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Research paper

Design of SRM for Air-conditioned Buck-Boost PFC Converter for Power Quality Improvement

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Abstract

Now-a-days, in many heavy duty applications Switched Reluctance Motor (SRM) is made as a primary choice having high efficiency and low maintenance. SRM has stator windings but no rotor windings, hence very simple in construction. SRM needs DC supply for its excitation, thus we need to convert the available AC supply to DC by using converters. The converter used for this drive produces very high distortion in the source voltage and current which is not permissible in the system. This paper describes, how to eradicate the disturbance in the input voltage and currents using Buck-Boost converter as power factor correction (PFC) converter to improve the power factor. Buck-Boost converter along with delivering required output dc link voltage performs the task of power factor correction (PFC) converter. The design analysis (calculations) of 200V, 2KW, 2500 RPM SRM was described. Basic operation of SRM was detailed along with the asymmetric converter topology. Control circuit of proposed system controls the switching process of converter and correction of power factor was achieved. Analysis of SRM drive for air-conditioner (ac) application with Buck-Boost converter for PFC was carried out in proposed work with various conditions like initial condition, fixed DC voltage, variation in supply voltage. MATLAB/SIMULINK model of SRM drive for different conditions said above were developed and results were also discussed in this paper. Speed and torque characteristics were shown for all the cases. Voltage and current waveforms representing power factor is shown for the SRM drive system with PFC Buck Boost converter. Comparison between Diode bridge rectifier fed SRM and with PWM and BBC fed SRM were given along with their THD. THD was reduced and limited within IEEE standards when operating SRM drive with PFC converter.

Keywords- *Switched Reluctance Motor (SRM), converter, Buck-Boost, DC Link, Air-Conditioner, Power Factor Correction (PFC), Harmonic Mitigation.*

1. Introduction

In Comparison with the existing ac machines, Switched Reluctance Motor is in advancement as a lot of importance is given to this machine. The benefits comprise low cost, higher performance, higher strength and high fault tolerance[1]. Various forms of converters area unit used for dominant the SRM drive. The major downside of SRM drive is massive torque ripples. However, this could be restricted to an outsized extent by part current overlapping. Therefore separate management is employed for the converters used in SRM drive. The torsion ripples area unit reduced by part current overlapping. The currents in stator coil lags behind the reference current that takes place during the commutation of SRM part current because of the infrequent electrical phenomenon is a one reason for the torque ripples. Negative torque and additional torque ripples are created during the commutation method when the part current approaches to zero with the slandered current. Whenever the commutation ability of part currents are exaggerated, the torsion ripples are going to be reduced [2]. Once the speed of the SRM increases, the commutation of part current interval is not reduced and this causes negative torque. The negative torque that is created can produce massive torque ripples. To beat this drawback the commutation of part current ought to be achieved additional quickly. The device should be designed to accomplish this. The torsion production and potency is inflated, if at activate and switch off instants di/dt is additional, in order that the negative torque production would not takes place and also the average torque created by the motor is additional.

2. Operation of SRM

Similar all electrical machines, SR Motor consists of a stator and a rotor. SR Motor has only winding on Stator and no windings on rotor. SRM is also named as doubly salient type machine as rotor just consists of steel laminations as salient poles, Stator poles are also salient type. SRM operates on a basic principle of alignment of rotor to low reluctance path provided when any pair of stator poles is excited. By sequential switching of stator poles, rotor tends to rotate for producing torque and is called reluctance torque [3].

The order of excited windings of stator gives the direction of rotation. To attain reluctance torque the number of rotor and stator poles must be different such that continuous torque can be produced by synchronizing the each phases excitation with rotor position**.** In the proposed work, 6/4 pole SR Motor drive is considered as in figure 1.

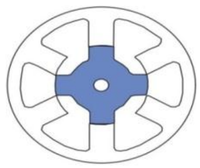


Fig.1: 6/4 pole. SRM

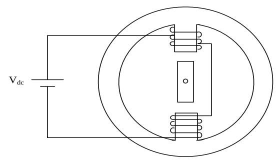


Fig.2: Aligned position

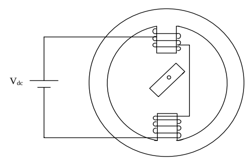


Fig.3: Unaligned position

The operation of SRM can be demonstrated in two positions. (i) Aligned position (ii) unaligned position.

The rotor pole and stator pole lie under the same axis in an Aligned position. In this case maximum flux and inductance is attained as in figure 2. In an Unaligned position the rotor pole axis lies between stator pole axis as in figure 3. The phase winding of SRM is excited under unaligned position and de energized in aligned position in motoring mode of operation[4].

3. SRM converter

To rotate the rotor of SR motor continuously they needs to switch the phases based on rotor position for this a converter to be employed [5]. Although different converters proposed in literature, asymmetrical converter is considered for simplicity as shown in figure 4.

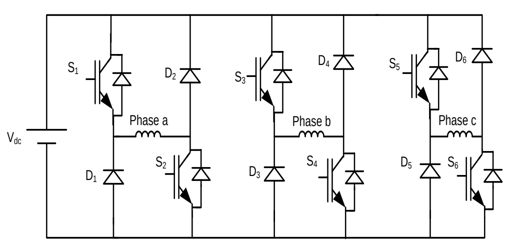
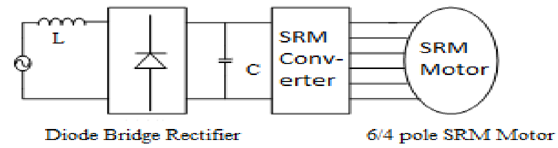


Fig.4: Asymmetrical converter

The current in the phase of drive is circulated by turning on any two power switches. Once the rotor moves towards stator ploes the switches are turned off. In figure 4 phase A winding is excited by swiching S1 and S2 for current control,by turning on S2 continuously and switching S1 switch. When the rotor and stator are in same axis S_1 & S_2 we will be turn-off then the current passes through D_1 and D_2 in the reverse direction to source.

4. Pfc converter fed sr motor drive

The diode bridge configured rectifier fed SRM referred in figure 5, the bridge rectifier is connected to ac supply and asymmetrical converter is on motor side. It has disadvantage of low efficiency and power factor[6,7].



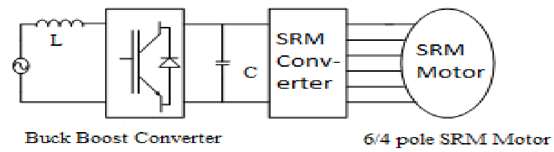


Fig.5: Diode Bridge Rectifier Based SRM Drive.
Fig.6: Buck Boost converter for SR Motor drive.

The proposed Buck-Boost converter SRM drive is shown in figure 6. The frontend converter contains of two MOSFET's controlled by PFC control strategy. SRM converter fed with DC to SRM drive function. DC link voltage is detects and distinguished with actual DC potential which gives error signal for power factor correction. Current signal will generates by reducing error signal with means of PI Controller. The actual current signal distinguishes with the obtained reference current value and then resultant signal is again compared to carrier triangular signal thus pulses obtained for the switches. Two switches are requisite to generate pulses for BBC.

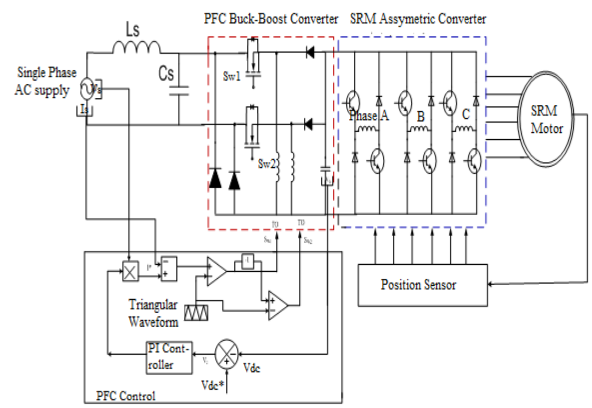


Fig.7: SRM Drive with PFC Buck-Boost converter

4.1. Design of SRM

To design SR Motor power output, Speed in rpm, allowable maximum phase current i in Amps and ac supply voltage Vp are required. Knowing the speed and output power the torque to be developed by the SRM is

$$T_{req} = \frac{P_{kw}}{2\pi\left(\frac{N}{60}\right)} Nm \quad (1)$$

$$T_{req} = \frac{2 * 10^3}{2\pi\left(\frac{2500}{60}\right)} = 7.64\ N - m$$

$$T_{req} = 7.64\ N - m$$

General dimensions of SRM:
In the preliminary design process of SRM, the values of voltage and current i.e., power rating of the machine is fixed. By knowing the speed, stack length the preliminary design process can be started for 6/4 SRM. Initially by fixing outer diameter and the number of poles of stator and rotor, stator pole arc, stator yoke width can be calculated. Initially frame size and bore diameter are assumed to be

same. The distance between the mounting holes and stack length of foot mounted machine are initially chosen to be equal. With the selection of preliminary values of ßs and ß,

the design process is continued. For the design process the following considerations were taken:
Electrical loading, A_S = 35000 AT/m
Magnetic loading, B_S = 1.62 wb/m^2
Speed, N_r = 2500 rpm
Stack length, L = 114 mm
The power output equation of a 6/4 pole SRM is

$$P = K\, D_{in}^2\, A_s\, B_s\, L\, N_r \quad (2)$$

Where, $K = K_1\, K_2\, K_e\, K_d$
Here, $K_1 = 1 - \frac{1}{\sigma_s \sigma_u} = 1 - \frac{1}{10}$ since the salience ratio lies between 0 and 10.
Then, K_1 = 9/10
$K_2 = \pi^2/120$ = 3.14^2/120=0.082246703
Efficiency, K_e = 0.85
Duty cycle, $K_d = 1$.
Therefore, $K = K_1\, K_2\, K_e\, K_d$
= 0.9 * 0.082246703 * 0.85 * 1
= 0.062918728.
Power equation can be written as

$$D_{in} = \left[\frac{P}{K\, A_s\, B_s\, L N_r}\right]^{1/2} \quad (3)$$

For power rating of 2KW (V = 200V, Amps = 10A) with 2500rpm speed,
Bore diameter can be written as,

$$D_{in} = \left[\frac{2000}{0.062918728 * 35000 * 1.62 * 114 * 2500 * 10^{-3}}\right]^{1/2}$$

$D_{in} = 44.3\ mm.$
Let the ratio, $\frac{D_O}{D_{in}} = 2$ $\quad D_O = 2 * D_{in}$

$$D_O = 88.6\ mm \quad (4)$$

With the considerations of As, Bs, Nr, and L the following parameters K, Din, Do, ψ and La are calculated and is listed in the table 1.
Here we consider 2KW SRM drive and various components designed are based on following equations for air-conditioner (ac) application.

Table-1: General dimensions of SRM

S.No.	Parameter	Value
1	Power (P)	2 kW
2	Voltage (V)	200 V
3	Current (I_p)	10 A
4	Torque (T)	7.64 N-M
5	Electrical loading (A_s)	35000 AT/m
6	Flux density (B_s)	1.62 Wb/m2
7	Speed (N)	2500 rpm
8	Stack length (L)	114 mm
9	Efficiency (K_e)	0.85
10	Duty cycle (K_d)	1
11	Inner diameter (D_{in})	44.3 mm
12	Outer diameter (D_0)	88.6 mm
13	Total Reluctance (ψ)	1418
14	Aligned Inductance(La)	30.3 mH

4.2. Selection of Capacitor Voltage and DC link Capacitor

For this drive, the minimum DC link voltage selection depends on desired rated DC link voltage(Vrated) and magnitude of AC voltage. It is more than or equal to the maximum value of source voltage(Vm) and equal to desired rated DC link voltage.

$$V_{dc} \geq V_m = V_{rated} \quad (5)$$

A 200V DC link is choosen using DC link capacitor and maintains the constant voltage. The selection of a DC link capacitor is,

$$C_{dc} = I_{dc}/2\omega V_{dcripple} \quad (6)$$

where I_{dc} is the DC link current which is obtained as,

$$I_{dc} = \frac{P_{dc}}{V_{dc}} = 10A \quad (7)$$

V_{dc} ripple is the I% of rated DC link voltage. The DC link capacitor is calculated as 1900 µF

4.3. Selection of Inductors interface

An inductor interface is connected between AC terminals of single phase voltage source converter and alternating current supply. At VSC terminal the fundamental rms voltage V_c is,

$$V_c = (mV_{dc})/\sqrt{2} \quad (8)$$

Where 'm' is modulation index, and it is considered I. V_{dc} is the reference DC link voltage (200V). The fundamental r.m.s voltage at VSC terminals obtained as 282.88V employs Equation (8). The relative among basic potentials at VSC ends is set as,

$$V_c = \sqrt{[}V_s^2 + (I_s^2 X_1^2) \quad (9)$$

Where Vs is R.M.S charge of contribution provide potential which is in use as 220V and I_s is R.M.S charge of provide current as,

$$I_s = \frac{P_{in}}{V_s} \quad (10)$$

Therefore, interface inductor is obtained.

4.4. Sketch of Voltage Source converter (VSC)

The design of Voltage source converter is based on the evident supremacy distributed in VSC. The RMS current in every leg of Voltage Source Converter is attained as 9.09A employ Expression (10). Where P_{in} the source power at VSC ends. The highest current in the course of IGBTs is evaluated as

$$I_{max} = 1.25\{I_{p-p} + \sqrt{2} I_{vsc}\} \quad (11)$$

4.5. SRM converter Design

The converter used for SRM contains 6 numbers of IGBTs as switches and choice of switches is support on esteemed current of the compel. The freeze (stall) current of SRMotor is 8.45A,
Utmost current during IGBT in every phase is

$$I_{max} = 1.25\{I_{pp} + \sqrt{2} I_{vsi}\} \quad (12)$$

Upper limit current throughout IGBTs is acquired as 15A while considering 10% peak to peak ripple in halt current. Therefore 600V, 15A IGBT's switches are chosen for a 3-phase converter.

5. Simulation result analysis

In this section, results for SR Motor drive system used with Buck-Boost converter are presented. MATLAB Simulink models and results of SRM with dissimilar circumstances are talk about as follows: Switched Reluctance Motor at initial circumstances, steady DC link energy, SRM with step variation in AC potential by maintain speed as constant.

Case I: Power Factor Correction Rectifier Based SRM at initial state

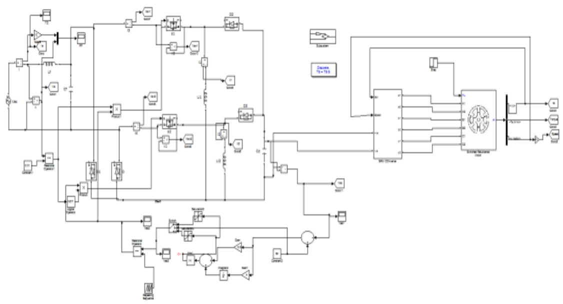


Fig.8: Imitation form of PFC rectifier based Switched Reluctance Motor at initial circumstance.

The simulation model of SRM drive with buck-boost converter for PFC at the time of starting condition is shown in fig.8. Its corresponding waveforms of source voltage, source current and the DC link voltage, speed, Torque and Armature Current is shown in fig. 9. Particularly SR Motor when worn with diode rectifier input current does not inhere of more ripples as and the DC link potential is preserved at constant 50V.

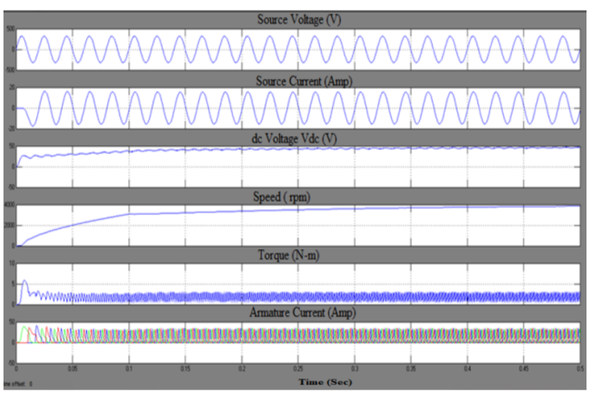


Fig. 9: Plots of ac voltage, ac current, dc link voltage, speed (N), Torque(T) and Ia of SRM at Vdc=50V

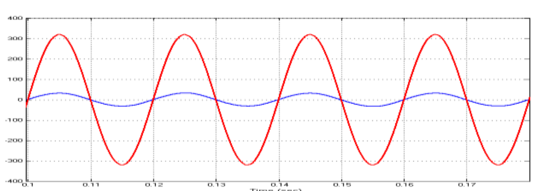


Fig. 10: Plot of Power factor with Buck-Boost Converter based SRM at starting.

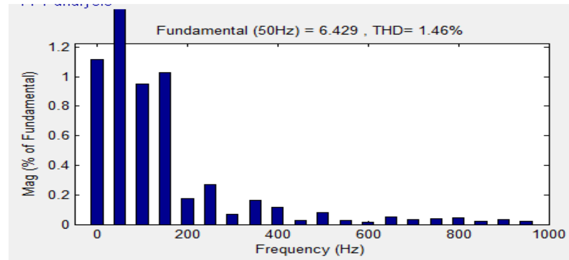


Fig. 11: THD of Source Current (Is) with PFC converter related to SR Motor.

In Fig. 10, the source potential and current of Power Factor Correction converter are within phase and then power factor is almost union. Fig. 11 shows the total harmonic distortion summary for key current. It is much lesser and acceptable charge after using Power Factor Correction converter at front terminal.

Case II: Switched Reluctance Motor using PFC Rectifier with 200V DC Link Voltage

The simulation waveforms of input voltage V_S, input current i_s, the DC link voltage V_{dc}, speed, torque and armature current of SRM drive with buck-boost converter at a dc link voltage 200 V are in figure 12.

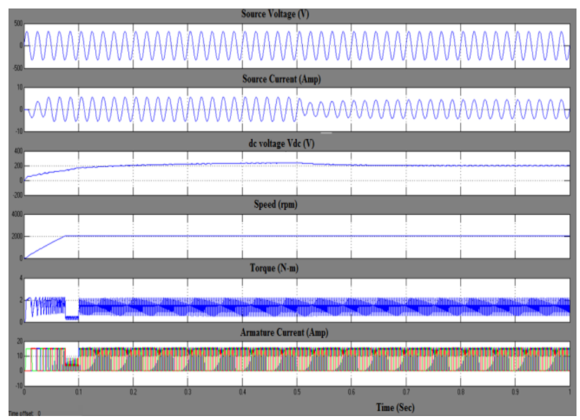


Fig. 12: Output waveforms of V_s, I_s & DC voltage, Speed, torque and armature current of SRM with 200volts dc link Voltage.

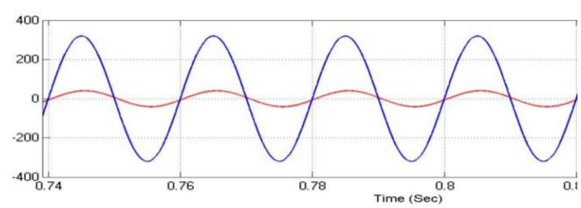


Fig. 13: Plot of Power factor of PFC Rectifier based SRM

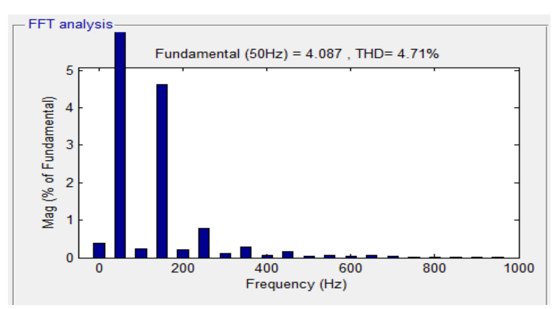


Fig. 14: Plot of THD

Machine speed is maintained as constant if SRM DC link voltage is protested at constant 200V. The Power Factor in terms of source electrical energy and current of Power Factor Correction converter is represented in fig. 13 and both are within phase. Then power factor is near to one. THD of SRM is shown in fig. 14 and is acceptable value.

Case III: Switched Reluctance Motor using PFC Rectifier with variation of AC Voltage from 320V to 120V.

The simulated model of SRM drive with buck-boost converter when the AC input potential is adjusted from 320V to 120V is shown in fig. 15. Its corresponding response waveforms of input voltage, input current, the DC link voltage, momentum, Torque and armature current are shown in fig. 16.

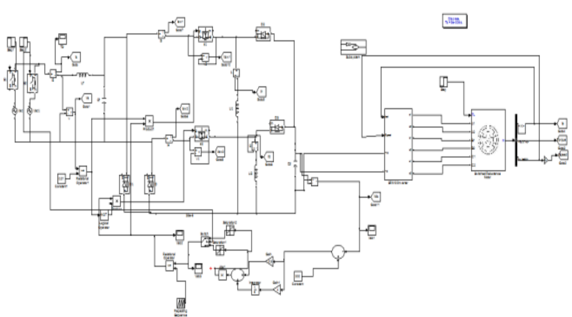


Fig. 15: Imitation model of proposed PFC SR Motor with variant of supply Voltage from 320V to 120V

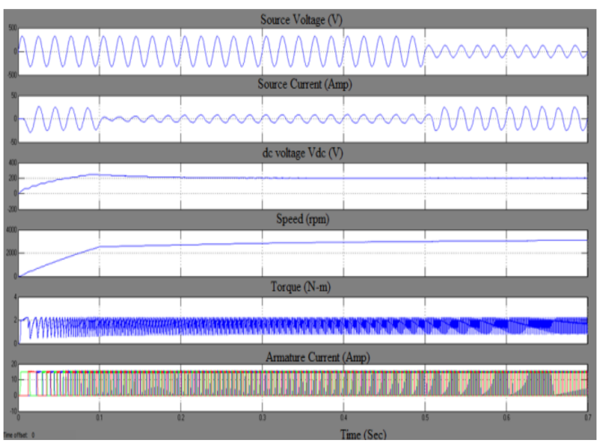


Fig. 16: Response waveforms of V_s, I_s & DC potential, momentum, torque and armature current of Switched Reluctance Motor with step deviation of AC Voltage from 320V to 120V.

When the input AC source voltage is reduced from 320 V to 220 V the corresponding source current increases and does not consists of ripples which can be observed from the results. Even if source voltage is varying, dc link voltage and machine speed is maintained as constant.

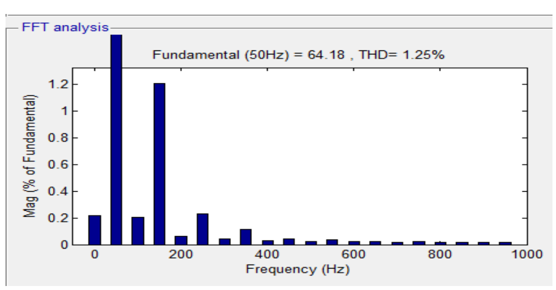


Fig. 17: Plot of THD of SRM at step variation of AC Voltage from 320V to 120V.

THD of SRM is shown in fig. 17 and is acceptable value. The source potential energy and current of Power Factor Converter is represented in fig. 18 and are in the same line or in phase. Then power factor is near to unity.

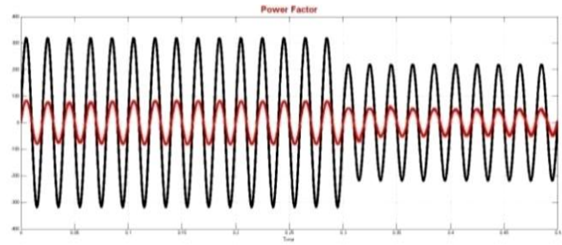


Fig. 18: Plot of Power factor with Power factor Correction Rectifier based SRM at step variation of Voltage from 320V to 120V.

Results confirm the usage of Buck-Boost converter for SRM drive improves power quality by maintaining near to power factor and by reducing THD as in table 2.

Table 2: Comparison of THD between DBR fed SRMD, PWM and BBC fed SRMD

SRM running condition	THD(%) _ PFC Converters		
	Diode Bridge Rectifier(without PFC)	PWM PFC Rectifier	Buck-Boost PFC Converter
Vdc varying from 100 V to 150 V	42	2.53	2.3
Vdc=200 V		4.51	4.7
Vac from 320 V to 220 V		1.68	1.25

6. Conclusion

Low cost, low maintenance and high efficiency makes SRM to use in many of the industrial applications now-a-days. For the operation of SRM, we need AC-DC converter and again DC-AC converter at frontend of SRM for the sequential switching of SRM to produce reluctance torque for the rotation of SRM. A easy diode bridge converter can be employ for this conversion of AC-DC at source side but induces distortions in the source currents and voltage eventually increasing THD and thus reducing power factor. For this power factor correction, Buck-Boost converter is used in this paper for SRM drive operation for air-conditioner application. Results shows that the distortions are eliminated in source currents and voltages and THD is reduced to acceptable value with less EMI when SRM drive used with Buck-Boost converter. The source current and voltage are in phase in SRM drive with Buck-Boost converter making the power factor nearer to unity. Analysis were carried out for SRM drive with Buck-Boost converter at different conditions like SRM at starting, when DC link voltage is kept constant and when AC voltage is varied (step-change). Buck-Boost converter fed SRM drive improved the power quality by maintaining near to unity power factor and by reducing THD. Design of SRM for 6/4 pole machine was done for the PFC correction fed SRM. Stator and rotor dimensions along with its airgap area was derived for 200V, 2KW, 2500 rpm 6/4 SRM. Reluctance is calculated. Machine constants like resistance and inductance were also calculated as part of design.

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