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Research Article

Design and Simulation of New Power Converter for SRM Drive with Power Factor Correction

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Abstract

In order to improve the power quality in terms of Power Factor Correction (PFC), reduce the total harmonic distortion (THD) at the input ac side and output the regulated dc several converter topologies have been introduced such as buck, boost, and buck-boost dc-dc converters. This paper presents PFC with boost converter which improves the PFC along with high output regulated dc using PI controller. The high speed drive systems are much interested in the field of industrial applications due to the compact size, reliability and high efficiency. In recent, the demands of high speed drives are much increased due to the mechanical advantages of high speed system. SRMs (Switched Reluctance Motors) have simple structure and inherent mechanical strength without rotor winding and permanent magnet. This paper also presents a new controller design for switched reluctance motor drive system. The proposed converter consists of one switch for each phase is the least number of switches among the converters used in the switch reluctance motor drive and also this converter performs phase current commutation faster. The simulation results based on Matlab/Simulink software are discussed in detail in this paper.

Keywords: *Switched Reluctance Motor Drive, Phase Current Commutation, PFC, THD, Boost Converter.*

1. Introduction

Ac–Dc conversion of electric power is widely used in several applications such as switch-mode power supplies (SMPSs), uninterrupted power supplies (UPSs), adjustable-speed drives (ASDs), and battery energy storage. Conventionally, ac–dc converters, also known as rectifiers, are developed using diodes and thyristors to provide uncontrolled and controlled dc power with unidirectional and bidirectional power flow. The main drawback of poor power quality in terms of harmonic current injection results to poor power factor at input ac mains, voltage distortion, and slow varying rippled dc output at load end; low efficiency and large size of ac and dc filters. This would lead to electric power pollution at the transmission or distribution side.

Switched Reluctance Motor (SRM) is a doubly salient, singly excited synchronous motor. Its construction is simplest of all other electrical machines. Only the stator has the windings mounted on it. The advantages of SRM are simple in structure, robustness and rotor contains no windings, brushes or permanent magnets. Due to its simple mechanical construction it is inherently less expensive, has high fault-tolerance, high torque per volume, efficiency is appreciably flat over wide speed range operations. The promising advantages have motivated many researches on SRM in the last decade. However, the mechanical simplicity of the device comes with some limitations. Like the BLDC motor, SRMs cannot run directly from a DC bus or an AC line, but it has to be electronically commutated always. The double saliency construction of the SRM, necessary for the machine to produce reluctance torque tends to non-linear magnetic characteristics making it difficult to control and analyze. 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.

Switched reluctance machines are used in electric vehicles, washers, dryers and aerospace applications as the machine is brushless, fault tolerant, maintenance free and rugged and simple in construction. However, some of its limitations are noise, torque ripple and low torque to volume. However, these problems are being solved by the advanced developments techniques in power electronics and suitable control methodologies. Many SRM drive

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topologies are introduced to overcome the torque ripple problem and improve the performance at higher speeds but the commutation process is not fast enough. A new control topology is designed to control the SRM drive at higher speeds. Fast commutation technique at higher speeds will reduce the torque ripples considerably.

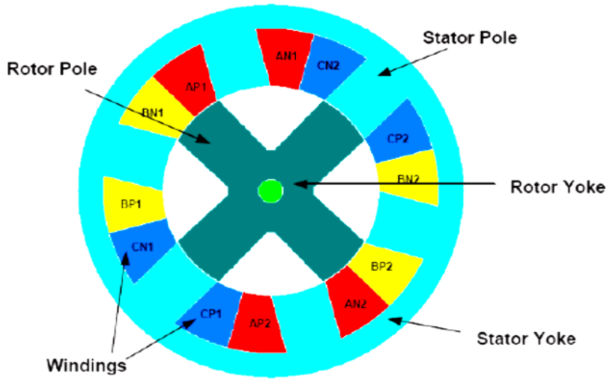

Fig.1 6/4 pole SRM

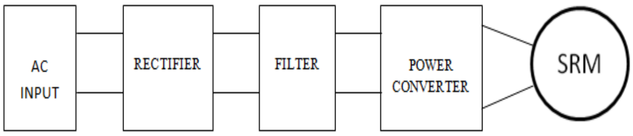

Fig.2 Block diagram of SRM without PFC

2. Proposed SRM Drive Converter

2.1 Converter Control Methodology

Fig. (3) Shows the three phase structure of the proposed SRM drive topology. The proposed converter operation is simple with a minimum number of switches .Proposed converter with least switches performs phase current commutation quickly. Regarding the number of switches used, the proposed converter is similar to that of R-dump converter, and functions like the C-dump converter. In case of C-dump converter the phase inductance energy is recovered. In addition to its simple structure, the proposed converter has higher efficiency than the R-dump converter and a simple structure and has high phase current commutation speed than the C-dump converter.

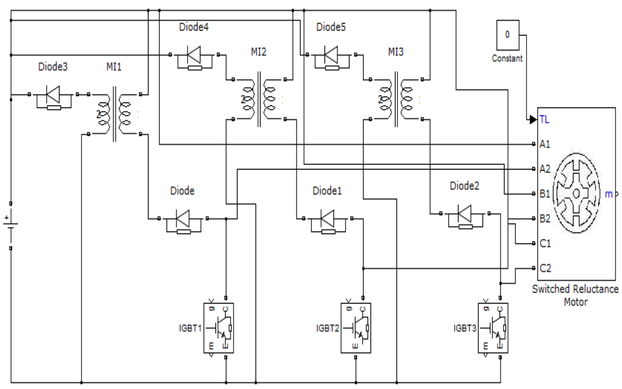

Fig.3 Proposed SRM 3 Phase Converter

Fig. (4) shows the operating modes of this converter for 2 phase SRM. As shown in Fig. (4-a), the magnetization mode, the switch T1 turns on in order to magnetize phase ‘a’. As Switch T1 turns on, the energy is transferred from the source to phase winding and the current in phase inductance increases. Also, in this mode if the magnetizing inductance of coupled inductors is not reset yet, diode D1 would conduct the magnetizing inductance current of the coupled inductors and the input voltage would reset this inductor. When the magnetizing inductance of coupled inductors is reset, Diode D1 turns off. The reset of coupled inductors magnetizing inductance is similar for other phases. When the phase current reaches the reference, T1 is turned off and demagnetization starts. This mode is shown in Fig. (4-b). Since the voltage across phase winding is reversed, diode D1 turns on in this mode. When D1 turns on, Db1 turns on and a negative voltage is placed across the phase winding in proportion to the coupling ratio which accelerates phase current commutation. Fig. (4-c) and Fig. (4-d) show two overlapping modes of stator phase currents. In the first mode, the phase inductance ‘a’ is being demagnetized and phase ‘b’ is being magnetized. In the second mode, both ‘a’ and ‘b’ phases are being demagnetized. As it can be observed, this converter has the ability to separately control phase currents.

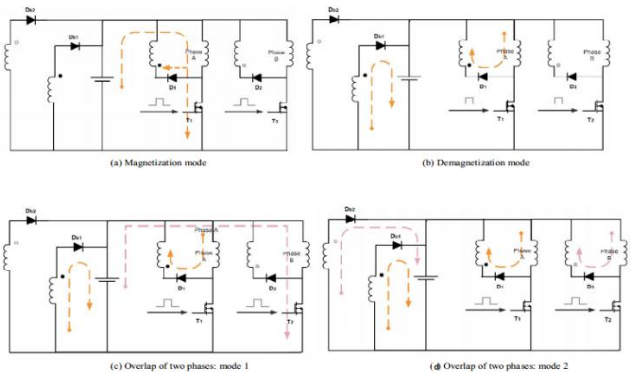

Fig.4 Modes of operation

Also, It is important to notice that the snubber circuit of each switch will absorb the voltage spikes across the switches that otherwise would occur due to leakage inductance of coupled inductors.

2.2 Design Considerations

For designing this converter, the coupled inductors ratio has to be determined considering the performing speed of the drive. If the phase current does not reach zero fast enough during the commutation, the phase current continues to exist in the negative torque production area and the phase torque becomes negative. This negative torque will cause large ripples in the torque generated by the motor. This is especially important at higher speeds, because higher speed requires faster commutation. So, each SRM drive can function to an extent of speed with regard to its converters structure. The maximum SRM drive speed depends on the type of converter used and is illustrated by the following equation.

$$T_f = \tau_a \ln[1 + \frac{R_S I_P}{V_C}] \quad (1)$$

where T_f is the time needed for the current to reach from reference value to zero.
τ_a is the electrical time constant of machine phases, Rs is the resistance of each phase winding.
V_C is the reverse voltage applied to the phase inductance during commutation.

The electrical time constant equation of the machine is as follows.

$$\tau_a = \frac{L_a}{R_s} \quad (2)$$

The phase inductance at the current commutation area equals to aligned inductance, thus L and τ would take a subscript a.

Current drop angle at speed ω is calculated as follows

$$\theta_f = \omega_m T_f = [\omega_m \tau_a] \ln[1 + \frac{R_S I_P}{V_C}] \quad (3)$$

As it can be observed from eq. (3), when speed increases, θf becomes larger resulting in a larger negative torque and, consequently, more torque ripples. Therefore, it is needed to look for a way to reduce θf at higher speeds. As it can be observed from (3), commutation can be carried out faster by increasing Vc. In the proposed converter, the reverse voltage across the phase winding can be increased for faster commutation purposes by increasing the coupled inductors L1 and L2 turns ratio. Also it is important to notice that Vc is constant in most of the converters introduced so far. But in this converter, Vc can be designed by changing the coupled inductors turns ratio considering the maximum SRM drive functioning speed.

Table.1 Comparison of various converters for SRM drive

	R-Dump converter	C-Dump converter	Asymmetric converter	New(proposed) converter
Number of phases	3	3	3	3
Number of switches	3	4	6	3
Phase Inductance Energy	Dissipate	recovered	recovered	recovered
Commutation	Not fast enough	Not fast enough	Not fast enough	Fast
Torque and Noise ripples	High	<R-Dump converter	Moderate	reduced
Efficiency	Low	>R-Dump converter	High	Higher
Applications	Low speed	Low speed	Low and Medium speed	Medium and High speed

3. Power Factor Correction

An ideal power factor corrector (PFC) should emulate a resistor on the supply side while maintaining a fairly regulated output voltage. In the case of sinusoidal line voltage, this means that the converter must draw a sinusoidal current from the utility; in order to do that, a suitable sinusoidal reference is generally needed and the control objective is to force the input current to follow, as close as possible, this current reference. The main aim of the power factor correction (PFC) technique is to bring the power factor closer to unity by reducing the effects of reactive power. In most of the cases, poor power factor is due to inductive loads which can be corrected by adding electrical devices such as capacitors into the circuit. In the market there are many PFC devices available to accommodate the each type of situation. Among them PFC involving capacitor fitting is the simplest. It is worth shopping around specialist companies and taking expert advice on the system that suits better. If a single machine has a poor power factor, capacitors can be connected in parallel with the device, that is, connected to the live and the neutral terminals of the reactive device, so that they compensate for the poor power factor whenever the machine is switched on. This is a form of 'fixed' PFC. If the power factor at a site is permanently poor and no single item of equipment is solely responsible, fixed PFC can be employed also. In this case, the PFC capacitors will be connected across the main power supply to the premises, that is, the capacitor banks' terminals are connected to each of the three phase cables as they enter the site. In this case, PFC can be linked with the switchgear. However, there are other circumstances where PFC is not so straightforward. Where many machines are switching on/off at various times, the power factor may be subject to frequent change. In these cases the amount of PFC needs to be controlled automatically – that is, the banks of capacitors need to be selectively switched in and out of the power circuit appropriately.

In order to determine which type of static power converter is most recommended for a given application several issues must be taken in to account, such as robustness, power density, efficiency, cost, and complexity. Within this context, numerous boost-type topologies have been proposed in the last few years with the aim of improving the characteristics of the traditional converter used for PFC purposes, such as the reverse recovery problem of the boost diode and increase of the output voltage. To combine the capabilities of power factor correction, active power filter and AC/DC converter, an advanced power factor correction technique using PFC Boost converter is proposed to work simultaneously as an active power filter to supply compensated currents that are equal to the harmonic currents produced from the nonlinear loads, and a AC/DC converter supplies the DC power to its load and takes a nearly sinusoidal current from the supply. This approach reduces the cost of the filter and also no special dedicated power devices are needed for the harmonics elimination. The proposed PFC technique consists of one full-bridge diode rectifier and one Boost PFC Converter. Here the full bridge diode rectifier is considered as the non-linear load which is the source of harmonics and output of this is given to the boost converter for PFC. A PI control is adopted to track the required line current command.

Fig.5. which shows the single-phase diode rectifier associated with the boost converter is widely employed in active PFC. In principle, the combination of the bridge rectifier and a dc-dc converter with filtering

and energy storage elements can be extended to other topologies, such as buck, buck-boost, and Cuk converter. Among all the topologies as said above, boost topology is very simple and allows low-distorted input currents, with almost unity power factor using different dedicated control techniques such as hysteresis control, PI control techniques.

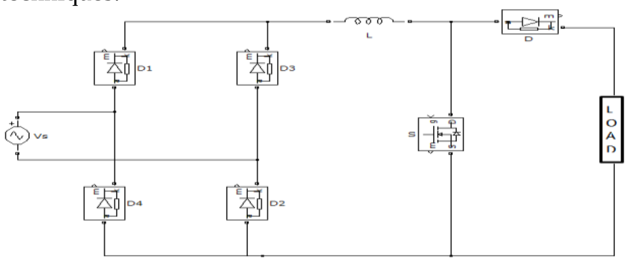

Fig.5 Active power factor correction technique using boost converter

4. Matlab Modeling and Simulation Results

Here simulation is carried out in different cases, the simulation results of SRM drive using the proposed converter is compared to the results of a SRM drive that uses a regular asymmetric converter and application to power factor correction technique.

Case 1: A Regular Asymmetric Converter Fed SRM Drive.

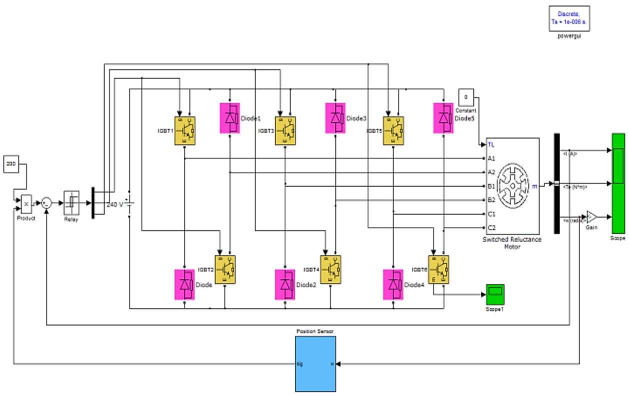

Fig.6 Regular Asymmetric Converter Fed SRM Drive using Matlab/Simulink

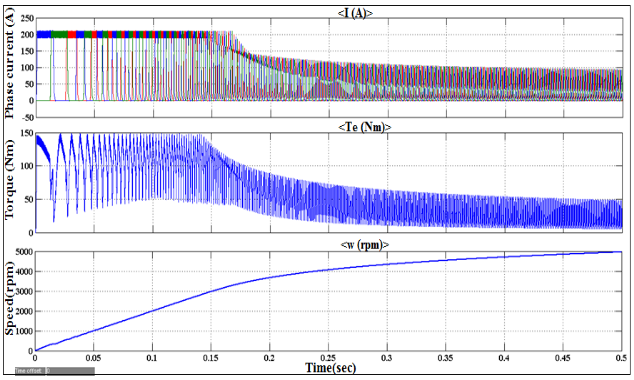

Fig.7 Phase Currents, Electromagnetic Torque, Speed waveforms of Asymmetric Converter

Case 2: A New Proposed Converter Fed SRM Drive

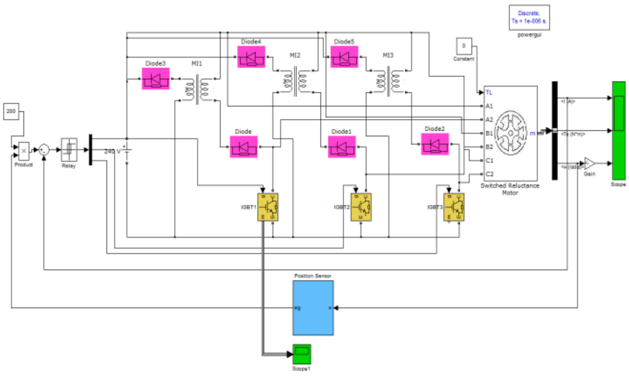

Fig.8 Proposed Converter Fed SRM Drive using Matlab/Simulink

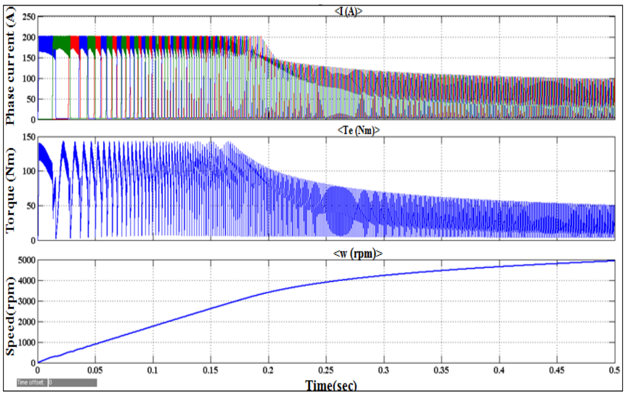

Fig.9 Phase Currents, Electromagnetic Torque, Speed waveforms of Proposed Converter

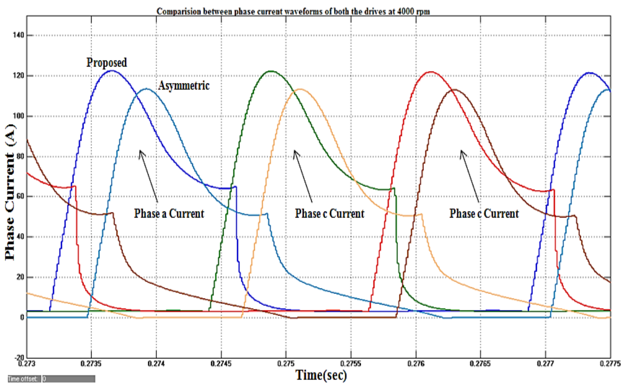

Fig.10 Comparison between phase current waveforms of both drives at 4000rpm

Fig.10. shows the comparison between the phase current waveforms of both the converter drives i.e., the proposed converter and the asymmetric converter at 4000rpm. It clearly shows that the proposed converter commutates faster than the asymmetric converter.

Case 3: Power Factor Correction Technique using Proposed Converter with SRM Drive.

Fig.12. and Fig.13. shows the input side and output side voltage and current waveforms of rectified topology

without filter. Without the filter source power factor is achieved at ac side, but the output voltage of rectified topology is unregulated dc.

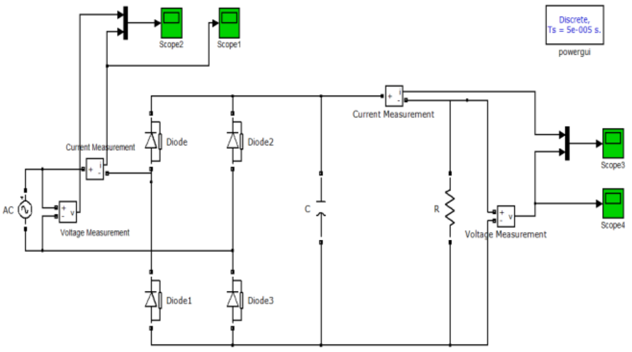

Fig.11 Rectifier Topology using Matlab/Simulink Platform.

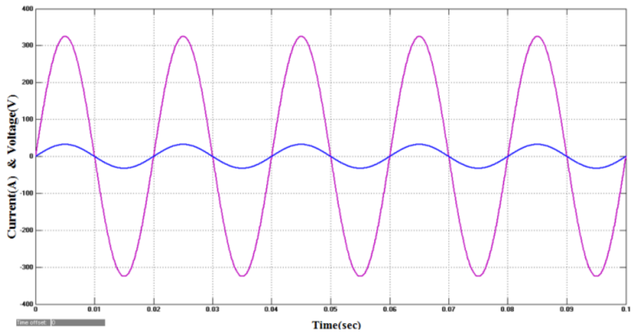

Fig.12. Input Voltage & Current waveforms of Rectified Topology without Filter

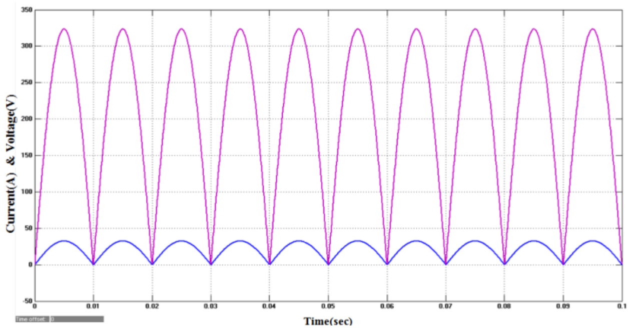

Fig.13 Output Voltage & Current waveforms of Rectified Topology without Filter

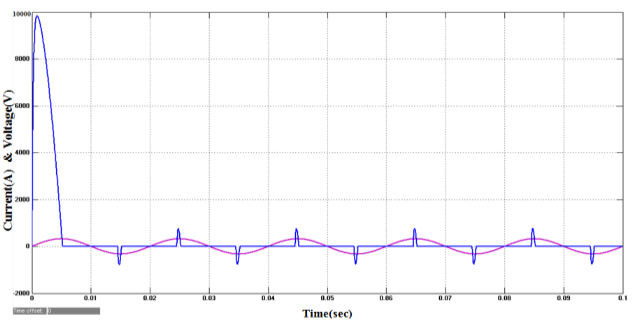

Fig.14 Input Voltage & Current waveforms of Rectified Topology with Filter

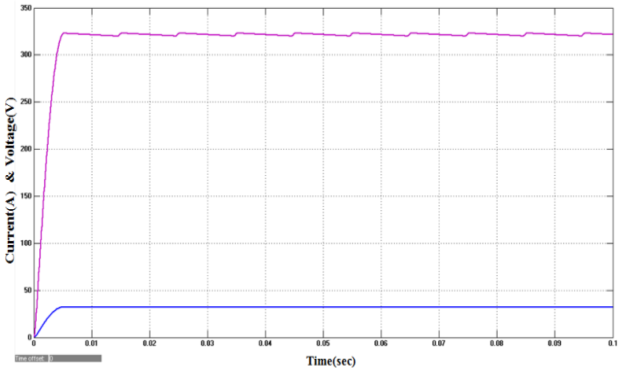

Fig.15 Output Voltage & Current waveforms of Rectified Topology with Filter

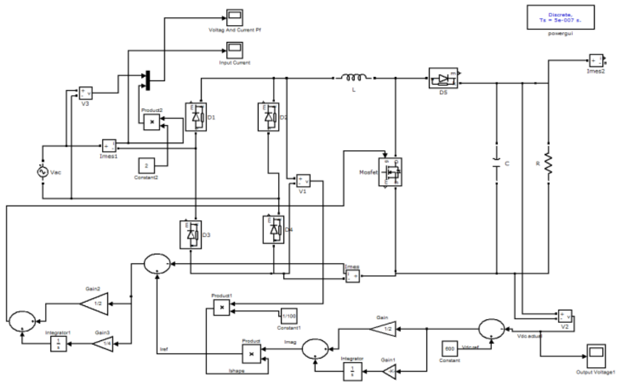

Fig.16 Matlab/Simulink Model of Power Factor Correction System

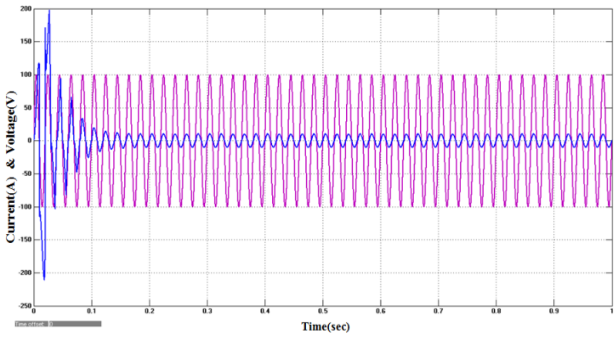

Fig.17 Input Voltage & Current of Proposed Converter Fed SRM Drive with Power Factor Correction

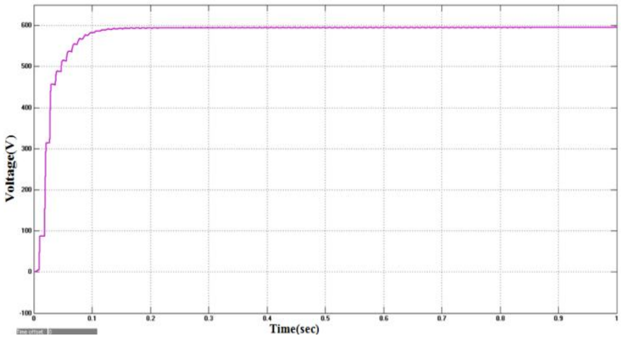

Fig.18 Output Voltage of Proposed Converter Fed SRM Drive with Power Factor Correction

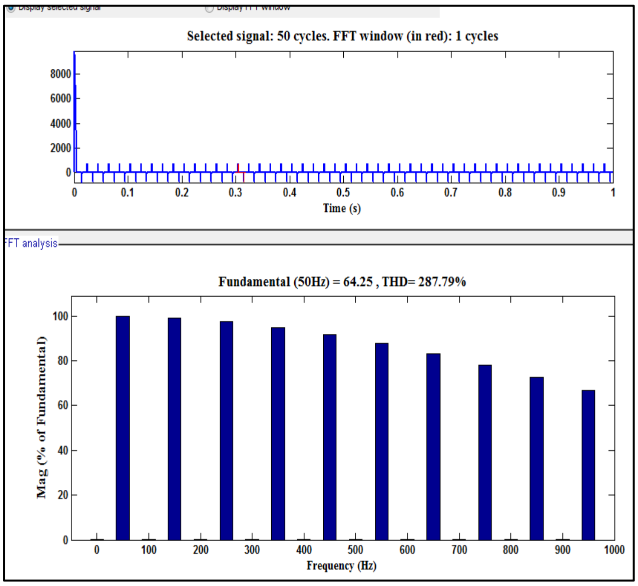

Fig.19 (a) FFT Analysis for Rectified Topology with Filter (THD= 287.79%)

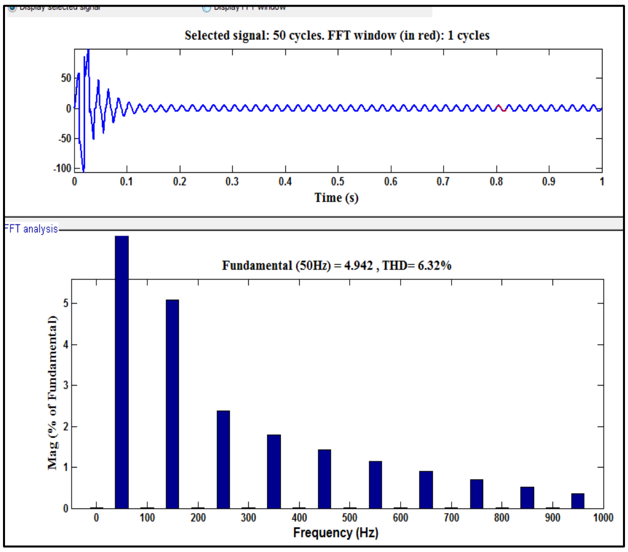

Fig.19 (b) FFT Analysis after PFC (THD= 6.32%)

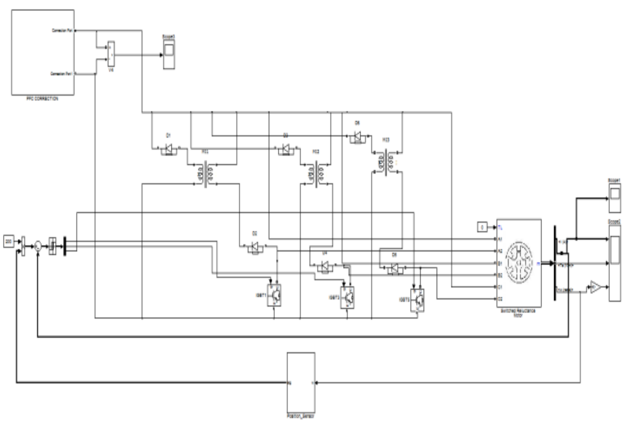

Fig.20 Proposed Converter Fed SRM Drive with Power Factor Correction using Matlab/Simulink Platform

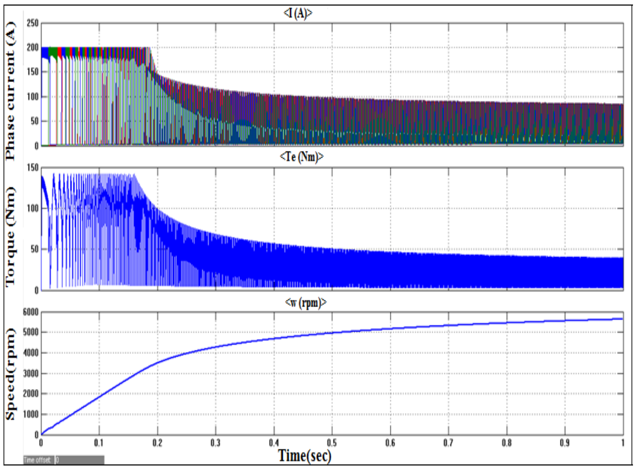

Fig.21 Phase Currents, Electromagnetic Torque, Speed waveforms of Proposed Converter Fed SRM Drive with Power Factor Correction

From the Fig.14 it is clear that, due to filter source current goes to distorts and get non-unity power factor, for improvement of these conditions we prefer two stage conversion techniques i.e., full bridge rectifier circuit followed by the boost converter circuit. Rectifier circuit converts the AC to unregulated DC and then the boost converter converts unregulated DC to regulated DC with the output voltage greater than the input voltage. Here we maintain unity power factor using two stage conversion techniques.

5. Conclusion

In this paper power factor correction is achieved by means of the boost converter and also a new SRM drive is introduced. The proposed converter for SRM is analyzed and its operating modes are discussed. The proposed converter uses one switch for each motor phase. Also, in the proposed converter the phase inductance energy is recovered to achieve high efficiency. Due to the inclusion of one (boost) converter in the circuit to eliminate the harmonic current that would otherwise generated by the non-linear load, doesn't require the use of any dedicated circuit. With the help of simulation study, it can be concluded that, this configuration removes almost all lower order harmonics, hence with this configuration we can achieve power factor nearer to unity and THD is reduced. Simulation results for SRM Drive with Power Factor Correction circuit are presented.

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