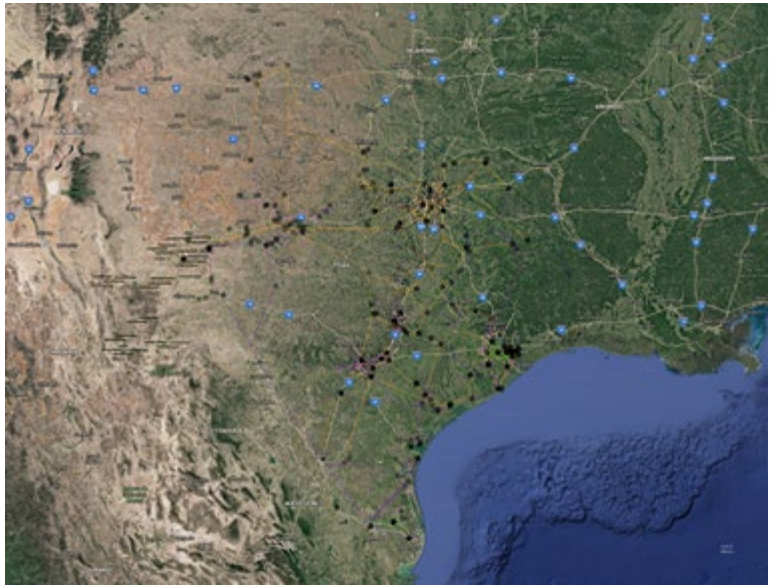
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE



E08 - Advanced Modeling, Dynamic Stability Analysis, and Mitigation of Control Interactions in Wind Power Plants

Mitigate Market Barriers – Grid Integration

Shahil Shah

NREL

August 3, 2021

FY21 Peer Review - Project Overview

Project Summary:

- Dynamic stability is a major concern in maintaining the security of power grids when they are operated with high levels of wind generation.
- Fast, complex, and diverse controls of wind turbines and unavailability of high-fidelity models from vendors to protect IP make it difficult to understand the stability problems involving wind power plants.
- This project is developing impedance-based testing, modeling, and analytical tools to evaluate the stability impacts of wind generation.
- Key project partners: University of South Florida (Paid), GE Research (Unpaid)

Project Start Year: FY19
Expected Completion Year: FY22
Total expected duration: 3 years

FY19 - FY20 Budget: $1,050,000

Key Project Personnel: Shahil Shah, NREL

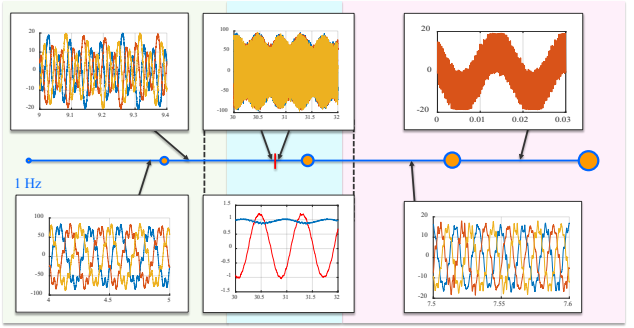
Key DOE Personnel: Jian Fu

Project Objective(s) 2019-2020:

- Develop first-of-its-kind impedance measurement system at NREL for multimegawatt wind turbines to characterize their dynamic behavior
- Develop a software tool to scan impedance responses of black-box PSCAD simulation models of wind turbines

Overall Project Objectives (life of project):

- This project will develop impedance scan, stability analysis, and co-simulation tools to enable transmission owners to perform project-specific dynamic stability studies for wind power plants.



Control Interactions and Stability Problems Involving Wind Power Plants

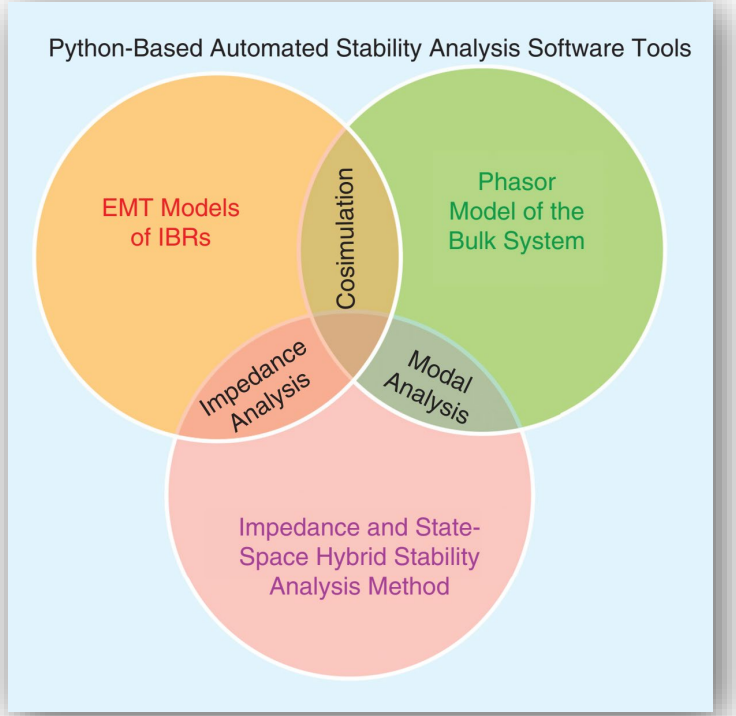
Project Impact

Problem

- Currently the industry does not have tools to evaluate the impacts of new and existing wind power plants on grid stability except for performing EMT simulations
- Simulation studies can only show if the system is stable or not for simulated conditions – low efficiency, cannot determine impact and participation of individual wind power plants in system stability modes and resonance problems

Solution

- Perform impedance measurements on actual wind turbine products or impedance scans on vendor-supplied high-fidelity black-box models
- Use this information to evaluate subsynchronous, super-synchronous, and near-synchronous stability and oscillation problems
- Software tools for project-specific studies



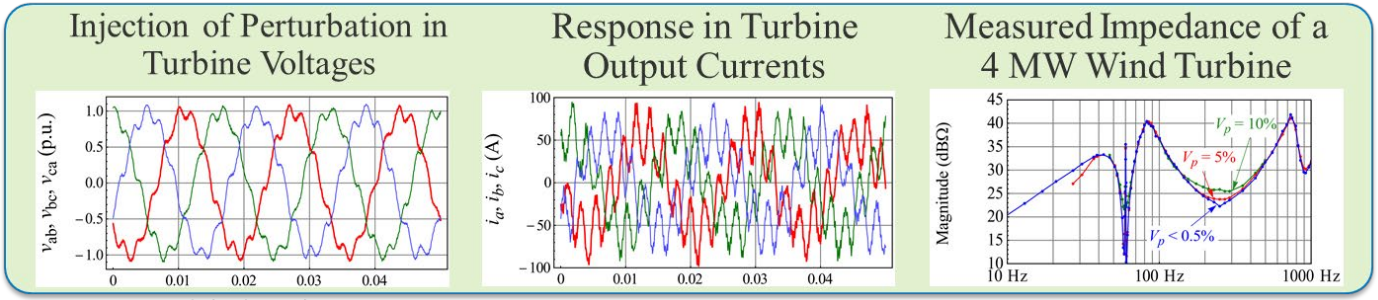
Program Performance – Scope, Schedule, Execution

FY19Q3 - FY22Q3 Project

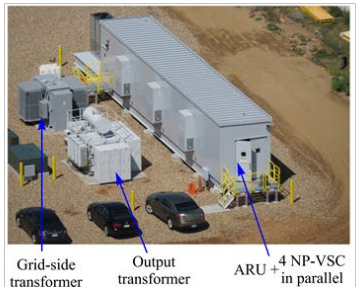
Key Milestones

- **FY19,20**: Develop impedance measurement system for wind turbines leveraging 7-MW grid simulator and 5-MW dynamometer; develop PSCAD models of wind turbines and collector system (completed)
- **FY 21**: Develop an impedance scan and stability analysis tools in python based on PSCAD electromagnetic transient simulation platform (in progress).
- **FY 22**: Demonstrate stability analysis for wind power plants in Texas synthetic grid model (2000-bus, 100 GW) using impedance scan and stability analysis tools (in progress)

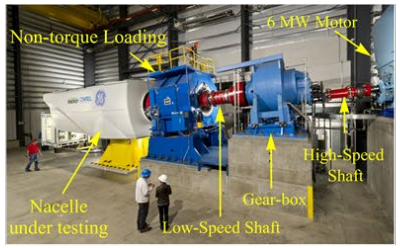
Major Accomplishments: First-of-its-kind impedance measurement system for wind turbines; analysis and mitigation of reactive power oscillations (demonstrated using a 4-MW wind turbines); impedance scan and stability analysis tools; co-simulation platform with ERCOT 2000-bus synthetic grid model



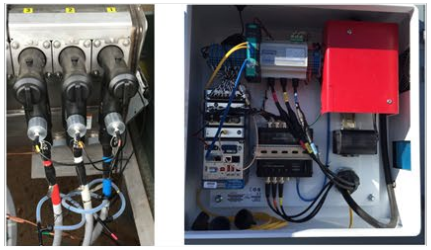
7-MVA grid simulator



5-MW dynamometer



Medium-voltage sensing



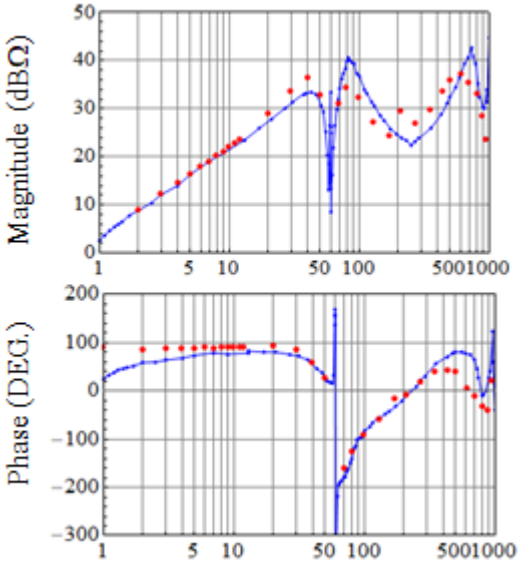
Program Performance – Accomplishments & Progress

Impedance Measurement System for Wind Turbines

- First-of-its-kind system in the world to comprehensively measure various types of impedance responses of multimegawatt wind turbines.

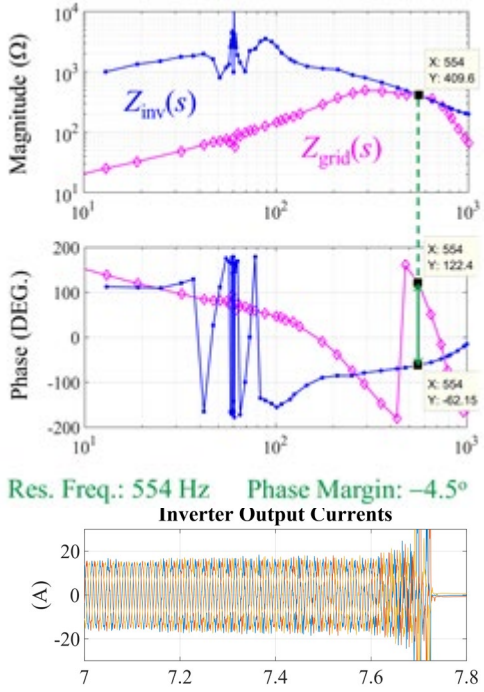
Applications:

- Model validation:

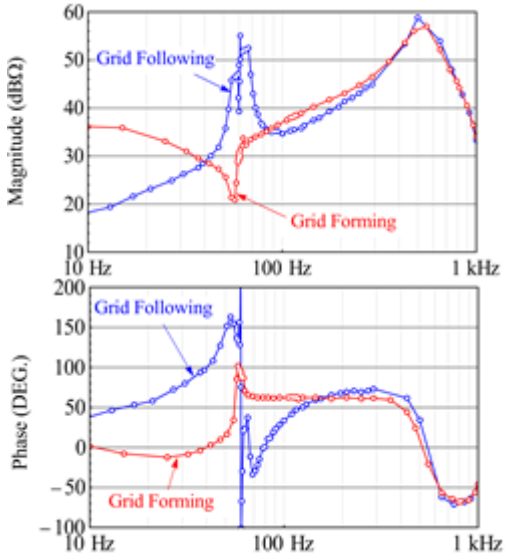


Blue: measurements of 4-MW DFIG
Red: PSCAD model from OEM

- Stability analysis:



- Researching new technologies:



Positive-seq. impedance of a 2.2-MVA inverter for GFL and GFM operation modes

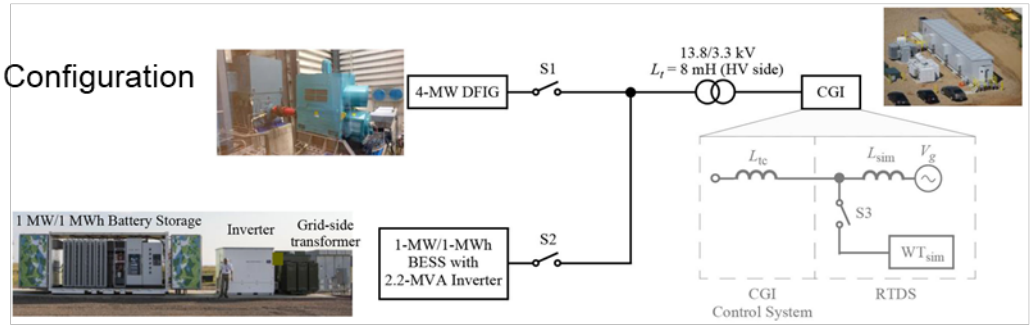
This system will serve as reference in the revised IEC 61400-21-4 standard for performing impedance measurement tests on utility-scale wind turbines

Program Performance – Accomplishments & Progress

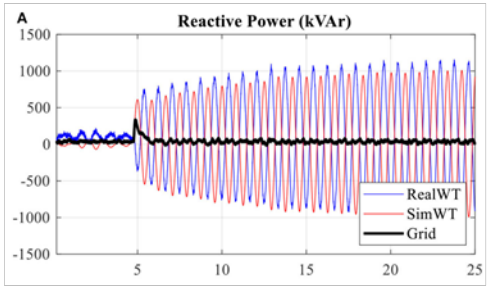
Analysis, Mitigation, and Experimental Study of Reactive Power Oscillations in Wind

- We worked with GE team to evaluate and mitigate reactive power oscillations in wind power plants, turbine-to-turbine and plant-to-grid, using a real 4-MW wind turbine product.
- This is an important problem to study and solve as shown by a UK National Grid report highlighting similar reactive power oscillations in an offshore wind power plant that were partly responsible for the August 2019 blackout event.

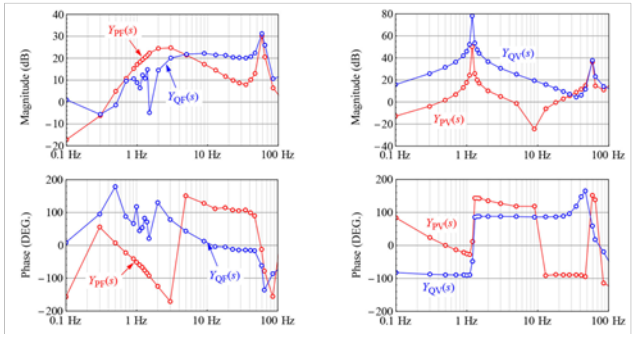
System Configuration

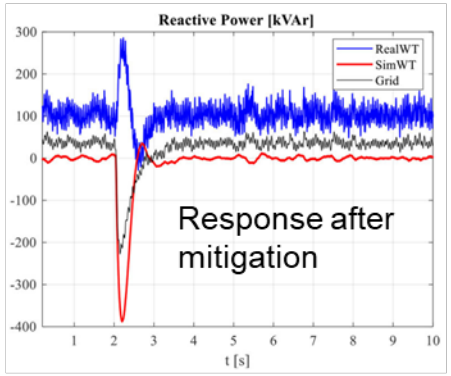


Reactive Power Oscillations



Impedance Characterization of a 4-MW Turbine

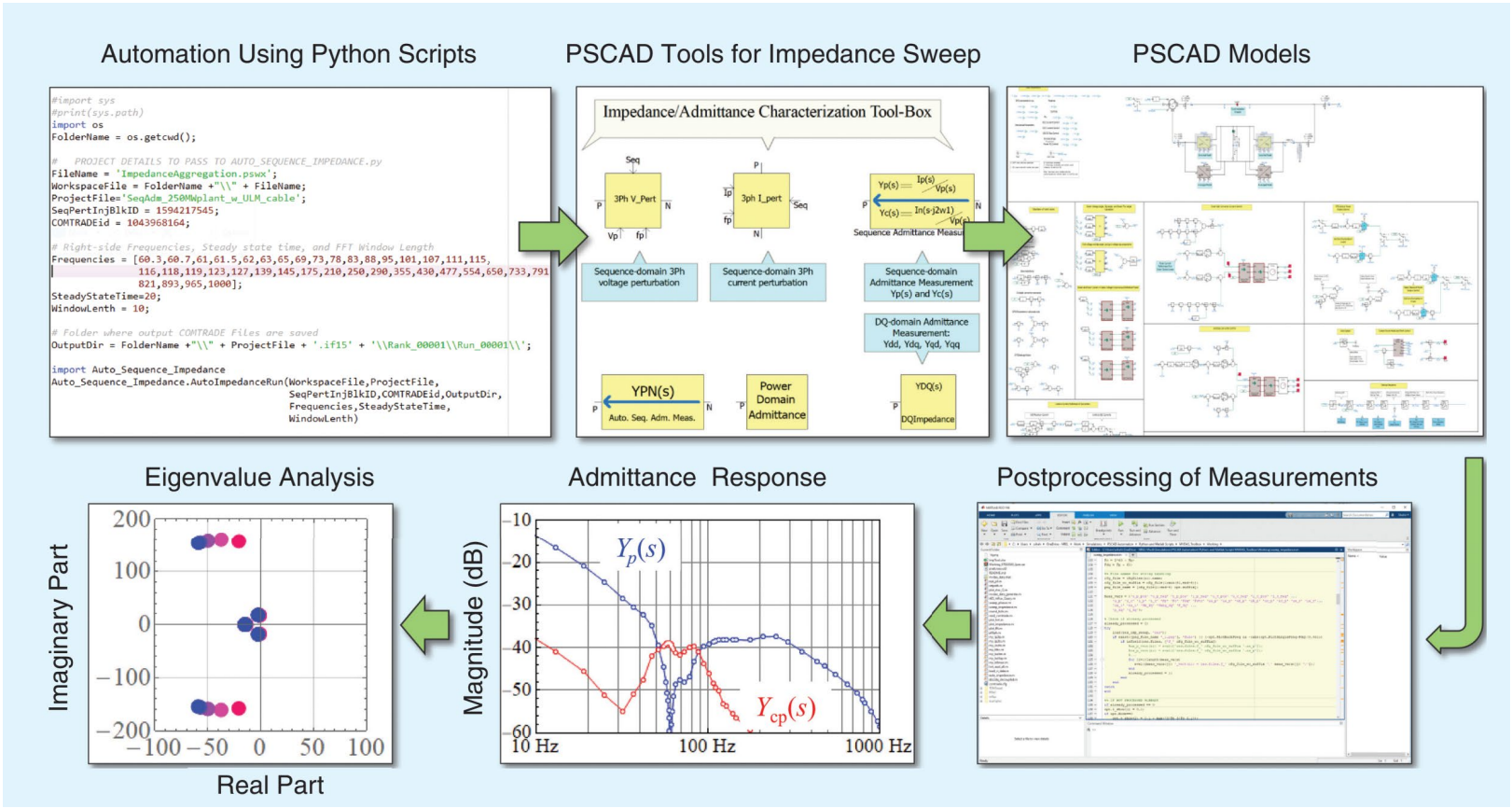




Program Performance – Accomplishments & Progress

Python tool for impedance scan and stability analysis using PSCAD models

- Can leverage black-box vendor-supplied models for performing stability studies

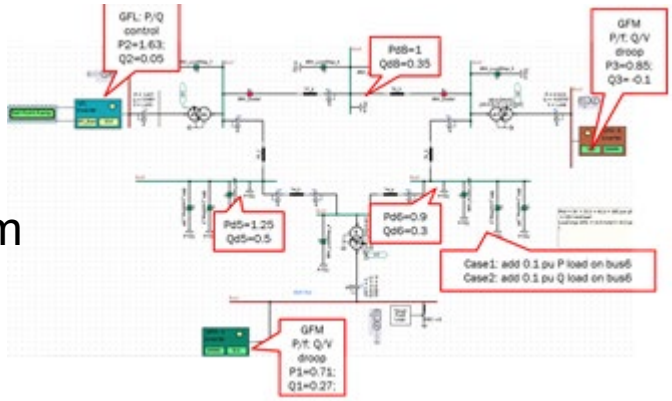


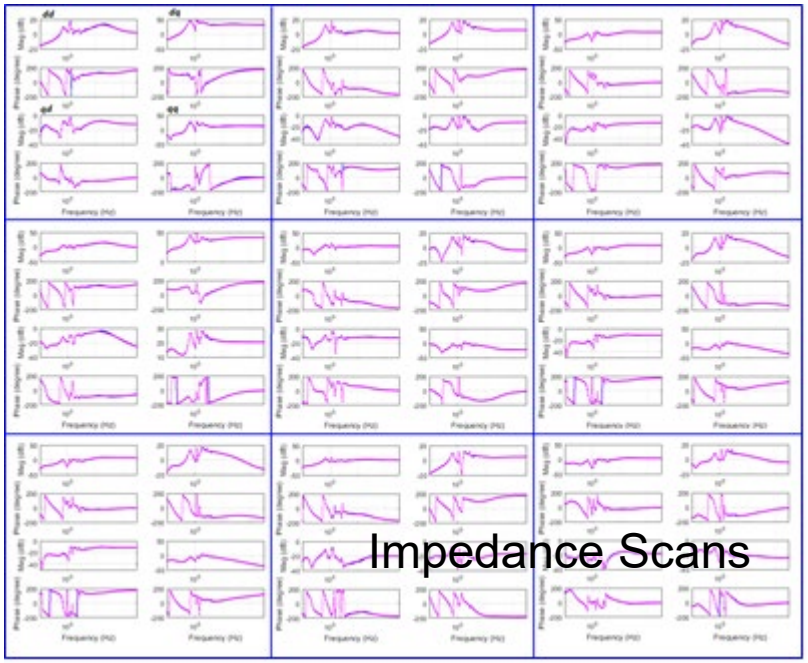
We have separately request for proposals from UK National Grid and Australian Grid operator AEMO to develop projects leveraging this tool for stability studies

Program Performance – Accomplishments & Progress

Stability analysis using impedance scans

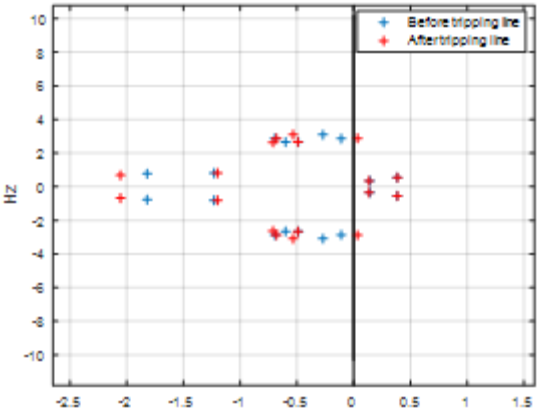
System

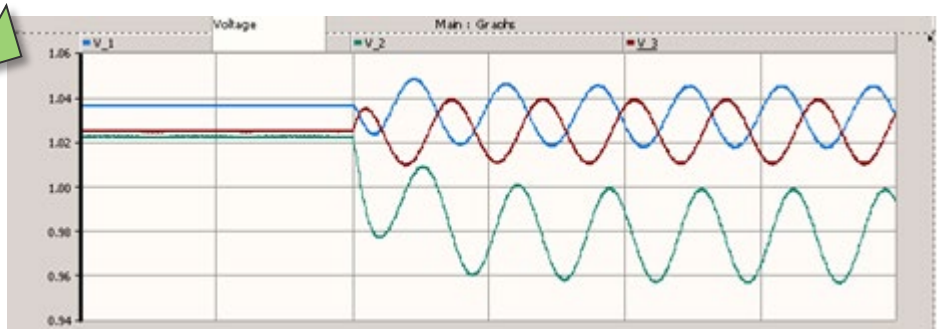




Impedance Scans

Eigenvalue Analysis



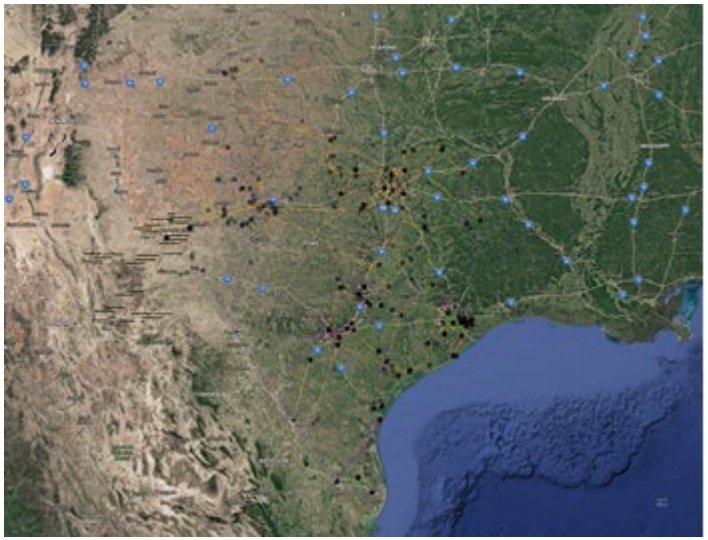


Project Performance - Upcoming Activities

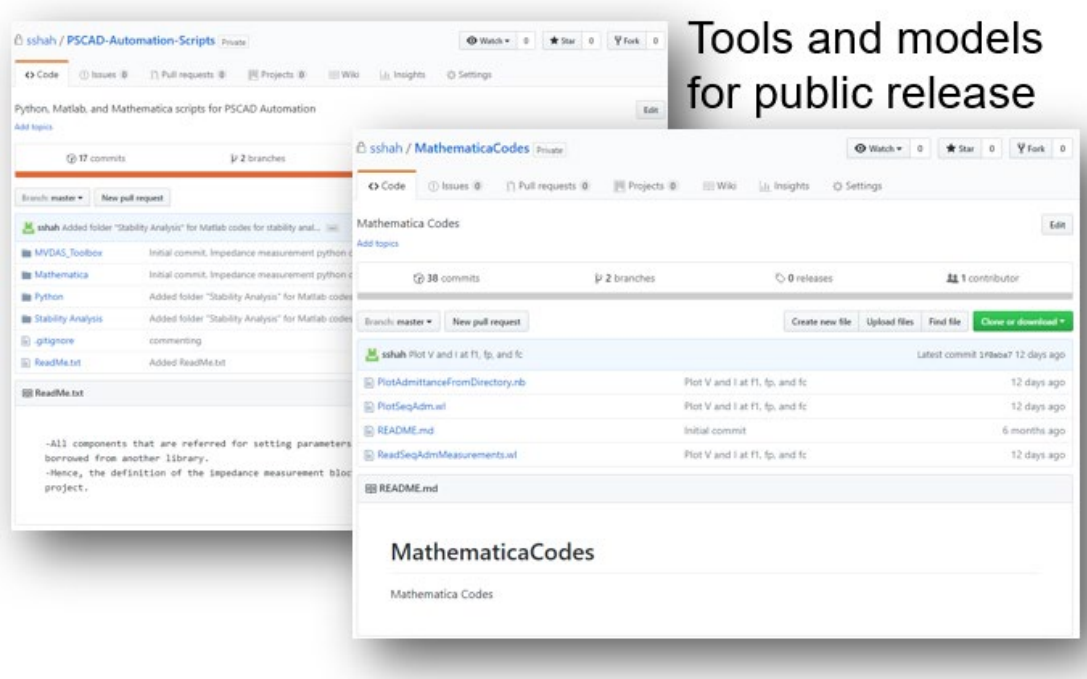
Plan for FY21 and FY22 Activities

- Finalize, integrate, and optimize impedance scan and stability analysis toolbox for public release
- Demonstrate project-specific studies by developing a co-simulation platform for simulating 2000-bus Texas synthetic grid model in transient stability PSSE simulator and wind power plant on electromagnetic transient PSCAD simulator
- Demonstrate the damping of system stability modes by wind power plants

ERCOT Synthetic Grid Model



Tools and models for public release



Stakeholder Engagement & Information Sharing

Presentations

- ESIG Spring Technical Workshops (03/2019, 04/2020)
- IEEE Power and Energy Society Webinar (08/2020)
- Webinar to engineers from stability study group of the Texas grid operator (11/2020)
- Panel presentations at IEEE PES General Meeting (08/2019, 07/2020)
- Invited talk at NSF workshop on power-electronics enabled power systems (11/2019)
- Presentation to IEA Wind Task 25 Stability Workgroup

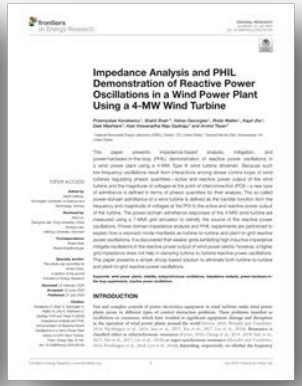
Publications

- 2 IEEE magazine articles; 5 IEEE Journal articles (2 NREL-led, 1 USF-led, 2 DTU-led); 2 conference papers (IEEE PES GM 2020 and 2019 Wind Integration Workshop)
- A chapter on impedance measurement of wind turbines in IEEE Technical Report: Wind Energy Systems Sub-synchronous Oscillations: Events and Modeling

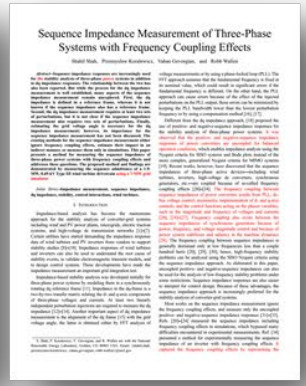
IEEE Electrification Magazine

NREL News Story

Journal paper with GE colleagues



Journal paper on impedance measurement



Journal paper on stability analysis

Joint paper with DTU