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Inverters for photovoltaic systems – comparative analysis

***Abstract**. The paper contains comparative analysis of few different topologies for photovoltaic inverters and the main advantages and disadvantages of them.*

Keywords: photovoltaic, converters, PV Inverters

Introduction

Growing number of photovoltaic (PV) installations is a good market for inverters which should have function of tracking the maximum power point of PV, generate low level of output voltage distortion and have a high efficiency. There are many different topologies of inverters for photovoltaic systems. To increase the efficiency of converters a SiC or GaN semiconductors can be used [5]. Also a better materials for HF transformer e.g. litz wires (instead of single wires) can be used as an windings of HF transformer. In this paper a comparison of different topologies of power converters is done.

Review of PV inverters

They are different groups of PV inverters, which are shown in Fig. 1 [1,2]. The most popular are inverters shown as Type B and C in Fig. 1, where is one inverter and one or more Maximum Power Point Trackers (MPPT). In type C every MPPT (here: a DC/DC converter) is connected to one string of PV modules so PV strings can work in different conditions (e.g. can have different space orientations). This type of PV systems can be found in domestic and small commercial applications.

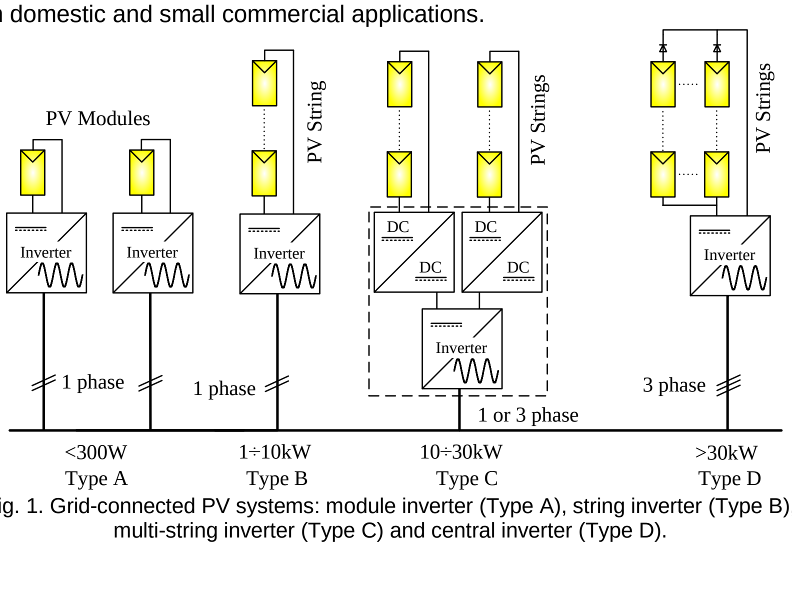

Fig. 1. Grid-connected PV systems: module inverter (Type A), string inverter (Type B), multi-string inverter (Type C) and central inverter (Type D).

Individual inverters for each PV panel (type A in Fig. 1) are used for small installations where PV modules can have different work conditions (different technology of PVs or solar exposure conditions). This solution is very flexible, very easy in expansion and allows to work in MPP for every module in PV system separately. However, it is less popular due to a high installation cost and relatively small efficiency. One central inverter which has connected with more than 2 strings to one input (type D) is used for large scale PV plants where all PV strings has the same parameters and the same solar exposure conditions (in that case every PV module has MPP in the same point). To avoid equalizing currents each PV string should have additional diode connected in series. One central inverter has usual higher efficiency and it is cheaper than in other solutions.

Usually due to a safety reasons and to reduce a leakage capacitance current it is recommended to keep galvanic separation between AC grid and PV panels. Galvanic separation can be done by Low Frequency (LF) transformer (50-60Hz), High Frequency (HF) transformer (with frequency higher than 20 kHz) or so-called: “floating capacitor” or “floating inductance” (where capacitor or inductance works as an energy accumulator and is periodically switched between energy source and a load). The last type of inverters are not popular due to safety reason (galvanic separation is done by resistance of transistors in non-conducting state). Inverters without transformer are usually very simply, has good efficiency and relatively small volume. They are not very popular due to the safety reason, necessary to output current filter and leakage voltage between ground and surface of PV panels, which generate a leakage PE current. The main advantages and disadvantages of PV inverter variants with are on the market are depicted in Fig. 2.

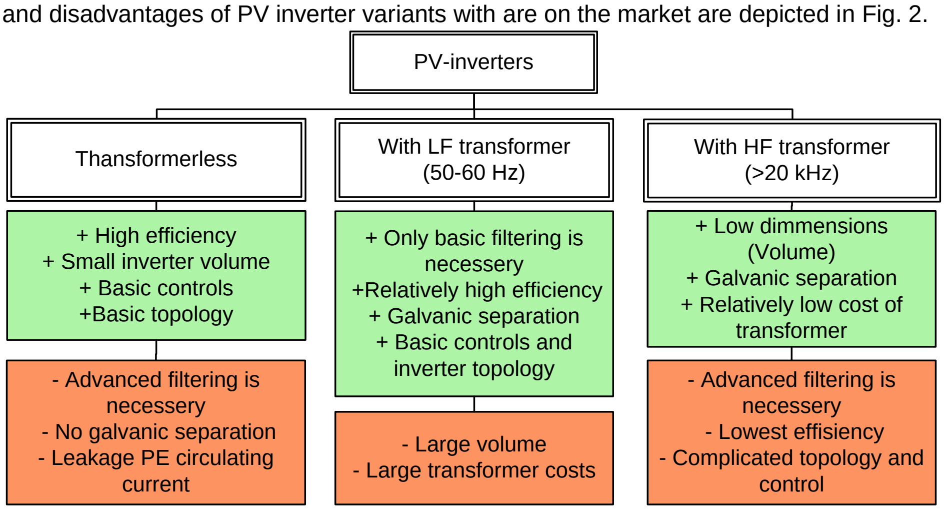

Fig. 2. Main features of different variants of inverters topology for PV installations.

PV inverters without galvanic separation and with LF transformer are usually very simple - they have 50 Hz or 60 Hz inverter (Fig 3 a.) and can have LF transformer (Fig. 3 b.). Common element of all PV inverter is a buffer which is necessary to keep input power on constant level while output power is periodically changing from zero to $2 \cdot P_{input}$ with low frequency (100-120 Hz) [5]. If power is converted with high frequency as a input buffer a low pass filter can be used.

All type of PV converters has a low pass filter on input which is used to keep MPP point in the optimal place. To reduce level of higher harmonics in currents and to reduce current stress for semiconductor switch there are commonly used a low pass filters on the output of PV inverters. In many cases a leakage inductance and capacitance of low frequency transformer is enough to decrease a level of current higher harmonics by itself. The indicative efficiency which are written on the right side of figures refer to inverters made with standard silicone semiconductors.

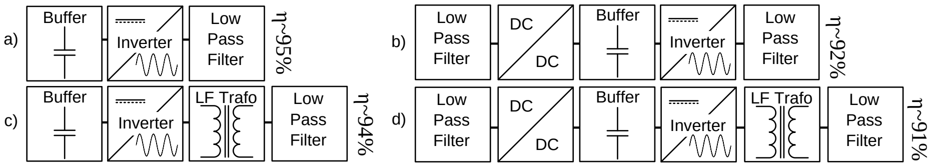

Fig. 3. Different solutions of PV inverters without transformer (a, b) and with LF transformer (c, d).

Fig 4 shows an example circuit of PV inverters which are on the market. Fig 4 a. shows circuit of PV inverter with a simple boost converter which is used to generate a half-sinusoidal waveforms while inverter (T1 .. T4) is changing only the polarity of output waveform. Thanks to this solution transistors in inverter (T1 .. T4) work with low frequency while only transistor in DC/DC converter is working with high frequency. If output voltage is momentary smaller than PV voltage a DC/DC converter can be bypassed by diode (dotted).

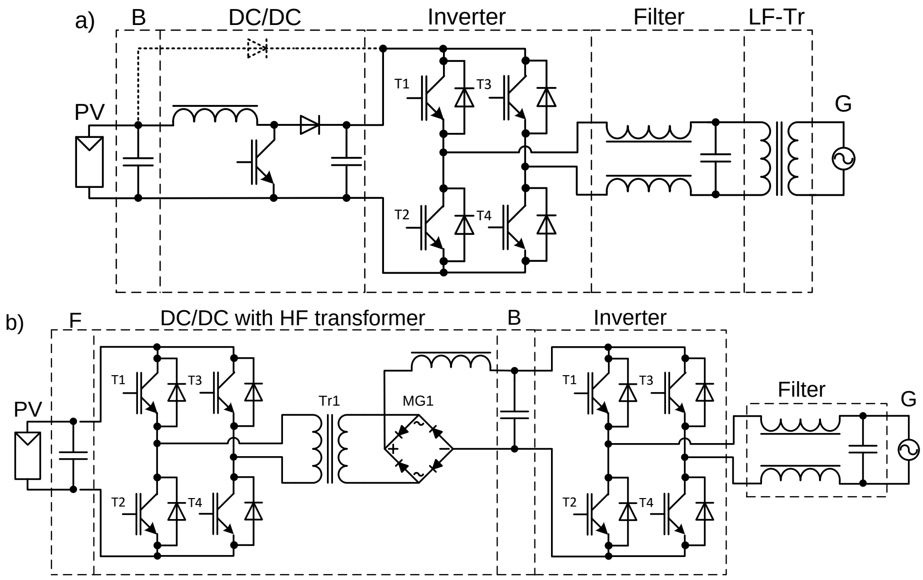

Fig. 4. An example of topologies that are on market: with LF transformer (a) and with HF transformer (b), where: F - Low Pass Filter, B - Buffer, G - power grid, Tr - transformer, PV - photovoltaic panels, LF - low frequency, HF - high frequency.

Fig. 4 b. presents PV inverter with High Frequency transformer which is on the market. This solution has relatively low efficiency due to a large number of semiconductors. This topology contain two inverters: first transfers energy by high frequency transformer and keeps PV string in MPP, second inverter generates 50 Hz (60 Hz) sinusoid waveform of output current.

Typical topology for inverters which are used in PV system are shown in Fig. 5 and Fig. 6 a. Full bridge or so call “H-bridge” (Fig 5 a.) is the most popular AC/DC converter – it can work as an voltage or current inverter. Half bridge (Fig. 5 b.) has usually higher efficiency than full bridge due to a lower number of semiconductors, but transistors work with two times higher current than in full bridge, output voltage is twice times smaller and generated output voltage has to be symmetric to keep symmetric voltages on capacitors (C1 and C2). 5T bridge (Fig. 5 c.) can be used to decrease cost of inverter. Transistor T5 should have small switching loses because it is used to generate in PWM mode half-sinusoidal waveforms. The rest transistors (T1 .. T4) work as a switch to change polarization of output voltage. This transistors can be cheap because they are switching with low frequency (50 or 60 Hz) without voltage (0 voltage switching). Bipolar Flyback converter (Fig. 5 d.) usually works with frequency higher than 100 kHz due to reduce size of magnetic core. In this converter HF transformer is also an energy buffer, so to decrease core volume and mass it is recommended to switch main transistor (T1) with high frequency. PWM signal of this transistor is responsible to generate half-sinusoidal waveforms of output voltages, while transistors T2 and T3 are choosing the polarity of output voltages.

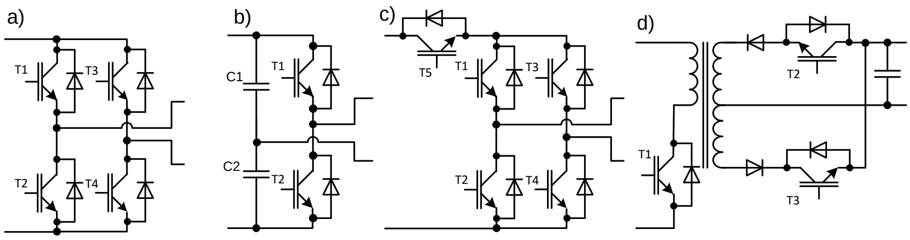

Fig. 5. Example of popular inverters: full-bridge (a), half-bridge (b), 5T bridge (c) and bipolar Flyback converter (d).

HERIC topology (Fig. 6 a.) [7] is used mainly with inductive load. By switching on transistors T5 and T6 it is possible to force zero voltage on output and to reduce a reactive power exchange. All this circuits can be a part of a DC/DC converter with a transformer or can be an output inverter to generate 50 Hz (60 Hz) sinusoidal waveforms. As an isolated DC/DC converters single-transistor converter eg. Flyback or Forward converter can be used. An example of Flyback converter is shown in Fig. 6 b. In transformerless PV inverter or in inverters with LF transformer on output an non isolated DC/DC converters can be used - an example of Boock (step-up) non-isolated converter is depicted in Fig. 6 c.

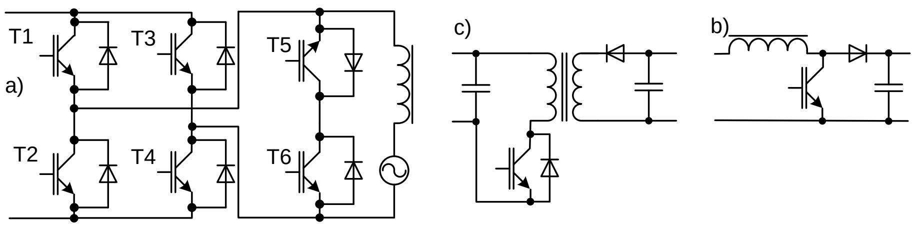

Fig. 6. a) Example of: HERIC inverter (a), boost DC/DC converter (b), and DC/DC Flyback converter (c).

They are numerous variants of PV inverters with HF transformer [3,4]. The most popular is to use a DC/DC converter with classic H-bridge (or half-bridge) (Fig. 7 b.) or

Forward or Flyback converter (Fig 7 a.). To have constant flow of power in this family of inverters it is necessary to use an energy buffer (usually a capacitor). In that reason most popular topologies have a DC bus (Fig. 4). The disadvantage of this family of PV inverters is a triple transformations of voltage waveforms (from DC to HF AC, from HF AC back to a DC and from DC to a LF AC). Other family of PV inverters with HF transformers is based on cycloconverters (Fig. 7 c. and d.). In this type of PV inverters there is no voltage conversion back to DC.

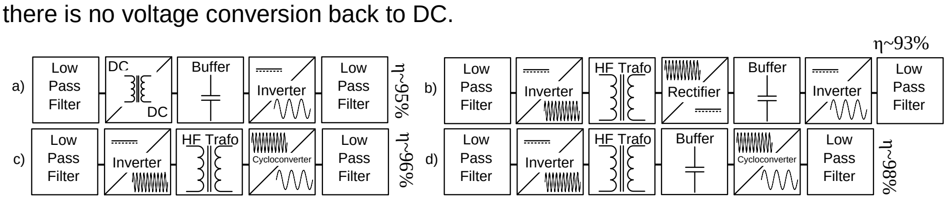

Fig. 7. Different variants of inverters topology for PV installations with HF transformers.

The efficiency of PV inverters with HF transformers can be increased by a resonance circuit connected in series with a transformer. Resonance circuit in a natural way allow to switch off the transistors in zero-current moments with reduce the switching loses. Fig. 8 a. and b. are showed example of series resonant circuit in series with primary and secondary windings of transformer respectively.

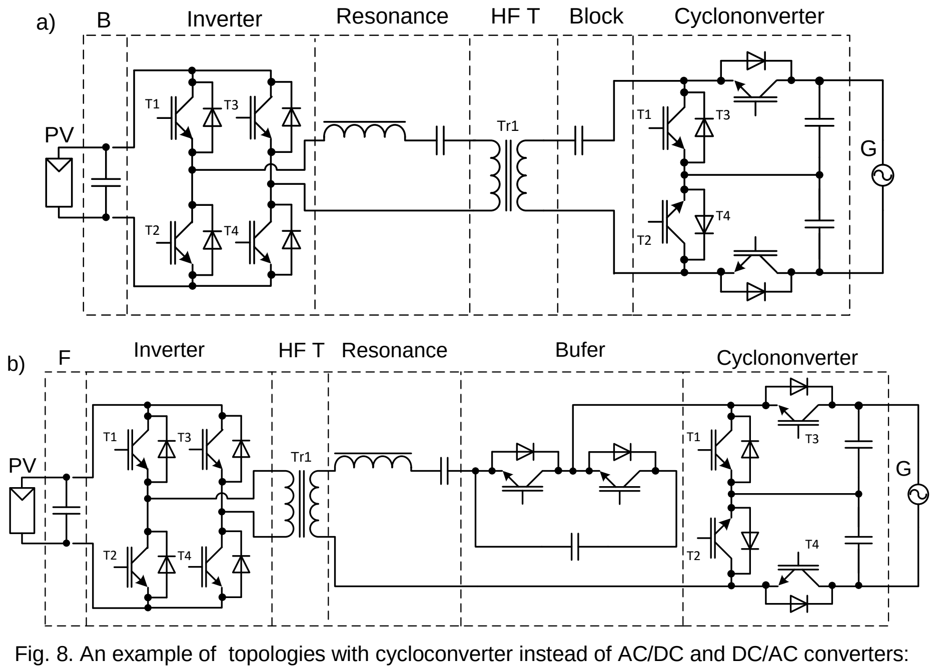

Fig. 8. An example of topologies with cycloconverter instead of AC/DC and DC/AC converters: without buffer (a) [6] and with a buffer (b) [5], where: F - Low Pass Filter, G - power grid, PV - photovoltaic panels, HF T - high frequency transformer, B – Buffer.

PV inverters with cycloconverters are converting high frequency AC voltage directly to low frequency AC voltage [6]. In this case once again it is necessary to use an energy buffer. To keep MPP in the one, optimum point it is required to keep the PV voltage ripple on a very low level. For that reason capacitance of buffers which are connected directly to PV panel should be relatively big [5]. To decrease volume of inverter an active buffer could be used. Example of converter with active buffer is shown in Fig. 8 b.

Conclusions

Inverters that have the highest efficiency has usually basic construction (like in Fig. 3 a.) or quite complicated topology with resonant circuit as are shown in Fig 7 c., d. and Fig. 8. Resonance converters are more complicated to control, especially when it is necessary to regulate input power to work in Maximum Power Point of PV but on the other hand they allow to operate transistors in zero-current-switching or zero-voltage-switching mode what minimize a switching loses. Selection of the best converter topology should depend on maximum costs, presence of galvanic separation, maximum power, input voltage and maximum volume of PV converter.

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