Modulation Technique for Single-Phase Transformerless Photovoltaic Inverters With Reactive Power Capability

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***Abstract*—This paper underpins the principles for generating reactive power in single-phase transformerless photovoltaic (PV) inverters. Two mainstream and widely adopted PV inverters are explored, i.e., H5 and HERIC. With conventional modulation techniques, reactive power cannot be realized in H5 and HERIC due to the absence of freewheeling path in negative power region. Based on the study, modulation techniques are proposed to provide bidirectional current path during freewheeling period. With proposed modulation technique, reactive power control is achieved in H5 and HERIC inverters, without any modification on the converter structures. The performances of the proposed modulation techniques are studied via MATLAB simulation and further validated with experimental results.**

***Index Terms*—Modulation technique, reactive power, transformerless.**

I. Introduction

PHOTOVOLTAIC (PV) energy has seen remarkable growth in recent decades owing to the renewable energy policy, feed-in-tariff and the cost-reduction of the PV installations. According to IEA-PVPS annual report [1], the cumulative capacity of installed PV reaches 230 GW by 2015, out of which the majority (∼90%) is grid-connected system. The increase in the demand of the PV installation, especially grid-connected PV system, indicates that there is a need for in-depth research and development.

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In grid-connected PV systems, an inverter is used to convert the direct current (dc) from the PV array into alternating current (ac) to supply the electricity to the utility grid. Generally, there are two types of grid-connected PV inverters, that is, with and without a 50/60 Hz transformer. Since a transformer is bulky, expensive, and has low efficiency, transformerless inverters have become a solution for high-performance application [2]–[4].

Various topologies and modulation techniques have been introduced and published [5]–[12]. H5 [7] and HERIC [8] are two mainstream transformerless PV inverters due to the simple structure and high efficiency. The leakage current has been successfully reduced to adhere to standard requirement. Even though transformerless inverters in literature are capable of suppressing the leakage current, most of which are designed for unity power factor operation only. In fact, reactive power support is required for next-generation PV inverter in order to allow high penetration of PV system in the utility grid [13], [14]. To achieve this target, many international standards have been revised. According to VDE-AR-N4105 [13], reactive power capability is essential for grid-connected PV inverters.

In light of this, conventional bipolar modulation is reported as a potential candidate for next-generation PV inverter [14]. Besides leakage current elimination, bipolar modulation technique is able to provide reactive power support. However, reactive power capability comes at a cost of high switching loss due to two-level modulation. In every switching transition, the voltage changes across the inductor by twice of input voltage. Thus, efficiency is low for bipolar modulation.

As a result, several transformerless PV inverter topologies with reactive power capability have been proposed [14]–[19] via three-level modulation (unipolar modulation). In order to provide reactive power control in conventional H5 topology, combined unipolar and bipolar pulse width modulation (PWM) was proposed in [15]. The PWM is switched from unipolar to bipolar during the negative power region. Although reactive power control is attained, the implementation is complicated. The current ripple and switching loss are high due to the adoption of bipolar PWM.

High-efficiency transformerless inverters with reactive power capability were recently proposed in [16] and [17] by utilizing MOSFETS and SiC diodes. Even though high efficiency is realized