CHAPTER 1

INTRODUCTION

1.1 Introduction

Power semiconductor devices constitute the heart of the modern power electronics, and are being extensively used in power electronic converters in the form of a matrix of on -off switches, and help to convert power from one form to another. There are four basic conversion functions that can be implemented namely; ac to ac, ac to dc, dc to ac and dc to dc. The switching mode power conversion gives high efficiency but the disadvantage is that due to the non- linearity of the switches, harmonics are generated in both the supply and load sides. The switches are not ideal and they have conduction, turn-on and turn off switching losses. Although the cost of the power semiconductor drives, may hardly exceed 20-30 percent, the total equipment cost and performance may be highly influenced by the topology of the circuit used for power conversion. Owing to the development of power electronics in power conversion, AC adjustable speed drives are becoming more and more popular for industrial applications. This equipment improves energy efficiency, but there are key issues, like efficiency and harmonic injection into the line, which affects the power factor, and the overall cost of the system, and these issues need to be considered before any drive is used for industrial or commercial purpose.

One way to increase the efficiency of the drive is by reducing the losses at possible places such as in the converter used along with the ac motor. These losses are computed as switching losses and conduction losses. It may also be improved as the number of circuit elements is minimized, because as the number of devices reduces the associated amount of switching reduces and so the losses are minimized.

Proliferation of nonlinear loads, such as three-phase rectifiers, adjustable speed drives and uninterruptible power supplies are prone to high harmonic injection into the utility, which powers them [1]. To reduce harmonic injections, improvement in displacement factor is considered and so power factor correction equipment like capacitors and filters are installed in the system. Harmonic currents cause resonance between utility and harmonic–producing loads or among multiple harmonic producing loads. These harmonic related phenomena result in de-rating of the system equipment such as transformers, higher transmission line loss and reduced system stability margin. Since electrical motors consume around 56% of the total consumed electrical energy the improvement in power factor of electrical drives as seen by the utility connection has been of major concern. Another consideration is the need to increase the VA capacity of motor drives, so that the full utilization of the isolated real power is possible [2].

In order to solve some of these problems, a large variety of control techniques and converter topologies have appeared in the literature [3]. Since good quality power factor systems are becoming more and more mandatory, power factor improvement is one of the key issues in designing a system.

Several methods have been attempted in order to obtain a satisfactory power quality from the supply mains. The use of terminal capacitors across the machine windings is very common, due to its low cost and simplicity. However, this method is often not often recommended for the adjustable speed drives employing inverters which are PWM operated, as the capacitor may draw high harmonic currents due to the harmonics present in the PWM terminal voltages, and the motor may experience self-excitation, which might cause over-voltages in its terminals [4].

In rural electric systems, the cost of bringing three-phase power to a remote location is often high due to high cost for a three-phase extension. Furthermore the rate structure of a three-phase service is higher than that for single-phase service. Therefore, single-phase to three-phase power converters are excellent choices for situations where three-phase power is not available. Such converters have a wide range of applications in which a three-phase motor is a main component and the available supply is single-phase. Other factors that influence the choice of a static converter and three–phase motor combination are listed as follows [5]:-

1. Three–phase motors are more efficient and economical than their single-phase counter parts.
2. Starting and inrush currents in a three-phase motor are less severe than in a single-phase motor.

Owing to wide applications of power converters, it is essential to develop single to three-phase converters, which are efficient, cost effective and give high quality performance. Presently, available converters for such applications are classified as rotary type; autotransformer with switched capacitors and lastly, the static converter type. The first two types of converters as given in [5] employ bulky magnetic components of considerable size and weight. The third category that employs static semiconductor devices for direct conversion of single-phase to three-phase is by far the most active research area in which the bulky magnetic part can be eliminated and embedded control of the line and the load can be achieved. The superiority of static converters is further reinforced with the advances in power semiconductor devices and their control logic.

Previous work on static single-phase converters involves the use of thyristors in combination with L, C components, as in [6]. The disadvantage of this scheme is the limited control range and the L-C values must be matched with the load impedances. Moreover the circuit topology is bulky due to the reactor used with the input. In [5] a number of reduced switch count converter topologies for generating high quality three-phase voltages from single-phase mains have been presented, in which the converters were classified as active input current shaping feature ones and those without the active input current shaping feature. The converters, which do not employ the input current shaping feature have reduced number of switches when compared to ones in which this feature was included, but in both types the converter size is large due to the inductor, in series with the single-phase supply.

In [7] a new single-phase to three phase converter for low cost ac motor drive was presented, which employed only six switches and incorporates an active input current shaping feature that results in sinusoidal input current close to unity power factor. This converter has the capability of bidirectional power transfer, an improvement on all the previously proposed converters. In [8] new topologies for single to three-phase power conversion was proposed in which the zero sequence voltage was used to control the supply side parameters. This allowed the integration of the load and supply control, and with this class of converters unity power factor operation was possible.

Low power drive systems typically in the range of fractional horse-power (hp) to 1 hp, due to their massive emerging applications in appliances and in industrial processes have been of great interest for researchers to explore their performance while improving the same. For these low power drives it is very common to use the single-phase to three-phase type of converter to drive the motor. The usual approach for these adjustable speed drives is to implement the power factor correction (PFC) feature in the power converter itself, which normally requires additional circuitry and controls. Some analysis has been done in order to evaluate the impact of these PFC schemes in the drive system in terms of performance and costs. It was concluded that, though a good system input power factor improvement can be achieved, the used of additional PFC control feature may not be very attractive for induction motor drives, due to cost and packaging factors. Hence, in order to make this scheme more cost effective, it is important to develop power converters with PFC schemes using a reduced number of components and more integrated controls.

The use of digital signal processor (DSP) as a way to integrate multiple control functions in a motor drive system is becoming more and more common now-a days. In this thesis an approach to work on the concept of integrating motor and PFC controls with reduced number of switches in the converter topologies has been presented with detailed analysis of dynamic model and control scheme.

Due to the variety of the topologies and control strategies, the converter topologies have been differentiated as Conventional converters and Sparse converters. In Conventional circuits the number of switching devices are sufficient enough to achieve independent control of both the converter and the three-phase inverter. In sparse converters the number of switching devices are not sufficient enough to achieve this independent control, thus the converter and inverter control actions are dependent on each other. As the number of switching devices are reduced the name sparse converters has been given.

1.2 Conventional Circuits

Figure 1.1 shows the schematics of conventional circuits for single-phase to three-phase power conversion, which can be used for power factor correction and speed control when cascaded with the motor. The main task of the PWM ac to dc converter is to synchronize with the ac input voltage for unity power factor and to maintain the dc link voltage to be a desired constant value.

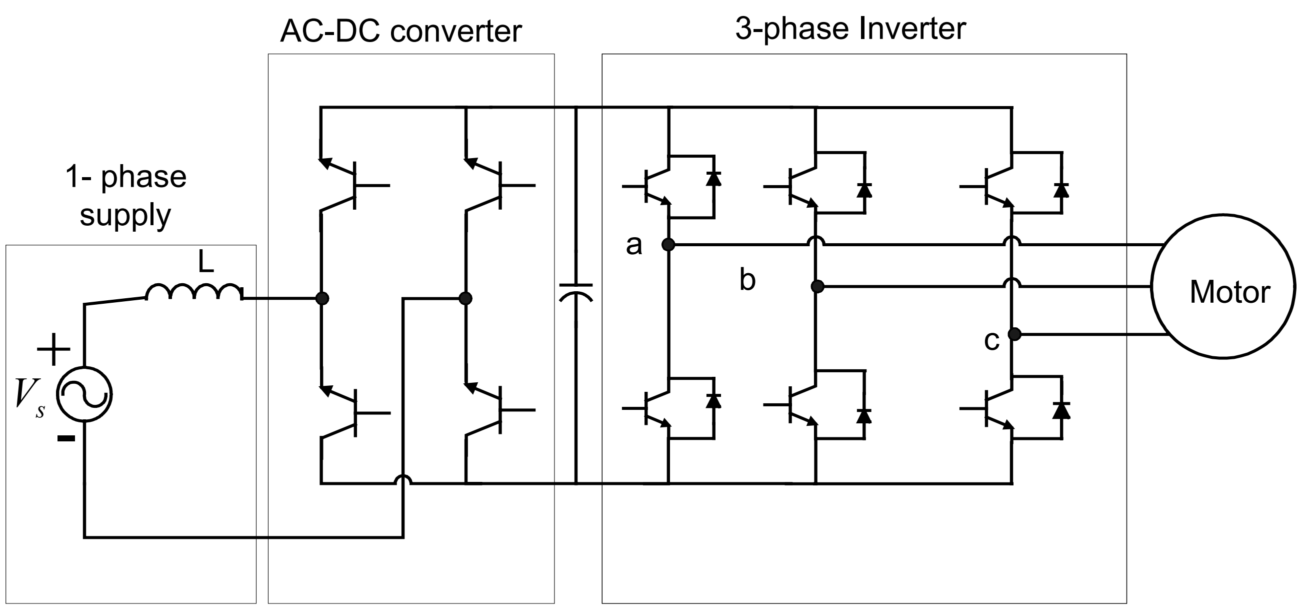
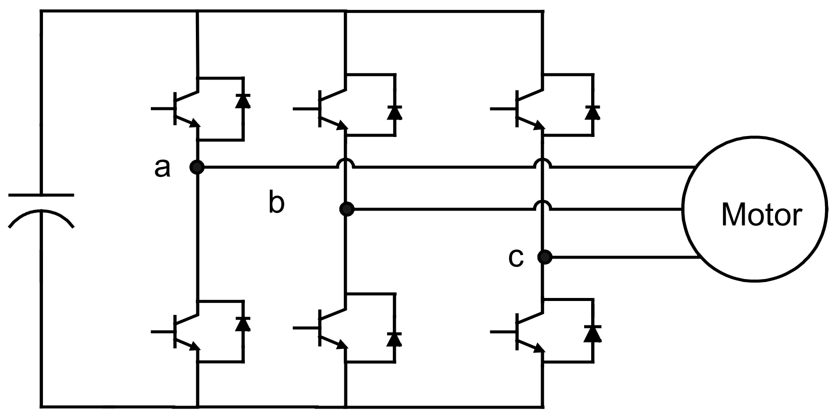
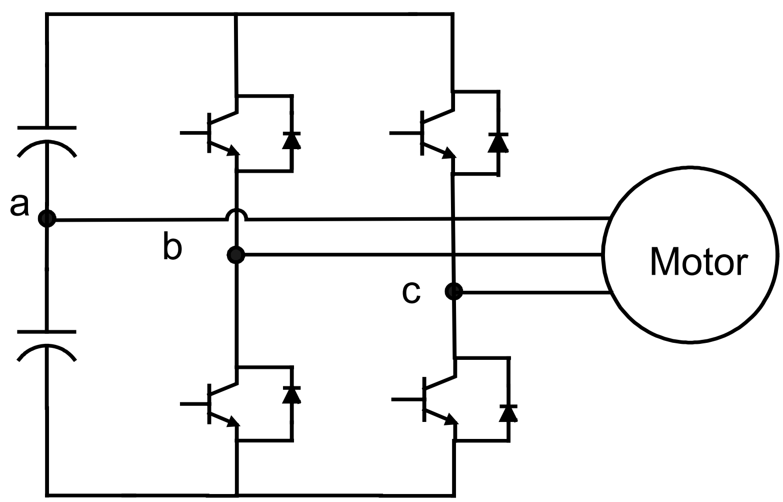


Figure 1.1: Model for Conventional circuits.



(a) Six-switch inverter



(b) Four-switch inverter

Figure1.2: PWM DC to AC inverter topologies, (a) Six switch inverter (b) Four switch inverter

For the PWM dc to ac inverter part there are two major configurations to drive three phase motors, such as the six and the four-switch configurations as shown in Figure 1.2 (a) and (b).

Due to the inherent voltage vector limitation in the four-switch inverter, three-phase 120° balanced currents profiles can only be obtained by using 60° phase shifted PWM control strategy. In order to properly utilize the four-switch inverter topology in a certain application, it is very important to understand its operational limitations. The main limitations are lower voltage utilization and higher harmonic components. Consequently, it can result in an increased harmonic copper losses and torque pulsations. Therefore, the four-switch inverter cannot be an alternative to the six-switch inverter configuration in all application areas, but can be a good choice in middle power range application, in which a certain harmonic level can be tolerated. For this circuit to be more effectively utilized advanced PWM control strategies should be developed for wide application in industry.

Applying the component minimization concept of the four switch inverter to the conventional three-phase to three-phase PWM converter system, we can reduce the number of switches from the conventional configuration and come up with the eight switch based configuration. One topology of the conventional circuits is shown in Figure 1.3, in which the power factor is typically about 0.6, and the input harmonic distortion is large. This highly distorted input current can be smoothed by the use of series ac side inductances, with the disadvantages in cost, size and losses. Since the converter fed loads are the most common type of non-linear load for the ac mains, there are various guidelines, such as in the IEEE-519, and are given in [1], which lists the allowed amount of harmonic current injection in the utility system.

The desirable functions of an active power factor correction scheme are line voltage rectification, bus voltage regulation and line current wave shaping. To perform these tasks an additional circuitry, based on a dc-dc converter, is added to the front-end rectifier. Among a number of dc-dc topologies proposed in the literature, the use of a boost converter has been considered very appropriate for many applications due to the following reasons.

1) The dc bus voltage is higher than the conventional diode bridge rectified ac voltage. This is very convenient to increase the range of operation of single-phase to three phase motor drive inverters.
2) It has an inductor in the input and a capacitor at the output, which is very convenient for filtering.

Figure 1.3 shows the conventional active power factor correction scheme based on the boost converter. The input current shaping is done by the boost action of the inductor and the switch ‘s’.

For efficient operation of the above scheme the circuit needs to be operating at a high switching frequency in tens of kHz range. At higher switching frequencies the switching losses increase, and the cost of high voltage diodes with fast reverse recovery characteristics prove to be costly.

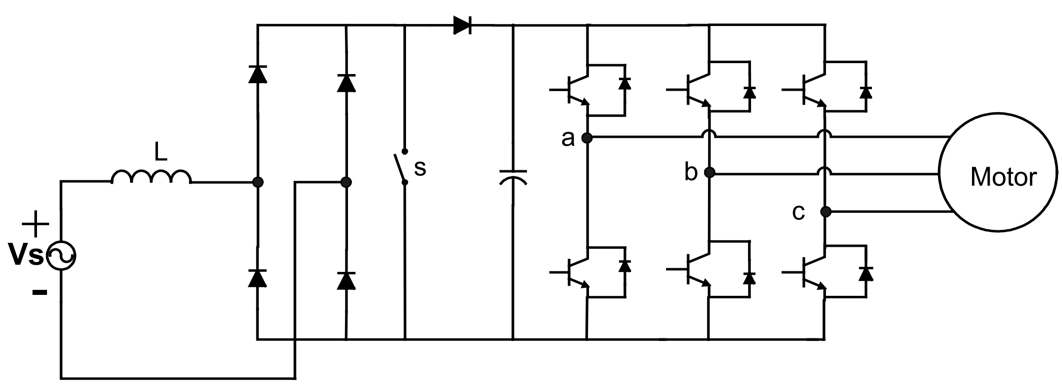


Figure 1.3: Conventional single to three-phase converter with power factor based on boost operation

This configuration does not provide bi-directional power flow between the dc bus and the ac mains, which is a very desirable feature for ac motor drives. Moreover, though the boosted dc bus improves the drive operating range, when compared to the conventional system, still there is a limitation for the system speed range. Several single-phase to three-phase topologies were proposed in [7] with bidirectional power flow and input current shaping capabilities and with reduced component count.

1.3 Research Objective

Recently, improved developments in DSP technology and the need for more compact motor drive systems, with reduced costs has emphasized research on drive systems, with more reduced component count and or more integrated controls. The conventional single-phase to three-phase circuit as shown in Figure 1.4, consists of a single-phase full bridge ac-to-dc converter and a three-phase inverter. This circuit has five legs each being a series connection of two switching devices. A reactor is connected in series with the single-phase power supply and the input is applied between the central points of the full bridge ac-to-dc converter legs. The single phase supply voltage us converter to dc voltage across the capacitor and then the dc voltage is converted to the required number of phase voltages here in this case three phase voltages across the load, which if the motor.

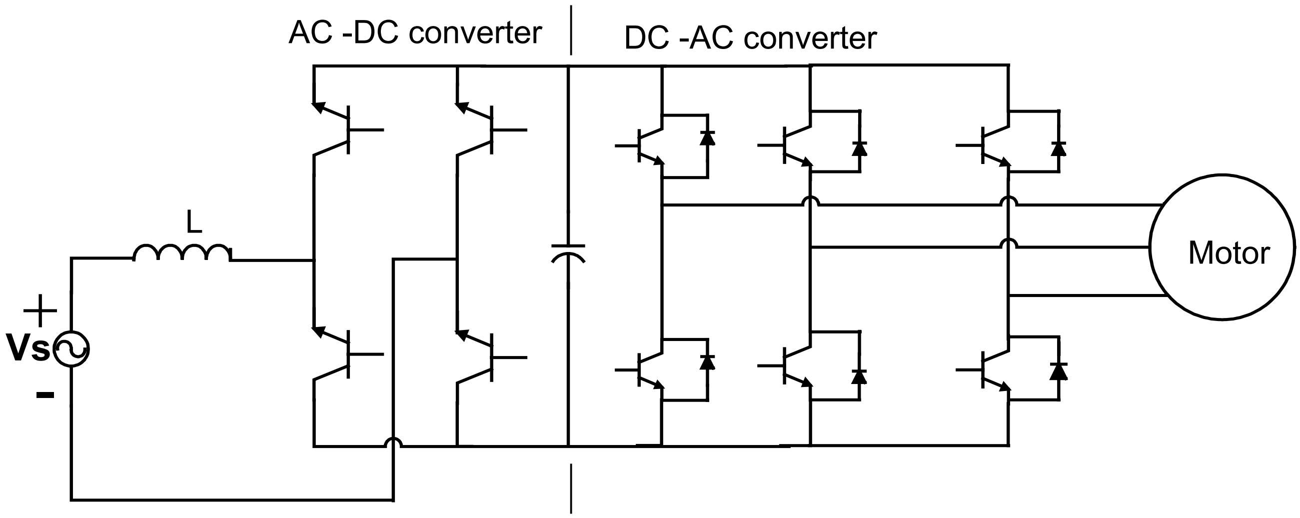


Figure 1.4: Conventional full-bridge AC/DC converter inverter circuit

The power supply current is controlled to be sinusoidal by the full-bridge ac-to-dc converter, while the motor input voltage is controlled by the pulse-width modulation inverter. These two control actions are independent and a capacitor is inserted for decoupling. To reduce the cost the full bridge converter can be replaced by a half-bridge converter in any case the input reactor is necessary which further increases the size of the system.

The three-phase inverter has eight switching states and each state correspond to a voltage in each phase, but in particular there exists two states during which the inverter does not output any voltage on the phases. This happens when all the top devices or all the bottom devices are ‘on’ at the same time. These corresponding state vectors are referred to as zero vectors. These zero vectors are equivalent in terms of generated line-to-line voltage, but differ in the induced voltage v_o between the neutral point of the star connected three phase load and the neutral point of the dc link, which is given as,

$$v_o = \frac{Vd}{2} \qquad \text{when all the top devices are on}$$

$$v_o = -\frac{Vd}{2} \qquad \text{when all the bottom devices are on}$$

Therefore the neutral point voltage of the load can be controlled by a proper use of the zero vectors. The model for the sparse converters is as shown in Figure 1.5. It consists of a motor, a three-phase inverter and an additional leg having the functionality of the ac-to-dc converter. The power supply is directly connected between the neutral point of the load, in doing so the input reactor as in conventional circuits becomes redundant as its purpose is served by the leakage inductance of the motor.

Since the power supply is connected directly to the load, power supply current and the output voltage control actions are no longer independent as in the case of the conventional circuits. Owing to the connection of the power supply the load currents carry an additional amount of the current, which is one third of the supply current, and this current is the zero phase sequence current.

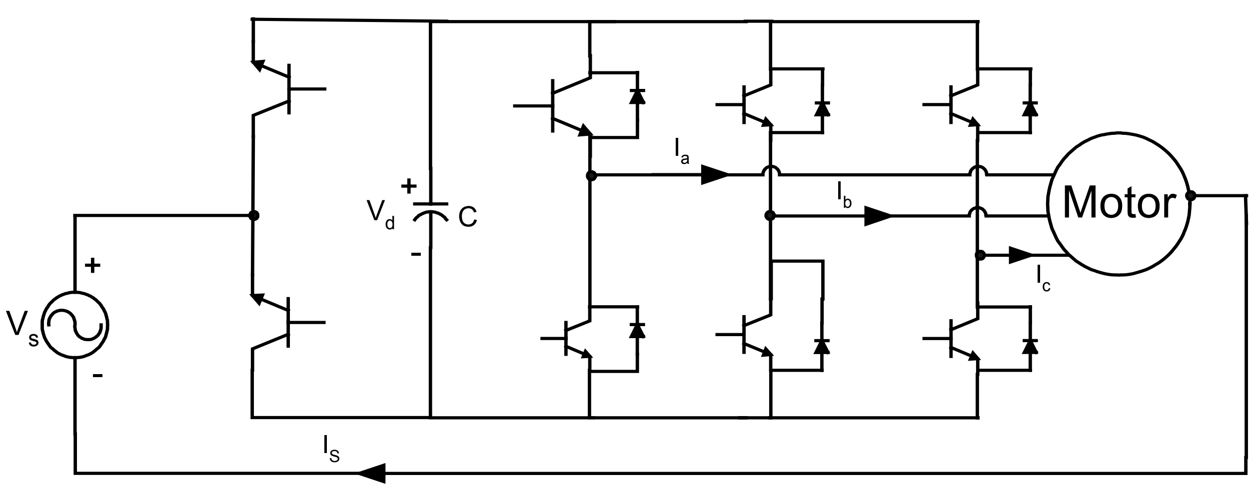
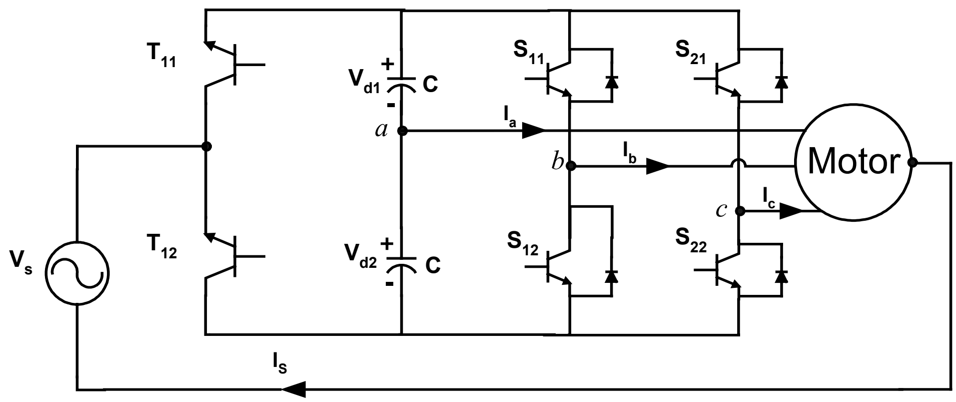


Figure 1.5: Model for Sparse converters.

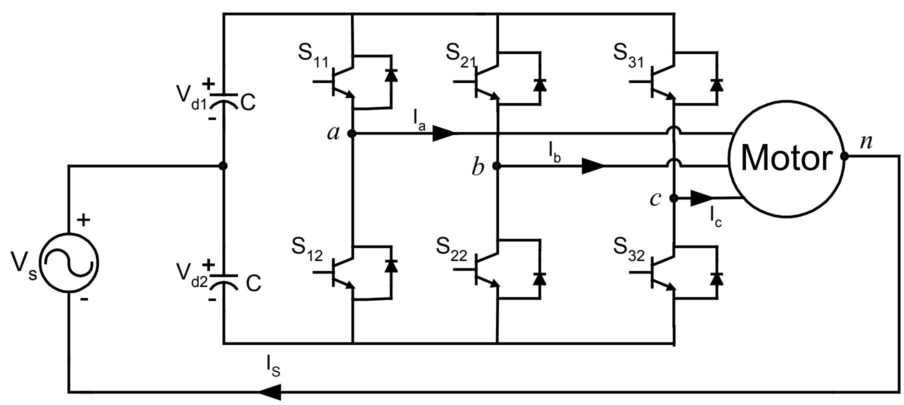
The zero-phase sequence current flowing in to the stator windings does not generate any torque and so therefore may be accepted as long as the related increase of copper losses is compensated by some advantages like the cost and size.

Thus comparing the conventional converter with the sparse converters they both are equal when considering the leakage inductance of the motor as input reactance for the full bridge ac-to-dc converter. The equivalence is achieved in spite of the reduced number of switching devices and a very simple structure for the ac-to-dc converter is obtained. Since the sparse converters use the zero-phase sequence voltage to control the power supply current, it requires higher dc link voltage than the conventional circuits.

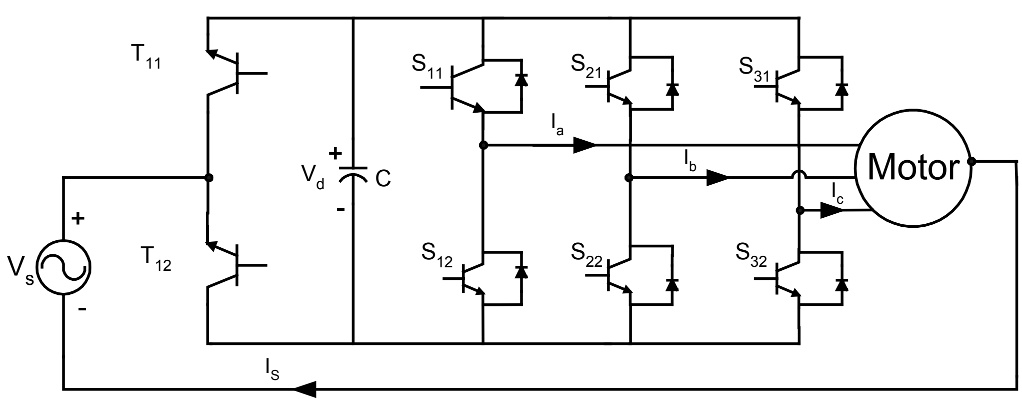
The main objective of this research is to develop a procedure to analyze the system of sparse converters and to design an integrated power factor correction and motor control, for which three converter topologies have been taken and simulated to test the functionality of the control schemes. The converters were named as Converter A, Converter B and Converter C. Converter B and Converter C were previously tested for functionality in literature [7], but a detailed analysis of the mathematical model has not been presented. Converter A is a new topology which was not found in the literature, the topology for Converter A has been obtained as a combination of reduced switch count dc to ac inverter and reduced switch count single phase to dc converter thus yielding a overall reduced switch single phase to three phase power converter. The topologies for Converter A, B and C are as shown in Figure 1.6.



(a)



(b)



(c)

Figure 1.6: Sparse Converter Topologies, (a) Converter A
(b) Converter B (c) Converter C.

1.4. Thesis Organization

In this thesis first an introduction is presented, where some important issues regarding the development of ac motor drives with improved power quality are addressed, along with literature review. Chapter 2 deals with single-phase inverter and some of the associated modulation schemes, like the unipolar, bipolar and the modified bipolar modulation schemes and lays out the functionality of these schemes along with a comparative study.

Chapter 3 gives a brief introduction on the operation and dynamic modeling of induction machine as it was used as the load in testing the functionality of the given converter topologies. In Chapter 4 the model for a three-phase inverter was presented along with the derivation of the switching functions for the devices.

In Chapter 5 the control scheme for the induction machine has been explored in great depth and also an introduction to the feedback linearization control technique has been presented. Moving on to Chapter 6 the working of the conventional converters was explained, the model equations and the derivation of the control scheme was given. Finally in Chapter 7 the Sparse converters were presented, in which the dynamic modeling of the converters and the working of the control scheme is explained. Finally conclusions on the results obtained are presented.

Appendix A contains the machine parameters while in Appendix B the steady state calculations for the reference values are given.