Improvement of Power Factor for Switched Reluctance Motor with Closed Loop Controller using Current Source Converter

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Abstract:
The interest over SRM is due to its advantages over the induction motor or permanent magnet synchronous motor. These advantages include low cost, super charged performance, equal or effective reliability, magnificent efficiency, frown volume and ease of production and storage. An SRM drive has made a successful entrance into various sectors of industry such as aircrafts, automotive, and household appliances. In this paper, a two-stage power converter based on the diode bridge rectifier (DBR) is aimed to ameliorate the power factor of Switched Reluctance Motor (SRM) drives. DBR stage in the input of the converter of SRM, which removes capacitors of DC link and create the capability of improving power factor of SRM drives interfacing using asymmetrical converter topology. The controls of two power stages are properly designed and digitally realized using a common digital signal processor.

Good winding current and speed dynamic responses of the SRM drive are obtained. In addition, the static operation characteristics are also improved. In the charging mode, the power devices that were embedded in the SRM converter and the three motor-phase windings are used to form a buck-boost switch-mode rectifier to charge the battery from utility with good power quality. In concept proposed concept has been implemented the closed loop speed control of the SRM drive. Ultimately closed loop controller (PI controller) for a three phase 8/6 SRM drive is modeled in Matlab/Simulink and the results are presented.

Keywords:
DC-Link, DC/DC Boost Converter, SRM, Closed Loop Operation.

I. INTRODUCTION:

Due to the advantages of high efficiency and high density of power the single-phase switch mode AC-DC converters are being used as front-end rectifiers for various applications. These conventional converters, gets non-sinusoidal input alternating currents which leads to low input power factors and harmonic injections into the lines [1]. Scientific explorations in quality of power, utility interference has gained much importance due to good regulation in power quality and rigid limits on total harmonic distortion (THD) of current input.

A well-defined linearized model around the steady-state operating point is possessed by AC-DC rectifiers presenting unity power factor as shown in fig.1 which shows the diagram of power factor correction technique which is improved. The SRM has become an attractive campaigner for different application of speed drives and is encouraging due to low-cost, high power switching devices and having many advantages, like elementary construction, having no windings or magnets on rotor, negligible mutual coupling, high fault tolerant and robust structure [2].

Due to lacking in operating power factor, ripple in torque which causes undesirable vibration and acoustic noise causes severe problem in switched reluctance motor drive. Torque ripple can be reduced either by motor design or by suitable controlling methods. Distribution system losses would be a cause due to Low power factor. Therefore, improvement of power factor is essential to enhancing their competitiveness [3]. The major problems associated with switched reluctance motor drive system are low operating power factor, torque ripple which results in undesirable vibration and acoustic noise.

Usually these torque ripples are nullified either by motor design or by suitable control methods [4]. Power factor maintenance stands as one of the stumbling blocks for every electrical engineer and improving it is essential to enhance their sustainability. In general low power factor can increase power distribution system loses. In the above mentioned strategy power factor is improved by using a two stage power converter based on current source rectifier (CSR) as an input stage of the asymmetrical converter [5]. Here front-end large filter capacitor helps the battery to charge in regenerative mode of SRM [6]. New applications for variable speed drives are cost sensitive while highly reliable, equally performing dc and induction motor drives at the minimum are also demanded.

SRM drives are promising systems to meet these demands in some select high-volume applications; hence, the spurt of activity in this field [7], [8]. A conventional converter for a SR drive uses a diode bridge rectifier and a large filter capacitor on the front-end. Since the diode rectifier draws a pulse current from the ac source side, the system is associated with low power factor (PF) and low system efficiency. Therefore, SR drive systems always have the disadvantages of a low PF and a high current and harmonics. On the other hand, due to its double saliency structure and concentrated magnetic flux, a SR motor is prone to higher levels of acoustic noise.

The noise and vibrations are specifically higher in low-speed operating regimes when the motor is typically controlled by a chopping-controlled mode [9-10].

II. PRINCIPLE & OPERATION OF SRM:

The SRM is the simplest of all electrical machines. Only the stator has windings. The rotor contains no conductors or permanent magnets. It consists simply of steel laminations stacked onto a shaft. It is because of this simple mechanical construction that SRMs carry the promise of low cost, which in turn has motivated a large amount of research on SRMs in the last decade. The mechanical simplicity of the device, however, comes with some limitations. Like the brushless DC motor, SRMs cannot run directly from a DC bus or an AC line, but must always be electronically commutated. Also, the saliency of the stator and rotor, necessary for the machine to produce reluctance torque, causes strong non-linear magnetic characteristics, complicating the analysis and control of the SRM. Not surprisingly, industry acceptance of SRMs has been slow.

This is due to a combination of perceived difficulties with the SRM, the lack of commercially available electronics with which to operate them, and the entrenchment of traditional AC and DC machines in the marketplace. SRMs do, however, offer some advantages along with potential low cost. For example, they can be very reliable machines since each phase of the SRM is largely independent physically, magnetically, and electrically from the other motor phases. Also, because of the lack of conductors or magnets on the rotor, very high speeds can be achieved, relative to comparable motors. Disadvantages often cited for the SRM; that they are difficult to control, that they require a shaft position sensor to operate, they tend to be noisy, and they have more torque ripple than other types of motors; have generally been overcome through a better understanding of SRM mechanical design and the development of algorithms that can compensate for these problems.

The torque ripple in fuzzy method is 0.1 Nm that is only about 32% of the hysteresis band method with 0.31 Nm torque ripple. This is one of the most noticeable advantages of the fuzzy control method. The stator flux ripple in fuzzy method experiences a significant reduction about 50% in comparison with hysteresis band method. Since the stator flux is an electrical parameter, its ripple reduction means that the high frequency harmonics of the motor input current and hence electromagnetic inference (EMI) are reduced.
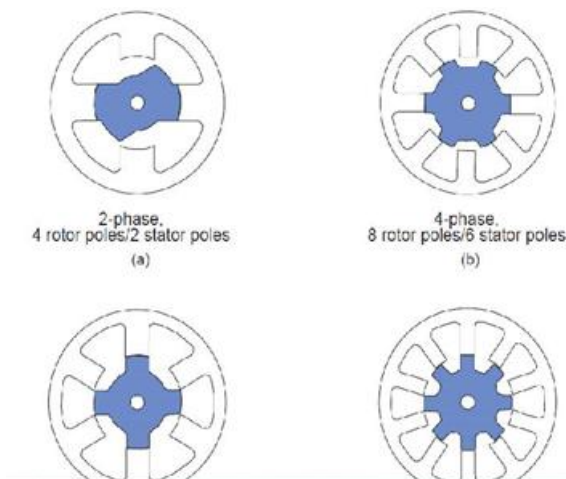

Fig.1. Shows the 4-Phase, 8 Rotor Poles/6 Stator Poles

In general, voltage or current command profile is used in different aspects of SRM such as torque, speed or position control and even for torque ripple reduction. Using DTC, Jinupun [3] succeeded in torque ripple reduction of SR motors. He used a new type of winding configuration and applied the concept of short flux pattern that links two separate poles of the stator. However, the need for special motor winding configuration is both expensive and inconvenient. Cheok et. al. [4] applied DTC method to a 3-phase 6/4 SRM with a very close concept to that of conventional DTC of ac machines. They introduced a comparable theory with conventional DTC of ac machines by using motor flux and torque equations.

III. MOTOR TORQUE-SPEED CHARACTERISTICS

The basic operating principle of the SRM is quite simple; as current is passed through one of the stator windings, torque is generated by the tendency of the rotor to align with the excited stator pole. The direction of torque generated is a function of the rotor position with respect to the energized phase, and is independent of the direction of current flow through the phase winding. Continuous torque can be produced by intelligently synchronizing each phase's excitation with the rotor position. By varying the number of phases, the number of stator poles, and the number of rotor poles, many different SRM geometries can be realized. Generally, increasing the number of SRM phases reduces the torque ripple, but at the expense of requiring more electronics with which to operate the SRM.

At least two phases are required to guarantee starting, and at least three phases are required to insure the starting direction. The number of rotor poles and stator poles must also differ to insure starting. The torque-speed operating point of an SRM is essentially programmable and determined almost entirely by the control. This is one of the features that make the SRM an attractive solution. The envelope of operating possibilities, of course, is limited by physical constraints such as the supply voltage and the allowable temperature rise of the motor under increasing load. In general, this envelope is described by Fig2
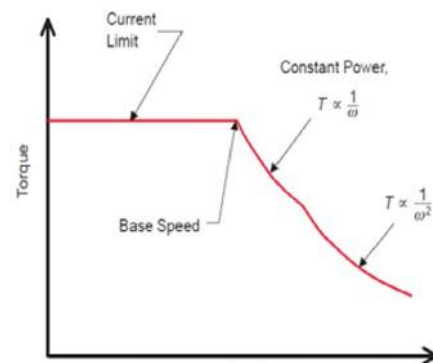

Fig.2. SRM Torque-Speed Characteristics.

Like other motors, torque is limited by maximum allowed current, and speed by the available bus voltage. With increasing shaft speed, a current limit region persists until the rotor reaches a speed where the back-EMF of the motor is such that, given the DC bus voltage limitation we can get no more current in the winding—thus no more torque from the motor. At this point, called the base speed, and beyond, the shaft output power remains constant, and at its maximum. At still higher speeds, the back-EMF increases and the shaft output power begins to drop. This region is characterized by the product of torque and the square of speed remaining constant.

IV. 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 and with 8/6 pole structure is shown in Fig. 3. SRM curves for whole entire rotor positions and phase currents are most important part of performance studying.
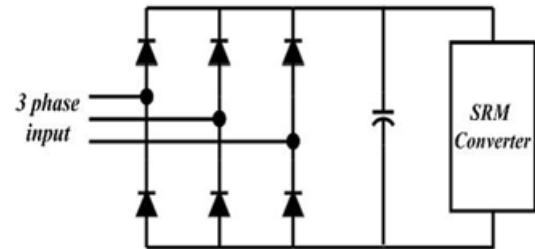

Fig.3. The Tested 8/6 SRM Inside View.

Fig.4 Conventional SRM Drive.

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.

V. 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.
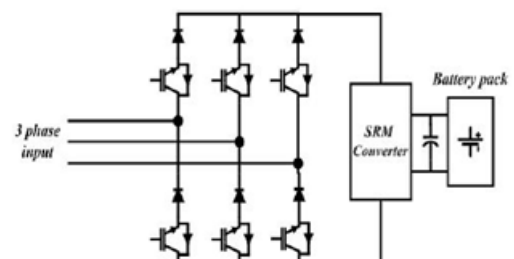

Fig.5. Proposed SRM Drive

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:

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

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:

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

Where mc is the modulation index, TS is the sampling interval and sc θ is the angle between the reference vector and the first active vector [8].
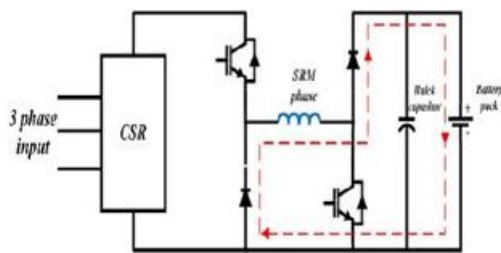
Fig.6 Battery Charging in Regenerative Mode of SRM.

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.

VI. SIMULATION RESULTS:

Here the simulation is carried out by two different cases 1) proposed 8/6 SRM 2) Closed loop operation of 8/6 SRM.
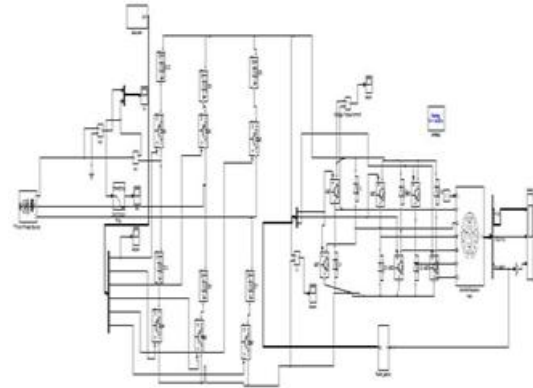
A. Case-1 Proposed 8/6 SRM

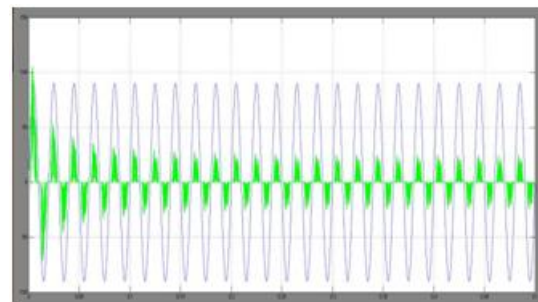**Fig.7. Matlab/Simulink Model of Proposed SRM Drive in Open Loop.**

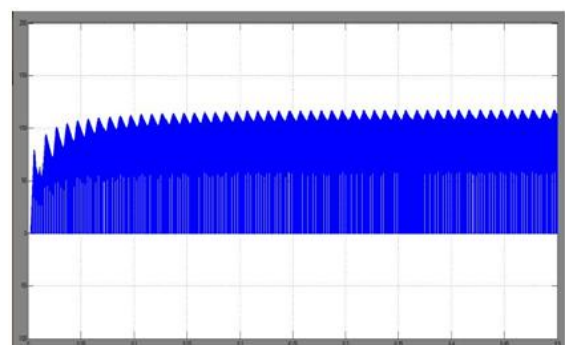**Fig.8. Simulated Input Voltage and Current Waveforms for SRM Drive with CSR.**

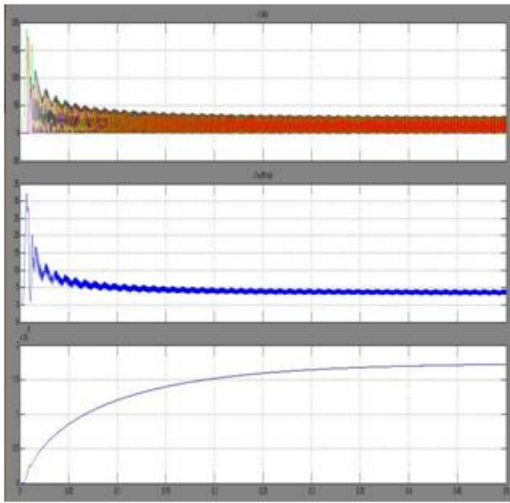**Fig.9. Simulated Output Voltage of CSR in Open Loop SRM Drive.**

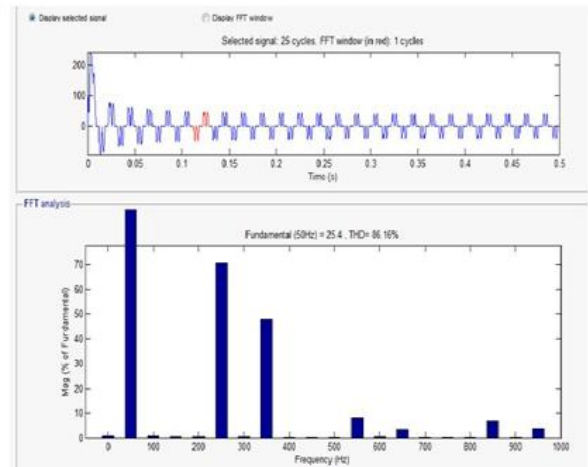**Fig.10. Simulated Output Current, Torque and Speed Waveforms of SRM Drive in Open Loop**

Fig.11. Matlab/Simulink Model of Battery Charging in Regenerative Mode of SRM.

Fig.12. Simulated Output Waveform of Battery Current.

Fig.13. Harmonic Analysis of Closed Loop SRM Is 86.16%

B. Case-2 Closed Loop Operation of 8/6 SRM

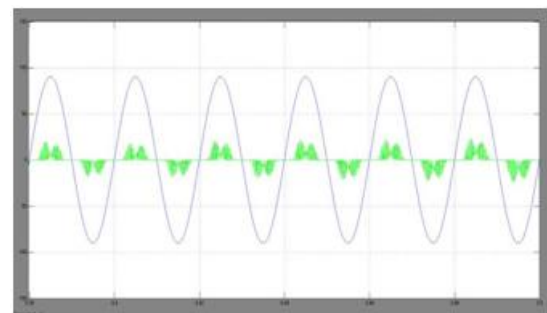**Fig.14. Matlab/Simulink Model of Closed Loop Controlled SRM Drive.**

Fig.15. Simulated Input Wave Form of Voltage and Current for Closed Loop Controlled SRM Drive.
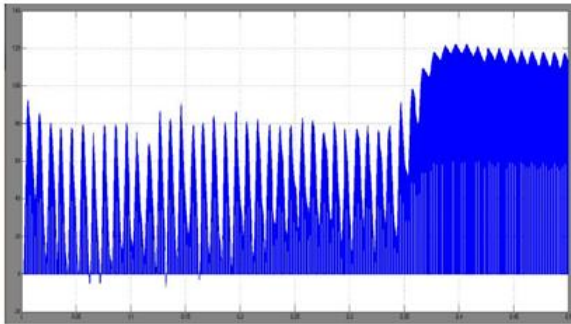
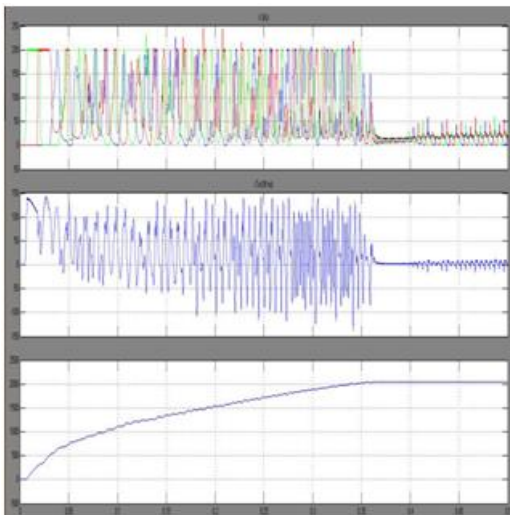**Fig.16 Simulated Output Voltage of CSR in Closed Loop SRM Drive.**

Fig.17 Simulated Output Current, Torque and Speed Waveforms of SRM Drive in Closed Loop at 2000 R.P.M Reference Speed.
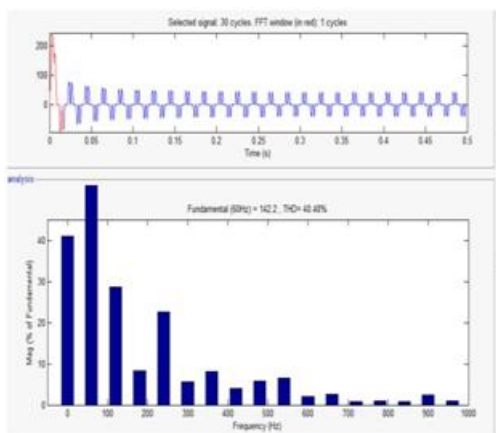

Fig.18. Harmonic Analysis of Closed Loop SRM is 40.48%.

VII. CONCLUSION:

In this paper, a four-phase 8/6-pole 4-kW SR motor drive Specialists Conference – PES. system is modeled and simulated. A CSR based converter is established to modify the input current of the drive, improving the power factor of SRM drive. By eliminating Dc link's capacitors 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 frequency spectra of the input phase current for both cases shows that the proposed converter greatly improves the THD of the current through correcting the power factor while allowing for speed control via controlling the link voltage using the modulation index. Closed loop control using a PI controller with Kp and Ki values are presented in this paper for achieving fast response, low steady state error and low torque ripples. Closed loop controller for an SRM drive with power factor correction is implemented in Matlab/Simulink environment.

VIII. REFERENCES:

[1]R. Krishnan, Switched Reluctance Motor Drives, Boca Raton, FL: CRC Press, 2001.

[2]J. Pyrh¨onen, T. Jokinen, V. Hrabovcova'; translated by H.Niemel¨a, textitDesign of Rotating Electrical Machines, John Wiley & Sons, 2008.

[3]D.H. Lee, Z.G. Lee, J. Liang, , J. Ahn, ―Single-phase SRM drive with torque ripple reduction and power factor correction,‖ IEEE Trans. On Industry Applications, Vol. 43, No. 6, pp. 1578-1587, Nov./Dec. 2007.

[4]V. Ramanarayanan, L. Venkatesha, D. Panda, ―Flux-linkage characteristics of switched reluctance. C 2008, Jun 15-19, 2008, pp. 1235 – 1241. motor,‖

Power Electronics, Drives and Energy Systems for Industrial Growth, Vol.1, pp. 281– 285, Jan. 1996.

[5]V. Ramanarayanan, D. Panda, ―Mutual coupling and Its effect on steadystate performance and position estimation of even and odd number phase switched reluctance motor drive,‖ IEEE Trans. on Magnetics, Vol. 43, No. 8, pp. 3445–3456, Aug. 2007.

[6]R. Krisinan, G. H. Rim, Modeling, ―Simulation An Analysis Of Variable Speed Constant Frequency Power Conversion Scheme with A Permanent Magnet Brushless DC Generator,‖ in Proc. 1988 IEEE Industrial Electronics Society Conf, IECON, pp. 332 – 337.

[7] L. Huber and D. Borojevic, ―Space Vector Modulated Three-Phase to Three-Phase Matrix Converter with Input Power Factor Correction,‖ IEEE Trans. Industry Applications, vol. 31, no. 6, pp. 1234-1246, Nov/Dec. 1995.

[8]H.R. Karshenas, J. Mousavi, ―A new direct sinusoidal input/output acac converter with unidirectional switches‖, in Proc. 2008 IEEE Electrical Machines and Systems Conf, pp. 1885–1890

[9]R. Krishnan, Switched Reluctance Motor Drives, Boca Raton, FL: CRC Press, 2001.

[10] M. Cacciato, A. Consoli, G. Scarcella and G. Scelba, ―A switched reluctance motor drive for home appliances with