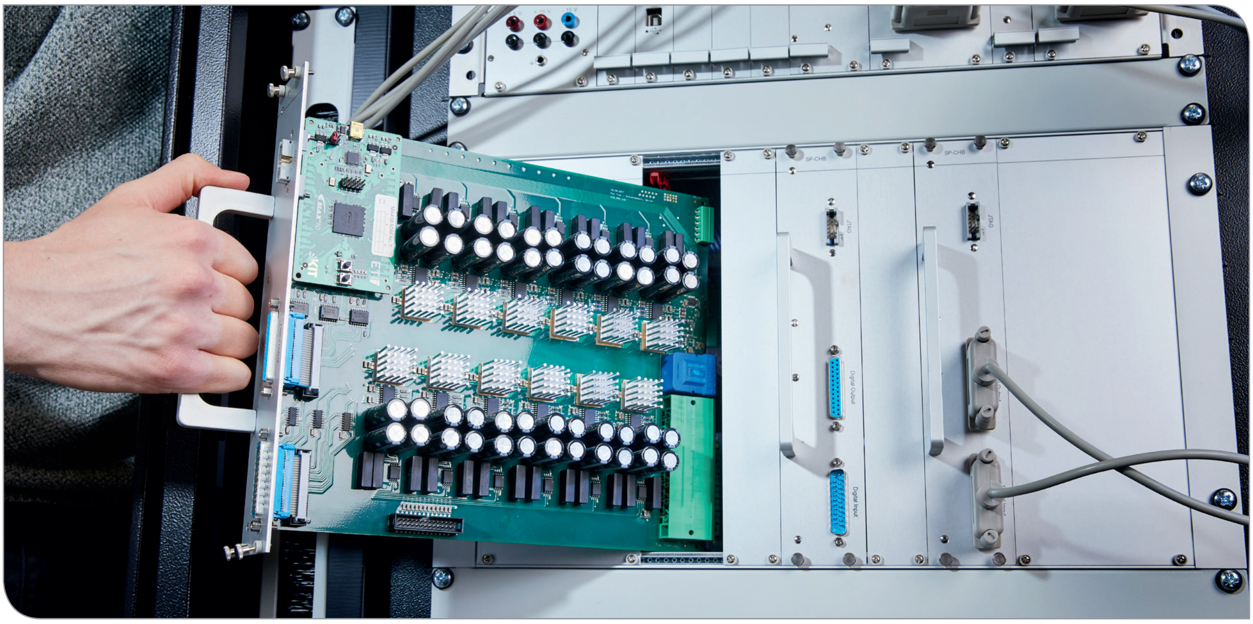
PHiL – Power-Hardware-in-the-Loop

Flexible Test Field for Future Power Electronics

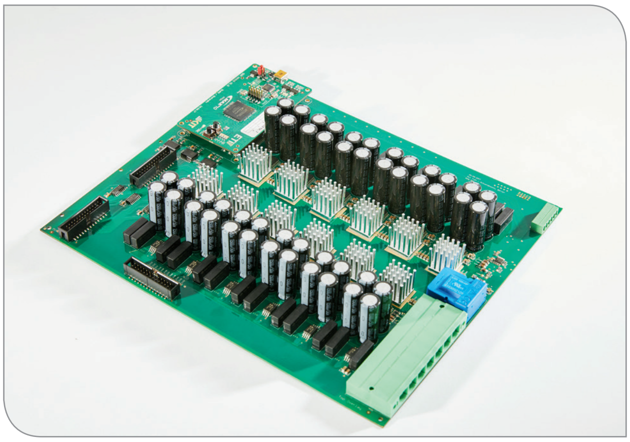
The energy transition requires development of new grid structures, adaptation of electric energy supply, and increased coupling of different energy sources. Growing regenerative energy production and the upswing of electric mobility are expected to result in an increasing number of power electronics frequency converters. Frequency converters precisely adjust voltage and current and, in this way, ensure safe and highly efficient generation, distribution, and use of electric power. To maintain the required voltage quality and ensure stable grid operation, frequency converters will have to comply with strict limits and render grid services that have mainly been provided by conventional power plants so far.

Grid-side frequency converters are applied among others in regenerative energy production, high-voltage direct-current (HVDC) technology, battery storage systems, and charging stations for electric mobility. Compliance with grid standards and execution of grid services, such as fault ride through (FRT) or voltage and frequency maintenance, require adequate designs of frequency converters. Strongly varying conditions at grid connection points make the design and testing of the frequency converters developed very difficult. Testing over the complete operation range taking into account all potential faults has been impossible so far. To solve this problem, the Institute of Electrical Engineering of Karlsruhe Institute of Technology develops Power-Hardware-in-the-Loop (PHiL) systems for reliable modeling of the electrical power grid and all faults occurring in it. Using a software model, an emulation-type frequency converter optimized for this application is given an electrical terminal behavior that corresponds to that of the electrical power grid in the ideal case. Modeling requires comprehensive and highly precise mathematical description of the physical behavior of the electrical power grid at the node connection point to be studied. Use of the easy-to-exchange software enables modeling of the terminal behavior at any grid connection point and for any fault by a single emulation-type frequency converter only. This is a major advantage of PHiL systems. They allow inexpensive and efficient testing of grid-side frequency converters in the development stage already. Contrary to tests applied so far, it is even possible to model severe grid faults.

The terminal behavior given by the software-based grid model is to be modeled by the emulation converter with



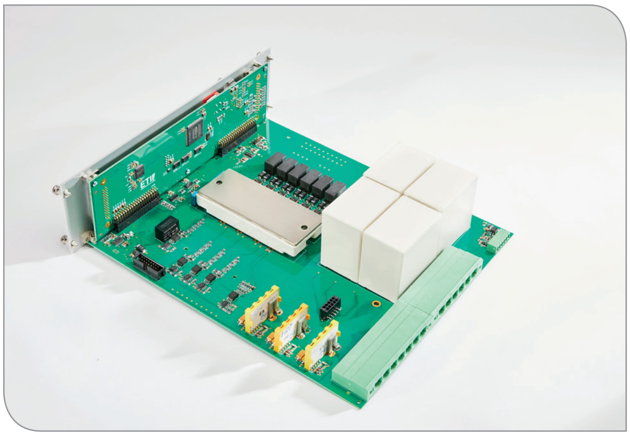
Emulation converter for the highly efficient modeling of the electrical power grid high accuracy. For this, the Institute of Electrical Engineering uses a novel type of switching concept, in which the high-power components of the system are decoupled from the low-power components. A high-performance two-stage frequency converter ensures active power transformation at low costs and high power density. Via an inductance, the frequency converter is coupled to a multilevel converter of high voltage quality that determines the terminal behavior of the PHiL system due to its direct parallel connection to the output. This combination results in a multilevel frequency converter of so far unreached power density that can be used for testing high-performance frequency converters and is optimally suited for modeling sinusoidal grid voltage due to its high number of output voltage levels. The complete system is highly modular, as all components are based on identically designed circuit boards. Variation of the number of components leads to the simple scalability of current and voltage and, hence, facilitates adaptation to the voltage and power class of the frequency converter to be tested. During operation, the terminal behavior is calculated in accordance with the implemented grid model on a real-time-capable signal processing platform. This also allows highly dynamic modeling of the transient grid behavior in cases of faults. Using the meanwhile third generation of signal processing platforms, all components of the system can be adapted flexibly and adjusted to each other. The PHiL emulation converter developed by the Institute of Electrical Engineering is ideally suited for testing grid-side frequency converters in the early development phase for their functionality, reliability, and behavior in cases of faults, at high output power under realistic grid conditions.



Single-phase module of a multilevel converter with 25 output voltage levels

Technical Data of the Exhibit

Nominal voltage	400 V
Nominal power	100 kW
Output voltage levels	25
Mean switching frequency	600 kHz
Total harmonic distortion (THD)	2.7 %



Three-phase module of a two-level frequency converter of 25 kW power

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