HiPAS GridLAB-D
Final Report Requirements Addendum

This addendum describes the specific requirements for HiPAS GridLAB-D relative to the DOE version of GridLAB-D. Functional requirements are driven by the needs of two software applications that interface directly with HiPAS GridLAB-D: (1) GLOW, and (2) OpenFIDO. In addition, the functional and performance requirements are driven by the four principal use-cases: (1) hosting capacity analysis, (2) electrification analysis, (3) tariff analysis, and (4) resilience analysis. Finally, performance requirements are also identified for the learning-accelerated powerflow solver, and remote data access.

Methodology

The HiPAS GridLAB-D project teams identified the requirement for upgrades to the simulation engine, modules, and supporting tools based on continuous input from the OpenFIDO and GLOW project teams, as well as requirements collected from the development of the four principal use-cases chosen for the project. Specific requirements were entered in the GitHub issues database as they were identified as enhancements. A total of 157 enhancements were submitted to the development team over the duration of the project. Of these, 123 were completed and 34 remain open.

GLOW Requirements

The GridLAB-D Open Workspace (GLOW) software developed by Hitachi America Labs uses HiPAS GridLAB-D as the primary simulation engine. The following specific functional requirements were identified.

- HiPAS GridLAB-D must be run in Docker containers from standard images generated by the GitHub CI/CD system.
- Flags must be provided in JSON data to indicate which parameters are required, and what the default values of optional parameters are.
- Global variables must provide control over which JSON object semantics are used for object properties, i.e., initialization value or current value.
- Latitude/longitude location information must be obtained from input models such as Cyme.

- Input and output document formats must be supported for report generation and graphic presentation of results.
- Recorder output must use a single-line CSV header instead of the multi-line comment block used by the DOE GridLAB-D version.
- JSON files must include complete model semantics, including modules, classes, header and data types, global variables, schedules, and filters.
- GridLAB-D must provide run-time progress information in the process status table.
- A JSON to GLM converter must be provided to convert JSON files back to GLM for compilation, initialization, and/or simulation.
- A pole failure model must be added to support the resilience use-case in GLOW.
- The California Integration Capacity Analysis (ICA), California's name for Hosting Capacity Analysis, methodology must be supported internally by the powerflow solver hosting capacity analysis subsystem.

OpenFIDO Requirements

The Open Framework for Integrated Data Operations (OpenFIDO) developed a number of distribution system simulation requirements that are met by HiPAS GridLAB-D. This section summarizes those requirements.

Usability

OpenFIDO requires HiPAS GridLAB-D to provide access to high-quality, high-volume, real-time, rapid-delivery of clean and complete results from simulation and analysis. The simulation must be hosted in the same computing environment that OpenFIDO runs on, i.e., a docker image able to run on multiple platforms including cloud-deployed, on-premise servers, desktop workstations, and laptop systems.

HiPAS GridLAB-D must utilize OpenFIDO's "plug-and-play" data import, cleaning, and graphing tools, as well as generate output in OpenFIDO standard file formats and file semantics. Simulations must run with individual and organization credential management, and operate in secure cloud, on-premise servers, workstation, and laptop environments.

Speed

HiPAS GridLAB-D must provide significant speed improvements to OpenFIDO users. This is accomplished by optimizing internal loops at every level of the simulation, providing access to job processing pools, supporting scalable simulation job control, utilizing share resources such as input data and intermediate results, and automated dispatch of processing pipelines within simulation, where possible.

In addition, HiPAS GridLAB-D makes learning-accelerated powerflow solvers available to OpenFIDO users.

Flexibility

The DOE GridLAB-D was generally used to run simulations of custom-generated models which were edited by users. HiPAS GridLAB-D must have the flexibility to load and link various model fragments that are acquired at runtime from multiple sources, including the following:

- Primary distribution network models from other products such as Cyme or NRECA's OMF.
- Load models generated from end-use load surveys, load simulations, AMI or SCADA data.
- Secondary system models from customer equipment databases.
- Pole, equipment, and other distribution asset models from other products such as Spidacalc.
- Weather, ground elevation, utility service territories, census, tariffs, vegetation, and fire hazard data from external sources such as NOAA, USGS, NREL, EIA, and Commerce Department databases.

Many of the models and data often must be linked to the primary network model using data from asset and GIS databases.

In addition, users need the flexibility to compile, initialize, solve, and run time series solution according to the use-case. These all must be done with scalable hosting on cloud, on-premise servers, workstation, and laptop systems with resource usage, cost tracking, and quota management.

Outputs from various scenarios must be collected and organized, converted to text or graphic form for inclusion in reports and presentations, as well as for online delivery in dashboards and user applications.

Validation

The DOE GridLAB-D provides substantial testing and validation mechanisms which HiPAS GridLAB-D uses. HiPAS GridLAB-D must upgrade and improve the validation test procedures to achieve the following:

- Formalize all the existing validation tests to ensure that they truly verify a required functionality.
- Minimize the overall testing time required to validate HiPAS GridLAB-D.
- Add all new tests and validations required by the addition of new capabilities and resources.

The HiPAS GridLAB-D validate test suite must be run whenever the "master" and "develop" branches are updated by developers.

The use-cases supported by the HiPAS GridLAB-D templates must be provided with their own independent validation tests, based on known results to which the templates' results can be compared. This includes the hosting capacity, electrification, tariff, and resilience analysis templates.

Reproducibility

HiPAS GridLAB-D must ensure maximum feasible reproducibility of results, while maintaining valid local entropy sources to ensure valid non-deterministic random number generation. The state of the random number generators must be saved as part of the model to ensure that reloaded models produce the same output when provided with the deterministic random number generator configuration.

HiPAS GridLAB-D must include a correlated random variable generator to ensure that random number generation best matches observed statistics in cases where correlations are found.

Use-Case Requirements

Four use-cases were identified in consultation with the Technical Advisory Committee. These use-cases guided the development of HiPAS GridLAB-D throughout the project.

1. Hosting capacity analysis (HCA) is a more general form of integration capacity analysis (ICA) because it addresses not only solar resource integration, but also battery, electric vehicle, and end-use load electrification.
2. Electrification analysis addresses the impact of end-use load electrification.

3. Tariff analysis addresses the revenue and cost impacts of different tariffs as loads change.
4. Resilience analysis addresses extreme weather event impacts on distribution systems and customer loads.

Hosting Capacity Analysis

The power flow solver hosting capacity analysis subsystem supports the California Integration Capacity Analysis (ICA), California's name for Hosting Capacity Analysis. The ICA tool gives insight into how much generation or load can be integrated with the distribution grid without (1) violating system operation constraints such as voltage limit and thermal limit and (2) further investment or upgrades by the utilities.

Electrification Analysis

The electrification analysis template computes the impact of converting non-electric loads to electric loads in the residential module. The convertible loads are heating, cooking, domestic hot water, and clothes drying. The residential module allows individual houses to partly or fully convert the end-uses to electric power. The house circuit capacity is updated to ensure sufficient panel capacity is available. If the circuit capacity exceeds the panel capacity, the house will be flagged as requiring a panel upgrade.

Tariff Analysis

The tariff analysis template computes the electricity delivery costs for all meter objects and all supported customer types in a model given the load behavior and network status. Tariff models for all California utilities are accessible, and in particular all approved tariffs for California IOUs. Cost calculations include all residential, commercial, and industrial customers, including seasonal single-phase and poly-phase energy rates, time-of-use rates, fixed, special, and subsidized tariffs. Revenue calculations are performed by aggregating meter-level cost calculations. Feeder cost calculations are performed by implementing wholesale energy costs using wholesale energy prices from the available market models, i.e., CAISO, ISO-NE.

Customer bills include bill day, bill date, total billing days, total bill, total charges, energy charges, capacity charges, ramping charges, fixed charges, total credits, energy credits, capacity credits, ramping credits, fixed credits, metering interval, and baseline demand.

Supported tariffs for PG&E, SCE, and SDG&E are listed in Appendix D.

Resilience Analysis

The resilience analysis template computes the grid asset vulnerability for pole and overhead power line objects within the distribution grid models. The template is capable of bulk pole analysis without the need of a detailed electrical network. Additionally, the solver features an automated pole and grid integration mechanism that populates the distribution network with the provided pole database.

The pole vulnerability calculation requires latitude and longitude of pole locations, and pole characteristics (e.g. material, height, diameter, age, weight of equipment, initial tilt). The weather data is obtained from NOAA and NSRDB. Physical pole model based on moment calculations correlates to the probability of the pole failing given an extreme wind scenario and internal pole degradation. Multiple failure modes are considered in the analysis: ground-level failure and superstructure failure. The model captures the effects of wire tension and ice loading.

The vegetation vulnerability integrates the effects of power line sag and sway with vegetation data obtained from California Forest Observatory on 3-10 m resolution. The model takes advantage of the geodata subcommand, which allows for inclusion of the following location specific datasets:

- **Address/location resolution** - The address package converts between geographic coordinates and addresses for locations in the GLM model.
- **Census data** - The census package obtains census region and division data from the US Census Data archive for locations in the GLM model
- **Distance calculation** - The distance package calculates the geographic distances between locations in a GLM model.
- **Ground elevation** - The elevation package calculates the ground elevation for locations in a GLM model.
- **Powerline sag and ground clearance** - The powerline package calculates the powerline and ground clearance for locations in a GLM model.
- **Utility service territories** - The utility package obtains utility service data for locations in a GLM model.
- **Local weather history and forecasting** - The weather package obtains weather data for locations in a GLM model.

- **Local vegetation height, density, and clearance** - The vegetation package obtains vegetation data for locations in a GLM model from the Salo Sciences subscription service.

- **Building data*** - Obtain building type and building size from NREL datasets.

- **Transportation data*** - Subscription to mobility traffic data from TrafficView service.

Aside from vegetation data, the vegetation risk assessment considers the powerline structure, the distribution network, pole characteristics and elevation.

(1) Powerline vertical sag and horizontal sway calculation

- GridLAB-D Geodata subcommand provides the feature of calculating the powerline vertical sag and horizontal sway given the powerline structure and wind speed. The input of the subcommand includes the latitude/longitude of the pole, conductor information, pole height, elevation data, and wind speed.
- To calculate the powerline sag/sway, powerline natural sag model (without wind or ice) is obtained. The calculation of the powerline vertical sag (the distance from the powerline to the ground) and horizontal sway (the horizontal distance due to wind blow) incorporates the pole height, elevation information, and wind speed.
- The calculated power sag/sway provides us useful information to further evaluate the powerline-vegetation contact.

(2) Vegetation data description and processing

- The vegetation data used in our model is from the California forest observatory. This data set includes vegetation height, base height, cover, and other information, in 10-meter resolution.
- To use this data set because additional information regarding the latitude/longitude is required. To address this issue, the original data set is mapped with the latitude/longitude.
- The vegetation height is used to calculate the vegetation flexibility, i.e., the horizontal sway under a certain wind speed, and the cover is used to calculate the final contact risk factor.

(3) Powerline-vegetation contact model

- An empirical model assesses the vegetation contact risk with the powerline sag/sway and the vegetation flexibility.
- The key idea of the empirical model stems from the fact that the less distance between the powerline and vegetation, the higher the risk.
- The relationship is captured by a quadratic function of the take-up distance to the vegetation right-of-way (horizontal clearance).
- Specifically, verification of whether the vegetation height exceeds the powerline sag occurs. If not, then the risk is zero. Otherwise, the risk factor is captured by the quadratic function mentioned above.

Lastly, the resilience analysis incorporates the reliability metrics which include the cost and outage information given an extreme event.

Performance Requirements

Modeling and simulation performance enhancements are a primary objective of the HiPAS GridLAB-D project. In addition to the four principal use-cases (hosting capacity, resilience, electrific, and tariff analysis) the project also addresses three additional key capabilities to enhance the broad applicability and impact of GridLAB-D as a tool for studying modern power distribution systems with high renewables and flexible energy resources: learning-accelerated powerflow solutions, remote data access, and a converter for reading network, load, and equipment models in Cyme databases.

Learning-Accelerated Powerflow Solver

The proposed learning-accelerated powerflow solver framework enables the following capabilities:

- Produce performance improvements over the standard Newton Raphson-based solver implementation in terms of speed of computation.

- Provide acceptable accuracy in powerflow solutions needed for the HiPAS GridLAB-D use-cases.

- Be robust to a variety of network characteristics and simulation scenarios and require minimal hyperparameter selection by the user.

- Adapt to changes in network topology and characteristics during the course of a simulation.

Cyme Converter

The DOE version of GridLAB-D supports only Cyme 5 data models. HiPAS GridLAB-D must support the currently extant version of Cyme, including Cyme 8 and Cyme 9 data models. The Cyme converter must also support the following capabilities.

- Extract all data in the Cyme models as CSV tables.
- Produce GLM files that separate network, equipment, and load models in the Cyme data model.
- Support extraction of distributed energy resource models.
- Automatically convert MDB files to GLM files when provided on the command line of GridLAB-D.

Hosting Capacity Analysis

Hosting capacity analysis is an enhanced integration capacity analysis (ICA) methodology that supports not only solar integration capacity analysis but also battery energy storage, demand response, and electric vehicle charger integration capacity analysis.

To enable high-performance analysis, hosting capacity analysis includes the following added limit violation checks to the power flow solver.

- Current limit violations on all "link" type objects in the network model. The current limits will depend on the object type, and no default limit is provided.
- Voltage limit violations on all "node" type objects in the network model. The voltage limit is set to the 5% ANSI standard by default.
- Voltage fluctuation violations on all "meter" type objects in the network model. The voltage fluctuation limit is set to the 3% California ICA standard by default.

Resilience Analysis

The resilience analysis, co-developed with the DOE GRIP platform, determines the distribution grid asset vulnerability due to extreme events.

HiPAS GridLAB-D's source code must contain

- The calculation for the pole vulnerability, physics based model. The analysis must allow for automated bulk pole data import from third party databases, such as SPIDACalc. Two types of analysis must be supported: bulk pole analysis with no distribution network with high efficiency performance (performance metric is based on speed compared to SPIDACalc as the baseline) and pole analysis with distribution model.

- The calculation of overhead line vulnerability must determine the risk metric of vegetation proximity to the grid assets while accounting for extreme wind exposure. The metric should include a tree strike model to both high voltage and low voltage power lines.
- The switching optimization based on fault location analytics must determine the optimal switching of the network, based on a number of datasets, such as wildfire risk, weather, DER availability, and critical assets. The performance metrics for HiPAS's algorithm must use the outage cost and outage hours as the baseline to compare the PSPS approach (sampled from PG&E data) to the HiPAS GridLAB-D optimal reconfiguration algorithm.

Electrification Analysis

The electrification analysis template allows the modeler to specify which residential end-uses are supplied by gas or electricity. The end-uses considered are heating, water heating, cooking, and clothes-drying. In addition, electric vehicle chargers are considered, insofar as they contribute indirectly to the decarbonization of personal transportation, although they do not contribute directly to the decarbonization of individual residences. The performance of the electrification template is evaluated based on the degree to which we can change the fraction of homes with fossil-fueled end-uses.

Tariff Analysis

The tariff analysis template allows the modelers to evaluate the consumer costs associated with the electric energy use. The performance of the tariff analysis template is based on the degree to which we can evaluate the different costs for different end-use mixes, under different weather conditions, with different utility tariffs.

Remote Data Access

A significant number of new capabilities rely on access to remote on-line data that is downloaded to the local host as needed. This includes weather, vegetation, fire risk, census, utility service territory, utility tariff, and other large datasets with national scope. Data caching is used to minimize the time needed to access data. In addition, data access APIs using the tools, subcommands, and geodata packages are used to standardize open access to these datasets. Validation tests ensure that these APIs perform according to their specifications.