



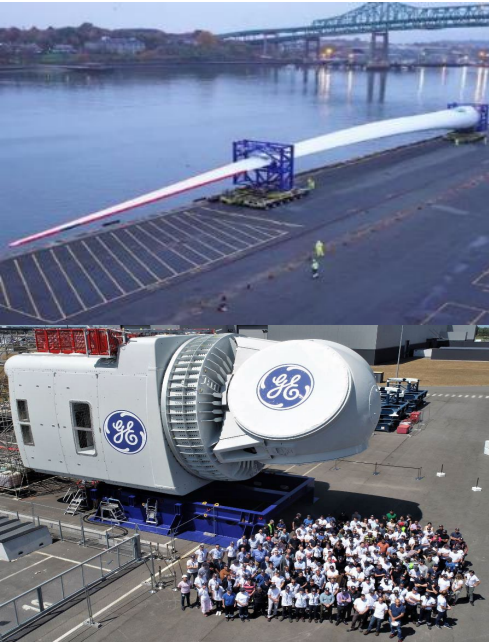
E06 - Atmosphere to Electrons to Grid (A2e2G)

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?

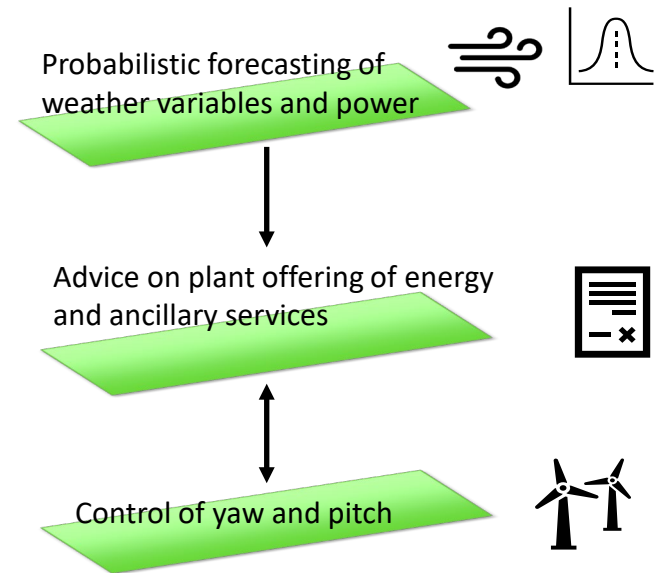
Platform that integrates:

- **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

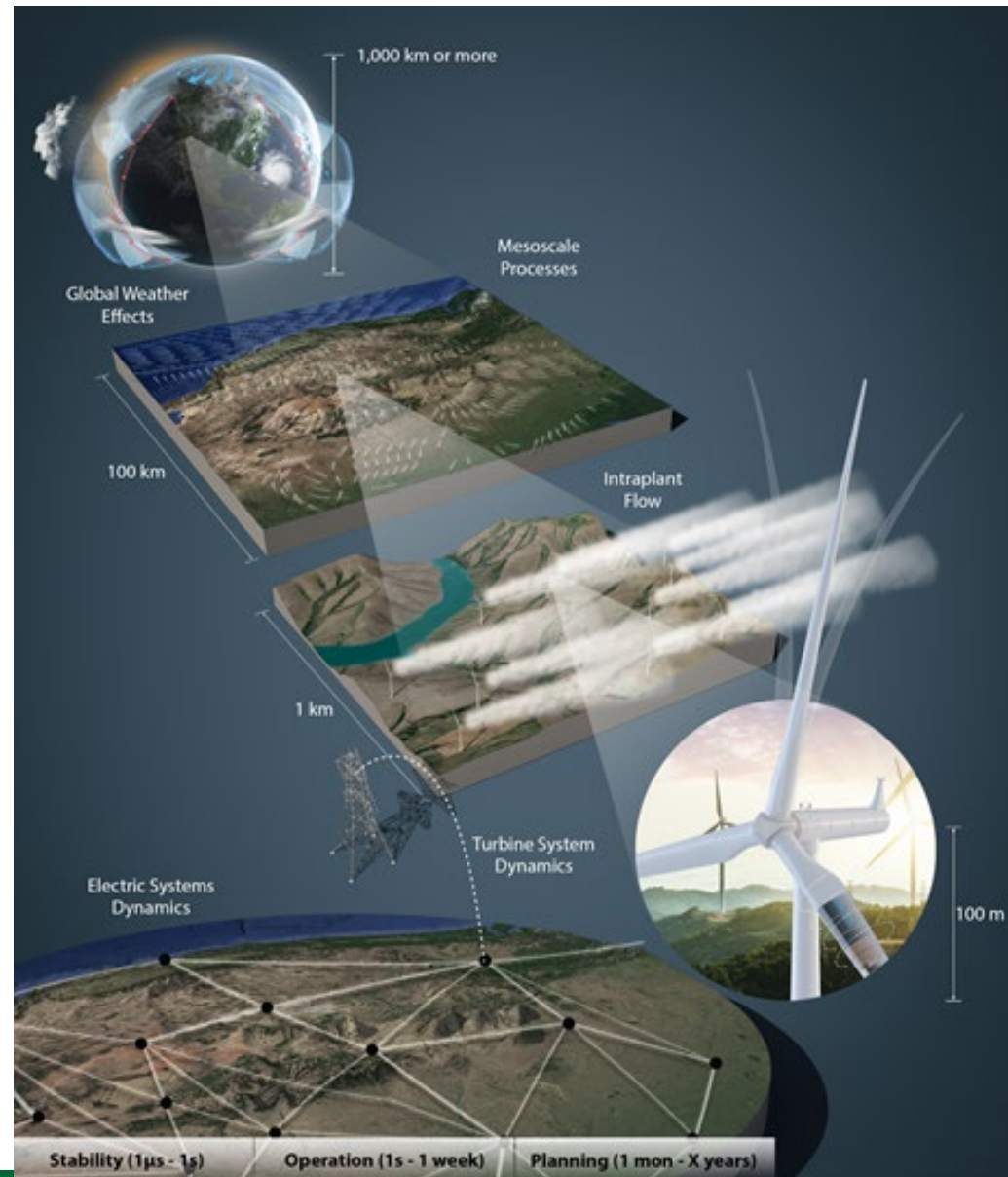
- Data- and physics-driven wind power probabilistic forecasting with high resolution and accuracy using advancements in wake dynamics modeling and neural networks
- Advanced wind plant power curve estimation including wake dynamics
- New analytical formulations for advisory offering by wind plants into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

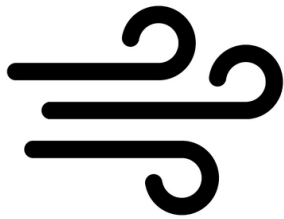
Market Participation

Predict wind conditions

Predict power output of wind farm

Bid into market

Market



Actual wind conditions and real-time forecasts/estimates

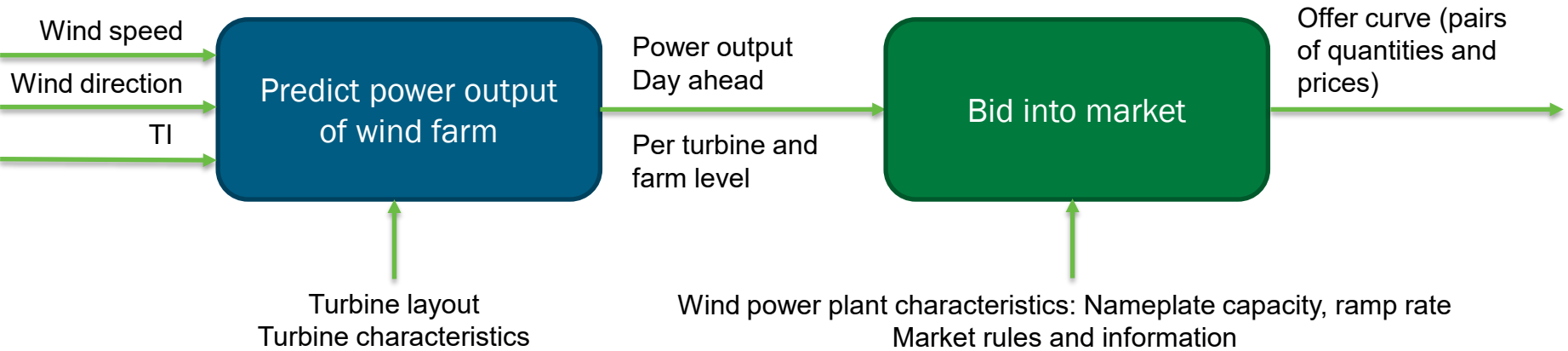
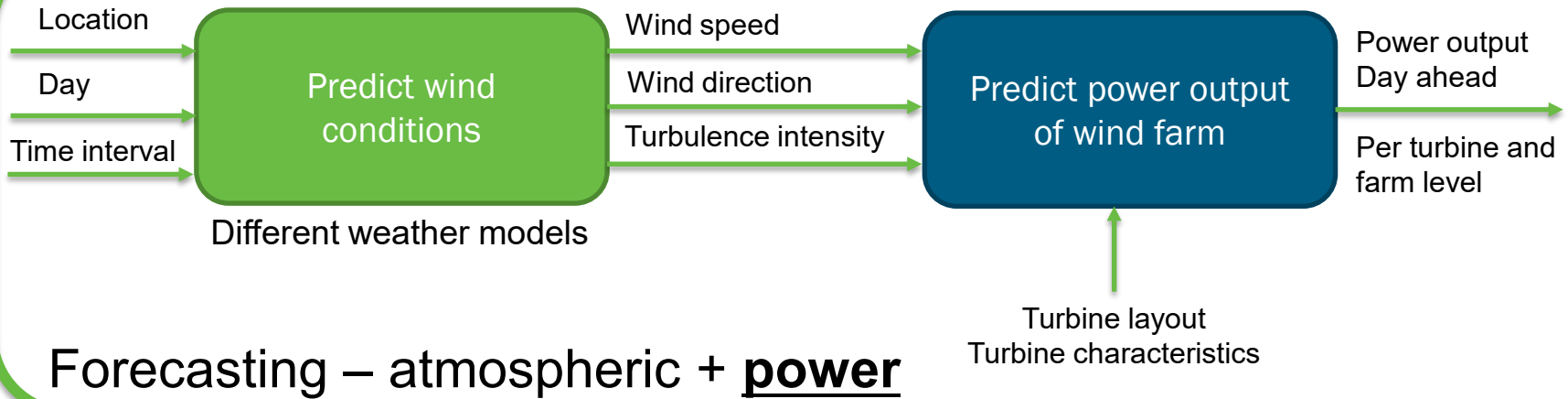
Decide control inputs for wind farm to get what grid needs

Load Frequency Control

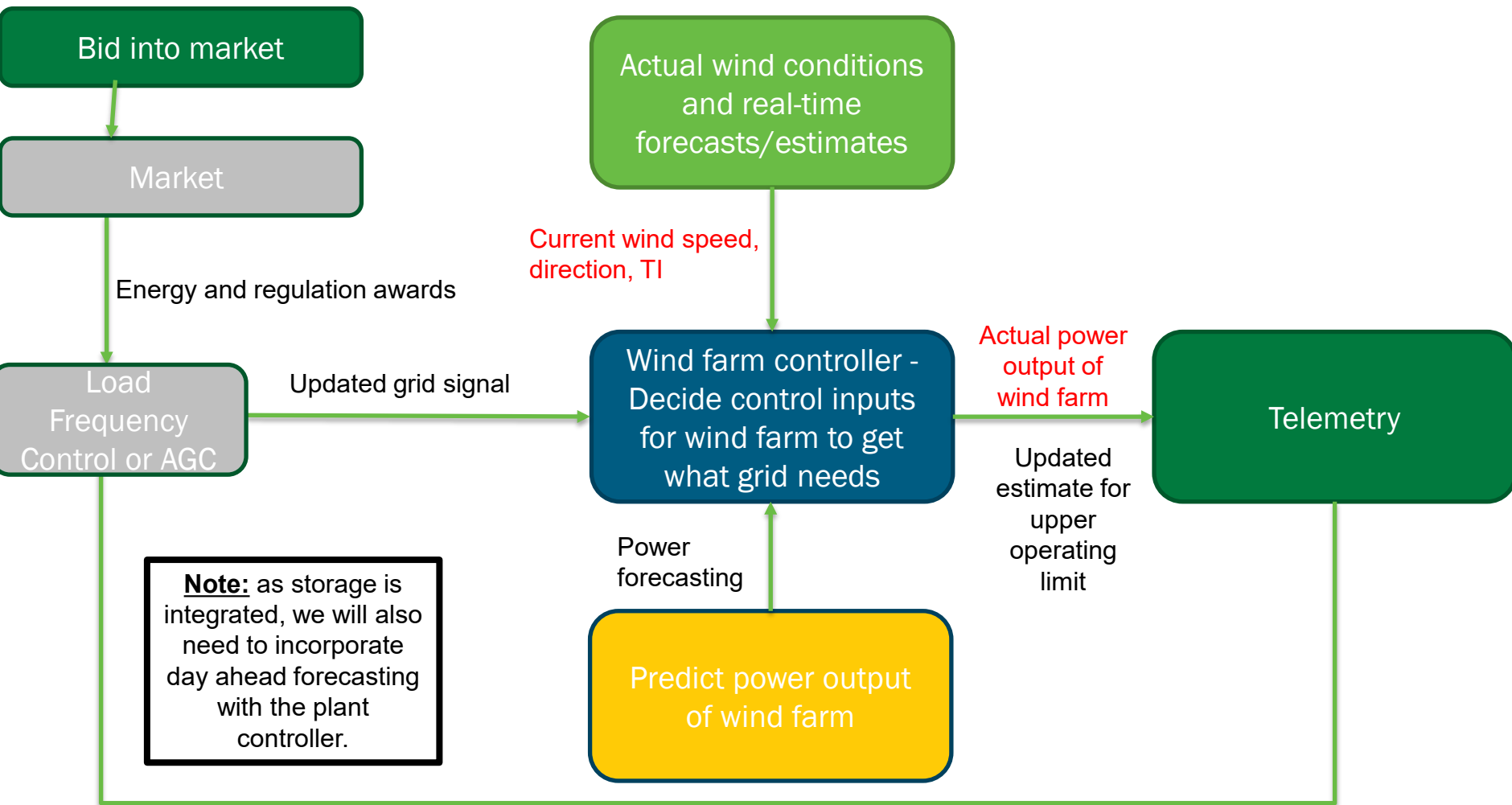
Real-Time Control

*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 Cohen, Yingchen Zhang, Yuhua Gevorgian

How do the despite the variability, both wind and solar plants are technically capable of providing regulation when they operate in a market mode i.e., they are committed to provide energy. However, they can also offer additional grid services such as regulation reserves. Additional grid services can provide an opportunity for additional value streams in wind and solar plants. However, the additional value might not be realized when operations deviate from performance targets. The delivery of regulation capacity is disrupted and settlement adjustments for delivery of regulation capacity are not realized. This article studies participation of variable resources in centralized regulation markets. We derive analytical results for regulation offers in terms of quantity and price assuming that a variable resource does not want to be dispatched as a regulation provider, leaving reserves or keeping more profitable opportunities. Our analysis suggests that 1) reserve-based market performance targets improve an offer based on the quantity of a variable resource's regulation offer, and settlement adjustments for delivery of regulation affect the price at which variable resources offer a unit of regulation capacity delivery.

Index Terms—regulation, wind power plants, solar power plants, supply offer, bid curve, performance targets, uncertainty, power control operations, power plant operations.

Deep Reinforcement Learning for Automatic Generation Control of Wind Farms

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

Abstract—This paper provides a model-free framework for real-time control of wind farms to accurately track a power reference signal. This problem requires tractable dynamical models for capturing the non-stochastic interaction between wind turbines and controllers that can make decisions in real-time given varying atmospheric conditions. In this paper, we propose a deep reinforcement learning framework to provide real-time law control of a wind farm. Modifications have been made to TD(0) Bellman and Iterative in Stochastic State (FLORES), a modeling tool that incorporates transient state behavior. The control problem is formulated to track a synthetic power reference signal based on historical atmospheric wind speed and direction information, price signals, and regulation deployment data from U.S. regional transmission operators. Results indicate that a wind farm, with this control paradigm, can achieve good tracking performance when tested with real atmospheric data.

I. INTRODUCTION

Wind farm control can be used to achieve a number of objectives including increasing power production in a wind farm, improving the lifetime of turbines in a wind farm, and tracking power reference signals to improve wind integration into the energy grid [1]. As increasingly more wind is integrated into the electric grid, wind energy will need to be able to provide essential grid services to maintain the

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

signal [2] which is achieved by using pitch and torque control of a turbine. More recently, research studies have shifted focus to implementing active power control strategies at a wind farm [3], [4]. As wind farms increase in size, computationally efficient algorithms are needed to perform real-time optimization and control. Traditional model-based approaches become computationally intractable to perform real-time optimization.

One approach to handle the computational limitations is to take a deep learning approach to the wind farm control problem. In particular, reinforcement learning has been researched quite a bit in the last few decades [5]–[8] as a model-free approach to controlling large-scale systems. Due to the computationally expensive nature of physics-based model approaches for wind farms, and the abundance of data, there is a significant opportunity for leveraging deep learning techniques to improve the performance of a wind farm as well as contribute to the reliability of the electric grid.

Reinforcement learning has been applied on individual turbines [9], [10] in the past. In addition, reinforcement learning has been addressed in the context of maximizing the power output of a wind farm [11], [12]. These studies

- **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

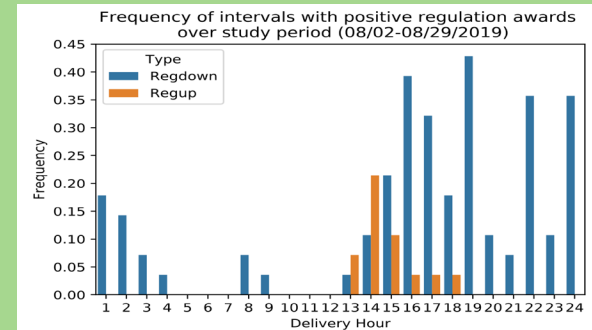
- 1. Development of a prototype for the A2E2G control platform**, a holistic Python tool with two modules that can be run in parallel and interact to
 - advise on market participation and
 - control and operate a wind power plant in real time

- 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.

Quality assessment of probabilistic forecasting

Computational time of A2E2G platform

Key analyses

Compliance with performance targets (set by system operators)

Profit Analysis