Title: Single phase voltage source inverters without transformer in photovoltaic application
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Single phase voltage source inverters without transformer in photovoltaic applications

Abstract: It is proposed to omit the transformer in voltage source inverters (VSI) for grid connected photovoltaic systems in order to reduce losses, costs and size. With respect to a tolerable level of the dc-voltage, the 1-phase three level VSI seems to be a promising approach to the input to grid below 5kW. The filter design, choice of switching frequency and control mode will be discussed in detail.

Introduction

Most commercial inverters for photovoltaic application include a transformer, which enables the selection of a suitable dc-voltage concerning the components and avoids ground loop between pv-generator and grid. Inverters including a transformer either use a line (50Hz/60Hz) or a medium frequency (20...50kHz) transformer. In this case inverters are primary pulsed and modulated in three sections of power conversion [1]. By the complexity of these inverters it seems to be worthwhile developing inverters without a transformer. Thus losses, costs, weight and size decrease. Basically, a 3-phase current source inverter can be used as described in [2]. For power levels below 5kW a single phase VSI is suitable, which is described in this paper.

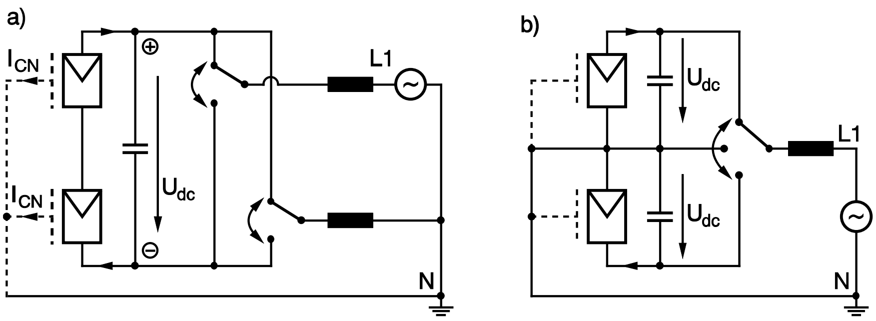

Fig. 1: 1-phase VSI without transformer a) full-bridge, b) half-bridge three level

In principle, there is no compulsion to use a transformer. The renunciation of a transformer brings up fundamental characteristics. First there is a galvanic connection of pv-generator and grid. This admits a leakage current I_{CN} through the capacitance between pv-generator and ground using a 1-phase full-bridge VSI as shown in Fig. 1a). The magnitude of this capacitance depends on environmental influences. It will be large when the pv-generator is covered with salty fog forming a conductive path to the grounded metallic frame of the pv-modules. Simulations show that in this situation the voltage between pv-generator and ground as well as the current I_{CN} may heavily oscilate and far exceed acceptable levels. The appearing leakage current also causes additional system losses and impairs the electromagnetic compabililty; thus the full-bridge VSI is considered not to be a practicable approach.

These disadvantages can be eleminated if the midpoint of the pv-generator is grounded in the 1-phase half-bridge VSI as shown in Fig. 1b). By the mode of operation (step-down) the dc-voltage U_{dc} must always be greater than the amplitude of the line-voltage. Fig. 2 shows the current-voltage characteristic of the pv-generator for a 1-phase VSI. The solar array voltage does not exceed 715V, which is tolerable for pv-modules. Due to this relatively high dc-voltage the 1-phase three level VSI is interesting, especially in the power range below 5 kW.

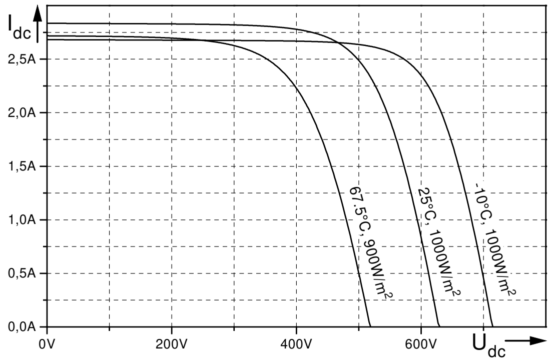

Fig. 2: Current-voltage characteristic of a 2.5kW pv-generator

Single phase three level VSI

Fig. 3 shows the 1-phase three level VSI with series connected switches. Simple estimations exhibit that a substantial improvement is achieved by using an ac-filter which consists of a L-C-L-combination (Fig. 3) instead of only one series L (Fig. 1b) concerning the required inductance. Operation with this profitable ac-filter needs an appropriate control mode. Especially for a utility grid connected pv-system an efficient disturbance restrain is desirable; disturbances, for example, are changes in amplitude or phase of the line-voltage. Even slight differences between the filter capacitor- and the line-voltage produce major currents across a comparatively small line-side inductance. In this case a controller with state feedback promises a beneficial dynamic performance (Fig. 4). A state controller expects stationary constant state variables; in the case of the ac-filter they will be sinusoidal,

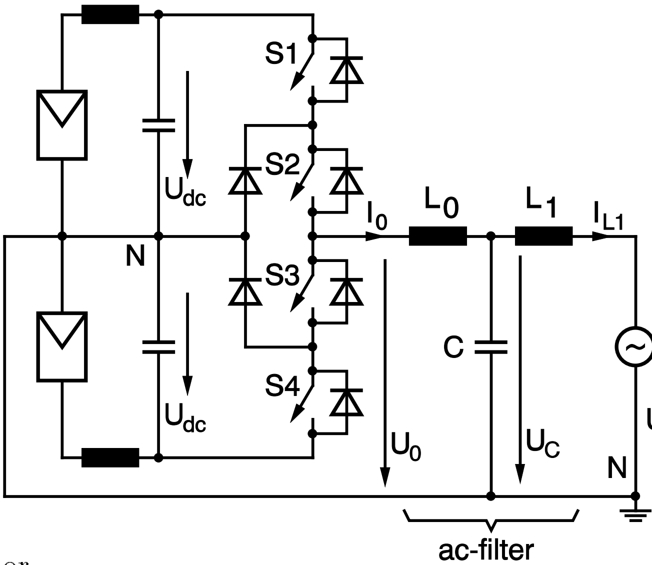

Fig. 3: 1-phase three level VSI

so the vector of the instantaneous state variables $\underline{X}$ has to be seperated into its stationary content $\underline{X}_S$ and error $\underline{X}_E$. Using a bang-bang control for the VSI output current I_0, the state variables are the capacitor voltage U_C and the line-side inductanc current I_{L1}. The feedback coefficients are determined by given poles. Good results are obtained by using a nearly constant switching frequency; this requires a variable hysteresis width.

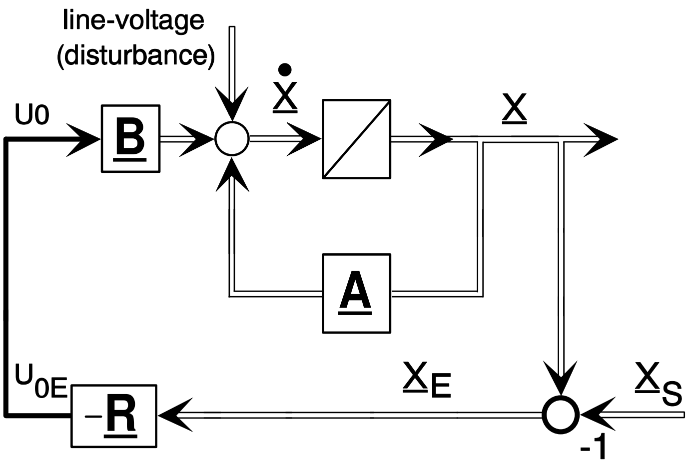

Fig. 4: Block diagram of the state controller

Fig. 5 illustrates simulation results of the VSI with an ac-filter for a 2.5kW nominal power pv-generator. Under normal conditions the inner devices S2 and S3 operate under zero-current-switching at the line-frequency, if the fundamental wave of the inverter current I_0 and voltage U_0 controlled to be in phase whereby switching losses decrease. The average switching frequency was set to 18kHz. The filter elements were chosen to $L_0 = L_1 = 1mH$ and $C = 50\mu F$.

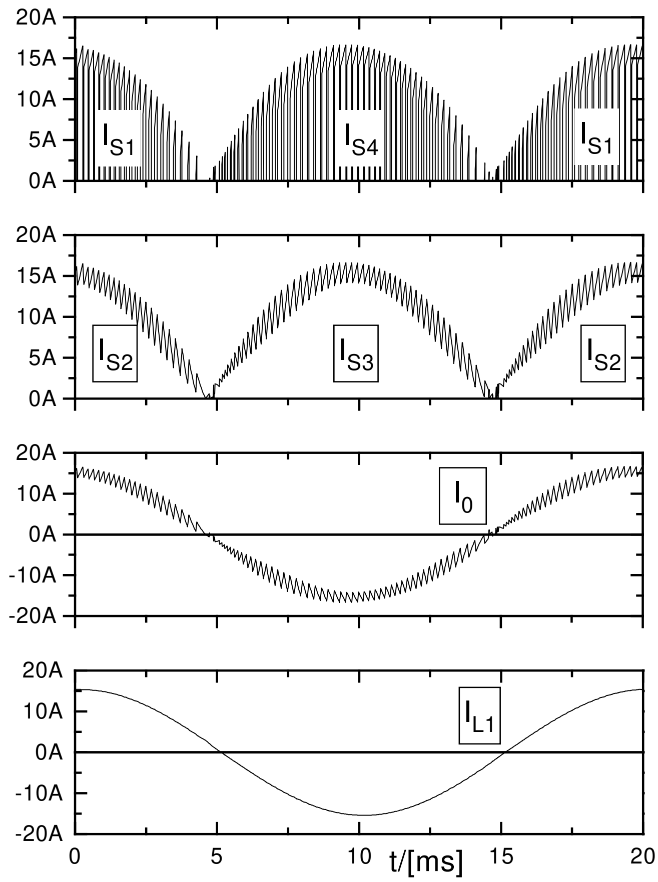

Fig. 5: Simulation results of the three level VSI

Switching frequency and ac-filter design

An essential aspect of the connection of the inverter to the utility grid is the permissible perturbation. The total harmonic distortion of the line-current depends on the switching frequency and the filter effect. In photovoltaic applications a high efficiency of the inverter is desirable, especially under part-load. In addition to the stand-by losses, the effeciency is determined by the device and filter-losses. For rising switching frequency, device losses increase and the filter effort decreases; thus filter losses decrease. The appearing problem is to find an optimized switching frequency at which the total loss will be minimal. In that procedure it must be considered that the net-input of the inverter is not constant. It depends on the temperature and radiating solar power and varies extremely. Consequently the total supplied annual energy of the pv-generator must be calculated and converted into quantized durations of discreete power levels. For each level, losses have to be determined and accumulated. By this method a suited switching frequency and filter-dimension will be established.

The described procedure and its results will be discussed in detail in the full paper.

References

[1] Steigerwald, R. L. et. al.: Investigation of a family of power conditioners integrated into the utility grid, Sandia National Labatories Report, SAND 81-7031, 1981

[2] Meinhardt, M., Mutschler, P.: Inverters without transformer in grid connected photovoltaic applications, European Conference on Power Electronics and Applications, pp 3.086-3.091