International Journal of Renewable Energy Technology Research
Vol. 2, No. 4, April 2013, PP: 138 - 143, ISSN: 2325-3924 (Online)
Available online www.ijretr.org

Research article

SINGLE PHASE MULTI STRING FIVE LEVEL INVERTER FOR DISTRIBUTED ENERGY SOURCES

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Abstract

Single phase DC/AC power conversion is necessary for distributed energy resources. In the conventional system, the DC/AC power conversion is done with cuk derived inverter with single DC source. In order to interface more than single dc source with DC/AC power conversion system, a multi string high step up boost converter with five level inverter is proposed. Instead of using two converters such as fly-back and cuk converter, a simple boost converter and instead of using conventional full bridge inverter, a five level inverter with six power switches are introduced to improve the power conversion. The five level inverter is operated with reduced voltage stress, switching loss and harmonics. MATLAB simulation validates the performance of the proposed system.

Index terms: DC/AC power conversion, boost converter, five level inverter.

I. INTRODUCTION

Nowadays, Distributed Generation (DG) technologies are increasing because of its environment friendly technology. Distributed Generation has advantages as less impact on global warming; In particular, DG resources such as photovoltaic, wind energy system and fuel cell systems have been widely promoted and deployed in many countries. These DG systems are used either to deliver electrical power to the utility grid or used as stand-alone power supplies in remote area. Solar cells or fuel cells, batteries, and ultra capacitors are low-voltage dc sources, hence, a high voltage gain dc/ac power conversion interface is essential and many dc/ac converter topologies have been proposed and reviewed recently. Naturally, the simplest way of solution is to use a high turn-ratio isolation transformer. However, this will induce both voltage/current spikes and rather high losses due to the existence of leakage inductance. A fly back-type auxiliary circuit is integrated with an isolated Cuk-derived voltage source inverter to achieve a much higher voltage conversion ratio. Due to the capacitive voltage dividing, the dc-side switch voltage stress can be reduced, and lower voltage rating devices can be used to further reduce both switching and conduction losses. The proposed multi string five level inverter achieves a much higher voltage gain than the conventional system. In this paper, the converter switching losses and conduction losses will be reduced. First, a review of conventional single stage DC/AC converter with single dc source is given in Section II. The topology of high step up converter stage is explained in Section II. The topology and operation principle of the proposed multi string five level inverter are presented in Section III. In Section IV, some simulation results are also given. Finally, conclusions are offered in the last section.

II. SINGLE STAGE DC/AC CONVERTER

A fly back-type auxiliary circuit is integrated with an isolated Cuk-derived voltage source inverter to achieve a much higher voltage conversion ratio. Due to the capacitive voltage dividing, the dc-side switch voltage stress can be reduced, and lower voltage rating devices can be used to further reduce both switching and conduction losses. Here, the system is operated with single dc source. The 30v dc input voltage is supplied to cuk derived inverter. In this system, the dc voltage obtained from cuk derived converter 230V is applied to the full bridge inverter then 230V ac is given to the R load with 500 ohm. The switching voltage 230V appears across two pair of switches S_1, S_5 and S_2, S_4. The voltage stress is high.

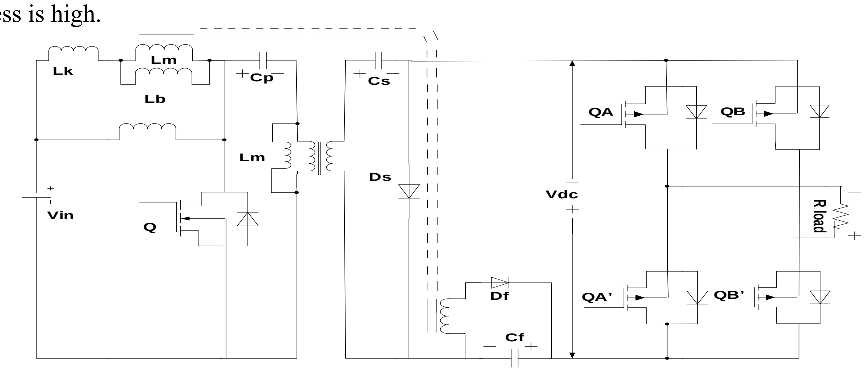

Figure 1: conventional single stage DC/AC converter

III. MULTI STRING FIVE LEVEL INVERTER

A. High Step Up Converter Stage

The coupled inductor of the high step-up converter in Fig. 2 can be assumed as an ideal transformer. The voltage of the primary winding can be derived as

$$V_{Pri} = V_{in} (D/ 1\text{-}D) \quad 1$$

Where V_{pri} represents the primary voltage, and V_{in} represents input voltage supplied to the converter stage, and D denotes the duty ratio.

In this paper, a high step-up converter topology is introduced to boost and stabilize the output dc voltage of various DERs such as PV and fuel cell modules el inverter. The high step-up converter is shown in Fig. 2, and is composed of different converter topologies: boost, flyback, and a charge-pump circuit.

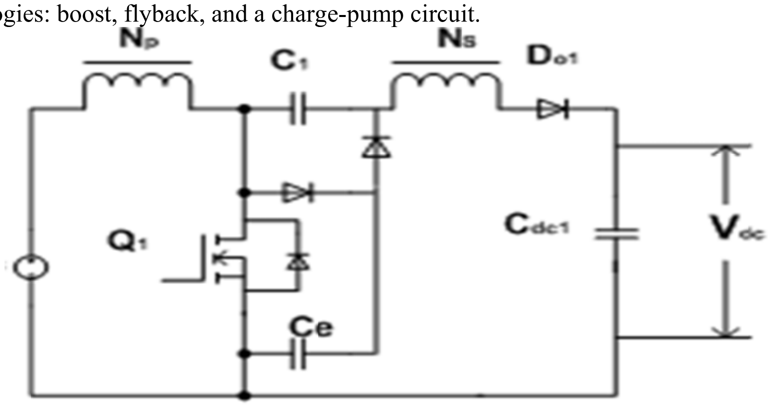

Figure 2: high step up converter

B. Five level inverter

This paper presents a multi string five level inverter for DERs application. The multi string five level inverter shown in Fig.3 is used to interface strings is interfaced with their own dc/dc converter to a common inverter. This centralized system is beneficial because each string can be controlled individually.

This topology configuration consists of two high step-up dc/dc converters connected to their individual dc-bus capacitor and a simplified five level inverter. Input sources, DER module 1, and DER module 2 are connected to the inverter followed a linear resistive load through the high step-up dc/dc converters. It offers strong advantages such as improved output waveforms, and reduced THD. It should be noted that, by using the independent voltage regulation control of the individual dc-dc converter, voltage balance control for the two bus capacitors C_{dc1}, C_{dc2} can be achieved naturally.

The switching function is defined as follows:

S_j= 1, switch is on,

0, switch is off. Where j=1, 2, 3, 4, 5, 6.

The operation modes of five level inverter are described as follows.

1. *Maximum positive output voltage 2V_s*: Switches S_1, S_4, S_6 are on. The voltage applied to the load is +2V_s.
2. *Half level positive output Vs*: the output voltage can be obtained by two different switching combinations. In the first combination, S_2, S_3, S_4 are on. In the other combination, the active switches S_1, S_2, S_6. The output voltage supplied to the load is +V_s.
3. *Zero ouput 0*: This output condition can be formed by either of the two switching structures. If the left or right switching leg is on, the load terminal will be short circuited. And the voltage applied to the load terminal is zero.
4. *Half level negative output V_s*: The output voltage can be obtained by two different switching combinations. In the first combination, active switches S_1, S_5, S_6 are on. In the other combination, the active switches S_3, S_4, S_5. The output voltage supplied to the load is -V_s.
5. *Maximum positive output voltage 2V_s*: during this stage, active power switches S_1, S_4, S_6 are on. The voltage applied to the load is -2V_s.

In these operations, it can be observed that the open voltage stress of the active power switches S_1 , S_3 , S_4 , and S_6 is equal to input voltage V_S ; moreover, the main active switches S_2 and S_5 are operated at the line frequency. Hence, the resulting switching losses of the new topology are reduced naturally, and the overall conversion efficiency is improved.
To verify the feasibility of the single-phase five-level inverter, a widely used software program MATLAB is applied to simulate the circuit according to the previously mentioned operation principle. The control signal block is shown in Fig. 3; $m(t)$ is the sinusoidal modulation signal. Both V_{tri1} and V_{tri2} are the two triangular carrier signals. The peak value and frequency of the sinusoidal modulation signal are given as m_{peak} = 0.8 and f_m = 50 Hz, respectively. The peak-to-peak value of the triangular modulation signal is equal to 1, and the switching frequency f_{tri1} and f_{tri2} are both given as 1.5 kHz.
The two input voltage sources with 17V are feeding from the high step-up converter is controlled at 115 V, i.e. V_{s1} = V_{s2} = 115 V. The simulated waveform of the phase voltage with five levels is shown in Fig. 7. The switch voltages of S_1, S_2, S_3, S_4, S_5, and S_6 are all shown in Fig. 6. It is evident that the voltage stresses of the switches S_1 , S_2 , S_4 , and S_6 are all equal to 115 V, and only the other two switches S_2 , S_5 must be 230 V voltage stress. The high switching frequency of the dc side switches are 5KHz.
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The switch voltages of S_1, S_2, S_3, S_4, S_5, and S_6 are all shown in Fig. 6. It is evident that the voltage stresses of the switches S_1, S_2, S_3,and S_4 are all equal to 115 V, and only the other two switches S_2, S_5 must be 230V voltage stress. The switching power losses of the conventional and proposed system are given as,

P_s, conventional α $4V_S f_S$ 2

P_S, proposed α $4V_S f_S + 2(2V_S)\, f_m$ 3

Table I switching configuration for inverter stage

S_1	S_2	S_3	S_4	S_5	S_6	V_{AB}
0	1	0	1	0	1	+2Vs
0	1	1	1	0	0	+VS
1	1	0	0	0	1	+V_S
1	1	1	0	0	0	0
0	0	0	1	1	1	0
1	0	0	0	1	1	-V_S

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0	0	1	1	1	0	$-V_S$
1	0	1	0	1	0	$-2V_S$

P_S, proposed α $4V_Sf_S$ 4

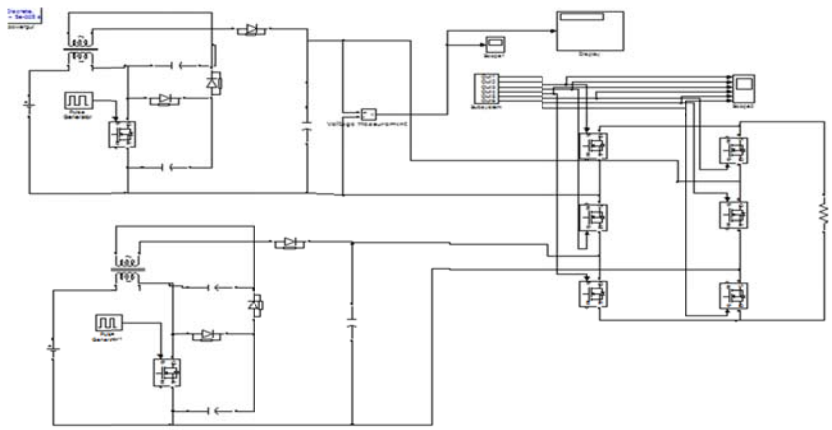

Figure 4: Single phase multi string five level inverter

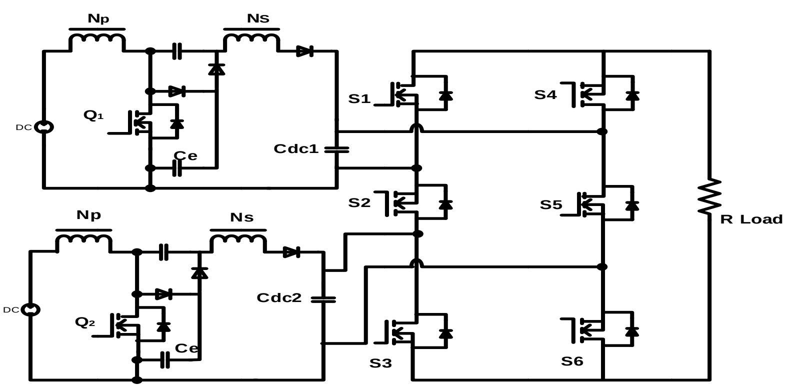

Figure 5: overall implementation of proposed system

V. SIMULATION RESULTS

The gate pulses for the switches S_1, S_2, S_3, S_4, S_5, and S_6 can be generated by modulation technique as shown in the figure 5. Two carrier signal with same amplitude and one reference signal (sine wave) used in this scheme in order to obtain the triggering pulse for both upper and lower group MOSFET switches of five level inverter. The pulses for middle switches S_2, S_4 are obtained by using relay.

Table II component parameters of multi string five level inverter

Components	**Symbol**	**Value**
Coupling inductor	N_s:N_p	1.02
capacitors	C_{pump}	4.7µH

Bus capacitors	C_{dc1}, C_{dc2}	200µH/100V
Load Resistance	R_{load}	100Ω

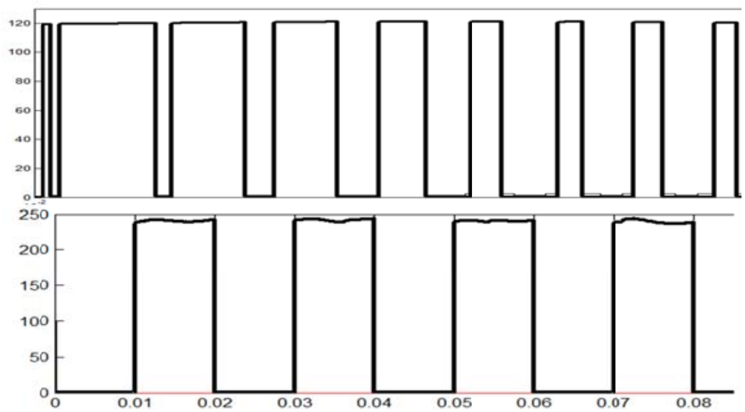

Figure 7: voltage stress across switches S_1, S_2

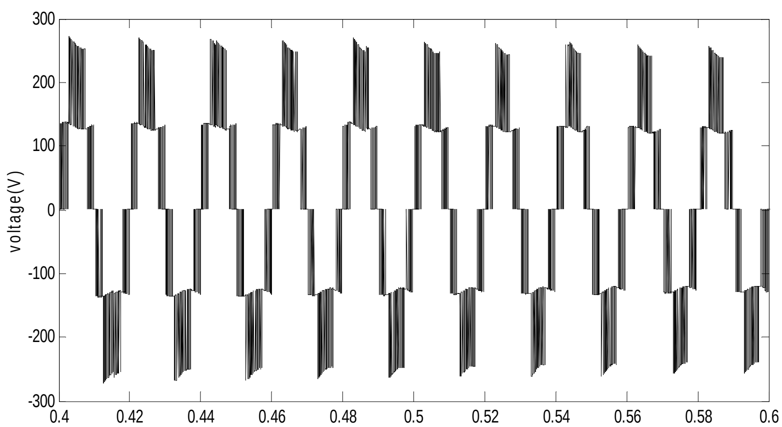

Figure 8: Load Voltage V_{AB} of five level inverter

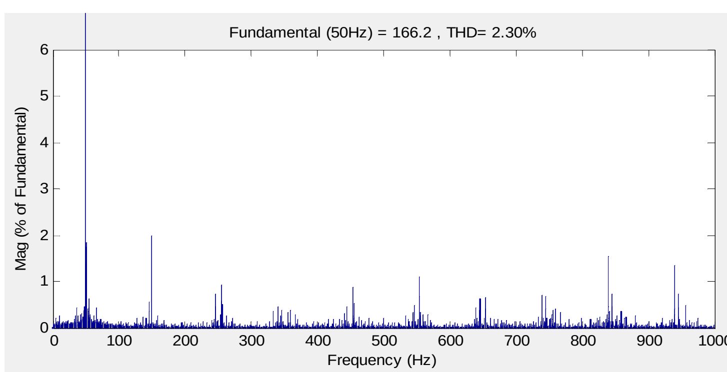

Figure 9: THD of proposed system

VI. CONCLUSION

In this paper, a high voltage gain single-phase multi string five level inverter is proposed for DER applications. The proposed system has a significant reduction in the number of power devices required to implement five level output for DERs. The studied inverter topology ensures advantages such as improved output waveforms and reduced THD. Simulation results show the effectiveness of the proposed system.

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