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A Comparison on Power Electronic Inverter Topologies

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Abstract:

This paper focuses on performances of different inverter topologies. Inverters are used in a large number of power applications. The function of an inverter is to convert DC power to AC; these are referred to as Voltage Source Inverters (VSI). VSI are divided up into three categories: Pulse-width Modulated Inverters, and Square-wave Inverters. The PWM inverters are classified in to Single PWM inverter, Sinusoidal PWM inverters, Space Vector PWM inverters and Third Harmonic Injection Technique. Pulse-width modulation inverters take in a constant dc voltage. Diode-rectifiers are used to rectify the line voltage, and the inverter must control the magnitude and the frequency of the ac output voltages. To do this the inverter uses pulse-width modulation using its switches. Square-wave inverters have their input connected to a controlled dc voltage in order to control the magnitude of the output ac voltage. The inverter only controls the frequency of the output where the input voltage is controlled the magnitude. The output ac voltage has a waveform similar to a square wave which is where the inverter got its name.

1.Introduction

Power Electronics is a fastest growing area in electrical machinery where the technology is associated with the adroit conversion control and conditioning of the electric power by static means from its available input form into the electrical output form in a desired manner. A power electronic inverter is a device that converts electrical energy from DC to AC. Ideally inverter output should with no harmonics and its magnitude and frequency should be variable and controlled. Different inverter topologies we have in general are

- Square wave inverters
- Pulse width modulated inverters
    - Single PWM inverter
    - Sinusoidal PWM inverter
    - Third harmonic injection technique based inverters
    - Space Vector PWM inverters

Generally an inverter performance is measured in terms of Distortion factor and T.H.D.

2.Square Wave Inverters

Square wave inverters are very simple functionally as well as cost point of view when compared to other topologies.

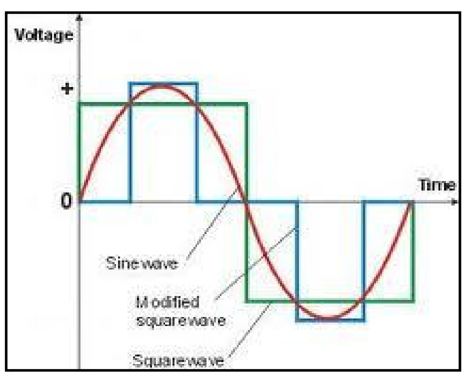
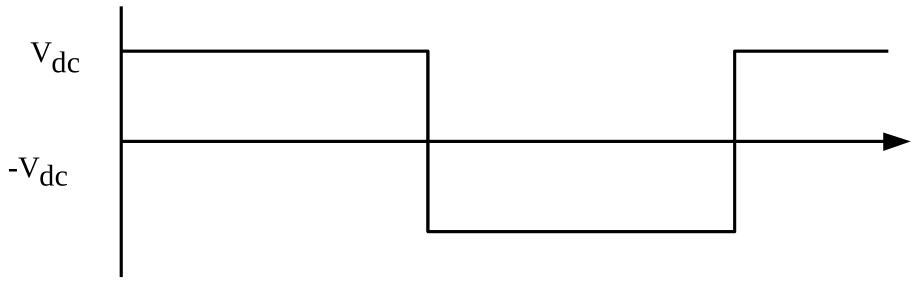


Figure 1

3.Inverter Output



Square wave inverters when analyzed in terms of Fourier series, we can infer that the harmonic content is very high. The harmonics start from third harmonic. Hence filter size is very big thereby also responsible for increase of cost. Also in order to control the magnitude variable source is required which is usually difficult to implement. Another possibility is to use two stage conversions which is a disadvantage when viewed in loss point of view. Frequency of the output can be obtained as desired by controlling duty cycle. In square wave inverters, maximum output voltage is achievable. However there in NO control in harmonics and output voltage magnitude. The harmonics are always at three, five, seven etc times the fundamental frequency. Hence the cut-off frequency of the low pass filter is somewhat fixed. The filter size is dictated by the VA ratings of the inverter. To reduce filter size, the PWM switching scheme can be utilized. In this technique, the harmonics are “pushed” to higher frequencies. Thus the cut-off frequency of the filter is increased. Hence the filter components (I.e. L and C) sizes are reduced. The trade off for this flexibility is complexity in the switching waveforms. Limited degree of harmonics control is possible.

4.PWM Inverters

The disadvantages are overcome in Pulse width modulation technique due to increased number of switching in a cycle. The output obtained when analyzed has its harmonics starting from factor representing frequency modulation index. Due to increased switching the energy from lower order harmonics is pushed to higher order harmonics. When compared to square wave inverters PWM inverters has increased total harmonic distortion. But as the order of first harmonic as pretty high when filter of small size which is very small when compared to filter of square wave inverter can be employed.

In PWM inverters both the frequency and magnitude are controlled using duty cycle and magnitude of control or reference wave respectively.

But the DC bus utilization is poor. If it is required to increase torque of the machine, for example, it is necessarily required to increase amplitude modulating index. But the problem is if the amplitude modulation index is increased beyond 1, the behavior of pulse width modulated inverter approaches square wave inverter. Hence the performance is limited to bus utilization which is poor.

The following PWM techniques are used for controlling the output ac rms voltage and frequency in an inverter:

- Single-Pulse-Width-Modulation.
- Sinusoidal-Pulse-Width-Modulation(SPWM)
- Space vector- pulse- width- modulation

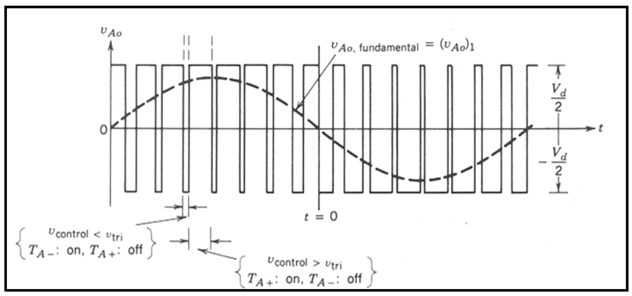


Figure 2: Pulse-width Modulation (PWM)

5.Single-Pulse-Width-Modulation

In single pulse width modulation control, there is only one pulse per half cycle and the output rms voltage is changed by varying the width of the pulse. The gating signals and output voltages of single pulse-width modulation are shown in fig 4(b). The gating signals are generated by comparing the rectangular control signal of amplitude V_c with triangular carrier signal V_{car}. The frequency of the control signal determines the fundamental frequency of ac output voltage.

The amplitude modulation index is defined as:

$$m_a = \frac{V_c}{V_{car}}$$

The rms ac output voltage

$$V_o = \left\{ \frac{2}{T} \int_{\left(\frac{T}{4} - \frac{t_{on}}{2}\right)}^{\left(\frac{T}{4} + \frac{t_{on}}{2}\right)} V_s^2 \, dt \right\}^{1/2} = V_s \sqrt{\frac{2 t_{on}}{T}} = V_s \sqrt{2\delta}$$

where $\delta = \text{duty ratio} = \frac{t_{on}}{T}$

By varying the control signal amplitude V_c from 0 to V_{car} the pulse width ton can be modified from 0 secs to T/2 secs and the rms output voltage V_o from 0 to V_s. In multiple PWM control, instead of having a single pulse per half cycle, there will be multiple number of pulses per half cycle, all of them being of equal width.

6.Sinusoidal-Pulse-Width-Modulation (SPWM)

In sinusoidal pulse width modulation there are multiple pulses per half-cycle and the width of the each pulse is varied with respect to the sine wave magnitude. The gating signals and output voltage of SPWM are unipolar switching. In this scheme, the switches in the two legs of the full-bridge inverter are not switched simultaneously, as in the bi-polar scheme.

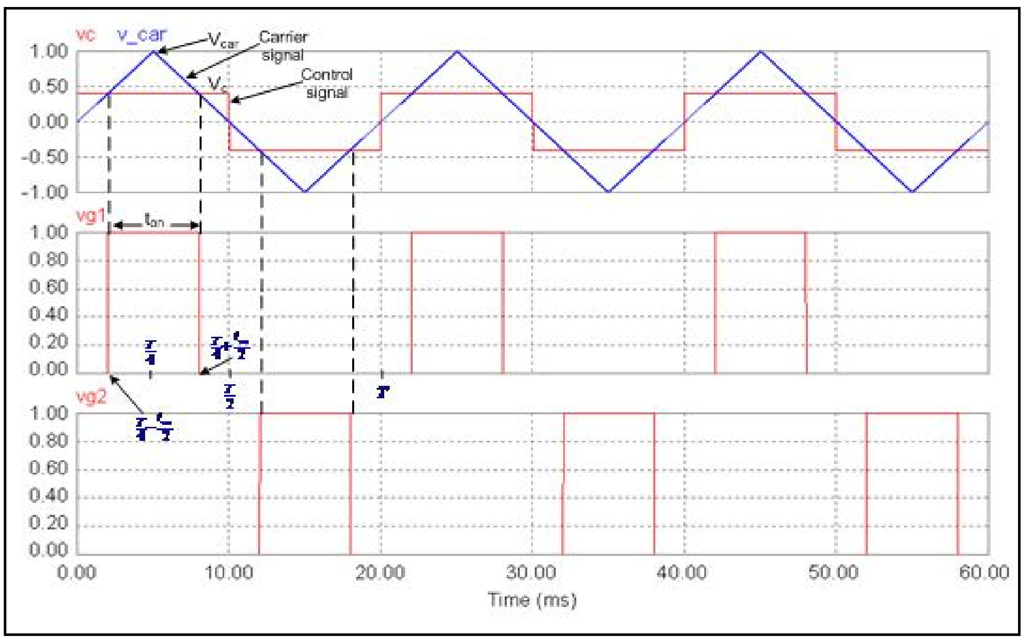


Figure 3

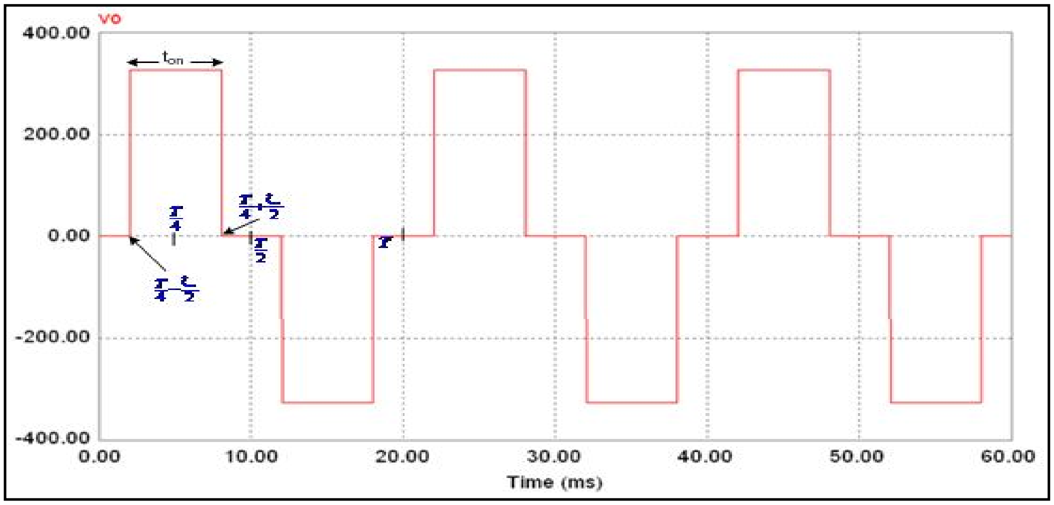


Figure 4

Fig 4(b) Gating signals and output voltage of Single pulse-width modulation

In this unipolar scheme the legs A and B of the full-bridge inverter are controlled separately by comparing carrier triangular wave v_{car} with control sinusoidal signal v_c and $-v_c$ respectively. This SPWM is generally used in industrial applications. The number of pulses per half-cycle depends upon the ratio of the frequency of carrier signal (f_c) to the modulating sinusoidal signal. The frequency of control signal or the modulating signal sets the inverter output frequency (f_o) and the peak magnitude of control signal controls the modulation index m_a which in turn controls the rms output voltage. The area of each pulse corresponds approximately to the area under the sine wave between the adjacent midpoints of off periods on the gating signals. If t_{on} is the width of nth pulse, the rms output voltage can be determined by:

$$V_o = V_s \left(\sum_{n=1}^{2p} \frac{2t_{on}}{T} \right)^{1/2}$$

The amplitude modulation index is defined as:

$$m_a = \frac{\hat{V}_c}{\hat{V}_{car}}$$

where, $\hat{V}_c$ = peak magnitude of control signal (modulating sine wave)

$\hat{V}_{car}$ = peak magnitude of carrier signal (triangular signal)

The frequency modulation ratio is defined as:

$$m_f = \frac{f_{car}}{f_c}$$

where, $\hat{f}_c$ = frequency of control signal (sine signal)

$\hat{f}_{car}$ = frequency of carrier signal (triangular signal)

7.Space Vector Pulse Width Modulation

Sinusoidal PWM technique though is a solution has disadvantages like poor D.C bus utilization and difficult to implement digitally. When compared with other modulating techniques, Space Vector Pulse Width Modulation relatively provides less harmonic content, effective utilization of dc bus, and complete digital implementation by a single chip microprocessor. A simple technique based on volt-second that is normally used with three-phase inverter motor- drive. Due to the advantages SVM has increasing applications in power converters and motor control. 2-level inverter is the first model developed using this technique. With the demand for the inverter to increase its power handling capability, 3-level inverter are developed with advantages improved power quality and voltage sharing between series devices when compared to 2-level. A space vector PWM technique is developed based on the combination of space vectors from dual inverters feeding the induction motor from both ends (open-end winding without neutral point). A total of 64 voltage space vector combinations are available for PWM voltage control of the inverter fed machine with open-end winding. A space phasor based PWM scheme is proposed with minimum number of switching in a cycle per inverter coupled with equal number of switching for each invert**er.**

8.Applications

- Uninterruptible Power Supply (UPS),
- Adjustable Speed Drives (ASD) for ac motors,
- Electronic frequency changer circuits used in induction heating, welding etc.,
- HVDC transmission at lower power levels

- Renewable Energy such as solar, fuel cell to AC conversion
- Electronic Ballast and Compact Fluorescent lamps
- Active Filters for power quality improvement
- Custom power devices: DSTACTCOM, DVR, UPQC,
- FACTS: STATCOM, SSSC, UPFC, etc.

9.Third Harmonic Injection Technique

This problem is solved by reducing peak of control wave which does not effect the response though the modulation index value increases beyond one. This is achieved by introducing a harmonic in the reference wave in such a way that it does not effect the quality of the output. . In this method four phase shifted carrier triangular signals are compared with one modulating signal to produce switching PWM pulses. The reference modulating signal is not sinusoidal but consists of both fundamental component and third harmonic component.

The sinusoidal reference signal can be injected by a third harmonic with a magnitude equal to 25% of the fundamental. This method employs two straight lines that are greater than or less than the peak value of the reference signal to control the shoot-through duty ratio. Inverter operates in shoot-through whenever the triangular carrier signal is higher than the positive straight line or lower than the negative straight line. The frequency of the modulating signal is taken as 50Hz.

The Third Harmonic Injection is a modification over the SPWM Technique wherein a suitable amount of third harmonic signal is added to the sinusoidal modulating signal of fundamental frequency. Then the resultant waveform (modified modulating waveform) is compared with the high frequency triangular carrier waveform. The comparator output is used for controlling the inverter switches exactly as in SPWM inverter. In other words, if a fundamental frequency signal having peak magnitude slightly higher than the peak magnitude of the carrier signal, is mixed with suitable amount of 3rd harmonic it may result in a modified signal of peak magnitude not exceeding that of the carrier signal which is suitable for three phase inverters. Thus the peak of the modulating signal remains lower than the peak of carrier signal and still the fundamental component of output voltage has a magnitude higher than what a SPWM can output by varying the modulation index. The maximum amplitude of fundamental in the reference and in the output voltages can be increased by the addition of third harmonic signal. Usually as we employ three phase, hence we inject third harmonic.

Using this technique the dc bus utilization can be improved by 15.5%.

10.Applications Of Inverters

Conversion of electric power from DC type energy sources to AC type load

- Battery
- Photovoltaic cell (Solar cell)
- Fuel cell

As a part of composite converter

- AC to DC to AC frequency converter (for AC motor drive)
- AC to DC to AC constant voltage constant frequency converter (for uninterruptable power supplies)
- AC to DC to AC Converters for induction heating
- AC to DC to AC to DC switching power supplies

11.Conclusion

Any modulation scheme can be used to create variable frequency and variable voltage wave forms. But sine PWM, being an analog technique is a bit complex to implement with digital system which is practiced usually. In contrast, SVPWM can be implemented digitally and has few more advantages like low harmonic content and higher modulation index. Because of its flexibility of manipulation, SVM has increasing applications in power converters and motor control.

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