CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

GLOW: A User-friendly Interface for GridLAB-D

March 2024| CEC-500-2024-025

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ACKNOWLEDGEMENTS

The authors acknowledge and thank the CEC for funding this research and development project. The authors thank Allen Le and Qing Tian of the CEC for their technical guidance, program management, and leadership. The authors also thank Mike Gravely, Loon Yee, and Brian McCullough of the CEC for their technical guidance.

The authors thank our collaborators at SLAC National Accelerator Laboratory including David Chassin, Alyona Teyber, Fuhong Xie, Elizabeth Buechler, Duncan Ragsdale, and Wan-Lin Hu. The authors also thank our collaborators at Gridworks including Matthew Tisdale, Deborah Shields, Rehana Aziz, Hector Tavera, and Katie Wu.

The authors recognize the contributions of the Hitachi team including Sadanori Horiguchi, Anastasia Osling, Kishan Prudhvi Guddanti, Shashank Danda, Pikkin Lau, Masanori Abe, Yoshihisa Okamoto, Sachiko Seya, and Rumiko Haydon.

The authors acknowledge the following individuals from Pacific Northwest National Laboratory, National Grid, Southern California Edison, and Pacific Gas and Electric for their technical support: Jason Fuller, Tom McDermott, Frank Tuffner, Pedram Jahangiri, Balaji Doraibabu, Frank Gonzales, Anthony James, and Saeed Jazebi.

The authors acknowledge guidance and feedback from Jose Aliaga-Caro, Gerhard Walker, Laura Fedoruk, Aram Shumavon, Laura Wang, Emmanuel Levijarvi, Frances Bell, Audrey Lee, Patrick Saxton, Kenneth Lewis, and Jamie Patterson. The authors also acknowledge the technical advisory committee and test masters for guidance and feedback.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

GridLAB-D is a power system simulation tool developed by the U.S. Department of Energy that provides valuable information to users who design and operate distribution systems and to utilities that want to take advantage of the latest energy technologies. A barrier to widespread use of GridLAB-D is the existence of only a command-line interface, which requires users to know how to use computer coding language to operate the program. This results in increased training costs for new personnel and delayed adoption of the tool, which in turn limits the deployment of advanced grid technologies that only GridLAB-D can model.

The outcome of this project is GridLAB-D Open Workspace or GLOW. GLOW is an open-source distribution planning platform for GridLAB-D. The web-based graphical user interface of GLOW augments the command-line interface for GridLAB-D in a more intuitive, user-friendly manner, contributing to wider use of the simulation technology. GLOW graphically and spatially displays the large amounts of data that GridLAB-D simulations generate in an easy-to-understand way. GLOW effectively facilitates the design, testing, and experiment of various distribution analyses for different stakeholders. GLOW is available in two versions: (1) GLOW as a cloud service and (2) Download Version.

GLOW benefits California electricity ratepayers by supporting the goals of the CPUC Distribution Resources Plans proceeding, as well as the broader goals of the state to support integration of DERs and planning for the grid of the future.

Keywords: power system simulation tool, distribution planning, web-based graphical user interface, open-source

Please use the following citation for this report:

Yang, Bo, Yanzhu Ye, Anthony Hoang, Panitarn Chongfuangprinya, Natsuhiko Futamura, and Matthew Tisdale. 2024. *GLOW: A User-friendly Interface for GridLAB-D.* California Energy Commission. Publication Number: CEC-500-2024-025.

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Executive Summary

Background

GridLAB-D is an open-source power system simulation tool developed by Pacific Northwest National Laboratory under the United States Department of Energy (U.S. DOE). The tool enables detailed modeling of distributed energy resource (DER) impacts on unbalanced three-phase power systems, as well as energy markets, building technologies, and other demand-side technologies that are becoming common in modern electricity systems. Traditional distribution systems delivered electricity from the provider to the customer. With the transition to modern electricity systems, customers now can add DER like rooftop solar panels to help provide their own energy. This causes incidental problems to the utility providers as traditional distribution systems are not well equipped to work with the new technologies on the customer side. GridLAB-D enables detailed modeling of DER impacts on the distribution systems, energy markets, building technologies, and other demand-side technologies that are becoming common in modern electricity systems. A barrier to widespread use of GridLAB-D is the program requires users to know how to use computer coding language to operate the program. Due to the higher level of training required, new users find the command-line interface very cumbersome and challenging. This results in increased training costs for new personnel and delayed adoption of the tool, which in turn limits the use of advanced grid technologies that only GridLAB-D can model.

Developing a better user interface that is intuitive and more convenient for non-expert users would help make GridLAB-D more widely used and increase access to simulation and modeling results for advanced power system solutions by technology developers, researchers, and public agencies.

Project Purpose and Approach

The team lead by Hitachi America Ltd developed GridLAB-D Open Workspace or GLOW, a user interface for GridLAB-D that provides a more intuitive and user-friendly environment for researchers, planners, developers, and regulators involved in advanced electric grid technology use. GLOW is a fully functional, freely available, and widely supported open-source tool based on existing GridLAB-D technology. The open-source tool aims to augment the command-line interface for GridLAB-D.

Hitachi America Ltd received technical support from Gridworks, National Grid, and two Department of Energy national laboratories, the Stanford Linear Accelerator Center, National Accelerator Laboratory and Pacific Northwest National Laboratory, whose staff were the original developers of GridLAB-D.

The project team used the following strategies:

- Performed ethnographic studies through the human-centered design process with technical advisory committee (TAC) members to understand preferences and technical requirements for graphical user interface, appearance, workflow, use-cases, etc.
    - TAC members are prospective users of GLOW. These are the California investor-owned utilities, DER developers, policymakers, open-source developers, and other outside groups involved in simulating distribution grids.
- Conformed with the design and interface requirements of the existing GridLAB-D platform.
- Prospective users will participate in the development process and engage in pre-release version testing and evaluation. Interaction between the TAC and the project team will support a positive feedback loop to ensure the proposed technical design meets the needs of TAC members.

The project team conducted several sessions of interviews with different user groups, including utilities, policymakers, and researchers. In addition to user interviews, the project team conducted workshops to understand and develop requirements, use cases, and task flows for several types of DER integration studies for GLOW.

Key Results

The result of this project is GridLAB-D Open Workspace, or GLOW, an open-source distribution planning platform for GridLAB-D. The web-based graphical user interface of GLOW augments the command-line interface for GridLAB-D in a more intuitive, user-friendly manner, contributing to wider use of the simulation technology.

The project team developed GLOW as a software complementing the coinciding project, High-Performance Agent-Based Simulation or HiPAS GridLAB-D to allow users to access the tool through point and click methods to easily use the tool through visual cues and functions. A key feature of GLOW is the advanced web-based graphical user interface, which effectively facilitates the design, testing, and experimentation of various distribution analyses for different stakeholders. GLOW graphically and spatially displays the large amounts of data that GridLAB-D simulations generate in an eloquent, easy-to-understand way.

The information architecture of the graphical user interface includes five major modules. The Home module is a landing page that includes login, user management, and access to other modules. The Model Library module allows a user to create and manage feeder models. The user can then use the Viewer module to visualize and modify the location and parameters of the equipment. The Simulation Library module allows a user to create and manage simulation scenarios. The friendly simulation setup wizard effectively guides users to set up and launch a new simulation use case quickly. The Post-Processing module facilitates the results. A user can create charts based on simulation results in the Post-Processing module. In addition, a user can visualize the simulation result in a map view of the Viewer.

High-level features of GLOW include:

- A distribution planning and modeling platform;
- Web-based graphical user interface for GridLAB-D;
- Open source;
- Support use on workstations or the cloud;
- Generate a feeder topology for visualization;
- Use Cases:
    - Power flow
    - Integration capacity analysis
    - Electrification Analysis
    - Grid Resilience;
- Post-processing for reaching results; and
- Designed for cross-organizational collaborations.

GLOW is available in two versions: (1) GLOW as a cloud service and (2) download version. A user can register through the GLOW website, https://glow.hero-energy.com, to access both versions of GLOW. After logging in, a user can start using GLOW as a service on the cloud or download the GLOW package and install in a local machine.

Results of the user survey conducted after the Beta Test show that GLOW is more user-friendly than GridLAB-D. In addition, GLOW augments the command-line interface of GridLAB-D very well. The primary benefit of GLOW, which provides an improved graphical user interface and visualization tool for GridLAB-D, is its support of increased modeling accuracy in decision-making surrounding DER technology adoption.

The GLOW project benefits California electricity ratepayers by supporting the goals of the California Public Utilities Commission's High-DER and Distribution Resources Plan proceedings, as well as the broader goals of the State to support integration of DERs and planning for the grid of the future. GLOW graphical user interface expands the number of users and markets for power systems analysis tools beyond just utilities to include local communities, technology developers, researchers, public agencies, and other organizations interested in assessing DER integration into the distribution grid.

Knowledge Transfer and Next Steps

In addition to biannual TAC meetings, annual workshops, and tutorials, the project team promoted and introduced GLOW to a broader audience over the past few years via several activities, including conference presentations, paper publications, an Institute of Electrical and Electronics Engineers (IEEE) webinar, an IEEE tutorial, a promotional brochure and video, and short tutorial videos. Current users of GLOW include more than 100 registered users from more than 15 organizations. Besides utility and researchers in the United States, GLOW has registered users from university and research laboratories in the United Kingdom, Brazil, Singapore, and Greece.

The layer architecture of GLOW is flexible and allows GLOW to expand to address challenges that are not part of the current scope of work. Examples of these challenges are: (1) utility use cases and processes; (2) extensive computational requirements for a utility-wide study; (3) variation of policies; (4) demand data that is not always available, among others.

Future development opportunities for GLOW include:

- Interface with enterprise system such as meter data management system to gain access to smart meter data directly or interface with other data sources;
- Simulation wizard and post-processing template for additional use cases such as long-term load forecasting, tariff design; and
- Optimized parallel simulation for simulation of multiple feeders.

CHAPTER 1: Introduction

GridLAB-D Advantages, Disadvantages, and Challenges

GridLAB-D is an open-source agent-based power system simulation tool developed by the Pacific Northwest National Laboratory (PNNL) under the U.S. DOE and released in 2007 (GridLAB-D, 2023) (Chassin et al., 2014). The tool enables detailed modeling of distributed energy resource (DER) impacts on unbalanced three-phase power systems, as well as energy markets, building technologies, and other demand-side technologies that are becoming common in modern electricity systems. A barrier to widespread use of GridLAB-D is the existence of only a command-line interface (CLI). Due to the higher level of training required, new users find the CLI very cumbersome and challenging. This results in increased training costs for new personnel and delayed adoption of the tool, which in turn limits the deployment of advanced grid technologies that only GridLAB-D can model.

Developing a better user interface (UI) that is intuitive and more convenient for non-expert users would help make GridLAB-D more widely used and increase access to simulation and modeling results for advanced power system solutions by technology developers, researchers, and public agencies. The user environment's development, however, is difficult due to the following technical challenges:

- **Complex information visualization:** As a powerful simulation engine, GridLAB-D can assess the impacts of DERs and controllable loads on distribution networks and substations from the perspectives of reliability, power quality, and market economics. Effective visualization of these complex yet correlated systems is critical to understanding planning impacts and decision making.
- **Scale-up capabilities for future needs:** With the increasing penetration of renewables and DER, more operational data is available to serve as input to GridLAB-D planning models. It is necessary for the user interface to support a flexible data loading architecture and provide scale-up capability to handle large volumes of data.

In recent years there have been some related activities for development based on GridLAB-D: Wang et al. (2012), Al Faruque & Ahourai (2014), Nasiakou et al. (2016), Hansen et al. (2015), and Anderson et al. (2014). In Wang et al. (2012), Al Faruque & Ahourai (2014), and Nasiakou et al. (2016) the MATLAB-GridLAB-D co-simulation framework was developed; however, these activities focus on limited use cases and selected feeder models. Wang et al. is for a demand response study, Al Faruque & Ahourai (2014) is for a microgrid study, and Nasiakou et al. (2016) only supports traditional power flow studies on IEEE-13, 37 node system. Also, as a proprietary tool, MATLAB has its limits on flexibility and compatibility across different platforms. Hansen et al. (2015) proposes a Python-GridLAB-D framework that focuses on dynamic interaction with ongoing GridLAB-D simulation, however, it lacks a flexible infrastructure to develop new use cases. Anderson et al. (2014) presented a cloud-based GridLAB-D simulation framework, which provides the flexibility to integrate and develop new functions; however, it lacks an advanced graphical user interface to fully provide interaction capabilities between users and various back-end features.

GLOW Objective

GridLAB-D Open Workspace or GLOW is a project to develop a high-end UI for GridLAB-D that provides a more intuitive and user-friendly environment for researchers, planners, developers, and regulators involved in advanced electric grid technology deployment. GLOW is a fully functional, freely available, and widely supported open-source tool based on existing GridLAB-D technology made available for a period of at least five years. The open-source tool augments and replaces the CLI for GridLAB-D. The interface has been developed to create input models and for the execution and control of the simulations. GLOW visualizes complex information, is scalable for big data simulation, and will be maintained by the team to encourage widespread utility adoption.

Anticipated Benefits for California

The state of California identified increasing DER as an important element of its strategy to achieve its clean energy goals. Integration of DER into the distribution grid must be done in a manner that supports electricity system reliability without compromising personnel or public safety, or unreasonably increasing the cost of electricity to consumers. One barrier to this goal is evaluating the impacts of DER on the distribution grid and making policy and investment decisions based on these results. Thus, one primary benefit of an improved user interface and visualization tool for GridLAB-D is support for increased modeling accuracy in decision-making surrounding DER technology adoption.

The GLOW project benefits California Investor-Owned Utility (IOU) electricity ratepayers by supporting the goals of the CPUC Distribution Resources Plan (DRP) and High-DER proceedings, as well as the broader goals of the state to support integration of DERs and planning for the grid of the future. An improved GridLAB-D user interface expands the number of users for power systems analysis tools beyond just utilities to include local communities, technology developers, researchers, public agencies, and other organizations interested in assessing DER integration into the distribution grid.

Distribution System Modeling with GridLAB-D

GLOW is one of three projects supported by the California Energy Commission (CEC) to deliver a set of open-source tools around distribution resource modeling and planning to enhance GridLAB-D. Stanford Linear Accelerator Center (SLAC) National Accelerator Laboratory or SLAC led the development of the other two related projects:

- High-Performance Agent-Based Simulation (HiPAS), EPC 17-046
    - HiPAS is an open-source upgrade to GridLAB-D that speeds up the analysis performance and computational efficiency of the tool, using intelligent, adaptive multi-threading to deploy highly granular parallelization in agent-based simulations.

- Open Framework for Integrated Data Operations (OpenFIDO), EPC 17-047
    - OpenFIDO is a data interchange, synthesis, and analysis framework allowing interoperability between different power system tools. This capability allows for a more reliable and efficient data exchange.

CHAPTER 2: Project Approach

GLOW is a project to deliver a web-based distribution planning platform for GridLAB-D. The open-source graphic user interface (GUI) aims to augment the CLI for GridLAB-D in a more intuitive, user-friendly manner, contributing to wider use of the simulation technology.

GLOW was directed by Hitachi America Ltd. (HAL), with technical support from Gridworks, National Grid, and two DOE national laboratories, SLAC and PNNL, whose staff were the original developers of GridLAB-D. GridLAB-D source code revisions and upgrades were implemented in a coordinated fashion with GLOW development.

At a high level, the project team used the approach as depicted in Figure 1 with the following strategies:

- Perform ethnographic studies through the human-centered design process with technical advisory committee (TAC) members to understand preferences and technical requirements for GUI, appearance, workflow, use-cases, etc.
    - TAC members are prospective users of GLOW. These are the California IOUs, DER developers, policymakers, open-source developers, and other outside groups involved in simulating distribution grids. The TAC members are responsible for providing input into the development of GLOW, including the use cases that inform GUI design. TAC members were consulted during the Alpha Testing process, notified with updates during the Beta Testing process, and consulted during the project finalization process to provide feedback on how to best launch GLOW and support new users.
- Conform with the design and interface requirements of the existing GridLAB-D platform, working closely with the existing GridLAB-D development to address any weaknesses and deficiencies directly in the GridLAB-D code base.
- Users will participate in the development process, define performance metrics, and engage in pre-release version testing and evaluation.
    - Interaction between the TAC and the project team will support a positive feedback loop to ensure the proposed technical design meets the needs of TAC members.

The design principle is a common ground for effective and constructive data sharing to facilitate communication and collaboration. This research was driven by the following design principles:

- Makes the complex simple;
- Tells a clear story with GUI;
- Expresses the meaning of the data;
- Reveals details as needed; and
- Personalized and customized for the user.

Figure 1: Design Approach

Source: Hitachi, Ltd.

Human-Centered Design Process

The project team developed GLOW requirements through a human-centered design process. The human-centered design process has many forms. The model that the project team used for GLOW has five key phases.

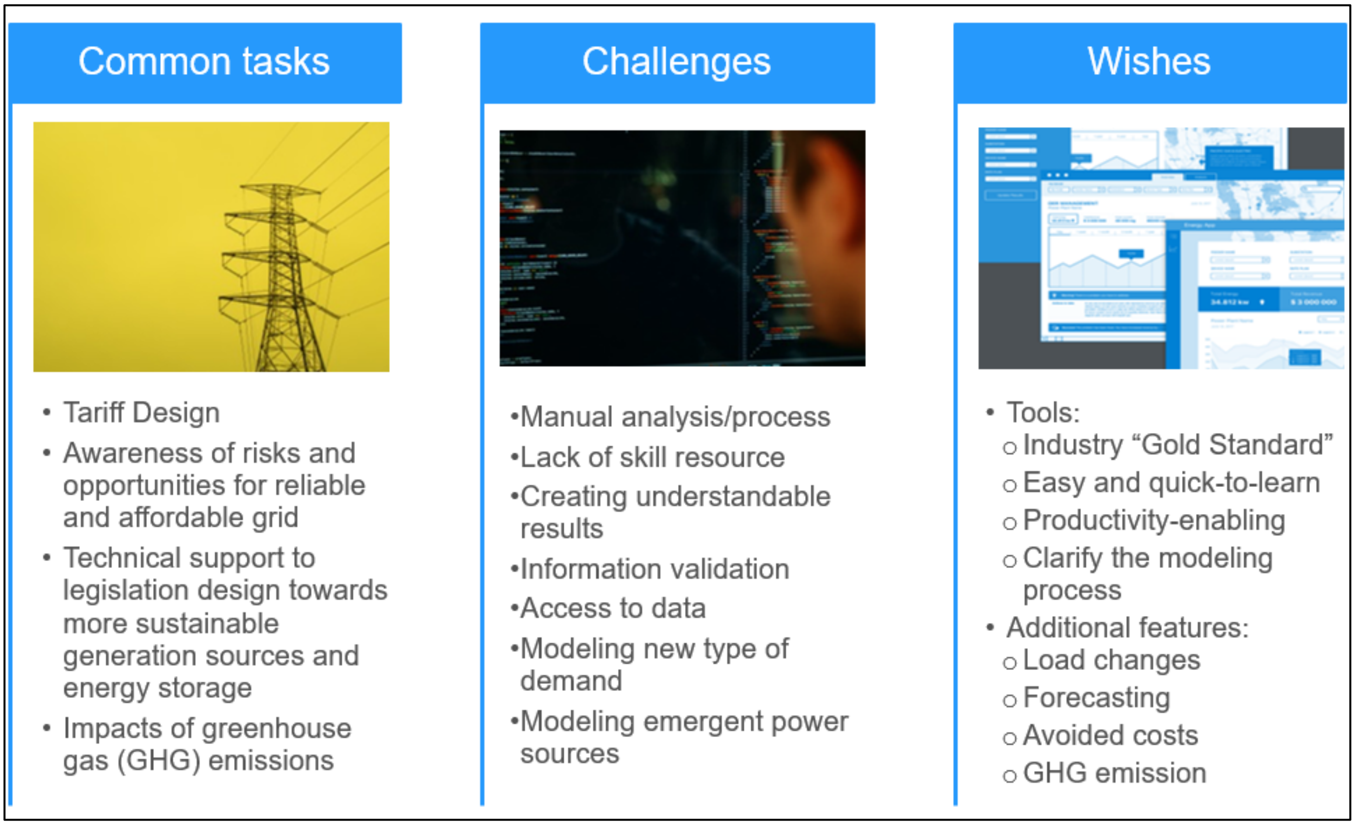
1. **Discovery:** Understanding the problem by communicating with actual users through interviews and workshops.
2. **Define:** Brainstorming to define the key actions that GLOW needs to accomplish and develop as many solutions to the problem as possible.
3. **Prototype:** Putting ideas into action by creating information architecture and wireframes to test ideas.
4. **Design:** Defining look and feel, colors, typography, iconography, and style for forms and widgets to create UIs that are consistent and scalable.
5. **Test and Iterate:** Testing with actual end users to identify flaws, weaknesses, and gaps in the design, then improve it along the way.

User interviews are an excellent way to gain insights from users when taking a human-centered approach to a project. It helps to examine user experience, use of current tools, work objectives, motivations, as well as pain points with current tools among many other things. The project team conducted several sessions of interviews with different user groups, including utilities, policy makers, and researchers. In addition to user interviews, the project team also conducted workshops to understand the requirements, use cases, and task flows of several types of DERs integration studies. The project team conducted a user interview with the following TAC members:

- Southern California Edison (SCE)
- Pacific Gas and Electric (PG&E)
- CEC
- California Public Utilities Commission (CPUC)
- Sunrun

Figure 2 is an example of findings from one of the user interview sessions with a TAC member.

Figure 2: Example of a Result of User Interview



Source: Hitachi, Ltd.

Common Challenges

From user interviews and workshops, the project team found the following common challenges:

1. Dealing with the scale, complexity, and uncertainty of the California electrical grid system;
2. Availability of and access to reliable data;
3. Varying levels of access to effective simulation tools;

4. Lack of transparency over organizational boundaries leading to difficulty in communications; and
5. An unmet need to collaborate and follow-through on shared interests and goals.

In addition, it is clear that a user is required to have highly technical expertise and extensive experience with coding to use GridLAB-D. An average user or any non-technical person would not be able to use the tool as it is.

The project team found a strong need for a powerful, yet user-friendly and intuitive tool that would enable policy makers to make meaningful recommendations to utilities that benefit both customers and the environment.

Utilities are heavily invested in proprietary tools. Considering the required investment for switching tools, utilities need further incentives to use a new tool. Sharing a tool would enable utilities to comply with government regulations and help them achieve renewable goals.

High-level GLOW Features to Address Challenges

Challenges from the industry that the project team focused on include:

- Manual analysis/process;
- Lack of skill resources;
- Creating understandable results;
- Information validation;
- Modeling a new type of demand;
- Modeling emergent power sources;
- Cyclical communications between stakeholders that make details difficult to share;
- Dependence upon independent tools for data sharing such as Google Drive; and
- Cybersecurity for data sharing.

High-level features of GLOW's design goals to address the above challenges are:

- A software on premise or cloud;
- Multi-user simultaneously;
- Hierarchical data access control for models and results; and
- Expandable function modules for modeling, simulation, editing, and post processing.

In addition, GLOW can be expanded to address the following challenges that are not part of the current scope of work:

- Lack of skill resources;
- Access to data;
- Evolving grid dynamics;
- Barriers to direct communications beyond the organizational boundary;
- Lack of demand data availability;
- Trust issues due to lack of adequate access to optimal data;
- Lack of regulated means or opacity of demand to provide value to grid; and
- State policy variations.

Lastly, the current GLOW design addresses the following capabilities which are beyond the scope of this project:

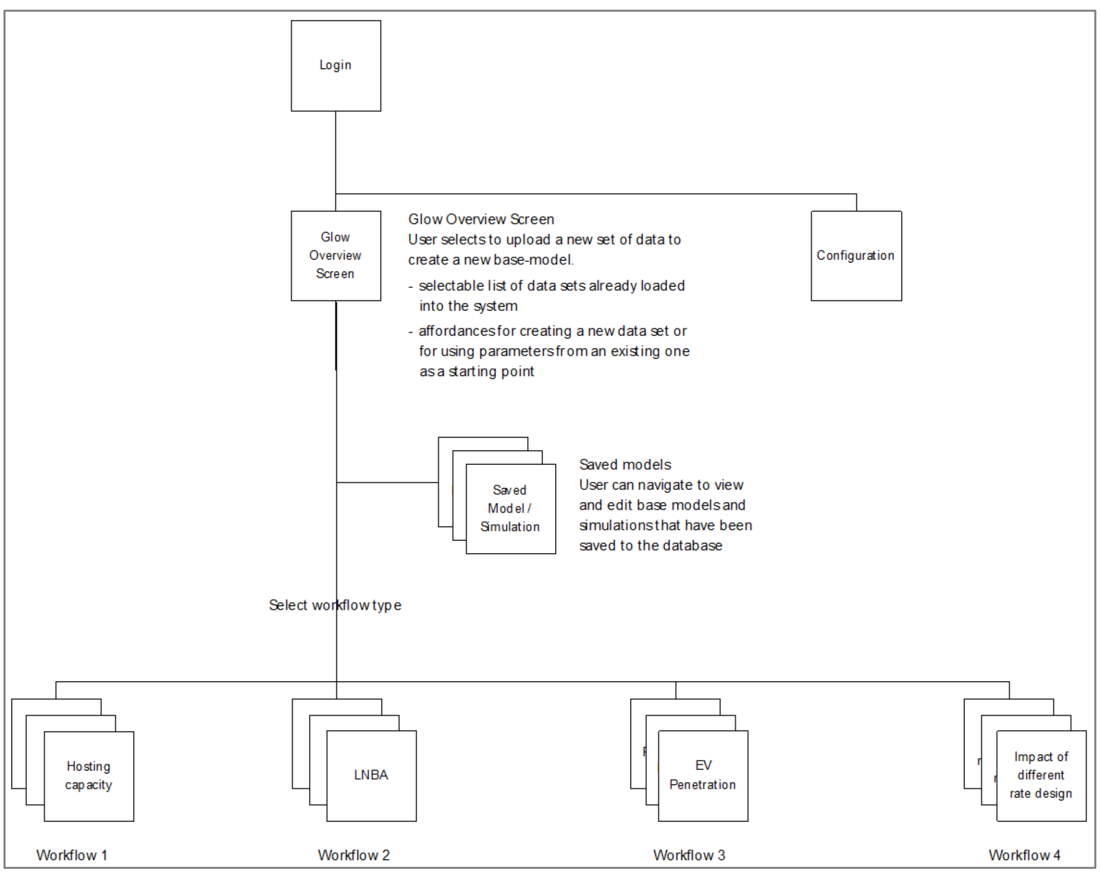
- Ease of adoption and integration;
- Interface with Advance Metering Infrastructure (AMI) and other data sources;
- Interface for field data collection;
- Protected access control to enable data sharing between organizations; and
- Streamlined analysis and studies with phase gate review.

GLOW Architecture Design

The project team started GLOW architecture design by developing a basic use case, such as power flow, and use cases that are related to DERs integration, the impact of electric vehicle penetration, and rate design analysis. The project team also developed user experience maps for each use case. The user experience map is a general visual diagram to view how the various areas and features are organized and can be navigated by users. An example of a user experience map in the early stages of development is depicted in Figure 3.

As a next step, an information architecture was developed to cover all use cases and task flows. The information architecture includes five major modules: (1) Home, (2) Model Library, (3) Viewer, (4) Simulation Library, and (5) Post-Processing. The results section provides detail on the information architecture.

Figure 3: Overall User Experience Map of GLOW



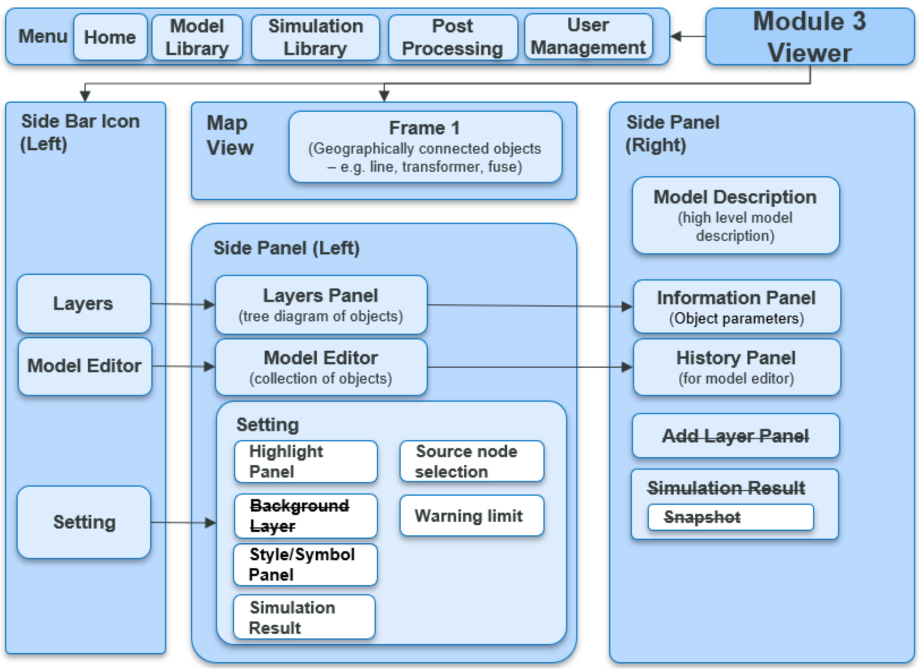
Source: Hitachi, Ltd.

Specification and Functional Requirements

Next, the project team developed specifications and functional requirements. Both were dynamic and could be revised according to priority, technical limitations, implementation time, and user feedback.

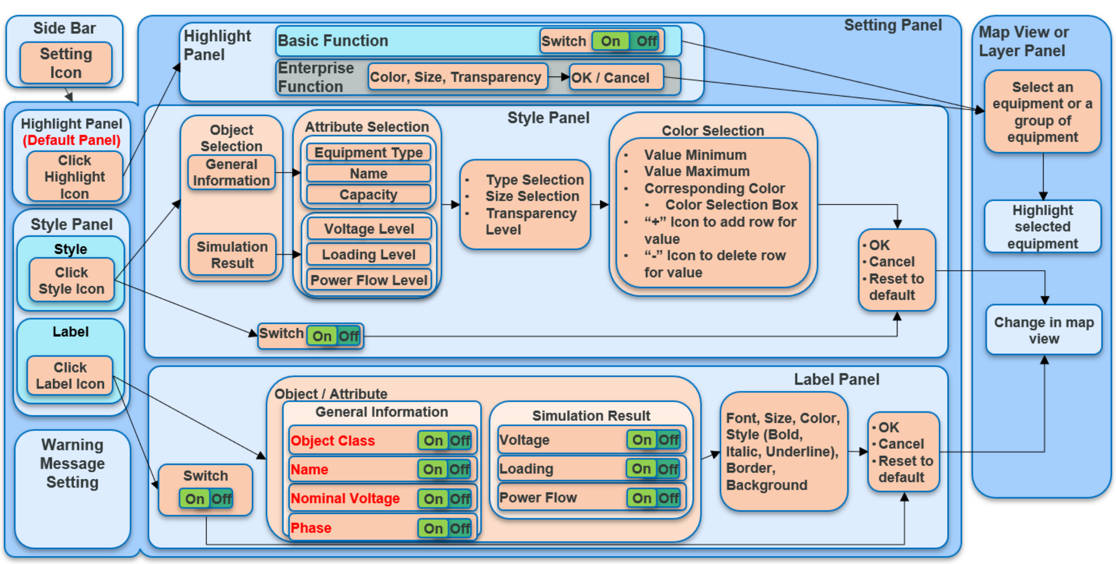
Figure 4 is an example of a sub-architecture for the Viewer module. It shows relationship of every component in the Viewer module. Figure 5 is an example of a flowchart of a sub-component in the Viewer module. Table 1 is an example list of functional requirements.

Figure 4: Viewer Module Architecture



Source: Hitachi, Ltd.

Figure 5: Flowchart for Setting Panel of Viewer Module



Source: Hitachi, Ltd.

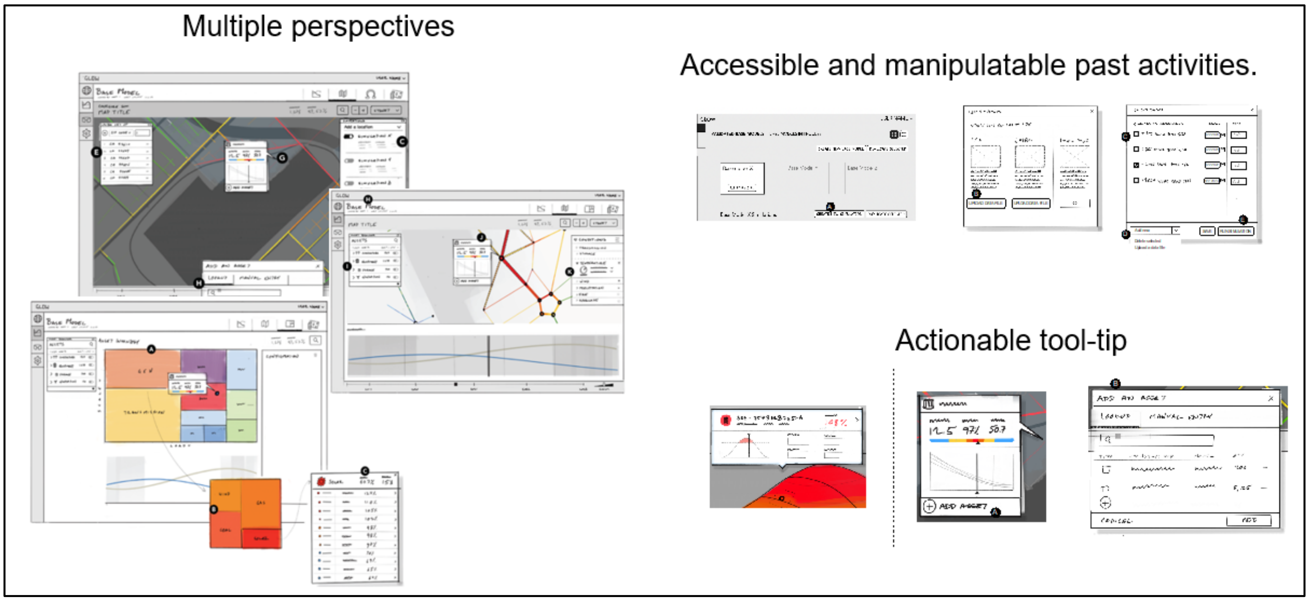
Table 1: Examples of Functional Requirements

ID	Section	Requirement
1.0.0	**Main**	
1		Home - link to
2		Model Management - link to
3		Simulation Library - link to
4		Post Processing - link to
3.0.0	**Viewer**	
3.1.0	**Menu**	
1		Icon to open menu
2		Icon to close or collapse “Menu Bar”
3		Mouse over any icon to display text description
4		Click menu icon to open “Menu Bar”
6		Standardize across every module to provide access to other modules: (1) Home, (2) Model Management, (3) Simulation Library
3.2.0	**Side Bar and Panel**	
1		Side Bar contains icon to show panel (1) Layers, (2) Model Editor, (3) Setting
2		Mouse over any icon to display text description
3		Click any icon on “Side Panel Icon Bar” to open Panel Window
4		Icon is highlighted or circled to show active status
6		User can adjust the width of any panel
8		Arrow to hide side panel windows
3.3.0	**Map View**	
3		Screen to display open network/model layers of map, feeder, equipment
6		Zoom in / out
7		Pan
8		Show information panel - Click Information Icon and then click any item on a map will open an Information Panel on the right hand side.
16		If there is no X-Y file from user, GLOW would generate coordinate for map view
17		All Link will be displayed by LINE (Different link object display by different line type)
18		All Node will be displayed by geometric shape (Different node object display by different (e.g. circle, square))
20		Link and Node are defined by object class from GLD
22		Other object classes (beside link and node) will be displayed in a boxes with text
23		By default - Only display Link object
24		By default - User can use the check box on a panel window to display location of other object

Graphical User Interface Design and Prototype

The project team developed GUI and functional requirements together since both are highly dependent on each other. The project team defined a base set of interaction patterns to create a consistent experience across the platform. These patterns guide future interface designs in the next step. Figure 6 shows some examples of patterns.

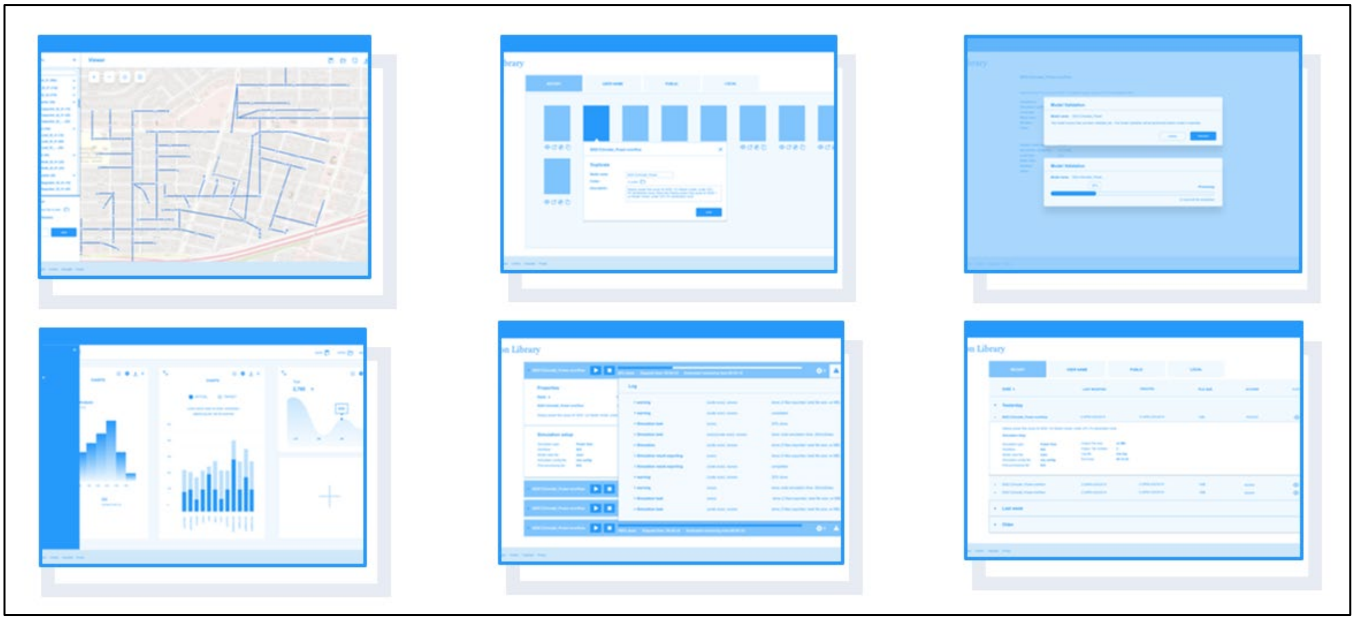
Figure 6: Patterns Samples



Source: Hitachi, Ltd.

To put ideas into action, the project team created and implemented wireframes according to functional requirements and patterns. Figure 7 shows example of wireframe implementation.

Figure 7: Wireframes



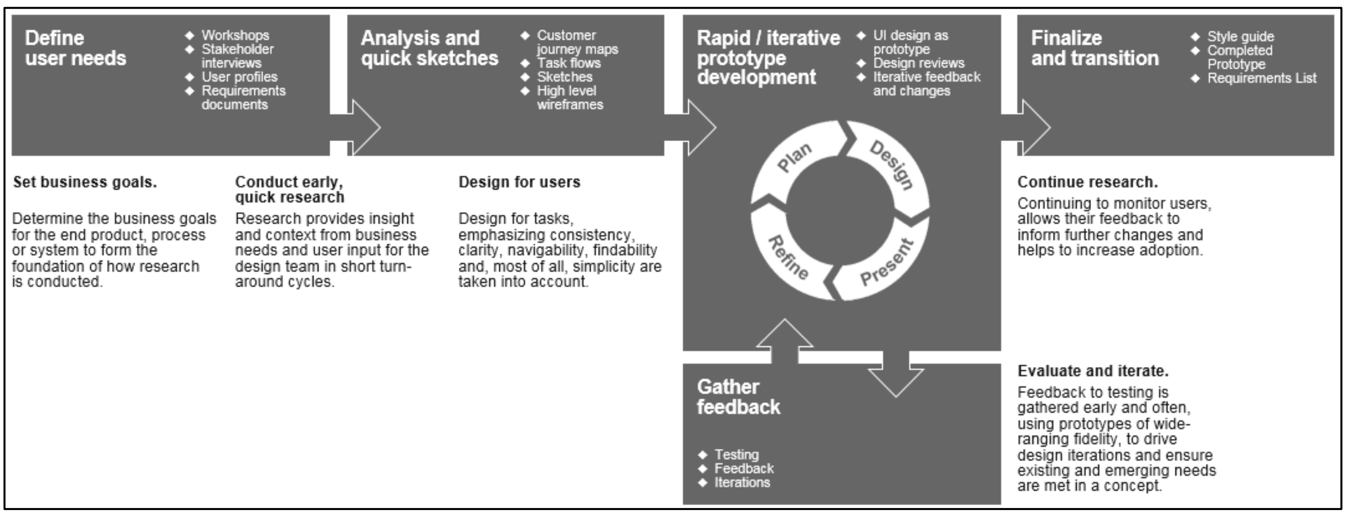
Source: Hitachi, Ltd.

Next, the project team created a high-fidelity GUI design, a style guide, page layout information, assets, icons, and fit and finish. The design was created specifically for 1920x1080 pixels screen resolution. The style guide was applied to all pages of GLOW and it includes information such as colors, fonts, buttons, and common icons. A style guide is a reference for additional features in the future as well.

Production Test

Testing is a crucial part of User Experience Design (UXD) process. Figure 8 shows the UXD process. The project team gathered requirements while demonstrating ideas on core user tasks in the system. During the testing process, the project team gathered continuous feedback from test masters, building on the design and defining the direction. These prototypes became working models, which were developed through iterations.

Figure 8: User Experience Design Process



Source: Hitachi, Ltd.

Test Plan

The project team developed a test plan for both the Alpha Test and Beta Test to address software issues from a system, integration, performance, and user perspective.

Alpha Test target audience was limited to only TAC members, while Beta Test target audience was expanded to technical society, including (1) Industry, (2) universities, (3) related regulatory/policy agency, and (4) research center, national labs (for example Power Systems Engineering Research Center (PSERC). However, it was still limited to only test masters with a valid organization email address.

Alpha Test

The project team performed an Alpha Test to identify all possible issues/bugs and validate all functionalities and non-functionalities per user requirements. The focus of the Alpha Test was to simulate real user scenarios. The aim was to carry out the tasks that a typical user might perform. The project team carried out an Alpha Test in a staging environment, similar to a production environment. The Alpha Test period was September 2020 – August 2021.

The first GLOW prototype, or GLOW Alpha version, contained approximately 40 percent of the overall requirements that were implemented based on priority. It contained only core functions and minimum viable features such as (1) load GridLAB-D dataset for power flow simulation, (2) graphic view of models, and (3) post-processing for only snapshot results.

Beta Test

A Beta Test was performed by real users of the software application in a real environment. The project team released the GLOW Beta version to a limited number of end-users of the product to obtain feedback on the product's quality. Beta Testing reduces product failure risks and increases the quality of the product through customer validation.

The GLOW Beta version contained approximately 80 percent of the overall requirements. Based on Alpha Test feedback, the project team added features and fixed bugs.

The following list is an example of some additional features included in the GLOW beta version.

- Create a model from scratch in GLOW
- Preloaded data (equipment library from the IEEE 8500 model)
- Display only required parameters as the default
- Clarification message for model validation error
- Post-processing – time-series chart

CHAPTER 3:
Results

Summary of GLOW

The outcome of this project is GLOW. GLOW is an open-source distribution planning platform for GridLAB-D. The web-based GUI of GLOW augments the CLI for GridLAB-D in a more intuitive, user-friendly manner, contributing to wider use of the simulation technology.

GLOW utilizes HiPAS GridLAB-D, developed by SLAC, to simulate in detail the interplay of every part of an electrical distribution system. GLOW graphically and spatially displays the large amounts of data that GridLAB-D simulations generate in an eloquent, easy to understand way. The purpose of the GUI is to make electricity modeling software accessible for all parties that might be interested, including those not as proficient in data manipulation and command-line programs.

High-level features of GLOW include:

- A distribution planning and modeling platform;
- Web-based GUI for GridLAB-D;
- Open source;
- Support deployment on workstation or the cloud;
- Generate a feeder topology for visualization;
- Standardized analysis examples:
    - Power flow
    - ICA
    - Electrification Analysis;
- Post-processing for result realization; and
- Designed for cross-organizational collaborations.

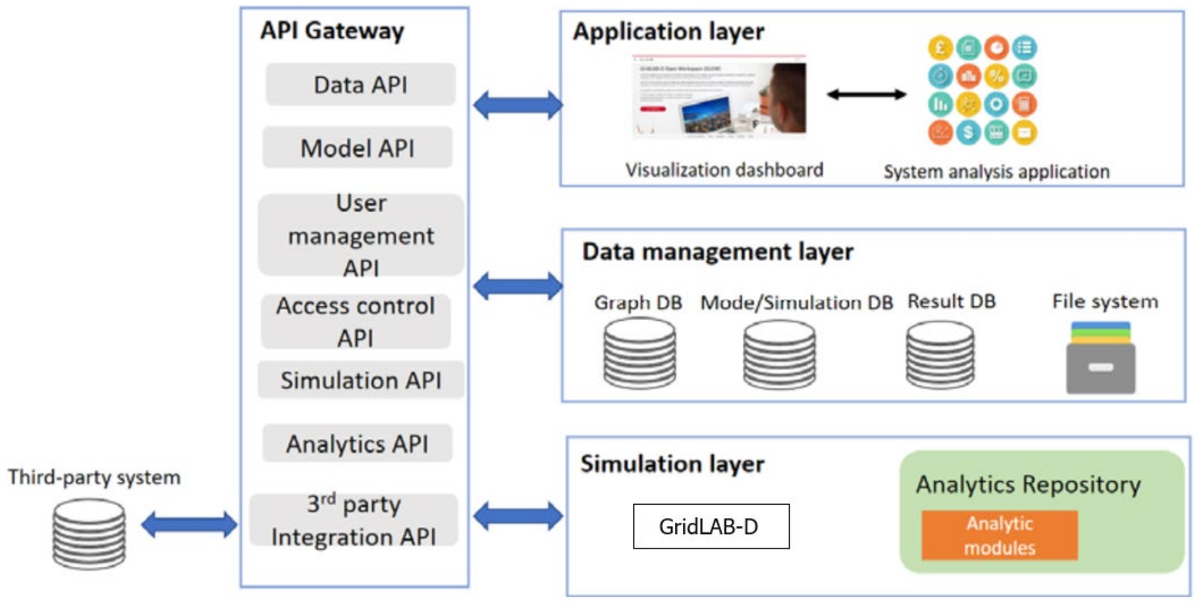
GLOW makes using GridLAB software easier, faster, and more accessible to non-technical users. GLOW will bring GridLAB-D to a new base of users and allow for easier testing, applications, and expansion of the tool.

GLOW System Architecture

This section provides an overview of the multi-layer architecture of GLOW and implementation details of each layer, as well as system data infrastructure (Ye et al., 2020).

Figure 9 displays the Layered Architecture of GLOW. GLOW consists of three major layers: (1) application layer, (2) data management layer, and (3) simulation layer. An application programming interface (API) gateway is designed and implemented to coordinate data and control interaction among the three layers and third-party systems.

Figure 9: Layered Architecture of GLOW



Source: Hitachi, Ltd.

Simulation Layer

The HiPAS version of GridLAB-D simulation engine is located on the simulation layer, which interacts with the other two layers to exchange both input and output of simulation data, receive and respond to different simulation workflow controls, and more. As an open-source tool, GridLAB-D provides interfaces to directly access network components, modify simulation settings, and control/monitor the simulation process. One is through the Representational State Transfer (REST) API and the other is through the GridLAB-D Python library. The project team utilized these APIs or libraries to establish the two-way communication interaction between the GridLAB-D engine and external control and analytical functions. Besides the GridLAB-D simulation engine, the project team can also deploy other third-party tools and customized analytical modules on the simulation layer.

Data Management Layer

The database management system on this layer oversees storing and managing different data types (such as system model data, advanced metering data, load profiles, simulation configurations, user information, or system analysis results). A variety of data formats will be collected, converted, processed, and then stored on a database. The data processing pipeline and data communication infrastructure are described in detail in the Data Communication Infrastructure section.

API Gateway

The project team designed and implemented an API gateway to coordinate data and control interaction among the three layers and third-party systems. The API gateway controls and manages access to a collection of back-end services such as data query, data processing, model management, user access control, simulation analysis control and more. One implementation example in GLOW is to use the Django REST framework, which is a powerful and flexible toolkit for building Web APIs. In Django, different functionalities are designed and implemented by using the RESTful technology to support the exposition and request of services.

The API gateway serves as the entry point for all API service requests in GLOW, which will make the simulation layer, application layer, and data management layer loosely coupled, increasing system scalability. Also, through these well-defined APIs, the application of system analytical functions is insulated from how these functions are implemented in detail on the back end, independent of the programming language.

Application Layer

The project team can develop various distribution system analysis applications as individual modules and deploy them on GLOW through these well-designed APIs managed on GLOW API gateways. The project team can organize these application modules around specific business goals, user groups, DER types, individual analytical functions, and more. These application modules can be as simple as a time-series power flow simulation, or as complicated as a system-wide integration capacity analysis (ICA) or AI-based system control. Each individual functional module can be wrapped and communicated through well-constructed APIs, so that a complicated application can be easily built up as a suite of small, individual functional modules.

Besides these analytical application modules, GLOW features a GUI to dynamically interact with the GridLAB-D simulator, access and manage these analytical functions, and visualize system analysis output, which is presented in the GLOW Graphical User Interfaces section.

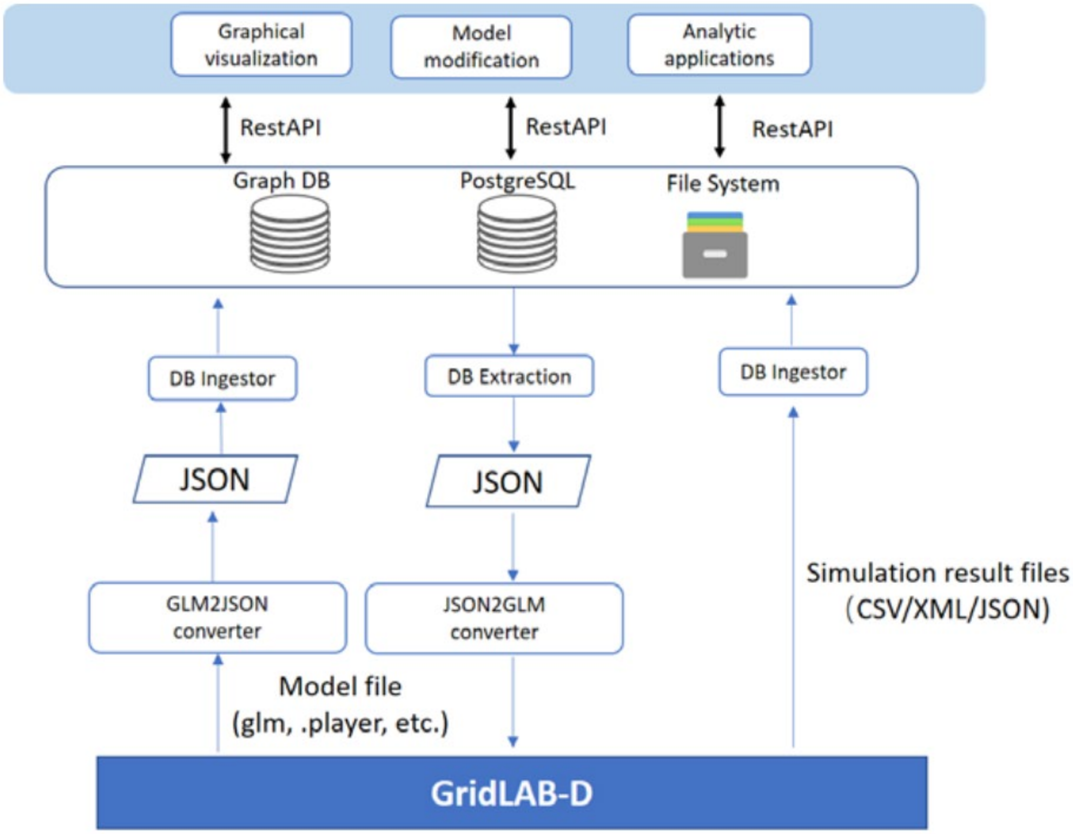
Data Communication Infrastructure

In GridLAB-D, the feeder model, simulation set-up, and simulation schedules are described using .glm file. This .glm file contains the detailed representation of power grid topology and its asset’s properties. The .glm file is the main input file format for GridLAB-D to run simulation. GridLAB-D also takes other file types as input to support simulation (for example csv, xml, tmy or weather file). The .glm file is relatively easy for users to read and edit; it is, however, not directly compatible with any major software tools. Currently, there is no effective tool for editing and parsing the .glm file.

Figure 10 shows the detailed data communication infrastructure in GLOW, including the data conversion pipeline, common data structures, and more. In this data infrastructure, the .glm file format will be converted to a common data structure – JSON, which is an open standard file format, and is completely language independent. It is easy for users to read and write and is also easy for machines to parse and generate. There exists a diverse range of applications, third-party libraries, which is compatible with the JSON data structure. These features make JSON an ideal data-interchange language.

The flexible model presentation in JSON format coupled with different processing modules can further fit different application use cases (Guddanti et al., 2020) (such as the conversion to network graph data structure for advanced graph analysis).

Figure 10: Data Communication Infrastructure



Source: Hitachi, Ltd.

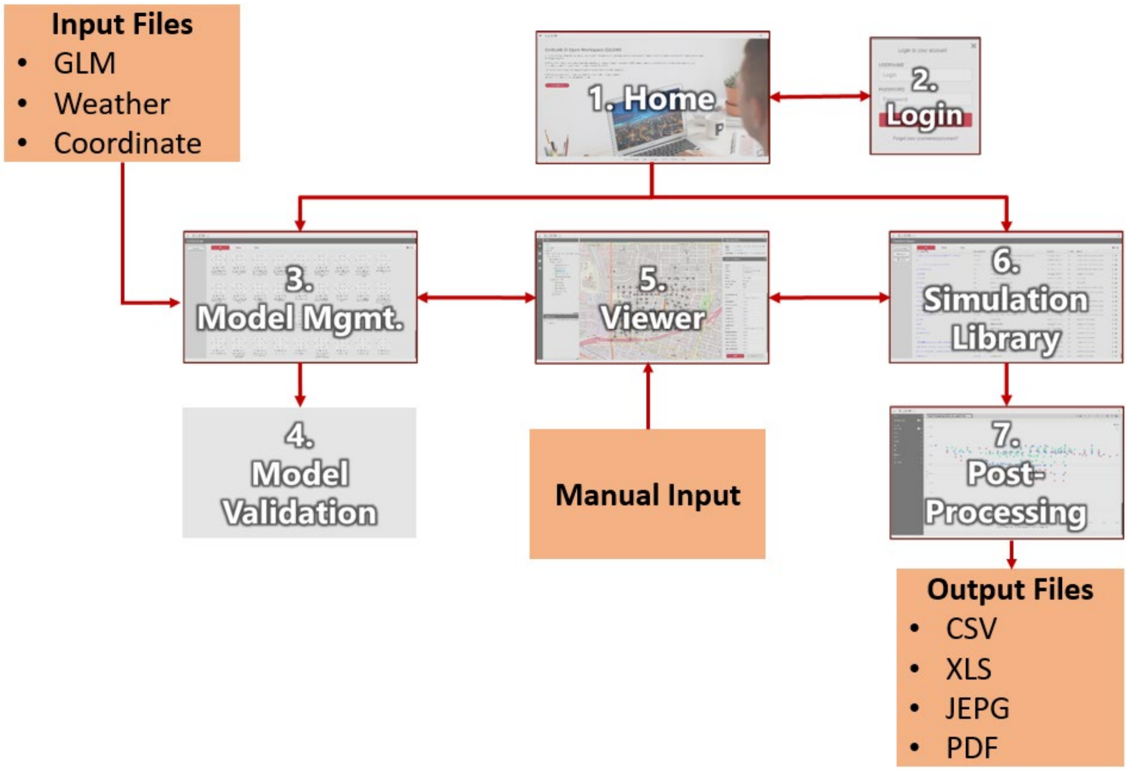
GLOW Information Architecture

GLOW's information architecture includes five major modules, as shown in Figure 11.

- **Home:** This is a landing page that includes login, user management, and access to other modules. The user can also register through this module to get access to GLOW.
- **Model Library:** The user can create and manage feeder models based on the existing equipment database and related data, such as geographical information and weather data.
- **Viewer:** The user can visualize and modify equipment location and parameters. The user can model end-use appliances such as a refrigerator, a space heater, and air conditioning. In addition, the user can visualize the simulation result in this module.
- **Simulation Library:** The user can create and manage simulation scenarios in the Simulation Library module and visualize the result in the Viewer module or the Post-Processing module.
- **Post-Processing:** This module is integrated into the GLOW platform to facilitate data analysis and result realization. The user can create charts based on simulation results.

Additionally, GLOW contains a Resources page that provides useful information to the user, including (1) GLOW introduction video, (2) GLOW download version, (3) Manual, (4) Example files, and (5) Short tutorial videos.

Figure 11: GLOW Information Architecture



Source: Hitachi, Ltd.

GLOW Graphical User Interface

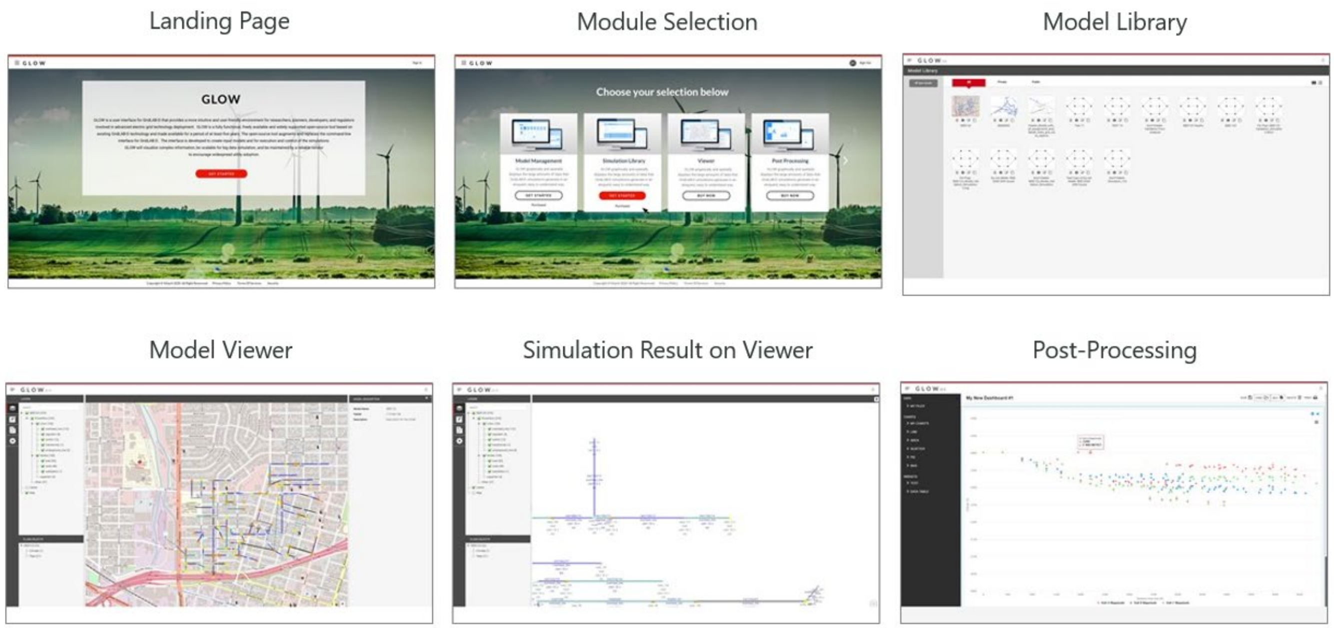
Figure 12 shows an example of GLOW GUI based on GUI Design and Prototype, which consists of several major GUI (for example Home Page, Module Selection, Model Library, Viewer, Simulation Result on Viewer, and Post-Processing). The key functions provided through GUI includes user authentication, feeder model import wizard, model explorer, simulation library, and simulation set-up wizard, among other functions.

In the Viewer module, the feeder model will be loaded and represented in the map view. If the imported models are provided with geographic information system (GIS) information, the GUI will directly provide a map view of the grid. If the models do not contain GIS information, an algorithm will be used to automatically generate artificial geolocation information for each node to lay out the grid network. Furthermore, in the Viewer module, the feeder model can be directly modified and updated.

In GLOW, the project team developed some common distribution analysis application modules and deployed them as workflow templates for various use cases (such as time-series power flow simulation, or ICA.). Then, through the simulation set-up wizard, the user can quickly set up, launch, and review results of these pre-deployed GLOW distribution analysis applications.

GLOW will automatically upload the analysis result onto the database and further load on-demand for viewing or post-processing.

Figure 12: Illustration of GUI of GLOW



Source: https://glow.hero-energy.com/

Production Test

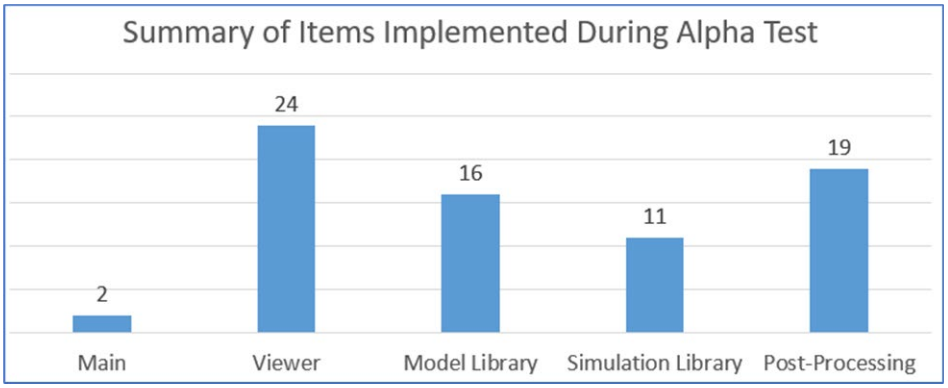
Alpha Test Result

The project team set up the GLOW Alpha Test environment on an Amazon Web Services (AWS) cloud server. Test masters were only from TAC member organizations. The project team and test masters mainly communicated through emails and monthly meetings. Feedback and suggestions were received and prioritized before being implemented in GLOW.

There were 16 test masters from six organizations registered for Alpha Test. The project team provided demonstrations, training, and tutorial to test masters. The project team organized 21 meetings between the project team and test masters to review the monthly update, provide suggestions, prioritize items, troubleshoot, and discuss the future improvements. The project team provided 10 monthly updates between September 2020 – August 2021.

Figure 13 displays implemented items of features, improvements, and bug fixes based on feedback and suggestions from test masters during Alpha Test for each GLOW module. The project team implemented 72 items during the Alpha Test period.

Figure 13: Summary of Items Implemented During Alpha Test



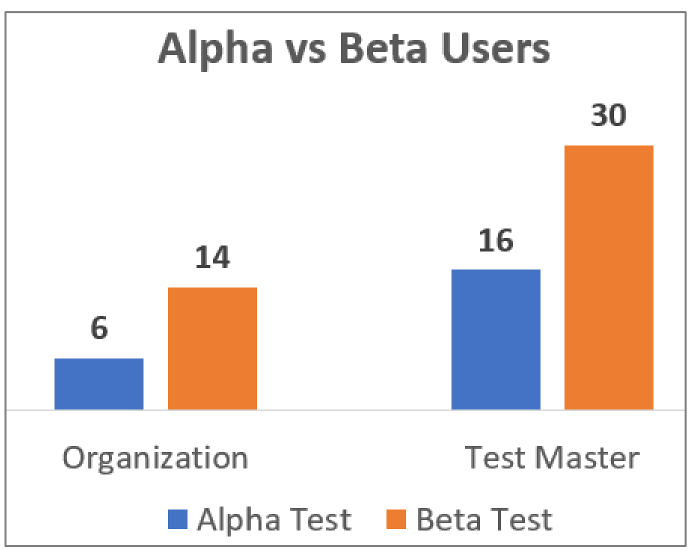
Source: Hitachi, Ltd.

Beta Test Result

GLOW Beta Test environment was the same as the Alpha environment on the AWS cloud server. Beta Test was for technical stakeholders including those from industry, university, and research centers. A new test master registered in GLOW from the registration section. For Beta Testing, the project team and test masters mainly communicated through emails. Feedback and suggestions from utilities were given relatively high priority for implementation. The project team still provided periodic meetings with test masters. The project team also provided demonstrations, training, and tutorials to test masters upon request.

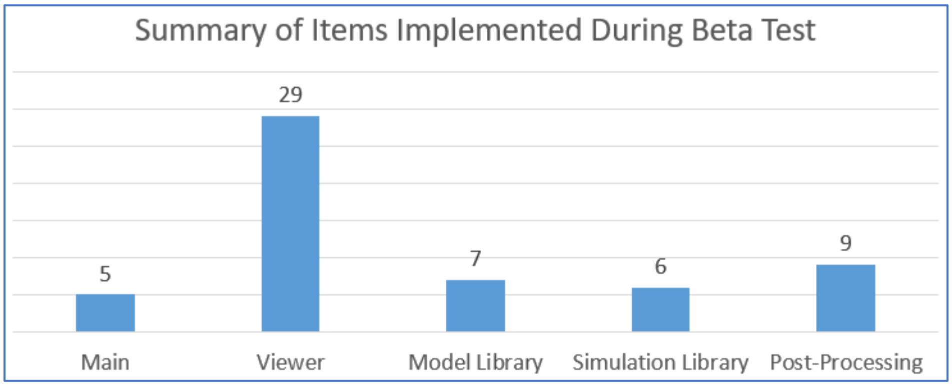
The beta test included 30 testers from 14 organizations. In addition to the test masters in the United States, test masters from universities and research laboratories in the United Kingdom, Brazil, and Singapore signed up to participate. Figure 14 displays a comparison of total test masters during Alpha and Beta Tests. Figure 15 displays implemented items of features, improvements, and bug fixes based on feedback and suggestions from test masters during Beta Test. The total number of implemented items in this period is 56.

Figure 14: Summary of Registered User



Source: Hitachi, Ltd.

Figure 15: Summary of Items Implemented During Beta Test



Source: Hitachi, Ltd.

User Experience Survey

The project team also conducted a user experience survey on GLOW toward the end of Beta Testing in August 2022. Survey questions were created to focus on the following project objective:

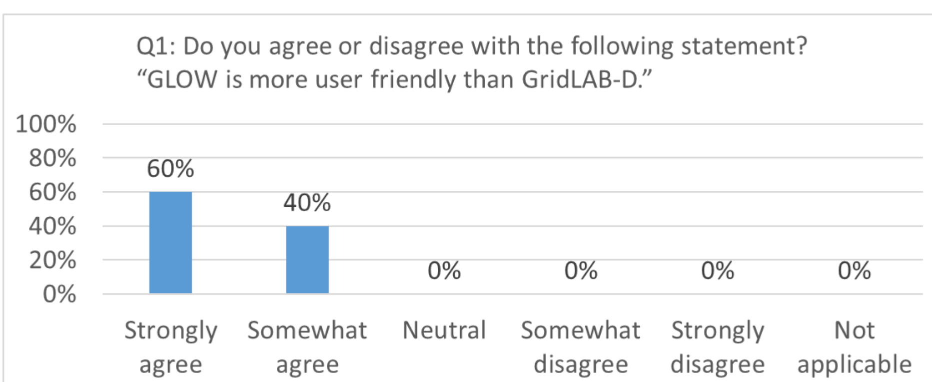
- To develop a high-end user interface for GridLAB-D that provides a more intuitive and user-friendly environment for researchers, planners, developers, and regulators involved in advanced electric grid technology deployment.

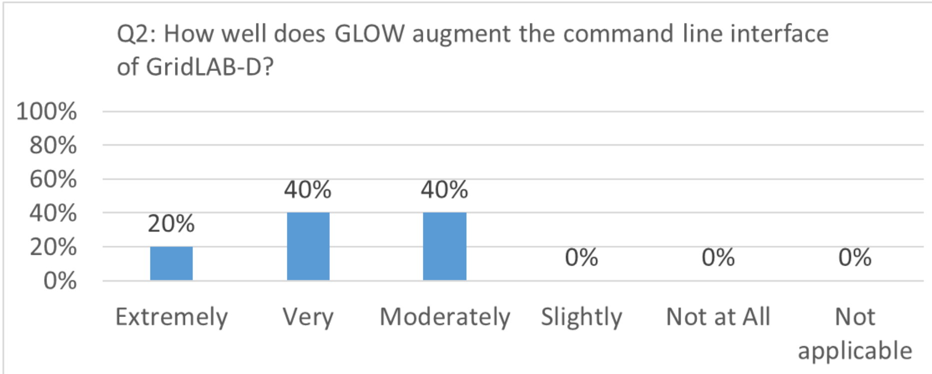
The three survey questions included:

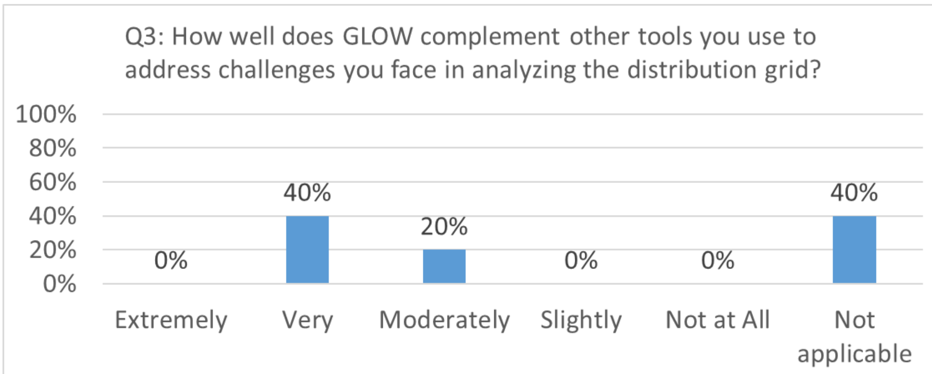
- Do you agree or disagree with the following statement? "GLOW is more user friendly than GridLAB-D.";
- How well does GLOW augment the command-line interface of GridLAB-D?; and
- How well does GLOW complement other tools you use to address challenges you face in analyzing the distribution grid?

Figure 16 shows the summary of user experience survey results, which was open from August 10 to August 31, 2022. All the responses were collected through an online survey service and the results were fully anonymous.

Figure 16: Summary of Survey Results







Source: Hitachi, Ltd.

GLOW Release

GLOW is available in two versions:

- GLOW as a service on the cloud
- Download Version

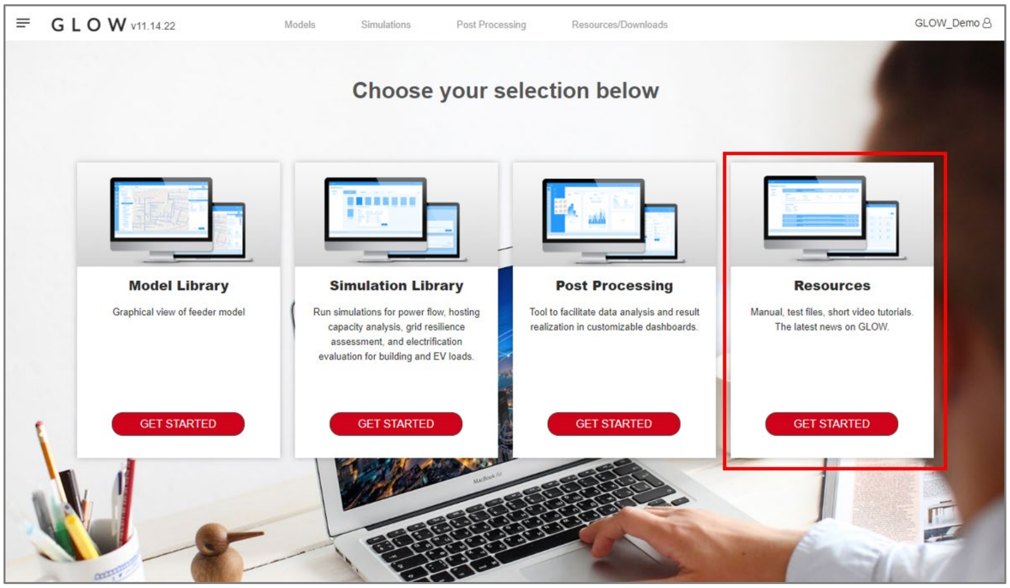
A user can register on the GLOW website to access both versions of GLOW. After logging in with the provided username and password, a user can start using GLOW as a service on the cloud or download the GLOW package and install it on a local machine.

- GLOW Website - https://glow.hero-energy.com/

GLOW Download Version

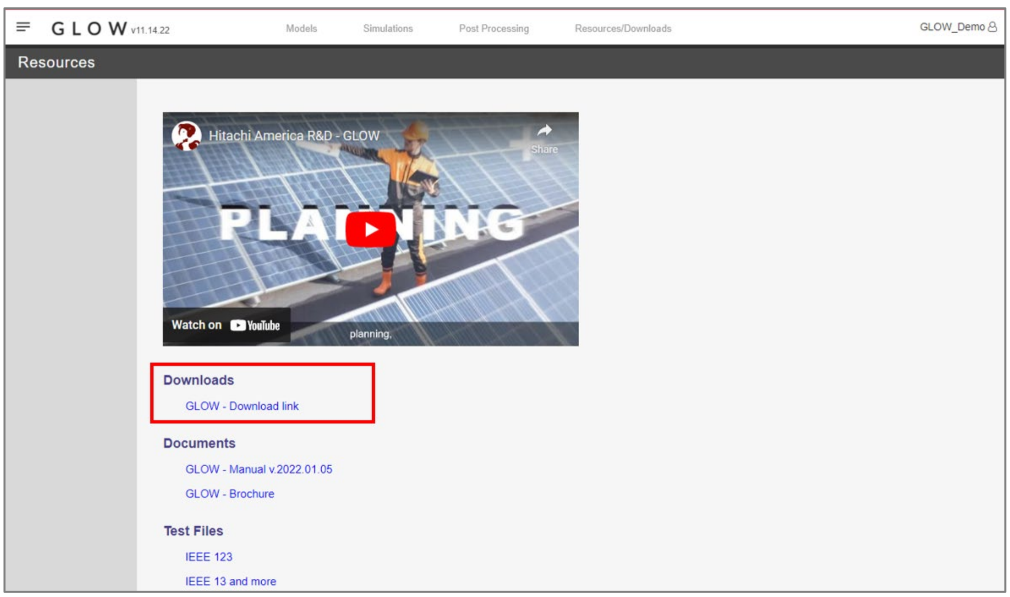
After logging in with the provided username and password, the user can go to the Resources page as shown in Figure 17 and use the download link in Figure 18 to download the GLOW Package.

Figure 17: Selection of Resources



Source: https://glow.hero-energy.com/

Figure 18: GLOW Resources with Download Link



Source: https://glow.hero-energy.com/

Minimum Requirements

System Requirement:

- CPU Architecture
  - AMD64
    - Example
      - i7 Intel(R) Core (TM) i7-8565U CPU @ 1.80GHz (tested)

- Operating System
    - Linux
        - Example
            - Ubuntu-22.04.1-desktop-amd64
            - Ubuntu-22.04.1 on AWS EC2 (tested)
    - Windows 10 Enterprise
        - GLOW cannot be installed directly in Windows 10. It can be installed within Virtual Machine such as Oracle Virtual Box. A user may need to enable virtualization in Bios to run Virtual Box properly.
        - Example
            - Windows 10 Enterprise with Virtual Box 6.1 and Ubuntu 22.04.1 (tested)
- Recommended System
    - Free Space
        - Before fresh installation of Linux = 40GB
        - Before installation of GLOW Package = 25 GB
    - CPU Core = 4 Cores
    - Ram = 4 GB
    - OS: Ubuntu 22.04.1
- Linux Software Package
    - Docker
    - Git

Known Issue:

- Security Software such as Zscala, might cause a problem for the GLOW Package to run properly. The user may turn it off before the installation of GLOW.

Use Cases

The project team developed four use cases for GLOW, including:

- Power Flow;
- ICA;
- Electrification Analysis; and
- Grid Resilience.

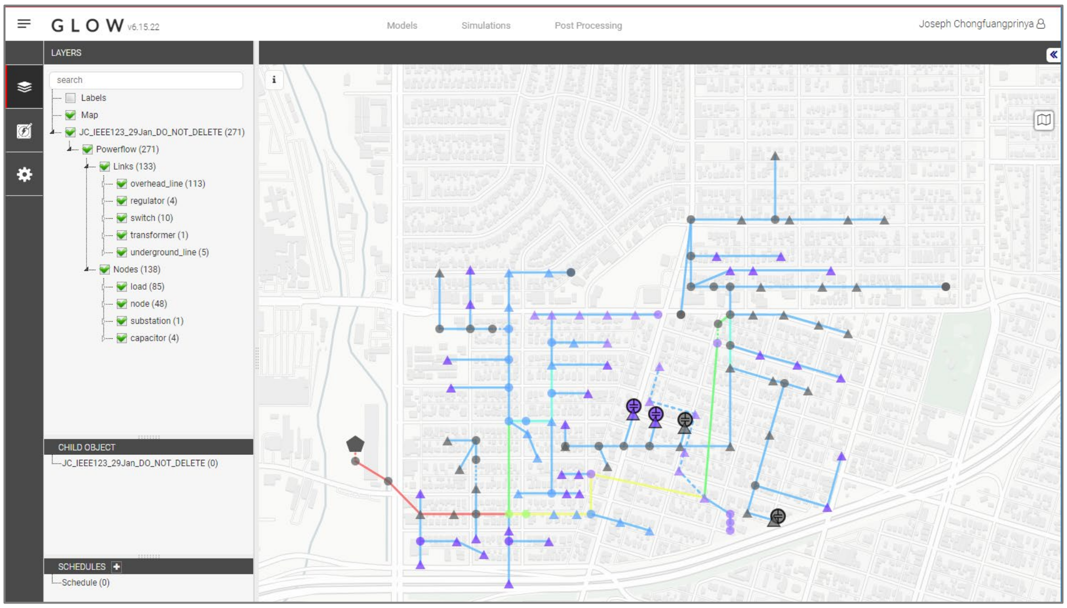
These use cases, process, and corresponding GUI of GLOW were developed based on user interviews, user experiences, and the feedback collected during the Interview and Design Process, Alpha Test, and Beta Test.

Power Flow

Power flow analysis provides simulated conditions of the feeder, such as voltage, active and reactive power, equipment status, and more. Users can create a feeder model with DER and simulate the condition of the feeder with and without DER. If the results of power flow exceed the operation limit, users may investigate further and determine a mitigation measure.

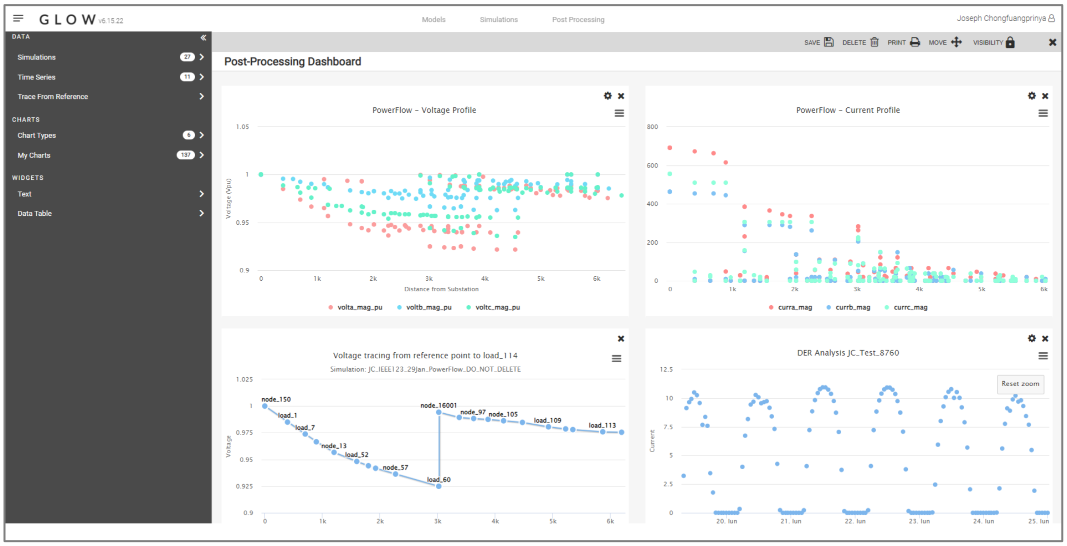
In GLOW, users can simulate either a snapshot or time-series for power flow analysis. Figure 19 displays an example of a power flow analysis result in a graphical view in the Viewer module. Users can customize color based on simulation results. Figure 20 displays examples of power flow analysis in the Post-Processing module.

Figure 19: Power Flow Result in Viewer



Source: https://glow.hero-energy.com/

Figure 20: Power Flow Result in Post-Processing



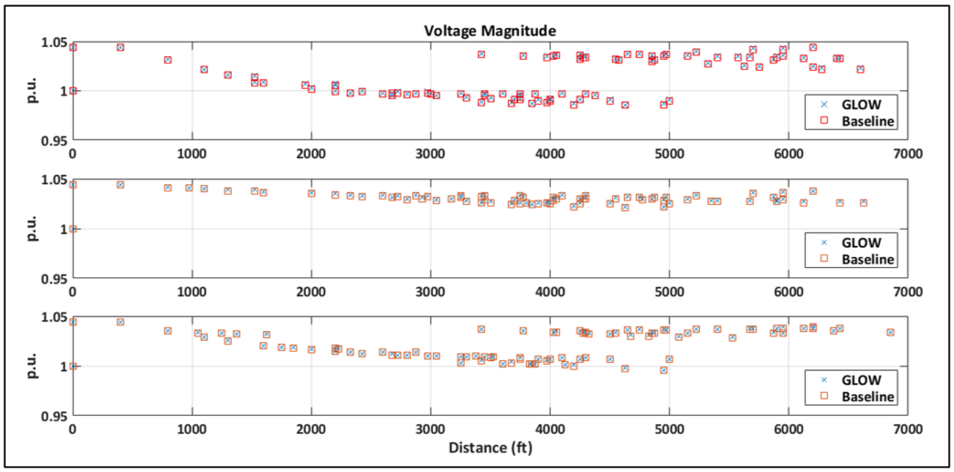
Source: https://glow.hero-energy.com/

Performance Comparison with Industry Standard

The project team benchmarked the performance of power flow results with (1) published results and (2) results from a commercial tool. The reference feeder model is IEEE 123 (IEEE 123 feeder model, n.d.). Figure 21 and Figure 22 show a comparison of voltage and line current between GLOW with GridLAB-D as the power flow engine and the IEEE 123 published datasheet. Both three-phase node voltages and three-phase line currents matched well.

Figure 21: Node Voltage Comparison (Phase A, B, C) with Published Data Sheet

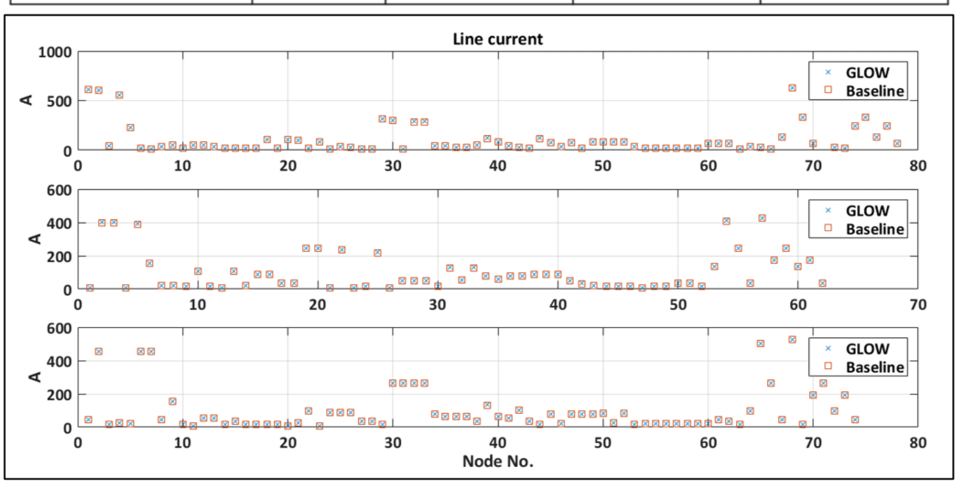
	Phase-A	Phase B	Phase C	Total
Average absolute difference (%)	**0.088**	**0.087**	**0.069**	**0.079**



Source: https://glow.hero-energy.com/

Figure 22: Line Current Comparison (Phase A, B, C) with Published Data Sheet

	Phase-A	Phase B	Phase C	Total
Average abs difference (%)	**0.95**	**0.84**	**0.25**	**0.68**



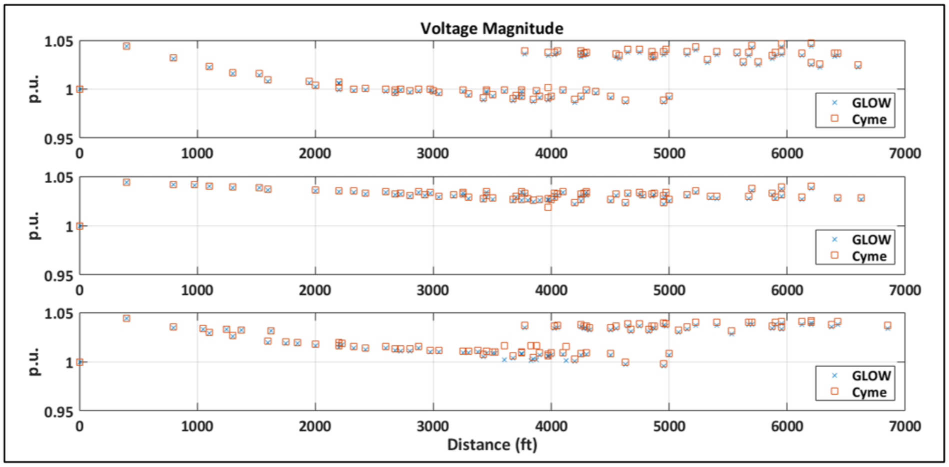
Source: https://glow.hero-energy.com/

Performance Comparison with Commercial Tool

Figure 23 and Figure 24 show a comparison of node voltage and line current between GLOW with GridLAB-D as the power flow engine and CYME. GLOW results closely matched results from the commercial tool, CYME. Both three-phase node voltages and three-phase line currents matched well.

Figure 23: Node Voltage Comparison (Phase A, B, C) with CYME

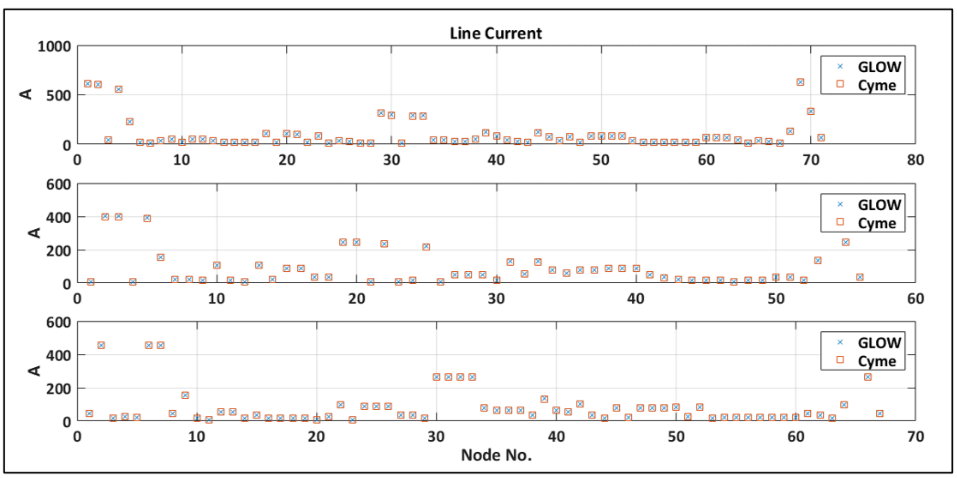
	Phase-A	Phase B	Phase C	Total
Average absolute difference (%)	**0.23**	**0.14**	**0.27**	**0.22**



Source: https://glow.hero-energy.com/

Figure 24: Line Current Comparison (Phase A, B, C) with CYME

	Phase-A	Phase B	Phase C	Total
Average absolute difference (%)	**0.98**	**0.88**	**0.40**	**0.75**



Source: https://glow.hero-energy.com/

Integration Capacity Analysis

ICA is also referred to as hosting capacity analysis (HCA). The objective of ICA is to identify the maximum DER size that can be integrated onto a distribution system down to the line section or node level, considering a variety of system operation limits such as steady state voltage (SSV) limit, thermal limit, and voltage fluctuation limit. The ICA tool gives insight into how much DER the distribution grid can integrate without further investment or upgrades by the utilities.

GLOW ICA follows CPUC DRP guidance (CPUC, n.d.), as shown in Table 2 of the GLOW ICA methodology matrix.

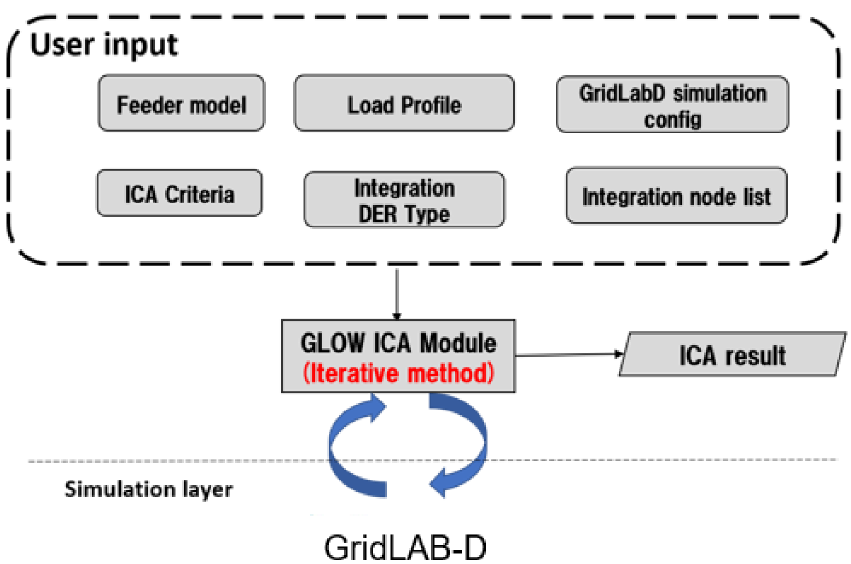
Table 2: GLOW ICA Methodology Matrix

	GLOW ICA	CPUC DRP requirement
Iterative approach	Yes	Yes
Three-phase node	Yes	Yes
Load-type ICA	Yes	Yes
Generation-type ICA	Yes	Yes
Thermal criteria	Yes	Yes
Voltage variation criteria	Yes	Yes
Voltage steady-state criteria	Yes	Yes
Accessible ICA results	Yes	Yes

Source: Hitachi, Ltd.

The project team used an iterative approach in combination with GLOW enhancements that include (1) Binary search (Guddanti et al., 2020) to reduce the number of iterations and (2) multi-threaded simulation to improve computational efficiency. Figure 25 shows the process of GLOW ICA.

Figure 25: GLOW ICA Process



Source: Hitachi, Ltd.

The project team tested GLOW ICA with IEEE 123 and four utility feeders with different system sizes. The results of the test are shown in Table 3.

Table 3: ICA Computation Time Test

Feeder	No of nodes	No of link	Nominal Voltage (V)	Run-time (sec) SSV Limit Criteria	Run-time (sec) Voltage Fluctuation Criteria	No of ICA node (3-phase only)
IEEE123	134	130	2041	1.7	12	70
Utility Feeder 1	1547	303	4200	19	31	142
Utility Feeder 2	990	921	4800	41	72	330
Utility Feeder 3	1364	408	4200	23	42	179
Utility Feeder 4	1670	1323	4800	81	144	371

Source: Hitachi, Ltd.

The project team found that the ICA run-time is impacted by:

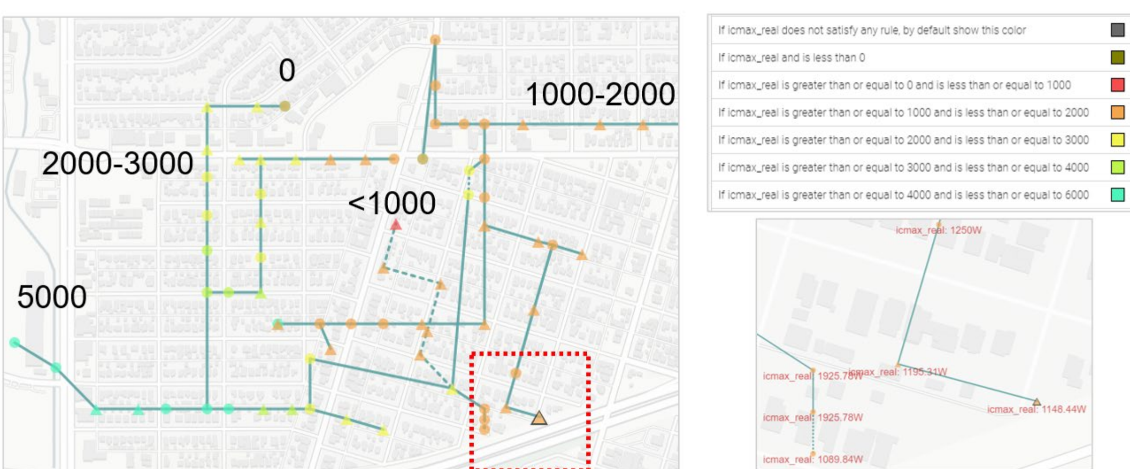
- Number of ICA nodes being studied;
- Feeder size; and
- Maximum integration capacity and ICA resolution.

Further improvement can be achieved through the implementation of parallel computation.

Figure 26 shows the result of GLOW ICA in Viewer module with customized color coding according to ICA results. Figure 27 and Figure 28 show examples of ICA report template. The content of the ICA report includes:

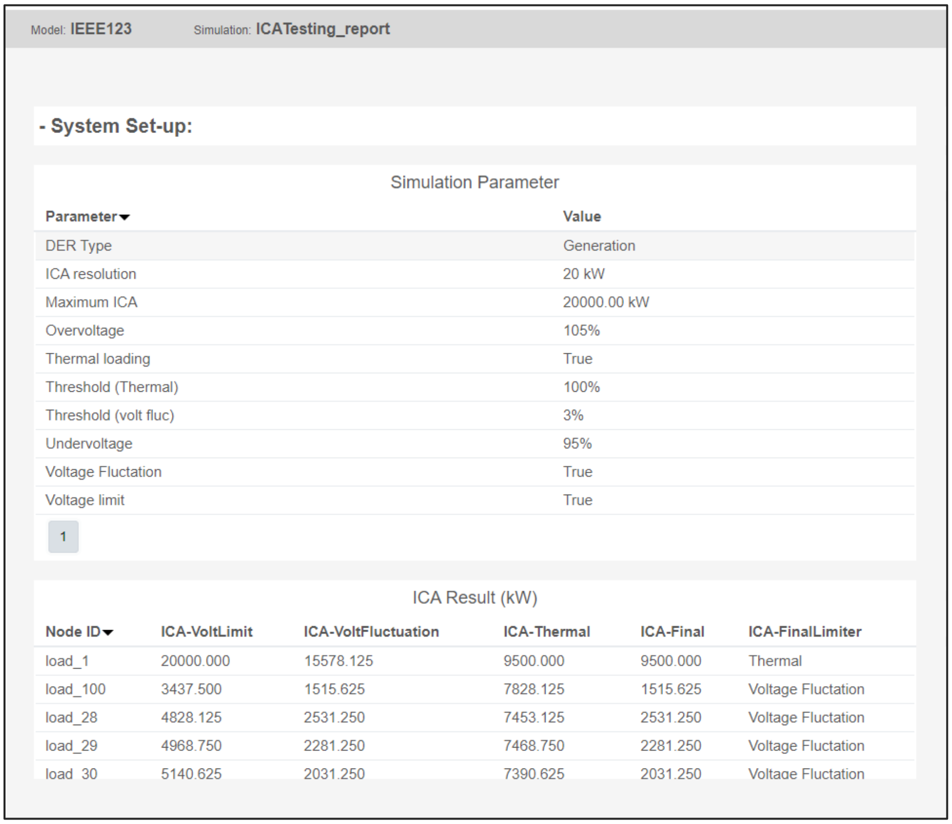
- System feeder model information;
- ICA settings;
- ICA result in table format; and
- ICA result plots.

Figure 26: ICA Result in Viewer with Color Coded



Source: https://glow.hero-energy.com/

Figure 27: ICA Report Template - System Set-up, ICA Settings and ICA Result Table



Model: IEEE123 Simulation: ICATesting_report

- System Set-up:

Simulation Parameter

Parameter	Value
DER Type	Generation
ICA resolution	20 kW
Maximum ICA	20000.00 kW
Overvoltage	105%
Thermal loading	True
Threshold (Thermal)	100%
Threshold (volt fluc)	3%
Undervoltage	95%
Voltage Fluctation	True
Voltage limit	True

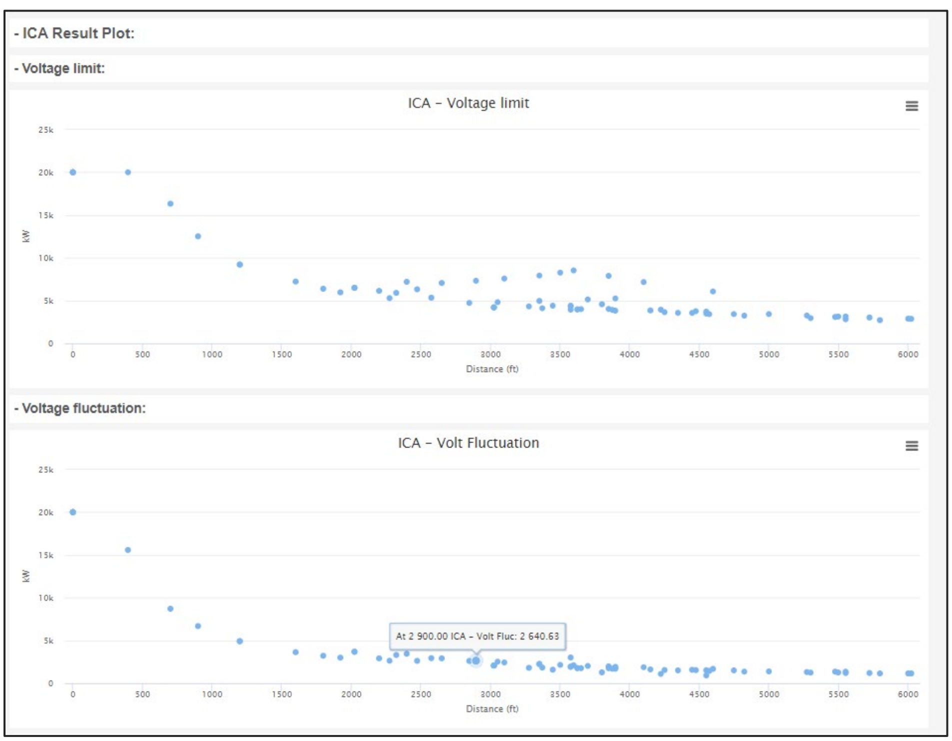
1

ICA Result (kW)

Node ID	ICA-VoltLimit	ICA-VoltFluctuation	ICA-Thermal	ICA-Final	ICA-FinalLimiter
load_1	20000.000	15578.125	9500.000	9500.000	Thermal
load_100	3437.500	1515.625	7828.125	1515.625	Voltage Fluctation
load_28	4828.125	2531.250	7453.125	2531.250	Voltage Fluctation
load_29	4968.750	2281.250	7468.750	2281.250	Voltage Fluctation
load_30	5140.625	2031.250	7390.625	2031.250	Voltage Fluctation

Source: https://glow.hero-energy.com/

Figure 28: ICA Report Template - ICA Result Charts

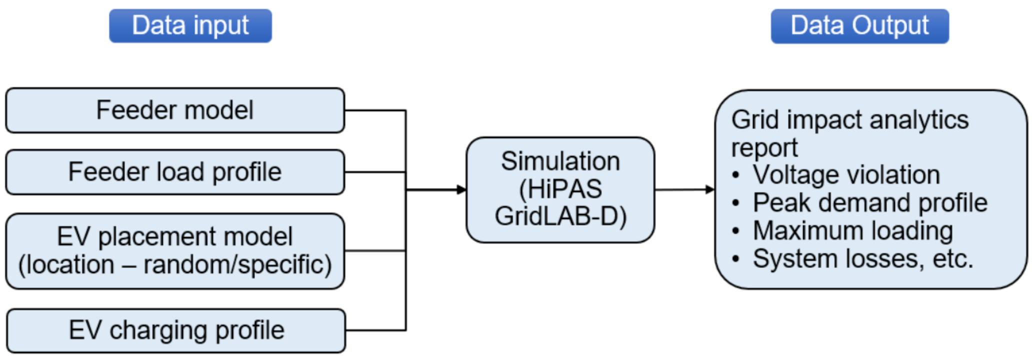


Source: https://glow.hero-energy.com/

Electrification Analysis

The objective of Electrification Analysis is to study the impact of electric vehicle charging station integration on distribution networks under different scenarios. This analysis utilized time-series power flow simulations from HiPAS GridLAB-D. Figure 29 displays the GLOW Electrification Analysis Process.

Figure 29: GLOW Electrification Analysis Process



Source: Hitachi, Ltd.

Figure 30 to Figure 32 show examples of the Electrification Analysis report template. The following are included in the Electrification Analysis report:

- System feeder model information;
- Simulation set-ups;
- Charging station deployment details;
- Charging station load profiles; and
- Grid impact analysis details
  - System voltage profile
  - Asset thermal loading
  - System demand profile (peak demand).

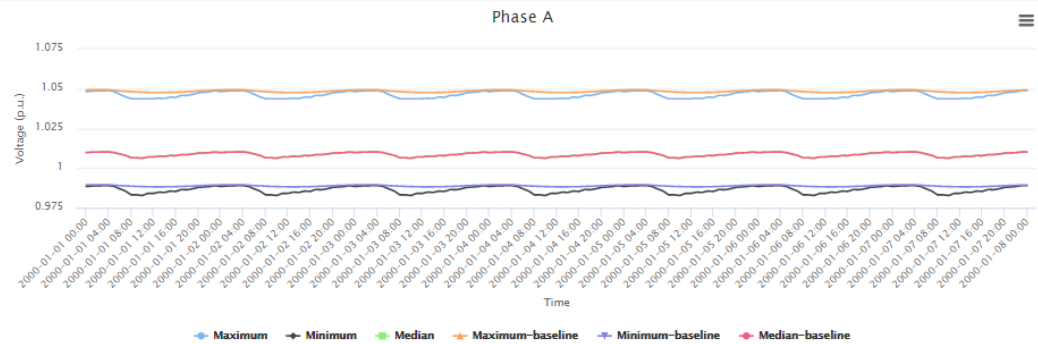
Figure 30: Electrification Analysis Report - System Voltage

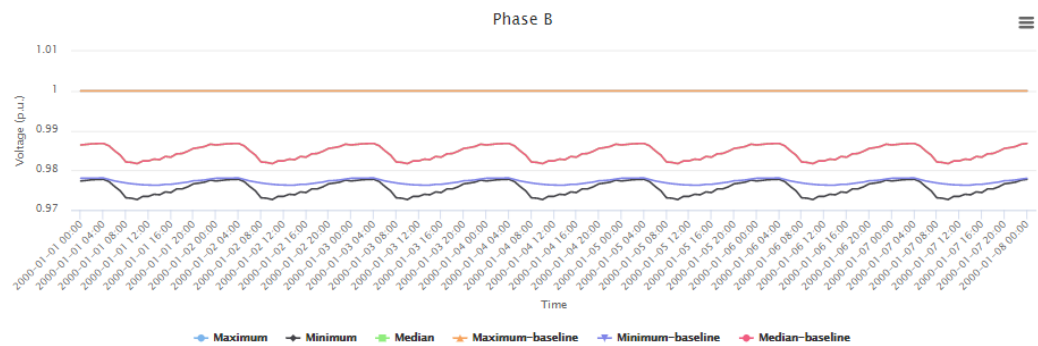
- Grid Impact Analysis:

Voltage:

Voltage Violation Node List

Node name	Minimal Voltage (p.u.)	Violation duration (%)	Phase
There are no voltage vilolation node list available			



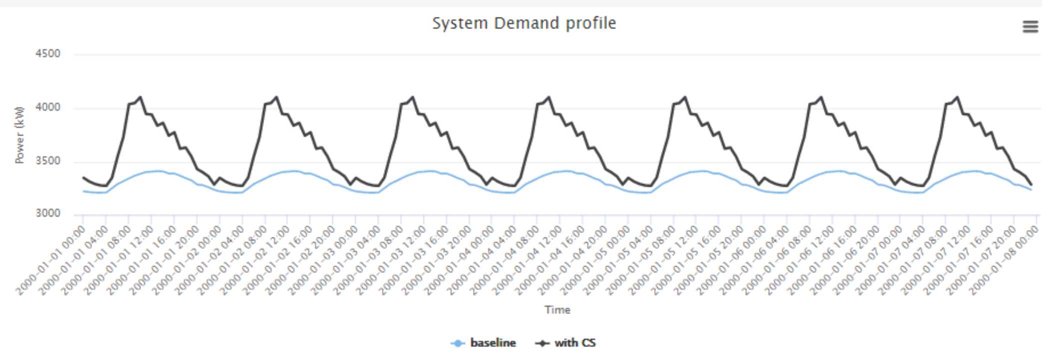


Phase C

Source: https://glow.hero-energy.com/

Figure 31: Electrification Analysis Report - System Demand

Feeder Demand



Peak demand comparison

Maximum Load with CS (kW)	Maximum Load w/o CS (kW)	% change
4106.57	3411.09	20.39

1

Source: https://glow.hero-energy.com/

Figure 32: Electrification Analysis Report - Thermal Loading

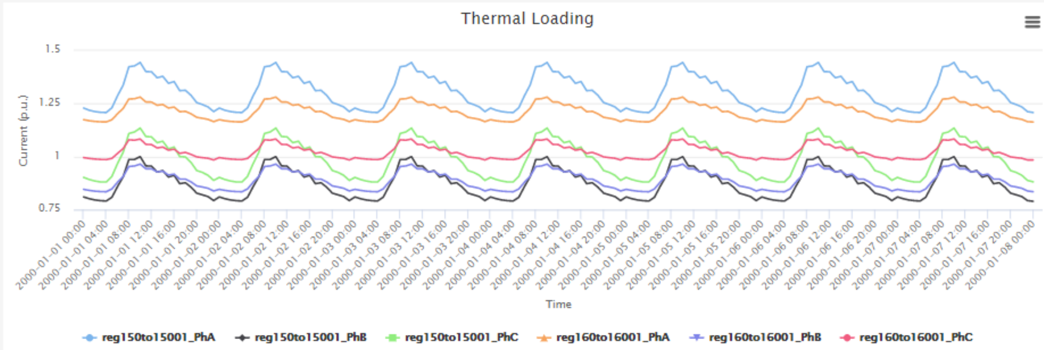
Thermal Loading:

Thermal loading violation asset

Component Name	Phase	Maximum Loading (p.u.)	Violation duration(%)
reg150to15001	A	1.44	100.00
reg160to16001	A	1.28	100.00
reg150to15001	B	1.00	4.14
reg150to15001	C	1.13	45.56
reg160to16001	C	1.08	57.99

1

**loading (p.u.) : phase current/continuous thermal rating

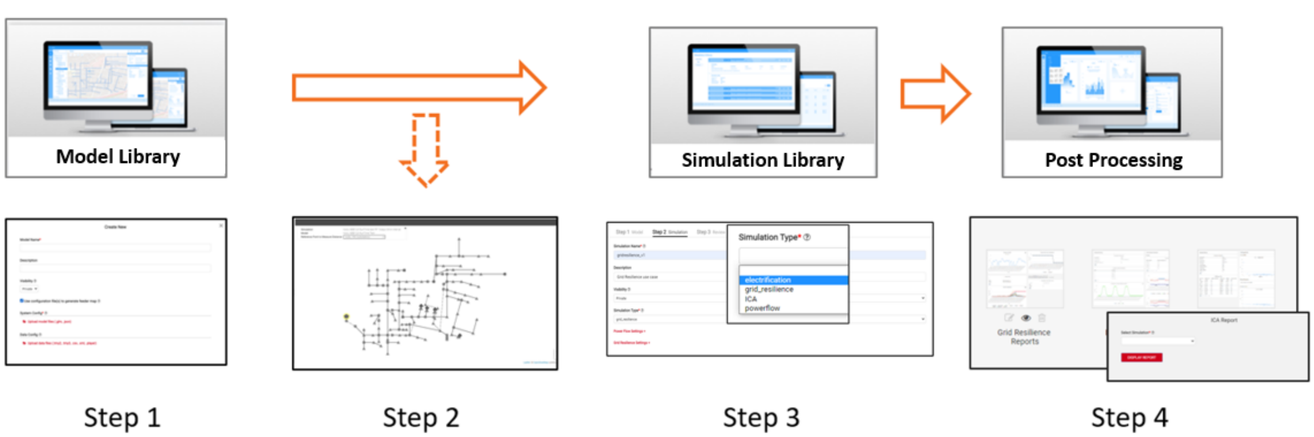


Source: https://glow.hero-energy.com/

Grid Resilience

The objective of Grid Resilience is to provide a modeling framework allowing utilities and policymakers to (1) assess grid resilience under natural disasters and severe weather conditions and (2) support quantitative analysis of mitigation measures to determine necessary long-term infrastructure investment. Figure 33 displays the GLOW Grid Resilience Modeling Framework.

Figure 33: GLOW Grid Resilience Modeling Framework

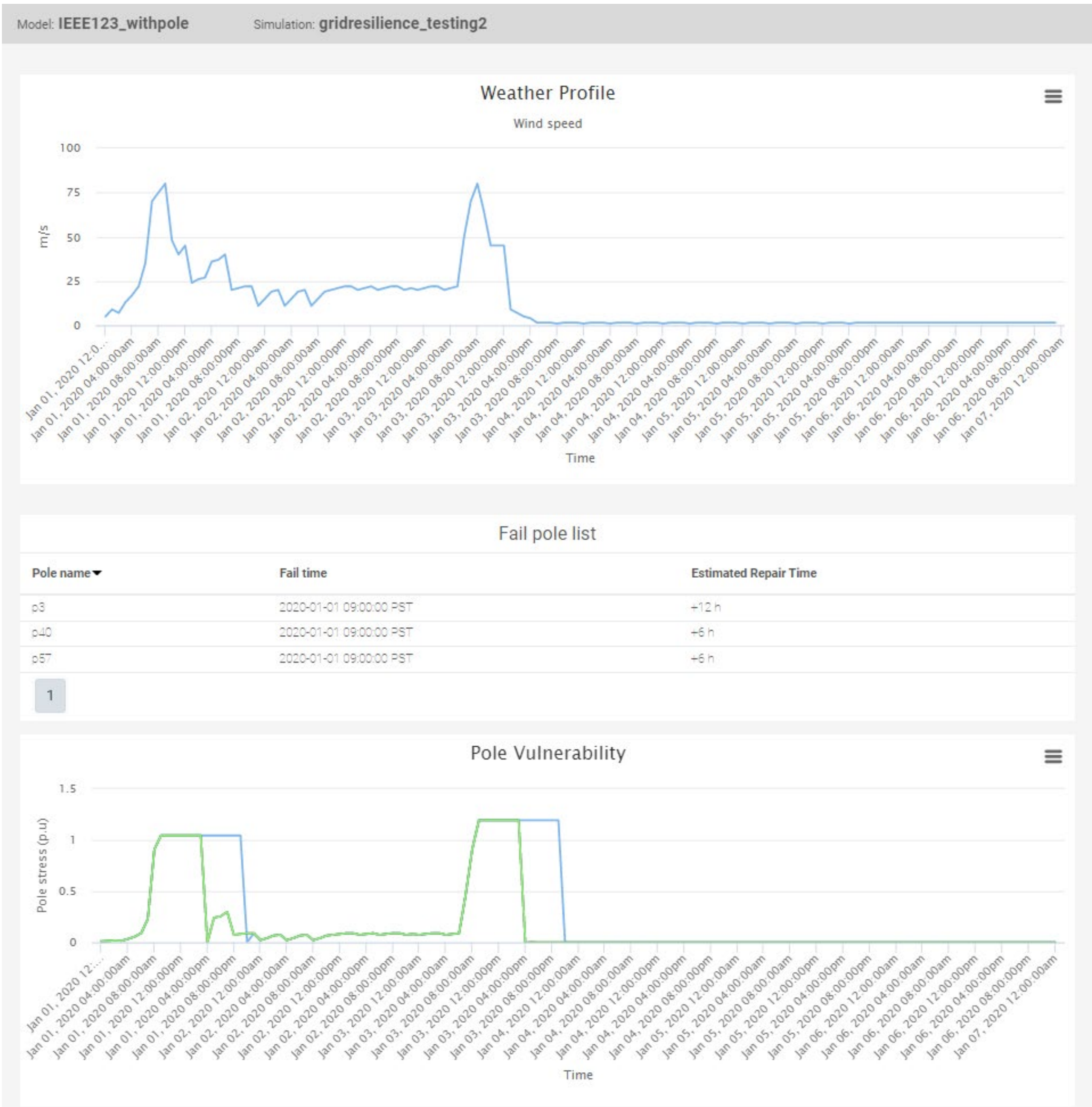


Source: Hitachi, Ltd.

Figure 34 shows an example of the Grid Resilience report template. The contents of the Grid Resilience report include:

- Feeder model information;
- Weather profile (such as wind speed);
- Pole vulnerability curves (for example pole total moment or pole stress); and
- Asset failure summary (Line/Pole).

Figure 34: Grid Resilience Report



Source: https://glow.hero-energy.com/

Knowledge Transfer/Public Outreach

This section describes the knowledge transfer activities and public outreach that introduced GLOW to a broader audience. Table 4 summarizes activities including presentations, webinars, publications, website development, and video tutorials.

Table 4: Knowledge Transfer and Public Outreach Activities

Activity	Detail
Conference Presentation	• Title: "The Latest Development of Distribution Resource Planning Methods and Modeling Tools" • Pedram Jahangiri, Bo Yang, Yanzhu Ye, Joseph Chongfuangprinya, David Chassin, Matthew Tisdale, Andrew Spreen • 2020 DistribuTech, San Antonio, TX, USA, 2020
Paper Publication	• Title: "Better Data Structures for Co-simulation of Distribution System with GridLAB-D and Python" • Kishan Prudhvi Guddanti, Yanzhu Ye, Panitarn Chongfuangprinya, Bo Yang, and Yang Weng • 2020 PES General Meeting, Chicago, USA, 2020
Paper Publication	• Title: "GLOW: A Novel Co-simulation Framework for Integrated Distribution Network Planning and Data Analysis using GridLAB-D" • Yanzhu Ye, Bo Yang, Panitarn Chongfuangprinya • 2020 CIGRE Canada Conference Toronto, Ontario, October 19-22, 2020
Webinar	• Title: "GLOW: An Open-source Distribution Planning Tool Based on GridLAB-D" • IEEE Webinar on 12/18/2020 • Bo Yang, Panitarn Chongfuangprinya
Promotional Video	• Title: "Hitachi America R&D – GLOW" • Marketing Video on YouTube released on 07/2021 • https://youtu.be/ep70nKCPct4
IEEE Tutorial	• Title: "Modeling and Planning of Distributed Energy Resources in Distribution System with Open-Source Software" • IEEE General Meeting Tutorial 2022 on 07/17/22 • Panitarn Chongfuangprinya, David Chassin, Bo Yang, Yanzhu Ye
Promotional Brochure	• Title: GLOW "A Cloud-based Distribution Modeling and Planning Platform" • Distributed at DistribuTech, Dallas, 2022 • https://glow.hero-energy.com/
Tutorial Video	• Series of ten GLOW tutorial videos • https://glow.hero-energy.com/

Source: Hitachi, Ltd.

CHAPTER 4: Conclusion

The Outcome of the Research

GridLAB-D Open Workspace, or GLOW is an open-source distribution planning platform for GridLAB-D. The web-based GUI of GLOW augments the CLI for GridLAB-D in a more intuitive, user-friendly manner, contributing to wider use of the simulation technology.

The project team developed GLOW with a multi-layer architecture, including a simulation layer, a data management layer, and an application layer. On the simulation layer, HiPAS GridLAB-D operates as the distribution system simulation engine. A well-designed API gateway coordinates the data and control interactions between the three layers and third-party tools. The API gateway controls and manages access to a collection of back-end services such as, data querying, data processing, model management, simulation analysis management, and more.

Another key feature of GLOW is the advanced web-based GUI, which effectively facilitates the design, testing, and experiment of various distribution analyses for different stakeholders. The purpose of the GUI is to make electricity modeling software accessible for all parties that might be interested, not just those proficient in data manipulation and command-line programs. GLOW graphically and spatially displays the large amounts of data that GridLAB-D simulations generate in an eloquent, easy-to-understand way. The information architecture of the GUI includes five major modules. The Home module is a landing page that includes login, user management, and access to other modules. The Model Library is a module that allows a user to create and manage feeder models. The user can then use the Viewer module to visualize and modify the location and parameters of the equipment. The Simulation Library module allows the user to create and manage simulation scenarios. The implementation of the friendly simulation set-up wizard effectively guides users to set up and launch a new simulation use case quickly. The Post-Processing module facilitates result realization. Users can create charts based on simulation results in the Post-Processing module. In addition, users can also visualize the simulation result in a map view of Viewer.

Below is a summary of the high-level features of GLOW:

- A distribution planning and modeling platform;
- Web-based GUI for GridLAB-D;
- Open source;
- Support deployment on workstations or the cloud;
- Generate a feeder topology for visualization;
- Use Cases:
  - Power flow
  - ICA
  - Electrification Analysis
  - Grid Resilience;

- Post-processing for result realization; and
- Designed for cross-organizational collaborations.

GLOW is available in two versions: (1) GLOW as a cloud service and (2) Download Version. A user can register through the GLOW website, https://glow.hero-energy.com, to access both versions of GLOW. After logging in, users can start using GLOW as a service in the cloud or download the GLOW package and install it on a local machine.

Benefits of GLOW

The state of California has identified increasing DER as an important element of its strategy to achieve its clean energy goals. Integration of DER into the distribution grid must be done in a manner that supports electricity system reliability without compromising personnel or public safety or unreasonably increasing the cost of electricity to consumers. One barrier to this goal is evaluating the impacts of DER on the distribution grid and making policy and investment decisions based on these results.

GLOW makes using GridLAB-D software easier, faster, and more accessible to non-technical users. Thus, one primary benefit of GLOW, which provides an improved GUI and visualization tool for GridLAB-D, is support for increased modeling accuracy in decision-making surrounding DER technology adoption. The GLOW project benefits California IOU electricity ratepayers by supporting the goals of the CPUC DRP proceeding, as well as the broader goals of the state to support integration of DERs and plan for the grid of the future. GLOW GUI expands the number of users and markets for power systems analysis tools beyond just utilities to include local communities, technology developers, researchers, public agencies, and other organizations interested in assessing DER integration into the distribution grid.

Future Development Opportunities

The layer architecture of GLOW is flexible and allows GLOW to expand in the future to address challenges that are not part of the current scope of work. Examples of these challenges are: (1) utility use cases and processes; (2) extensive computational requirements for a utility-wide study; (3) variation of policies; and (4) demand data that is not always available, among others. Future development opportunities may include working with utilities to develop customized GUIs for particular use cases, such as long-term load forecasting or ICA, based on utility processes and requirements. For example, the project team can develop a new functional module to replicate a process and automate the data integration, conversion, and simulation for a utility. The project team may integrate a discrete model validation step into GLOW. Individual scripts can tie together data and model sources for automatic updating and reporting. The project team can also leverage more up-to-date data from enterprise systems, such as smart meter data from a meter data management system and model data from an advance distribution management system, so the planning models and load profiles can be streamlined for the analysis. In addition, some utility use cases may require analysis for the whole utility for hundreds or thousands of feeders. The project team can implement an advanced parallel computation algorithm to optimize server resources and computation time for these types of studies. Advanced parallel computation algorithms can reduce simulation time from months or weeks to days or hours for a particular analysis.

LIST OF ACRONYMS

Term	Definition
API	application programming interface
AWS	Amazon Web Services
CLI	command-line interface
CPUC	California Public Utilities Commission
DER	distributed energy resource
DRP	CPUC Distribution Resources Plan
GIS	geographic information system
GUI	graphic user interface
HAL	Hitachi America Ltd.
HCA	hosting capacity analysis
HiPAS	High-Performance Agent-Based Simulation
ICA	integration capacity analysis
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor-Owned Utility
OpenFIDO	Open Framework for Integrated Data Operations
PG&E	Pacific Gas and Electric
PNNL	Pacific Northwest National Laboratory
PSERC	Power Systems Engineering Research Center
REST	Representational State Transfer
SCE	Southern California Edison
SLAC	Stanford Linear Accelerator Center
SSV	steady state voltage
TAC	technical advisory committee
UXD	User Experience Design

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Project Deliverables

This is a list of the Project Deliverables from the key technical tasks:

- UI Design Presentation
- User Requirements Presentation
- Input/Output Data Requirements Document
- Architecture and Implementation Plan Presentation
- Implementation Checklist
- User Requirements Presentation Materials with revisions highlighted
- Integration Test Presentation
- Manual and Instruction Document
- Final Alpha Test Plan
- Email Notification for GLOW - Production Candidate One Release
- Email Notification for GLOW - Production Candidate Two Package Release
- Final Beta Test Plan
- GLOW Production Test Document
- New Use Cases Using the GLOW Document
- Email Notification for GLOW Version 1.0 Package Release
- Final GLOW Version 1.0 Release Document

Project deliverables, including interim project reports, are available upon request by submitting an email to ERDDpubs@energy.ca.gov

GLOW is available in two versions:

- GLOW as a service on the cloud
- Download Version

A user can register on the GLOW website to access both versions of GLOW. After logging in with the provided username and password, a user can start using GLOW as a service on the cloud or download GLOW package and install it on a local machine.

- GLOW Website - https://glow.hero-energy.com/

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Appendix A: GLOW Package Installation Guide

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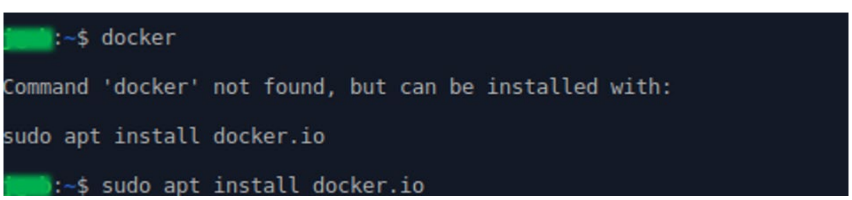
APPENDIX A:
GLOW Package Installation Guide

GLOW local installation guide:

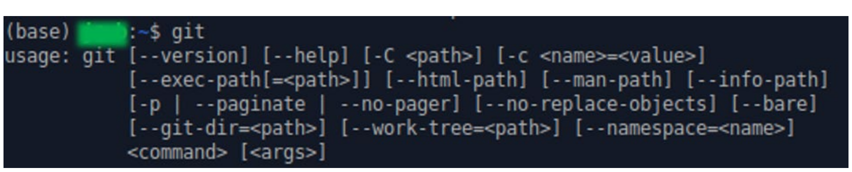
1. Install “docker” and “docker-compose” on the host machine (tested by Ubuntu-22.04.1)
   - Figure A-1 shows example of executing command to check availability of Docker software package and to install Docker software package when it is not available.
2. Install “git” on the host machine.
   - Figure A-2 shows an example of executing a command to check the availability of the Git software package.
3. Download and unzip GLOW Package on the host machine.
4. At the root of the GLOW Package Directory, execute "docker compose up"
   - The user may execute the command "sudo docker-compose up -d" depending on how the host computer is set up.
   - Figure A-3 shows an example of executing a command to run GLOW Package under the “glow_docker” directory.
   - This step may take over an hour to build container images.
   - The user should be able to see something similar to Figure A-4 after successful execution of this step.
5. GLOW will be accessible from http://[url of host machine]/.
   - Example: “http://localhost”

Figure A-1: Execution Command to Check Availability of Docker Software Package



Source: Hitachi, Ltd.

Figure A-2: Execution Command to Check Availability of Git Software Package



Source: Hitachi, Ltd.

Figure A-3: Execution Command to Run GLOW Package

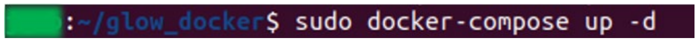
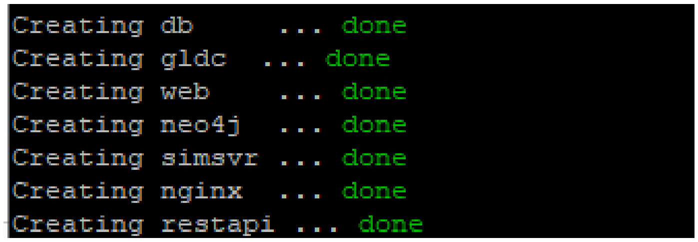


Figure A-4: GLOW is Ready



Source: Hitachi, Ltd.

Stopping GLOW:

- At the root of the cloned repository, execute "docker compose down"
- The user may execute the command "sudo docker-compose down" depending on how the host computer is set up.

Resetting GLOW to its initial state:

- Stop GLOW-Docker by executing the command "docker compose down"
- Delete all the files within the "storage" folder under the root of the cloned folder.
- Start the GLOW-Docker by executing the command "docker compose up -d"

Re-creating the container image for the new version of GLOW-Docker:

- Run the following command: "docker compose build --no-cache"

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Appendix B: HiPAS and GridLAB-D Resources

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APPENDIX B:
HiPAS and GridLAB-D Resources

- From SLAC
  - GLOW utilized the HiPAS GridLAB-D developed by SLAC. HiPAS GridLAB-D User Documentation can be found at:
    - https://docs.gridlabd.us/
  - Source codes:
    - https://github.com/slacgismo/gridlabd
- From PNNL
  - This is a detailed tutorial of GridLAB-D from PNNL. It may not cover some functions supported by GLOW and HiPAS GridLAB-D from SLAC.
    - http://gridlab-d.shoutwiki.com/wiki/GridLAB-D_Wiki:GridLAB-D_Tutorial_Chapter_0_-_Introduction#Table_of_Contents
- Other resources
  - https://github.com/gridlab-d/course
  - https://github.com/gridlab-d/course/blob/master/ThreeDayCourse_v22.zip
  - https://github.com/gridlab-d/course/blob/master/GridLAB-D%20Architecture.pptx
  - https://github.com/gridlab-d/data