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Reduction of Harmonics in Output Voltage of Inverter

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***Abstract*— This paper presents advances in pulse width modulation techniques which includes a method of carrying information on train of pulses and then being encoded in the width of pulses. Pulse width modulation is used to control the inverter output voltage. Pulse width modulation variable speed drives are gaining importance in many new industrial applications that require better performance. Pulse width modulation inverters play a significant role in the field of power electronics. Recently, developments in power electronics and semiconductor technology have improved power electronics systems. Space vector modulated PWM (SVPWM) is the popular PWM method and possibly the best among the PWM techniques as it generates higher voltages with low total harmonic distortion.**

Keywords*— Harmonics reduction; Pulse width modulation; Conventional techniques; Advanced techniques.

I. INTRODUCTION

Inverters are most important power electronic equipment which is being used for various purposes such as variable speed AC drive (VSD), uninterrupted power supplies (UPS),Static frequency changer (SFC), etc. Among them VSD continues to be the fastest growing application.

Voltage source inverter and current source inverter. A voltage fed inverter is one in which the DC source has small or negligible impedance. In other words, a voltage source inverter has a stiff voltage source at its input terminals. A current fed inverter (CFI) or current source inverter (CSI) is fed with adjustable current from a DC source of high impedance, i.e. from a stiff DC current source.

Voltage source inverters are generally classified into two types viz pulse width modulation and square wave. These inverters are introduced in early 1960’s during the introduction of force commutating techniques. The major disadvantage of this inverter is that the output voltage contains lower order harmonics for low or medium power applications. And lower order harmonics create a lot of distortion and are hard to eliminate. The type of driver has been largely superseded by recent development in pulse width modulation drives and there have been number of clear trends in the development of PWM concepts, strategies and methodology since 1970’s. In the mid of 1980’s a form of PWM called space vector modulation (SVM) was proposed which claimed to offer significant advantages over conventional and simple regular pulse width modulation in term of ease of application, maximum transfer ratio and in term of performance.

Recent developments in semiconductor material, technologies and power electronics have brought significant improvement in power electronics system. Hence different circuit configurations, namely multilevel inverters have become popular and considerable interested by researcher are given to them due to increased efficiency and performance.

Inverters play important role in the field of power electronics. The inverters in the power electronics domain denote a class of power conversion circuits which is required for converting from one source to other either from DC to AC and vice- versa depending upon the source given to the circuit.

These level voltages fed PMW inverters are recently showing the popularity for multi megawatt industrial drive applications. The main reason for this popularity is that the output voltage waveforms in multilevel inverters can be generated at low switching frequencies with high efficiency and low distortion and large voltage between the series drive sis easily shared. Space vector PWM techniques are one of the most popular techniques gained interest recently. This technique results in higher magnitude of the fundamental output available compared to sinusoidal PWM.

The organization of the paper is as follows: next section discusses the Lag Compensator followed by the discussion of its design procedure in the third section. In the fourth section simulation results are presented and in the last section presents the conclusion of the work.

II. HARMONICS IN ELECTRICAL SYSTEM

One of the biggest problems in the power quality aspects is the harmonic contents in the electrical system. Harmonics are the distortion of the normal electrical current waveform,generally transmitted by non linear loads. Example of nonlinear loads- switched mode power supplies,variable speed motors and drives, photocopiers, etc.

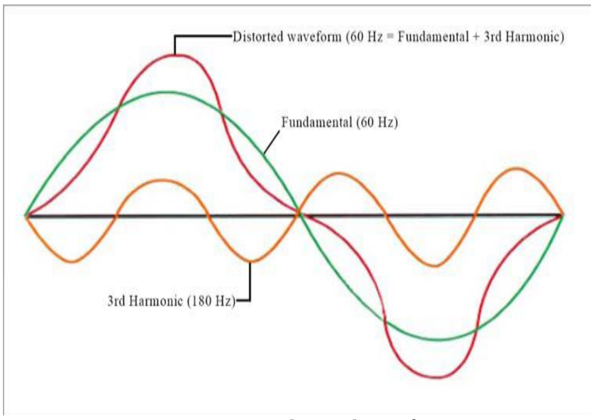

Fig. 1. Harmonics in electrical waveforms

Electronic harmonic currents generated by non linear loads increases heat losses and power bills of end users. These harmonics related losses reduces system efficiency, causes apparatus overheating, and power and air conditioning costs. As the number of harmonics producing loads have increased in the recent year, it has become necessary to address their influence during addition or changes to an installation. Harmonic currents can have significant impact on the electrical distribution system and the facilities they feed. Distortion travels back into the power source and can affect other equipment connected to the same source. Generally harmonics are divided into two types:1.voltage harmonics 2. Current harmonics.

Current harmonics are usually generated by harmonics contained in voltage supply and depends on the type of load such as resistive load, capacitive load and inductive load. Both harmonics can be generated either the source or load side.

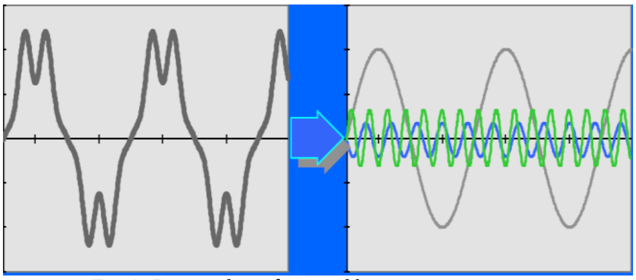

Fig. 2. Distorted wavform and harmonics component

III. Reduction of Harmonics in Inverter Output Voltage

There are several industrial applications which may allow a harmonic content of 5% of its fundamental component of input voltage . The harmonic content can be brought to a reasonable limit of 5 % by one of the methods, by inserting filters between the load and inverter. If there is a high frequency harmonics, these can be reduced by a low size filter. But for the attenuation of low frequency harmonics, size of filter components increases and it makes the filter bulky, costly, weighty and additionally sluggish transient response of the system .

A. Harmonic Filter:

High frequency harmonics can be reduced to a reasonable limit by using filters. The following are the normally used filters:

a. LC Filter

It consists of L and C component. The L offers a high impedance to harmonic voltage, higher the harmonic number, higher will be impedance and lower will magnitude of the harmonic at the output . The C offers a shunt path for the harmonic current .As the impedance of the Capacitor will decrease, increases frequency and it in turn increases the impedance of the inductor.

b. OTT Filter

It is used extremely in conjunction with parallel inverter . It performs three important functions . It provides a sine wave output thus leads elimination of harmonic content to the load. It provides good load regulation while at the same time maintaining a capacitive load to the inverter over a large range of load power factor.

c. Resonant Arm Filter

The output voltage of the inverter will have a certain harmonic content, however, an approximately sinusoidal output may be required. A sinusoidal output voltage can be realized by mean of a combined series parallel resonant filter circuit tuned to the fundamental of the output voltage. The sinusoidal output current driven by the sinusoidal output voltage will give rise to an AC component on the DC side of the inverter and therefore it will augment the ripple in the input current.

B. Harmonic Reduction By PWM:

In the case of single pulse width modulation, the pulse width is adjusted to reduce the harmonics. It has one of the disadvantages of additional commutation per cycle and this leads to more switching losses in the thyristor.

C. Harmonic Reduction By Transformer Connection

The harmonic content of output voltage can be reduced by the output voltage from two or more inverters, can be combined by mean of transformer. The essential condition of this scheme is that the output voltage waveform from inverter must be similar but phase shifted from each other.voltage . In this scheme, transformer have 1:1 turn ratio. It has disadvantage that it needs more number of inverters of transformer of similar rating.

D. Using Stepped Wave Inverter :

This method of reduction of harmonic is also known as stepped wave inverter, in which pulses of different widths and heights are added to produce a resultant stepped wave with reduced harmonic content. Two stepped wave inverters fed from a common DC supply . Both the transformers used have different turn ratio. The turn ratio from primary to secondary is assumed 3:1 for transformer 1 and transformer2. The inverter 1 is so gated that its output voltage is V_{01}. During 1^{st} half cycle, output voltage level is either zero or positive . During 2^{nd} half cycle, the output voltage would be either zero or negative . This output voltage waveform is named as two level modulation. The output voltage of inverter 2 is V_{02}. The waveform of V_{02} shows that the output voltage is positive , negative or zero during the 1^{st} half cycle, it is named three level modulation . By superimposing the outputs of both inverter the resultant output voltage from a series combination of inverter 1 and inverter 2 is obtained.

E. PWM Techniques:

The output voltage of an inverter can also be controlled by providing a control within the inverter itself. The most efficient methods of doing this is by pulse width modulation control used within an inverter. In this method a fixed DC input voltage is given to the inverter and a controlled AC output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as pulse width modulation control.

Different types of Pulse Width Modulation(PWM) are:

a. Single Pulse Width Modulation(SPWM)
b. Multiple Pulse Width Modulation(MPWM)
c. Sinusoidal Pulse Width Modulation(SPWM)

a. Single Pulse Width Modulation(SPWM)

In this modulation control method there is only one pulse per half cycle and the width of the pulse is varied to control the inverter output voltage.The gating signals are generated by comparing a rectangular reference signal of amplitude , E_r, with a triangular carrier wave of amplitude E_c. The ratio of E_r to E_c is the control variable and is defined as the amplitude modulation index.

b. Multiple Pulse Width Modulation (MPWM)

In this modulation method , the harmonic content can be reduced using several pulses in each half cycle of output voltage. By comparing a reference signal with a triangular carrier wave, the gating signals are generated for turning on or turning off of a thyristor.The Carrier frequency ,f_c, determines the number of pulses per half cycle , m, where the frequency of reference signal sets output frequency, f_o.The modulation index controls the output voltage.This type of modulation is known as Symmetrical Pulse Width Modulation.

c. Sinusoidal Pulse Width Modulation

In this method of modulation, several pulses per half cycle are used as in the case of MPWM. Instead of maintaining the width of all pulses the sames as in the case of MPWM, the width of each pulse is varied proportional to the amplitude of a sine wave evaluated at the center of same pulse.By comparing a sinusoidal reference signal with a triangular carrier wave of frequency , f_c , the gating signals are generated. The frequency of the reference signal , f_r , determines the inverter output frequency , f_o , and its peak amplitude ,E_r controls the modulation index and then in turn RMS output voltage.

Advantages of pulse width modulation techniques:

1.Without using additional components controlled output voltage can be obtained.
2.Within this method lower order harmonics are minimized along with output voltage control and higher order harmonics can be easily filtered thus minimizing the filtering equipment requirement.
3. Power factor of the system is good.
4.commutative ability of PWM inverters remains constant compared to variable DC link.
5.The amplitude of torque pulsation is minimized even at low speed.
6. A sophisticated pulse width modulation techniques eliminate lower order harmonics in the motor current, low speed torque pulsation and cogging effects.
7. The presence of constant DC supply permits the parallel operation of several independent pulse width modulation inverters on the same rectifier power supply.

F. Advance modulation techniques

a.Trapezoidal modulation:

By comparing a triangular carrier wave with a reference trapezoidal wave, switching instance to semiconductor devices are generated. This type of modulation increases the peak fundamental output voltage and but output voltage contains lower order harmonics.

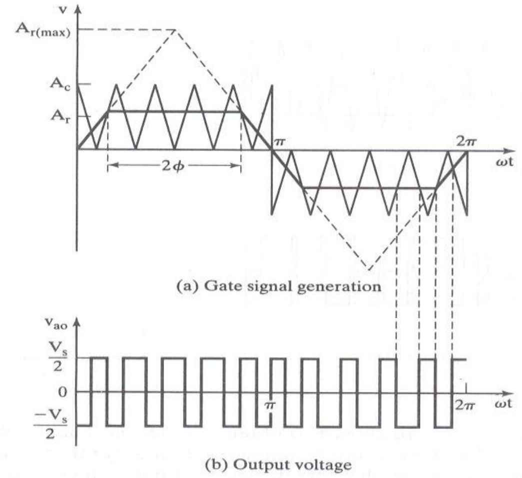

Fig. 3. Trapezoidal modulation

b.Staircase modulation:

In staircase PWM the modulated wave eliminates specific harmonics. In order to obtain the desired quality of output voltage ,the modulation frequency ratio and the number of steps are chosen. If the number of pulses isles than 15 per cycles this is optimized pulse width modulation.

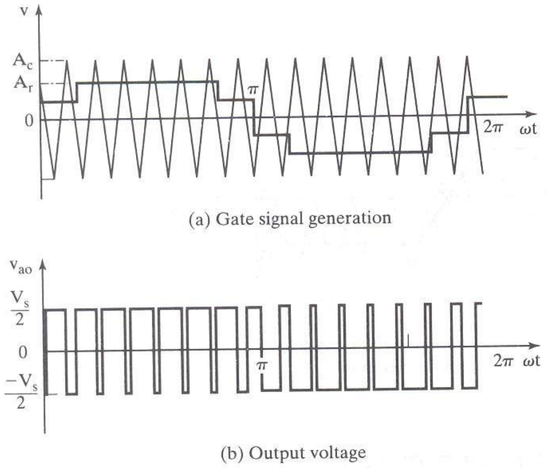

Fig. 4. Staircase modulation

c.Stepped modulation:

In this modulation technique the signal given is stepped wave. In order to control the magnitude of the fundamental components and to eliminate particular harmonics the wave is divided into specific intervals with a wave, with each interval being controlled individually.

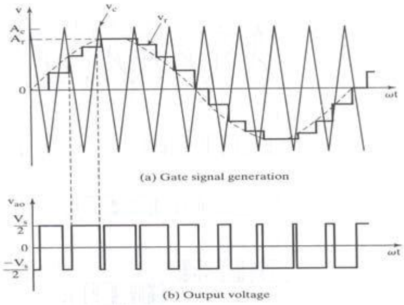

Fig. 5. Stepped modulation

d.Harmonic Injected Modulation:

In this modulation the signal is controlled by injecting harmonics to the sine wave. The result is that a flat tapped waveform and it reduces the amount of over modulation in the signal.

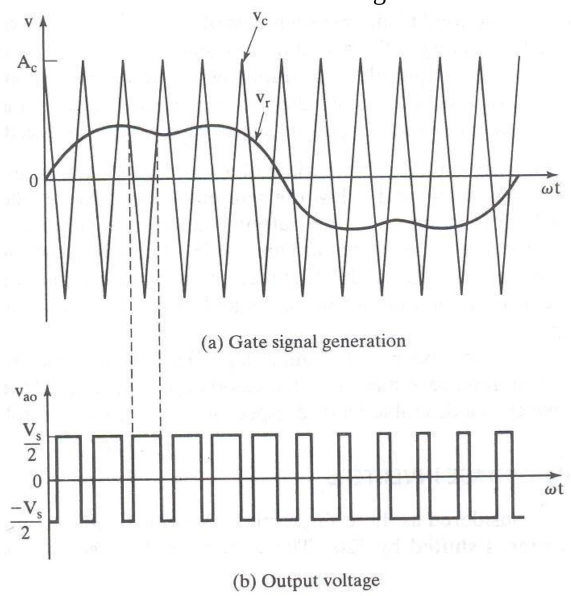

Fig. 6. Harmonic injected modulation

e.Delta modulation:

In this modulation a triangular wave is allowed to oscillate around a defined window above and below the reference wave.

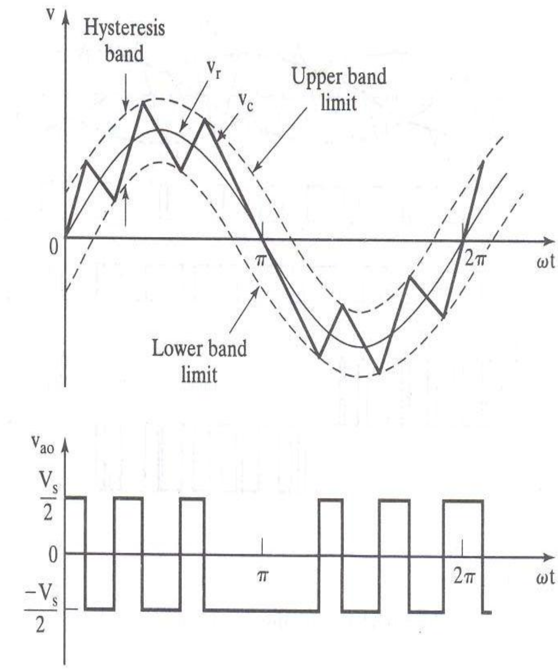

Fig. 7. Delta modulation

f.Space vector pulse width modulation:

This modulation is relatively new and commonly accepted popular technique in controlling motor drive.

The classical Space Vector modulation strategy, first proposed by Holtz and Van der Broeck, has become popular owing to its simplicity and good operating characteristics due to the generation of specific sequences of states of the inverter.

The topology of a three-leg voltage source inverter is shown in figure. Because of the constraint that the input lines must never be shorted and the output current must always be continuous a voltage source inverter can assume only eight distinct topologies.

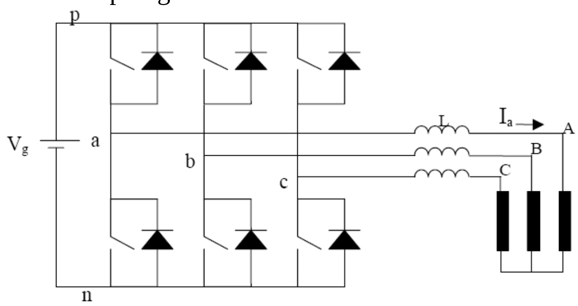

Fig. 8. Topology of three leg voltage source inverter

These topologies are shown. Six out of these eight topologies produce a nonzero output voltage and are known as non-zero switching states and the remaining two topologies produce zero output voltage and are known as zero switching states.

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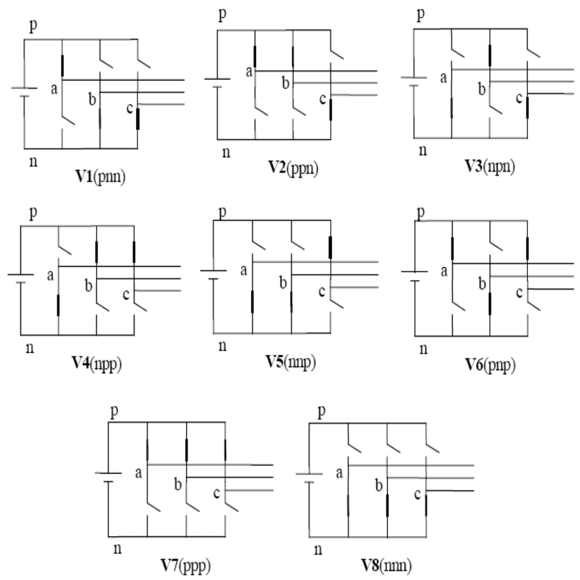


Fig. 9. Eight switching state topologies of voltage source inverter

The application of SVPWM to a variable speed electric drive is applied in and a switching sequence is proposed for a multilevel multiphase converter such that it minimizes the number of switching.

One of the major issues faced in PWM schemes is the reduction of harmonic content in the inverter voltage waveforms. As a result of intensive investigations in this area during the past three decades, several methods such as Newton-Raphson iteration methods, based on genetic algorithm have been proposed to achieve the optimal switching. The commonly used are selective harmonic elimination technique as the fundamental frequency, for which transcendental equations characterizing harmonics are solved by the Newton Raphson method to compute optimal switching angles.

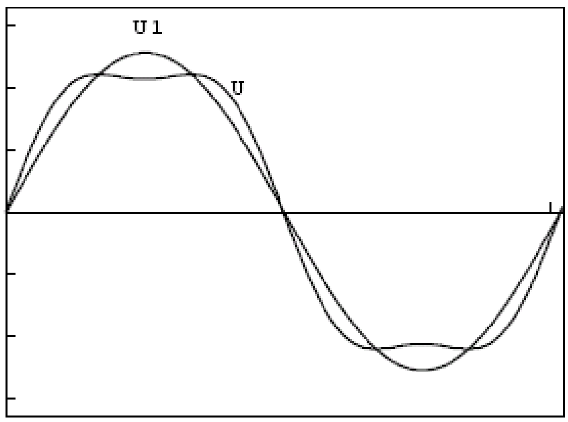


Fig. 10. Comparison of Sinusoidal PWM and Space Vector PWM Phase-to-center voltage by space vector PWM

1) In the fig above, U is the phase-to-center voltage containing the triple order harmonics that are generated by space vector PWM, and U1 is the sinusoidal reference voltage. But the triple order harmonics do not appear in the phase-to-phase voltage as well. This leads to the higher modulation index compared to the SPWM.

2) SPWM only reaches to 78 percent of square-wave operation, but the amplitude of maximum possible voltage is 90 percent of square-wave in the case of space vector PWM. The maximum phase-to-center voltage by sinusoidal and space vector PWM are respectively ;

$V_{max} = V_{dc}/2$: for Sinusoidal PWM
$V_{max} = V_{dc}/\sqrt{3}$
where, V_{dc} is DC-Link voltage: for Space Vector PWM. This means that Space Vector PWM can produce about 15 percent higher than Sinusoidal PWM in output voltage.

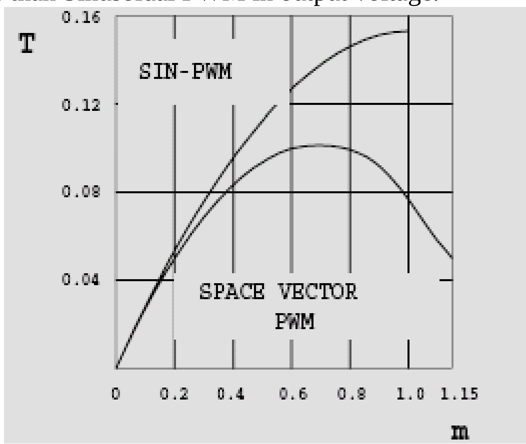
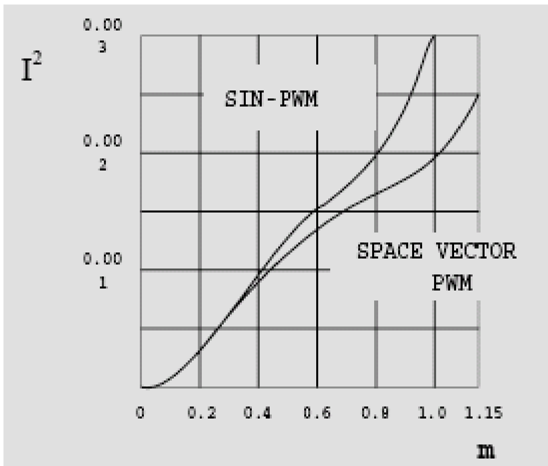


Fig. 11. Rms harmonics current



V. CONCLUSION

This paper presents harmonic elimination techniques at the output of inverter voltage. PWM techniques discussed here, which includes conventional and advanced methods. Advanced methods contain trapezoidal modulation,staircase modulation,stepped modulation,delta modulation,SVPWM. Comparison between SVPWM and sinusoidal PWM, it is concluded that space vector PWM is much popular PWM technique and possibly the best among the PWM techniques as it generates high voltage with low total harmonic distortion and works very well with Field oriented vector control schemes for motor control. Evolution of SVM overcomes the drawback of different PWM techniques. SVM has a finite number of switching states. SVM

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