Final Project Report Template

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The purpose of the final project report is to share the key takeaways from your completed project–-including the project approach and results–-with policymakers, technology developers, researchers, and the public, among others. Project reports also serve to demonstrate the value of public investment in research and technology development.

Report Checklist

Please complete the following report checklist by checking off the box next to each item.

☒ Composed report, including appendices, in this Final Project Report Template.
To ensure proper formatting, the CEC advises drafting in this template.

☒ Length of report main body (Introduction through Conclusion) is **10,000 words or fewer**.

☒ Length of appendices is **15 pages or fewer**.

Note: For reports that are the primary product of the project and for certain other projects, it may be appropriate to produce a longer report. Please request approval of the Commission Agreement Manager (CAM) to exceed the length limitations above.

☒ Completed all report sections in the following order:
- ☒ Webpage Abstract
- ☒ Title Page
- ☒ Table of Contents (optional for reports with fewer than 10,000 words)
- ☒ List of Figures (optional for reports with fewer than 10,000 words)
- ☒ List of Tables (optional for reports with fewer than 10,000 words)
- ☒ Executive Summary
- ☒ Introduction
- ☒ Project Approach
- ☒ Results
- ☒ Conclusion
- ☒ Acknowledgments
- ☒ References

- ☒ List of Project Deliverables
- ☒ Appendices (if included)

☒ Checked that text is organized, clear, and understandable to broad audiences, with consistent and accessible technical terminology.

☒ Formatted report, including appendices, is in accordance with the Writing Style and Formatting Guidance section at the end of this template.
https://www.energy.ca.gov/publications/2020/style-manual-fourth-edition-used-california-energy-commission-staff-lead

☒ Checked report, including appendices, meets American Disability Act (ADA) compliance as outlined in the Accessibility Guidelines section at the end of this template.

☒ Completed spell-check.

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Webpage Abstract

California utilities, customers, consulting engineers and regulators need to exchange power system data, yet this can be cumbersome and error prone, raising barriers to effective resource integration, curbing growth of these resources and limiting how quickly California can reach its climate change mitigation goals.

OpenFIDO provides a framework for interorganizational data exchange, data and model synthesis, and system performance analysis across multiple power systems tools. OpenFIDO is used to (1) collect data from a wide variety of sources; (2) transfer model and telemetry data between tools; and (3) enable creation of permanently available reproducible results.

OpenFIDO allows utility planners and grid researchers to move data quickly between applications. OpenFIDO supports emerging user groups including DER system integrators and aggregators who use multiple tools to analyze DER grid impacts, and governments and agencies using models for oversight and planning clean energy deployments.

Project results include (1) identifying data analysis requirements needed to support critical electricity use-cases; (2) delivering a new open-source utility data analytics workflow management platform designed for interoperability using workstation-only, on-premise servers, and cloud infrastructure; and (3) supporting an open-source analytic tool delivery environment to enable key utility use-cases. OpenFIDO is commercialization-ready as a scalable utility data analytics platform.

FINAL PROJECT REPORT

Open Framework for Integrated Data Operations (OpenFIDO)

Agreement Number: EPC-17-047

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Month Year | CEC-500-XXXX-XXX

Table of Contents (Optional)

List of Figures (Optional; examples below)

List of Tables (Optional; examples below)

Executive Summary

The Open Framework for Integrated Data Operations (OpenFIDO) is a data interchange, model synthesis, and analytics support framework that provides access to open-source data and model exchange and analytics tools for power systems researchers, utility planners, and regulators. OpenFIDO is used to apply system models, weather data, load and system telemetry data exchanged between various software products as part of the suite of tools widely used by utilities, distributed resource engineers and regulators in California.

OpenFIDO is designed for utility planners and grid researchers that need a tool to quickly and consistently move data and models from one application to another and apply these to their engineering, planning, and review activities. OpenFIDO supports emerging user groups such as distributed energy resource (DER) integrators and aggregators that use multiple tools to manage the grid impacts of DERs, as well as governments and agencies that use these data and models in both their oversight role and identifying opportunities for new energy and climate policies.

OpenFIDO identified requirements for four electricity use-cases: ICA, electrification, tariff design, and resilience analysis. The system was delivered open-source through the Linux Foundation Energy for multi-organization interoperability that runs on individual workstations, on-premise servers, and cloud infrastructure services.

Background

California utilities, customers, consulting engineers and regulators need to reliably and consistently exchange power system data and models to help the state achieve its climate response goals. Yet this process can be cumbersome and error prone, raising barriers to effective resource integration, curbing growth of these resources and limiting how quickly California can reach its climate change mitigation goals.

Utilities require a framework for inter-organizational data exchange, data collection, model synthesis, and system performance analysis across multiple power systems tools. Utility and analysts specifically are required to (1) collect data from a wide variety of sources; (2) transfer model and telemetry data between tools; and (3) create permanently available reproducible results.

There is an emerging community of users for such a tool, including utility engineers, DER system integrators and aggregators who use multiple tools to analyze DER grid impacts, as well as governments and agencies using models for oversight and planning clean energy deployments. These users need an open-source, readily extensible, community supported, and commercially sustainable tools that can provide for these needs.

Project Purpose and Approach

The purpose of OpenFIDO is to reduce the time and effort involved in setting up models, assembling data, and running analysis of various scenarios in order to better plan and study distribution system investments, with particular emphasis on studies involving renewable energy resource integration and energy system decarbonization.

The specific objectives of OpenFIDO projects included the following:

- Identify data exchange and analysis requirements by working with California's Investor Owned Utilities (IOUs), Pacific Gas & Electric, San Diego Gas & Electric, and Southern California Edison, and tool vendors through understanding their planning processes;
- Develop and test a platform that can use data and models from IOUs and convert them to those used by emerging data-intensive analysis and agent-based simulation tools;
- Demonstrate data exchange and analysis in the primary use-cases identified by IOUs.

OpenFIDO implements a scalable data curation framework capable of (1) ingesting data from various sources, including cloud-hosted data systems, power system simulation tools, and web-based endpoints; (2) running data-intensive analysis and agent-based simulations; and (3) delivering data to external users through modern data-exchange infrastructure.

OpenFIDO builds upon several capabilities introduced in the DOE VADER system (Sevlian 2017), a scalable data management platform. OpenFIDO has 3 core components that are oriented toward highly efficient, scalable, and customizable data processing: methods, pipelines, and workflows. Each component builds on the previous in a self-similar architecture that facilitates speed, diverse execution environments, and open-source distribution.

Methods: Methods are primitive data operations needed to perform basic data processing functions, such as obtaining data from remote sources, manipulating data, and delivering data to endpoints for access by other tools. Methods are generally distributed through open-source repositories, such as GitHub, but can also be distributed through private repositories.

Pipelines: Pipelines are simple data operations that require zero or more inputs, perform multiple data processing steps, and generate one or more outputs. Pipelines are always composed of zero or more methods that must be executed in series. Pipelines are generally distributed through open-source repositories, such as GitHub. Pipelines can also be distributed through private repositories.

Workflows: Workflows are complex data operations that require zero or more inputs, perform multiple data processing steps, and generate one or more outputs. Workflows are always composed of two or more pipelines that can be executed in parallel. Workflows are generally distributed through open-source repositories, such as GitHub. Workflows can also be distributed through private repositories.

OpenFIDO was developed using the following approach:

1. Workshops and interview utility engineers and potential users to gather use-cases and data requirements. Two workshops were held and interviews conducted with IOU, municipal, and cooperative utilities, reliability organizations, government agency users, vendors and consultants as well as a select group of people who have served in technical advisory groups. The interviews provided insight into the data handling requirements among various tools used in the process of planning distribution systems.

2. Develop a platform to support planning process data exchange: The platform comprises the methods, processing pipelines, and analysis workflows described above. The platform also delivers the data handling tools and services to convert data to and from different power system tools used by the industry.

3. Gather sample datasets: Sample data and model files were collected from the industry to test and validate the framework.

4. Design and Develop data architecture for the data interchange platform: Presence Product Group designed the system architecture to meet the needs of users and developers.
5. Develop and test platform features using real-world use cases: The platform was tested and validated for four use-cases identified by the project team in collaboration with two other CEC-funded projects, HiPAS (EPC-17-046) and GLOW (EPC-17-043):
    1. **Integration capacity analysis (ICA):** utilities need to complete system-wide hosting capacity analysis to determine the maximum node-level resource integration limit for a circuit to remain within key power system criteria.
    2. **End-use electrification:** utilities need to study the impact of increasing electrification of fossil-fueled end-use loads, specifically heating, cooking, hot water, clothes drying, and light-duty vehicles.
    3. **Tariff design:** utilities need to study the revenue impacts of emerging technologies and planning scenarios that include high penetration of DER and end-use electrification.
    4. **Resilience analysis:** utilities need to study the resilience impacts of emerging technologies that support high penetration of DER and end-use electrification in the presence of increasing climate change impacts on system operations and planning.
6. Organize technology workshops and plan the commercialization of OpenFIDO.

Key Results

The OpenFIDO project achieved four important results that addressed the challenge of open data analytics for electric utilities.

1. OpenFIDO identified the key data analysis requirements that are needed to support critical electricity use-cases, specifically ICA, electrification, tariff design, and resilience analysis.
2. OpenFIDO delivered a new open-source utility data analytics workflow management platform specifically designed for interoperability across multiple organizations using workstation-only, on-premise servers, and cloud infrastructure services.
3. OpenFIDO supports an open-source analytic tool delivery environment, including the methods, pipelines, and workflows that support key utility use-cases identified in the project, as well as future products based on as-yet-unidentified use-cases.
4. OpenFIDO was commercialized through the Linux Foundation Energy as a scalable utility data analytics platform by one or more vendors and cloud services hosting platforms.

Knowledge Transfer and Next Steps

The project team developed a Knowledge Transfer Plan for OpenFiDO, GLOW, and HiPAS. This Knowledge Transfer Plan aims to provide a platform for lessons learned and knowledge gained over the course of the three inter-related initiatives.

The target audiences include the staff at the California Energy Commission, the California Public Utilities Commission, load-serving entities, DER vendors, public interest organizations, research institutions, and other interested parties.

The Knowledge Transfer Plan includes Project Fact Sheets and Presentation Materials for public distribution. Project Fact Sheets and Presentation Materials shared in Technical Advisory Committee (TAC) meetings or ad hoc workshops and webinars were all published on the project website hosted by Gridworks.

Over the course of the project, the team held biannual public meetings with the TAC in the spring and fall. The meetings were an opportunity to update the TAC and other interested stakeholders on the project status, including sharing methods, validation models, and model results. Over five TAC meetings between 2018 and 2020, 172 people participated and heard updates and provided input on the development of OpenFIDO.

Training materials were developed and deployed when the OpenFIDO project was completed. To maximize efficiency, training materials were developed and deployed in concert with materials to support GLOW and HiPAS.

OpenFIDO was submitted for adoption by the Linux Foundation (LF) Energy, which is an open-source foundation focused on the power systems sector, and hosted within The Linux Foundation. LF Energy provides a neutral, collaborative community to build the shared digital investments that are needed to transform the world's relationship to energy. Once adopted, LF Energy will provide the user community support and contribution infrastructure needed to ensure the longevity and usefulness of OpenFIDO in the coming years.

Introduction

The electric utility industry is highly reliant on data, analytics, models, and simulation to plan and operate distribution systems. Data comes from many sources including customers, system operations, electric markets, and partner organizations. Analytics are used to develop an understanding of the system and assist in producing action plans based on past behavior.

Utilities develop and maintain detailed models of their systems in order to study their future behavior, plan for growth and adoption of new technologies, and sustain reliable and cost-effective operations. Simulations ensure that devices and equipment continue to function properly and expansion plans meet existing and emerging requirements. Simulators are increasingly used for essential studies such as reliability and resilience analysis, distributed resource (DER) interconnection permitting, tariff design, and load electrification impact studies, among other things.

Climate change and policy responses are changing analysis demands for these simulation tools as well. There is an increasing amount of environmental, advanced technology, and consumer behavior data that needs to be incorporated in simulations for results to remain valid. For example, satellite and LIDAR data of vegetation changes in proximity to power lines is now available for all of California from www.forestobservatory.com. This data can be fused with network models to determine which power lines are at risk from vegetation falls during high-wind events. Similarly, the availability of automated meter infrastructure (AMI) data enable nearly real-time generation of customer-class loadshape data for use in tariff, electrification, and customer load clustering analysis.

Existing methods are less valid as key assumptions hold less frequently. Many of the existing methods supporting power system analyses made by the utility are obsolete or evolving quickly in the face of changing and emerging requirements. For example, reliability studies do not consider the role of battery storage in performance metrics like SAIDI, SAIFI, CAIFI where customers can provide backup power in ways that are not considered in the metrics' original purpose, which is to provide an aggregate measure of how long customers are without an energy source.

Emerging conditions have high uncertainty and are often more data intensive. This is particularly true for studies involving the environment surrounding utility equipment, such as public safety power shutoffs (PSPS). Access to vegetation and weather data is vital to access the long-term performance of distribution systems, as well as forecasting near and long-term interactions between vegetation and power systems. This data is many orders of magnitude larger and more difficult to manage than traditional utility data, including SCADA and AMI data.

Data analysis is also an increasingly simulation-centric activity. Historically, many utility analytics used reduced-order models that do not require highly detailed asset data. This had a significant advantage because utilities did not need to use simulations to run these detailed models, and typically could avoid the need for Monte-Carlo simulations to determine the possible ranges of outcomes. With the advent of agent-based simulations that can perform quasi-steady time-series (QSTS) simulations on high-performance computing infrastructure, running large-scale simulations many times is now possible, and new kinds of analysis methods are emerging that cannot be performed using reduced-order models. For example, comprehensive integration capacity analysis (ICA) requires running multiple time-series simulations with different levels of resources to determine when voltage regulator controls become unable to compensate for local generation resources.

OpenFIDO is designed to support a growing reliance on simulation at scale to provide important analysis results for climate change response and technology integration challenges. By allowing researchers, vendors, and users to access an open-source library of analysis methods, tools, and workflows, OpenFIDO provides an environment in which methods can be developed, evaluated, and deployed easily and flexibly while reducing concerns about ongoing support, licensing fees, or compatibility.

Project Approach

OpenFIDO provides a comprehensive open-source data integration and exchange approach pioneered on the open-source VADER platform developed at Stanford University (Chassin 2014). OpenFIDO provides a flexible data analytics and visualization environment for multiple data sources, including AMI data, distribution system models, and environmental data. OpenFIDO can be installed in secure cloud infrastructure, on premise data centers behind enterprise firewalls, on as a standalone system on a workstation or laptop computer. OpenFIDO is used to facilitate the use of a common collection of distributed energy resource planning and analysis tools. OpenFIDO already supports a number of input data formats, general CSV and JSON data that enable large data ingests such as AMI, SCADA, and climate data, as well as network models from tools such as GridLAB-D and CYME.

Concept of Operations

OpenFIDO was developed with a multi-organization concept of operations designed to allow users across multiple organizations to import, analyze, and share results with a high degree of access control granularity independent of the type and structure of the data. This concept of operations is quite complex and was challenging to deliver in a general purpose, open-source, and highly secure platform. The focus of the development and validation of OpenFIDO up to this point has been to ensure and verify high reliability, security, and flexibility for the users.

OpenFIDO uses a concept of operations founded on the following principles, which are detailed in the subsections below.

1. **Platform portability**: OpenFIDO runs on Docker, an open platform for running applications that enables separation of the application from the host system on which it is running.

2. **Open-source distribution**: OpenFIDO is completely open-source and may be used by anyone for any purpose without licensing fees to the creators of the platform.

3. **Scalable computing**: OpenFIDO can run on most platforms that support Docker, and thus can be run on anything from a laptop computer to ultra-large scale cloud infrastructure.

4. **Open analytics**: OpenFIDO methods, pipelines, and workflows are available on GitHub and can be published and used by anyone at any time on all deployments of OpenFIDO.

5. **Application-level security**: OpenFIDO requires full authenticated access to all endpoints at all times. Users must login to access data artifacts and analysis results.

6. **Endpoint interfaces**: All application endpoints may be accessed using standard URLs, provided access is granted to the requestor.

7. **Separate formats and semantics**: All data can be delivered in multiple formats without consideration of data semantics, i.e., data transmitted can be transmitted as CSV or JSON regardless of the contents, e.g., AMI, SCADA, or weather, and vice-versa, e.g., AMI data can be transmitted as either CSV or JSON, as determined by the recipient.

8. **Organization-oriented access control**: All users and data may be partitioned and access controlled based on membership to organizations within the platform, e.g., different jurisdictions, different utilities, different groups within a utility, different teams within a group.

9. **Navigation tools**: users and administrators can access and manage previous analysis results, view graphs and download data for local use in writing reports, and manage settings such as names, descriptions, passwords, and access control lists.

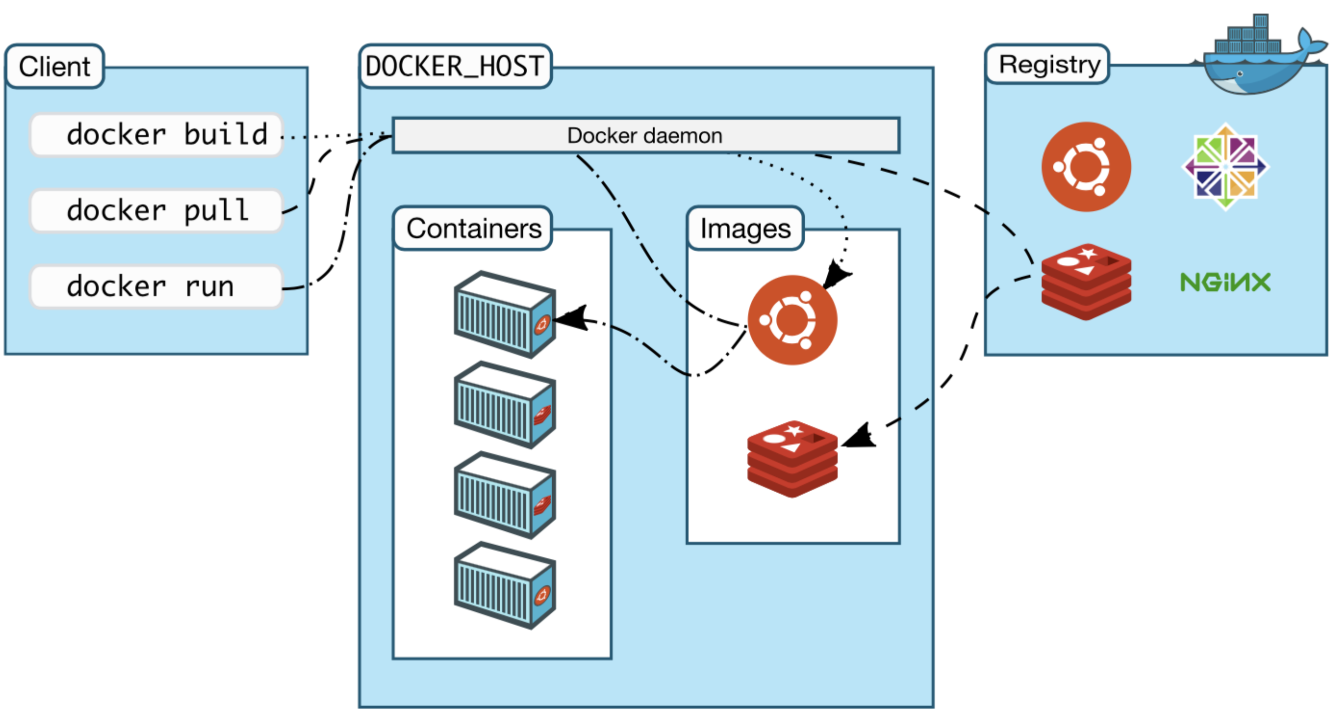
In addition a number of synergistic activities were undertaken to encourage adoption of the OpenFIDO support for advanced simulation tools by the user community.

Platform Portability

OpenFIDO runs on Docker, an open-source platform for running applications that enables separation of the application from the infrastructure on which it is running. Docker is supported on most host systems, including ApplmacOS, Microsoft Windows, and Linux systems.

Docker uses a client-server architecture shown in Fig. 1, where the Docker *client* talks to a Docker *daemon* that does all the work of building, running, and distributing Docker containers. The Docker client and daemon can run on the same system, or you can connect a Docker client to a remote Docker daemon. The client and daemon communicate via a REST API using Unix sockets or a network interface. Another widely used Docker client is *Docker compose*, which is used to build applications that use sets of containers that are coordinates. This is how OpenFIDO is built and delivered so that it provides consistent support for the widest possible range host systems.

Figure 1: Docker Client-Server Architecture



Open-Source Distribution

OpenFIDO is completely open-source under a BSD-3 License and may be downloaded and used without licensing fees to the creators of the platform. Content creators for OpenFIDO may choose to use OpenFIDO to provide additional methods, tools, and/or data for a fee, but the underlying system will always be available at no cost to the user.

The following open-source resources are publicly available on GitHub.

- http://github.com/openfido/ (GitHub Organization)
    - openfido-client: *main client image*
    - openfido-utils: *service utilities image*
    - openfido-app-service: *application services image*
    - openfido-auth-service: *authentication services image*
    - openfido-workflow-service: *workflow manager images*
    - cli: *command line interface*
    - cyme-extract: *CYME to GridLAB-D model conversion pipeline*
    - resilience: *Grid Resilience Intelligence Platform anticipation analysis pipeline*
    - gridlabd: *general HiPAS gridlabd simulation, data, and model converters pipeline*
    - ica-analysis: *integration capacity analysis pipeline*
    - loadshape: *loadshape analysis pipeline*
    - weather: *weather forecasting and historical data access pipeline*
    - census: *TIGER shape files for census regions and tract mapping pipeline*
    - address: *general address resolution for geographic data pipeline*
    - tariff_design: *tariff design analysis pipeline*
    - electrification: *electrification analysis pipeline*

Scalable Computing

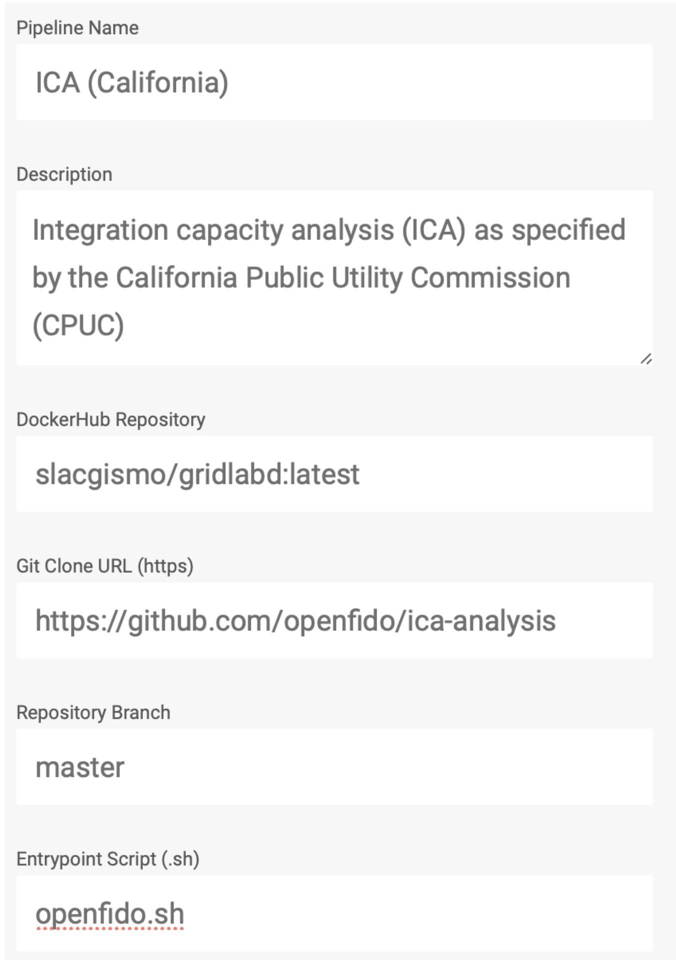
The long-term goal of OpenFIDO is to support all major cloud platforms, enable on-premise deployment, and workstation/laptop operations. Scalability and portability are therefore primary design considerations throughout the development of the OpenFIDO platform. All aspects of OpenFIDO have been integrated within a containerization environment using the Docker toolset. This allows the full functionality of the platform to run across a wide array of deployment contexts, including on premise servers, workstation, laptop, and cloud systems.

Additionally, while the initial implementation was deployed to the AWS cloud environment, the development of the platform has avoided any vendor lock-in to AWS specific technologies. As such, OpenFIDO can run within any environment that supports containerization technologies including Azure, GCP, Kubernetes, a single user's desktop, etc. Proof of this portability has been established and successfully tested via the development of a single integrated container that can be easily pulled and run with minimal configuration.

Open Analytics

OpenFIDO methods, pipelines, and workflows are available on GitHub and can be published and used by anyone at any time on all deployments of OpenFIDO. OpenFIDO users may specify the environment (DockerHub Repository), pipeline code (Git Clone URL), and version (Repository Branch) of any pipeline they use, as shown in Figure 2.

Figure 2: Pipeline specification



Application-Level Security

OpenFIDO requires full authenticated access to all endpoints at all times. Users must login to obtain access to results. This security is provided above and beyond the security provided by the hosting platform, e.g., Amazon AWS, Google Cloud, Microsoft Azure, on premise services, or the local workstation firewalls and user credentials.

Endpoint Interfaces

All application endpoints may be accessed using standard URLs, provided access is granted to the requestor. Endpoints are generated for each input and output artifact using a globally unique identifier (GUID). These endpoints may have limited or unlimited lifetime. The current release of OpenFIDO provides only limited duration endpoints to ensure long-term security of the data. It has not been determined which future release of OpenFIDO will support unlimited endpoint lifetime or how data managers will manage the duration.

Separate Formats and Semantics

To achieve open analytics, OpenFIDO uses common files formats, e.g., GLM, CSV, and JSON, and semantics, e.g., labeled columns CSV, GridLAB-D models and templates, to ensure that data and models can be moved from tool to tool with minimal manual intervention.

Data is generally transferred using CSV and JSON file formats, depending on whether the data can be represented in 2D tabular form. File semantics include data with and without labels. When labels are not present, method code may use either numpy or pandas modules. Only pandas modules may be used on labeled data.

Models must be tagged with semantic labels, including "application", "version", and all tags required by the application version indicated. Only JSON file formats may be used for models. Some OpenFIDO pipelines may support other file formats, e.g., GLM, MDB, and additional semantics, e.g., CYME, OMF. But these pipelines generally serve as file format converters because they either only output JSON or only accept JSON input.

All methods, pipelines, and workflows are published with support files to assist in use and deployment. These include the following:

- openfido.sh: the default script to run a pipeline
- openfido.json: the default configuration for a method
- manifest.json: the pipeline run data requirements script
- requirements.txt: the list of required python modules

Note that at the current time, workflows are not directly supported by GitHub repositories in the OpenFIDO user interface and can be managed only using the OpenFIDO API.

Organization-Oriented Access Control

All users and data may be partitioned and access controlled based on membership in organizations specified within the instance of OpenFIDO, e.g., different jurisdictions, different utilities, different groups within a utility, different teams within a group.

Navigation tools

Users and administrators can access and manage previous analysis results, view graphs and download data for local use in writing reports, and manage settings such as names, descriptions, passwords, and access control lists.

Administrators may invite users with an email address. When the user accepts the invitation, they are added to the authorized user list and granted password-controlled access. Administrators can also delete users. Although the user's access is revoked, data associated with the user is retained and remains available to other users if access is granted.

Administrators may also create organizations and appoint users to administer these organizations, with the same invite/delete/create administrative rights limited to that organization.

Synergistic Activities and Use-Cases

OpenFIDO was developed in coordination with and in support of two other CEC projects that seek to advance the state of the art for power system simulation and analysis the utility industry. These projects in consultation with their Technical Advisor Committees (TACs), as well as two DOE projects, and one industry association recommended the use-cases for the development of OpenFIDO. In this section, the use-cases originating in these projects are described.

CEC High-Performance Agent-Based Simulation

CEC funded the High-Performance Agent-based Simulation (HiPAS – EPC-17-046) effort to modernize GridLAB-D, an open-source agent-based simulator developed by the US Department of Energy at Pacific Northwest National Laboratory (Schneider 2011). GridLAB-D has been used to study utility problems such as conservation voltage reduction under changing load compositions (Sevlian 2017). GridLAB-D has emerged in recent years as a powerful tool for studying emerging utility problems such as renewable resource integration, rate design in the presence of high penetrations of renewable resources, and high end-use load electrification impacts on distribution systems.

Tariff Design

HiPAS GridLAB-D's effectiveness and capabilities are demonstrated using a Tariff Design use case which explores the impact of new rate designs under California Investor Owned Utilities and Community Choice Aggregation Programs. This template allows for the user to execute a full consumer cost analysis on commercial, residential, or industrial loads. This use-case requires a significant amount of data ingestion and user input which is automated by OpenFIDO. The pipeline allows the modeler to input the rate design structure, as well as regional preferences, weather, load characteristics, and distribution system characteristics. OpenFIDO, then leverages the analytics built into GridLAB-D to generate customer billing profiles based on the given specifications. The advantage of this process is that it can be automated to study a wide range of electricity rates for a variety of load profiles within the same distribution network.

Load Electrification

California is at the forefront of deep electrification. To prepare the grid for an ambitious decarbonization goal, the electrical utility stakeholders are seeking tools and strategies that help mitigate the effects of building and transportation electrification on the distribution grid. In combination, HiPAS and OpenFIDO allow the user to explore different scenarios of electrification and the impacts on the grid. These tools can give insight into management of coincident and non-coincident load peaks, as well as reveal the magnitude of the afternoon ramp in the high electrification scenario. OpenFIDO allows for ingestion and manipulation of data to solve challenging electrification forecasting issues. The typical data sets that enable the use-cases described below involve appliance loading data, census data, and location services data to name a few.

<u>Modeling Impacts of Increasing Residential building Electrification:</u>

Incremental impacts of building electrification on the distribution were considered by exploring the replacement of natural gas appliances in the following four categories: heating / cooling / ventilation, water heating, cooking and clothes drying. The use-case does not consider a one-to-one replacement of the natural gas heating unit due to the likelihood of the unit being replaced with heat-pump technology which can increase cooling load in the summer temperature highs that was not present prior to electrification. In addition, the scenario considers the thermal integrity of the buildings, which presumes that the building being modelled is upgraded during electrification to account for items such as additional insulation which change the behavior of the load. Modeling the explicit parameters and accounting for electrical and thermal effects using GridLAB-D infer the propagating effects of the load on the distribution grid. The tool leverages a number of additional house definition parameters, including thermostat settings, house size, thermal integrity, appliance contents, and typical usage specifications. The use-case deploys the template configuration within HiPAS GridLAB-D and uses OpenFIDO framework to input the necessary parameters modeled in the use-case.

Modeling Impacts of Transport Electrification:

Capturing the grid impacts due to deep electrification of the transportation sector can be achieved using the OpenFIDO platform by analyzing the human behavior through location services data to model the expected driving profiles in a fully electric transportation sector as illustrated in Fig. 3.

Figure 3. Sample travel route between 2 zip codes as identified by the location data. The results includes time spent at each location and estimated electric energy required by the vehicle for the trip (Newman 2020).

Figure 4. Estimated charging profile given duration and driving profile.

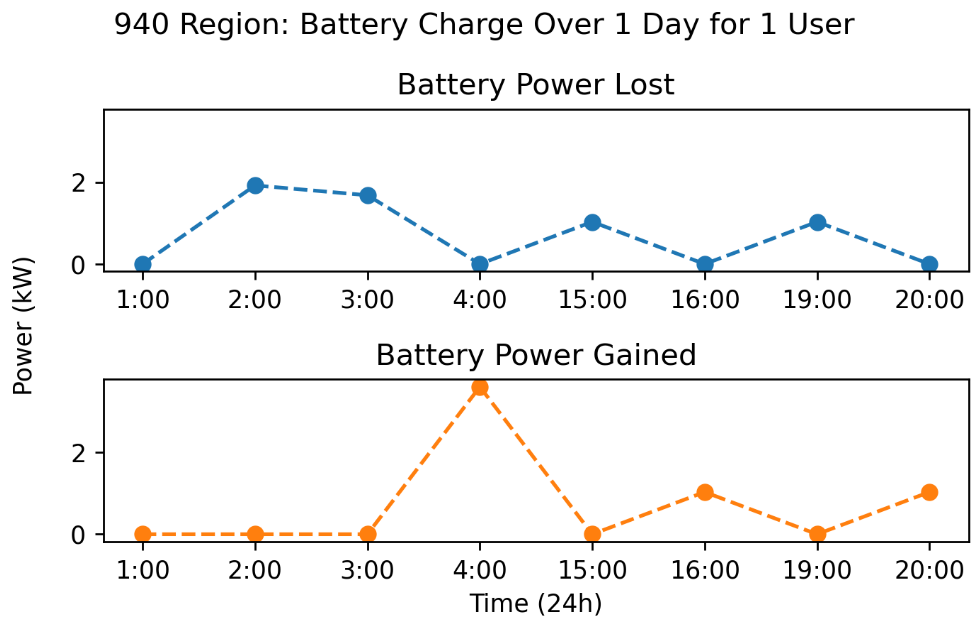
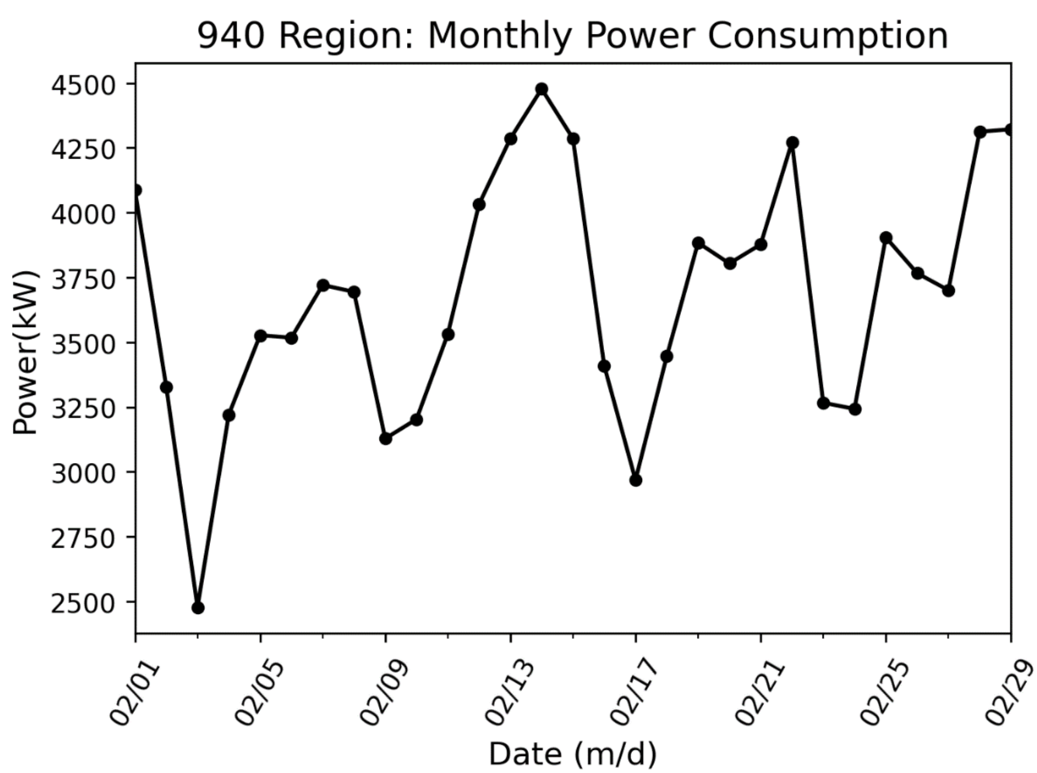


Figure 5. Estimated power consumption by a specific zip code given driving profiles defined in location services database.



This information shown in Figs. 4 and is pre-processed using OpenFIDO and was combined with grid data to determine the baseline charging profiles and give rise to constrained optimization problem to advise the grid-optimal charging locations in turn affecting the driving / charging behavior as part of HiPAS GridLAB-D analytics.

CEC GridLAB-D Open Workspace (GLOW)

CEC funded the GridLAB-D Open Workspace (GLOW) project to deliver a web-based distribution planning platform for GridLAB-D. The open-source graphical user interface of GLOW aims to augment the command-line interface for GridLAB-D in a more intuitive, user-friendly manner, contributing to wider use of the simulation technology. The purpose of the graphical interface 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 brings GridLAB-D to a new base of users and allow for easier testing, application, and expansion of the tool. GLOW shares the same Integration Capacity Analysis (ICA) methodology as HiPAS GridLAB-D and OpenFIDO.

Integration Capacity Analysis (ICA)

In California, Investor Owned Utilities (IOUs) are required to complete system-wide integration capacity analysis (ICA) to determine the maximum node level hosting capacity for a circuit to remain within key power system criteria. System ICA results are used to expedite interconnection permitting for distributed energy resource (DER) additions. ICA with DER growth scenarios are also required for all annual IOU distribution system planning processes. In addition, a CPUC ruling in January 2021 added new requirements, including support for customers adding EV chargers and reducing natural gas usage, reducing the amount of data redacted from ICA maps, improving ICA data practices to avoid undetected errors, and more broadly improving the ICA process.

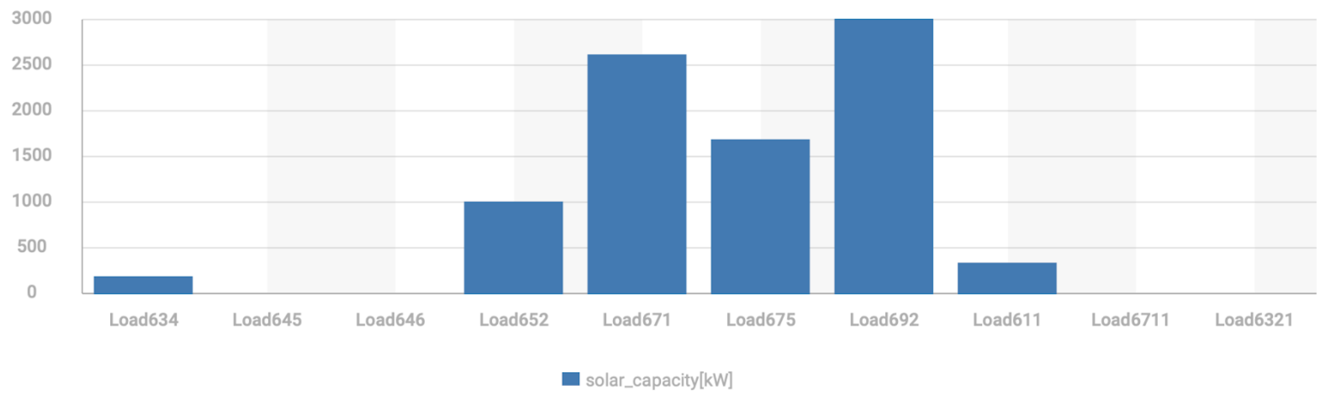
The ICA program on the OpenFIDO platform quantifies the potential DER generation that can be connected without violating distribution system constraints. The process uses a system-wide iterative power flow simulation. The DER generation level is varied at each node, independently. At each iteration, the simulation checks all lines, transformers, regulators, and meters for constraint violations. For details on the properties that are checked against constraints, see Table 1. If a violation occurs, the details of the violation are recorded. The ICA value for that load bus is the maximum power injection associated with any violation criteria, as shown in Fig. 6.

Table 1. Properties that may be checked for violations during ICA

Class	Property
Underground & Overhead Lines	Current Rating (summer)
	Current Rating (winter)
Transformers	Power Rating
	Top Oil Rise
	Winding Hot Spot Rise
Regulator	Raise Taps

	Lower Taps
	Continuous Rating
Triplex Meter	Nominal Voltage
Meter	Nominal Voltage

Figure 6. Maximum power injection at each load bus of IEEE-13 model.



DOE Advanced Load Modeling

The DOE Office of Electricity Advanced Grid Modeling Program funds an ongoing effort to provide utilities and reliability organizations advanced load model data in support of annual interconnection reliability planning studies performed by NERC. This program includes efforts to (1) study of heating and cooling sensitivity nationwide to understand the effect of the shift away from resistive heating toward heat-pumps; (2) redevelop and deploy the commercial and residential building model originally created for WECC; and (3) create models to support electrification impact studies, including decarbonization of residential end-uses and vehicle charging infrastructure growth scenarios.

LoadInsight

The US Department of Energy's Office of Technology Transitions (DOE/OTT) funded the commercialization of LoadInsight to leverage the benefits of commercial data analytics platforms like VADER, OMF, and HERO by integrating advanced load data analytics developed for DOE under previous projects conducted at SLAC, Stanford, PNNL, and LBNL. For example, VISDOM uses AMI data to address a vital utility need to perform more accurate load forecasts and design efficient and fair tariffs. This is achieved by identifying the most common load shapes found among their customers and determining how many customers correspond to each load shape. Utilities can then maximize their customer program impacts while minimizing their operational impacts. Utilities can quickly identify how many and which customers would benefit from an evening time-of-use (TOU) rate rather than midday TOU rate. Similarly, the Advanced Load Modeler (ALM) from the DOE Office of Electricity's Advanced Grid Modeling program uses SCADA data to identify the load compositions NERC requires for the composite load models used in transmission reliability and resource adequacy studies. The merger of

VISDOM and ALM tools allow each to validate the other to improve overall accuracy of analysis results.

The OpenFIDO platform is based on the same architecture as LoadInsight and has many common implementation elements including the same overall user experience, similar data ingestion, job control, and data delivery infrastructure, and the same user credentials and access control mechanisms. While LoadInsight's target use-case is primarily centered on end-use load analysis, OpenFIDO is much more general inasmuch as it supports many other types of analyses needed by utilities beyond just the end-use load shape, load composition, and load weather and/or price sensitivity supported by LoadInsight. Many of LoadInsight's capabilities were adopted by OpenFIDO, and vice-versa. As these products both mature and progress they will likely converge while maintaining their distinct target audience and branding.

DOE GMLC Grid Resilience Intelligence Platform

Extreme weather events such as Atlantic hurricanes and regional wind storm events pose an increasing threat to the nation's electric power systems and the associated socio-economic systems that depend on reliable delivery of electric power. While utilities have software tools available to help plan their near and long-term operations, these tools do not include capabilities to help them plan for and recover from extreme events. Software for resilience-by-design and fast recovery is not widely available commercially and research efforts in this area are preliminary. With this in mind US DOE GMLC has funded a multi-lab initiative to develop Grid Resilience and Intelligence Platform (GRIP) to develop and deploy a suite of novel software tools to anticipate, absorb and recover from extreme events. The tools are integrated into an extensible and open platform, aiding future efforts in this area. This research aids the DOE OE and EERE Resilient Distribution Grid R&D mission of developing cutting edge resiliency technologies that are deployed to utilities and reducing outage costs to meet the MYPP goal and DOE major outcome of a "10% reduction in the economic costs of power outages by 2025."

The project uses HiPAS GridLAB-D as the baseline power flow solver for the platform. The GRIP project enhanced the existing powerflow solver to include a pole failure and vegetation vulnerability solver that allow the user to evaluate vulnerability metrics for grid assets during extreme weather conditions.

<u>Pole Failure:</u>

Using the Southern California Edison pole data format, and the capabilities from the CYME to GridLAB-D converter, OpenFIDO ingests both data sources and links the pole data to the electrical grid distribution models from CYME and Spidacalc to compile a model populated with pole parameters. The output of this use-case illuminates the vulnerable components of the grid and their failure timelines, which can be used to plan and dispatch preventive action.

<u>Vegetation Analysis:</u>

Using Salo Sciences database generated from the California Forest Observatory, which contains information regarding grid-asset surrounding vegetation, OpenFIDO ingests LIDAR data such as tree height, vegetation density, and surface fuels and integrates it with HiPAS GridLAB-D analytics to generate geographic data which identifies asset vulnerabilities due to vegetation overgrowth and decline.

NRECA Open Modeling Framework

The National Rural Electric Cooperative Association has deployed GridLAB-D as part of the Open Modeling Framework (OMF). The OMF data format is called OMD, and it a JSON representation of a GLM file similar to the standard GridLAB-D JSON file with additional data related to the OMF interface. OpenFIDO can convert GLM and JSON models to and from OMF using the NRECA OMF file input/export functionality. Although this is currently supported through HiPAS GridLAB-D, the method for this conversion has not yet been deployed in an OpenFIDO GitHub repository. This will likely be included in a future release of OpenFIDO.

Results

The OpenFIDO project achieved four important objectives that addressed the challenge of open data analytics for electric utilities.

1. OpenFIDO identified the key data analysis requirements that are needed to support critical electric utility use-cases, specifically ICA, electrification, tariff design, and resilience analysis.

2. OpenFIDO delivered a new open-source utility data analytics workflow management platform specifically designed for interoperability across multiple organizations using workstation-only, on-premise servers, and cloud infrastructure services.

3. OpenFIDO supports an open-source analytic tool development and delivery environment, including the methods, pipelines, and workflows that support key utility use-cases identified in the project, as well as future products based on as-yet-unidentified use-cases.

4. OpenFIDO is ready for commercialization as a scalable utility data analytics platform by one or more vendors and cloud services hosting platforms.

The application services are validated and deployed on AWS under the openfido.org domain. In addition, ten pipelines have been made public for OpenFIDO users, including the four main use-cases, hosting capacity, tariff design, electrification, and resilience analysis, which use HiPAS GridLAB-D templates. In addition, the following pipelines have been validated and deployed to OpenFIDO: loadshape clustering, weather data, census geography, address resolution, and Cyme model extraction.

The real-time validation status of both the application services and pipelines can be viewed at the main OpenFIDO repository page located at https://source.openfido.org/. The application services build, validation and deployment status is shown in Figure 7.

Figure 7: Application Status

App Service	Auth Service	Workflow Service	Client Service
Test-build passing	Test-build passing	Test-build passing	Test-build passing
Deploy Staging passing	Deploy Staging passing	Deploy Staging passing	Deploy Staging passing
Deploy Production passing	Deploy Production passing	Deploy Production passing	Deploy Production passing

The pipeline status is shown in Figure 8. Note: three failures are shown for illustrative purposes. In the final release of OpenFIDO, these pipelines are passing.

Figure 8: Pipeline Status

Pipeline	Status
Tariff Design	validation failing
Loadshape	validation passing
Weather	validation passing
HiPAS GridLAB-D	validation passing
Census	validation passing
Resilience	validation failing
Hosting Capacity	validation passing
Electrification	validation failing
Address	validation passing
Cyme Converter	validation passing

Use-case pipelines (hosting capacity, tariff design, electrification, and resilience) are additionally validated by the HiPAS GridLAB-D template (see https://github.com/slacgismo/gridlabd-template). In addition, loadshape clustering is implemented as a HiPAS GridLAB-D template. The remaining pipelines are implemented as HiPAS GridLAB-D geodata packages (e.g., Census, Address), converters (e.g., Cyme extract), and subcommands (Weather). HiPAS GridLAB-D itself is validated as a complete tool (see https://github.com/slacgismo/gridlabd for details).

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

The project team developed a combined Knowledge Transfer Plan for OpenFiDO, GLOW, and HiPAS. This Knowledge Transfer Plan aims to provide a platform for lessons learned and knowledge gained over the course of the three inter-related initiatives.

The target audiences include the staff at the California Energy Commission, the California Public Utilities Commission, load-serving entities, DER vendors, public interest organizations, research institutions, and other interested parties.

The Knowledge Transfer Plan includes Project Fact Sheets and Presentation Materials for public distribution. Project Fact Sheets and Presentation Materials shared in Technical Advisory Committee (TAC) meetings or ad hoc workshops and webinars were all published on the project website hosted by Gridworks.

Over the course of the project, the team held biannual public meetings with the TAC in the spring and fall. The meetings were an opportunity to update the TAC and other interested stakeholders on the project status, including sharing methods, validation models, and model results. Over five TAC meetings between 2018 and 2020, 172 people participated, heard updates and provided input on the development of OpenFIDO.

Training materials were developed and deployed when the OpenFIDO project was completed. To maximize efficiency, training materials were developed and deployed in concert with materials to support GLOW and HiPAS.

OpenFIDO was submitted for adoption by the Linux Foundation (LF) Energy, which is an open-source foundation focused on the power systems sector, and hosted within The Linux Foundation. LF Energy provides a neutral, collaborative community to build the shared digital investments needed to transform the world's relationship to energy.

LF Energy brings together stakeholders to solve the complex, interconnected problems associated with the decarbonization of energy by using resilient, secure and flexible open source software. The digitalization of power systems enables the abstraction of the world's largest machine into composable software defined infrastructure. Digitalization also means that operators can "network electrons" by orchestrating the metadata about an electron in ways never before possible. Digitalization facilitates a radically energy-efficient future. When every electron counts, renewable and distributed energy provides humanity with the tools to address climate change by decarbonizing the grid, powering the transition to e-mobility, and supporting the urbanization of world populations.

LF Energy leverages transparent, open source development best practices, along with existing and emerging standards, to efficiently scale, modernize and digitally transform the power systems sector. By providing frameworks and reference architectures, LF Energy minimizes toil and alleviates pain points such as cybersecurity, interoperability, control, automation, virtualization, flexibility, and the digital orchestration and balancing of supply and demand.

Benefits to California

OpenFIDO enables regulators, researchers, and other interested stakeholders to access and analyze electric grid data that has historically been inaccessible due to the use of proprietary software tools. The data exchange platform increases the transparency of the electric grid and empowers stakeholders to work with utilities and regulators to integrate DERs more quickly, reliably, and cost-effectively.

In addition, OpenFIDO provides a framework with which all tools used in DER resource financing, planning, and permitting processes can interoperate. The capabilities of OpenFIDO help utilities and other stakeholders more reliably and efficiently exchange system model data with analysts, regulators, and vendors. The reduction in labor intensity and cost of staff training will improve utility staff productivity, help expedite utility resource integration reviews, and simplify utility regulator compliance activities. All these work reductions will ultimately result in savings to ratepayers.

Conclusion

Among stakeholders in electric power system planning, operations, and regulator data sharing and data exchange remain an enduring challenge. The creation of OpenFIDO has addressed some key elements of this challenge. Among the most important of OpenFIDO achievements are the following.

Scalable computing: OpenFIDO runs on an open-source interoperability platform called Docker that facilitates running applications on a wide-variety of host systems, including laptops, workstations, on-premise servers, and cloud infrastructure.

Open-source distribution: OpenFIDO is completely open-source and may be used by anyone for any purpose without licensing fees to the creators of the platform.

Open analytics: OpenFIDO methods, pipelines, and workflows are available on GitHub and can be published and used by anyone at any time on all deployments of OpenFIDO. In addition, anyone can submit new methods, pipelines, and workflows to OpenFIDO for private or public use.

Future pipeline research and development

A number of new pipelines are currently proposed or in development by other projects, including the following.

Load decomposition: analysis to permit extraction of end-use load shapes from AMI data and SCADA data.

Census data: access consumer demographic data to enhance load models using economic and population data.

Advanced building loads: utilize satellite data to identify the location, size, and type of buildings in communities, and automatically link the building models to power system network models.

Grid resilience: public safety power shutoff (PSPS) alternative/standardized outage optimization methodology, and long-term climate change impacts on electric load, distribution infrastructure, and data-driven asset planning and hardening.

Advanced workflow research and development

The more advanced workflow implementation is available in the application services, but it not available to users of the interface. In addition, workflow management tools such as Apache Beam are now widely accepted as efficient and scalable solution that OpenFIDO could use in place of the existing workflow service. The project team recommends follow-up development to incorporate modern batch and streaming analysis technology in future OpenFIDO deployments.

Shared/public data/models security and integrity

The current data sharing model uses widely accepted digital security methods. However, this may not be fully satisfactory for utilities to satisfy critical infrastructure cyber-security standards. The project team recommends follow-up research and development work to identify and deploy digital artifact sharing mechanisms that allow utilities to share selected data from software, databases, and repositories with authorized users in a reliable and secure manner.

Legacy data handling and data aging strategies

Historical data is a critical component in developing long-term system performance models such a building loads, asset degradation, and human behavior. Consistent long-term access to weather, demographic, building stock, energy consumption, and power demand data is an ongoing challenge and a barrier to adopted of new analytics tools and methods, particularly as modern and more advanced data management and data sharing capabilities become widely accepted. The project team recommends further research and development into data handing strategies to future proof critical existing data sets and ensure that new data analytics have access to much of the valuable existing historical data that makes these analysis worth deploying at scale.

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Project Deliverables

The following project deliverables are available upon request by submitting an email to ERDDpubs@energy.ca.gov. These documents may also obtained from the OpenFIDO GitHub repository https://github.com/openfido/docs.

- Data exchange requirements and assessment presentation
- Data exchange implementation and validation plan presentation
- CPR Report #1
- Testing and validation presentation
- Develop and user training documentation
- Benefits questionnaire
- Project fact sheet
- Technology transfer plan
- Technology transfer report

Appendix A: OpenFIDO GitHub Product Repositories

The following repositories are available to public as part of the production release of OpenFIDO.

Application Services

- Main application: https://github.com/openfido/openfido-app-service
- Authentication: https://github.com/openfido/openfido-auth-service
- Workflow: https://github.com/openfido/openfido-workflow-service
- User experience: https://github.com/openfido/openfido-client-service

Pipelines

- Tariff design: https://github.com/openfido/tariff_design
- Loadshape analysis: https://github.com/openfido/loadshape
- Weather data: https://github.com/openfido/weather
- HiPAS GridLAB-D simulation: https://github.com/openfido/gridlabd
- Census geographic data: https://github.com/openfido/census
- Resilience analysis: https://github.com/openfido/resilience
- Hosting capacity analysis: https://github.com/openfido/hosting_capacity
- Electrification: https://github.com/openfido/electrification
- Address resolution: https://github.com/openfido/address
- Cyme converter: https://github.com/openfido/cyme_extract

NOTE: Unable to remove the following picture and text, even though it is unrelated to this project

Figure is on an aerial photo base map, centered on Desert Center. An inset map at the upper right shows the location of the project within Riverside County. The Oberon Study Area is shown to the north of Interstate 10, outlined in purple. Desert Sunlight Solar, Desert Harvest Solar, and Athos Solar are all shown to the north of the Oberon Study Area. East of the study area are Arica Solar, Victory Pass Solar, and Palen Solar. North and west of the project is Joshua Tree National Park, shown in green. The multi-species linkage area is shown in green dashed lines, located to the north and east of the Oberon Study Area. Areas of Critical Environmental Concern (ACECs) are shown in light green, with the Desert Lily Preserve ACEC to the northeast, Alligator Rock ACEC and Corn Springs ACEC to the south, and Palen Dry Lake ACEC to the east.