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To Reduce Leakage Current in Cascaded Multilevel Inverter Based PV System

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Abstract: Renewable energy sources are getting more and more widespread, mainly due to the fact that they generate energy by keeping the environment clean. Most of these systems have an isolation transformer included, which if excluded from the system would increase the efficiency and decrease the size of PV installations, furthermore it would lead to a lower cost for the whole investment. The design and control issues associated with the development of single phase grid-connected photovoltaic system incorporating a multi-level cascaded inverter are discussed in this paper. The transformer less cascaded multilevel inverter (CMI) is considered to be a promising topology alternative for low-cost and high-efficiency photovoltaic (PV) systems. However, the leakage current issue resulted from the parasitic capacitors between the PV panels and the earth remains a challenging in designing a reliable CMI-based PV system. In this paper, the leakage current paths in PV CMI are analysed and the unique features are discussed. The advantages of this CMI topology is that the amplitude of the output voltage, compared with a single HB topology, is higher and makes possible the power injection into the grid without a voltage boost stage. Numerical result show that the proposed modulation strategy reduces the leakage current and make the topology suitable for transformer-less PV applications.

Keywords: Cascaded multilevel inverter (CMI), leakage current, photovoltaic (PV), qZSI(Quasi Z Source Inverter), transformerless inverter

I. Introduction

This document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please contact the conference publications committee as indicated on the conference website. Information about final paper submission is available from the conference website. The distributed generation emerged as a way to integrate different power plants for increasing the reliability, reducing emissions, and providing additional power quality benefits. The photovoltaic (PV) modules are particularly attractive as a renewable source for distributed generation systems due to their relatively small size, noiseless operation, and simple installation and the possibility to put them close to the user. Many topologies for PV systems have a dc–dc converter with a high-frequency transformer that adjusts the inverter dc voltage and isolates the PV modules from the grid. However, the conversion stages decrease the efficiency and make the system more complex [6]. The transformer less centralized configuration with one-stage technology uses only one inverter and a large number of PV modules connected in series, called strings, to generate sufficient voltage to connect to the grid .TO maximize the energy harvest from the photovoltaic (PV) panels, the cascaded multilevel inverter (CMI) topology has been considered in PV applications. The CMI topology features separate dc inputs, making possible the string or even panel level maximum power point tracking. The energy harvest can be maximized in case of mismatch in the PV panels due to panel aging, shading effect or accumulation of dust in the panel surface. The cascaded structure can also generate high-quality output waveforms with each semiconductor device switching at lower frequency. In addition, cheaper power semiconductors with lower voltage rating can be utilized in the CMI compared with the central/string inverters. Currently, the CMI has found its applications in both utility scale and residential/commercial PV systems. A review of some reported CMI based PV systems is illustrated in Fig. 1. Where the point of common coupling (PCC) voltage and device switching frequency information are provided. It is noticed that modified CMI with

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integrated high-frequency transformer is usually utilized in large-scale PV systems.

The transformer is necessary for insulation purpose, because the several kV PCC voltage may impose directly across the PV panel electrical section and its frame when there is no transformer and it could cause hazardous dielectric breakdown. Besides, the integrated transformer can isolate the circulating leakage current paths. On the other hand, for residential/ commercial applications with low PCC voltages, because there is no aforementioned insulation concern, transformerless PV CMI is preferred due to the lower cost and higher efficiency

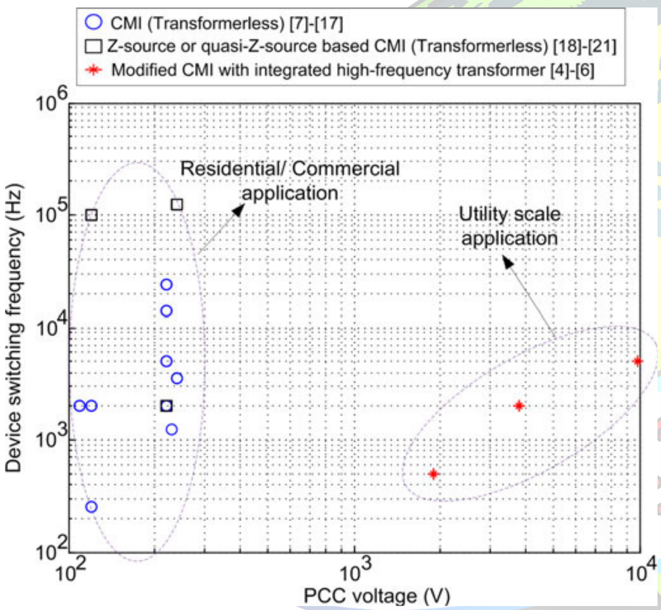

Fig 1 CMI in PV application

The transformerless CMI structure can be readily accomplished by extending the number of cascaded modules. However, removal of the transformer would result in galvanic connections among the grid and the separate PV panels/strings interfaced with different cascaded inverters. Due to the parasitic capacitance between the PV panels and the earth, circulating leakage currents can flow through the panels and grid ground, leading to increased output harmonic content, higher losses, safety, and electromagnetic interference (EMI) problems. So far, there is rarely publication dealing with the leakage current issue in transformer less CMI-based PV systems.

II. CASCADE MULTILEVEL INVERTER

Multilevel converter topology incorporates cascaded single-phase H-bridges with separate dc sources. This requirement makes renewable energy sources such as fuel cells or photo voltaic a natural choice for the isolated dc voltage sources needed for the cascade inverter. Fig shows a single-phase structure of an m-level cascade inverter .Each SDCS is connected to a single phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs,+Vdc,0,-Vdc by connecting the dc source to the ac output by different combinations of the four switches,S1,S2,S3,and S4.To obtain +Vdc, switches S1 and S4 are turned on. Turning on switches S2 and S3 yields –Vdc. By turning on S1 and S2 or S3 and S4,the output voltage is 0.The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m=2s+1, where s is the number of separate dc sources.

In order to analyse the HB-CMI topology for a transformer less application, it is necessary to include the stray capacitances which are embodied between the PV cells and the grounded frame that covers the edge of the PV panel. These capacitances can be modeled by small capacitors connected in each positive and negative terminals of the PV panels, as it is shown in Fig. In transformer-less applications, high-frequency variations of the PV voltage in relation to ground must be avoided, since this leads to large charge/discharge currents which can partially flow to the ground throughout the stray capacitances. The leakage currents increase the harmonic distortion, power losses and may cause safety and electromagnetic interference problems.

Fig. 2(a) shows a generic diagram of a CMI-based PV system where the parasitic capacitors are added to study the leakage current issue. The parasitic capacitor for each cascaded module is designated as Cpvi, i = 1, 2, ..., n. There are two symmetrical line inductors L at the total output of the inverter. The equivalent circuit can be obtained in Fig. 2(b) by modelling each inverter phase leg as a voltage source with respect to the negative terminal of its dc bus.

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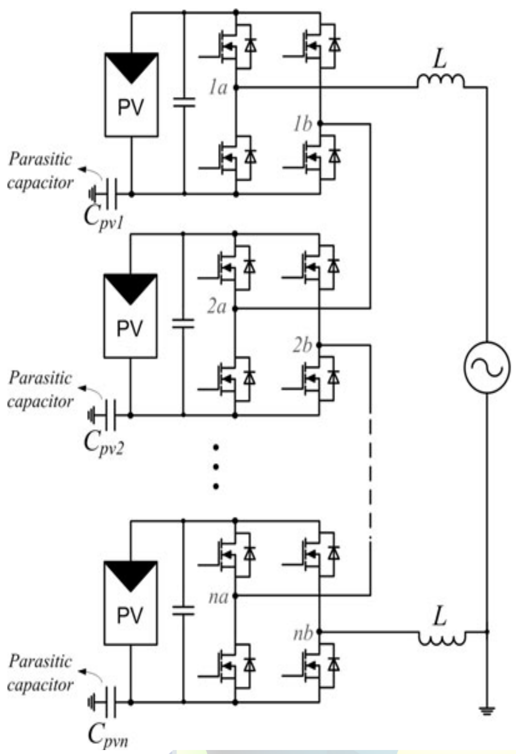

Fig 2 (a) Cascade multilevel inverter topology

The phase-leg voltage sources are named as via and vib, i = 1, 2, ... n. via and vib are pulse-width modulation(PWM) voltages which are composed of dc components, fundamental-frequency components and baseband harmonics, carrier harmonics and its sideband harmonics [34] . The carrier harmonics and its sideband harmonics are the main contributors to the leakage current issue. The magnitudes of these harmonics depend on the inverter input voltages and modulation strategy .Due to the parasitic capacitors and several grounding points, multiple circulating leakage current loops are formed in the CMI. These loops can be divided into two different types and examples of the two kinds of loops are revealed in Fig. 2(b). The first kind of leakage current loop is formed by the parasitic capacitor, Inverter Bridge, line inductor, and grid ground. Since the line inductor and grid ground are involved in the loop, this loop is indicated as module-line leakage current loop. The other kind of loop is formed among the inverter bridges, so it is indicated as inter module leakage current loop

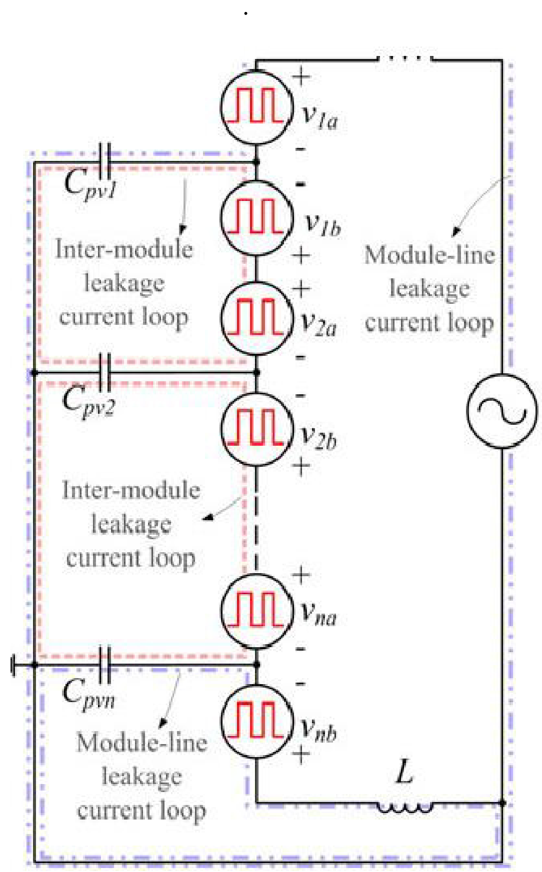

Fig 2 (b) Equivalent circuit

III. Proposed Modulation Strategy

The PV CMI with transformer less structure is preferred in residential/commercial applications due to the lower cost and higher efficiency. However, due to the parasitic capacitance between the PV panels and the earth, circulating leakage currents can flow through the panels and grid ground, leading to increased output harmonic content, higher losses, safety and EMI problems. So far, there is rarely publication dealing with the leakage current issue in transformerless CMI-based PV systems. This chapter firstly identifies the leakage current paths in PV CMI. The differences between the transformerless CMI and string inverter concerning the leakage current behaviours are also discussed. Then two leakage current suppression solutions are presented for the PV

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CMI by adding properly located and designed passive filters in the inverter. The first method is more suitable for the CMIs operated at high switching frequency. The second method extends the application to the CMIs operated with lower switching frequency by bringing in extra wire connections among the cascaded modules and the grid output. Simplified leakage current analytical models for the PV systems with the two suppression solutions are developed respectively to demonstrate the principles and introduce the filter design criteria. Finally the proposed first solution is applied in the PV system based on cascaded qZSIs. The second solution is executed in a PV system with two cascaded H-bridges where each switching device is operated at 10 kHz.

PROPOSED LEAKAGE CURRENT SUPPRESSION SOLUTION 1

The circuit configuration of a PV CMI with leakage current suppression solution is illustrated in Fig. The dc-side CM chokes, CM capacitors and ac-side CM chokes Lcm _ac are added in each inverter module. The voltage across and the current through are denoted as v and n= 1,2,... respectively. The leakage current flowing into the grid ground is labelled as where the leakage inductance of the CM chokes is ignored due to its minor impact on the leakage current issue. It is also noticed that the L _cm dc can be merged to the same position in the equivalent circuit, which implies that they would have the same contribution on leakage current suppression. L _cm ac and L _cm dc are both used in the circuit is because they can respectively help mitigate the ac-side and dc-side EMI CM noises due to their same position with the ac and dc side EMI filters. Therefore, the design effort for the ac and dc side EMI filters can be lessened, and this could compensate the cost of cm ac L _cm dc and L _cm ac to some extent. Because this work is emphasized on the leakage issue, cm ac L _cm dc will be designed as one choke L_cm dc. The optimal distribution of L _cm ac and L _cm dc should further consider the EMI problem, because the requirements for the ac and dc side EMI filters are different.

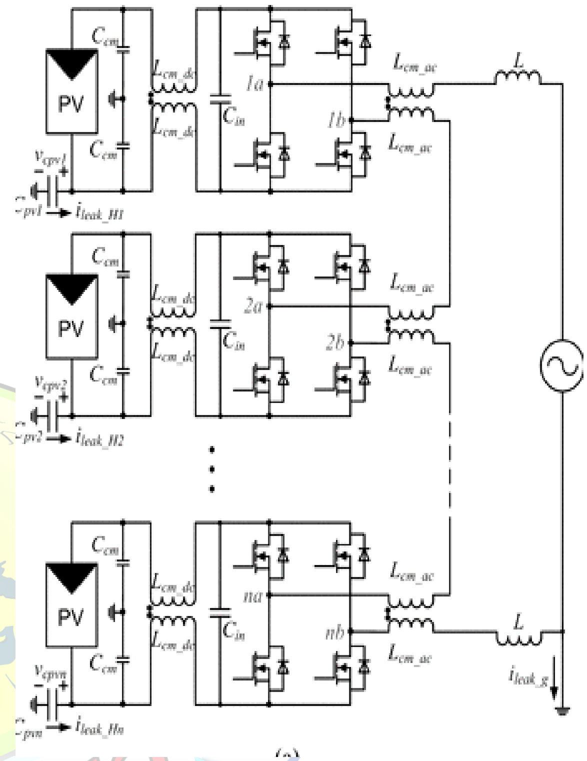

Fig 3 Circuit diagram

IV. Simulation And Results

That there were a lot of carrier harmonics in vcpv1 and vcpv2 which induced huge leakage currents in the circuit. vcpv1 and vcpv2 contained around 0.38 pu 10-kHz harmonics. Ileak_ H1 was pulse wise current due to the capacitive inter module leakage current loop. When the leakage current suppression was applied, the high-frequency noises in Cpv1 and Cpv2 were significantly reduced.

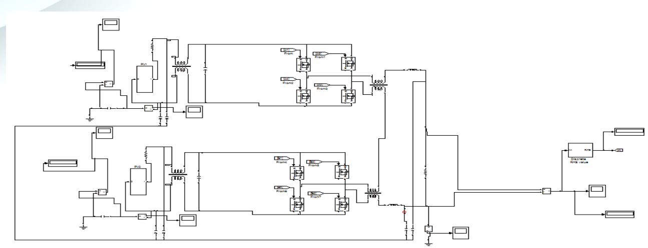

Fig 4 Simulation diagram

The simulated result by employing the sinusoidal pulse width modulation as shown in fig.

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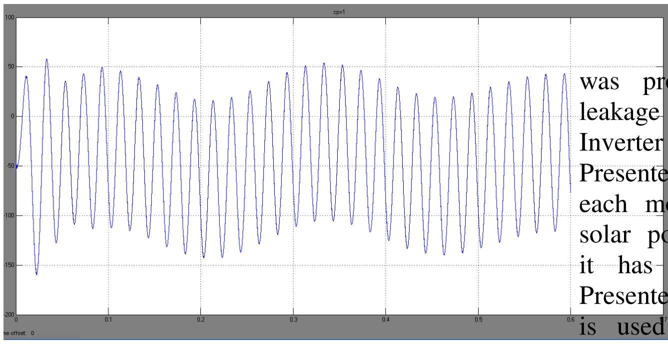

Fig 5 Voltage Across Vcpv1

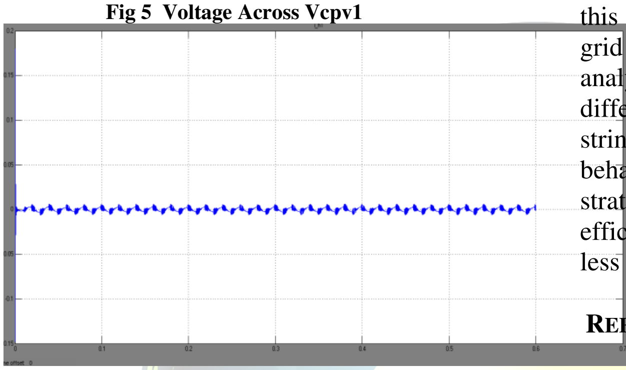

Fig 6 Leakage current through Vcp1

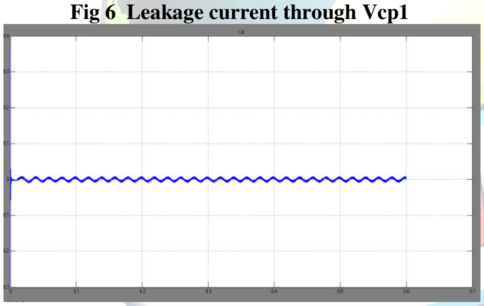

Fig 7 Leakage current through grid ground

Output voltage

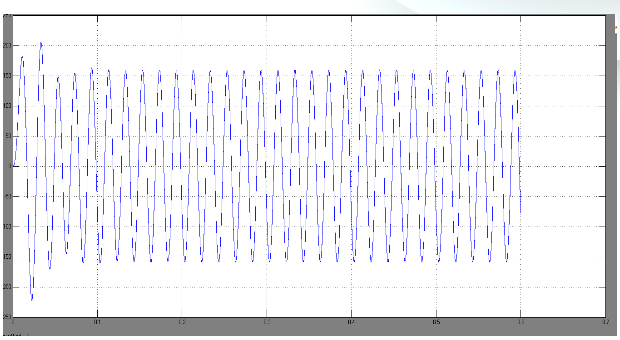

Fig 8 Output voltage

V. CONCLUSION

A PWM modulation strategy for the HB-CMI was proposed in this paper in order to solve the leakage current problem. The Cascaded Multilevel Inverter is Suitable for PV Solar power generation. Presented circuit is providing separate DC supply for each module, which is a good option for photovoltaic solar power generation system. It is easy to build and it has more redundancy than any other topologies. Presented topology has high efficiency. If this inverter is used in rural areas for photovoltaic systems, than this Multilevel inverter will be a good alternative to grid supply in rural industries. This project first analysed the leakage current issue in PV CMI. The differences between the transformerless CMI and string inverter concerning the leakage current behaviours were discussed. The proposed modulation strategy has a very good performance regarding efficiency, being a convenient solutionin transformer-less PV applications.

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