Active Power Control on Wind Turbine Machines

Cooperative Research and Development Final Report

CRADA Number: CRD-11-00430, Project A, Modification 0

NREL Technical Contact: David Corbus

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Office of Energy Efficiency & Renewable Energy
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Technical Report
NREL/TP-5D00-97042
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Cooperative Research and Development Final Report

Report Date: August 23, 2025

In accordance with Requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the DOE Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Electric Power Research Institute (EPRI)

CRADA number: CRD-11-00430, Project A (Mod 0)

[EPRI Contract ID No. EP-39301/C17458]

CRADA Title: Active Power Control on Wind Turbine Machines

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Wind Energy Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$500,000.00
Year 2, Modification #1	$500,000.00
Year 3, Modification #2	N/A
Year 4, Modification #3	N/A
TOTALS	$1,000,000.00

Executive Summary of CRADA Work:

This project will evaluate the effectiveness of active power control by wind turbine machines.

CRADA Benefit to DOE, Participant, and US Taxpayer:

Currently, there is over 36,000 MW of wind power installed in the United States. This leads to about 1% of the total generation. Many countries in Europe are currently integrating over 10% of their energy from wind power. Some balancing areas in the US are already experiencing instantaneous wind energy production values of 25-50% of total generation. One of the primary system concerns with high levels of variable renewable generation is the perception that these resources are non-dispatchable and unable to contribute to any system function other than energy provision. While this has been true for many wind plants installed to date, the lack of dispatchability has been more of a result of the choice of controlling the wind turbines for maximum energy capture rather than a technical limitation of the machines to respond to system needs. There are many controls that can be built into wind turbines and wind power plant farms that can be modeled to follow directions from a control center operator or even autonomously through grid signals. In most areas, utilities and system operators do not think of this as a reliable source of control, and some may not even know that the capability exists.

Manufacturers and wind plant owners do not build or operate with these "system responsive" controls because there is no incentive or requirement to do so. By demonstrating the different ways that these controls can be implemented to support power system reliability and ancillary services, wind power generation can gain tremendous acceptance as a contributor to reliable and secure system operation. It is believed that the response capabilities may actually be better than some conventional resources. Further, in many systems, some of these response capabilities are acquired through markets where a payment is given to the resources that provide the service. Therefore, this would provide an additional potential revenue stream to wind plant owners, increasing the economic viability of wind power plants throughout the country. One study showed that a 120MW wind plant could have made an additional $3.5M during one year if it had provided one of these services. Lastly, some systems have found that these response capabilities are lacking and that future needs are needed for a reliable power system. This project would show power system operators that they can rely on these resources to provide a reliable power system. Overall, the project would promote advancement and acceptance of wind power in the United States and lift some current barriers to their entry into the electrical energy markets.

Summary of Research Results:

Purpose

Active power control is an essential service on a power system and is necessary for keeping frequency stable and preventing damage to power system machines, under frequency load shedding, and blackouts. Currently this service comes from conventional generating sources, but with renewable technologies like wind generation and solar PV generation pushing more conventional generation offline at any given time, it will be important to have this capability come from a diverse source of facilities. The project will test these capabilities on wind turbines at the National Wind Technology Center on the NREL Flatirons Campus in Boulder, Colorado and possibly at a commercial wind plant yet to be designated. The project will use a unique skill set including controls engineers and power systems engineers from both NREL and the Electric Power Research Institute in Knoxville, Tennessee. With the knowledge of controls research on different wind turbine technologies at NREL and the background and expertise in power systems control from EPRI, the project would look to be a great success in both the demonstration of the capability as well as detailed research reports on the optimal control techniques that could be used in industry. Showing this ability from a wind turbine will create huge successes for the wind industry in terms of acceptance and economic advances. Optimizing and verifying the ability of a new set of resources to provide certain system reliability functions and ancillary services will provide the utility industry with more control capability and flexibility on its system.

Statement of Work -Task Descriptions

Task 1 – Inertia Response

On a power system, disturbances occur that can cause issues in supplying the load. Loss of supply resources (generation) will result in the need for the other generation resources and frequency dependent loads to reduce their rotational speed in order to provide additional inertial energy onto the system. Conversely, a loss of a block of load will result in the need for generation resources and frequency dependent loads to increase their rotational speed in order to absorb the excess energy. This inertia that is provided by all synchronous machines is important system frequency performance in that it helps reduce the initial rate of change of frequency and frequency deviation to prevent under-frequency load shedding or under-frequency generation trip that could cause a cascading event. Many wind turbine technologies are variable speed and are electrically decoupled from the electrical frequency of the power system (i.e., asynchronous). Therefore, under control strategies implemented to date, they do not provide an inertia response as system frequency varies. The rotating blades of wind turbines have inertia, however. If the wind turbines are controlled in a manner to convert this inertia into additional electrical energy immediately following a system disturbance, it could be a great benefit to the power system.

This project proposes to test and demonstrate various control techniques to provide desired inertial response to system frequency deviations. Initially, a literature review will be involved to learn of the work that has been done so far in this area. We then plan to put together a project plan for the different types of inertial responses that can be provided. The plan will include simulations using the simulation software that mimics the behavior of the NWTC Controls and Research Turbines (CART). The next step would be to provide field tests of the response on the CART providing synthetic disturbances via frequency input signals. The results of the power output with time will be captured at high resolution. The final step of the project would be to use the same control techniques on the GE 1.5 MW turbine that is on site at the NWTC. Since this is a commercial turbine that is very common throughout the United States, it will be the best machine to show demonstrations of its response through the results data. Analysis of the response will be mathematically combined to show the response of large 100-turbine size wind farms and the change in frequency response on practical systems with the addition of this response technique. The project team also envisions engaging a commercial wind farm to participate in the demonstration by implementing a commercial control package from a large turbine vendor to verify the inertial response of a large wind plant.

Task 1 Result:

Our analysis showed that wind power can support power system reliability by providing different active power controls. Our analysis also showed that forms of APC that currently have existing markets can allow wind to earn additional revenue and reduce production costs to consumers, although the magnitude of these revenues will highly depend on the trends of these markets, as typical prices are highly volatile. This study also analyzed how new ancillary service markets could be designed for the services that do not currently exist. Lastly, this study determined that any loading impacts caused from providing these controls are very small and, when considered with the benefits of reduced loading from de-rating the turbine, will actually have a positive effect on loading.

For additional information and graphics demonstrating test results, please see https://www.osti.gov/biblio/1117060 [1]

Task 2 – Primary Frequency Control

In the first several seconds of a system frequency disturbance, turbine governors respond to control the speed of conventional generators to arrest the frequency deviation and stabilize the frequency of the power system. This primary frequency response is important to keep the frequency at a stabilized level following the disturbance. Many studies have shown that the frequency response of the interconnections within the United States, and especially the Eastern Interconnection, has been declining in past years.1 This governor response is primarily provide from conventional synchronous generators. Currently, wind plants rarely provide this type of service. With increasing penetrations of wind power it will likely be a needed technical service from wind plants as other generators will be displaced. ERCOT has already added interconnection requirements that mandate new wind plants within the ERCOT footprint provide governor response to over-frequency events.

This project proposes to test and demonstrate wind plant control techniques to provide primary frequency response to system frequency deviations. Initially, a literature review will be involved to learn of the work that has been done so far in this area. We then plan to put together a project plan for the different types of primary frequency responses that can be provided. The plan will include simulations using the simulation software that mimics the behavior of the NWTC Controls and Research Turbines (CART). The next step would be to provide field tests of the response on the CART providing synthetic disturbances via frequency input signals. The results of the power output with time will be captured at high resolution. The final step of the project would be to use the same control techniques on the GE 1.5 MW turbine that is on site at the NWTC. Since this is a commercial turbine that is very common throughout the United States, it will be the best machine to show demonstrations of its response through the results data. Analysis of the response will be mathematically combined to show the response of large 100-turbine size wind farms and the change in frequency response on practical systems with the addition of this response technique. The project team also envisions engaging a commercial wind farm to participate in the demonstration by implementing a commercial control package from a large turbine vendor to verify the inertial response of a large wind plant.

This project demonstrated wind plant control techniques to provide primary frequency response to system frequency deviations. The tests included simulations using the simulation software that mimics the behavior of the NWTC Controls and Research Turbines (CART).

Results are documented at https://www.osti.gov/biblio/1117060 [1]

Task 3 – Secondary Automatic Generation Control

While the frequency is stabilized with the primary frequency control response, it is not returned back to its nominal level of 60 Hz without changing the control set point. This is where automatic generation control is needed. Automatic Generation Control, or AGC, is where control is directed by a centralized control center (utility or system operator) and control signals are sent to the regulating resources to follow. The AGC is also used to move the regulating resource to follow the minute-to-minute changes in system load and generation to maintain the area control error (ACE) within acceptable limits. Currently, wind plants do not provide regulating response, but like the other control techniques we see it as a need going forward. Participation in AGC requires a much slower response than primary control but requires a response over a longer time period. Therefore, different control techniques might be needed for the response to be held as long as the control center is giving the signal.

This project proposes to test out these response techniques. Initially, a literature review will be involved to learn of the work that has been done so far in this area. We then plan to put together a project plan for the different types of secondary AGC responses that can be provided. The plan will include simulations using the simulation software that mimics the behavior of the NWTC Controls and Research Turbines (CART). The next step would be to provide field tests of the response on the CART providing both synthetic disturbances and actual AGC directions from the control Center of the Public Service Colorado. The results of the power output with time will be captured at high resolution. The final step of the project would be to use the same control techniques on the GE 1.5 MW turbine that is on site at the NWTC. Since this is a commercial turbine that is very common throughout the United States, it will be the best machine to show demonstrations of its response through the results data. Analysis of the response will be mathematically combined to show the response of large 100-turbine size wind farms and the change in frequency and ACE response on practical systems with the addition of this response technique.

Results are documented at https://www.osti.gov/biblio/1117060 [1]

Task 4 – Full Integration

This task included the scenario of a wind turbine that is relied upon to provide all three services – inertial control, primary frequency, and regulation and AGC. This included a combination of all control techniques and an evaluation of how they interact with each other. All wind regions, upward and downward response, and different size disturbances and ACE changes were evaluated and combined to evaluate the comprehensive behavior of a wind turbine if it were to be providing all these control services simultaneously.

Results are documented at https://www.osti.gov/biblio/1117060 [1]

Task 5 – Parameter Tuning, Identification, and Sensitivity Analysis

EPRI has an on-going R&D project looking at the potential extension of an existing tool/technique (they have developed for the purpose of model validation and parameter estimation for synchronous generation using on-line disturbance measurement data) for model validation of wind generation models. This task collaborated with EPRI on their project to investigate the development of parameter estimation techniques for model validation and parameter estimation for the WECC generic wind turbine models to match measurement data or the corresponding detailed models for type 1 through type 4 wind turbine generators. This work was done in collaboration with the WECC Renewable Generation Modeling Task Force.

The four types of the wind turbine models covered in this project:

- Type 1: Induction Generator (fixed-speed wind turbine generator)
- Type 2: Wound Rotor Induction Generator (variable-slip wind turbine generator)
- Type 3: Doubly Fed Induction Generator (variable-speed wind turbine generator with partial rating power converter).
- Type 4: Full Processing Power Converter (variable-speedwind turbine generator with full power converter interface between the generator and utility).

A report should be prepared that details the process and any learning with respect to the models and recommendation on any changes to the model structures, the challenges in the model validation process, and lessons learned. This report will be made public.

Results are documented at https://www.osti.gov/biblio/1117060 [1]

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Article X.

The work completed under this CRADA has been documented in OSTI as, "Active Power Controls from Wind Power: Bridging the Gaps." OSTI ID: 111760. A link to the report is provided https://doi.org/10.2172/1117060.

References:

1. Ela, E; Gevorgian, V.; Fleming, P.; Zhang, Y. C.; Singh, M.; Muljadi, E.; Scholbrook, A.; Aho, J.; Buckspan, A.; Pao, L.; Singhvi, V.; Tuohy, A.; Pourbeik, P.; Brooks, D.; Bhatt, N.; "Active Power Controls from Wind Power: Bridging the Gaps," *U.S. Department of Energy Office of Scientific and Technical Information www.OSTI.gov*, DOI:https://doi.org/10.2172/1117060 Technical Report OSTI ID:1117060 (01 January 2014), https//www.osti.gov/biblio/1117060.

Subject Inventions Listing: None.

ROI #: None.