TRANSFORMERLESS THREE LEVEL DIODE CLAMPED INVERTER FOR SINGLE PHASE GRID CONNECTED PHOTOVOLTAIC SYSTEM

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\textbf{ABSTRACT}

The traditional grid-connected PV inverter includes either a line frequency or a high frequency transformer between the inverter and grid. The transformer provides galvanic isolation between the grid and the PV panels. In order to increase the efficiency, to reduce the size and cost, the effective solution is to remove the isolation transformer. It leads to appearance of common mode (CM) ground leakage current due to parasitic capacitance between the PV panels and the ground. The common mode current reduces the efficiency of power conversion stage, affects the quality of grid current, deteriorate the electric magnetic compatibility and give rise to the safety threats. In order to eliminate the common mode leakage current in transformerless PV system, split-inductor neutral point clamped three level inverter (SI-NPCTLI) with neutral line of the grid connected to the midpoint of capacitor’s bridge leg of the inverter is proposed in this paper. The simulation result of the proposed topology using MATLAB/SIMULINK is presented.

\textbf{Keywords:} Boost Converter, Common Mode leakage current, P&O MPPT algorithm, Photovoltaic System, Split inductor neutral point clamped inverter.

I. INTRODUCTION

Renewable energy sources are becoming very important part of the total energy production in the world. Today the energy production from solar energy compared to the other renewable energy sources is very low since the output voltage of pv system is low, but the photovoltaic systems are one of the fastest growing energy systems in the world. The price of PV system components, especially the PV modules are decreasing and the market for PV is expanding rapidly, so that solar energy production can be increased and can meet the energy crisis in the present scenario. Solar power will be always dominant over others because of its availability and reliability. Photovoltaic inverters, which are necessary for the power conversion, became more and more widespread among both private and commercial circles. These grid-connected inverters convert the available direct current supplied by the PV panels and feed it into the utility grid and also can be directly feed to the load.

There are two main inverter topologies namely, with and without galvanic isolation used in the case of grid-connected PV systems [2]. Galvanic isolation is in the form of a high-frequency dc–dc transformer that can be on the dc side or also in the form of a big bulky ac transformer on the grid side. Both of these solutions offer the safety and advantage of galvanic isolation such as high voltage gain to boost the input voltage, but the efficiency of the whole system is decreased due to power losses in these extra components. In case of the transformer less isolated inverters the efficiency of the whole PV system can be increased with an extra 1%–2%.

The efficiency of commercial PV panels is around 15-20%; therefore it is very important that the power produced by these PV panels is not wasted by using any inefficient power electronics systems. The efficiency and
reliability of both single-phase and three phase PV inverter systems can be improved using transformer less topologies, but it has to dealt with problems related to leakage current and safety that occurs in transformer less topology. If the transformer is avoided in order to increase the efficiency the common mode (CM) ground leakage current will appear on the parasitic capacitor between the PV panels and the ground [3] [4]. The existence of the CM current can reduce the power conversion efficiency, will increase the grid current distortion, deteriorate the electric magnetic compatibility, and give rise to the safety threats [4]. A novel split-inductor NPCTLI (SI-NPCTLI) with hysteresis current control that offers an excellent current reference tracking performance is proposed in this paper, which can overcome the problems of leakage current.

II. CONDITION OF ELIMINATING THE COMMON-MODE LEAKAGE CURRENT

When the transformer is not used, a galvanic connection between the ground of the grid and the PV array exists; as a consequence of this, a common-mode resonant circuit appears which consist of a stray capacity between the PV modules and the ground. A varying common-mode voltage can excite this resonant circuit and it can generate a common-mode current. These currents can cause severe electromagnetic interferences, distortion in the grid current and additional losses in the system [5].

To avoid leakage currents, the common-mode voltage must be kept constant during all commutation states. The common-mode voltage can be defined as the average of the sum of voltages between the outputs and the common reference. The differential-mode voltage is defined as the difference between the two voltages [3] [6].

![Fig 1. Common-mode model for a single-phase grid-connected inverter](image1)

![Fig 2. Split Inductor – Neutral Point Clamped Three Level Inverter](image2)

In the positive half-cycle:
- Common mode voltage: \( V_{CM} = (V1N + V3N)/2 \) (1)
- Differential mode voltage: \( V_{DM} = V1N - V3N \) (2)

In the negative half-cycle:
- Common mode voltage: \( V_{CM} = (V2N + V3N)/2 \) (3)
Differential mode voltage $V_{DM} = V_{2N} - V_{3N}$ \hspace{1cm} (4)

The term $V_{CM,DM}$ indicates the influence of the differential mode voltage to the common-mode voltage:

$$V_{CM,DM} = -V_{DM}/2 \hspace{1cm} (5)$$

If the total common mode voltage produced by the SI-NPCTLI is a constant value resonant circuit cannot be excited then it will not introduce any leakage current in transformer-less PV grid-connected applications. $V_{CM} + V_{CM,-DM} = \text{constant at all conduction states}$

III. PROPOSED TOPOLOGY

In this topology, neutral line of the grid is directly connected to the midpoint of capacitor’s bridge leg, as shown in Fig.2. By using SI-NPCTLI, switching and conduction losses are reduced and the efficiency can be improved. Before analysis, the following assumptions are given: a) all power switches and diodes are the ideal devices b) all inductors and capacitors are ideal and $C_{dc1} = C_{dc2} = C$, $L_{1} = L_{2} = L$; and c) the inverter operates at the unity power factor, i.e., the inductor current $i_{L1,2}$ is in phase with the grid voltage $U_{g}$. Four modes of operation is described below:

- **Mode 1**
  Switches S1 and S2 ON, and S3 and S4 OFF, the output voltage of the bridge leg is the voltage of capacitor $C_{dc1}$, i.e., $u_{13} = (1/2)U_{pv}$. At this duration, the current of inductor $L_{1}$, indicated by $i_{L1}$, increases:
  
  $V_{1N} = U_{pv}$
  $V_{2N} = U_{g} + U_{pv}/2$
  $V_{3N} = U_{pv}/2$
  $V_{CM} = (V_{1N} + V_{3N})/2 = 3U_{pv}/4$ \hspace{1cm} (6)
  $V_{DM} = V_{1N} - V_{3N} = U_{pv}/4$ \hspace{1cm} (7)
  $V_{CM,DM} = -V_{DM}/2 = -U_{pv}/4$ \hspace{1cm} (8)
  $V_{CM} + V_{CM,-DM} = U_{pv}/2 \hspace{1cm} (9)$

- **Mode 2**
  S1 OFF, S2 ON, and S3, S4 still OFF, the voltage on S1 is clamped to the half of the input voltage by the diode D5, and the output voltage of the bridge leg is zero, i.e., $u_{13} = 0$. At this duration, the current of inductor $L_{1}$ is in freewheeling stage and $i_{L1}$ decrease:
  
  $V_{1N} = U_{pv}/2$
  $V_{2N} = U_{g} + U_{pv}/2$
  $V_{3N} = U_{pv}/2$
  $V_{CM} = (V_{1N} + V_{3N})/2 = U_{pv}/2$ \hspace{1cm} (10)
  $V_{DM} = V_{1N} - V_{3N} = 0$ \hspace{1cm} (11)
  $V_{CM,DM} = -V_{DM}/2 = 0$ \hspace{1cm} (12)
  $V_{CM} + V_{CM,-DM} = U_{pv}/2 \hspace{1cm} (13)$

- **Mode 3**
  S3, S4 ON and S1, S2 OFF, the output voltage of the bridge leg $u_{23} = - (1/2) U_{pv}$, $i_{L2}$ indicating the current of inductor $L_{2}$ increases in the negative half cycle:
  
  $V_{1N} = U_{g} + U_{pv}/2$
  $V_{2N} = 0$
  $V_{3N} = U_{pv}/2$
  $V_{CM} = (V_{2N} + V_{3N})/2 = U_{pv}/4$ \hspace{1cm} (14)
  $V_{DM} = V_{2N} - V_{3N} = -U_{pv}/2$ \hspace{1cm} (15)
  $V_{CM,DM} = -V_{DM}/2 = U_{pv}/4$ \hspace{1cm} (16)
  $V_{CM} + V_{CM,-DM} = -U_{pv}/2 \hspace{1cm} (17)$

- **Mode 4**
  With S4 OFF, S3 ON, and S1, S2 OFF, the voltage on S4 is clamped to the half of the input voltage by the diode D6, and the output voltage of the bridge leg is zero, i.e., $u_{23} = 0$. At this duration, the current of inductor $L_{2}$ states in the freewheeling stage and $i_{L2}$ decrease:
  
  $V_{1N} = U_{g} + U_{pv}/2$
  $V_{2N} = U_{pv}/2$
During the positive half-cycle of the grid voltage, the output-voltage levels of the bridge leg include zero and \((1/2)U_{pv}\) and during the negative half-cycle, the output voltage have two levels of zero and \(-\left(1/2\right)U_{pv}\).

Common mode voltage is constant at all operating conditions, as illustrated in (9), (13), (17) and (21). Therefore it will not introduce leakage current.

IV. PROPOSED MODULE TOPOLOGY

- **PV Module**
  Photovoltaic solar energy is clean renewable energy with long service life and high reliability. It is the power conversion unit of PV generator system. Solar cell converts solar energy into electrical energy. The conversion occurs in material, which has the property of capture photon and emit electron. Output characteristics of PV module depend on solar insulation, cell temperature and output voltage of PV module. Output voltage of solar cell is only about 0.5-0.7v therefore solar cells need to be connected in series and parallel to meet the capacity demand

- **MPPT and Boost Converter**
  When energy generated by using PV, efficiency of energy conversion is low and initial cost of its implementation is high and it becomes necessary to use techniques to extract maximum power from these to achieve maximum efficiency. There is only one maximum power point for a PV cell, therefore to achieve maximum efficiency, cells need to be operated at this point [7][8]. There are many methods to achieve maximum power point. Perturbation and observation (P&O) technique is used here. In a fixed period of time, the load of the PV system is adjusted to change the terminal voltage and output power of the PV modules. The changes of the output voltage and power before and after variations are then observed and compared to the reference for increasing or decreasing the load in the next step by adjusting the perturbation. If the output power of PV modules is greater than that before the variation perturbation is adjusted such that the output voltage of PV modules will be varied toward the same direction. Otherwise, if the output power of PV modules is less than that before variation, then the varying direction in the next step should be changed to maintain the maximum power point.
Output of mppt is compared with a ramp signal to generate the gating signal for the boost converter, which will boost the output voltage of the PV module to the required level to feed to the inverter.

**Control of Split Inductor Neutral Point Clamped Three Level Inverter**

Hysteresis current control, which is a nonlinear control method, possesses high performance, simple realization circuit high stability, inherent current-limiting capability, and fast & dynamic response [9][1]:

\[
h = \frac{U_g(U_{pv} - 2U_g)}{U_{pv}Lfs}
\]  
\[
(22)
\]

The basic implementation of hysteresis current control is based on deriving the switching signals from the comparison of the current error with a fixed tolerance band. This control is based on the comparison of the actual phase current with the tolerance band around the reference current associated with that phase. Comparing real time \(h\) with error of inductor current and reference current generates driving signals.

V. **SIMULATION RESULTS**

Simulation is done in MATLAB Simulink. PV array is simulated with \(Np2 = 144\) to get O/P voltage of about 176V and it is fed to the boost converter which is simulated and the O/P voltage is 400V which is the source to the SI-NPCTLI. The capacitor is replaced by 2 equivalent sources and it is synchronized to the grid.
Fig 5. Output of PV Module

Fig 6. Output of Boost Converter

Fig 7. Output Current of the Proposed Inverter
Fig 8. Output Voltage of the Proposed Inverter

Fig 9. Leakage Current

Fig 10. THD analysis of SI-NPCTLI
VI. CONCLUSION

Novel split inductor neutral point clamped three-level inverter for transformer-less grid connected topology has been described in this paper. In each mode of operation, common mode voltage is held constant; thus eliminating a major disadvantage in transformer-less topology, leakage current. The proposed inverter can achieve high efficiency, low cost, low leakage current, and high reliability to satisfy the requirements of the transformer-less PV grid-connected inverter. Hysteresis current control is used for generating pulses for the inverter switches which can track the inductor current.

REFERENCES