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# A New and Advances Future Trends of Transformer less Inverter using Single Phase Grid Connected Photovoltaic Systems

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ABSTRACT: The research significance of various scientific aspects of photovoltaic (PV) systems has increased over the past decade. Grid-tied inverters the vital elements for the effective interface of Renewable Energy Resources (RER) and utility in the distributed generation system. Currently, Single- Phase Transformerless Grid-Connected Photovoltaic (SPTG-CPV) inverters (1–10 kW) are undergoing further developments, with new designs, and interest of the solar market. In comparison to the transformer (TR) Galvanic Isolation (GI)-based inverters, its advantageous features are lower cost, lighter weight, smaller volume, higher efficiency, and less complexity. In this paper, a review of SPTG-CPV inverters has been carried out. The basic operational principles of all SPTG-CPV inverters are presented in details for positive, negative, and zero cycles. A comprehensive analysis of each topology has been deliberated. A comparative assessment is also performed based on weaknesses, strengths, component ratings, efficiency, total harmonic distortion (THD), semiconductor device losses, and leakage current of various SPTG-CPV inverters schemes. Typical PV inverter structures and control schemes for grid connected three-phase system and single-phase systems are also discussed, described, and reviewed. Comparison of various industrial grids-connected PV inverters is also performed. Loss analysis is also performed for various topologies at 1 kW. Selection of appropriate topologies for their particular application is thoroughly presented. Then, discussion and forthcoming progress are emphasized. Lastly, the conclusions are presented. More than 100 research publications on the topic of SPTG-CPV inverter topologies, configurations, and control schematics along with the recent developments are thoroughly reviewed and classified for quick reference.

**KEYWORDS**:Renewable Energy Resources; Solar Photovoltaic; Single-Phase Grid-Connected; Transformer less Inverter.

#### I. INTRODUCTION

Long-term national strategies prove that the conventional power generation resources are unsustainable. In the last decade, extensive installation of renewable energy resources (RERs), i.e. hydropower, wind energy, solar photovoltaic (PV) energy, ocean energy, geothermal energy, biomass energy, tidal energy, and thermoelectric energy, has been enhanced for grid inter-connection [1–3]. Over the past several years, solar PV energy installation is booming at a rapid rate and in some countries, it plays a vital role in electricity generation [4]. For instance, solar PV systems fulfill approximately 7.9% of annual electricity demands throughout 2014 in Italy. By the end of 2014, its installed capacity reached to 38.2 GW (mostly for residential purposes) [4–6]. In 2017, the installed capacity of solar PV and wind energies was 405 GW and 540 GW, respectively [5]. It is forecast that in the near future (2020) the installed capacity of solar PV (772 GW) will surpass wind energy (735 GW) [7].

The power converters play a key role in the integration of RER, including solar PV, in the grid [6,8]. Power semiconductor devices are associated with advancement [9], therefore, the power electronics part is accountable for efficient and reliable power conversion from inexhaustible, clean and pollution-free solar PV energy. That's why a large number of PV power converters for grids are advanced and commercialized [7,10–15]. In the grid-connected PV system, the popularity of inverters that converts DC power from the PV module into AC power for grid injection is increasing day by day. Usually a voltage source inverter (VSI) or current source inverter (CSI) in combination with a DC/DC converter is used for integration of PV systems into the grid. A sophisticated control structure is also required to achieve better performance and obtain the desired output from the system. In control mechanisms, an inverter plays an important role in controlling the injection of grid current. Hence, it maintains the DC link voltage value at the desired level and control the flow of both active and reactive power to the grid [9,15].



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There is a significant variation of grid-connected PV systems from a few hundred Watts (small- scale DC modules) to hundreds of megawatts (large scale). In comparison to the transformer (TR) GI- based inverters its advantageous features are lower cost, lighter weight, smaller volume, higher efficiency, and less complexity. On the basis of leakage current reduction approaches these topologies are principally categorized as: GI with common mode voltage (CMV) clamping and without CMV clamping. By incorporating extra switches, the GI can be acquired either on AC side or DC side of full bridge (FB) or neutral point clamped (NPC) topology, due to the fact a lower number of switches in conduction path AC side decoupling offers high efficiency. As stated earlier, a large portion of residential applications consists of PV systems and these are expected to greatly spread in the near future. The technological development in the power electronics sector has brought high efficiency and large varieties of transformerless inverters into existence that are derived from the H-bridge inverter design. These derived inverter topologies have higher efficiencies and low EMI/CM (H5, HERIC). This review comprehensively reviews the development and control of transformerless topologies. The remainder of this survey is systematized as follows: a discussion about power converter technology for PV systems along with a categorization of transformerless inverter topologies are carried out in Section.

#### II. POWER CONVERTER TECHNOLOGY FOR PV SYSTEMS

Referring to progressing technologies to transfer to and organize the PV power in the grid, there are mainly five configuration concepts [1,10,16,17] available, as presented in Fig 1. According to the power rating and the output voltage of the PV panels, each configuration comprises a sequence of parallel strings of PV panels, followed and configured by DC-AC inverters and DC-DC converters (power electronics converters).

Typically, the power converters are classified into string inverters, multi-string inverters, central, and module level (AC module and DC module) inverters [10,11]. For solar power farms/plants configured as three-phase systems, the central and multi-string converters are widely utilized [18–20]. Comparatively, in residential applications configured as a single-phase system, string and module converters are intensively adopted [21,22]. Though the configuration of the power converters is different, the power converters have the same major functions, including islanding detection and protection, reactive power control, grid code compliance, synchronization, power transfer and DC to AC conversion, and PV power maximization [10,16–24]. Advanced and intelligent controls are required for effective incorporation of these functionalities and to fulfill customized demands. Additionally, the PV integration can be enhanced by forecasting, monitoring, and communication technology [18–22].



Fig 1. Power converter technology for PV system: (a) Residential/small systems, (b) residential/small systems, (c) residential, (d) residential /commercial, and (e) utility-scale/commercial PV applications [22].

String inverters, multistring inverters, and modular concept inverters are mostly used in single- phase PV system applications as depicted in Fig 1. In all these inverters the GI for safety is an important problem to be resolved. Conventionally, isolation is provided by a low frequency isolation transformer or a high frequency isolation transformer. The low frequency isolation transformer is used on the grid side while high frequency isolation transformers are used between the power electronics converters. With an overall efficiency of 93%–95%, both the abovementioned grid-connected technologies are commercially available, constituted mainly by bulky transformers. A



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large number of transformerless PV inverters have been developed [5,7,10] and are progressing daily, in order to enhance the overall efficiency.

#### III. H-BRIDGE BASED INVERTER STRUCTURES

In 1965, McMurray first developed the FB or H-bridge inverter family [23]. In power converter technology, the FB is one of the important developments. The force-commuted semiconductor devices, also called thyristors was first effectively utilized by this structure. This topology can be implemented with one switching leg (in half bridge form) or with two switching legs (in FB form), they can be utilized for both DC-AC and DC-DC conversion, so it's also a versatile topology. The basic structure of FB is presented in Fig 2.



Fig 2.Basic structure of FB inverter [43].

We consider a single stage inverter in our analysis for easiness, in single stage inverter MPPT DC- DC converter is not required. In case of half-bridge (HB) capacitive divider central point is grounded to limit the leakage current to guarantee the regulation of CMV. This leakage current flows though the parasitic capacitance of solar PV modules [21]. Low cost is the distinguishing feature, but the output voltage waveforms with two levels, switches must withstand high potential and highly distorted output current results in high electromagnetic inference (EMI) emissions and is considered a drawback of this topology.

#### Full-Bridge Zero Voltage Rectifier-(FB-ZVR) Inverter

The other modification of the classical H-bridge is known as FB-ZVR, as presented in Figure

15. The derivation of this topology is based on the HERIC topology, using a diode clamp to the DC midpoint and one switch (S5) and a diode bridge, the bidirectional grid short-circuiting switch is executed. By turning S5 on and turning the FB off the zero voltage is achieved.

Fig 16 presents the generation of AC currents for the positive and negative switching states. The main function of FB-ZVR topology is as follows:

Like in bipolar modulation, the switches are diagonally switched in FB. The zero state is introduced by turning off all switches of the bridge except S5 in Fig 3.

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Fig 3.Schematic diagram of the FB-ZVR inverter.

#### Analysis

In terms of low leakage and high efficiency, the advantageous of the HERIC are inherited by the FB-ZVR. The efficiency is lower than HERIC, because of the high switching frequency of S5, however, it has the advantage that it can work at any power factor in Fig 4.





#### FB-Derived Inverter Topologies: An Overview

Actually, the 2-level FB (or HB) converter can be modified into three level converters by using FB- DCBP, REFU, H5, and HERIC topologies. The input voltage stress on both output inductor and the switches are reduced to half thus increasing the efficiency. By using additional DC bypass (FB-DCBP) or AC bypass (REFU or HERIC) or higher switches of the bridge (H5), the zero-voltage condition is accomplished by shorting the grid. FB-DCBP and REFU clamp the neutral to the center point of the DC link while HERIC and H5 isolate the grid from the PV panels at zero voltage. Together HERIC and REFU use the AC bypass however, HERIC utilizes two switches in series (back to back) and REFU uses two switches in antiparallel configuration. Therefore, in the AC bypass for the REFU topology, the conduction losses are lower. The efficiency of H5 and REFU is to some extent higher in comparison to FB-DCBP and HERIC. H5 and REFU has only one switch that operate on high switching frequency while two switches are operated with high frequency in case of FB-DCBP and HERIC converters.

The implementation of the FB-ZVR is different, although it's derived from HERIC, it uses one switch and diode bridge as a bidirectional switch. This topology can also work with non-unitary power factor and have constant VPE, but moderately high efficiency (higher than FB-BP but lower than HERIC).

#### **IV. NPC BASED INVERTER STRUCTURES**

In comparison to the two-level FB inverter, NPC has lower switching stress as well as dV/dt. Because of the versatile nature of the NPC topology, it is effective in both three phase and single phase (HB or FB) systems. The NPC topology is the single-phase inverter operating with multi-level topology applied in high power motor operation.

#### **Conergy NPC Inverter**

#### An ISO 9001:2008 Certified Journal



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The variation of classical NPC yields to the HF topology whose output is clamped to the neutral using two back-toback IGBTs based bidirectional switch. This topology is presented in Fig 5 and patent by Conergy. An alternative of the same concept topology is depicted, where instead of HB, a FB is used and in place of series connection, a parallel connection of unidirectional clamping switches is carried out in Fig 5.

The NPC HF inverter is based on the main concept in which zero voltage is acquired by utilizing S+ or S- based on the sign of the current, the output is clamped to middle point (ground) of the DC bus, as presented in Fig 20. The main functions of Conergy NPC topology are: (a) the possible zero voltage conditions are: S+, D+ = ON and S-, D- = ON, (b) S+ (S-) and S1 (S2) are switched at high frequency.



Fig5.Schematic diagram of the Conergy NPC inverter.

#### Analysis

Due to the slightly higher efficiency comparative with classical NPC, low filtering requirements, and low EMI, this topology is thus very appropriate for use in transformerless PV systems in Fig 6. Currently, it is commercialized by Conergy in string inverter IPG series (2-5 kW), with extreme efficiency of 96.1% (Photon International, July 2007) and a maximum European efficiency of 95.1%.



Fig6.Switching positions of Conergy NPC in case of (a) positive cycle and (b) negative cycle.

#### NPC-Derived Inverter Topologies: An Overview

All the NPC-derived inverter topologies are three-level topologies. The advantageous features of these topologies are: (a) because of grounded DC link center practically no leakage current; (b) during the zero-voltage state, its efficiency is higher due to clamping of PV panels, and (c) unipolar voltage across the filter. In comparison with FB-derived topologies because of the higher complexity, with ratings over 10 kW (mini-central) three-phase inverters these topologies are typically used. Besides, in the range of hundreds of kW, i.e. high power (central inverter), where multilevel inverters are too significant, these topologies are also very attractive.



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#### V. TRANSFORMERLESS PV INVERTERS: COMPARATIVE AND CHARACTERISTICS OVERVIEW

#### **Parameter Comparison**

The various topologies discussed, described, and analyzed till now are comprehensively compared in this section on the basis of different performance parameters such as number of input capacitors and capacitance, power semiconductors, output voltage, number of MPPTs, and leakage current as presented in Tables 1 and Fig 7.

Parameters for losses Simulation		Parameters for universal Simulation	
Parameter	Value	Parameter	Value
Device	GT50J325	Input voltage	400 V <sub>dc</sub>
Frequency	50 Hz	Load	100 ohm
Saturation voltage Vce (SAT)	2 V	Rated power	1 kW
Forward Voltage, VF	2.5 V	Switching	10 kHz
		Frequency	
Junction temperature, Tj (max)	150 <b>a</b>	Dead Time	2.5 us
Turn-on energy losses, Eon@Vdc =	1.30 mJ	DC-link capacitors	2200 uF, $Vdc = 400$ V
300V		-	
Turn-off energy losses, $Eoff@dc = 300V$	$1.34\mathrm{mJ}$	IGBT	GT50J325 $V_{CE} = 600$ V,
			$I_{C} = 60 \text{ A}$
Pcond_Q calibration factor	1	Fast-recovery diodes	RHRP30120 $V_{RR} = 1200 \text{ V}, I = 30$
		-	A
Psw Q calibration factor	1	Filter inductors	3 mH
Pcond D calibration factor	1	Filter capacitors	6 nF
Psw D calibration factor	1	Stray capacitors	100 nF





#### VI. CONCLUSION AND FUTURE WORK

Grid-tied inverters are the vital components for the effective interface of RER and utility in the distributed generation system. Currently, single-phase transformerless grid-connected photovoltaic (SPTG-CPV) inverters (1–10 kW) are attracting additional consideration. In comparison to the transformer (TR) GI-based inverters, their advantageous features are lower cost, lighter weight, smaller volume, higher efficiency, and less complexity. Based on leakage current minimization approaches these topologies are principally categorized as: GI with CMV clamping and without CMV clamping. By incorporating extra switches, the GI can be acquired either on DC side or the AC side of H-Bridge or NPC topology.

The technological development in power electronics sector have brought high efficiency and large varieties of transformerless inverters into existence that are derived from the H-bridge inverter. These derived inverter topologies have higher efficiencies and low EMI/CM. In this paper, a survey of grid- connected single-phase photovoltaic inverters based on transformerless topologies has been presented. The basic operational principle of all SPTG-CPV inverters is presented for positive, negative, and zero cycles in details. The advantages, disadvantages, and a complete analysis of each topology are also reviewed in this survey. A comparative assessment is also performed based on weaknesses, strengths, component ratings, efficiency, total harmonic distortion (THD), semiconductor device losses,



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andleakage current of various SPTG-CPV inverter schemes. Loss analysis for various grid connected transformerless inverter topologies at 1 kW is presented. Control schemes for grid connected three- phase system and single-phase PV systems are also discussed, described and reviewed in detail.

The conclusion of the review is that the efficiency of AC side decoupled topologies (HERIC, REFU, FBZVR) is high in comparison with DC side decoupled topologies (H5, FB-DCBP). This is due to the independency and isolation of AC bypass switches from the conduction path. This significantly reduces the conduction losses by providing a freewheeling path. In addition, in terms of loss, the AC-decoupling device family is superior to the DC-decoupling family. Losses analysis and study are useful for the engineer to choose and design the high-efficiency transformerless topology. In comparison with FB- derived topologies because of the higher complexity, with ratings over 10 kW (minicentral) three-phase inverters NPC topologies are typically used. Besides, in the range of hundreds of kW, i.e. high power (central inverter), where multilevel inverters are too significant, NPC topologies are also very attractive. In the near future, the understanding of power converters is necessary for integration of RER (i.e. solar PV) with the grid and fulfilling the grid code requirements provided by the grid operator with a minimum harmonic injection. Currently, lowefficiency PV arrays are available, to ensure maximum efficiency investigation into the materials for the fabrication of the PV panels is also needed. Additionally, the overall performance and efficiency of grid-connected solar PV system will improve, and costs will be minimized. The new topologies of grid connected inverters are in a progressive stage since last decade. The main focus area of this research is increasing the power density and reliability, improving the efficiency of overall performance of power converters. There are also certain important topics in transformerless inverter that are: (a) utilization of multilevel transformerless inverters to achieve medium voltage for grid connection; (b) future power conditioner Quasi Z Source Network (c) development of power storage converters having LVRT capability. Furthermore, in the near future SiC will mostly use as a power device in converters and modification of GaN converters with SiC devices will usher in a new era of power converters by enhancing the efficiency of converters. In addition, the emergence of thin-film PV panels and wide-bandgap devices will probably steer the research in new directions, modifying the landscape of the most effective and most widespread converter architectures. The authors expect that this survey will prove as a benchmark for researchers, creators, engineers and designers working in the field of transformerless PV inverters. Furthermore, it will help users selectrelevant topologies for their specific applications...

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