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Regenerative Mode of Charging Capability with Power Factor Correction and Speed Control using Current Source Converter for SRM Drive

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Abstract

In this paper, the proposed system is to improve power factor of switched reluctance drive and also battery charging capability in regenerative mode of a two-stage power converter based on current source rectifier (CSR). At the CSR stage in the input of SRM converter, eliminate dc link's capacitors and the charging capability of energy saving in regenerative operation mode of SRM drive. And also it controls the speed and current. This paper describes the design of new converter, consisting of half-bridge IGBT modules and Current source rectifiers with battery charging capability of SRM for closed loop control of switched reluctance drive are proposed. The validity and effectiveness of the proposed approach is shown by MATLAB /simulation.

Keywords: *IGBT, Current Source Rectifier, Switched Reluctance Motor Drive, DC-Link, Battery, and Closed Loop Operation*

1. Introduction

Reluctance motor is a type of electric motor on the Ferro magnetic rotor that induces non-permanent magnetic poles. Torque is generated through the phenomenon of magnetic reluctance. The SRM has become an attractive entrant for variable speed drives applications and is rapidly progressing due to the advancement of inexpensive, high power switching devices. While the rotors have no windings or magnets, negligible mutual coupling, higher or comparable reliability due to fault tolerant robust structure and low cost [2]. Unlike conventional motor types, power is delivered to windings in the stator rather than the rotor .This simplifies mechanical design the power does not have to be delivered to a moving part, but it complicates the electrical design as some sort of switching system needs to be used to deliver power to the different windings. Common uses for an SRM include applications where the rotor must be held stationary for long periods.

SRM possess several important features, which make favorable for use in adjustable speed drives. The applications which it includes precision position control systems for robotics, low-power servomotors and high power traction drive [4]. As rotor in SRM carries no winding, SRM's with rotor speed more than 2×10^5 rpm can be built.

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2. Operation of Switched Reluctance Motor

The reluctance motor has consists stator and rotor. The stator and rotor are designed in such a manner that the variation of the inductance of the windings is sinusoidal with respect to the rotor position. The Figure1 shows Cross Section of 6/4 inside view of SRM.

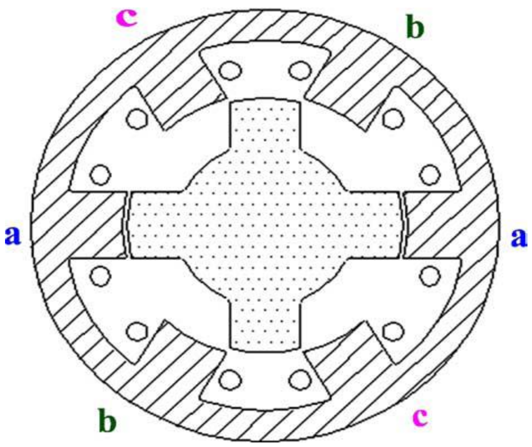

Figure 1. Cross Section of 6/4 SRM Inside View

SRM can be operated from unidirectional drive circuits; cost of micro and power electronics is reduced. The reluctance motor characteristic is non linear behavior. Due to non linearity the motor can produce the torque ripples which causes undesirable vibration and acoustic noise are major problem in switched reluctance drive system. Torque ripple can be reduced either by motor design or by suitable control methods [5].

Therefore, power factor improvement, speed control and current controllers are essential to enhancing their competitiveness. 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 it draws a pulse current from the ac source side. Switched reluctance motor coupled within a battery-charging circuit has been proposed in, and is a good choice for low-cost battery-powered applications, as it combines high efficiency and high reliability with low manufacturing costs [3].

2.1. Mathematical Model for SRM

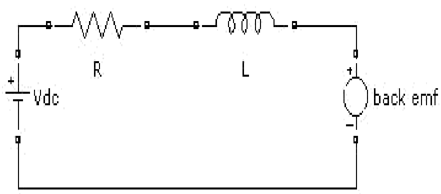

Figure 2. Equivalent Circuit

The per phase equivalent circuit of the SRM neglecting mutual inductances was given as below

$$v = Ri + \frac{L(\theta, i)di}{dt} + \frac{idL(\theta, i)}{dt} \tag{1}$$

Where v= applied phase voltage

R=resistance per phase
Ri= resistive voltage drop

From the analysis the motor is considered to be steady state the speed of the machine and field current are assumed to constant in this case the equations of motor is as below

$$v = Ri + L\,{}^{di}/_{dt} + K\omega_{ma} \tag{3}$$

$$\mathbf{T=B\omega_m} \tag{4}$$

A control technique to overcome this nonlinear characteristics and the undesirable dynamic behavior of the motor is to switch the SRM phases with a phase shift by measuring the speed and current of the drive continuously. Here we are using current source converter to switch the SRM phases simultaneously [12]. The switching angle α is given by

$$\propto = \cos^{-1}\frac{Vc}{Vcm} = \cos^{-1}(Vcn) \tag{5}$$

For rotor position estimation including the reference position, the input current is directly measured as [13]

$$\Psi=\int (v - Ri)\,dt \tag{6}$$

Based on approximated rotor position estimation the speed w can be calculated with [13]

$$\omega = \frac{\Delta\theta}{\Delta t} \tag{7}$$

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, controlling the speed and current also in this converter. Front-end large filter capacitor can be used to battery charging in regenerative mode of switched reluctance motor [1]. Proposed two-stage power converter validation through significant 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.

3. Characteristics of Switched Reluctance Motor

The number of poles on the SRM's stator is usually unequal to the number of the rotor to avoid the possibility of the rotor being in a state where it cannot produce initial torque, which occurs when all the rotor poles are aligned with the stator poles. Figure 3 shows a 6/4 SRM with one phase asymmetric inverter. This 3-phase SRM has 6 stator and 4 rotor poles, each phase comprises two coils wound on opposite poles and connected in series or parallel consisting of a number of electrically separated circuit or phases. These phase windings can be excited separately or together depending on the control scheme or converter [7]. Due to the simple motor construction, an SRM requires a simple converter and it is simple to control.

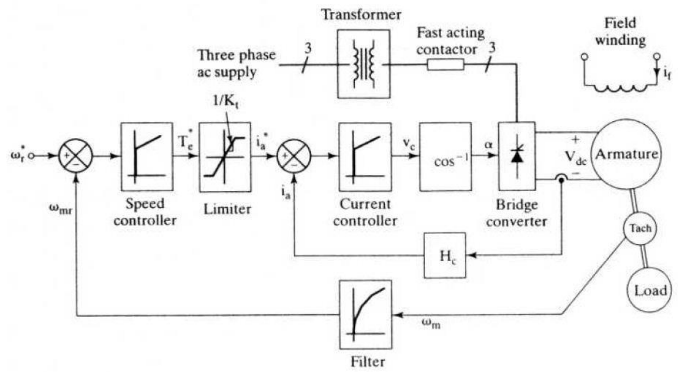

Figure 3. Closed Loop Speed Control System of SRM Drive

The torque-speed operating point of an SRM is as shown in below. For speeds below w_b the torque is limited by motor current or controller current. The precise value of current at a given operating point depends on load characteristics, the speed, and the regulator and control strategy. The speed range below w_b the firing angles can be chosen to optimize efficiency or minimize torque ripple.

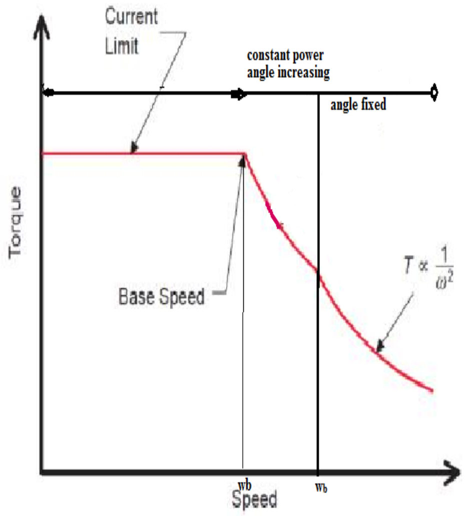

Figure 4. SRM Torque- Speed Characteristics

The corner point or base speed w_b is the highest speed at which maximum current can be supplied at rated voltage, with fixed firing angles if these angles are still kept fixed, the maximum torque at rated voltage decreases with speed squared. If the conduction angle is increased (by advancing the turn on angle) there is a considerable speed range over which maximum current can still be forced in to the motor , and these sustains the torque at a level high enough to maintain a constant power characteristics.

At very low speeds the torque – speed capability curve may deviate from the flat torque characteristics. If the chopping frequency is limited it may be difficult to limit the peak current without help of self emf of the motor and the current reference may have to be reduced.

4. Proposed Control Approach for SR Drive

Half-bridge IGBT modules are the popular choice to build asymmetric bridge converters for proposed control approach and It makes the circuit less trustworthy and more complicated. Figure 5 illustrates the phase branch with half-bridge modules for typical SRM converters. Therefore, the use of half-bridge switch modules in asymmetric bridge converter brings low utilization and high count of switch devices [8].

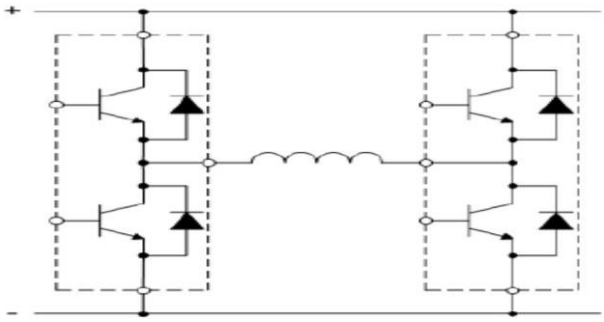

Figure 5. Phase Branch with Half-bridge Modules

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 Phase winding energizing is done by machine side converter as second stage [2]. 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.

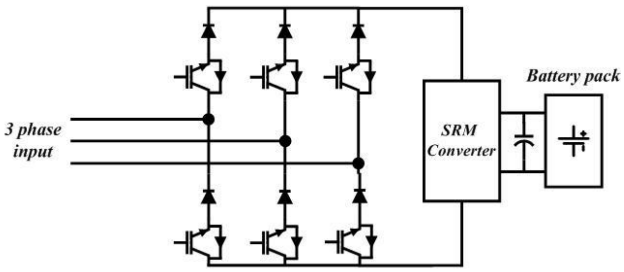

Figure 6. Proposed SRM drive

In this converter, dc link capacitors can be used to battery charging in regenerative mode of switched reluctance motor. Figure 7 shows the regenerative operation of SRM drive. Turn on and turn off Angles affect dc link current ripple and rms value.

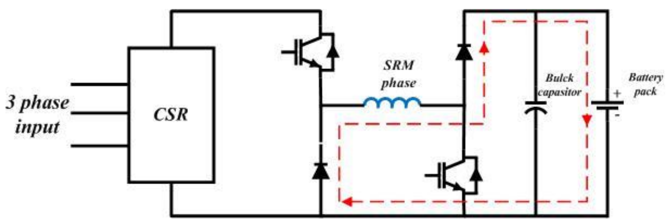

Figure 7. Battery Charging in Regenerative Mode of SRM

A PWM control does not have an inherent current control capability; a current limiter has to be introduced. A proportional controller provides the reference for the current limit. The current was made to stay within a maximum and minimum limit. Reference speed value was set digitally, and a speed loop was used to compare the actual speed and the reference speed, based on the error duty cycle for the next period was determined [5].

Figure 8 shows a simple closed loop system. The output signal is fed back to the input to produce a new output. A well-designed feedback system can often increase the accuracy of the output.

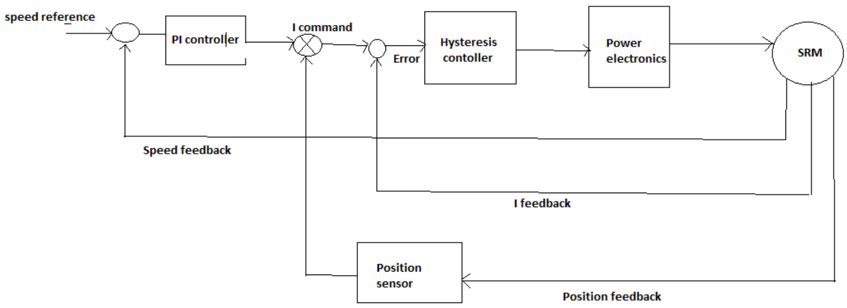

Figure 8. Block Diagram of a Closed Loop Speed Control System

In the control method the magnitude of the current flowing into windings is controlled using a control loop with a current feedback. The current in a motor phase winding is directly measured with a current/voltage converter or a current sense resistor connected in series with the phase. The current is compared with a desired value of current, forming an error signal. The current error is compensated via a control law, such as a PI, and an appropriate control action is taken. The block diagram above shows that both current and position feedback are needed for controlling the SR motor [4]. Position feedback is needed to synchronize the current flow, with respect to the rotor position, in order to generate the desired motoring torque. Position feedback is also needed to compute the rotor mechanical speed, which is compared with the desired value of speed.

5. Results and Discussions

The proposed block diagram of SRM is as shown in Figure 9.

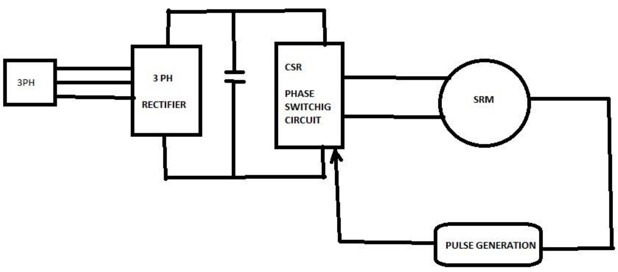

Figure 9. Closed Loop Block Diagram for SRM Model

The performance results are exhibited in Figure 10-15

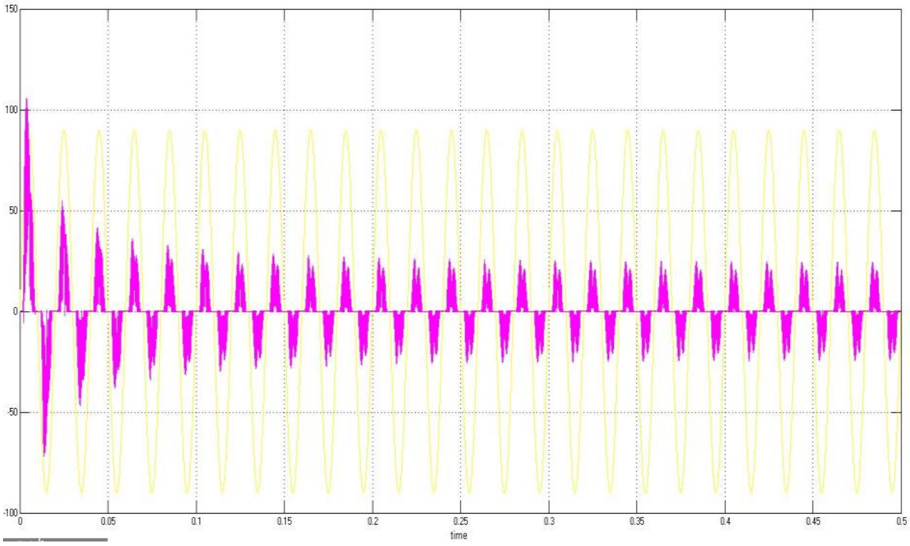

Figure 10. Response of Voltage and Current for Closed Loop Controlled SRM Drive

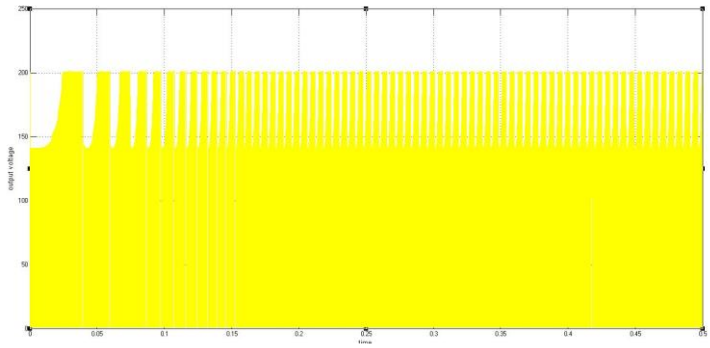

Figure 11. Output voltage of CSR in Closed Loop SRM Drive

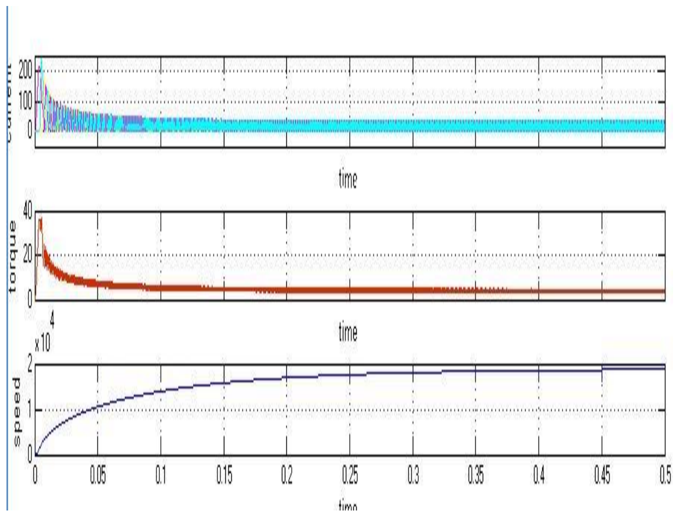

Figure 12. Output Current, Torque and Speed Waveforms of SRM Drive in Open Loop

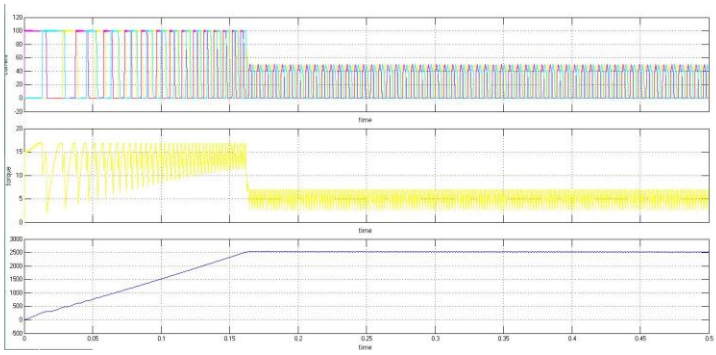

Figure 13. Current, Torque and Speed Responses of SRM Drive in closed Loop at 2500 r.p.m Speed Command

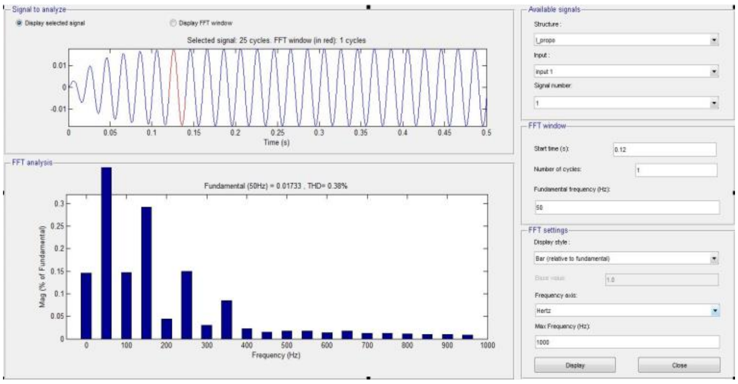

Figure 14. Harmonic Analysis of Closed loop SRM

Battery pack current for fixed angle control of SRM is shown in Figure 15. Turn on and turn off Angles control ripple, RMS and average value of dc link current.

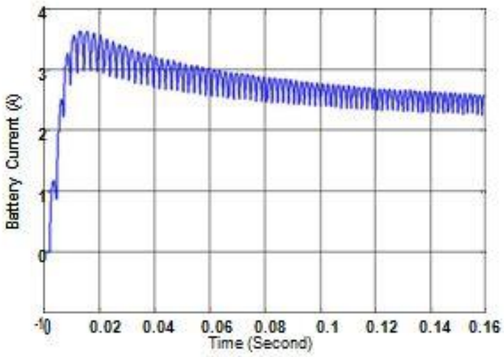

Figure 15. Battery Pack Current

6. Conclusion

In this paper, a three-phase 6/4-pole SR motor drive system is modeled and simulated. A two stage power converter is also proposed that both the power factor correction and speed control using Current Source converter. A current source rectifier (CSR) based converter is established to modify the input current of the drive, improving the power factor and controlling the speed 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 and with controlling the speed as an application, front-end large filter capacitor can be used to battery charging in regenerative mode of switched reluctance motor.

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