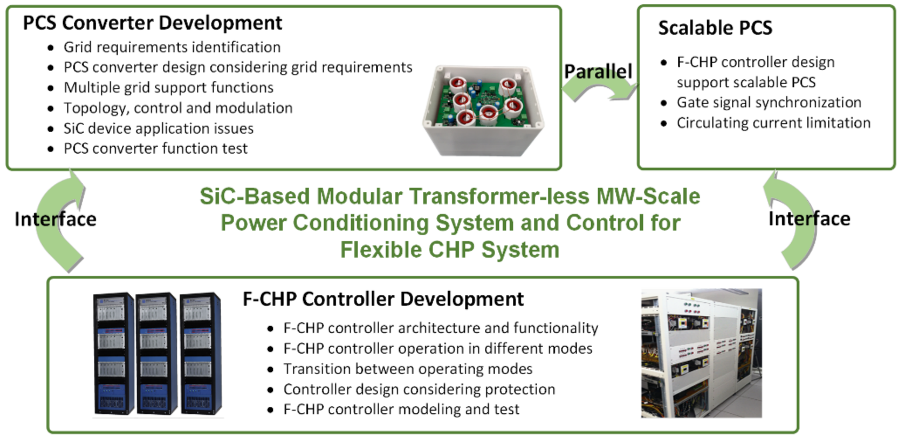
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY



Summary diagram of the key project technologies being developed: The power conditioning system (PCS) converter, scalable PCS, and the flexible CHP (F-CHP) controller. *Graphic courtesy of the University of Tennessee, Knoxville*

SiC-Based Modular Transformer-less MW-Scale Power Conditioning System and Control for Flexible CHP System

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 can provide needed 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 development of advanced power electronics and controls for flexible CHP systems is needed to meet grid interface standards, have the ability to respond to rapidly changing grid conditions, and achieve high resiliency and low cost.

This project aims to address this challenge by developing a MW-scale modular silicon carbide (SiC)-based power conditioning system (PCS) and a corresponding control system for flexible CHP applications. The PCS will be capable of grid support functions, such as low/high frequency and voltage ride through, as well as dealing with other abnormal grid conditions, including unbalance, faults, and overvoltage. The transformer-less (i.e., no 60 Hz transformers) PCS will utilize a four-wire system to support both three- and single-phase loads. It will take advantage of fast-switching SiC metal-oxide-semiconductor field-effect transistors (MOSFETs) to enable additional system-level functions like harmonic filtering and stability enhancement, as well as feature a lighter and more compact modular design. The technology being developed will enable automatic control of the CHP grid support functions.

Benefits for Our Industry and Our Nation

This technology is expected to provide increased reliability, resilience, and energy efficiency to small and mid-sized manufacturing plants by enabling CHP systems to provide grid services, such as additional generating capacity during times of peak demand and voltage regulation.

In addition, having such flexible CHP systems could provide significant financial benefits not only 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. CHP applications in the 1-20 MW size range are appropriate for many small and mid-size manufacturing facilities with both electrical and thermal loads. CHP technology is broadly applicable across a variety of industrial sectors, including the chemicals, food and beverage, plastics, and fabricated metals industries. Applications can also include medium voltage motor drives and photovoltaic inverters.

Project Description

The project goal is to develop a SiC-based, modular, transformer-less, MW-scale, four-wire DC/AC power conditioning system, and a corresponding control system for flexible CHP applications using general purpose controller hardware.

This technology will advance the state-of-art in two key ways. For power electronics, current silicon technology is mature, but cannot provide a cost-effective solution with grid support capabilities. This project will utilize more advanced SiC technology and focus on developing system level benefits. For the control system, the project will develop a low-cost controller for flexible CHP systems that considers different fuels and operating modes, which will allow flexible operation and easy deployment.

Barriers

- Designing the controller to meet grid requirements and enable automatic transfer between various operation modes, including a dynamic microgrid boundary to maximize utilization of resources
- Achieving performance requirements while also meeting the Institute of Electrical and Electronics Engineers (IEEE) P1547 standard for interconnecting distributed resources with electric power systems and the IEEE P2030.7 standard for the specification of microgrid controllers
- Managing circulating current ripple at the switching frequency and circulating current at the fundamental frequency in a paralleled and scalable PCS converter

Pathways

This project consists of three phases. In the first phase, team members will design a PCS converter that connects CHP sources with a medium voltage (MV) grid, fully considers grid requirements, and is able to provide grid support services. The CHP controller will be designed and implemented in a general-purpose controller hardware.

In the second phase, a single PCS converter with 100 kW power rating will be built. A MV test platform will be constructed and PCS functions will be demonstrated in the platform. The CHP controller will first be tested in hardware in the loop (HIL) environment and then validated in a flexible CHP system simulated in a grid emulator hardware testbed (HTB).

In the third phase, the PCS converter paralleling technology will be developed. Two 100 kW PCS converter prototypes will be built for validation of the scalability of the PCS converter. The capability of the CHP controller to handle the scaled PCS will also be validated in the HTB.

Milestones

This three-year project began in late 2018:

- PCS converter design completed and flexible CHP controller architecture developed and implemented in a general purpose controller to meet grid requirements (2019)
- PCS converter tests meet all requirements, including >98% efficiency, >300 Hz voltage control bandwidth, and >1 kHz current control bandwidth (2020)
- Tests completed in the HIL platform and the grid-emulation HTB (2020)
- Scalable PCS converter developed and validated in the HTB platform (2021)
- Medium voltage test platform built for scalable PCS converters (2021)
- Two 100 kW scalable PCS converters successfully built and tested (2021)

Technology Transition

Upon successful completion of the project, this technology will be actively promoted to utilities and commercial and institutional customers, such as manufacturing facilities, hospitals, and university campuses. The potential target market can also include medium voltage motor drives and photovoltaic inverters that can utilize the 10kV SiC MOSFETs being developed. Several strategies are being considered for commercializing the converter and control technology. These strategies include transferring the technology to General Electric, other University of Tennessee industrial partners, a startup company, or helping to establish a startup company to promote and commercialize the technology.

Project Partners

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DOE/EE-1916 · February 2020