Enabling High Penetration PV Solar through Next Generation Power Electronic Technologies

October 11-12, 2016
Venue: ESIF, NREL

OVERVIEW

The U.S. Department of Energy's SunShot Initiative is a collaborative national effort that aggressively drives innovation to make solar energy cost-competitive with traditional energy sources by 2020. SunShot's strategic research and development programs support efforts by private companies, universities, and national laboratories to drive down the cost of solar electricity to $0.06 per kilowatt-hour, and to enable the safe, reliable, and cost-effective integration of large scale solar generation onto the U.S. electric power grid.

The Systems Integration program of the SunShot Initiative envisions that hundreds of gigawatts of variable solar (photovoltaics (PV) and concentrated solar power) generation will be interconnected to the grid as the solar industry moves toward achieving the SunShot goal. Therefore, it becomes imperative to identify the associated technical, economic, and regulatory challenges, and to develop impactful solutions in order to ensure compatibility with the existing grid and smooth transition to a secure, reliable, and resilient grid of the future.

The purpose of this workshop is for participants to identify critical challenges and opportunities associated with integrating high levels of solar energy into the electric grid, specifically in the advanced power electronic area. Participants will assess the state-of-the-arts in power electronic component technologies and system designs, identify the near- and long-term gaps, and propose a set of pathways for research and development. The workshop co-organizers (NREL, NETL, and ORNL) will present preliminary findings from their ongoing SunShot-funded research and seek industry inputs on their market relevance and commercialization opportunities. The DOE SunShot team will collect and analyze new ideas, opinions, and comments from this workshop as valuable inputs to the development of research roadmaps and future funding opportunities. Participants are encouraged to provide additional feedback after the workshop as well.

BACKGROUND

.

The installed cost of solar photovoltaics (PV) and concentrating solar power (CSP) have fallen rapidly in recent years, spurring significant growth and accelerating deployment of solar energy systems. In 2015, the total installed solar power in the U.S. was over 28 GW. To proactively anticipate and address potential challenges under a scenario in which hundreds of gigawatts (GW) of solar energy are interconnected to the electricity grid, the Systems Integration program has identified the challenges to be addressed in four broad, inter-related areas:

- **Grid Performance and Reliability:** Maintain and enhance the efficiency and reliability of electric transmission and distribution systems in a cost-effective, safe manner with hundreds of gigawatts of solar generation deployed onto the nation's power system.
- **Dispatchability:** Ensure that solar power is available on-demand, when and where it is needed and at the desired amounts, in a manner that is comparable to or better than conventional power plants.
- **Power Electronics:** Develop intelligent devices that maximize the power output from solar power plants and interface with the electric grid (or end use circuits), while ensuring overall system performance, safety, reliability, and controllability at minimum cost.
- **Communications:** Create infrastructure that is used to inform, monitor and control generation, transmission, distribution and consumption of solar energy effectively under broad temporal and spatial scales.

In the power electronics area, the SunShot Systems Integration program has recently completed research, development and demonstration projects through competitive funding initiatives that address the challenges associated with high-level solar penetration onto the grid. For example, the Solar Energy Grid Integration Systems – Advanced Concepts (SEGIS-AC) program (http://energy.gov/eere/sunshot/solar-energy-grid-integration-systems-advanced-concepts) seeks to develop solar power electronics that incorporate advanced functionality for enabling high penetrations of PV as well as system cost reduction. The High Penetration Solar Deployment program (http://energy.gov/eere/sunshot/high-penetration-solar-deployment) seeks to model, test, and evaluate solutions to mitigate the impacts of high penetrations of PV on distribution systems. In addition, SunShot has been funding power electronics research at national laboratories. For more information, visit www.solar.energy.gov/sunshot/systems_integration.html.

CHALLENGES AND OPPORTUNITIES

Power electronics, as critical components in PV systems and the larger electricity grid, are responsible for converting electricity from DC to AC and delivering it to the end customers. In

2005, approximately 30% of the electricity flowed through power electronic devices somewhere between generation and end use. With the rapid growth of renewable energy (e.g. solar PV) and the transformation and modernization of electricity grid, it is projected that in 2030, 80% of electricity could flow through power electronics. [1]

Typical power conversion topologies are DC to AC, DC to DC, AC to DC, and AC to AC. For PV generation, the ratings of power electronics can range from about 250 W for module level power electronics (MLPE) to MW level ratings for utility-scale inverters. Besides PV inverters, other power electronic devices of interests are DC/DC converters, energy storage chargers/inverters, solid state transformers, and other power flow control devices. These system designs are enabled by foundational materials and component technologies such wide band gap power semiconductors, advanced magnetics, and thin film capacitors as well as innovative packaging techniques.

Power electronics are intelligent devices that maximize power output from the PV arrays using Maximum Power Point Tracking (MPPT) techniques, and at the same time serve as the interface between PV systems and the transmission and distribution grid.

Most power electronics are capable of self-diagnostics, automated control, and fault protection to ensure overall system safety, reliability, and controllability. Power electronics can also be integrated with smart weather stations, energy storage, and customer loads to provide a wide range of services. For example, smart inverters are enabling PV systems to provide a host of beneficial grid-support services in addition to electricity generation. These services include voltage control, reactive power support, frequency regulation, ramp rate control, and much more. Remote operation by grid operators is achieved through communication and Supervisory Control and Data Acquisition (SCADA) interfaces. In order to realize the potential benefits of smart inverters, it is crucial to coordinate the operation of power electronic devices and legacy grid devices.

The state of the power electronic technology, as concluded in one recent article, [2] is that "although approaching the limits of its internal metrics indicates internal maturity, the external constituent technologies of packaging, manufacturing, electromagnetic and physical impact, and converter control technology still present remarkable opportunities for development. As power electronics is an enabling technology, its development, together with internal developments, such as wide bandgap semiconductors, will be driven externally by applications in the future." One of the most exciting and challenging applications is the interconnection and integration of hundreds of gigawatts of solar generation into the electricity grid.

[1] L.M. Tolbert, et al., "Power Electronics for Distributed Energy Systems and Transmission and Distribution Applications: Assessing the Technical Needs for Utility Applications," ORNL Technical Report, 2005.
[2] J.D. van Wyk and F.C. Lee, "On a Future for Power Electronics," IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 1, No. 2, June 2013.

TECHNICAL TARGETS

The SunShot SI team has developed preliminary target performance metrics for the next generation power electronics for solar applications:

- **Conversion Efficiency:** > 98%. Defined as the ratio of the usable output power (AC or DC) versus available input power from the PV panels. Typically, the PV inverters in the U.S. are tested to the CEC (California Energy Commission) efficiency using a weighted formula

- **Service Life and Reliability:** > 25 years. Defined as the useful life of the power electronic subsystems to support the required plant availability under normal operation and maintenance

- **Power Density:** > 100 W/in3 for residential and small commercial systems. Defined as the ratio of rated output power versus device volume and weight.

- **System Cost:** Defined as the lifetime cost of the power electronic device, including initial capital cost and the operation and maintenance (O&M) cost over the service life.
    - < $0.10/W, utility scale
    - < $0.125/W, commercial scale
    - < $0.15/W, residential scale

- **Advanced Control Functions:** In compliance with ANSI, IEEE, and NERC standards. These include a host of smart inverter functions such as anti-islanding, volt/var, volt/watt, frequency/watt, voltage ride-through, power factor control, reactive power support, ramp rate control, and emerging grid-forming capabilities. These functions can be activated either autonomously through default settings or remotely through utility SCADA commands.

- **Interoperability:** In compliance with Open Standards. This is the capability of the power electronic devices to exchange and readily use information—securely, effectively with other system components. Open standards include SunSpec Modbus, Smart Energy Profile (SEP 2), IEC 61850, MultiSpeak, DNP3, and emerging standards.

- **Cybersecurity:** In compliance with Cybersecurity Standards. This is the capability of the power electronic devices to ensure and maintain cybersecurity throughout their lifecycles and prevent issues at the external interfaces. Systems for critical applications need to withstand cybersecurity events with no loss of critical function.

QUESTIONS FOR DISCUSSIONS

BREAKOUT SESSION 1 – Component Perspective

1. What are the top 3 component-level technologies that are the most critical to future PV power electronic designs in each of the market segments (residential, commercial, and utility-scale)?

2. Will Wide-Band-Gap technologies (SiC and GaN) replace Si in PV applications? If yes, what are the deciding factors for the transition and how soon? If no, what are the critical barriers?

3. Will high-frequency (HF) magnetics replace conventional magnetics in PV applications? If yes, what are the deciding factors for the transition and how soon? If no, what are the critical barriers?

4. Compare and contrast PV and other (energy storage, EVs, industrial motors) power electronics systems. What are the best approaches to ensure component technologies meet the specific application requirements while maintain the common features?

5. What are the critical challenges in manufacturing and reliability for the wide adoption of these technologies?

6. What are the learning curves of various (WBG devices, HF magnetics) power electronic technologies in terms of cost and performance? Is there a "Moore's law"?

BREAKOUT SESSION 2 – System Perspective

1. Which market segment (residential, commercial, and utility-scale) need the most improvement in power electronic designs in the mid- to long-term? Why?

2. What are the critical technical challenges in power electronic system design for PV applications? What are top 3 enabling technologies at the system level?

3. What are the potentials for medium voltage power electronics for PV applications? What are the critical challenges?

4. What are the potentials for module level power electronics for PV applications? What are the critical challenges?

5. Are the preliminary metrics too incremental, too aggressive, or just right? What other metrics are missing from the list?

6. As deployment of PV and grid power electronics devices increases, is cybersecurity a big concern?