GRID INTEGRATION STUDIES: DATA REQUIREMENTS

Grid integration studies require a variety of inputs, including data on renewable resource availability. *Photo by Warren Gretz, NREL 00215*

A grid integration study is an analytical framework used to evaluate a power system with high penetration levels of variable renewable energy (VRE). A grid integration study simulates the operation of the power system under different VRE scenarios, identifying reliability constraints and evaluating the cost of actions to alleviate those constraints. These VRE scenarios establish where, how much, and over what timeframe to build generation and transmission capacity, ideally capturing the spatial diversity benefits of wind and solar resources. The results help build confidence among policymakers, system operators, and investors to move forward with plans to increase the amount of VRE on the grid. High quality data are critical to robust and reliable grid integration studies.

WHAT KIND OF DATA INFORM EFFECTIVE GRID INTEGRATION STUDIES?

Grid integration studies usually include several interrelated analyses (see Table 1). Input data for integration studies may include the following:

Renewable energy resource data provide the basis for estimating solar and wind generation potential, characterizing variability and uncertainty, and identifying the best locations for new renewable energy generators. Resource data describe the quantity and type of fuel (e.g., solar radiation and wind) available at a specific location and time to power renewable energy systems. Data sources include direct measurements from existing solar or wind generators, meteorological towers, and other field-based devices, or simulations based on satellite measurements (for solar) and mesoscale numerical weather prediction models (for wind) [1]. Wherever possible, modeled resource data should be calibrated using historic patterns and validated using on-the-ground measurements [2]. At a minimum, integration studies require one year of resource data for locations under consideration for renewable energy generation; multiple years of historical data will better support estimation of inter-annual variability and capture extreme events.

Load data are essential for understanding when and where electricity supply is needed within the power system and how quickly electricity demand changes. Load data provide information about the magnitude, location, and timing of electricity demand. Like solar and wind resource data, load data can be measured directly or simulated using models. In either case, load data is most useful when it is time *synchronous* with wind and solar data: the time-steps (year, day, hour, etc.) should align chronologically among the datasets so that planners can understand correlations and major trends with respect to the variability and magnitude of both electricity demand and VRE resource availability.

Forecast and forecast error data, allow power system planners to estimate generation and reserve requirements and are a key input to unit commitment and dispatch models [1,3]. Forecast data predict future electricity demand and renewable energy resource availability over a certain time horizon (e.g., hour- or day-ahead). To allow power system models to mimic the uncertainty present in power system operations, grid integration studies also require data on operational forecast errors, e.g., the difference between actual and predicted wind and solar resource and/or demand on an hourly or shorter timescale. Operational forecast errors can be simulated or derived from actual historic forecast error

IMPROVING DATA

The following measures can help improve input data in many power systems:

- Include requirements for independent power producers and self-generators to provide data on forecasts, real-time generation, meteorological conditions, forced outages, etc., into interconnection and power purchase agreements. This practice provides data to inform centralized forecasting, grid integration scenario development, and resource modeling by grid operators.
- Archive operational forecast errors for demand and VRE resources into a centralized database.
- Arrange nondisclosure agreements or other mechanisms to use proprietary data (e.g., resource data measured by project developers and power-plant specific characteristics and emission rates) for grid integration model development and calibration.
- Collect and archive sub-hourly data where possible.
- Monitor and incorporate best practices in forecasting methodologies. The international Utility Variable-Generation Integration Group (UVIG) hosts an annual forecasting workshop that can be a source of information on the evolution of solar and wind forecast methodologies.

statistics. Forecast methodologies are evolving and accuracy improving, so integration studies with long analysis horizons (e.g., 20–30 years) should assume higher forecasting accuracy over time [2].

Wind and solar equipment characteristics are used in system stability analyses to determine how solar and wind generation facilities interact with the grid, and the extent to which they supply services such as voltage and frequency stability [2]. Data on equipment characteristics describe system specifications and control features of wind turbines (e.g., fault ride through, active power frequency response, inertial response, and reactive power capabilities) and solar power systems (e.g., PV panel and inverter efficiency, orientation, and fault ride through and reactive power capabilities). If possible, studies should incorporate the actual characteristics of the wind turbine and solar PV technologies under consideration for deployment, but in the absence of technology-specific characteristics, generic specifications are sufficient.

Conventional Fleet Characteristics are critical to understanding operational costs as well as the flexibility of the system to handle significant VRE penetration. Input data on the conventional fleet capture location, fuel type, and performance factors such as ramp rates, minimum output levels, start-up time, heat rates as a function of load, active and reactive power capabilities, and outage rates. Because the integration of VRE to the power system may require increased cycling of fossil-fueled plants, data on ramping-related maintenance needs and costs; numbers and costs of hot, warm, and cold starts; and emission factors during ramping are also relevant. Projections of future fuel prices and efficiencies for conventional sources also inform grid integration scenarios. Data sources for conventional fleet characteristics include manufacturers, utilities, and, in some cases, transmission and system operators.

For hydropower plants, data needs include storage levels, water inflow, and non-power constraints to outflow (e.g., ecological and downstream irrigation impacts) [4].

Demand response and storage characteristics, enable grid integration analyses to reflect the potential for these resources to provide flexibility. Data needs vary according to the different demand response and storage mechanisms under consideration, but could include the timing, magnitude, and duration of demand response measures; types, capacities, charging (and discharge) times, and efficiency rates of electricity storage technologies; and operational practices and costs associated with both types of interventions. Possible data sources for demand response and storage costs and characteristics are discussed in [2].

Analysis/Data type	Capacity value calculations	Unit commitment and dispatch simulations	Load flow analyses	System stability studies
VRE resource	✓	✓	✓	✓
Load	✓	✓	✓	✓
Forecast & forecast errors		✓		
VRE equipment characteristics	✓	✓	✓	✓
Conventional fleet characteristics	✓ [Capacity and forced outage rates]	✓	✓	✓
Demand response & storage characteristics	✓ [If operational practices are known]	✓	✓	✓
Transmission grid	✓	✓	✓	✓

Table 1. Common grid integration analyses and their data requirements. (Adapted from [2])

Transmission data are used to determine power flows under various VRE scenarios. Transmission data depict the spatial distribution of the existing and/or planned network and provide information on rated line capacities, impedance, and line ratings. The number, location, and characteristics of interconnections to neighboring grids and control structures such as transformers are also useful in various grid integration analyses [2]. Sources of transmission data include transmission system operators, transmission reliability organizations, and utilities.

REFERENCES

[1] Milligan, M., Ela, E., Lew, D., et al. (2012). “Assessment of Simulated Wind Data Requirements for Wind Integration Studies.” *IEEE Transactions on Sustainable Energy*, Vol. 3(4): 620-626.

[2] Holttinen, H., ed. (2013). *Expert Group Report on Recommended Practices: 16. Wind Integration Studies*. IEA Wind (Task 25).

[3] Forecasting publications from the National Renewable Energy Laboratory (NREL): *http://www.nrel.gov/electricity/transmission/forecasting.html.*

[4] Ibanez, I., Magee, T., Clement, M., et al. (2014). “Enhancing hydropower modeling in variable generation integration studies.” *Energy*, Vol. 74: 518-528.

For an example of a wind data set, see NREL’s “Western Wind Data Set” website at http://www.nrel.gov/electricity/transmission/western_wind_methodology.html.

For methods of developing sub-hourly solar data, see Hummon, M., Ibanez, E., Brinkman, G., and Lew, D. (2012). *Sub-Hour Solar Data for Power System Modeling from Static Spatial Variability Analysis*. NREL/CP-6A20-56204.

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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.

FOR MORE INFORMATION

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