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Comparison of Multicarrier PWM Techniques for Cascaded H-Bridge Multilevel Inverter

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ABSTRACT

One of the preferred choices of electronic power conversion for high power applications are multilevel inverters topologies finding increased attention in industry. Cascaded H-Bridge multilevel inverter is one of these topologies reaching the higher output voltage, power level and higher reliability due to its modular topology. Level Shifted Carrier Pulse Width Modulation (LSCPWM) and Phase Shifted Carrier Pulse Width Modulation are used generally for switching cascaded H-bridge (CHB) multilevel inverters. This paper compares LSCPWM and PSCPWM in terms of total harmonics distortion (THD) and output voltage among inverter cells. Simulation for 21-level CHB inverter is carried out in MATLAB/SIMULINK and simulation results are presented.

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1. INTRODUCTION

The concept of the multilevel inverter is come from the idea of a step approximation of a sinusoidal voltage. The output voltage waveform of multilevel inverter can be achieved by parallel connection of the switching devices, but the more common objective of the multilevel topologies is to generate a high voltage waveform using lower voltage rating switching devices connected in series. Typically, series devices are switched sequentially, giving an output pattern which consists of discrete predefined voltage steps. Every one of the switches blocks its rated normal voltage, but the total output voltage can be much higher [1]-[4]. In electrical power industry, multilevel inverters have become very important. They offer a new set of contributions for high voltage high power application. The main three types of multilevel inverters are: cascaded H-bridge multilevel inverter, diode clamped multilevel inverter and capacitor clamped multilevel inverter, each one strongly depending on the application. Especially the cascaded H-bridge multilevel inverter has been successfully commercialized for high power and power quality demanding applications up to a range of 31MVA [5]. There is various modulation schemes used in the multilevel inverter. Generally, the modulation schemes aim to generate train of pulses, which have the same fundamental voltage-second average as a base reference waveform at any instant. The major difficulty with these pulse trains is that they also contain unwanted harmonic components, which should be minimized. The main objective is to determine the most effective way of arranging the switching processes to minimize unwanted harmonic distortion, switching losses, etc [6]. Different methods have been used in the literature works for multicarrier PWM techniques in multilevel inverters. As In [7] the level- and phase-shifted pulse width modulation (LPS-PWM) and level-shifted pulse width modulation (LS-PWM) are applied to the seven-level switched-capacitor (SC) inverter. It is confirmed that the power conversion efficiency of the seven-level switched-capacitor (SC) with LPS-PWM is higher than that with LS-PWM because of the less voltage reduction during the discharging term of SCs. PS-PWM technique for the flying capacitor (FC) multi-level converter in [8] have been proposed an improved that enhances the quality of the output line-to-line voltages and currents. The proposed PS-PWM has natural capacitor voltage balance, it combined with voltage balancing methods to improve the voltage balancing dynamics. In [9], PSC PWM method has been proposed for modular multi-level converters (MMCs) to achieve an easy application and to solve the redundant control.

In this paper, carrier based PWM techniques such as level-shifted PWM and phase-shifted PWM techniques have been applied for a 21-level for CHB Multilevel Inverter for comparison purpose in order to identify the best PWM modulation techniques for it by considering the voltage output among cells and output THD. The rest of this paper is organized as follows: section 2 gives the concept of cascaded H-bridge multilevel inverter. Carrier based modulation schemes described in section 3, in section 4 the simulation results and analysis are discussed and finally conclusions are mentioned in section 5.

2. CASCADED H-BRIDGE MULTILEVEL INVERTER

Cascaded H-Bridge multilevel inverter is composes of several full bridge (cell) connecting in series per phase. Figure 1 depicts the three-phase inverter which consists of cascaded connection of 10 cells of H-Bridge in each phase of the inverter. Each bridge consists of four insulated-gate bipolar transistor (IGBT) switches driven by pulse width-modulated (PWM) gate circuits, and isolated DC source.

Figure 2 shows the power circuit for one phase leg of a three-level cascaded inverter. The circuit generates three voltages at the output (+Vdc, 0, -Vdc) as in Table 1. We assume that the DC bus of the VSC is constant. Then, The AC output phase voltage is constructed by adding the voltages generated by the different cells. One advantage of this structure is that the output waveform is nearly sinusoidal [10]-[12].

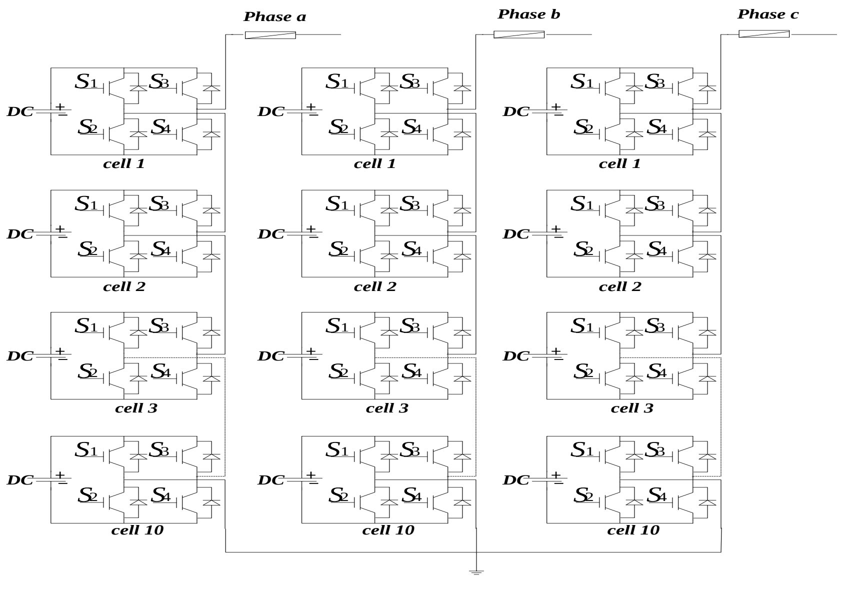

Figure 1. Three phase 21-level cascaded H-Bridge multilevel inverter (Y- connected)

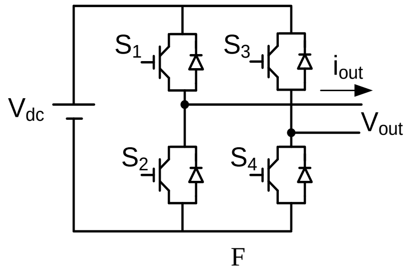

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Figure 2. One cell structure of cascaded inverter

Table 1. The Switching States Corresponding to Figure 2

S1	S2	S3	S4	Vo
1	0	1	0	+Vdc
1	0	1	0	0
0	1	0	1	0
0	1	1	0	-Vdc

3. CARRIER BASED MODULATION SCHEMES

The carrier based PWM techniques used to control each phase of the multilevel inverter separately and allow the line-to-line voltage to be developed implicitly. Multicarrier based PWM schemes classified into two categories as [9]:

a. Phase-Shifted Carrier PWM (PSCPWM)
b. Level- Shifted Carrier PWM (LSCPWM)

Phase-shifted carrier PWM For an n-level multilevel inverter requires n-1 triangular carriers with same frequency and amplitude, but there is a phase shift between any two adjacent carriers, given by

$$\varphi_{\text{carrier}} = \frac{360}{n-1} \quad (1)$$

The logic to create the gating signal for switches is that the reference waveform for each phase is compared with these carriers to determine how the phase leg should be switch. Figure 3b, shows the principle of phase-shifted for 21-level cascaded H-Bridge multilevel inverter which is used as the main circuit in this paper. The phase different between any two adjacent carriers according to Equation (1) is18°. The frequency modulation index is given by:

$$m_f = f_{cr}/f_m \quad (2)$$

Where f_{cr} and f_m are carriers and fundamental frequencies respectively. The amplitude modulation index is given by:

$$m_a = V_m/V_{cr} \quad (3)$$

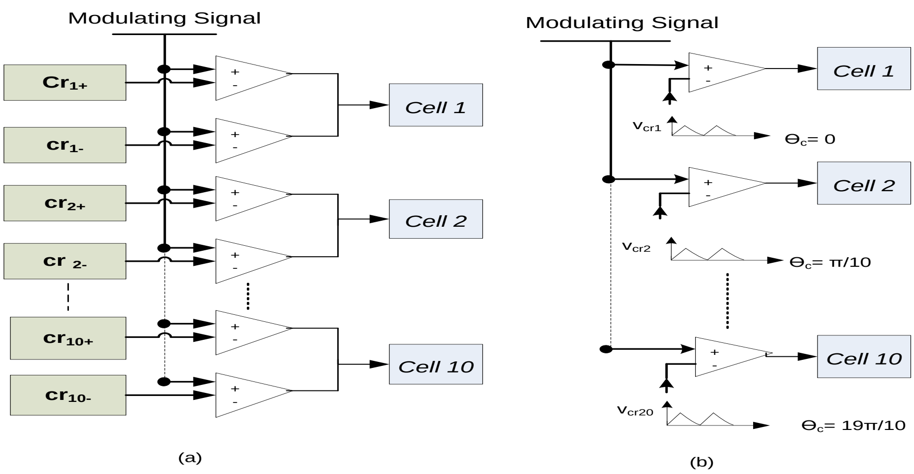


Figure 3. Simplified modulation schematic for 21 -level cascaded H-Bridge multilevel inverter (a) Level-Shifted Carrier PWM scheme (b) Phase-Shifted Carrier PWM scheme

On the other hand level-shifted carrier PWM shown in Figure 3.a , for an n-level of cascaded H-Bridge multilevel inverter the level shifted modulation requires $(n-1)$ carriers, all this carriers have the asme amplitude and frequency [13]-[14]. For multilevel inverters, the amplitude modulation index m_a, and the frequency modulation index, m_f, are defined as:

$$m_a = V_m/((n-1)V_{cr}) \text{ For } 0 \le m_a \le 1 \quad (4)$$

$$m_f = f_{cr}/f_m \quad (5)$$

Where V_m and V_{cr} denote the amplitude of modulating and carrier signals; f_m and f_{cr} denote the frequency of the modulating and carrier signals.

4. SIMULATION RESULT AND ANALYSIS

In this section, a three phase 21-level cascaded H-bridge inverter was simulated in MATLAB/SIMULINK. The system parameters load of 1MW, 6.6kV, 50 Hz. Figure 4a and Figure 4b shows the carrier waveforms of the level shifted and phase shifted modulation respectively with parameters in Table 2.

The simulation results for 21-level three-phase cascaded H-Bridge inverter are: Figure 5 and Figure 6 show the output of inverter phase and line-to-line voltages waveform and their corresponding spectrum (THD) using LSC PWM. On the other hand the output of inverter waveforms obtained using PSC PWM are shown in Figure 7 and Figure 8. Figure 9 shows the comparison of output voltage distribution among cells for the different carrier based PWM modulation strategies. It can be seen from Figure 9 that when PSCPWM is applied to 21-level CHB inverter, the output voltage among cell is equal, while when LSCPWM is applied to it.

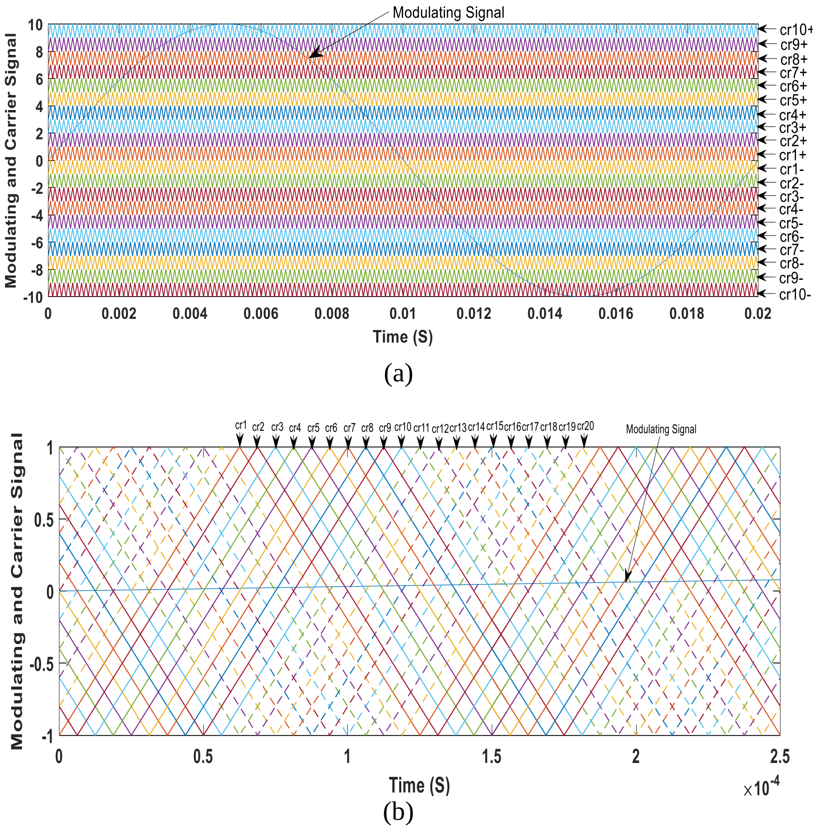
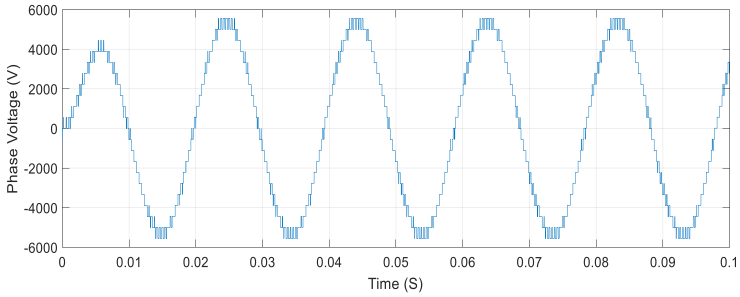


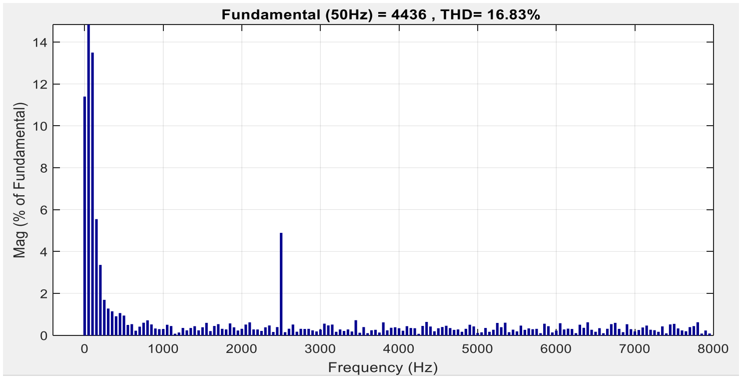
Figure 4. Carrier based for 21 -level cascaded H-Bridge multilevel inverter (a) with level shifted modulation (b) phase shifted modulation

Table 2 Parameters used for phase and level shifted modulation technique

Parameters	PSC	LSC
Modulation frequency (f_m)	50Hz	50Hz
Modulation amplitude signal (V_m)	1pu	10pu
Carriers frequency (f_{cr})	8kHz	8kHz
Carriers amplitude (V_{cr})	1pu	1pu
V_{dc} per H-bridge cell	560V	560V

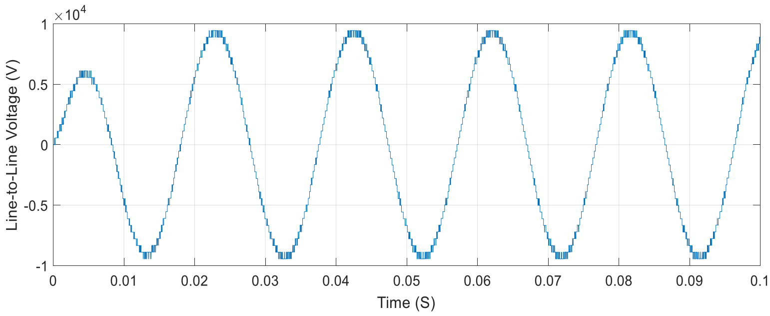


(a)



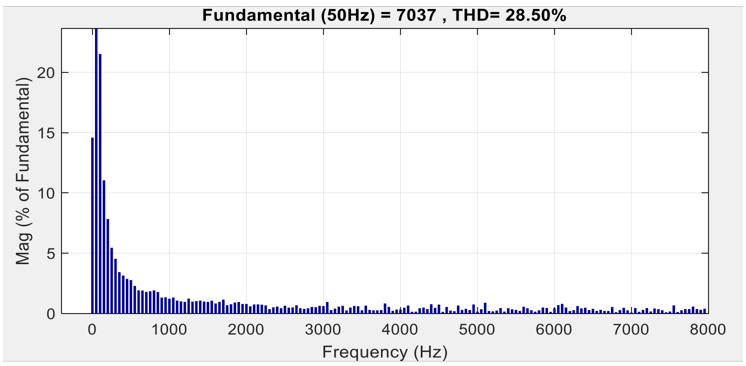
(b)

Figure5. output for 21-level CHB inverter with LSC PWM (a) Phase voltage (b) THD



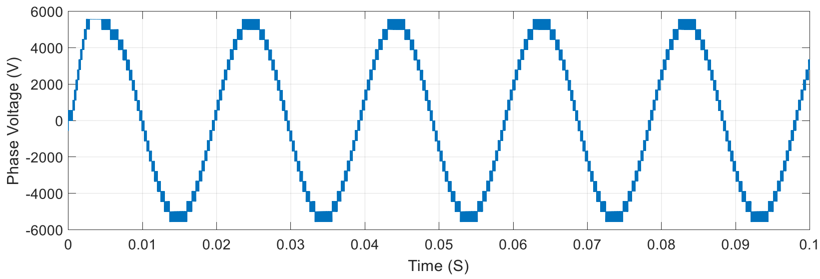
(a)

Figure 6. Output for 21-level CHB inverter with LSC PWM (a) line-to-line voltage

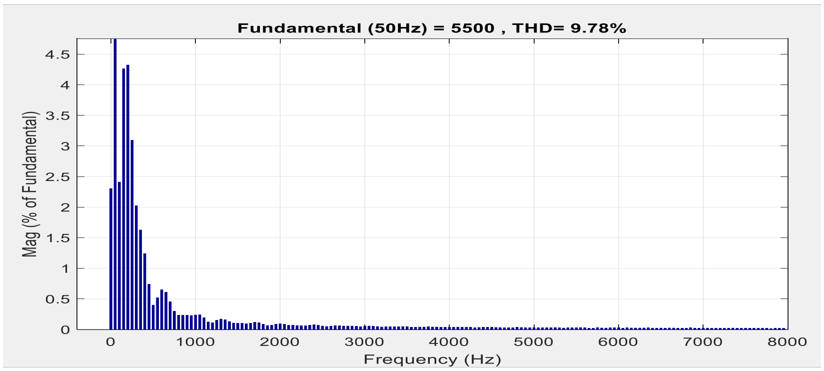


(b)

Figure 6. Output for 21-level CHB inverter with LSC PWM (b) THD

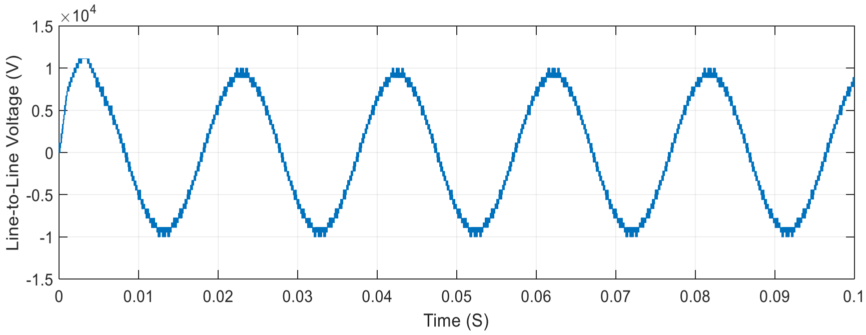


(a)

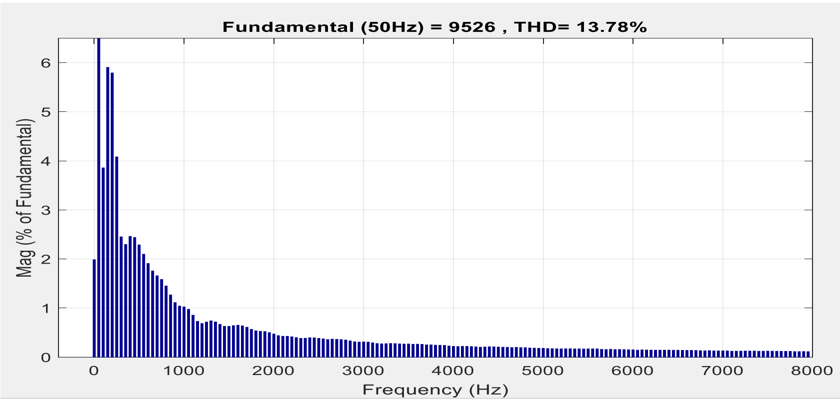


(b)

Figure 7. Output for 21-level CHB inverter with PSC PWM (a) Phase voltage (b) THD



(a)



(b)

Figure 8. Output for 21-level CHB inverter with PSC PWM (a) line-to-line voltage (b) THD

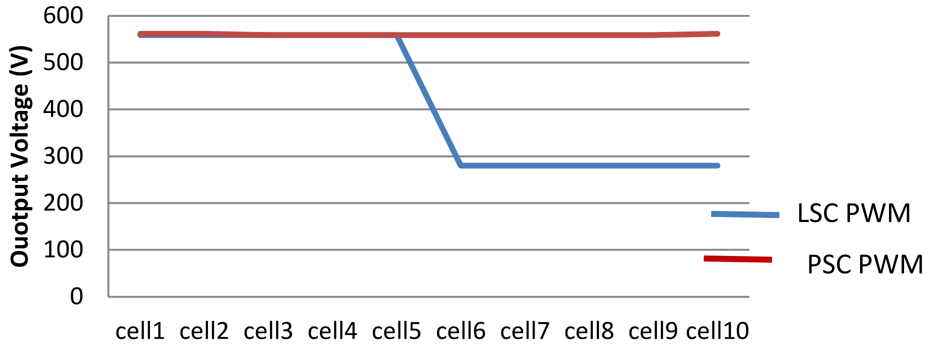


Figure 9. Voltage output among 10 cells for 21-level CHB

5. CONCLUSION

In this paper, PSC PWM and LSCPWM have been applied for 21-level cascaded H-bridge multilevel inverter through MATLAB simulation. Using LSCPWM in CHB multilevel inverter does not cause the equal output voltage among the cells, but when we use PSCPWM it cause equal voltage output among cells. As far as THD is concerned, PSCPWM strategies produce lower harmonics which compare with LSCPWM. We can conclude that PSCPWM strategy should be used for CHB multilevel inverter, as overall performance is superior than using LSCPWM strategy for it.

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