A Review of Carrier Based Modulation Techniques

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Abstract: *A review of different carrier based pulse width modulation techniques is presented in this paper. These modulation techniques are used for switching the power electronic devices which are used in inverters and converters. A detailed explanation of pulse width modulation techniques with their principle of operation, advantages and disadvantages is described. The modulation technique which helps in reducing the total harmonic distortion is generally employed.*

Keywords: Review, Carrier based modulation, PWM, Total Harmonic Distortion (THD), Modulation Index

1. Introduction

Inverters are the electronic devices that convert DC power into AC power. So, they are very useful in remote or inaccessible areas where power is not always available. So, when there is need of power it can be utilized from the inverter. Inverters convert the incoming DC into AC and also step up the resulting AC to the needed voltage level with the help of a transformer. Pulse-width modulation (PWM) is one of the efficient methods of controlling the output of the inverters. It helps in achieving output of inverter which is closer to sinusoidal output. These techniques are used for switching and operating the semiconductor devices in inverters and controlled converters to produce output voltages and currents with higher qualities for different types of loads. The operation in the switched mode ensures that the efficiency of power conversion is high [1]. In order to obtain desired amplitude and frequency with the desired quality the switching electronic devices have to be controlled using modulation technique. The fundamental idea of the PWM technique is to compare a high frequency wave or signal known as the carrier signal to a signal of low frequency known as the reference modulating signal[4].PWM techniques can be either carrier-based or carrier-less. There are many types of carrier based modulation such as;
- Sinusoidal pulse width modulation (SPWM)
- Modified pulse width modulation (MPWM)
- Random pulse width modulation (RPWM)
- 3rd harmonic injection PWM
- Space vector modulation (SVM)

Pulse width modulation (PWM) is the first approach of modulation techniques which was developed in the mid of 60s by Kirnnich, Heinrick and Bowes. The quality of these techniques can be measured by the following factors:
- The amplitude of the fundamental component
- The harmonic content in the inverter output
- The switching losses,
- Controllability and Implementation.

2. The Modulation Techniques

2.1 Conventional Pulse Width Modulation (SPWM)

Carrier-based SPWM is the most popular and widely used PWM technique because of its simple implementation in both analog and digital realization [3]. In this method, there is only one pulse per half cycle and the width of the pulse is varied to control inverter output voltage. The gating signals are generated by comparing a rectangular reference signal of amplitude V_R with a triangular carrier wave of amplitude V_C. The fundamental frequency of output voltage is determined by the frequency of the reference signal. Pulse width can be varied from 0^0 to 180^0 by varying V_R from 0 to V_C. Ratio of V_R to V_C is the control variable and is defined as amplitude modulation index which is given as –

$$M = \frac{V_R}{V_C}$$

This modulation technique is the most popular as compared to other techniques as it has various advantages such as easy implementation, simple control, compatible with digital systems and total harmonic distortion is less. However it suffers from the drawback that when its THD is reduced by increasing the switching frequency it leads to the increase of switching losses.

2.2 Modified Pulse Width Modulation (MPWM)

The working principle of the Modified Pulse width modulation is based on the comparison between two low-frequency modulating signals with a triangular high frequency carrier. The first modulating signal is similar to the fundamental signal of the desired output voltage. The other modulating signal is also similar to the first signal but has a phase shift of 180 electrical degrees. The advantage of the MPWM over the conventional SPWM is in the location of the first harmonic. Where the SPWM is pushing back the harmonics towards the high frequencies by which the first significant sideband of the output voltage spectrum is located in the switching frequency sideband, However the MPWM is able to shift back the first significant harmonic to a frequency equal to twice of the switching frequency. This means that the THD of the MPWM is less than that of the SPWM with the same switching frequency, but the fundamental component is not too high. This method is easy to implement and control, but it has some disadvantages in high switching stresses on the semiconductor devices and also its effect of the harmonic content on the input side is high as well.

2.3 Random pulse width modulation (RPWM)

Random pulse width modulation technique is basically based on randomizing the frequency of the carrier signal in order to

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distribute the concentrated energy of the harmonic frequency of the inverter output voltage in a narrow high frequency band. The main purpose and advantage of this technique is to reduce the energy of the harmonics, which in turn will reduce the THD of the inverter output voltage. However, this action will also affect the energy of the fundamental frequency component, i.e. the amplitude of the fundamental frequency component will be reduced as well, which is the main disadvantage of this technique. Also it has a significant drawback, which is the rapid deterioration of quality of operation at low values of modulation index. Moreover, randomizing the carrier frequency adds an extra switching losses and extra stresses to the semiconductor devices which in turn lead to add more harmonics to the current signal in the input side.

2.4 3rd Harmonic injection PWM (3HPWM):

By injecting the 3rd harmonic to the three-phase sinusoidal modulating signals, the inverter fundamental frequency voltage can also be increased without causing over modulation. The modulating signal is composed of the fundamental component and the third harmonic component, making the signal somewhat flattened on the top. As a result, the peak fundamental component can be higher than the peak triangular carrier wave which boosts the fundamental voltage. The injected third harmonic component will not increase the harmonic distortion in the output voltage. Although it appears in each of the inverter terminal voltages, the third-order harmonic voltage does not exist in the line to line voltage. This is because the line to line voltage is given by the relation $V_{ab}=V_{an} - V_{bn}$, where the third-order harmonics in V_{an} and V_{bn} are of zero sequence with the same magnitude and phase displacement and thus cancel each other. The main disadvantage of this technique is that there is no defined procedure for determining the proper amount of the added third harmonic component.

2.5 Space vector modulation (SVM)

Space vector PWM (SVPWM) is a digital modulating technique because its control strategies are implemented in digital systems. The purpose of this technique is to produce PWM load line voltages which are in average equal to given (or reference) load line voltages[4]. Space vector pulse width modulation (SVPWM) is an optimum pulse width modulation technique for an inverter used in a variable frequency drive applications. It is computationally rigorous and hence limits the inverter switching frequency.

Space vector PWM has the advantages of lower harmonics and a higher modulation index in addition to the features of complete digital implementation by a single chip microprocessor, because of it flexibility of manipulation; SVPWM has increasing application in power converters and motor control [5]. Space vector modulation for three-leg VSI is based on the representation of the three phase quantities as vectors in a two-dimensional (α, β) plane. To make the output current to be always continuous, and also the input lines must never be shorted, the voltage source inverter can assume only eight distinct switching topologies. The desired

three phase voltages at the output of the inverter could be represented by an equivalent vector U rotating in the counter clock wise direction. The tip of the space vector follows a circular locus. There are four types of SVM
1) The right aligned sequence,
2) The symmetric sequence which has the lowest THD because of the symmetry and the switching losses are almost similar to the first one,
3) The alternating zero vector sequence, where the switching losses for this scheme are to be ideally low as compared to those of the previous two schemes and the THD is significantly higher due to the existence of the harmonics at half of the sampling frequency.

The converter input voltage can be represented by the space vector U. The space vector U once can take one of the eight different positions resulting from the permissible combinations of the conduction states. Vectors U_1 to U_6 have fixed modulus of ⅔ ×U_{dc} and are phase-shifted by π/3. They are called active vectors and refer to the conduction states of the power semiconductor switches during which the respective phases are supplying the DC-link load. While the three upper or three lower power semiconductor switches are conducting simultaneously, the supply line is short-circuited. These states are described by two zero vectors U_0 and U_7. The zero vectors are located in the origin of coordinates and they are represented by the two concentric points. The converter input PWM voltage space vector would change its position every π/3inside the hexagon if the six active conduction states were successively forced in the rectifier. The optional position of the reference vector U* inside the sector can be reached by providing the symmetrical control pulses represented by the following switching sequence: U0-U1-U2-U7-U2-U1-U0. In case when the reference vector U* is moving throughout the first sector. In the other sectors two next adjacent vectors should be considered.. The Total Harmonic Distortion ratio of the line current and voltage are equal THD$_I$ = 1.6% and THD$_V$ = 26.7% respectively [15]. For the linear modulation the maximal length of the reference vector U* is equal to U*$_{max}$ = $U_{dc}/ \sqrt{3}$. The space vector modulation corresponds to the sinusoidal modulation with the additional zero sequence signals.

3. Conclusion

This paper has presented an analysis of the various state of art of modulation techniques. An investigation is carried out on the most important modulation techniques. All of the investigated techniques have advantages and disadvantages except the wavelet modulation which have been recently invented. It has been found that this technique is met with all measuring factors that are used to calibrate the performance of any other modulation techniques:
1) The amplitude of the fundamental component is high,
2) The harmonic content in the inverter output is low,
3) The effect of harmonics on the source is low,
4) The switching losses are low,
5) Controllability is easy,
6) Implantation is simple.

On the other hand, all other techniques have shortcoming in at least one of the aforementioned factors. That is in turn will reduce the efficiency of that technique. The three phase wavelet modulated WM inverter has shown significant

capabilities in terms of the quality of the output voltages and currents. It provided output voltages and currents with low harmonic content along with high magnitudes of the fundamental frequency component of the output voltage. In addition, the performance comparison of the WM and all the other modulation techniques revealed that the new WM inverter can out-perform all of them under same operating conditions.

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