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Common-Ground-Type Transformerless Inverters for Single-Phase Solar Photovoltaic Systems

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ABSTRACT

This paper proposes a family of flying capacitor transformer less inverters for single-phase PV systems. Each of the new techniques proposed here are based on a flying capacitor principle and requires only four power switches and diodes, one capacitor, and a small filter at the output stage. To minimize the switching loss, a simple unipolar sinusoidal pulse-width modulation technique is used for output current ripple, and the filter requirements. The main advantages are: (1) There is no leakage current because of negative polarity of the PV is directly connected to the grid (2) capability of reactive power compensation and (3) the output ac voltage peak is equal to the input dc-voltage. A complete description of the operating principle with modulation techniques, design guidelines, and comprehensive comparisons are presented to reveal the properties and limitations of each topology in detail. Finally, experimental results of 1-KVA prototypes are presented.

Index Terms—*Transformerless inverter, flying capacitor, microinverter, RB-IGBT inverters, photovoltaic system*

I. INTRODUCTION

GRID-TIED inverters for photovoltaic (PV) systems, particularly low power single phase systems (up to 5 kW) are growing rapidly for both utility-scale and distributed power generation applications due to the declining prices of the PV panel, government incentives for PV energy, and advancement in power electronics and semiconductor technology [1]. Continued technological advancements and further cost reductions will expand these opportunities in both developed and developing countries where favorable solar conditions exist. In 2014, more than 178 GW of PV are installed globally, multiplying the installed capacity by a factor of 100 in only 14 years of development, which represents a new all-time record in the history of global PV deployment.

In PV applications a transformer is often used to provide galvanic isolation and voltage ratio transformations. However, these conventional iron and copper-based transformers increase the weight/size and cost of the inverter whilst reducing the efficiency and power density. It is therefore desirable to avoid using transformers in the inverter, however additional care must be taken to avoid safety hazards such as ground fault currents and leakage currents, e.g. via the parasitic capacitance between the PV panel and/or its frame and ground. Consequently, grid connected transformerless PV inverters must comply with strict safety standards recently, there is a strong trend in the PV inverter technology to use transformerless topologies in order to obtain both higher efficiencies and very low ground leakage current. In addition, it also reduces the cost and weight when compared to their counterparts using a transformer. Various research works have been proposed recently to eliminate the leakage current using different techniques in a transformerless. However, they require a large number of active and passive components (more than 6 switching devices except H5), which increases complexity, cost, and size of the inverter. In addition, the higher number of switches in the current path during the active state increases the total on-state resistance *RD on*, and hence, increases the conduction loss in the system, e.g., in H5, H6, oH5, and similar topologies proposed inwhere ≥3 devices are in series during the active state. The multilevel neutral-point-clamped (NPC) .inverter is also suitable for reducing the leakage current; however, the input voltage or dc-link voltage must be more than twice that of the H-bridge type inverters (H5, HERIC, oH5 etc.). A flying capacitor similar to the NPC multilevel converter is also described .however; it suffers from a similar problem apart from a complex pre-charge control circuit with additional capacitors. A flying inductor also called “Karschny” is also proposed, but this topology is not capable of delivering reactive power to the grid. Common ground type PV inverter can effectively reduce the leakage current of the PV system and has attracted a lot of interest from both academia and industry. A common ground transformerless inverter is proposed. However, it requires five switches and a relatively large filter inductor (8 mH) to meet the power quality requirements. This is primarily due to a virtual dc bus, which is created by a capacitor, and it charges only during the positive power cycle. There is no path to charge the capacitor during the negative cycle, where it requires a sustaining voltage at the so-called virtual dc-bus. This not only distorts the output voltage waveforms and thus requires a large virtual dc-bus capacitor and a filter inductor, but also unnecessarily increases the current stress in the switches. The charging process has been much improved, where the capacitor charges during both the positive and negative cycle. However, it requires two additional diodes with a large filter inductor (5 mH). A common ground type three-switch three-state single-phase Z-source inverter (TSTS-ZSI) is introduced with higher voltage gain. Although higher voltage gain is obtained, the three inductors ($L1$, $L2$ and $L3$) in the TSTS-ZSI make the circuit a bit bulky and heavy. In addition, the switch signals of the inverter is relatively complicated .However, the two-stage charge transfer process (Vin to C1 and C1 to C2) increases the number of power components and losses in the system. Several other transformerless inverter topologies with a common ground are described .However; all of them have the disadvantage of higher active and passive components with less efficiency.

A new common-ground-type transformerless inverter with only four switches (Type-I) based on a flying capacitor principle is proposed. In this, the neutral of the grid is directly connected to the negative pole of the dc-bus, which eliminates the leakage current. Although the essence of Type-I inverter topology is already presented in , the paper lacks mathematical analysis including components stress and design guidelines. To explore the possibility of extending the circuit with similar principle and concept, two new common-ground type transformerless inverter (Type-II and type-III) are investigated in this paper. The details of the circuit

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including its comparative study, design guidelines, common-mode characteristics and efficiency analysis with Type-I is presented in this paper. Further, optimal selection of various components based on capacitance value and modulation ratio are illustrated appropriately.

For all these three topologies, only four active switches are required to realize the basic inverter circuit. This relates to a minimal switch in the current path during the active states, which reduces the total on-resistance of the switches in the current path, and hence, minimizes the total conduction losses. Unlike conventional topologies with ≥ 3 switches in the load current path, the proposed topology has ≤ 2 switches in the load current path during active states . In addition, a simple unipolar sinusoidal pulse-width modulation (SPWM) technique is used to modulate the inverter, which further minimizes the switching loss, output current ripple, and filter requirements.

Their operating modes are discussed in detail in Section III. A comprehensive comparison with design rules and components selection is presented in Section IV. Simulations and experimental results of each of the 1-kW inverter topologies are eventually provided.

II. HEADINGS:

(1)Introduction

(2) Proposed Topologies And Principles Of Operation

- 2.1 Principle of Operation
- 2.2 Flying Capacitor Inverter Topologies

(3) Operating Modes Of The Proposed Topologies

- 3.1 Type-I: Two switches in series during the positive cycle
- 3.2 Type-II: Single switch in series during positive cycle
- 3.3 Type-III: H-bridge type

(4) Operating Modes Of The Proposed Topologies

- 4.1 Comparison of proposed topologies
- 4.2 Comparison with different conventional topologies
- 4.3. Non-unity power factor operation
- 4.4 Common-mode behavior
- 4.5 Design Guidelines and Components Selection

(5) Simulation And Experimental Results

- 5.1 Type-I Topology
- 5.2 Type-II Topology
- 5.3 Type-III Topology
- 5.4 Efficiency

(6) Conclusions

(7)Reference

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III. FIGURES AND TABLE

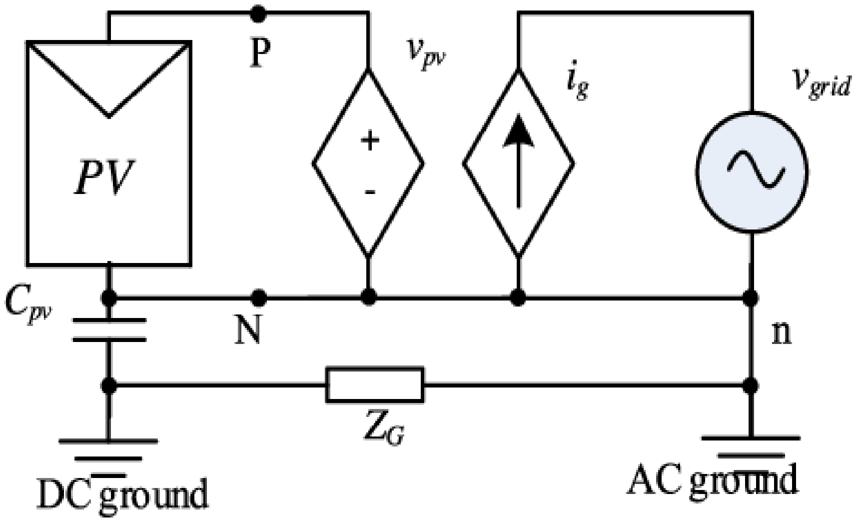

Fig 1.*Equivalent circuit of the proposed common-ground transformerless inverter for analyzing common-mode voltage and leakage current*

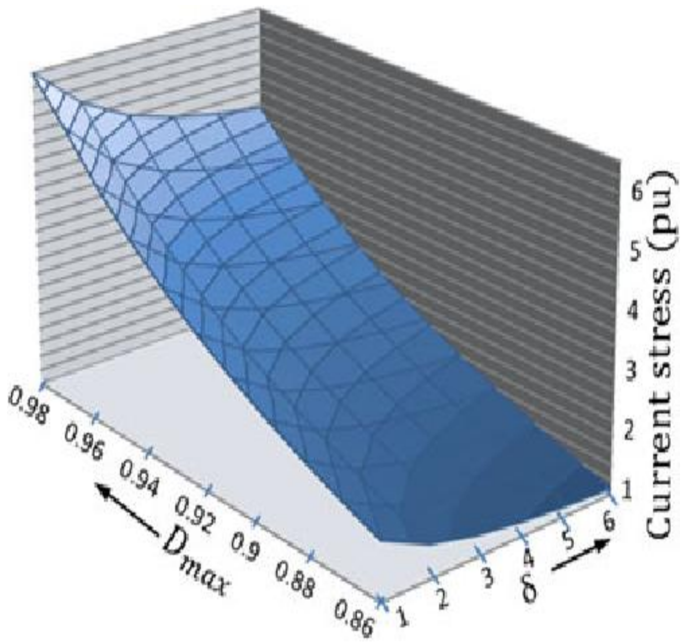

Fig 2. Illustration of current stress in Type-I topology (S1 and D) as a function of δ and $Dmax$

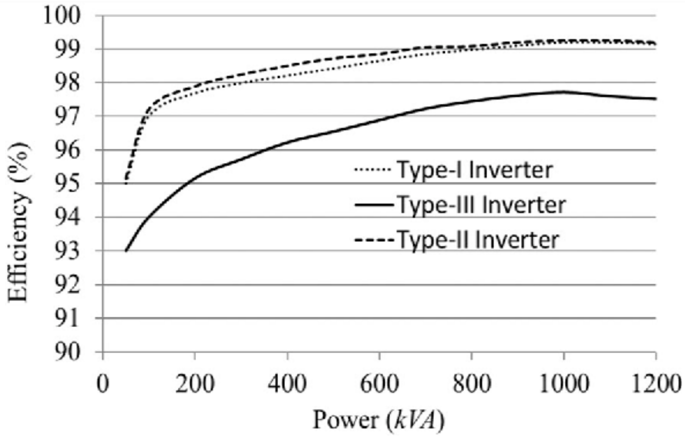

Fig 3 efficiency

IV. CONCLUSIONS

This paper unveils three new single-phase transformerless inverters for a grid-connected PV system. The operating principle of these inverters is based on the flying capacitor principle, and it utilizes a minimum number of active and passive components. Besides a common ground for the grid and source, which effectively eliminates the leakage currents, the three new topologies have three levels of output voltage, which reduces the output current ripples, EMI, and filter requirements. In addition, only few switches (≤ 2) are in series during the active state, which helps in reducing the conduction loss in the system.

Further, a uniform voltage stress across all switches in the Type-I topology allows the implementation of industry standard half bridge modules, which saves the overall cost and volume of the system. The expected performances demonstrated by each 1-kVA laboratory prototypes are promising for a practical grid connected PV system.

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