CHAPTER – 6

SRM DRIVE SYSTEM FOR
AIR-CONDITIONER APPLICATION WITH
HIGH POWER FACTOR CORRECTION
CAPABILITY
6.1 INTRODUCTION

Transformation of electric energy is broadly used in many domestic applications like air-conditioning systems, variable speed drives, switch mode circuits and un-interruptible power devices. The absence of direct energy sources for several applications in real world has major concerns like power processing issue by using power electronic apparatus [53]. The classical AC-DC conversion is realized by rectifiers, it is designed by either diodes/thyristors that depends on un-controlled/controlled objective. Different power converter topologies are becoming more popular and they depend on the application; medium voltage-high speed drive strategies have been installed for air-conditioning application [55].

The main contributors of power pollution by poor power quality are the large semi-conductor devices utilized for power processing. The power processing units required additional passive filter circuitry for obtaining pure DC voltage/current for specific application [56]-[61]. The use of high grade converter circuits and filter units may produce the harmonics in voltage/current, high THD content, low efficiency, greater switch loss, need additional circuitry, other than harmonic standards of IEC 1000-3-2. This concern would lead to electric power pollution at the PCC distribution level.

The AC-DC power conversion supply systems with isolated transformer circuits are typically developed with enhanced power factor to comply with certain harmonic standards like as IEEE and IEC tolerances. Moreover, it is highly possible to support these standards by placing additional filter to formal conversion schemes, this makes converter to be very bulky, and cost will be very high. Here the author explores two major common approaches for obtaining enhanced power factor
correction (PFC) [62]. The primary approach is two stage conversion scheme and secondary is single stage conversion scheme using coupled transformers.

The proposed two stage conversion scheme includes firstly a front-end AC-DC converter to give rippled DC outcome, the resulting DC outcome acts as a main source of DC-DC converter stage for the generation of desired DC output voltage with low harmonic content at source PCC level. Using this two stage scheme becomes complex, having high cost, more space requirement due to many stages and low efficiency. Hence, this stage has led to emergence of single stage conversion with enhanced power factor conversion schemes as proposed earlier in [63]-[69]. So as to minimize the cost, complexity and size and to get greater efficiency the proposed single stage conversion using Cuk converter topology is used.

This chapter 6 highlights the decisive converter topology for speed control of SRM using proposed single stage conversion with improved power quality features [70]-[72]. With a certain end goal to obtain the great transient reaction, the proposed scheme is executed in a closed loop set-up using effective PI controller. The performances of formal and proposed schemes are evaluated using Matlab/Simulink software.

6.2 FORMAL TWO-STAGE CONVERSION SCHEME

The switched reluctance motor (SRM) drive system is highly recognized for air-conditioning applications, it is single excited with dually salient motor. The construction of SRM drive system is very simple over all other motor drives due to mounted windings on stator alone. Several advantages of SRM drive are more robustness, simple design, less expensive, high capability of fault tolerance, more torque/volume ratio, appreciate efficiency and wide speed range [73]-[82]. It is very
reliable drive system since every phase of the SRM drive is independent physically, magnetically and electrically from other phases.

![Fig.6.1 Block Diagram of Formal Two-Stage Power Factor Correction Technique](image)

Different types of power converter topologies have been designed since many years exclusively in conjunction with the SRM drives. A review of numerous power converter topologies for SRM drive is available for obtaining improved power quality features; the Fig.6.1 shows the formal two stage power factor correction technique as proposed in [83]-[86]. Several converters topologies are evaluated based on prominent requirements for optimal selection of topology in chapter 5. Among those converter topologies, asymmetric power converter topology performs best. In this, each phase branch consists of dual switching devices and dual free-wheel diodes as depicted in Fig.6.2.

The operation of proposed converter is as follows: when switches $T_1$ and $T_2$ are ON, the A-phase is energized [87]. The operating free-wheel diodes $D_1$ and $D_2$ are switched ON when the $T_1$ and $T_2$ switches are in OFF state and forms the closed circulated conduction mode.
After one cycle of operation, phase-A is de-energized and continuous operation is done with all other respective operation in phases B and C. The overall drive system is designed with a closed loop operation for 6/4 SRM drive for obtaining
the fast transient response, low peak over shoots, good stability index [88]. The formal two-stage scheme explores the closed loop PI controller fed SRM drive system with embraced control objective. In that, the reference voltage is normally driven from the constant voltage value, the real boost outcome voltage is compared with that for generation of change in current error value. The respective PI controller form indicates the errors support with an efficient current gain regulation [89]. The actual current gain signal is multiplied with a sine outcome signal coming from utilized PLL unit. The reference coming load current is subtracted from the actual signal to be handled over the explored reference signal generation.

The substituted reference current indication is adjusted with the current controlled component for production of optimal gating signals [90]-[91]. The hysteresis current controller embraces the upper/lower bands may produce the obliged gating sequences for switch ON/OFF the main switch $S_w$ in DC-DC converter stage. When this switch $S_w$ turns ON for conversion of constant isolated DC voltage, that DC voltage is directly interfacing to input of the SRM drive system. But this two stage system has several disadvantages with the conversion being more complex, high cost, more space requirement due to many stages, low efficiency.

6.3 A NOVEL SINGLE STAGE CONVERSION SCHEME

Formal two stage power correction scheme based SRM drive system utilizes an approach of constant DC voltage with more switching stages of the asymmetric converter. The speed controlled by duty ratio of high frequency current controlled gating signals for certain power factor gives high switching losses which makes efficiency to be very low. The switching loss always depends on the square of the switching frequency ($P_{sw}$ loss $\propto f_s^2$) due to double switching action at front-end conversion. Based on disadvantages in formal two-stage conversion scheme, the
author proposes a new single stage conversion scheme for obtaining improved power factor with low THD content at source side.

The schematic diagram of Proposed Single-Stage Cuk-Asymmetric converter fed switched reluctance motor drive using a current multiplier control objective for better resolution over formal schemes is shown in Fig 6.3.

![Schematic Diagram of Proposed Single-Stage Power Factor Correction Technique](image)

**Fig.6.3 Schematic Diagram of Proposed Single-Stage Power Factor Correction Technique**

The schematic diagram of proposed single stage Cuk-Asymmetric converter fed switched reluctance motor drive using a current multiplier control objective for better resolution over formal schemes is shown in Fig.6.3. A high frequency MOSFET (metal oxide semi-conductor field effect transistor) is used in proposed Cuk converter topology for better reduction of switching loss [72]-[84]. The PFC Cuk converter operated in CCM mode by utilizing current controlled approach as depicted in Fig.6.4. The majorly the CCM mode replicates, current flows through input/output inductors \((L_i/L_o)\) and the intermediate capacitor voltage \((V_{C1})\) remains continuous switching state. A proposed Cuk converter is developed to operate in a continuous conduction mode of operation; its performance is evaluated for a wide speed/voltage control with unity power factor at AC mains.
The main operation of Cuk converter in CCM mode is illustrated in Fig. 6.5 (a), which shows the modes of Cuk converter in two different intervals of a switching state and Fig. 6.5 (c) shows the respective waveforms associated with switching states.

Fig. 6.4 Overall Schematic Diagram of Proposed Single-Stage Cuk Conversion Scheme Fed 6/4 SRM Drive System using Current Multiplier Approach
**Switching State-A:**

When switch $S_w$ is switch ON, the inductor $L_i$ stores energy while capacitor $C_1$ goes to discharges through switch $S_w$ to transfer its energy to DC link capacitor $C_d$ as depicted in Fig.6.5 (a). The $I_{L_i}$ input inductor current goes on increasing while the capacitor voltage $V_{c1}$ goes on decreasing as depicted in Fig.6.5 (c).

![Switching State-A](image)

**Switching State-B:**

When switch $S_w$ is switch OFF, the stored energy in inductor $L_o$ is transferred to DC link capacitor $C_d$ and the input inductor $L_i$ transfers its own energy to capacitor $C_1$ as depicted in Fig.6.5 (b). The proper way is to design $L_i$, $L_o$, and $C_1$ with large values such that a finite range of energy is always stored in these respective components in an acquired switching states.
6.4 RESULTS AND DISCUSSIONS

6.4.1 AC-DC CONVERSION WITH and WITHOUT FILTER

Fig. 6.5 Operating Principle of Cuk Converter in CCM under (a) Switching State-A, (b) Switching State-B and (c) Associated waveforms.
The AC-DC conversion is done with different cases, in that the first case represents the conversion of AC-DC without any filter, due to absence of filter a perfect DC voltage consists of ripples. This rippled DC is not suitable for specific application to move the drive, but source side voltage and current are in pure sinusoidal nature (distortion less). Simulation results of AC-DC conversion without using filter is shown in Fig.6.6.

![Graph](image1)

(a) DC Output Voltage of Diode Bridge Rectifier without filter

![Graph](image2)

(b) Source side Voltage and Current without Load side Filter

**Fig.6.6 Simulation Results of AC-DC Conversion without Filter**

Based on above concern, a filter at load end is used for obtaining better DC voltage with less ripples. By using this analogy, we achieve better DC voltage, but the source parameters (voltage and current) get distorted which makes source power factor to be 0.6 lag. Simulation results of AC-DC conversion with Filter is shown in Fig.6.7.
6.4.2 AC-DC CONVERSION WITH DC-DC CONVERTER

At last, high step gain DC/DC converter is utilized for getting constant DC without any ripples. This makes source side voltage and current are nearly sinusoidal, which is
in-phase with each other and giving low THD content over previous conversion stage.

The source power factor also nearly unity shown in Fig.6.8(c).
The THD value with the use of Filter is 364.78% which is out-off IEEE standards. While the same with DC-DC converter stage is 4.92% and is well within IEEE standards. This is the prominent requirement for consuming this two stage conversion scheme for 6/4 SRM drive system.

**6.4.3 FORMAL TWO STAGE CONVERSION SCHEME WITH DC-DC CONVERTER**

Fig.6.9 Shows simulation results of two-stage conversion scheme using DC-DC converter, in that (a) DC Link Voltage, (b) Source side Voltage and Current, (c) Source Power Factor, (d) THD analysis of Source Current, (e) Armature Current response of SRM Drive, (f) Electromagnetic Torque response of SRM Drive, (g) Speed response of SRM Drive. In this, presence of two-stage DC-DC conversion scheme doesn’t require any load side filter to get constant DC voltage. With the closed loop feedback current controller regulates the output DC voltage as constant. This makes source side voltage and current in-phase with each other resulting source power factor nearly unity and the THD value for this two stage conversion scheme is 4.86% is well within IEEE standards.
(a) DC Output Voltage with proposed two stage DC-DC Converter

(b) Source side Voltage and Current with proposed two stage DC-DC Converter

(c) Source side Power Factor with proposed two stage DC-DC Converter
(d) THD Analysis of Source Current with proposed two stage DC-DC Converter

(e) Armature Current response of SRM Drive

(f) Electromagnetic Torque response of SRM Drive

(g) Speed response of SRM Drive

Fig. 6.9 Simulation Results of Two-Stage Conversion Scheme Using DC-DC Converter
6.4.4 A NOVEL SINGLE STAGE CONVERSION SCHEME WITH CUK CONVERTER

The Table-II shows Parameters of Proposed Single-Stage Conversion Scheme Fed SRM Drive System are given in APPENDIX-I. Fig.6.10 Shows simulation results of single-stage conversion scheme using Cuk-converter, in that (a) Source side Voltage and Current, (b) Source Power Factor, (c) THD analysis of Source Current, (d) Armature Current response of SRM Drive, (e) Electromagnetic Torque response of SRM Drive, (f) Speed response of SRM Drive. In this method, presence of single-stage CUK conversion scheme doesn’t require any additional stage to get constant DC voltage. The closed loop feedback current controller regulates the output DC voltage and keeps it constant. This shows source side voltage, current are sinusoidal and in-phase with each other. The source power factor is also unity, the THD value with proposed single stage conversion scheme is 2% and is well within IEEE standards and it is better compared to two-stage scheme. This single stage conversion scheme is key prominent topology for proposed 6/4 SRM drive system, to get better speed regulation and low torque ripples compared with two stage converter.

![Graph](image)

(a) Source side Voltage and Current with Cuk-Converter
(b) Source Power Factor with Cuk-Converter

(c) THD Analysis of Source Current with Cuk-Converter

(d) Armature Current response of SRM Drive
Table 6.2 shows analysis of settling time of SRM Drive with different power factor schemes. SRM Drive is taking 0.18 sec of settling time with two-stage DC-DC Converter, but it is 0.125 sec with Single-stage Cuk converter.

Table 6.2 Analysis settling Time of SRM Drive with different Power Factor Schemes

<table>
<thead>
<tr>
<th>Power Factor Scheme</th>
<th>Settling Time(T_s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Two-Stage DC-DC Converter</td>
<td>0.18</td>
</tr>
<tr>
<td>With Single-Stage Cuk Converter</td>
<td>0.125</td>
</tr>
</tbody>
</table>

Table 6.3 shows the THD analysis of source current with proposed scheme over different formal schemes. The proposed single stage conversion scheme with Cuk
converter topology provides low THD and better power factor regulation over other formal schemes. The source voltage and current are mutually in-phase with each other, which shows that unity power factor is obtained at source side and the THD values are also well within IEEE standards.

Table 6.3 THD Analysis of Source Current with Different Schemes

<table>
<thead>
<tr>
<th>THD (%)</th>
<th>With Filter</th>
<th>With DC-DC Converter</th>
<th>With Two-Stage Conversion</th>
<th>With Single Stage Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Current</td>
<td>364.78%</td>
<td>4.92%</td>
<td>4.86%</td>
<td>2.00%</td>
</tr>
</tbody>
</table>

6.5 CONCLUSION

The SRM drive has fulfilled several requisitions of air-conditioner applications for its best robust performance. Orientation is very simple to provide best outcome voltage quality with low harmonic distortions within the tolerances of newly proposed single stage configuration. This chapter highlights the DBR is secured to improve the input current, improve the power factor of SRM drive system. Several DC link capacitors should be dispensed with for subsequent use making the proposed DC-DC converter topology as a sustained SRM drive. The proposed single stage Cuk converter fed asymmetric SRM drive scheme operating under CCM has been implemented for obtaining a unity power factor at AC supply mains. The speed of the switched reluctance drive has been effectively controlled by changing the reference speed related to DC link voltage of Converter, which allows switching state for reduced switch loss. A detailed comparison of all cases has been presented based on feasibility in design as well as in cost constraint for use with intended air-conditioner application. The proposed drive system shows the satisfactory results in all aspects and is recommended solution for high power SRM drives.