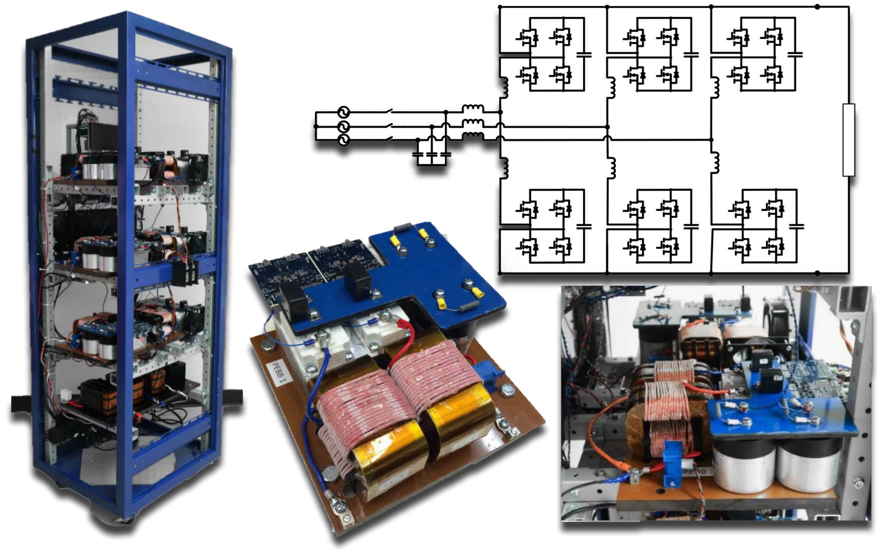
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY



A 100 kW three-phase modular power converter built with full-bridge power cells based on 1.7 kV silicon carbide (SiC) metal-oxide-semiconductor field-effect transistor (MOSFET) devices. This project will be designed to utilize advanced high-power 10 kV SiC MOSFET devices. *Photo courtesy of Virginia Tech*

High-Efficiency Modular SiC-Based Power Converter for Flexible CHP Systems with Stability-Enhanced Grid Support Functions

Combined heat and power (CHP) systems provide both electricity and heat for their host facilities. CHP systems have mostly saturated the large industrial facility market, where economies of scale and the required presence of technical staff make the deployment of large systems—greater than 20 megawatt (MW) electrical capacity—cost effective and practical. There remains, however, substantial room for growth of smaller CHP systems suited for small and mid-size manufacturing facilities.

In addition to manufacturing facility energy and cost benefits, the needs of the modern electric grid are also emerging as key drivers for further deployment of CHP systems. As intermittent renewable generation resources constitute a growing and increasingly significant portion of electricity generation, the need for dispatchable generation (i.e., sources of electricity that can be used on demand at the request of power grid operators, according to market needs) to maintain the stability of the grid grows. Many small and mid-size manufacturing facilities would be ideal hosts for flexible CHP systems that provide grid services, while also generating an additional income stream for the facilities.

However, in order for CHP systems to seamlessly integrate with the grid and provide more advanced grid services, further technical development is needed. In particular, the current state-of-the-art in medium voltage, multi-megawatt power electronic systems does not support advanced grid functions, traditionally due to limitations in power electronics and other required applications. The development of advanced power converters and controls is needed for these CHP systems to be cost-effective and able to respond to rapidly changing grid conditions.

This project will develop a modular and scalable medium voltage (MV) power converter with grid support functions for grid interface applications in flexible CHP plants. The converter will use a modular circuit topology that is scalable both in voltage and current by interconnecting power-cell building blocks to flexibly meet the needs of CHP systems in the 1-20 MW range. Furthermore, the converter will be designed to utilize advanced high-power 10 kV silicon carbide (SiC) metal-oxide-semiconductor field-effect transistor (MOSFET) devices, taking advantage of the high-blocking voltage capability of these devices, their high efficiency, power density, and high switching frequency capacity.

Benefits for Our Industry and Our Nation

Flexible CHP systems could be utilized in small and mid-sized U.S. manufacturing plants. With its modular structure, the converter will help reduce costs and complexity, and provide the means to increase reliability, availability, and resiliency in CHP and microgrid applications. Having such flexible CHP systems could not only provide significant financial benefits to host facilities, but also to the grid system operator and all ratepayers. According to a 2018 manufacturing sector analysis conducted for the U.S. Department of Energy, widespread deployment of flexible CHP systems that are able to provide grid services could result in annual financial benefits of approximately $1.4 billion in the state of California alone. These savings consist of reduced energy bills for industrial facilities, reduced grid operating costs, and increased generation capacity of the new electric generators (alleviating the need to construct new centralized power plants).

Applications in Our Nation's Industry

Flexible CHP systems that can provide grid services are expected to be financially attractive investments in markets with high penetration of intermittent renewable resources, such as California, Texas, and several Midwestern states. The system will be designed to be fully compliant with the Institute of Electrical and Electronics Engineers (IEEE) Standard 1547, for operation in local areas with high aggregated distributed energy resource penetration. The system will also be compliant with the IEEE standard for the specification of microgrid controllers, IEEE Standard 2030.7, with the goal of enabling flexible CHP systems for both stand-alone and microgrid applications. CHP technology is broadly applicable across industrial sectors, including the chemicals, food and beverage, plastics, and fabricated metals industries.

Project Description

The first outcome of this project will be to demonstrate the viability of a SiC-based modular converter as a platform for seamlessly connecting CHP systems to the grid, showing sufficient flexibility and capability to meet the needs of industrial facilities in the 1 to 20 MW range, along with enhanced efficiency and power density levels.

The second outcome of this project will be the demonstration of the converter's stability-enhanced grid support functions, including ability to: (1) operate in over-excited and under-excited reactive power generation modes; (2) participate in voltage and frequency regulation; (3) respond to abnormal conditions; (4) operate in and detect unintentional and intentional islanding conditions; and (5) monitor grid stability conditions and adjusting its operating point and control scheme to avoid the onset of dynamic interactions.

Barriers

- Demonstrating stability-enhanced grid support functionality
- Meeting system performance requirements to support advanced grid functions while keeping system costs in check
- Ensuring the converter operates in compliance with IEEE Standard 1547

Pathways

This project consists of three phases. In the first phase, the project team will initially model and design the CHP converter, followed by development of the converter digital control platform, including hardware and software. This is followed by design and implementation of a duty cycle-based impedance measurement and stability assessment capability for the converter. The first phase will end with programming the power hardware-in-the-loop (PHIL) unit and the microgrid controller.

The second phase will focus on system testing, starting with commissioning of the converter through functional (standalone mode) testing of the converter, including main control loops and all grid support functions. This will be followed by testing of the communications between the microgrid controller and the converter, and finally by testing of the CHP and microgrid models in the PHIL system.

The final phase of the project will begin with a test bed demonstration of the converter with the microgrid controller in the PHIL system under nominal operating point conditions. This will be followed by exhaustive testing of the converter to evaluate its power processing and system grid-interface performance. The project will conclude with qualification tests to verify compliance with standards.

Milestones

This three-year project began in late 2018.

- CHP converter design meets efficiency (>98%) and power density (>10 kW/L) targets, and the developed controllers demonstrate the required grid support services and monitoring functions (2019)
- Successful functional testing of the CHP converter: the microgrid controller communicates with the converter controller and the PHIL unit, with the latter emulating the CHP generator and the microgrid system (2020)
- Successful compliance testing for IEEE-1547, UL-1741, and IEEE-2030 standards; meeting >98% efficiency and 10 kW/L power density targets; and demonstrating grid support functions (2021)

Technology Transition

The project team will leverage a variety of resources in order to best transition the outcome of this project into the market. The project team will work with the Mid-Atlantic DOE CHP Technical Assistance Partnership (TAP) to coordinate and plan the CHP technology transition. Activities will include CHP TAP feasibility analyses to demonstrate the benefit of the technology, as well as attending regional workshops to engage with interested industrial organizations. The project team will also leverage the 83 members of the Center of Power Electronics Systems (CPES) industrial consortium, as well as Siemens' considerable reach to potential technology adopters. Upon successful project completion, it is estimated that 3–5 years will be needed to fully develop and commercialize the CHP converter and its modular subsystems.

Project Partners

Virginia Polytechnic Institute
Blacksburg, VA
Principal Investigator: Rolando Burgos
Email: *rolando@vt.edu*

Siemens Corporate Technology
Princeton, NJ

For additional information, please contact

Bob Gemmer
Technology Manager
U.S. Department of Energy
Advanced Manufacturing Office
Phone: (202) 586-5885
Email: *Bob.Gemmer@ee.doe.gov* ■

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