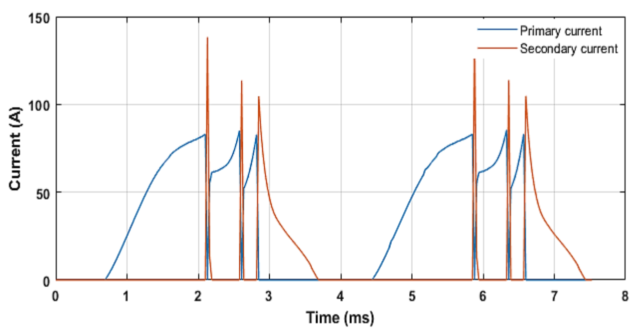

Figure 3: Phase currents with a turns ratio of 1.92.

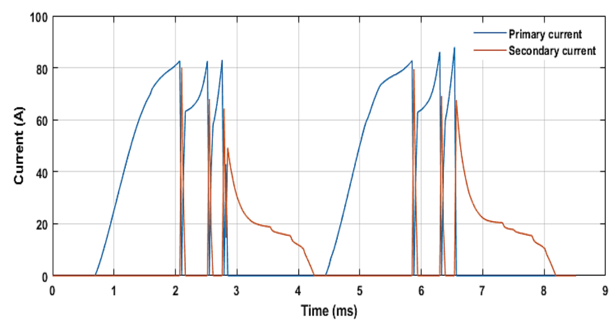

Figure 4: Phase currents with a turns ratio of 1.08.

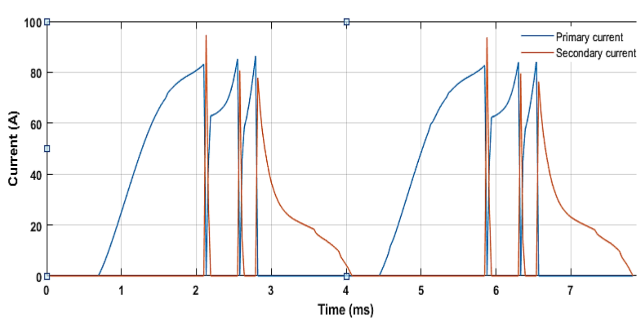

Figure 5 (a): Phase currents with a turns ratio of 1.28.

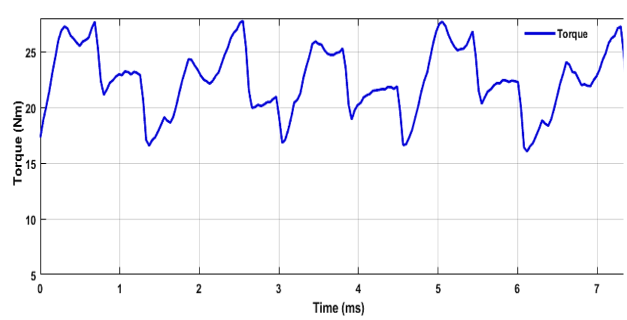

Figure 5 (a): Average torque at 2000 rpm with a turns ratio of 1.28.

EFFICIENCY COMPARISON

Motor efficiencies of BSRM are compared with the conventional SRM. As mentioned earlier, the geometric model for both the motors are maintained the same. Efficiency maps for the full drive cycle are computed. The efficiency map of conventional SRM and BSRM is shown in figures 6 and 7 respectively. From the figures, it can be seen that on average there is a 2% increase in the efficiency of BSRM over the conventional SRM. The efficiency of conventional SRM ranges from 67-95% whereas the efficiency of BSRM is ranging from 69-96%. BSRM have better performance at the high speed.

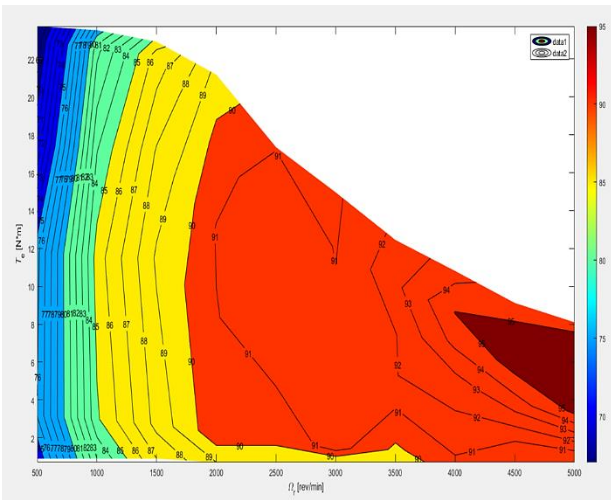

Figure 6: Conventional SRM efficiency map.

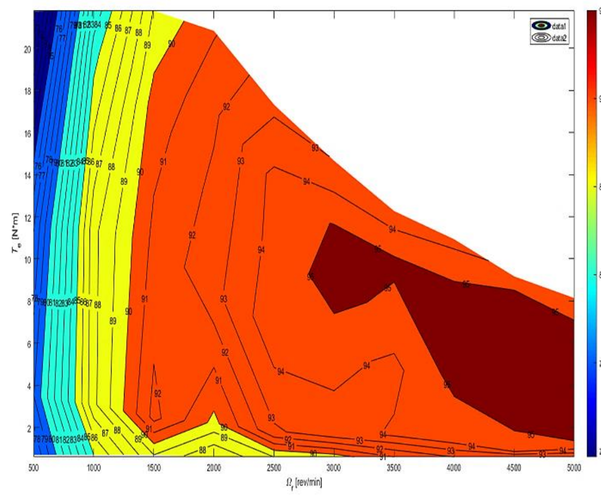

Figure 7: BSRM efficiency map.

The conventional half-bridge converter to drive the SRM has in total 6 power switches and 6 diodes whereas, the bifilar winding converter has 3 switches and 3 diodes. The device ratings for the bifilar winding converter is higher to take into account the higher voltage overshoot across the switch due to leakage inductance and sudden fall in current when the switch is turned OFF. The power rating of the devices used for both conventional and bifilar winding converter is given in table II. Table III shows the computed loss for the devices and the overall efficiencies for both the converters at low speed (500 rpm) as well as high speed (4500 rpm). Overall, the bifilar converter seems to have good performance with an efficiency of 92.25 % compared to 85.56 % of the conventional converter. At high speed both the converter efficiencies are close however, the motor efficiency of BSRM is slightly higher at high speed.

TABLE II. POWER DEVICE RATINGS

Conventional converter device ratings		**Bifilar winding converter device ratings**	
Mosfet		**Mosfet**	
V_{DS}	250 V	V_{DS}	650 V
I_D	146 A	I_D	170 A
R_{DS} (on)	≤ 7.4 mΩ	R_{DS} (on)	≤ 13 mΩ
Diode		**Diode**	
V_R	400 V	V_R	400 V
I_F	210 A	I_F	280 A
trr	40 ns	trr	40 ns

TABLE III. CONVERTER LOSSES AND EFFICIENCY COMPARISON

	500 rpm (1.2 kW)		**4500 rpm (3.0 kW)**	
	Conventional Converter	**Bifilar Converter**	**Conventional Converter**	**Bifilar Converter**
Total Mosfet Loss	106.05 W	111.32 W	42.0 W	26. 47 W
Total Diode Loss	140.0 W	29.15 W	40.0 W	11.77 W
Efficiency	85.56 %	92.25 %	97.56 %	98.80 %

CONCLUSIONS and FUTURE WORK

In this paper, the performance of the BSRM is presented. The effect of winding turns ratio on the overshoot and demagnetization of the secondary current was analyzed and optimal turns were selected for both the winding. The efficiency of BSRM slightly higher at a higher speed compared to the same size conventional SRM was observed. Also, the bifilar converter has an overall better performance compared to the conventional converter. In the full paper, a more detailed analysis of the machine design, motor, and inverter efficiencies will be provided with experimental validation.

REFERENCES

[1] T. J. Miller, "Brushless Reluctance Motor Drives," in *IEEE Engineering Journal, vol. 1,* 2010, pp. 325-331.

[2] L. Shelly, S. Paramasivam, and M. Vijayakumar. "A Review of Various Converter Topologies for SRM Drives." *SAE International Journal of Alternative Powertrains 3*, May 2014, Vol. 3, pp. 113-128.

[3] Y. Yoon, S. Song, T. Lee, C. Won, and Y. Kim, "High performance switched reluctance motor drive for automobiles using C-dump converters," *2004 IEEE International Symposium on Industrial Electronics,* Ajaccio, France, 2004.

[4] J. Kim and R. Krishnan, "High Efficiency Single-Pulse Controlled Switched Reluctance Motor Drive for High Speed (48k RPM) Application: Analysis, Design, and Experimental Verification," *2008 IEEE Industry Applications Society Annual Meeting, Edmonton,* AB, 2008, pp. 1-8.

[5] M. Asgar, E. Afjei, A. Siadatan, and A. Zakerolhosseini, "A new modified asymmetric bridge drive circuit switched reluctance motor," *2009 European Conference on Circuit Theory and Design, Antalya,* 2009, pp. 539-542.

[6] M. Ehsani, J. T. Bass, T. J. E. Miller, and R. L. Steigerwald, "Development of a Unipolar Converter for Variable Reluctance Motor Drives," *in IEEE Transactions on Industry Applications,* vol. IA-23, no. 3, pp. 545-553, May 1987.

[7] H. Bagherian, M. Asgar, and E. Afjei, "A new C-dump converter for bifilar winding switched reluctance motor," *2011 2nd Power Electronics, Drive Systems, and Technologies Conference,* Tehran, 2011, pp. 467-472.

[8] W. Cui, Y. Gong and M. H. Xu, "A Permanent Magnet Brushless DC Motor With Bifilar Winding for Automotive Engine Cooling Application," *in IEEE Transactions on Magnetics,* vol. 48, no. 11, pp. 3348-3351, Nov. 2012.

[9] B. M. Gordon, H. S. Rajamani and R. A. McMahon, "An investigation of bifilar wound three-phase induction motor drives operating with only low side switches," *1996 Sixth International Conference on Power Electronics and Variable Speed Drives (Conf. Publ. No. 429),* Nottingham, UK, 1996, pp. 413-418.

[10] S. Ebrahimi, V. Najmi, S. Ebrahimi, and H. Oraee, "A ZVS-resonant bifilar drive circuit for SRM with a reduction in stress voltage of switches," *International Aegean Conference on Electrical Machines and Power Electronics and Electromotion, Joint Conference,* Istanbul, 2011, pp. 125-128.