The space vector pulse width modulation for two-level inverter is described in detail. The switching states determination, switching time calculations and optimized switching sequence are clearly indicated. The important multilevel inverter topologies are also briefly explained. The literature review is also included for sinusoidal PWM, space vector PWM and multilevel inverters.

Chapter-2

STATEMENT OF THE PROBLEM

2.1 INTRODUCTION

The output voltage of power inverter is to be a pure sinusoidal waveform with minimum distortion. But for the practical inverters, the output voltage is a series of rectangular waveforms. The major issues for the control of the power inverters are to get suitable modulation methods to control the output rectangular waveforms to synthesize the desired waveforms. Therefore, a modulation control method is required to get a desired fundamental frequency voltage and to eliminate higher order harmonics as much as possible. In the previous chapter, a brief review on pulse width modulation techniques, the concept of space vector, features of space vector pulse width modulation, various multilevel inverter topologies and brief literature review on SVPWM technique have been discussed in detail. In this
chapter, the statement of the problem and main contribution of the thesis have been included.

2.2 STATEMENT OF THE PROBLEM

Higher frequencies are employed in traditional pulse width modulation methods because of the undesirable harmonics occur at higher frequencies, which can be filtered easily and several kHz is well above the acoustic noise level. But, the traditional pulse width modulation methods cause electromagnetic interference (EMI). The rapid change in voltage (dv/dt) is the cause of electromagnetic interference. A high dv/dt produces common-mode voltages across the windings of motor and leads to damage.

In multilevel inverters, as the switching involves several small voltages, the rapid change in voltage is smaller. Further, switching at the fundamental frequency will also result in decreasing the number of times these voltage changes occur per fundamental cycle. But harmonic elimination is the major issue for multilevel inverters. The harmonic elimination in multilevel inverters have been proposed in this thesis for the following reasons.

- Harmonics in output voltage create power losses in equipments.
- Harmonics are the source of electromagnetic interference (EMI).

The protecting devices like snubber circuits and filters have to be incorporated in the designed circuits for the elimination of harmonics. Hence cost of the circuits becomes more.
• The electromagnetic interference can interfere with control signals used to control the power electronic devices and radio signals.

• The harmonics can create losses in power equipments.

  Harmonic currents in an induction motor will dissipate power in stator and motor windings.

• Harmonics can lower the load power factor.

  As mentioned earlier, the multilevel inverters result in a better approximation to a sinusoidal waveform because of increased number of dc voltages. These increased number of dc voltages provides an opportunity to eliminate more harmonic contents. The remaining harmonic content can be easily eliminated by less expensive smaller filters. In multilevel inverters, several switches are needed, because of the large number of dc voltages. Since switch stress is reduced and lower switch ratings are used. If any component fails in the inverter, it will be still usable at reduced power level. In multilevel inverter there will be more than one way to generate the desired voltages due to switching redundancies. This will allow for the utilization of smaller and more reliable components. One disadvantage of multilevel inverters is that they require more devices than traditional inverters. The system cost may increase. The probability of system failure increases and control of the switches is also more complicate due to more number of devices.

  There are four kinds of control methods for multilevel inverters. They are traditional PWM control method, selective harmonic
elimination method, space vector control method and space vector pulse width modulation method. Space vector PWM is considered a better technique of PWM implementation owing to its associated advantages like better fundamental output voltage, better harmonic performance and easier implementation in digital signal processor and microcontrollers.

For these reasons, in this thesis, the space vector pulse width modulation based algorithms are proposed and implemented for neutral point clamped multilevel inverter fed induction motor. These space vector based algorithms generate not only the desired fundamental frequency voltages, but also eliminate the harmonics up to the maximum extent and consequently reduces the total harmonic distortion (THD).

2.3 MAIN CONTRIBUTION OF THE THESIS

In this thesis, the various space vector pulse width modulation based algorithms for multilevel neutral point clamped inverter fed induction motor are proposed and implemented. The results have been analyzed and presented. The performance of these algorithms are evaluated in terms of inverter output voltage, current waveforms, total harmonic distortion, speed of induction motor and torque ripples.

The following algorithms have been proposed in this thesis:

1. The space vector pulse width modulation (SVPWM) algorithm for a three-level inverter fed induction motor is proposed and is used for the analysis of two-level inverter and three-level
inverters. The voltage vector selection procedure, switching
time calculation and switching pattern generation for three-
level inverter are described in detail. This space vector pulse
width modulation algorithm contributed for the reduction of
switching power losses and proved the advantages of three-
level inverter that carries out voltage with contents of less
harmonic injection than two-level inverter. The above method
has been discussed in detail and results have been presented
and analyzed.

2. The space vector pulse width modulation for multilevel using
fractal approach has been proposed and implemented for
three-level and five-level inverters. As the level of inverter
increases, the sector identification and switching vector
determination and dwelling time calculation become more
complex. The computational complexity and the execution time
increase. This method is mainly based on the fact that the
switching vector representation of any multilevel inverter has
an inherent fractal structure, which is the basic unit of this
structure being the triangle formed by the vertices of three
adjacent inverter voltage space vectors. The proposed method
uses simple arithmetic for determining the sector and does not
require look up tables, hence fractal approach is applied for
multilevel inverters using SVPWM. The results have been
presented and analyzed. The complexity and feasibility of this
algorithm have been discussed.
3. A qualitative space vector pulse width modulation algorithm is proposed and implemented for neutral point clamped multilevel inverter. In this method, the duty cycles of reference voltage vectors are corrected accordingly for identifying the location of the reference voltage vector in each region. The appropriate switching sequence of the region and calculation of the switching ON times for each state is estimated. This scheme can be extended to high-level inverters as well. This algorithm has been discussed in detail and results have been presented and analyzed for two-level, three-level, four-level, five-level, six-level and seven-level inverters. The total harmonic distortion have been calculated and compared with lower levels also.

4. An analytical space vector pulse width modulation method for multilevel inverter is proposed and implemented for neutral point clamped multilevel inverter. This method is based on the intrinsic relation between multilevel and two-level space vector pulse width modulation. In this method, the dwelling time of vector calculation is derived from two-level inverter. By using linear transformation, the dwelling time of vectors for two-level inverter can be transformed into multi-level inverter. A novel classification of voltage vectors is proposed to determine switching pattern of PWM sequence and used upto the eleven-level inverter. This method has been discussed in detail and results have been presented and
analyzed for three-level inverter, five-level inverter, seven-level inverter, nine-level inverter and eleven-level inverters, which can be extended to n-level inverter as well.

5. The space vector pulse width modulation algorithm for multilevel inverters using decomposition method is proposed. In this method, the space vector diagram of multilevel inverter is decomposed into several space vector diagrams of two-level inverters. To proceed with the switching state determination, first one of the two-level hexagons is selected based on the location of the target voltage vector and the original voltage reference vector is decremented by the voltage vector that locates the origin of the selected two-level hexagon. This, then, allows the determination of switching sequence and calculation of the voltage vector duration to be done in the same manner as a conventional two-level inverter. This method has been explained in detail and results have been presented and analyzed for three-level inverter, five-level inverter and seven-level inverters.

2.3 ORGANIZATION OF THE THESIS

This thesis is organized in the following manner:

Chapter-1 discusses the introduction and literature review on pulse width modulation, sinusoidal pulse width modulation, space vector pulse width modulation and various topologies of multi-level inverters. The literature review of existing space vector pulse width modulation algorithms is also discussed in this chapter.
**Chapter-2** presents the statement of the problem, the main contribution of thesis and organization of thesis.

**Chapter-3** proposes the space vector pulse width modulation (SVPWM) algorithm for a three-level inverter fed induction motor. This SVPWM algorithm provides high safety voltages with less harmonic components compared to two-level structures. The results and analysis of this method have been presented and analyzed in this chapter.

In this chapter, another method for the generation of space vector PWM for multilevel inverters based on fractal approach have been proposed and applied for three-level and five-level inverters. The fractal reduces the algorithm complexity and execution time. The results and analysis of this method have been presented and analyzed in this chapter.

**Chapter-4** presents three different space vector based algorithms for neutral point clamped multilevel inverter fed induction motor. The first method, qualitative space vector pulse width modulation algorithm for neutral point clamped multilevel inverter. In this method, the duty cycles of reference voltage vectors are corrected accordingly for identifying the location of the reference voltage vector in each region. The appropriate switching sequence of the region and calculation of the switching ON times for each state is estimated. Based on the above method the results have been presented and analyzed in this chapter.
In this chapter, the second algorithm, an analytical space vector pulse width modulation for multi-level VSI has been proposed to improve the performance of the inverter. This method based on the intrinsic relation between multi-level and two-level space vector pulse width modulation. In this method, the dwelling time of vector calculation is derived from two-level inverter. This method is applied upto the eleven-level inverter, which can be extended to n-level inverter as well. Based on the above method, the results have been presented and analyzed.

Finally, a space vector pulse width modulation algorithm using decomposition method is also presented for seven-level inverter in this chapter. In this method, the space vector diagram of the seven-level inverter is decomposed into six space vector diagrams of four-level inverters. In turn, each four-level inverter is decomposed into three-level inverters and finally three-level inverter is decomposed into six space vector diagrams of two-level inverters. The proposed method reduces the algorithm complexity and the execution time. It can be applied to the multi-level inverters above the seven-level also.

Chapter-5 presents the final conclusions of the proposed space vector pulse width modulation based algorithms for neutral point clamped multilevel inverter fed induction motor drive and the scope of future work.

In this chapter, statement of the problem is explained in detail. In addition to this, the main contribution of the thesis and organization of thesis are also presented.