DESIGNING WIND AND SOLAR POWER PURCHASE AGREEMENTS TO SUPPORT GRID INTEGRATION

Flexibility and grid reliability are important considerations for power systems pursuing higher levels of VRE integration. Electric utilities can facilitate wind and solar generators to contribute to these needs by integrating relevant provisions in renewable energy PPAs. *Photo from Alamy Stock Photo*

Many electric utilities around the world use power purchase agreements (PPAs) to procure variable renewable energy (VRE) from independent power producers. Under a PPA, an electricity buyer (utility) enters into a long-term contract with a wind or solar power plant to purchase typically 100% of the facility's electricity generation.

A PPA between an electric utility and a VRE generator establishes all the contractual aspects of the sale of electricity, including the electricity price, the contract term (typically 20+ years), the legal obligations of all parties, and the interconnection and operating requirements (or references to associated documents).

> Modern large-scale wind and solar systems are capable of enhancing grid stability and can be a source of power system flexibility, a key attribute of power systems with high penetrations of VRE.[1]

Typically, an electric utility expresses interest and outlines criteria for a PPA through a competitive solicitation, or a request for proposals (RFP). In some cases, an RFP includes a model PPA, or template, which includes project parameters that developers use to determine the ultimate bid price.

KEY PPA TERMS

Automatic generation control (AGC): A system to remotely and automatically adjust the output from a generator based on load and grid frequency.

Curtailment: The practice of temporarily decreasing electricity supply from a VRE generator below what it could potentially produce from available VRE resources.

Interconnection agreement (IA): A contractual agreement between an electricity seller, transmission line owner, and system operator for the purpose of interconnecting a generating unit to the transmission network. An IA establishes operational requirements for generators interconnecting to the power system.

Park potential: The total available energy output from a VRE generator based on ambient VRE resources.

Supervisory control and data acquisition (SCADA): An automated information and data acquisition system found in power plants and other industrial facilities that enables remote monitoring and control of complex energy systems by electric utilities.

INCORPORATING FLEXIBILITY CONSIDERATIONS IN PPAs

In many jurisdictions, grid codes inform an **interconnection agreement** (IA) between the VRE generator, transmission system operator, and/or transmission system owner. The IA can include requirements for wind and solar generators to provide grid services, both during normal operations and disturbances (e.g., unplanned generator or transmission line outages). However, in a PPA, electric utilities can include operational requirements above and beyond those specified in an IA. PPAs may also include mechanisms for VRE generators to receive financial compensation for their contributions to system reliability and flexibility.

To enable VRE generators to contribute to grid reliability, PPAs may include requirements such as:

- *Frequency range*, which is a lower and upper bound for operational frequency of the VRE generator, typically expressed in hertz (Hz). While VRE generators may need to disconnect from the grid during severe frequency deviations to protect equipment, a predefined frequency range ensures that VRE generators do not disconnect during normal frequency variations of the grid. Keeping renewable energy generators connected within a reasonable frequency range contributes to grid reliability.
- *Voltage limit*, which specifies the operational voltage of the VRE generator, expressed in kilovolts, and establishes an acceptable percentage deviation (e.g., maximum allowable voltage fluctuation of ±2%). Voltage regulators, commonly found at modern VRE power plants, contribute to grid stability by maintaining a constant voltage level.
- *Power factor,* which is the ratio of real power to apparent power and indicates the effect of a plant's output on overall system efficiency. Power factor requirements can enable modern VRE generators to operate in various modes (power factor, reactive power, or voltage control) that can influence the overall system efficiency. System operators can choose a facility's mode based on local grid needs.
- *Voltage ride-through*, which requires both wind and solar generators to stay online during system voltage disturbances. Ride-through can prevent a cascading failure of electricity supply by enabling VRE generators to remain connected and operational during periods of severe under- or over-voltage.

1 See the "*Sources of Operational Flexibility*" fact sheet on GreeningTheGrid.org to learn more about flexibility in electric power systems.

PPAs can also incorporate additional flexibility considerations, such as:

- *Advanced* ***supervisory control and data acquisition*** *(SCADA) systems for monitoring and control*. While most modern VRE generators employ SCADA systems, a PPA can require additional SCADA parameters to significantly improve the system operator's ability to monitor VRE plant performance and respond to system conditions. For example, outage data for individual wind turbines or solar arrays and information about ***park potential*** can enable system operators to optimally dispatch reserves and issue ***curtailment*** orders as needed to maintain grid stability.
- *Data to facilitate VRE forecasting*. VRE forecasting is a cost-effective way to optimize power system flexibility. For decentralized forecasting, a PPA can include provisions that require the VRE generator to provide day-ahead generation forecasts with time intervals close or equal to the system operator's dispatch interval (e.g., hourly or 15 minutes). For centralized VRE forecasting, data to collect from generators include specific geographic location, installed capacity, historic hourly (or higher resolution) generation, and detailed meteorological data. More advanced forecasting systems may benefit from collecting additional information on real-time generation, wind turbine or solar array availability, and park potential.[2]
- *Ancillary services.* PPAs can include opportunities for VRE generators to provide grid services through advanced turbine and inverter capabilities, including synthetic inertial response, primary frequency response, voltage control, and ramp limitations. Including these provisions as part of a PPA can encourage VRE generators to provide ancillary services in jurisdictions where market incentives for these services are not available or adequate.
- ***Automatic generation control*** *(AGC) capabilities*. Integrating VRE generators into the power system's AGC fleet can enable system operators to utilize VRE generators for load following and secondary frequency response.

2 See the *"Forecasting Wind and Solar Generation"* fact sheet on GreeningTheGrid.org to learn more about VRE forecasting to improve system operations.

CURTAILMENT RULES AND COMPENSATION

System operators may be required to curtail VRE generators due to transmission constraints, system balancing needs, and/or to address voltage, frequency, and stability issues [1].

Curtailment can impact the financial viability of VRE generators because it decreases the revenue stream, which is paid by the kilowatt-hour. A well-designed PPA can enable system operators to strategically curtail VRE while mitigating negative financial impacts for VRE generators. In general, there are two categories of curtailment, which a PPA can define.

- *Compensable curtailment:* Curtailment for which the electricity buyer must compensate the VRE generator, measured as potential generation less actual electricity delivered and any non-compensable curtailment.
- *Non-compensable curtailment*: Curtailment for which no payment is due to the VRE generator. This can include curtailment for emergency conditions (e.g., transmission system outages), interconnection limits, or plant maintenance outages. Some PPAs also include provisions for allowable curtailment, which is a bank of otherwise compensable curtailment, in units of energy or hours of outage, that may be credited by the buyer without payment.

BENEFITS OF FLEXIBILITY-INFUSED PPAs

PPAs that include measures to enhance the ability of wind and solar generators to contribute to grid reliability and flexibility can significantly contribute to VRE deployment goals and greenhouse gas reduction targets. PPAs represent one of many institutional tools that power systems can use to improve grid services from VRE generators, particularly in jurisdictions where IA requirements do not reflect the state-of-the-art wind or solar technology and power system operational practices. Establishing financial remuneration parameters within the PPA can incentivize VRE generators to provide a broad spectrum of flexibility and reliability services to the grid.

EXAMPLES OF GRID-CONSCIOUS PPAs

Northern States Power Company. (2013). Xcel Energy's Model Wind PPA

- Xcel Energy, an investor-owned electric utility in the United States, provides a Model Wind PPA that includes requirements for wind generators to share relevant forecasting data with the system operator and integrate AGC capability and establishes parameters for curtailment payments.

Public-Private Partnership in Infrastructure Resource Center. (2006). Power Purchase Agreement Produced for Pakistan.

- Developed by the World Bank Public-Private Partnership in Infrastructure Resource Center, this sample wind power PPA includes opportunities to specify power factor, frequency range, and voltage regulation parameters for wind power generators in Pakistan.

REFERENCES

[1] Bird, Lori, Jaquelin Cochran, and Xi Wang. (2014). *Wind and Solar Energy Curtailment: Experience and Practices in the United States.* NREL/TP-6A20-60983.

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Greening the Grid provides technical assistance to energy system planners, regulators, and grid operators to overcome challenges associated with integrating variable renewable energy into the grid.

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