EPRI | ELECTRIC POWER RESEARCH INSTITUTE

incubate:energy labs

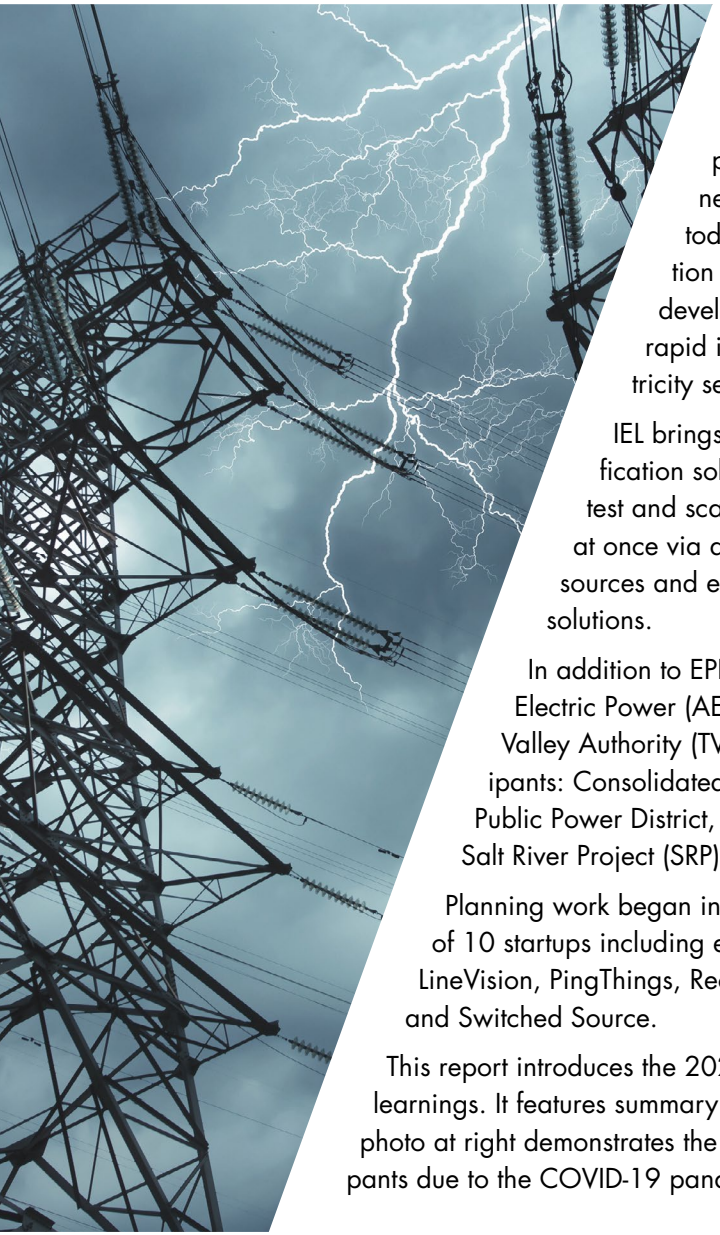


2020 CHALLENGE

Final Report & Pilot Demonstration Summaries

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Introduction



Overview

Launched in 2019, EPRI's Incubatenergy Labs® (IEL) provides quick, objective assessments of how disruptive new technologies can be demonstrated and applied in today's rapidly changing energy system. IEL's open innovation process borrows concepts from design thinking, agile development, and the business model canvas to enable the rapid identification and demonstration of innovations for electricity service providers and consumers.

IEL brings together startups working on clean energy and electrification solutions with utilities that have the desire and resources to test and scale them. The startups benefit by engaging many utilities at once via a single demonstration, and the utilities leverage the resources and expertise of their peers in screening and testing multiple solutions.

In addition to EPRI, the 2020 IEL program featured Ameren, American Electric Power (AEP), Southern California Edison (SCE), and Tennessee Valley Authority (TVA) as host utilities and the following additional participants: Consolidated Edison of New York (Con Edison), ENEL, Nebraska Public Power District, New York Power Authority, Portland General Electric, Salt River Project (SRP), and Xcel Energy.

Planning work began in 2019, culminating in the selection of a 2020 cohort of 10 startups including ev.energy, Grid Fruit, IND Technology, Kognitiv Spark, LineVision, PingThings, Recurve, RUNWITHIT Synthetics, SHARC Energy Systems, and Switched Source.

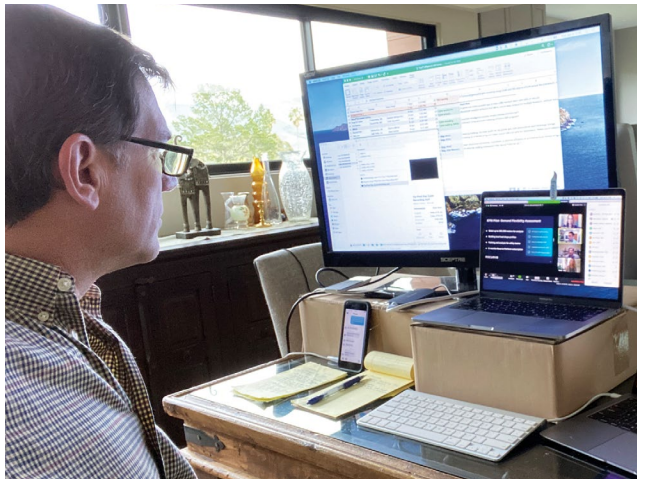
This report introduces the 2020 IEL program, challenges and successes, and key learnings. It features summary reports for each of the 10 pilot demonstrations. The photo at right demonstrates the virtual engagement model employed by project participants due to the COVID-19 pandemic.

Innovation Challenge Topics

In November 2019, the 11 participating utilities reviewed their respective innovation priorities and identified six challenge areas that were consistent across the group:

- Customer & Community Engagement
- Customer & Community Resilience
- Digital Utility
- E-Mobility
- Integration of Distributed Energy Resources
- Workforce of the Future

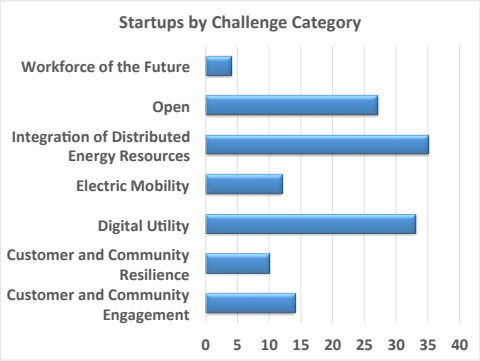
In addition, EPRI and utilities agreed to include an "open" innovation challenge category in their outreach to the startup community.



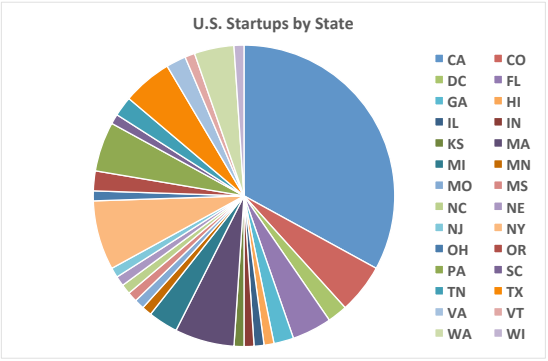
EPRI's Erik Steeb joined colleagues across the U.S. and worldwide in a successful Incubatenergy Labs 2020 experience

Startup Applicants

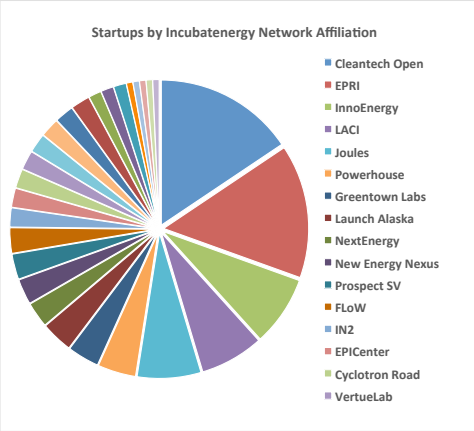
In December 2019, the 2020 IEL program was publicly launched, and the innovation challenge topics were communicated to the startup community through the IEL website and EPRI's Incubatenergy Network, which brings together leading U.S. and international incubators and accelerators having a proven track record in supporting clean energy entrepreneurs. A total of 248 startups responded to the call for expressions of interest, with 136 complete applications submitted by the deadline on January 17, 2020. The breakdown of applicants by challenge topic, Incubatenergy Network affiliation, and location is shown in the figures below.



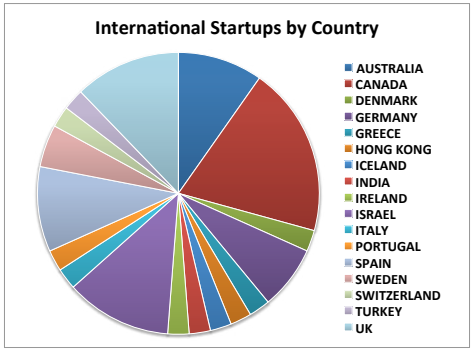
Startup applicants by innovation challenge



Startup applicants by U.S. location



Startup applicants by Incubatenergy Network affiliation



Startup applicants by international location

Cohort Selection and Participation

The review of applications was crowd-sourced across more than 70 subject-matter experts (SMEs) from EPRI and participating utilities. They reviewed online submissions and engaged with startups through Zoom meetings to narrow the group to 17 finalists, who were invited to present at virtual Pitch Day in May 2020. Based on those pitches, 10 startups were selected to participate in paid demonstration projects. Scoping and contracting were accelerated into a 6-week effort, and projects were run over the following 16 weeks, culminating in the 2020 Incubatenergy Labs Demo Day, which was hosted by Ameren on October 14, 2020.

Barriers

Through IEL, participants push each other to break down barriers to learning, to move quickly, and to adjust as they learn. This approach, which applies both to the process of engaging startups and to how demonstrations are run, was tested almost immediately with the onset of the COVID-19 pandemic, an unanticipated barrier to success augmenting several known hurdles. Top among those are contracting processes, data access provisions, and cybersecurity orthodoxies that have been built over decades to ensure quality and reliability. Other less tangible barriers include utility reluctance to adopt new approaches, especially in unfamiliar technical areas, as well as the perceived risks of innovation, particularly involving operations and customer data.

IEL 2020 was originally envisaged as a series of face-to-face events and "full contact" demonstration projects. By February 2020, it was clear that the entire program would need to be reimagined. Pitch Day became a lively Zoom event, startups reimagined their demonstration concepts as fully virtual engagements, and the group carried on remotely right through Demo Day in October. While disappointed not to be able to engage in person, 2020 participants agreed that many of the learnings from the online engagement will become best practices for future cohorts.

To speed contracting, EPRI and utility legal/contract teams collaborated early in the process to craft simplified and standardized contracts for startups to work with EPRI and utilities in engagements where no intellectual property is created. To further simplify the process, the EPRI contracting team executed all initial agreements with the startups. As the 16-week demonstrations progressed and showed promise, utilities had time to onboard startups in their vendor systems.

Finally, to address any reluctance to engage in testing innovations, SMEs from utilities and EPRI collaborated on the scoping of individual demonstrations and participated in regular meetings to provide support as each project progressed. This allowed interactive discussion of uncertainties and concerns, and SMEs were able to gain perspective from their peers, creating a culture for demystifying utility testing of solutions in previously unfamiliar technical areas.

Success Metrics

EPRI and participating utilities set expectations on several aspects of the IEL 2020 program related both to the execution of the process and to the success of the demonstration projects themselves.

IEL 2020 Targets & Results

Criteria	Target	Result
Common Innovation Topics	5-6	6
Startup Applicants	>100	136
Demonstration Projects	8	10
Weeks to Scope and Contract Projects	4	6
Weeks to Complete Projects	12	16

Our energy system is undergoing a rapid transformation: in the way we generate, distribute, and use energy; in our relationships with customers; and in ensuring the safety, resilience, and sustainability of our communities and workforce. As utilities around the world strive to be more nimble in leading this transformation, Incubatenergy Labs provides an efficient vehicle for collaborating with peers from around the globe to discover and engage a diverse field of startups in demonstrating and deploying the most promising solutions.

Rob Chapman, Senior Vice President, Energy Delivery & Customer Solutions, EPRI

In terms of execution, the group was striving to become more agile, collaborate on the selection of the startups, accelerate back-office processes, execute on a tight schedule, and collaborate on results. Targets and results are shown in the table at bottom left.

The IEL program has a somewhat different perspective on project-level success, relative to many other incubator and accelerator programs. In the world of transformative innovation, typically success is only achieved through failure or, maybe more accurately, by testing hypotheses incrementally and iterating based on what does and does not work. A high failure rate is seen as acceptable so long as the value of learnings achieved exceeds the investment deployed.

IEL does not, however, start at ground zero in the innovation process. The program focuses on demonstrating solutions that are near market-ready and therefore typically have already gone through some amount of technical validation and market testing. In screening for demonstrations, few technologies are expected to be outright failures. Some may be ready for market scale, while most may require continued testing or even further development.

By agreeing on common innovation challenges up front, crowd-sourcing the screening, and encouraging utilities to participate in each other's demonstrations, IEL is intended to generate follow-on projects as a key measure of success. For startups, success depends on the ability to parlay their engagement with one host into opportunities with other utilities. For utilities, success is defined by an ability to learn from projects hosted by their peers and to quickly identify how to apply promising solutions in their own environments. Seven of the 10 startups had identified follow-on opportunities among the group of participating utilities even before Demo Day took place in October 2020.

Key Learnings

Proving the Process. The IEL process facilitated open, focused engagement between EPRI, the 11 participating utilities, and the 10 selected startups. The initiative helped demonstrate to utility business personnel that they can work effectively with startups. Utilities also learned that early-stage companies can deliver when the scope is well-defined and the data and support structures needed to execute the task are in place.

Addressing Technology Uncertainty. IEL provided a way to test out how products work at specific utility sites with real personnel trying to accomplish real tasks. The small-scale demonstration and pilot approach lent credibility to a different way of assessing new technology. It provided direct experience for utility personnel and delivered relevant, tangible results

The EPRI team did a terrific job of collaborating with the 11 utilities and 10 startups in a short period of time. My company got a lot out of it: We now have new capabilities in improving situational awareness on our transmission assets; helping our customers charge electric vehicles to reduce their carbon footprint; finding struggling small businesses that are trying to help our underserved communities and targeting them with energy efficiency programs; and better ingesting and creating value out of advanced metering infrastructure data. We did all that within 12 to 16 weeks! Incubatenergy Labs is a terrific opportunity to take EPRI's collaborative model and apply it in a time-boxed way to drive results faster than normal. We talk about needing to be more agile; this is a way to be more agile. I encourage everybody to seriously consider joining us for 2021.

Steve Kidwell, Vice President of Corporate Planning, Ameren

in a short period of time. It showed that utilities can effectively test out new solutions in unfamiliar technical areas. For the startups, it provided a way to leverage one demonstration potentially across multiple utilities.

Learning from Cultural Differences. Utility participants found that bridging the cultural divergence between the background and experience of startup entrepreneurs and that of utility staff was easier than anticipated. This may be due to the increasing realization at utilities that new ways of identifying and implementing new technology are needed—and that startups are one source of this innovation. In fact, the cultural differences led to mutually beneficial outcomes: Startups encouraged utilities to open their eyes to new solutions, and utilities encouraged startups to consider applications of their technologies in additional subject areas.

Learning During the Process. Utility participants found that the process is as important as the outcome. Before, during, and after the demonstrations, the process helped change how utilities articulated the innovation challenges, the startup solutions, and benefits of the solutions. The process also led to insights into better ways for utilities to work with startups in embracing beneficial innovation.

Next Steps

In the final quarter of 2020, utilities participating in the 2020 IEL program were joined by additional interested utilities. They defined the next innovation challenge topics and kicked off the 2021 IEL program by issuing a request for information from startups. Based on 2020 experiences, the lessons learned and best practices in virtual engagements between utilities and startups will be applied in 2021, and continued evolution and improvement are anticipated. An in-person Demo Day represents the hoped-for culmination of the 2021 program.

The remainder of this report provides an overview of the 2020 IEL projects. As noted, many of the startups in the 2020 cohort had already identified folllow-on engagements across the group of participating utilities before the conclusion of their pilots. Follow-on activities include expanded deployments with the utility that hosted the original project and engagements with additional participating utilities. For some startups, the pandemic limited the 2020 project engagement to modeling efforts, and the follow-on will include physical deployments.

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2020 PILOT PROJECTS

AI-Based Control for Commercial Refrigeration

GRID FRUIT

SOUTHERN CALIFORNIA EDISON®
An *EDISON INTERNATIONAL®* Company

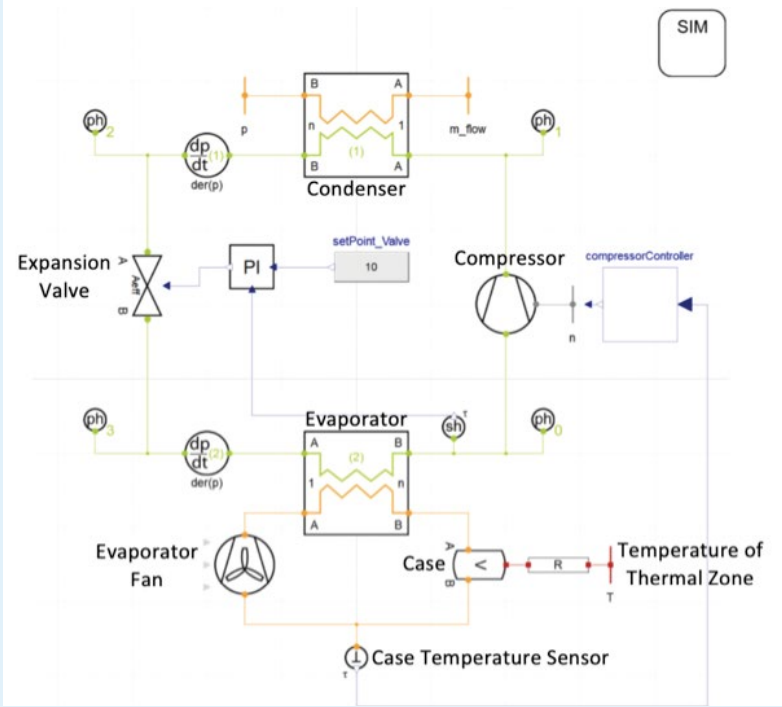
Startup
Grid Fruit

Host
Southern California Edison (SCE)

Technology Solution

Refrigeration is a significant driver of overall electricity use and peak power demand for convenience stores, supermarkets, and other retail food outlets. Generally, these entities run on small profit margins and face additional challenges in operating and maintaining refrigeration systems and controls to optimize both for food quality and energy consumption. Thermal storage systems that form ice off peak then provide cooling during peak periods are an established solution for mitigating peak loads but require up-front investments in hardware.

This pilot project was launched to demonstrate Grid Fruit's data and software platform as a low-cost measure for optimizing refrigeration defrost control in convenience stores. Drawing on artificial intelligence (AI) methods, Grid Fruit builds digital twin models, which are physics-based and data-driven models of the building envelope and energy profile of individual stores, including the refrigeration (cooling and freezing), lighting, and heating, ventilation, and cooling (HVAC) systems that dominate consumption. The twins, when connected to real-world stores, guide implementation of control strategies for optimizing refrigeration operations to maintain food quality and achieve cost saving, peak demand reduction, greenhouse gas reduction, and other objectives on the basis of weather, utility rates, and additional variables.



Refrigeration model using Modelica

Project Overview

Working in collaboration, Grid Fruit, EPRI, and SCE defined a project scope for estimating the potential consumer cost, peak demand, and carbon emission savings available from AI-based optimization of refrigeration defrost controls in convenience stores across the utility's service territory. This simulation-based scope was revised from the original pilot project concept—involving both digital twin simulation and field

Challenge: Customer and Community Engagement

Potential Cost, Demand, and CO_2 Emission Reductions Based on Simulations

Annual:	TOU Charge	Demand Charge	Electricity Charges	CO_2 Emissions	Average Peak
Riverside County – Climate Zone 10 – 756 Stores					
Present Operations	$13.1M	$8.6M	$21.7M	35.8 kt CO_2	20.8 MW
Optimal Operations	$12.6M	$7.6M	$20.1M	34.1 kt CO_2	20.5 MW
Simulated Reduction	$0.5M	$1.0M	$2,061/Store	1.7 kt CO_2	0.3 MW
Percent Reduction	4.2%	11.8%	7.2%	4.7%	1.4%
San Bernardino County – Climate Zone 14 – 672 Stores					
Present Operations	$10.9M	$7.3M	$18.2M	29.9 kt CO_2	18.5 MW
Optimal Operations	$10.4M	$5.7M	$16.2M	28.5 kt CO_2	18.3 MW
Simulated Reduction	$0.5M	$1.6M	$3,054/Store	1.4 kt CO_2	0.2 MW
Percent Reduction	4.6%	21.3%	11.3%	4.9%	1.1%
SCE Territory – Nine Climate Zones – 5,345 Stores					
Present Operations	$92.7M	$55.2M	$147.9M	255.4 kt CO_2	145.5 MW
Optimal Operations	$88.7M	$45.6M	$134.3M	243.7 kt CO_2	139.0 MW
Simulated Reduction	$4.0M	$9.6M	$2,518/Store	11.7 kt CO_2	6.5 MW
Percent Reduction	4.3%	17.4%	9.1%	4.6%	4.5%

implementation—due to the COVID-19 pandemic and its associated restrictions.

Grid Fruit began by modeling a typical California 7-Eleven store using EnergyPlus and Modelica co-simulations to develop the digital twin models. Based on weather data and other inputs, EnergyPlus simulated buildings and fine-grained control and component conditions for all store refrigeration systems.

Some refrigeration simulation capabilities included control of compressors, fan speed, and expansion valve position, as well as complete monitoring of case temperature. A total of six refrigeration units were included in the store models: 10-door reach-in case; 5-door reach-in case; 2-door reach-in freezer; 1-door reach-in ice storage case; standalone open-case wrap-around display refrigerator; and standalone freezer/ice cream chest. All refrigeration cases reject heat to the merchandise thermal zone. Condensers for the standalone cases reject heat to the merchandise zone or outdoors.

Using the digital convenience store twin models, the project team simulated current typical operations versus optimized refrigeration operations in all stores across the SCE service territory over a 1-year period. The optimized adjustments to refrigeration controls were limited to defrost scheduling parameters for individual units, an intervention that does not affect food quality or jeopardize food inventory.

To confirm realistic electricity consumption by end use and individual intervention, Grid Fruit benchmarked its simulated twin models against the documented demand of the average U.S. convenience store. Pricing was computed according to SCE rate schedules, including time-of-use (TOU) and seasonal rates. Weather data files for California climate zones in SCE's service territory were obtained from the Climate One Building website.

Results & Learnings

Pilot project results are shown in the tables at left for two representative counties and SCE's service territory. Year-long simulations using Grid Fruit's optimization algorithm to account for climate zone and utility pricing showed the potential for $13.5 million in annual customer electricity cost savings—an average of 9.1%—simply by rescheduling refrigeration defrost cycles for convenience stores across the service territory. Benefits are greater in cooler climate zones, where HVAC is a smaller load and smaller proportion of the total store load: Because refrigeration has a larger load share, rescheduling refrigeration loads makes a big difference in the overall energy bill.

In these simulations, Grid Fruit's algorithm was configured to put store cost reduction as the highest priority. Even without prioritizing peak shaving, the simulations showed SCE-wide reductions of 6.5 MW (4.5%) in the average evening peak (4:00-9:00 pm). Additionally, reductions in CO_2 emissions of 11.7 thousand tons (kt) per year (4.6%) were observed.

As a final step in the project, Grid Fruit evaluated the potential benefits of implementing the recommended defrost controls across almost 12,000 convenience stores in California, spanning 16 climate zones. Customer cost savings totaled $24 million annually—an average of about $2000 for each store. Statewide reductions in average evening peak load and CO_2 emissions were similar to those for SCE's service territory on a percentage basis and totaled 14.7 MW and 25.9 kt/year, respectively.

This pilot was limited in important ways due to the pandemic and related factors. Optimization did not prioritize peak demand or carbon emission reduction. Grid Fruit offers more involved interventions—notably adjusting compressor operations—for further reducing a store's energy use, costs, demand, and electricity-related emissions and for achieving other goals such as resilience against power outages. This pilot considered only low-cost defrost control. Field validation of digital twin simulation results, through demonstration of refrigeration interventions in real-world stores, is needed.

Implications & Next Steps

Despite the altered scope of this 2020 pilot, Grid Fruit's digital twin simulation has quantified substantial customer, grid, and societal benefits available from implementing software-based refrigeration controls in convenience stores. The project generated optimal scheduling commands to coordinate high-demand refrigeration cycles in stores operating within the SCE service territory, accounting for climatic conditions, time-of-day pricing, and other grid incentives.

The original plan for field implementation by Grid Fruit will now benefit from project results and learnings, with SCE initiating store connections in Southern California for a potential future demonstration project. By integrating the Grid Fruit software platform with customer equipment and running digital twin store models, the field test would evaluate use of improved control settings for time-shiftable, high-demand defrost cycles in refrigeration. Anticipated benefits include reductions in energy bills and peak demand costs at the store level, and, when managed in aggregate, smoothed power demand across the study area and reduced CO_2 emissions.

TESTIMONIAL: Grid Fruit

Despite restrictions on in-store deployment in 2020, we are grateful for the opportunity to partner with SCE and EPRI to show significant benefits for individual counties and across the utility's service territory, in terms of cost reductions and emissions. With their support, we were also able to scale our algorithms and demonstrate potential benefits over all of California.

Jesse Thornburg

TESTIMONIAL: SCE

We're excited that Grid Fruit was able to validate to a fairly good degree of certainty where the opportunities are and to bring value in this way.

Edwin Hornquist

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RECURVE

Customer Targeting for Energy Efficiency Services

Ameren

Startup

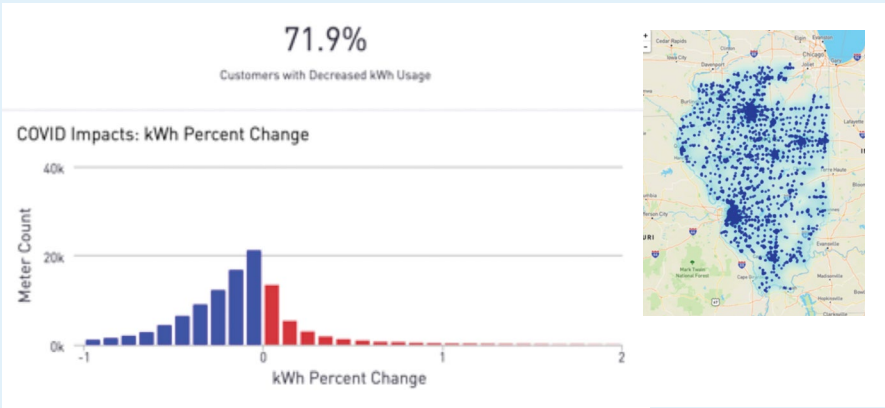
Recurve

Host

Ameren

Technology Solution

Utility energy efficiency programs face continuing challenges in engaging and acquiring business customers. These challenges have been exacerbated as businesses struggle with the realities of COVID-19 and focus on survival. Meanwhile, utilities with advanced metering infrastructure (AMI) are generating massive streams of data characterizing the usage patterns of individual consumers with unprecedented granularity.



*This pilot demonstrated use of meter-based analytics to analyze energy consumption during the pandemic **(left)** to support identification of high-potential customers **(right)***

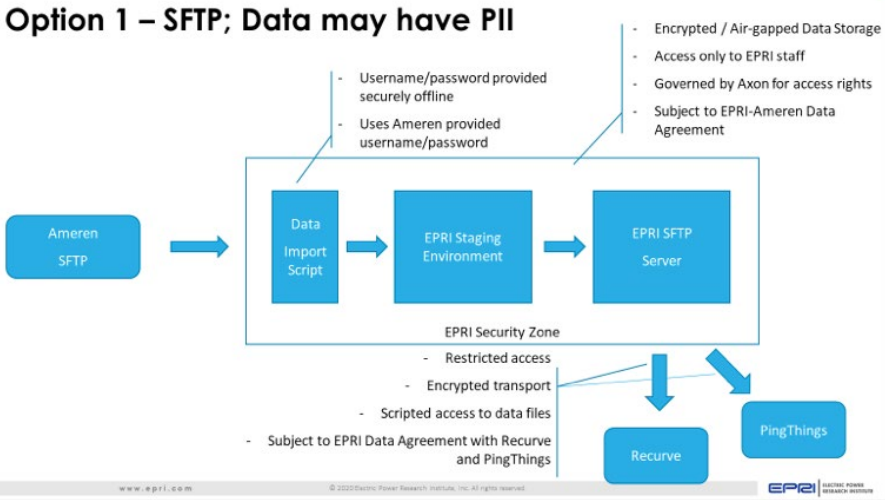
This pilot was designed to explore the use of Recurve's Resource Planner tool and evaluate how AMI data could be applied for identifying and targeting business customers hit hardest by COVID-19. The Recurve platform analyzes the data generated by all customer meters in a utility's portfolio to disaggregate usage characteristics and identify the potential for behind-the-meter interventions. Robust meter-based analytics identify which individual customers will likely derive the most bill savings from specific energy efficiency, demand response, or renewable energy measures while also delivering benefits to the grid.

Project Overview

Recurve, EPRI, and Ameren worked together to enable the utility's Illinois Energy Efficiency Business Program to leverage AMI data and better support struggling enterprises through this challenging time by increasing the depth of customer targeting prior to direct utility engagement. According to Ameren's data, business customers showed an average 14% reduction in energy consumption in the early months after COVID-19. However, as shown above, individual accounts ranged from nearly a 100% reduction to a 200% increase, and around 28% of electric meters and 33% of gas meters exhibited greater usage.

Ameren and EPRI collaborated with Recurve to focus its analytics on increasing uptake of lighting measures and heating, ventilation, and air conditioning (HVAC) measures. Underlying goals included identifying those customers who would benefit most from efficiency retrofits with a high persistence of savings, streamlining the customer acquisition process, and reducing administrative costs to pass maximum benefits on to consumers.

Challenge: Customer and Community Engagement



Option selected for transfer of data from Ameren to EPRI to Recurve

To ensure both secure and timely transfer of AMI data for use in this pilot, project participants agreed on data flow from Ameren to EPRI and then from EPRI to Recurve. The following options were considered:

1. **Secure FTP (SFTP) for data that may have personally identifiable information (PII):** Set up an SFTP transfer from Ameren to EPRI to Recurve. The EPRI environment, governed by Axon and an Ameren-EPRI data agreement, would include a mechanism to script the data transfer into a staging area and an EPRI SFTP server. Recurve would be provided with username/password-based access to download data from the EPRI SFTP server.
2. **Amazon S3 bucket with transfer acceleration:** Set up an Amazon S3 bucket so that secure data transfer could take place from Ameren's S3 bucket to EPRI's S3 bucket and Recurve could download the data from EPRI's S3 bucket.
3. **Physical hard drive:** Set up a secure EPRI environment for data transfer from Ameren to EPRI. The environment would include a mechanism to script the data transfer into a staging area from which the data would be transferred into a physical hard drive. The hard drive would then be shipped to Recurve.

The SFTP option, illustrated in the figure at left, was chosen as the best approach, certified by Ameren's architecture review board, and approved by EPRI's IT policy compliance officer. The set of files that were transferred included meter-level AMI data along with metadata providing account information, including information pertaining to the businesses owning these accounts.

Results & Learnings

The secure data transfer approach adopted in this pilot supported the end-to-end process of transforming raw AMI data into insights that helped identify specific small business accounts significantly impacted by the COVID-19 crisis. Recurve's software-based platform ingested and analyzed vast amounts of AMI data to differentiate temperature-based baseline loads, other baseline loads, and discretionary loads and then to determine inefficient uses and the types of energy efficiency programs and measures that would deliver the most benefit for individual customers. "Targeting dashboards" displayed results in a simple, interactive, and user-friendly format.

Identifying customers most likely to benefit from lighting upgrades. Because most lighting is not used continously, consumers with high, non-temperature-dependent discretionary loads are likely to have the highest energy usage from lighting. To identify these customers, Recurve generated a targeting dashboard for lighting using the following parameters:

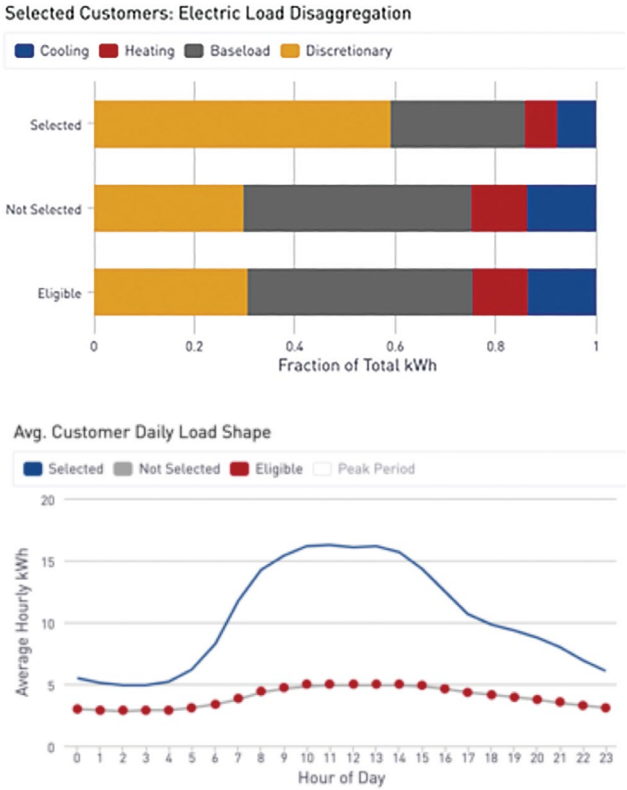
- Annual Usage: Top Three Quarters
- Percent Discretionary: Top Quartile

Business customers fitting these criteria have high potential for lighting upgrades: Discretionary consumption accounts for 55% of their usage, as opposed to 20% for the average. The dashboard includes additional filters for further targeting through program design and via marketing campaigns—for example, to the 3,066 customers who have increased their usage throughout the pandemic, to ensure that they receive the support needed to remain open; or to the 14,324 customers whose usage has decreased, to help them reduce energy costs and weather the storm.

Improving outcomes by targeting customers with high potential for HVAC savings. Recurve generated targeting dashboards for both cooling and heating, as shown on the next page. For cooling, the following criteria were applied:

- Cooling kWh: Top Quartile
- Percent Cooling: Top Quartile

A subset of 10,421 Ameren customers—9% of the total base—were identified as high-potential targets because cooling represents over 30% of their electricity usage. In comparison, non-targeted customers use, on average, less than 10% of their energy on cooling. Among targeted customers, 1,390 exhibited increased energy consumption during the pandemic, while the remainder experienced a decrease. Such further segmentation could help in fine-tuning marketing and outreach to specific customers based on how the pandemic has impacted their business.



Targeting dashboards highlight the load curves and usage breakdowns of customers identified as having high potential for specific efficiency measures

For gas heating, Recurve applied these criteria:

- Heating Therms: Top Half
- Percent Heating: Top Half

The targeting dashboard identified 1,867 customers (4.4%) who consume over 97% of their gas for heating; the non-targeted subset uses less than 70% for heating. Among the targeted class, 149 customers showed increased gas and electric usage during the pandemic, while the remainder exhibited a decrease. Again, these insights can aid in customizing messaging during program outreach.

TESTIMONIAL: Ameren

Recurve's dashboards easily allowed Ameren to filter and target specific customers that not only were hit hardest by COVID-19 but also could best benefit from energy efficiency programs.

Implications & Next Steps

This pilot demonstrated that targeting dashboards for lighting, cooling, and heating created by Recurve based on Ameren's AMI data can facilitate the identification and further segmentation of customers with high energy-saving potential. These customers are most likely to be relying on inefficient technologies, to be struggling with high energy bills on a year-round or seasonal basis, and to be receptive to investing in efficiency upgrades.

The Ameren business effiency team has been trained to adjust dashboard filters to further analyze and refine the attributes of customer subsets, inform program design and marketing, and create targeted customer lists for use in deployment of lighting and HVAC initiatives. Using targeting to deliver solutions to the customers that need them most will help the utility streamline outreach and thereby pass on the maximum program benefit to its customer base. Recurve's Resource Planner platform also provides Ameren with the opportunity to dig further and identify high-value customers for any business offerings.

This pilot was focused solely on analyzing AMI data for customer targeting by efficiency programs, but the dynamic platform also can monitor real-time impacts at the meter, deliver insights on load shapes, and assess program performance. Working with programs in other states, Recurve observed that targeting can increase energy savings by over 70% per customer—potentially enabling higher savings claims relative to typical values. In addition, high-potential customers showed peak savings exceeding 200% of the expected total, which translates to double the grid value per project implemented.

This pilot showed the potential for meter-based analytics to lead to greater near-term cost-effectiveness for efficiency programs, as well as to enable the design and implemention of initiatives focused on increasing grid flexibility and resiliency, meeting other operational and business objectives, and supporting progress toward decarbonization.

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Piranha™ Wastewater Heat Recovery

Startup

SHARC Energy Systems

Host

EPRI

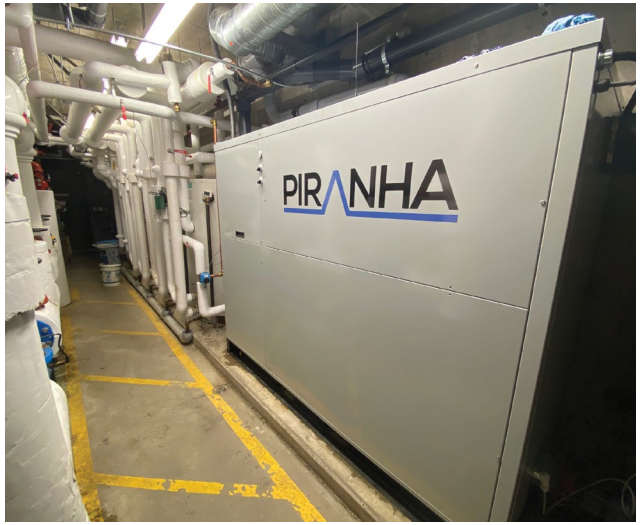
Technology Solution

Rising climate change awareness and new government laws, regulations, and incentives that focus on cutting carbon emissions are positioning cleantech and green building innovations as very relevant in the residential and commercial building sectors. Just as exhaust air from buildings is run through heat-recovery ventilators, wastewater represents a potential contributor to energy and cost savings. Thermal energy sources may include black and gray water, laundry effluent, sanitary sewers, lift stations and treatment centers, and steam condensate.

The SHARC pilot was designed for field demonstration of Piranha technology, which supplies domestic hot water by capturing and reusing heat contained in wastewater. Thermal energy is extracted from wastewater and transferred to a refrigerant using an electric heat pump and direct expansion heat exchanger that enable high-efficiency operation year-round, in any climate.

The Piranha T10 HC model also integrates cooling capabilities for simultaneous delivery of up to 100% of domestic hot water needs throughout the year, plus supplemental space conditioning. The system can provide significant energy cost savings to customers while avoiding consumption of gas or other fossil fuels and, consequently, greenhouse gas (GHG) emissions.

Challenge: Customer and Community Engagement

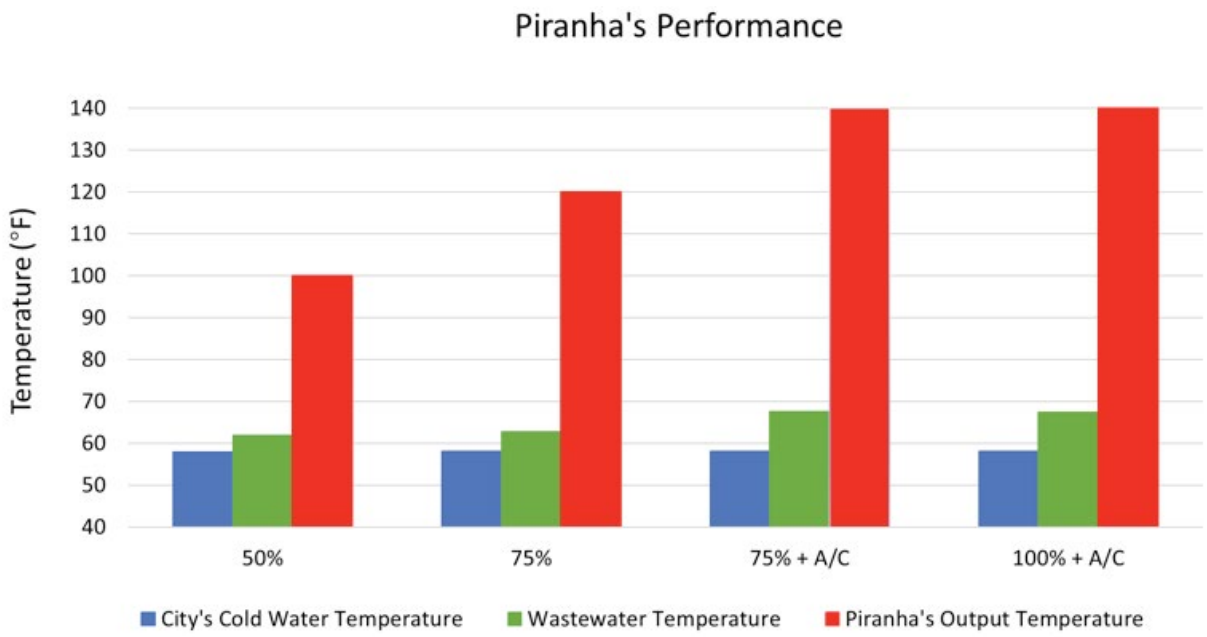


Installed Piranha T10 HC system

Project Overview

This project's objectives were to assess the performance of a Piranha T10 HC system, with a heat capacity of 120,000 Btu/h, relative to its impact on building energy use and GHG emissions; and to evaluate its cost-effectiveness as an energy storage and load management resource for utilities. The SHARC team coordinated with EPRI and interested utilities—including Ameren, AEP, Con Edison, SCE, and TVA—to develop a test plan.

The site chosen to perform the study was the Seven35 Building, a 60-unit multi-family complex with a variety of sustainable features located in North Vancouver, British Columbia, Canada. The average hot water



Temperature plots for incoming municipal water, wastewater, and Piranha output for varying domestic water heating loads

usage at the Seven35 is 2,000 gallons per day at an average exiting temperature of 20°C (68°F).

On the basis of this thermal energy resource, the Piranha system was deployed, connecting on one side to the building's gray water system and on the other to the existing hot water distribution system. Additional flow meters, temperature sensors, and electrical and gas meters were installed for test purposes to provide a comprehensive picture of water and energy flows. The primary refrigerant used to run the system was R513A, which has a much lower global warming potential (GWP) than the incumbent chemistry.

The study was performed in phases, where the domestic hot water load provided by the Piranha was increased progressively, from 50% load (100°F) and 75% load (120°F) with peak avoidance to 100% load (140°F) with and without peak avoidance. The air conditioning (AC) system operation was performed in the last phases, at 75% and 100% load. The existing natural gas boiler was left in place as a backup or to supply non-domestic hot water applications.

TESTIMONIAL: EPRI

In this brief demonstration, we were able to learn about the operation of a new promising water heating and air conditioning technology. I'm excited to see a heat pump with high COP year-round while utilizing a lower-GWP refrigerant.

Doug Lindsey

Results & Learnings

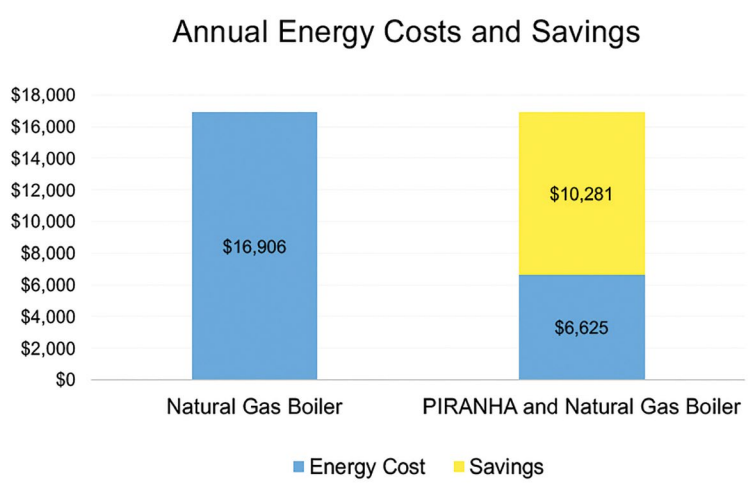
The figure at left shows the temperature gain achieved by the Piranha system. On an overall basis, results show that domestic wastewater heat recovery has value in the residential and commercial building retrofit markets, in new construction, and in developing integrated strategies for reducing carbon emissions at the community level and for urban areas. The Piranha T10 HC was able to produce 100% of the building's hot water at 140°F and also to provide cooling, with an average coefficient of performance (COP) of 3.7 and average running time over 13 hours/day. The system created no noise issues and has no need for defrosting.

A reduction of almost 100% in GHG emissions was calculated, due to the local utility's reliance on renewable electricity generation. The Piranha system is expected to result in a 60% savings in annual energy cost compared to the gas boiler at the Seven35 site, as well as offer the capacity to shift peak load due to the 878 gallons of wastewater storage capacity. This creates opportunities to reduce customer demand charges and benefit the grid.

According to the building manager of the Seven35 facility, the Piranha fit within a small room in an underground parking lot but quickly had a big impact by helping recapture heat from gray water that was going down the drain to significantly reduce energy bills. Additionally, residents have taken pride in the system's contributions toward carbon neutrality.

Implications & Next Steps

This pilot helped in demonstrating favorable cost-performance potential for the innovative concept of wastewater heat recovery for electricity-based



Comparison of annual energy costs for standalone gas-fired system and for the Piranha system supplying 100% of domestic hot water needs plus air conditioning, with gas backup

domestic water heating, as illustrated in the figure at left. Piranha systems are available in different sizes to serve a wide range of residential and commercial building types as well as industrial facilities. In addition to supplying hot water, the technology can also provide space heating and cooling.

The next step is to conduct a longer and broader demonstration involving independent evaluation of the Piranha product line's operating characteristics and performance in different types of settings, such as larger apartment buildings, laundromats, and commercial kitchens. Working in collaboration with utilities to understand and integrate the technology within energy efficiency, demand response, electrification, and emission reduction programs will support broader implementation.

TESTIMONIAL: SHARC

Working with the Incubatenergy Labs 2020 team proved to be very beneficial for the development of our Piranha product line. We were able to complete a first-class, real-time equipment test supervised by EPRI and our utility partners with meaningful verified outcomes. The exposure we received from the broader EPRI audience has meant an exponential growth in inquiries and implementations of Piranha systems. The credibility of EPRI, coupled with the value proposition of our technology, has launched us into a market that was looking for the Piranha. Incubatenergy Labs has been a catalyst to our corporate success.

Lynn Mueller

TESTIMONIAL: Con Edison

SHARC figured out how to reuse the heat from the wastewater we all generate on a daily basis, so it's a renewable wastewater heat. They are on track to make a positive impact by not only cutting the cost of domestic water heating and space conditioning for customers but also reducing air emissions and thermal discharges.

Silvia Khurrum

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PingThings

PredictiveGrid™ Time-Series Data Platform

Ameren

Startup

PingThings

Host

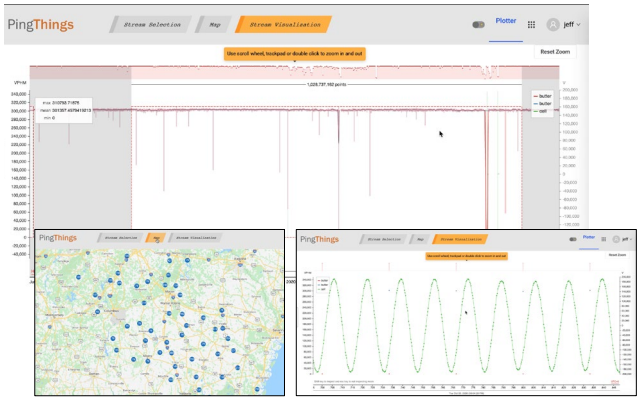
Ameren

Technology Solution

Utilities and other distribution system operators need modern, data-driven approaches for planning infrastructure improvements, diagnosing issues, and preventing outages. In the last 20 years, tens of millions of smart meters have been installed at residential and commercial endpoints to provide additional insight into distribution grid and customer behavior, and each one can take more than 100,000 measurements per year. Additional advanced metering and monitoring devices, including distribution synchrophasors, also are being widely deployed. The immense promise of the smart grid remains largely unrealized due to the challenges in handling, managing, and analyzing the vast trove of sensor data. For utility engineers and analysts, the faster they can visualize, explore, manipulate, and analyze data—transforming ideas into prototypes, testing and improving use cases, and deploying the applications to run at scale—the more value they can create.

This pilot was launched to demonstrate the PingThings PredictiveGrid™ platform for creating data-driven applications for realizing the full value of utility time-series data assets. PredictiveGrid is a data management, analytics, and artificial intelligence platform designed to work with time-series measurements from any grid sensor, from advanced metering infrastructure to synchrophasors to power quality and continuous point-on-wave monitoring. The platform, architected for speed, scalability, and ease of use, can be deployed through cloud providers—such as Amazon Web Services (AWS) and Microsoft Azure—and also as an on-premise solution.

Challenge: Customer and Community Engagement



Sample PredictiveGrid user interface

Project Overview

This project engaged PingThings, Ameren, and EPRI in evaluating the performance and capabilities of the PredictiveGrid platform when working with millions of streams of smart meter data. Ameren internally maintains a metadata table for 3.29 million smart meters across 1,387 substations in Missouri and Illinois. This table is presumed to be 80% to 90% accurate for phase and meter-secondary transformer mappings, but this has not been comprehensively tested as manual verification is prohibitively expensive.

The specific challenge was for PredictiveGrid to ingest more than 1 year of data and then implement, test, and enhance several large-scale machine learning algorithms for smart meter time-series data. The intended application was to develop predictions for correcting mis-specified phase designations and meter-transformer mappings to support the creation

of hyper-accurate network models, which have high business value as foundational to an advanced grid. Since the best approaches are not known *a priori*, the pilot provided a test of the rapid prototyping and experimentation capabilities provided by the PingThings platform.

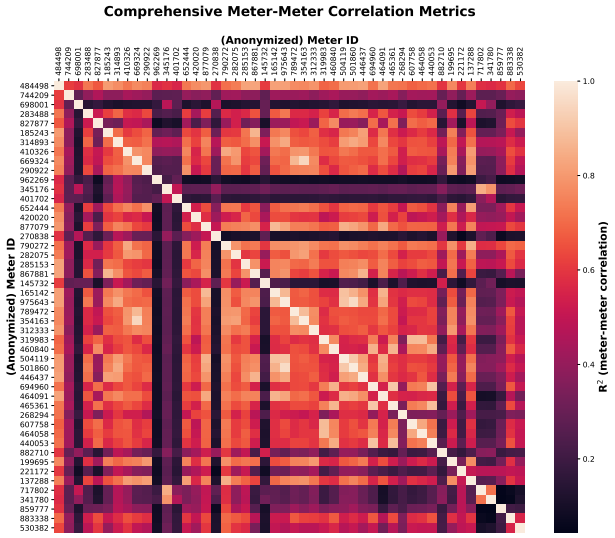
This proof-of-concept project was completed within the required 3-month timeline mainly through the efforts of a single individual. Approximately 12 months of data for 1 million smart meters were imported into the PingThings platform. Each meter reports voltage, real current, and reactive current measurements once every 15 minutes. Three "meter-meter similarity" algorithms were developed, tested, refined, and benchmarked:

- **Pearson correlation**. A simple statistical correlation that ranges from 0 to 1.
- **Spectral clustering-based method.**[1] A machine learning method based on network theory.
- **Bottom-up grouping.**[2] A method based on statistical regression analysis that also yields estimates of physical features like resistance and reactance.

In parallel, the Ameren team assembled a solution from pre-existing AWS components (including S3 and EMR) to develop and test the same algorithms. This supported benchmarking all aspects of the PredictiveGrid in comparison to the AWS-assembled solution, including explicit cost, raw technical performance, time to value, and business process metrics.

Results & Learnings

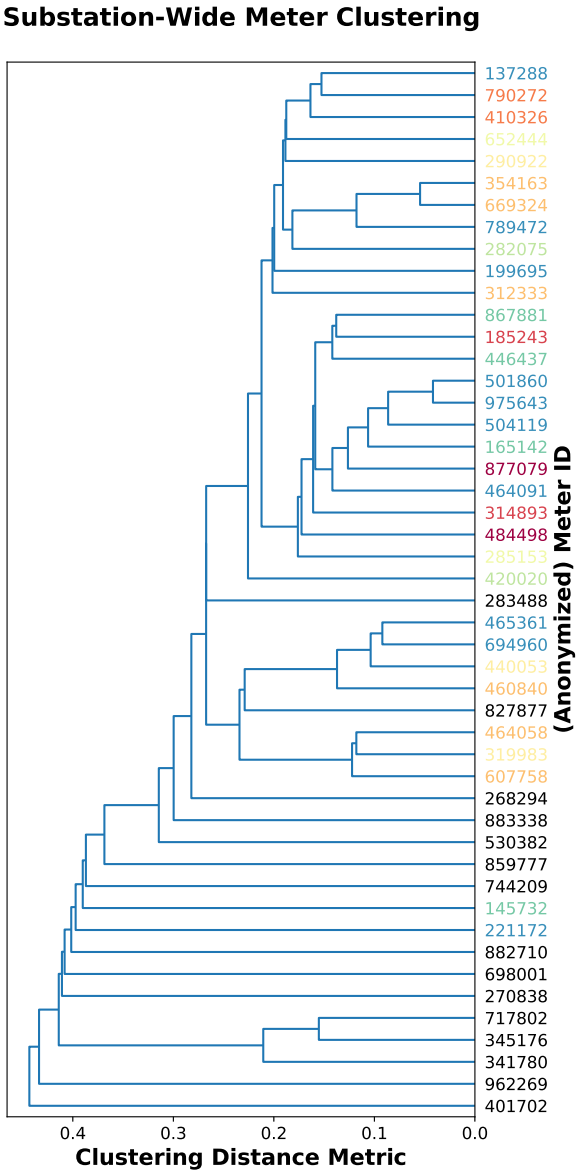
PingThings deployed the PredictiveGrid platform, ingested and evaluated the quality of the supplied smart meter data, and prototyped and benchmarked the three algorithms. Rapid prototyping showed all algorithms to yield useful predictions, as shown in the accompanying figures. Both algorithm development



*Sample results from the methods used for inferring smart meter organization within a small substation: **(top)** heat map visualizing statistical similarity between all pairs of meters based on 1 full year of power, voltage, and current time-series data; and **(right)** hierarchical clustering results using similarity values (meter identification colors correspond to Ameren's internal grouping label)*

and large-scale testing were enabled by the platform's ability to store, load, and analyze data using best-in-class data science tools. Prototyping was performed on a small amount of ground-truth data in addition to the meter metadata table. Results suggest that the two more complex algorithms produced more accurate results, and next steps will examine this in more detail.

For the Pearson correlation method, complete data loading and analysis of all available data across 64 substations were achieved in under 40 minutes on the PingThings platform using a single compute node. This was more than twice as fast as the AWS-based solution while using 64 times fewer resources, all at significantly lower cost. The more complex algorithms, which each require millions of individual calculations,



finished within 20 minutes for substation networks thousands of meters in size. All analytic methods tested were efficient enough to allow for easy parameter tuning and prediction scoring.

TESTIMONIAL: PingThings

Working with Ameren and EPRI has been great, and we have really appreciated the opportunity to show the industry just how powerful the PredictiveGrid is for all types of utility time-series data.

TESTIMONIAL: Ameren

The PredictiveGrid is a high-performance data analytics platform that can ingest and store grid data, enable easy interactions, and accelerate building artificial intelligence solutions.

The AWS-based analytics implementations by Ameren were hindered by limitations imposed by the AWS services and software but not apparent at the beginning of the process. Pilot results demonstrate that the PingThings platform provides technical advantages such as fast time-series data storage and loading and flexible and customizable analytics development to meet specific user needs. In addition, experimentation with time-series data is encouraged rather than penalized by the platform's pricing model.

This proof-of-concept project involved a one-time data export and transfer from Ameren through EPRI to PingThings. While challenges encountered resulted in some delays, project learnings will guide development of a more robust pipeline and schedule to transfer data continuously into the PingThings platform in an automated fashion.

Implications & Next Steps

Unlike many other data analytics offerings for advanced metering infrastructure, the PingThings platform assists utilities in creating their own solutions as opposed to being handed a "black box" machine that lacks observability and cannot be tuned. Importantly, utilities often underestimate the difficulty of data wrangling—getting all of the relevant data securely into one place in a form that is usable (ingestible) by analysis software. Regardless of the data analytics application or choice of platform, this portion of the process should be thoroughly assessed and tested during planning to refine the time estimate and resource commitment.

In the specific use case considered, the analytics developed and refined using the PingThings platform demonstrated high potential value as a viable alternative to field verification of phase and meter-transformer mappings, which requires each meter to be examined and measured at its location. Further, because the platform is an emerging alternative to the big data technologies of leading providers, a significant and valuable part of this project involved deploying an AWS implementation to support an objective comparison for Ameren.

For 2021, Ameren plans to continue to evaluate the PredictiveGrid platform and how it can fit into the utility's overall sensor and analytics architecture and strategy.

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2. T. A. Short, "Advanced Metering for Phase Identification, Transformer Identification, and Secondary Modeling." *IEEE Transactions on Smart Grid,* vol. 4, no. 2, pp. 651-658, June 2013, doi: 10.1109/TSG.2012.2219081.

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Managed EV Charging Software

Startup

ev.energy

Host

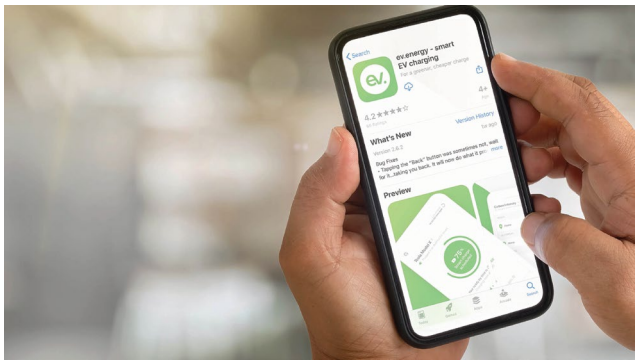
Ameren

Challenge: E-Mobility

Technology Solution

According to the International Energy Agency, electric vehicle (EV) sales have been growing at a rate of 50% per year since 2013, and the Edison Electric Institute forecasts 20 million EVs on U.S. roads by 2030. EVs represent a significant opportunity for utilities to sell more electrons but could have grid impacts at high penetration. Unmanaged EV charging at peak can strain distribution networks, create resource inefficiencies, and increase costs for customers. Managed EV charging shifts EV loads to off-peak times or curtails them entirely during high-intensity events, providing utilities with a non-wires alternative for meeting charging needs. In addition, managed charging can schedule load to align with renewable generation and help customers to benefit from cheaper off-peak rates.

This pilot focused on testing ev.energy software as a telematics-based solution for helping utilities and their customers manage residential EV charging. The software platform connects wirelessly to compatible vehicles and L2 chargers to control charging via an algorithm that calculates the optimal charging schedule given inputs including current charge level, desired ready-by time, charge rate, forecast generation mix, wholesale price, network intensity, local feeder load, and/or the customer's rate schedule. Utilities can monitor EV loads and schedules on the back end, while a smartphone app allows the customer to connect their vehicle and/or charger, set a ready-by time, earn rewards for adhering to managed charging, override managed charging if needed, and track energy consumption, costs, and savings.



The ev.energy app was customized for this pilot

Project Overview

Through this collaborative pilot, Ameren sought to deploy ev.energy's managed charging software with its employees and interested customers within its service territories in Missouri and Illinois, consistent with both long- and near-term commitments. Notably, Ameren committed to net-zero carbon emissions by 2050 through $8 billion of investment in wind and solar generation, and EVs provide a flexible source of demand for optimizing utilization of variable-output renewables. Also, Ameren's 5-year capital investment plan for grid modernization includes provisions for smart grid software and EV charging infrastructure.

Given the ongoing COVID-19 pandemic and related shelter-in-place restrictions, the pilot deployment was entirely remote. The ev.energy app was customized for Ameren, and EV drivers were given a link to download the app on their phone. Participants on-boarded over the course of a few weeks in June 2020,

enabling them to connect their Tesla vehicle to ev.energy's platform, confirm their rate plan, and begin managed charging. Between July and September 2020, 40 Tesla vehicles had their charging managed for a period of 8 weeks. Two weeks were used for establishing a baseline, and the other 6 weeks were used to manage charging.

The 40 participating Teslas were divided into four 10-vehicle groups, each with charging optimized according to a different variable:

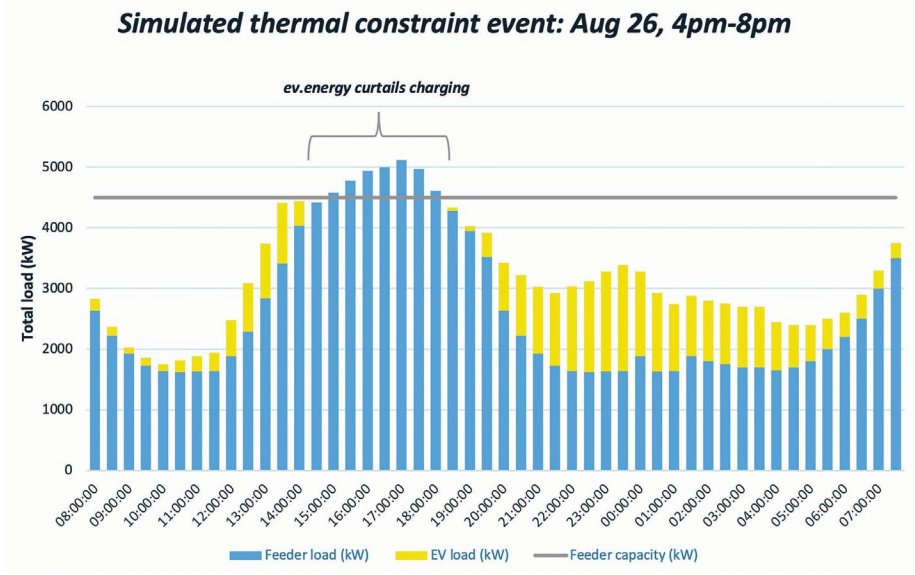
1. **Static time-of-use pricing**: shift EV charging to off-peak times under Ameren Missouri's time-of-day rate plan
2. **Dynamic hourly pricing:** schedule EV charging for the lowest-priced hours in Ameren Illinois' Power Smart Pricing program
3. **Low-carbon generation:** align charging with periods served by the least carbon-intensive supply mix on the MISO grid, drawing on generation forecasts
4. **Network intensity:** aggregate 10 Teslas into a virtual neighborhood drawing from the same 12kV feeder line and shift/curtail charging according to virtual load signals provided by Ameren's Distributed Technologies team

Participants in the first two groups were given the option of donating their accumulated savings to a charity of their choice. Those in the other two groups earned points for each managed charging session greater than 10 kWh, which they could also redeem in exchange for a donation to a chosen charity.

Results & Learnings

Comparing the 2 weeks of baselining data with the 6 weeks of managed charging data, ev.energy's solution demonstrated the following benefits to Ameren and its customers:

- **Energy bill savings:** Missouri customers on time-of-day rates saved an average of $11 per month on their EV charging, compared to the baselining period. This is largely due to the large price difference between the peak (30.5¢/kWh) and off-peak (7.2¢/kWh) prices; ev.energy shifted 80% of unmanaged EV load to off-peak times. Illinois EV drivers enrolled in the Power Smart Pricing program saved an average of $3 per month. Though ev.energy was able to schedule 90% of EV loads to the lowest-priced hours, the smaller differential between the higher-priced (~4¢/kWh) and lower-priced hours (~2¢/kWh) did not result in significant savings.
- **Reduced carbon emissions:** By drawing on a live application programming interface displaying MISO's regional generation forecast, ev.energy was able to align EV charging schedules to periods of lower-carbon generation, which tend to be overnight due to lower demand and sizable installed wind capacity. The carbon intensity of the electricity delivered to customer EVs, measured in lbs CO_2/kWh, was reduced by 20%. This cut the average EV driver's total emissions from EV charging by 112 lbs CO_2 per month. Even greater emission reductions are possible for EVs charged by grids with larger daily variations in carbon intensity, such as CAISO.
- **Reduced feeder loading:** Using virtual loading data from a 12kV feeder line, ev.energy's algorithm overlaid real EV charging demand and shifted and curtailed EV loads to prevent the line from exceeding its upper limit. Over the course of the 6 weeks of managed charging, 40 potential thermal constraints were avoided by either delaying the start of charging sessions or curtailing sessions already in progress, as shown in the figure above. This test demonstrated the viability of the ev.energy solution as a non-wires alternative.



Modeling demonstrated curtailment of EV charging at times of high feeder loading

Implications & Next Steps

This successful pilot has three key implications. First, telematics can serve as a cost-efficient and scalable way for utilities to manage EV charging. Drawing on smart phones and the intelligence embedded in vehicles and chargers, this approach requires no additional hardware but provides utilities with a high degree of control over EV loads. It reduces costs for both the utility and the customer, and it can be deployed remotely and scaled up quickly. Second, user-friendly apps and rewards programs can be



Managed charging benefits customers and the grid

TESTIMONIAL: ev.energy

We're glad that our software solution was able to be deployed remotely to customers despite the ongoing COVID-19 pandemic. The opportunity to work with Ameren to deliver managed charging to EV drivers across two states was a great way to prove the value of our solution for reducing costs for customers and utilities.

TESTIMONIAL: Ameren

Ameren is proactively preparing for increased adoption of EVs and renewables across the communities we serve and is always looking for ways to help our customers reduce their energy costs and carbon footprints. We were impressed with the bill savings and emission reductions some of our customers realized by using the ev.energy app, and we are looking forward to making the benefits of managed charging programs available to our customers as soon as is practical.

effective in helping customers reduce their energy bills, track consumption and savings, meet environmental goals, and adhere to managed EV charging through gamification and rewards.

Third, the benefits of managed charging are not mutually exclusive and can instead be stacked to deliver multiple sources of value for a utility and its customers. For example, given that bill savings and low-carbon generation align in the overnight hours in MISO and other regions, load shifting to off-peak periods can provide a cost-effective non-wires alternative while delivering a cheaper and greener charge to customers.

As a next step, Ameren continues to support grid integration of renewable generation. In parallel, ev.energy is continuing to expand its range of vehicle and charger integrations, to build new features for EV drivers and managed charging programs, and to explore additional partnerships with U.S. utilities.

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KOGNITIV SPARK

RemoteSpark Subject-Matter Expert Tool

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Startup

Kognitiv Spark

Host

EPRI

Technology Solution

Today's utilities are looking for new and innovative ways to enhance knowledge transfer. Workforce attrition and reduced staffing levels have resulted in a loss of institutional knowledge, while incoming workers are inexperienced but tech savvy. Innovations that seamlessly connect field workers with remote subject-matter experts (SME) have great potential for facilitating knowledge transfer when needed and ensuring that critical activities may be performed safely and effectively. Learning necessary skills and resolving questions and uncertainties at the point of work can provide hands-on guidance and reduce errors. Sharing of documents, images and drawings, and animated equipment models in real time can add additional value by allowing work to continue without interruption.

The RemoteSpark pilot project was established to demonstrate the feasibility and value of implementing the remote SME solution developed by Kognitiv Spark (KS) using a commercially available augmented reality (AR) product, the Microsoft HoloLens2. The RemoteSpark application offers capabilities uniquely suited for industrial environments and isolated work sites. Importantly, no third-party software is required. This ensures a high level of security and, where necessary, the ability to deploy completely "on premise" with no need to connect to the internet or to other outside systems. As a result, RemoteSpark is able to optimize efficiency and facilitate fully enabled video calls, to include sharing of 3D holographic models, using bandwidth as low as 256Kb.

Challenge: Workforce of the Future



AR image of 3D hologram of SEL relay

Project Overview

In designing this project, the KS-EPRI team sought to demonstrate the core functionality of the RemoteSpark application for utilities while addressing the following questions:

1. Can the technology be evaluated in simulated work scenarios directly applicable to those encountered by utility field workers?
2. Can the technology enable field workers to troubleshoot and complete tasks in a manner that leads to significant positive impacts in workflow and error reduction?

Specific use cases related to power generation and transmission were developed with reference to original equipment manufacturer (OEM) literature and to actual utility procedures. Interested utilities serving on

a project steering committee, as well as technicians at the EPRI High Voltage Lab in Lenox, Massachusetts, were instrumental to this process. The scenarios included the following:

- SF6 high-voltage breaker
  - o Routine inspection to check condition and function
  - o Field verification of proper breaker isolation and clearance for maintenance
- SEL751 relay
  - o Connection to the relay to upload settings or download data
  - o Investigation of relay-initiated trip to determine cause and review captured data

EPRI's Lenox lab houses fully functional versions of each of these components. KS team members created animated 3D holograms of the components and tasks based on photos and OEM operational data. The animated holograms were designed to support and/or replace written documentation of the procedures. An EPRI technician not involved in developing the use cases was provided with a HoloLens2 headset to gain familiarity with wearing and using the device.

Results & Learnings

To mimic a real-world application, the EPRI technician used the AR headset before going to the work site to become familiar with each task before execution, viewing the stepped animations of the 3D holograms detailing the inspection steps and showing the specific components referenced. Once in the field at the Lenox lab in Massachusetts, the technician used RemoteSpark to initiate video communication calls through the head-mounted device to an EPRI counterpart, acting as the remote SME and located in Florida.

While performing the agreed-upon procedures on the breaker and the relay, the technician was in full video/audio contact with the remote SME, who could ask them to stop and inspect a specific component more closely or guide them through additional steps. The stepped animations were viewed and referenced during task execution as both a guide and a validation tool. The remote expert was able to capture screen shots and video, make annotations on the technician's field of view, and send additional reference documents and holographic models.

The technician was able to successfully complete all procedures using the HoloLens2 and RemoteSpark application. Test scenarios highlighted the value of using head-mounted devices with the KS solution, as technicians can keep hands free for work tasks. The new flip-up feature of the HoloLens2 headset allowed the field technician to move the lens up and out of the way, leaving an unobstructed view of the work area and also improving situational awareness of their surroundings.



EPRI technician using Hololens2 with RemoteSpark at the Lenox High Voltage Lab

After each test case, discussions were held to determine ease of use, efficiencies gained, confidence in task completion, improvement opportunities, and overall perceptions. Initial feedback indicated that the headset and holograms made the procedures

TESTIMONIAL: EPRI Technician

The goggles – the HoloLens2 operating RemoteSpark – proved to be a wonderful learning and support tool for someone not very familiar with either the relay or breaker. Having information in my view and on hand, along with an expert in the background, was absolutely amazing. In this time of social distancing and limited travel, the next best thing to having experts with you in the field is to have them essentially in your head, while you are working hands free.

significantly easier to perform. The Lenox technician especially liked that the remote SME was able to capture photos and videos without requiring specific action by the user, which allowed uninterrupted focus on the task. Significant error reduction is anticipated as a result of using the guided hologram for visual identification of components and verification of steps.

While the pilot demonstrated the capabilities and potential benefits of RemoteSpark, a couple of challenges were encountered relating to the HoloLens2. The technician was unable to use the headset with a hardhat. This is a recognized need for utility and other industrial uses, and solutions are in development by several vendors. Also, bright sunlight tends to wash out the headset display. Shading the work area or applying window tint to the lens (https://www.youtube.com/watch?v=cw11KQSe9Tk) have been shown to be effective.

Additionally, the 3D holographic models used in this pilot were created by the KS team, but these models may be created at the customer level by remote experts following a few suggested guidelines provided by KS, as follows: Using modeling and rendering software such as 3DS Max, the first step is to convert a standard 3D CAD file to a glTF 2.0 file. This can also be achieved directly from many industry-standard CAD programs using a built-in or plugin glTF exporter. Node animations (for transformation, rotation, and scaling) can also be generated by the modeler and embedded directly in the glTF file. These animations can contain a single sequence or a stepped (multiple track) animation. The file is zipped by the modeler, a thumbnail is added, and then they can be sent to the HoloLens headset by drag and drop during a RemoteSpark video call.

Implications & Next Steps

In this pilot demonstration, RemoteSpark used with the HoloLens2 provided a unique, high-value, hands-free tool for assisting an inexperienced field worker and showed broad applicability for on-the-job training and for expert support during critical or seldom-performed tasks.

The ability to walk through a job task using the holographic animation, refer to the virtual model and other resources as needed during execution, and maintain direct, real-time voice and video contact with remote SMEs is expected to translate into a range of benefits. These include greatly decreasing the likelihood of error, improving knowledge transfer to less experienced colleagues, and increasing the confidence of the field worker. Cost savings, in the form of improved task efficiency, reduced equipment downtime, and less technical support travel, are also anticipated.

Several utilities have expressed interest to EPRI in conducting field trials of the RemoteSpark solution for specific worker-job-task scenarios. As partnerships develop and lead to demonstrations, EPRI plans to monitor progress and publish results to facilitate broader industry adoption.

TESTIMONIAL: Kognitiv Spark

This engagement sharpened our focus on fundamental questions surrounding the introduction of augmented reality capabilities to power industry settings. Will our product work where utilities need it to work? Will it help the workforce operate with less cognitive burden whilst achieving higher levels of safety and accurate task completion? Even during the limited course of this project, we found our focus rewarded by seeing a growing appetite for these capabilities among participating EPRI members.

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IND.T
INTELLIGENT NETWORK
DIAGNOSTIC TECHNOLOGY

Early Fault Detection for Power Lines

Ameren

Startup
IND Technology

Host
Ameren

Technology Solution

Overhead transmission and distribution (T&D) lines connect urban environments and span continental grids, frequently traversing remote and difficult-to-access terrain. Stringent reliability, vegetation management, and fire protection standards create the need for utilities to navigate along power line corridors and to conduct inspections from the ground, by helicopter, and by unmanned aerial vehicle. Periodic inspection is inefficient and incapable of detecting many failures, creating opportunity for innovation.

This pilot tested the early fault detection (EFD) technology developed by IND Technology (IND.T), which applies radio-frequency (RF) sensors and advanced analytics for monitoring power line conditions to detect and accurately locate failing network assets—those that are deteriorated, damaged, or compromised by external factors such as vegetation encroachment. In essence, EFD finds failure-causing faults before they happen. EFD data collection units are installed about every 3 to 5 miles along power lines to supply RF signal data for algorithms running on a secure cloud server and trained for electrical circuit diagnostics. EFD systems could potentially revolutionize utilities' network operation, asset management, and work planning processes while cutting the number of T&D line faults causing customer supply outages and fires.



*EFD capacitive coupling sensor mounted on a steel lattice tower to monitor a 138kV conductor **(left)**; and IND.T data collection unit affixed to tower leg showing three coaxial cables from up-tower sensors **(right)***

Project Overview

Working in collaboration with IND.T, Ameren and EPRI initiated a pilot project to assess EFD technology by importing 15 RF sensor and data collection units from Australia and installing them on 138kV wood pole and steel lattice tower lines and 34kV lines with underbuilt 12kV distribution circuits remotely located in rugged terrain in rural Missouri. As a secure EFD cloud server was already in place to support trials on high-fire-risk networks in California, installation of the RF sensor units was the only step required to commission the EFD systems.

Challenge: Customer and Community Resilience

The three power line routes were selected for the trial based on their history of "unknown cause" faults in order to increase the chance of issues being present in the relatively brief pilot period, as well as to observe the efficacy of the sensors and diagnostics. The first EFD unit was installed on August 20, 2020 on a wood pole 138kV transmission line at Dorsett South. After additional deployments, the project team explored the ability of the EFD system and its information outputs to gauge the timeliness of insights and prevent and mitigate potential failures. Avoided cost and ease of use also were evaluated.

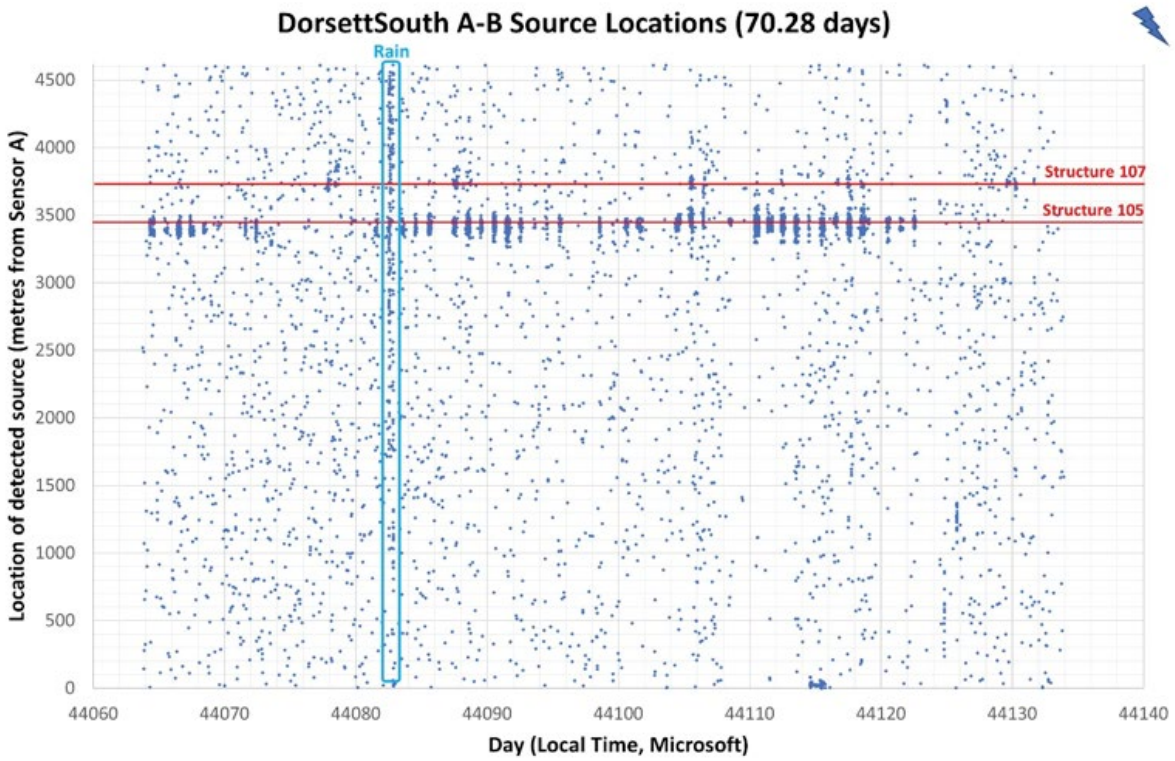
Results & Learnings

Ameren's EFD systems almost immediately identified and accurately located a range of issues on the trial power lines. The first suspect asset became apparent just 15 hours after commissioning the EFD system. Problems identified included a 138kV porcelain insulator string with partial discharge and a handful of distribution transformers with internal discharge, plus instances of suspected conductor damage and vegetation encroachment. Ameren responses, including some forensic investigations, have been scheduled for each of these issues.

The EFD system located issues within plus or minus 30 feet and demonstrated very sensitive detection of incipient faults. Its frequency-time signature analysis and pattern recognition gave indications of the type of failure detected and whether it was located on the monitored power line path or away from it on a tap-line or secondary supply service line. Issues were identified down to individual phases.

Some useful lessons were offered by the project:

- While EFD data collection units can be installed on most poles and towers, sometimes the selected locations were changed by a span or two to avoid constraints. This did not affect the operation of the EFD systems. All the EFD units installed by Ameren were powered from nearby 120V supplies. Each unit draws an average of only 5 watts, and solar power is feasible.
- The distance between the monitored conductor and the capacitive coupling sensors that feed signals to the EFD data collection unit must be close to the same (within plus or minus 2 inches) at each installation along the line. New pole and tower mounting methods were easily developed that achieved this.
- Some detected issues are inherently invisible to inspection because they are hidden within the asset, such as transformer internal discharge. In these cases, confirmation of the detection comes when the asset is swapped out. Other defects such as broken conductor strands can be readily seen on EFD-prompted site visits. This mirrors other EFD experience in Australia and California.
- The project was successfully completed under COVID-19 restrictions that prevented travel to the US by members of the IND.T team in Australia. Online training, procedure videos, and web-based meetings were sufficient for the installations to be fully successful through collaboration among IND.T and Ameren staff.



EFD chart showing intermittent partial discharge activity at an 138kV insulator string on Phase A, Structure 105

Implications & Next Steps

The Ameren pilot confirmed that IND.T's EFD system detects and locates incipient asset failures on power lines ranging from 12kV wood-pole distribution to 138kV steel lattice tower construction. In some cases, the EFD data were rich enough to remotely identify the probable cause and assess risk and urgency prior to a site visit. There is clear potential for utilities to use EFD results to inform grid operations, network maintenance, and asset management activities. This IND.T trial indicates opportunity for potentially radical beneficial change in these functions.

Once Ameren completes installation of all 15 units, EFD technology will continue to undergo demonstration testing through mid-2022, complementing field trials on networks on the U.S. west coast. Ameren is evaluating possible next steps for applying the technology in improving T&D asset health monitoring to deliver value into its network businesses in Missouri and Illinois.

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TESTIMONIAL: IND.T

We were proud to be selected for a trial of EFD on Ameren's networks and enjoyed working with such an enthusiastic team, though COVID-19 kept us physically a world apart. We were particularly excited to see EFD installed on transmission lines—our lab tests had confirmed EFD works on high-voltage lines, but this was our first real-life install. Finding a failing insulator string first day really capped it off.

***Tony Marxsen,** Chairman*

TESTIMONIAL: Ameren

The idea that you can identify problems on your transmission system that are soon to come—event anticipation—is really, really important. Eliminating customer outages, driving affordability because we can efficiently group our work instead of heading out to fix things whenever they fail, and, dearest to my heart, risk management—not just put in better protection to respond to faults and limit consequences, but actually manage the risk of faults happening—all I can say is this tech is magic.

***Jeff Hackman,** Senior Director, Business Development and Special Projects*

Phase-EQ Dynamic Phase-Balancing Technology

Startup
Switched Source

Hosts
EPRI and Ameren

Challenge: Customer and Community Resilience

Technology Solution

Utility distribution feeders commonly experience phase imbalance due to the use of single-phase laterals for loads like homes and small commercial customers. This creates the potential for voltage, thermal, or other operational constraints. Large clusters of rooftop solar, electric vehicles (EV), and other distributed energy resources (DER) introduced in a neighborhood can exacerbate imbalance issues. Utility deployment of voltage regulators helps mitigate one aspect of the problem but does not address the root cause. Localized upgrades via line reconductoring and phase rebalancing by manually re-tapping laterals require customer outages and may need to be repeated with load and DER growth.

This pilot project investigated the potential of Switched Source's Phase-EQ technology for mitigating phase imbalance in distribution systems. The Phase-EQ, an innovative technology for dynamic phase balancing using solid-state power electronics, is undergoing an initial utility demonstration in New York. It is designed for deployment along a three-phase feeder or at the substation on wye-configured 4-15kV distribution systems. The Phase-EQ measures the complex phase current and voltage and shifts power from one phase to another in real time to significantly reduce the local neutral current caused by imbalances. Resulting reductions in phase current and voltage imbalance can improve power system operations and customer power quality. Dynamic phase balancing also can increase circuit capacity to support additional distributed generation, as well as load growth.

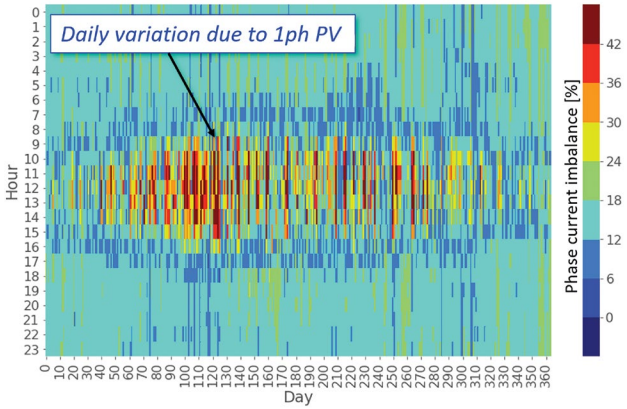


Phase-EQ device, ready for initial deployment

Project Overview

The objective of this collaborative demonstration project was to investigate the techno-economic benefits of deploying the Phase-EQ for dynamic phase balancing on distribution feeders. The project was divided into three components: (i) identifying the severity of phase imbalance issues, (ii) capturing the technical capabilities of the PhaseEQ device, and (iii) performing cost-benefit analysis.

Quantifying phase imbalance on distribution feeders is becoming increasingly important as single-phase loads grow and become more dynamic. Current utility practice may not provide a clear picture of the complexity of this issue. EPRI, Ameren, and Switched Source worked together to conduct power system modeling and simulation to better understand time-varying phase-level imbalances and the ability



Plot illustrating time-varying phase imbalance exacerbated by single-phase solar systems

of the Phase-EQ to mitigate these issues. This was performed using data from actual distribution feeders provided by Ameren and a device model provided by Switched Source. The cost-benefit analysis focused on assessing the different value streams associated with voltage optimization and reduced capital and operational expenditures.

Results & Learnings

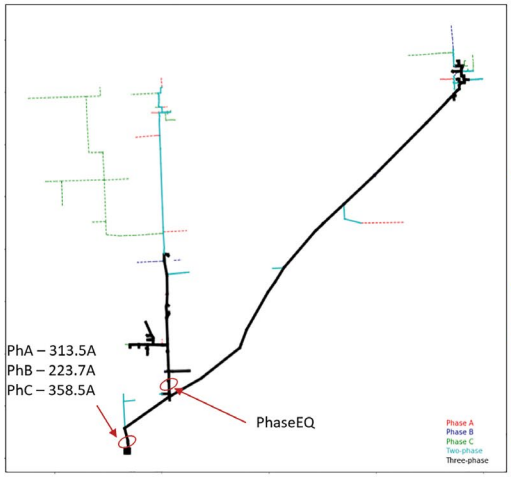
The first component of this project was to recognize and characterize the severity of phase imbalance on distribution feeders. Modeling and simulation results supported three key insights:

- **Phase imbalance is location-dependent:** Phase imbalance varies not only from feeder to feeder but also across the different sections of a feeder depending on the topology and load distribution.
- **Phase imbalance is time-varying:** Depending on the load composition (residential, commercial, industrial), phase imbalance may vary on a seasonal, hourly, or daily basis. Importantly, imbalance at feeder peak demand may no longer represent the worst-case condition.
- **Phase imbalance can be exacerbated by single-phase DER:** Technologies such as rooftop solar and EVs can increase the imbalance on feeders, which limits hosting capacity unless corrected.

The second component involved feeder-level modeling to investigate the technical capabilities of the Phase-EQ device. Different feeders and deployment locations were modeled and tested to assess efficacy, demonstrating that device performance depends on location and grid conditions. Through scenario testing and simulations, EPRI identified deployment criteria. The technology proved effective in reducing the neutral current due to phase imbalance, which in turn reduced the current imbalance and the voltage imbalance.

For a sample feeder and location, the table below compares simulation results (a) before deploying the Phase-EQ, (b) after deploying the Phase-EQ while operating with local measurement, and (c) after deploying the Phase-EQ while operating with remote measurements, in this case voltage and current at the feeder head. The Phase-EQ reduced the local neutral current caused by phase imbalance by 98.22% and the current imbalance by more than half. Leveraging remote measurements, the Phase-EQ also reduced the imbalance upstream of the device by more than half, decreasing the imbalance in feeder-head current from 25.07% to 11.60%.

The third component of this project was to investigate diverse potential value streams from deploying the Phase-EQ for dynamic phase balancing. Relative to traditional utility solutions, device capabilities and benefits were considered in five technical areas: balancing phase voltage, balancing phase current, enabling higher DER penetration, reducing neutral current, and improving feeder efficiency. Additionally, approaches to monetize each value stream were proposed.



		Before		Local Measurement		Remote Msrmnt	
		Mag.	Imbal.	Mag.	Imbal.	Mag.	Imbal.
Voltage @ phase EQ	PhA	0.9830		0.9797		0.9771	
	PhB	0.9926	1.53%*	0.9884	0.56%	0.9875	0.81%
	PhC	0.9652		0.9875		0.9908	
Current @ phaseEQ	PhA	198.3		196.8		189.5	
	PhB	135.9	31.04%	167.6	14.61%	175.0	14.96%
	PhC	257.0		224.5		226.5	
Neutral Current @ phaseEQ		101.91		1.80	98.22%	27.18	73.33%
Feederhead current	PhA	313.5		311.7		304.2	
	PhB	223.7	25.07%	255.7	13.97%	263.2	11.60%
	PhC	358.5		324.1		325.8	
Neutral Current		115.5		23.27	79.95%	2.00	98.27%

***(left)** Topology of a distribution feeder model highlighting the Phase-EQ location and remote measurement location; and **(right)** simulation results showing local phase voltage/current, neutral current at the Phase-EQ, and the phase current and neutral current at the feeder head*

TESTIMONIAL: Switched Source

Communicating the value of a new technology to busy industry stakeholders can be difficult. This EPRI-utility collaboration created a perfect environment to perform technical diligence and assess the techno-economic value of our Phase-EQ device. It drastically streamlined a challenging and typically lengthy process and provided us with a credible data set to use as a starting point with potential customers and collaborators moving forward.

TESTIMONIAL: Ameren

Across the industry, distribution system planning best practices identify and address potential phase imbalance situations. Ameren continuously evaluates and explores technologies and opportunities that help us mitigate reliability concerns in prudent, cost-effective, and innovative ways. This engagement helped Ameren reduce the R&D and time involved in exploring and evaluating the economic and technical viability of the Phase-EQ technology.

Deferral of capacity investments through balancing phase currents was found to be one of the most promising use cases for deploying this device. In addition, the Phase-EQ doubled the peak load reduction achieved by Volt-VAR optimization in some cases. Value stacking, aiming to capture multiple value streams from a single deployment, also improved the business case in certain scenarios.

As a modeling study, this project had inherent limitations that can be addressed in field demonstrations of the Phase-EQ. In addition, validating Switched Source's device model (available in CYME or OpenDSS) was considered outside the scope of this pilot, but third-party engineers have validated the model in previous projects.

Implications & Next Steps

This project demonstrates that the Phase-EQ provides utility planners with another tool for mitigating phase imbalance on distribution feeders to improve power quality and system operations, increase DER hosting capacity, and accommodate load growth. Results indicate that ideal host feeders are wye-configured, 11-15kV distribution feeders with significant phase imbalance on three-phase lines.

Applications where the Phase-EQ could be considered as a potential mitigation measure include feeders

- with phase imbalance above 10% at the feeder head,
- with imbalances that cannot be cost-effectively addressed by conventional approaches,
- with imbalances that need to be repeatedly addressed,
- where reconductoring—especially over a significant length—is proposed for an unbalanced three-phase line, or
- with a high concentration of single-phase DERs on a single-phase lateral.

Building on lessons learned from this study, Ameren has analyzed additional feeders to identify potential locations for a possible follow-on pilot involving field deployment and evaluation of the Phase-EQ.

Utilities interested in considering the Phase-EQ in system planning studies can reach out to Switched Source for access to the device model. In addition, EPRI and Switched Source are available to help evaluate potential device deployments from technical and economic perspectives.

Resources

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Synthetic Environments for Resilience Planning

RUNWITHIT SYNTHETICS

EPRI ELECTRIC POWER RESEARCH INSTITUTE

SRP

Startup

RUNWITHIT Synthetics

Host

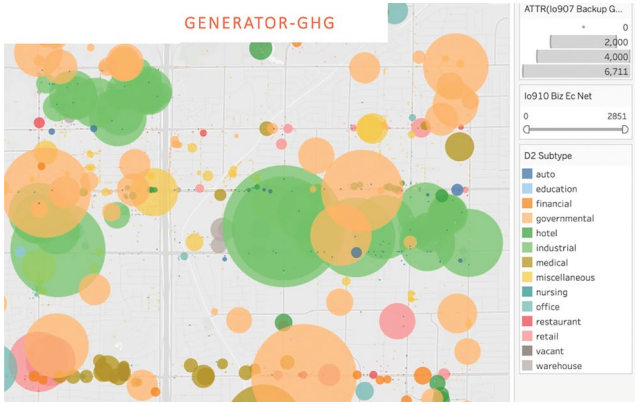
EPRI and Salt River Project (SRP)

Technology Solution

Resilience is a necessary part of modernizing grid infrastructure to prepare for and mitigate hazards of all types. Among the most daunting challenges utilities face are predicting and dealing with natural disasters, especially high-impact, low-frequency (HILF) scenarios that can affect not only utility systems but also other critical infrastructures and can have cascading impacts on customers and society. Simulating potential impacts and possible resilience measures is extremely difficult given the immense physical systems involved, the complex interdependencies, and human dynamics across many dimensions.

The RUNWITHIT (RWI) pilot project involved proof-of-concept testing of modeling tools based on artificial intelligence (AI) for simulating a dual-disaster scenario from a utility perspective, exploring impacts, and testing pre-emptive countermeasures. RWI creates single synthetic environments (SSE) as digital living models of cities, including entities such as geospatially accurate utility infrastructure, other infrastructure and community services, residents and businesses, and different types of technologies. These SSEs interact to support sophisticated scenario modeling and analysis through a hyper-localized virtual laboratory and visualization tool drawing on data and intelligence from diverse sources. Inflections such as new technologies, policies, and procedures can be trialed, optimized, and validated.

Challenge: Customer and Community Resilience



Screenshot mapping hyper-localized, time-based GHG emissions from backup generators during the outage based on energy consumption patterns and generator types for area businesses

Project Overview

Working in collaboration with SRP and EPRI, RWI set out to demonstrate an SSE application in utility resilience, creating the dual-disaster scenario of a power outage within the utility's service area during the time of COVID-19. Proof-of-concept goals were to simulate how dual events can stress critical infrastructures and create health and safety risks, as well as demonstrate the use of AI-based modeling and visualization in diagnosing and mitigating vulnerabilities.

SRP directed RWI to focus on a 15.6-square-mile area in metro Phoenix/Tempe to simulate a 7-hour outage, starting on a typically sweltering July afternoon, during the pandemic with shelter-in-place guidelines. This outage affected 18,249 homes and over 2,000 businesses. RWI's goal was to bring this area to life, synthetically generating entities for grid assets,

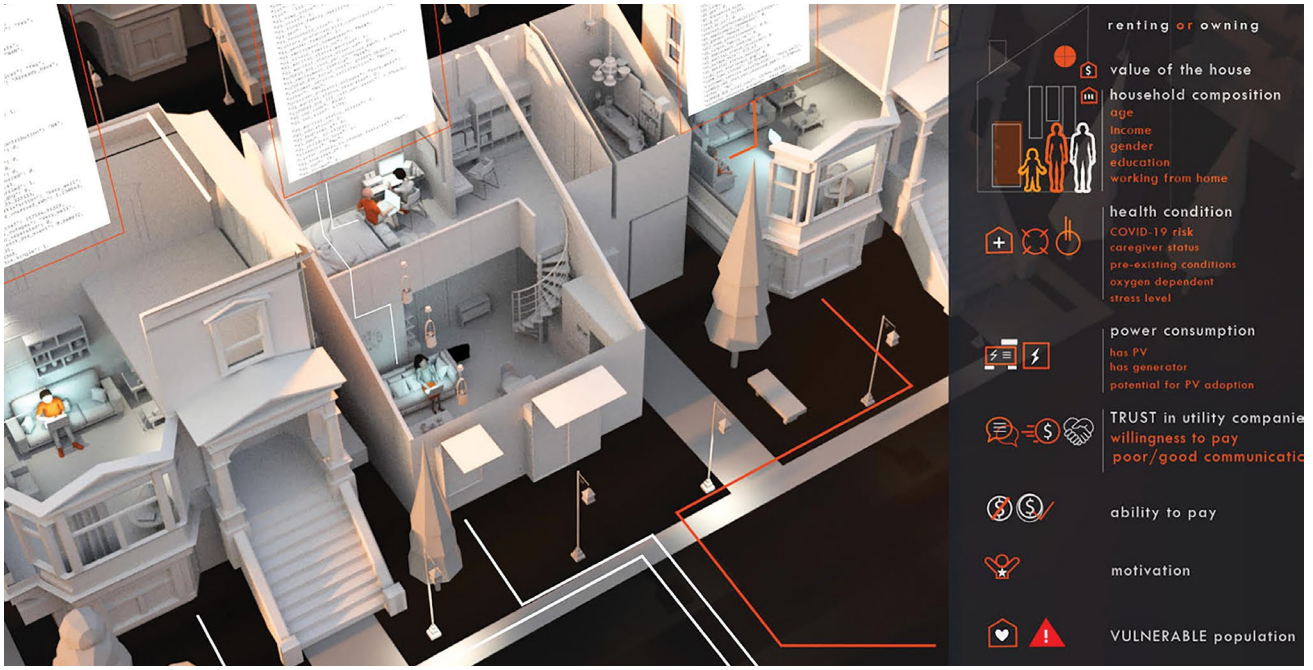
COVID-19 consumption curves, and economic conditions, as well as customers' psychographics, health, economics, demographics, and access to backup power. Emergency response and medical access in the community also were represented. These entities—and their behavior before and during the outage—were synthesized from more than 200 interconnected models.

Because consequences for end-use consumers are the focus of utility resilience efforts, RWI concentrated modeling around key aspects of SRP's commercial and residential customer base. The models incorporated businesses, their existing backup and auxiliary power capacity, and their plans around outage response, power sources, and greenhouse gas emissions (GHG) during outages.

To synthesize the residential population in the area in great detail, model inputs included census data, property and taxation data from Maricopa County, health data from Arizona Department of Health Services, and additional sources. Also incorporated were forward-looking energy plans, customer segmentation data from the Smart Energy Consumer Collaborative's "Wave 7" Report, and survey data characterizing how willingness to pay depends on the type and length of outages and is contingent on household characteristics.

Results & Learnings

Modeling and simulation of this portion of SRP's service territory under the dual-disaster scenario produced billions of data points from various outage scenarios reflecting differing levels of communications effectiveness, increases in the availability of backup power generation, and COVID-19 infection rates. Pilot project work highlighted key aspects of RWI's approach and generated a number of important insights.



Screenshot capturing human impacts of the outage based on interconnected household demographics and psychographics, including willingness to pay, health risk, and consumption patterns

Incorporation of research, domain expertise, and data. The RWI approach to synthetics decomposes complexity and scope into manageable models that capture the contributions of individuals and teams in building out the virtual laboratory. These models combine to form the SSE, a collaborative energizer and a focal point for those who provide research and expertise.

Synthetic grid asset modeling. RWI uses public data sources as well as power system engineering expertise to generate grid assets and locations in the SSE. The capability to synthesize the grid removes roadblocks to integrated analysis and experimentation that are introduced by regulatory and internal controls, as well as alleviates concerns of data breaches.

Hyper-localized customer insight. Through the layering of research and public data from disparate local and national sources, RWI quickly synthesized an accurate representation of SRP's customers and their activities, status, and plans.

"Trust in utility" modeling. RWI's psychographic and human behavior model measures trust shifts and outcomes under different outage conditions. The data from these models furnish valuable insight into long-term customer engagement and allow comparison among targeted inflections, such as improving communications and education on community resilience. Maintaining and improving trust form a critical part of resilience planning.

Equitable and inclusive planning and response. RWI's monitoring of the status of individuals in SSE scenarios furnishes unique perspectives. In this case, locating vulnerable populations and exploring the particulars of their experiences provided opportunities to assess

the impact of specific programs and resilience measures.

Informed priorities. SSEs often deliver unanticipated value. With COVID-19, residents face new and unique vulnerabilities to their health and safety, exacerbated by outage conditions. By quantifying multiple risk and stress factors, RWI was able to generate a repair priority heat map based on human impacts and outcomes to assist utility planners in weighing trade-offs and making complicated decisions.

Bringing research to life. Survey-based research on consumer segmentation and sentiment is conducted inside the SSE. Via machine learning, RWI administered surveys to the entire synthetic population—in one case, administering surveys every 15 minutes during the lengthy outage to gauge as-it-happens changes in trust and willingness to pay for various interventions. U.S. Department of Energy calculations around economic losses were also run to keep a dynamic tally of outage impacts. Perspectives on customer sentiments and impacts, interleaved with other data and maps, can enhance and validate findings.

Informing strategic planning and program development. The SSE improved understanding of current installations of backup generators and plotted their GHG emissions during the outage. Additionally, businesses and residences mostly likely to next adopt backup supply were projected, along with resultant GHG emissions. These findings can support decisions regarding incentive programs, investments, and opportunities to engage with businesses and residential customers.

Implications & Next Steps

This pilot demonstrated use of advanced computer simulation techniques, coupled with powerful visualizations, for creating a realistic synthetic environment of a utility service area and its customers to support analysis of diverse future scenarios for utility risk assessment and strategic planning. The SSE created by RWI in conjunction with SRP and EPRI exists as an extensible modeling tool suitable for deeper investigation of the case studied—simulating an extended peak-summer outage during the pandemic to understand resilience-related vulnerabilities, interdependencies, perspectives, interventions, and outcomes—and for other applications.

RWI is engaged in multiple sectors including defense, energy, mobility, health, policy, and environmental resource management. This cross-sector activity informs SSE projects in areas such as disaster planning, technology validation and penetration, and security. For example, RWI and university researchers have created an SSE that models consumer adoption of technologies such as solar, electric vehicles, and battery storage. Users can visualize and explore human factors and other drivers influencing adoption, where and when various consumers might decide to deploy, and where and which grid assets might be impacted.

Based on this pilot, RWI plans to evaluate the sharing of customer assets like these for improving resilience, shaving peaks, and meeting additional electric utility needs. Adding microgrids, other infrastructures and utilities, disaster and weather layers, and the like promise further insights and broader opportunities. Active participation by consumers is an essential element in modernizing grids and decarbonizing energy systems. Utilities interested in exploring the use of SSEs for combining deep engineering understanding with human dimensions to plot favorable paths forward are encouraged to reach out to the participants in this pilot project.

TESTIMONIAL: RWI Synthetics

Our experience with EPRI was key in helping RWI understand the ways that our technology and techniques can help navigate challenges and opportunities in building energy futures.

Myrna Bittner

TESTIMONIAL: SRP

RWI's synthetic intelligence is a powerful tool to analyze the complex interactions between utility assets, community infrastructure, and human behavior during multiple simultaneous disasters. In fact, it is the only practical method I've seen.

Gary Rector

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Overhead Transmission Line Monitoring

Startup

LineVision

Host

Tennessee Valley Authority (TVA)

Technology Solution

Utilities are constantly striving to maintain safe and reliable operation while increasing the performance and productivity of overhead transmission lines. Adhering to design limits for conductor temperature is essential to prevent annealing damage and loss of strength, and maintaining physical clearances from trees and structures is necessary for meeting safety and reliability objectives. Additionally, utilities must have a good understanding of remaining asset life, and they require methods and tools for optimizing asset utilization by balancing system risks with increased power flow and streamlined maintenance effort.

The LineVision pilot was aimed at demonstrating the types of data that can be provided by a novel transmission line monitoring system and to explore asset health and other potential use cases based on continuous access to information on thermal loading, line clearance, and other parameters. The LineVision V3 system integrates non-contact field sensors installed at both ends of a transmission span with weather model data, historical utility load information, modeling and analytics, and a display portal. Field instrumentation includes two self-powered components, an electric and magnetic field (EMF) sensor for continuous monitoring of electrical properties and a LiDAR scanner for precisely identifying conductor locations.

Challenge: Customer and Community Resilience



LineVision system as deployed in the field

Project Overview

This collaborative project was designed to conduct a proof-of-concept demonstration of the LineVision V3 system and to investigate the value proposition of a rigorous field trial, which for transmission line health monitoring technologies typically takes about 1 year to complete. The project approach included field testing of LineVision technology and a parallel data gathering effort by TVA and EPRI to support comparative analyses and follow-up investigations.

Based on discussions with LineVision representatives, TVA identified lines with different types of conductors, operating voltages, load profiles, bundling, and surrounding environments to identify demonstration

sites for illuminating the strengths and weaknesses of the technology. One of the test lines was selected due to its connection to energy storage and because of routine heavy loading; traditionally, line monitoring systems tend to perform better under these conditions.

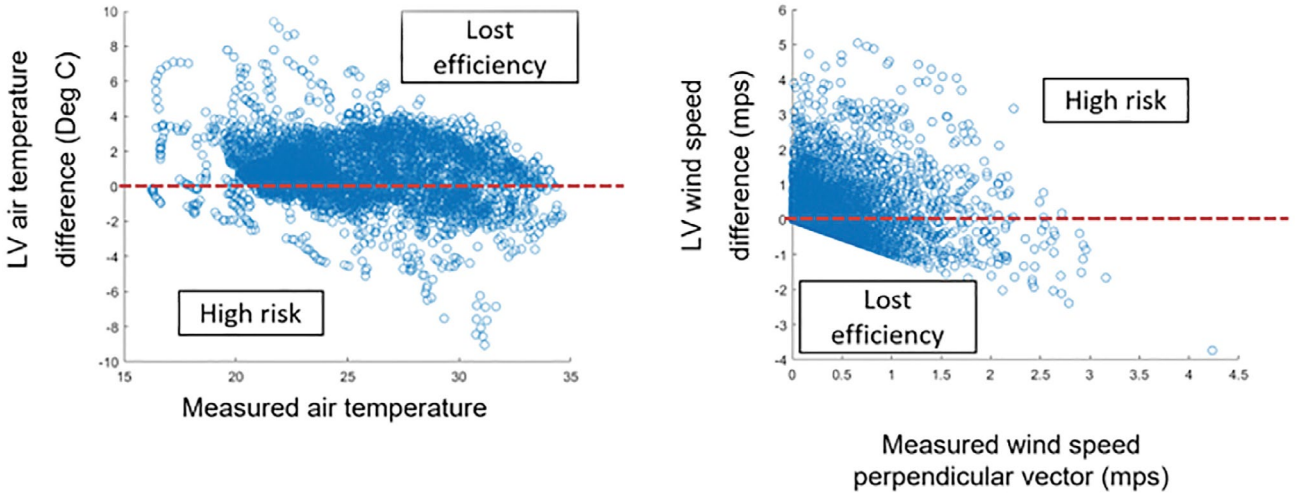
The LineVision and EPRI systems were installed by TVA line crews on towers at three sites in fewer than 2 days. One span was between dead ends at Raccoon Mountain, and two spans were at Chickamauga.

TVA collected line loads at multiple locations to compare against loads calculated by the LineVision V3 system. EPRI collected weather information to compare against the system's weather model data and calculated parameters such as wind cooling of conductors. Because known industry standards for conductor temperature and annealing are based on weather-related data, the accuracy of LineVision's modeled and calculated values has a clear and measurable effect on its results. Additionally, assessing the real-time accuracy of LineVision's weather model data provides insight into its historical annealing analyses.

Results & Learnings

After minor updates to the deployed instrumentation, both the LineVision and EPRI systems were able to collect and make data available in real time via web portals. The LineVision portal displayed measured values for line sag and blowout; calculated values for conductor temperature, line rating, line load, and effective wind speed; and model data for air temperature, rain rate, and solar intensity. The EPRI portal displayed weather and line rating information.

The LineVision system continuously analyzes the accuracy of the data from field sensors and, when necessary, reverts to using weather model data. In this study, the sensors were utilized approximately



Example of data comparisons from the Chickamauga 161kV line location

31% of the time. For the Chickamauga test site, air temperature and wind speed data are shown above. EPRI-measured data are plotted on the horizonal axis and LineVision model or calculated data on the vertical axis.

Air temperatures from the LineVision model showed general agreement but with some periods having differences approaching as much as 10°C (18°F). For periods when LineVision sensors were utilized, calculated effective wind speeds were typically within 2 m/s (6.5 ft/s) but occasionally exhibited greater variation from EPRI-measured data.

Accurate wind speed data are essential for estimating the effect of real-time conditions on annealing potential. Importantly, EPRI's ultrasonic anemometers measure wind speed at a point in space on a transmission tower, whereas the LineVision system's LiDAR sensor determines wind speed along the length of the span between two towers. While the spans involved in this pilot are relatively short and have consistent levels of wind sheltering by trees, differences in measurement strategy are an inherent source of variability.

The figure on the next page provides a comparative analysis of the line load data. Loads estimated by LineVision were within ±5% of TVA's measured loads about 75% of the time for Widows Creek, 64% for Raccoon Mountain, and 21% for Chickamauga. Some of the discrepancy can be attributed to methodology: the LineVision system provides instantaneous values, whereas TVA measured a 10-minute average.

A longer study period would increase the statistical significance of these comparative analyses, and different patterns may emerge with more data. Based on the analyses across the three test sites, the LineVision system appears to perform best when a line is isolated—the only circuit within the right-of-way. Performance appears to decline in scenarios with adjacent circuits such as in the case of the Chickamauga line, where underbuilt distribution is present.

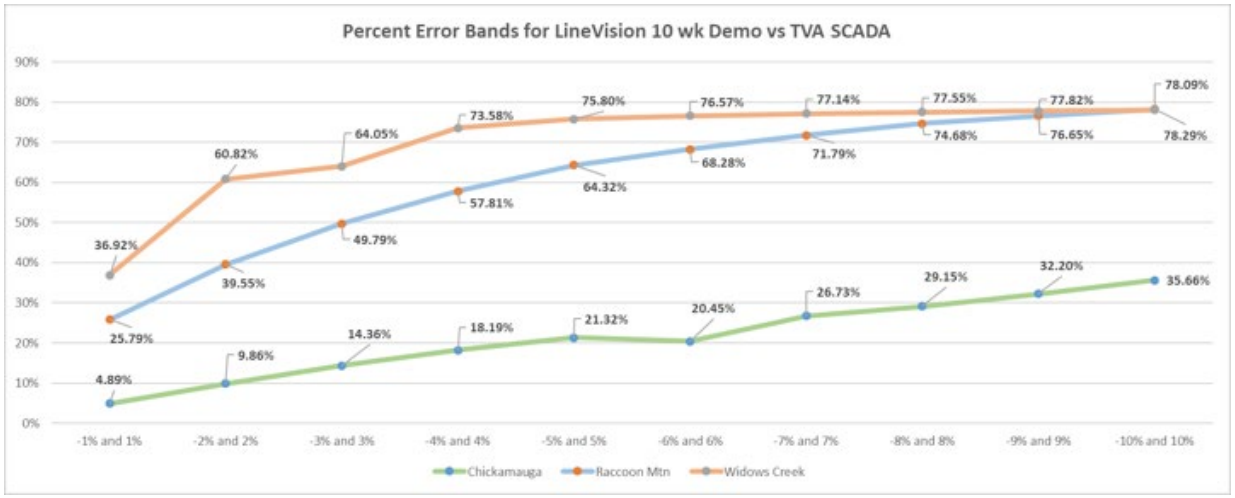
Methods were identified for improving the rigor of future assessments of the LineVision system. For example, sample testing can verify the remaining strength of conductors, and direct measurements can validate calculated conductor temperatures. Additional study also would help improve understanding of factors underlying the LineVision system's assessment of the effects of real-time and historical conditions on annealing. The system applies the same weather data to evaluate real-time conditions and assess historical annealing potential, but it is unknown if identical weather models are used. The system applies real-time loading estimates to calculate conductor temperatures and gain insight into conditions that may cause loss of life, whereas utility-provided line load data are used for historical assessment of annealing damage.

Implications & Next Steps

This 3-month field trial has helped TVA understand the potential of online transmission line monitoring and gain insight for better aligning technical capabilities with specific utility needs. Valuable information can be obtained from continuously monitoring and analyzing transmission line health parameters and physical clearances, but there are challenges in using this approach relative to existing methods.

Typically, utilities perform periodic LiDAR overflights on a rotating basis—for example, one-third of lines annually, thereby covering all lines within 3 years. This provides routine access to point-in-time information relating to line sag and sag-tension relationships for all spans. The LineVision system is designed to provide continuous monitoring on spans between dead-end structures. In this demonstration, the focus was on assessing health monitoring capabilities.

There is a high degree of commonality between measurements used to track annealing and to calculate ratings, as both rely on understanding the conductor temperature as it relates to design limits and, in fact, use the same IEEE-783 equations. Considering cost-benefit as compared to existing overflight practices, TVA sees a potentially stronger use case in the dynamic line rating capabilities of the LineVision system if the sensor accuracy can be demonstrated to be sufficient.



Data comparison of line loads based on percentage of data within an accuracy bin

TVA is interested in extending the field trial with an adjusted focus on dynamic line rating. To achieve this, additional monitoring of the conductors will need to be performed. Discussions with LineVision are ongoing to increase accuracy compared to that observed in the initial demonstration project. Potential improvements include obtaining line loads directly from utility SCADA and integrating local air temperature measurements within the LineVision system. Other utilities interested in evaluating applications are encouraged to reach out to the team involved in this pilot project.

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LineVision uses non-contact LiDAR sensing technology to aid in providing situational awareness of the health of transmission line assets. As utilities look for new technology for modernizing the grid, innovations that improve understanding of asset health conditions can help in ensuring system integrity. Working with LineVision has helped our engineers think of more innovative ways of using technology and solving problems.

Upon reviewing the project summary on the previous pages, LineVision expressed disagreement with certain aspects, as highlighted below.

LineVision Response to EPRI-TVA Analysis

Differences in measurement approach between EPRI and LineVision sensors

EPRI and LineVision both installed sensing equipment on transmission towers. However, these sensors measure and report different pieces of information and should not be misconstrued as generating comparable data. EPRI installed a weather station, and LineVision installed a non-contact LiDAR-based conductor monitoring system. EPRI's ultrasonic anemometer and thermometer represented localized weather conditions at a singular point in space. The LineVision system represented the net effective perpendicular wind speed along the entire stringing section of conductor.

As such, the two systems should not be assumed to exhibit a natural correlation. The anemometer's measured wind speed and direction are subject to localized effects. All spans in the conductor's stringing section act as a coupled thermo-mechanical system, and the LineVision effective perpendicular wind speed thus represents the net collective effect of all varying wind speeds impacting the various sections along the stringing section.

CIGRE Technical Bulletin 498 warns against the direct use of spot measurements: "It should also be noted that the [conductor] temperature changes along the span. The cooling effect of the wind will vary from place to place on the line. The measurement at one point is thus not a true representation of the temperature at other points on the line, thus is not representative of the sag and line rating."

LineVision sensor utilization percentage

The EPRI-TVA project summary incorrectly states that LineVision's sensor is utilized only 31% of the time. LineVision's sensor is utilized 100% of the time. It is used to collect conductor position, EMF values, and other information from which additional conductor properties are calculated. When adequate heat rise is present on the conductor as compared to ambient temperatures, the LineVision system has the appropriate confidence level to report the effective perpendicular wind speed and calculate the dynamic line rating.

When line loading is low and conductor temperature is near ambient, temperature-based monitoring systems of any variety cannot compute the apparent convective cooling rate, the effective perpendicular wind speed, or a dynamic line rating with acceptable certainty. Under these conditions, the LineVision system employs a secondary calculation using weather model data for wind speed to produce a dynamic line rating value. In this particular study, conductor heat rise was sufficient 31% of the time, largely due to relatively low line loading patterns.

LineVision line loading analysis

The EPRI-TVA project summary includes a comparison of the line loading values as reported by LineVision's EMF sensors and TVA's substation current transformers (CT). However, the analytical approach applied failed to consider multiple influential factors when performing a comparison:

- LineVision's load data were instantaneous measurement values, whereas TVA's load data were 10-minute averages.
- TVA's own CTs had inherent error and reported inaccurate values below 72 amps, but these data points were still used in the comparison.
- TVA had CTs at the origin and terminus substations for both the Chickamauga and Widows Creek lines. Those CTs exhibited error when comparing their reported values, but amperages should be constant along a closed circuit. TVA's average absolute errors (amps) were 20.4 and 12.4, respectively, while the LineVision readings showed average absolute errors (amps) of 26.6 and 13.2, respectively.
- EPRI used a simple percentage difference approach when comparing values for average absolute error (amps), but % average absolute error is a more appropriate approach to data science. The percent difference approach will yield misleadingly high percent errors when looking at smaller numbers; for example, comparing readings of 12 amps to 10 amps will yield an error of 20% while the absolute error is just 2 amps, a negligible amount when looking at transmission lines carrying hundreds or thousands of amps.

Line loading error assessment

To more appropriately perform the data analysis and resolve the problems mentioned in the previous section, LineVision took the following steps when creating

comparisons of percent average absolute error and average absolute error:

1. Corrected any negative amperage values to 0 and zeroed out values below 72 amps as this inaccuracy is a known CT issue identified by TVA.
2. Updated formulas to omit periods of zero loading and null values, since a fraction cannot be evaluated with 0 in the denominator.
3. Updated the LineVision current values to conform to a pseudo-interval to match TVA's interval averaging data and LineVision's instantaneous readings.

This allowed for more accurate comparisons. As shown in the figure at right, results indicate a percent average absolute error of 2-6% and error rates consistent with those between TVA CTs on the same line.

Legend

LV = LineVision loading data

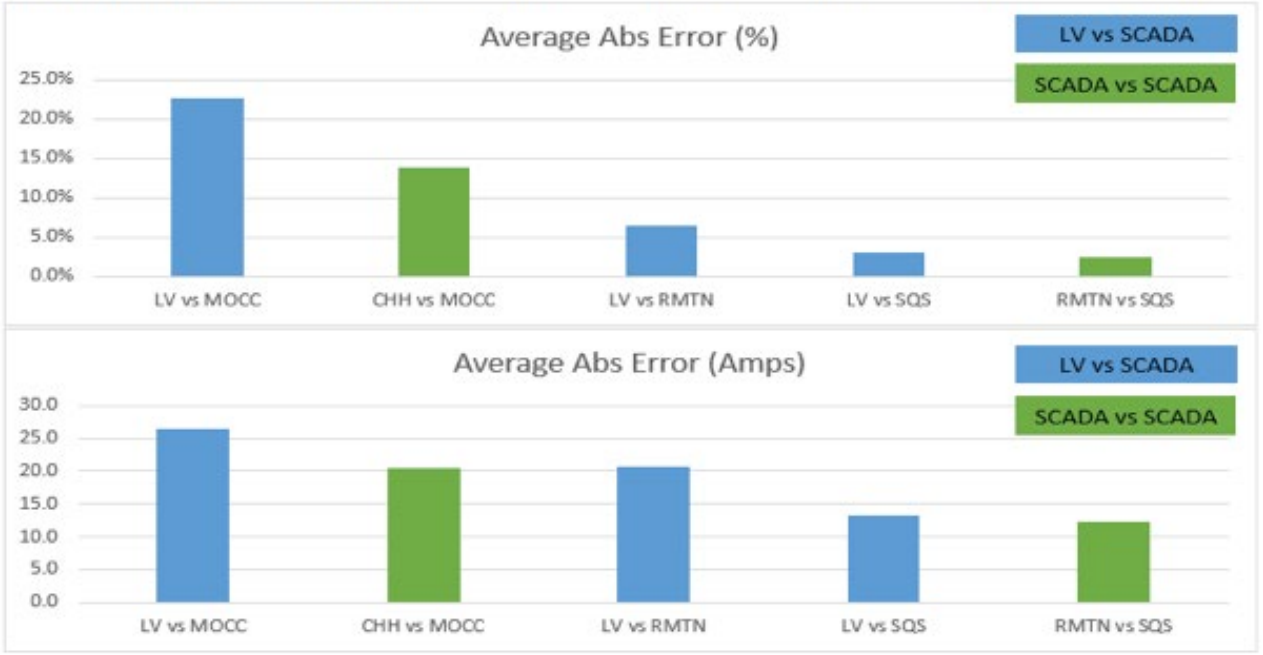
MOCC = Moccasin Substation CT loading data

CHH = Chickamauga Substation CT loading data

RMTN = Raccoon Mountain Substation CT loading data

SQS = Widows Creek Substation CT loading data

	Chickamauga		Raccoon	Widows Creek	
	LV vs MOCC	CHH vs MOCC	LV vs RMTN	LV vs SQS	RMTN vs SQS
% between -5% and 5%	24.0%	36.9%	68.5%	92.0%	97.7%
% Avg Abs Error	22.6%	13.8%	6.4%	3.1%	2.4%
Avg Abs Error (Amps)	26.6	20.4	20.8	13.2	12.4
% Avg Abs Error (>300 amps)	6.6%	6.3%	3.0%	2.1%	2.0%



LineVision assessment of line loading data errors

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