CHAPTER 2

LITERATURE REVIEW

2.1 Three Phase VSI PWM Schemes

Pulse width modulation technique using sine triangle intersection was first proposed by Schönung and Stemmler in 1964 [3.1]. Due to the ease of implementation, the sinusoidal PWM is found in a wide range of applications. The drawback of this scheme is that the output is linear between 0% and 78.5 % of the six- step voltage value. Thus there is inefficient use of the DC bus voltage. The direct digital technique or the Space Vector Modulation technique was proposed by Pfaff, Weschta and Wick in 1982 [3.2]. This scheme was further developed by van der Broeck, Skudelny, and Stanke [3.3]. The development of micro controllers made the direct digital technique possible. This scheme became more and more popular due to its merits of high utilization of the DC link voltage, possible optimized output distortion and switching losses, and compatibility with a digital controller. It has been widely used for high performance three-phase drive systems. In 1989 it was shown in [3.4] that the absence of neutral current path in three wire loads provides a degree of freedom in determining the duty cycles of the inverter switches. This degree of freedom is achieved by partitioning of the null states. The equivalent degree of freedom in triangle intersection method is observed by selection of appropriate modulator [3.5]. The absence of a neutral wire in star-connected three-phase loads provides this degree of freedom in modulation methodology. Since the voltage between the neutral of the load and the reference of the DC source, V_{no} can take any value. This zero sequence waveform is used to alter the duty cycle of the inverter switches and alternatively the modulating signals [3.5],[3.6]. Appropriate zero sequence signal injection causes increase in voltage linearity, waveform quality and reduced switching losses without affecting the output conditions. In 1974 King employed zero sequence injection technique using analog hardware, and showed that the output voltage linearity was between 0% and 90.7%. This technique is also known as a Space Vector PWM. Many other techniques were developed for harmonic elimination in order to suppress the lower ordered harmonics. The third harmonic injection (THIPWM) techniques as mentioned in [3.7] explains that by adding a measure of third harmonic to the output of each phase of a three-phase inverter, it is possible to obtain a line-to-line output voltage that is 15 percent greater than that obtainable when pure sinusoidal modulation is employed. The line-to-line voltage is undistorted. The method permits the inverter to deliver an output voltage approximately equal to the voltage of the ac supply to the inverter. This method is still being used in dedicated applications as in [3.8] [3.13], which describes a technique of injecting third harmonic zero sequence current components in the phase currents, which greatly improves the machine torque density. Of all the PWM techniques only a few PWM strategies have been accepted mainly due to the simplicity of implementation [3.9].

2.1.1 Discontinuous modulation in three phase VSI.

In 1977 Depenbrock [3.10] developed a discontinuous modulation technique and illustrated that the scheme resulted in high voltage linearity range, reduced switching losses, and superior current quality waveform. The scheme had a limitation of poor performance in the lower modulation region. The same modulators were studied in [3.11] [3.12] [3.13] from the perspective of switching losses and harmonic analysis. [3.11] explored the dependency of the conduction and switching losses in a three phase inverter system for various modulating signals. It is concluded that there is a significant increase in the effective switching frequency. By using an optimal modulation for minimum switching loss, the harmonic loss in the higher modulation region is greatly reduced. [3.12] proposes a Minimum- Loss Vector PWM (MLVPWM). It implies minimization of switching losses in the inverter due to low switching frequency ratio and absence of switching in the vicinity of the load current peaks in a given phase. The correlation between space vector PWM and Carrier based PWM was established by Blasko [3.14]. By changing the duty cycles weights of the zero state by the factor named "k_0" it was proved that the modified space vector PWM can be implemented as triangle comparison method with added zero sequence. This relationship was derived and laid out for each sector in [3.15]. This helped in comprehensive analysis of the null state vectors and their relationship with the carrier based signals. The implementation of this scheme is further explained in [3.16]. Hava *et.al.*

[3.17] developed a high performance generalized discontinuous PWM algorithm. This algorithm employed conventional space-vector PWM in the low modulation region and generalized discontinuous PWM algorithms in higher modulation region. The same approach termed as adaptive space vector modulation was explained in [3.18], which considered full control range including over modulation and six-step operation. It reduced the switching loss by 50% at 33% reduction in the switching frequency. The over modulation characteristics of these modulators were studied in [3.19]. The modulator evaluation revealed the improved performance in the higher modulation region with reference to minimum pulse width control and voltage gain characteristics of the inverter.

2.2 Current source Inverter

The six-step or square wave inverters switching leads to large amount of harmonics in load voltage and current, the widespread application of this inverter has been curbed [4.1].

The PWM CSI are feasible with the advent of GTO's, but due to the restriction on switching speed, this approach has limited application. Hence the PWM CSI are less common in practice than VSI PWM inverters, in comparison with a square wave inverter. PWM CSI topology has t he output filter capacitors to remove the harmonics due to the switching currents [4.2]. Topologies as shown in Figure 2.1 wherein the IGBT is in series with the diode has distinct disadvantage of low efficiency because in every period of conduction, the total loss is loss in series diode and IGBT which is twice much higher than that in VSI counterpart in very high power applications.

In spite of these drawbacks, the performance of CSI with IGBT in series with diode is being explored with high performance adaptive PWM algorithms. It should be possible to stretch the performance of these topologies to obtain high quality AC waveforms along with higher output power by utilizing various or adaptive PWM algorithms.

2.2.1 PWM strategies in CSI

Currently there are the following PWM strategies for current source inverters:

i. Square wave control
ii. Harmonic elimination technique
iii. Trapezoidal PWM
iv. Carrier based PWM technique
v. Space Vector PWM

Six stepped or square wave inverter has maximum utilization of the input DC voltage to generate the desired output currents and voltages. The main drawback is that the outputs are accompanied by harmonics and spikes [4.1].

Offline programmed PWM patterns or selective harmonic elimination (S.H.E) techniques [4.2], [4.3], [4.4], [4.5] aids in reducing the low order harmonics. But issues such as resonance between the input output filter capacitors and inductors are found with these techniques. Another S.H.E or unified approach has mentioned in [4.6] explains that by finding chopping angles or switching instances and locating the shorting pulses, and solving a set of nonlinear solution dedicated to CSI the fundamental and low ordered harmonics can be controlled.

The trapezoidal modulating schemes is explained in [4.7] and [4.8] enables higher frequency of operation for CSI and using shoot through pulses, thus making it possible to suppress the output voltage and current spikes and thereby generating sinusoidal current and voltages. But this is a dedicated rather than a generalized approach using base for modulating schemes as in VSI.

The space vector approach used in [4.9] shows that the restrictions of three phase CSI modulation in equivalent stationary reference frame. It proves that the same modulation relevant for VSI modulation is applicable to CSI. In [4.10] the modulator for CSI known as linearizing pulse width modulator (LPWM) has been explored. It uses the space vector approach with a complicated circuitry to derive the modulator. In all the above-mentioned schemes, the online carrier based PWM scheme [4.11], [4.12] and [4.13] is the easiest to implement.

In VSI PWM schemes where in by adding zero sequence voltages to the existing modulating signals in high modulation region, the switching loss, voltage linearity, and over modulation performance of the inverter is optimized [4.16]. In a similar way if we can adapt these modulation strategies into a CSI then the advantages of the modulation schemes in VSI can be extended into a CSI.

2.3 Four legged converter.

2.3.1 Neutral clamped split DC capacitor four legged converter.

A three-legged power converter is incapable of dealing with zero-sequence unbalance. To solve the limitation, normally split DC link capacitors are used. The zero-sequence current path is provided by tying the neutral point to the middle point of the two DC link capacitors. [5.1] presented a scheme using split DC link capacitors to handle the zero-sequence for active power filter application. The drawback of this scheme is that excessively large DC link capacitors are needed, therefore cost is high especially for high voltage applications.

To allow the conduction for the neutral current, the conventional way is to use a split DC link capacitor. The neutral current pass through this DC link capacitors. The ground is calmped at half the DC link voltage. This scheme has a drawback of insufficient utilization of the DC link voltage. Thus inorder to achieve higher output voltage, high DC link capacitor is to be used. The second drawback is high value of capacitor required to handle the neutral currents[5.2].The four legged inverter was proposed by Enjet and Kim[5.3] where the fourth leg is an active filter independent from the three phase legs and the neutral point is provided by two split capacitors. The fourth leg is controlled to nullify the zero-sequence current due to unbalanced load or nonlinear load so that the neutral current does not flow through the DC link capacitors. This approach allows a smaller DC link capacitance to be used for the same voltage ripple, cancellation of the triplen harmonic currents in the neutral wire. However, this scheme still suffers from insufficient utilization of the DC link voltage.

2.3.2 Applications of four legged inverters

The first voltage source four-legged inverter used for an aircraft power generation application was presented in [5.4] in 1993 to provide the neutral connection and to handle the neutral current. Since it is a resonant DC link inverter (RDCL inverter), it is controlled with a pulse density modulation scheme. The same topology was proposed in [5.5] in 1992 for active filter applications to deal with a zero-sequence component in a power system.

Another application of four legged inverter for reduction of common mode noise was explored in [5.6].

In the emerging distributed energy systems which are to augment existing distribution power systems, four-leg converters finds significant application as interface between generator systems such as micro-turbines and wind turbines to provide three-phase balanced output voltages with neutral connections [5.7]. Introduction of utility deregulation implies that this converter would gain much importance [5.8] [5.9] as mentioned in [5.7].

They also provide fault tolerance in three phase four wired PWM rectifiers in addition to deal with line distortions and unbalance [5.10] [5.11].

2.3.3 PWM Schemes in four legged converters

The PWM schemes for this converter used were pulse density modulation for resonant DC link converter [5.4], hysterisis modulation for voltage source active filters [5.5] , independent control of the fourth leg to nullify the neutral current through split DC capacitor [5.1]. The space vector modulation for current source rectifiers was introduced in [5.10] and bidirectional active filters were explained in [5.14]. The first 3-D SVPWM was discussed in [5.2] and the same method was used for comparison of various switching schemes in [5.15]. In 2002 a comprehensive and concise modulation strategies were laid out and the vast possibilities of modulating signals were explored [5.13] [5.14].