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Comparative Analysis of Different Switching Techniques for Cascaded H-Bridge Multilevel Inverter

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Abstract – *Multilevel inverters have capability to producing AC staircase output waveform without bulky passive filter. Therefore, among different types of inverters the multilevel inverters are gaining popularity for photovoltaic applications. However, if the switching angle arrangement technique is not selected carefully then the total harmonic distortion (THD) of voltage output waveform may become unacceptable. In this paper, selective harmonics elimination pulse width modulation (SHEPWM) and Equal Phase (EP) switching angle arrangement techniques are applied to a cascaded H-Bridge multilevel inverter. PSIM software is used for evaluation and compare the performance of 9-level cascaded H-Bridge multilevel inverter with two switching angle arrangement techniques. Simulation results shown that SHEPWM technique can produce an output voltage waveform with the lowest THD. On the other hand, the output voltage waveform produced by EP technique had the highest fundamental voltage component.*

Keywords: Multilevel Inverter, Total Harmonic Distortion, Selective Harmonics Elimination Pulse Width Modulation, Switching Angle

1.0 INTRODUCTION

Nowadays, the development of renewable energy such as solar, wind and geothermal etc. has been increased due to the concerns of global warming and continuing rise of oil prices. The solar energy is among the most important source of renewable energy available today. Photovoltaic system converts solar radiation to electricity through photovoltaic panels.

The power generated by photovoltaic panel is in DC form. Therefore, it needs to be converted into AC form using a power inverter [1-2]. Several inverter topologies have been proposed in the past and each inverter topology has different characteristics. The conventional inverter requires a bulky filter to produce sinusoidal AC output voltage waveform [3].

Recently, multilevel inverters gain popularity in PV system. Unlike the conventional inverter, the multilevel inverter does not require bulky filter to generate near sinusoidal AC output waveform [4]. Among different types of multilevel inverter, cascaded H-Bridge multilevel inverter is gaining popularity for stand-alone PV systems [5]. However, if the proper switching angle arrangement technique is not applied then the resulted THD of cascaded H-Bridge multilevel inverter may become unacceptable. Therefore, in this paper two different types of switching techniques are

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presented. The switching angle drives using aforementioned techniques and applied to cascaded H-Bridge inverter.

This paper is organized into sections such as in Section II, the principle of operation of cascaded H-Bridge multilevel inverter are explained, whilst the details of switching angle arrangement techniques are discussed in Section III. In Section IV, the simulation results of 11-level cascaded battery boost inverter having two different sets of switching angles are compared and discussed.

2.0 PRINCIPLE OF OPERATION OF CASCADED H-BRIDGE MULTILEVEL INVERTER

The cascaded H-bridge multilevel inverter was proposed by Jih-Sheng and Fang Zheng [6]. Cascaded H-bridge (CHB) multilevel inverter is among the most popular inverter topology in stand-alone PV systems. In figure 1 shown the block diagram of cascaded H-bridge multilevel inverter. H-bridge inverters are connected in series with their output voltages are totaled up and hence, it has voltage boosting capability. It is highly reliable with lowest voltage unbalance problem. With N number of H-bridge inverters, the output staircase AC voltage produced consists of 2N+1 level [7]. This inverter topology requires separate DC source for each H-bridge inverter as can be seen in Figure 1.

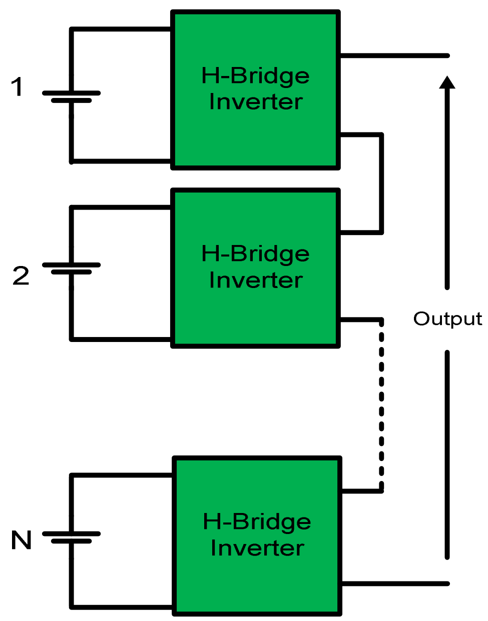

Figure 1: Cascaded H-Bridge Multilevel Inverter

3.0 METHODS TO DETERMINE THE SWITCHING ANGLE

The multilevel inverters have various topologies and many advantages. But the exiting topologies are unable to produce sinusoidal output waveform due to poor total harmonics distortion (THD) because the switching angles are not carefully arranged. In order to obtain good power quality, different switching angle arrangements are carefully investigated to achieve the lowest THD [8].

The switching angle is basically the moment of the level change. In Figure 2 shown the output voltage waveform for an m-level multilevel inverter. For an m-level waveform in the period 0°-90° degree, there are 2(m-1) switching angle to be determined. The switching angles are defined as $\theta_1, \theta_2, \dots. \theta_{m-2}, \theta_{m-1}$ by the time sequence. The sine wave is dividing into four quadrants. The switching angles in first quadrant period (0°-90°) are defined as main switching angles.

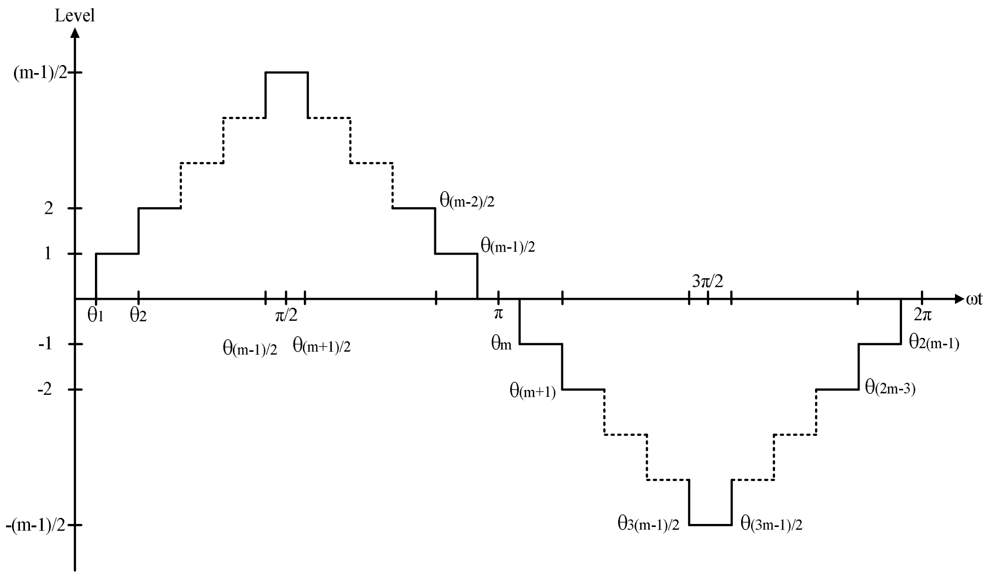

Figure 2: Output Voltage Waveform for Multilevel Inverter

For an m-level (m is an odd number) waveform, the main switching angles are (m-1)/2. From figure 2 the switching angles have four relations. The main switching angles in first quadrant (i.e., 0° – 90°) are $\theta_1, \theta_2, \ldots . \theta_{(m-1)/2}$.The switching angles in the second quadrant (i.e., 90°– 180°) are $\theta_{(m+1)/2} = \pi + \theta_1$.In the third quadrant the switching angles in the second quadrant (i.e., 180° – 270°) are $\theta_m = \pi + \theta_{(m-1)/2}$ .The switching angles in the forth quadrant (i.e., 270° – 360°) are $\theta_{(3m-1)/2} = 2\pi - \theta_1$.

For the purpose of this analysis, only main switching angles need to be determined. The other switching angles can be derived from the main switching angles in the first quadrant (0° – 90°):

$\theta_1, \theta_2, \ldots . \theta_{(m-1)/2}$.

3.1 Equal Phase Method

The Equal Phase Method is derived from the simplest idea, to equally distribute the switching angles in the range 0 – π. The main switching angles are calculated by formula:

$$\theta_i = i \left(\frac{180^\circ}{m} \right) \text{ where } i = 1, 2, \ldots \frac{m-1}{2} \tag{1}$$

3.2 SHEPWM Method

Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) is widely used to control multilevel inverter and produced output voltage with low total harmonic distortion (THD) [9]. The output AC voltage as shown in Figure 2 can be represented mathematically in a Fourier series as given by

$$v_{out}(\omega t) = \sum_{i=1,3,5,\ldots}^{\infty} \frac{4V_{DC}}{i\pi} \left[\cos(i\theta_1) + \cos(i\theta_2) + \cdots + \cos(i\theta_N) \right] \sin(i\omega t) \tag{2}$$

The peak voltage of each i^{th} harmonic component is given by

$$V_{p(i)} = \frac{4V_{DC}}{i\pi} \left[\cos(i\theta_1) + \cos(i\theta_2) + \cdots + \cos(i\theta_N) \right] \tag{3}$$

The SHEPWM equations can be written with the desired fundamental peak voltage of V_1 and peak voltage of higher order harmonics are zero.

$$\begin{aligned} V_1 &= \frac{4V_{DC}}{\pi}\left[\cos(\theta_1)+\cos(\theta_2)+\cdots+\cos(\theta_N)\right] \\ 0 &= \cos(3\theta_1)+\cos(3\theta_2)+\cdots+\cos(3\theta_N) \\ &\vdots \\ 0 &= \cos((2N-1)\theta_1)+\cos((2N-1)\theta_2)+\cdots+\cos((2N-1)\theta_N) \end{aligned} \tag{4}$$

By solving the SHEPWM equations in (4), switching angles at fundamental frequency can be obtained with higher order harmonics are eliminated.

4.0 RESULTS AND DISCUSSION

In this section, analysis results are presented, based on the simulation of 9-level cascaded H-bridge multilevel inverters using two switching strategies with input DC voltage of 120 and 10Ω resistive load. PSIM software is accurate simulator for this task which is mentioned before.

The cascaded H-bridge multilevel inverter is simulated for 9-level multilevel inverters. The data of simulation is achieved and analyzed based on the comparison of Total Harmonic Distortion (THD) resulting from EP and SHEPWM switching technique. The switching angles for 9-level cascaded H-bridge multilevel inverter are generated by using switching strategies EP and SHEPWM as shown in Table 1.

Table 1: Switching Angles for 9-level Cascaded H-bridge Multilevel Inverter

Angle	EP	SHEPWM
θ_1	20	10.02
θ_2	40	22.14
θ_3	60	40.75
θ_4	80	61.77

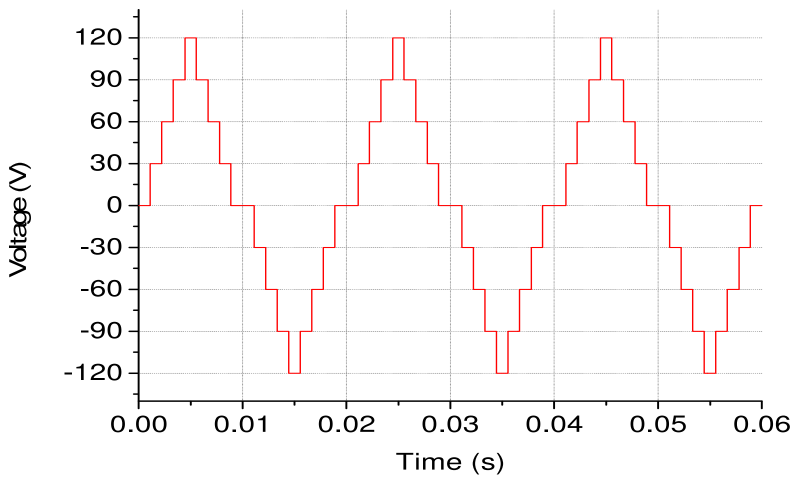

Figure 3 (a): Output Voltage with EP

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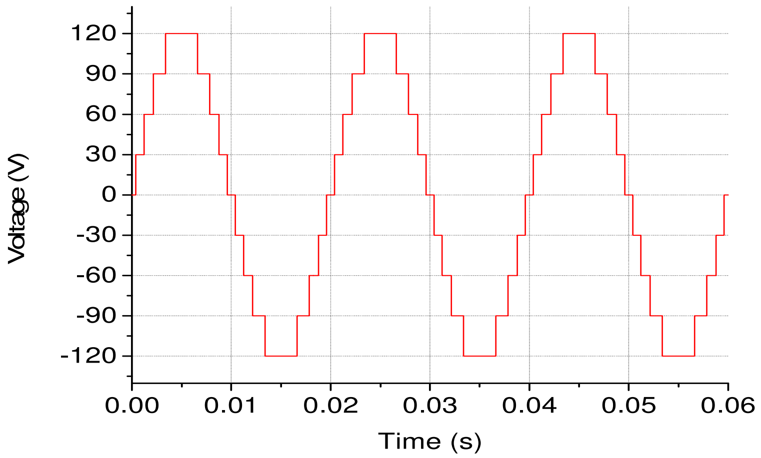

Figure 3 (b): Output Voltage with SHEPWM

The waveforms of the output voltages for the 9-level cascaded H-bridge multilevel inverter (CHB) are shown in Figures 3(a) and (b) whilst, Figure 4(a) and (b) shown the voltage harmonic spectrum (FFT analysis) of a 9-level cascaded H-bridge multilevel inverter.

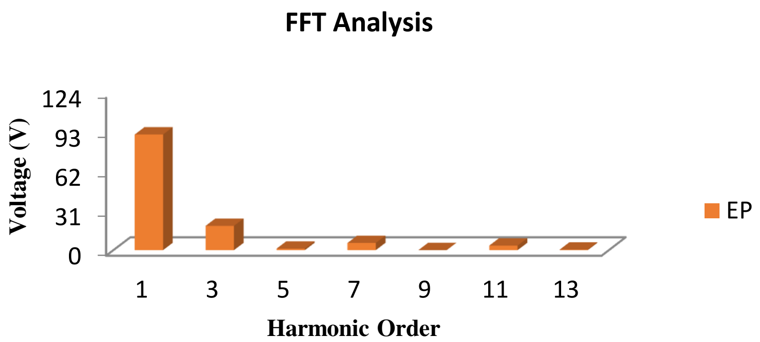

Figure 4(a): Voltage FFT Spectrum by Applying EP Method

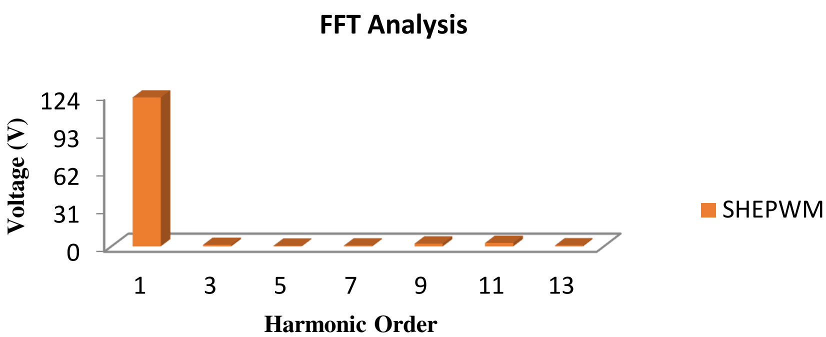

Figure 4(b): Voltage FFT Spectrum by Applying SHEPWM Method

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The switching strategies that are presented indicate that the width of the top levels of the output waveforms affected the fundamental components. The output waveform from SHEPWM had a more narrow top-level than EP switching strategy and AC become more near to sinusoidal and the obtained total harmonic distortion from SHEPWM method is lowest than EP method which is 09.03% and EP method had 25.57% which is higher than SHEPWM method.

CONCLUSION

It is clearly shown that the selection of the switching techniques is an important factor for such a multilevel inverter. Without a proper switching strategy and techniques implemented, the output voltage distortion of cascaded H-Bridge multilevel inverter can become worse. We provide the comparison of two switching strategies for obtained the lowest THD from cascaded H-Bridge multilevel inverter. It is perceived with performance matrix of these techniques that the simulation results are good and acceptable to substantiate the research objective and help researchers and developers to improve these techniques and look forward on its improvement.

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