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Digital Twin Technology for Rural Electric Cooperatives

A Guide For 3D Reality Capture, Data Integration & Visualization

This report is a joint publication by the National Rural Electric Cooperative Association, Jo-Carroll Energy, and DMI.

If you are interested in participating in any emerging technology projects, for additional information, or to schedule a demo, please contact:

Adaora Ifebigh
Program Director, Energy Access
Business and Technology Strategies
NRECA
Adaora.Ifebigh@nreca.coop
703.907.5849

Jesse Shekleton
Director of Engineering
Jo-Carroll Energy, Inc (NFP)
jshekleton@jocarroll.com
800.858.5522

Nathan Greiner
President, Co-Founder, CTO
DMI, LLC
nathan@precisionreality.com
563.587.8778

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Overview

Rural Electric Cooperatives (RECs) are faced with large amounts of data which are not easily accessible, aggregated, secure, or visually optimized for key stakeholders when they need it most. Using digital twin technology on a centralized, single-source platform provides a visualization ecosystem for co-ops to aggregate, manage and display data from disparate systems via multiple visualization methods including desktop, virtual reality (VR), and augmented reality (AR). (Read an intro to AR/VR technology on the NRECA website here: An Overview of AR/VR Technology and Co-op Case Studies.)

Working together, Jo-Carroll Energy (JCE) and DMI are streamlining procedures and developing best practices within DMI's proprietary platform, Precision Reality™ to showcase digital twin technology to NRECA members. Precision Reality™ is a digital twin platform connecting data and visualization solutions to deliver actionable insights in real-time. RECs can use the information captured in this platform for activities such as: virtual visits to sub-stations, outage response and technical support, document management, member engagement, etc.

Creating a digital twin of a REC's network and assets uses a multi-tiered approach with built-in flexibility to ingest multiple data formats, give the data a contextual visual framework, and make it accessible via several application channels. Each part of the ecosystem delivers benefits on its own, but the convergence creates a robust system to improve safety, productivity and efficiency. See Figure 1 below.

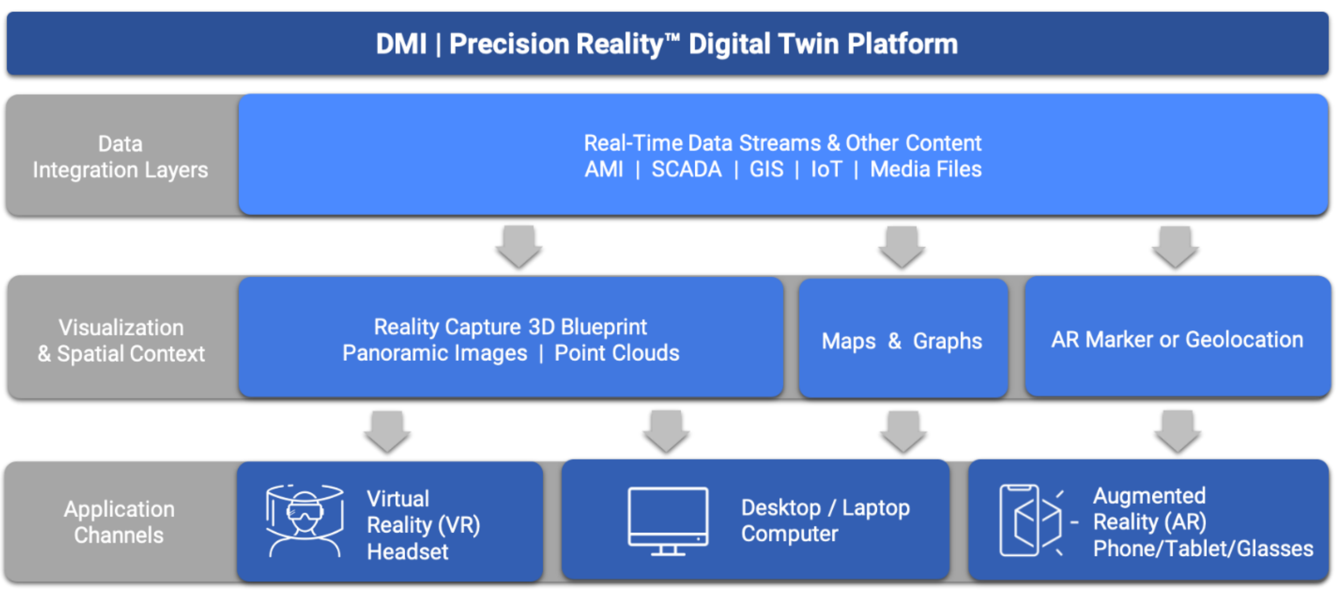

Figure 1: Precision Reality™ Digital Twin Platform Ecosystem (Image courtesy of DMI)

1: Reality Capture

Jo Carroll and DMI began this project with a focus on 3D Visualization and Spatial Context. Using a technology process called Reality Capture, a laser scanner was used to capture major network hubs including substations and create digital 3D blueprints of those environments which can be viewed remotely from a computer or with a virtual reality headset.

Reality capture is the foundation for creating a digital twin (see Figure 2); it begins with building a visual framework to give spatial context to data. These visualizations, even used alone without additional layered data, are extremely impactful and valuable for RECs. Being able to remotely access 3D imagery of each substation from a safe and secure location provides a spectrum of benefits (bonus: increased productivity on rainy days!). A few of these benefits range from simply increasing understanding in collaborative projects to design and planning support to operational and situational awareness for safety training. Below is an overview of the Reality Capture/laser scanning process.

Figure 2: Reality Capture Operation at a Substation
(Image courtesy of DMI)

Equipment

Laser scanning equipment can be purchased or rented from many companies, including DMI. Renting is a cost-effective option for RECs who are just getting started with pilot projects but purchasing may be more cost-effective long term or for multiple, larger projects. Whether renting or purchasing, equipment should include a LiDAR (Light Detection and Ranging) scanner capable of scanning and capturing panoramic images both indoors and outdoors, an adjustable height fiberglass tripod (non-conducting material to mitigate risk in high voltage environments), a compatible tablet if using an app to trigger or manage the scanning operations, and all adapters, batteries, and cables as needed. For this project, a Leica Geosystems BLK360 terrestrial scanner was used. With this scanner, each scan took approximately 3-5 minutes requiring ±15 scans at small substations around 3,000 square feet and upwards of 70 scans at substations closer to 30,000 square feet. Important technical specifications to take into account when choosing a laser scanner are range and precision. The BLK360 has an accuracy of 6mm at 10m distance with a maximum range of 60m which fell within the parameters required for this project. As laser scanning technology evolves at a rapid rate, we are continuing to test and implement new hardware and methods with better capture fidelity, faster capture time, and more integration capabilities.

Services

For-hire laser scanning services can include the actual scanning operation, post processing of the scan data, and creation of all other value-added downstream deliverables such as 2D drawings and 3D models. Due to the dangers associated with substation environments, RECs may choose to conduct the scanning capture operations themselves with trained employees to mitigate risk. If

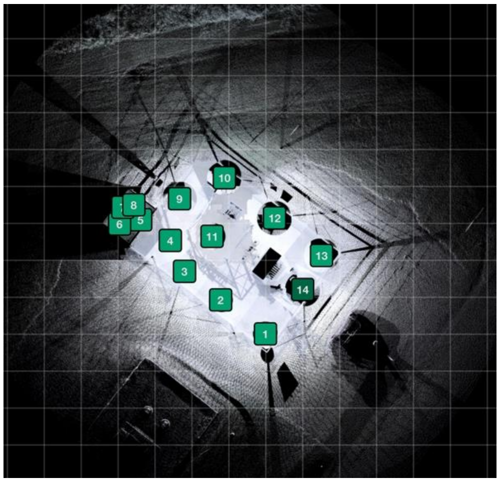

Figure 3: Reality Capture Mobile App Scan Map Interface
(Image courtesy of DMI)

hiring an outside service, it is important to conduct training and review safety measures for all those who are on site at the substation. Post-processing and value-added deliverables both require special software to work with the scan data. While a REC can purchase software and train someone internally, it is usually more time and cost-effective to contract with an outside service for these processes. For this project, DMI and JCE worked together to scan the first couple substations until JCE was familiar enough with the operations to continue scanning their remaining substations by themselves. DMI performed all the post-processing and downstream deliverables on the scan data. See Figure 3.

Setup & Operation

This section includes an overview of the reality capture setup and operation for informational purposes. Before beginning an actual scanning project, collect and review the detailed information and training documentation provided by the laser scanning retailer, rental company, or service provider.

Before scanning, always alert any management, gatekeepers, employees, and/or people at the scan site about the project in order to obtain necessary approval and access to the site, as well as request limited interruption during operation. It is critical to ensure familiarity with any onsite security, alarms and safety procedures. Work to limit environmental movement including people and objects as much as possible; the scanner uses overlapping data to connect scans together, so less movement equals more overlap and a better chance of successful alignment of the scans. All control building doors should be opened, and lights turned on for the duration of the scan session to help move quickly from scan to scan and improve the probability of successful scan alignment.

Most scanners allow a scan to be triggered with a manual on-device push-button or by using a mobile app to control the process. The scan will begin with a rotation to gather luminosity data, then additional rotations to capture panoramic imagery and measurement data. The scanner will indicate when each scan is complete and ready to be moved to the next scan location. Scanning continues with each subsequent scan located within line-of-sight and a short distance from at least one previous scan. We recommend a distance of no more than 20 feet in open areas and shorter distances in closed spaces. Take care not to disrupt or touch the interior scanning components on the scanner. Smudges, scratches, or debris on the lenses will render the scans unusable. Scan data will remain on the device until exported for processing.

Post-Processing

When scanning is complete, the raw scan data is uploaded to a computer from the laser scanning device. A process called "registration" is then used to stitch all of the individual scans together into one single piece. This single piece is the initial output called a "point cloud." The name comes from the scanning process which collects millions of data points using a method to measure distance by illuminating a solid object with the emitted laser and recording the time it takes to reflect back. Those points are then colorized with the photo imagery providing a realistic 3D image with true dimensions. DMI used a software called Leica Cyclone Register 360 to post-process the scan data from this project, a compatible software suite to the Leica BLK360 laser scanner. Different software may be required depending on type of laser scanner or capture process used.

Final Output

Once the post-processing is complete, the scanned site can be viewed in its entirety in multiple formats including as online embedded viewers in the Precision Reality™ software. It can also be processed further into 2D site plans, 3D models, and virtual reality experiences. See Figure 4. The data from the scanned spaces is stored in perpetuity within the Precision Reality™ software using a SaaS (Software-as-a-Service) subscription-based model (contact DMI for current pricing). New site scan sets can be taken as a whole, or existing scan sets amended if remodels occur or new equipment is added at a substation. To learn more about how Jo Carroll is using reality capture to power virtual reality applications, read the case study: Case Study: Bringing Substations into the Office with Virtual Reality.

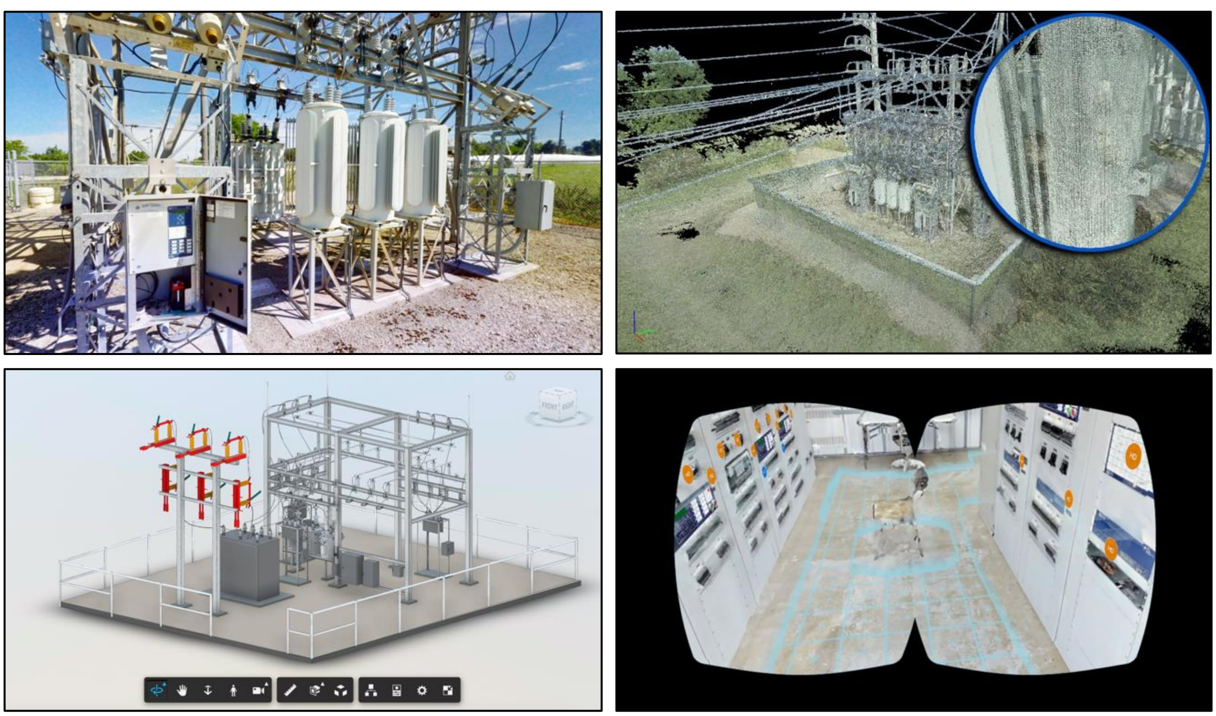

Figure 4: Reality Capture Outputs: 360 Panoramic Images, Point Cloud, 3D Model, and VR Simulation
(Image courtesy of DMI)

Cost, Impact, & Return on Investment

An Enterprise Impact Matrix was developed that showcases the various deliverable use cases throughout the cooperative departments. Safety, Training, Operations, Engineering, and Public Relations were identified as key areas in which the scan data deliverables will have the most initial impact. Within these departments, types of impact were identified as virtual visits, outage response, documentation, member engagement, and other downstream applications. Virtual visits are the easiest way to garner an initial return on investment as demonstrated by planning for substation updates within engineering and operations. The reality capture data was utilized on a virtual meeting, saving travel time for all parties involved. This will be especially useful for those who have a large distribution network. The data was also converted into a virtual reality view, so that training programs can be revitalized, making substation visits available during inclement weather when crews are not able to travel. Outage response and tech support has also been impacted, allowing the linemen to gain "muscle memory" through familiarity with the substation, enabling them to better prepare for any onsite procedures. The virtual environment is also being used by supervisors to talk through issues with linemen who are physically at the substation, creating a visual remote assistant capability for a more experienced lineman to work with field personnel. In the documentation, the scan data is used to develop a 3D model and subsequently attach all relevant documentation to the virtual assets in the data viewer. This allows for more accurate as-builts and a management system that pairs pertinent documents to the assets. Knowing that RECs value member engagement, organizational public relations teams can use the scan data on the desktop or in VR to provide a safe way to educate members about the substation in the distribution network. Other applications have been added to integrate operational programs like ESRI mapping and programs to use the scan as a visual framework for augmented reality operational applications. See Table 1.

Table 1: Reality Capture Enterprise Impact (Various Uses in REC)

	Site Virtual Reality Visit (Familiarity with Equipment, Asset ID, Crew Competency	Outage Response & Tech Support	Document Management (CAD Design, As-Built)	Member Engagement	Other Application Integrations
Safety	x	x		x	
Training	x				x
Operations	x	x			x
Engineering		x	x		x
Public Relations/Comms				x	

For this project phase, twenty substations were scanned, and metrics were captured to include the time associated with each step in the reality capture process. The process of scanning itself is typically a few hours per substation and while the laser scanner does capture images and points, we found that images that are created do not have a high enough resolution to read small text contained in wire names on the back of relay switches in a control house. Therefore, we recommend as a best practice to scan and also take high resolution photos with a camera of those name plates. The photos can then be attached to the scan data during post processing in the exact location within the virtual substation in which the image appears. Considering the multiple processes and cost variables, the cost for a typical project is generally three to seven thousand dollars per substation.[1] See Table 2. A REC may choose to capture their entire portfolio of substations over several years or in a condensed time frame. To minimize cost, a phased approach can be undertaken in which substations are laser scanned and converted to 3D models later or not at all, if not needed. While the use cases continue to grow, this study has determined that **the return on investment for a single substation scan can be achieved in just one meeting where travel is eliminated, and design features are directly in front of all stakeholders**. Therefore, when applied to the entire network of substations, the payback is immediate once the stakeholders engage in this new method of collaboration. Please note that any expansions or major changes would require rescanning to update the virtual model.

Table 2: Typical Cost of Substation Scanning

Substation Size	Approx. Substation Specs	Scanning Hours	Scanner Rental Cost ($3,000/Wk) *Assumes Multiple Subs Scanned Per Week*	Point Cloud Post-Processing Hours	Point Cloud Post-Processing Cost (@ $150/Hr)	Geotagging Post-Processing Hours	Geotagging Post-Processing Cost (@ $150/Hr)	3D Modeling Post-Processing Hours	3D Modeling Post-Processing Cost (@ $150/Hr)	Total Scan & Post-Processing Costs	Ongoing Monthly Hosting Cost Per Substation
Small	1 Input / 1 Feeder Exit	2	$300	2	$300	2	$300	16	$2,400	$3,300	$50
Large	2 Input / 2-4 Feeder Exits	4	$600	4	$600	4	$600	32	$4,800	$6,600	$50

Jo-Carroll and DMI continue to test with new methods and scanners to get the best workflow established for the application. The initial scanning method was with terrestrial scanners (BLK360), but recently used a mobile scanner (BLK2GO) that allows the ability to walk around or use a bucket truck to capture all aspects of the substation structure at multiple elevations. Next, plans are underway to test a persistent laser scanner (BLK247) that is installed permanently on the substation structure. This laser scanner allows for constant monitoring and change detection at the substation. This new technology will begin testing in early 2021.

[1] Please note that other variables may apply and final costs could be specific to each cooperative's needs.

2: Data Integration Layers

Another component in the Precision Reality™ digital twin development is Data Integration. In this step, data layers were identified and integrated directly into the desktop software via maps, graphs, and live data streams. Data can also be geo-located and integrated into augmented reality applications. Continued development is planned for AR; early experiences have been positive and additional feedback is being obtained to optimize the geolocation features and data integration.

In addition, data can be layered into the reality capture 3D blueprints. Integrating data streams provides a safe and secure virtual environment to remotely monitor and protect critical systems, automate compliance, and make decisions from a desktop in real-time. It also allows users to respond to issues immediately, increasing operational uptime and productivity. Analysis of usage data over time can be used to implement cost-savings activity-based maintenance.

The architecture diagram below shows the basis for flexible downstream consumption of all data. The internal data (SCADA, AMI, GIS) all flow into a secure SQL database that is integrated into the downstream apps. Data consumption is expected to continue to grow as decision makers and stakeholders discover the benefits of the system data and expanding use case applications.

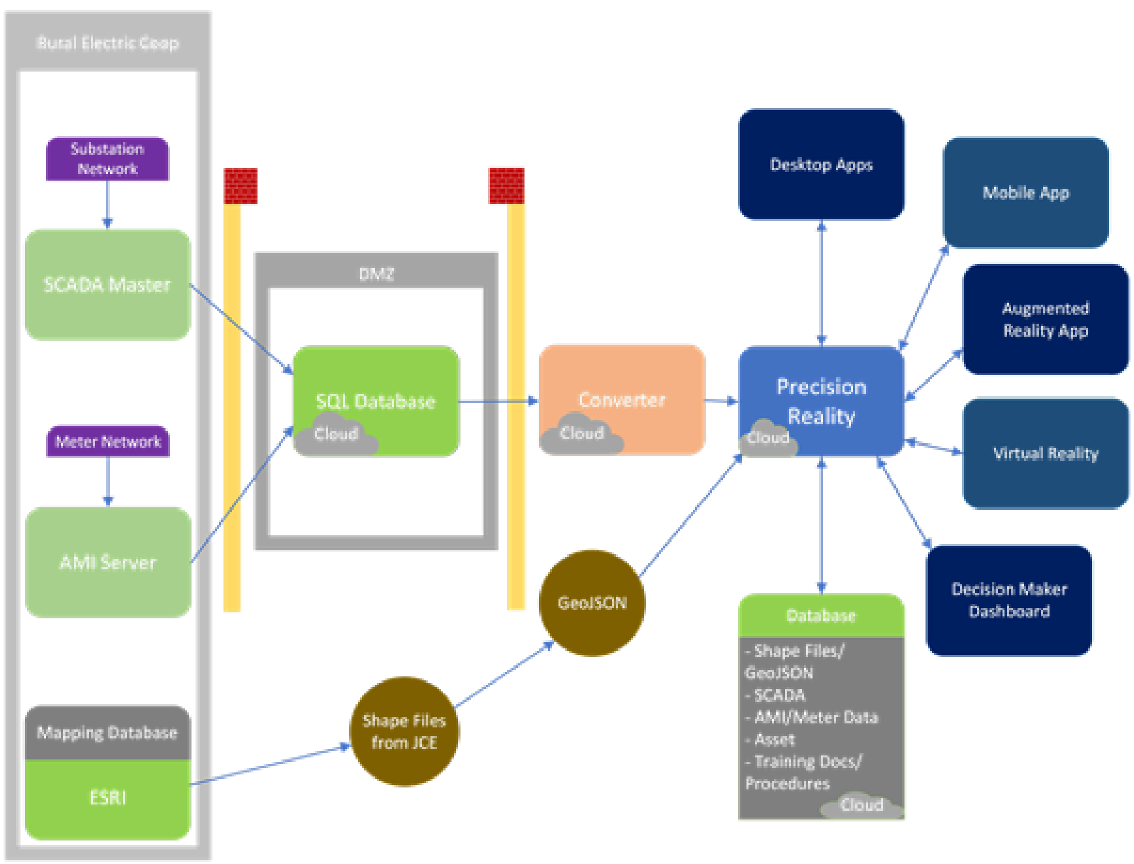

Figure 5: Data Integration Architecture Diagram (Image courtesy of DMI)

SCADA Data Integration

The initial objective with SCADA data was to integrate substation data that is only available with security credentials. Pertinent data fields were identified and integrated for AR/VR applications which include items similar to the following chart: (flat file).

Table 3: SCADA Data Fields Identified for Integration (Courtesy of Jo-Carroll Energy)

	Real Power	Reactive Power	Phase A Current	Phase B Current	Phase C Current
Time	**Men1_2001,P**	**Men1_2001,Q**	**Men1_2001,IA**	**Men1_2001,IB**	**Men1_2001,IC**
10/31/2019 15:30	637.1	1.21	25.82	34.39	23.47
10/31/2019 15:25	670.09	7.61	27.08	34	26.94
10/31/2019 15:20	650.48	1.87	24.34	34.78	26.37
10/31/2019 15:15	636.62	0	24.56	37.71	21.39
10/31/2019 15:10	646.85	3.84	27.41	32.68	24.76
10/31/2019 15:05	633.22	0	23.28	36.37	23.55
10/31/2019 15:00	652.32	19.28	26.02	36.33	23.36
10/31/2019 14:55	634.15	13.52	27.29	33.38	22.49
10/31/2019 14:50	628.22	15.62	26.68	32.73	23.12
10/31/2019 14:45	558.08	0	22.02	30.03	21.28
10/31/2019 14:40	584.83	0	20.99	32.03	23.72

This SCADA data replication must first be made visible for cloud delivery and downstream app consumption (JCE uses Survalent SCADA software). To start, an SQL database was replicated that made the substation data available to various apps. See Figure 6. Streamlining the development, JCE leveraged an existing SQL Dataweb infrastructure that encompassed security and sharing for third parties of the existing SQL database.

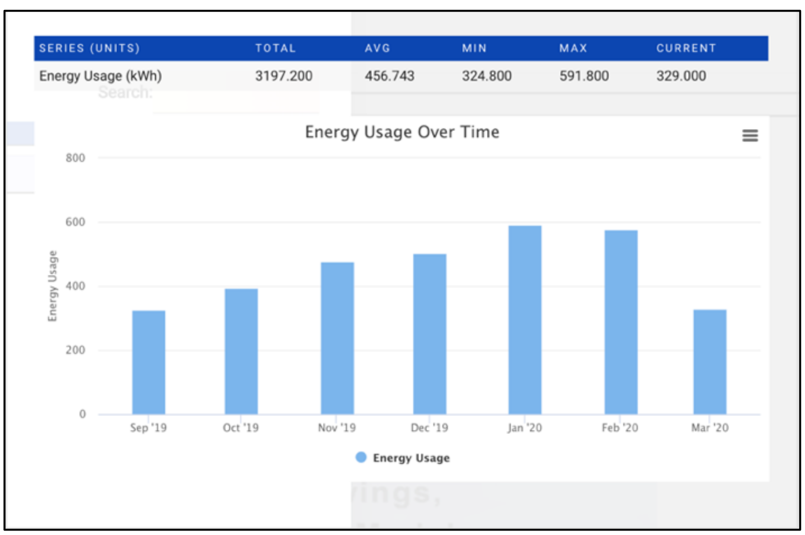

Figure 6: Meter Data Integrated into Precision Reality™
(Image courtesy of DMI)

AMI Meter Data Integration

To include the REC members in the development of AR and VR as well, as prepare for future enhancements, the AMI meter data was also integrated in this project. First, the pertinent data fields were identified, which included meter number, member number, data and energy usage. As JCE already has a security layer to pass their meter data from their network server over to their billing system nightly, essentially the system was already in place and working. Leveraging existing billing file structure, flat file forwarding was utilized at scheduled intervals to the cloud endpoint. This allowed the meter data to be replicated for cloud delivery and future downstream app consumption. See Figure 7.

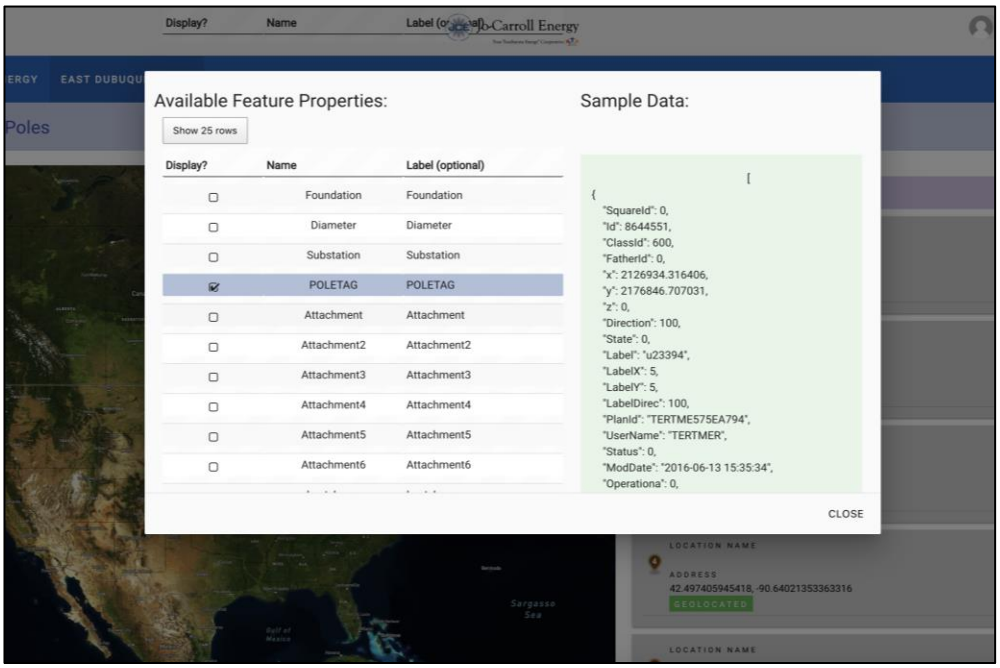

Figure 7: GIS Attribute Selection to Display in Precision Reality™
(Image courtesy of DMI)

GIS Data Integration

To integrate GIS data, each data set was queried from the current GIS application (OCRs, poles, 3 phase cutout fuse locations, etc.) and a shapefile was selected for export. For conductors, the data was organized by class such as 3 phase OH, 3 phase UG, 1 phase OH, and 1 phase UG. Currently, the GIS data format ingestible by Precision Reality™ is GeoJSON. The data may need to be organized into grouped sections to ensure the ingestion process is successful.

The next step was to convert the exported shape files into GeoJSON. To do this, all shape files/folders were unzipped and organized so that a set of files consisting of only DBF, PRJ, SHP, and SHX remained. Those files were then rezipped and uploaded to a file converter; (MyGeodata Converter was used in this project). While there are other conversion tools available, it was important to make sure that the data is converted to a GeoJSON format with World Coordinate System set to WGS 84 to ensure continuity with the platform's settings. Once the file was converted and downloaded, it was uploaded into the Precision Reality™ platform where the user could choose which asset features and attributes to display; an option toolset which is editable at any time in the future. See Figure 8.

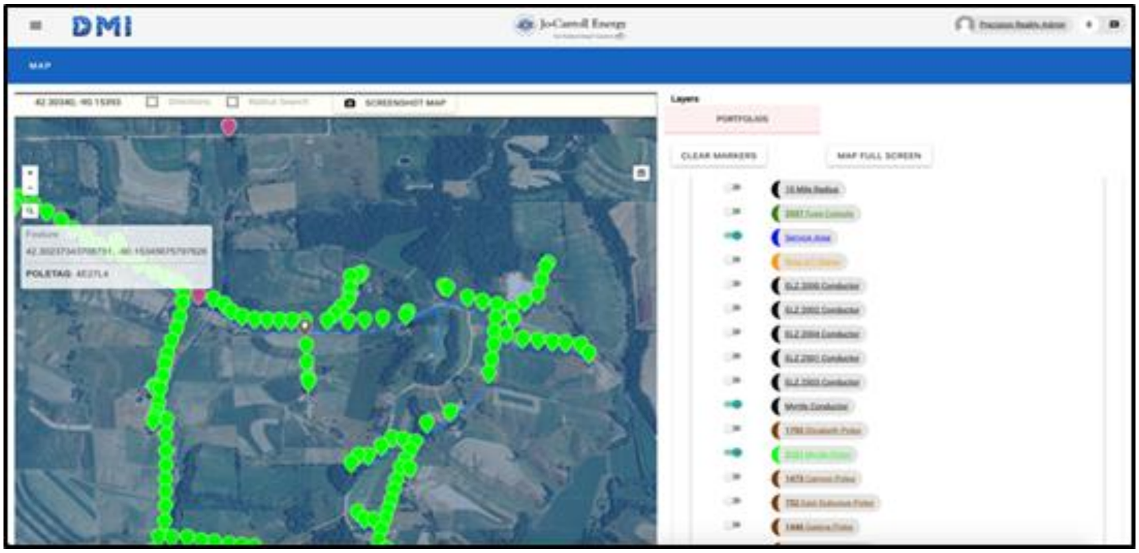

Figure 8: GIS Data Integrated into Precision Reality™
(Image courtesy of DMI)

3: Future Development Roadmap

With most of Jo Carroll's substations scanned, future development will focus on additional data integration layers. As development continues and data is transferred to the Precision Reality™ platform, future plans are to deploy IoT infrastructure and integrate the collected data similar to other data layers. In the next phase, there will be a focus on REC lineperson and technician feedback for continued development and iteration.

IoT Integration

DMI and JCE are piloting network infrastructure and sensor technology to automate the collection of data for asset condition monitoring, usage-based maintenance, and asset tracking initiatives. The platform is uniquely designed to work with any sensor type to ensure there are no limits on integrating the best solution from the growing utility IoT ecosystem. JCE is currently piloting fuse cutout monitoring devices, recloser counter devices, transformer temperature monitoring devices, fault detection devices, pole tilt monitoring devices, and asset tracking devices.

NRECA Member Content Library

After collecting and visualizing large amounts of data, it became clear that a centralized and searchable cloud repository, accessible by all NRECA members, would be immensely useful. Plans are in place to define an architecture for such a library, thoroughly test, and deploy to members for on-demand access to shared content and databases to house reality capture 3D models, AR and VR apps (see Figure 9), and various media and procedural materials for training, engineering, and visualization applications. The project is looking for other distribution utilities to partner with to develop more library assets. If you are interested in getting involved, please contact NRECA.

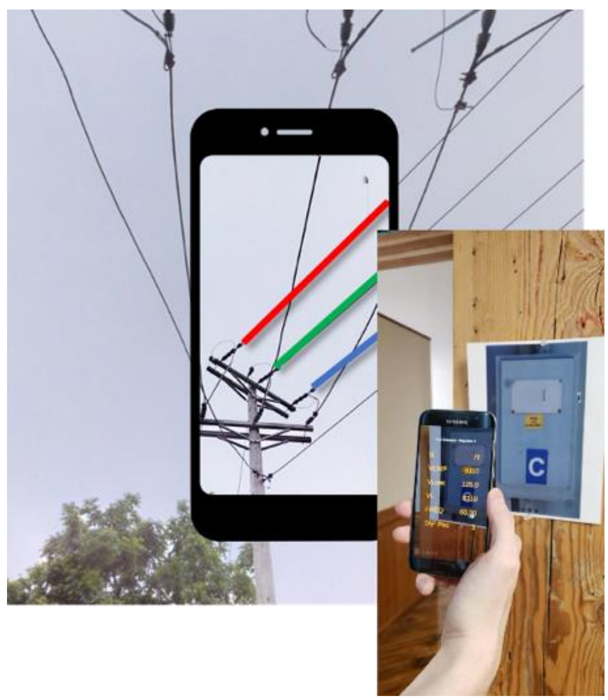

Figure 9: Augmented Reality Application to View Field Data on Mobile Device
(Image courtesy of DMI)

4: Glossary

AR (Augmented Reality)
An enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device such as a smartphone camera.

Digital Twin
Digital twin refers to a digital replica of potential and actual physical assets, processes, people, places, systems and devices that can be used for various purposes.

DMZ (Demilitarized Zone)
A physical or logical subnet that separates an internal local area network from other untrusted networks, usually the public internet.

IoT (Internet of Things)
The networking capability that allows information to be sent to and received from objects and devices (such as fixtures and kitchen appliances) using the Internet.

LiDAR (Light Detection and Ranging)
Lidar, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

Point Cloud
A point cloud is a set of data points in space representing a 3D shape or object. Each point has its set of X, Y and Z coordinates.

Reality Capture
Reality capture is the process of capturing accurate data from a real environment, generally using a laser scanner or photogrammetry software.

Registration
The process by which individual point clouds created from laser scans are connected together and optimized to form a larger point cloud.

SaaS (Software-as-a-Service)
A software licensing and delivery model in which software is licensed on a subscription basis and is centrally hosted.

VR (Virtual Reality)
An artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment.