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A Novel Energy Stored Quasi Z Source Based Cascaded-Multilevel-Inverter for PV Systems with Leakage Current Suppression Capability

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Abstract: "A novel energy stored quasi z source based Cascaded-Multilevel-Inverter for PV Systems with leakage current suppression capability" A grid-connected PV power generation system is one of the most promising applications of renewable energy sources. The transformerless cascaded multilevel inverter (CMI) is considered to be a promising topology alternative for photovoltaic (PV) systems. 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. The qZSI inherits all the advantages of the ZSI, which can realize buck/boost, inversion and power conditioning in a single stage with improved reliability. The proposed qZSI based PV power generation system is intended as a grid connected system and transfers the maximum power from the PV array to the grid by maximum power point tracking technology. In that case, the efficiency would be improved and the cost would be reduced with the proposed one stage power conversion system. A quasi z source based cascaded h-bridge multilevel inverter for PV system to achieve minimized leakage current and it is reduced from 17.64% to14.1%, minimized shoot through effect, and also reduced harmonics distortions from 17.74 % to 14.16%.

Keywords: Cascaded multilevel inverter (CMI), photo voltaic (PV), quasi Z source Inverter (qZSI).

I. INTRODUCTION

To maximize the energy harvest from the photovoltaic (PV) panels, the cascaded multilevel inverter (CMI) topology has been considered in PV applications for decades. 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. 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.

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 transformerless CMI-based PV systems.

Traditionally, two-level PWM inverter is used for grid-tied operation. In case of a two-level inverter, the switching frequency should be high or the inductance of the output filter inductor need to be big enough to satisfy the required THD. To cope with the problems associated with the two-level inverter, multi-level inverters (MLIs) are introduced for grid connected inverter.

Several MLI topologies have been suggested so far and they can be mainly classified as three types neutral point clamped (NPC), flying capacitor (FC), and cascaded type. Advantage of the MLIs is that their switching frequency and device voltage rating can be much lower than those of a

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traditional two-level inverter for the same output voltage. Therefore, IGBT switching loss can be reduced significantly and thus the inverter system efficiency can be increased`

II. Transformer Less Inverter

The leakage current suppression techniques for transformerless string inverters have been well established. They can be categorized into three different groups: modulation solutions, topology solutions, and filter solutions. The bipolar modulation strategy can significantly reduce the leakage current because the common-mode (CM) voltage of the inverter is maintained constant. But the output current quality is degraded and the conversion efficiency is decreased. Nevertheless, these two solutions cannot be directly adopted in CMI to tackle the leakage current problem owing to the unique circulating current loops found among the cascaded modules.

The full-bridge inverter with unipolar sinusoidal pulse width modulation (SPWM) has a lot of advantages, such as higher dc voltage utilization, smaller current ripple in the filter inductor, and higher processing efficiency.

However, the common-mode voltage at the switching frequency is brought in so that this kind of inverter cannot be directly equipped in the transformerless photovoltaic (PV) grid-connected power system. In order to improve the common-mode performance of the unipolar SPWM full-bridge transformerless grid-connected inverter, a lot of in depth research works, where the new freewheeling paths are constructed to separate the PV array from the grid in the freewheeling period, have been done in . Several methods can be divided into the ac-side bypass and the dc-side by pass. The goal is to structure a simple, efficient, and reliable transformerless inverter topology for transformerless PV grid-connected application.

III. Z- Source And Quyasi Z-Source

With the photovoltaic (PV) power generation becoming more and more popular, the applications and researches of multilevel inverter based PV power systems are growing continuously due to multilevel inverters' advantages and large power-scale/high voltage grid-tie demands. Cascaded multilevel inverter (CMI) has unique advantages in applied to the PV power system, because it can achieve the distributed maximum power point tracking (MPPT) to increase the system efficiency, and achieve high-voltage/high power grid-tie without transformer. However, in the conventional CMI based PV power system, each module is a buck inverter, and its dc-link voltage changes along with the PV panel voltage. So when the MPPT is employed in each module, the unbalanced dc-link voltage will happen between all modules. Z/quasi-Z-source cascaded multilevel inverters (ZS/qZS- CMIs) overcome above disadvantages of conventional CMI through combining ZS/qZS network and H-bridge module together, because of the ZS/qZS inverter's (ZSI/qZSI) buck/ boost and inversion in a single stage.

The 2nd harmonic voltage and current ripples always exist in each module of CMI. A huge dc-link capacitor is required in each H-bridge module of traditional CMI to limit the voltage ripple. Similarly, the ZS/qZS-CMI also has the voltage and current ripples in each ZS/qZSI module. Some literatures focus on analyzing and eliminating low frequency ripples of each capacitor voltage and inductor current. An ac equivalent model is built to analyze the 2□ripples of the qZSI module in, but the built model contains five equations, where the coupled relationship makes the analysis and design difficult, and there is no experimental verification. The low frequency harmonic elimination PWM is proposed in through analyzing the relationship of 2□voltage and current ripples with ZS capacitance, inductance, shoot-through duty ratio, and modulation index, but the obtained equations are too complex for ZS network design. Two smoothing-power circuits are employed in to reduce the 2ripple of dc-link peak voltage in single-phase ZSI, but the additional circuits increase the system cost and complexity. New research progress is desired on building accurate 2□ripple analytic model and the detailed design method of the capacitance and inductance for ZSI/qZSI module.

IV. Leakage Current Analysis In Cmi-Based Pv Systems

The transformerless CMI-based PV systems can be built based on basic H-bridge inverters or modified ones, such as Z-source inverter (ZSI) and qZSI . The replacement of the basic H-bridge inverter with the ZSI or qZSI is mainly to cope with the PV wide-range input voltage. Though the topology is slightly different, the CM characteristics of these CMIs are quite similar. This is because the Z-source/quasi-Z-source network can offer low-impedance paths for the high-frequency noises. Consequently, the basic CMI will be used to study the leakage current issue. The conclusions can also be applied to the ZSI- or qZSI-based CMI. Fig. 1(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

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symmetrical line inductors *L* at the total output of the inverter. The equivalent circuit can be obtained in Fig.1 (b) by modeling each inverter phase leg as a voltage source with respect to the negative terminal of its dc bus. 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 . 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. 1(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 intermodule leakage current loop. It is a capacitive coupling path with negligible inductance, so the high-frequency PWM voltages would generate pulsewise leakage current in the loop. This phenomenon will be demonstrated in later case studies. Compared with the transformerless string inverter, the intermodule leakage current loop is a unique loop exists in the PV CMI. And it cannot be eliminated even if there is a transformer at the total output of the cascaded inverter. For transformerless string inverters, the leakage current is mainly determined by the inverter CM output . Several modified inverter topologies and modulation strategies are proposed to maintain the CM output to be constant to solve the leakage current issue. In CMI, we can define *vDMi* = *via* − *vib* and *vCMi* = (*via* + *vib*)/2 as the differential-mode (DM) and CM outputs of the *i*th module, respectively.

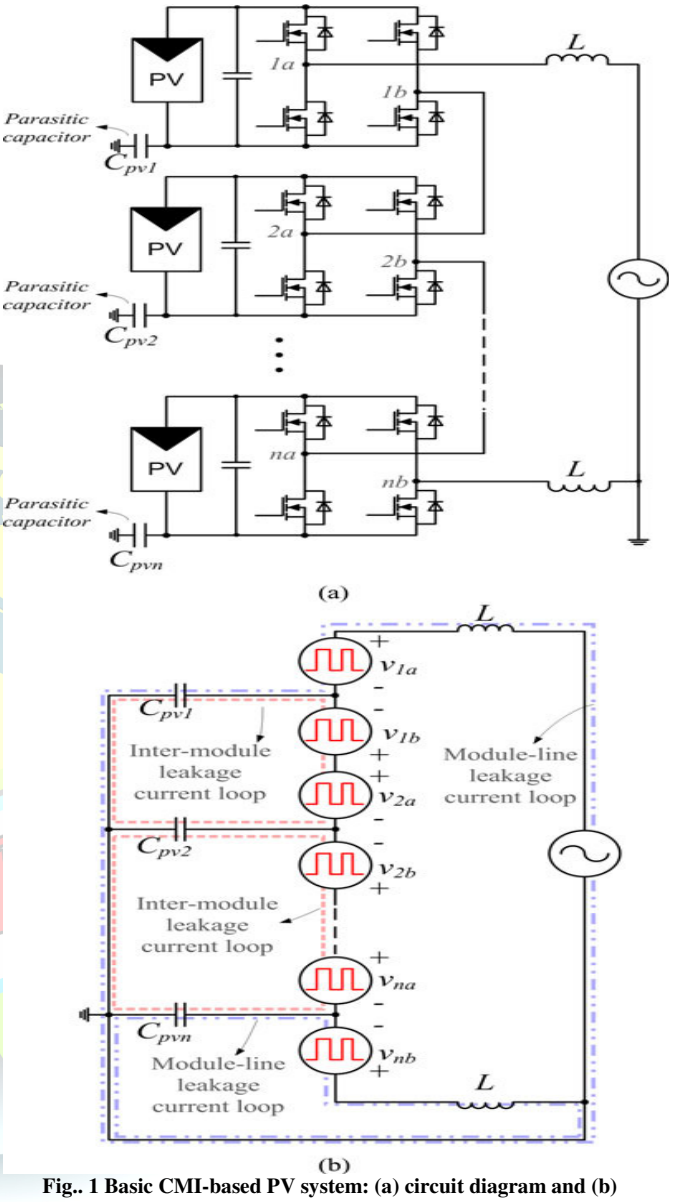

Fig.. 1 Basic CMI-based PV system: (a) circuit diagram and (b) equivalent circuit.

V. PROPOSED LEAKAGE CURRENT SUPPRESSION SOLUTION

Photovoltaic (PV) power generation is becoming more promising since the introduction of the thin film PV technology due to its lower cost, excellent high temperature performance, low weight, flexibility, and glass-free easy installation. However, there are still two primary factors limiting the widespread application of PV power systems.

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The first is the cost of the solar cell/module and the interface converter system; the second is the variability of the output (diurnal and seasonal) of the PV cells. A PV cell's voltage varies widely with temperature and irradiation, but the traditional voltage source inverter (VSI) cannot deal with this wide range without over-rating of the inverter, because the VSI is a buck converter whose input dc voltage must be greater than the peak ac output voltage. Because of this. a transformer and/or a dc/dc converter is usually used in PV applications, in order to cope with the range of the PV voltage , reduce inverter ratings, and produce a desired voltage for the load or connection to the utility. This leads to a higher component count and low efficiency, which opposes the goal of cost reduction.

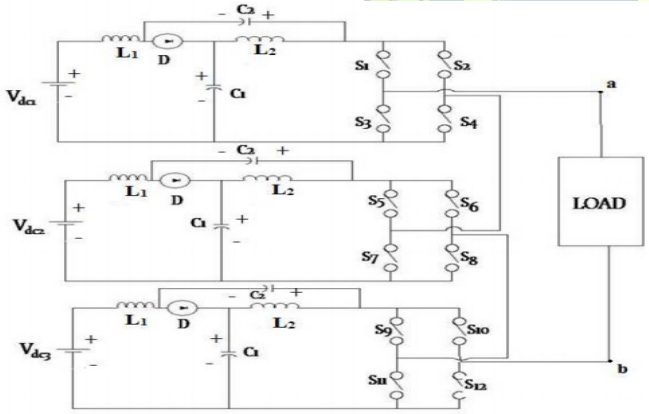

Fig. 2 Proposed Leakage current suppression circuit Diagram

The proposed system consists of *PV* array, filter, energy stored quasi-Z source, and cascaded multi-level inverter and controllers. Here the electrical power from the solar system is transferred into ac loads or ac grid by means of multilevel inverters. The leakage current caused by parasitic capacitance effect at solar panel side is removed by dc side filters.The shoot through effect caused by h-bridge which is used in CHB multilevel inverter is reduced with the help of energy stored quasi-z source network. Finally the dc ripples at ac side is minimized with the help of ac side filter. A single-phase structure of an m-level cascaded inverter is illustrated in Fig. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter Each inverter level can generate three different voltage outputs, +Vdc , 0, and –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, whereas –Vdc can be obtained by turning on switches S2 and S1. By turning on S1, S2, 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 MLI 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.

VI. PULSE WIDTH MODULATION TECHNIQUE

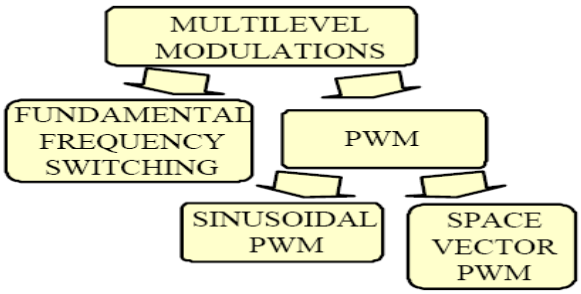

Fig. 3 Pulse with Modulation Technique

The advent of the transformerless multilevel inverter topology has brought forth various pulse width modulation (PWM) schemes as a means to control the switching of the active devices in each of the multiple voltage levels in the inverter. The most efficient method of controlling the output voltage is to incorporate pulse width modulation control (PWM control) within the inverters. In this method, a fixed d.c. input voltage is supplied to the inverter and a controlled a.c. output voltage is obtained by adjusting the on and–off periods of the inverter devices. Voltage-type PWM inverters have been applied widely to such fields as power supplies and motor drivers. This is because: (1) such inverters are well adapted to high-speed self turn-off switching devices that, as solid-state power converters, are provided with recently developed advanced circuits; and (2) they are operated stably and can be controlled well.

The PWM control has the following advantages:

(1) The output voltage control can be obtained without any additional components.

(2) With this type of control, lower order harmonics can be eliminated or minimized along with its output voltage control. The filtering requirements are minimized as higher order harmonics can be filtered easily.

The commonly used PWM control techniques are: Sinusoidal pulse width modulation (sin PWM) Space vector PWM SINUSOIDAL PULSE WIDTH MODULATION.

In the Sinusoidal pulse width modulation scheme, as the switch is turned on and off several times during each half-cycle, the width of the pulses is varied to change the

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output voltage. Lower order harmonics can be eliminated or reduced by selecting the type of modulation for the pulse widths and the number of pulses per half-cycle. Higher order harmonics may increase, but these are of concern because they can be eliminated easily by filters. The SPWM aims at generating a sinusoidal inverter output voltage without low-order harmonics. This is possible if the sampling frequency is high compared to the fundamental output frequency of the inverter. Sinusoidal pulse width modulation is one of the primitive techniques, which are used to suppress harmonics presented in the quasi-square wave. In the modulation techniques, there are two important defined parameters: 1) the ratio P = □c/□m known as frequency ratio, and 2) the ratio M_a = Am/Ac known as modulation index, where □c is the reference frequency, □m is the carrier frequency, Am is reference signal amplitude and Ac is carrier signal amplitude.

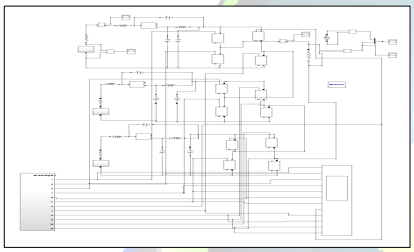

Fig. 4 Simulation Circuit Diagram

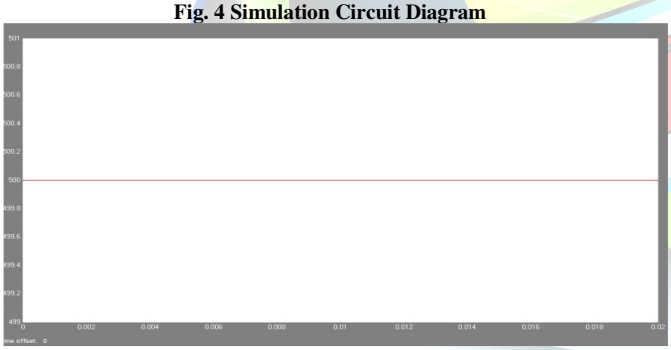

Fig. 5 Input Voltage

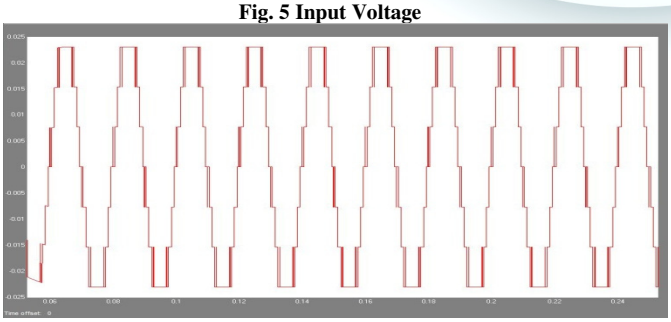

Fig. 6 Leakage Current

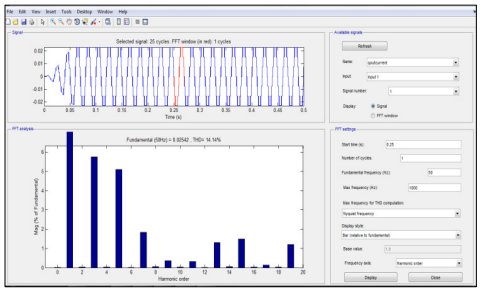

Fig. 7 THD

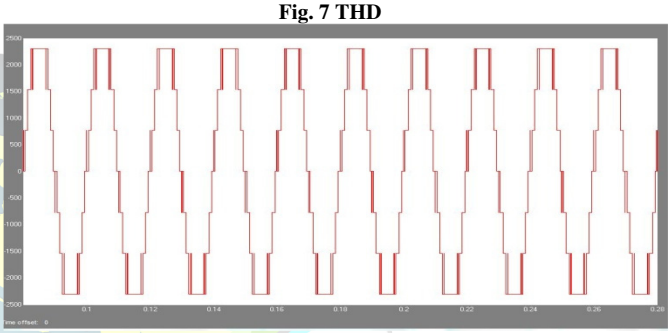

Fig. 8 Output Voltage

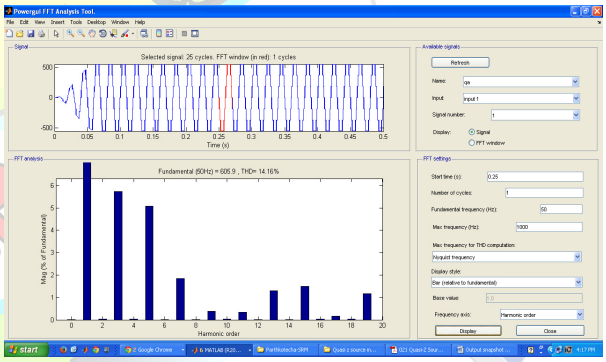

Fig. 9 THD

In Proposed system we use combination of quasi-z source and cascaded multilevel inverter. In this the input voltage is given 500 and the output voltage 2400 is achieved In the output voltage the harmonic distortion is reduced from 17.74 % to 14.16% and Output current harmonic distortion is reduced from 17.67 % to 14.14%

VII. Conclusion

The leakage current issue in PV CMI features the intermodule leakage current loops formed among the cascaded inverter modules. The intermodule leakage current loop exists even there is a transformer at the total output of the CMI and it prevents the existed string inverter leakage current suppression techniques to be directly applied in the

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CMI. The filter-based method is considered suitable for addressing the leakage current issue in PV CMI. Two leakage current suppression solutions were proposed for the PV CMI by constructing LC filters in the leakage current paths to attenuate the high-frequency noises. The simplified leakage current analytical models were developed to demonstrate the principles and introduce the filter design criteria. The proposed qZSI has advantages of continuous input current, reduced source stress, and lower component ratings when compared to the traditional method.

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