



2014 Smart Grid R&D Program Peer Review

Project Summary

Project Title: GridLAB-D Analysis and Development

Organization: Pacific Northwest National Laboratory

Presenters: Kevin Schneider & Jason Fuller

FY 2014 Funding (\$K): Development – 400, AMI Diagnostics - 250

Project Objectives, Significance, and Impact

Development

GridLAB-D™ provides an agent-based, multi-disciplinary environment for examining and evaluating emerging technologies. It encompasses unbalanced distribution power flow, detailed modeling of individual end uses in populations of buildings, distributed generation and storage resources, and retail markets. GridLAB-D has already been used to examine the benefits of a wide range of technologies, including volt-VAR optimization, distribution automation, demand response, energy storage, and distributed generation. GridLAB-D is a valuable tool for designing demonstration projects and evaluating technical potentials prior to the cost and effort of actual deployment. By providing a multi-disciplinary simulation environment, GridLAB-D makes it possible to bring together diverse teams of experts from multiple fields of study to examine complex systems holistically.

GridLAB-D provides a framework that enables DOE to be a catalyst for driving smart grid technologies into practice. The capability of GridLAB-D to model an increasingly broad range of smart grid assets and their operation provides a transformational opportunity to enhance the value, penetration, and business case for smart grid assets. Commercially available software packages effectively analyze the traditional peak capacity planning problem faced by utilities when designing traditional power grids. Many are also beginning to see the value in time-series analysis, and are incorporating the capability into the design tools. However, these software packages have not been designed to examine the complex multi-disciplinary

problems presented by new smart grid technologies. GridLAB-D provides a new capability to industry and academia to systematically examine and evaluate the emerging benefits and limitations of new technologies. This fosters the relationships between vendors and utilities, providing a conduit for equipment, sensors, and controls that are more effective and lead to stronger business cases for smart grid investments that help U.S. industry.

AMI Diagnostics

Distribution utilities operate their systems with little to no real-time observability, and as a result, equipment generally operates autonomously with no operator knowledge of material condition. This is especially important with secondary service transformers and underground cables where repeated loss of load diversity can result in damaging high load conditions. Without direct observations, it has not been possible for utilities to know when their equipment is near failing. Automatic Meter Infrastructure (AMI) is a technology that has produced a large amount of data, but for which there have been relatively few uses other than its primary revenue function. This work is attempting to develop a method of utilizing off-line analysis of AMI data to identify slow mode failures in secondary service transformers and underground cables. These failure mechanisms can include, but are not limited to, pinpoint arcing in splices and connections, and water treeing of insulation. By better understanding the material condition of their systems distribution utilities will be able to increase system reliability and resiliency.

Technical Approach

Development

Despite the numerous successes achieved with GridLAB-D, significant additional successes can be achieved with further development. In FY14, we focused on supporting current GridLAB-D analysis efforts (microgrids), integrating new capabilities developed in support of analysis projects, and improving performance and validation processes. To support this, four major tasks were used in FY14:

1. **Support GridLAB-D analysis projects:** Support ongoing DOE-funded analysis and development projects that employ GridLAB-D as the principal analysis tool for integrated power systems, building environments, system controls, and energy markets. This includes maintaining documentation on the SourceForge hosting site, maintain build and validation computing infrastructure, distribute final releases, validate enhancements, and manage and dispatch bugs.
2. **Support new and current users:** As the experts in GridLAB-D development and usage, PNNL staff provide significant user support to external users via openly available user forums. These interactions expand the current user base while giving developers an insight into what users may need in the future. Additionally, PNNL provides online instructional training to new and advanced users in a series of webinars every other month to expand the active user base.

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3. **Further expand GridLAB-D capabilities:** While analysis projects tend to expand the analysis capability of the tool by building out model and simulation features, this task will focus on expanding basic software functionality. This includes creating APIs for integrating new tools, increasing data extraction capabilities, increasing performance and scalability, and working with users to identify additional requirements.
 4. **Participate in Grid Analytics Association expansion:** FY13 saw the launch of the Grid Analytics Association. PNNL continued to provide leadership to this fledgling organization which will provide a user-driven forum for supplementing DOE funding for the long-term development of the GridLAB-D, and encourage the growth of the user community. PNNL will be actively involved in the Association, hosting virtual meetings, encouraging/driving adoption of charters and membership documentation, organizing working groups, and continuing recruitment efforts.

AMI Diagnostics

This work is developing an off-line analysis method using AMI data to identify slow mode failures in secondary service transformers and secondary cables. This method uses AMI data and system planning models to perform a full unbalanced three phase state estimation that is used as the input to a parameter estimation scheme. Normalize measurement residuals and Lagrangians are used to identify parameter errors, and then these errors are tracked over time to identify non-diurnal variations. In order to achieve the necessary signal to noise ratio for error detection a method of concatenating data across multiple time steps has been used that allows hours, days, and even weeks of data to be analyzed. The ability to concatenate across long time frames increases the sensitivity of the method, but it limits its ability to identify fast mode faults.

Technical Progress and Results

Development

Working with partners and users, new versions of GridLAB-D were released and will be released this year. In December 2013, version 3.1 was released. This contained considerable new “sub-second” features used to support microgrid evaluation. Version 3.2 will be released in the summer of 2014 and will contain additional microgrid enhancements along with upgrades to parallelization and performance. Significant improvements to online documentation were made, including documentation of new capabilities, formalization of requirement / specification procedures, and a developer’s handbook. PNNL staff continued to support the user community through the online forums, averaging between 3-4 forum posts per weekday. For the first time, external users committed significant amounts of code to be included in the public release – PNNL staff validated and integrated this code for the release of v3.2.

The Grid Analytics Association hosted its inaugural meeting in July 2013 with approximately 25

attendees, which was then followed by multiple virtual meetings. In partnership with NRECA, the Association was legally formed in May 2014. Continuing activity will focus on growing membership and establishing rules and dues.

AMI Diagnostics

FY14 focused on six major improvements to the AMI diagnostic framework that was started in FY 13:

1. Extension of the unbalanced state estimation process so that it is based primarily on AMI measurements. This includes the triplex secondary systems.
2. Apply AMI based parameter error identification techniques at the distribution level, including residual sensitivity and Lagrangians.
3. Concatenation of data to improve redundancy and improve the Signal-to-Noise Ratio (SNR). Because of the low SNR, it is necessary to concatenate multiple time steps worth of data. The concatenation data window can extend for hour, days, or even weeks.
4. Testing and validation of the process using simulated AMI data under multiple operating conditions (various levels of measurement error, various levels of parameter error, various level of step change in parameter value, etc.).
5. Work is beginning to examine the sensitivity thresholds using various size concatenation windows.
6. Work has also begun to examine the effectiveness of the proposed system on actual AMI data, provided by Avista Utilities. This will allow for an examination of the impact of complex issues such as unmetered load, gross topology errors, and missing data.

Project Collaborations and Technology Transfer

Development

Currently Alstom Grid; Southern Cal Edison; Ausgrid; NRECA; Washington State University; Iowa State University; Stanford University; University of California, University of Washington; and other organizations have R&D efforts utilizing or expanding the current capabilities of GridLAB-D. American Electric Power and the University of New Mexico have recently used GridLAB-D to quantify the benefits and understand the behavior of technologies in their smart grid demonstration projects. Use of GridLAB-D to extrapolate field results from demonstration and grant projects is a key mechanism for showing that programmatic goals for load factor and reliability metrics have been achieved. GridLAB-D is also currently being used to teach students about smart grid and distribution automation at multiple universities, including the University of Washington, WSU, Stanford, and Caltech.

When it is possible (i.e., if no Intellectual Property is being used), PNNL encourages partners to transfer capabilities to the open-source repository. Additionally, when PNNL develops new

capabilities outside of DOE funding, we highly encourage the transfer to open source, rarely keeping any of the code, processes, or additional tools private. This allows the user community to grow the capabilities of the tool, while leveraging DOE funds to support validation and integration. This allows for much greater growth and development than a closed-source project.

AMI Diagnostics

This work is being done in collaboration with Avista Utilities to ensure that the developed techniques are of value to distribution utilities. The proposed work has also been presented at a Natural Rural Electrical Cooperative Association (NRECA) workshop where there was significant interest; ideas from this workshop have helped to shape the research focus. A paper on the underlying mathematics of state and parameter estimation at the distribution level using AMI is about to be submitted to the IEEE transactions on Power Systems. A second paper on the overall method of using AMI measurements as a diagnostic tool, i.e. based on actual utility data, has been started as a follow-up.

This work has significant practical value to distribution utilities and can help improve the resiliency of the nation's electrical infrastructure. Adoption of this technology would be low cost because it leverages already deployed hardware and data systems, and it would in fact provide a measurable benefit to the hardware and data systems already deployed.