Renewable Energy Development and Integration, Microgrids, ESS and Power Systems

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**Power Systems and Renewable Energy Technologies**

- **Mission**
  - Perform scientific research and engineering to enable development, deployment and integration of renewable energy and power system technologies

- **Product Areas**
  - Wind Energy
  - Solar Energy
  - Power Systems (including micro/smartgrids)
  - Bioenergy
  - Nuclear
  - Geothermal Energy
  - Hydropower
INL has 20+ years of experience with DOD and DOE high reliability power systems, backup power and energy security, renewable energy integration and microgrids (development and design, implementation, assessments, modification and applied research).

Many project examples:
- FE Warren AFB wind turbines and backup grid energy security test
- Ascension Island power plant and wind farm
- Marine Forces Reserve wind turbines and microgrid projects
- DOE Pantex wind farm ESPC
- Assessment and repair of Tooele Army wind turbine
- Navy San Nicolas Island battery and island grid testing and modeling
- Dynamic transmission line rating research
- Hybrid power systems applications research with solar PV and CSP, wind, batteries, fueled generators, controls/integration, power electronics, load management, RAM studies, etc.
INL Microgrid and Renewable Energy Experience

Project examples continued:

- Multiple Army and other ECIP solar and wind projects
  - Tooele Utah 1.5 MW sterling concentrated Solar
  - 4 MW Photovoltaic at FHL
  - 2 MW PV at Camp Parks
  - 2 MW PV at Dugway, others
  - Multiple involvements utilizing energy storage
  - Various microgrid and EMCS involvements (Tooele, Dugway, FHL, Ft. Bliss, others)
  - Multiple energy conservation project efforts (all under ECIP)
  - 1.5 and 1.79 MW wind turbines at Tooele UT
  - Potential INL and larger federal wind farm developments
  - Malmstrom AFB wind energy economic assessment
  - Vandenberg AFB, Dugway electrical futures planning studies
Energy Storage Systems (ESS)

• The cost targets necessary for the implementation of ESS into grid and microgrid applications are typically in the $100-500/kWh range for large applications, with smaller applications moving into cost ranges above $500/kWh, and only applications with special or higher energy security needs being able to justify costs above $1000-1500/kWh.
  
  • Need enough cycle life to push cycle cost per kWh into range needed for the application (i.e. $300/kWh / 4000 cycles = $0.075/kWh + O&M costs).

• Currently, few technologies meet these demands and are not competitive with other storage technologies such as pumped hydro and gas generation, which are typically in the $150-300/kWh range (or approximately $0.08+/kWh for pumped hydro when cycle life and other factors are included, and $0.07-0.30/kWh or more for SCCT generation depending on use hours and other factors).

One of the INL’s Secondary-use Li-ion Battery/Inverter Combinations
ESS, continued

• For ESS and energy resource/power grid couplings to become more competitive, a direct understanding of how different forms of ESS can be used in a full system (for example, to improve wind and solar grid integration) and how the expected use impacts ESS performance and aging is critical.

• Other critical considerations that will have long-term cost implications:
  • Cycle life and use-case/thermal effects.
  • Supply chain, chemistry and materials/systems choices.
  • System efficiencies, usable ranges and duty cycles.
  • Ability to replace modules, components.
  • Recycling/disposal.
  • Etc.
**Flow Batteries**

- **Chemistries:** Aqueous (Fe/Zn), Vanadium Redox, others
- **Size:** Typically in 20-40’ containers
- **Cost:** Moving below $1000/kWh, potential for below $500/kWh is good
- **Efficiencies improving,** >69% on AC side, >85% on DC side
- **Need for more performance validation, use-case testing and integration improvement**
Other ESS

- Secondary use (LFP/graphite, NMC/graphite, NCA/graphite, NiMH)
- Super capacitors
- Flywheels
- UPS (advanced PbA, Li-ion) for critical systems
- Also differentiate cost of power electronics, BMS systems, systems integration and what is included and not included.
Why INL is interested in ESS

- Significant background in battery testing and R&D for EV programs (DOE, USABC, etc.)
- DOD and other micro/island grid work (R&D, testing, development, implementation support)
- Improve integration options for renewable energy, DER
- Installations with high energy security needs, continuing to invest in backup power systems, UPS’s, etc. With new technologies, improved systems architectures need to be considered.
- Energy storage, load control and shifting can enable improved use of fueled generation resources, stretch fuel supplies, improve reserves and dispatch options, and in many cases lead to improved long-term business case/economics.
- Users with these types of energy security assets could offer interesting business and technical interaction potential with serving utilities.
What Can Be Done With Significant Levels of Storage?

- Above: extreme example of 50+% solar penetration, storage energy content of about 50% of solar energy content (daily average over course of year).
INL Microgrid R&D Testbed

Grid energy storage R&D, testbeds, collaboration and testing activities expanding significantly at National Laboratories (also Grid Modernization).

An example of layered control.
Multi-domain Integration and Testing

- Incorporation, standardization and improvement of integration and testing experiences from DOD, existing microgrid work and EV group application testing/R&D.

Many systems integration /testing experiences with various DOD projects:
Demonstrate ESS value to grid as services

- Power-Hardware-In-the-Loop (PHIL) of ESS components
- RTDS® will be used for assessing ESS dynamic and transient performance using a grid emulator under real world conditions
- Distribution and Transmission network models will be used for analyzing ESS performance

- Challenges involved:
  - Communication interfaces between RTDS® and ESS components will be different for batteries and supercapacitors
  - Time of response of the grid emulator to maintain real time simulation
Problem Statement: Transmission line ampacity ratings, traditionally limited by conductor thermal capacity, are defined by a static rating using predetermined environmental conditions. Without accurately measuring environmental conditions and their effects, existing transmission lines can be significantly underutilized. Using a dynamic line rating system to accurately monitor these conditions will lead to improved line ampacity ratings, better knowledge of operational/reliability issues and potentially safer operation of the overall system.

Impact of Project: Wind power production stands to directly, and most immediately benefit from increased transmission capacity through improved dynamic line rating systems, due to environmental effects. The system being developed and tested improves overall dynamic line rating quality and leads to average capacity improvements of 10-30%, or more in certain areas.
Technical Approach

- Installation of 17 wind data loggers in a 600mi² test area that monitor wind speed, wind direction, ambient air temperature, and solar radiation for 4 transmission lines: (2) @ 138kV and (2) @ 230kV.
  - Installable on voltages up to and including 500kV
  - Expandable for end to end monitoring and analytics
- Development of topographic and roughness models of the terrain area
- Establishment of a communications system (900MHz radio, cellular, and satellite modem options available) and programming to integrate the data into the Utilities operations SCADA/EMS network
- Integration of IEEE 738-2006 standard for static/dynamic line rating
- Implementation of programming and databasing to handle data and perform line temperature and ampacity calculations
- Significant data handling and Computational Fluid Dynamics (CFD) modeling efforts for test area to monitor modeled points between the real-time data points
- Development of SCADA/EMS data displays and analysis for utility operations and planning
Why Try This Method

• Most other existing methods are costly per unit and cover very limited area, unless combined with many more units or other measured data.

• Can be difficult to extend temperature, sag or tension measurements to other line areas unless weather data is also collected.

• Wind and weather modeling, communication systems, and computational capabilities have improved to the point where trying this is possible.

• Cost per unit allows many more data points to be collected to improve uncertainties and concerns.

• Weather data of such high resolution (and corresponding developed databases/statistics) can be used for many other aspects of utility operations and design.
Project Area Expansion

Approximate Area: 6,600mi² (17,100km²)
Approximate Total Line Length: 450mi (730km)
Line Capacity Comparison

Graph of % Line Capacity Increase on one of the lines in the test area compared to wind and hydro generation in the same area, using Alpha-version calculation software version and PI database software.
Estimated vs. Actual Wind Speed

Graph of estimated wind speed (+/- 20% error bars) versus actual wind speed at one of the test/validation locations. Estimate is calculated using modeling results and lookup tables applied to real-time (3 minute) weather data points, then used to calculate line capacity with IEEE Standard 738-2006.
Field Validation Results: Conductor Temperature

Completed 3-month field demonstration using INL’s DLR methodology coupled with Promethean Devices, LLC’s non-contact IR based transmission line monitoring system.

- Achieved +0.968 correlation coefficient between the thermal conductor temperature measurements.
- Identified geographic dependencies on ambient air temperature, affecting calculated conductor temperature and available ampacity.
- Investigated IEEE-738 impacts due to zero wind speeds.
Field Validation Results: One Month’s Worth
Field Validation Results: Available Ampacity

Completed 3-month field demonstration using INL’s DLR methodology coupled with Promethean Devices, LLC’s non-contact IR based transmission line monitoring system.

- Calculated conductor temperature using collected weather data, CFD-based lookup tables from models, and the IEEE steady-state conductor temperature equations.
- Calculated the maximum available ampacity over a 60-minute time period using the IEEE transient current rating function.
- Determined that high-resolution weather data needs to be collected at critical locations with modeling in between.
- Determined that using mesoscale climatology data without local measurements and sophisticated CFD modeling for areas between actual measurements often leads to minimal thermal and ampacity improvements above the static IEEE standard ratings, with large uncertainties.
Wide Area Terrain Modeling: High-Resolution CFD

- Completed CFD model updates, including new weather stations.
- Expanded area includes the same four transmission lines modeled in the alpha phase, but it incorporates an end-to-end solution for testing and validation at an operational scale.
  - Modeled terrain area increased from about 600 to 6,600 mi²
  - INL identified 47 total weather station locations needed to support a DLR of more than 450 line miles: two lines at 230 kV and two lines at 138 kV.
FE Warren AFB Wind Project, WY

- **First Air Force wind project in the continental U.S.**
- **Expected to save the Air Force more than $3 million in energy costs over the next 20 years.**
- **Phase One – 2-660 KW Vestas Wind Turbines, on-line in 2005.**
- **Phase Two – 1-2.0 MW Gamesa Wind Turbine added, completed in Spring 2009.**
FE Warren AFB Wind Project, WY

• Phase I – INL design and technical oversight, Base CE performed contracting. Phase II – INL performed all aspects, with Base CE providing basic support for base interfaces.

• Phase II included an energy security test that was performed in 2010. Included detailed analyses of distribution system islanding architecture options, and systems/dynamics modeling with PSS/E and RTDS.
FE Warren AFB Energy Security Test

Energy Security Test Performed April 2010

Test assumed approximately 1/3 of Base load and created microgrid consisting of load, base infrastructure, diesel generators, and wind farm.

Test results highly successful;
  • Data analyzed and report issued in 2010
  • Fuel reductions over 25.5%
  • Able to extend Energy Security
  • Frequency Stayed between 59.6 and 60.4 Hz
  • All mission equipment stayed on line
  • Stable system voltages
  • Maximum wind penetration with Gamesa turbine was 82.7%
  • Maximum wind penetration with Vestas turbines was 53.6%
  • Total loads supplied varied between approximately 2.1 and 3.1 MW.
  • Replicable at many bases around the world
  • Can apply to Solar as well as wind
  • Field results compared with models, lessons learned for future modeling/analysis and testing efforts
Temporary Diesel Genset Arrangement for Test
Additional Idaho National Laboratory micro/smartgrid efforts

Recent work includes:

- Multiple DOD micro/island-grid projects
- Development of new INL micro/smartgrid testbed and demonstration
- Renewable integration study involvements and IRP planning/R&D input with utilities
- Demand Response and controllable load, energy storage research, application and testing
- Battery testing with Navy
- INL/Idaho Power Dynamic Line Rating
- Power systems futures planning projects (include voltage regulation, distributed generation, smart inverters and other technologies)
- Developing potential to apply INL cybersecurity and resiliency teams/experience
Thank you!!!!!!

Questions ????
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INL Renewable Program information www.inl.gov
Frequency and Voltage Plots During the FEW Test
INL Advanced Grid Integration Capabilities

- Key Capabilities
  - Power engineers and onsite utility O&M
  - Cyber security researchers and engineers
  - Control and systems engineers
  - Wireless/communications researchers
  - Vulnerability, RAM and PRA Assessment SMEs

- Key Assets
  - Isolatable grid for transmission and distribution testing (138KV)
  - Real Time Digital Simulator (RTDS) modeling
  - Extensive outdoor wireless test bed with low RF background and spectrum authority
  - Extensive GIS systems and engineering support
Innovative ESS aspects; INL testbed ideas

For grid applications, incumbent battery technologies, such as Lithium ion, NaS, or lead acid, cannot meet the life cycle requirements of many applications under best case conditions. In real utility use-cases, both Lithium ion and NaS typically fail at 5,000-7,000 cycles or less, even with significant limitations on permissible duty cycles. When multiple 100% DoD per day and rapid cycling at partial state of charge are added to the duty cycle, both Lithium ion and NaS will fall below 2,000 cycle life. Integration and testing of more cycle able systems is greatly needed for grid and microgrid applications. These systems can include shorter-term power (supercapacitors, flywheels) and longer-term energy (flow batteries) for life cycle performance and cost optimization R&D in controlled, standardized test environments.

One system/chemistry slated for INL integrated testing is the ViZn system, based on a Zinc-Iron Redox Flow battery technology first developed by Lockheed Martin. Under this technology, battery charge is realized through an ion exchange process occurring through a membrane that separates two liquid electrolyte solutions. This technology has several key advantages:

- Electrolyte and chemistry is non-toxic, non-flammable, and inexpensive.
- Intrinsic structure of the chemical process isolates the system life cycle from the duty cycle.
- High flow and replenishment rates enable demanding duty cycles to be achieved without overheating the battery.
- Battery structure readily enables the realization of various optimized installations to meet different performance metrics.
- Modular installation structure provides significant flexibility and scalability to meet a wide array of energy storage demands.