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9-LEVEL CASCADED MULTILEVEL INVERTER WITH MULTICARRIER PULSE WIDTH MODULATION TECHNIQUE

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ABSTRACT

The multilevel inverters generate low harmonic waveforms at the output voltage when compared with the conventional inverters. The Conventional inverters makes the load failure due to high harmonic distortion. This can be overcome in multilevel inverters which makes effective supply of high power to the loads and provides harmonic compensation. Renewable energy sources such as the photovoltaic cells are used as input due to increasing energy demand. The above said objectives is said to achieve by introducing a single phase hybrid multilevel inverter by cascading a full bridge cell and a half bridge cell. The capacitors in the half bridge cell performs the work of balancing the voltage at variable load. The multicarrier PWM techniques here produces 9-levels at the output. The simulations would demonstrate the efficiency of the cascaded multilevel inverter presented here.

INTRODUCTION

Renewable energy sources are of great significance which are supplied to the grid. The electrical energy consumption is globally still rising, increasing the power capacity. The power production and distribution using the renewable energy is technologically increasing with the incentives of saving energy at end-user and is working as challenges for scientists and industries. The Renewable sources include solar, wind, biomass, hydro,etc . One of the sources are interfaced into the power production which produces increased reliability, security, flexibility, low power losses and increased power quality. This needs number of power generators and transmitting lines as the energy demand is still increasing. Photovoltaic is converting solar energy into direct current electricity. Photovoltaic mounting systems are used to fix solar panels on surfaces such as roofs, building facades, or the ground. The solar array of a PV system can be mounted on rooftops. An useful and regulated AC voltage is obtained from DC voltage using a single phase inverter.

Power electronic converters are capable of generating AC voltage from DC sources produced by Photovoltaic cells. These DC sources are given by the photovoltaic panels. A new hierarchy of Multilevel inverters are introduced for overcoming the high Total Harmonic Distortion produced by other 2 or 3 level conventional inverters. Due to the reduced cost of semiconductor switches and combination of DC sources this has been very useful to many industries. The output produced by the multilevel inverters has more levels resembling like a double sided staircase waveform which almost closely attains a sinusoidal waveform.

The most popular multilevel inverter topologies which are been manufactured by big companies are: **Cascaded H Bridge (CHB)** and **Neutral Point Clamped(NPC).**Photovoltaic systems support greatly for Domestic loads which has been provided various topologies by Single- Phase Multilevel inverter. Since this uses the concept of multilevel inverter complicated switching techniques to produce respective pulses. Voltage balancing feature is a special characteristic of this system which is being developed by multilevel SVM. Multilevel inverter faces the main challenge of using less number of DC sources, switches in order to reduce the complication and to increase the number of capacitors for balancing the load, however the load changes. This produces high voltage in the output.

This paper proposes a 9-level hybrid multilevel inverter using one full bridge cell and half bridge cells. These are implemented by cascading the full bridge and half bridge cells unlike the CHB. PWM strategy using lesser number of switches as the conventional inverter uses more number of

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switches. The control strategy of the capacitors in the half bridge cells has the capability of balancing the load voltage irrespective of the load changes. Section II includes the explanation of existing 7-level Cascaded H Bridge inverter. The proposed 9-level cascaded hybrid multilevel inverter is explained in the Section III. Finally some simulations are performed using Matlab/Simulink to show the efficiency of the proposed inverter.

Existing Cascaded H Bridge

One phase of a seven-level CHB topology is shown in figure1. CHB includes full-bridge single-phase inverter as a cell that generates five voltage levels (+2Vdc,+Vdc, 0, -Vdc, -2Vdc). This uses more number of cells and switches with equal or unequal DC sources.

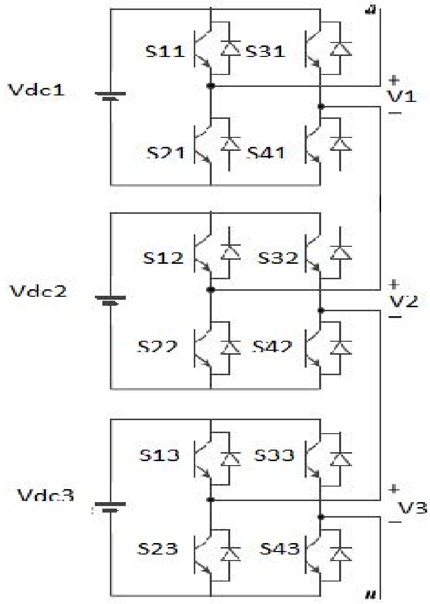

Figure 1 7-Level single phase CHB

This type of connection produces more voltage in the output and reduces the harmonics. If the number of cells is m then the output levels produced is going to be 2m+1.The output voltage is going to be

Van=V1+V2+V3
Where,V1, V2, V 3 are output voltages of each cell and Van is going to be the phase voltage.
If two equal sources are used as follows:
Vdc1=Vdc2= Vdc2=E
Then the output voltage will have five levels including 0,±E, ±2E, ±3E

This system consists of more number of switches which makes the system bulk and produces more voltage only on using more switches and does not balance the voltage irrespective of the voltage.

Proposed Multilevel Inverter

This shows that not only the inverter with Cascaded H Bridge using full bridge cells can produce multilevel output voltages but also the inverter with both full bridge and half bridge cells can also produce the desired multilevel output. To show the extensibility of the proposed inverter, one more half-bridge has been added. The half-bridge cells Generate ±Vdc at the output and full bridge cell produces 0, ±Vdc levels. The combination of these levels is a seven level output voltage including 0,±Vdc,±2Vdc,±3Vdc.
Van=V1+V2+V3

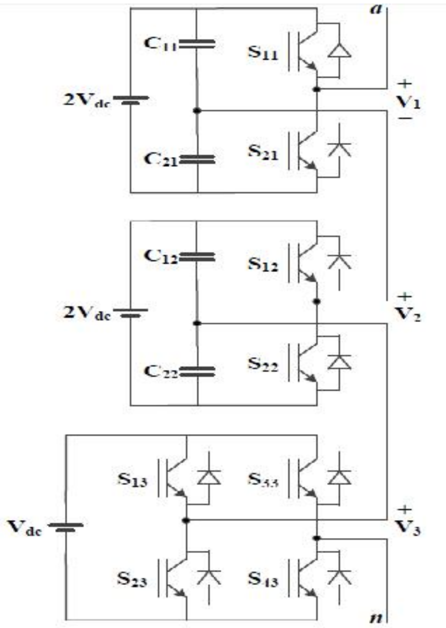

Figure 2 Proposed hybrid seven-level inverter

This is a new combination of cascaded half bridge cell and full bridge cell inverter, which has reduced the number of switches as eight switches and three DC sources are used to generate seven-level voltages of Van. The switching states are shown in table. The redundancy states are not mentioned in the below table, approaches. Because it is clear that it has more switching states generating same voltage at the output.

SWITCHING STATES OF THE HYBRID SEVEN-LEVEL INVERTER

S_{11}	S_{21}	S_{12}	S_{22}	S_{13}	S_{23}	S_{33}	S_{43}	V_1	V_2	V_3	V_{an}
1	0	1	0	1	0	0	1	$+V_{dc}$	$-V_{dc}$	$+V_{dc}$	$-3V_{dc}$
1	0	1	0	1	0	1	0	$+V_{dc}$	$-V_{dc}$	0	$-2V_{dc}$
1	0	1	0	0	1	1	0	$+V_{dc}$	$-V_{dc}$	$-V_{dc}$	$+V_{dc}$
1	0	0	1	1	0	1	0	$+V_{dc}$	$-V_{dc}$	0	0
0	1	0	1	1	0	0	1	$-V_{dc}$	$-V_{dc}$	$+V_{dc}$	$-V_{dc}$
0	1	0	1	1	0	1	0	$-V_{dc}$	$-V_{dc}$	0	$-2V_{dc}$
0	1	0	1	0	1	1	0	$-V_{dc}$	$-V_{dc}$	$-V_{dc}$	$-3V_{dc}$

Table1 Switching states for 7-level hybrid inverter

This is the extension of the above said Hybrid 7-level inverter with 4 DC sources. This greatly reduces the Total Harmonic distortion up to 5%, which benefits the users such as industries and houses. This involves 10 switches with capacitors as it considers the voltage sharing feature in between the half bridge cells.

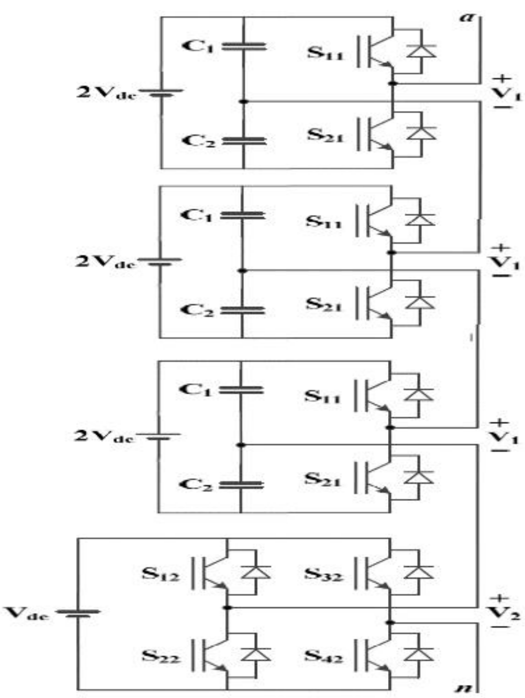

Figure 3 Hybrid 9-level inverter with 7 DC sources

This multilevel inverter has four DC sources and 10 switches that can generate nine level voltages at Van while using three equal sources as:

Vdc1=Vdc2=Vdc3= Vdc4=E

In this topology three DC sources Vdc1, Vdc2 and Vdc3 must be identical to have appropriate waveform at the output which will include 0, ±E, ±2E, ±3E, ±4E This topology has been mentioned earlier in three-phase with independent DC supplies.

This topology can be simply modeled as below

The switching functions are defined as the following

Output voltage (Vo)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
0	0	1	0	1	0	1	0	1	0	1
V_{dc}	1	1	0	0	0	1	0	1	0	1
$2V_{dc}$	1	1	0	0	1	1	0	0	0	1
$3V_{dc}$	1	1	0	0	1	1	0	0	1	1
$4V_{dc}$	1	1	0	0	1	1	0	0	1	1
$-V_{dc}$	0	1	0	1	0	1	0	1	0	1
$-2V_{dc}$	0	1	0	1	0	1	0	1	0	0
$-3V_{dc}$	0	1	0	1	0	0	1	1	0	0
$-4V_{dc}$	0	0	1	1	0	0	1	1	0	0

Table.2 Switching states for 9-level hybrid inverter

Proposed Multicarrier PWM Technique

In this section the multicarrier PWM technique is designed which will be different from the one usually used for CHBs[17]due to the fact that the half-bridge cell will not generate zero level so to obtain this level at the output, combination of positive and negative voltages of two cells are added at the output. In a nine-level inverter eight offset carriers are required to generate appropriate pulses and command the switches to have desired voltage level at the output. As shown in figure 5, these eight carriers' waveforms (Cr1 to Cr4) are shifted vertically to cover the reference sinusoidal wave In standard multicarrier PWM method, the carriers from top to bottom have the responsibility to generate pulses with highest voltage level to the lowest one using a simple comparator. But as said above, the required pulses for implementing the half-bridge cell need some modification.

To balance the capacitors voltages (C1, C2), it should be noted that when the C1 is connected to the load, the DC source charges C2 while C1 is discharging. On the other hand, when C2 is connected to load to produce negative voltage at the half bridge cell output, the C1 is charged and C2 is discharging.

The C1 voltage (Vc1) can be measured with a voltage sensor and sends it to the switching input which controls the charge and discharge times results as well as balances two capacitors voltages. Each capacitor should have its value equals to Vdc. Thus changing the switching pattern supports them to maintain the suitable charging level.

It is important to note the zero level voltage generation and divide third rule into two sub-items. *Sij*=1 shows the switch should be ON and the other switches behave in complementary manner of the other ones.

The designed switching technique also uses the switching patterns in which the switching frequency will be kept low and constant. A feedback from the higher capacitor voltage will be sent to the switching technique which helps for the betterment of the circuit.

SIMULATION AND RESULTS

The proposed hybrid five-level inverter shown in figure 3 has been simulated in Matlab/Simulink as a single-phase inverter supplying an RL load. The designed switching technique has been applied on the inverter to produce the appropriate of five levels.

Load Voltage Frequency	60 Hz
Switching Frequency	2 KHz
C_1& C_2	1 mF
DC Voltage	150 V
Load Resistance	40 Ω
Load Inductance	20 mH

Table 3 Simulation Parameters

The identical voltage levels prove the efficiency of the voltage balancing plan. The THD of the output voltage is demonstrated. The harmonic analysis of the output (load) voltage waveform shows good performance of the inverter and switching technique in eliminating the low harmonics. The only prominent harmonic order in figure 7 is related to the switching frequency which is 2 KHz

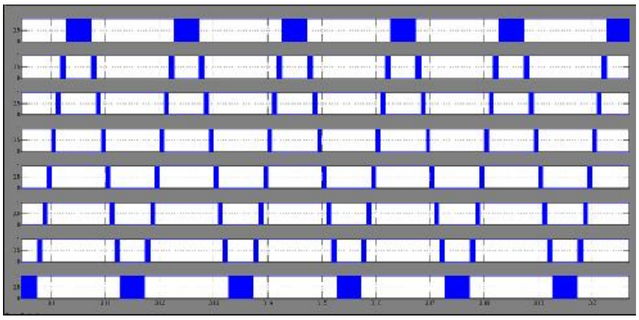

Figure 4 9-Level load voltage

Fundamental (60Hz) = 135.85, THD= 5.18%

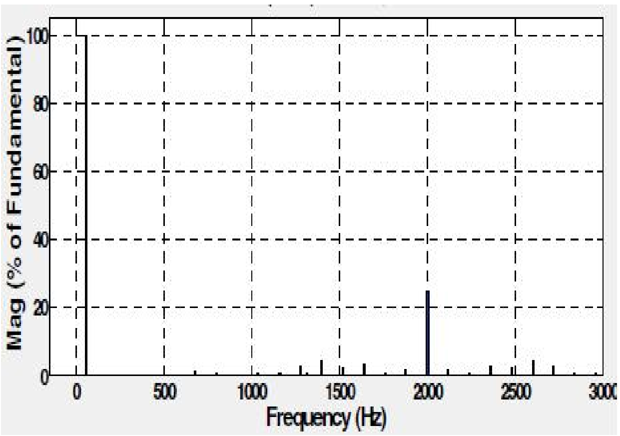

Figure 5 Harmonic Analysis of output voltage waveform

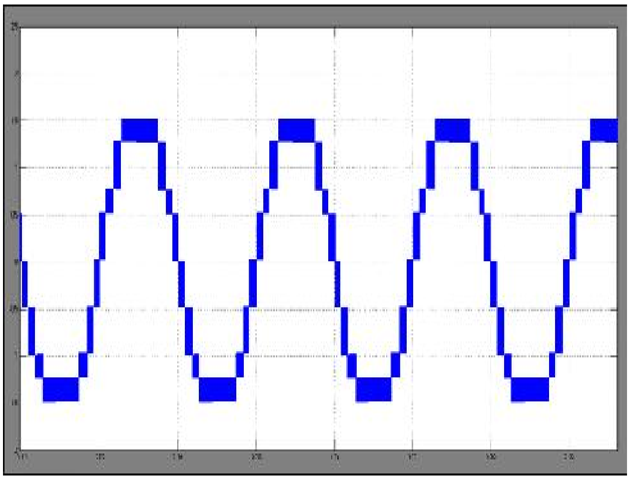

Figure 6 Harmonic analysis of Load current

The load current is shown in figure 8 which is sinusoidal with THD of 0.518 %. In order to validate the efficiency of the voltage controller combined with switching technique, another simulation has been performed with change in the load values. In this case, a 40Ω series resistor has been added to the load for about 0.5 second and disconnected again. The equal load would be 80 Ω and 20 mH during the variation. Therefore, the load current will be decreased and the load voltage should remain unchanged. As it is expected, figures 9 include the desired results of the load voltage and current waveforms respectively. There is a change in current and no variation in the voltage waveform.

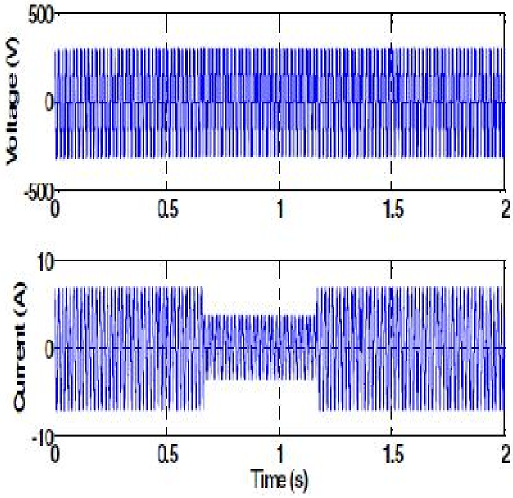

Figure 7 Load voltage during change in the load

CONCLUSION

The 9-level Cascaded Hybrid Multilevel inverter greatly supports for the usage of all domestic appliances and Industrial applications. Also it reduces THD almost to the minimal level and also uses the solar power greatly. The Total Harmonic Distortion which is affects the output voltage obtained is minimized to a significant level.

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