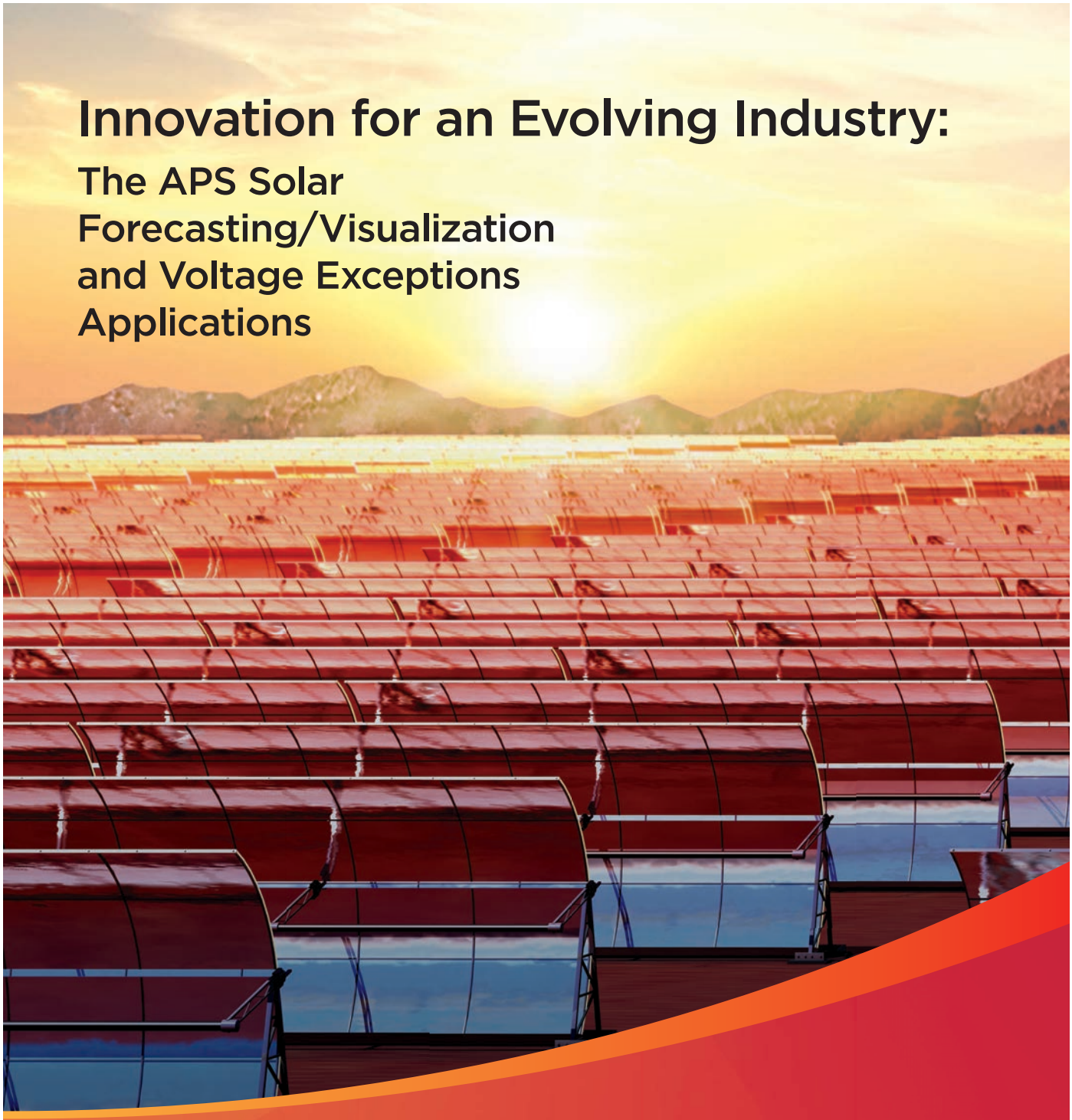
Innovation for an Evolving Industry:

The APS Solar Forecasting/Visualization and Voltage Exceptions Applications



2016 Edison Award Nomination
Arizona Public Service

aps®

EXECUTIVE SUMMARY

Arizona has one of the highest penetration rates of customer-sited solar generation in the western United States – penetration rates that will continue to increase as rooftop solar continues to grow in popularity. As the state's largest and longest serving electric company, APS is dedicated to providing safe and reliable service to our customers. In the face of the rapid growth of rooftop solar, the industry had not yet developed effective analysis and forecasting tools for evaluating the contribution and effects of distributed energy resources (DER) to the system. To uphold and advance our commitment to our customers—and in the process provide the industry with a valuable resource for managing the expanding impact of DER—APS was challenged to take the lead in developing new tools to efficiently manage this emerging energy source.

The dramatic growth of rooftop solar—which represents the majority of DER on our system—presents a variety of issues across multiple business functions. Among the operational issues was an inability to proactively manage voltage exceptions caused by behind-the-meter solar. With no existing systems capable of accurately measuring and reporting voltage exceptions, we also made a goal of developing a technological solution to a problem that was certain to become increasingly critical to the industry as DER continues to proliferate.

A highly developed foundation of two-way communication between APS and our customers' premises provides a powerful potential resource for addressing these challenges. Through a significant investment in technologies to update our distribution system, APS has become one of the first electric utilities to achieve a near-total adoption of advanced metering infrastructure (AMI) throughout our service territory. Leveraging the wealth of data provided by this high degree of AMI penetration would allow us to develop the innovative tools needed to analyze and forecast the impact of DER on our operations.

In 2015, APS launched our **Enterprise Analytics Initiative**. The initial focus of this initiative was the development of business intelligence tools that would integrate AMI data with Geographic Information System (GIS) locational tags, customer information and work-management data. A pair of innovative, first-of-their-kind applications were developed that successfully integrate advanced grid

data with other data resources to make valuable information easily accessible across multiple business units. Both applications were delivered on a single platform that presents data and analytical solutions visually, thereby rapidly focusing a user's attention on critical pieces of information which improves a wide range of processes.

The **Solar Forecasting/Visualization** application provides a system-wide geographic view of the DER generation contribution to overall energy delivery. This revolutionary application helps analyze and forecast how increased levels of solar penetration will affect the system, from one-way to two-way power flow.

The **Voltage Exceptions** application analyzes and maps all instances of meters recording energy delivered outside of a specified voltage range. This groundbreaking application promotes safety and reliability in the distribution network. Used in conjunction with the Solar Forecasting/Visualization

application, it provides a powerful tool for identifying potential voltage issues caused by rooftop solar.

Through increased efficiency across multiple business units, these two complementary and innovative applications are expected to deliver a combined annual benefit of **$4 million**. Additional cost savings are expected as further uses for these tools are developed and additional visualization and analytics are added.

The Solar Forecasting/Visualization and Voltage Exceptions tools employ innovative business intelligence algorithms to position APS at the industry's leading edge in fully exploring and capitalizing on the benefits of AMI. They also allow us to better accommodate our customers in making the choice to install rooftop solar, both safely and efficiently. And by providing a technological platform that encourages a proactive approach, these cross-functional applications increase efficiency and strengthen operational reliability to the ultimate benefit of all our customers. For an evolving electric industry, these tools represent a significant breakthrough in managing the ongoing growth of DER and their impact to the electrical grid.

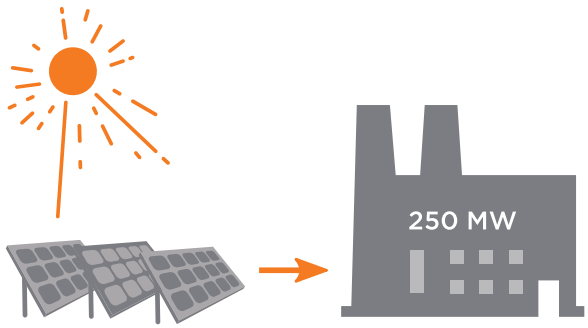
As the first applications of their kind, these tools provide a roadmap for the industry to address growing DER impact. They offer compelling evidence of the benefits of leveraging AMI data and can significantly accelerate the learning curve for other utilities to adopt solar forecasting quickly and efficiently. Through practical experience with these tools, we expect to develop unique operational best practices with DER integration for the industry's collective benefit.

$4 MILLION

Through increased efficiency across multiple business units, these two complementary and innovative applications are expected to deliver a combined annual benefit of $4 million.

THE CHALLENGE: KEEPING PACE WITH DER GROWTH

With 1.2 million customers spread out over 35,646 square-miles—the nation's sixth largest service territory—APS relentlessly works to maintain the highest levels of operational excellence. Included in our system are more than 40,000 solar interconnections, placing us in the top five among utilities nationwide for distributed solar. Those 40,000-plus solar meters represent 40,000-plus separate generation sources on the system.



40,000+ SOLAR SITE INSTALLATIONS

EQUIVALENT TO 250MW GENERATED POWER

The growing presence of DER has changed our grid and challenged us to adapt and develop new business practices. A traditional distribution system features one-way power flow from generation through the transmission system to customers at the end of the line, but now APS customers with DER are producing energy that is put back on the grid, increasing voltage and reversing power flows. This two-way power flow has necessitated a transition of voltage management from seasonal to dynamic and year-round. What were once no more than two dozen interconnection points with centralized power generation are now tens of thousands of interconnection points.

As technologies and usage patterns evolve, the distribution network must evolve along with them to maintain the expected quality of service, particularly in the face of DER growth. With limited capability to analyze and manage the generation of behind-the-meter solar, APS's distribution engineers were challenged with maintaining operational reliability in areas with high levels of DER. The lack of technology with the ability to capture timely solar data meant that correlating and studying data could take weeks.

Existing applications did not provide operational information that was either timely or easily focused on specific areas. Performing critical functions such as accurately measuring the total load on any given feeder was difficult due to an inability to calculate the amount of load being masked by DER. That meant APS essentially had no information about generation sources representing the equivalent of a 250 MW power plant on our system.

Not knowing the actual DER contribution at any given time also made it challenging to effectively manage operational issues that required switching feeders or picking up load from alternative sources. This lack of accurate data could cause reliability issues to multiply while posing the threat of potential damage to company or customer equipment.

The inability to determine the impact of DER on the grid was also highly problematic for our Marketing & Trading department. Accurate load forecasts are critical for the efficient trading of power and dispatching of generation resources. Behind-the-meter solar represents one of the biggest variables in load forecasting, and the lack of timely, accurate data also made it one of the most significant sources of forecast error, which can represent substantial financial liability in the power-trading process and the commitment of generation resources.

The lack of timely data also made it difficult to view trends and analyze voltage exceptions, which have the potential to increase in areas with a high degree of rooftop solar on a single feeder. Collecting information on voltage issues was virtually impossible until an interruption of service or a power quality issue was reported by a customer. The inability to perform suitable analysis of voltage exceptions caused by behind-the-meter solar prevented any possibility of effectively managing this problem.

Addressing these challenges would require APS to pioneer a solution in an industry that is just beginning to feel the impact of rooftop solar. Industry analysts expect a 300% increase in installed capacity across the global DER market, from 130 GW in 2015 to more than 500 GW in 2024. With DER having such a significant effect on many diverse facets of the company's operation, an ideal tool would have to be highly adaptable and cross-functional. The key to resolving these issues would be improving the quality and enhancing the availability of critical data.

The web browser-based analytics applications are accessible to every employee at APS to foster collaborative problem solving.

THE SOLUTION: VISUALIZING IMPACT

Industrywide we are challenged with reinforcing and upgrading our distribution networks to maintain high service levels and keep pace with rapidly growing DER. As part of its Grid Modernization Ops Vision 2025 plan, APS is investing in advanced grid technologies and the development of sophisticated data analytics to update our distribution system with a goal of enabling customer choice, improving efficiency and reinforcing reliability.

APS was an early adopter of AMI. Not only does AMI provide timely data-collection capabilities that legacy meters don't offer, it delivers the ability to capture more granular data, such as load values at hourly or even 15-minute intervals. It also measures quantities such as average voltage and reports voltage exceptions.

APS has also established an industry leadership position in the adoption of solar production meters. We have invested in equipping all of our rooftop solar customers with these advanced meters specifically to measure solar output. Solar production AMI meters build on the information provided by AMI billing meters with solar-specific data.

With nearly 100 percent AMI penetration in our service territory, and rapidly growing numbers

of solar production meters, APS has a unique resource to capture data for analysis. This wealth of data represents a powerful opportunity to improve our operational reliability and overall efficiency. The high penetration of AMI and DER facilitated the development and implementation of two innovative applications that would provide game-changing data integration and analytics through the mapping and visualization of grid-related operational deviations on APS infrastructure.

This revolutionary Solar Forecasting/ Visualization application helps analyze and forecast how increased levels of solar penetration will affect the system, from one-way to two-way power flow.

Used in conjunction with the Solar Forecasting/Visualization application, the Voltage Exceptions application provides a powerful tool for identifying potential voltage issues caused by rooftop solar.

Situational intelligence software created by geospatial analytics company Space-Time Insight provided a platform for creating the new tools. Systems integration solutions company BRIDGE Energy Group worked with APS subject-matter experts to design and develop applications that transform AMI data into visual analytics interfaces. Together, the two applications that were developed have effectively changed our operational approach to DER. The Solar Forecasting/Visualization application and the Voltage Exceptions application connect the mapping of company assets to load information and translate data into easily accessed visualizations.

The Solar Forecasting application provides visibility to the amount of generation being provided by residential solar. Operators are able to view impacts on feeders as well as view a forecast of the anticipated hourly solar contribution up to one week in advance.

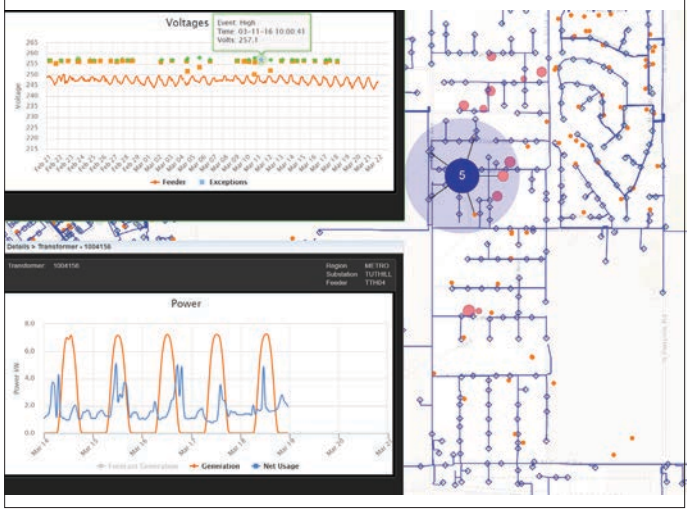
The Voltage Exceptions application enables the visualization of geographic areas impacted by high or low voltage and accumulates these findings, making it possible to view trends in voltage exceptions. It offers an additional layer of crucial information to the Solar Forecasting/Visualization application to better understand and manage overall DER impact.

These applications integrate disparate data sources, instantly visualizing data and making it available to employees across business units. Data formerly available only in a tabular format now is presented in a geospatial format that users can view on a map. Rather than requiring a team of data analysts to merge spreadsheets and databases, the new applications automatically aggregate and correlate data to enable users to make informed decisions and take action quickly and efficiently.

The new tools offer visualizations and reporting to support the proactive management of power quality issues, which assists planners in developing more expeditious response to and more effective maintenance plans for the distribution network. Both tools display data for the entire APS distribution network, including substations, transformers, feeders and meters.

The applications also work together to contribute to improved safety practices for operations employees. For example, APS troublemen in the field will have the ability to be aware of all generation sources, including behind-the-meter solar, while working on power lines.

Working Together



Used together in a single layered visualization, the applications can identify potential voltage issues caused by rooftop solar.

SOLAR FORECASTING/VISUALIZATION

The Solar Forecasting/Visualization application allows APS to monitor, analyze, project and manage the effects of increased amounts of distributed solar penetration on our distribution system. This application is driven by DER data supplied by all APS solar production meters, including residential rooftop meters, commercial building rooftop sites and rooftop sites in our Schools & Governments program.

An algorithm was developed by APS, in partnership with the University of Arizona, to leverage AMI data, historical weather data, historical solar production data and seven-day weather forecasts in order to calculate and forecast generation.

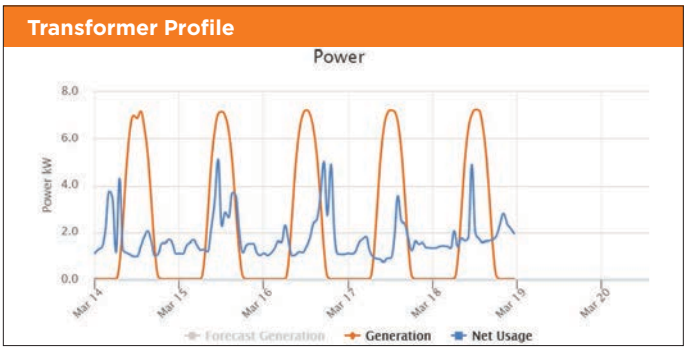
AMI data is used to graph hourly solar production, which allows us to assess the impact of distributed solar on various grid devices, such as substations, transformers and feeders. Dynamic graphs provide the ability to quickly summarize DER contribution to the total system load. Users can view data on a system-wide level or drill down to a specific customer site for resource planning, distribution engineering and customer service purposes.

The Solar Forecasting/Visualization application provides a geospatial view of all DER solar sites and a dynamic dashboard to display the total solar generation, load and solar forecast for each site. Regional aggregations of this data can be selected to provide a complete view of the distributed solar generation, load and distributed solar forecast at an appropriate level for market trading. The system delivers valuable, timely data that is used by cross-functional APS business units, including the following:

300%

Industry analysts expect a 300% increase in installed capacity across the global DER market, from 130 GW in 2015 to more than 500 GW in 2024.

Example of a neighborhood with a high density of solar installations.



Example of distributed solar generation aggregated at a transformer level. Graphs dynamically adjust as users select the data they want to view.

- **Distribution Planning & Engineering**—The application helps planning engineers determine the most economical and reliable way to configure the distribution network while providing continuous power within prescribed voltage limits.
- **Distribution Operations**—Having precise data regarding the solar production on a feeder exposes previously unseen loads and eliminates uncertainty in managing the total load on any given feeder. Access to this information is also critical during outage restoration, especially during cold-load pick-up scenarios when DER are not able to reconnect to the system after outages in time to respond to immediate customer loads.
- **Marketing & Trading**—More accurately forecasting rooftop solar improves resource planning and power trading decisions. Incorporating the solar generation forecast into planning and power-purchasing strategies maximizes the accuracy of load forecasts and minimizes costs for all APS customers.

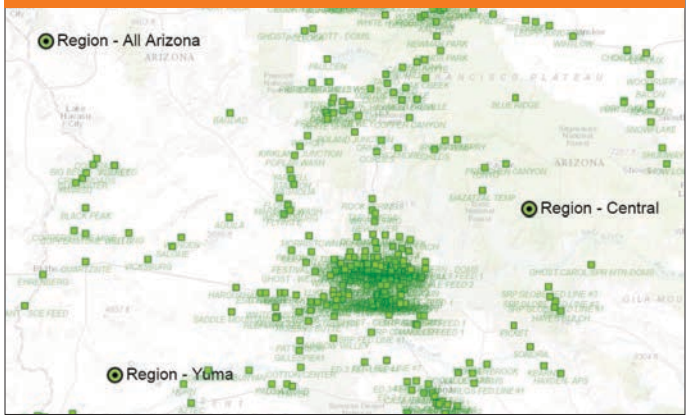
- **Solar Planning & Development**—Integrating rooftop solar generation data with commercial scale and APS-owned grid-scale solar data provides a single pane of visibility across all types of solar generation in our service territory.
- **Technology Assessment**—Analysis of the new APS Solar Partners Program is maximized by integrating data from advanced inverters utilized by the program and layering it with existing rooftop solar generation data.

A weather forecasting methodology employed by the application was developed in a unique partnership with the University of Arizona, which maintains weather stations statewide that provide granular weather data, particularly global horizontal irradiance data that is relevant to solar production. Each day, new weather forecast information is used to update the solar forecast. Solar forecasting algorithms also are updated as solar forecasts using weather actuals are compared to actual DER generation.

Weather changes can have sudden, significant impact on loads, especially during Arizona's summer monsoon season. Having access to accurate weather data and forecasts has allowed our Marketing & Trading department to be more agile and proactive in dealing with rapidly changing conditions. The weather forecast provided through the University of Arizona partnership is based in part on satellite data and incorporates solar irradiance factors, including airborne particulates such as dust, smog and ozone.

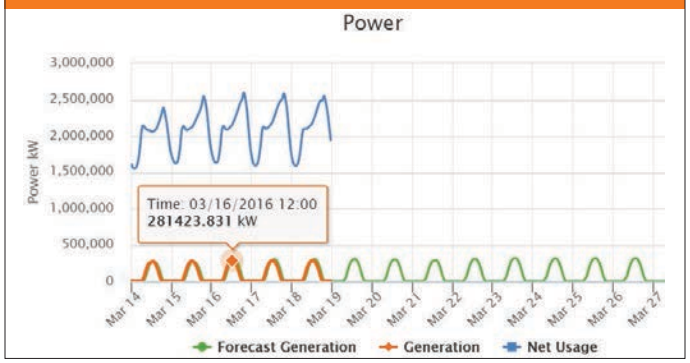
High-value data on the impact of solar generation on the grid supports accuracy in load forecasting. The Solar Forecasting/Visualization application helps Marketing & Trading generate cost-savings through greater efficiency in the ability to manage

Energy Regions



A system-wide map displays regional aggregations of DER generation/ net usage as well as substation locations.

Solar Forecast



Hourly forecasted DER generation can be viewed in the graph to help develop more accurate resource and power plans.

our generation fleet and manage market trading opportunities. Rather than having to estimate the amount of DER on our system, they are now able to develop more accurate resource and power plans based on precise AMI data including solar contributions for any given hour. This data also gives them the ability to more effectively plan for the amount of traditional generation ramp and the rate of that ramp as solar comes and goes on the system.

The Distribution Planning & Engineering department previously was unable to determine the impact rooftop solar was having on feeder peak loads at certain times of day. This made it difficult to ensure that adequate equipment was allocated to handle peak loads. As a consequence, an operational choice might have to be made to either shut off some load during peak hours to protect equipment or overload

40,000

Included in our system are more than 40,000 solar interconnections, placing us in the top five among utilities nationwide for distributed solar.

equipment to avoid outages. The Solar Forecasting/Visualization application gives the group the ability to determine peak loads both with and without solar contribution, which is critical in designing the distribution system to handle peak loads without exposing equipment to damage. This helps users forecast long-term system needs to determine if any capital improvement projects to the infrastructure will be required to accommodate continued load growth or growth of rooftop solar in the coming years.

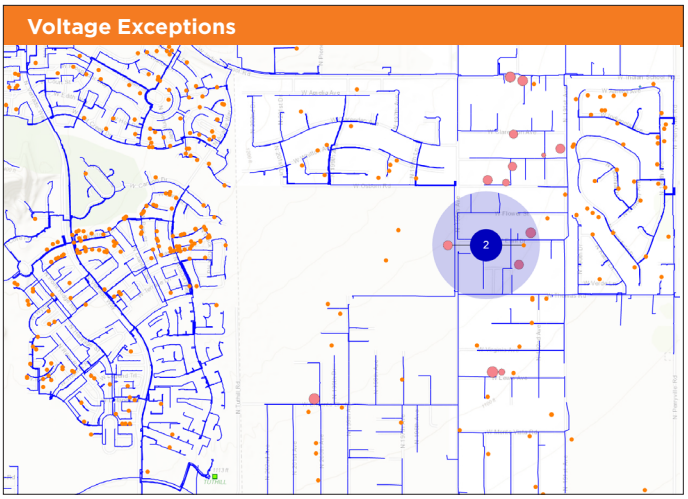
Having the ability to view and analyze behind-the-meter solar gives APS an expanded capacity for hosting additional DER as penetration levels continue to grow. In addition to reducing operating costs, the Solar Forecasting/Visualization application supports employee efficiency by supplying the information needed to make timely, informed decisions. Rooftop solar installations are readily identifiable which makes it easier for distribution planning and engineering to conduct solar saturation studies. Increased efficiency in the way we generate power translates into cost savings for our customers. Access to accurate records of actual DER generation, weather details and load data adds value to a wide range of functions, including training, research and business process improvement.

The development of this tool provides the electric industry with a potent resource for managing the ever-increasing impact of DER. Even in its early stages of deployment, the application is attracting substantial interest from other leading utilities that are anxious to get ahead of the DER curve. We are also working with our product partners to make the technology available throughout the industry so other utilities can efficiently apply solar-forecasting to their operations. APS has hosted other Association of Edison Illuminating Companies (AEIC) utility members to share best practices from our investments in solar production meters and the Solar Forecasting/Visualization application.

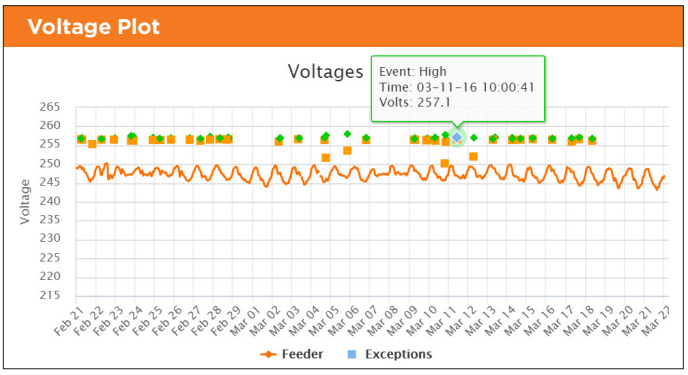
VOLTAGE EXCEPTIONS

With legacy meters, dealing with voltage exceptions was strictly a reactive process driven primarily by service disruptions and customer reports of power quality issues. The near-total penetration of AMI that APS has achieved provides us with the ability to accurately measure and report average voltage and exceptions outside ANSI standards. By leveraging the AMI platform, the Voltage Exceptions application allows us to uncover power quality issues in a more timely fashion and helps our planners evolve and maintain the distribution network more effectively.

The Voltage Exceptions application generates a visual representation of the amount of high or low voltage events beyond acceptable range at the meter. This assists planning engineers in providing the most economical and reliable way to configure the distribution network or implement needed system upgrades in order to deliver continuous power within



Using metadata, the user can view the locations of all meters reporting voltage exceptions. Example of star burst selection option also shown.



Graph of feeder voltage and meter voltage exceptions for the last 30 days. Users can hover over the exceptions to view event data details.

prescribed voltage limits based on the ANSI C84.1 standard. Combined with the Solar Forecasting/ Visualization application, it effectively identifies potential voltage issues caused by rooftop solar. The geographical visualizations depicting AMI reports of energy delivered outside of prescribed voltage limits enable engineers, operations personnel, customer service personnel and field service technicians to proactively diagnose issues before they adversely affect service to our customers.

- The Voltage Exceptions application delivers several beneficial features, including: Visualization of meters reporting significant voltage extremes and/or voltage exception alarms
- A dynamic graph of the voltage, exception alarms and time-stamps recorded by the meter for the past month
- User ability to add the Solar Forecasting/ Visualization functionality as a layer in order to visualize any voltage issues specifically associated with DER

Easy access to pertinent data supports fast and accurate analytics. Working in tandem, both applications help Distribution Operations adopt a proactive approach to voltage management by evaluating data for individual feeders, determining DER contribution and identifying trends in voltage exceptions and other operating conditions. This allows for mitigation strategies to be developed prior to issues occurring that might impact customers. Rather than having to rely on models or proxies to evaluate the impact on company assets, users can access specific loading information in order to properly size distribution assets.

Through practical experience with these tools, we expect to develop unique operational best practices with DER integration for the industry's collective benefit.

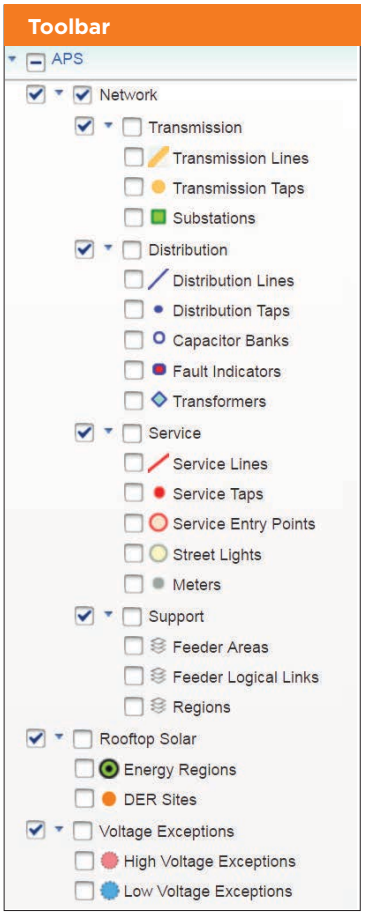
The Voltage Exceptions application has significantly reinforced our ability to enhance safety and reliability as well as protect company assets and our customers' equipment. It expands the effectiveness of the Solar Forecasting/Visualizing application and provides the electric industry with another state-of-the-art solution to the challenges posed by DER growth.

HOW THE APPLICATIONS WORK

Both the Solar Forecasting/Visualization application and the Voltage Exceptions application were developed with a layered paradigm and dynamic dashboards. From their workstations, users can view visualizations of relevant data in a graphical, geographically-related format.

WHEN A USER SELECTS A VISUALIZATION:

- The items identified in that visualization are displayed on the map
- Any visualization can be displayed as an independent, stand-alone layer
- Any layer can be displayed simultaneously with any other visualization in multiple layers, to make the effect cumulative
- Users can display and hide layers of any visualization as needed, making the experience of working with large data sets seamless and simple
- Users can easily zoom in or zoom out to increase or decrease the granularity of data as desired



Toolbar for selecting information to display in visualization.

Users can select various types of information for viewing in a graphic, geographically-related format. Data can be displayed either individually or in map/data layers that allow users to compare data points from different layers. All layers may be selected for view at any given time. Layers include the following:

- Transmission lines
- Distribution lines and equipment
- Service meters
- Rooftop solar sites
- Voltage exceptions

Users can view data for specific facilities, dates or times, including forecast generation, actual generation and net usage. A dynamic dashboard can be accessed to view detailed information about any displayed facility or be configured to display summary/area data. Visualizations are available for the following information:

- Geographical locations of DER, meters, substations, feeders and transformers on the grid. Users can pan, zoom in or zoom out on any asset displayed on the map.
- Usage and generation forecast for each solar installation along with 24-hour and seven-day forecasts
- Solar production meters and their usage for selected feeders
- Solar production forecast for selected feeders
- The service network between transformers and meters
- All transformers and voltage control devices (where data is available) for selected feeders
- Advanced meters (billing and production) for selected feeders
- Aggregated usage and generation values from advanced meters, with roll-ups for connected transformers, feeders, substations and regions
- Primary and secondary distribution networks for selected feeders
- Load along each element of the grid, including estimates of the DER contribution to energy supply
- Special icons can be configured to display sizes relative to the frequency of an event

MOVING FORWARD

The Solar Forecasting/Visualization and Voltage Exceptions analytics applications have quickly made a positive impact for APS. These groundbreaking tools are on track to yield more than $4 million in combined benefits in their first full year of use.

Based on the success of these applications, APS has created an analytics development roadmap to further expand our analytical capabilities by incorporating user input.

The Solar Forecasting/Visualization application will be further enhanced to provide a deeper level of analysis of DER data. The application can be expanded to accommodate additional types of DER, including microgrids, advanced inverters and battery storage. New users are steadily being added, and new functions are being developed to further analyze DER. Also under consideration are other potential uses for the application, including providing customers with visualizations to help them better manage their rooftop solar installations.

The next phase of analytics development includes the creation of two more applications using the same situational intelligence software that was used to develop the Solar Forecasting/Visualization and Voltage Exceptions tools. A new Asset Intelligence application will help identify risk and predict failures in assets. This system will allow personnel to evaluate the maintenance requirements and operational history of equipment, as well as compare it to similar assets. This process of weighing all variables and calculating risk will support the development of a capital plan for replacing identified assets.

Also under development is an Outage Intelligence application. This application will leverage AMI and work with an outage management system to identify undetected outages and project potential outages before they occur. It will be integrated with the Solar Forecasting/Visualization and Voltage Exceptions applications to provide users with an additional layer of critical information.

The success of these initiatives has positioned APS as a leader in creating technological solutions that leverage AMI and DER data analytics. They are just the first step in exploring and capitalizing on the vast opportunities for industry progress represented by these emerging technologies. By making this technology and our experience available to other utilities, we hope to encourage similar success across the industry in addressing the growing impact of DER—all with an ultimate goal of improving our collective ability to deliver safe, reliable service to consumers.

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