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Volume 06, Issue 13, Page No: 364 – 369.

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SWITCHED RELUCTANCE MOTOR (SRM) DRIVE FOR AN ELECTRIC VEHICLE WITH VOLTAGE BOOSTING AND ON BOARD POWER FACTOR CORRECTED CHARGING CAPABILITIES

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ABSTRACT

The main aim of this project is a compact battery-powered switched-reluctance motor (SRM) drive for an electric vehicle with voltage-boosting and on-board power-factor-corrected-charging capabilities. Although the boost-type front-end DC/DC converter is externally equipped, the on-board charger is formed by the embedded components of SRM windings and converter. In the driving mode, the DC/DC boost converter is controlled to establish boostable well-regulated DC-link voltage for the SRM drive from the battery. During demagnetization of each stroke, the winding stored energy is automatically recovered back to the battery. Moreover, the regenerative braking is achieved by properly setting the SRM in the regenerating mode. 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. The validity and effectiveness of the proposed approach is shown by simulation results. In concept proposed concept has been implemented the closed loop speed control of the SRM drive.

Index Terms- DC-link, DC/DC boost converter, SRM, closed loop operation

I.INTRODUCTION

Switched reluctance motors have been used since 1969 for variable speed applications due to the advent of inexpensive, high power switching devices. They have the wound field coils of a dc motor for their stator windings while the rotors have no windings or magnets. Being brushless, SRM drives enjoy such unique features as concentric windings, low resistance, low moment of inertia, comparable power density, negligible mutual coupling, higher or comparable reliability, and low cost, which make them ideal for many industrial applications. However, they suffer from a poor operating power factor, which results in increased losses in powerdistribution systems. Therefore, improving the power factor is beneficial to enhancing their commercial competitiveness. Moreover, vibrations and the resulting acoustic noise are mentioned as drawbacks of SRM machines [1].

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

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spurt of activity in this field [2], [3]. 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 a 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.

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 magneticcharacteristics, 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.

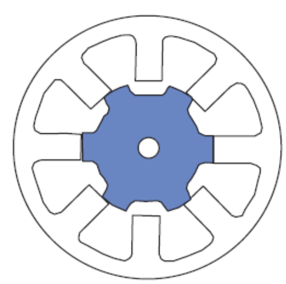

Fig.1 shows the 4-phase,8 rotor poles/6 stator poles

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

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flux pattern that links two separate poles of the stator. However, the need for special motor winding configuration is both expensive andinconvenient. 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 Figure 3

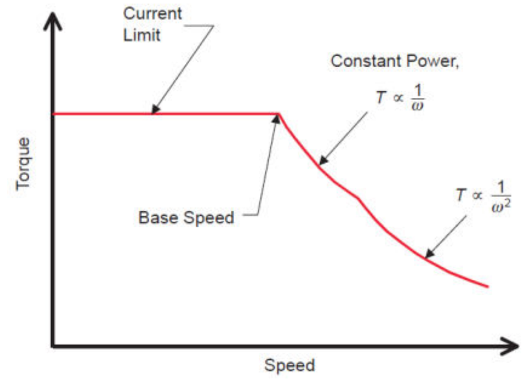

Fig.3 SRM Torque-Speed Characteristics

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 DCbus 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 it's 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.

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Fig.3 The tested 8/6 SRM inside view

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.

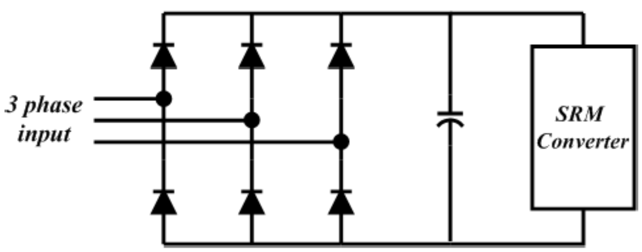

Fig.4 conventional SRM drive

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.

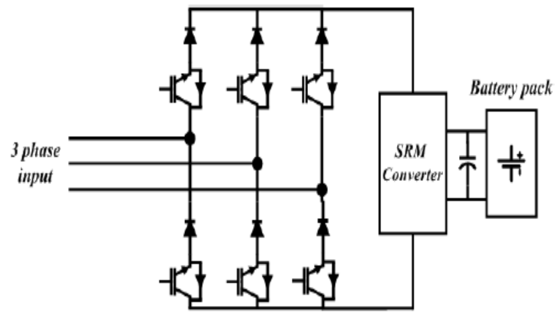

Fig.5 proposed SRM drive

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:

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

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:

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

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].

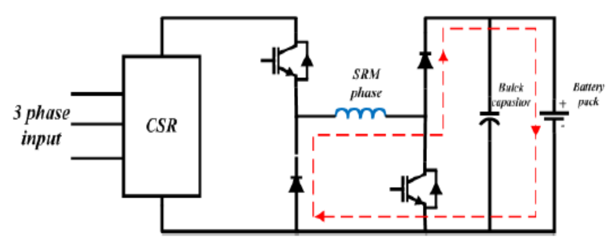

Fig.6 Battery Charging in Regenerative Mode of SRM

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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.IMULATION RESULTS

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

Case-1 proposed 8/6 SRM

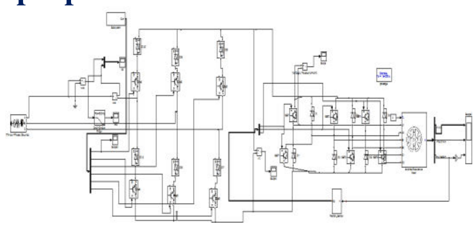


Fig.7 Matlab/Simulink model of proposed SRM drive in open loop

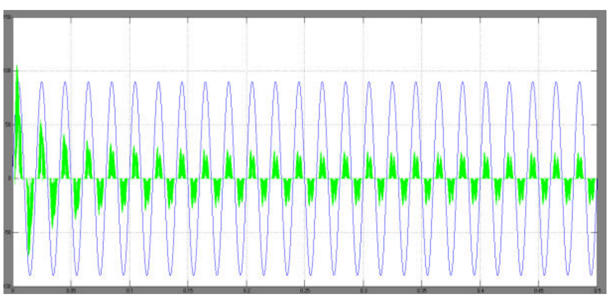


Fig.8 Simulated input voltage and current waveforms for SRM drive with CSR

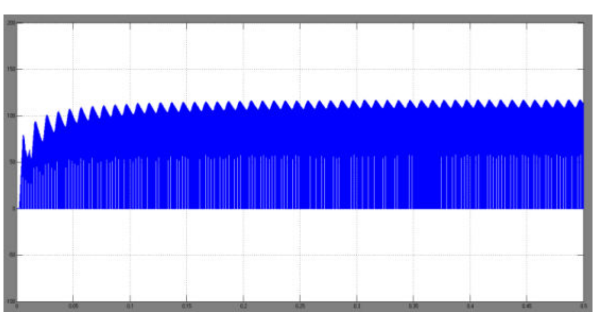


Fig.9 Simulated Output voltage of CSR in openloop SRM Drive

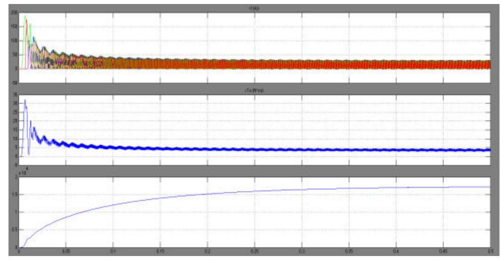


Fig.10 Simulated output current, torque and speed waveforms of SRM drive in open loop.

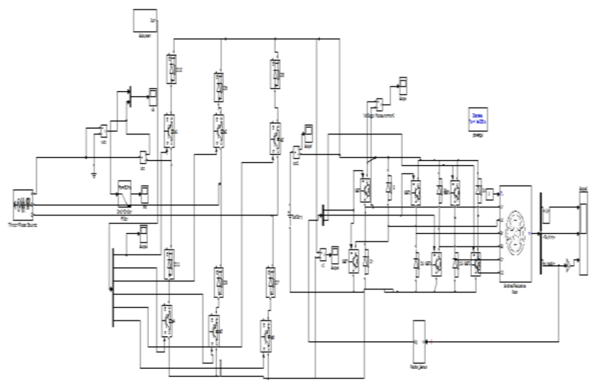


Fig.11 Matlab/Simulink model of Battery Charging in Regenerative Mode of SRM

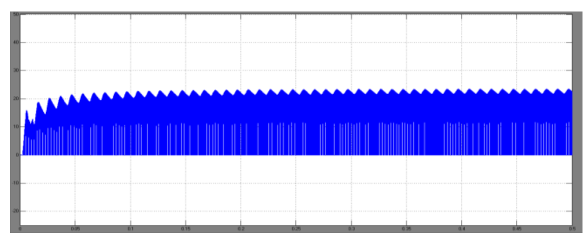
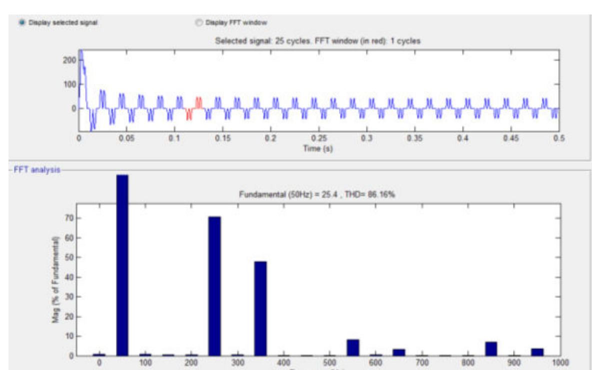


Fig.12 Simulated output waveform of Battery current



Fih.13Harmonic analysis of closed loop SRM is 86.16%

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Case-2 Closed loop operation of 8/6 SRM

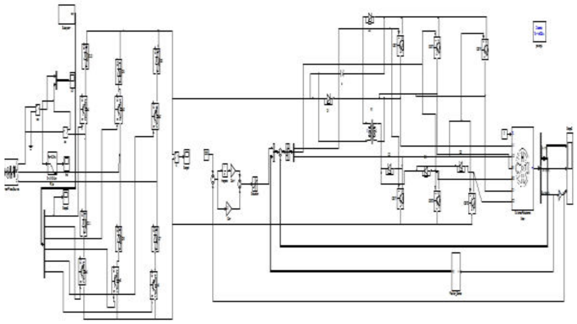

Fig.14 Matlab/Simulink model of closed loop controlled SRM drive

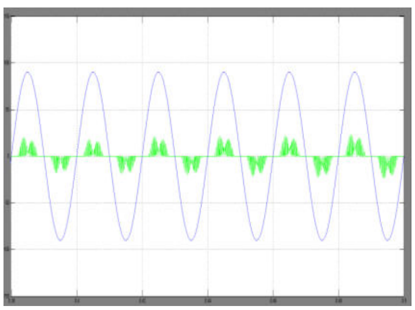

Fig.15 Simulated input wave form of Voltage and current for closed loop controlled SRM Drive

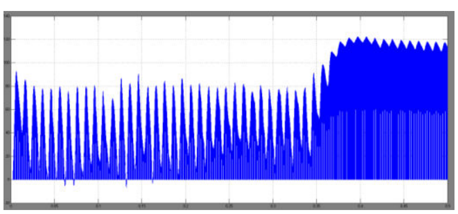

Fig.16 Simulated Output voltage of CSR in closed loop SRM Drive

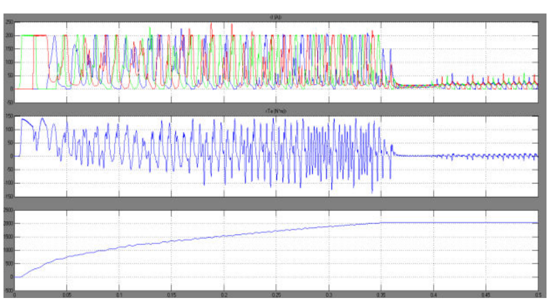

Fig.17 Simulated output current, torque and speed waveforms of SRM drive in closed loop at 2000 r.p.m reference speed

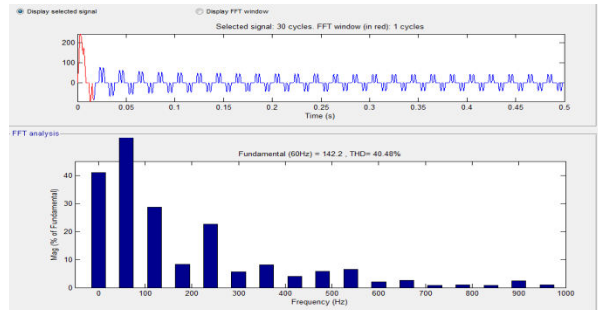

Fig.18 Harmonic analysis of closed loop SRM is40.48%

VII. CONCLUSION

In this project, a four-phase 8/6-pole 4-kW SR motor drive system is modeled and simulated. A two stage power converter is also proposed that both improve the power factor. 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. 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.

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