A Transformerless Inverter With Virtual DC Bus For Eliminating Common Mode Leakage Current In Grid Connected PV Power System.

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Abstract - ***The photovoltaic based power generation systems are popular nowadays. For low power grid connected application, a single phase converter can be used. In PV application it is possible to remove the transformer in the inverter to reduce losses, cost and size. Galvanic connection of the grid and the DC sources in transformerless system can introduce additional common mode ground leakage currents due to the ground parasitic capacitance. These current reduce the efficiency of power conversion stage and affect the quality of grid current. To eliminate this common mode leakage current,virtual DC bus concept is used in this paper. By connecting the grid neutral line directly to the negative pole of the dc bus, the stray capacitance between PV panels and ground is bypassed. The CM ground leakage current can be suppressed completely.***

Key Words: Common mode (cm) current, transformerless inverter,virtual dc bus.

1. INTRODUCTION

Day by day the contribution of renewable energy is increased in total energy consumed in the world. Among all renewable sources like solar, wind, hydro; the solar system or photovoltaic (PV) system is most stable and reliable energy. Now a day, the solar energy technologies have becomes more efficient and less expensive than the traditional technologies.

A grid connected PV system is mainly consisting of set of PV arrays as a DC generator, inverter for power conversion and filter. Generally in grid connected PV system low frequency or high frequency transformer is placed between grid and power conversion stage. The low frequency transformer provides isolation between PV system and grid ground so that the leakage current is greatly limited. However this transformer increase size, cost and weight of PV system and reduces the efficiency. To increase efficiency, high frequency transformer is placed in DC stage of inverter. This inverter provides galvanic isolation between PV system and grid ground but again it increase size, weight and cost[1].

Now a days, transformerless PV-grid connected system is evolved which has high efficiency, low weight, low size and low cost. Due to elimination of transformer, there is galvanic connection is forms between PV panels and grid ground. As a result strong leakage current is flows between PV panels and grid ground [2-][3]. So to eliminate this common mode leakage current, it is necessary to develop power conversion stage in such a way that it must keep common mode voltage constant.

2. VIRTUAL DC BUS CONCEPT

The concept of virtual dc bus is shown in fig.1 The grid neutral line directly connected to negative pole of the PV panel so that voltage across the parasitic capacitor C_{pv} is clamped to zero. This prevents any leakage current flowing through it.

According to the state of the switch bridge, the ground point N, the voltage at midpoint B is either zero or + V_{dc} The virtual dc bus is used to generate the negative output voltage, which is necessary for the operation of the inverter. If a correct method is designed to transfer the energy between the real bus and the virtual bus, the voltage across the virtual bus is kept the same as the real one. The positive pole of the virtual bus is connected to the ground point N, so that the voltage at the midpoint C is either zero or − V_{dc}. The dotted line indicates that the connection may be realized directly by a wire or indirectly by a power switch. By a smart selecting switch, points B and C joined together the voltage at point A can be of three different voltage levels, namely + V_{dc}, zero, and − V_{dc} [4].

By this structure of the circuit, the CM current is eliminated naturally .There is no any limitation on the modulation strategy that means the advanced modulation technologies such as the unipolar SPWM or the double-frequency SPWM can be used to satisfy various PV applications[5]-[6].

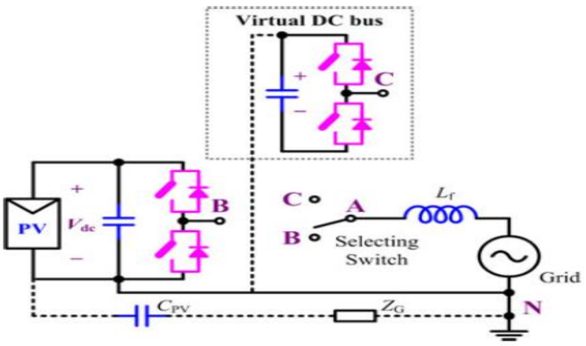


Fig -1: Virtual DC bus concept

3. PROPOSED TOPOLOGY& MODULATION SCHEME

On the basis of virtual dc bus concept, a novel inverter topology is derived as, which is shown in Fig.2. It consists of five power switches S_1-S_5 and single filter inductor L_f. The PV panels and capacitor C_1 form real dc bus while virtual dc bus is provided by C_2.In switched capacitor technology, capacitor C_2 is charged by the real dc bus through S_1 and S_3 for maintaining a constant voltage. This topology can be modulated with the unipolar SPWM & double-frequency SPWM. The detailed analysis is introduced as follows.

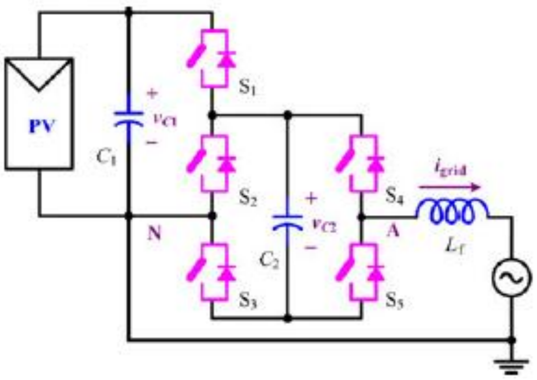


Fig -2: Proposed Topology

3.1 Unipolar SPWM

Following fig shows the waveform for the unipolar SPWM of the proposed inverter. According to the relative value of the modulation wave u_g and the carrier wave u_c, the gate drive signals for the power switches are generated. For the positive half grid cycle, ug >0, S1 and S_3 are turned ON. S_2 is turned OFF, while S_4 and S_5 commutate complementally with the carrier frequency. The C_1 and C_2 are connected in parallel and the circuit rotates between states 1 and 2 as shown in Fig.5. During the negative half cycle,u_g <0. S_5 is turned ON and S_4 is turned OFF. S_1 and S_3 commutate with the carrier frequency synchronously and S_2 commutates in complement to them. The circuit rotates between states 3 and 2 and at state 3, S_1 and S_3 are turned OFF while S_2 is turned ON. By the virtual dc bus C_2, the negative voltage is generated and the inverter output is at negative voltage level. At state 2, S_1 and S_3 are turned ON and S_2 is turned OFF. The inverter output voltage v_{AN} equals zero and C_2 is charged by the dc bus through S_1 and S_3.

The various operation modes of different swinches (S1-S5) are tabulated as below

Table -1: Different modes

MODES	SWITCHES				
	S1	S2	S3	S4	S5
1	ON	OFF	ON	ON	OFF
2	ON	OFF	ON	OFF	ON
3	OFF	ON	OFF	OFF	ON
4	OFF	ON	OFF	ON	OFF

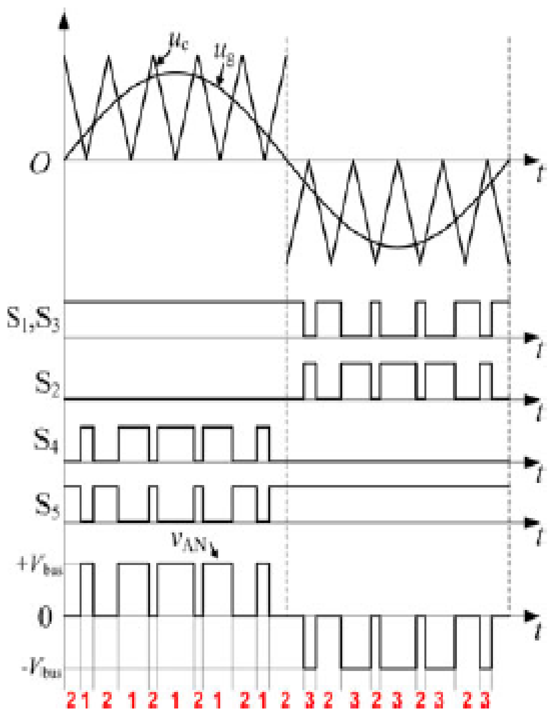


Fig -3: Unipolar SPWM

3.2 Double-Frequency SPWM

The proposed topology can work with double-frequency SPWM to achieve a higher equivalent switching frequency, as shown in Fig.4. In the double-frequency SPWM, the five power switches are separated into two parts, and are modulated with two inverse sinusoidal waves respectively. S_1, S_2, and S_3 are modulated with u_{g1}, while S_4 and S_5 are modulated with u_{g2}.

During the positive half grid cycle, the circuit rotates in the sequence of “state 4 – state 1 – state 2 – state 1,” and the output voltage v_{AN} varies between + V_{dc} and the zero with twice of the carrier frequency. During the negative half grid cycle, it rotates in the sequence of “state 4 – state 3 – state 2 –state 3,” and the output voltage v_{AN} varies between $-V_{dc}$ and zero.

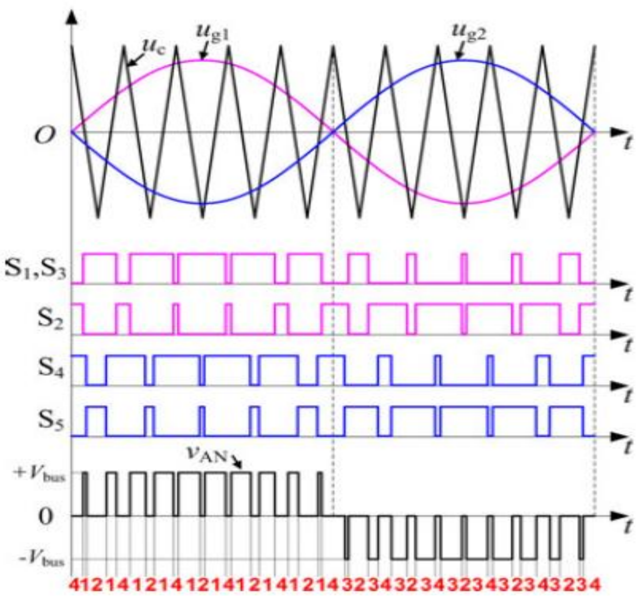
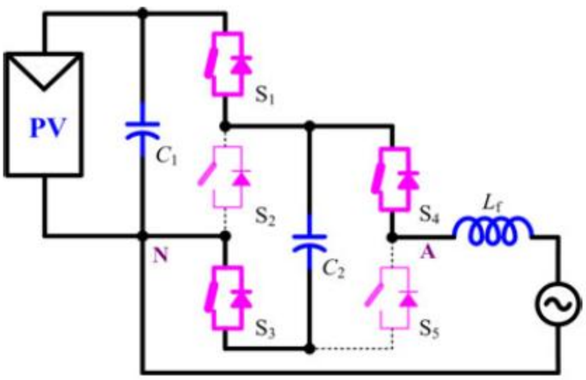
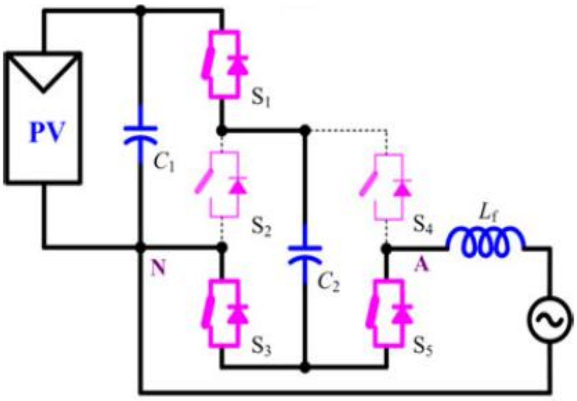


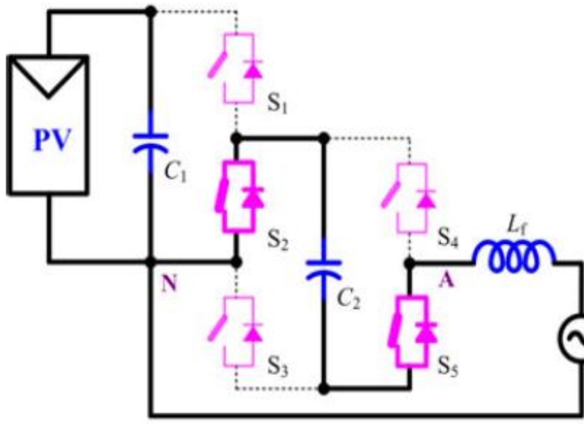
Fig -4: Double-frequency SPWM



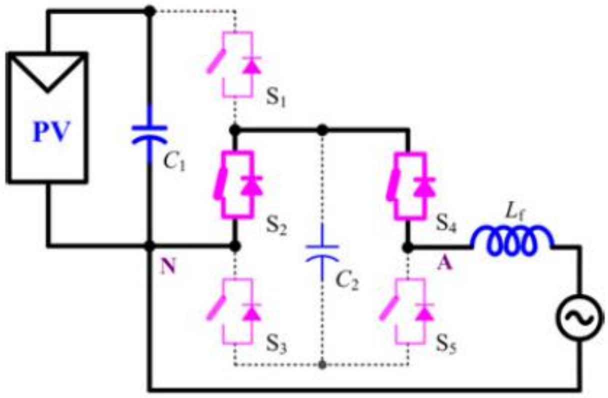
(a)



(b)



(c)



(d)

Fig -5: Four operation states for the proposed topology:

(a) state 1; (b) state2; (c) state 3; (d) state 4

4. SIMULATION MODEL

The proposed novel inverter model as shown in fig.2 is simulated by using MATLAB SIMULINK which is shown in fig.6.

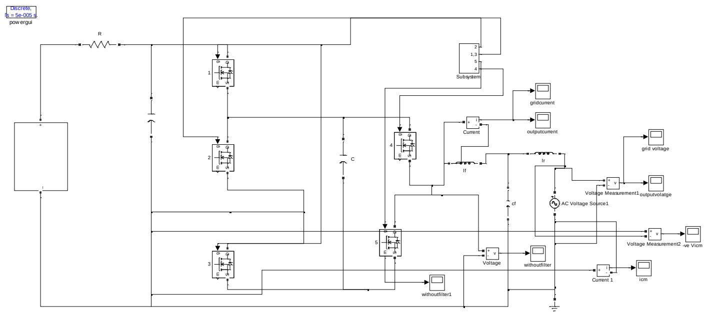


Fig -6: Simulink model of proposed system

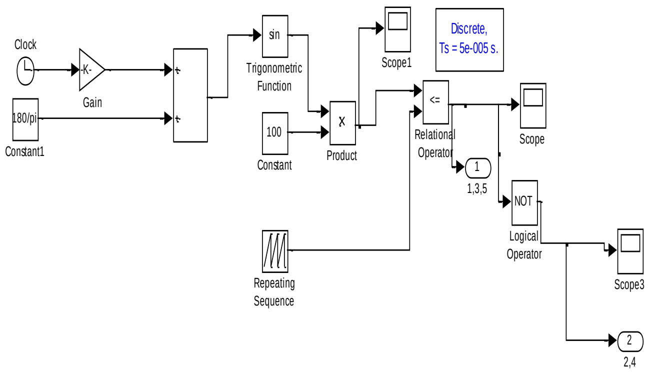


Fig -7: Simulink model of unipolar SPWM technique

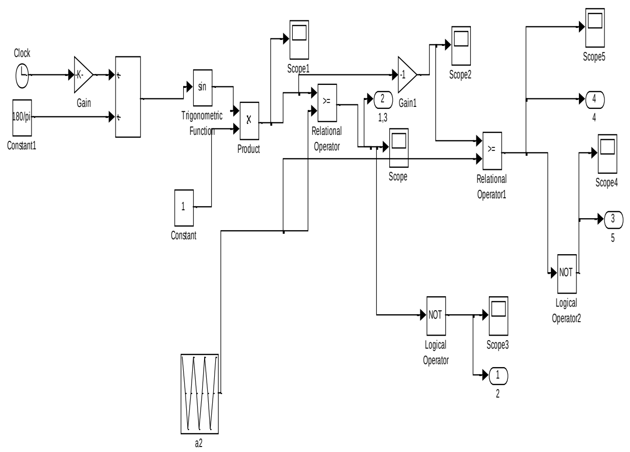


Fig -8: Simulink model of Double frequency SPWM technique

5. SIMULINK MODEL RESULT

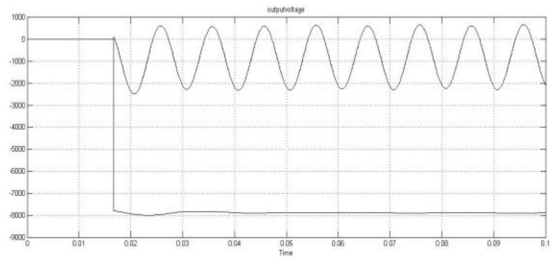


Fig -9: Simulation waveform for active & reactive power genration

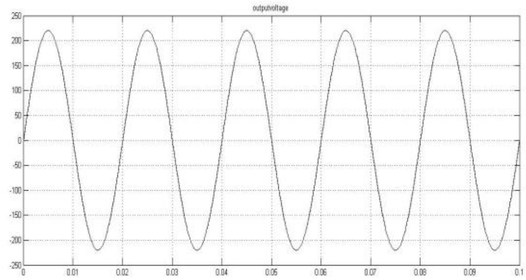


Fig -10: Simulation waveform for output voltage

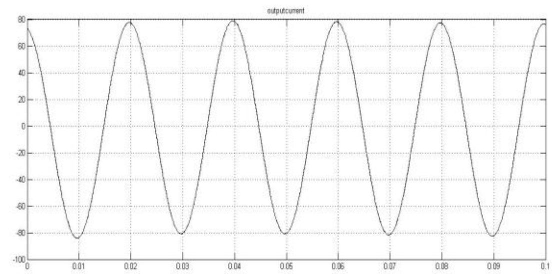


Fig -11 Simulation waveform for Output current

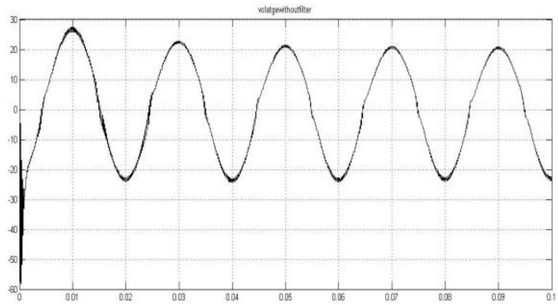


Fig -12: Simulation waveform without filter

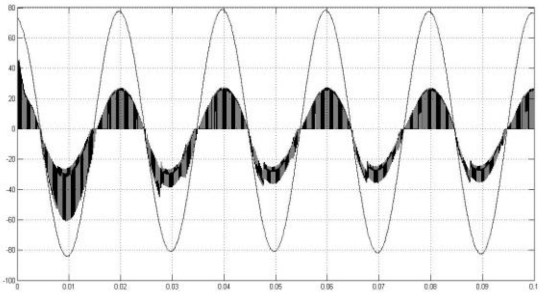


Fig -13: Current stress on S3

6. CONCLUSIONS

The work presented in this thesis deals with the performance of proposed transformerless inverter with different control techniques. In this project virtual dc bus concept is used for solving common mode leakage current problem in grid connected PV inverter. By connecting the negative pole of the dc bus directly to the grid neutral line, the voltage on the stray PV capacitor is clamped to zero. This eliminates the CM current completely. Meanwhile, a virtual dc bus is created to provide the negative voltage level. Based on this design, a new inverter topology is projected with the virtual DC bus concept by adopting the switched capacitor technology. It consists of only five power switches and a single filter inductor. The proposed topology is especially fitting for the small-power single-phase applications, where the output current is comparatively small so that the extra current strain caused by the switched capacitor does not cause severe stress for the power devices and capacitors. With outstanding presentation in eliminating the Common Mode current, the virtual DC bus concept provides an exceptional key for the transformer-less PV connected inverters.

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