U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

E07 - Wind Power as Virtual Synchronous Generation (WindVSG)

Mitigate Market Barriers – Grid Integration

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NREL

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FY21 Peer Review - Project Overview

Project Summary:

- Main research challenge to address by this project: How to design and control future wind power plants, so that they can provide adequate grid forming (GFM) capability combined with the full range of central reliability and resiliency services along with dispatchability and flexibility of conventional sources.
- Project demonstrates how to control the inverters of wind turbine generators and battery energy storage, so that combined they act like a synchronous machine-based power plant with a conventional prime mover
- General Electric is the main project partner

Project Objective(s) 08/2019-2020:

- Develop a theoretical basis of GFM operation and services by wind power along with enhancing technologies such as energy storage
- Develop GFM models of Type 3 and 4 wind power plants
- Perform theoretical analysis to identify stability benefits of GFM wind power on power system

Overall Project Objectives (life of project):

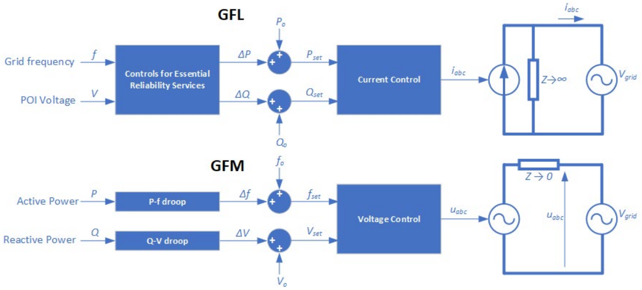
- Investigate the theory, implement it in hardware, and validate the Virtual Synchronous Generator Wind Power Plant (WindVSG) concept by combining the advantages of modern dynamic inverter technologies with static, dynamic, and transient electromechanical properties of synchronous machines.

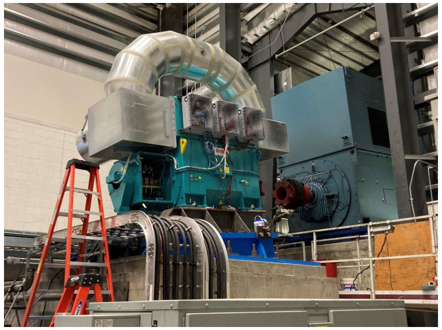
Project Start Year: FY19
Expected Completion Year: FY22
Total expected duration: 3 years

FY19 - FY22 Budget: $1,450,000

Key Project Personnel:
V. Gevorgian, S. Shah,
W. Yan, D. Corbus,
P. Koralewicz, NREL

Key DOE Personnel: Jian Fu

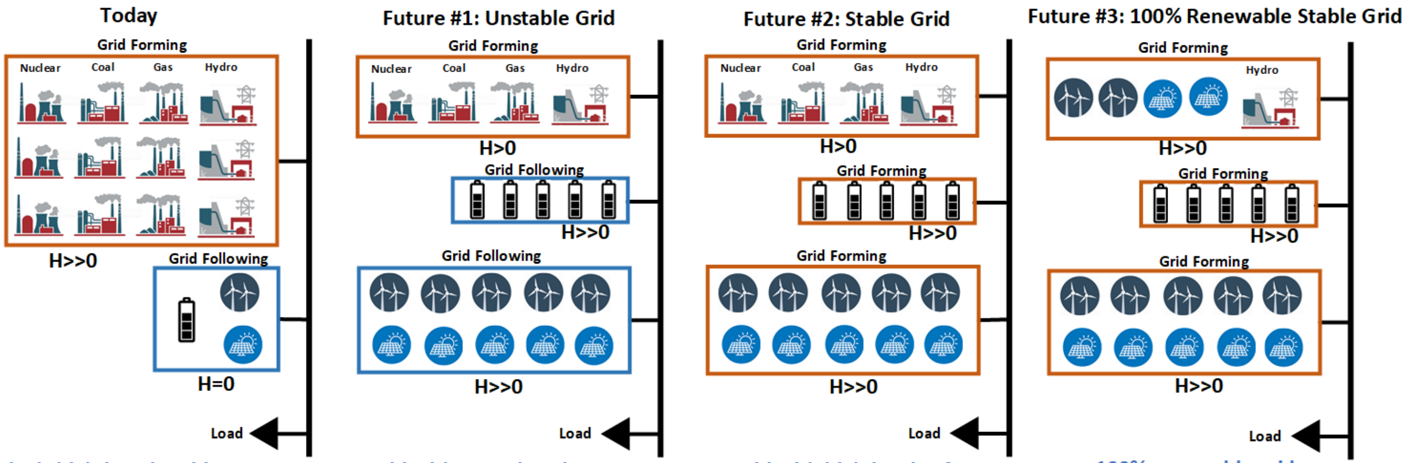




Project Impact

- The power system cannot stably operate without sufficient voltage sources regardless of how much inertia is present. Alternatively, systems without inertia that have a high rate-of-change-of-frequency (ROCOF) and enough grid forming capacity can still operate in a stable manner if proper controls are implemented, from which we can conclude that in future scenarios grid forming may be more important than inertia. Grid forming inverters are also capable of providing all existing and future advanced reliability services similar or better than any conventional technology and they help to enhance grid resiliency and security by provision of other services such as islanded operation, black start, etc.
- This project develops and investigates the concept of grid forming controls of utility-scale wind power plants adopting modeling, hardware implementation and testing approaches. It will also develop a theoretical basis of virtual wind turbine as a synchronous generator concept that can demonstrate the same functionality as conventional generators. The project research will be focused first on wind power only to provide a grid forming capability, and then also evaluation of energy storage as an enhancing technology for grid forming and grid services.

The intended audience of this project include utilities, ISOs/TSOs, wind farm developers, wind turbine and HVDC transmission OEMs, DOE program offices, standardization groups (IEEE, IEC, CIGRE), FERC/NERC, ESIG, academia, and wind turbines testing community.



Today's high-inertia grid

Grid with some inertia (rotating mass only), but no sufficient grid forming – inherently unstable system

Grid with high levels of synthetic inertia and sufficient grid forming – stable system

100% renewable grid dominated with high levels of synthetic inertia and sufficient grid forming – stable system

Program Performance – Scope, Schedule, Execution

FY19-FY22 project (started in Q4 of FY19)

Key Milestones:

- FY19-20:Theoretical analysis and preliminary models of VSG concept with provision of grid forming capability in combination with essential reliability services (completed)
- FY21: Develop and implement a WindVSG plant level controller (in progress, some hardware tasks were delayed due to COVID-19)
- FY22: Demonstration and validation at NREL using GE 2.8 MW drive train (in progress)

Project execution plan: FY19-20 Theoretical analysis and model development

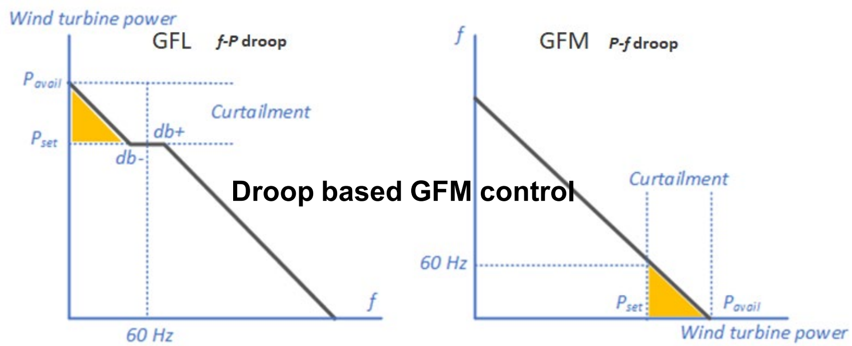
Complete initial theoretical analysis	End Date	Type / Status
Complete initial theoretical analysis of control function needed for wind forming by Type 3 and Type 4 wind turbine generators	12/31/2019	Quarterly Progress Measure 100%
Develop PSCAD models of grid forming for single Type 3 and Type 4 wind turbine generators. Project results are planned to be presented at the ESIG Spring Technical Workshop (if accepted), or a similar venue. Complete execution of GE subcontract.	3/31/2020	Quarterly Progress Measure 100%
Develop PSCAD model of complete Wind VSG system (with and without battery) with plant level controls.	6/30/2020	Quarterly Progress Measure 100%
Conclusion of theoretical work, implementation of VSG controls at turbine and turbine levels.	9/30/2020	Annual Milestone (in progress, hardware task was delayed* due to subcontract implementation issues and COVID-19 situation)

*We had a delay in the testing/demonstration project schedule due to lengthy GE subcontract approval process that had to address legal and terms/conditions issues.

The GFM controls implementation and testing will be conducted in collaboration with GE (cost shared partner)

Program Performance – Accomplishments & Progress

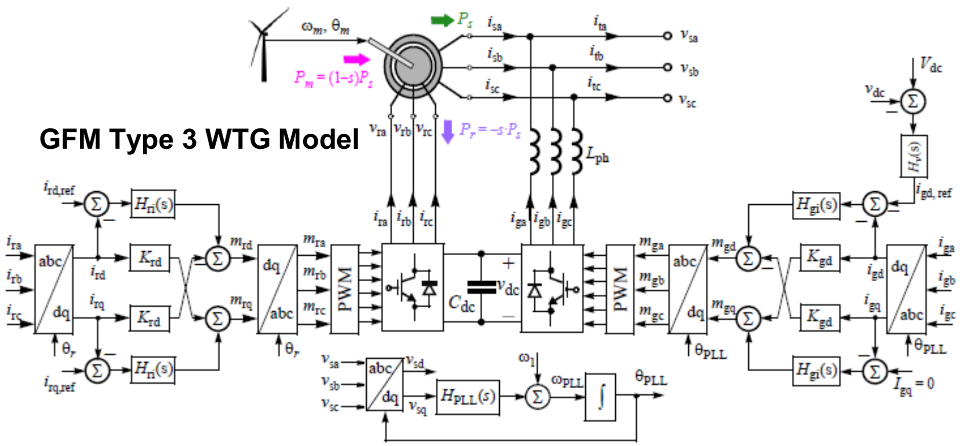
- Developed PSCAD models of Type 3 and Type 4 GFM wind turbine generators
- Conducted studies demonstrated benefits of GFM wind power on a large system level using 39-bus test system (up to100% invert-based system case)
- Conducted simulations demonstrating ability of GFM wind power plants to provide wide-area stability services in the form of power system oscillation damping



Droop based GFM control

Program Performance – Accomplishments & Progress

- Developed impedance-based models of Type and Type 4 GFM wind turbine generators to be used in stability studies
- Developed PSCAD model of GFM battery energy storage (BESS) and conducted simulations demonstrating ability of GFM wind power plants to operate in parallel with GFM BESS
- Simulated black-start scenarios with GFM wind power plants
- Developed a method for real-time estimation of available headroom in curtailed wind power plai



GFM Type 3 WTG Model

Major Publications:

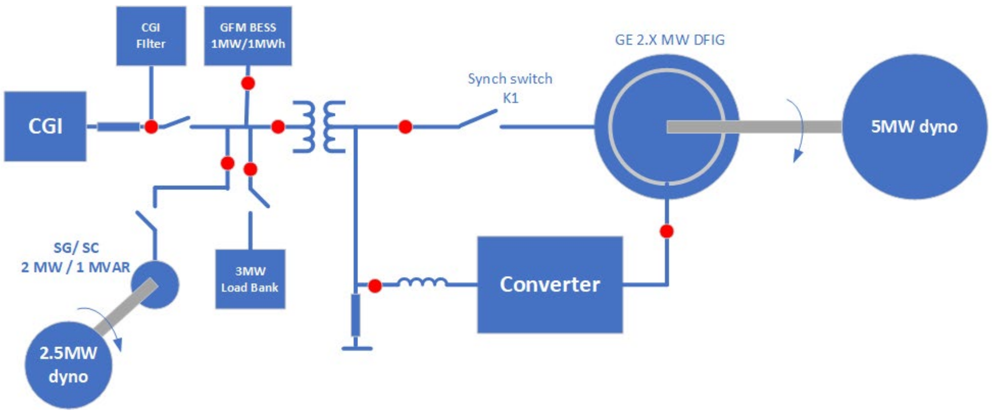
- **Control, Operation, and Stability Characteristics of Grid-Forming Type III Wind Turbines,** Authors: S. Shah, V. Gevorgian (NREL, United States), Paper presented at 19th Wind Integration Workshop
- Impacts of Inverter-Based Resources: Stability Analysis Tools for Modern Power Systems S Shah, P Koralewicz, V Gevorgian, H Liu, J Fu. IEEE Electrification Magazine 9 (1), 53-65
- Island Power Systems With High Levels of Inverter-Based Resources: Stability and Reliability Challenges, A Hoke, V Gevorgian, S Shah, P Koralewicz, RW Kenyon, B Kroposki, IEEE Electrification Magazine 9 (1), 74-9
- Impedance Methods for Analyzing Stability Data-driven optimal control strategy for virtual synchronous generator via deep reinforcement learning approach, Y Li, W Gao, W Yan, S Huang, R Wang, V Gevorgian, DW Gao, Journal of Modern Power Systems and Clean Energy

Project Performance - Upcoming Activities

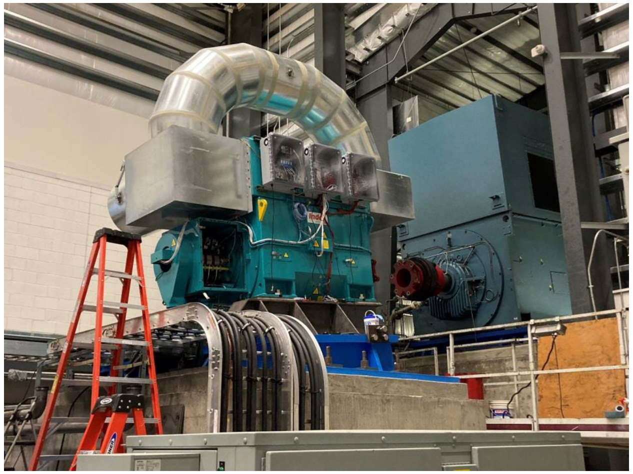
Summary of work in FY 21 and portion of FY22:

- Continue modeling simulation activities for a large power system (ERCOT synthetic model) using PSCAD-PSS/E cumulation technique with parallel computing
- Complete deployment and commission GFM controls on GE 2.8 MW Type 3 generator installed at NREL's 5 MW dynamometer and 7 MVA controllable grid interface (CGI)
- Conduct testing and demonstrate ability of GFM wind turbine generator to operate in parallel with grid and In islanded mode, operate in parallel with other technologies (BESS, synchronous generation), provide all types of reliability services to the grid, demonstrate black-start controls.

Experimental setup for demonstrating GFM controls on Type 3 wind turbine



GE 2.3 MW DFIG generator on NREL dynamometer



Stakeholder Engagement & Information Sharing

- Results of this project have presented at the top grid integration venues including ESIG and 19th Wind Integration Workshops. The paper on GFM Type 3 wind turbine impedance modeling received a best paper award at 2020 Wind Integration Workshop.
- The intended audience of this project include utilities, ISOs/TSOs, wind farm developers, wind turbine and HVDC transmission OEMs, DOE program offices, standardization groups (IEEE, IEC, CIGRE), FERC/NERC, ESIG, academia, and wind turbines testing community
- The project findings and outcomes will be further disseminated through ESIG and Ackerman workshops, journal publications, conference presentations, webinars. NREL will hold a final project review meeting to share the outcomes with stakeholders (FERC, system operators, utilities).
- GE is a cost-shared partner in this project
- University partners: Univ of Auburn, Univ. of Denver

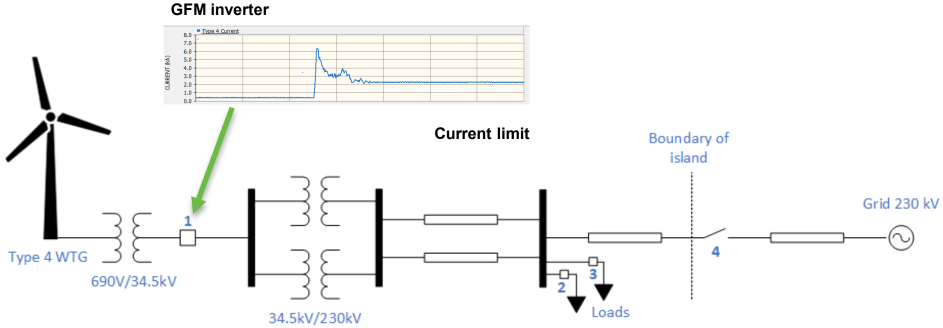
Key Takeaways and Closing Remarks

Project Impact: develop and investigate the concept of grid forming controls of utility-scale wind power plants adopting modeling, hardware implementation and testing approaches. First project in the world demonstrating ability of Type 3 wind power plants to provide grid forming services.

Project Performance: The project in on track, modeling activities demonstrated ability of GFM wind power to improve stability of the grid and provide full range of reliability services to the grid. These finding will be confirmed through testing in FY21.

Stakeholder Engagement: Key stakeholders are informed on outcomes. GE is the cost-shared partner

Energizing transformers and transmission line – current limiting by GFM inverter



Comparison of positive Sequency Impedance Response for Type 3 GFM DFIG wind turbine