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Photovoltaic Based a 7- Level Multilevel Inverter with Reduced Number of Switches

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Abstract

Cascaded Multilevel Inverters are being used in Solar Photovoltaic Systems. In cascaded Multilevel Inverter more number of power semiconductor switching devices are required. Here in this paper another multilevel inverter with reduced number of semiconductor switches is discussed. Photovoltaic source is used and a mathematical model for the PV panel is developed and implemented with Multilevel Inverter, as these systems are becoming more widespread with the increasing energy demand and environmental friendly nature. For high voltage & high power applications, A Multilevel Inverter is a power electronic device that is used with the advantage of low switching stress and lower total harmonic distortion (THD).For 7- level Multilevel Inverter model, it uses 12 switches, whereas the proposed model uses only 9. The system will be modeled with the help of MATLAB / SIMULINK.

Keywords: *Photovoltaic System, Inverters, Multilevel Inverter (MLI), Reduced Switches Multilevel Inverter, PWM Technique, etc.*

1. Introduction

Renewable energy means energy from a source that is no depleted when use. The more renewable energy we use, the less fossil fuel are needed. It is a clean energy, environment friendly and contributes towards green and pollution free environment. Photovoltaic (PV) technology converts one form of energy (sunlight) into another form of energy (electricity) using no moving parts, consuming no conventional fossil fuels, creating no pollution, and lasting for decades with very little maintenance. The use of a widely available and reasonably reliable fuel source, the sun with no associated storage or transportationdifficulties and no emissions makes this technology eminently practicable for powering remote scientific research platforms. Indeed, numerous examples of successfully deployed systems are already available. The completely scalable nature of the technology also lends itself well to varying power requirements from the smallest autonomous research platforms to infrastructure-based systems. This technology can be limited, however, by annual fluctuations in solar isolation, especially at extreme latitudes.

Basically Inverter is a device that converts DC power to AC power at desired output voltage and frequency. Demerits of inverter are less efficiency, high cost, and high switching losses. To overcome these demerits, we are going to multilevel inverter. The term Multilevel began with the three-level converter. The concept of multilevel converters has been introduced since 1975. The cascade multilevel inverter was first proposed in 1975. In recent years multi-level inverters are used high power and high voltage applications .Multilevel inverter output voltage produce a staircase output waveform, this waveform look like a sinusoidal waveform. The multilevel inverter output voltage having less number of harmonics compare to the conventional bipolar inverter output voltage. If the multilevel inverter output increase to N level, the harmonics reduced to the output voltage value to zero. The multi-level inverters are mainly classified as Diode clamped, Flying capacitor inverter and cascaded multi-level inverter. The cascaded multilevel control methodis very easy when compare to other multilevel inverter because it doesn’t require any clamping diode and flying capacitor. There are two PWM methods mainly used in multilevel inverter control strategy. One is fundamental switching frequency and another one is high switching frequency.

In this paper the different parameters (like voltage, current, THD) in Single Phase Full Bridge Inverter, 7-level Cascaded Multilevel Inverter with reduced number of switches are observed. By these observations it can be seen that the total harmonic distortion is reduced with the increase in the levels of Cascaded Multilevel Inverter and also as the levels increases the output approaches to the sine wave.

2. Photovoltaic system

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.

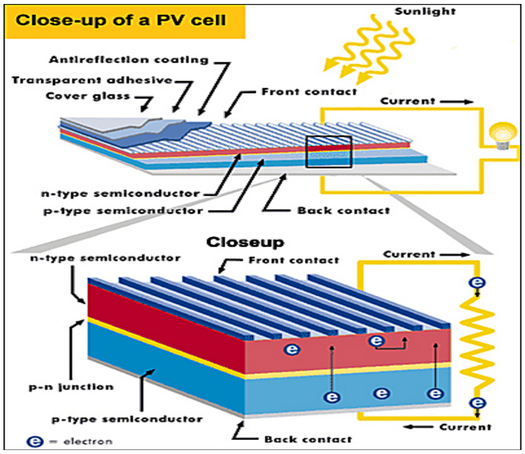

Figure1: Solar cell

Photons of light with energy higher than the band-gap energy of PV material can make electrons in the material break free from atoms that hold them and create electron and hole pairs. These electrons however, will soon fall back into holes causing charge carriers to disappear. If a nearby electric field is provided, those in the conduction band can be continuously swept away from holes toward a metallic contact where they will emerge as an electric current. The electric field with in the semiconductor itself at the junction between two regions of crystals of different type, called a p-n junction. The PV cell has electrical contacts on its top and bottom to capture the electrons. When the PV cell delivers power to the load, the electrons flow out of the n-side into the connecting wire, through the load, and back flows in the opposite direction from electrons.

3. Modeling of PV Array

PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Figure3.

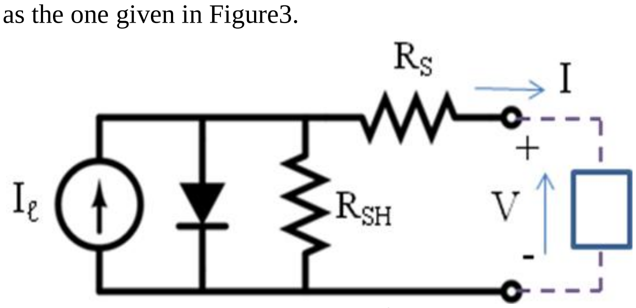

Figure3**:** Equivalent circuit for a PV cell

The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar Irradiation level during the operation.

$$Vc = \frac{AkT_c}{e} ln\left(\frac{I_{ph} + I_0 - I_c}{I_0}\right) - R_s I_c$$

Where the symbols are defined as follows:
e: electron charge (1.602 × 10-19 C).
k: Boltzmann constant (1.38 × 10-23 J/°K).
Ic: cell output current, A.
A: curve fitting factor used to adjust the I-V characteristics of the cell
Iph: photocurrent, function of irradiation level and junction temperature (5 A).
I0: reverse saturation current of diode (0.0002 A).
Rs: series resistance of cell (0.001 Ω).
Tc: reference cell operating temperature(20 °C).
Vc: cell output voltage, V.

If the temperature and solar irradiation levels change, the voltage and current outputs of the PV array will follow this change. Hence, the effects of the changes in temperature and solar irradiation levels should also be included in the PV array model.

4. Inverters

The inverter's main functions are: transformation of DC electricity into AC, wave shaping of the output AC electricity, and regulation of the effective value of the output voltage. The most important features of an inverter for PV applications are its reliability and its efficiency characteristics. They are designed to operate a PV system continuously near its maximum power point. The technology for high-switching-frequency inverters (typically 20 kHz or higher) is made possible by switch-mode semiconductor power devices. Power MOSFETs and bipolar transistors are used in low-power inverters, whereas thyristors are used in high-power applications. Novel devices, such as insulated-gate bipolar transistor (IGBT) inverters are capable of handling several hundred kW, running at frequencies up to 50 kHz. They deliver an AC output wave, which has a form very close to the pure sinusoidal one, with very little filtering at the output. This eliminates the bulky, expensive, and energy-consuming power filters.
Inverter interfacing PV module(s) with the grid involves two major tasks. One is to ensure that the PV module(s) is operated at the maximum power point (MPP). The other is to inject a sinusoidal current into the grid.

5. Sinusoidal Pulse-Width Modulation (SPWM)

With Sinusoidal Pulse-width modulation(SPWM) control, the switches of the inverter are controlled based on a comparison of a sinusoidal control signal and a triangular switching signal. The sinusoidal control waveform establishes the desired fundamental frequency of the inverter output, while the triangular waveform establishes the switching frequency of the inverter. The ratio between the frequencies of the triangle wave and the sinusoid is referred to as the modulation frequency ratio.

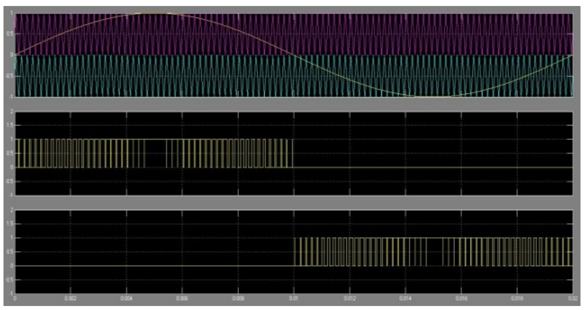

Figure 4: Sinusoidal Pulse-width modulation

6. Total Harmonic Distortion(THD)

Harmonics may cause degradation of equipment. Equipment need to be de-rated. Total Harmonic Distortion (THD) is a measure to determine the quality of a given waveform.

$$THDv = \frac{\sqrt{\sum_{n=2}^{\infty}(V_{n,RMS})^2}}{V_{1,RMS}} = \frac{\sqrt{\sum_{n=2}^{\infty}(V_{RMS})^2 - (V_{1,RMS})^2}}{V_{1,RMS}}$$

Where *n* is harmonic number

Current THD can be obtained by replacing the harmonic voltage with the harmonic current.

$$THDi = \frac{\sqrt{\sum_{n=2}^{\infty}(I_{n,RMS})^2}}{I_{1,RMS}}$$

$$I_n = \frac{V_n}{Z_n}$$

Zn is the impedance at harmonic frequency.

7. Cascaded H-Bridge Multilevel Inverter

A cascaded multilevel inverter uses set of series connected full-bridge inverters with separate DC sources in a modular setup to create the stepped waveform. A full bridge inverter is in itself a 3 level cascaded multilevel inverter and every module added in cascade to that extends the inverter with two more voltage levels, which then increases the number of steps in the waveform. A typical 5-level for a single phase leg is shown below. One can observe from here that it requires 8 switches. For a 7-level inverter model, it uses 12 switches, whereas the proposed model uses only 9.

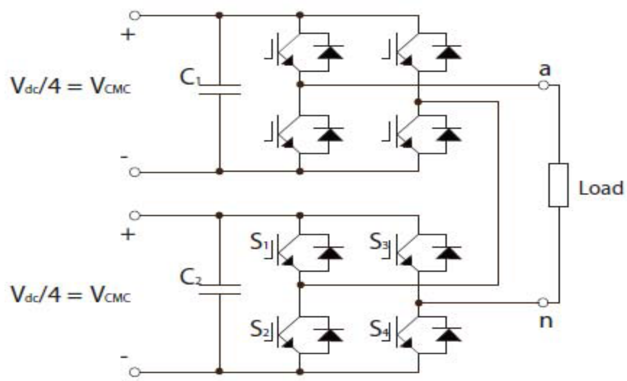

Figure 1. Typical 5-level cascaded multilevel inverter circuit.

The traditional two or three levels inverter does not completely eliminate the unwanted harmonics in the output Waveform. Therefore, using the multilevel inverter as an alternative to traditional PWM inverters is investigated. Cascaded H-bridge multilevel inverters typically use IGBT switches.

8. Multicarrier PWM Technique

Carrier based PWM Techniques has been extensively put to use in multilevel inverters. Multicarrier PWM Techniques are categorized in two groups namely Carrier Disposition methods (CD) and Phase Shifted (PS) PWM methods. In the CD-PWM method the reference waveform, in our case a sine wave of 50Hz is sampled through a number of triangular carrier waveforms displaced by contiguous increments of the reference waveform amplitude. In the PS-PWM methods, multiple carriers are phase shifted accordingly and compared with a reference sine wave. For this particular topology Phase Opposition Disposition (POD) method was selected for the simulation.

9. Reduced Switches Multilevel Inverter

The proposed topology has a set series connected smaller multilevel inverter blocks shown below. Switch S1 and switch S2 should be conducting at different instances in order to prevent any short circuit across the voltage source. Whenswitch S1 (S2 off) is turned on the output will be equal to Vdc and when S2 is turned on (S1 off) output voltage will be zero.

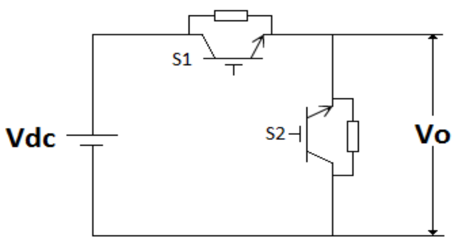

Figure 2.Basic multilevel inverter block.

A series connected set of basic multilevel inverter blocks will achieve a stepped waveform. Each of the power DC sources used is equal to Vdc; hence the circuit can also be described as a symmetrical multilevel inverter. Hence more power sources, more steps in the waveform. A more sinusoidal wave inverter will power devices and loads with more accuracy, leading to less power losses, consequently less heat generation. In this paper a 7-level inverter will be simulated in MATLAB/Simulink.

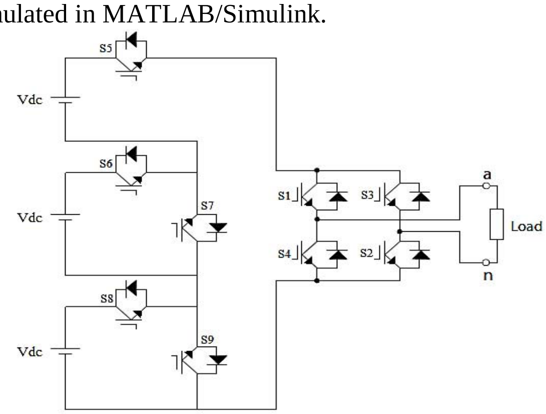

Figure 3: 7-level proposed topology.

Each smaller multilevel unit will produce a voltage of Vdc, therefore the Vo (overall maximum output voltage) will be equal to 3Vdc. To create both positive and negative voltage levels an H-bridge is added to the circuit. Three levels will appear in the positive half, three levels in the negative half, and including the zero level, a total of 7 levels can be generated. In “Fig. 3”, the total switch count is 9 for a seven level inverter, whereas for a conventional cascaded multilevel inverter it would be 12. With three switches being omitted in this topology the gate driver circuit count also drops down by three, reducing the complexity of the overall circuit.

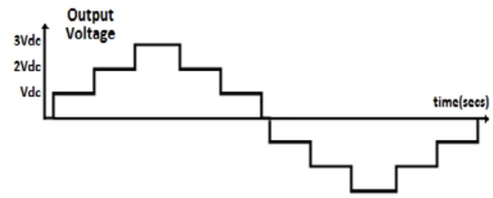

Figure 4: 7-level waveform.

In the H-bridge, switches in the same leg should not conduct simultaneously, appropriate gate pulses should be given in order prevent short circuit condition. The primary objective of this paper is to minimize the number power semiconductor devices of the conventional cascaded multilevel inverter. Each switch requires its own gate driver circuit. One can observe that with this suggested topology the number of switches utilized is less than the conventional cascaded multilevel inverter. It reduces the installation area, gate drivers needed, and consequently the cost of the whole setup.

Table 1: Switch States of Reduced Switches MLI

State	***Switch states***					***Output voltage***
	S5	S6	S7	S8	S9	
1	ON	OFF	ON	OFF	ON	Vdc
2	ON	ON	OFF	OFF	ON	Vdc+Vdc
3	ON	ON	OFF	ON	OFF	Vdc+Vdc+ Vdc

10. Simulation Results

The simulation model of Reduced Switches Cascaded 7-level MLI of designed using MATLAB/SIMULINK Software. The gating signals for the inverter are generated by using multicarrier modulation technique. The circuit was simulated with RL load. The simulation parameters are shown in below table 2

Table 2: Simulation Parameters

Sr.No	***Items***	***Values***
1	PV array parameters	Pmax- 60 W Voc- 22 V Isc- 3.75 Amp
2	LOAD(RL load)	P- 1000 W Q- 500 VAR
3	Inverter switching frequency	5 KHz
4	Inverter output frequency	50 KHz

Here in this section simulation results and observations of Photovoltaic Application based 7- level Cascaded MLI with Reduced No. of Switches is presented. The different parameters (like voltage, current, THD) are observed. Figure 5 shows the MATLAB Model of Photovoltaic based 7- level Cascaded MLI with reduced no. of switches

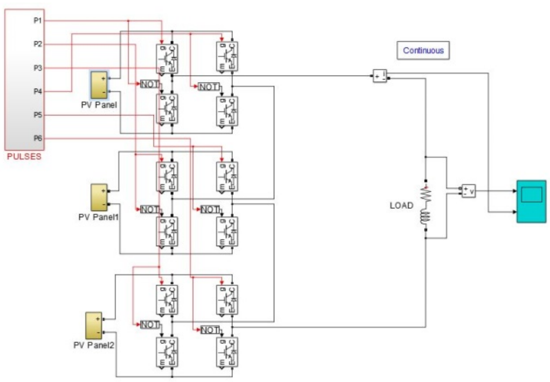

Figure 5: MATLAB model of 7- level Cascaded MLI

Figure 6 shows output voltage and current of 7- level cascaded MLI and Figure 7 and Figure 8 shows THD spectrum of voltage and current for Cascaded 7- level MLI.

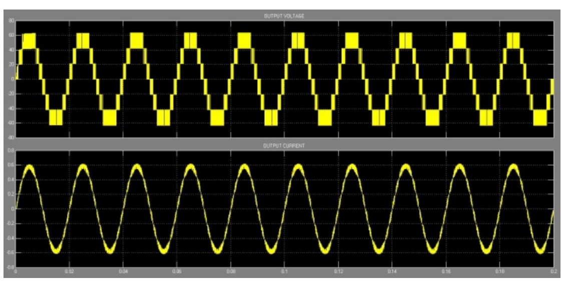

Figure 6: Output voltage and current of 7- level Cascaded MLI

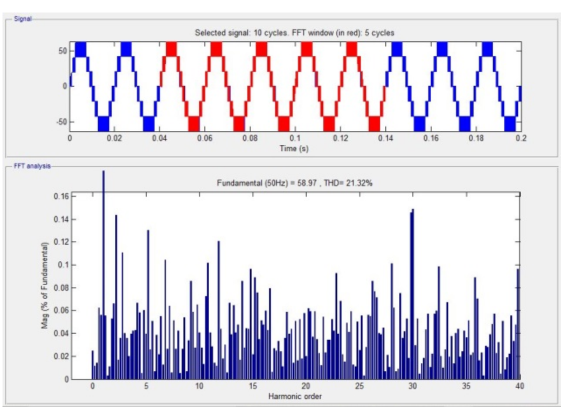

Figure 7: THD spectrum of voltage for 7- level Cascaded MLI

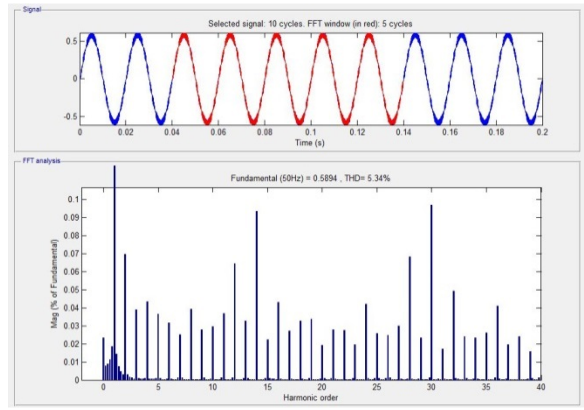

Figure 8: THD spectrum of current for 7- level Cascaded MLI

Figure 9 shows the MATLAB model of Cascaded 7- level MLI with reduced number of switches. Figure 10 shows the output voltage and current of Reduced Switches Cascaded 7- level MLI.

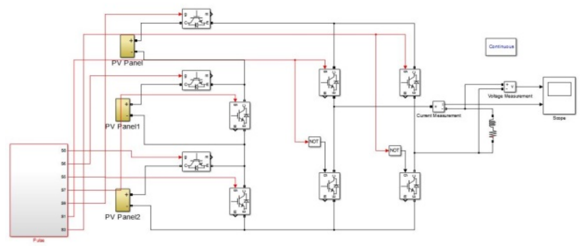

Figure 9: MATLAB model of 7- level Reduced Switches Cascaded MLI

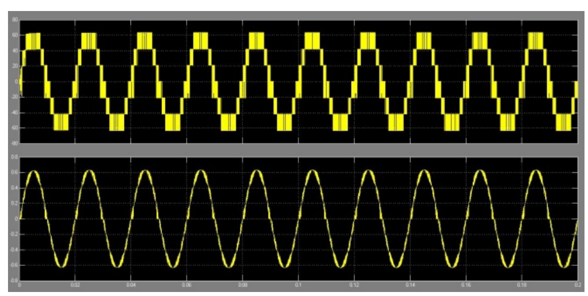

Figure 10: Output voltage and current of 7- level Reduced Switches Cascaded MLI

Figure 11 and Figure 12 shows the THD spectrum of voltage and current for Reduced Switches Cascaded 7- level MLI.

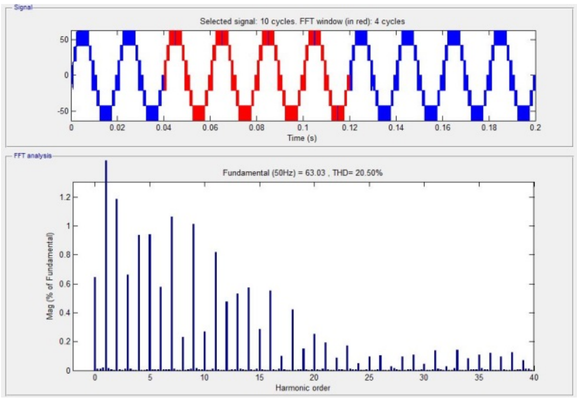

Figure 11: THD spectrum of voltage for 7- level Reduced Switches Cascaded MLI

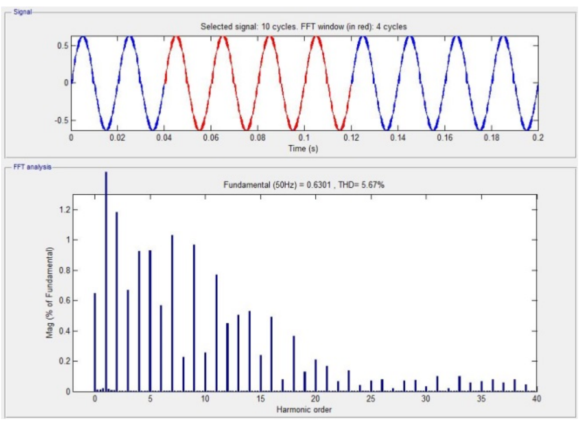

Figure 12: THD spectrum of current for 7- level Reduced Switches Cascaded MLI

10. Conclusion

Photovoltaic based applications are increasing day by day. Since most of the electrical application are in AC, so some efficient Power Electronics DC to AC converters are required for converting photovoltaic DC output to AC. In this paper a Photovoltaic application based 7- level Cascaded MLI has been shown to produce an increased stepped output with less number of semiconductor switches, and due to which controlling the overall circuit becomes less complex, the size and installation area reduces.A single phase Photovoltaic Array fed Cascaded H-Bridge MLI with Reduced number of Semiconductor Switches is simulated in MATLAB / SIMULINK environment.It is inferred with the help of simulation results the Multicarrier PWM techniques produced a lower THD than with PWM technique involving the comparison between triangular and constant values.

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