An Integrated Platform for Wind Plant Operations: From Atmosphere to Electrons to the Grid

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Background: Wind Plant Operations

Example model

Source: https://www.spp.org/documents/28867/energymeteo_spp_qa.pdf

What can affect delivery?

Weather uncertainty

Wake dynamics in the example model are ignored

What is the impact of deviation?

- Balancing market settlements
- Over-/under-generation penalties
- Disqualification if behavior persists.

Bids for energy and ancillary services

Awards for energy and ancillary services

Accounts for congestion
Background: Status Quo and Forward-Looking Scenarios

Status quo:
- “Only a handful of wind generators have opted to qualify for the ancillary services provision in ERCOT, and their participation in regulation markets is currently minimal (Matevosjana 2018)” [1].
- “Risk is higher for generators selling day-ahead...the potential of incurring a forced outage and having to buy back energy at real-time prices” [2].

Forward-looking scenarios:
- Prices for ancillary services might increase under high variable renewable energy scenarios [3].

Figure 1. Ancillary service prices under varying renewable penetration scenarios [3]

Research Question

Can we develop a platform that integrates:
- **Forecasting** tools to account for weather uncertainty
- With **aerodynamic models** to account for wake dynamics
- And **economic** models to account for impact of deviations

To advise on **bidding and operation** for a “price-maker” wind power plant so that its **value** streams for energy and ancillary services increase?
The A2E2G will be a holistic Python tool with two modules that can be run in parallel and possibly interact to:
• Advise on market participation
• Control and operate a wind power plant in real time.

**Advise on market participation:**

- **Forecasting of weather variables**
  - *Time series:* Wind speed, Wind direction, Turbulence intensity
- **FLORIS [4]: Turbine & wake dynamics**
  - *Time series:* Wind speed, Wind direction, Turbulence intensity
- **Module for advisory bidding of wind plant**
  - *Time series:* Forecasted power production and imbalance prices

**Output:** Advisory bidding decisions

**Real-time control and operation:**

- **Most recent forecast and actuals**
  - *Time series:* Wind speed, Wind direction, Turbulence intensity
- **FLORIS [4]: Turbine & wake dynamics**
  - *Time series:* Power limit, Yaw set points
- **Output:** Control signal

A2E2G Integrated Platform: Novel Features

A2E2G integrated platform:

- Forecasting of weather variables
- Wind plant modeling
- Module for advisory bidding of wind plant

Modeling of wake dynamics to:
- Forecast probability distribution functions of wind power dynamically
- Capture the value of wake steering for real-time controls.

Bid curves that consider:
- Probabilistic forecasts for wind power
- Expected imbalance costs
- Compliance performance targets for ancillary services.
A2E2G Integrated Platform: Forecasting and Wake Steering

- Current focus: 1) Regulation [5]–[7] 2) Day-ahead forecasting
Note: We plan to expand to other horizons and products.


Bidding Module: Design

Wind power uncertainty

Imbalance price uncertainty

Penalties for over-/undergeneration

Compliance qualification targets

Examples for compliance qualification targets

Source: [9]

(b) An IRR or IRR Group must have a GREDP less than the greater of X% or Y MW for 85% of the five-minute clock intervals in the month during which the Resource or a member IRR of an IRR Group was carrying an Ancillary Service Resource Responsibility.

Source: [10]

When the historical performance score falls below 40 percent by signal type, PJM will notify the resource owner and the resource will no longer be eligible to offer into the regulation market for the applicable signal type.


**Example 1: Compliance qualification target**
A resource disqualifies from providing regulation when they deviate outside the tolerance window more than 15% of the time.

**Example 2: Imbalance price expectation [11]**
Assume that our imbalance price modeling suggests that the imbalance price will be $9,500/MWh.

Use probabilistic forecast

15th quantile

Price ($/MWh)

Wind output (MW)

0.15*9500 = 1,425

Price ($/MWh)

Wind output (MW)

Research Question

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**B** to advise on **bidding and operation** for a wind power plant so that its **value** streams for energy and ancillary services increase?
Performance of the A2E2G Integrated Platform: Use Case

A2E2G platform mode: day-ahead advice on market participation

Day-ahead market: ISO-operated

A2E2G platform mode: real-time advice on market participation

Real-time market: ISO-operated

Load frequency control (AGC)

A2E2G platform mode: actual control and operation
Performance of the A2E2G Integrated Platform: Testing

- **A2E2G platform mode: day-ahead advice on market participation**
  - Day-ahead market: ISO-operated (simulations)

- **A2E2G platform mode: real-time advice on market participation**
  - Real-time market: ISO-operated (simulations)

- **Load frequency control (AGC) (simulations)**
  - A2E2G platform mode: actual control and operation

We are conducting simulations to demonstrate the platform and its capabilities.
Simulations of day-ahead and real-time market and load frequency control

Starting Fall 2020: “Price-maker”

This presentation: Price-taker

Desktop analysis based on historical prices and regulation deployment from ERCOT

Market simulations that endogenously consider updated wind bids

Demonstration of capability by estimating frequency and magnitude of deviations from independent system operator (ISO) signal

Demonstration of value through estimates of short-term revenues from market participation

Note: highly depends on market design
FLORIS: Module for forecasting of weather variables & wake dynamics
- Turbine & wake dynamics
- Module for advisory bidding of wind plant
- Energy and regulation awards
- Load frequency control
- Most recent forecast and actuals
- FLORIS: Wake steering
- Wind turbine controller

**Facilitation of market participation**

- LFC sends signals that are within the wind plant’s capability
- Wind plant can follow the grid signal almost perfectly
- FLORIS output (power and yaw) == input for turbine controller

**Real-time control and operation**

- Energy and regulation awards
- Load frequency control
- Wind turbine controller

**Figures and statistics on performance:** example with perfect foresight for a 3 by 3 wind farm with GE turbines at 1.5 MW
Example for Demonstration of Value: Design (1/4)

Wind plant short-term revenue from participation in energy and regulation markets

Hypothetical wind plant with capacity at 1/1000 system-wide ERCOT

Day-ahead wind power forecast
- Actual 5-minute data
- Day-ahead forecast (ERCOT)
- Day-of real-time prices
- Day-of real-time prices
- Empirical probability distribution function for same hour in 2019—worst case
- Price cap ($9,500/MWh)
- Price taker at $0/MWh in day-ahead

Forecast for imbalance prices
- For evaluation

Note: Same real-time prices used for evaluation
Example for Demonstration of Value: Limitations (2/4)

Revenue streams considered: (1) day-ahead energy and regulation, (2) real-time energy, (3) metered/deployment, (4) over-/undergeneration penalty

13-day study period because of data availability (We are working to extend it.)

One example for limitation by short study period

The 13-study period does not capture the tails, e.g., 3.4% of intervals have price >$50/MWh in study period vs. 4% in rolling year.
Example for Demonstration of Value: Discussion (3/4)

Wind plant short-term revenue from participation in markets

Upper bounds

Practical

Perfect foresight
Volumetric uncertainty
Naïve price forecast
Worst case price forecast
No price forecast

Average daily revenue ($/day) over 13-day study period in April 2020

- 1,000
1,000 2,000 3,000 4,000 5,000 6,000 7,000 8,000

Case to be facilitated by A2E2G platform—during limited study period:
• +3% short-term revenue
• Participation in energy and regulation markets.

The “worst-case price forecast” results in no participation in day-ahead.
During the limited study period, we observe how the A2E2G platform could facilitate participation in regulation products and capture some value for the wind plant from that participation (assuming it is valuable for the system).

Note: During the 13-day study period under the naïve price forecast case, regulation-up was provided only 1 hour in the day-ahead market.
Ongoing and Future Research

• The A2E2G platform could increase **value** streams for wind plants and/or lead to system benefits by accurately estimating their **capability** of providing energy and other products.

• The focus of our ongoing and future research is:
  • Testing with realistic configurations, e.g., Biglow Canyon Wind Farm in Oregon
  • Expanding A2E2G capabilities to:
    • Include improved probabilistic forecast that accounts for wake steering and estimations of price uncertainty that consider market interactions
    • Consider hybrid systems including solar and storage.
  • System-wide analysis to study:
    • **Forward-looking scenarios** with higher renewable penetrations and broad participation of renewables in ancillary services
    • System benefits from the use of A2E2G informed strategies.