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Grid interconnection of PV system based on interleaved boost converter and combined cell cascaded multi level inverter

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Abstract- In recent years, renewable energy sources such as photovoltaic (PV), wind, fuel cell, etc gain importance due to the limitations of conventional energy sources. Renewable energy sources play an important role in rural areas where the power transmission from conventional energy sources is difficult. Other advantages of renewable energy sources are clean, light and does not pollute atmosphere. In order to meet the required load demand, it is better to integrate the renewable energy sources with the grid. The grid interconnection of PV system requires a boost converter for stepping up of low voltage dc and an inverter to converter this high voltage dc into ac voltage. This paper proposes a grid interconnection of PV system using two phase interleaved boost converter (IBC) and combined cell cascaded multilevel inverter (MLI). The working of IBC is, same as that of conventional boost converter, but it has coupled inductor, one extra switch and diode to achieve interleaving technique. The advantages of IBC are high efficiency, low current ripple, faster transient response and improved reliability. The output voltage obtained from the IBC is converted into AC voltage by using cascaded cell multilevel inverter with reduced number no of switches. Combined cell cascaded MLI with five switches and four diodes is designed in this paper to achieve five-level output voltage. The proposed scheme is simulated and results are obtained using MATLAB/SIMULINK software.

***Keywords*- PV, interleaved boost converter, combined cell cascaded MLI, grid interconnection.**

I. INTRODUCTION

Fossil fuels are energy sources such as coal, oil and natural gas. The world virtually depends on the supply of fossil-fuel for energy. But the common issue is that fossil-fuels are running out. It would take millions of years to completely restore the fossil fuels that we have used in just a few decades. This means fossil fuels are non-renewable sources of energy. Renewable energy comes in as a resolution for this global issue. Renewable energy is any natural source that can replenish itself naturally over a short amount of time. As green renewable energy resources such as Photovoltaic (PV) system have gained great acceptance as a substitute for conventional costly and scare fossil fuel energy resources.

In this paper, a PV system for grid connection is proposed. PV produces low voltage dc output but grid interconnection of this system requires power converters to meet the grid requirements like voltage amplitude, frequency, and phase angle. First convert the low voltage dc into high voltage dc by using boost dc-dc converter and then convert this dc voltage into ac by using inverters and finally connect the whole system to grid. This type of system (dc-dc and dc-ac conversion) is called two stage conversion system. Conventional dc-dc boost converter has the following disadvantages

- When a large duty ratio is required for a large voltage boost, which places a practical limit on the achievable voltage step-up due to the large volume and weight of the required capacitance.
- Furthermore, since both dc and ac current are being sourced through the inductor, the inductor must be designed such that the cores will not saturate during high power operation.

In order to address the above concerns, an interleaved design involving parallel operation of two boost converters, is going to evaluate as a means to reduce the burden on the output capacitor and weight of the inductor. In IBC, we are using coupled inductor, where a core is shared by multiple converters instead of using multiple discrete inductors, offers a potential approach to reducing parts count, volume, and weight. Coupled inductor topologies can also provide additional advantages such as reduced core and winding loss as well as improved input and inductor current ripple characteristics. Once the high voltage dc obtained from the IBC, it is converted to AC by using an inverter to interface with the grid. Conventional multi level inverter requires more number of switches for their operation. Due to large number of switches, switching losses are high and cost also increases. For eliminating the above disadvantages, this paper proposes a combined cell cascaded multi level inverter requires only five switches and four diodes for five level output voltage, when compared to normal conventional cascaded MLI which requires eight switches.

II.CONCEPT OF INTERLEAVING TECHNIQUE

The interleaving means that N identical converters are connected in parallel and the currents through the each switch is dispersed. When the each converter provides the same current as the non-interleaved converter, the output current is the N times higher. Interleaved method used to improve power converter performance in terms of efficiency, size, conducted electromagnetic emission, and transient response. The benefits of interleaving include high power capability, modularity, and improved reliability. This technique consists of a phase shifting of the control signals of several cells in parallel operating at the same switching frequency. As a result, the input and output current waveforms exhibit lower ripple amplitude and smaller harmonics content than in synchronous operation modes. The resulting cancellation of low-frequency harmonics allows the reduction of size and losses of the filtering stages. Moreover, a converter employing the interleaving strategy can feature a great power density without the penalty of reduced power-conversion efficiency.

The interleaved interconnection of two switching cells requires the individual switching instants of the two cells to be sequentially phased over equal fractions of a switching period. To reduce the converter ripples, two configurations are optimal: when one switch is ON at the same time the other one is OFF. In these optimal configurations, the inductor current of one cell is increasing while the other one is decreasing, therefore the inductor current waveforms of the two switching cells have slopes with opposite signs. For this reason, their sum, which is the slope of the total interleaved input current, is reduced as well as its ripple. Consequently, if the aim is to obtain low input and output ripples, the interleaved circuit has to be controlled to turn on the switches in a complementary way. This complementary interleaving offers more simplicity in the control design than other kinds of interleaving, because one activation signal is the opposite of the other activation signal.

III.WORKING PRINCIPLE OF IBC

The basic circuit diagram of a two phase interleaved boost converter is shown in the figure1. It consists of two switches S1 and S2, coupled inductor and two diodes. The two phases of the converter are driven 180 degrees out of phase, this is because the phase shift to be provided depends on the number of phases given by 360/n where n stands for the number of phases [1]. Each transistor is switched at the same frequency but at a phase difference of π. The corresponding switching signals for S1 and S2 are shown in figure 2. Since two phases are used the ripple frequency is doubled and results in reduction of voltage ripple at the output side. The input current ripple is also reduced by this arrangement.

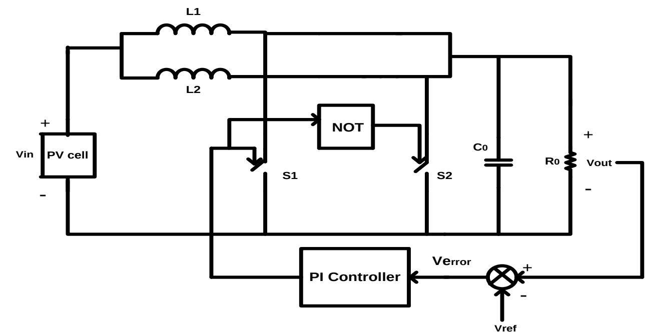

Fig. 1 Circuit Diagram of a 2-phase interleaved boost converter

When gate pulse is given to the first phase for a time t1, the current across the inductor rises and energy is stored in the inductor. When the device in the first phase is turned OFF, the energy stored is transferred to the load through the output diode D. The inductor and the capacitor serve as voltage sources to extend the voltage gain and to reduce the voltage stress on the switch. The increasing current rate across the output diode is controlled by inductances in the phases. Gate pulse is given to the second phase during the time t1 to t2 when the device in the first phase is OFF. When the device in the phase two is ON the inductor charges for the same time and transfers energy to the load in a similar manner as the first phase. Therefore the two phases feed the load continuously. In this paper, closed loop control is adapted for the interleaved boost converter to get the faster transient response. The PI controller is used in the closed loop control to regulate the voltage error and generates the required switching signals for the switches S1 and S2.

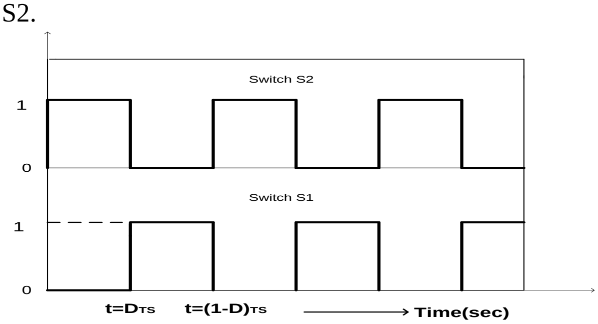

Figure .2 Switching signals for S1 and S2

III.MULTI LEVEL INVERTERS

The importance of multilevel inverters has been increased since last few decades [2], [3]. These new types of inverters are suitable for high voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum and with less THD.

Numerous topologies have been introduced and widely studied for utility of non conventional sources and also for drive applications. The multilevel inverter [MLI] is a promising inverter topology for high voltage and high power applications. This inverter synthesizes several different levels of DC voltages to produce a stepped AC output that approaches the pure sine waveform [4]-[6]. The attractive features of a multilevel converter can be briefly summarized as follows.

● Generate better output waveforms with a lower dv/dt than the standard converters (power quality).
● Increase the power quality due to the great number of levels of the output voltage: in this way, the AC side filter can be reduced, decreasing its costs and losses (low switching losses).
●Can operate with a lower switching frequency than two-level converters, so the electromagnetic emissions they generate are weaker, making less severe to comply with the standards (EMC).
●Can be directly connected to high voltage sources without using transformers; this means a reduction of implementation and costs.

Generally the multi level inverters are classified into three categories namely, 1) Diode clamped MLI, 2) Flying capacitor MLI and 3) Cascaded MLI. The diode clamped MLI requires eight switches and six diodes to get five level output voltage. Due to the more number of switches, the switching losses and cost also increases in diode clamped MLI. Another disadvantage in diode clamped MLI is it requires extra diodes. In flying capacitor MLIs, control is complicated to track the voltage levels for all of the capacitors. Another disadvantage of flying capacitor is the large numbers of capacitors are more expensive. For eliminating the above disadvantages, a cascaded MLI with reduced number of switches called as combined cell cascaded MLI is proposed in this paper.

A. Combined Cell Cascade Multilevel Inverter

Conventional cascaded MLI requires eight switches to get five level ac output voltage from dc voltage to interface with the grid. This topology has more switching losses and cost is also high. For eliminating these disadvantages, this paper proposes a combined cell cascaded MLI, which has reduced number of switches (five only). The configuration of cascaded cell MLI is shown in the figure 3. In this structure, each cell increases the number of the original output levels. In fact all the cells are finally gathered together like separated multilevel inverter. In the structure, each cell increases the number of the original output levels. In fact all the cells are finally gathered together like separated multilevel inverter.

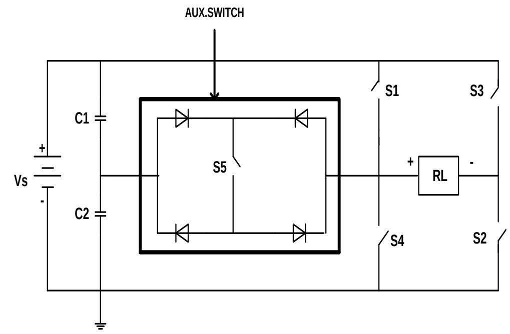

Figure3. Combined cell cascade multilevel inverter

If it uses more capacitors and auxiliary switches, the number of output voltage levels is increased. The number of output voltage levels of each cell is equal to:

$$M = 2C+1$$

Where, C is the number of capacitors. Output voltage and switching state of the combined cascade multilevel inverter cell is presented in Table I.

TABLE I
OUTPUT VOLTAGE AND SWITCHING STATE OF COMBINED CASCADE MULTILEVEL INVERTER CELL

Sw1	Sw2	Sw3	Sw4	Sw 5	V_{RL}
on	On	off	off	off	V_s
off	On	off	off	On	$\frac{V_s}{2}$
off	On	off	on	off	0
off	Off	On	off	On	$-\frac{V_s}{2}$
off	Off	On	on	off	$-V_s$

IV. PROPOSED GRID CONNECTED PV SYSTEM

The block diagram of the proposed grid connected PV system is shown in the figure 4. It consists of a PV system, interleaved boost converter and combined cell cascaded MLI to interface with the grid.

V. GRID-CONNECTED HYBRID ENERGY SYSTEM BASED ON THE BOOST INVERTER

The configuration of a grid-connected hybrid energy system is shown as Fig.7

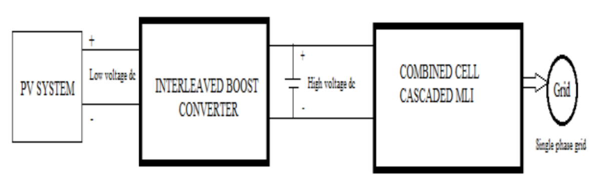

Figure.4 Grid tied photovoltaic system (PV)

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From figure4, the PV cell converters the solar energy into low voltage dc [7]. The voltage obtained from the PV is converted into high voltage dc by using interleaved boost converter (IBC). Once the high voltage dc obtained from the IBC is converted to ac voltage by using combined cell cascaded MLI.

V.MATLAB MODELING AND SIMULATION RESULTS

The following figure (5) and (6) shows the simulink diagram of interleaved boost converter (IBC) and its output voltage waveform.

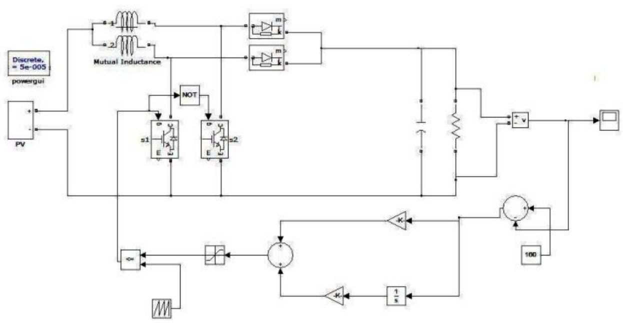

Figure (5) Simulink Diagram of closed loop control of interleaved boost converter

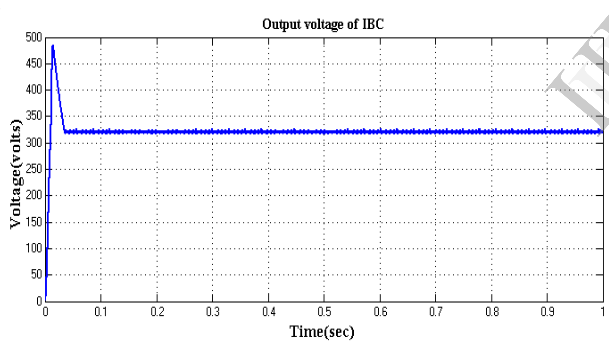

Figure (6) Output voltage of IBC when it is supplied from the PV system

The interleaved boost converter is implemented in MATLAB/SIMULINK software. The closed loop control of IBC is achieved by using PI controller which tracks the error between the reference voltage and actual output voltage. In this control, the error between the reference voltage and actual output voltage is given to PI controller. The PI controller generates the appropriate switching signals for the switches S1 and S2 based on the voltage error. The advantages of closed loop control is that it gives better performance, makes the voltage error almost zero and also it gives faster transient response. The output voltage obtained from the IBC is nearly 320V.

The following figures (7) and (8) show the simulink diagram of combined cell cascaded MLI and corresponding five level output voltage waveforms respectively. The output voltage obtained from the IBC is converted into AC by using combined cell cascaded MLI. It uses only five switches for the required operation, Hence the cost and switching losses are decreases when compared to conventional cascaded H-bridge MLI.

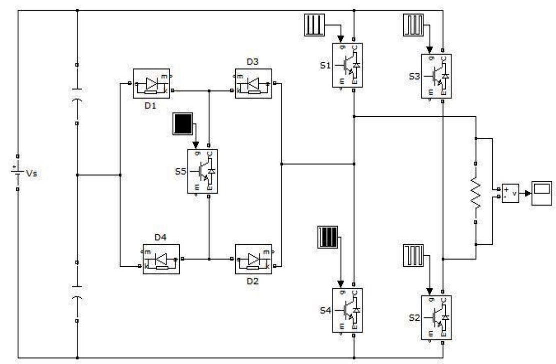

Figure 7.Simulink diagram of combined cell cascaded MLI

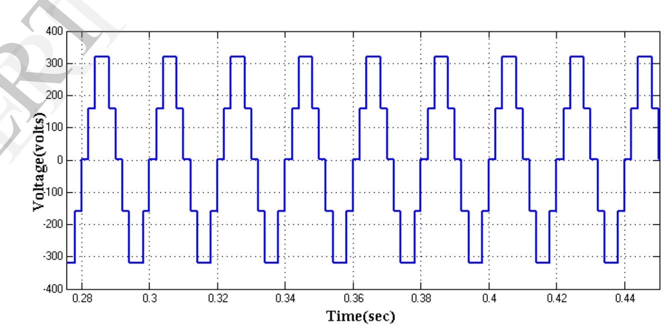

Figure (8). Five level output voltage of combined cell cascade MLI

Simulink diagram of the proposed grid connected PV system based on IBC and combined cell cascaded MLI is shown in figure 9.

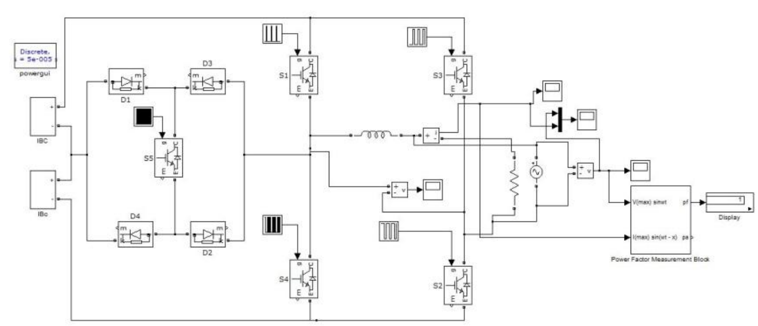

Figure 9 Simulink diagram of proposed system

Interleaved boost converter and combined cell cascaded MLIs are used to interface the PV system with the grid. The combined cell cascaded MLI produces a 320V ac which is equal to the grid voltage .The following figure (10) shows the grid voltage and connected current, which are in phase with each other.

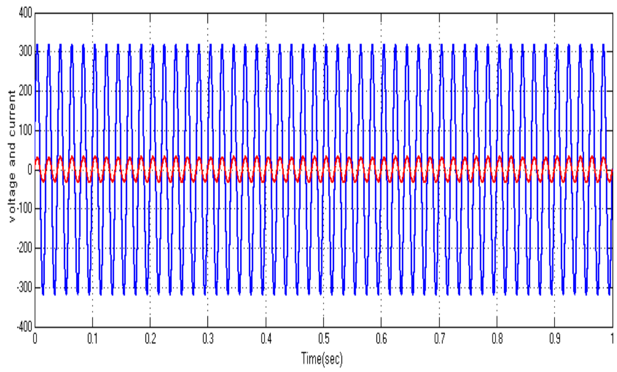

Figure 10. Grid connected current and grid voltage

The following figure (11) shows the THD of grid connected current, and is equal to 3.29 which is under the tolerance levels of IEEE standards.

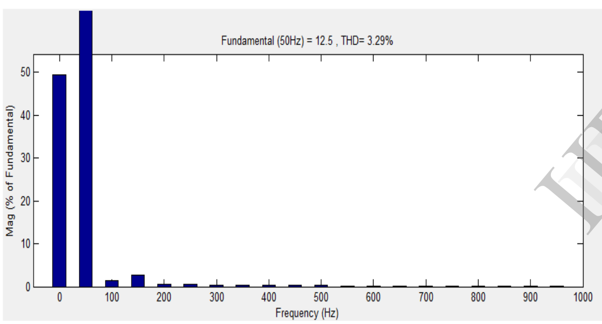

Figure 11. THD of grid connected current

V CONCLUSION

This paper proposes a grid connected PV system based on IBC and combined cell cascaded MLI. The advantage of this system is that, the IBC converter boost up the low voltage dc into high volage without much stress on the switches compared to conventional boost converter. Combined cell cascaded MLI inverter converters this high voltage dc into ac, with reduced number of switches. Hence the switching losses and cost of the combined cell cascaded MLI inverter is less compared to conventional cascaded MLI. The grid voltage and grid connected current are in phase and the THD of load current is 3.29% which is in the acceptable level.

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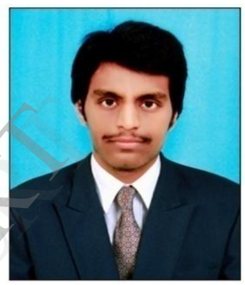

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