CHAPTER 1

INTRODUCTION

1.1 Introduction

The challenge of supplying the nation with reliable, high-quality electrical energy at a reasonable cost is the heart of the nation's economy. The electric power system is one of the nation's oldest infrastructures, which is closely tied with the gross domestic product. Power electronics devices will play a very important role in this regard. These devices are finding increased applications for the transformation of electrical energy into useful forms, especially at higher power levels. In recent years, there has been an increased interest in renewable energy sources. Developments in these areas recognize power electronics systems as a core enabling technology. The important criterion which makes the power electronics solutions unique is that they are fundamentally multifunctional and can provide not only their principle interfacing function but also various utility functions. The general trend in power electronics devices has been to switch power semiconductors at increased frequencies in order to minimize harmonics and reduce passive component sizes.

There are several areas in which power electronics plays a vital role. The research areas of power electronics include:

- Interfacing with distributed energy resources such as micro turbines, fuel cells, and solar cells.

- Multilevel converters for utility applications such as static var compensation, voltage sag support, HVDC intertie, large variable speed drives.
- Harmonics, power quality, and power filter design.
- Hybrid electric vehicle (HEV) applications such as motor drives or dc-dc converters.
- Soft switching inverters and dc-dc converters.
- Areas like transportation and utility applications.

There have been new trends in the AC/DC and DC/AC power conversion. The pulse width modulated two-level converters have been the dominant topology in the low power and some selected medium power applications. There has been on-going research on these power converters and as technology evolves and matures various new trends and performance of the converter can be identified. Several important issues play a key role in new trends. Factors like increasing the power density, improving performance of the converter, reducing the cost of the converter, and also increasing the VA ratings of the converter. There are several ways in which these factors can be achieved such as in case of the increasing the power density; this can be realized by reducing the switching losses due to the devices by using soft-switching techniques, efficient power devices, and improving the thermal management. Next issue is increasing the performance of the system, which is achieved by reducing the total harmonic distortions, reducing the EMI problems, and by increasing the dynamics of the system.

The important criterion, which plays a major role, is the cost of the converters. Tremendous amount of research work is going in an attempt to reduce the cost of the converters by reducing number of devices (Sparse converters)[1-3]. Sparse converters are the kind of converters that deliver the same performance with lesser number of devices. Also, reducing the cost of the passive devices can reduce the cost of the converter. Since there has been a continuing increase in power demand, the converter power ratings should also increase. If the conventional two-level converters are to be used in these high power applications, the rating of the devices has to be increased such as the blocking voltage rating, current rating, thermal management, and so on. Hence in case of increasing the power ratings of the converters by using the low rating devices, multilevel converters are the important converters.

Recently, multilevel converters have attracted attention in medium and high power applications so as to reduce the voltage stress of power semiconductors, voltage harmonics, and electromagnetic interferences. Multilevel power conversion began with neutral point clamped inverter topology proposed by Nabae et al. [4] Multilevel converters incorporate a topological structure that allows a desired output voltage to be synthesized from among set of isolated or interconnected distinct voltage sources. Numerous topologies to realize the connectivity have been proposed [4-8].

The general function of the multilevel converters is to synthesize a sinusoidal voltage out of several levels of dc voltages. The multilevel converter can therefore be described as a voltage synthesizer. The voltage blocking capability of each device determines the maximum voltage level output. There are several advantages of multilevel inverters such as

- Low manufacturing costs as low rating devices are used;
- Improved waveform quality as levels in the converter are increased;
- Compact modules and no transformer needed;

- Better synthesizing of the output waveforms which reduces the output filters and the rating of the passive components;
- Many possible connections are available such as single-phase, three-phase, and multi phase connections;
- Low switching frequency yields high efficiency.

When series connected capacitors are used to divide the dc-link voltage, three-level inverters (multilevel converters in general) have a dc-link voltage problem due to the following reasons:

- Unequal capacitor values due to manufacture tolerances.
- Unequal loading of the capacitors due to unintended switching delays.
- Unequal loading of the capacitors due to nonlinear loads containing even order harmonics.
- Dead-time implementation, which is always necessary in voltage source converters.
- Transformer-secondary leakage inductance or voltage imbalance due to manufacturing tolerances.
- Unbalanced load due to imbalances between the phases of the three-phase load.
- Dynamic operating conditions such as acceleration or deceleration of a motor.
- Imbalances in the parameters of the power semiconductors switching devices.

This is an important problem associated with the multilevel converters. Under certain conditions, the dc-link neutral point potential can significantly fluctuate or continuously drift to unacceptable levels. As a result, the switching devices may fail due to over stress on the devices. Though it is possible to reduce the neutral point voltage deviation by excessively increasing the dc-link capacitors and the bleeding resistor size, such a solution is prohibitive from the cost and size perspectives. Hence the choice of modulation scheme becomes important in controlling the neutral point voltage.

1.2 Organization of the Thesis

Chapter 1 presented the introduction to the thesis. It stated the problem, an overview of the suggested solution to the problem, and the scope and limitations of the research.

Chapter 2 presents the literature survey conducted in realizing this research. This includes a study of different multilevel converter topologies and comparing the performances of the topologies. Also it includes study of the previous modulation schemes and control techniques for controlling the neutral point voltage and neutral current and provides the limitations of these modulation schemes.

Chapter 3 presents the different topological structures that are available in the multilevel converters. Also it provides the operation principle and the mathematical model of each topology in detail. The carrier-based scheme and the phase disposition technique are explained in detail.

Chapter 4 presents the continuous and discontinuous modulation schemes proposed for the control of multilevel converters. Firstly the continuous modulation scheme using a single carrier and N modulation signals will be provided. The generalization of the scheme and some simulation results are provided. Also the chapter presents the limitations of using the single carrier modulation scheme. Next part of the chapter deals with the discontinuous modulation scheme. Also included are detailed and step-by-step procedure of analyzing and deriving the discontinuous modulation scheme. The chapter also provides the hardware implementation and experimental results to validate the proposed control scheme.

Chapter 5 presents the control of the neutral point voltage using the generalized carrier-based discontinuous pulse width modulation. Also the chapter includes the control of neutral currents based on the concept of sharing functions.

Chapter 6 presents the development of the control scheme based on the natural variable utilization. The chapter includes the control of a three-phase voltage source inverter and rectifier under unbalanced load conditions using a natural reference frame controller. Also it provides a detailed analysis of the control methodology and the selection of parameters. Simulation results will be provided to validate the methodology.

Chapter 7 presents the detailed analysis and control of a three-phase three-leg three-level rectifier. This chapter begins with a brief introduction to the multilevel rectifiers and provides the objectives of the control scheme. Also it provides an explicit mathematical modeling of the rectifier and a detailed analysis of the control scheme and selection of the control parameters. Steady state, dynamical analysis, and also the qd modeling of the converter are provided. Simulation results will be provided to conclude the chapter.

Chapter 8 presents a detailed analysis and control scheme of a three-phase two-leg three-level rectifier. This chapter briefly explains the topology and all its modes of operations. Also it provides the objectives of the control scheme and gives a detailed mathematical analysis of the control methodology and explains a way to select the control parameters. Simulation results are provided.

Chapter 9 presents the control of an unbalanced three-phase three-level rectifier. This chapter provides the causes for unbalance operations and the control methodology to achieve the regulation of the dc voltage and constant power transfer. Simulation results are provided.

Chapter 10 presents the hardware implementation of the three-level diode clamped inverter. A detailed procedure of selection of the components and a step-by-step procedure in building the inverter are explained. The carrier-based implementation using the TMS320LF2407 DSP is detailed in this chapter.

Chapter 11 presents the contributions of the work with some conclusions. Also it provides some future extension of the present work.