U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

E06 - Atmosphere to Electrons to Grid (A2e2G)

Mitigate Market Barriers – Grid Integration

Dave Corbus, Jen King
NREL

3 August, 2021

FY21 Peer Review - Project Overview

Project Summary:

- The A2e2g project is a platform that integrates 1) forecasting tools to account for weather uncertainty with 2) aerodynamic models to account for wake dynamics and wind plant operation, and 3) economic models to advise on offering of energy and ancillary services and operation for a "price-bidder" wind power plant so that its value streams for energy and ancillary services can increase compared to current practice.
- The A2E2G platform is a holistic Python tool with two modules that can be run in parallel and interact to 1) advise on market participation and 2) control and operate a wind power plant in real time. In year one the focus was on wind plants without energy storage and regulation reserves.

Project Objective(s) 2019 (August) -2020:

- The purpose of the Atmosphere to Electrons to Grid (A2e2g) project is to design a wind plant control platform that merges forecasting tools with aerodynamic and economic models to maximize a wind plant's value streams for energy and ancillary services

Overall Project Objectives (life of project):

- The value proposition is that optimized wind plant performance leads to lower LCOE of wind energy and more reliable grid operation.
- The advancements made under the A2e2g project will enable the wind industry to provide plant controls that will equal or better conventional generators, especially when coupled with energy storage, and pave the way for grid operators to value wind plants for not only energy but grid services.

Project Start Year: FY19 (08/21)
Expected Completion Year: FY22
Total expected duration: 3 years

FY19 - FY20 Budget: $500,000

Key Project Personnel: Dave Corbus, Jennifer King, Elina Spyrou, Andrew Kumler, Christopher Bay, Sanjana Vijayshankar, Yingchen Zhang, Vahan Gevorgian

Key DOE Personnel: Jian Fu

Overview - What is A2e2g?

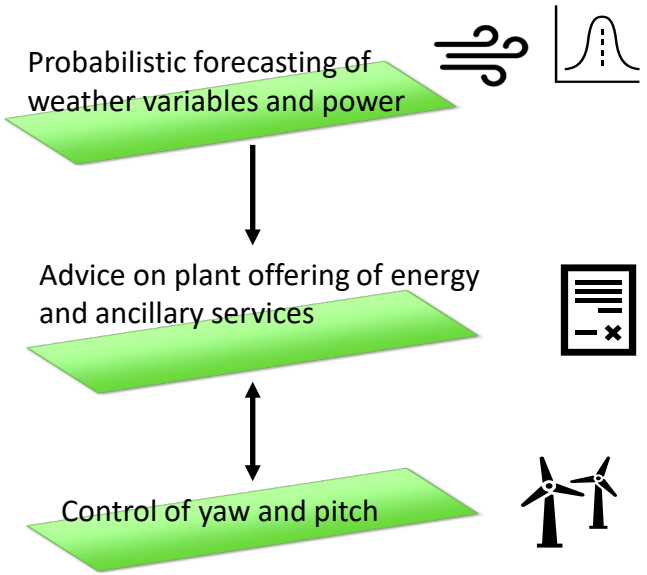
Platform that integrates:

- Forecasting tools to account for weather uncertainty
- With device-specific models e.g., aerodynamic models for wind plant wake dynamics
- And decision analysis frameworks that consider power system operator rules and account for trade-offs among plant's options for market participation in energy and grid services

And aims to increase the wind plant's (can include storage) value streams by

- advising on energy and ancillary service **offering** under uncertainty and
- **Controlling operations** to deliver contracted energy and ancillary services under variable conditions compared to current practice.

A2E2G integrated platform:



A2e2g Impact

1. **New technologies**

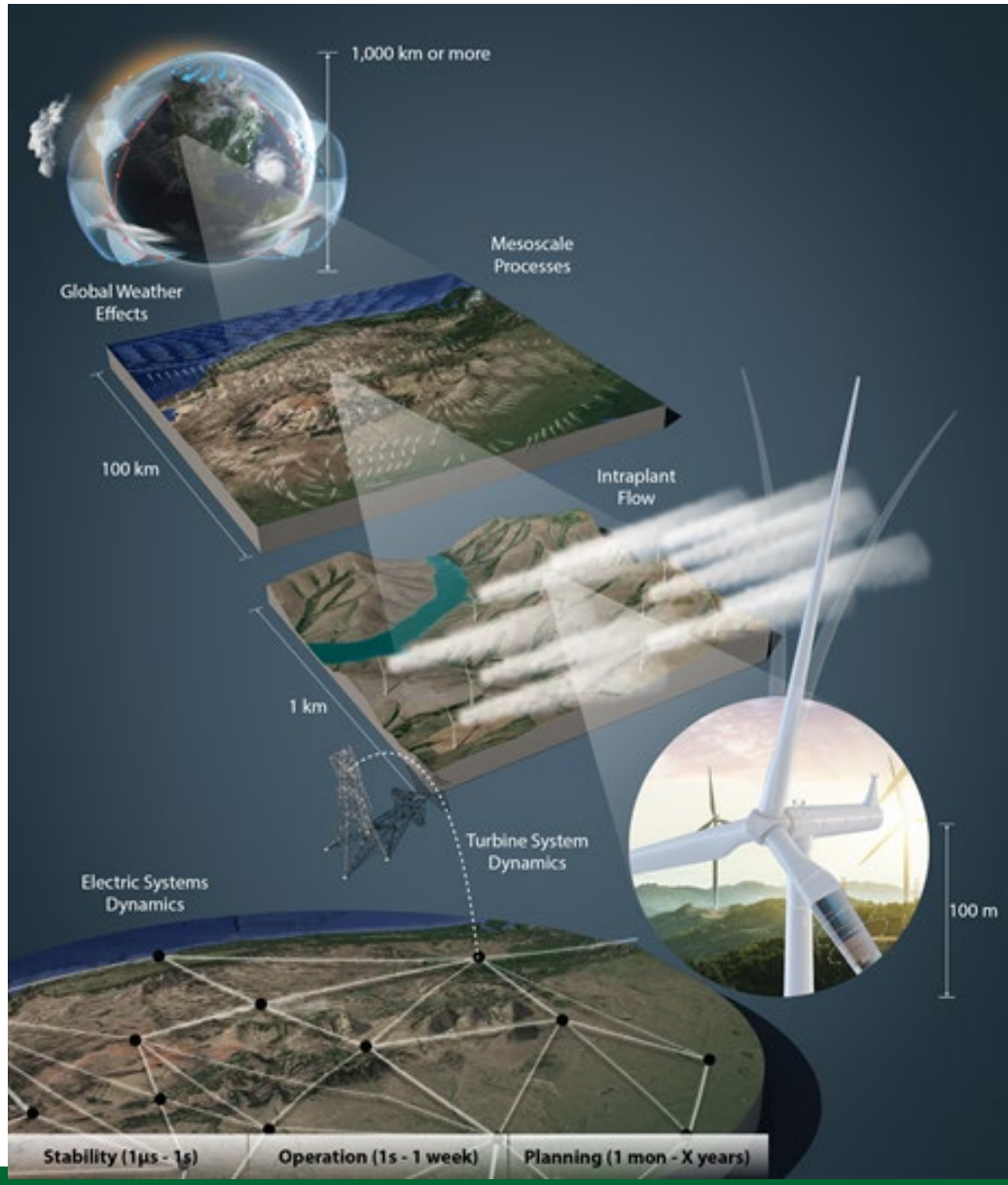
- Data- and physics-driven wind power probabilistic forecasting with high resolution and accuracy using advancements in wake dynamics modeling and neural networks
- Advanced wind plant power curve estimation including wake dynamics
- New analytical formulations for advisory offering by wind plants into regulation markets

2. **Improved wind plant benefits**

- Value both energy and grid services under uncertain and variable conditions
- Novel plant controls that will equal or better conventional generators, especially when coupled with energy storage

3. **Reliable grid operations**

Novel plant controls meet power system operator's performance targets



Performance – Scope, Schedule, & Progress

- All milestones were met on time and the go/no go was approved; key milestones include:
  - Summary of control modeling architecture that presents hierarchical control modeling, simulation, and test methodology for advanced A2e2g wind plant controller prototype
  - Demonstrate preliminary co-optimized wind turbine controller at Flatirons facility
  - Enhance the optimizer tool to consider regulation-related revenue streams, performance targets and settlement schemes for multiple US power system operators, uncertainty in wind output through ensemble-based probabilistic day-ahead forecast of power
- The research findings from year one of this project are that the A2E2G platform can increase the value streams for wind plants and lead to system benefits by accurately estimating their capability of providing energy and grid services
  - Simulations use one second wind plant time series data and historical ERCOT market prices
  - A2e2g prototype controller demonstrated at Flatirons with GE 1.5 turbine
- Publications
  - IEEE paper submitted 8/20 - Offering of Variable Resources in Regulation Markets with Performance Targets: An Analysis , E. Spyrou lead
  - Journal of Renewable and Sustainable Energy paper submitted 9/20 – Deep Reinforcement Learning for Automatic Generation Control of Wind Farms.
  - American Control Conference - Uncertainty-aware Deep Reinforcement Learning for Active Power Control of Wind Farms accepted 9/20, S. Vijayshankar lead,
  - Presentation on A2e2g at FERC technical conference; June 25, 2020; https://www.ferc.gov/sites/default/files/2020-06/H1-1_Spyrou_et_al.pdf

Performance – Control Framework Development

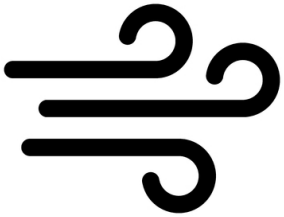
Market Participation

Predict wind conditions

Predict power output of wind farm

Bid into market

Market



Actual wind conditions and real-time forecasts/estimates

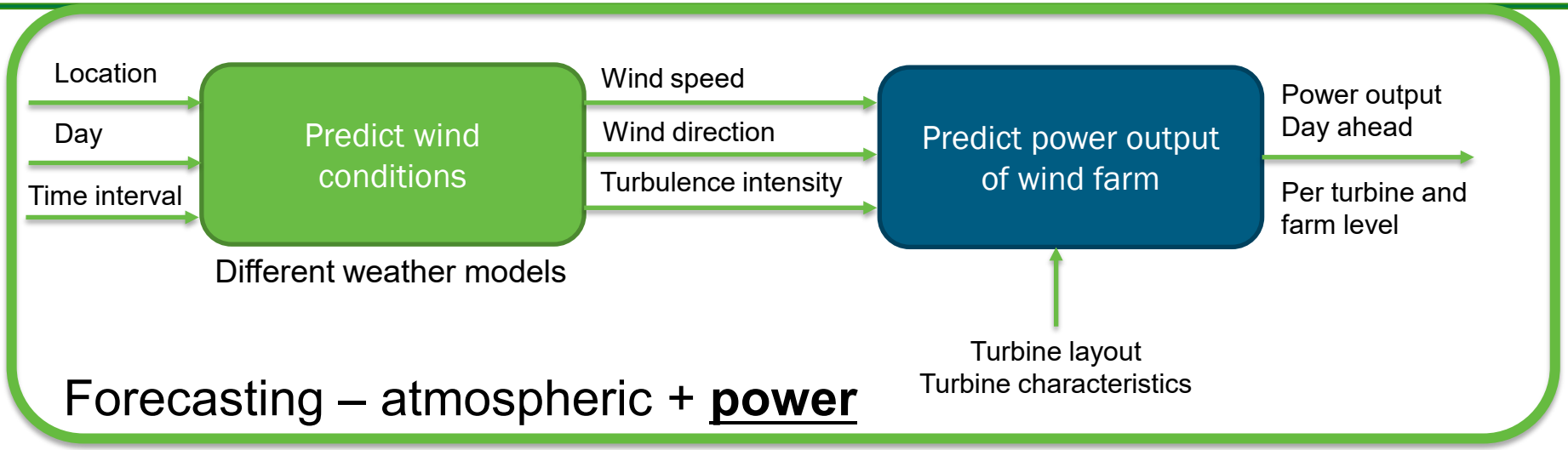
Decide control inputs for wind farm to get what grid needs

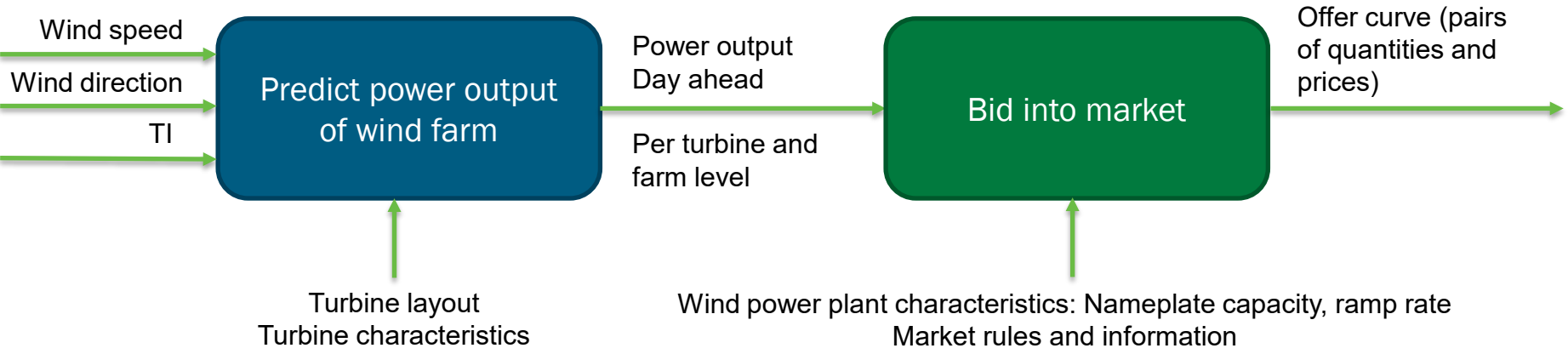
Load Frequency Control

Real-Time Control

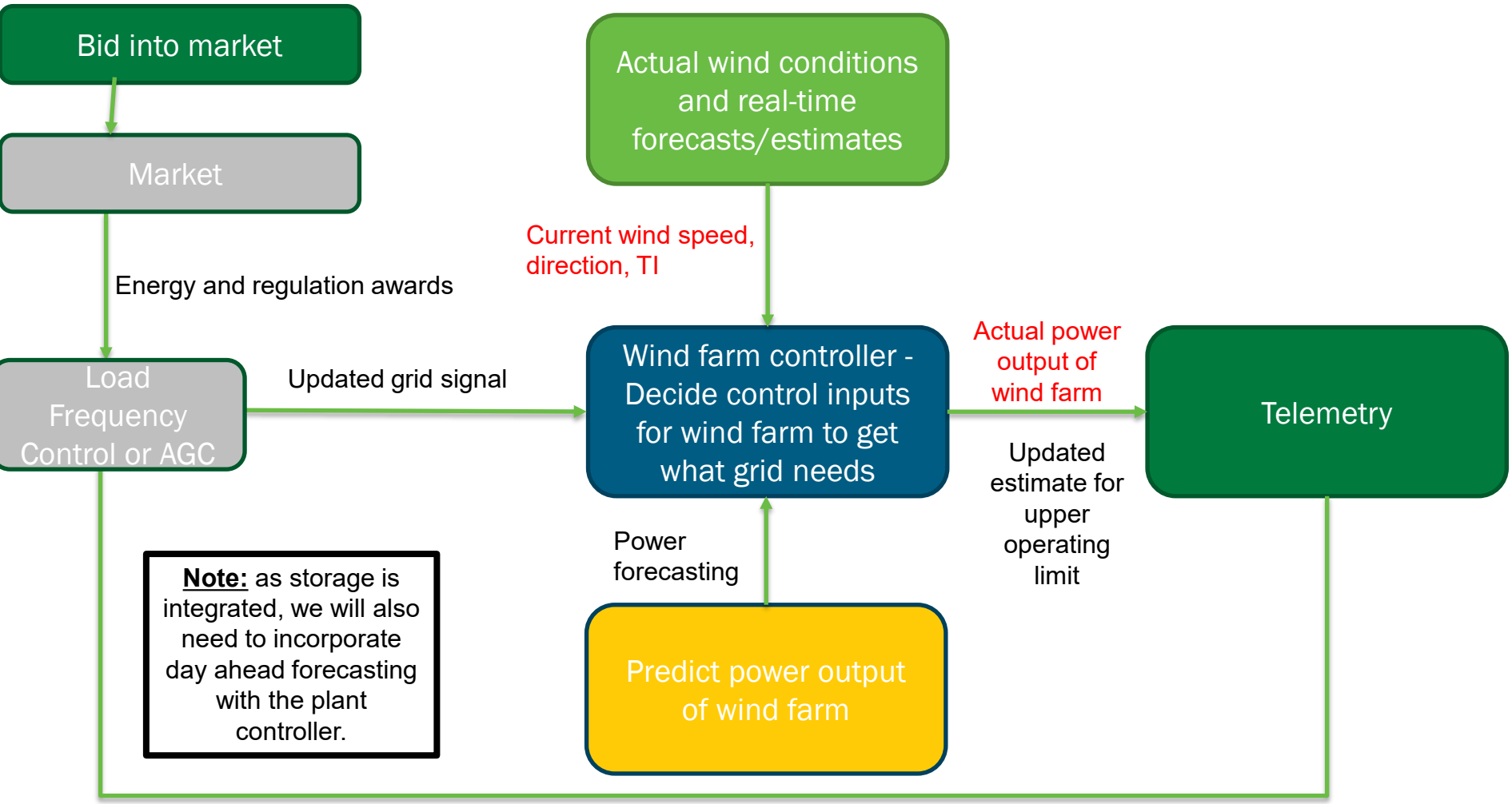
*The grey boxes are not part of the A2E2G platform.

Performance : A2e2g Inputs and Outputs





Performance: Inputs and Outputs – Real-Time



*Note: Red indicates measurements, everything else are forecasted quantities

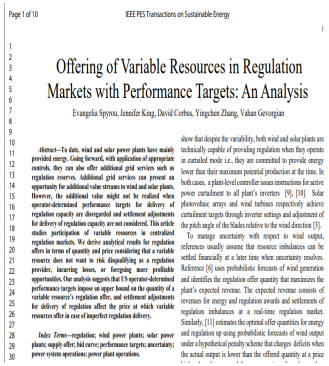
Stakeholder Engagement & Information Sharing

- **Publications and presentations**

IEEE Transactions on Sustainable Energy paper submitted - *Offering of Variable Resources in Regulation Markets with Performance Targets: An Analysis, E. Spyrou lead*

Conference on Decision and Control paper - *Uncertainty-aware Deep Reinforcement Learning for Active Power Control of Wind Farms, S. Vijayshankar lead*

FERC technical conference, "An Integrated Platform for Wind Plant Operations: From Atmosphere to Electrons to the Grid"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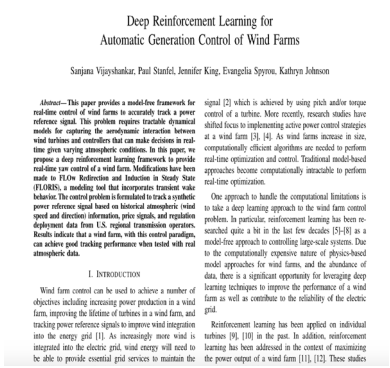
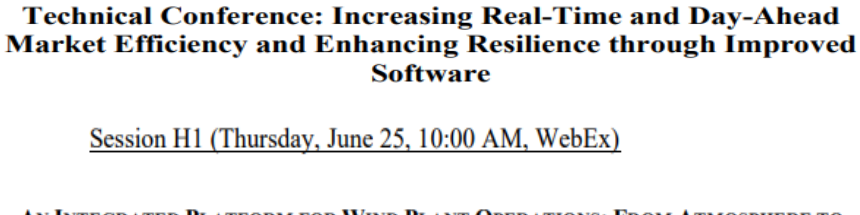
Offering of Variable Resources in Regulation Markets with Performance Targets: An Analysis

Evangelia Spyrou, Jennifer King, David Corbus, Yingchen Zhang, Vahan Gevorgian


Deep Reinforcement Learning for Automatic Generation Control of Wind Farms

Sanjana Vijayshankar, Paul Stanfel, Jennifer King, Evangelia Spyrou, Kathryn Johnson


Technical Conference: Increasing Real-Time and Day-Ahead Market Efficiency and Enhancing Resilience through Improved Software

Session H1 (Thursday, June 25, 10:00 AM, WebEx)

AN INTEGRATED PLATFORM FOR WIND PLANT OPERATIONS: FROM ATMOSPHERE TO ELECTRONS TO THE GRID

- **Extensive industry outreach**

- Meetings include ERCOT, NextEra, ESIG, IEA Task 25, AWS Scientific
- Stakeholders engaged from forecasting, wind plant owners and operators, wind plant control experts, and market experts

- **Information sharing**

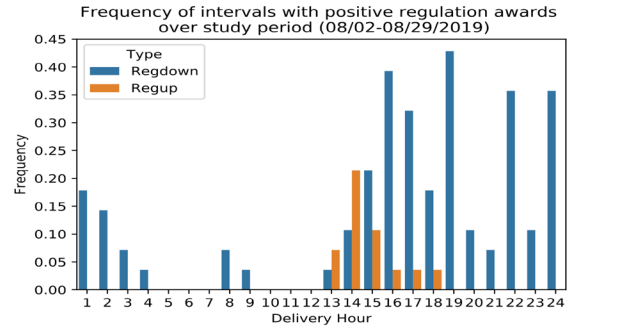
- Not able to get NextEra wind plant data (as initially planned) due to issues with proprietary information; Solution: use actual data NREL has already access to in order to demonstrate methods

A2e2g Year 1 Summary Accomplishments and Next Steps

1. **Development of a prototype for the A2E2G control platform,** a holistic Python tool with two modules that can be run in parallel and interact to
   - advise on market participation and
   - control and operate a wind power plant in real time

2. Probabilistic forecasts created from ensemble, passed onto FLOw Redirection and Induction in Steady-state (FLORIS) model

3. Derived analytical formulations for advisory offers for regulation using probabilistic wind power forecasts.
Approach: Translate power system operator's rules to constraints for plant-level optimization problem.
Preliminary result from FY20: the graph shows for a preliminary case study during August 2019 how frequently a wind plant in Texas would have positive awards for regulation reserves.



4. Next steps (FY22)
- Demonstration with combined hardware, simulation, and impact of energy storage
- Case study: Estimate value streams for a wind plant over a set of characteristic days using historical prices and all novel methods developed in this project.