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Title: **SEAMLESS POWER TRANSFER FOR SWITCHED RELUCTANCE MOTOR DRIVES USING CURRENT SOURCE RECTIFIER**

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SEAMLESS POWER TRANSFER FOR SWITCHED RELUCTANCE MOTOR DRIVES USING CURRENT SOURCE RECTIFIER

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Abstract — In this paper, a two-stage power converter based on current source rectifier (CSR) is proposed to improve the power factor of Switched Reluctance Motor (SRM) drives and Battery Charging Capability in Regenerative Mode. CSR stage in the input of SRM converter, eliminate dc link's capacitors and create the capability of energy saving in regenerative operation mode of SRM drives. The space-vector modulation (SVM) is used in the CSR switching. The validity and effectiveness of the proposed approach is shown by simulation, also it is verified experimentally by using a laboratory 4-KW SRM setup based on TI TMS320F2812 platform. The results demonstrate a good agreement with the required conditions.

I. INTRODUCTION

The SRM has become an attractive candidate for variable speed drives applications and is rapidly advancing due to the advent of inexpensive, high power switching devices and since possesses many distinguished merits, such as simple construction while the rotors have no windings or magnets, negligible mutual coupling, higher or comparable reliability due to fault tolerant robust structure and low cost [1]. Poor operating power factor, torque ripple which causes undesirable vibration and acoustic noise are major problem in switched reluctance motor drive system. Torque ripple can be reduced either by motor design or by suitable control methods. Low power factor can increase power distribution system losses. Therefore, power factor improvement is essential to enhancing their competitiveness [2]. SRM conventional converter consist a front-end large filter capacitor and diode bridge rectifier which results low power factor (PF), high current harmonics and low system efficiency since draws a pulse current from the ac source side. Switched reluctance motor coupled within a battery-charging circuit has been proposed in [3], and is a good choice for low-cost battery-powered applications, as it combines high efficiency and high reliability with low manufacturing costs [4]. A two-stage power converter based on current source rectifier (CSR) as an input stage of the asymmetrical converter is proposed in order to improve the power factor, also in this converter, front-end large filter capacitor can be used to battery charging in regenerative mode of switched reluctance motor [5]. Proposed two-stage power converter validation through significant

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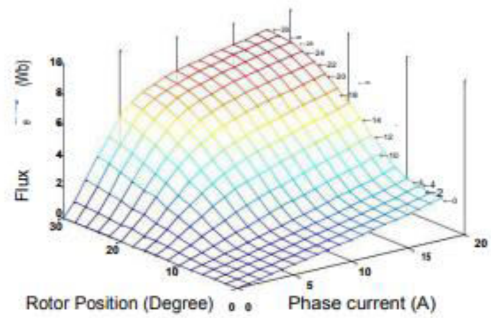
reduction of the THD value of the supply current with line drawn current quality and power factor improvement are evaluated by computer simulations with MATLAB/Simulink and then testing experimentally on a DSP-based four-phase 8/6 pole 4kW oulton SRM.

II. NONLINEAR CHARACTERISTICS OF SWITCHED RELUCTANCE MOTORS

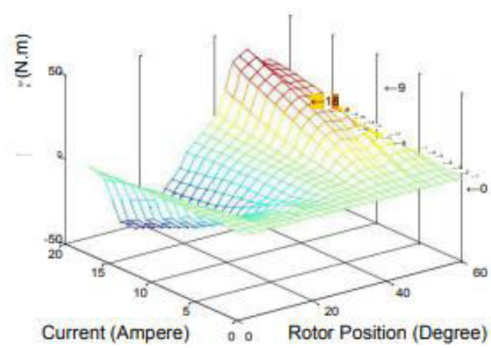
The switched reluctance machine doubly salient construction presents a nonlinear operation, thus torque and flux are function of position and current and the magnetic saturation at certain operation regions, so high-performance SRM drive is a challenge. Hence to achieve high dynamical performance is needed to accurately model these physical characteristics. In most cases, Phase mutual coupling is neglected for usual applications. The inside view of used SRM whose parameters are given in TABLE I (see appendix) and with 8/6 pole structure is shown in Fig. 1. SRM curves for whole entire rotor positions and phase currents are most important part of performance studying.

Figure 1. The tested 8/6 SRM inside view.

The electromagnetic characteristics are achieved by FE method where Fig. 2 (a) and (b) display flux linkage and electromagnetic torque characteristics. Correctness determination and verifying the results have been done by measuring technique proposed in [5]. The setup layout used for experimental test of this technique is shown in Fig. 3.



(a)



(b)

Figure 2. Measured characteristics of used SRM. (a) Flux linkage. (b) Measured Torque.

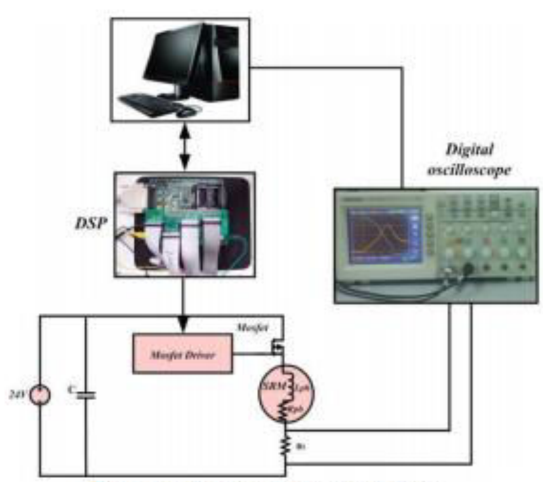


Figure 3. data measuring experimental layout.

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The conventional SRM drive with unipolar power converter is shown in Fig. 4. The drive circuit has a three phase diode rectifier, a bulk dc link capacitor and an asymmetric bridge converter. Conventional SRM drive is very simple, but the capacitor charges and discharges, which draws a pulsating ac line current, and results in a low Power Factor. The low Power Factor of the motor increases the reactive power of the power line and decreases efficiency of drive system.

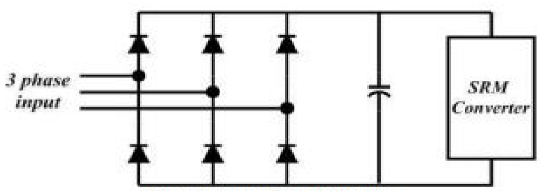

Figure 4. conventional SRM drive.

III. PROPOSED SRM DRIVE

Proposed two -stage converter can be seen in Fig. 5. Front end converter in first stage is placed as controllable rectifier diodes with advantage of improving low power factor and eliminating high input line harmonics (Current Source Rectifier) . Phase winding energizing is done by machine side converter as second stage [6, 7]. The CSR in modified SRM drive have six bidirectional self-commutated switches. No short circuit must be applied to the mains filtering capacitors and No open circuit must be applied to the output current.

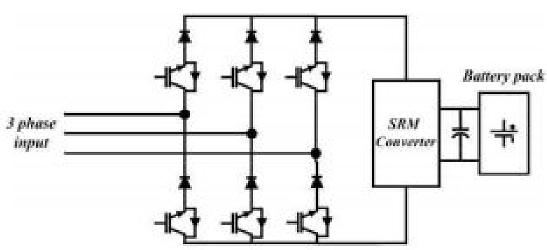

Figure 5. proposed SRM drive.

The reference current vector can be realized by using the two limiting active vectors of the sector. The resulting output line-voltage space vector defined by:

$$\bar{V}_{OL} = v_{AB}(t) + a \cdot v_{BC}(t) + a^2 \cdot v_{CA}(t) \qquad (1)$$

Where $a = 1\angle 120^{\circ}$ The switching technique applied to the CSR is space vector modulation (SVM) expressing the required instantaneous input current vector according to the voltage vector. Unit power factor will be achieved through this approach. The switching state vectors duty cycles are:

$$d_\mu = T_\mu / T_S = m_c \cdot \sin(60^{\circ} - \theta_{sc}),$$
$$d_\upsilon = T_\upsilon / T_S = m_c \cdot \sin(\theta_{sc}), \qquad (2)$$
$$d_{0c} = T_{0c} / T_S = 1 - d_\mu - d_\upsilon$$

Where mc is the modulation index, TS is the sampling interval and θ sc is the angle between the reference vector and the first active vector [8]. In this converter dc link capacitors can be used to battery charging in regenerative mode of switched reluctance motor. Fig .6 shows the regenerative operation of SRM drive. Turn on and turn off Angles affect dc link current ripple and rms value.

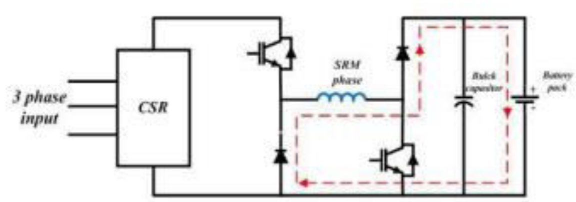

Figure 6. Battery Charging in Regenerative Mode of SRM.

IV. SIMULATION AND EXPERIMENTAL RESULTS

The performance of the proposed method is demonstrated in simulation and experimentally using a 4-KW SRM drive

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that a dc machine is mechanically coupled to it. The experimental setup is based on fixed-point TMS320F2812 eZdsp board as a suitable choice for implementing motor controllers applications and executing the control algorithm. All the experimental hardware used for evaluating the 8/6 SRM drive illustrate in Fig. 7.

Figure 7. SRM drive test setup used for experimentation.

The current control is implemented by a closed-loop control with hysteresis switching control of the converter. The SRM rotor position is obtained from an optical encoder which is installed on the rotor shaft. The SRM drive system is conducted on a partial load. The current reference is 3 (A). Fig. 8 and 9 show a typical current and voltage phase of the SR motor obtained with turn on and turn off angles.

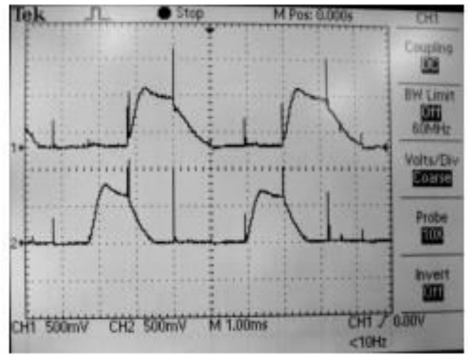

Figure 8. phase current of SRM (scale: phase current= 1.75A/div).

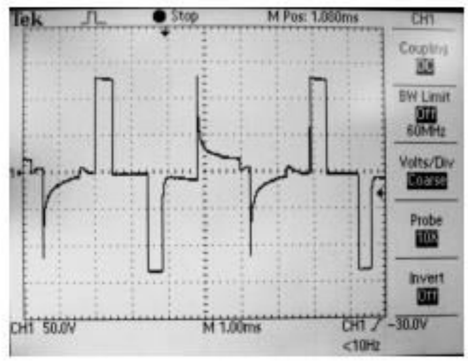

Figure 9. Phase voltage of SRM (scale: phase voltage= 50V/div).

In CSR stage two switches are on for every switching state thus, only one of the three switches at the top and at the bottom of the bridge must be ON at any time. Fig. 10 and 11 display the switching signals for two switches in one state. In practical view this two switches must be overlapped (Fig. 11).

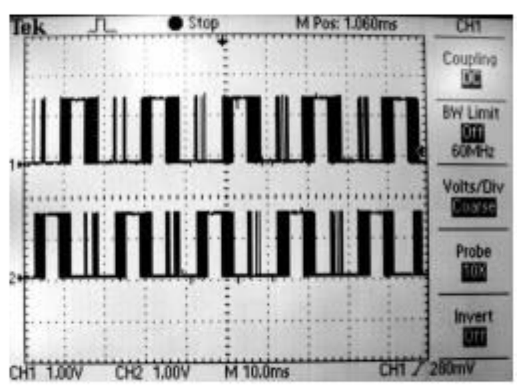

Figure 10. CSR switching signals.

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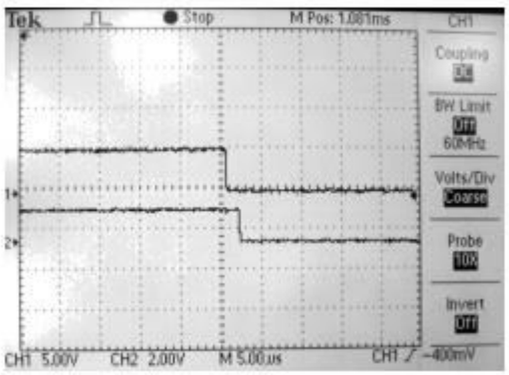

Figure 11. overlapping of switching signals.

Fig. 12 and 13 show the simulation and experimental output voltage of CSR, where the output voltage waveform of CSR shows clearly six order harmonics riding over a dc voltage. The waveform is very similar to a conventional three phase diode bridge output with chopping. High frequency harmonics can be eliminated with a small size capacitor in dc link.

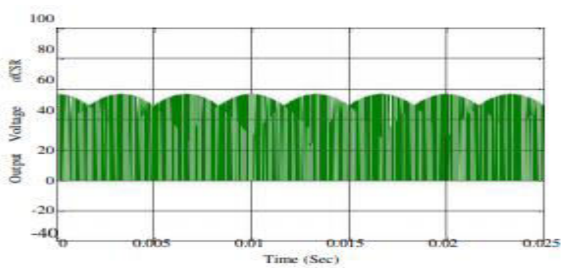

Figure 12. Output voltage of CSR in simulation.

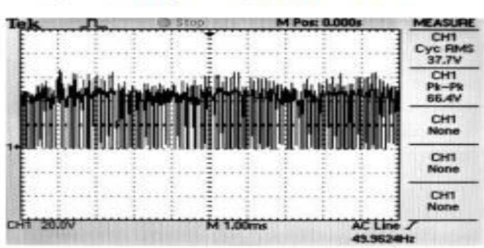

Figure 13. experimental Output voltage of CSR.

The line current of conventional and proposed SRM drive is given in Fig. 14 and 15. The current spectra of ordinary and two-stage converters are shown in Fig. 16 and 17, respectively. Proposed topology harmonic content is lower than common type. The power factor values are given in Table III. In the proposed converter, the power factor is higher than it is in the standard topology.

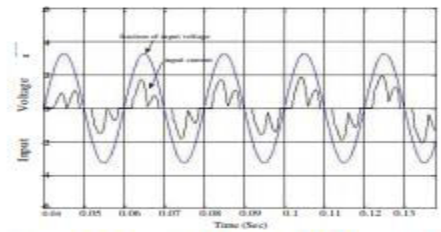

Figure 14. Input voltage and current of SRM drive Without CSR.

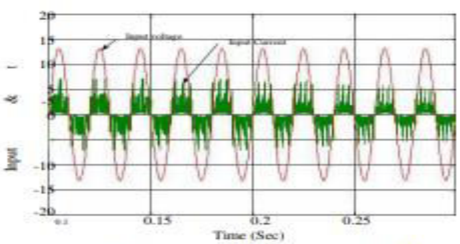

Figure 15. Input voltage and current of SRM drive With CSR.

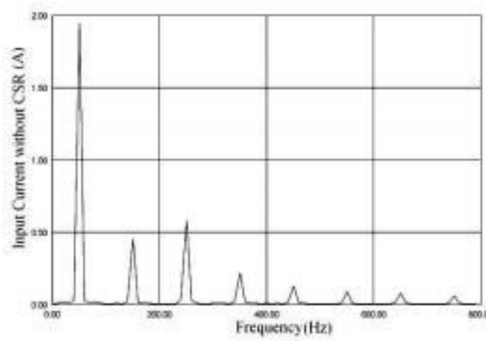

Figure 16. Spectra of the input line current of SRM drive Without CSR.

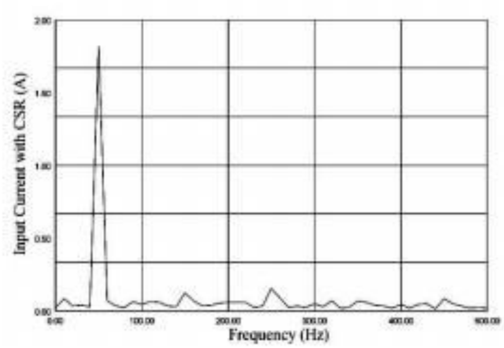

Figure 17. Spectra of the input line current of SRM drive With CSR.

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Battery pack current for fixed angle control of SRM is shown in Fig. 18. Turn on and turn off Angles control ripple, RMS and average value of dc link current.

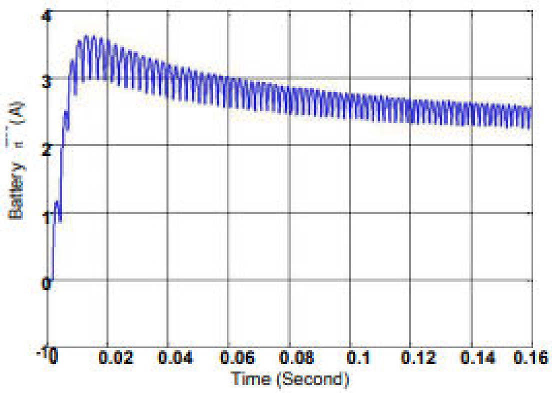

Figure 18. Battery pack current.

TABLE III. POWER FACTOR AND CURRENT DISTORTION EVALUATION

Power	Power Factor		THD I%	
	SRM Drive	*With CSR*	*SRM Drive*	*With CSR*
100 W	0.4	0.83	39	3
600 W	0.55	0.86	44	6

CONCLUSIONS

A current source rectifier (CSR) based converter is established to modify the input current of the drive, improving the power factor of SRM drive. Dc link's capacitors eliminating and as a result creating capability of energy saving in regenerative operation mode of SRM is achieved by CSR based converter. The input phase current frequency spectra clearly illustrate current THD improvement through power factor correcting. As an application, front-end large filter capacitor can be used to battery charging in regenerative mode of switched reluctance motor. The switching topology and control algorithm is implemented on DSP-equipped SRM. The simulation and experimental results demonstrate the desired condition.

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