INL/EXT-16-40751

Summary: Concurrent Cooling

1. **Project Information**
   a. Full Project Title: **Operational and Strategic Implementation of Dynamic Line Rating for Optimized Wind Energy Generation Integration**
   b. Organization or Affiliation: Idaho National Laboratory
   c. Principal Investigator: Jake P. Gentle
   d. Project duration (Start and End Date): FY14-Current

2. **Project Purpose and Objectives**

One primary goal of rendering today's transmission grid "smarter" is to optimize and better manage its power transfer capacity in real time. Power transfer capacity is affected by three main elements: stability, voltage limits, and thermal ratings. All three are critical, but thermal ratings represent the greatest opportunity to quickly, reliably and economically utilize the grid's true capacity. With the "Smarter Grid", new solutions have been sought to give operators a better grasp on real time conditions, allowing them to manage and extend the usefulness of existing transmission infrastructure in a safe and reliable manner.

The objective of the INL Wind Program is to provide industry a Dynamic Line Rating (DLR) solution that is state of the art as measured by cost, accuracy and dependability, to enable human operators to make informed decisions and take appropriate actions without human or system overloading and impacting the reliability of the grid. In addition to mitigating transmission line congestion to better integrate wind, DLR also offers the opportunity to improve the grid with optimized utilization of transmission lines to relieve congestion in general.

As wind-generated energy has become a bigger part of the nation's energy portfolio, researchers have learned that wind not only turns turbine blades to generate electricity, but can cool transmission lines and increase transfer capabilities significantly, sometimes up to 60 percent. INL's DLR development supports EERE and The Wind Energy Technology Office's goals by informing system planners and grid operators of available transmission capacity, beyond typical Static Line Ratings (SLR). SLRs are based on a fixed set of conservative environmental conditions to establish a limit on the amount of current lines can safely carry without overheating. Using commercially available weather monitors mounted on industry informed custom brackets developed by INL in combination with Computational Fluid Dynamics (CFD) enhanced weather analysis and DLR software, INL's project offers the potential of safely providing line ampacities up to 40 percent or more above existing SLRs, by using real time information rather than overly conservative SLR.

3. **Alignment with Program**

This project aligns with the following DOE Program objectives / priorities:

A. Lowering the cost of wind energy
   i. Wind plant optimization: INL's Transmission Line Planning and Routing Toolkit provides wind developers an optimization tool that assists in the selection of overhead transmission conductors and structures to minimize capital expenditures through the use of dynamic line rating intelligence.

B. Facilitating robust and responsible deployment
   i. Information synthesis and dissemination: provides the wind industry (utilities, developers, landowners, general public) technologies to support the broader integration of Wind.

ii. *Wind energy workforce and education development*: supports small and large businesses expand their technology offerings by assisting them through NDA's, CRADA's, and commercialization.

iii. ***Advancing grid integration*: INL's Concurrent Cooling portfolio of projects, officially known as "Operational and Strategic Implementation of Dynamic Line Rating for Optimized Wind Energy Generation Integration" directly enhances the Wind Industry by providing technologies and a methodology that enables greater access to the grid without the need of major capital equipment expenditures, all while remaining safe and reliable.**

C. Creating and sustaining market growth

i. *Commercialization of innovations and technology transfer: INL's R&D value has been industry supported and confirmed through NDA's, CRADA's, and commercialization and technology transfer efforts. Multiple industry partners are coordinating business model negotiations on how current and future R&D developments at INL can be transferred and utilized.*

ii. *World-class test and user facilities: INL owns and operates one of the largest R&D testbeds for full scale transmission and distribution research with more than 150 miles of distribution lines, 70 miles of transmission lines, seven substations, and a fully operational control center. INL has used this testbed experience and lessons learned to work with industry to establish an operational DLR testbed (>450 lines miles) in complex terrain in southern and western Idaho.*

iii. *Advanced technology demonstration projects: INL's focus has been to work directly with industry partners to develop and demonstrate technologies and methodologies that interact at the full scale.*

iv. *Technical engagement initiatives: INL's Concurrent Cooling portfolio has supported multiple industry attended workshops, and routinely uses Technical Review Committee feedback.*

v. *Standards and certification: INL's Concurrent Cooling R&D is being used to inform IEEE and CIGRE standards association efforts through Task Forces and Working Groups to develop best practices, technical reports, brochures, and informed standards.*

4. **Technical Approach**

INL's technical approach is to use computational fluid dynamics and historical, real-time, and forecasted weather data to develop an industry standard "true" dynamic line rating methodology. The goal is to open up marked increases in power carrying capacity of existing overhead lines using programs and procedures that can be seamlessly implemented in control rooms with minimal distraction or the need for operators to constantly shift their focus from panel to panel.

The project is using The Human System Simulation Laboratory (HSSL) at INL, a reconfigurable virtual control center for safely testing new technologies and data displays before they are implemented within industry. It is an ideal testbed for key software involved in Dynamic Line Rating to prove effective data integration to operators and stakeholders before going live in control rooms.

In 2016, HSSL researchers developed observation protocol and interview questions for utility operators, completed two control room observations and interviews, and developed a first prototype of a flowgate display presentation with integrated model outputs. A survey has been developed for operators using DLR in their operations and planning, and is scheduled to be distributed in the fourth quarter of 2017.

<u>Software programs developed and adapted since 2014 include:</u>

Generalized Line Ampacity State Solver (GLASS): Processes weather data and line current data in real time to calculate the maximum current a particular line can carry. Since 2014, GLASS has evolved to include Steady State Temperature calculations, Transient Temperature calculations and Transient Ampacity calculations. INL has developed a set of requirements for input data and is working to promote the standardization through IEEE and CIGRE standards bodies.

Planning and Routing Tool: Utilizes DLR data to find the power line path that can carry current at the lowest cost. In 2015, initial development used Python code, allowing for a database of shape files to be computed with weather data in order to create hypothetical line routes. In 2016, translation of the system into a fully featured Java-based GUI application, complete with scrollable map, enabled full integration with GLASS-produced DLR output values at every point along a GIS grid. This toolkit is industry supported through a partnership with wind developers and international engineering consulting firm.

Computational Fluid Dynamic Models: Simulates wind data, maps and creates look-up tables for highly complex terrain. Because of the software development collaboration with WindSim, INL has a custom version of the code for areas roughly four times the size of other customers' software solutions. INL has supported the Wind Industry to enhance their resource assessment tools through the efforts of the DLR projects.

SAND: Organizes historical weather data to drive GLASS computations. Enables System Planners the engineering version of GLASS to work on studies projects and predicted scenarios without impacting the real-time operations version of the DLR software.

Hardware: The INL DLR team supervised the fabrication of a system of brackets that allow weather stations to be installed on utility standard poles or lattice structures designed to stand up to harshest conditions and ease of installation by linemen, with little to no additional training.

5. **Research Integration, Collaboration, and Technology Transfer**

The project has involved partners and collaborators from all over the United States and Canada, as well as companies in the United Kingdom and Norway. Interactions with industry and academia include more than 15 non-disclosure agreements and more than $1 million invested over a three-year period. One CRADA project has been executed and another initiated. One Strategic Partnership (funds into INL) agreement has been executed.

Key collaborators include:

WindSim AS –CFD software development and commercialization partner; Idaho Power Co.: Test area (~500 line miles), 50+ weather stations; AltaLink, LLC, CRADA: Test area (~4 line miles), four weather stations. Other collaborators include: AESO, Bonneville Power Administration, Southwest Power Pool, Oklahoma Gas and Electric, NERC, WECC, Underground Systems, Inc., Nexans, the Valley Group, Southwire Company, Lindsey Manufacturing, NOAA, StormGeo, Vaisala, Inc., TechFlow, OSIsoft, Stantec, Power Engineers, Genscape (Promethean Devices), Idaho State University, Boise State University, Durham University (UK), Montana Tech, University of Idaho.

In the summer of 2016, the INL DLR team took part in DOE's Lab-Corps program, a specialized training "boot camp" curriculum aimed at accelerating the transfer of clean energy technologies from national laboratories into the commercial marketplace. The training provided an entrepreneurial education to national laboratory researchers and connects them to potential customers and industry partners, helping to close the knowledge gap between researchers and the marketplace.

6. Project Milestones and Technical Accomplishments

2014 (Total-22), Highlights: *3 Peer review Journals and Periodicals* including an **IEEE Transaction on Power Delivery** journal article and **Best Conference Paper** on Markets, Economics and Planning at IEEE PES; *6 Peer Reviewed conference publications*; *4 Transmission and Distribution publications*; and *9 invited presentations*.
2015 (Total-21), Highlights: *3 Peer Reviewed Journals and Periodicals*; *4 Peer Reviewed Conference Papers and Posters; 3 Transmission and Distribution Publications; 15 Invited Presentations;* and *1 Copyright assertion*
2016 (Total-35), Highlights: *1 Peer Reviewed Journals and Periodicals*; *6 Peer Reviewed Conference Papers and Posters*; *3 Transmission and Distribution Publications; More than 25 Invited Presentations*; More than 95 *Lab Corps Interviews.*

	FY2014	FY2015	FY2016
Quarter One	Evaluate the Beta, Java based DLR software with IPCo Beta test area and analyze/optimize. Cooperate with commercial CFD vendor—created new DLR/transmission features for commercial use. Delivered Letter report communicating completion of Milestones and related achievements	DLR: Test and improve GLASS robustness by subjecting to GLASS_Gen data generation tester; Test CFD DLR/transmission module and generated computationally efficient wind models; P&R: Begin meteorological, forecast and planning and routing incorporation research with team of partners.	N/A - GMLC Delayed Start (No FY16 Funding available)
Quarter Two	Evaluate system cost for weather based DLR with IPCO. Deliverable: Report describing achievement	DLR: analyzed and IPCo DLR data sets visualized in 3D CAVE. Initiate large scale CFD WindAtlas. True dynamic rating for GLASS conceived. P&R: Investigate Planning and Routing tool concept with existing industry tools.	N/A - GMLC Delayed Start (No FY16 Funding available)
Quarter Three	Form a multi-institution team to begin investigation of the feasibility of integrating dynamic line rating data sets in Transmission Planning and Routing Toolkit.	DLR: Investigate meso-scale vs. persistence vs. micro-scale forecasting techniques for DLR for future cross-cut project. Investigate resilient CFD methods against failure of single weather stations. P&R: INL will create a CFD-based DLR GIS layer and system architecture.	Idaho National Laboratory will update (GLASS), to enable IEEE standard modes. Road map for the P&R tool plug-in integration with web-based and/or other industry software toolsets. Finally, INL will launch Human Factors with observations and interviews at electric utilities.
Quarter Four	DLR: Evaluate GIS based development platforms to capture key features for DLR Planning and Routing Toolkit. Delivered: letter report describing above. P&R: Report Wind Atlas large scale CFD on the IPCo test area. Delivered: comprehensive report.	DLR: GMLC proposal submitted—AOP mod extending FY15 work in anticipation of delayed GMLC funding. INL installation into Idaho Power connected to EMS data system. Promote DLR as Chair the Smart Grid Track at the IEEE Conference on Technologies for Sustainability in July of 2015. Delivered report and 2015 publications P&R: Completed python prototype of P&R tool.	Minimum of two publications submitted on DLR research at Idaho National Laboratory Additionally; Planning and Routing tools was proof-of-concept demonstrated to show potential optimization for a prospective wind farm to an existing transmission line currently under study with Idaho Power Co. Summary report of Human Factors efforts and plans

7. Budget History

FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$500k	**$246k***	**$500k**	**$251k****	**$600k**	**$200k**

Industry In-Kind, WFO (FY14), and CRADA (FY15)

AltaLink: FY14 - $0k; FY15 - $158k ($130k CRADA**); FY16 - $8k (labor, equipment, software integration and testing)
Idaho Power: FY14 - $201k ($151k WFO*); FY15 - $53k; FY16 - $150k (labor, equipment, software integration)
WindSim: FY14 - $45k; FY15 - $40k; FY16 - $27k (labor, software, simulation support).
Oklahoma Gas and Electric: FY14 - $0k; FY15 - $0k; FY16 - $15k (control center observations and Flowgate R&D).