International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 10, October - 2013

A Novel of the Transformer less Photovoltaic Inverters and Home Applications

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Abstract

This paper study based renewable energy sources are getting more widespread, last two decades we have research in renewable energy, mainly due to the fact that they generate energy by keeping the environment clean. We find many alternative options. We have seen many types of these systems an isolation transformer included, this transformer is power efficiency reduced so we improve efficiency and reduced size of systems and 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. This paper is aim to analyze and compare the most common single-stage transformerless PV inverter topologies.

1. Introduction

Grid connected photovoltaic (PV) systems have an important role in distributed power generation. According to the latest International Energy Agency Photovoltaic Power Systems (IEA-PVPS T1-15:2006) report, the annual rate of growth of the cumulative installed capacity in the IEA PVPS countries was at an impressive 42%. The majority of these installations were rooftop systems due to the high

A single-phase system means that there is a pulsating AC power on the output, whilst the input is a smooth DC. Large DC capacitors are required which decrease the lifetime and reliability of the whole system. On the other hand in a three phase system, there is constant AC power on the output, which means that there is no need for large capacitors, leading to smaller cost and a higher reliability and lifetime of the whole system. Also the power output of these systems can be higher, reaching up to 10-15 twp. in case of rooftop applications. For safety reasons, most PV systems have a galvanic isolation, either in the DC-DC boost converter in the form of a high frequency transformer, or on the AC output side, in the form of a bulky low frequency transformer. Both of these added galvanic isolations increase the cost and size of the whole system and decrease the overall efficiency. A higher efficiency, smaller size & weight and a lower price for the inverter is possible in the case where the isolation transformer is omitted [1]. These transformerless solutions offer all the aforementioned advantages, but there are some safety issues caused by the solar panel parasitic capacitance to ground, which is formed between the PV array terminals and the frame, which is normally grounded. Fig. 1 shows a typical grid connected PV system with the modelled parasitic capacitances, marked with grey lines, present at the DC+ and DC- terminals of the PV array.

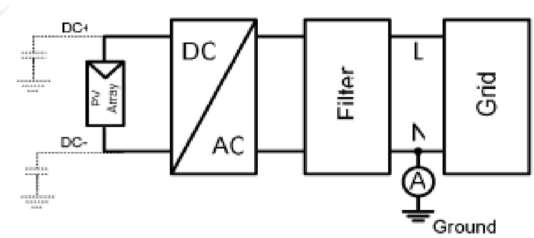

Fig.1 Grid connected PV system including the parasitic capacitance to ground of the PV array.

The PV terminals are marked with P (DC+ terminal) and Q (DC- terminal) and their potential is defined relative to ground. Voltage fluctuations of the P and Q terminals would cause leakage currents flowing from the panel terminals to the ground. The level of the leakage current depends on the amplitude and frequency content of the voltage fluctuations, as well as the value of the parasitic capacitance [1], also called leakage capacitance.

This resulting leakage capacitance value depends on many factors; some of these are enumerated below [1]

- PV panel and frame structure
- Surface of cells, distance between cells
- Module frame
- Weather conditions
- Humidity
- Dust or salt covering the PV panel
- Type of LCL filter.

The aim of the work presented in this paper is to introduce a common-mode model based on analytical approach for the three-phase inverter connected to the utility grid. This model will be used to predict the common-mode behaviour, at frequencies lower than 50 kHz, of the selected topologies and to explain the influence of system imbalance on the ground leakage current. It will also be shown, that the neutral inductance has a crucial influence on the common-mode behaviour of the topology, thereby directly influencing the ground leakage current of the system.

2. Form Overview and state of the scheme

If inverter and PV-generator are treated as a system, basically four different configurations can be identified. They are shown in figure 2. PV-modules are connected in combinations of series and parallel configurations to get a higher power level for the PV- system. Very common is a series connection of modules (the cells inside the modules are connected in series, too). The series connection of modules is called a string. The voltage of such a PV-string can be between 150 V and 1000 V for today grid connected PV-systems. DC-voltages which are higher than the peak voltage of the grid (325 VDC for 230V-AC-grids) have the advantage that the inverter does not need to step- up the voltage by a DC/DC-stage or a transformer. In this case often single-stage full-bridge inverters are used, which can have a high efficiency. The peak current which can be delivered by one string is determined by the size of the solar cells used in the modules. To achieve a higher system power several strings can be connected in parallel, like in the system shown in figure 1a. The resulting large PV-generator is connected to the input of a central inverter. This is why inverters for this configuration are called Central Inverter. In some papers [1], [3] central inverters are described as the past of PV-systems. It is true, that this configuration has disadvantages especially for smaller rooftop applications, like mismatching losses between the modules or strings and missing individual Maximum-Power- Point-Tracking (MPPT) for each string. This leads to relatively high forfeits in the energy gain from the system, when shading or different orientation of modules occurs. On the other hand this configuration has advantages like high inverter efficiency because of the higher power level in comparison to string- inverters, simplicity and low cost. Therefore central inverters are still the first choice for medium- and large scale PV- applications, where shading or different orientation of modules is avoided already at the planning stage and therefore plays no role (Solar Parks, large rooftop applications). Central inverters are mainly build with single-phase full-bridges (using IGBTs) and low-frequency transformers [4].

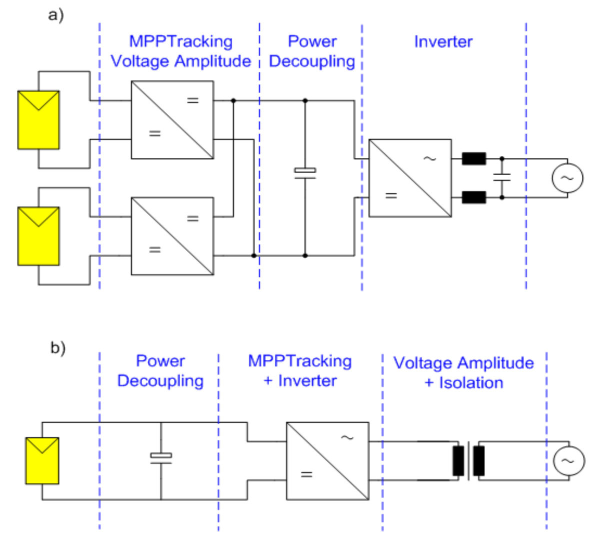

Fig. 2. Configurations for PV-systems for Building Blocks of Inverters

When the focus is on smaller applications, for instance on the roofs of private houses, the drawbacks of central inverters become more eminent. When a PV-generator is installed on an existing roof, in many cases the modules cannot be installed with the same orientation and are subject to different shading conditions during the day. For such applications the string inverter, shown in figure 2b is state of the art. This configuration does not have parallel connections of strings; instead smaller inverters for each string are used. By doing this, each string has its own MPPT, which means that all strings are completely independent from each other. So it is easy to build PV-systems even under constraints like different orientation of parts of the roof, difficult shading conditions or even various types or number of PV-modules. Of course, the modules of each string should be matched and operated under the same conditions because of the series connection within the string. A disadvantage of string-inverters in comparison to central inverters is the higher price per kW because of the rather low power level (1..5 kW) per unit. String inverters are build as single-phase inverters due to the low power level. A very common classic topology is the full-bridge with a low- frequency transformer on the AC-side for galvanic isolation. Newer developments are often build as transformerless inverters using special topologies, which are explained later in this paper [1], [6].

3. Scheme blocks and topologies

To get a better understanding of the needs, constraints and possibilities of topologies for PV-inverters scheme, it is very helpful to use an analytical approach similar to the one proposed in

[1]. When the focus is on the power electronic functions of a PV-inverter and all additional features like communication, monitoring, and safety functions are ignored, five basic functions can be identified for all PV-inverters:

3.1MPPT for the DC-input:

The inverter controls the DC- voltage in order to operate the PV-modules at their maximum power point. The MPP varies with the insolation, the module temperature and the shading conditions. Therefore sophisticated tracking algorithms are used. For good efficiency of the MPPT it is important that not only the mean values of voltage and current of the module are tracked to the MPP, but also the behaviour at higher frequencies has to be considered. If the power electronic topology of the inverter introduces a voltage ripple at the PV-terminals, that ripple has to be kept small. Otherwise the operating point of the PV-generator would not stay stable in the MPP at all times. Most state of the art string-inverters use a one-stage topology, in which the DC-link is directly connected to the PV-input. By controlling the grid current (and thus the power delivered to the grid) the DC-link voltage can be influenced. But also topologies with a separate DC/DC-stage for MPPT can be found.

3.2Change of the voltage amplitude:

If the PV-inverter uses a voltage sourced inverter (VSI) as a grid interface, this inverter has a buck-characteristic. This means that its output voltage is always smaller than the input voltage. If the PV-system delivers a voltage that is smaller than the peak value of the grid voltage, a voltage boost is needed. This can be done with use of a transformer or by a DC/DC-stage (e.g. boost converter).

3.3Grid interface:

This is the main function block of the inverter. Most common is the use of a VSI. It can be build as a standard full-bridge for inverters with a transformer at the AC-side. For transformerless inverters other topologies (NPC, H5, HERIC, will be explained later) are used.

3.4Power decoupling between DC- and AC-side:

The power fluctuations between DC- and AC-side of the inverter (switching, frequency and double the grid frequency for single-phase inverters) have to be decoupled by an energy storage. Most common are electrolytic capacitors forming a DC-link. Because the minimization of the DC-link-capacity seems to be essential to achieve higher inverter lifetimes (film-capacitors could be used) a trend to 3-phase-inverters can be expected even for smaller power levels within the 1.5 kW range [8], [4].

3.5Galvanic isolation between input and output:

The converter can be achieved by the use of transformers. Classically trans- formers operated at grid-frequency are used, which have severe drawbacks like high weight, high cost, additional losses and a non-unity power factor, especially under low load conditions. New developments use high-frequency transformers. A third solution is to leave out the transformer and the isolation between input and output of the inverters. The resulting transformer less inverters have very high efficiencies, a low weight and have lower costs. The commercial inverter SMC8000TL from SMA reaches a peak efficiency of 98% [10]. Transformer less inverters will be discussed in more detail later. In figure 2b a classic string inverter is shown. It consists of a DC-link, a full bridge inverter and a transformer operated at grid-frequency. The transformer accomplishes voltage change and isolation, while the MPPT is taken over by the inverter- bridge. By the control of the AC-current the power that is fed into the grid is controlled. When the power fed into the grid is changed at a constant DC-power, the DC-link is charged or discharged, thus changing the voltage at the terminals of the output inverter.

4. Single phase transformer less pv inverter

As mentioned above, transformerless topologies for PV- inverters are an upcoming technology. This is due to the fact that transformers operated at grid frequency are bulky and expensive and produce losses. In addition the transformer limits the freedom to control the grid current of the inverter. Especially at low load the reactive power used for the magnetization of the transformer leads to a lower power factor.

In order to verify the level of leakage currents of different topologies simulations and experimental measurements have been done. Simulations were done using MATLAB Simulink and toolbox, used for simulation of electrical circuits within the Simulink environment. The most widespread single phase topology is the full bridge one. This topology can be chosen to have bipolar or a unipolar PWM controlled switches. Using unipolar switching Strategy the inverter pulses will have twice the frequency that is in case of bipolar switching, therefore the output filter can be smaller, than in case of the bipolar.

All simulation results are based on the general simulation model presented on Fig. 1 for the single-phase topologies. Same filter and grid parameters have been used throughout the simulations, these are listed below:

LCL filter parameters: Lfi=0.7mH - filter inductance

Inverter side, Lgi=2mH - filter inductance, Cf=2.2pF filter Capacitance, Rcfs= 1mQ - capacitance ESR
Inverter parameters: fsw = 1OkHz
Grid parameters: Vg=22OVrms -grid RMS voltage, f=5OHz grid frequency, Zg=0.5+1 1e-3 -grid impedance.
Whenever galvanic isolation is not important, transformer- less PV-inverters get more interesting: They use simpler topologies, have higher efficiencies and are cheaper. That is why my main focus is on these topologies transformerless topologies, Constraints due to System Grounding, Ground leakage Currents. One of the most important aspects when considering topologies for transformerless inverters is, that a single-phase inverter is system grounded at the AC-side. In addition to the grounding at the AC-side a grounding of the DC-side can also occur. One possibility is system grounding of the positive or the negative terminal. The other possibility which has to be taken into account is, shown in figure no.3 and figure no.4 that a PV- generator without system grounding forms a parasitic capacity against earth. This capacity can reach considerable values, because of the big area of the generator, the grounded frames and conducting water or dirt layers on top of the modules.

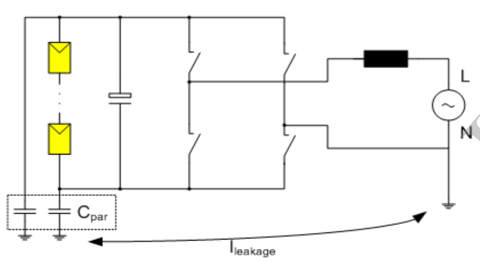

Fig. 3. Full-bridge with one inductor

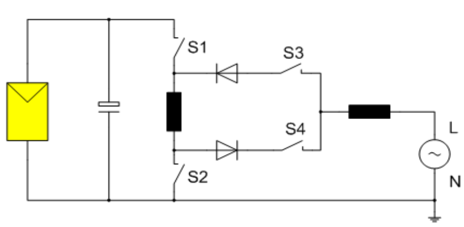

Fig. 4. Karschny-topology

The H5-Topology [5] shown in figure 5 only needs one more switch compared to the normal full bridge. The switches S5, S2 and S4 are operated at high frequency, S1 and S3 at grid frequency. During free-wheeling S5 is open, disconnecting DC- and AC-side. The free-wheeling-path is closed via S1 and the inverse diode of S3 for positive and S3 and the Diode of S1 for negative current. Compared to HERIC, H5 has the advantage of using less components while HERIC uses less switches in series on the other hand. A closer explanation of the topologies is given in shown figure 5. [4].

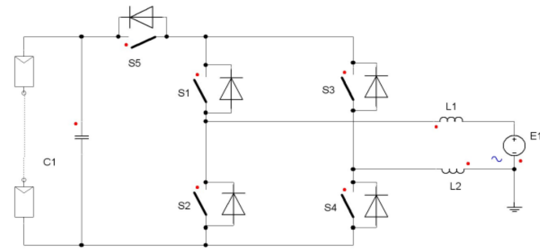

Fig. 5. H5-topology

5. Measurement

As a first experiment to get some knowledge about the leakage currents of modern transformerless topologies, the leakage currents of an inverter using the H5 technology is measured. The setup is shown in figure 6. Instead of a PV- generator a switch-mode-DC-supply is used for simplicity. The leakage current in this setup is determined by the capacity between the DC-terminals and earth. The main contributions to this capacity are the EMI-Y-capacitors in the EMI-filters of both, the DC-supply and the inverter. Together, the capacity of the DC-part of the setup against earth is approximately 500 nF. In an actual system this capacity would be determined by the PV-generator. The leakage current is measured with a current probe, which is put around the AC-connections of the inverter, as shown in figure 6 and MATLAB output Voltage result figure 7.

6. Conclusion

PV-systems offer a wide range of possibilities and configurations for the use of power electronic converters. An overview over technologies and transformerless topologies is given and the technology is presented as promising for the future. In addition some problems from the application side are given. Future work will be to compare the transformerless topologies with special respect to the induced ground leakage currents by simulation and measurements on an experimental setup. Experimental measurements are important, because parasitic effects, which are difficult to understand only by simulation, play a role for the paths of the leakage currents at higher frequencies.

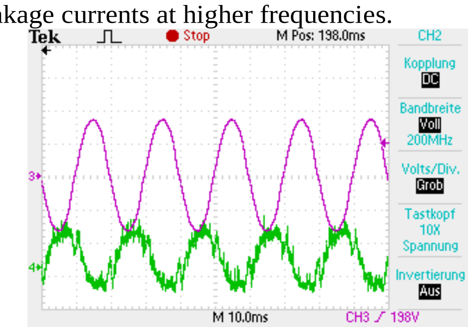

Fig. 6 Spectrum Output Voltage result

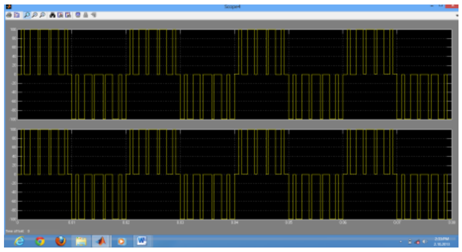

Fig.7 MATLAB Project Simulation Result

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