

## Comparison of PWM Techniques and Selective Harmonic Elimination for 3-Level Inverter

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### ABSTRACT

In this paper comparison of Selective Harmonic Elimination (SHE) method with different Pulse Width Modulation (PWM) technique which are used as gate pulse for firing the IGBT's. Higher order harmonics are easily eliminated by selecting a proper tuned value filters but lower order harmonics such as 3rd, 5th, 7th, and 9th are not easily eliminated. This paper includes Newton- Rapson method with random initial guess is used for SHE reduction and shows where the solution can exit by solving transcendental non linear equations. With the use of this method lower order harmonics as well as Total Harmonic Distortion (THD) will get reduce. In this paper a cascaded H-bridge Multilevel Inverter using MATLAB/Simulink blocks is presented.

**Keywords**-Flexible AC Transmission System, Multilevel Inverter, Power Electronics, Selective Harmonic Elimination, SPWM-Sinusoidal Pulse Width Modulation

### I. INTRODUCTION

Multilevel Inverter is most popular power electronics converters and is widely used in many industrial applications, where the requirement is medium voltage and high power applications. These are widely used in chemical, oil, and liquefied natural gas plants, water plants, marine propulsion, power generation, energy transmission, and power-quality devices, FACTS Devices [1-3]. Here, Cascaded H-bridge converter topology is used and particularly useful for renewable energy and DSTATCOM applications [4-5], [9]. While in comparison with 1 two-level voltage source inverters, multilevel inverters have several advantages. The main advantage is that of its stepwise output voltage. This advantage results in higher power quality, lower switching losses, higher voltage capability, it has low distortion, and low dv/dt and can operate with a lower switching frequency. With several number of dc voltages as inputs desired output can be obtained from multilevel inverter. By increasing the number of levels the output voltage and current waveform approaches to the sinusoidal waveform. Different topologies, control strategies and modulation techniques used for multilevel inverters have been presented in [6-7].

The generalized formulation of Selective Harmonic Elimination of multilevel inverter is presented in literature recently. SHE involves nonlinear equations which can be solved by different methods like Newton Rapson, genetic algorithm, particle swarm optimization, bee algorithm and bacterial foraging. This paper

involves solving of nonlinear equations by using Newton-Rapson method and MATLAB/Simulink.

### II. REVIEW OF GENERALIZED SHE FOR MULTILEVEL INVERTER

The A multilevel cascade inverter consists a number of H-bridge cells that are connected in series per phase, and each module needs separate DC source for generation of voltage levels at the output of inverter.

$$V_{out} = \begin{cases} +V_{dc} & \text{In}_1, \text{In}_4 \text{ ON} \\ 0 & \text{In}_1, \text{In}_3 \text{ ON} \dots (1) \\ -V_{dc} & \text{In}_2, \text{In}_3 \text{ ON} \end{cases}$$

The switching inputs shown as  $S_i$ ,  $i=1$  to 4 in the Fig. 1 allows obtaining output voltage as per (1). The H-bridge cells are serially connected over AC outputs to obtain expanded phase voltage levels. Cascade Multilevel Inverter (CMLI) is one of the most important topology.

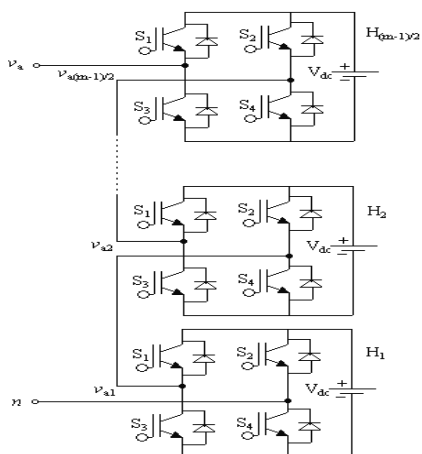


Fig.1 Cascaded H-Bridge Multilevel Inverter

As compared to diode-clamped and flying capacitors it requires least number of components. The minimum number of levels and the voltage rating of the active devices (IGBTs, GTOs, power MOSFETs, etc.) are inversely proportional to each other. A higher voltage rating of the devices will require minimum number of levels and vice versa. The cascaded multilevel inverter consists of a number of H-bridge inverter units which require separate dc source for each unit and is connected in cascade as shown in Fig. 1. The output voltage levels as seen from Fig. 2.

$$m = 2s + 1 \dots\dots (2)$$

$$\begin{aligned} \text{Switching devices} &= 2(m-1) \\ \text{DC Bus capacitors} &= (m-1)/2 \dots\dots (3) \end{aligned}$$

Where 's' is the number of bridges, 'm' is the number of levels. The Fourier series expansion of the general multilevel stepped output voltage is given in (4), where n is the harmonic number of the output voltage of inverter.

$$V(\omega t) = \sum_{n=1}^{\infty} V_n \sin(n\omega t) \dots\dots\dots(4)$$

Where

$$V(n) = \frac{4V_{dc}}{n\pi} \sum_{i=1}^s \cos(n\theta_i) \quad \text{for odd } ns$$

$$0 \quad \text{for even } ns$$

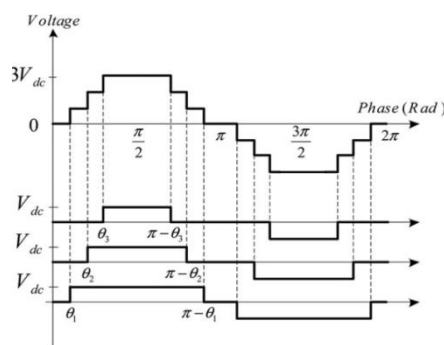


Fig. 2 Output voltage waveform of 7-level Cascaded Multilevel Inverter

The switching angles can be chosen so that minimum voltage harmonics is obtained. Normally, these angles are chosen so as to reduce lower frequency harmonics. The selective harmonic elimination method is also called fundamental switching frequency method based on the harmonic elimination theory proposed in this paper. The major difficulty for selective harmonic elimination methods is to include the fundamental switching frequency method and methods to solve the transcendental equations for switching angles.

To obtain fundamental voltage and to eliminate 5th and 7th harmonics, three nonlinear equations are as follows.

$$V_1 = \frac{4V_{dc}}{\pi} [\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3)] = V_1^* \dots\dots\dots (5)$$

$$\begin{aligned} V_5 &= \frac{4V_{dc}}{5\pi} [\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3)] \\ &= 0 \dots\dots\dots (6) \end{aligned}$$

$$\begin{aligned} V_7 &= \frac{4V_{dc}}{7\pi} [\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3)] \\ &= 0 \dots\dots\dots (7) \end{aligned}$$

$$\text{Subject to } 0 < \theta_1 < \theta_2 < \theta_3 < \frac{\pi}{2}$$

These equations are nonlinear transcendental equations are solved by Newton-Raphson method using Random Initial Guess, as the solution doesn't depend upon the guess. This paper presents a multilevel inverter model with mathematical model for SPWM modulator to minimize THD.

### III. DIFFERENT TOPOLOGIES OF PWM METHOD

PWM methods are classified in three parts

- 1) Single-pulse-width modulation.
- 2) Multiple-pulse-width modulation.
- 3) Sinusoidal pulse-width modulation.

### Single pulse width modulation

Single pulse width modulation involves only one pulse per half cycle and the width is varied to control inverter output voltage. The gating signals are generated by comparing a rectangle reference signal with a triangular reference signal. Fig shows generation of gating signals:-

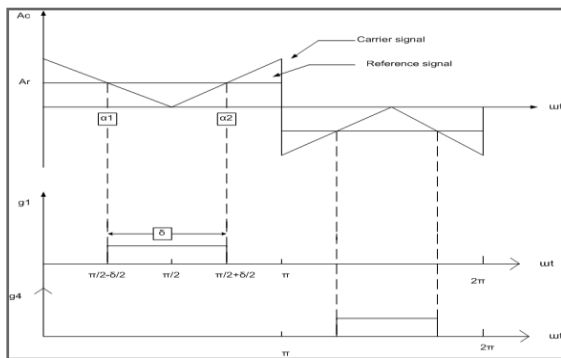


Fig- Gate pulse generation of Single Pulse Width Modulation

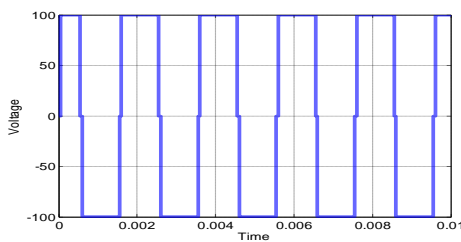


Fig. 3 Voltage waveform of single pulse width modulation method

### Voltage Equations

Modulation index is given as

$$M = A_r / A_c$$

The rms output voltage can be found from

$$V_o = \left[ \frac{2}{2\pi} \int_{(\pi - \delta)/2}^{(\pi + \delta)/2} V_1^2 d(\omega t) \right]^{1/2} = V_1 \sqrt{\delta / \pi}$$

By varying  $A_r$  from 0 to  $A_c$ , pulse width  $\delta$  can be modified from 0 to 180 and the rms output voltage  $V_o$  from 0 to  $V_s$ .

### Multiple-pulse-width modulation

Multiple-pulse-width modulation multiple pulse per half cycle is used. The gating signals are generated by comparing reference signal with a triangular reference signal. Harmonic content is reducing in this technique.

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Fig shows generation of gating signals:-

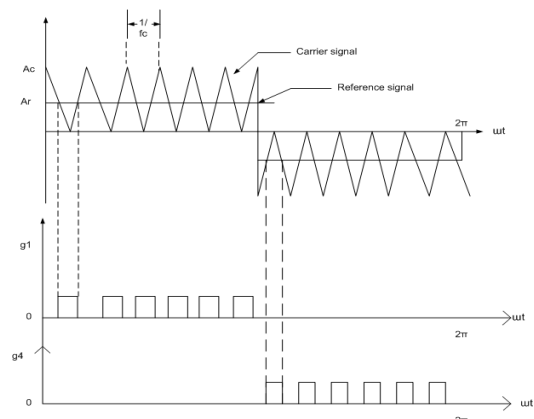


Fig- Gate pulse generation of Multiple Pulse Width Modulation

### Voltage Equations

The number of pulses per half cycle is given as

$$p = f_c / 2 f_o = m_r / 2$$

Where

$$m_f = f_c / f_o$$

The rms output voltage can be found from

$$V_o = \left[ \frac{2p}{2\pi} \int_{(\pi/p - \delta)/2}^{(\pi/p + \delta)/2} V_s^2 d(\omega t) \right]^{1/2} = V_s \sqrt{p \delta / \pi}$$

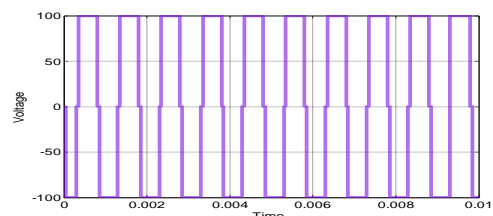


Fig- Voltage Waveform of Multiple Pulse Width Modulation method

### Sinusoidal pulse-width modulation

The number of pulses per half cycle depends on carries frequency and width of each pulse is varied in proportion to the amplitude of sine wave. The gating signals are generated by comparing sinusoidal wave as reference signal with a triangular reference signal. Harmonic content is reducing in this technique.

The rms output voltage can be varied by varying the modulation index  $M$ .

If  $\delta_m$  is the width of  $m$ th pulse the rms output voltage

$$V_o = V_s \left( \sum_{m=1}^{2p} \delta_m / \pi \right)^{1/2}$$

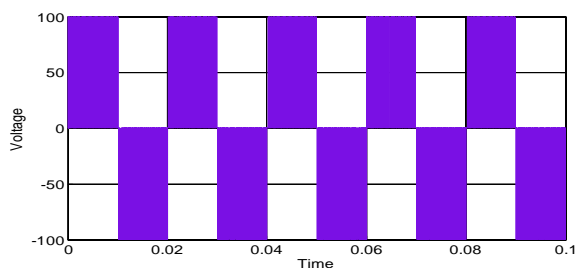


Fig- Voltage Waveform of SPWM method

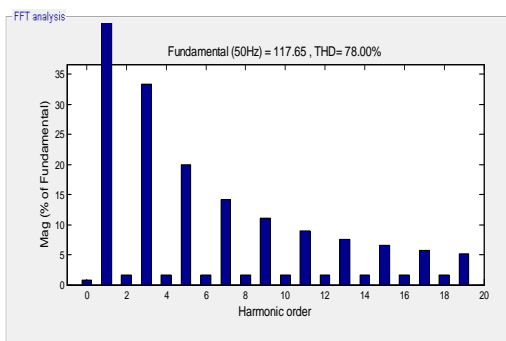


Fig- FFT analysis of SPWM Technique

#### IV. SELECTIVE HARMONIC ELIMINATION METHOD

In this technique sinusoidal wave is compared with a constant. Intersection points of sinusoidal wave n constant generate the gate signal. This gate signal is given to trigger the IGBT/MOSFET. SHE technique contains transcendental equation which can be solved by

This method is used to find the switching angles. The switching angles lie between 0 to  $\pi/2$  producing fundamental voltage with elimination of 5<sup>th</sup> & 7<sup>th</sup> harmonic component. The N-R method is basically based on trial and error method with random initial guess and modulation index  $m_1$  for which solution exists. Initial guess ranges from 0 to  $\pi/2$  and switching angles along with the error are computed for complete range of  $m_1$  by increasing its value in small steps (let 0.0001).

Algorithm for N-R method is given as

- 1) Assume any random initial guess for switching angles (say  $\alpha_0$ ) such as  $0 \leq \alpha_1 < \alpha_2 \leq \pi/2$ .
- 2) Set  $m_1 = 0$ .
- 3) Calculate  $F(\alpha_0)$ ,  $B(m_1)$  and Jacobian  $J(\alpha_0)$ .

- 4) Compute  $\Delta\alpha$  during the iteration using following equation,  

$$\Delta\alpha = J^{-1}(\alpha_0)(B(m_1) - F(\alpha_0)).$$
- 5) Update the switching angles i.e.  

$$\alpha(k+1) = \alpha(k) + \Delta\alpha(k).$$
- 6) To bring switching angles in range solve the following equation  

$$\alpha(k+1) = \cos^{-1}(\cos(\alpha(k+1))).$$
- 7) Repeat steps (3) to (6) for number of iterations to attain error goal.
- 8) Increment  $m_1$  by a fixed step.
- 9) Repeat steps (2) to (8) for range of  $m_1$ .
- 10) Plot the switching angle as a function of  $m_1$  and different solution sets would be obtained.
- 11) Take one solution sets at a time and compute complete solutions set for the range of  $m_1$ , where it exists.

#### The output equation with switching angles

$$4V_{dc} / \pi [\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) + \dots + \cos(\alpha_s)] = V_1$$

where

$$V_{1max} = 4sV_{dc} / \pi$$

Modulation index is given as

$$m_1 = \pi V_1 / 4sV_{dc}$$

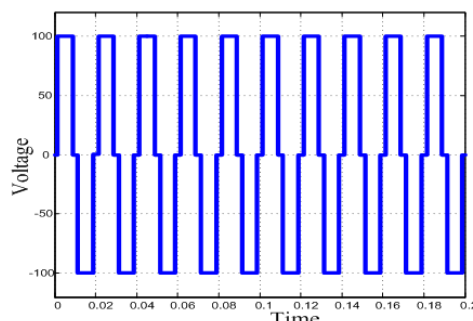
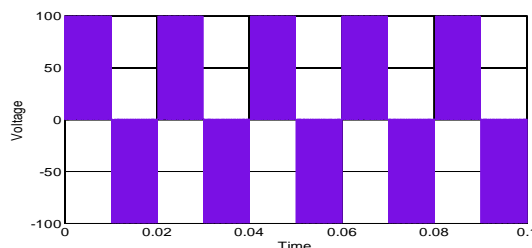


Fig- Voltage waveform of SHE technique

By using the algorithm of N-R method switching angles is calculated. With respect to these switching angles respective THD and 3<sup>rd</sup> harmonic is also calculated. These switching angles and harmonic are shown in below table.

TABLE 1- Switching Angles and % of Harmonics

M	Switching angle(deg)	3 <sup>rd</sup> Harmonic %	THD %
0.8	29.475	0.30	31.17

By inserting notches at a particular instant, total THD is reduced to 31.17%.

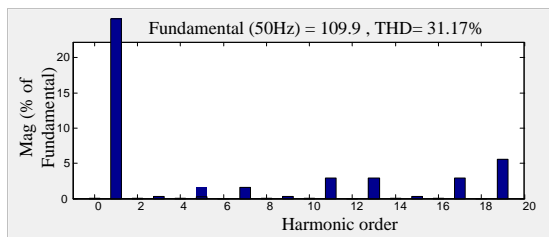


Fig- FFT analysis of SHE Technique

### Comparison of PWM Techniques And She Technique\

S.No	Techniques	3 <sup>rd</sup> harmonic %	5 <sup>th</sup> harmonic %	7 <sup>th</sup> harmonic %	THD %
1	Single pulse width modulation	38.61	24.42	50.38	79.9
2	Multiple pulse width modulation	36.61	25.07	48.31	77.68
3	SPWM	33.31	20.02	17.32	72.21
4	Selective harmonic elimination	0.03	1.98	2.01	31.17

### V. CONCLUSION

The results obtained from simulation of MATLAB/Simulink shows that the harmonic THD contents and also third, fifth and seventh harmonics are within 3% tolerance and other higher order harmonics are eliminated by filter. From above comparison of PWM Technique and SHE-PWM Technique we can conclude that SHE-PWM technique contains less % of harmonic compared to other PWM techniques.

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