STUDY OF SINGLE PHASE VOLTAGE SOURCE INVERTER WITH SPWM AND PPWM TECHNIQUES

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Abstract
This paper deals with performance analysis of single phase Voltage Source Inverter (VSI) by using different switching techniques like Sine Pulse Width Modulation and Programmed Pulse Width Modulation or Selective Harmonic Elimination technique. The main focus of this paper is to observe the Total Harmonic Distortion of the waveform for output voltage of single phase VSI by using simulation tool for Sine Pulse Width Modulation and Programmed Pulse Width Modulation. . The simulation tool used for this purpose is Matlab Simulink. After simulation a comparative study is done to interpret the conclusions.
Index Terms: Voltage Source Inverter, Sine Pulse Width Modulation and Programmed Pulse Width Modulation.

I. INTRODUCTION

The square wave voltage-source inverter finds application in many low cost ac motor drives, uninterruptible power supply units and in circuits utilizing electrical resonance between an inductor and a capacitor like induction heating units and electronic ballasts for fluorescent lamps. The operation this inverter involves the operating the switches in each leg of the inverter in a complementary manner. There are various approaches used to carry out operation of switches like Single pulse width modulation, multiple pulse width modulation, Sine Pulse Width Modulation (SPWM) and Programmed Pulse Width Modulation (PPWM) [1]. In the SPWM switching techniques there are pulses of constant amplitude with a different duty cycle for each period. The most common method to generate this signal is to compare a sinusoidal with a triangular waveform. The SHE technique or PPWM method is used to eliminate specific harmonics in output voltage waveform. The purpose of this paper is to simulate the square wave single phase voltage source inverter based on switching methods mentioned earlier and to carry out harmonic analysis of output voltage waveform. The paper is organized in four sections. Section I introduces the paper , section II gives brief theory of single phase voltage source inverter, section III demonstrates simulations results and the paper is concluded in section IV.

II. SINGLE PHASE VOLTAGE SOURCE INVERTER [1]

Inverter in Power-Electronics refers to a class of power conversion circuits that operate from a dc voltage source or
a dc current source and convert it into a symmetric ac voltage or current. It does reverse of what ac-to-dc 'converter' does. The input to the inverter is a direct dc source or dc source derived from an ac source. For example, the primary source of input power may be utility ac voltage supply that is converted to dc by an ac - dc rectifier with filter capacitor and then 'inverted' back to ac using an inverter. Here, the final ac output may be of a different frequency and magnitude than the input ac of the utility supply. If the input dc is a voltage source, the inverter is called a Voltage Source Inverter (VSI). The simplest dc voltage source for a VSI may be a battery bank or a solar photovoltaic cells stack. An ac voltage supply, after rectification into dc can also serve as a dc voltage source. A voltage source is called stiff, if

the source voltage magnitude does not depend on load connected to it. All voltage source inverters assume stiff voltage supply at the input. Output of voltage waveforms of ideal inverters should be sinusoidal. However practical inverter waveforms are non-sinusoidal and contain certain harmonics. For low and medium power applications square wave or quasi square wave voltages are acceptable. A variable voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. On the other hand, if the dc input voltage is fixed then variable output voltage can be obtained by varying the gain of the inverter. This can be accomplished by Pulse Width Modulation-PWM control within the inverter. PWM means the width of the square pulse in positive and negative halves can be adjusted according to the rms of the output required. The inverter gain may be defined as ratio of the ac output (rms) voltage to dc input voltage. In Square Wave PWM technique the output ac rms voltage is fixed when input dc voltage is fixed.

A. Circuit diagram

Fig 1. Shows the power circuit diagram for single phase bridge voltage source inverter. In this four switches (in 2 legs) are used to generate the ac waveform at the output. Any semiconductor switch like IGBT, MOSFET or BJT can be used. Four switches are sufficient for resistive load because load current i_o is in phase with output voltage v_o. However this is not true in case of RL load where the i_o is not in phase with v_o and diodes connected in anti-parallel with switch will allow the conduction of the current when the main switch is turned off. These diodes are called as Feedback Diodes since the energy is fed back to the dc source.

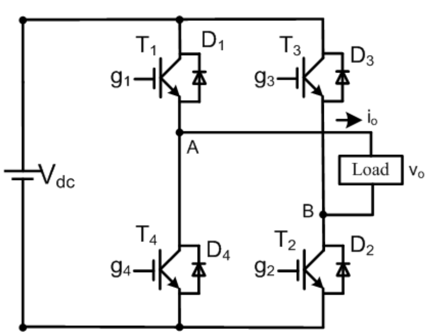


Fig. 1 Single phase voltage source inverter.

III. SINE PULSE WIDTH MODULATION [1]

In sinusoidal pulse width modulation, several pulses per half cycle are used. Instead of maintaining the width of all the pulses the same, the width of each pulse is varied proportionally to the amplitude of a sine wave. Sinusoidal pulse width modulation technique is the most advanced control technique for Pulse Width Modulation. Sinusoidal pulse width modulation technique is adopted in order to reduce the harmonic content of output voltage and to obtain an electrical near sinusoidal output voltage. Near sinusoidal output voltage is very desirable especially in high power applications. In SPWM technique, the carrier signal is a high frequency triangular wave and it is compared with the reference sinusoidal signal. By comparing, the gating pulses are generated which are then applied to the switching devices.

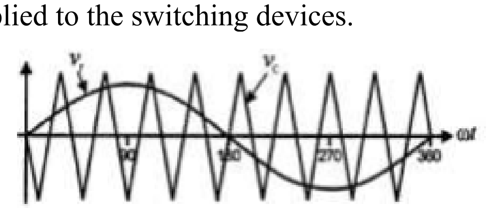


Fig. 2 Concept of SPWM

Where Vc is the high frequency carrier wave. Vr is the reference sinusoidal signal.

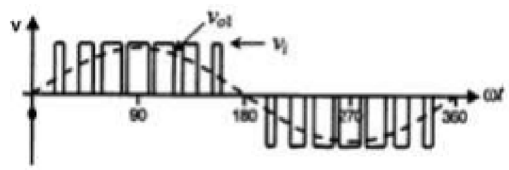


Fig. 3 Pulses obtained by SPWM

Vo1 is the fundamental component of output voltage of frequency 50Hz. Vi is the instantaneous output voltage. The advantages of SPWM are , the output voltage obtained is near sinusoidal and the harmonic content in the output voltage is reduced.

IVSHE or Programmed Pulse Width Modulation [1-5]

A. PRINCIPLE OF HARMONIC ELIMINATION TECHNIQUE

The two-state output waveform of the single-phase inverter is approached from an analytical point of view and a generalized method for theoretically eliminating any number of harmonics is developed. The basic square wave is chopped a number of times and a fixed relationship between the number of chops and possible number of harmonics that can be eliminated is derived. Figure 4 shows a generalized output waveform with N chops per half-cycle. It is assumed that the periodic waveform has half-wave symmetry and unit amplitude.

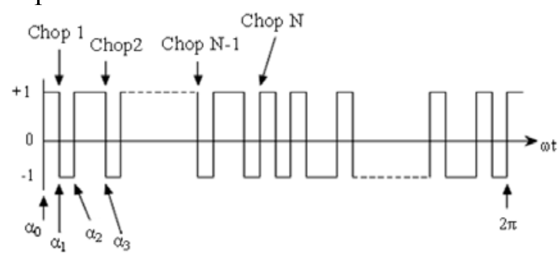


Fig.4 Generalized output waveform of single phase inverter.

B. Determination of switching angles

The general expressions to eliminate an arbitrary *N − 1 (N − 1 = 3, 5, 7, . . .)* number of harmonics are given by

$$-\sum_{k=1}^{N}(-1)^k\cos(n\alpha_k)=\frac{\pi}{4}\ \frac{v_{o1}}{v_i}$$

$$-\sum_{k=1}^{N}(-1)^k\cos(n\alpha_k)=0 \quad \text{for } n=3,5,\ldots,2N-1$$

Eq. (1)

The Equations obtained for N=5. Harmonics to be eliminated are 3rd, 5th, 7th and 9th. By using equation (1) following harmonic equations are obtained

$2\cos\alpha 1 - 2\cos\alpha 2 + 2\cos\alpha 3 - 2\cos\alpha 4 + 2\cos\alpha 5 = \pi\,(v01/vi)\,4$ …Eq. (2)

$2\cos 3\alpha 1 - 2\cos 3\alpha 2 + 2\cos 3\alpha 3 - 2\cos 3\alpha 4 + 2\cos 3\alpha 5 = 0$ …Eq. (3)

$2\cos 5\alpha 1 - 2\cos 5\alpha 2 + 2\cos 5\alpha 3 - 2\cos 5\alpha 4 + 2\cos 5\alpha 5 = 0$ …Eq. (4)

$2\cos 7\alpha 1 - 2\cos 7\alpha 2 + 2\cos 7\alpha 3 - 2\cos 7\alpha 4 + 2\cos 7\alpha 5 = 0$ …Eq. (5)

$2\cos 9\alpha 1 - 2\cos 9\alpha 2 + 2\cos 9\alpha 3 - 92\cos 9\alpha 4 + 2\cos 9\alpha 5 = 0$ …Eq. (6)

C. Procedure

i. Any N harmonics can be eliminated by solving the N+1 equations obtained from setting equation (6) to zero for any value of N.
ii. Number of harmonic equations to be solved (N) = Number of harmonics to be eliminated (N) + 1.
iii. The additional equation is for the fundamental component of the waveform.
iv. In order to eliminate harmonic, it is desired to find values of switching angles.
v. By considering any value of N harmonic equations are formed and a matrix f(α) is formed. The Jacobian J(α) of f(α) is also formed.
vi. In order to find correct values of notching angles, the switching angle characteristics for various values of modulation indices are plotted.
vii. For finding values of α Newton's iterative method is used.
viii. The solution is obtained by writing code in Matlab.

D. Newton's iterative method for calculating values of switching angles

i. The values of initial angles *αinit* are substituted in the matrices f(α) & J(α).
ii. The value of Δα is found by , Δα = Inv{J(α)}* f(α) ,using Gauss elimination procedure.
iii. The values of Δα obtained are compared with the tolerance error value.
iv. If the value of Δα is lesser than the error tolerance, then exit the loop.
v. If not, the new values of α are found by α(new) = α(old) – Δα.
vi. The new values of α are substituted in the matrices J(α) and f(α).

Then the loop is repeated from step (ii).
Initial angles are calculated by using

$\alpha(j) = 180° * j/(2N+1)$, j= 1to N

E. Estimation of switching angles For N=5 and for modulation index equal to 0.85

The switching angles are found by plotting trajectories of switching angles for various values of modulation index i.e. ratio *v01/vi.* This is accomplished by writing Matlab code for N-R method. Following steps are involved to complete this task.

i. The initial switching angles are
α1= 16.4, **α2=** 32.7, **α3=** 49.1, **α4=** 65.5, **α5=** 81.8
ii. Matrix **f(α)**

$$f(\alpha)=\begin{pmatrix} 2\cos\alpha 1 - 2\cos\alpha 2 + 2\cos\alpha 3 - 2\cos\alpha 4 + 2\cos\alpha 5 - \pi(v01/vi)4 \\ 2\cos 3\alpha 1 - 2\cos 3\alpha 2 + 2\cos 3\alpha 3 - 2\cos 3\alpha 4 + 2\cos 3\alpha 5 \\ 2\cos 5\alpha 1 - 2\cos 5\alpha 2 + 2\cos 5\alpha 3 - 2\cos 5\alpha 4 + 2\cos 5\alpha 5 \\ 2\cos 7\alpha 1 - 2\cos 7\alpha 2 + 2\cos 7\alpha 3 - 2\cos 7\alpha 4 + 2\cos 7\alpha 5 \\ 2\cos 9\alpha 1 - 2\cos 9\alpha 2 + 2\cos 9\alpha 3 - 92\cos 9\alpha 4 + 2\cos 9\alpha 5 \end{pmatrix}$$

iii. Jacobian Matrix **J(α)**

$$J(\alpha) = \begin{pmatrix} -2\sin\alpha_1 & 2\sin\alpha_2 & -2\sin\alpha_3 & 2\sin\alpha_4 & -2\sin\alpha_5 \\ -6\sin 3\alpha_1 & 6\sin 3\alpha_2 & -6\sin 3\alpha_3 & 6\sin 3\alpha_4 & -6\sin 3\alpha_5 \\ -10\sin 5\alpha_1 & 10\sin 5\alpha_2 & -10\sin 5\alpha_3 & 10\sin 5\alpha_4 & -10\sin 5\alpha_5 \\ -14\sin 7\alpha_1 & 14\sin 7\alpha_2 & -14\sin 7\alpha_3 & 14\sin 7\alpha_4 & -14\sin 9\alpha_5 \\ -18\sin 9\alpha_1 & 18\sin 9\alpha_2 & -18\sin 9\alpha_3 & 18\sin 7\alpha_4 & -18\sin 9\alpha_5 \end{pmatrix}$$

The algorithm has been implemented using Matlab code and a graph between switching angle and modulation index is plotted as shown in figure 5.

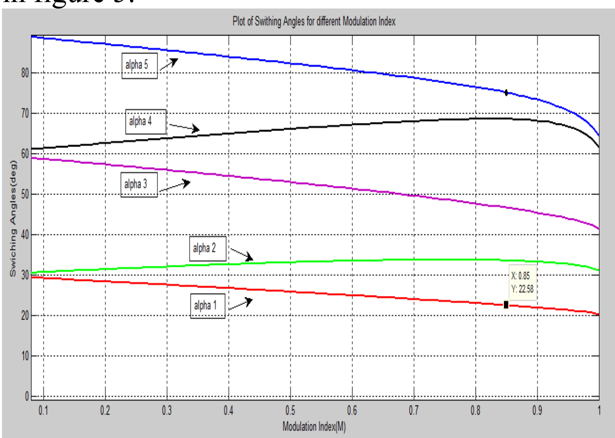


Fig.5 Switching Angle Trajectories obtained for N=5.

For modulation index value m=0.85 the values of switching angles obtained are

$\alpha_1 = 22.58°$, $\alpha_2 = 33.6°$, $\alpha_3 = 46.64°$, $\alpha_4 = 68.5°$, $\alpha_5 = 75.1°$.

IV. SIMULATION RESULTS

A. Matlab Simulink Simulation Parameters

Table 1 shows parameters used for simulation.

Table 1 Inverter Parameters

Input DC Voltage	100 V
Load Resistance (R)	100 ohm
Load Inductance	1e-3
Solver	Ode 45
Simulation Time	0.5 sec

B. Simulation of 1 -phase inverter with Sine PWM

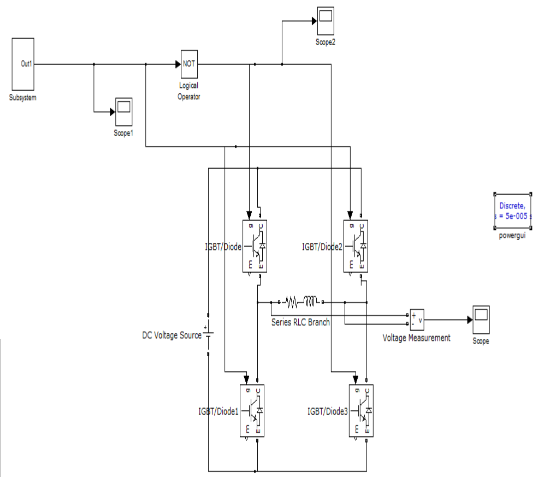


Fig. 6 Simulation model of single phase inverter with SPWM.

C. Harmonic profile for SPWM

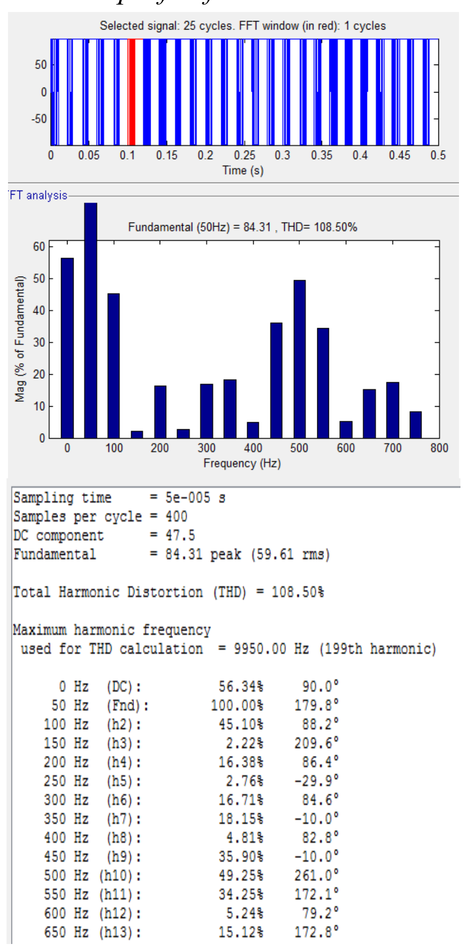


Fig. 7 Harmonic profile of Simulation model of single phase H-bridge inverter with SPWM

Total harmonic distortion is 108.50 % with 3rd, 5th, 7th and 9th harmonics 2.22%, 2.76%, 18.15% and 35.90% respectively.

D. Simulation of 1 -phase inverter with Selective harmonic Elimination (SHE)

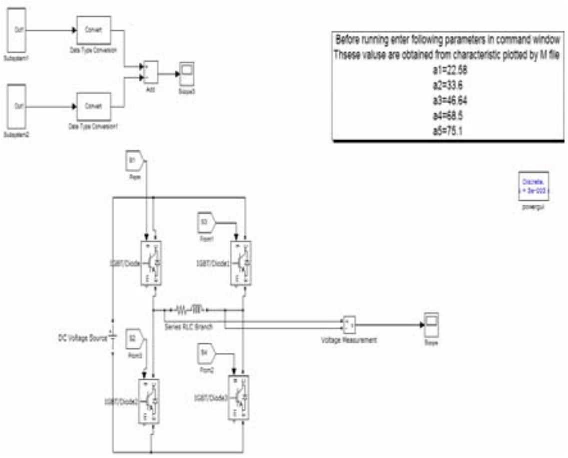
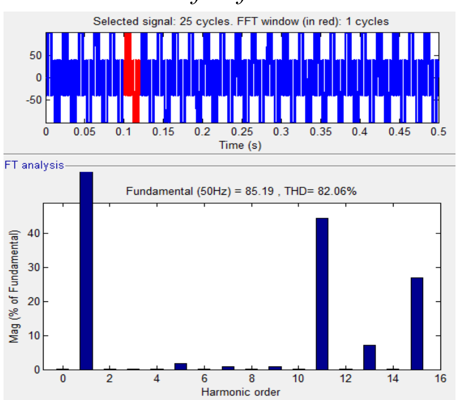


Fig. 8 Simulation model of single phase H-bridge inverter with SHE

E. Harmonic Profile for SHE

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Sampling time      = 5e-005 s
Samples per cycle = 400
DC component       = 1.993e-007
Fundamental        = 85.19 peak (60.24 rms)

Total Harmonic Distortion (THD) = 82.06%

Maximum harmonic frequency
 used for THD calculation  = 9950.00 Hz (199th harmonic)

    0 Hz  (DC):        0.00%    270.0°
   50 Hz  (Fnd):     100.00%     -0.7°
  100 Hz  (h2):        0.00%     88.3°
  150 Hz  (h3):        0.23%    -26.9°
  200 Hz  (h4):        0.00%     84.7°
  250 Hz  (h5):        1.71%    176.3°
  300 Hz  (h6):        0.00%     81.9°
  350 Hz  (h7):        0.87%    160.1°
  400 Hz  (h8):        0.00%     86.8°
  450 Hz  (h9):        0.83%    -38.4°
  500 Hz (h10):        0.00%     82.3°
  550 Hz (h11):       44.66%    171.4°
  600 Hz (h12):        0.00%    260.0°
  650 Hz (h13):        7.21%    -12.4°
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Fig. 9 Harmonic profile of Simulation model of single phase inverter with SHE.

Total harmonic distortion is 85.19 % with 3rd, 5th, 7th and 9th harmonics 0.23%, 1.71%, 0.87% and 0.83% respectively.

V. CONCLUSION

In this paper a simple and effective, minimization technique to solve the selective harmonic elimination using computed PWM control method for single phase voltage source inverters has been discussed. By solving the harmonic equations, the values of notch angles are obtained, which control the switching instants of the PWM wave. The PWM wave generated by the computed PWM technique takes less time when compared to the sine triangular comparison method. They do not involve any 'trial and error' procedures and the PWM pulse can triggered accurately at the desired values of the notch angles. The comparison between two techniques shows that the proposed method successfully eliminates 3rd, 5th, 7th and 9th harmonic components along with dc and even harmonics.

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