

Study of Five Level Inverter for Harmonic Elimination

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Abstract— Multilevel Inverter technology has emerged recently as a very important alternative in the area of high power, high voltage energy control. It came into picture and it has gained more attention in market for various applications like renewable energy systems, industrial motor drives, etc. It can generate stepped waveform by reducing harmonic distortion with increase in the number of voltage level. For high-power applications, cascaded H-bridge (CHB) inverters are conventionally controlled by selective harmonic Elimination (SHE) method. This technique is applied to reduce the switching loss and the optimized switching angles are calculated to mitigate low-order harmonics at the output voltage. Further the three phase five level CHB inverter is integrated with PV module as CHB inverter is suitable for PV application as each PV module act as a separate DC source for each CHB module. The simulation of three phase five level CHB inverter is done using MatLab R2010a version Software. The output shows better performance results of the proposed inverter.

Keywords- %THD, CHB multilevel inverter, SHE technique, PV module, MATLAB/Simulink software

I. INTRODUCTION

The tremendous increase in energy demand led to call of high power converter technology to transmit the power with high accuracy. When dealing with high voltages, conventional inverters produce output voltages of low quality and high harmonic content which affects the equipment performance. So new power converter topologies were invented known as multilevel inverters and gained importance in industry applications because of high power ratings and better harmonic performance suitable for medium and high power applications. The output voltage of multilevel inverters is in form of stepped waveforms and obtained easily without use of transformers which decreases the cost of inverter. Improved quality of waveforms can be obtained by increasing number of steps in the output waveforms and the harmonic content also comes down. Multilevel Inverters are classified into three topologies namely diode clamped, flying capacitor and cascaded type inverters. PWM is a technique in which width of gate pulses are controlled and used for various applications. Different types of PWM techniques are proposed for multilevel inverters like sinusoidal pulse width modulation, selective harmonic elimination and space vector modulation. The elimination of specific low-order harmonics from a given voltage/current waveform generated by a voltage/current source inverter using what is widely known as optimal, "programmed" or selective harmonic elimination PWM (SHE-PWM) techniques, has been dealt with in numerous papers and for various converter topologies, systems, and applications [10]. The main challenge of SHE-PWM techniques is to obtain the solutions, i.e., switching angles, associated with the nonlinear transcendental equations that contain trigonometric and exhibit multiple sets of solutions. Photovoltaic (PV) sources are used today in many applications as they have the advantages of effective maintenance and pollution free. PV inverter, which is the heart of a PV system, is used to convert dc power obtained

from PV modules into ac power to be fed into the grid. Improving the output waveform of the inverter reduces its respective harmonic content and, hence, the size of the filter used and the level of Electromagnetic Interference (EMI) generated by switching operation of the inverter[9]. Here SHE-PWM is used for modeling of three phase five level cascaded H-bridge inverter. The design and modeling of three phase five level CHB is done in MATLAB/SIMULINK. In this proposed concept uses the IGBT semiconductor switches.

II. CASCADED H-BRIDGE MULTILEVEL INVERTER (CHMLI)

The cascade inverter in the figure 1, can produce a phase voltage with five voltage levels. The resultant inverter phase voltage is $V_{AN} = V_{H1} + V_{H2}$, which is the voltage at the inverter terminal A with respect to the inverter neutral N. The output voltage can be 0, $\pm E$, $\pm 2E$. The voltage levels which correspond to various switching states are summarized in table 1. It can be observed from the table that some voltage levels can be obtained by more than one switching state. These redundancies are common in multilevel inverters. It provides a great flexibility for switching pattern design, especially for space vector modulation schemes. In a general way If H is the number of single-phase H-bridges per phase, the number of levels of the inverter is:

$m = (2H+1)$ where, H is the number of H-bridge cells per phase leg. The voltage level m is always an odd number for the CHB inverter. The total number of active switches (IGBTs) used in the CHB inverters can be calculated by, $N_{sw} = 6(m - 1)$ Where, N_{sw} is total number of switches and m is a voltage level. [1]

Advantages:

1. The multilevel inverter is composed of multiple units of identical H-bridge power cells, which leads to a reduction in manufacturing cost .

- Lower voltage THD and dv/dt. The inverter output voltage waveform is formed by several voltage levels with small voltage steps. Compared with a two-level inverter, the CHB multilevel inverter can produce an output voltage with much lower THD and dv/dt.

Disadvantages:

- Large number of isolated dc supplies- The dc supplies for the CHB inverter are usually obtained from a stiff DC supply employing an expensive phase shifting transformer.
- High component count- The CHB inverter uses a large number of IGBT modules. A five-level CHB inverter requires 24 IGBTs with the same number of gate drivers.

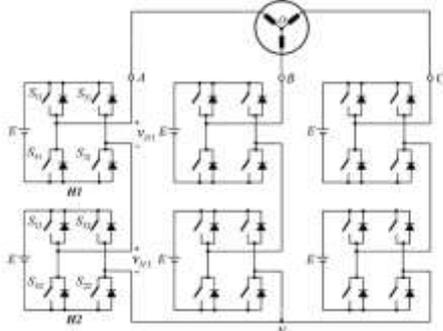


Fig1 Five-level cascaded H-bridge inverter

In this diagram, the 24 no. of IGBTs are used and after that get the output 5 level voltage. The output is given to the 3-Phase load like as R-L load taken normally. The pulses are generating by comparing the triangular wave and sinusoidal wave. For 5 level output, the triangular wave are taken N-1. Means 4 triangular waveform required. Which are compare to sinusoidal waveform and pulse are given to the each IGBT .

Output voltage VAN	S11	S31	S12	S32	VH1	VH2
2E	1	0	1	0	E	E
E	1	0	1	1	E	0
	1	0	0	0	E	0
	1	1	1	0	0	E
	0	0	1	0	0	E
0	0	0	0	0	0	0
	0	0	1	1	0	0
	1	1	0	0	0	0
	1	1	1	1	0	0
	1	0	0	1	E	-E
	0	1	1	0	-E	E
-E	0	1	1	1	-E	0
	0	1	0	0	-E	0
	1	1	0	1	0	-E
	0	0	0	1	0	-E
-2E	0	1	0	1	-E	-E

Table 1.

III Harmonic Reduction Technique

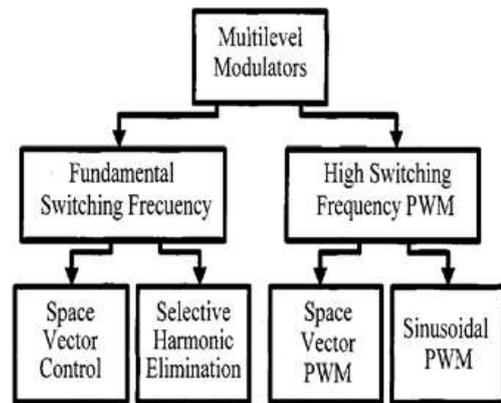


Fig2. classification of multilevel inverter control techniques

Selected Harmonic Elimination PWM

The undesirable lower order harmonics of a square wave can be eliminated and the fundamental voltage can be controlled as well by what is known as selected harmonic elimination (SHE) PWM. In this method, notches are created on the square wave at predetermined angles, as shown in Figure 3. In the figure, positive half cycle output is shown with quarter-wave symmetry. It can be shown that the four notch angles $\alpha_1, \alpha_2, \alpha_3$ and α_4 can be controlled to eliminate three significant harmonic components and control the fundamental voltage. A large number of harmonic components can be eliminated if the waveform can accommodate additional notch angles.[8]

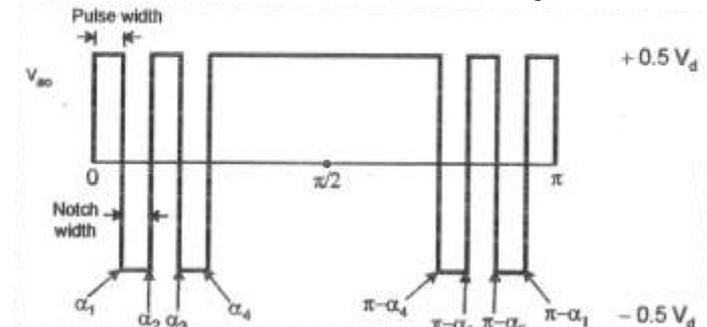


Fig.3 Phase Voltage wave for Selected Harmonic Elimination PWM

The general Fourier series of the wave can be given as,

$$v(t) = \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \tag{1}$$

Where

$$a_n = \frac{1}{\pi} \int_0^{2\pi} v(t) \cos n\omega t d\omega t \tag{2}$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} v(t) \sin n\omega t d\omega t \tag{3}$$

For a waveform with quarter-cycle symmetry, only the odd harmonics with sine components will be present. Therefore,

$$a_n = 0 \tag{4}$$

$$v(t) = \sum_{n=1}^{\infty} b_n \sin n\omega t \tag{5}$$

Where

$$b_n = \frac{4}{\pi} \int_0^{\pi/2} v(t) \sin n\omega t d\omega t \tag{6}$$

Assuming that the wave has unit amplitude, that is, $v(t) = +1$, can be expanded as,

$$b_n = \frac{4}{\pi} \left[\int_0^{\alpha_1} (+1) \sin n\omega t d\omega t + \int_{\alpha_1}^{\alpha_2} (-1) \sin n\omega t d\omega t + \int_{\alpha_2}^{\alpha_3} (+1) \sin n\omega t d\omega t + \dots + \int_{\alpha_{K-1}}^{\alpha_K} (-1)^{K-1} \sin n\omega t d\omega t + \int_{\alpha_K}^{\pi} (+1) \sin n\omega t d\omega t \right] \tag{7}$$

Using the general relation

$$\int_{\theta_1}^{\theta_2} \sin n\omega t d\omega t = \frac{1}{n} (\cos n\theta_1 - \cos n\theta_2) \tag{8}$$

The first and last terms are

$$\int_0^{\alpha_1} (+1) \sin n\omega t d\omega t = \frac{1}{n} (1 - \cos n\alpha_1) \tag{9}$$

$$\int_{\alpha_K}^{\pi} (+1) \sin n\omega t d\omega t = \frac{1}{n} \cos n\alpha_K \tag{10}$$

Integrating the other components of Equation (7) and substituting (9) and (10) in it yields,

$$b_n = \frac{4}{\pi} [1 + 2(-\cos n\alpha_1 + \cos n\alpha_2 - \dots + \cos n\alpha_K)] = \frac{4}{\pi} [1 + 2 \sum_{K=1}^K (-1)^K \cos n\alpha_K] \tag{11}$$

Note that Equation (11) contains K number of variables (i.e., $\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_K$), and K number of simultaneous equations are required to solve their values. With K number of α angles, the fundamental voltage can be controlled and $K-1$ harmonics can be eliminated. It can be seen that the lower order, significant harmonics (i.e., 11th and 13th) have been considerably boosted as a result of lower order harmonics elimination. The effect of these harmonics will possibly be small because of their large separation from the fundamental. Also note that the 5th and 7th harmonics can be eliminated up to a voltage level of 93.34 percent (100 percent corresponds to the square wave) where $\alpha_1 = 0$. The single notch remaining on the outer side of the half-cycle can be narrowed symmetrically by reducing the α_2 angle, and then dropped to attain the full square wave. [8]

IV Integration with PV module

SOLAR PV MODULE

Renewable energy resources will be an increasingly important part of power generation in the new millennium. Photovoltaic systems produce DC electricity when sunlight shines on the PV array without any emissions. Structure of a solar cell is given below.

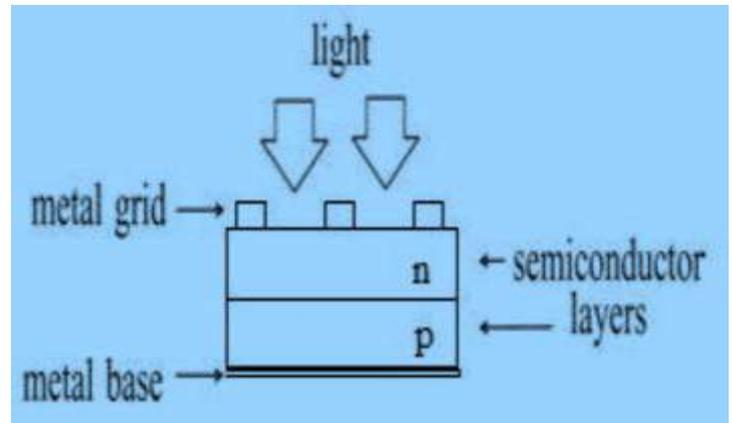


Fig-4 Structure of a PV Cell

A solar cell consists of a p-n junction fabricated in a thin wafer or layer of semiconductor (usually silicon). In the dark, the I-V output characteristic of a solar cell has an exponential characteristic similar to that of a diode. When solar energy (Photons) hits the solar cell, with energy greater than band gap energy of the semiconductor, electrons are knocked loose from the atoms in the material, creating electron-hole pairs. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. The characteristics of this diode therefore set the open circuit voltage characteristics of the cell.[11]

EQUIVALENT CIRCUIT OF THE PV CELL

The simplest equivalent circuit of a solar cell is a current source in anti-parallel with a diode. When exposed to light, a dc current is generated. The generated current varies linearly with the solar irradiance.[11]

Equivalent Circuit of a PV Cell

The standard equivalent circuit of the PV cell is shown in fig 5

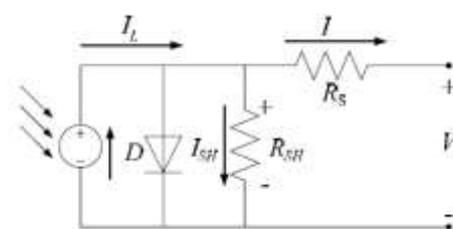


Fig-5 Equivalent Circuit of a PV Cell

IV SIMULATION AND RESULTS

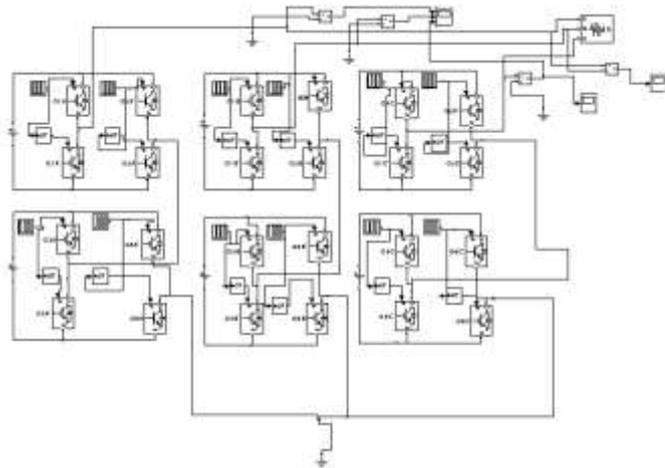


Fig 4(a) Simulation circuit diagram of 3 phase five level CHB inverter.

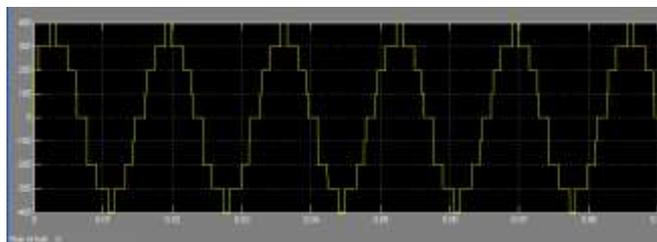


Fig 4(b) Showing the output voltage of 5level CHB inverter.

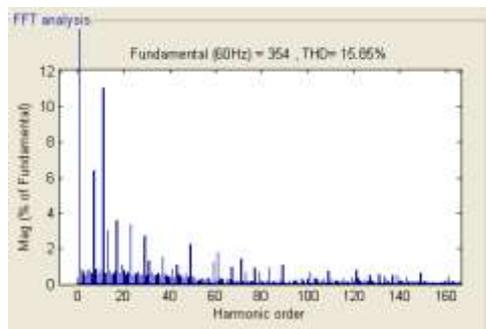


Fig-4 (c) Frequency spectrum of three phase five level CHB inverter

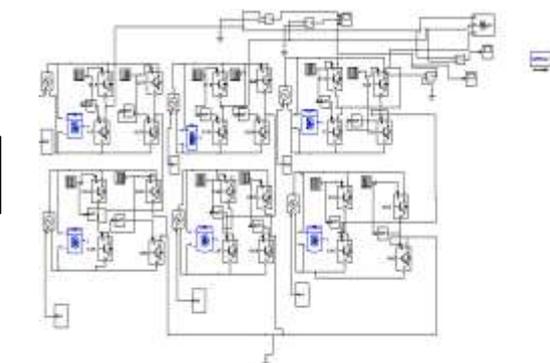


Fig 4(d) Simulation circuit diagram of 3 phase five level CHB inverter integrated with PV module.

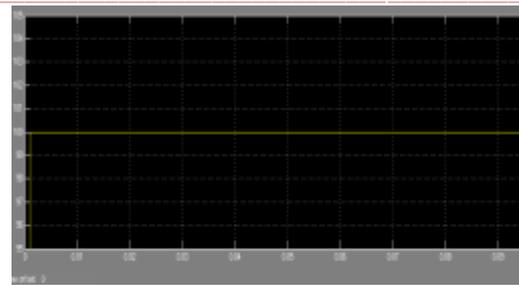


Fig-4(e) DC Output of Solar System.

V CONCLUSION

Multilevel inverter are very suitable for PV generation .H bridge cell with PWM control is very promising solution not only for having medium and high voltage but for improving the quality of the voltage i.e. reduction of THD. In this paper performance and study of three phase five level CHB inverter using SHE technique has been analyzed. The SHE technique used over here reduces THD to 15.85% . It has been demonstrated by simulation that 5th order harmonic is eliminated in the line voltage of 5level CHB inverter. The simulation is done using MATLAB R2010a version software. Further 5level CHB inverter is integrated with PV module to get DC output voltage .

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