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POWER FACTOR IMPROVEMENT USING CURRENT SOURCE RECTIFIER WITH BATTERY CHARGING CAPABILITY IN REGENERATIVE MODE OF SPECIAL MOTOR DRIVES

[1]v.sai sowmya, [2]k.kavitha
[1]Student,Sri sunflower college of engineering and technology
[2]Associate professor,Sri sunflower college of engineering and technology
saisowmya71@gmail.com
kavitha.kondaveeti@gmail.com

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
.

1. INTRODUCTION

Power electronic converters can be broadly classified as AC-DC, AC-AC, DC-AC and DC-DC converters. The focus of the work presented in this thesis is in the AC-DC conversion area. Most AC-DC converter applications desire a constant DC output voltage which will be further used for other purposes. Till very recently the attention of all manufacturers and users of AC-DC converters was on the DC side of the same. In this sense, the most popular AC-DC converter is the rectifier with C filter at lower power levels and the phase-controlled rectifier with LC filter at higher power levels. Currently, the concern in rectifiers include power quality issues relating to the source end as well. The reason for this is the undesirable AC line current harmonics drawn from the utility by the standard rectifiers. The presence of harmonics in the line current results in
the distortion of the voltage at the Point of Common Coupling (PCC) due to the presence of source inductance. This may cause malfunction of other loads, power system protection and monitoring devices. Some of the other problems caused by line current harmonics are, overheating of the neutral line, interference with communication and control signals etc. With presence of lower-order harmonics in input current, power factor comes down. Poor power factor of operation implies interactive use of the volt-ampere rating of the utility equipment. These problems have resulted in the additional concern relating to source current quality . The work presented in this thesis attempts to address these issues. The following section introduces some of the terms that will be used extensively in the thesis. The succeeding sections deal with the problems arising out of the conventional techniques used for AC-DC conversion and also some of the existing techniques for rectifying those problems.

1.1 Power Factor:

The power factor is defined as the ratio of the average power to the apparent power at an AC terminal. Assuming an ideal sinusoidal input voltage source, the power factor can be expressed as the product of two factors, the distortion factor and the displacement factor.

The distortion factor kd is the ratio of the fundamental root-mean-square (RMS) current to the total RMS current. The displacement factor kq is the cosine of the displacement angle between the fundamental input current and the input voltage.

$$PF = K_d \; K_\theta$$

$$K_d = \frac{I_{rms(1)}}{I_{rms}}$$

$$K_\theta = \cos\theta$$

When a converter has less than unity power factor, it means that the converter absorbs apparent power higher than the real power it consumes. This implies that the power source should be rated with higher VA ratings than the load needs. In addition, the current harmonics the converter produces deteriorate the power source quality, which eventually affect the other equipment. The simple solution to improve the power factor is to add a passive filter, which is usually composed of a capacitor and an inductor. However, this passive filter is bulky and inefficient since it operates at the line frequency. Therefore, a power factor correction stage has to be inserted to the existing equipment to achieve a good power factor. Usually, two types of power factor correction methods are used: The VAR/harmonics compensation method employs a switch-mode power converter in parallel with the nonlinear load to supply a reactive power and/or line current harmonics to cancel the displacement and the line current harmonics created by the nonlinear load. This method cannot cancel all the line current harmonics, however, and this additional line current harmonics compensator cannot regulate the output to the load. The high frequency switch mode power factor correction converter called a PFC stage, is usually inserted in the equipment to shape the line input current into a sinusoidal waveform and its line current is in phase with the line voltage.

2. LITERATURE SURVEY

2.1 SWITCHED RELUCTANCE MOTOR

Switched Reluctance Motors (SRM) have inherent advantages such as simple structure with non winding construction in rotor side, fail safe because of its characteristic which has a high tolerances, robustness, low cost with no permanent magnet in the structure, and possible operation in high temperatures or in intense temperature variations. The torque production in switched reluctance motor comes from the tendency of the rotor poles to align with the excited stator poles. The operation principle is based on the difference in magnetic reluctance for magnetic field lines between aligned and unaligned rotor position when a stator coil is excited, the rotor experiences a force which will pull the rotor to the aligned position. However, because SRM construction with doubly salient poles and its non-linear magnetic characteristics, the problems of acoustic noise and torque ripple are more severe than these of other traditional motors.

The torque ripple is an inherent drawback of switched reluctance motor drives. The causes of the torque ripple include the geometric structure including doubly salient motor, excitation windings concentrated around the stator poles and the working modes which are necessity of magnetic saturation in order to maximize the torque per mass ratio and pulsed magnetic field obtained by feeding successively the different stator windings. The phase current commutation is the main cause of the torque ripple.

The torque ripple can be minimized through magnetic circuit design in a motor design stage or by using torque control techniques. In contrast to rotating field machines, torque control of switched reluctance machines is not based on model reference control theory, such

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as field oriented control, but is achieved by setting control variables according to calculated or measured functions. By controlling the torque of the SRM, low torque ripple, noise reduction or even increasing of the efficiency can be achieved. There are many different types of control strategy from simple methods to complicated methods. In this book, motor design factors are not considered and detailed characteristics of each control method are introduced in order to give the advanced knowledge about torque control method in SRM drive.

2.1.1 Construction of SRM

The Switched Reluctance Motors is an electric machine that is characterized mainly by its constructive simplicity. It has salient poles on both stator and rotor and its magnetic core consists of laminated steel. It is a doubly salient, single excited motor. Each stator pole has a simple concentrated winding and there are no conductors of any kind on the rotor which makes the construction cheaper, reliable, and rugged. The schematic diagram of an SRM with eight stator and six rotor poles is shown in Fig 2.1. The stator windings on diametrically opposite poles are connected in series to form one stator phase. The rotor is also laminated. Thinner laminations of silicon steel are preferred in SRM as eddy current dominates the core losses due to higher commutating frequency compared to AC motor of comparable speed and rating. For very high speed application, Cobalt-iron and variants are used for laminations (Miller, T.J.E (1993). The stator and rotor poles appear in pairs but are usually of unequal numbers. This is to avoid the eventuality of the rotor being in a state of producing no initial torque, which occurs when all the rotor poles are locked in with the stator poles. A unique feature of SRM is that it can be operated, even though with reduced power output, even when there is a loss of one of the phases. The choice of the number of poles and number of phases is not unique. Although the number of phases and the number of poles must be minimum to reduce the number of switching devices and the associated commutation, the torque capabilities will influence its selection. Different configurations have been studied and its influence on the performance has been reported (Miller, T.J.E (1993). In order to guarantee that the SRM can be started at any initial rotor position, and to get smooth torque capacity per resolution, SRM's with multi-phase as well as multi-rotor-pairs are developed. The number of stator and rotor poles is generally different. Some possible combinations are: $N_s = 6$, $N_r = 4$; $N_s = 8$, $N_r = 6$; $N_s = 12$, $N_r = 10$, etc. These combinations ensure that the rotor is never in a position where the summation of the electromagnetic torque generated by each phase is zero. The larger the stator and rotor poles number, the less the torque ripple. By choosing a combination where there are two more stator poles than rotor poles, high torque and low switching frequency of the power converter can be achieved. Three phase 6/4 pole and four phase 8/6 pole configurations are popular among different configurations.

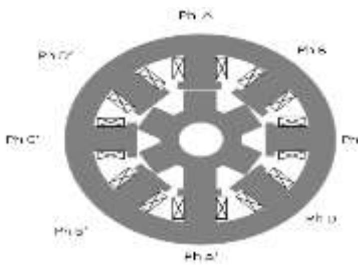

Fig 2.1 Cross section of a 8/6 SRM

2.1.2. CHARACTERISTIC OF SWITCHED RELUCTANCE MOTOR

The SRM is an electric machine that converts the reluctance torque into mechanical power. In the SRM, both the stator and rotor have a structure of salient-pole, which contributes to produce a high output torque. The torque is produced by the alignment tendency of poles.

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The rotor will shift to a position where reluctance is to be minimized and thus the inductance of the excited winding is maximized. The SRM has a doubly salient structure, but there are no windings or permanent magnets on the rotor [Lawrenson, 1980]. The rotor is basically a piece of steel (and laminations) shaped to form salient poles. So it is the only motor type with salient poles in both the rotor and stator. As a result of its inherent simplicity, the SRM promises a reliable and a low-cost variable-speed drive and will undoubtedly take the place of many drives now using the cage induction, PM and DC machines in the short future. 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. Fig.2.1 shows a 8/6 SRM with one phase asymmetric inverter. This 4-phase SRM has 8 stator and 6 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. Due to the simple motor construction, an SRM requires a simple converter and it is simple to control.

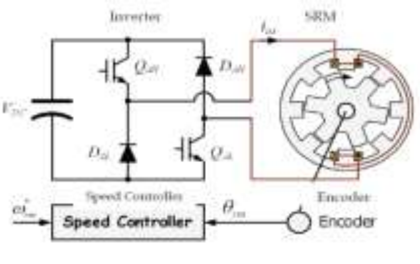

Fig. 2.2. SRM with one phase asymmetric inverter

The aligned position of a phase is defined to be the situation when the stator and rotor poles of the phase are perfectly aligned with each other (θ_1-θ_2), attaining the minimum reluctance position and at this position phase inductance is maximum. The phase inductance decreases gradually as the rotor poles move away from the aligned position in either direction. When the rotor poles are symmetrically misaligned with the stator poles of a phase the position is said to be the unaligned position and at this position the phase has minimum inductance . Although the concept of inductance is not valid for a highly saturated machine like SR motor, the unsaturated aligned and unaligned incremental inductances are the two key reference positions for the controller.

The relationship between inductance and torque production according to rotor position is shown in Fig. 2.3 There are some advantages of an SRM compared with the other motor type. The SRM has a low rotor inertia and high torque/inertia ratio; the winding losses only appear in the stator because there is no winding in the rotor side; SRM has rigid structure and absence of permanent magnets and rotor windings; SRM can be used in extremely high speed application and the maximum permissible rotor temperature is high, since there are no permanent magnets and rotor windings [Miller, 1988].

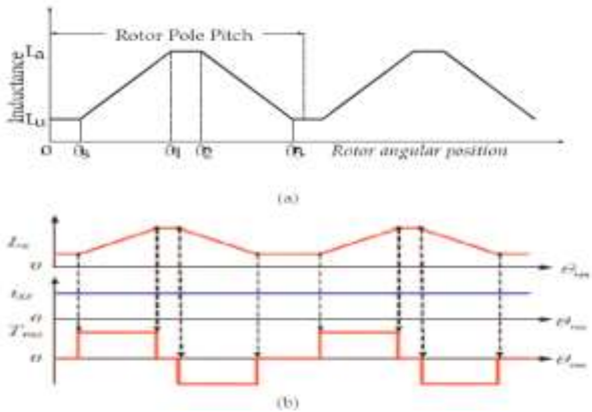

Fig. 2.3. (a) Inductance and (b) torque in SRM

Constructions of SRM with no magnets or windings on the rotor also bring some disadvantage in SRM. Since there is only a single excitation source and because of magnetic saturation, the power density of reluctance motor is lower than PM motor. The construction of SRM is shown in Fig. 2.3. The dependence on magnetic saturation for torque production, coupled with the effects of fringing fields, and the classical fundamental square wave excitation result in nonlinear control characteristics for the reluctance motor. The double saliency construction and the discrete nature of torque production by the independent phases lead to higher torque ripple compared with other machines. The higher torque ripple, and the need to recover some energy from the magnetic flux, also cause the ripple current in the DC supply to be quite large, necessitating a large filter capacitor. The doubly salient structure of the SRM also causes higher acoustic noise compared with other machines. The main source of acoustic noise is the radial magnetic force induced. So higher torque ripple and acoustic noise are the most critical disadvantages of the SRM.

3. PROPOSED SRM AND STEPPER MOTOR CONCEPT

3.1 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 reduction of the THD value of the supply current with line drawn current quality and power factor improvement are evaluated.

3.2 NON LINEAR 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. SRM curves for whole entire rotor positions and phase currents are most important part of performance studying.

The conventional SRM drive with unipolar power converter is shown in Fig. 3.1. The

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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.

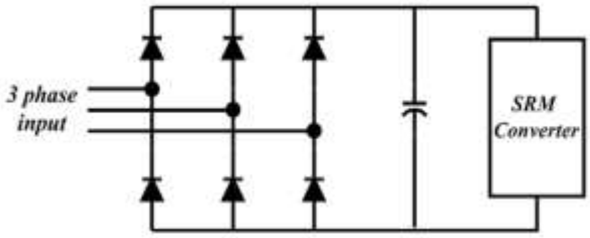

Figure 3.1. conventional SRMdrive.

3.3 PROPOSED SRM DRIVE

Proposed two-stage converter can be seen in Fig. 3.2. 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.

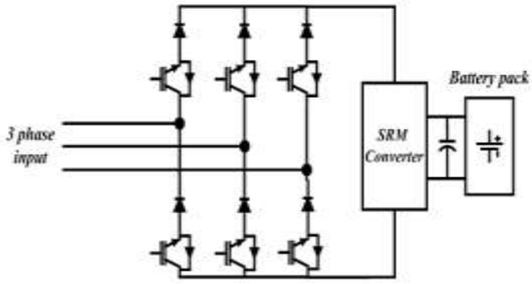

Figure 3.2. proposed SRM drive.

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:

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

(3.1)

Where $\bar{a} = 1\angle 120^0$. 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:

$$d_\mu = {T_\mu}/{T_S} = m_c \cdot \sin(60^\circ - \theta_{sc}),$$

$$d_\upsilon = {T_\upsilon}/{T_S} = m_c \cdot \sin(\theta_{sc}),$$

$$d_{0c} = {T_{0c}}/{T_S} = 1 - d_\mu - d_\upsilon$$

(3.2)

Where mc is the modulation index, TS is the sampling interval andsc θ is the angle between the reference vector and the first active vector [8].

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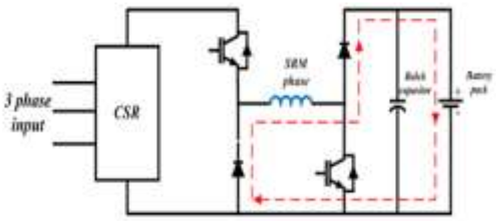

Figure 3.3. Battery Charging in Regenerative Mode of SRM.

In this converter dc link capacitors can be used to battery charging in regenerative mode of switched reluctance motor. Fig .3.3 shows the regenerative operation of SRM drive. Turn on and turn off Angles affect dc link current ripple and rms value.

3.4 STEPPER MOTORS

3.4.1 Stepper Motor Construction And Working

Figure 3.4 Stepper Motor

A stepper Motor is basically a synchronous Motor. In stepper motor there is no brushes. This motor does not rotate continuously , instead it rotates in form of pluses or in discrete steps. That's why it is called stepper motor. There are different types of motors available on the basis of steps per rotation, for example- 12 steps per rotation, 24 steps per rotation etc. We can control or operate Stepper motor with the feedback or without any feedback. A simple image of stepper motor is shown in above picture.

Working Principle Of Stepper Motor:The principle of Working of stepper motor is Electro-Magnetism. It constructs of a rotor that is of permanent magnet and a stator that is of electro-magnets .The following figure shows the construction of a practical stepper motor.

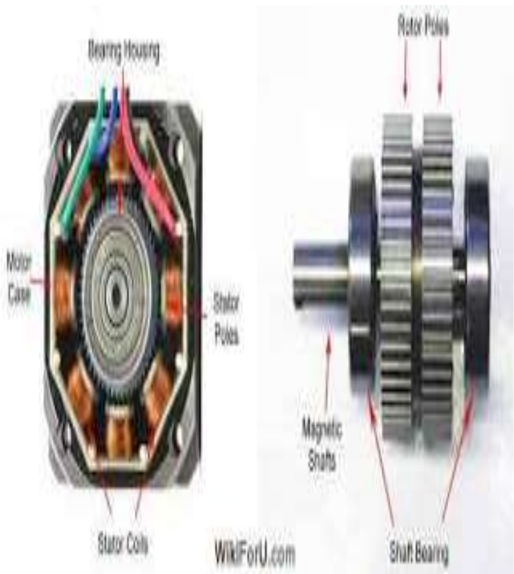

Figure 3.5 working of stepper motor

Now when we give's supply to stator's winding. There will be a magnetic field developed in the stator. Now rotor of motor that is made up of permanent magnet, will try to move with the revolving magnetic field of stator. This is the basic principle of working of stepper motor. Now we are going to discuss its types. In this note you will find the real method of working of specific type of servo motor.

4. SIMULINK RESULTS

4.1 CONVENTIONAL MODE CIRCUIT

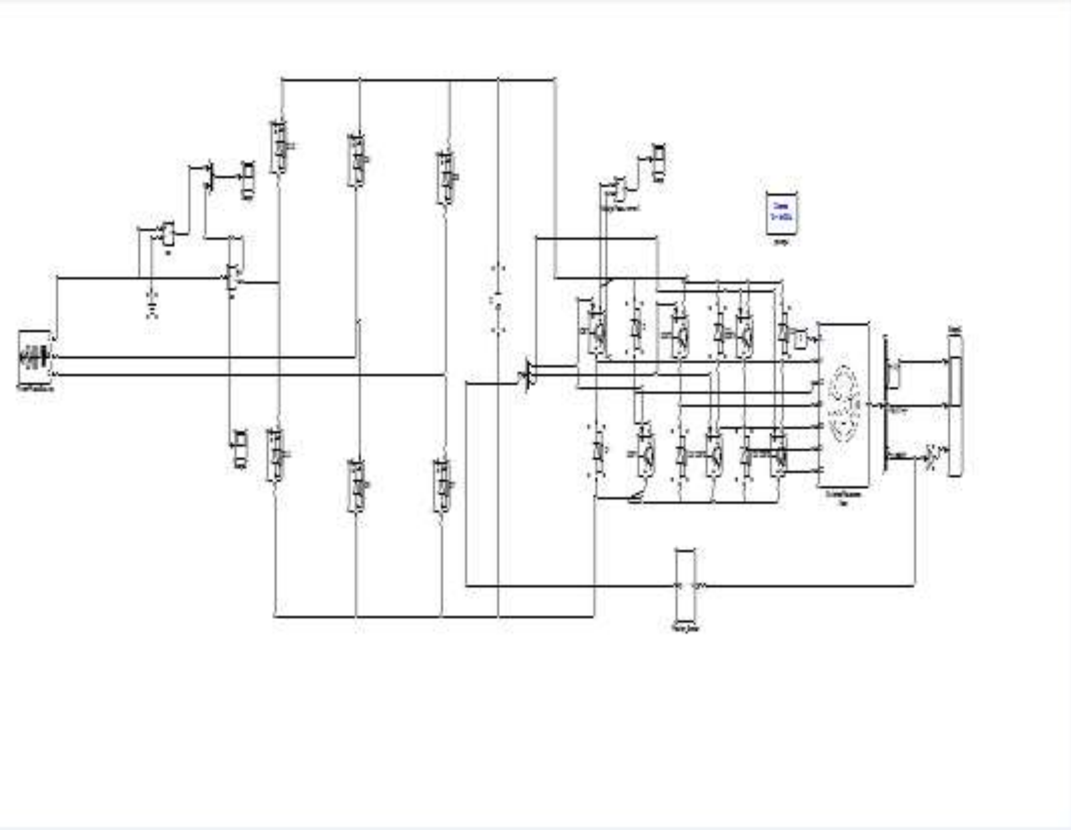

Figure 4.1 Simulation Diagram for Conventional Controller

RESULTANT WAVE FORMS

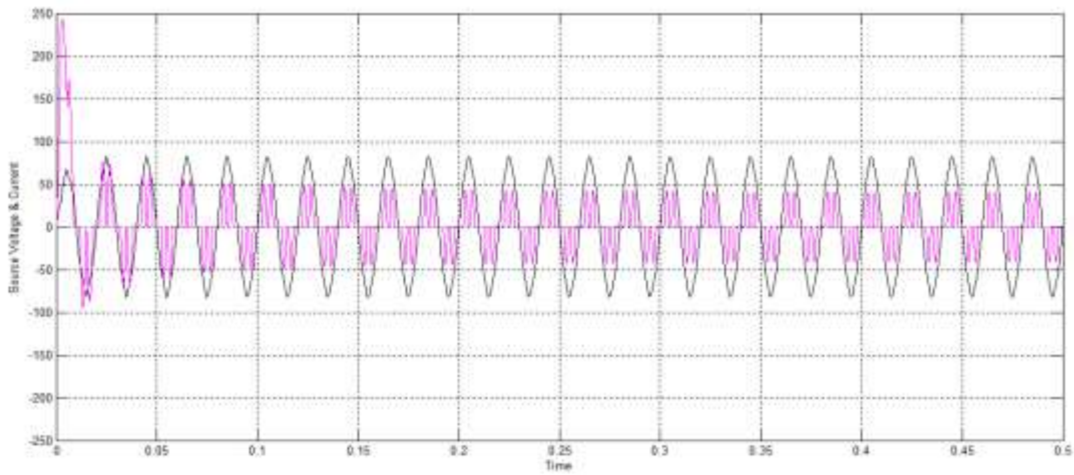

Figure 4.2. Simulation Result for Source Voltage and Current

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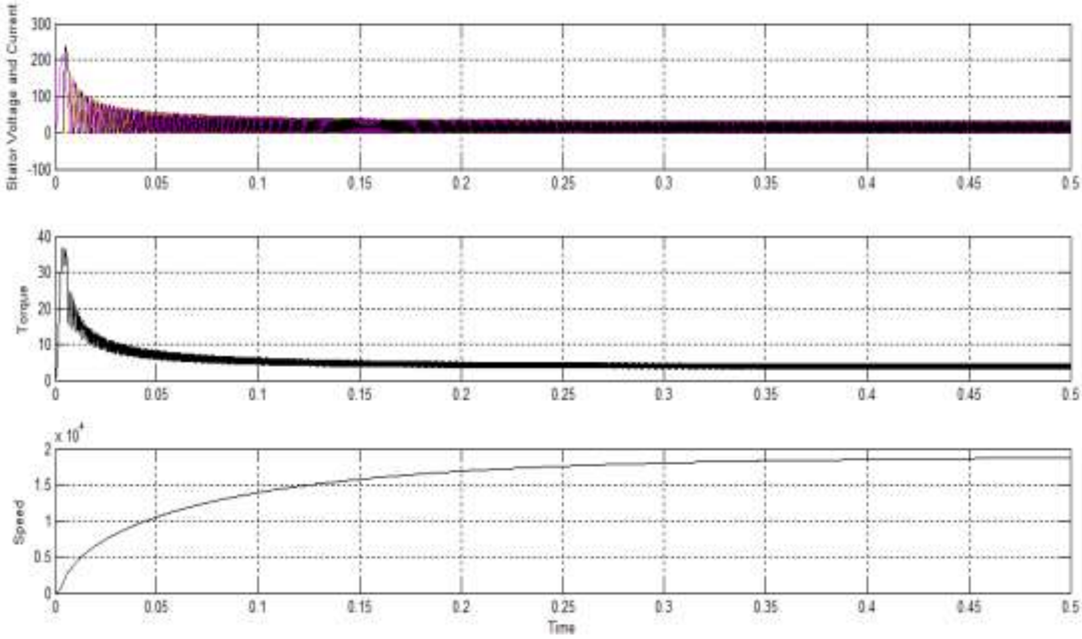

Figure 4.3. Simulation Result for SRM Motor Parameters

4.2 PROPOSED MODEL CIRCUIT

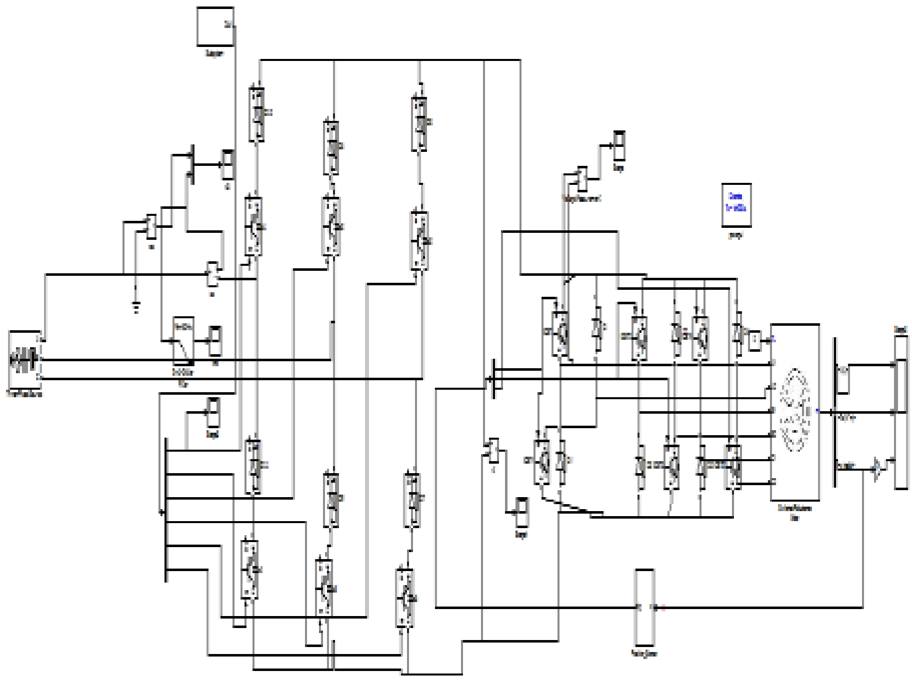

Figure 4.4. Simulation Diagram for Proposed Controller

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RESULTANT WAVE FORMS

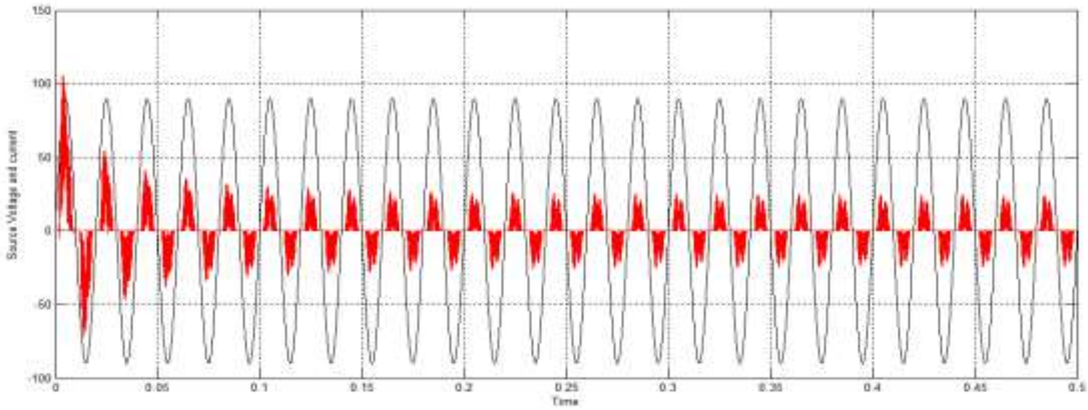

Figure 4.5 Simulation Result for Source Voltage and Current

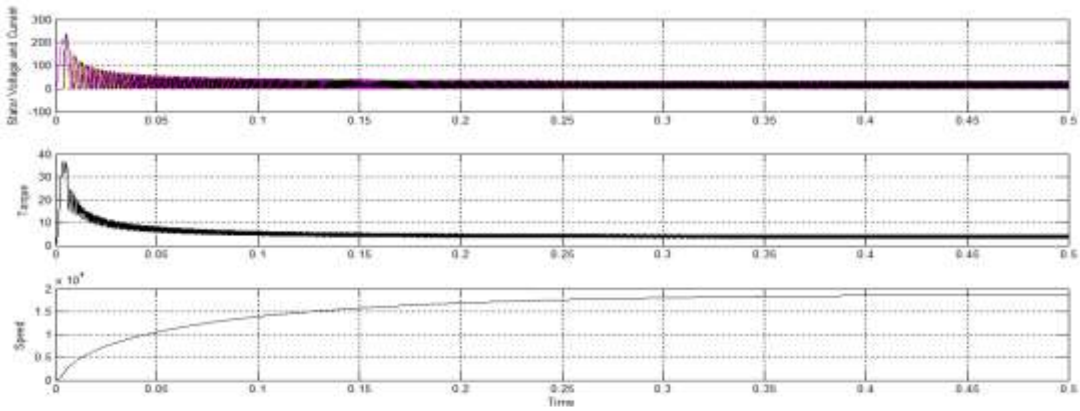

Figure 4.6: Simulation Result for SRM Motor Parameters

4.3 PROPOSED REGENERATION CIRCUIT

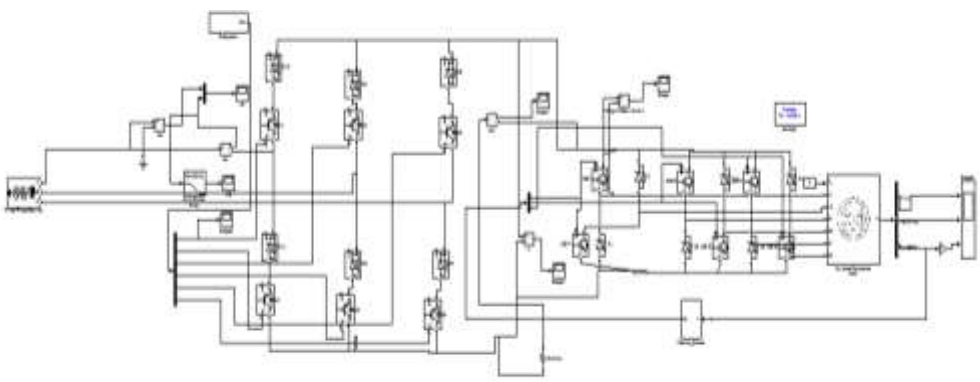

Figure 4.7: Simulation Diagram for Proposed regeneration Controller

CONCLUSION

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.

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