Hybrid Utility-Scale PV-Wind Storage Plants for Dispatchability and Reliability Services

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Grid Integration Challenges for Variable Generation

- **Solutions**
  - Improved Market Design
  - Joint Market Operation
  - New Ancillary Service Markets
  - Transmission Expansion
  - Transmission Reinforcement
  - Advanced Network Management
  - Coal, CCGT, and Hydro Ramping
  - Balancing Areas Consolidation
  - Sub-hourly Dispatch and Scheduling
  - Improved Forecast
  - Grid Services by Renewables
  - New Grid Codes
  - RE Curtailment
  - Demand Response
  - Energy Storage
  - Hybrid Renewable Plants

- **Markets**
- **Grids**
- **Flexibility**
- **Operation**
- **Load**
- **Storage**

- **Variability**
- **Uncertainty**
- **Location-Specificity**
- **Non-Synchronous Nature**
- **Low Capacity Factor**

- **Dispatchability**
- **Flexibility**
- **Reliability**
- **Renewable Integration**
- **Transmission Services**
- **Distribution Services**
- **End-user Services**
- **Reliability and Resilience Services**
- **Islands and Microgrids**
- **Technology Hybridization**
- **Power Quality**
Thinking Beyond Conventional Variable Generation Plants

- New source of **dispatchability, flexibility, and reliability**
- Potential to disrupt the market for traditional single-technology players
- Potential transformational impacts on global renewable energy markets.
Ingredients of the Hybridization Recipe

Bringing “taller” economic wind power to areas rich in solar resource

- Unlocking wind energy’s potential across an additional 700,000 miles$^2$
- Potential for vast expansion of the geographic areas where the complementary nature between economic solar and wind resources can exist
- Geographical overlap between solar resource-rich areas and new land areas that can achieve a minimum 30% net capacity factor for wind generation at 140-m hub height.
GE–NREL Concept

- Benefits?
- Use cases?
- How to size?
- How to control?
NREL NWTC Test Site

- Current total of more than 12 MW variable renewable generation
- 7-MVA controllable grid interface (CGI)
- Multi-MW energy storage test facility
- 2.5-MW and 5-MW dynamometers (industrial motor drives)
- 13.2-kV medium-voltage grid.
NWTC Controllable Grid Platform

NWTC Wind Turbines
- Alstom 3 MW
- GE 1.5 MW
- Gamesa 2 MW
- Siemens 2.3 MW

SunEdison
- 1 MW PV Array

First Solar
- 430 kW PV array

GE 1.25 MW / 1.25 MWh BESS

1 MW / 1 MWh BESS

Controllable Grid Interface (CGI) for Grid and Fault Simulation (7 MVA continuous / 40 MVA s.c.)

Regular grid, Xcel Bus

Controlled grid, CGI Bus

Switchgear Building

Xcel Substation

13.2 kV tie-line

115 kV

Aerial view of the site
Controllable Grid Interface

**Power rating**
- 7-MVA continuous
- 39-MVA short-circuit capacity (for 2 s)
- 4-wire, 13.2 kV.

**Possible test articles**
- Wind turbine types 1, 2, 3, and 4
- Capable of fault testing largest Type 3 wind turbines
- PV inverters, energy storage systems
- Conventional generators
- Combinations of technologies.

**Voltage control (no load THD <3%)**
- Balanced and unbalanced voltage fault conditions (LVTY, ZVRT and 130% HVRT)—independent voltage control for each phase on 13.2-kV terminals
- Response time: 1 ms (from full voltage to zero—or from zero back to full voltage)
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0–10 Hz)—SSR conditions
- Programmable impedance (strong and weak grids)
- Programmable distortions (lower harmonics 3, 5, 7)

**Frequency control**
- Fast output frequency control (3 Hz/s) within range of 45–65 Hz
- 50/60-Hz operation
- Can simulate frequency conditions for any type of power system
- PHIL capable (coupled with RTDS, Opal-RT, etc.)
Hybrid Systems Test and Control Validation Platform

Real-Time RODEO tool (Revenue, Operation, and Device Optimization model)—5-min time step

Optimized dispatch
Island Power System Model in RTDS (IEEE 9 Busses)

- Hybrid plant voltage FRT test
- Extreme wind ramps
- 30–40-ms response time
- BESS response times

Diagram showing:
- Load 1, Load 2, Load 3
- G1, 80 MVA
- G4, 30 MVA
- G3, 40 MVA
- G5, 30 MVA
- 230 kV grid
- 1.5MW PV
- 2.3 MW
- 1MW/1MWh BESS
- Ground Fault Emulation Logic
- CGI POI
Hybrid Plant P-Q Capability

Hybrid plant: 1.5-MW PV, 1.5-MW wind, 1-MW BESS—strong grid

BESS only—strong grid
BESS P-Q Capability

Strong grid

20% line impedance
Dispatchable Hybrid Power Plant

Main control panel

Reduced ramps

No curtailment
Examples of Dispatchable Operation Demo

Dispatchable wind power plant

\[ P_{bess}(t) = P_0 - 2H \frac{df}{dt} - \frac{\Delta f}{droop} + K_P \cdot ACE \]
BESS Emulating Response of Rotating Generator

\[ \Delta P = -2H \cdot f \cdot \frac{df}{dt} \]

- BESS can operate with programmable H.
- Different shapes of inertial response can be implemented.
- ROCCF deadbands are implemented to reduce impacts on battery life.

Inertia-like response
BESS Providing PFR

BESS providing 3% droop while charging

3% droop response
BESS Participating in AGC

- PSCO historic area control error (ACE) time series (updated every 4 s)
- ACE is scaled down to match BESS rating.
POD Controls by BESS

Demonstration of power oscillations damping control by BESS

\[ P(t) = P_m e^{-\frac{t}{\tau}} \sin (2\pi ft + \varphi) \]
Emulated Inertial Responses of Individual Wind Turbines in a 150-MW Wind Power Plant

Frequency event emulated by CGI—1 Hz/s ROCOF

Results of 65 inertial response test by G 1.5 MW wind turbine generator
Aggregate Inertial Response of Large Wind Power Plant

BESS Enhancing Inertial Response by Wind Power

- Inertial response by wind power
- Total response (Wind + BESS)
- Energy provided by BESS
- Wind only response
- Beginning of frequency event

18 turbines operating at nominal power

Power (MW) vs. Time (sec)

Loss: ΔE = -251 MWs
Services by Multi-Technology (Hybrid) Power Plants

- Dispatchable renewable plant operation
  - Long-term and short-term production forecasts
  - Capability to bid into day-ahead and real-time energy markets like conventional generation
- Ramp limiting, variability smoothing, cloud-impact mitigation
- Provision of spinning reserve
- AGC functionality
- Primary frequency response (programmable droop control)
- Fast frequency response (FFR)
- Inertial response:
  - Programmable synthetic inertia for a wide range of H constants emulated by BESS
  - Selective inertial response strategies by wind turbines
- Reactive power/voltage control
- Black start by BESS
- Advanced controls: power system oscillations damping
- Stacked services
- Plant electric loss reduction, AEP increase
- Selective plant configuration for BESS: ability to serve a whole wind power plant, or selected rows/turbines
- Battery SOC management
- Optimization model-predictive control strategies – work in progress
- Revenue optimization – work in progress
Thank you

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