- Propose incremental advancement to existing or near-term standards. Projects for extensive standards development are not of interest
- Seek to develop strategic organizational change, workforce, and technology support services to address cybersecurity concerns

Topic Area 5.3: Control and Coordination of a Hybrid PV Plant

This topic area seeks research that advances control and coordination of hybrid PV plant technologies to address current limitations of hybrid PV plants in providing flexibility, stability, and grid-forming capability. This research will increase the value of solar as it begins to operate collaboratively with other resources in a hybrid PV plant for improved reliability and resilience.

A hybrid PV plant[108] in this FOA is defined as a group of PV and one or more generation or storage resources, such as wind, batteries, pumped hydro or fuel cells, that is connected as a single resource to the grid. Such a hybrid plant provides an opportunity to internally optimize and coordinate in a way that will provide enhanced grid stability and grid services. For example, a PV-plus-storage hybrid plant can be designed to provide energy at any time of day.

This research will also work to develop new grid-forming capabilities of solar PV at the bulk grid. Traditional “grid-following” PV systems require an outside signal from the electrical grid to inject power into the grid. In these systems, the power from the grid provides a signal that the inverter tries to match. More advanced grid-forming inverters can generate the signal themselves.

Renewable electricity generation is projected to account for over 30% of the U.S. electricity supply in 2050, according to the U.S. Energy Information Administration Annual Energy Outlook 2019.[109] Of the 30% renewables, nearly half will come from solar PV and the rest from wind, hydro, geothermal, and other sources. Electricity from solar and wind is variable, meaning it fluctuates throughout the day, and requires the grid operator to use other generation sources to balance the grid. Storage, like batteries and pumped hydro, could also offset variability, and solar inverters could provide advanced grid services to help grid operators match demand and supply.

Today, grid operators rely primarily on gas-powered plants or pumped hydro to ramp up quickly and manage variability in electricity supply. There is an opportunity for the individual resources to co-locate. This would enable them to better coordinate and use their potential flexibility to improve variability management and provide advanced grid

[108] National Renewable Energy Laboratory. *Hybrid Utility-Scale PV-Wind Storage Plants for Dispatchability and Reliability Services.* Gevorgian, et. al. 2018. https://www.nrel.gov/docs/fy18osti/71551.pdf
[109] EIA *Annual Energy Outlook 2019.* https://www.eia.gov/outlooks/aeo/

services. Flexibility in generation refers to the capability of generators to start and stop easily, increase or decrease generation on demand, and respond quickly to ensure stability and reliability. The hybrid PV plant model in this FOA topic would operate the plant as a single, flexible generating resource. This topic addresses technological challenges both within a hybrid PV plant and in coordination with multiple hybrid PV plants.

The hybrid plant concept has been adopted by many industries worldwide, from few megawatts (MW) in size to several hundred MW.[110] In a September 2019 workshop[111] organized by the North American Generator Forum, the North American Electric Reliability Corporation, and Energy Systems Integration Group, electric industry representatives discussed the advantages of hybrid plants. One of the most common types of hybrid plant is solar-plus-storage. In 2016, SETO ran the Sustainable and Holistic Integration of Energy Storage (SHINES) funding program, which focused exclusively on connecting solar power to storage. The solutions developed under this program incorporated dynamic load management, advanced forecasting techniques, utility communication and control systems, and smart buildings and smart appliances to work seamlessly to meet both consumer needs and the demands of the electricity grid at lowest cost. However, from a grid operation perspective, these early solar-plus-storage hybrid plants still operate with limited flexibility and limited market participation.

Key technological challenges that remain for hybrid PV plants include providing enhanced grid services, flexibility, AC/DC coupling, coordinated control, and emerging grid-forming capabilities, to name a few. This topic specifically looks at advancing hybrid PV plant technologies to enable greater flexibility and value for the bulk grid.

The scope of hybrid plant research for this FOA is organized into two research areas:

1. Internal hybrid plant design and control
2. Control and coordination among hybrid plants

Projects may address one or both of these research areas. Successful projects will create and field-test a suite of tools, software, and firmware that enhance the functionality of hybrid PV plants so that they may be grid forming and flexible in generation. The first area of research is focused on the design and control of a single hybrid PV plant with generation capacity greater than 20 MW. While there's been progress in developing hierarchical controls and cost optimization of resources within a hybrid plant, enhanced

[110] 5th International Hybrid Power Systems Workshop: http://hybridpowersystems.org/

[111] NERC/NAGF/ESIG Battery Storage, Hybrid Resources, Frequency Response and Grid Services Workshop: https://www.esig.energy/event/nerc-nagf-esig-battery-storage-hybrid-resources-frequency-response-and-grid-services-workshop/

flexibility tools are still limited. As an example, current state of the art is restricted to grid-following hybrid plants. These plants cannot provide a voltage source at the point of common coupling, which limits their ability to offer enhanced grid stability and grid services. Providing enhanced grid-forming controls[112] within the hybrid plant would enable the plant to jumpstart the grid when it is down, stabilize the grid under low inertia, and provide voltage and frequency regulation. The topics of interest for internal hybrid PV plant design and control include:

- Novel optimization approaches within a hybrid plant to holistically optimize for cost, efficiency, reliability, and performance among multiple generating resources
- Advanced grid-forming controls, including each inverter based resource (IBR) separately within the hybrid plant, if AC-coupled
- Provision of enhanced grid services, such as optimal dispatch, flexible generation, predictable output, enhanced inertia control, and other services that were not previously possible with individual plants
- Novel AC and/or DC coupling of different IBR within a hybrid plant for improved power conversion efficiency
- Integrating controls among multiple IBR, which may include novel combinations of wind, solar, fuel cells, batteries, supercapacitors, and other IBR
- Enhanced accuracy in forecasting internal hybrid-plant output, which will enable high confidence in market participation by the plant operator

The second area of research is control and coordination between multiple hybrid PV plants. Current state of the art has focused on one hybrid plant, but there are opportunities for a combination of hybrid plants to improve the reliability of the power grid when they are co-managed inside the same balancing area but not necessarily co-located. The topics of interest for this area of research include:

- Steady-state and dynamic modeling of hybrid plants with grid-forming capabilities at various time scales
- Enhanced stability for the overall bulk grid, contributed by a set of hybrid plants
- Grid-forming and frequency control by a set of hybrid plants
- Other novel control and coordination strategies among hybrid plants to provide enhanced flexibility

It is important to address the economic considerations so that hybrid PV plants continue to be relevant. The research topics can be supplemented with economic considerations, with participation by plant owners, operators, utilities and ISOs, which include:

- Reduction of capital expenditures and O&M costs
- LCOE calculations and reduction methods
- Ability for enhanced market participation

[112] J. Matevosyan, et al. "Grid-Forming Inverters: Are They the Key for High Renewable Penetration?" *IEEE Power and Energy Magazine*, vol. 17, no. 6, pp. 89-98, Nov-Dec 2019.

Performance Metrics for Topic Area 5.3

- Plant design and operation should be in alignment with North American Electric Reliability Corporation (NERC) reliability standards.[113] Innovative capabilities for grid forming or other enhanced grid services should inform the IEEE P2800 standard development[114] via public reports, testing outcomes, or other disseminated deliverables that industry can use to advise the proposed standard.
- Applicants are encouraged to develop metrics for plant flexibility.
- Individual resources within a hybrid plant should be mostly co-located and connected at a single point of common coupling or interconnection with the bulk grid.
- Each hybrid plant should be at least 20 MW due to the topic focus on bulk grid integration.
- For plants with multiple IBR, each IBR within the hybrid plant must provide grid-forming controls if AC-coupled, including at the point of common coupling to the bulk grid.
- Each hybrid plant should provide higher reactive-power capability, with a power factor ranging from ± 0.75.
- Each hybrid plant should provide black-start resources when in need and form the grid in less than one second.
- Each hybrid plant should accurately follow the Automatic Generation Control (AGC) signal.
- Hybrid plant(s) should enhance dynamic transient stability under fault conditions.
- Hybrid plant(s) should provide primary and secondary frequency control.
- Field validation of the hybrid PV plant is expected at a minimum of 1 MW. Applicants may retrofit existing PV plants or use large-scale testing facilities or other means to field validate at 1MW. Under this topic area, DOE will not fund applicants to design or build hybrid PV plants.
- Applicants should prove scalability of algorithms to 20 MW or higher, in a controlled environment or lab simulations.

Applications Specifically Not of Interest

Applications will be deemed nonresponsive and declined without external merit review if they:

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[113] North American Electric Reliability Corporation: https://www.nerc.com/pa/Stand/Pages/ReliabilityStandards.aspx

[114] Institute of Electrical and Electronics Engineers (IEEE) - P2800 - Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems: https://standards.ieee.org/project/2800.html

- Look only at economic considerations
- Propose engineering designs or construction of a hybrid PV plant
- Propose control and coordination of hybrid PV plants smaller than 20 MW, as per the Federal Energy Regulatory Commission Small Generator Interconnection Agreement[115]
- Concentrate on off-grid and backup hybrid plants
- Propose extensive standards development

vi. Topic Area 6: Solar and Agriculture: System Design, Value Frameworks, and Impacts Analysis

This topic area will build upon and expand ongoing SETO projects related to the co-location of solar and agriculture by developing technology, evaluating practices to date, and conducting research and analysis that enable farmers, ranchers, and other agricultural enterprises to gain value from solar technologies while maintaining availability of land for agricultural purposes. The goal is to facilitate and expand the co-location of solar and agricultural activities where it is beneficial to both industries and to the local community. For this topic, co-location is defined as agricultural production (i.e., crop or livestock production, or pollinator habitat) underneath solar panels and/or in adjacent zones around the solar panels.

Background

Ground-mounted solar PV deployment is projected to increase from 32 GW of installed capacity[116] to 92 GW by 2030,[117] which is estimated to require less than 0.1% of the land in the contiguous U.S.[118] Although the land requirements are a small percentage of the country, the growth in ground-mounted solar can create local land-use competition with agricultural land. The co-location of solar PV and agriculture could provide agricultural enterprises with diversified revenue sources and ecological benefits, while reducing land-use competition and siting restrictions.[119] Current system designs and business practices, however, are not optimized to enable simultaneous land use for multiple industries.

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[115] Federal Energy Regulatory Commission. https://www.ferc.gov/industries/electric/indus-act/gi/small-gen.asp

[116] As of August 2019: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_01_a

[117] See Table 16: https://www.eia.gov/outlooks/aeo/tables_ref.php

[118] Land-use percentage based on 181 GW of PV and 28 GW of CSP: https://publications.anl.gov/anlpubs/2016/10/130700.pdf

[119] *Agrivoltaics Provide Mutual Benefits Across the Food–Energy–Water Nexus in Drylands*. Barron-Gafford, G.A., Pavao-Zuckerman, M.A., Minor, R.L. et al. *Nature Sustainability* 2, 848–855 (2019). https://www.researchgate.net/profile/Greg_Barron-Gafford/publication/335583033_Agrivoltaics_provide_mutual_benefits_across_the_food-energy-water_nexus_in_drylands/links/5da87eda4585159bc3d5a0e7/Agrivoltaics-provide-mutual-benefits-across-the-food-energy-water-nexus-in-drylands.pdf?origin=publication_detail