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Improved Single Phase Transformless Voltage Source Inverter for Photovoltaic Grid-Connected System with Common-Mode Leakage Current Elimination

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Abstract-This paper presents how to eliminate the common-mode leakage current in the transformerless photovoltaic grid-connected system, an improved single-phase inverter topology is present. Eliminating the leakage current is one of most important issues for transformer less inverters in grid connected photovoltaic applications. The technical challenge is how to keep the common mode voltage constant to reduce the leakage current. For this purpose an improved single phase transformer less inverter is proposed. Here in improved transformerless topology we used additional two switches.The improved trans- formerless inverter can sustain the same low input voltage as the full-bridge inverter and guarantee to completely meet the condition of eliminating common-mode leakage current. unipolar sinusoidal pulse width modulation (SPWM) control strategy can be applied to implement the three-level output in the presented inverter.

Keywords —*Common-mode leakage current, junction capacitance,phase shift, photovoltaic (PV) system, sinusoidal pulsewidth modulation (SPWM) strategy, transformerless inverter.*

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I. Introduction

In recent year, the gird-connected photovoltaic (PV) systems specially the low-power single-phase systems, are use for high efficiency, small size, light weight, and low-cost grid connectedinverters. Most of the commercial PV inverters employ either line-frequency or high-frequency isolation transformers.However, line-frequency transformers are large and heavy, making the whole system bulky and hard to install. The high-frequency transformers consist ofseveral power stages, due to which increases the system complexity and reduces the system efficiency. Hence nn order to increase the efficiency and to reduce the size and cost of grid connected power systems, the effective solution is to remove the isolation transformer. But due to this removing of transformer there is common mode leakage current is presence of parasitic capacitance between the PV panel and the ground. The common-mode leakage current flows via parasitic capacitance of the panel to the system which is not meant to be energized. It causes personal safety problems, degradation in panels, system losses, reduces the grid-connected current quality and induces the severe conducted and radiated electromagnetic interference.

In order to avoid the common-mode leakage current, theconventional method is to employ the half-bridge inverteror the full-bridge inverter with unipolar sinusoidal pulse width modulation (SPWM), because no variable commonmode voltage is generated Unfortunately, there are some safety issues becausea galvanic connection between the grid and the PV arrayexists in the transformerless systems. A common-mode leakagecurrent flows through the parasitic capacitor between the PV array and the ground once a variable common-mode voltage is generated in transformerless grid-connected inverters.The common-mode leakage current increases the system losses,reduces the grid-connected current quality, induces the severe conducted and radiated electromagnetic interference, and causes personal safety problems**.**

II. Common Mode Current

If the transformer is omitted, the common mode (CM) ground leakage current may appear on the parasitic capacitor between the PV panels and the ground. The existence of the common mode (CM) current may reduce the power conversion efficiency, increase the grid current distortion, deteriorate the electric magnetic compatibility, and more importantly, give rise to the safety threats . The common mode (CM) current is formed by the power switches, filters, ground impedance ZG and the parasitic capacitance CPV between the PV panels and the ground.

III. Condition for elimination of common mode leakage current

Without an isolated transformer in the PV grid-connectedpower systems, there is a galvanic connection between the grid and the PV array, which may form a common-mode resonant circuit and induce the common-mode leakage current. The simplified equivalent model of the commonmode resonant circuit has been derived in as shown in the Fig. 1, where C_{PV} is the parasitic capacitor, L_A and L_B are the filter inductors, icm is the common-mode leakage current.

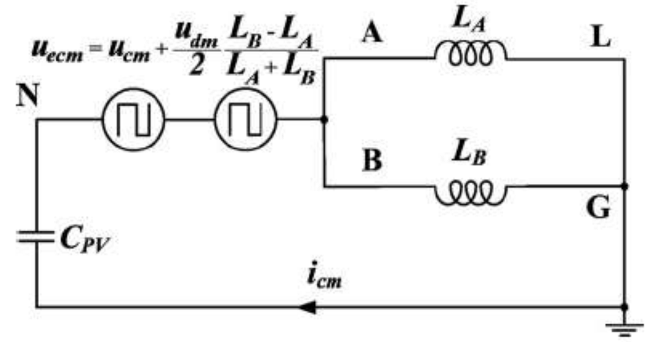


Fig. 1. Simplified equivalent model of common-mode resonant circuit.

circuit and induce the common-mode leakage current. The simplifiedequivalent model of the common-mode resonant circuit has been derived in as shown in Fig. 2, where $C_{PV}$is the parasitic capacitor, L_A and L_B are the filterinductors, icm is the common-mode leakage current. And, an
equivalent common-mode voltage uecm is defined by

$$u_{\rm ecm} = u_{\rm cm} + \frac{u_{\rm dm}}{2}\frac{L_B - L_A}{L_A + L_B}$$

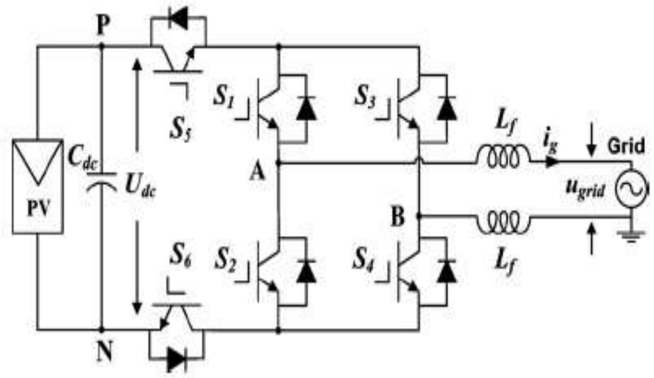


Fig. 2.Improved inverter topology.

It is clear that the common-mode leakage current i_{cm}isexcited by the defined equivalent common-mode voltageu_{ecm}.. Therefore, the condition of eliminating commonmodeleakage current is drawn that the equivalentcommon-mode voltageu_{ecm} must be kept a constant asfollows,

$$u_{ecm} = u_{cm} + \frac{u_{dm}}{2}\frac{L_B - L_A}{L_A + L_B}$$

$$= \frac{u_{AN} + u_{BN}}{2} + \frac{u_{AN} - u_{BN}}{2}\frac{L_A - L_B}{L_A + L_B}$$

= Constant

In the full-bridge inverter family, the filter inductors $L_A$and L_B are commonly selected with the same value. As a result, the condition of eliminating common-mode leakage current is met that,

$$u_{ecm} = u_{cm} = \frac{u_{AN} + u_{BN}}{2} = \text{constant}$$

$L_A = L_B$ = Constant

IV. Unipolar SPWM Strategy

In unipolar SPWM there are four modes of operation and here in unipolar SPWM Strategy the common mode voltage can remain constant during all the four modes of operation. Also the switching voltages of all commutating switches are half of the input voltage, so compared with the full bridge inverter topology the switching losses are reduced. Here the switches in one phase leg operating in grid frequency , switches in another phase leg operating in switching frequency and the additional switches are operating in grid frequency and switching frequency alternately. Thisfour modes of operation generate the three level output.

In the positive half cycle switches S_1 and S_6 are always ON and switch S_4 and S_5 commutates at switching frequency. In the negative half cycle switches S_2 and $S_5$are always ON and S_3 and S_6 commutates at switching frequency.

Mode 1:

During positive half cycle when S4 and S5 areON the inductor current increases through S5, S1, S4 and S6.Then common mode voltage is

$$u_{\rm cm} = \frac{1}{2}(u_{\rm AN} + u_{\rm BN}) = \frac{1}{2}(U_{\rm dc} + 0) = \frac{U_{\rm dc}}{2}.$$

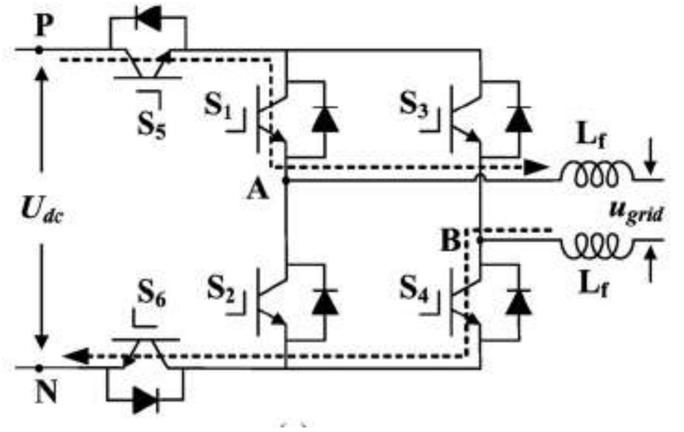


Fig.3 Operating modes of improved transformer less inverter Mode 1.

Mode 2:

In mode 2 S_4 and S_5switches are turnedOFF, then voltage uANfalls and the voltage uBNrises until their values are equal. The anti parallel diode D3 across the switch S3 conducts. The current decreases through the path S1, D3.Then common mode voltage is changes to

$$u_{\mathrm{cm}} = \frac{1}{2}(u_{\mathrm{AN}} + u_{\mathrm{BN}}) = \frac{1}{2} \quad \frac{U_{\mathrm{dc}}}{2} + \frac{U_{\mathrm{dc}}}{2} \quad = \frac{U_{\mathrm{dc}}}{2}.$$

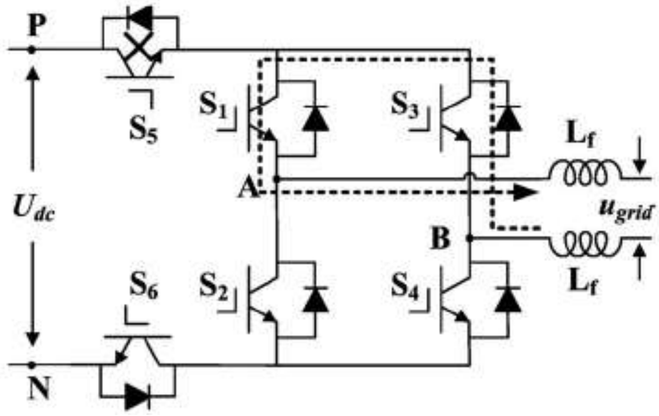


Fig.4 Operating modes of improved transformer less inverter Mode 2.

Mode 3:

When switch S_3 and S6 are ON, $u_{AB} = -U_{dc}$ and the inductor current increases inversly through the switches S_5 , S_3 , S_2 , and S_6 . The common-mode voltage is

$$u_{\mathrm{cm}} = \frac{1}{2}(u_{\mathrm{AN}} + u_{\mathrm{BN}}) = \frac{1}{2}(0 + U_{\mathrm{dc}}) = \frac{U_{\mathrm{dc}}}{2}.$$

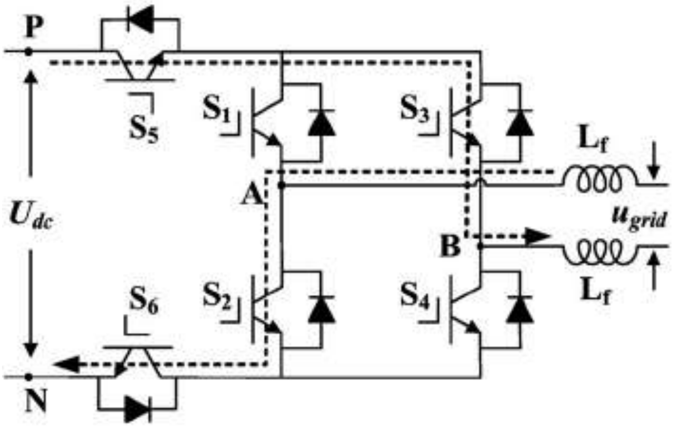


Fig.5 Operating modes of improved transformer less inverter Mode 3.

Mode 4:

In this mode S_3 and S_6 are OFF, The voltage U_{AN}risesand the voltage falls until U_{AN}= U_{BN}.The anti parallel diode of S4, D4 conducts and the inductor current decreases through switch S_2 and diode D_4.Then,The common-mode voltage u_{cm}=$U_{dc}/2$

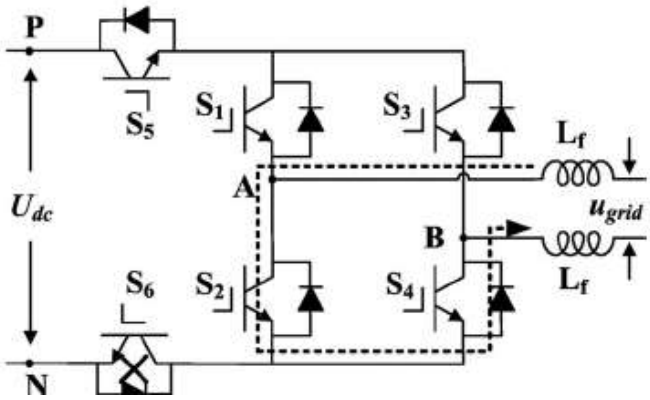


Fig. 6 Operating modes of improved transformer less inverter Mode 4.

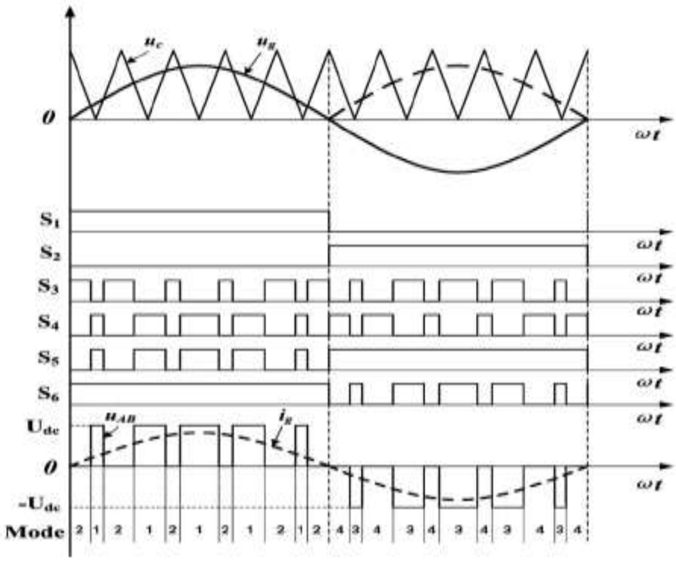
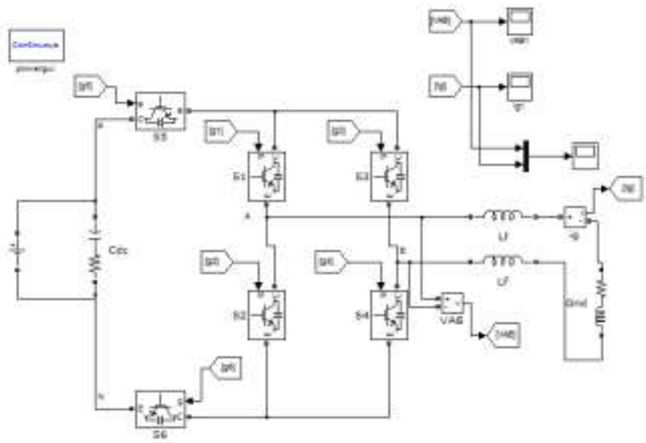


Fig. 7. Ideal waveforms of the improved inverter with unipolar SPWM.

V. MATLAB / SIMULINK MODEL



Improved inverter simulation model

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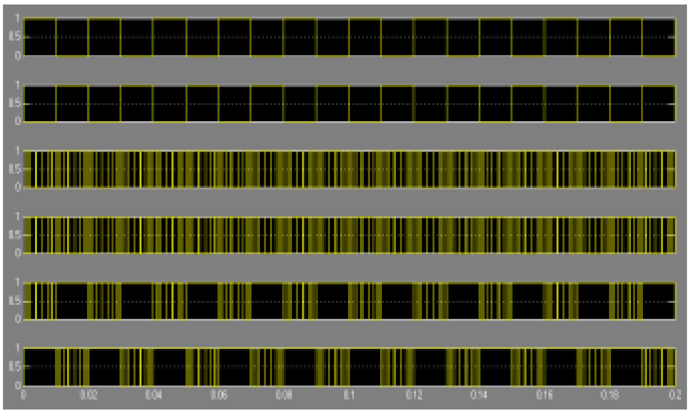
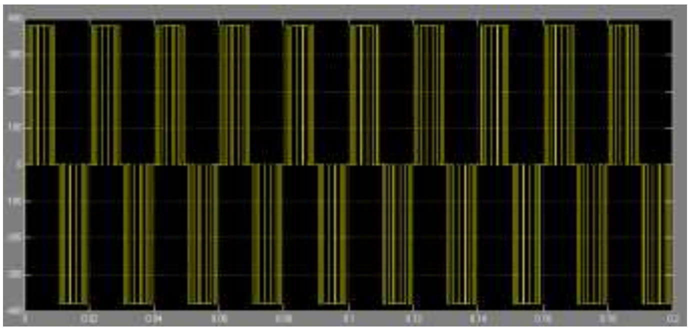
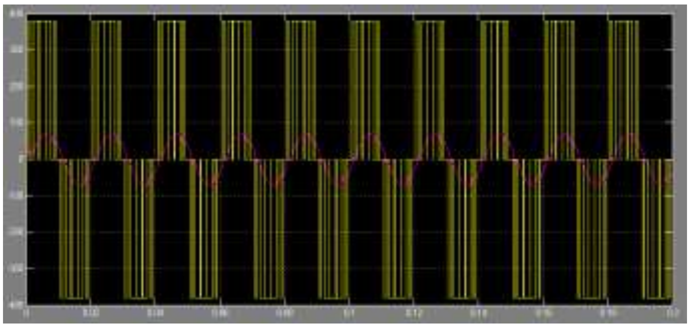


Switching technique waveform

VI. Results



Output Voltage



Output Waveforms of the improved inverter with unipolar SPWM.

Conclusion:

This paper presented to eliminate common mode leakage current problem in transformerless inverter is solved by using the improved transformer less

inverter. The improved topology has decouplingof two additional switches S5 and S6 connected in the dc side of the invertertopology for transformerless PV systems. The unipolar SPWM control strategies is implemented with three-level output in the presented inverter, which can eliminatethe common-mode leakage current because the condition of eliminating common-mode leakage current is met. Furthermore, the switching voltages of all commutating switches are half of the input dc voltage and the switching losses are reduced greatly. Moreover, by adopting the the smaller filter inductors are employed and the copper losses and core losses are reduced accordingly.

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