© 2017 IJSRSET | Volume 3 | Issue 2 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Generalized Design of Transformer Less Photovoltaic Inverter for Elimination of Leakage Current and Pulsating Power in Grid Connected System

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ABSTRACT

This paper presents a transformer less inverter topology, which is capable of simultaneously solving leak- age current and pulsating power issues in grid-connected photovoltaic (PV) systems. Without adding any additional components to the system, the leakage current caused by the PV-to-ground parasitic capacitance can be bypassed by introducing a common-mode (CM) conducting path to the inverter. The resulting ground leakage current is therefore well controlled to be below the regulation limit. Furthermore, the proposed inverter can also eliminate the well-known double-line-frequency pulsating power that is inherent in single-phase PV systems. By properly injecting CM voltages to the output filter capacitors, the pulsating power can be decoupled from the dc-link. Therefore, it is possible to use long-lifetime film capacitors instead of electrolytic capacitors to improve the reliability of the PV system.

Keywords : Multi Input Transformer(MIC), Maximum Power Point Tracking(MPPT), Power flow management.

I. INTRODUCTION

Photovoltaic (PV) systems, particularly low-power single-phase systems (up to 5 kW), are becoming more important worldwide. They are usually private systems where the owner tries to get the maximum system profitability. Issues such as reliability, high efficiency, small size and weight, and low price are of great importance to the conversion stage of the PV system [1]–[3]. Quite often, these grid-connected PV systems include a line transformer in the power-con- version stage, which guarantees galvanic isolation between the grid and the PV system, thus providing personal protection. Further more, it strongly reduces the leakage currents between the PV system and the ground, ensures that no continuous current is injected into the grid, and can be used to increase the inverter output voltage level [1], [2], [4]. The line transformer makes possible the use of a full-bridge inverter with unipolar pulse width modulation (PWM). The inverter is simple. It requires only four insulated gate bipolar transistors (IGBTs) and has a good trade-off between efficiency, complexity and price [5]. Due to its low frequency, the line transformer is large, heavy and expensive. Technological evolution has made possible the implementation, within the inverters, of both ground-fault detection systems and solutions to avoid injecting dc current into the grid. The transformer can then be eliminated without impacting system characteristics related to personal safety and grid.

In addition, the use of a string of PV modules allows maximum power point (MPP) voltages large enough to avoid boosting voltages in the conversion stage. This conversion stage can then consist of a simple buck inverter, with no need of a transformer or boost dc–dc converter, and it is simpler and more efficient. But if no boost dc–dc converter is used, the power fluctuation causes a voltage ripple in the PV side at double the line frequency. This in turn causes a small reduction in the average power generated by the PV arrays due to the variations around the MPP. In order to limit the reduction, a larger input capacitor must be used. Typical values of 2 mF for this capacitor limit the reduction in the MPPT efficiency to 1% in a 5-KW PV system [8]. However, when no transformer is used, a galvanic connection between the grid and the PV array exists. Dangerous leakage currents (common-mode currents) can flow through the large stray capacitance between the PV array and the ground if the inverter generates a varying common-mode voltage [1], [4].

II. COMMON-MODE CURRENTS IN TRANSFORMERLESS PV SYSTEMS

When no transformer is used, a galvanic connection between the ground of the grid and the PV array exists. As a consequence, a common-mode resonant circuit appears, consisting of the stray capacity between the PV modules and the ground, the dc and ac filter elements, and the grid impedance (Fig. 1). A varying common-mode voltage can excite this resonant circuit and generate a common-mode current. Due to the large surface of the PV generator, its stray capacity with respect to the ground reaches values that can be even higher than 200 nF/kWp in damp environments or on rainy days [1], [4]. These high values can generate ground currents with amplitudes well above the permissible levels, such as those concerning the standards [6].

Figure 1

Its attract tiveness is that it does not require any additional switches to resolve these two difficulties, and the circuit configuration is very simple, with only one additional current sensor introduced for current control. The leakage current can be controlled by introducing a CM conducting path inside of the PV inverter, so that it will not flow through the ground. By further injecting CM voltages to the output capacitors, the second-order pulsating power that originated from the ac side can be decoupled, and it will not be seen by the dc-link as well as the PV input. In this case, the dc capacitance requirement can be substantially reduced, and it is feasible to design an all-film-capacitor sup- ported PV inverter with high efficiency and high reliability.

III. CIRCUIT DIAGRAM OF THE PROPOSED SYSTEM

The proposed transformer less PV inverter is essentially de- rived from a conventional full-bridge inverter with an output *LC* filter. The *LC* filter is split into two identical parts, having $L_{f1} = L_{f2} = L_f$ and $C_{f1} = C_{f2} = C_f$. They are distributed into the two switching legs as shown in Fig. 1. More advanced *LC L* or *LLC L* filters can also be adopted, but they may increase the complexity of the system [34]–[36]. The midpoint of the two capacitors is then connected to the negative dc bus in order to provide a conducting path for the CM current. Because of the symmetrical circuit configuration, its differential mode (DM) operation, i.e., active power injection and reactive power support, will not be affected. In order to investigate the ground leakage current, the equivalent CM circuit is presented in Fig. 2, where the grid voltage is neglected because it is of fundamental frequency only.

In order to limit the reduction, a larger input capacitor must be used. Typical values of 2 mF for this capacitor limit the reduction in the MPPT efficiency to 1% in a 5-KW PV system. Due to the large surface of the PV generator, its stray capacity with respect to the ground reaches values that can be even higher than 200 nF/kWp in damp environments or on rainy days of . The leakage current can be controlled by introducing a CM.

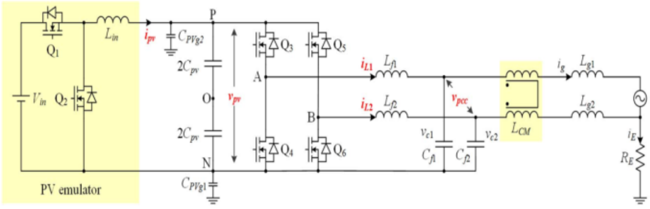


Figure 2

Fig 2 (Circuit diagram transformer less inverter)Z_{CM} is the equivalent CM loop impedance, consisting of the impedance of the output filter inductors Z_{Lf} , the impedance of the output filter capac- itors Z_{Cf} , the impedance of the parasitic capacitors Z_{CPVg} , the grid impedance Z_{Lg} , and the grounding impedance Z_E . As discussed previously, the leakage current is induced by the CM voltages at switching frequencies (usually in the kilohertz range), where the impedance of the capacitors is very small. By considering the worst case situation and neglecting the grid impedance

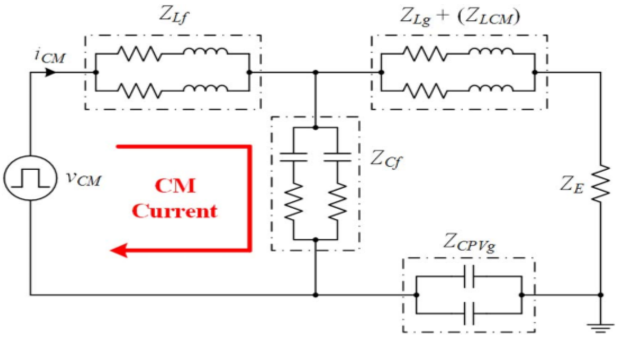


Figure 3. (Equivalent circuit of proposed PV inverter)

The amplitude of the CM current is usually in the range of several amperes, which significantly exceeds the 300-mA limit specified in [5], if there is no leakage current suppression method applied to the system. However, the equivalent circuit in Fig. 3 shows that the filter capacitors C_{f1} and C_{f2} may provide a new conducting path for the high-frequency CM current, which can be used to block the CM current from flowing through the parasitic capacitors C_{PVg1} and C_{PVg2}. For a stiff ac power grid where the grid impedance is negligible, the ground leakage current in such systems will be very small because the value of the filter capacitors is usually inherent is to shift the resonance frequency of the grounding loop to be away from the switching harmonics. Therefore, the value of L_{CM} is chosen to be slightly higher than the worst case grid inductance. Moreover, the CM choke will not be bulky in size because the CM current is very low and it will not cause saturation issues. In this case, the CM choke can be constructed with high-permeability cores, implying much reduced core size and less number of winding turns.

Another uncertainty of the grounding loop comes from the parasitic capacitance, which can reach the microfarad level if rainy weathers and film-type PV modules are considered. the PV module frames should be grounded in transformer less PV systems in order prevent electric shocks and fire hazards. Moreover, a residual current device (RCD) should also be installed to monitor the leakage current. The RCD will disconnect the inverter if a 30-mA jump in the leakage current is detected or the leakage current exceeds 300 mA.

IV. CONTROL BLOCK DIAGRAM

The closed-loop controller design of the proposed transformer less PV inverter becomes straightforward if the two operation modes are separately analyzed. Its DM equivalent circuit is essentially a conventional Unipolar-modulated full- bridge inverter operated in the grid-connected mode.

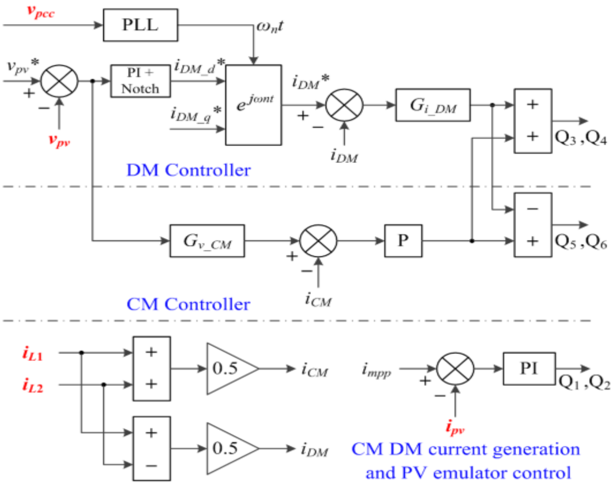


Figure 4. Over all block diagram of the controller

It is possible to arrive at the final modulation signals for the DM operation.For the CM controller design, Fig. 4. can be used, and the ground leakage loop can be neglected because it does not affect the power decoupling control. In this case, the equivalent circuit under CM operation becomes two paralleled buck converters, with each of them loaded by an *LC* impedance, i.e., L_f and C_f Based on this equivalent circuit model voltage at the point of common coupling (PCC) and the PV output current, they can be treated as the disturbances and cancelled by feedforward control. Since the response of the voltage control loop is usually much slower than that of the current control loop, the dynamics of v_{PV} can be neglected.

The additional magnetic component needed for the proposed solution can be obtained, to a first approximation, adding a third winding to the standard common-mode inductors used at the output of power converters in order to comply with electromagnetic compatibility (EMC) standards. By adding another winding to the common-mode choke (see Fig. 7), it ipossible to consider this new magnetic component as a common-mode transformer.

V. RESULTS AND DISCUSSION

1. Simulation Circuit and Results Introduction

This chapter deals with the simulation circuits and results. The circuit has been simulated using MATLAB R2010a software with Simulink toolbox. Simulink is a software package for modeling and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in discrete time, continuous time, sampled time or a hybrid of above.

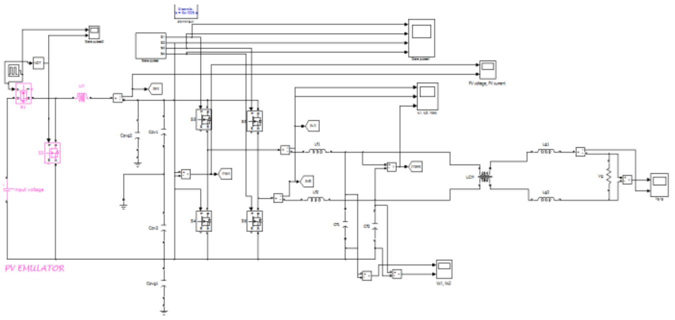
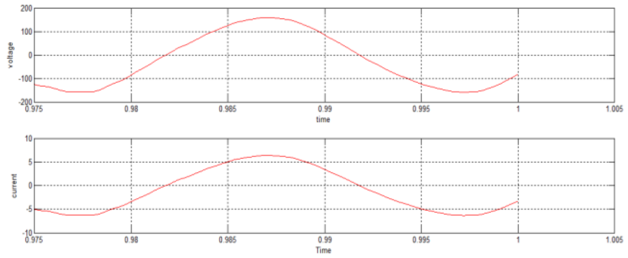


Figure 5. Simulink Model of the Proposed Method

2. Simulation of Solar Panel Subsystem

The figure shows the Simulink of solar panel subsystem. The photovoltaic panel produces an output of 24V.The solar subsystem consists of Photovoltaic panel which has the input parameters of Irradiation level, temperature and the voltage. The energy management is designed for the irradiation level varying from 900 w/m2 to 1400 w/m. In order to get 24V DC, for each cell voltage is assume to be 0.6V it is then multiplied with 40 cells to get 24V dc supply.

3. Simulation Result Of Grid Voltage And Current



4. Simulation Result Of Voltage Across VC1 and VC2

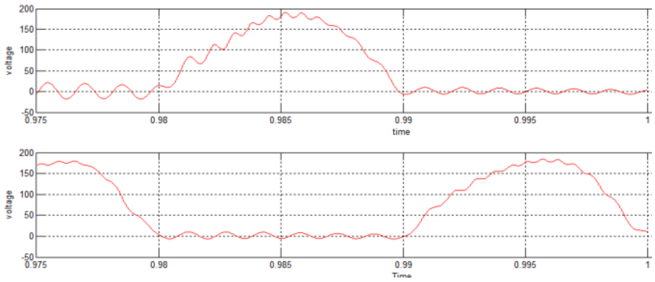


Figure 6. voltage across capacitors

5. Simulation Result of Voltage And Current Across PV Emulator

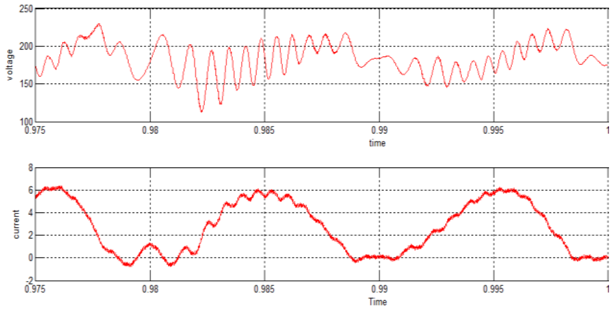
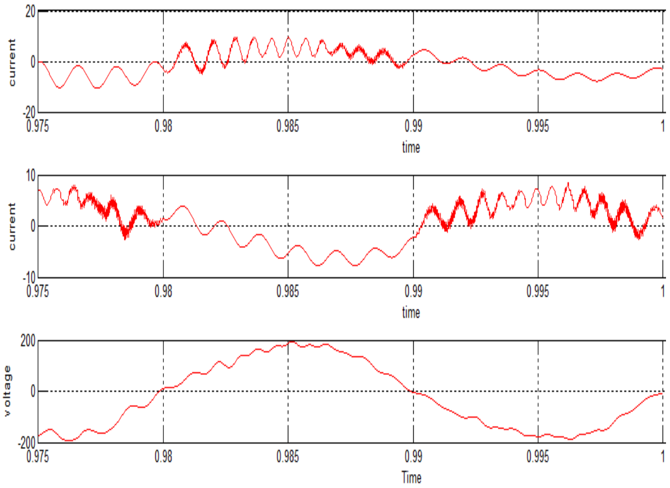


Figure 7. Simulation result of Converter Output Voltage

6. Simulation Result of Inductor Current And Parasitic Capacitor Voltage



The steady-state performance of a grid-connected hybrid PV and wind system with battery storage is analyzed in [4]. This paper focuses on system engineering, such as energy production, system reliability, unit sizing, and cost analysis. In [5], a hybrid PV-wind system along with a battery is presented, in which both sources are connected to a common dc-bus through individual power converters. In addition, the dc-bus is connected.

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