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A Single Phase Eleven Level Cascaded H-Bridge Multilevel Inverter for Photovoltaic Systems Using Multicarrier Pwm

M.S.Sivagamasundari, [1] P.Melba Mary[2]
1(Assistant Professor, Department of EEE,V V College of Engineering,Tamilnadu,INDIA)
2 (Principal, Department of EEE,V V College of Engineering,Tamilnadu,INDIA)

Abstract: *A Cascaded H-Bridge Multilevel Inverter is a power electronic converter built to synthesize a desired ac voltage from several levels of dc voltages with better harmonic spectrum. Such inverters are suitable for high voltage and high power applications and have been an important development in recent years. This paper presents the performance of a eleven level cascaded H-Bridge multilevel inverter topology with multicarrier pulse width modulation technique for photovoltaic cell. This inverter is capable of producing eleven levels of output voltage from the dc supply voltage. This topology magnifies the fundamental output voltage with reduction in total harmonic distortion . The output is drawn near the sine wave because of more levels. It can also be easily extended to an m-level inverter. The performance of the proposed PWM strategy in terms of output voltage and THD is shown using MATLAB/Simulink.*

Keywords: *Multilevel inverter, Cascaded H-Bridge multilevel inverter, Multicarrier pulse width modulation, PV cell, Total harmonic distortion.*

I. INTRODUCTION

Renewable energy is a challenging aspect for now and future of the world's increasing energy demand. Since last three Decades, there is a growing effort to make renewable energy more feasible due to its particular characteristics and high costs.

Among renewable energy sources, photovoltaic energy is one of the most considerable sources because of its advantages like being widely available and cost free, clean and abundant.

Furthermore, being a semiconductor device it is free of moving parts which results little operation and maintenance costs [1].PV cell is especially attractive for applications in where sunshine is available for most of the time. Such a system generates electricity by converting the Sun's energy directly into electricity. [2].

Power switches with the suitable switching frequency at ratings above 5kV are rare; hence it is difficult to achieve inverter output voltage which is compatible to the medium voltage grid. One approach is to utilize the MLI structure. Multilevel inverter is an array of power semiconductor switches and voltage sources which is switched in a manner that an output voltage of stepped waveform is generated. Several multilevel topologies have evolved: most common are the diode-clamped inverter (neutral-point clamped), capacitor-clamped(flying capacitor) requiring only one dc source and the cascaded bridge inverter requiring separate dc sources.[3]. The latter characteristic, which is a drawback when a single dc source is available, becomes a very attractive feature in the case of PV systems, because solar cells can be assembled in a number of separate generators. In this way, they satisfy the requirements of the Cascaded H-Bridge multilevel inverter, obtaining additional advantages such as a possible elimination of the dc/dc booster (needed in order to adapt voltage levels), a significant reduction of the power drops caused by sun darkening (usually, it influences only a fraction of the overall PV field), and, therefore, a potential increase of efficiency and reliability [4].

Performance of the multilevel inverter (such as switching loss and THD) is mainly decided by the modulation strategies. For the cascaded multilevel inverter there are several well known pulse width modulation strategies. [5].

Compared to the conventional method, the proposed method is subjected to a new modulation scheme adopting the multicarrier pulse width modulation concept which uses multiple modulating signals with a single carrier reduces the total harmonic distortion and switching losses. In this paper, a PV array is connected to eleven level cascaded H-bridge multilevel inverter to achieve sinusoidal output voltage waveforms and the simulation results are shown.

II. MATHEMATICAL MODEL OF THE PV ARRAY

2.1. Equivalent model

A Photovoltaic cell is a device used to convert solar radiation directly into electricity. It consists of two or more thin layers of semiconducting material, most commonly silicon. When the silicon is exposed to light, electrical charges are generated. A PV cell is usually represented by an electrical equivalent one-diode model shown in fig.1.

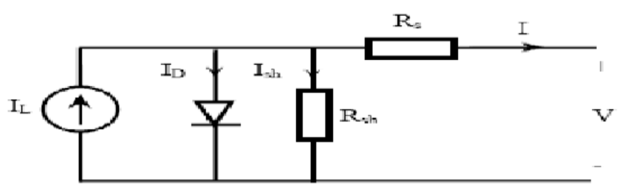

Fig. 1. Single PV cell model

The model contains a current source, one diode, internal shunt resistance and a series resistance which represents the resistance inside each cell. The net current is the difference between the photo current and the normal diode current which is given by the equation.

$$ID = IO\ [e^{\frac{q(V+IRs)}{KT}} - 1] \quad \text{..............................} (1)$$

$$I = I_L - I_O\ [e^{\frac{q(V+IRs)}{KT}} - 1] - \frac{V+IRs}{Rsh} \quad \text{........................} (2)$$

Where
I is the cell current (A).
q is the charge of electron (coul).
K is the Boltzmann's constant (j/K).
T is the cell temperature (K).
I_L is the photo current (A).
Io is the diode saturation current.(A)
Rs , Rsh are cell series and shunt resistances (ohms).
V is the cell output voltage (V).

2.2. Current – Voltage Curve for PV cell

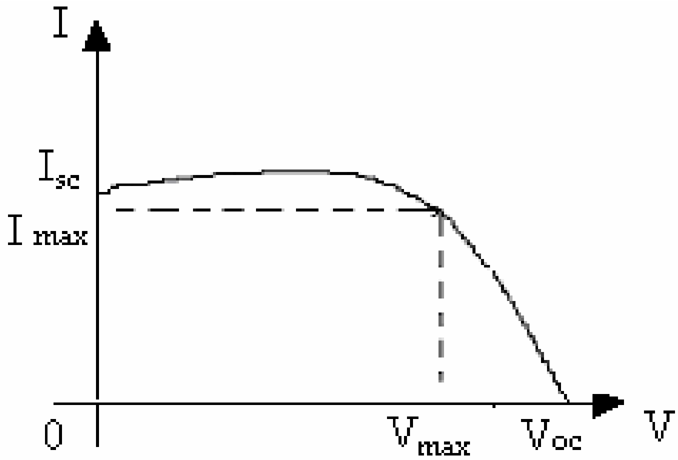

Fig.2.Current – Voltage curve

The Current – Voltage characteristic curve of a PV cell for a certain irradiance at a fixed cell temperature is shown in fig.2. The current from a PV cell depends on the external voltage applied and the amount of sunlight on the cell. When the PV cell circuit is short, the current is at maximum and the voltage across the cell is zero. When the PV cell circuit is open, the voltage is at maximum and the current is zero.

2.3. Power – Voltage Curve for PV cell

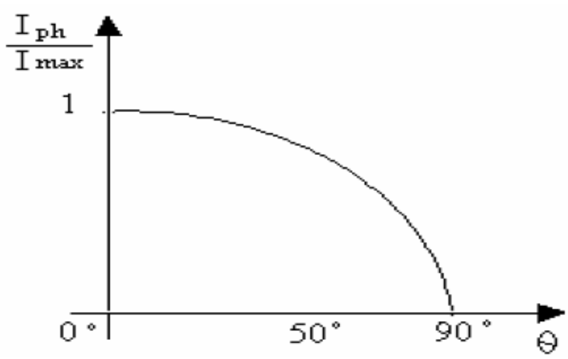

Fig.3.Power – Voltage curve

The Power – Voltage curve for PV cell is shown in fig.3. Here P is the power extracted from the PV array and V is the voltage across the terminals of the PV array. This curve varies due to the current insolation and temperature. When insolation increases, the power available from PV array increases whereas when temperature increases the power available from PV array decreases.[5].

2.3. Variation in Available Energy due to Sun's Incident Angle

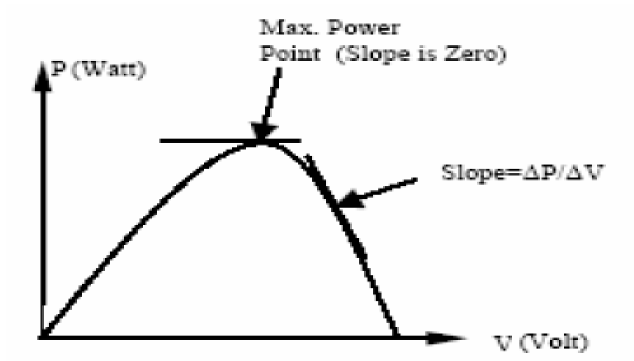

Fig.4.Variation in Available Energy due to Sun's

Incident Angle PV cell output with respect to sun's angle of incidence is approximated by cosines function at sun angles from 0° to 50°. Beyond the incident angle of 50° the available solar energy falls of rapidly as shown in the fig.4. Therefore it is convenient and sufficient within the normal operating range to model the fluctuations in photo current versus incident angle is given by Eq (3).[5].

$$Iph = Imax\cos\theta \qquad \ldots\ldots\ldots\ldots (3)$$

III. CASCADED H-BRIDGE MULTILEVEL INVERTER TOPOLOGY

A single-phase structure of an m-level cascaded inverter is illustrated in Figure.5. Each separate dc source is connected to a single-phase full bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $–V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $–V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources.

An example phase voltage waveform for an 11-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure.6. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$.

The Fourier Transform for a stepped waveform such as the one depicted in Figure 6 with s steps is as follows [6]:

$$V(\omega t) = \left(\frac{4VDC}{\pi}\right) \Sigma\, [\cos(n\,\theta 1) + \cos(n\,\theta 2) +$$

where n = 1, 3, 5, 7, …(4)

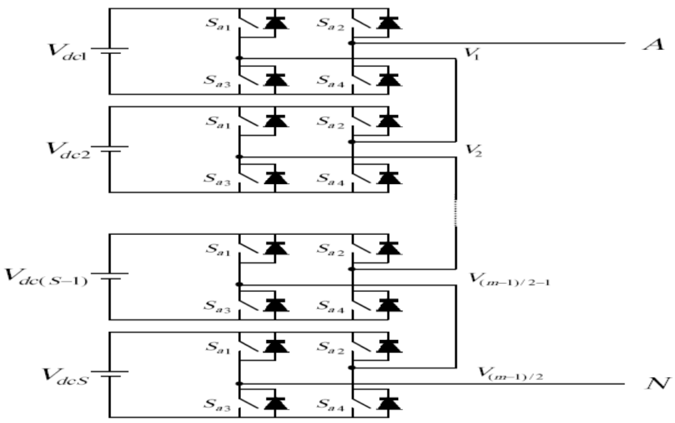

Fig.5.Single-phase structure of an m level cascaded H-bridge multilevel inverter

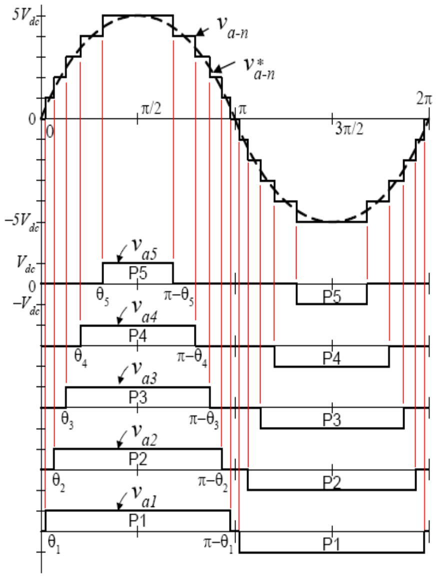

Fig.6.Output voltage waveform of an 11-level cascade inverter

The conducting angles, $\theta_1, \theta_2, ..., \theta_S$, can be chosen such that the voltage total harmonic distortion is minimum. Generally, these angles are chosen such that predominant lower frequency harmonics 5th, 7th, 11th, and 13th harmonics are eliminated. [7].

IV. MULTICARRIER PWM TECHNIQUE

The Multicarrier PWM technique was introduced and uses several triangular carrier signals and only one modulating sinusoidal signal as reference wave to generate the PWM switching signals. If an 'n' level inverter is employed, 'n-1' carriers will be needed. At every instant each carrier is compared with the modulating signal. Each comparison gives one if the modulating signal is greater than the triangular carrier, zero otherwise. The results are added to give the voltage level, which is required at the output terminal of the inverter. [8].

Frequency modulation ratio is defined as the ratio of carrier frequency and modulating frequency.

$$Mf = fc / fm \quad .... (5)$$

Amplitude modulation ratio is defined as the ratio of amplitude of modulating signal and amplitude of carrier signal.

$$Ma = Am / (n-1) Ac \quad …………….(6)$$

Using this technique THD value can be reduced.

V. PROPOSED TOPOLOGY

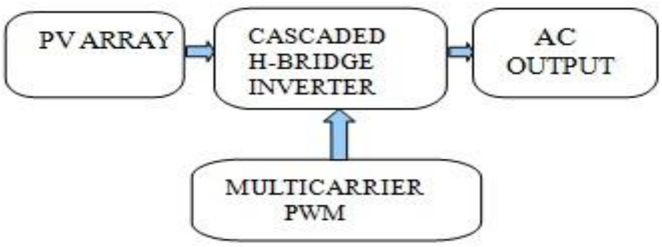

Fig.7.Block diagram of the proposed multilevel inverter

Fig.7. shows the block diagram of the proposed multilevel inverter. The PV array which is connected to the Cascaded H-Bridge Multilevel inverter converts sunlight directly into DC power. Cascaded H-Bridge multilevel inverter converts DC power into AC power for AC load and it is controlled by multicarrier PWM technique.

The Proposed Cascaded Multilevel Inverter is simply a number of conventional five-level bridges, whose AC terminals are simply connected in series to synthesize a five level square wave output voltage waveform. The circuit needs independent dc source which is supplied from photovoltaic cell. Fig.8. shows the power circuit for a single phase eleven level cascaded H-bridge inverter and the cascaded output is shown in fig.9.

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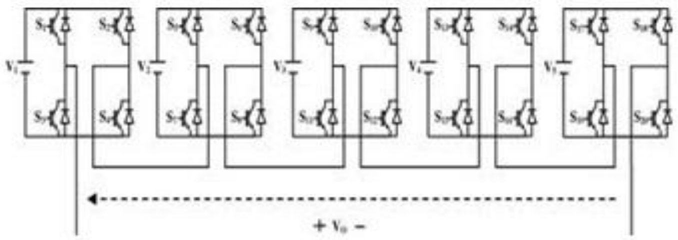
Fig.8. Proposed power circuit for an eleven-level inverter

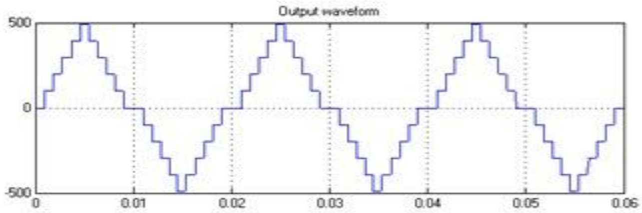

Fig.9.Output voltage waveform of an eleven level inverter

The switching angles of the waveform will be adjusted to obtain the lowest output voltage THD. Harmonics are disagreeable in current or voltage waveform. They exist at some fraction or multiple of the fundamental frequency. The harmonics order and magnitude are depending upon the type of inverter and the control techniques for example in single phase VSI, the output voltage waveform typically consists only of odd harmonics. The even harmonics are not existing due to the half wave symmetry of the output voltage harmonics. [9].

In this paper, the simulation model is developed using MATLAB/Simulink. The SIMULINK model for the power circuit is shown in figures.10.1, 10.2, 10.3 &10.4.

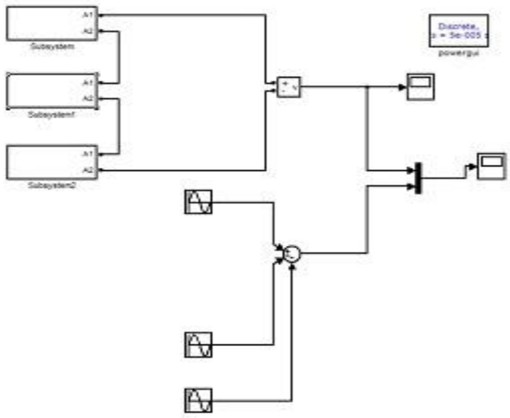
Fig.10.1.Simulation circuit of the proposed method

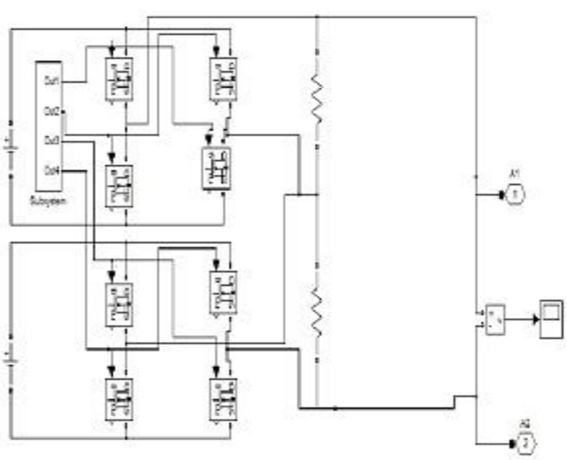
Fig.10.2.Sub circuit

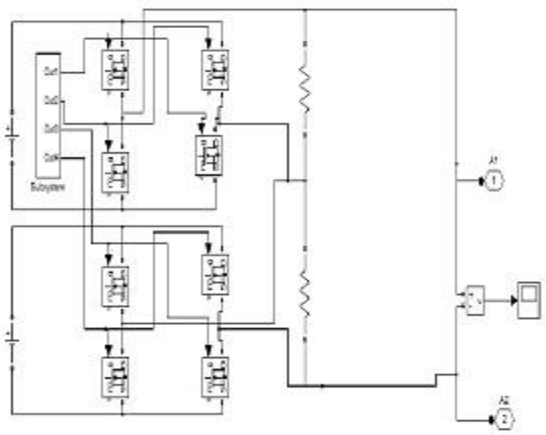

Fig.10.3.Sub circuit 1

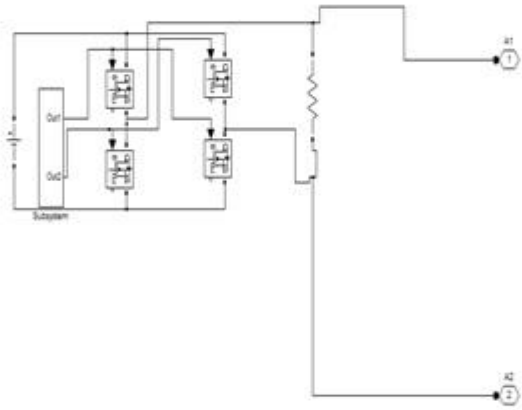

Fig.10.4.Sub circuit 2

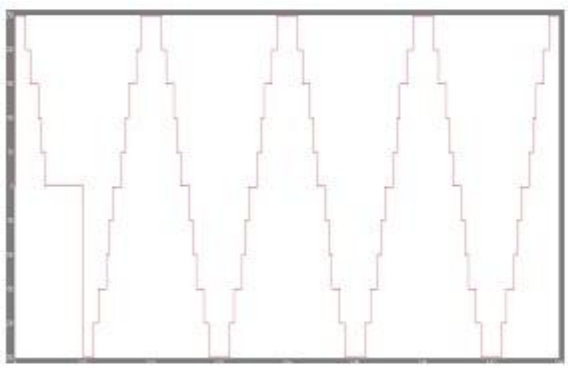

Fig.11.Output voltage waveform of the proposed method

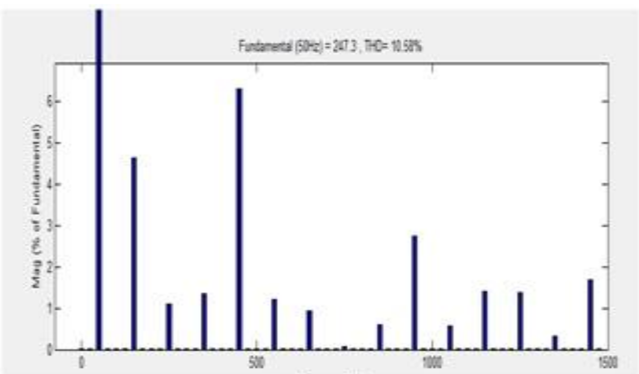

Fig.12.Harmonic spectrum

Fig.11.and Fig.12.shows the simulation results of output voltage and current harmonics spectrum waveforms respectively.

VI. CONCLUSION

In this work , a Photovoltaic cell based eleven level Cascaded H-bridge Inverter employing multicarrier pulse width modulation tehnique is developed which enhances the fundamental output voltage and hence reduces the total harmonic distortion to 10.58% compared to the conventional method .The operation and performance of the proposed multilevel inverter is verified through MATLAB/SIMULINK. It can be also shown for any number of phases or levels.

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