Three-Phase Two-HF-Switch PV Inverter with Thyristor Interface

To feed-in an alternating current into the medium voltage AC grid several requirements have to be kept. Next to rugged and interference-insusceptible electronics, attention has to be given to the new grid connection guidelines in Germany since 2008. Such new rules significantly affect the cost of inverters nowadays, especially when usual semiconductor devices like IGBTs are employed. This paper, awarded as best paper at PCIM 2010, deals with an inverter-topology which combines the rugged properties of well known thyristor-circuits with the features of modern inverters. **Christian Nöding, Benjamin Sahan, Peter Zacharias, Center of Competence for Distributed Power Technology (KDEE), University of Kassel, Germany**

Photovoltaic inverter technology rapidly improved during last decades, achieving more than 98% conversion efficiency. In terms of efficiency this leaves little space for major improvements. However, inverter cost are still relatively high, corresponding to approximately 250€/kW. In order to compete with conventional energy sources cost must be drastically cut down without significant prejudice on the efficiency, functionality and power quality. An approach to this is to minimize the amount of HF-switches and to combine high performance IGBTs or SiC switches with rugged low-cost switches like thyristors.

The thyristor is a proven technology since its development in the late 1950s. Because of its high current switching capability and its robustness this device is still popular in high power applications. Inverter topologies consisting of this technology are well known but only able to produce a rectangular output current and therefore require large magnetic components which cause higher weight and size of the devices.

Inverter function principle

An inverter with six thyristors and two buck converters in the front-stage (Figure 1) is capable of modulating sinusoidal output currents. Each buck converter creates a 180° phase shifted DC current which is superimposed by a multiple of the 3rd harmonic. This kind of DC current is then distributed by the thyristor-bridge to all phases of a standard 3-phase transformer in star-delta configuration (Figures 2, 3 and 4). Such a transformer is inherent to large-scale PV generation units (>200kW) which are connected to the medium voltage grid. The star-delta configuration eliminates the 3rd harmonic component, resulting in a

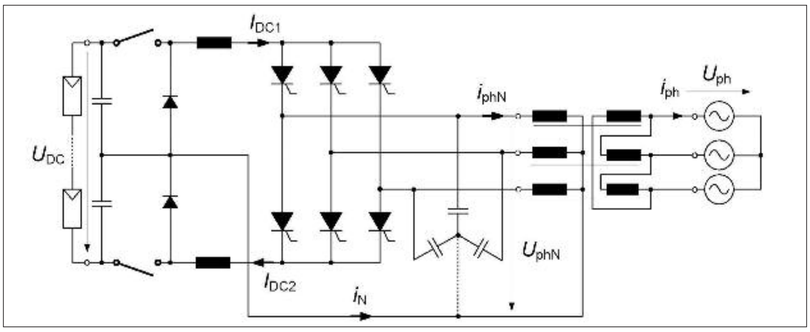


Figure 1: Inverter topology (Minnesota Inverter) with six thyristors and two HF-switches (IGBT or SiC MOSFET)

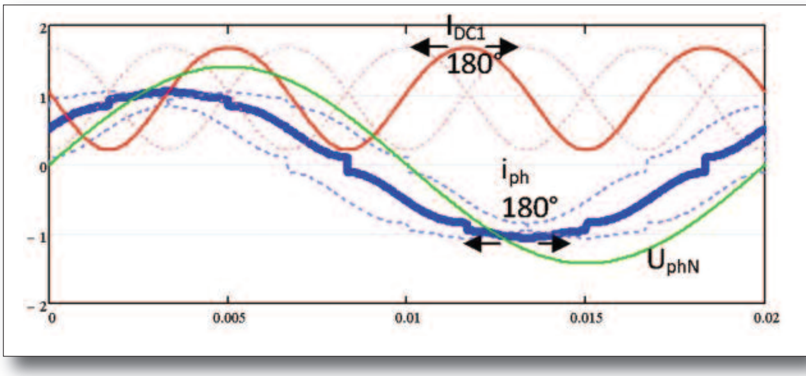


Figure 2: Phase shifted DC-link currents, input voltage and shifted input currents of transformer

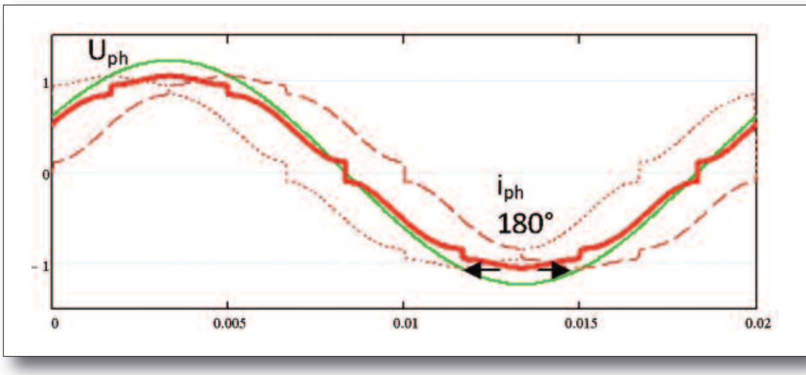


Figure 3: Output voltage and phase shifted output currents of transformer

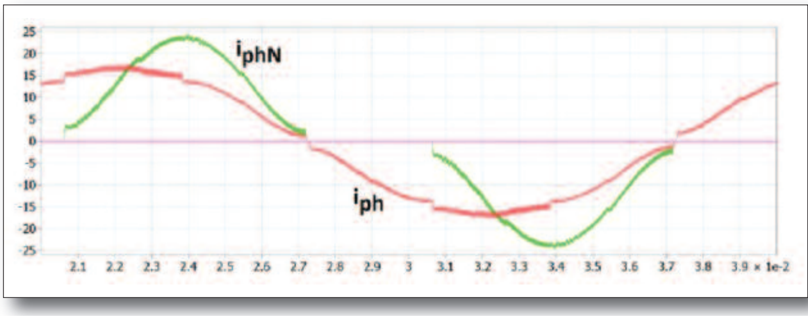
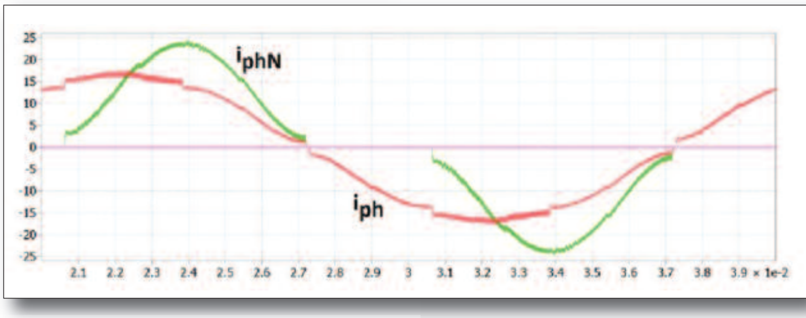


Figure 4: Simulated phase current of transformer

Figure 5: Simulated current of buck converters, neutral point of transformer and AC output



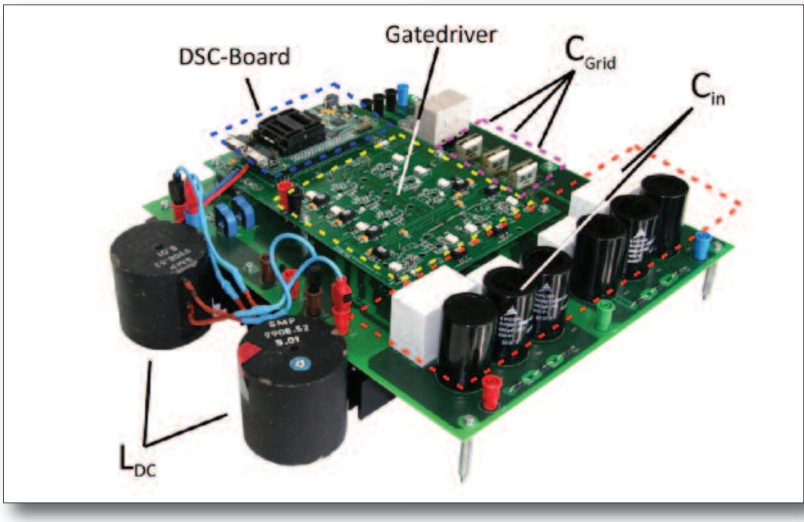


Figure 6: Prototype having a nominal power of 5kW and 800VDC input voltage

nearly sinusoidal output current.

A common problem of thyristor inverters is the loss of stability at firing angles above α=180°. This topolo-yy mitigates the problem because the DC-link current can be actively set to zero by the two buck converters (Figure 5). After this turn-off the commutation process in the next phase can be performed as usual. While keeping the DC-link voltage of the buck converters positive at any time this allows an adjustment of the firing angle _ between -30° and +30° around the pure active power point at α=180° (Figure 2 and 3). The circuit is therefore capable of shifting the output current between inductive (α=150°) and capacitive (α=210°) reactive power continuously without any steps, complying with the requirements of the new medium voltage grid code to stabilise the grid voltage with reactive power. This operation mode is new to thyristor based inverters and was so far reserved for self-commutated IGBT topologies.

To classify the performance of the presented system a comparison with three well known standard topologies was done. Important values of each circuit will be normalized to achieve comparably factors. In methods for comparing different topologies are described in detail. These comparison-factors include number of HF-switches, total rms- and mean-current of

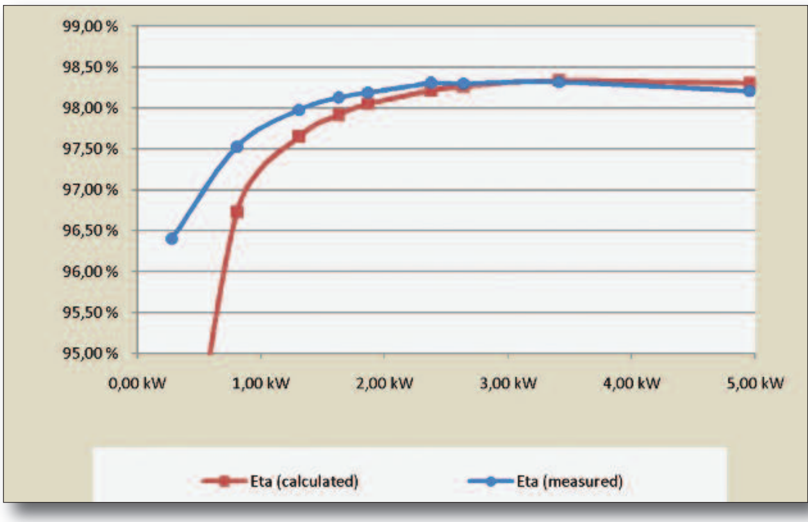


Figure 7: Calculated and measured efficiency of the prototype at U_{DC}=800V

Table 1: Simulation results (Simulink/PLECS) for four topologies normalized to the 2-level inverter

	2-Level	NPC	BS-NPC	MI
HF-Switches	6	12	12	2
LF-Switches	0	0	0	6
Maximum blocking voltage of HF switches	1,00	0,50	1,00	0,50
Inductor volume factor	1,00	0,50	0,50	0,48
Total mean current factor	1,00	2,00	1,21	1,74
Total RMS current factor	1,00	2,01	1,15	2,32
Total switch. loss factor 1	1,00	0,44	0,39	0,46
Total switch. loss factor 2	1,00	0,11	0,20	0,11

the semiconductors, total switching-loss values and number and volume of required inductors. All factors are normalized to the values of the well known 2-level inverter.

To estimate the pros and cons of each circuit, factors for four topologies were calculated with simulation results (Simulink/PLECS) and listed in Table 1. All factors are normalized values in reference to the 2-level inverter topology at a modulation index of 1 and cosφ=1.

Experimental results

A laboratory prototype (Figure 6) has been built having a nominal power of 5kW, 800VDC input voltage and switching frequency of 16kHz to verify the feasibility of the approach.

To estimate the potential of this topology the calculated efficiency was compared to the measured one feeding an ohmic load (Figure 7). A peak efficiency of 98.4% could be achieved. Due to a pessimistic switching loss assumption the calculated efficiency within low power region is below the measured one.

Conclusions

An inverter topology for photovoltaic systems connected to the medium voltage grid using inexpensive thyristors and high performance IGBTs or SiC switches has been presented. A three-phase sinusoidal current can be generated while complying with the reactive power specifications of the new medium voltage grid code. Reactive power is an important part of modern inverters for grid stability and compensation features. The major advantages of the circuit are the high performance/cost ratio and the robustness of the semiconductors. Using factors for comparing different types of topologies a comparison between common inverters was made to show the benefits of the presented system. The feasibility of this topology was proved by experimental results presented in this paper, showing its correct operation even with firing angles above α=180°. With only two IGBT switches a peak efficiency of 98.4% could be reached with this laboratory setup. Further research of this concept will be focused on behavior of the circuit on single- and multi-phase errors defined in the new grid code.

Literature

Christian Nöding: "Evaluation of a Three-Phase Two-HF-Switch PV Inverter with Thyristor-Interface and Active Power Factor Control", PEE Sponsored Best Paper Award in Session "Inverters for Renewable Energy and UPS", PCIM Europe 2010, May 6, Room London