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Enhanced Performance of H6 Full Bridge Inverter in Reducing the Leakage Currents in Transformerless PV system

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Abstract

The global electrical energy consumption is raising and there is a steady increase of demand on the power capacity, efficient production, distribution and utilization of energy. The traditional power systems are changing globally, a large number of dispersed generation units, including both renewable and non renewable energy sources such as wind turbines, photo voltaic generators, fuel cells, small hydro and wave generators are integrated into power systems at distribution level. Power electronic, the technology of efficiently processing electric power, plays an essential part in the integration of the dispersed generation units for good efficiency and high performance of the power system. Due to the characteristics of low cost and high efficiency, the transformer less photo Voltaic grid-connected inverters have been popularized in the application of solar electric generation system in the residential market. Unfortunately, the leakage currents through the stray capacitors between the PV array and the ground are harmful. This paper presents neutral clamped method for suppressing of leakage currents and obtains excellent common mode voltages which are better compared to previous bridges.

Keywords:Grid-tied inverter, Common-mode voltage, leakage current, photovoltaic generation system, transformer less inverter.

INTRODUCTION

Photovoltaic (PV) and renewable energy sources (RES) have experimented a great development in recent years, mainly because of the growing concern about climate change and the oil price increase, which has led many countries to adopt new regulations to promote this kind of energy. In power converters for RES, and especially in grid connected PV inverters, efficiency and cost are key factors. Many of these inverters use an isolation transformer between the PV panels and the grid, but these low-frequency transformers are bulky and expensive. Furthermore, they produce additional losses. Using a two-stage topology with high-frequency isolation can reduce the size and price of the transformer, but the overall efficiency of the system is reduced, since at least two cascaded power stages are used (dc–dc + inverter).Therefore a large number of transformer less inverter topologies have been proposed in the past years. These inverters are cheaper, more compact and more efficient than their counterparts. Regarding the size of grid-connected PV inverters, a change of paradigm has been observed in the past few years. Large central inverters (above 100 kW) are being substituted by string inverters around a few kilowatts that process the energy of a small group of PV panels, improving the maximum power point tracking (MPPT) of a PV system, as the modules could be exposed to different solar irradiation levels. In this context, the use of single-phase inverters has gained great interest. Especially in residential areas, to solve problems like different orientation of PV panels, partial shadows or accumulated dust. Furthermore, the possibility of producing energy close to the consumption points by means of a large number of small distributed energy generators has raised many expectations. The distributed generation scenario is promoting the research about power converters to reduce the impact of the partial shadowing problem.

Thus, module integrated converters (MICs), microinverters and multi-input string inverters are being developed. However, MICs and microinverters usually require cascade conversion stages that decrease the efficiency and make the system more complex. Therefore string inverters are most commonly used. Besides, there are some topologies of string inverters that reduce the partial shadowing problem, by means of independent control of the multiple PV inputs. The principle of serial connection of PV strings with maximum power extraction from each individual string by means of a single inverter has raised a high interest in the past years. The grid-connected PV inverter presented in this paper is a5 kW multi-input transformerless string inverter with simultaneous MPPT of two PV sources. This topology, called neutral point clamped (NPC) + generation control circuit (GCC), solves the typical issues of transformerless PV inverters related to leakage currents from the PV panels to ground because of high-frequency common mode voltages. Moreover, the auxiliary dc–dc converter used in this topology (the GCC circuit) exhibits low losses, since it only processes the power difference between both PV strings. Therefore the efficiency of this double-stage converter is similar to that of a single-stage inverter.

COMMON MODE VOLTAGE PROBLEM

PV modules have a very large conductive surface which may have a large parasitic capacitance to ground under certain operating conditions (e.g. humidity, dust or in some kinds of facility), with capacitance values up to 150 nF/kW for crystalline-silicon cells and up to 1 μF/kW for thin-film cells. The parasitic capacitances between ground and both terminals of the PV source, Cparasitic1 and Cparasitic2, are depicted in the single-phase transformerless grid-connected PV inverter of Fig. 1.The AC voltages at the PV module terminals (v_1 and v_2) produce leakage currents to ground through the parasitic capacitances Cparasitic1 and Cparasitic2. The currents induced by those voltages can be classified into differential mode currents and common mode currents.

The differential mode voltage, $v_{DM}= v_1 - v_2$, generates a current that flows from one pole of the PV modules to the other one; this current does not generate leakage problems. The common mode voltage, VCM = (V1 + V2)/2, generates a leakage current(I Leakage) that flows from the poles of the PV source, through the ground of the PV source, to the ground of the grid, which is connected to the neutral of a single-phase utility grid. This current may produce problems in the PV system (e.g. protections triggering, efficiency degradation, safety problems and electromagnetic compatibility problems). When using the newest technologies of PV cells, like back-contact cells, amorphous silicon thin-film cells (a-Si)or cadmium telluride cells (CdTe), the leakage current can produce irreversible effects on the PV cells, affecting the efficiency of the overall system permanently. If the common mode voltage at the PV module is purely sinusoidal with a root mean square (RMS) value VCM_RMS, and both parasitic capacitances are similar (Cparasitic1 ≃Cparasitic2≡Cparasitic), the RMS value of the leakage current can be derived as (1), where Cparasitic_eq = 2Cparasitic and f denotes the frequency of the common mode voltage. As the leakage current is proportional to the frequency of the common mode voltage, the most disturbing common mode voltages are those containing switching frequency harmonics. Therefore current research on transformerless inverters focuses on finding new topologies and modulation strategies which have an almost dc or low frequency common mode voltage, thus generating very low leakage currents

$$I_{LEAK_{RMS}} = 2pfC_{Parastic_{eq}} V_{CM_{RMS}} \tag{1}$$

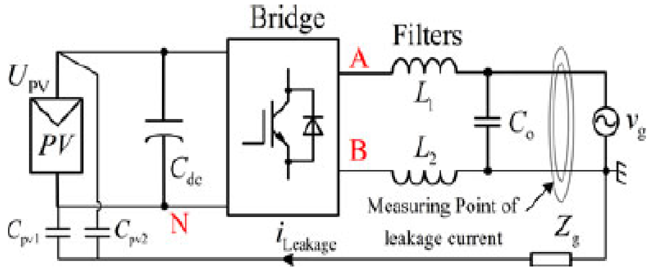


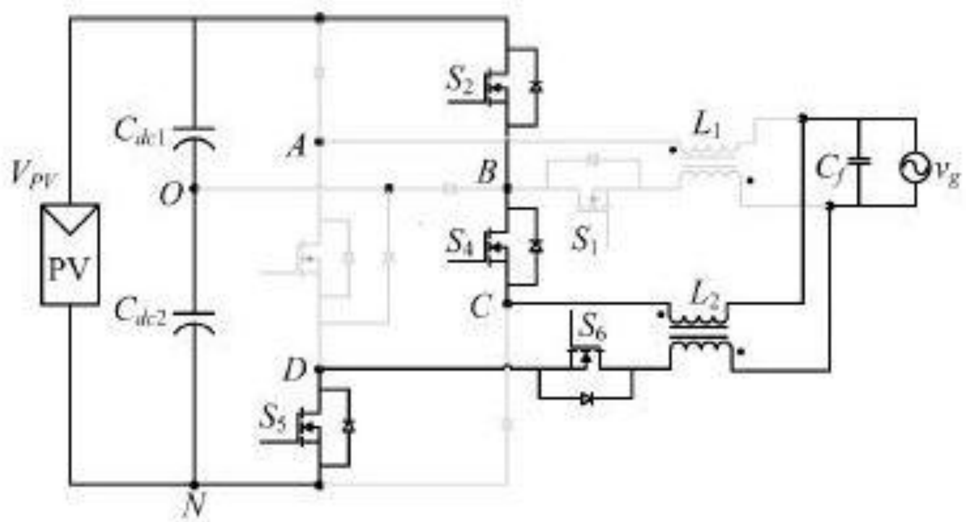
Figure 1. Leakage current path for transformer less PV inverters.

PARTIAL SHADOWING PROBLEM

A string is a group of PV modules connected in series, where the total PV source voltage is the sum of the individual modules voltages, whereas all modules share the same current. When the solar irradiation level at one individual module of the string decreases, its maximum current decreases too, limiting the current in the whole string, because of the series connection. When limiting the current of the string, it is also being limited the maximum power of the PV source, so that it is impossible to have all the modules working at its maximum power point (MPP).In these conditions, the voltage–power curve of the PV source presents some local MPPs, all of them with a power lower than the sum of the achievable MPPs of the individual modules. To reduce the partial shadowing problem, many string inverters use as a first stage a dc–dc converter (e.g. a boost converter) for each module or for a small group of series connected modules. It is worth pointing out that the smaller the number of interconnected PV modules, the better is the MPP tracking under partial shadowing. The dc–dc converter performs the MPPT of each module or group of modules. The outputs of the dc–dc converters are connected in parallel to the grid connected inverter. However, the overall efficiency and reliability of the whole power conversion system are affected, as it is formed by power converters.

PROPOSED NPC H6 TOPOLOGY

The proposed new NPC H6 topology with unipolar SPWM method [20-22] not only can achieve unity power factor, but also has the ability to control the phase shifts between voltage and current waveforms. The modulation strategy is shown in Fig.5. The drive signal is in phase with the grid-tied current. Therefore, it has the capability of injecting or absorbing reactive power.



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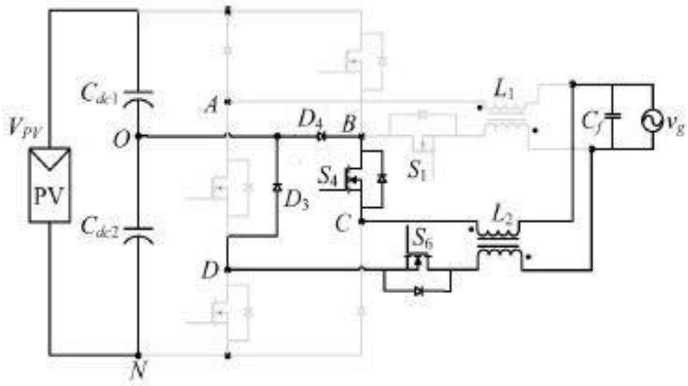

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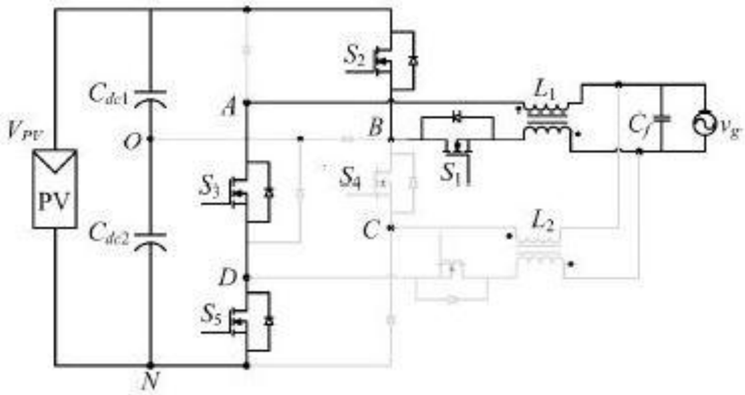

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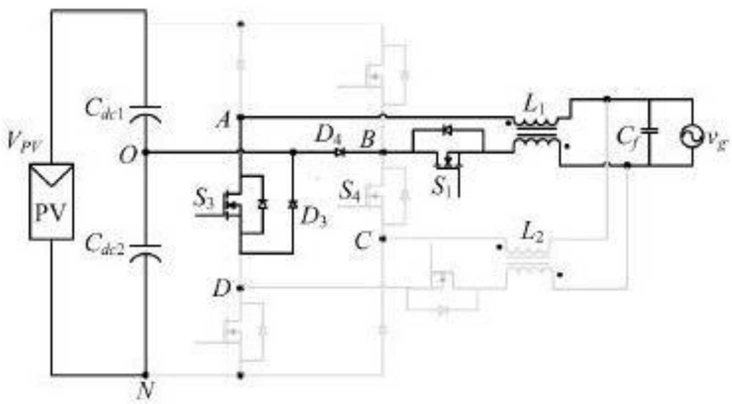


(d)

Figure 5: Operating modes of proposed NPC- H6 inverter. (a) active mode during positive half grid cycle, (b) freewheeling mode in positive half grid cycle, (c) active mode during negative half grid cycle, (d) freewheeling mode in negative half grid cycle.

The power stage shown in Fig. 5 is considered for analyzing the modes of operation and leakage current .The unipolar SPWM scheme for the proposed NPC transformer less inverter where, G_1-G_6 represent gate signals for the switches S_1-S_6 respectively. The control signal V_{cont} is obtained from current controller. The switches S_2 and S_5 are commutated simultaneously at switching frequency to modulate inverter output current. In the positive half cycle of grid current. S_4, S_6 are kept ON and S_1 , S_3 are turned OFF. Similarly in the negative half cycle of grid current,S_1,$S_3$are kept ON and S_4,S_6 are turned OFF.Fig.5 shows the four operating modes of the transformer less NPC inverter. These modes are explained below.

A. Mode 1

This is the active mode in positive half cycle of grid current shown in Fig.5(a). Switches S_2,S_4,S_6 and S_5 turned ON and the remaining are turned OFF. The coupled filter inductor L_2 is energized and current increases through S_2,S_4,$S_6$and S_5.

The total common-mode voltage is given by,

$$V_{tCM} = \frac{V_{CN}+V_{DN}}{2} + \left(V_{CN} - V_{DN}\right)\frac{(L_{2C}-L_{2D})}{2(L_{2C}+L_{2D})} = \frac{V_{PV}}{2} \qquad (2)$$

B. Mode 2

This is the freewheeling mode in positive half cycle of grid current shown in Fig. 5(b). Switches S_2 and S_5 are turned OFF. The current flowing through $L2$ freewheels through $S4$,$S6$, $D3$ and 4 and the potential at points C and D is clamped at $0.5V_{PV}$. The total common mode voltage is,

$$V_{tCM} = \frac{V_{CN}+V_{DN}}{2} + \left(V_{CN} - V_{DN}\right)\frac{L_{2C}-L_{2D}}{2(L_{2C}+L_{2D})} = \frac{V_{PV}}{2} \qquad (3)$$

C. Mode 3

This is the active mode in negative half cycle of grid current shown in Fig. 5(c). Switches $S2$, $S1$, $S3$ and $S5$ are turned ON and the remaining switches are turned OFF. The coupled filter inductor $L1$ is energized and current increases through $S2$,$S1$, $S3$ and $S5$.

The total common-mode voltage is,

$$V_{tCM} = \frac{V_{CN}+V_{DN}}{2} + \left(V_{CN} - V_{DN}\right)\frac{(L_{2C}-L_{2D})}{2(L_{2C}+L_{2D})} = \frac{V_{PV}}{2} \qquad (4)$$

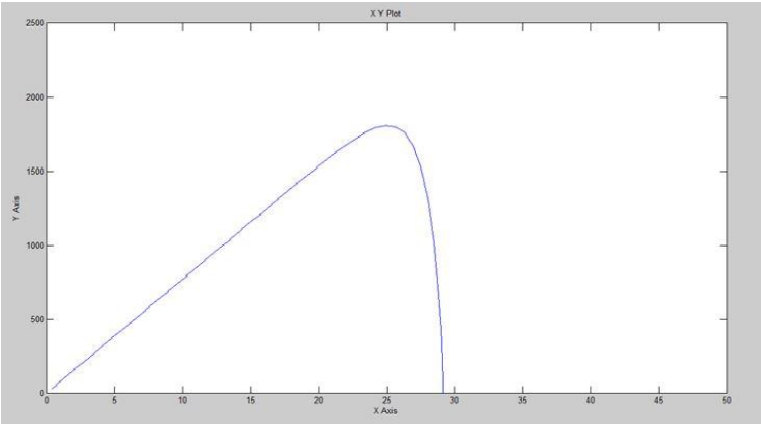
D. Mode 4

This is the freewheeling mode in negative half cycle of grid current shown in Fig. Switches $S2$ and $S5$ are turned OFF. The coupled filter inductor $L1$ current freewheels through $S1$,$S3$, $D3$ and $D4$ and the potential at points A and B is clamped at $0.5V_{PV}$. Therefore, V_{AN}=V_{BN}=0,v_{AB}= 0 and the total common-mode voltage is,

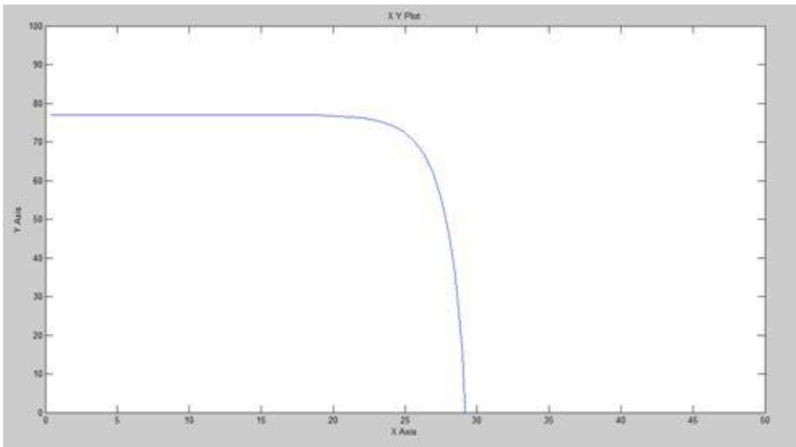
$$V_{tCM} = \frac{V_{AN}+V_{BN}}{2}\left(V_{AN} - V_{BN}\right)\frac{L_{1A}-L_{1B}}{2(L_{1A}+L_{1B})} \qquad (5)$$

It is clear from that the antiparallel diode of$S4$ is reverse biased. Therefore, the coupled filter inductor $L2$ is not energized in the negative grid half period. It can be observed from that the total common mode voltage is maintained at $0{:}5VPV$ in all operating modes. Therefore, the common-mode resonant circuit shown in Fig.5(c) and 5(d) are not activated and leads to low leakage current. In the positive half cycle of grid current *Mode1* and *Mode 2* are used to generate V_{PV} and 0 at the output. In the negative half cycle of grid current $-V_{PV}=0$ are generated by continuously switching between *Mode 3* and *Mode 4*. The voltage stress on $S2$, $S5$ is equal to half of the input voltage and for remaining switches is equal to input voltage.

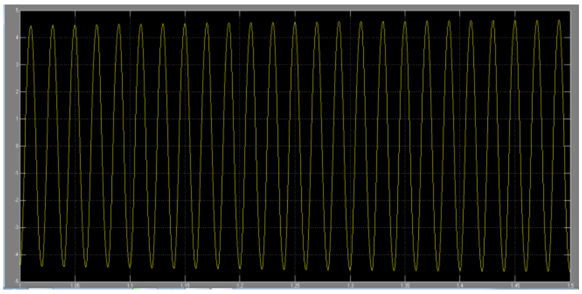
SIMULATION RESULTS



P-V characterstics of PV panel



I-V Characteristics of PV Panel



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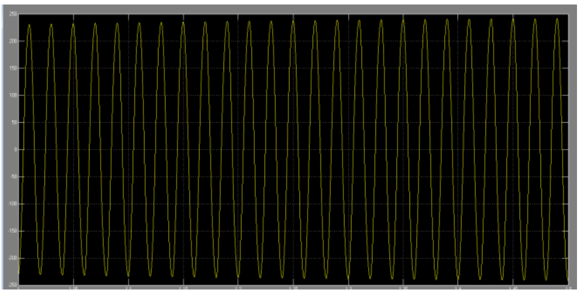

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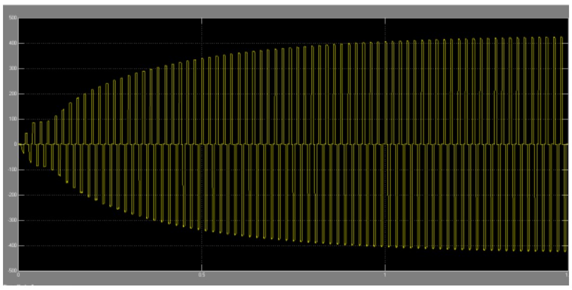

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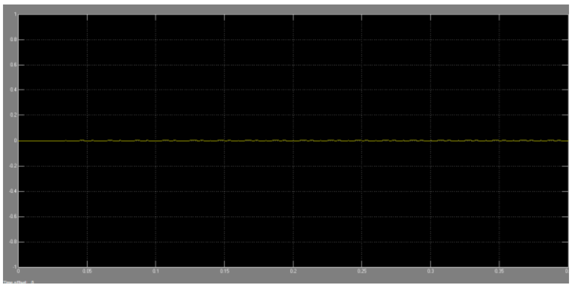

(d)

Figure 6: Proposed H6 type results (a) Output voltage (b) Output Current (c) Common mode Voltage (d) Leakage Current

CONCLUSION

In this paper, from the topological relationship point *of* H5,H6-type, HERIC and, NPC. In the H5 topology, a new current path is formed by inserting a power device between the terminals of PV array and the midpoint of one of bridge legs. As a result, a family of single-phase transformer less full-bridgeH6 inverter topologies with low leakage currents is derived. The proposed H6 topologies have the following advantages and evaluated by experimental results:

1) The conversion efficiency of the novel H6 topology is better than that of the H5 topology.
2) The leakage current is almost the same as HERIC topology, and meets the safety standard;
3) The excellent DM performance is achieved like the isolated full-bridge inverter with uniploar SPWM. Therefore, the proposed H6 topologies are good solutions for the single phase transformer less PV grid-tied inverters.

This paper presents an improved single-phase neutral point clamped transformerless inverter for grid-connected PV system. The effect of common-mode voltage is analyzed, taking parasitic capacitance of switches into account. The desired relation between the values of parasitic capacitance, which can keep common-mode voltage constant is proposed. The effectiveness of the proposed solution is ascertained though the simulation studies. The improved single-phase NPC inverter has following advantages.

1) The common-mode voltage is approximately clamped at a constant level and thus the leakage current is reduced effectively.
2) The leakage current performance of inverter is independent of dead time provided between the switches connected across the upper half of dc link.
3) The excellent differential-mode characteristics as in the isolated full-bridge inverter with unipolar SPWM is achieved. Thus, the improved NPC inverter can be a good solution for transformerless single-phase grid connected PV system.

COMPARISION TABLE

Type	No of switches	Common mode voltages	Leakage Currents
H5	5	500V	8mA
Heric	6	420V	4mA
H6	6	400V	4mA
H6 NPC	6	400V	1.25mA

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