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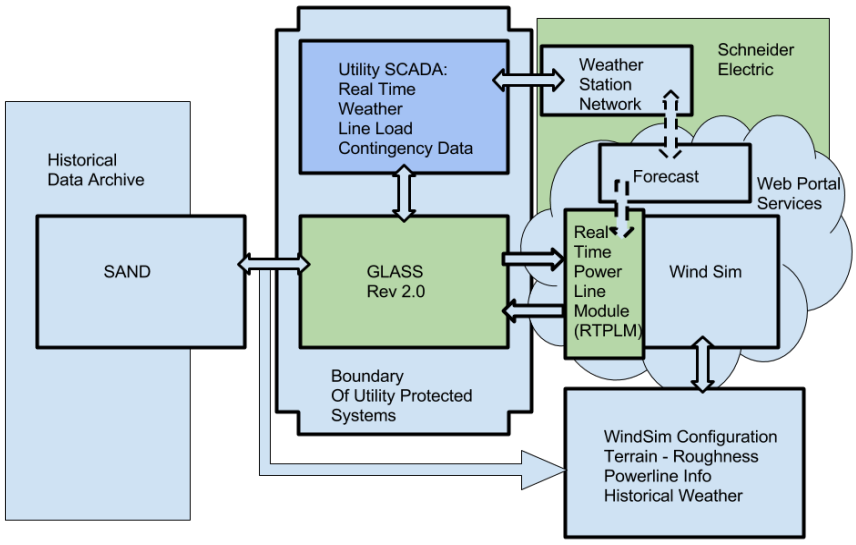
Technical Summary/Abstract for Public Release

This technical abstract describes the Technology Commercialization Fund proposal to advance the research software for real-time dynamic line rating of overhead transmission lines from a technology readiness level (TRL) 5 to a near production TRL 7 / 8. Based upon the validation pilot studies successfully concluded in recent years, and information we have received via the Summer 2016 DOE Lab Corps program, we believe this combined dynamic line rating (DLR) solution has a unique competitive market advantage, and represents a disruptive energy solution that can provide a lower-cost method for removing power flow constraints. System planners and grid operators will be informed of available transmission and distribution capacity that was previously restricted by Static Line Ratings (SLR), which, when integrated into utility operations, leads to lower energy costs for consumers, with up to and often beyond 40% increases in capacity above conservative static line limits. Adoption of DLR technologies will enable a smarter and more reliable electric grid. The commercialization path described in this proposal builds on the currently "loosely" interfaced components of the INL developed Generalized Line Ampacity State Solver (GLASS) - Rev 1.0, WindSim CFD Software and WindSim Real Time Power Line Module to build a tightly coupled commercial package with a real time interface between GLASS Rev 2.0 and WindSim Real Time Power Line Module (RTPLM). The illustration, below, shows the block diagram of the modules and data flow. The interface between GLASS and RTPLM is intentionally divided at a critical boundary for both the utility customers and for the commercial interests of flexibility in the Software as a Service (SaaS) deployable of modules. Requirements on information security exist at utilities to maintain sensitive information within the "firewalls" of the utility; thus, GLASS rev 2.0 is configured to remain inside that boundary with defined interface to utility SCADA system. The RTPLM, WindSim and Forecast module rely on data sources of models that can take advantage of cloud resources more efficiently and provide business models for deployment desireable to the market. Web-portal access for real-time information exchange is envisioned at the prefered embodiment of the software platform. Schneider Electric, a commercial service provider to over 700 utilities globally, will join the team for development of the Web Services portal and weather station communication including interfaces to forecast data streams. The anticipated benefit is the accuracy and dependability of the transferred climatologies over the simplified reduced order approximations previously used. The outcomes of this TCF project will include: "Shrink wrapped" commercial software, commercialization, promotion and investment strategy, and partnership agreements which formalize CRADA and licensing with INL and partners.



Commercialization Plan

Target Markets

The initial target for the proposed technology will be power transmission markets where a need for increased transmission capacity has been identified. Through the application of DLR, existing power line usage can be optimized through better situational awareness of the operating limits and state of thermally limited overhead transmission lines which account for up-to 16,000 miles of the transmission system in North America. Implementation of DLR on these constrained networks will help extend transmission capacity without costly investments in infrastructure upgrades or rebuilds which can cost as much as $3M/mile.

We believe the market size for the INL DLR solution represents the dollars lost due to congestion & grid management costs; $1.3 billion being spent annually by independent system operators (ISO) in USA. There are 160,000 miles of high voltage transmission lines in the USA and 500 power companies. 5%-10% of the lines have operating constraints resulting from thermal limitations. Overcoming these limitations by installing new conductors is often cost prohibitive.

Possible technical barriers for commercialization include software compatibility and integration into existing systems as well as proper weather monitoring support. Regulatory barriers also exist in the form of utility rate adjustment rules. Current rules nominally disincentivizes utilities from making capital investment in non-wires alternatives to relieving transmission congestion. Exceptions to this trend do exist in notable non-wires alternatives projects.[1] Such exceptions have enabled realization of alternative, more productive investments that defer capital expenditure to the benefit of utilities or public interest. This barrier is further diminished through the application in infrastructure that is not readily improved due to right of way constraints or public opposition.

Competing Technologies/Products

The technology landscape includes several vendors that offer dynamic line rating products based upon different principles, complexity levels, and prices. The applicable technologies have a variety installation, maintenance, and cost attributes. They range from line contacting direct measurement of temperature or tension, to LIDAR or visual methods of measuring line sag, to indirect methods that are derived from sparse or wide area weather measurements but do not include computational fluid dynamics methods of forecasting.[2] The INL technology solution is well positioned based upon system cost and system impact to industry. Competitive advantages include lowest cost of quality and highest accuracies, flexible and portable solution, smart grid interoperability, and the solution can represent an enhancement to existing solutions deployed. The teams LabCorp finders are that implementation can be made with 30% cost savings to current implementations with large over all improvement of line rating abilities. Coopetition business model is a potential with sensor and device manufacturers, where weather based DLR provides an economical wide area application to bolster and be bolstered by inclusion of direct measurements of

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[1] microgridknowledge.com/utilities-embracing-disruptive-energy-non-wires-alternatives/

[2] E. Fernandez, I. Albizu, M.T. Bedialauneta, A.J. Mazon, P.T. Leite, Review of dynamic line rating systems for wind power integration, Renewable and Sustainable Energy Reviews, Volume 53, January 2016, Pages 80-92, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2015.07.149.
(//www.sciencedirect.com/science/article/pii/S1364032115007960)

sag, line temperature, etc. on a limited number of spans for real-time cross validation of independent measure to provide highest confidence data possible. The synergistic application of weather based DLR has market expanding potential for both existing and this new commercial approach.

Proposed Commercialization End State

The commercialized state will be a software application licensed to INL industry partners and solution providers that will be made available for purchase by utility customers in combination with support of the product and related services. The objective is to provide a full solution that will have minimal impact on utilities existing infrastructure, while enabling new dynamically calculated line rating limits to be used in transmission line operations. Modern EMS/SCADA systems make this integration possible. The role of the solution provider will be to provide access to the line-based alerting technology using either current weather observations or weather forecasts as part of a Software as a Service (SaaS)-based platform which is currently in development by Schneider Electric and will be available for this project once ready. This will be extremely useful for DLR customers to have a real-time view into changing line ampacities and take immediate action based on these alerts.

Commercial Success

The Commercial Success of the proposed technology will be determined by implementation of the associated products in areas of the world where power lines operate at or near capacity. Such wide scale adoption will be possible once the technology's potential to generate operational and capital expenditure cost savings are demonstrated. Continued work on standardization activities will stimulate the use of DLR technologies enabling even broader acceptance.

Innovative Improvement

Based upon three industry validated pilot studies and information we have received from countless industry interviews and standards association meetings and conferences, we believe this combined solution has a unique competitive market advantage, and represents a disruptive "smarter grid" energy solution that can provide a lower-cost method for removing artificial or systematic power flow constraints. This will be done by informing system planners and grid operators of available transmission and distribution capacity that was previously restricted by Static Line Ratings (SLR), which, when integrated into utility operations, leads to lower energy costs for consumers. No other DLR technology integrates real time weather station data with terrain dependent computational fluid dynamics (CFD) wind flow modeling and weather forecasting.

State of Industry

The US produces 4.1 trillion Kilowatt-hours of electricity per year. There is a substantial challenge in moving this energy to cities, factories, military bases in the right amounts when needed. Power utilities operate transmission lines based on static ratings, which set a conservative limit on the amount of current the lines can safely carry without overheating. Without accurately measuring the environmental conditions and their effects, lines can be critically underutilized. Dynamic Line Rating technologies enable transmission owners to determine capacity and apply line ratings in real time. This enables system operators to take advantage of additional capacity when it is available. Idaho National Laboratory uses commercially available weather monitors in combination with sophisticated weather analysis and line rating software called GLASS resulting in up to 40% enhancement, or more in certain instances, in transmission line capacities.

Various validation cases and field testing of dynamic line rating technology solutions have been applied over a 15 to 20 year period, and benefits have been proven in various markets, both foreign and domestic. Customer pain points include transmission congestion relief, grid reliability and safety, better consumer pricing, reduced curtailments, the ability to integrate renewable power, and optimize asset utilization.

The market is highly regulated, and outreach activities to influence regulatory policies are necessary for wide scale deployment of DLR solutions. A market shift in the utility revenue model that allows utilities to profit from improved use of existing transmission lines would enable further deployment and corporate adoption. Validating the benefits of dynamic line rating technologies will accelerate this shift by further incentivizing utilities through public utility commission's goal of providing the lowest cost - highest reliability service to industrial, commercial, and residential customers.

The dynamic line rating TCF project will result in a fully featured software package. Market deployment will require this team's key solution partners and system integrators to interface and service the grid operator. These partners have been identified, and this proposal announces the partnership with Schneider Electric, a commercial service provider to over 700 utilities globally. To date three "Phase I" pilot projects have been completed successfully and published in industry recognized publications and marketing strategies; these include IEEE, AWEA, AMS, CIGRE, EWEA, NWA.

This TCF development project is needed to buy down the risk that utilities see in applying full dynamic line ratings with forecasts to their systems by performing the necessary commercialization steps with key partners necessary to provide utilities with a valuable and supportable product and commercial team. While DOE research has supported the validation of the method, the true value of DLR is with the integration of weather and load forecasts enabling utilities to realize full monetization by selling the added capacity in various futures markets. As the DOE TCF program recognizes, commercialization is accelerated with industry investments. The TCF is anticipated to identify and initiate a first utility paid full pilot implementation, to further establish the commercial viability of the technology to reduce congestion on thermally limited transmission by up to 40%, better utilizing the existing transmission infrastructure.

The business and commercial operation plan includes installation of the Dynamic Line Rating Technology into a minimum of five utility control rooms within five years of the inception of the TCF project.

Technical Narrative

Below is a technical description of the project including the objects from each of the partner participants in bringing a commercial product to market.

INL contribution:

As utilities replace aging infrastructure and incorporate renewables from remote locations, unlocking extra capacity within existing transmission lines offers profound advantages beyond efficiency and reliability. By enhancing the capacity of existing transmission infrastructure, Generalized Line Ampacity Solver (GLASS) and its Dynamic Line Rating capabilities will help reduce the cost of bringing new wind generating capacity online, making renewable energy production more economically feasible. Expanding the capacity of existing infrastructure also will give planners more leeway and flexibility as they determine which lines to replace or rebuild, allowing for expenses to be spread out over longer periods of time. Providing advanced data directly to control rooms will allow operators to make decisions based on

reliable data with less uncertainty. Ultimately, the GLASS software will help industry more readily adopt Dynamic Line Rating to optimize Smart Grid network capacity.

As part of the DOE-EERE-Wind Energy Technology Office - Dynamic Line Rating Project, the applications GLASS and Systematic Analyzer of Numeric Data (SAND) have been under development for the past 2 years. GLASS supports INL's Dynamic Line Rating methodology by informing system planners and grid operators of available transmission capacity beyond traditional Static Line Ratings (SLRs). SLRs are based on a fixed set of conservative environmental conditions to establish a limit on the amount of current a line can safely carry without overheating. INL's approach uses commercially available weather stations mounted on industry-informed custom INL brackets. The data from these stations, in combination with Computational Fluid Dynamics (CFD)-enhanced weather analysis, allows utilities to safely provide more robust line ampacities using DLR instead of the overly conservative SLR that have been the norm. The GLASS software utilizes physics-based algorithms found in IEEE Standard 738, an international standard defined by the Institute of Electrical and Electronics Engineers for "Calculating the Current-Temperature Relationship of Bare Overhead Conductors." GLASS also uses Geographic Information System (GIS)-based terrain data, with elevation and surface roughness and land use layers; databases containing previously measured weather conditions; pre-computed Computational Fluid Dynamics (CFD) model look-up tables; and system parameters and load data describing the operating electrical infrastructure. The INL contribution to the commercial success is through a revision of the existing software to a level of product hardened application and the creation of the interface to connect with the assets contributed by WindSim and Schneider Electric.

WindSim Contribution:

INL and WindSim have a R&D collaborative relationship that has spanned a period of six years. The relationship has grown from INL being a customer of WindSim to a cooperative partnership targeted at improving technology for the electricity sector by improving the capability to model and transfer weather conditions to the detailed points needed to accurately perform DLR across a larger geographic area in a cost effective manner. GLASS currently utilizes a simplified model computed by WindSim to approximate wind conditions at all transmission line spans in a computationally efficient method. For being able to run WindSim and Glass consecutively look-up tables were produced by WindSim which could be used by GLASS. These are the simplest CFD results which describe the relation between the weather station points and the line midpoints. More advanced options could not be used due to the fact that the WindSim source code would need to be open to INL.

As we now want to focus on the commercialization and integration of the products as a solution set, it is important to get the best possible results and therefore WindSim needs to extract the relevant part of their commercial code and put that into an API which can be used by GLASS to get real time results. This part is named the WindSim Real Time Power Line Module (RTPLM) and will contain parts of the commercial code of WindSim CFD software. The advantage of creating as modules will be that individual customers can drive the solution that meet their needs: the complete application can then reside inside the "firewall" of the utilities and no connection to external web portals will be necessary or portions can reside as SaaS connected through a secured interfaced that also provides the conduit to weather station and forecast data to the system (see Schneider Electric section below). The development is planned for Task 2 (T2) identified below and will take around 300 hours. In addition, 300 hours of commercialization support will be committed to. This includes identifying and recruiting an interested utility partner for the next validation pilot, broadening awareness through exhibitions, presentations, and white papers, contributing

to the success of industry workshops, developing business plan, proposed structure of commercial venture, and overall support in de-risking the path to commercialization.

Schneider Electric Contribution:

Schneider Electric will provide support to the TCF through the following activities and cost share to enable the project to bring seamless integration to existing energy management systems:

•Access to licenses for our software platform to explore feasibility of front-end integration for a SaaS-based Dynamic Line Rating offer
•Commercial offering of and collaboration to support the generation of forecasts for any weather station locations involved in the project
•Data management of weather stations involved in the project (not covering any non-standard activity that might be required to make the data compliant with our systems)
•Access to the line-based alerting technology using either current weather observations or weather forecasts as part of the SaaS-based platform which is currently in development and will be available for this project once ready – This will be extremely useful for DLR customers to have a real-time view into changing line ampacities and take immediate action based on these alerts
•Time commitment per month from a Schneider Electric resource for project discussions
•Support identifying and/or recruiting an interested utility partner for the project based on our existing customers within the utilities industry.

Project Plan

The project is structured around a 24 month plan that includes a 3 month period for a CRADA to be negotiated and an anticipated business continuation through a utility funded projected. The bulk of the software development and system hardening will occur over an accelerated and focused 10 month period. The individual milestones are delineated in Table 1 with tasks separated between technical and business development. The technical tasks are required to align the partners distinct existing platforms into one commercial offering. The business tasks are required to align the agreements and models necessary for a successful launch of a sustainable business. Note, the DOE funded portion of the TCF is compressed to a 17 week schedule as spending will not commence until CRADA is signed, including all formal agreements for cost share is finalized. The final 4 months of the 24 month project is anticipated to be used for business development towards a customer funded pilot project. Table 2 gives a logical progression and expectations of progress

The technical milestones will be completed by month 18. INL has primary responsibility for GLASS software productization (T1). In parallel, WindSim will develop the RTPLM (T2). The interface between the two will be established in a joint effort between INL and WindSim (T3). Finally the platforms will be connected to the Schneider Electric web portal in an all partner collaboration effort with Schneider Electric providing the access and consultation to INL and WindSim development teams.

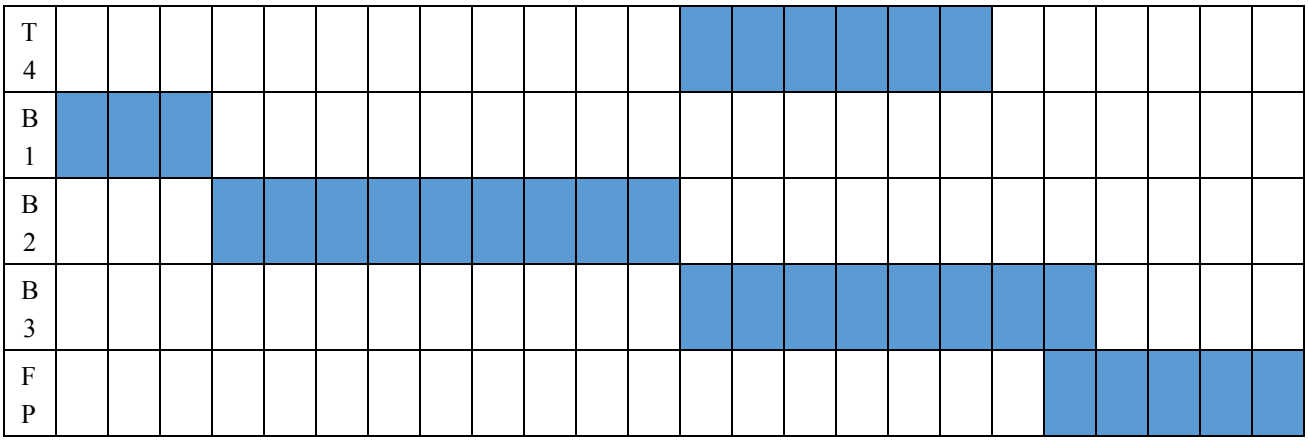
The business milestone will run in parallel with the technical milestones and will be completed by week 20 of the project. These include executing the three party CRADA (B1), refining and instituting the business plan created in LabCorp Cohort 3 in 2016 (B2), and forming the business organization tailored to customers and investors for the defined technology product (B3). The final phase of the project which is in reality the first venture of the newly defined business is a funds in pilot project that will provide both the evidence of success and the start of a sustainable commercial entity as an ultimate dissemination of the prior research support from DOE.

Table 1. Milestone description and goal/outcome.

Milestone	Description	Goal/Outcome
1	Technical 1(T1): GLASS Core Productization (5 months)	Implementation of GLASS rev 2.0 core functionalities. Lightweight streamlined version of research GLASS rev 1.0 including interface to SCADA interface
2	T2: Design and Implementation RTPLM (5 months)	Implementation of real time engine for WindSim PowerLine Module to input weather station
3	T3: TechRTPLM-to-GLASS Interface Definition Implementation (4 months)	Design and Implement function interface from GLASS to RTPLM and Forecast engine interface
4	T4: Develop and Implement and test integration through Schneider Electric web portal including communication for weather stations (6 months)	Customer interface to DLR information and conduit to rating and
5	B1: CRADA formation	Negotiate the binding document for the commercialization including licensing terms for business commercialization partners
6	B2: Refine Business Plan	A plan that outlines a successful path to commercialization taking into consideration all areas of the business model canvas developed during 2016 Lab Corps Cohort 3
7	B3: Structure Commercial Venture	Create an organization that is attractive to customers and create a baseline for the marketing of the product line.
8	FP: Business development towards customer funded pilots	Anticipated utility industry funded project for first commercial rollout of TCF product.

Table 2. Milestone schedule 24 Month Development.

Period of Performance (POP) by Month																								
M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
T1																								
T2																								
T3																								



Team and Resources

The team for this TCF is made up of three key pieces that were identified during DOE LabCorp in 2016. The senior subject matter expert is the principal investigator, and includes supporting team members from the Power and Energy Systems research and development program at INL. The INL team provides the core expertise in overhead line rating including GLASS. DOE has funded the research effort including participation of development of revised standards for IEEE and CIGRE beginning in 2013 to develop the understanding to improve the transmission system. The key to the technology is the incorporation of computational fluid dynamics provided by WindSim whose software tools are used by over 300 companies worldwide, for more than 20% of the world installed wind capacity, trusted by developers, utility, manufactures, investors and academic institutes. To effectively integrate into utility control rooms through industry accepted means, Schneider Electric forms the third partner. They are a global specialist in energy management and automation, with revenues of ~$29 billion in FY2015 and 160,000+ employees serving customers in over 100 countries. Schneider Electric will provide the communication backbone and customer interface through an established commercial infrastructure.

Team Members--see detailed qualifications in attached:

- Jake Gentle - PI - Power Systems Engineer, Program Manager; INL
- Timothy McJunkin - Senior R&D Engineer; INL
- Jacob Lehmer - GLASS Software Development; INL
- Donna Rennemo - Entrepreneurial Lead and Business Liaison; WindSim
- Catherine Meissner - Software Development Manager; WindSim
- Matteo Mana - Software Development Power Forecasting; WindSim
- Arne Gravdahl - CFD Software Architect and Founder; WindSim
- Shylesh Muralidharan - Global Solutions Product Manager Energy Division; Schneider Electric

INL

INL is the nation's lead laboratory for nuclear energy research, development, demonstration and deployment and we are engaged in the mission of ensuring the nation's energy security with safe, competitive and sustainable energy systems and unique national and homeland security capabilities. In the

areas of energy and environment, we're addressing energy production challenges with contributions in renewable energy integration, transportation transformation, water utilization, energy critical materials, biomass feedstock assembly, and advanced manufacturing. Within the renewable energy integration mission, INL has demonstrated leadership in developing leading research in concurrent cooling of transmission lines for greater wind energy adoption. INL provides the core expertise and foundational technology to support the development of the commercial product and business line proposed in this TCF.

WindSim

Almost every country has created wind resource maps to find potential windy places suitable for building new wind plants. Modelers use a wide range of methods to create these wind resource maps. Yet new methods are needed to capture the detail required to enable dynamic line rating, which could boost transmission and distribution line capacity by 10 to 40 percent.

Idaho National Laboratory researchers are working with the simulation company WindSim to develop a new wind atlas method using specialized software. The new approach enables dynamic line rating modeling and simulation that can expand over hundreds of miles. To be as accurate as possible, the method combines wind speed and wind direction data from smaller simulation areas, and is based on scaling against measurements where available.

WindSim pioneered the use of CFD (Computational Fluid Dynamics) technology to optimize wind turbine placement, and offers CFD software, training, independent technical and engineering services to the wind industry. The company has a global presence in over 20 countries, and has been the thought leader and expert on CFD within the wind industry. www.windsim.com

WindSim and Idaho National Laboratory (INL) researchers have been collaborating for 4 years developing the weather based dynamic line rating with CFD (WindSim Power Line) and using U.S. Department of Energy Idaho National Laboratory's General Line Ampacity State Solver (GLASS). Three industry pilot validation cases have been successfully completed showing transmission line capacity can be increased by up to 40% by deploying this new method; combining wind speed and wind direction as calculated by WindSim CFD software with the cooling calculation done by the GLASS tool developed by INL. WindSim developers continue to work closely with the INL team in harding the dependencies between GLASS and WindSim PowerLine software.

This past summer WindSim joined the INL team as the Entrepreneurial Lead in the U.S. Department of Energy's Lab Corps program, which enabled our teams to begin to de-risk the path to commercialization for the technology solution. There is a great deal of market intelligence that was collected based upon over 100 customer/ industry interviews. INL and WindSim explored the commercial ecosystem and have a thorough understanding of the opportunities and challenges to launching a viable commercial outlet for this technology solution. The specific plan will be to harden the minimum viable product including GLASS software to commercial technology readiness. The steps include; refactoring and streamlining GLASS software, refine the business plan and structure the commercial venture to create an organization that is attractive to customers and create a baseline for the marketing of the product line.

WindSim has identified key alliance partners on a global scale confirmed to support the success of the technology solution. And continue the process of identifying technology partners for business growth and development. The team has prioritized securing an utility interested in participating in a full scale pilot that tests the hypothesis that the weather forecast is a key driver to enable utilities to monetize extra capacity and move power on a scheduled basis, address key pain points like congestion and grid safety. Integration of the forecast data into GLASS is key to development of the minimum viable product MVP.

An important aspect of the industry pilot is to test the integration of the solution into the utility energy management system (EMS) and SCADA systems to ensure seamlessness.

WindSim is committed to working with the INL team towards securing private industry and government investments, contributing to industry communications through participating in pilot studies and validation cases, and impacting industry standardization activities to ensure wide scale adoption of DLR technologies enabling a smarter and more reliable electricity grid. WindSim understands the financial support and in-kind contributions required for this application.

Dynamic Line Rating (DLR), the process by which transmission line ampacity ratings are dynamically calculated in real-time, is of high interest to utilities, and has an urgent need for added forecasting R&D to be deployed within the next few years. Utilities are beginning to embrace non-traditional means to ease system overloads instead of conventional, capital intensive construction projects with long lead times, often delaying or prohibiting the advancement of fast paced and cost sensitive renewable energy projects. This past summer, Schneider Electric was introduced to the Weather-based Dynamic Line Rating (DLR) with Computational Fluid Dynamics (CFD) + Forecasting solution, as developed by Idaho National Laboratory, and WindSim AS. Based upon the validation pilot studies and information we have received, we believe this combined solution has a unique competitive market advantage, and represents a disruptive energy solution that can provide a lower-cost method for removing power flow constraints. This will be done by informing system planners and grid operators of available transmission and distribution capacity that was previously restricted by Static Line Ratings (SLR), which, when integrated into utility operations, leads to lower energy costs for consumers.

Schneider Electric
Schneider Electric is a commercial service provider to over 700 utilities globally. We recognize that there is still uncertainty about how this new technology solution will be commercialized, and have decided to support the Technology Commercialization Fund 2017 proposal as we see value in supporting this technology going forward and getting a head start in bringing this technology to market.

Our business is willing to provide an in-kind contribution as follows:
•Access to licenses for our software platform to explore feasibility of front-end integration for a SaaS-based Dynamic Line Rating offer
•Commercial offering of and collaboration to support the generation of forecasts for any weather station locations involved in the project
•Data management of weather stations involved in the project (not covering any non-standard activity that might be required to make the data compliant with our systems)
•Access to the line-based alerting technology using either current weather observations or weather forecasts as part of the SaaS-based platform which is currently in development and will be available for this project once ready – This will be extremely useful for DLR customers to have a real-time view into changing line ampacities and take immediate action based on these alerts
•Time commitment per month from a Schneider Electric resource for project discussions
•Support identifying and/or recruiting an interested Utility partner for the project based on our existing customers within the Utilities industry.
In return, Schneider Electric is interested to have as much “exclusive” rights to commercialize the technology as possible once it is market-ready. We welcome the opportunity to join this collaborative knowing wide-scale adoption of DLR technologies will enable a smarter and more reliable electricity grid.