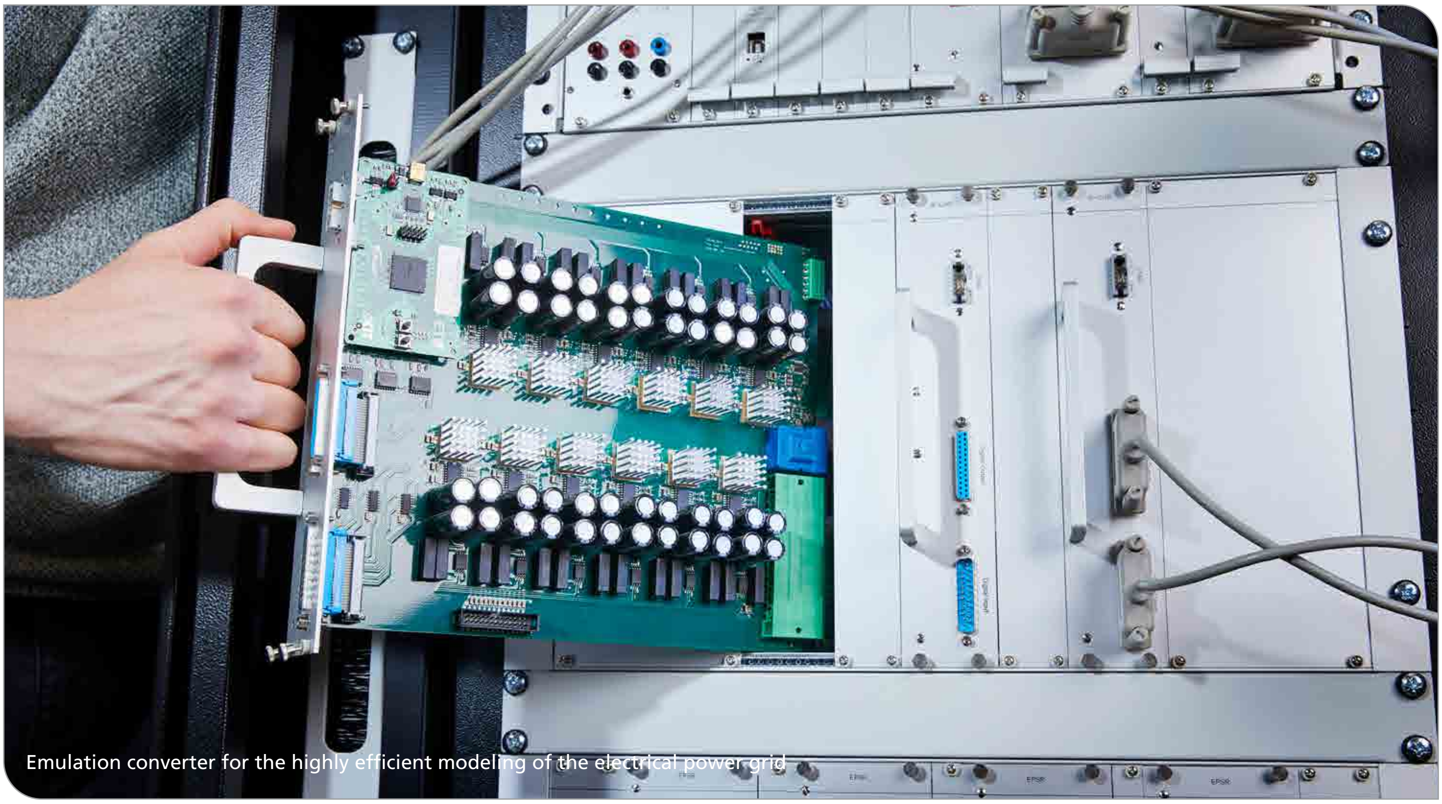
PHiL – Power-Hardware-in-the-Loop
Flexible Test Field for Future Power Electronics

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 provide 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 supply 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 converter optimized for this application is given an electrical terminal behavior that corresponds to that of the electrical power grid in the ideal case. The modeling requires comprehensive and highly precise mathematical description of the physical behavior of the electrical power grid at the node connection point under investigation. Use of the easy-to-exchange software enables modeling of the terminal behavior at any grid connection point and for any fault by the developed emulation converter. This is an important advantage of PHiL systems, which enable cost-effective and efficient testing of grid-and machine-side frequency converters already in the development stage. Contrary to the grid conditions that can be tested so far, it is even possible to model severe grid faults.



Emulation converter for the highly efficient modeling of the electrical power grid

The terminal behavior given by the software-based grid model is to be modeled by the emulation converter with high accuracy. For this purpose, 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-level 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 converter with unprecedented power density which can be used for testing high-performance frequency converters. Due to its high number of output voltage levels, it is optimally suited for modeling sinusoidal voltages. The complete system is highly modular, as all components are based on identically designed circuit boards. The variation in the number of components results in easy scalability of current and voltage, making it easier to adapt the voltage and power class of the frequency converter under test. 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. By using the meanwhile third generation of signal processing platforms, all components of the system can be flexibly adapted and tuned to each other. The PHiL emulation converter developed by the Institute of Electrical Engineering is ideally suited to test grid- and machine-side frequency converters in the early development phase for their functionality, reliability, and behavior in the event of failure, at high output power and under realistic grid conditions.

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

Technical Data of the emulation converter

Nominal voltage	400 V
Nominal power	100 kW
Output voltage levels	25
Switching frequency of the multilevel converter	600 kHz
Nominal power of the multilevel converter	10-15 kW
Switching frequency of the two-level converter	8-20 kHz

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

Karlsruhe Institute of Technology
Engelbert-Arnold-Str. 5
76131 Karlsruhe, Germany

Elektrotechnisches Institut

Prof. Dr. Marc Hiller
Institute of Electrical Engineering (ETI)
Phone: +49 721 608-42474
Email: marc.hiller@kit.edu

Karlsruhe Institute of Technology (KIT) · President Professor Dr.-Ing. Holger Hanselka · Kaiserstraße 12 · 76131 Karlsruhe, Germany