Transformerless Inverter with Interleaved Boost Converter for Single Phase PV systems

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***Abstract* — *Recently, there is a strong trend in the Photovoltaic(PV) inverter technology to usetransformerless topologies in order to acquire higher efficiencies combining with very low ground leakage current.The photovoltaic cells which give very low output voltage,so that a DC-DC boost converter has to connected with PV source inorder to increasethe available voltage. Here a PV system is proposed which consist of a DC-DC boostconverter with MPPT algorithm. Boost converter suffers from large input currentripple. Inorder to improve the efficiency of converter and reduce the ripple current, aninterleaved boost converter is used. An interleaved boost converter consists ofseveral boost converters connected in parallel with same switching frequency and aphase shift of 180 degree. A modified transformerless inverter with interleaved boostconverter for a grid connected PV system is implemented in this work. The neutralof grid can be directly connected to the negative terminal of the source (PV). Asimple unipolar sinusoidal pulse width modulation technique is used to modulate theinverter to minimise switching losses, output current ripple and filter requirements.In this work peturb and observe method is used to extract the maximum possiblepower from solar panel. The topology is simulated in MATLAB/SIMULINK R2017asoftware. It is observed that the output of the inverter is 230V,50Hz AC that canbe directly connected to the grid. The converter is controlled using dsPIC30F2010controller. Experimental results obtained from a 10.2W converter prototype confirmthe theoretical considerations and the simulation results.*

Keywords—*Solar Panel, Interleaved boost converter, Transformerless Inverter, P&O Method*

I. INTRODUCTION

Grid connected inverters for photovoltaic (PV) systems, particularly low power singlephase systems (up to 5 kW) are growing rapidly for both utility-scale and distributedpower generation applications due to the declining prices of the PV panel, governmentincentives for PV energy, and advancement in power electronics and semiconductor technology [2]. Continued technological advancements and further cost reductions willexpand these opportunities in both developed and developing countries where favorable Solar conditions exist.In PV applications a transformer is often used to provide galvanic isolation and voltageratio transformations. However, these conventional iron and copper-based transformersincrease the weight/size and cost of the inverter whilst reducing the efficiency and powerdensity. It is therefore desirable to avoid using transformers in the inverter, howeveradditional care must be taken to avoid safety hazards such as ground fault currentsand leakage currents, e.g. via the parasitic capacitance between the PV panel and/orits frame and ground. Consequently, grid connected transformerless PV inverters mustcomply with strict safety standards [3]

Common ground type PV inverter can effectively reduce the leakage current of thePV system and has attracted a lot of interest from both academia and industry. Acommon ground transformerless inverter is proposed in [12]. However, it requires five switches and a relatively large filter inductor to meet the power quality requirements.This is primarily due to a virtual dc bus, which is created by a capacitor, and it chargesonly during the positive power cycle. There is no path to charge the capacitor duringthe negative cycle, where it requires a sustaining voltage at the so-called virtual dc-bus.This not only distorts the output voltage waveforms and thus requires a large virtual dc-bus capacitor and a filter inductor, but also unnecessarily increases the current stressin the switches.Several other transformerless inverter topologies with a common groundare described in [4]-[6]. However, all of them have the disadvantage of higheractive and passive components with less effciency.

To explore the possibility of extending the circuit with similar principle and concept, new common-ground type transformerless inverter (Type-II) is investigated in this.For this topology, only four active switches are requiredto realize the basic inverter circuit. This relates to a minimal switch in the current pathduring the active states, which reduces the total on-resistance of the switches in thecurrent path, and hence, minimizes the total conduction losses. Unlike conventionaltopologies with 3 switches in the load current path, the proposed topology has 2switches in the load current path during active states. In addition, a simple unipolarsinusoidal pulse-width modulation (SPWM) technique is used to modulate the inverter,which further minimizes the switching loss, output current ripple, and filter requirements.

II. DESCRIPTION OF THE PROPOSED GRID CONNECTED PV SYSTEM

Fig.1 shows circuit diagram of the grid connected PV system. In which a common groundtype transformerless inverter along with interleaved boost converter is used to convert the PV voltage to a practical gridvoltage 230V AC.

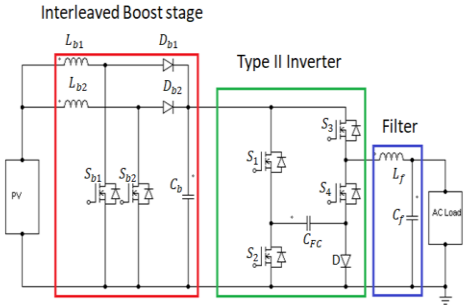

Fig 1: Circuit Diagram of Grid connected PV system

A. Inverter Operation

There are mainly 3 modes of operation in this inverter.These three operating modesrepeat after each power cycle and create a unipolar positive and negative voltage before the filter, which is filtered out to get a pure sinusoidal voltage and current waveformat the output. These operating states are described in detail as follows

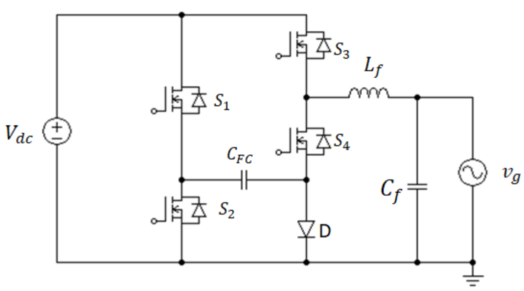

Fig 2: Type II Inverter

***Mode 1*:** In this state, the switch S_3 switches at a high switching frequency to create a unipolar positive voltage before the filter. Turning off S_2automatically turns diode D to forwardbiased, which charges the capacitor through the switch S_1. This process helps inprecharging the capacitor for the negative power cycle. Fig.3 shows the Mode of operation.

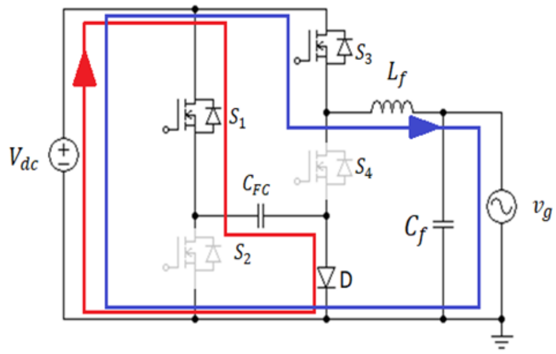

Fig 3: Mode 1

Mode 2: The precharge capacitor acts as a virtual dc-bus during this state. The switch S_2switches at a high switching frequency to create a unipolar negative voltage before the filter using the precharge capacitor C_{FC}. As S_4remains on for the whole negativecycle, turning the switch S_2 on reverse biases the diode D and helps in avoiding shortcircuiting the capacitor.

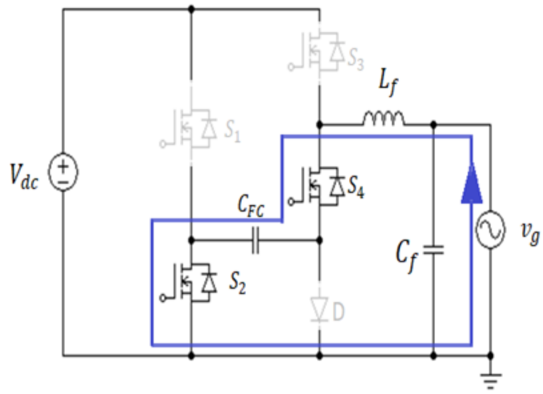

Fig 4: Mode 2

Mode 3: Following the positive or negative active state, turning the switch S_2 off automaticallyforward biases the diode, which charges the capacitor. At the same time, the switchS_4 turns on to create a zero voltage across the filter which is shown in Fig.5.

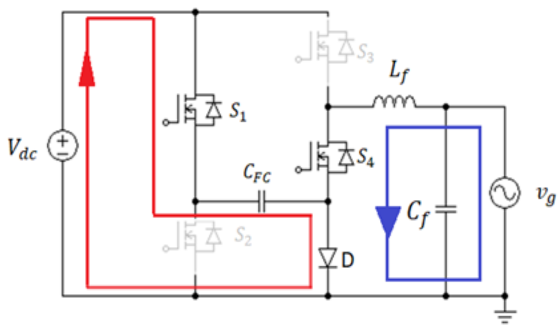

Fig 5: Mode3

III. SIMULATION AND EXPERIMENTAL RESULTS

In order to validate the performance of the proposed PV system, MATLAB simulations and experiments are carried out. The designed parameters are listed in TABLE I. Duty ratio for switch $S_1$of converter is given as 50%and S_2 is complimentary to S_1. Simulation is done for an output voltage of 230V,50HzAC.The simulation results are shown below.

TABLE I
SIMULATION PARAMETERS

System Specification	Parameters
PV output voltage	170 V
DC link Voltage (V_{dc})	340 V
Carrier Frequency (f_c)	50 kHz
Line Frequency (f_s)	50Hz
Flying Capacitor C_{FC}	470 µF
Filter C_f&L_f	2.2µF,0.35mH
Load	47Ω+80mH

A. *Simulation Results of converter*

Interleaved Boost converter is working in boost mode with an input voltage of 17 V. An output voltage of 34 V is getting in the DC-link side. Here 2.2µF capacitor is used as DC-link capacitor. Voltage waveforms of input (PV output) and output (DC-link output) of the converter areshown in Fig. 6.

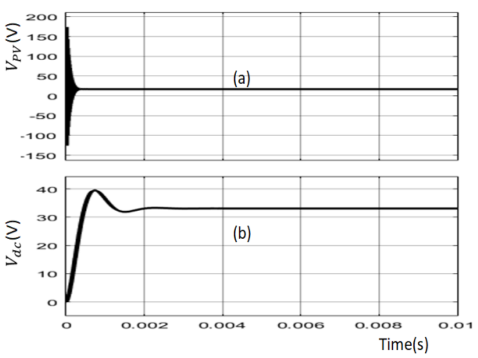

Fig 6: (a)PV Voltage (b)DC-link Output Voltage

B. *Simulation Results of Inverter*

The simulation results of flying capacitor transformerless inverter using unipolar sinusoidal pulse width modulation technique are shown here. R L load of 47Ω+80mH is used in the load side for an input voltage of 340 V. Output voltage obtained from simulation is 230V,50Hz AC .

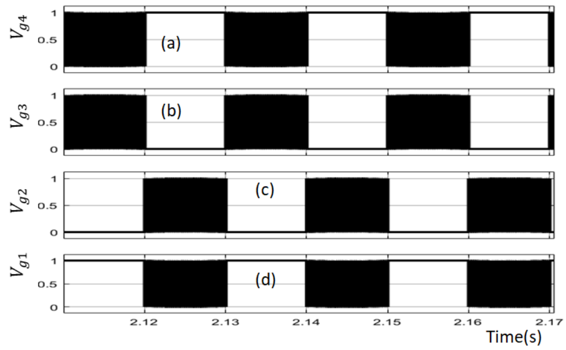

Fig 7: Gate Pulse for (a) Switch S_1 (b)Switch S_2 (c) Switch S_3 and (d)Switch S_4

Gate pulses for switches S_1, S_2,S_3 andS_4 are shown in Fig.7. Here S_1 and S_2 ,S_3 and S_4 are complimentary pairs.Fig.8 shows switching stress for each switches S_1, S_2,S_3 andS_4. All switches experience the same switching stress that is equal to the Dc-link voltage except the switch S_3.Switch S_3 has a stress which is two times the DC-link voltage.

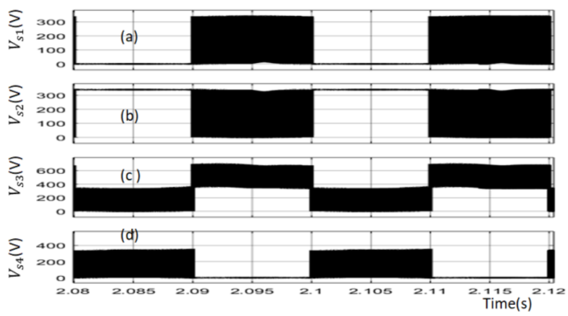

Fig 8: Switching stress for (a) Switch S_1 (b)Switch S_2 (c) Switch S_3 and (d)Switch S_4

Fig. 9 shows the simulation result of output AC voltage and current which are230V and 5.5A respectively.And also it shows the waveform of flying capacitor voltage and three level output voltage before the filter.

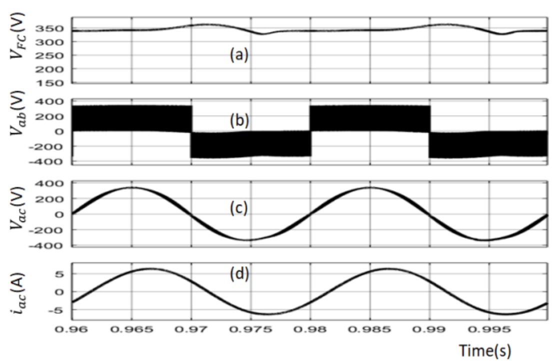

Fig 9: (a)C_{FC} Voltage (b)Three level output voltage (c)Output Voltage (d)Output Current

C. Analysis of the Inverter

Efficiency versus power curve is plotted in Fig. 10. Here efficiency is maximum when power is 1kVA.

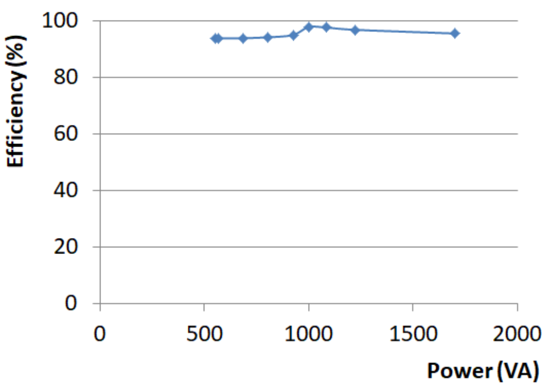

Fig 11: Graph of Efficiency Vs Power

FFT analysis of output voltage and current of inverter shown in Fig.11 and Fig.12 respectively.The THD of output voltage and current are 2.62% and 1.92% respectively. From that it can be conclude that the THD of output voltage and current are <3%.

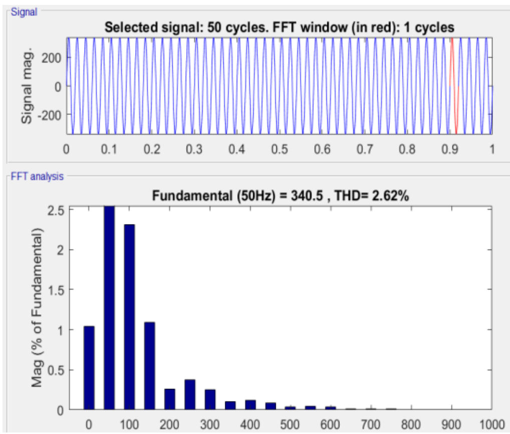

Fig 11: FFT of Output Voltage

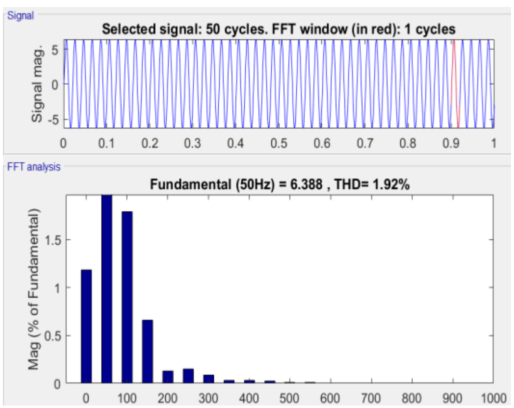

Fig13: FFT of Output Current

IV. EXPERIMENTAL RESULTS

Inorder to verify the performance of the transformerless inverter with interleaved boost converterexperimental setup is implemented. A 10.2W converter prototype is implemented in the laboratory.The prototype with the parameters given in TABLE II was built. The power supply consist of astep down transformer, full bridge diode rectifier, filter capacitor and a regulator IC (7812). IRF540 MOSFET is used as switches. TLP250 driver isused to drive the MOSFET. To generate the switching signal dsPIC30F2010 was programmed in the laboratory and necessary waveforms are obtained. The switches of converter are working in 100kHz frequency and have a duty ratio of 0.5. An output voltage of 34V is obtained for an input of 17V from boost operation.The experimental test setup is presented in Fig. 14 and results of converter operations are given in Fig. 15.

TABLE II
COMPONENTS USED FOR PROTOTYPE

Components	Ratings
PVVoltage (V_{PV})	17V
DC-link Voltage (V_{dc})	34 V
Switching Frequency (f_s)	100 kHz
Rated Power (P)	10.2 W
L_1 and L_2	10 mH
C_{dc}	2.2 μF

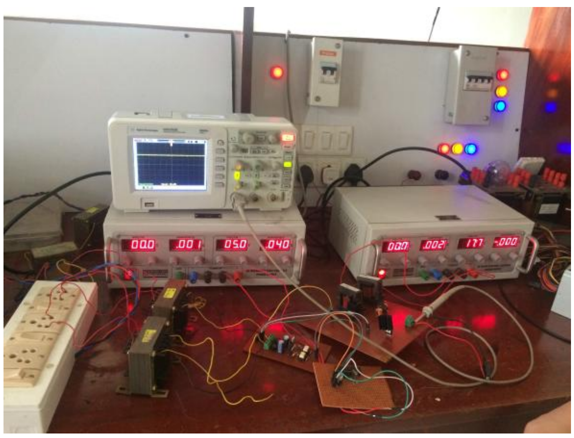

Fig 14: Experimental Setup of Converter

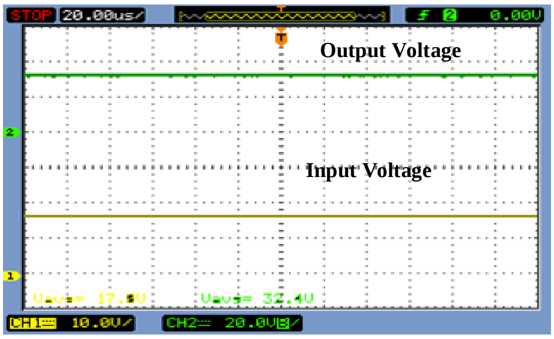

Fig 15: Output Voltage of interleaved converter

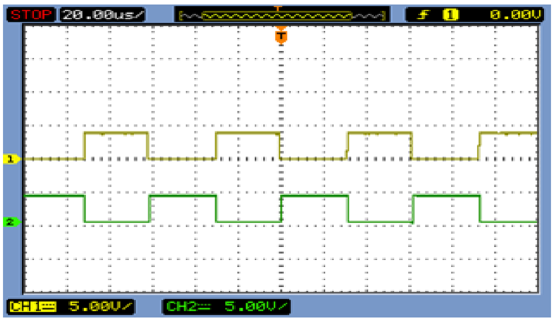

Fig 16: Switching pulse for converter switches

V. CONCLUSIONS

In this project a grid connected PV system is presented. The operating principle of these inverters is based on the flying capacitorprinciple, and it utilizes a minimum number of active and passive components. Besidesa common ground for the grid and source, which effectively eliminates the leakagecurrents, the three new topologies have three levels of output voltage, which reducesthe output current ripples, EMI, and filter requirements. In addition, only few switches(less than 2) are in series during the active state, which helps in reducing the conduction lossin the system.The experimental prototype of the interleaved boost converter is implemented and ouput voltage is verified.

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