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Performance Comparison of High Frequency Single Phase PWM Inverters Using PSpice

Samidha Garg[1]

S.N.Singh[2]

Abstract

This paper presents PSpice simulation of sinusoidal PWM inverters and their performance comparison . An HPWM inverter has been included with its analysis and simulation results. Also BPWM, UPWM and HPWM inverters have been shown by using PSpice simulation package and the performance of all the three inverters has been computed and compared; their switching losses by calculating their individual power ratios at different conditions. The conclusion drawn is that BPWM inverter has a poorer performance as compared to the other two methods and the remaining methods i.e. HPWM and UPWM have almost an equally good performance. In case of soft switching, HPWM has a better performance than UPWM.

[1]*Sr. Lecturer, NIET, Gr. Noida*

[2]*Director, IIMT College, Gr. Noida*

Introduction

As power semiconductor converters are very widely used nowadays for industrial applications, like industrial drives, u.p.s. etc., dc to ac converters are called inverters. The function of an inverter is to convert the input dc voltage into output ac voltage. The output of an ideal inverter is sinusoidal ac but in practical cases we can't get pure sinusoidal output. The output voltage of an inverter could be fixed or variable at fixed or variable frequency. A variable output voltage can be obtained by varying the input dc voltage and maintaining the inverter parameters constant.

On the other hand, the dc input voltage is fixed and it is not controllable. A variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by pulse width modulation control within the inverter itself. The inverter gain may be defined as the ratio of ac output voltage to the input dc voltage.

The output voltage waveforms of an ideal inverter should be sinusoidal. However, the waveforms of a practical inverter are not sinusoidal and contain certain harmonics. For low and medium power applications, square wave voltage may be acceptable and for high power application, low distorted sinusoidal waveforms are required. With the availability of high speed power semiconductor devices, the harmonic contents of output voltage can be reduced significantly by switching techniques.

Inverters are very widely used in industrial applications like variable ac motor drives, induction heating, uninterruptible power supplies etc. The input of the inverter may be a battery, fuel cell, solar cell or wind power generator.

Sinusoidal PWM Inverters

In these inverters, the input dc voltage is essentially constant in magnitude, such as in the circuit Fig 1, where diode rectifier is used to rectify the line voltage. Therefore, the inverter must control the magnitude and frequency of the output ac voltage. This is achieved by PWM of the inverter switches and hence such inverters are called PWM inverters. There are various schemes to pulse width, modulate the inverter switches in order to shape the output ac voltage to be as close to sinusoidal as possible. Out of these various PWM schemes, a scheme called the sinusoidal PWM will be discussed in detail. The sinusoidal PWM inverters may be broadly classified as in three phase and single phase inverters.

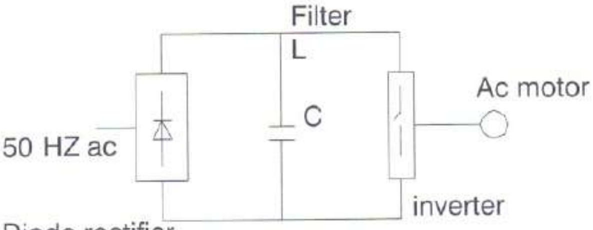
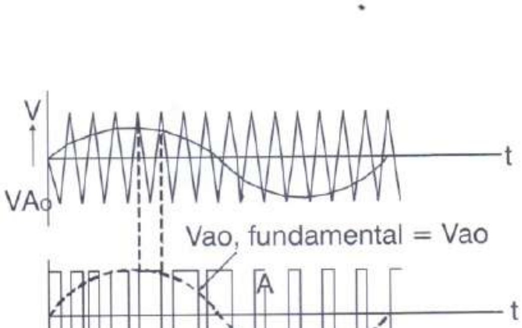


Fig1

IIa- PWM Inverters

In inverter circuit the PWM is a bit more complex. We would like the inverter output to be sinusoidal with magnitude and frequency controllable. In order to produce a sinusoidal output voltage waveform at the desired frequency, a sinusoidal control signal at the desired frequency is compared with a triangular waveform, as shown in fig 2.



The frequency of the triangular waveform establishes the inverter switching frequency and

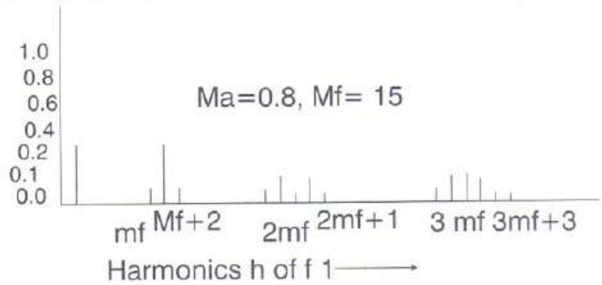


Fig 2 Pulse width modulation

is generally kept constant along with the amplitude Vtria. Before discussing the PWM behavior, it is necessary to define a few terms. The triangular waveform Vtria in fig 2.2a is at a switching frequency with which the inverter switches are switched (is also called the carrier frequency). The control signal vacant is used to modulate the switch duty ratio and has a frequency f1 which is the desired fundamental frequency of the inverter voltage output (f1 is also called the modulating frequency), the inverter output voltage will not be a perfect sine wave and will contain voltage components at harmonic frequency of f1. The amplitude modulation ratio ma is defined as

$m_a = V_{cont}/V_{tri}$

where, Vcont is the peak amplitude of the control signal. The amplitude Vtria of the triangular signal is generally kept constant. The frequency modulation ratio mf is defined as

$mf = f_s/f_1$

IIB-Selection of switching frequency

Now we discuss the selection of the switching frequency and the frequency modulation ratio mf. Because of the relative ease in filtering harmonic voltage at as high a switching frequency as possible except for one significant drawback, switching losses in the inverter switches increase proportionally with ht switching frequency. Therefore, in most applications the switching frequency is selected to be either less than 6KHZ or greater than 20KHZ to be above the audible range. If the optimum switching frequency (based on the overall system performance) burns out to be somewhere in the 6-2kHZ range then the disadvantages of increasing it to 20KHZ are often outweighed by the advantage of audible noise with fs of 20KHz or greater[6].

Therefore, in 50-60HZ type applications, such a motor drives 9 where the fundamental frequency of the inverter output required to be as high as 200HZ) the frequency modulation ratio mf may be 9 or even less for switching frequencies of less than 2KHZ. On the other hand mf will be larger than 100 for switching frequencies higher than 20KHZ.

The desirable relationships between the triangular waveform signal and the control voltage signal are dictated by how large mf is. Here it is assumed that the amplitude modulation ratio ma is less than 1.

IIC-Over modulation (ma>1)

The desirable features of a sinusoidal PWM are in the liner range. One of the drawbacks is that the maximum available amplitude of the fundamental frequency component is not as high as we wish. To further increase the amplitude of the fundamental frequency component in the output voltage, ma is increased beyond 1.0 resulting in what is called over modulation. Over modulation causes the output voltage to contain many more harmonics in the side bands as compared with the linear range (ma≤1.0), as shown in figure3.

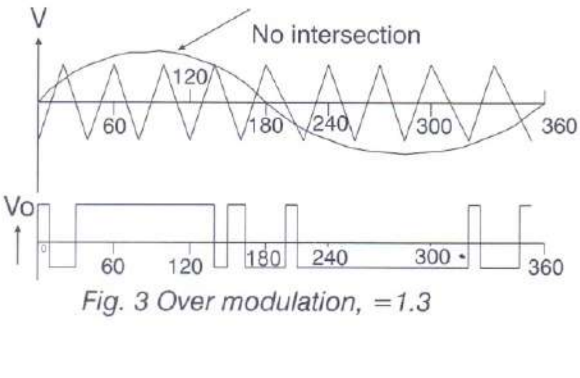
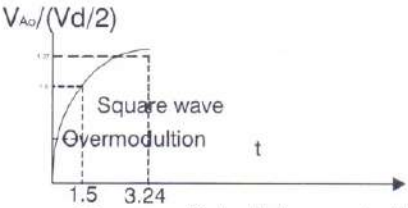


Fig. 3 Over modulation, =1.3



Mf = 15 *Fig4a Voltage control by varying Ma*

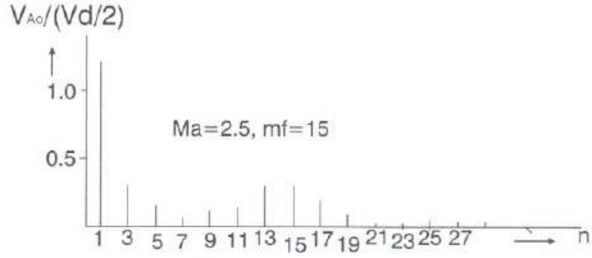


Fig4b Harmonics due to over modulation

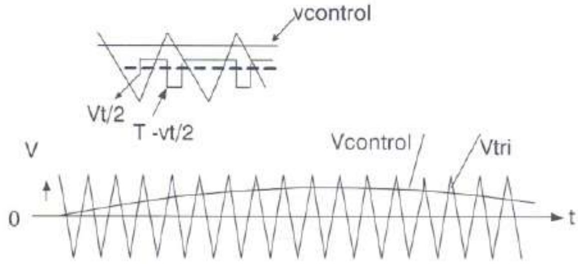


Fig4C Sinusoidal PWM

Bipolar PWM

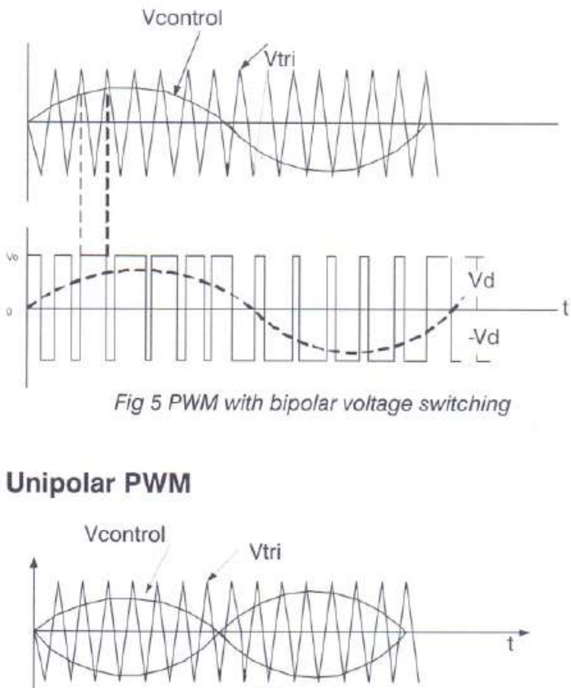
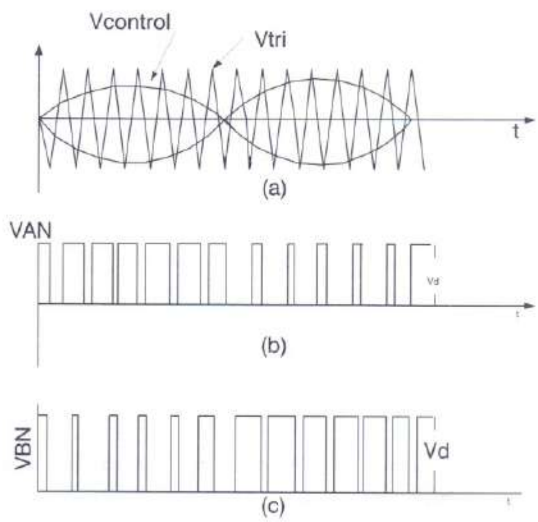


Fig 5 PWM with bipolar voltage switching

Unipolar PWM



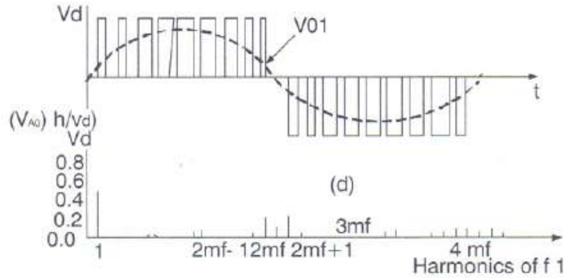


Fig 6 PWM with unipolar switching

HYBRID PULSE WIDTH MODULATION INVERTER

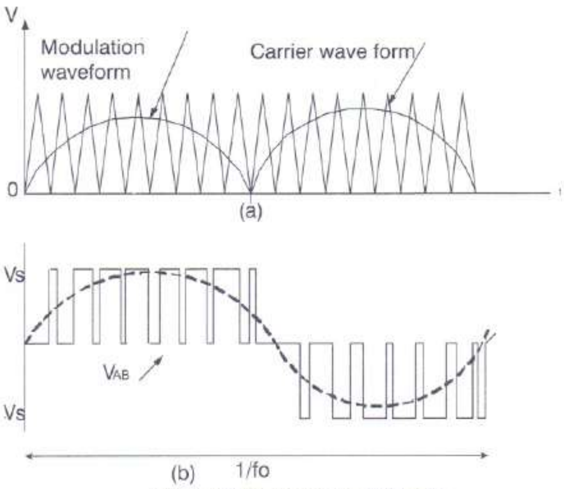


Fig 7 (a) Modulation and Carrier Waveform (b) V_{AB} For HPWM

IID-Filtering of harmonics in the inverter output voltage

The harmonics in the output of the inverter should be filtered out to get sinusoidal output voltage. An LC filter can be used to filter out the harmonics. One of the advantages of PWM inverters is that the harmonics are shifted to higher frequencies; hence it is easy to filter them. As the frequency of the harmonics is higher, the size of the filter components can still be reduced significantly.

III- Simulation process

In power electronics, several types of analysis need to be carried out. For each type of analysis there is an appropriate degree of simulation detail in which circuit components and the controller should be represented. It is important to note that at each step as may be desirable to verify simulation results by a hardware prototype in the laboratory.

SPICE:

The abbreviation SPICE stands for Simulation Program with Integrated Circuit Emphasis. It was developed at the University of California, Berkely. There are several commercial versions of SPICE that operate on personal computers under several popular operating systems. One commercial version of SPICE is called PSpice.

In PSpice. many features are added to make it a multilevel simulator where the controllers can be represented by their behavior models, that is by their input-output behavior, without resorting to a device-level simulation. There is an option for entering the input data by drawing the circuit schematic. In addition to its use in the industry, PSpice has also become very popular in teaching institutions to understand core subjects like power electronic and communication engineering.

Square wave inverter: A square wave inverter for output frequency of 50HZ has been simulated on PSpice. IRF 840 MOSFET has been used as switches input dc voltage is 220V. The output voltage output current, input current and the frequency spectrum of the output voltage are shown on the computer prin touts.

Bipolar PWM: An operational amplifier has been used as PWM generator and IRF 840 MOSFETs are used as the switches.The switching frequency of the inverter is 850HZ and the output frequency is 50HZ and hence mf= 17. The peak of the triangular waveform is 6.625V, peak of the sinusoidal waveform is 5.3V and hence ma 0.8. In the simulation bipolar voltage is given to the switch because it is easy to simulate and it does not need any digital circuit components like NOT GATE and AND GATE

In addition to that, the bipolar nature switching requires no blanking time and other gate drive circuits to drive the switch. The disadvantage of this type of switching is that magnitude of the output voltage will be somewhat less than the unipolar switching signal case due to reverse voltage appearing during the off period of the switch.

Unipolar PWM: The unipolar PWM is simulated for m=0.8 and mf=18 (effective mf) on PSpice. The simulation circuit, output voltage waveform, input current and frequency spectrum of the output voltage are shown in the computer printouts. Similar components as in the bipolar PWM has used for simulation

HPWM Inverter: The modified PWM inverter has simulated for ma = 0.8 and mf = 18. The slow speed switches are replaced with thyristors and simulated the circuit for resistive load. The results of this circuit are also similar to those of the earlier MOSFET inverter. As the thyristors are connected in series with MOSFET for resistive load the current in the thyristors will be zero when the MOSFET in the circuit is off. The output: Input current and frequency spectrum of the output voltage are shown on the computer printouts.

IV- Comparison of harmonics

In the square wave inverter, all odd harmonics starting from 3rd order are present. It is very difficult to filter out the lower order harmonics. Hence this inverter is not recommended for drives applications. The square wave inverter is unavoidable. For resistive loads like lighting the harmonics will not have any impact, hence it is recommendable. In bipolar PWM the lower order harmonics are shifted to around switching frequency and its multiples.

The harmonics around the he switching frequency are high magnitude hence they can be filtered. When compared with the UPWM, this type of inverter is not recommendable for drive applications. In UPWM lower order harmonics are eliminated and shifted to around switching frequency and its multiples. As the frequency of harmonics is higher, they can be filtered out easily. Hence by putting a filter we can get the sinusoidal output. This type of inverter is recommendable for drive applications.

But in SPWM inverters it is somewhat high even though it is not having any serious impact on the load because these harmonics occur at switching frequency and its multiples.

Comparison of switching losses

In the square wave inverter the switches are operated at the output frequency hence the switching losses are very low. We can't compare them with the pwm inverters. In bipolar PWM inverter all four switches will be changing states at every switching, hence switching losses will be maximum. It is also not recommendable in the point of switching losses. In UPWM inverters only two switches are changing state at all switching except at the 180 and 360. Hence the switching losses will be much lower than the bipolar pwm. It is also recommendable in the point of switching losses. In the hpwm only switches are operated at high frequency and remaining two switches are operated at low output frequency, hence the switch losses will be lesser than the upwm the slow speed switches are replaced with low conduction loss switches. In that case therefore it is more preferable than the upwm.

Switches losses of the bpwm, upwm, hpwm are compared as follow. These three inverters are simulated for the same switching frequency and ma calculated the output fundamental component's power by using the relation where P_o1 is the fundamental power component of the inverter output V_{o1} is the fundamental component of output voltage of inverter (r.m.s. value) i_{o1} is the fundamental component of output current of inverter (r.m.s. value) The input power is calculated by using the relation $P_d = V_d I_d(avg)$ where P_d is the dc fundamental power V_d is the input dc voltage Id is the average value of dc current fundamental power ratio of the given inverter is calculated as the ratio of fundamental output power to input power.

Power ratio calculations

To compare the power ratios of different inverters these inverters are simulated for the same condition like ma, mf, load power factor etc.

	ma	mf	Vrms	Irms	Ro	Id(avg)	Power ratio
UPWM	0.8	18 (eff)	205.448	4.11	50	2.949	95.36%
BPWM	0.8	17	288.974	5.78	50	5.777	96.36%
HPWM	0.8	18	203.56	4.071	50	2.926	945%

For resistive load

	ma	mf	Vo1	io1	I0	Ro	Id	Power ratio
UPWM	0.8	18 (eff)	230.3	3.171	116 mh	50Ω	1.20	995.6%
BPWM	0.8	17	227.02	3.668	116 mh	50 Ω	1.217	92.4%
HPWM	0.8	18	231	116 mh	116 mh	50 Ω	1.23	94%

For inductive load Lo=116mh and Ro=50Ω

BPWM inverter For calculation of power ratio bpwm inverter has simulated with the following details

V_d=300V, m_a= 0.8, m_f= 17, Load inductance= 50mh , Load resistance= 50Ω

The following readings are taken from the simulation results

	m_a	m_f	Vo_1	io_1	l_o	R_o	I_d	Power ratio
UPWM	0.8	18	227.084	4.346	116mh	50Ω	1.209	95.6%
BPWM	0.8	17	227.02	3.668	116mh	50 Ω	1.217	92.4%
HPWM	0.8	18	231	116mh	116mh	50 Ω	1.23	94%

For inductive Load L_o=50mh, R_o= 50Ω

where V_{rms} is the rms value of output voltage

I_{rms} is the rms values of current

V_d is the input dc voltage

I_d is the average value of input dc current

By comparing the power ratio values in the above table it is to be noted that the hpwm inverter is having poor power ratio than other two.

The hpwm and upwm have approximately the same power ratios. Hence bpwm is not recommended for practical applications.

In the hpwm inverter all switching losses occur in the two pwm operated switches so the heat dissipation in that switches will increase hence it is also not recommended. In addition to that, operating frequency of the pwm switches in hpwm is double that of the upwm. But in case of soft switching, the hpwm inverter has advantages over the upwm inverter because the switching losses in soft switch inverter are nearly zero hence there is no switching loss dissipation in the switches.

By using the low power loss devices in place of slow operating switches, we can reduce the conduction losses. Hence in case of soft switching it is recommended and for low switching frequencies also it is recommended because the overall switching losses will be decreased significantly. If we replace the slow speed switches with the (GTO), the readings in the above tables are taken at steady state conditions.

V- Inverter selection for a specific application

The selection of inverter for specific application depends upon the load requirement. For example for restive loads, there will be no problem due to harmonics and hence square wave converter can be selected. For inductive loads like induction motors. The harmonics should not present particularity at low frequencies. For that application, the harmonics should eliminated.

To eliminate the harmonics the output filter is needed. If the frequency of the harmonics is low the filter size will be increased. In the PWM inverters the frequency of the harmonics will be shifted to high frequency i.e. at the switching frequency and its multiples. Hence the filter size required to eliminate the harmonics will be reduced at cost of inverter switching losses. Therefore for drive application output filter is essential.

VI- Conclusions

In this paper, different types of sinusoidal PWM inverters are simulated on the PSpice Microsoft package. In the square wave inverters we have all lower order harmonics (odd) i.e. $3^{rd,}$ 5^{th} etc. For drive applications these harmonics should not be there. To avoid these harmonics filters are needed.

For lower frequency harmonics, the size of the filter components required is large. Hence it is not recommended to face lower frequency harmonics. In addition to that, to control the drive motors variable frequency and variable magnitude supply are needed. It is easier to get variable frequency and variable magnitude voltage from the sinusoidal pwm inverters than from square wave inverters.

The main disadvantage of sinusoidal pwm inverters is the high switching losses. In the square wave inverter the switches are operated at the low ouput frequency hence the switching losses are little. But in sinusoidal pwm inverters, the switches are operated at high switching frequency i.e. at the carrier frequency hence the switching losses will be more as compared to a square wave inverter.

In the sinusoidal pwm inverters the harmonics occur around the switching frequency and its multiples. As the switching frequency increases the harmonics frequency will also increase. So at the cost of switching losses were pushing the harmonics to higher frequency.By this simulation we observed the harmonics spectrum of each inverter hpwm and upwm have same harmonics spectrum and same power ratio but hpwm has less power ratio and poor harmonic spectrum.

Hence for any kind of application upwm is more suitable than the hpwm and hpwm because the operating frequency of the switches in hpwm is double the operating frequency of upwm and all switch losses occur in high frequency switches only. Heat dissipation in the high frequency switches will be higher.

In sinusoidal pwm inverters however, the switches are operated at high switching frequency i.e. at the carrier frequency hence the switching losses will be more as compared to the square wave inverter. In this way we simulated the three phase sinusoidal pwm inverter single phase square wave inverter, UPWM and HPWM with filters. In case of soft switching hpwm inverter is advantageous over the upwm. We replace slow speed switches with low conduction loss switches like GTO, it is better to use the hpwm over upwm.

Appendix

A three phase inverter has been simulated for $m_a=0.8$ and $m_f=15$ and results of the simulation are given here. The power ratios of BPWM, UPWM, HPWM with filter was calculated which are as follows:

	m_a	m_f	V_{o1}	i_{o1}	I_0	Ro	I_d	Power ratio
BPWM	0.8	17	235.85	4.503	50	50	2037	84%
UPWM	0.8	18	234.4	4.475	50	50	1.815	92%
HPWM	0.8	18	232.25	4.431	50	50	1.8	91%

Power rations with filters at L_o = 50mh, R_o = 50ohm

CALCULATION OF THD

$THD = \sqrt{(V_{ORMS}2-V_{o1}2)}/V_{O1}$

BPWM At m_a = 0.8 and m_f=17 L_o= 50mh R_o= 50ohm L_f= 116mh and C_f= 80uF

THD = 15.5oo

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A neural network-based CAD model is developed for the design of a rectangular patch antenna, which is robust both from the angle of time of computation and accuracy. A distinct advantage of neuro computing is that, after proper training, a neural network completely bypasses the repeated use of complex iterative processes for new cases presented to it. The single network structure can predict the results for patch dimensions provided that the values of ?r, f1, f2 and h are in the domain of training values.

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