San Diego Gas & Electric Company

EPIC Final Report

Program	**Electric Program Investment Charge (EPIC)**
Administrator	**San Diego Gas & Electric Company®**
Project Number	**EPIC-1, Project 2**
Project Name	**Visualization and Situational Awareness Demonstrations**
Module Name	**Module 2, Additional Use Case Work**
Date	**October 4, 2018**

Attribution

This comprehensive final report documents the work done in this EPIC activity.

The project team for this work included the following individuals, listed alphabetically by last name.

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EXECUTIVE SUMMARY

The initial scope of the EPIC-1, Project 2 was expanded in this added project module to accommodate further demonstration of some applications. This resulted in advanced and integrated versions of the initially developed applications. The results include advanced modelling of Geographic Information Systems (GIS) data model, prediction analytics, and custom applications that support integrated approach to existing methodologies.

Sempra Energy Utilities are utilizing data analytics to keep in par with the growing knowledge and real-time data. With the influx of various modern technologies and sensors to acquire data in real time and 3D (third dimension or altitude), creation of prediction models to aid engineers in field offices, or decision makers, is turning into a reality.

Objectives (EPIC-1, Project 2)

The objective of this demonstration project was to explore how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances grid monitoring and situational awareness. This project addressed how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators.

When transformed and presented in a visually integrated manner, this data can be invaluable for utilities to optimize grid operations as well as provide insights into the performance of the overall utility system. This visual framework also provides insights into customers' energy consumption behavior to serve them more effectively, foster energy conservation, and reduce peak demand. The demonstrated specific visualization and situational awareness concepts will be used to help San Diego Gas & Electric Company® (SDG&E®) make better choices on which options should be commercially adopted into the future visualization and situational awareness system.

Scope

The following five use cases, addressing a wide range of SDG&E® business needs within the visualization area, were selected for this project module: (1) Transmission Fault Location Visualization, (2) Load Curtailment Visualization, (3) AMI for Operations, (4) Imagery Management, and (5) GIS Visualization infrastructure modernization.

Approach

The work on implementing each of the use cases included 1) requirements definition for the visualization and situational awareness to be provided by the use case, 2) prototyping the data integration schemes, displays, and algorithms, 3) implementation of a testing plan and 4) data analysis and reporting.

Results

The key element of the solutions for all use cases is the use of GIS data and GIS visualization capabilities to visually and functionally integrate other types of relevant data like SCADA. An emphasis throughout the project was on developing solutions that are responsive, flexible, configurable, and reusable. Therefore, a successful demonstration of these novel solutions not only addressed the current business needs of the

five use cases, but also provided a knowledge base and software artifacts that will help SDG&E® find better solutions for its future visualization and situational awareness needs.

The developed solutions collectively cover a truly wide spectrum of SDG&E® business areas, users, business applications, and technology topics that had to be addressed:

- Business Areas: Transmission Operations, Distribution Operations, Emergency Operations Center (EOC), Transmission and Distribution Engineering, Distribution Planning, Maintenance and Construction Services, and Vegetation Management
- Business Functions: Accurate geographic location of transmission faults, geospatial data visualization for situational awareness, load curtailment dashboard for EOC use, and improvements in asset management, operations, and GIS maintenance afforded by new network model, process improvements via automation and geospatial awareness in combination with business intelligence, and empowering end users via enhanced mobility and configurability to match their business needs

Recommendations

Based on the outcomes of pre-production demonstrations in Module 2 of EPIC-1, Project 2, the results for use cases 1 through 3 are being moved into commercial use. Results of use cases 4 and 5 (Imagery Management and GIS Visualization Infrastructure Modernization) have met the objectives set for each of those use cases. However, in both instances, these efforts are initial steps of investigation and additional foundational work is needed, before the cumulative results are ready for commercial use.

Conclusions

- Through the performed work, SDG&E® has demonstrated novel solutions to the selected use cases, and, in the process, has also gained substantial experience in integrating GIS, historical, asset management, and other major SDG&E® computer systems. Both aspects will provide usability well beyond that immediately produced by the project module. The experiences gained through the project, due to the novel nature of what was being demonstrated, should be very useful for SDG&E® and the industry at large. The knowledge is transferrable to the industry at large scale for establishing a general workflow for using these novel solutions.

TABLE OF CONTENTS

List of Figures

Acronyms and Definitions

AF (PI AF)	PI Asset Framework (PI AF) is a single repository for asset-centric models, hierarchies, objects, and equipment (hereafter referred to as elements)[1].
AMI	Advanced Metering Infrastructure
API	Application Program Interface
Basemap	Basemap contains reference geospatial information based on what the cartographer is trying to communicate. Information is added to a basemap by overlaying other information on top of basemap to create a final map.
EOC	Emergency Operations Center
EDO	Electric Distribution Operations
eGIS	Enterprise GIS
ETL	A database usage process to Extract, Transform, and Load information. Typically associated with Data Warehouse activities.
Feature (on a map)	Individual item on a map
Feature layer	A feature layer is a grouping of similar geographic features (e.g., electric circuits, poles, buildings, parcels, cities, roads, and earthquake epicenters). Features can be points, lines, or polygons (areas). Feature layers are used for visualizing data on top of basemaps. In the context of integration with PI, feature layer is a collection of AF elements based on the same AF template.
Feature service	A collection of related feature layers. Feature services are managed by Esri ArcGIS. Real time updates of feature services are done via Esri ArcGIS GeoEvent Processor (new name: ArcGIS GeoEvent Extension for Server)
GIS	Geographic Information System
GPU	Graphics Processing Unit
HTTP; HTTPS	Hyper Text Transfer Protocol. HTTPS is over Secure Sockets Layer (SSL) to ensure secure data transfer in transit.
ID	Identifier
IED	Intelligent Electronic Device
IIS	Internet Information Services (formerly Server), an extensible web server created by Microsoft
IoT	Internet of Things
JSON	JavaScript Object Notation

[1] PI AF - Overview - OSIsoft Tech Support, https://techsupport.osisoft.com/Products/PI-Server/PI-AF/Overview/

Lat/Long	Latitude/Longitude of a geographical point
LiDAR	Light Detection And Ranging (also called LIDAR, LiDAR, and LADAR) is a surveying method that measures distance to a target by illuminating that target with a pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3D-representations of the target
LMP	Locational Marginal Price
NMS	Network Management System (SDG&E®)
PNode (pnode)	CAISO pricing node, the location in the network at which LMPs are provided
PV	Photovoltaic (solar) cells for producing electricity from Sun energy
RT	Real Time
SOM	Summary Operating Map
SSL	Secure Sockets Layer. It uses encryption for data in transit
UC	Use Case
UI	User Interface
Widget	An element of a graphical user interface (GUI) that displays information or provides a specific way for a user to interact with the operating system or an application

1 INTRODUCTION

This report documents the demonstration work and results for Module 2 of SDG&E's EPIC-1, Project 2, Visualization and Situational Awareness Demonstration, describes key lessons learned, and identifies opportunities to provide additional value to SDG&E®and other users in the future by leveraging the insights and the specific solution patterns of this project.

Decades ago, *situation awareness* (SA) was formally defined by Endsley[2] in terms of three concepts - perception, comprehension, and projection: "SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". While tweaks to this definition have been suggested since, the essential elements still remain, which is that, for situational awareness, one needs to consider perceptions within the contexts of both time and space. To do this, one has to be able to readily understand the information contained in the observations, and from these two and other domain knowledge, project the status in the near future.

In the power system industry, the systems that manage and present geo-spatial and other kinds of slowly changing data (e.g., spatial data) have existed largely in separate silos from the systems that deal with operational, time-varying data. Yet, both kinds of data are essential for comprehension of the true state of the system at a point in time, especially during emergencies, and for assessing a progression of that state into the near future.

In the case of SDG&E®, geo-spatial data is handled by Esri ArcGIS, and operational data eventually flows into OSISoft PI Data Historians. Each of the systems is very powerful in its own domain and is constantly being updated and extended with new features for analysis and presentation of results. The combination of the capabilities of the two brings the situational awareness contributions that neither of the two systems can achieve alone. For this reason, several of the activities in this task are centered on the technologies used to merge the information of the two aforementioned (and other) systems (i.e., geospatial and time series data), as necessary to fulfill specific SDG&E® business needs.

The third major component used in this project is Power BI from Microsoft. Out of the box, this tool brings Excel-like capabilities for end users to programmatically, or through a Graphical User Interface (GUI), configure the data sources to use, perform data analytics on the collected data, and select desired built-in or newly developed visualization widgets for display. During this project, SDG&E® has developed a Java programming-based functionality to incorporate Power BI widgets within Esri geospatial features, so the users can see and interact with the map or Power BI widgets in a coordinated fashion. For example, a selection of an element in a Power BI table highlights the corresponding element on a geospatial map, and vice versa.

A brief overview of each of these commercial building blocks is presented in the appendix.

[2] Mica R. Endsley, "Toward a theory of situation awareness in dynamic systems," Human Factors, 1995, Vol 37, pp. 32-64

1.1 Project Objectives

The objectives of the EPIC Visualization and Situational Awareness Demonstration project were to:

- Examine how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators
- Demonstrate how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances utility system monitoring and situational awareness. The project was divided into two modules. The first module was completed in 2017, and its final report is available on www.sdge.com/epic. This document is the final report for the second module.

1.2 Scope of Work- Use Cases

The second project module added to the use case work of the first module. The second module was focused on the following five use cases:

1. Transmission Fault Location Visualization
2. Load Curtailment Visualization
3. Advanced Metering Infrastructure (AMI) for Operation Visualization
4. Imagery Management
5. GIS Visualization Infrastructure Modernization.

1.3 Main Visualization Components

Use cases were implemented by combining functionality of core components from Esri, OSISoft, and Microsoft with third party applications and custom applications developed by the SDG&E® team. An overview of the SDG&E® components that comprise the demonstration system, plus other interacting systems and components in Figure 1-1. The GIS (Geographic Information Systems) components are on the left side of the figure; OSISoft PI components are on the right side; Power BI is in the cloud in the middle of the figure; and Smart Grid components, T&D Operations, and AMI components complement the picture. The main end-user interactions are through the web portal (in the middle of the figure), while the developers have local access at various points throughout the system.

A brief overview of functionality of the core commercial components is provided in the appendix; the programming methodology used by SDG&E®, developed to only achieve EPIC project use cases objectives, is discussed in the context of specific solutions for the various use cases.

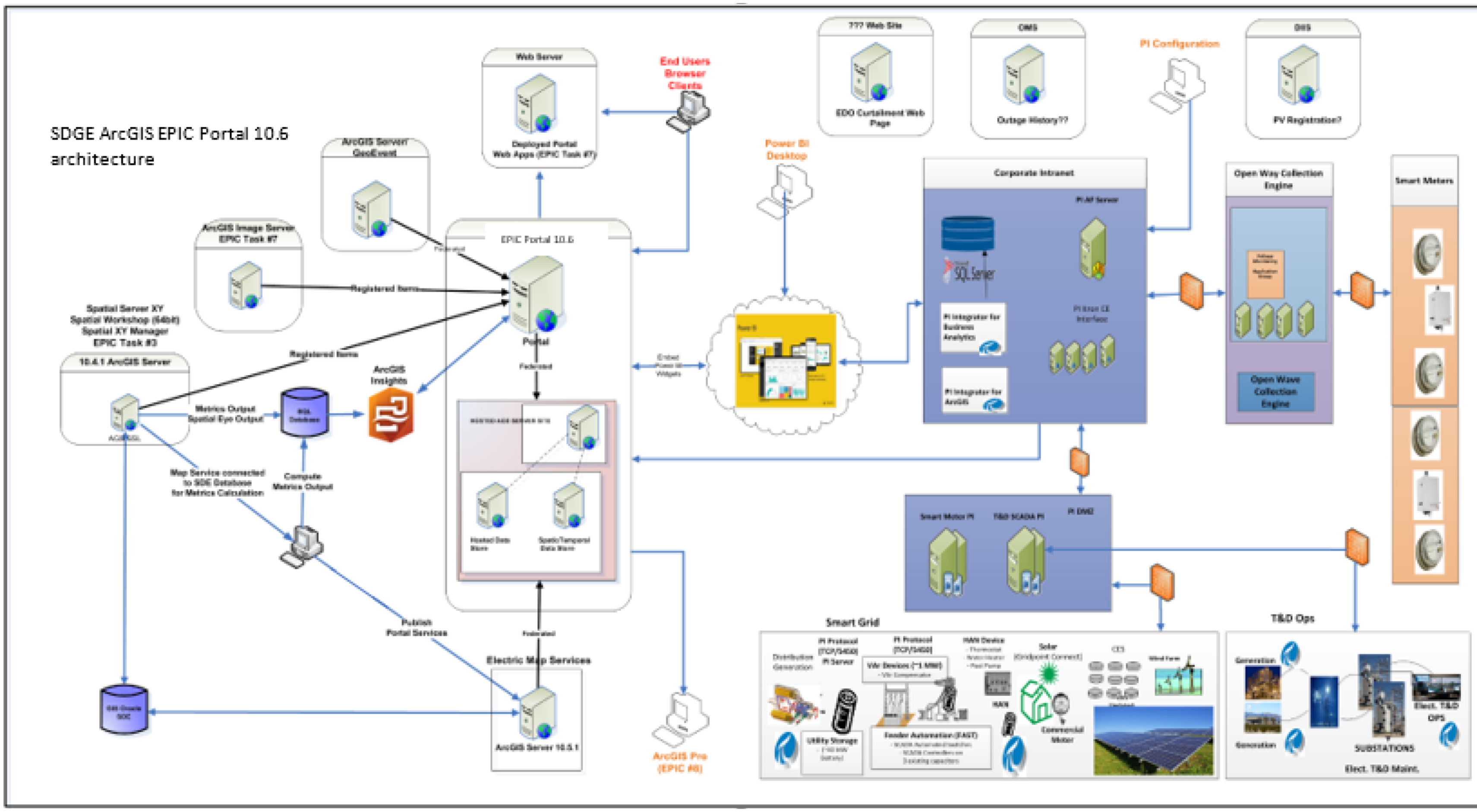


Figure 1-1. Main Components of Visualization and Situational Awareness Demonstration

2 USE CASES FOR DEMONSTRATION

This project module was comprised of five use cases covering a broad range of SDG&E® smart grid business needs. The description of use cases in this section consists of the following:

- Background
- Objectives
- Users
- Solution Approach, Solution Components, and Work Flow
- Results
- Observations, Challenges, and Lessons Learned

2.1 Transmission Fault Location Visualization (UC 1)

2.1.1 Background

At SDG&E®, substation relays are equipped with a function to compute a linear distance (i.e., a distance from the substation housing the relay along the line) to the line fault. When a fault occurs, relays detect it and compute the linear distance. This information eventually flows into the PI archiving system, from which an existing program called *PI Notification* sends text e-mails to relevant users with information about the fault.

At SDG&E®, in order to prepare for unexpected fault shifts, substation relays are equipped with a function for computing linear distance (i.e., a distance from the substation housing the relay along the line) to the fault line. When a fault occurs, relays detect it and computer the linear distance. This information eventually flows into the PI archiving system (PI Data Historian), from which an existing program called *PI Notification* sends text e-mails to relevant users with information about the fault.

The intent of Use Case 1 was to demonstrate the Transmission Fault Location application that will enhance situational awareness about the fault by: (1) extending the e-mail message with a link to a specific web page on the ArcGIS Portal; (2) developing the functionality to generate the target web page and show a geospatial map on the page with the electric circuits and fault indicators at the exact location of the fault; and (3) showing any other geospatial layers, such as weather, fire, earthquake, etc., that may be available in the GIS system.

2.1.2 Objective

The objective of this use case was to demonstrate the ability for end users to see fault locations and associated data on a geographical map within ArcGIS Portal.

2.1.3 Users

- Transmission operation group (Grid Operations)
- Maintenance crew - Kearny Maintenance and Ops
- System protection - System Protection and Control Engineering (SPACE)

2.1.4 Solution Approach, Solution Components, and Work Flow

Components involved in the solution:

- PI Notification: sends e-mails to users
- PI Integrator: pushes dynamic data updates to update maps
- ArcGIS Geo Processing: a service to convert linear distance to a fault obtained from PI to the latitude and longitude (Lat/Long) of the fault by using the geometry of the asset in the geospatial database
- GeoPortal: displays geospatial maps with electric circuit overlays, along with fault indicator(s) on the affected electric circuits, and any other layers, such as weather, fire, lightning strikes, etc.

The technical solution uses two cooperating processes. The first is supported by an SDG&E® custom program and by components from both the PI system and Esri GIS system. This is an event-driven process, with the event being an arrival of new fault data to PI Data Historian. When this event triggers, the custom program retrieves the description of the fault from PI Data Historian (tieline, substation, and the linear distance from the substation along the tieline) and invokes an ArcGIS Geo Processing service called ArcGIS Linear Referencing Geoprocessing service to compute the Latitude/Longitude (Lat/Long) of the faulted location. After receiving the results, the custom program updates PI Data Historian with this Lat/Long data. The second process is based on leveraging the "out of the box" functionality of PI Integrator for Esri ArcGIS and is shown in a simplified form in Figure 2-1.

Data flow:

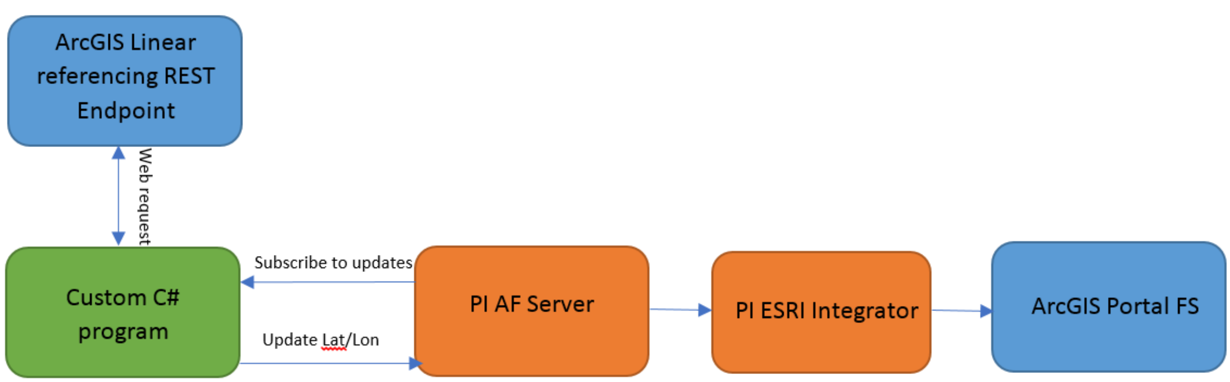


Figure 2-1. Transmission Fault Location Data Flow Diagram

The process consists of the following steps:

1. The PI Integrator for Esri ArcGIS publishes the PI Fault Distance template to ArcGIS Portal, where it gets registered as a feature service, with its own URL
2. When the feature layer is added to a map, the ArcGIS client makes a periodic request (at pre-configured intervals, e.g., every 2 seconds) to the registered PI Esri integrator URL for the Fault Distance layer data
3. The PI Integrator for Esri ArcGIS then requests the data from the PI system, specifically from the Asset Framework (AF) Server (if it is not cached) and returns the data to the client

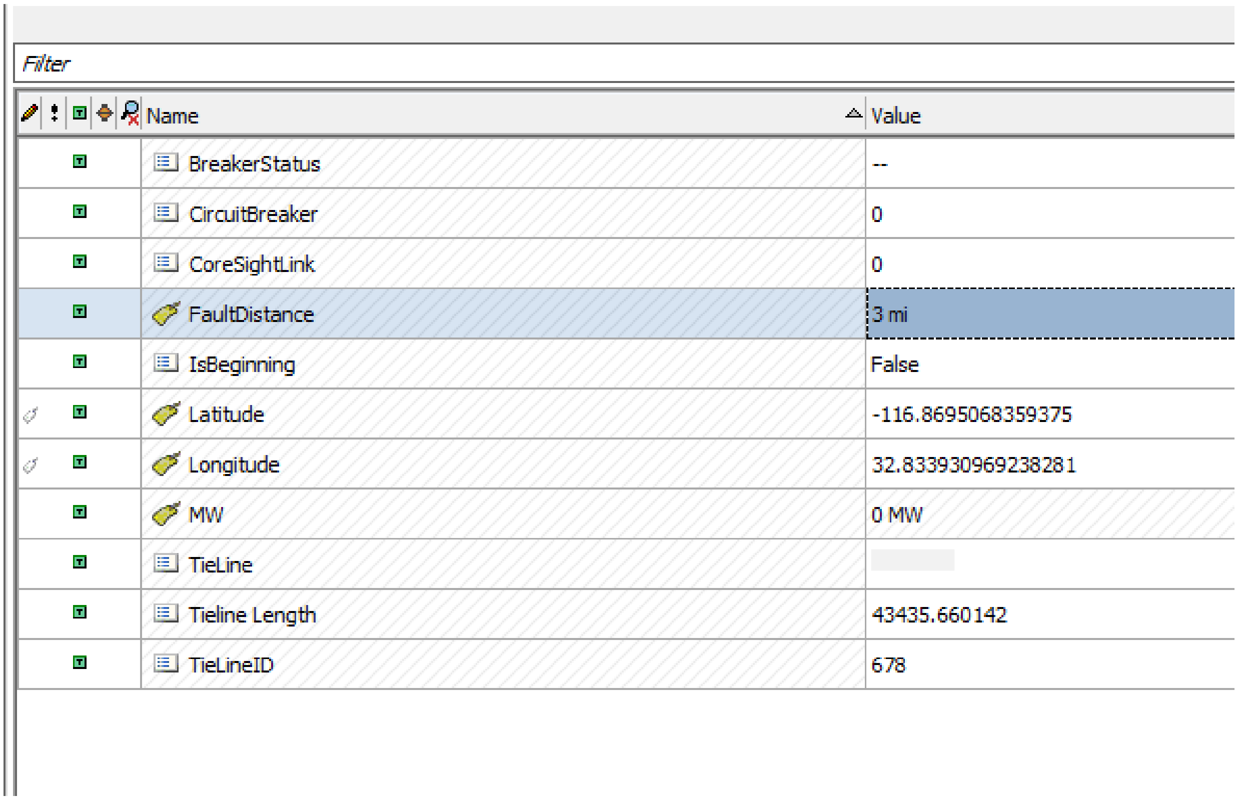
4. The requested features are drawn on the map according to the retrieved data, including redrawing of the fault locations based on the latest retrieved Lat/Long data

The mechanism for dynamic map feature updates described above is the same for any use case that uses PI Integrator for Esri ArcGIS. The only differences are which of the PI data templates (such as the fault Lat/Long in this use case) drive the display.

A JavaScript Object Notation (JSON) code snippet illustrating a request from the ArcGIS of a Linear Referencing endpoint is shown in Figure 2-2.

The ArcGIS Linear referencing service automatically updates the computed Lat/Long result in PI (Figure 2-3).

Figure 2-2. Request from ArcGIS Geoprocessing Service



Filter

Name	Value
BreakerStatus	--
CircuitBreaker	0
CoreSightLink	0
FaultDistance	3 mi
IsBeginning	False
Latitude	-116.8695068359375
Longitude	32.833930969238281
MW	0 MW
TieLine	
Tieline Length	43435.660142
TieLineID	678

Figure 2-3. PI Fault Location Template – Highlighted Item Updated by ArcGIS Linear referencing service

2.1.5 Results

2.1.5.1 Representative Results

Figure 2-4 shows two fault locations. In this example, the user has clicked the pin for the latter fault, and a popup display provides more details, including name (which is the name of a relay in PI comprised of a tieline ID, and a substation ID), circuit name, fault distance, and the exact coordinates of the fault.

However, at this level of detail, it is not possible to say if there are multiple circuits in the affected area. By zooming in (Figure 2-6), it can be seen that there are actually several circuits (at different voltage levels), and the Fault Pin pinpoints exactly the affected circuit (matching the description in the popup table of the previous figure).

Incidentally, these two figures also illustrate the useful automatic decluttering capability of the GIS software.

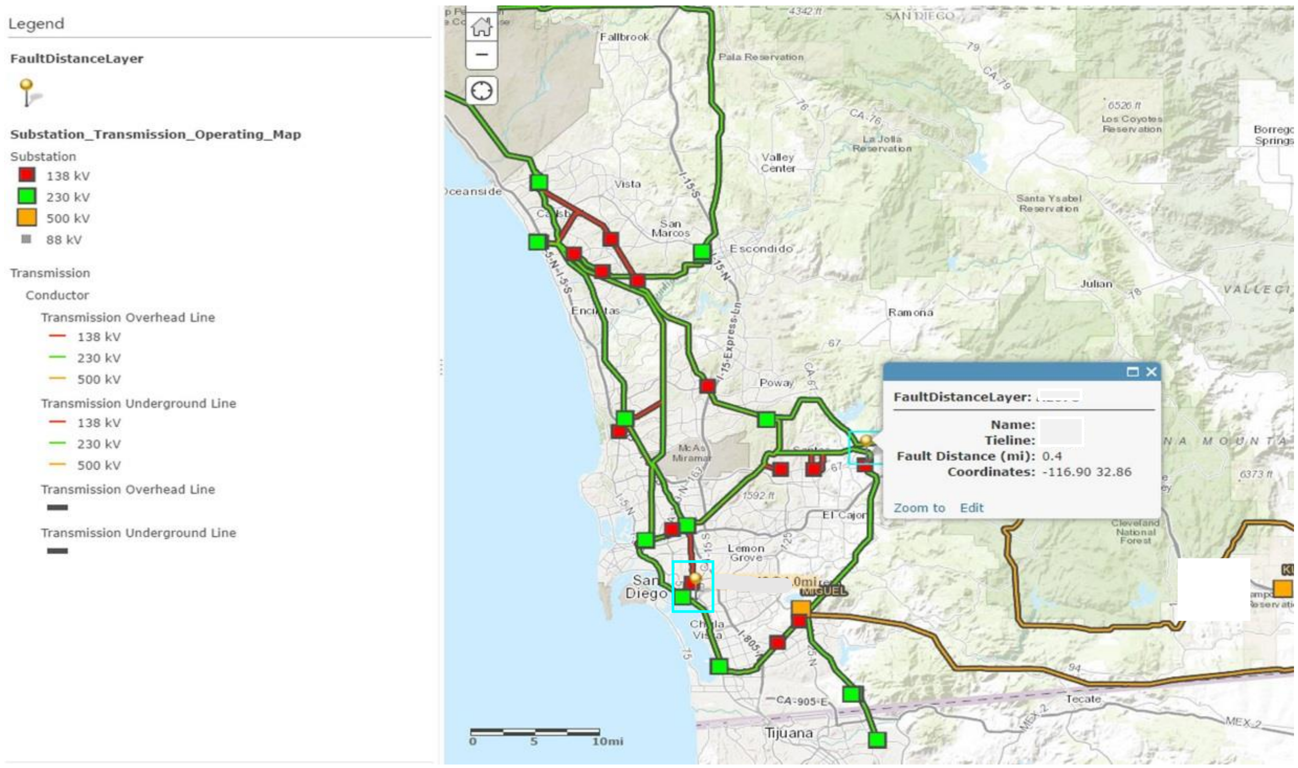
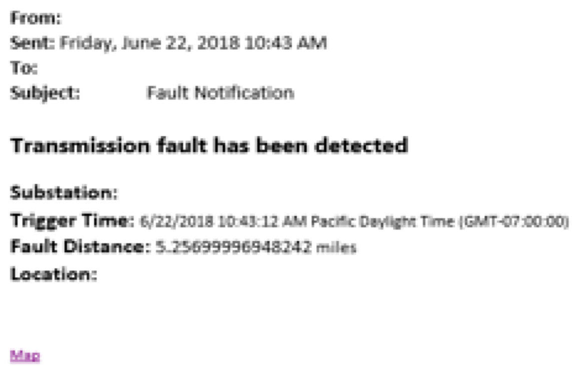


Figure 2-4. Map with Fault Location



From:
Sent: Friday, June 22, 2018 10:43 AM
To:
Subject: Fault Notification

Transmission fault has been detected

Substation:
Trigger Time: 6/22/2018 10:43:12 AM Pacific Daylight Time (GMT-07:00:00)
Fault Distance: 5.25699996948242 miles
Location:

Map

Figure 2-5. Email generated after fault detection

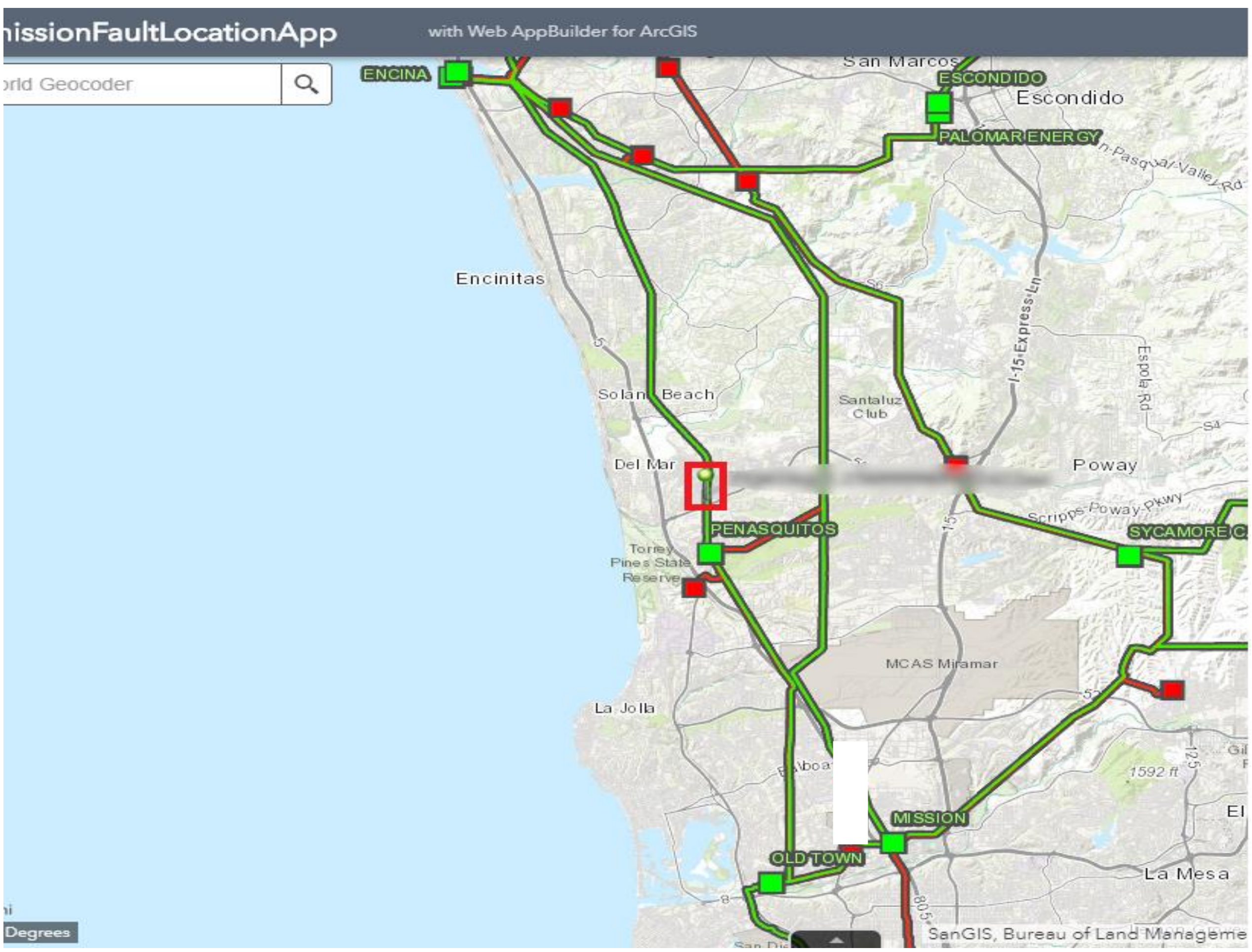


Figure 2-6. Map Detail with Fault Location (indicated by a pin)

2.1.6 Observations, Challenges, and Lessons Learned

<u>Challenges and Resolutions</u>

- SDG&E® may eventually want to use a double-ended fault algorithm to provide even more accuracy
- Handling of faults on tapped lines is a challenge, especially when the single ended fault location algorithm is used – as for some fault locations, it is ambiguous if the fault has occurred on the main trunk or a tapped line. The work on overcoming this challenge is still in progress, with an expectation that the use of a double-ended fault algorithm will help in the resolution. Nevertheless, in the vast majority of fault location cases, the existing solution is fully functional.
- Creation of the reference layer of electrical circuits (from which the fault x-y coordinates and the x-y coordinates of the circuits themselves are derived): the GIS database may have a line asset represented as multiple line segments, each with a "from" and a "to" side and with a significant number of other attributes. ArcGIS has a service called ArcGIS Geoprocessing Service to convert a linear distance (along an asset) to the x-y coordinates of the point at the end of the linear distance. However, this service is time consuming when there are many segments to peruse. To increase the ArcGIS Geoprocessing Service performance, it was necessary to perform an upfront work to appropriately concatenate line segments and create a new, simplified, composite line that always spans two substations. The line ID of this composite line needs to be provided to PI, where it serves as a key for linking the x-y information of the fault computed by ArcGIS Geoprocessing Service with operational data from PI. Any time there is a reconfiguration of a physical line, this process of so-called "digitizing" (i.e., updating of the composite line) needs to be repeated (only the very first time and after a reconfiguration). The initial effort to "digitize" all the lines, given that all 69-kV and higher voltage lines are included, was substantial. Once initially completed, an incremental effort to update after a reconfiguration is much less intensive, as such events are relatively infrequent, and the scope is much smaller (as it involves only the reconfigured lines).

<u>Recommendations</u>

- The labor to create the initial reference layers of electric circuits is significant and should be planned for in advance
- A process is needed to "re-digitize" lines any time there is a reconfiguration, or to digitize new lines, with an associated process to reflect the changes, if any, of the line ID in PI.
- Enhancing the User Interface (UI) of the web page and overall design could improve end user experience.

2.2 Load Curtailment Visualization (UC 2)

2.2.1 Background

Currently, SDG&E® Electric Distributions Operations (EDO) updates load curtailment plans via a spreadsheet (shown later in Figure 2-8). The spreadsheet is posted on the EDO Website.

The spreadsheet shows the current total MegaWatt (MW) request for load shedding from CAISO, the amount of load already shed, as well as a list of circuits in groups according to the order in which they need to be opened to affect the load shedding. The groups are labeled Run 1, Run 2, and so on, and are arranged so that the circuits in Run 1 are opened first. Then, if there is need for more load shedding, the circuits of Run 2 are opened, and so forth. The coloring of circuits is chosen to reflect the likelihood of load shedding, with red designating the first group of circuits to open.

The information in the spreadsheet is a combination of asset names and real-time load data. The intent of this use case is to display the same tabular (i.e., the spreadsheet) information but through a geospatial map, with visual cues identifying the order in which the circuits are to be opened. Examples in the results section illustrate additional options and benefits provided by the geospatial displays that in total should provide a better visual sense of when and where the load is being shed. This aspect of being able to quickly grasp the extent and location of load shedding may be very important, taking into account that load shedding is seldom required, but when it is, it is usually associated with emergency situations during which effective situation assessment is paramount.

2.2.2 Objective

The objective of Use Case 2 was to demonstrate an ArcGIS Portal map to visualize the current SDG&E® load curtailment plan.

2.2.3 Users

- Emergency Operations Center (EOC) personnel, during emergencies
- Distribution Operations

2.2.4 Solution Approach, Solution Components, and Work Flow

Components:

- Internal SDG&E® Web site: the current load curtailment plan published to the site (existing functionality)
- Custom Python program periodically “scrapes” EDO Curtailment Webpage and writes the parsed curtailment results to PI
- PI Integrator for Esri ArcGIS publishes Curtailment Template to GIS Portal
- Current values of the map’s dynamic widgets (e.g., current total loads on each of the circuits marked for curtailment are updated through periodic queries from Esri portal client via PI Esri Integrator to the PI Data Historian); this can be seen later in Figure 2-8
- Esri Operations Dashboard for ArcGIS: a dashboard with the Load Curtailment map as one of its elements (example shown later in Figure 2-10)

A simplified diagram of the major data flows is shown in Figure 2-7.

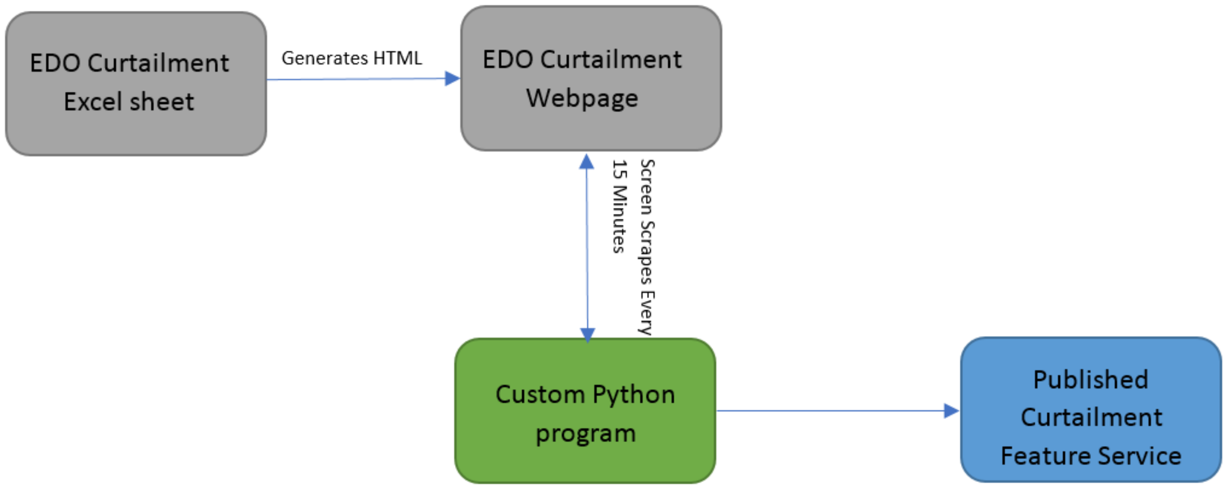


Figure 2-7. Load Curtailment Data Flow Diagram

An example of an EDO HTML Load Curtailment Page (the source of data for this use case) is shown in Figure 2-8.

An ArcGIS Portal map of load curtailment is shown in Figure 2-9. The legend on the left shows use of color to convey the status of circuits with respect to load shedding (e.g., previously or currently curtailed, early restored, or one of the exempt circuits); or it is a circuit in the first group to be curtailed (red), or in one of the later rounds (orange, light orange, yellow, etc.).

The Curtailment layer has every circuit, and each circuit has an associated Status field. When the Status field is blank, the corresponding circuit is filtered out from the display.

The map is made into a dashboard using the program Esri Operations Dashboard (Figure 2-10). Multiple circuits can be selected by interactively encircling a region of interest. The widget on the lower right will then summarize the total MW dropped from the selected circuits. The list on the left side contains only the circuits that are due for curtailment.

SDGE
A Sempra Energy utility

30 Set Refresh Rate

Legend Manual Subs

Electric Distribution Operations

Last Update: 6/1/2016 3:25:05 PM

Daily Totals **	
ISO Requested MW:	0.00
SDG&E MW Total:	0.00
PGP MW Total:	0.00
MW Dropped:	0.00
Cust Affected:	000

Current Run:
NONE

	Run #1	Run #2	Run #3	Run #4	Run #5	Run #6	Run #7	Run #8	Run #9	Run #10
ISO Requested MW:	25.00	25.00	25.00	25.00	25.00					
SDG&E Contribution:	27.51	27.88	27.03	25.71	26.32					
PGP:	0	0	0	0	0					
Run Start Time:	0									
Run End Time:	0									
Total MW Dropped:	27.51	27.88	27.03	25.71	26.32					
Customers Affected:	21,465	20,893	12,629	23,549	31,641					

Index	Block	Circuit	Total Customers	Community Area	Breaker Status	MW Dropped (Run #1)	MW Dropped (Run #2)	MW Dropped (Run #3)	MW Dropped (Run #4)	MW Dropped (Run #5)	MW Dropped (Run #6)	MW Dropped (Run #7)	MW Dropped (Run #8)	MW Dropped (Run #9)	MW Dropped (Run #10)
1	1A	434	2,172	MIRA MESA	CLOSE	2.98									
2	1A	229	1,820	MIRA MESA	CLOSE	2.18									
3	1A	524	1,838	BARRETT LAKE, CASA DE ORO, DEHESA, JAMUL	CLOSE	1.46									
4	2A	463	1,993	CHULA VISTA S, OTAY MESA, SAN YSIDRO	CLOSE	4.87									
5	2A	456	2,313	ESCONDIDO E, ESCONDIDO NE	CLOSE	2.88									
6	2A	715	1,639	MISSION VLY, NAS-MIRAMAR	CLOSE	3.92									
7	3A	831	4,510	MIRA MESA, NORTHCITY WEST	CLOSE	4.78									
8	3A	244	2,648	BLOSSOM VALLEY, LAKESIDE, LAKESIDE E, SAN VICENTE	CLOSE	2.34									
9	3A	63	2,532	NORTHCITY WEST, RHO SANTA FE S, SOLANA BEACH	CLOSE	2.09									
10	4A	83	2,365	LA MESA N, MISSION GORGE	CLOSE		0.90								
11	4A	72	2,655	ELCAJON W	CLOSE		2.08								
12	4A	382	970	MISSION VLY	CLOSE		3.74								
13	5A	988	1,267	ORTEGA	CLOSE		1.25								
14	5A	944	1,724	RHO DEL REY	CLOSE		0.74								
15	5B	177	1,440	POWAY N, POWAY S	CLOSE		0								
16	6A	500	2,835	LAKE HODGES S, RHO BERNARDO	CLOSE		1.46								
17	6A	740	2,438	PT LOMA N	CLOSE		4.40								
18	6B	258	2	CHULA VISTA W	CLOSE		0								
19	7A	850	445	VISTA S	CLOSE		5.80								
20	7A	1153	0	MIRA MESA	CLOSE		0								
21	7A	1166	321	ALPINE W, BARRETT LAKE, DEHESA, JAMUL WEST	CLOSE		0.02								
22	8A	358	1,120	ALPINE W, DEHESA, VIEJAS	CLOSE		4.37								
23	8A	291	3,140	LAKE HODGES S, RHO BERNARDO	CLOSE		2.80								
24	8A	210-172R	171	WARNER SPRINGS	CLOSE		0.31								
25	9A	443	3	SAN YSIDRO	CLOSE			2.65							
26	9A	103	1,833	BAY PARK, MISSION BAY	CLOSE			2.65							
27	9A	512	2,596	DEL MAR, NORTHCITY WEST, SOLANA BEACH	CLOSE			2.82							
28	10A	290	3,119	RHO BERNARDO	CLOSE			1.67							
29	10A	768	1,528	LAGUNA HILLS, LAGUNA NIGUEL, MISSION VIEJO	CLOSE			1.77							
30	10A	775	506	CLAIREMONT	CLOSE			3.70							
31	11A	797	2,447	LAGUNA NIGUEL	CLOSE			0.44							
32	11A	588	109	CARLSBAD	CLOSE			7.15							
33	11A	774	488	CLAIREMONT, NAS-MIRAMAR	CLOSE			4.19							
34	12A	452	3,804	ESCONDIDO E, ESCONDIDO NE, LAKE WOHLFORD	CLOSE				1.32						
35	12A	517	453	ESCONDIDO S, ESCONDIDO W	CLOSE				2.32						
36	12B	487	0	OCEANSIDE	CLOSE				0						
37	13A	745	20	TORREY PINES	CLOSE				3.65						
38	13A	986	2,526	MISSION VIEJO, ORTEGA	CLOSE				1.82						
39	13A	975	1,339	RAMONA E, SDCOUNTRY ESTATES	CLOSE				0.37						
40	14A	590	2,663	BONITA, OTAY MESA, RHO DEL REY	CLOSE				1.09						
41	14A	468	126	CENTER CITY	CLOSE				2.19						
42	14A	1117	2,866	CARLSBAD, ENCINITAS S	CLOSE				2.26						
43	15A	296	1,309	SAN MARCOS W	CLOSE				2.46						
44	15A	438	4,485	MIRA MESA	CLOSE				3.17						
45	15A	68	1,494	FAIRBANKS RCH S, NORTHCITY WEST, RHO BERNARDO	CLOSE				2.75						
46	16A	112	2	CENTER CITY	CLOSE				0.88						
47	16A	947	654	FLETCHER HILLS	CLOSE				0.19						
48	16A	510	1,808	DEL MAR, NORTHCITY WEST	CLOSE				1.25						
49	17A	951	390	MIRA MESA	CLOSE					3.90					
50	17A	502	4,427	LAKE HODGES S, RHO BERNARDO	CLOSE					2.71					
51	17A	73-14R	728	DEHESA, DESCANSO, JAPATUL, VIEJAS	CLOSE					0.49					
52	18A	410	2,148	ELCAJON W, GRANITE HILLS, SINGING HILLS	CLOSE					0.60					
53	18A	561	2,570	LAGUNA HILLS, LAGUNA NIGUEL	CLOSE					1.76					
54	18A	65	3,131	LA JOLLA N, TORREY PINES	CLOSE					2.17					
55	19A	188	[illegible]	ESCONDIDO NW, ESCONDIDO W, SAN MARCOS E	CLOSE					1.85					

Figure 2-8. Example EDO HTML Load Curtailment Page

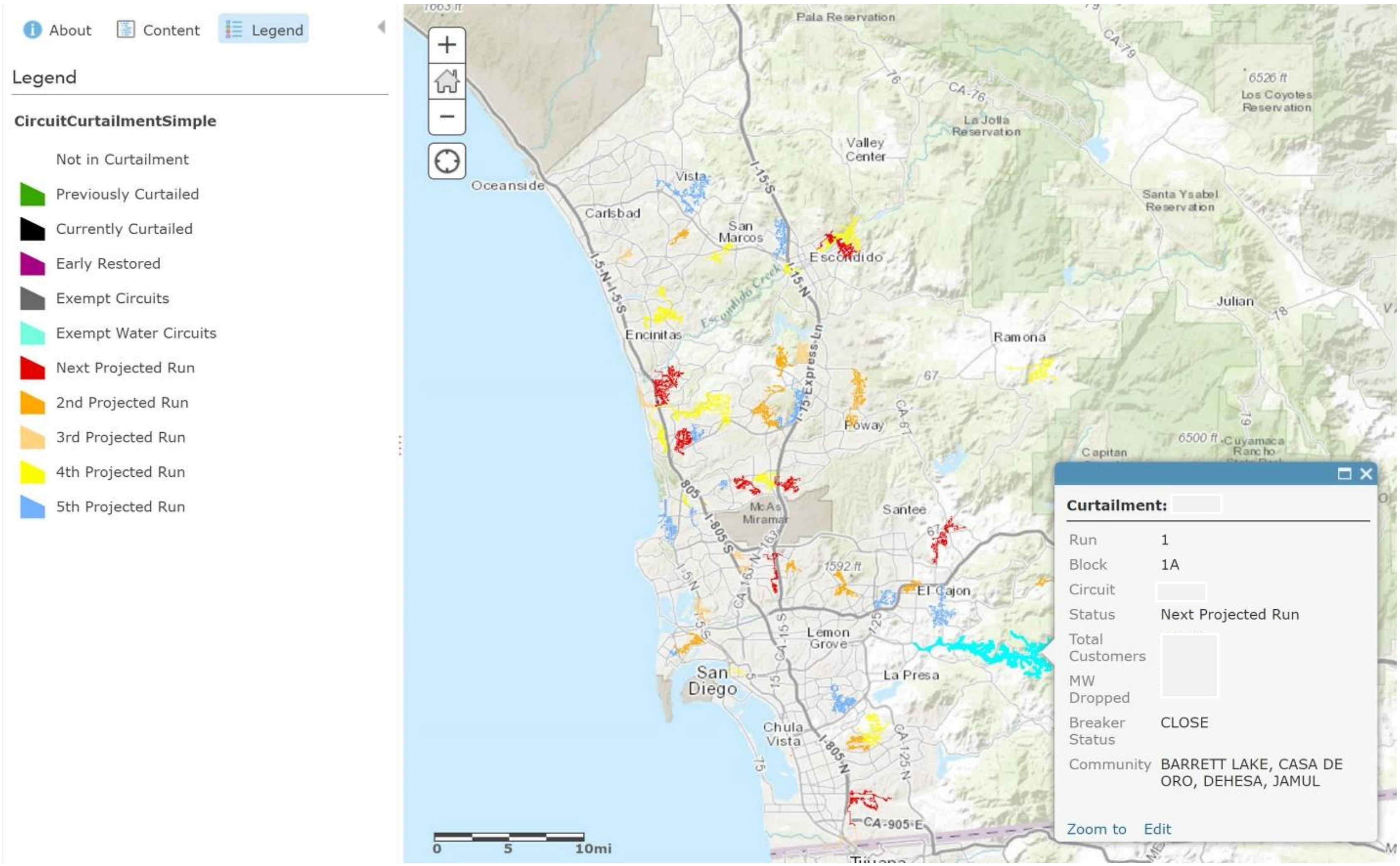


Figure 2-9. Example Load Curtailment Map

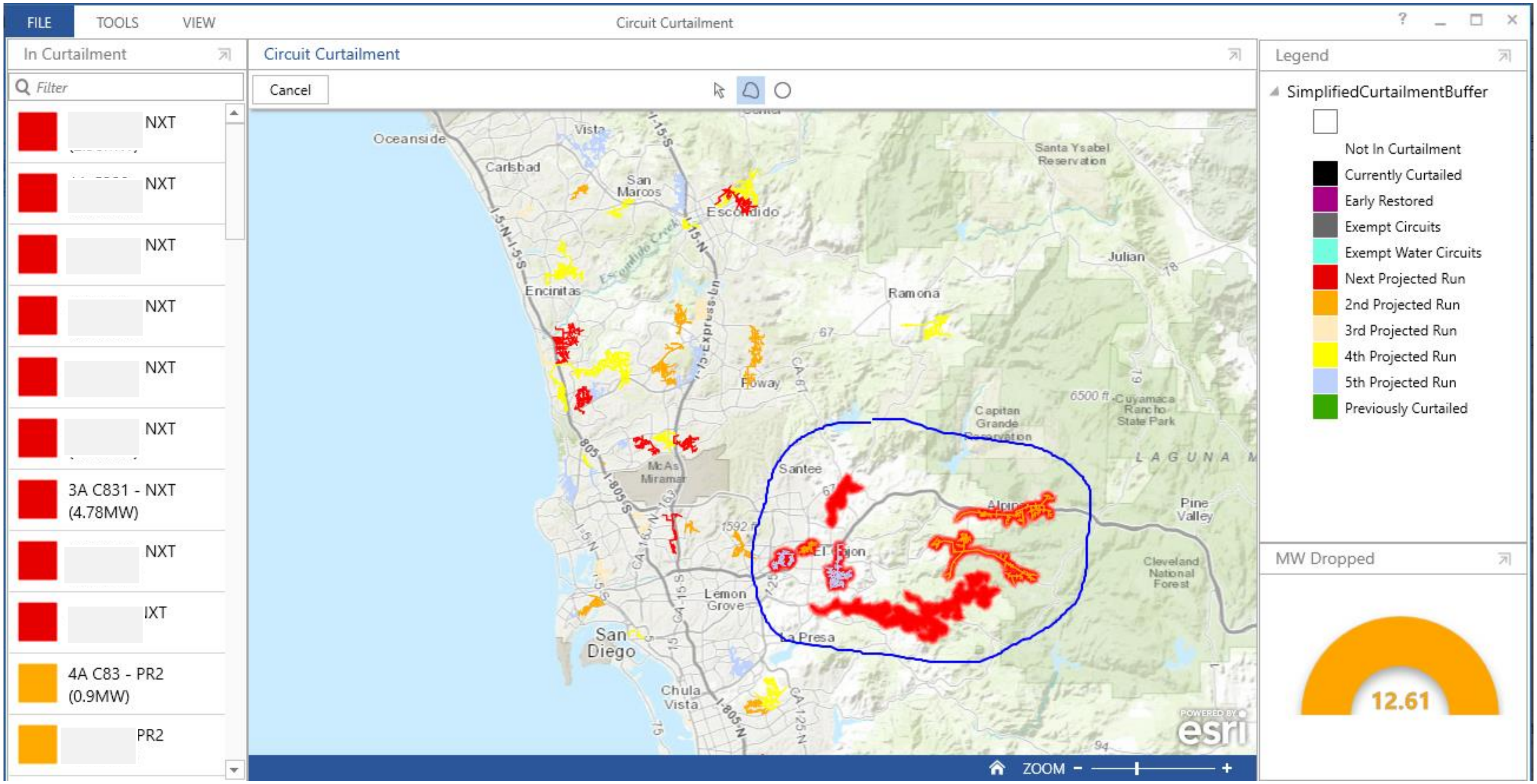


Figure 2-10. Load Curtailment Dashboard

This dashboard example illustrates how the end users are empowered by this solution – they can merely draw a boundary around a region of interest, and the display will automatically update with the total MW to be dropped within the region based on the actual load at the time of inquiry. Note that the legend adapts to the selected region of interest. This example also illustrates how the solution enables a user to get information of interest very quickly and in an intuitive way.

2.2.5 Results

2.2.5.1 Features

- Geospatial maps show the circuits for load shedding (either just finished, in progress, or planned)
- Color coding used to indicate both the (near) real time and the planned load shedding status
- Automatic decluttering of circuits that are not involved in load shedding
- Built in capabilities of GIS system can be leveraged to quickly create load shedding dashboard, which further extend usability of the displays by empowering users to make ad-hoc inquiries about load shedding amounts in any region of interest

2.2.5.2 Representative Results

The figures shown above illustrate the basic functionality and features of the load shedding use case.

2.2.6 Observations, Challenges, and Lessons Learned

Challenges and Resolutions

- In the absence of available Application Program Interfaces (API) to interact with the SDG&E® Web legacy system where the load curtailment schedules are posted, an interface to this system was implemented by scraping the site's web pages. Such technology is inferior to an interface based on a dedicated API.
- The electrical line circuits' information used for GIS visualization is rebuilt nightly to ensure the circuits' layer is a good reference for all the uses in need of this information. A coordination with PI data (at the level of line ID updates where new lines are created, or existing lines are retired) is also required any time the electrical circuit layout and connectivity change.
- Initially, the circuit layer visualization on the map was very slow. Significant improvements were made by using the Esri "generalization" tool to remove extreme details such as many vertices. The result is circuit representation without a visually perceptible loss of information yet enabling a substantial speedup of rendering. For example, it originally took upward of 20 seconds to render the electric circuit layers; it now takes a fraction of a second. When zooming in, the circuit layout is still sufficiently accurate.

Recommendations

- From a development perspective, it is recommended to replace scraping of web pages with an interface via a dedicated API
- From a usage standpoint, the commercial adoption team will seek further feedback from the managers of EOC after a planned demonstration of the function is presented to them in the near future

2.3 AMI for Operations (UC 3)

2.3.1 Background

A widespread availability of AMI data provides an opportunity to get a clearer real-time picture of the voltage situation across the SDG&E® network. The purpose of Use Case 3 is to overlay the AMI and SCADA voltage data onto a GIS map containing the electrical circuit topology and to create a heat map that shows the voltage swell and sag data. This visualization capability is expected to assist during emergency operations under various scenarios, such as the following:

- Storm
- Red Flags (e.g., High Winds –such as “Santa Ana Winds”)
- Earthquake
- Wildfire

After the fact, the historical playback capability should allow analysis of voltage behavior during different situations and, thus, provide a valuable insight about the need for system upgrades.

2.3.2 Objective

The objective of this demonstration was to overlay the AMI and SCADA voltage data onto a GIS map with circuit topology and create a heat map that shows the voltage swell and sag data on the GIS map.

2.3.3 Users

- Electric T&D Engineering
- Electric Distribution Planning
- Electric Distribution Operation

2.3.4 Solution Approach, Solution Components, and Work Flow

Solution components:

- Smart Meter PI
- DMZ PI
- Power BI
- PI Event Frame: detect voltage changes that constitute an event (e.g., voltage above 1.05%)
- ArcGIS picks up 10 years’ worth of the events captured by PI Event frame
- Esri Web AppBuilder to integrate Power BI widgets and other customizations for GIS Portal
- GIS Portal

An ability to show the substation SCADA data and the field devices’ power quality data as map layers is created by the PI Integrator for Esri ArcGIS, and custom components indicated in green in Figure 2-11.

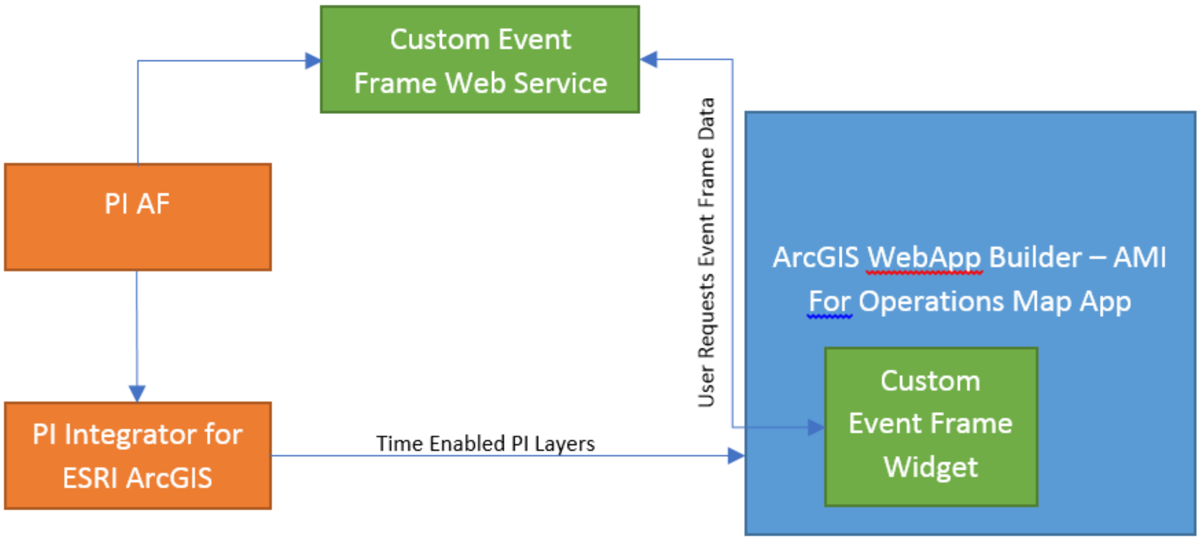


Figure 2-11. AMI for Operations Data Flow Diagram

2.3.5 Results

2.3.5.1 Features

- Voltage for primary distribution circuits with visual indicator % of nominal voltage and Visualization display for additional parameters available in Historian (PF, THD, voltage & load unbalance, etc.).
- Trending granular distribution circuit voltage analysis based on AMI data with the intent to identify possible future problem areas.
- Visualizations for other Intelligent Electronic Device (IED) data beyond typical SCADA such as microprocessor-controlled circuit breakers, relays, transformers, regulators, and capacitors. The System Protection and Control group can provide detail.
- Visualizations for emergency operations various scenarios:
- Storm, Red Flag (Wind – Santa Ana), Earthquake, Wildfire

2.3.5.2 Representative Results

Figure 2-12. through Figure 2-15. illustrate (self-explanatory) custom widgets for configuring various display attributes for this use case.

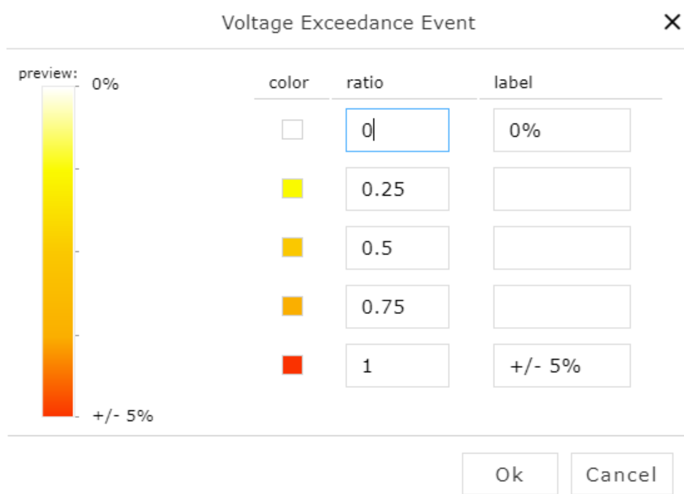


Figure 2-12. Custom Widget: Customizable Heat Map Colors

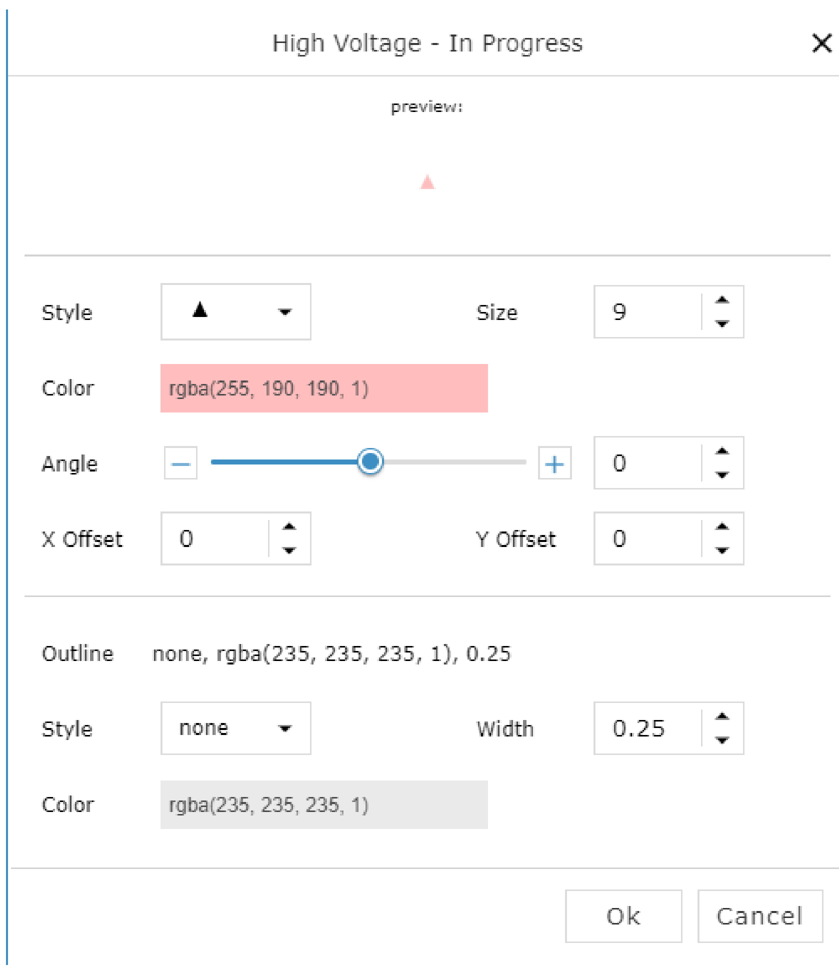


Figure 2-13. Custom Widget: Customizable Symbols

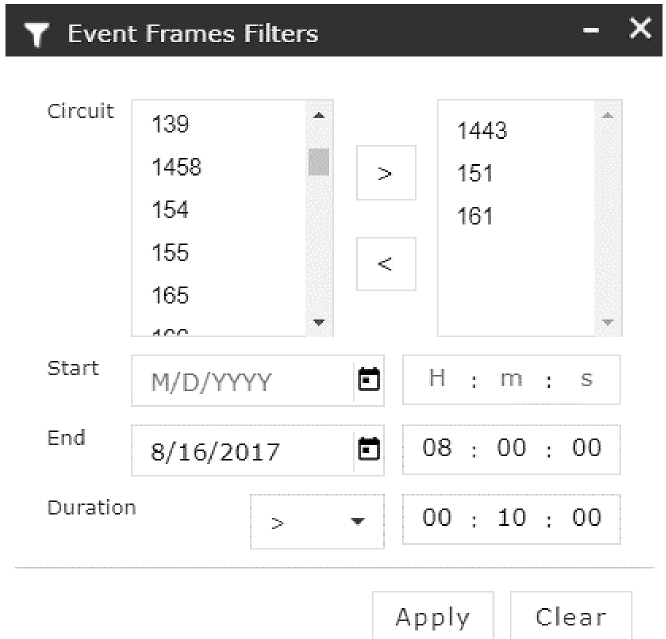


Figure 2-14. Custom Widget: Selecting Facilities of Interest

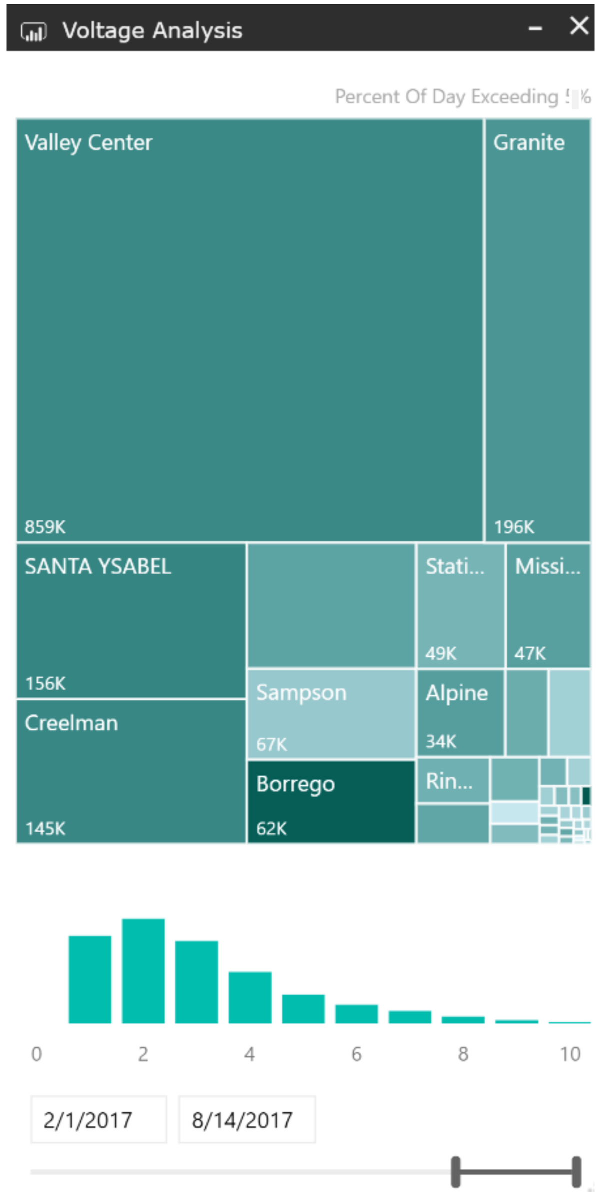


Figure 2-15. Power BI Display of Voltage Exceedance Events (tile size proportional to # of events)

The histogram at the bottom is the distribution of metering errors over the time horizon indicated in the timeline at the bottom of figure (from 2/1/2017 to 8/14/2017).

Selecting any of the boxes is akin to zooming in. For example, by "clicking" on Valley Center, the display will update to show the counts on meters within that station only, and the histogram will update to show exceedance by all meters in the Valley Center substation.

By a further zoom-in action, one can get to a breaker of interest shown in the left-hand side of Figure 2-16; details on the number of exceedances as shown by tile size on the right; the histogram of metered deviations below the tiles; and the timeline bar at the very bottom.

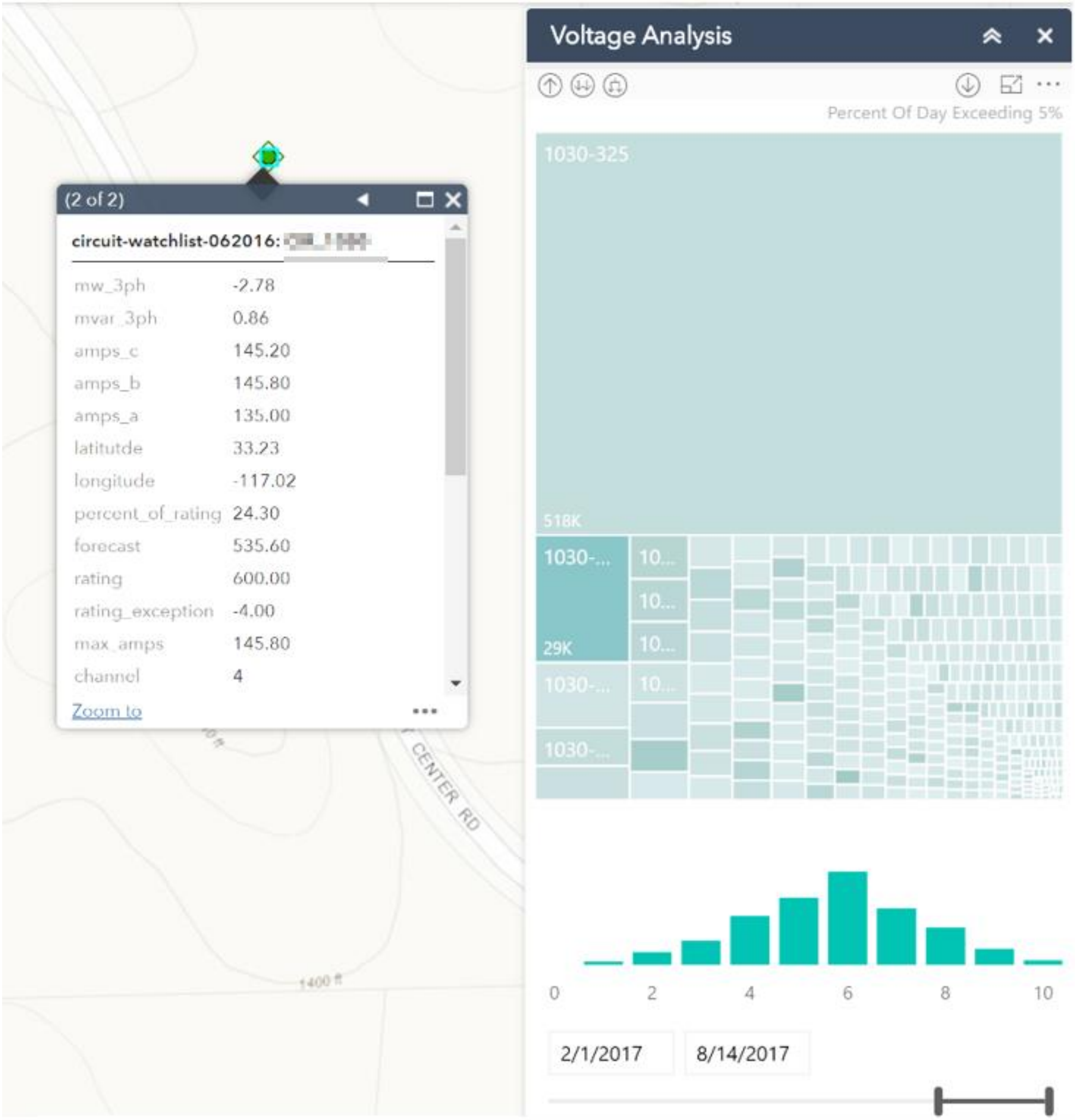


Figure 2-16. Breaker CIR_XX Events

Figure 2-17 shows an event loader configured to retrieve and display events for a given date, and an interval relative to that date specified by the values in the "From" and "To" fields. The asterisk (*) in the date field means current time; solid icon colors mean the event is still in effect at the end of the selected interval; hollow icons mean the event occurred and completed prior to the end of the specified interval.

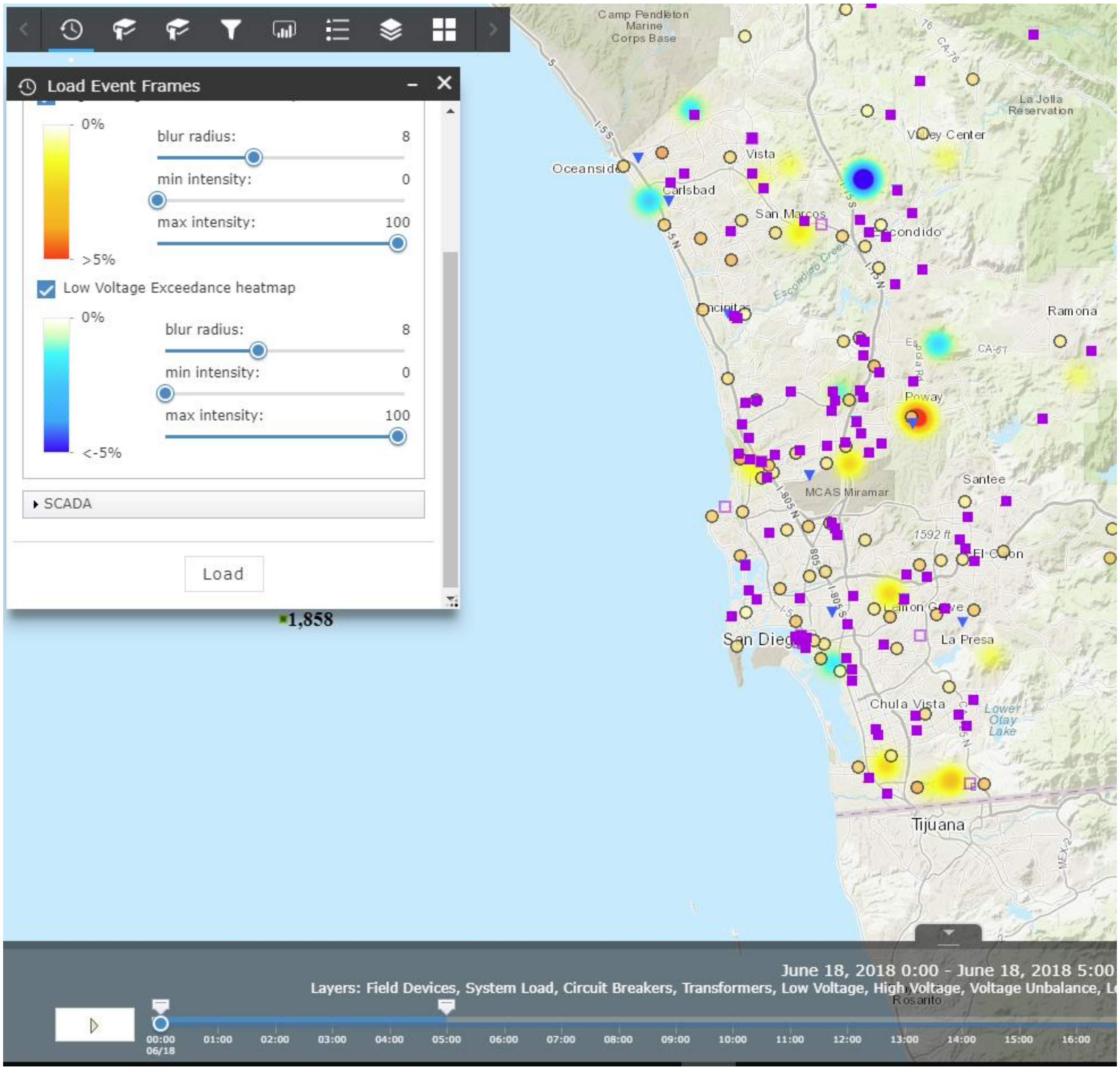


Figure 2-17. Custom Widget: Dynamic Heat Map of Voltage Exceedances over a Specified Time Interval

By "clicking" on an event, one gets additional details. For example, Figure 2-18 shows a, b, and c phase currents from SCADA at the event time. This illustrates a still ongoing event; hence, the square is filled with color, and End date/time is not filled in.

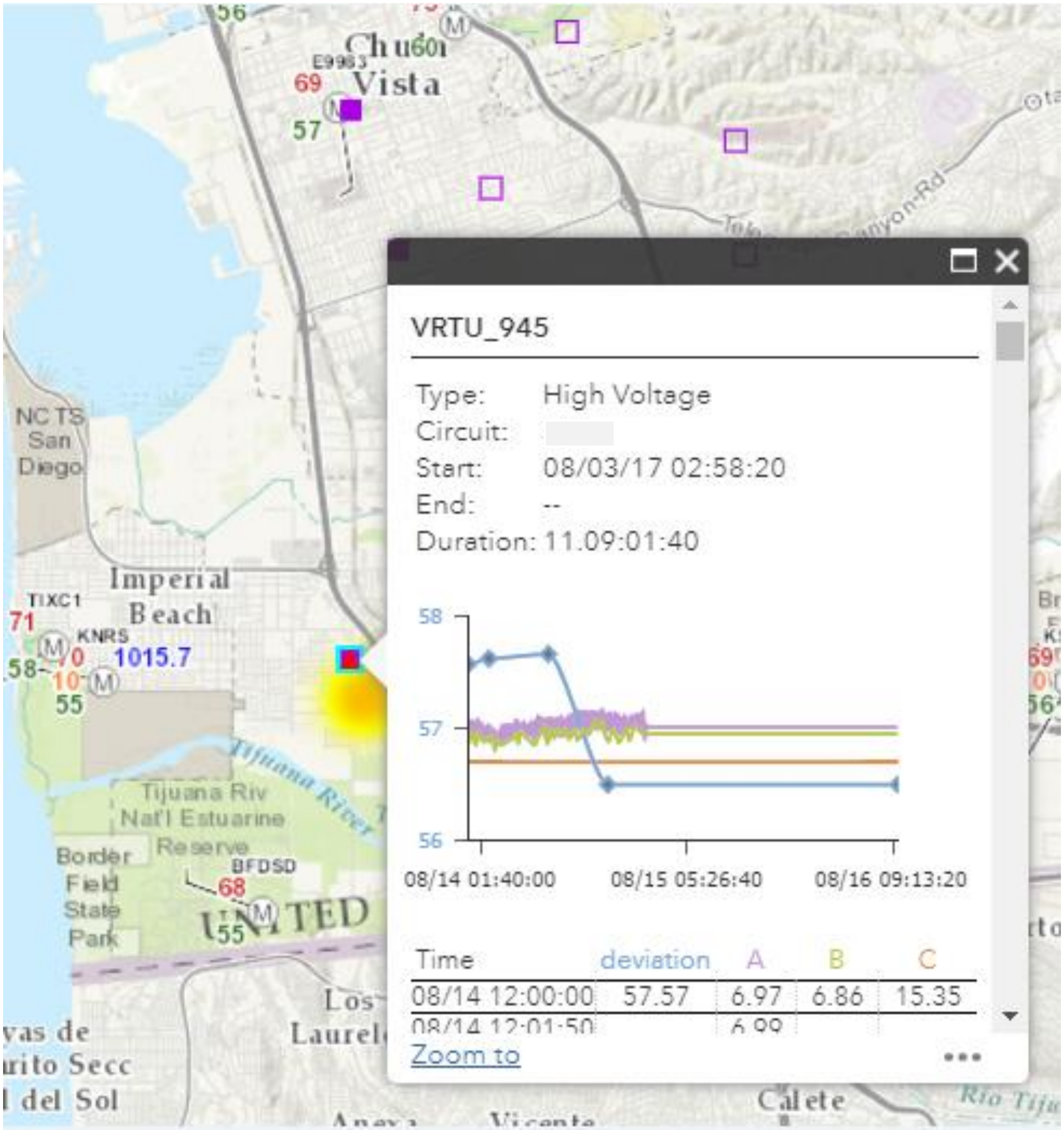


Figure 2-18. Event Detail: Voltage Chart

Figure 2-19 is a Power BI custom widget in conjunction with a geospatial display, showing tabular details of the events configured according to Figure 2-19. Due to the integration of Power BI with geospatial visualization, by selecting any element in the table, the corresponding element on the map is identified.

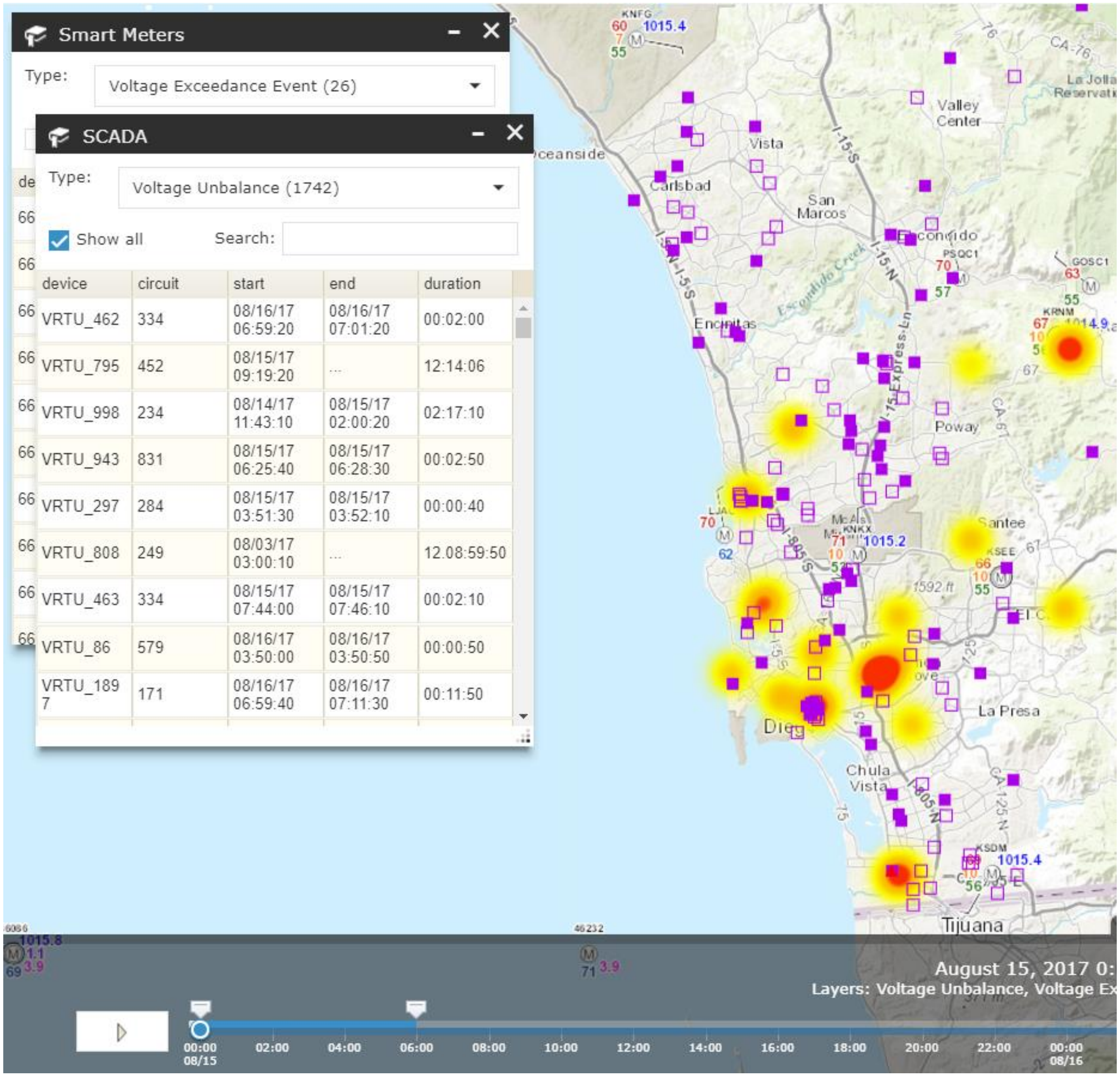


Figure 2-19. Custom Widget: Power BI Showing Voltage Exceedance

2.3.6 Observations, Challenges and Lessons Learned

<u>Challenges and Resolutions</u>

- Coming up with a solution to integrate Power BI and ArcGIS, with the solution that is configurable, so it can be reused. The task has been successfully solved with a custom program.
- Customizing Power BI widgets.
- Esri has a component for integrating Power BI with Esri maps, but that solution requires Power BI to also be on premises. In this case, Power BI was a cloud-based solution, and hence, SDG&E® needed to develop an alternative solution for integrating Power BI widgets within Esri maps.

- An early user's feedback indicated a need for customizable widgets, such as different symbols for the items that can be displayed on maps. As a result, the team developed a customizable widget for configuring symbols by the end user.
- Authenticating users with MS OAUTH (used by Power BI users) was a challenge: Power BI is a cloud-based application, the rest of the needed applications are on premises. The challenge was to implement a single sign-on in this hybrid environment due to a lack of templates (for accomplishing this task) and due to terse documentation. After a good deal of trial and error, the hurdle was overcome.

- Attempting to scale up the map event frames with PI AF would hinder resolution consistency. The decision to replace tasks handled by PI AF with SQL Server solved this issue. The SQL Server was already being used for Power BI, so it added consistency to the project.

- Currently gathering data from ~19,000 smart meters, scaled up from the previous 4,000. The project will be scaled to ~300,000 smart meters in Q3 2018, with new PI AF servers to be deployed to meet the demand for the influx of data.

<u>Recommendations</u>

- It is suggested to design custom widgets to be as generic as possible. In this project, that approach has proven to be very helpful, and it is expected that it will continue to be helpful in future projects.
- Applications should be designed to be customizable by end-users, which helps with usability, and ultimately, with adoption of the function.

2.4 Imagery Management (UC 4)

2.4.1 Background

An anticipated increase in the amount and variety of data from drones, imagery, video, and 3D sources necessitates a comprehensive data management strategy. The use case in module 1 explored and demonstrated technologies for integration and management of Light Detection And Ranging (LiDAR) data, imagery, and 2D data, with the goal to learn how to manage multidimensional data information efficiently. With successful building of an Image catalog to visually search through a wide variety of data, the use case further investigated, on how to use previously collected drone data with existing GIS data to improve data quality and analytic capabilities. And the possible uses for each type of data that is a part of Image Catalog are examined. Especially since LiDAR is more accurate spatial and temporal data, LiDAR data processing and deployment into web applications is studied in the below use case.

LiDAR data is considered appropriate mostly for surveying and engineering designs and used with surveying precision software like PLS CADD, but recent evolution of processing techniques in GIS software made it possible to visualize and analyze the LiDAR data in web applications, although not in surveying grade. This makes the LiDAR data readily available for a wide range of audience through GIS applications, either as a background for GIS data or as stand-alone application to develop predictive models for general overview.

2.4.2 Objective

The use case aims to demonstrate the ability to make the LiDAR data available through GIS applications, and compare against GIS data in 3D for visualization purposes. The use case also covers the research of prediction models for LiDAR data based analysis and possibility to construct these models into GIS as widgets to be used in a web application.

2.4.3 Users

- Vegetation Management
- Construction services
- Electric Transmission and Distribution Engineering

2.4.4 Solution Approach, Solution Components, and Work Flow

LiDAR data is available for multiple years and from multiple vendors, on a common NAS drive. The data is stitched into 1 dataset through Esri ArcPro tools. By converting to web manageable (web scene) format through ArcPro, the LiDAR data is hosted in ArcGIS portal web application for visualization in 3D. GIS tools can be modelled to manage this LiDAR data based on the algorithms mentioned below.

Solution Components

The following components are used for this use case,

1. ArcPro 2.0 – for processing LiDAR data and packaging it as a web scene
2. Web AppBuilder v2.7 – for building 3D web applications with LiDAR or 3D GIS data
3. ArcGIS Portal 10.6 is used for hosting the web scene as a service that can be consumed into the web application

Work Flow

The LiDAR data is cleaned for any outliers that occur during the collection of data. This data is considered as noise that can interfere with data analysis. To get accurate results the outliers are removed, and the misclassified data is corrected manually by selecting as many points as possible for recalibrating the data.

The recalibrated data is used for creation of the LiDAR dataset tiles. These datasets are published as scene service in ArcPro 2.0 to facilitate the consumption of point cloud data into web applications using Esri Web AppBuilder v2.7.

In this task, 3 sub use cases are researched for the LiDAR data based analytics for various departments. They are,

Sub use case 1: Compare 3D and projected 2D data

Overlay of projected 2D data such as poles with exaggerated heights to compare with LiDAR data for visual analysis of differences in heights. Such analysis will be more accurate with frequently updated LiDAR data.

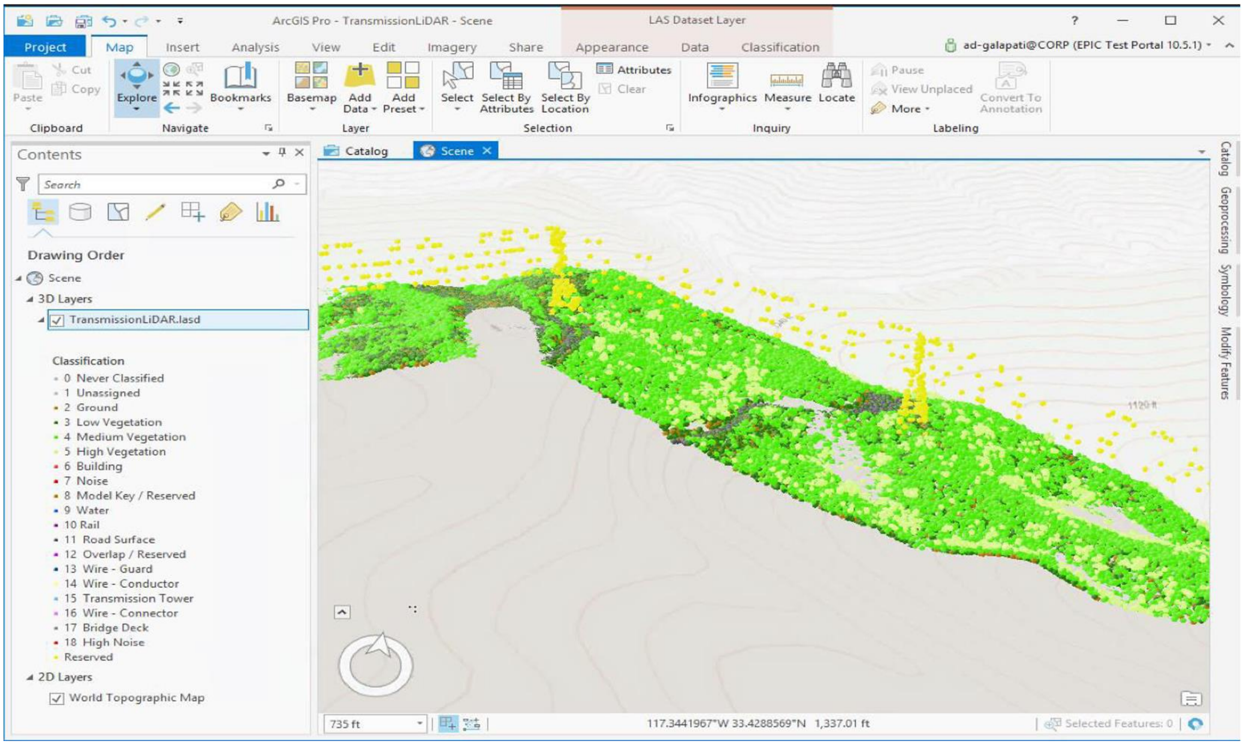


Figure 2-20. LiDAR data in ArcPro 2.0

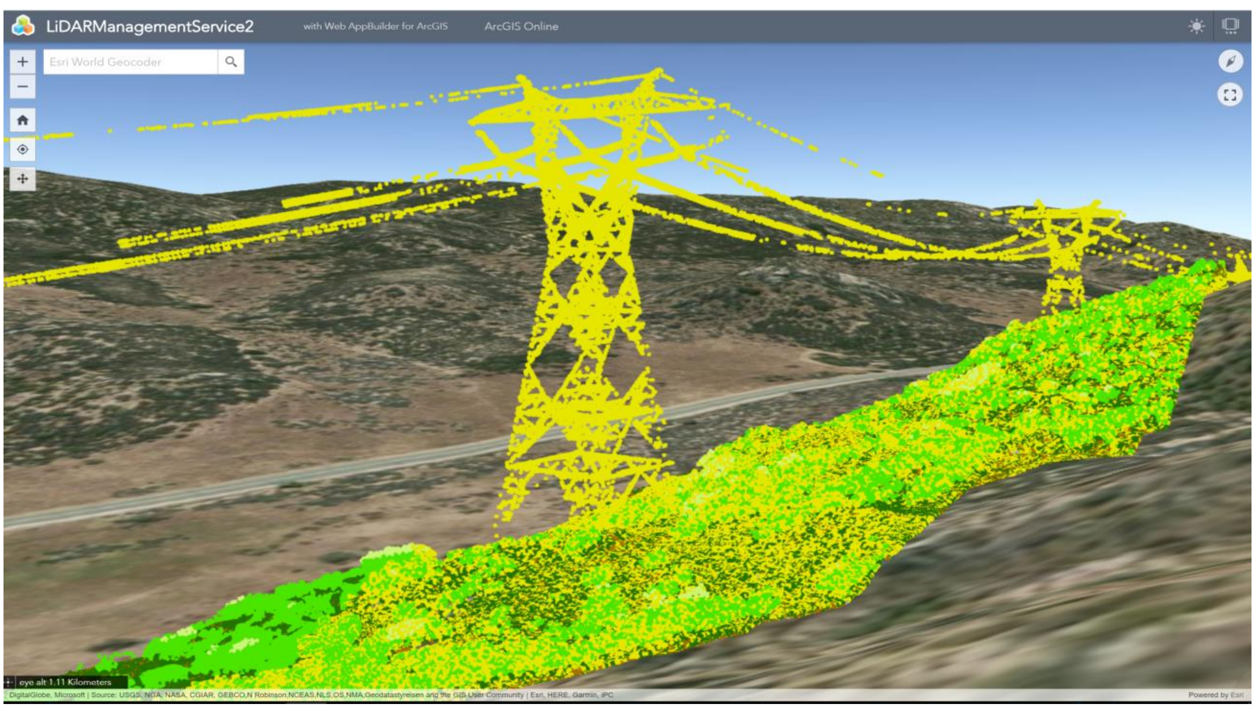


Figure 2-21. SDG&E LiDAR data in web application

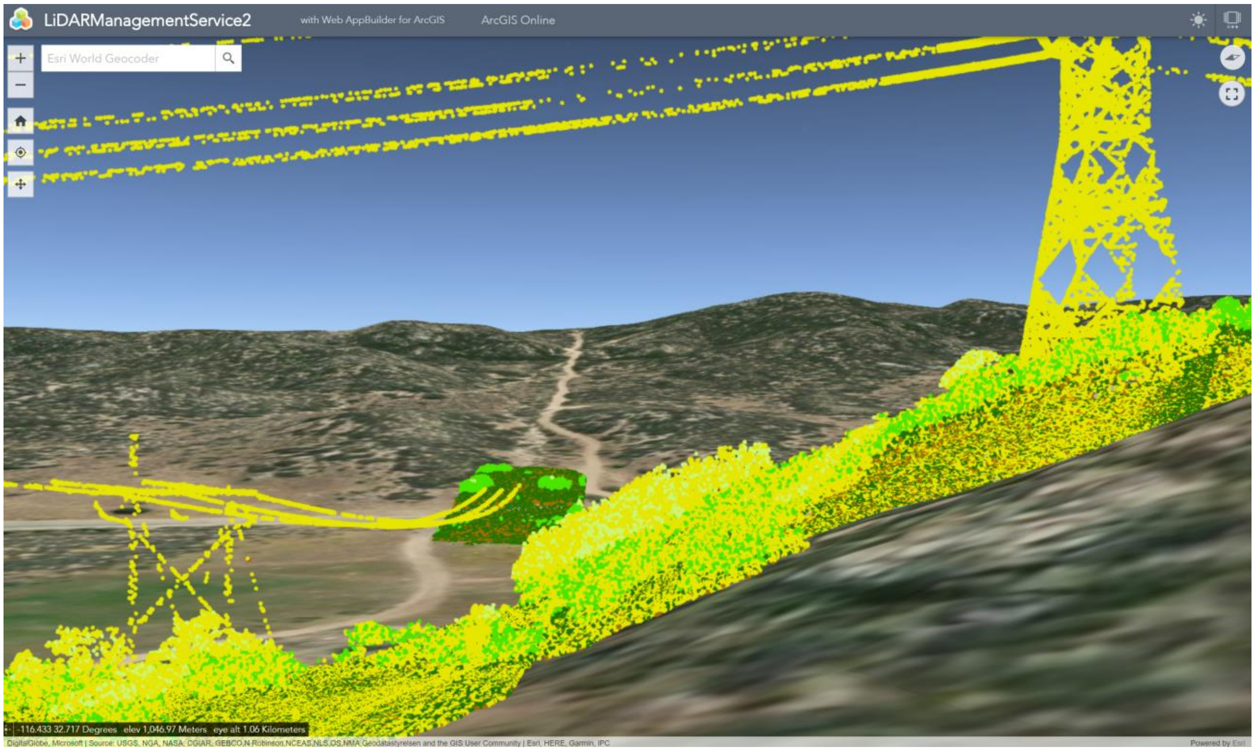


Figure 2-22. SDG&E® LiDAR data for both Transmission and Distribution data

The algorithms are researched according to the variables selected for the prediction models, to arrive at accurate variables for building the models. Although not demonstrated in this use case, the models will be built into widgets using geoprocessing service that can run the models.

<u>Sub use case 2: Line sag/sway analysis</u>

Line sag maximum under given wind and temperature

- Modelling of a custom widget to calculate deviation of line sag of a conductor will help model the maximum load conditions and to prevent any unnecessary load failures in wire conductors.

*Sag of Line (S)= Proportional constant(C) * Linear Expansion of material (ΔX) = C * {e * (T2 – T1) * X}*
*Height of the wire conductor above ground (Y_e) = (Y – S) *3.28 ft.*
*Sway in Line = Max sway of line for given wind conditions (S_W) per second= ($W_V * V$)/ (X * W) m*

- Parameter variables:
    - *Predicted temperature at the given location (In Degree Fahrenheit): T2*
    - *Standard wind pressure for wires: W_v^n N.m^{-2}*
- Assumptions: C*onsidering the linear expansion ∞ sag of conductor*
- *Variables for formulae:*
    - *Current temperature at the given pole location (in Degree Fahrenheit): T1*
    - *Co-efficient of linear thermal expansion: e*
    - *Surface of conductor exposed to the wind in m ^{2}:A_V*
    - *Length of wire in meters: X (derived in GIS)*
    - *Height of wire in ideal conditions from ground in meters: Y (derived from LiDAR data)*

- *Weight of conductor: W kg* *(constant value)*
- *Radius of the wire conductor in meters: r* *(derived in GIS)*

- *Wind forces on conductor*[3]*(* W_V *)* = $W_v^n \cdot A_V$ N
- *Volume of conductor V = π * r*^{2} *** X m*^{3}

Sub use case 3: Vegetation encroachment for wire conductor

Vegetation encroachment can be calculated based on sites that may be in danger of interacting with the wire conductors and possible outage.

- Assumptions: the wind speed is standard, and the sway is only within the radius 'X' feet of the wire conductor. And the modelled sag is based off the maximum temperature
- Derived Δ of vegetation encroachment $(D) = W_T - \sum_{k=1}^{X} Z_V$
- *Modelled wire sag maximum Y from corresponding ground point (*W_T*) = W -* W_S *ft.*
- *Max. height of vegetation in a radius of 'X' feet =*Z_v *(derived from LiDAR data)*
- *Max. wire sag in Y direction =* W_S *ft.* *(derived from Line Sag algorithm)*
- *Current height of the wire conductor = W ft.* *(derived from LiDAR data)*
- *The max. height* Z_v *is iterated until all the levels of S1, S2, and S3 are calculated.*
- *S1, S2, S3 etc. specified vegetation encroachment levels and will be based on the 'D' value of the vegetation*

The resulting shapefile graphics is added as temporary graphics to the GIS map. The graphics are symbolized by severity.

2.4.5 Results

The LiDAR data based web application can serve for visualization of data in 3D and shared across the departments based on user access. Further, by creating custom widgets to analyze the data these 3D applications can be used for various purposes like line sag analysis based on predicted weather scenarios, vegetation encroachment analysis to make decisions on vegetation trimming.

2.4.6 Observations, Challenges, and Lessons Learned

Challenges and Lessons Learned

The key approach to establish the algorithms and develop the tools is a challenge. Although various factors will affect the real-world scenarios, these prediction models will try to close the gap between ideal and real-world scenarios.

These predictive models combined with regular data collection, will assist field engineers and decision makers to get a general idea of the field conditions in extreme weather situations.

The initial phase of testing the LiDAR data usage in GIS is successful. The testing of the prediction models will require considerable amount of time and effort and the variables to create correct predictive

[3] ***Wind Load of Overhead Electrical Lines Exceeding AC 1 kV** By Stanislav Ilenin, Ladislav Varga*

models should be tailored to the utilities based on data available and previous experiences of the utilities.

Future considerations

Esri is developing Alpha version of LiDAR analytic tools that will be integrated in future version of ArcPro software, for a more flexible way of building models based on LiDAR data. This could leverage GIS software like Esri to handle LiDAR analysis with more efficiency.

The 3 tools that are currently in alpha version are,

1. Create initial 3D catenary
2. Line adjustments
3. Line sag correction

1. Create initial 3D catenary: This tool takes as input attachment points and creates 3D catenaries between the points using default sag for each line. This tool is handy when the user only has attachment points and nothing else. It will create catenary lines, as illustrated in **Error! Reference source not found.**.

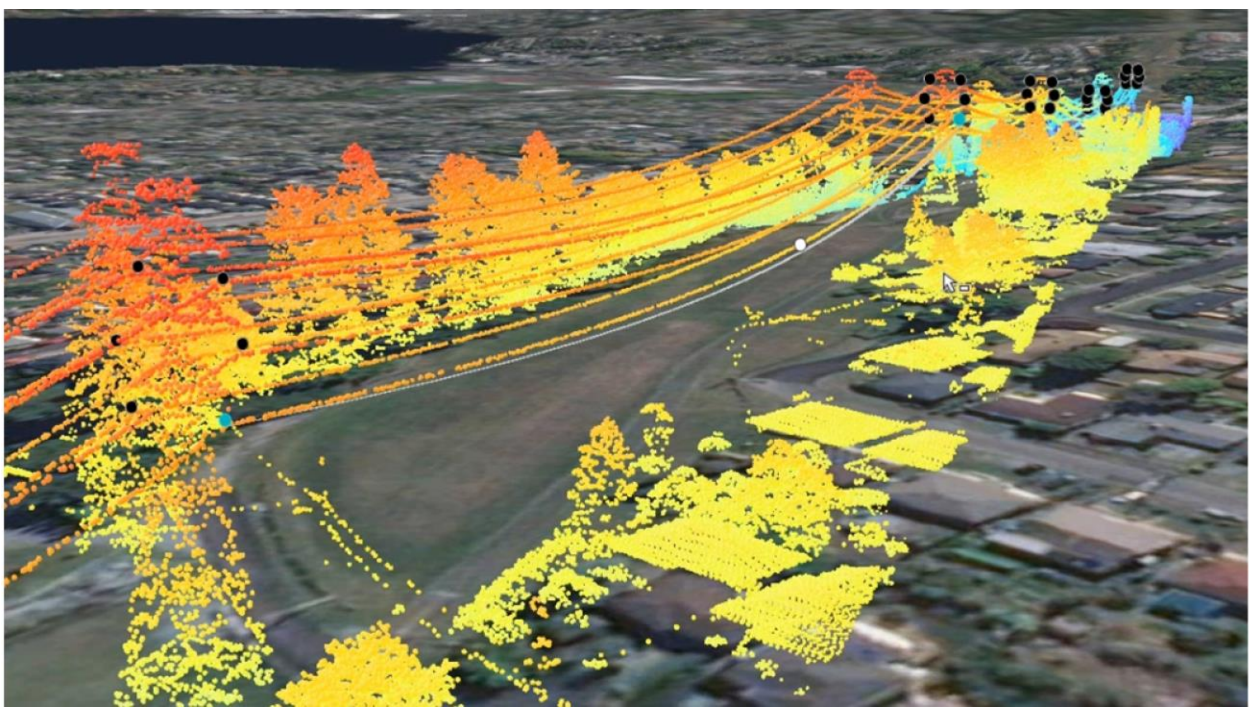


Figure 2-23. Initial catenary

2. Line adjustments: Line adjustments can be made that will allow the user to manually adjust 1 line per span to the LiDAR data (if they have that), giving a sag adjustment factor, which then can be used to improve the sag of the other lines in the span. **Error! Reference source not found.** represents the adjustment of lines as a result of the processing.

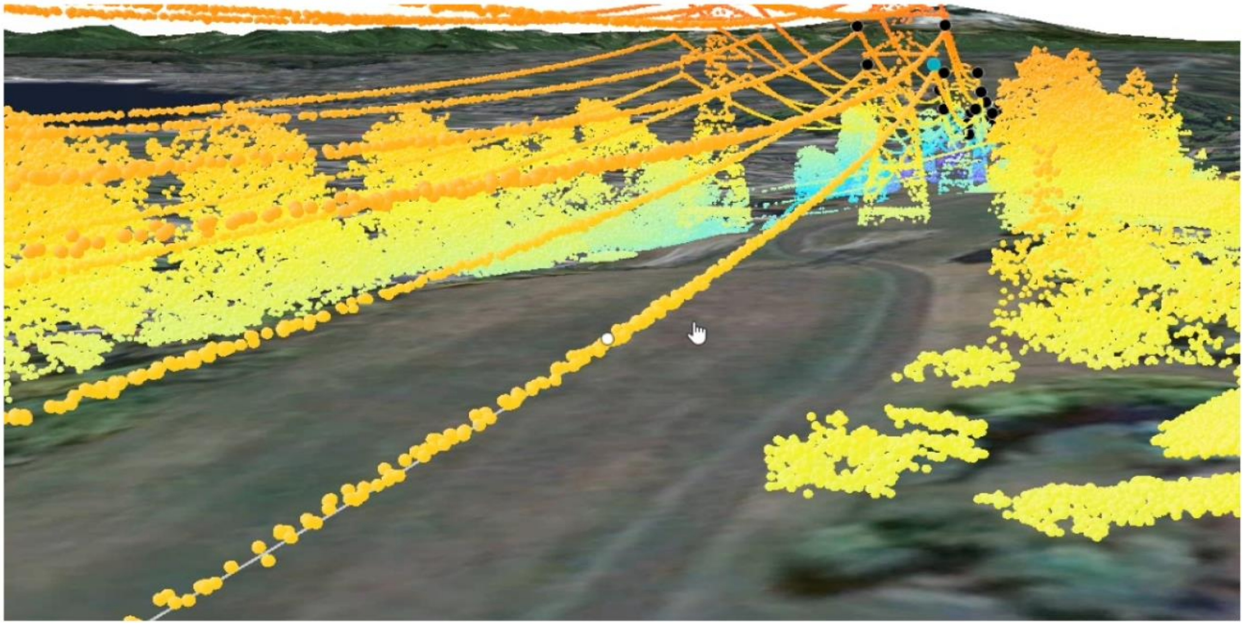


Figure 2-24. Line adjustment

3. Line sag correction: This tool will allow the user to enter wire information, tension information, for automatic calculation of correct sag by calculating line sway. The modelling of the tool by creating a mesh with the sway as radius to find LiDAR points intersecting, is demonstrated below in Figure 2-25

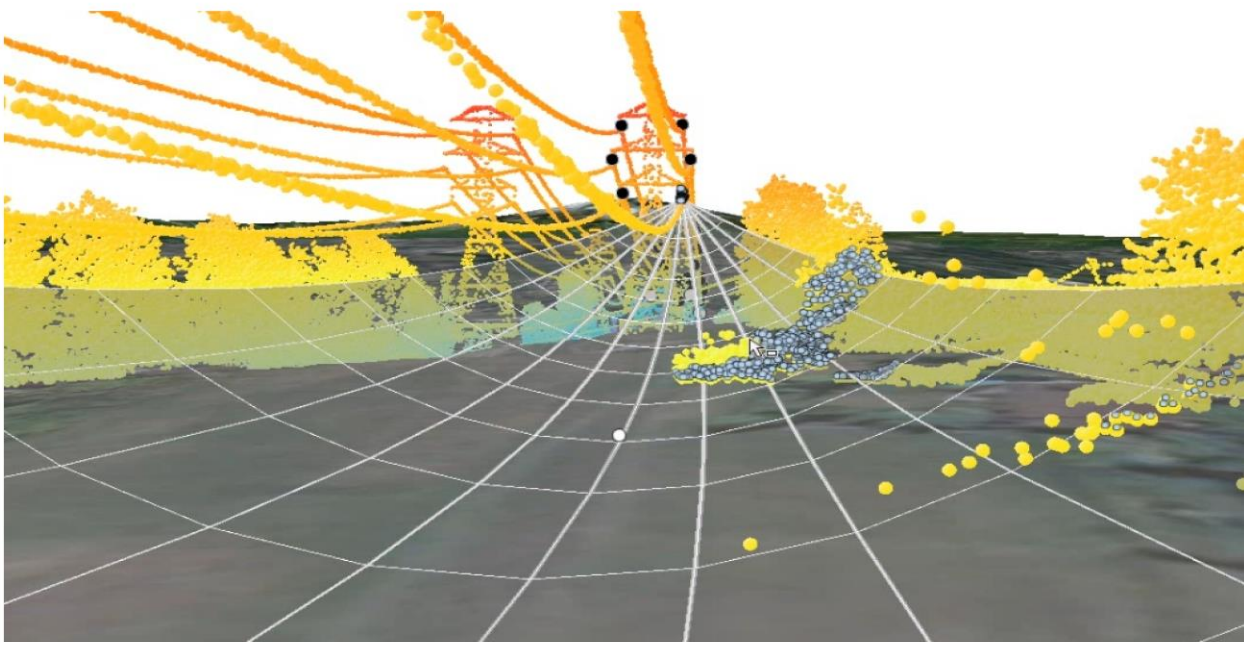


Figure 2-25. Modeling line sway and calculation of LiDAR points that might interfere.

The diagrams Figure 2-23 through Figure 2-25 represent the results of the tools using synthetic data and the figures do not reflect SDG&E data. The development of these tools will enhance the quality of prediction models in GIS. The level of detail that can be achieved and the reliability of the prediction models demonstrated in the use case will increase. As these tools reduce the burden of programming pre-modelling data preparation of the LiDAR data.

Recommendations

- The initial effort to stitch the data and clean the data for any outliers or recalibrate misclassified data, is considerable. More automated processes will help reduce the time required for this initial setup.
- The algorithms need to be fine-tuned by testing against real time data.

2.5 GIS Visualization Infrastructure Modernization (UC 5)

2.5.1 Background

At San Diego Gas and Electric (SDG&E®), the GIS technologies currently implemented for visualizing assets and electrical connectivity as 2D circuit maps and schematics are being considered for upgrade to latest technologies to explore the new functionalities.

Over the last few years, the GIS-specific technologies, and broader technologies with a potential to impact GIS visualization, have seen significant transformation. The most notable of these changes are:

- More expressive utility network modeling capabilities that allow for a more comprehensive details capture, as well as more powerful and functional engines that process these models
- Hardware virtualization
- GPU processing
- Software component interfaces via Web Service architecture
- Web browser functionality for viewing, editing, and tracing electric networks
- 3D maps that can support augmented and mixed reality consumption
- Real-time data from drones, Internet of Things (IoT), and smart devices
- Open source technologies
- Machine learning

It is inevitable that at least some of these advancements will find a way to improve GIS visualization capabilities in the industry at large and at SDG&E® in particular. With a view toward inevitability of improvements in the SDG&E® GIS capabilities through accommodations of more advanced GIS and GIS-related technologies, SDG&E® envisions a need to research and identify those modernizations in the industry (including hardware, software, data model, connectivity, and databases) that can help to better support SDG&E® visualization of asset maps and schematic diagrams, both in the office and in the field. The specific modernizations of interest are:

- **Hardware:** Modernize CPU with GPU processor
- **Virtualization:** Modernize Citrix with VM Ware
- **Software:** Modernize 32-bit ArcMap with 64-bit ArcGIS Pro
- **Architecture**: Modernize direct database transactions with services-based transactions

- **Data Model:** Modernize the current Electric data model with Utility Network data model
- **Data Content:** Modernize asset content by reducing abstraction from field and as-built conditions
- **Connectivity:** Modernize Geometric Network with Utility Network
- **Database:** Modernize Oracle
- **Apps:** Modernize front-end Web technology with Node.JS-based technology

These examinations will require significant effort, spread over time. Examinations within this use case constitute a beginning of this effort and have as its objective a subset of the required activities as listed in the next section.

2.5.2 Objective

The objective of Use Case 5 was to conduct an initial investigation of hardware and GPU virtualization, the digital model for electric network/connectivity in GIS, as well as options to modernize the front-end Web technology.

2.5.3 Users

- GBS – GIS Business Solutions
- T&D Engineering
- Electric T&D Construction

2.5.4 Solution Components, and Approach

2.5.4.1 Solution Components

- GPU Hardware Appliance
- GIS Desktop Software (ArcGIS Pro)
  - Avineon Model Manger Add-In for ArcGIS pro
- Avineon GN2UN Tools
- GIS Server and Portal Software (ArcGIS Enterprise)
- ArcGIS Web AppBuilder Software widgets
- Web AppBuilder widgets for ArcGIS
  - Net Explorer by Avineon

2.5.4.2 Solution Approach

Hardware and Virtualization

As part of the EPIC technology demonstration, SDG&E® through Avineon used ArcGIS Pro and Esri Utility Network (UN) together with a Hypervisor hardware/software appliance equipped with NVIDIA GRID technology. In other words, a virtual desktop and virtual application approach was used to provision the new GIS and network utility model.

The Hypervisor is a powerful server that is used for running Virtual Machines (VM) to deliver the ArcGIS Pro application to the end users. At SDG&E®, desktop GIS users use the VMware ESXi 6.0. At the Hypervisor Operating System level, the VMware ESXi is an operating system running its own kernel that manages the desktop VM. A VMware product known as vSphere allows for an administrator to provision and manage the VM. In vSphere, administrators can configure and allocate vGPU (virtual Graphics Processing Unit) for the VM pool.

For the EPIC demonstration project, SDG&E® acquired two Tesla M60s to make up the NVIDIA GRID GPU portion of the Hypervisor appliance, allowing for a total of 16 GB of DDR5 VRAM (Video RAM) (8 GB's per GPU). NVIDIA's GRID vGPU Manager allows administrators to create 1-GB through vPC license, 2-GB, 4-GB, or 8-GB through vWS license, vGPU's for the Virtual Desktop pools. The respective profile details for vPC and vWS licenses are outlined in **Error! Reference source not found.**, Figure 2-27

For load testing, the following ratios are estimated: 1 GB = 16 Virtual Machines, 2 GB = 8 Virtual Machines, 4 GB = 4 Virtual Machines and 8 GB = 2 Virtual Machines. Using the various profiles, SDG&E® plans to obtain performance metrics to help understand user density optimizations. For this EPIC demonstration, the configuration applies to the VMware products ESXi, vSphere, and Horizon View.

At a high level, the diagram (Figure 2-28) from NVIDIA illustrates how it works.

GRID Virtual GPU	Intended Use Case	Frame Buffer (Mbytes)	Virtual Display Heads	Maximum Resolution per Display Head	Maximum vGPUs per GPU	Maximum vGPUs per Board
M60-1Q	Power User, Designer	1024	2	4096×2160	8	16
M60-0Q	Power User, Designer	512	2	2560×1600	16	32

Figure 2-26. vPC profile details

GRID Virtual GPU	Intended Use Case	Frame Buffer (Mbytes)	Virtual Display Heads	Maximum Resolution per Display Head	Maximum vGPUs per GPU	Maximum vGPUs per Board
M60-8Q	Designer	8192	4	4096×2160	1	2
M60-4Q	Designer	4096	4	4096×2160	2	4
M60-2Q	Designer	2048	4	4096×2160	4	8

Figure 2-27. vWS profile details

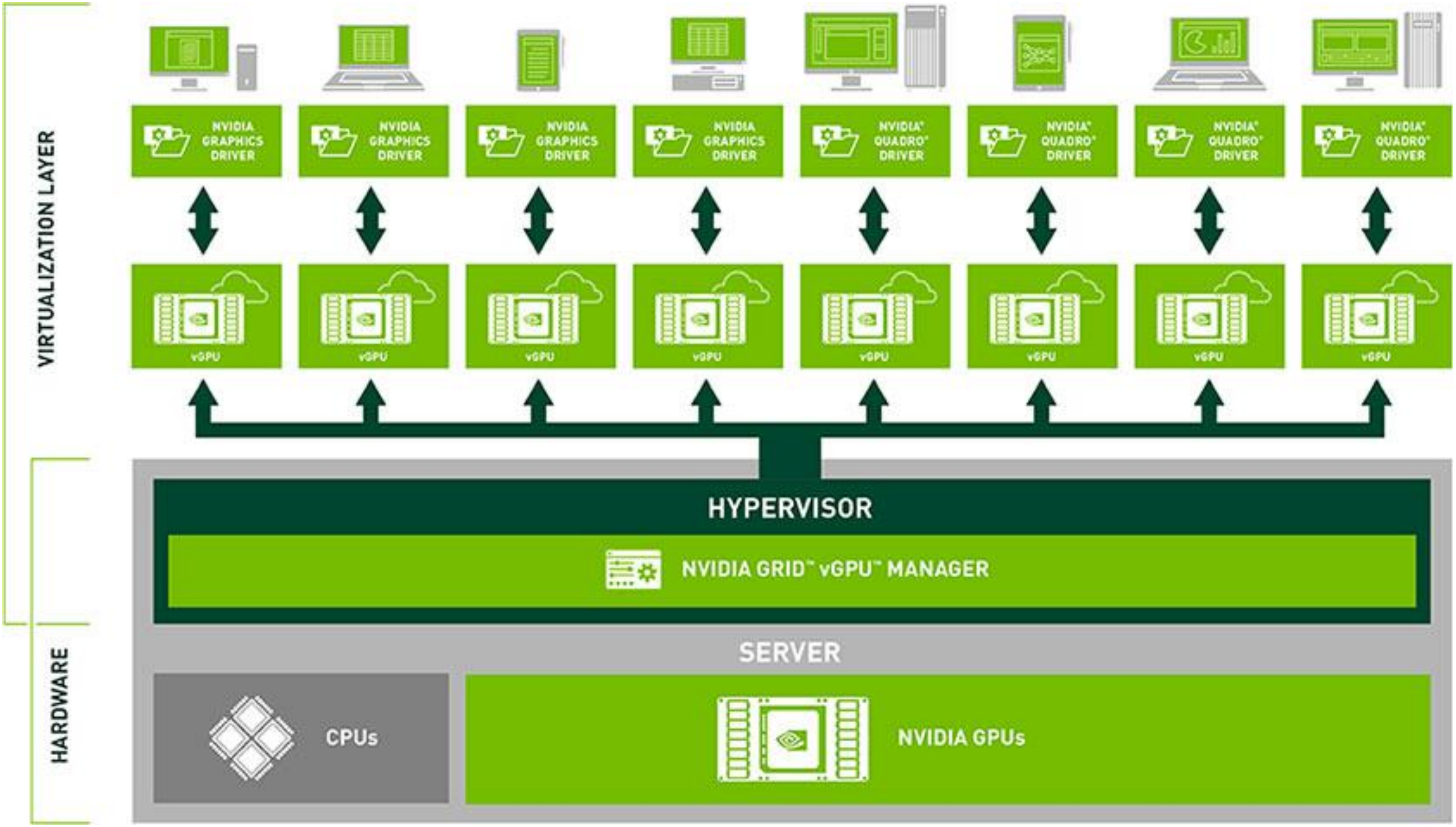


Figure 2-28. Virtualization of GPUs

VDI versus Terminal Services Discussion

As noted, the GPU server Hypervisor servers can also be supported on the VMware or the comparable Citrix environments (XenServer and XenDesktop). Currently at SDG&E®, the electric GIS desktop is deployed using a Citrix XenApp (terminal services) approach. From the business user's perspective, they are accustomed to using several applications at the same time. For productivity, their preference is to access multiple applications using the same virtual desktop window. To satisfy this need, using the XenDesktop approach would require the various applications that would require a different Virtual Desktop images. Additionally, they would need different Virtual Desktop pool deployments to support the different application licensing. With XenApp, it is not possible to simply add all applications into one image to meet each of the user needs.

From an IT perspective, the preference is also to deploy a desktop using the Citrix XenApp application virtualization rather than XenDesktop (VDI). The XenApp allows the teams to rapidly deploy GIS updates. From the Citrix administration standpoint, dealing with the client image management and non-GIS applications users' need is of less of concern.

For the EPIC technology demonstration, the focus was on VDI deployment. Via discussions with the technology vendors, it was found that using XenApp paired with ArcPro resulted in reduced application performance. This was not a Citrix limitation or an issue with ArcGIS Pro but rather the Server Operating System (Microsoft Windows). In a XenApp scenario, one typically assigns a vGPU to a Virtual Server. When a user launches an instance of ArcGIS Pro via XenApp, a session is created on the Virtual Server with no resource allocation guarantee for users. Essentially, what ends up happening is, as users spin up sessions on the Virtual Server via XenApp, the Frame Buffer (a portion of the VRAM for storing bitmaps which make up screen display to the user) runs out of memory. After about four users, XenApp Server reaches a state of reduced performance.

This will be something that SDG&E® needs to consider in the future because the current deployment relies on XenApp. With the expected production deployment of ArcPro and Esri Utility Network several years away, it is hoped that there will be sufficient time to design a strategy to deliver Virtual Desktops to GIS users that present them with a good experience.

2.5.4.3 Software, Architecture and Apps

Desktop Software and Architecture

The ArcGIS 64-bit ArcGIS Pro desktop software to modernize the current 32-bit ArcMap along with services-based transactions were investigated for analyzing, viewing and editing the digital model. This investigation was performed using one distribution circuit (520) and two transmission lines in SDG&E's service territory. It included the configuration and testing of following out-of-the box capabilities in ArcGIS Pro, as illustrated in the **Error! Reference source not found.**

1. Network Topology
2. Associations (Connectivity, Structural Attachment and Containment)
3. Advanced Network Tracing
4. Network Diagrams
5. Subnetwork Management

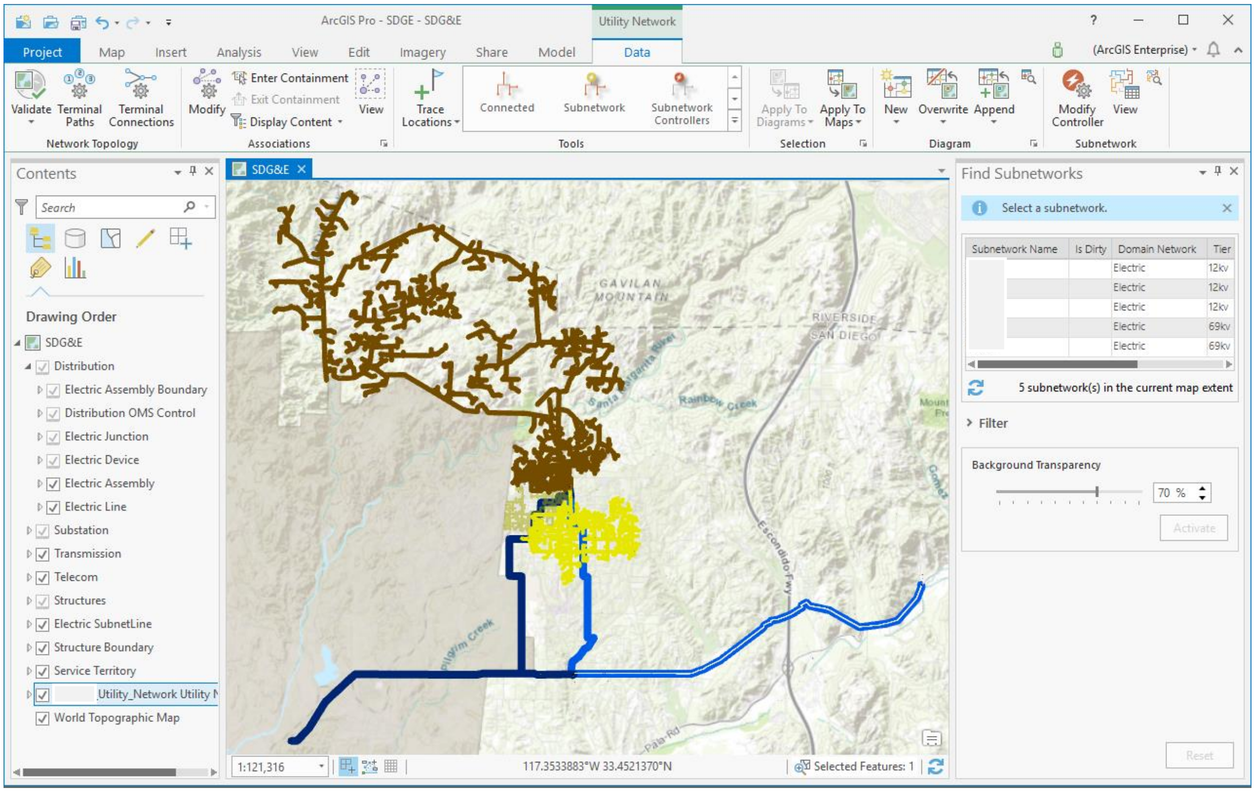


Figure 2-29. Out-of-the box capabilities of ArcGIS Pro for Utility Network model

The out-of-the box ArcGIS Pro tools for subnetwork controllers, terminal connectivity, network connectivity, non-graphical associations, and containments were tested across the distribution circuit and transmission lines as illustrated in **Error! Reference source not found.**

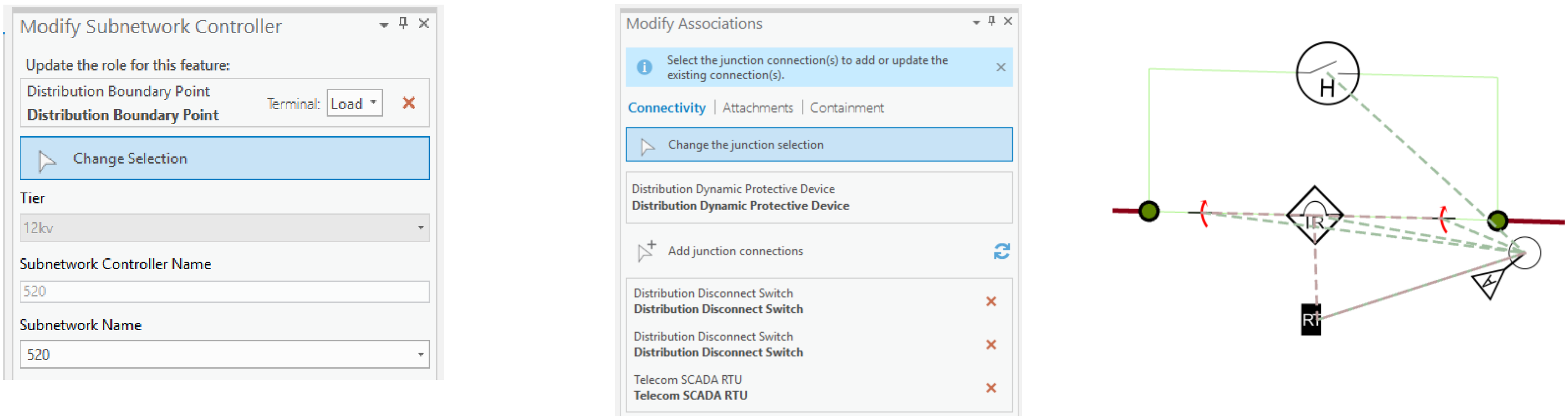


Figure 2-30. Out-of-the box ArcGIS Pro tools

The services-based transactions for visualizing and editing assets data and connectivity within the digital model using ArcGIS Pro were examined and contrasted to the current ArcMap database connected transactions in Figure 2-31.

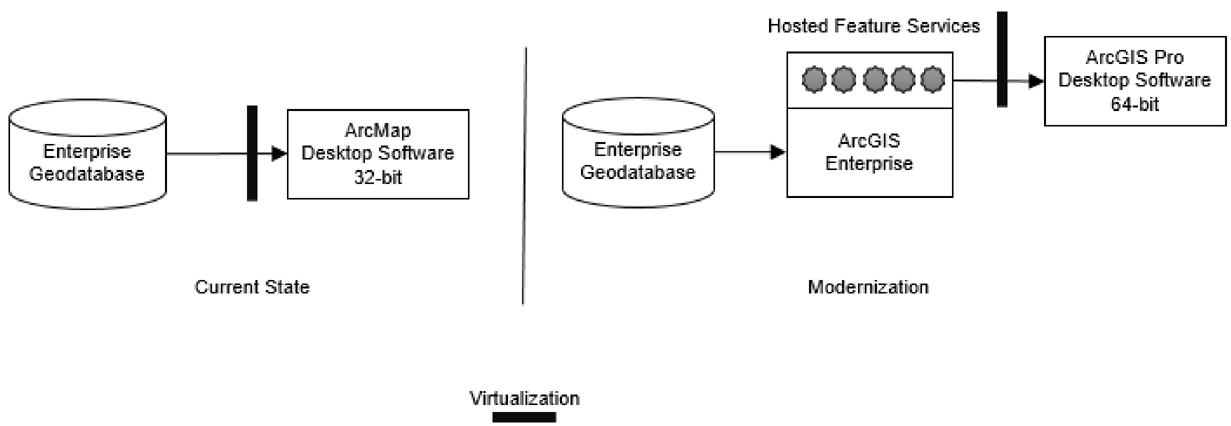


Figure 2-31. Architecture of database editing within Utility Network model

The resulting data model is examined for the individual layer properties to understand the basic differences in the previous data model to utility network data model in the Figure 2-32.

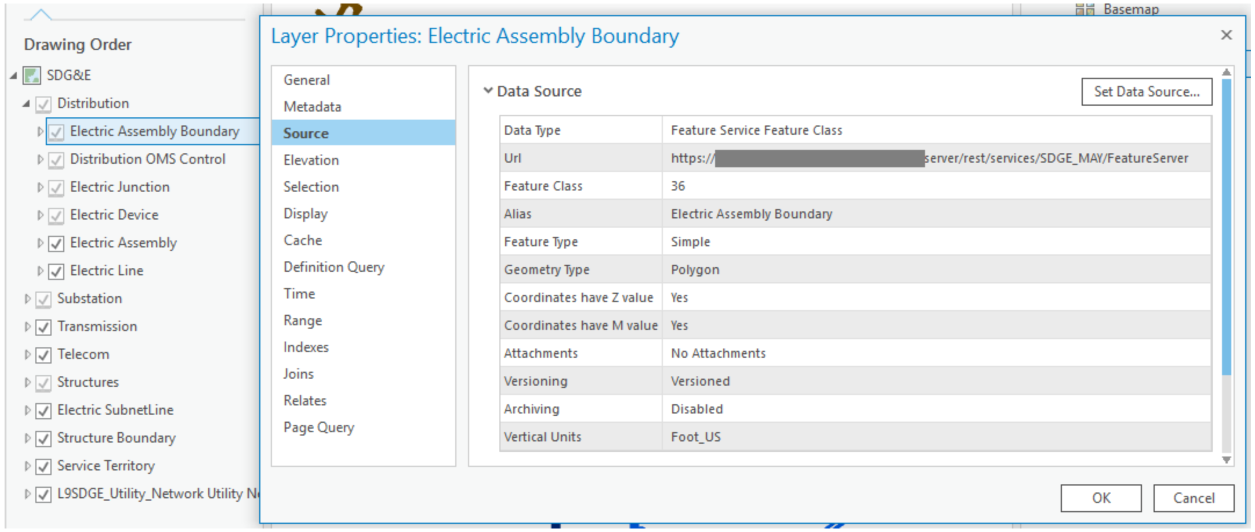


Figure 2-32. Layer properties

The investigation included the effort to examine the generation of Summary Operating Map (SOM) diagram for a circuit as illustrated in **Error! Reference source not found.**. A preliminary analysis for modernizing the current SDG&E® custom schematic diagrams capabilities with the modern network diagrams capabilities was conducted.

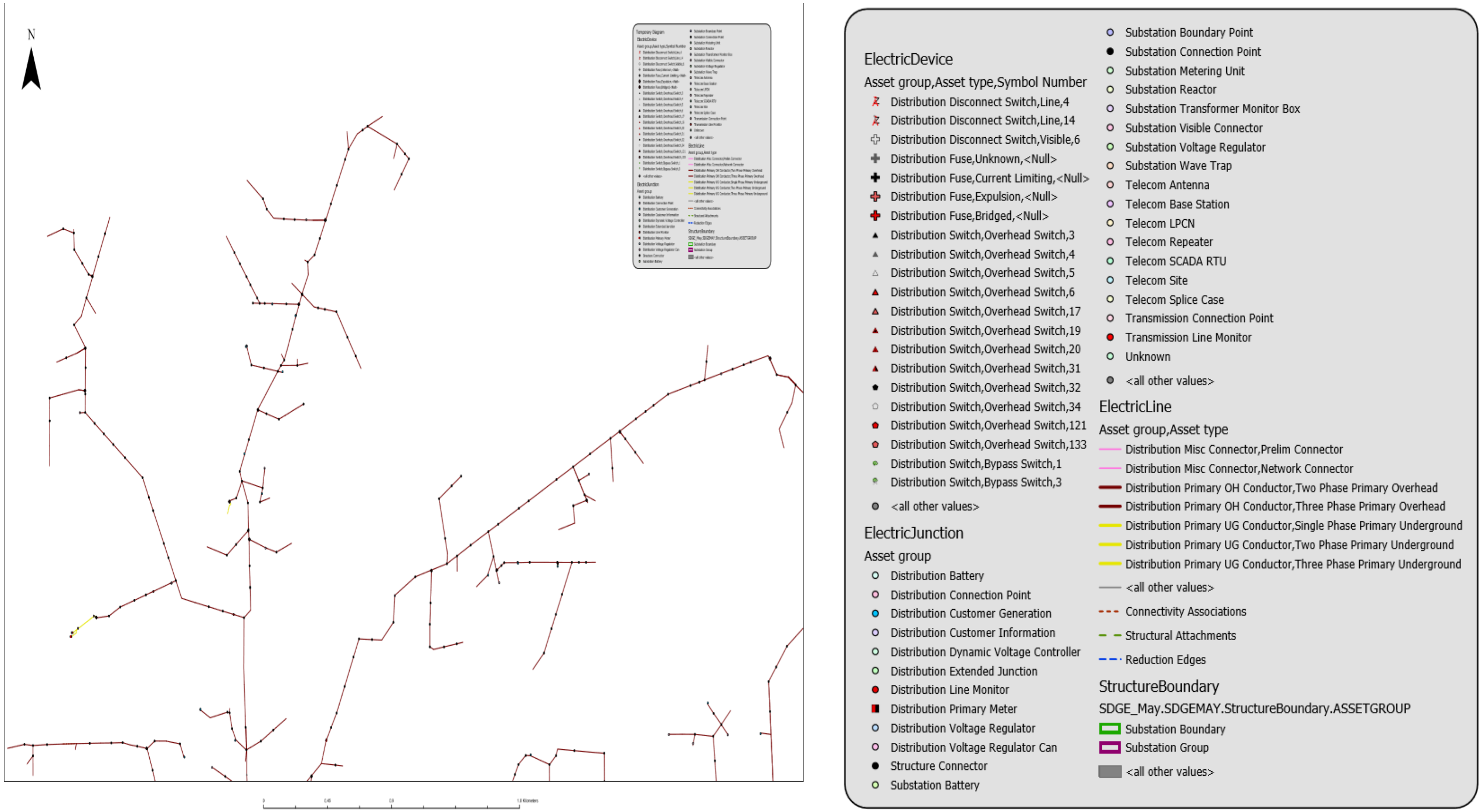


Figure 2-33. SOM diagram and legend of the circuit

Front End Web Technology

ArcGIS Web AppBuilder is used to develop the web application and was used to test the visualization and analysis of electric network from web browser. The Javascript widgets (Node.JS) were utilized in place of legacy Microsoft Silverlight technology within the web application. The 2D ArcGIS widget library served as the primary source for examining the data visualization and analysis functionality for front end web application. In addition, the NetExplorer widget from Avineon demonstrated an opportunity to modernize Silverlight technology.

NetExplorer

NetExplorer widget is used in this use case to trace, visualize, and report on electric/gas/water networks within GIS web application. The widget supports electric tracing in geometric network connectivity (current state at SDG&E®) as well as the modernized state (utility network connectivity).

Similar to the tracing functionality available in desktop GIS, this web widget provides the following functionality for users to perform:

a) One-Click traces
b) Specify starting points and stopping points (optional) and run traces as demonstrated in Figure 2-35

The key capabilities of this widget are:

1. Select Trace to Run
2. Key In Parameters
3. Select Stopping Points (optional)
4. Run the Trace
5. View Summary of Trace Results
6. Summarize Trace Results By Fields of Interest
7. Interact with Trace Results
8. Save Trace Inputs for Reuse
9. Select Network to Trace
10. Specify Trace Task
11. Specify Starting Points for the Trace
12. Specify Trace Options

When a trace is run the results are displayed along with related features if the ‘Show Related’ on Output tab shows related information for the selection. In the ‘Details’ tab, there is an option to display related records by features. The results can be saved with a name and shared with other users.

The configuration of this widget is demonstrated in Figure 2-34

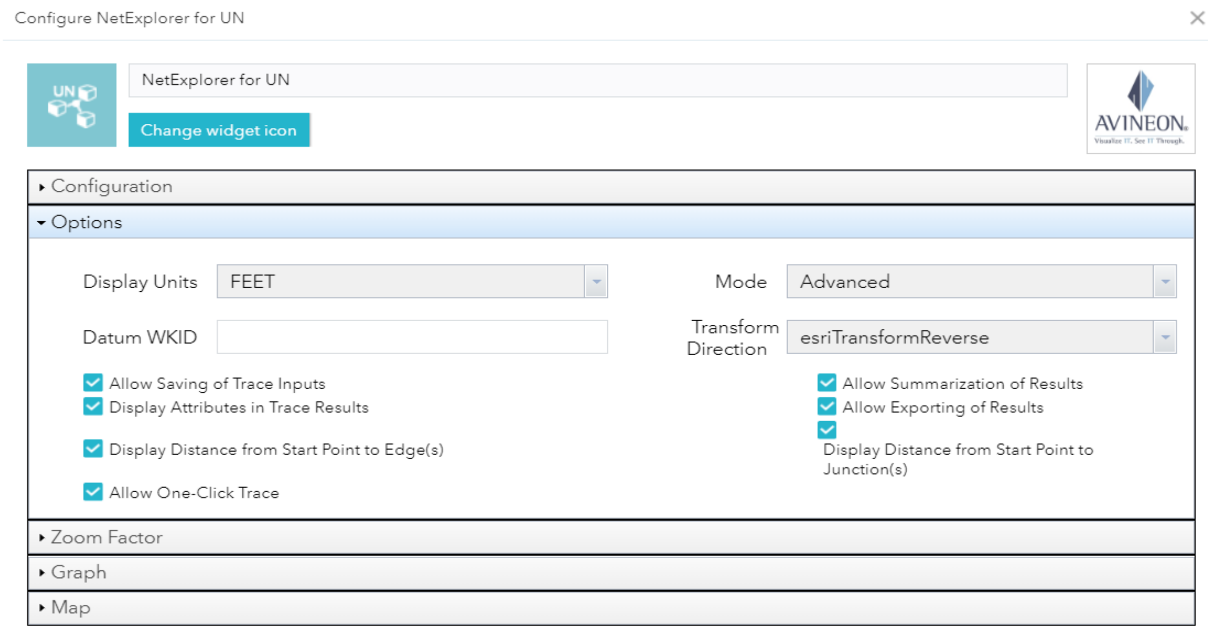


Figure 2-34. Configuration of the NetExplorer widget

The trace results displayed on the map are summarized by each GIS layer as demonstrated in Figure 2-36. The trace results are also available for deeper interrogation and analysis. The widget have ability to publish re-usable trace libraries for end users such as Network Off an Asset, Protective and Isolation Devices, etc.

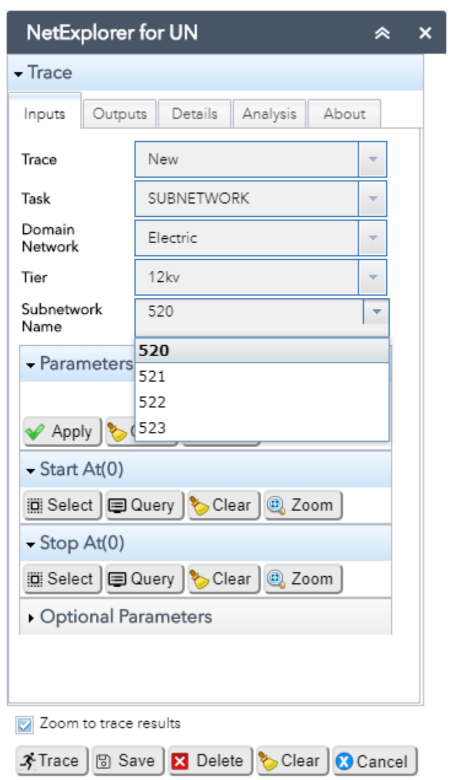


Figure 2-35. Input parameters for NetExplorer widget for utility network

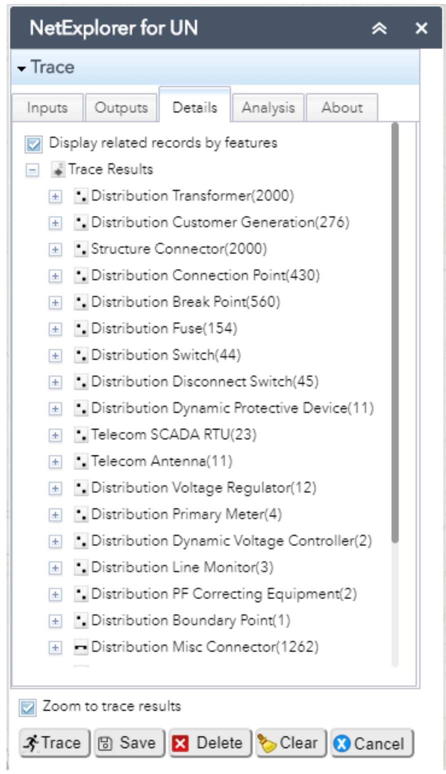


Figure 2-36. Displaying results for the tracing utility network

Figure 2-37 illustrates the use of NetExplorer widget for subnetwork and downstream tracing, the ability to highlight the results in a map view and interact with them through a tree view.

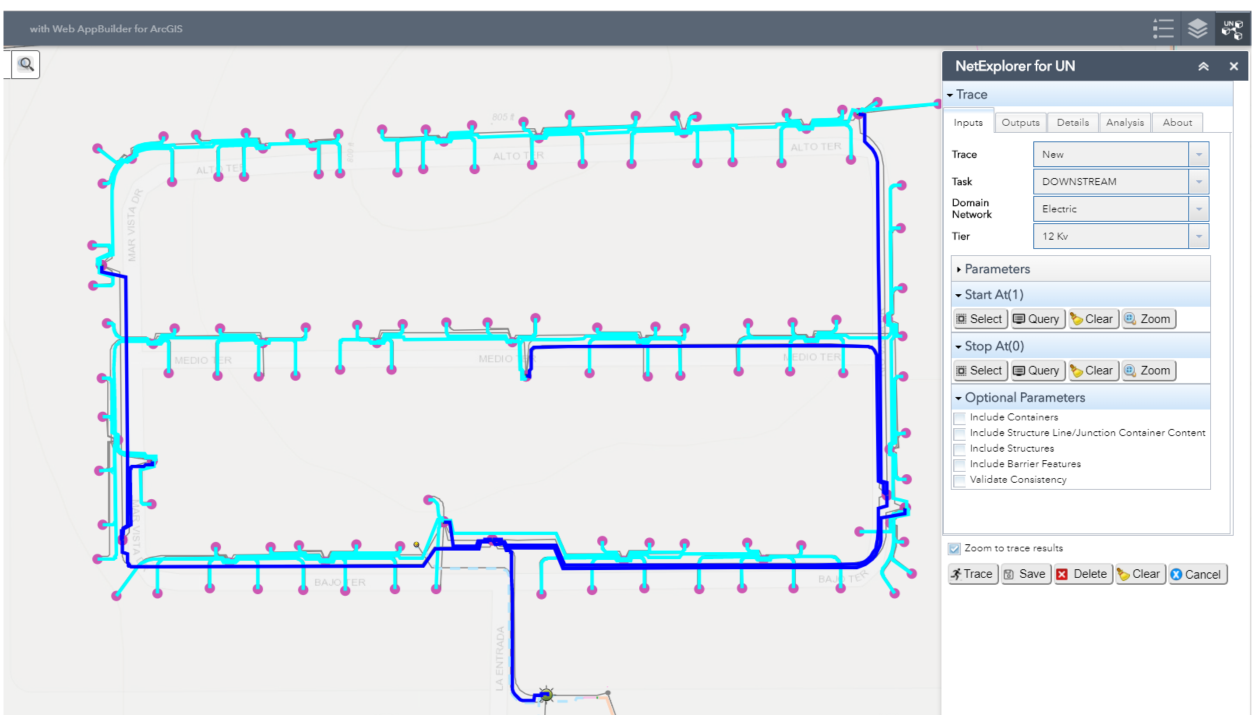


Figure 2-37. Displaying trace results on map

The results of asset connectivity are easy to visualize, along with interface to interact with trace results in

a) Map View
b) Tree View
c) Graph View
d) Summary Tables

The widget provides functionality to visualize network connectivity as graphs illustrated in Figure 2-38. This capability enables condensed view of network connectivity spread across a large geographic area.

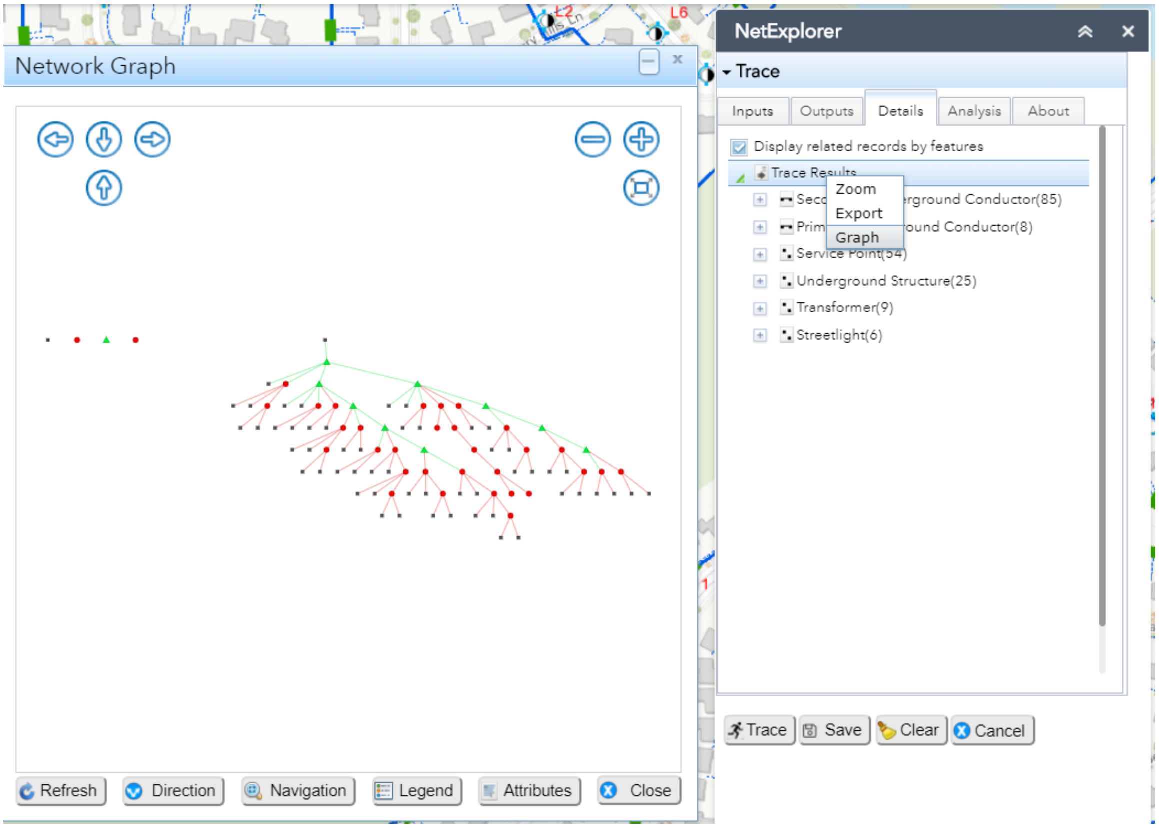


Figure 2-38. Display Trace Results as Graph

This widget also provides user the choice to select the fields of interest compute asset summaries such as length of cable of phase and type, switch count by type, etc. as illustrated in Figure 2-39.

Results Summary

Name	NOMINALVOLTAGE	OPERATINGVOLTAGE	YEARMANUFACTURED	SWITCHSTATUS	SWITCHTYPE	Measure
D Boundary Point	...	...	...	...	...	1
Dynamic Protective Device	...	...	...	...	...	8
Primary Overhead Conductor	...	...	...	...	...	15 | 4187.5 FEET
Primary Underground Conductor	...	...	...	...	...	19 | 5846.4 FEET
Switch	12	12.0 kV	null	Do Not Operate Energized	Switch Position	1
Switch	12	12.0 kV	null	Not Applicable	HOOK STICK	1
Switch	12	12.0 kV	null	null	HOOK STICK	1
Transformer Device	...	...	...	...	...	2
Customer Information	...	...	...	...	...	2

Export Close

Figure 2-39. Summarize Trace Results

2.5.5 Results

Data Model, Data Content, Connectivity and Database

The SDG&E® electric GIS data model, data content, and connectivity based on geometric network technology has many customizations and went through incremental upgrades over the years.

The ArcGIS Utility Network technology offers new modeling capabilities for modernizing the digital model in GIS and leverage the platform capabilities for the Smart eco system use cases. A robust foundation based on current age technology is essential for GIS to integrate with technologies such as Mixed Reality, ADMS, IoT, Machine Learning, Digital Assistant, Drones, etc. to support the following use cases in the future:

- Modeling controlling and communication equipment for DER
- Modeling energy storage equipment
- Integration of secondary voltage data
- Visualization for augmented reality applications
- Inputs and outputs for unmanned aircraft systems

A detailed analysis of the current electric GIS data model was performed to examine the opportunities for modernization, the foundational digital network/connectivity model using ArcGIS Utility Network Management technology. This effort resulted in the identification and testing of following capabilities:

1) Modeling Transmission, Substation and Distribution into contiguous connectivity model
2) Modeling Tiers By Voltage
3) Modeling Asset Groups for Transmission, Substation, Transmission, Telecom and Distribution
4) Modeling Asset Types within each Asset Group
5) Modeling Associations in place of Relationships
6) Modeling Rules for Asset Connectivity and Data Quality
7) Modeling Representative Network Attributes, Categories and Propagators

These modeling optimizations have resulted in a leaner, richer, capable, and performant digital model with 115 asset groups and 160 asset types for SDG&E's electric system. Over 2500 rules matching the current environment were established to govern asset connectivity and manage the integrity of data in the new digital model. This analysis has demonstrated the potential for following improvements in the data model:

1) Up to 85% Reduction in Feature Classes
2) Up to 41% Reduction in Object Classes
3) Up to 90% reduction in Database Relationships
4) Up to 70% reduction in fields

These modeling choices are examined using Utility Network Toolbox in ArcGIS Pro. The Model Manager ArcGIS Pro Add-In illustrated in Figure 2-41 through Figure 2-43. was used for this purpose.

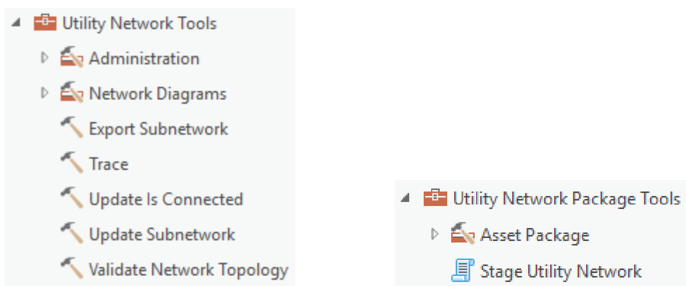
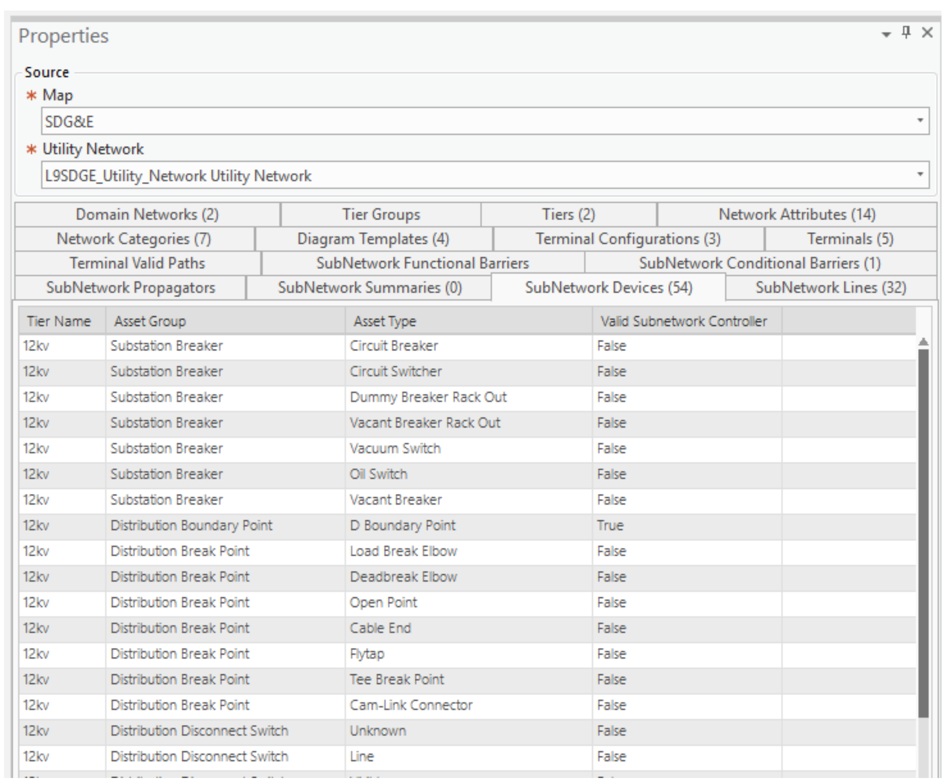
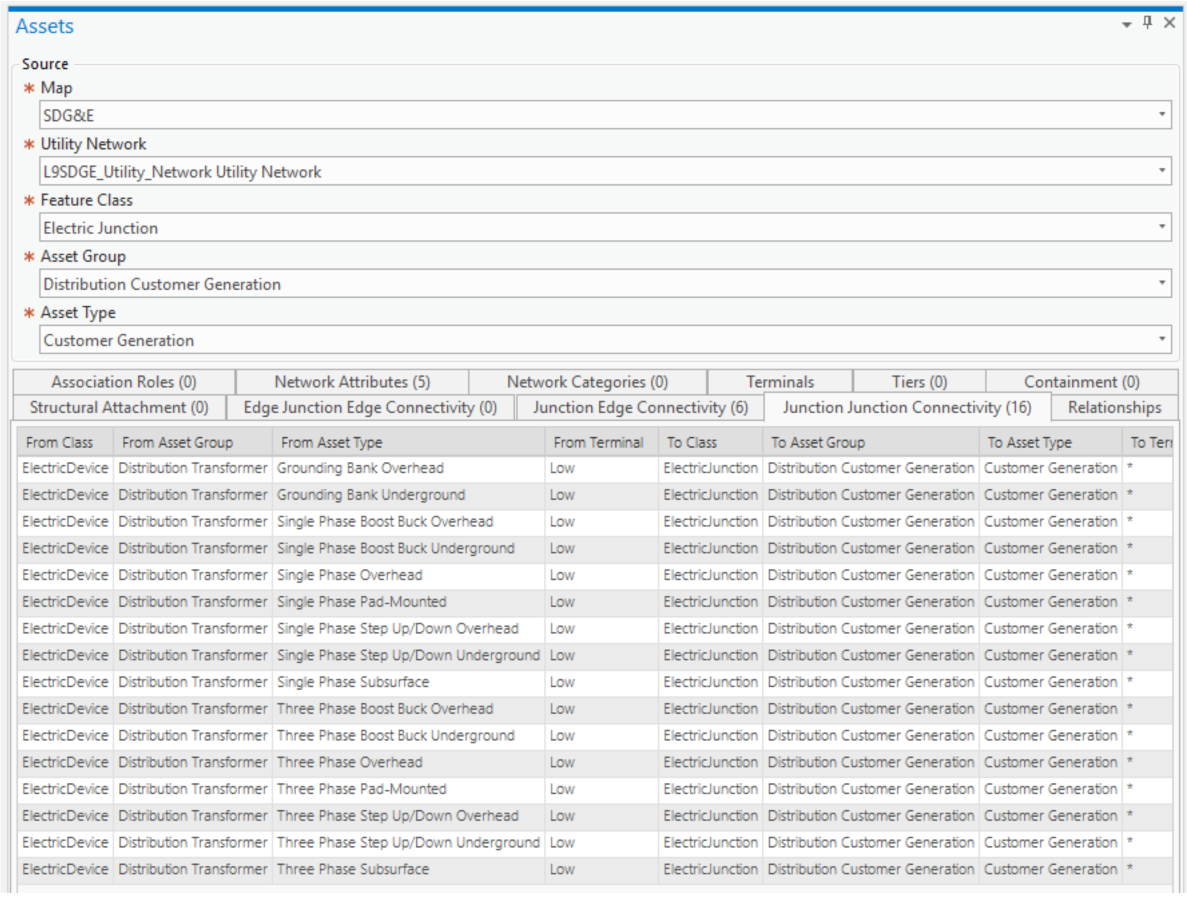


Figure 2-40. ArcGIS Pro Utility Network Toolboxes



Tier Name	Asset Group	Asset Type	Valid Subnetwork Controller
12kv	Substation Breaker	Circuit Breaker	False
12kv	Substation Breaker	Circuit Switcher	False
12kv	Substation Breaker	Dummy Breaker Rack Out	False
12kv	Substation Breaker	Vacant Breaker Rack Out	False
12kv	Substation Breaker	Vacuum Switch	False
12kv	Substation Breaker	Oil Switch	False
12kv	Substation Breaker	Vacant Breaker	False
12kv	Distribution Boundary Point	D Boundary Point	True
12kv	Distribution Break Point	Load Break Elbow	False
12kv	Distribution Break Point	Deadbreak Elbow	False
12kv	Distribution Break Point	Open Point	False
12kv	Distribution Break Point	Cable End	False
12kv	Distribution Break Point	Flytap	False
12kv	Distribution Break Point	Tee Break Point	False
12kv	Distribution Break Point	Cam-Link Connector	False
12kv	Distribution Disconnect Switch	Unknown	False
12kv	Distribution Disconnect Switch	Line	False

Figure 2-41.Utility Network Properties in Model Manger



From Class	From Asset Group	From Asset Type	From Terminal	To Class	To Asset Group	To Asset Type	To Ter
ElectricDevice	Distribution Transformer	Grounding Bank Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Grounding Bank Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Boost Buck Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Boost Buck Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Pad-Mounted	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Step Up/Down Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Step Up/Down Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Subsurface	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Boost Buck Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Boost Buck Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Pad-Mounted	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Step Up/Down Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Step Up/Down Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Subsurface	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*

Figure 2-42. Asset Properties viewed in Model Manger

The investigation included the analysis of data loading, viewing, editing, analysis workflows spanning:

1) 16590 Devices
2) 351 Assemblies
3) 24963 Junctions
4) 40464 Line segments
5) 17269 Structures
6) 22817 Structure Line Segments
7) 6 Structure Boundaries

The non-graphical objects in the digital model such as transformer units are modeled as graphical objects that fully participate in the network connectivity. The data model/data modernization workflow illustrated in Figure 2-43 was utilized for creating the visualization model for the distribution circuits and Transmission lines using ArcGIS Toolbox and GN2UN Tool.

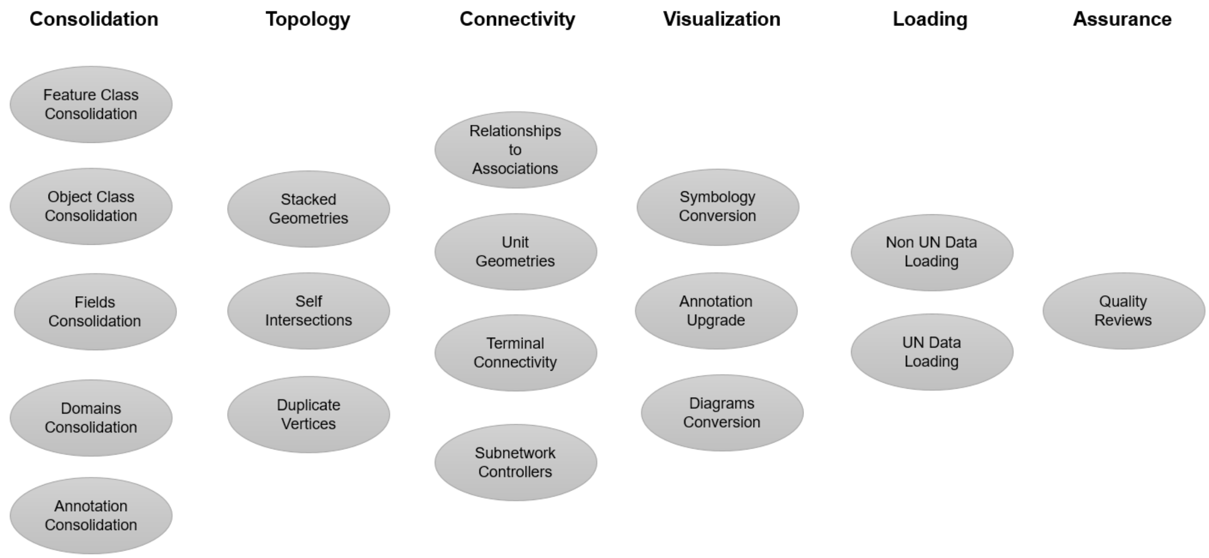


Figure 2-43. Data Model/Data Modernization work flow

2.5.6 Observations, Challenges, and Lessons Learned

<u>Observations</u>

- Modernization of GIS offers following benefits:
    - Robust digital model capable of integrating with technologies such as ADMS, SCADA, IoT, Machine Learning, Virtual Reality, Digital Assistant etc.
    - Out of the box capabilities to perform network editing from web and mobile applications
    - Reduce timelines and operational costs to upgrade to newer releases of GIS software is expected
    - Increased demand on server infrastructure for processing web/feature service loads
    - Reduced demand on virtualization and desktop software
- ArcGIS Utility Network Technology has improved considerably during the course of this investigation. At a minimum, the following capabilities need further examination as the technology continues to offer advancements and choices for:
    - Modeling transmission system
    - Modeling conduits and ducts
    - Modeling and Visualizing As Switched Vs As Built
    - Modeling and Visualizing Active Vs. Prelim
    - Modeling and Visualization Work History
- The technology provides flexibility for phasing the modernization by:
    - View and Analysis Use Cases
    - Desktop Editing Use Cases
    - Web and Mobile Use Cases
    - Integration Use Cases

<u>Challenges and Resolutions</u>

- SDGE will have to perform analysis of new Utility Network models to see what new capabilities can be leveraged and how to migrate existing data model to the new data model. A pilot approach before full-scale implementation is definitely useful.

- Currently, geoprocessing is slow when the new full-facility models are used (some other use cases within this project even used simplifications of the existing, old asset models to speed up rendering to an acceptable level for those use cases, and the new models are significantly more complex, with the corresponding effect on rendering speed). Therefore, an objective of this use case was to assess if and what new virtualization-based HW platform improvements are required to be able, in the future, to configure an environment for SDG&E® users with sufficient performance for GIS rendering of new models.
- The solutions exercised in this use case are based on brand new components (e.g., some of the components are in beta release), with little experience in the industry to draw from.
- This is still a work in progress relative to the larger scope of modernizing SDG&E® GIS infrastructure, but the completed results of this use case have produced initial observations and experiences that will be leveraged in the ongoing efforts on this subject.
- The typical User Experience for Enterprise GIS at SDG&E® scaled solutions has not met user's expectations. With a complex GIS data model utilized at SDG&E®, the application response time has been a known limitation. Moving to next level of using new Esri platforms ArcGIS Pro for building 3D applications will increase workloads for backend processing components such as servers, graphic cards and memory utilization. Using the new system architecture will benefit the performance at enterprise level.
- SDG&E® is still working on establishing the modern architecture. Due to the amount of time required to complete the deployment of servers it is considering as an option for future use. Having explored the limitations, and performance of model architecture through technology vendors, provided scope for SDG&E® to decide on the future for such architecture at SDG&E®.

Lessons Learned

- The electric industry package from Esri served as a good reference. It was not adequate to fully model the SDG&E®electric network.
- This investigation provided opportunity to examine some of the opportunities and the general path for modernization. It also identified the areas that require a deeper analysis to fully quantify and understand the business impact and value for the longer term.
- The ArcGIS Utility Network Technology offers many modeling choices, the evaluation and selection of which requires methodical and diligent analysis of data, applications, interfaces, and user experience center around existing uses cases as well newer use cases focused on spatially driven digital experiences for consumers. Such an effort center around innovation is crucial towards defining the full business value for electric consumers from modernizing GIS.
- Information Technology teams need to understand performance, scaling and system architecture patterns to support the new Esri platforms.
- There are other applications that would benefit from the specialized graphics cards, primarily the PLS CADD and other 3D applications.

3 KEY ACCOMPLISHMENTS AND RECOMMENDATIONS

3.1 Key Accomplishments

With the solutions demonstrated in the project, the SDG&E® project team has made significant improvements over the state-of-the-art approaches at SDG&E® in each of the areas addressed by the five use cases. The following lists some of the key accomplishments of these efforts:

- Real-time feature updates on maps based on the time varying data from PI has been successfully resolved by the use of OSISoft PI Integrator for Esri ArcGIS and Esri GeoEvent Extension for Server products. This mechanism is reusable and has been extensively used across multiple use cases.
- The team has successfully integrated standard and custom PowerBI widgets within various maps, in combination with other feature layers. In the course of the widget development, the emphasis was placed on the widgets' reuse, resulting in a reuse on multiple use cases.
- Electrical circuits layers are extensively used in some of the use cases. The team has found a way of simplifying the asset models of electrical circuits for an improved (better than an order of magnitude) rendering speed of electrical circuits' layers. Where it was taking in excess of 20 seconds to render circuit layers at the beginning of the project, it now takes an acceptable (sub-seconds) time for the same task.
- All use cases have solutions that produce map updates at speeds compatible with expectations of interactive users.
- SDG&E® has completed an initial setup of GIS web applications to host LiDAR data to compliment imagery utilization effort. Ability to use real time data like LiDAR data with GIS data will lead to more effective use and management of these valuable resources in the future.
- SDG&E® has explored 3D utility network modeling and the associated computing infrastructures needed to support eventual widespread use of this advanced modeling approach. This new modeling approach has the potential to reduce the amount GIS models required to achieve this through previous GIS technologies.

SDG&E® is planning to continue with further refinements and extensions of the demonstrated solutions, especially in response to feedback from operational use. Although the basic architectural solutions are believed to be solid, future developments will need to include periodic assessments of the architecture, a search for more robust implementations where possible, and training of future users.

3.2 Recommendations and Insights

Based on the outcomes of pre-production demonstrations, the results for use cases 1, 2, and 3 are being implemented for commercial purposes. Results of use cases 4 and 5 (Imagery Management and GIS Visualization Infrastructure Modernization) have met the objectives set for each of those use cases; however, in both instances, the nature of the research is vast and the efforts are initial steps to establish ground framework for extensive development and investigation (i.e., the cumulative results of use cases 4 and 5 are not ready for production).

In the course of implementation, each of the use case teams had to overcome certain challenges and each has gained valuable insights from doing so. The most notable insights for each use case follow.

UC 1: Transmission Fault Location

- The labor to create the initial reference layers of electric circuits is significant and should be planned for.
- There is a need to setup a process to "re-digitize" electrical circuit lines any time there is a reconfiguration, or to digitize new lines, with an associated process to reflect the changes in PI.

UC 2: Load Curtailment

- From a development perspective, a replacement for the scraping of web pages with a more direct interface would be desirable.
- From a usage standpoint, the development team is expecting quite a bit of feedback from the managers of Emergency Operations Center after a planned demonstration of the function is presented in the near future.

UC 3: AMI for Operations

- Design custom widgets to be as generic as possible. In this project, that approach has proven to be very helpful, and such an approach is expected to continue to be helpful in future projects
- Allowing the application to be customizable by end-users helps better match system functionality with user needs, and ultimately it helps with adoption of the function

UC 4: Imagery Management

- With the processing speed required for LiDAR data analytics and the limitations of GIS as an evolving software in 3D visualizations especially raster or point cloud visualizations presented challenges
- One of the key efforts is to make LiDAR data available through GIS web applications for wide range of audience. Therefore, the LiDAR data is no more a stand-alone dataset, but is an integral part of GIS systems ready to be part of GIS analysis for broader uses and prediction models.

UC 5*: *Visualization Infrastructure Modernization

- Combining high speed processors like NVIDIA GRID GPUs with advanced data models for GIS like UN models will hold future for simplifying the complex relationships between various components of utilities in GIS databases. This opens doors to many possibilities like 3D data models, improved performance of GIS databases etc.

3.3 Technology Transfer Plan for Applying Results into Practice

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within SDG&E® and across other IOUs, the stakeholder industries and communities. In order to facilitate this knowledge sharing, SDG&E® has been sharing the results of the EPIC SDG&E® Visualization and Situational Awareness Demonstrations project at suitable industry workshops and conferences.

The project team believes that visualization and situational awareness solutions developed in this project will be useful beyond SDG&E®, and, therefore, the solution ideas and lessons learned will continue to be shared with other stakeholders, to promote further advancements of the integration and visualization solutions initiated in this project.

This final report and all other public papers and presentations on this project will continue to be posted on SDG&E's EPIC public website at *www.sdge.com/epic*.

4 CONCLUSIONS

This project examined how data currently unexploited and separately processed at SDG&E® can be integrated and visually presented for strategic use by system operators. The project also demonstrated technical solutions at a pre-commercial level for how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances grid monitoring and situational awareness.

Enhanced monitoring and situational awareness is achieved by providing a geospatial context for a wide variety of operational, historical, and metering data. Consequently, through the numerous use cases undertaken within this project, it has been illustrated how the data commonly used to support diverse business needs at SDG&E® can be combined with geospatial data to significantly enhance insights.

The project has successfully achieved all of its key objectives. In the process, the project team and other SDG&E® stakeholders have gained valuable experience and a solution framework that can be reused to speed up future developments in the area of situational awareness and integration of real-time and geospatial data.

5 METRICS AND VALUE PROPOSITION

5.1 Project Metrics

The project tracking metrics included the milestones in the project plan. Technical project metrics included the completion of the initial specification for a visualization and situational awareness system, the demonstration of a system display mock-up, and the specifications and recommendations regarding adoption by SDG&E®. The primary documentation metric was the delivery of this final report to the California Public Utilities Commission (CPUC).

In addition, major project results were submitted in technical papers and presentations for consideration by major technical conferences and publications.

This section provides more information about the metrics and benefits of the project. The most important benefits are in areas of:

Safety, power quality, and reliability

a. Ability to monitor, visualize, and analyze visualization information can help reduce number of outages, as well as their frequency and duration. Transmission fault location use case is particularly useful for this purpose.
b. Public safety improvement and hazard exposure reduction can also be accomplished by advanced visualization tools. For example, the AMI for operations use case, where the voltage swell, and sag are visually monitored for 19000 smart meters and was increased to 300,000 in Q3 2018. This feature is used for monitoring in emergency scenarios, such as red-flag fire alerts and earthquakes.
c. Improved access and awareness company wide. For example, the load curtailment visualization use case, where the load curtailment is visually represented to help users to visualize the curtailment locations and details as data on map. This feature is expected to be useful in emergencies.
d. Utility worker safety improvement and hazard exposure reduction by improving the access of real-time 3D data to company-wide applications. It will help the field teams to better estimate the field conditions (steep slopes, obstructions etc.) before visits. Imagery management use case was a good demonstration of how LiDAR data can be useful for this purpose. In this use case, SDG&E discovered that between various departments and projects, there are about 7000 LiDAR tiles that can be used in GIS 3D applications.

Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy

a. SDG&E's EPIC visualization infrastructure modernization project was designed to advance the current infrastructure. The EPIC demonstration project's use of new technologies in combination with renewed GIS data models proved to be effective by improving accuracy and reducing data. The project also identified possibilities for creating next generation 3D applications for more reliability and accuracy.
b. The project increased use of cost-effective digital information and control technology to improve reliability, security, and efficiency of the electric grid (PU Code § 8360).
c. The project provided identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (PU Code § 8360).

Effectiveness of information dissemination

a. The visualization platform enables the creation of numerous reports and fact sheets for various users, not only within SDG&E® but also on a wider basis, via preparation of conference presentations, papers, and other relevant material.

Adoption of EPIC technology, strategy, and research data/results by others

a. The technology demonstrated in the project provides a promising basis for building upon and for development of a commercial version of the monitoring and visualization platform that can be effectively utilized by various stakeholders both at SDG&E® and beyond.

After further development of all presented use cases and additional testing, it would be beneficial to prepare a comprehensive description and documentation of the work and results, to support commercial adoption processes.

5.2 Value Proposition: Primary and Secondary Guiding Principles

The value proposition is to address how the project met the EPIC principals.

Table 5.1 summarizes the specific primary and secondary EPIC Guidelines Principles advanced by the Visualization and Situational Awareness Project.

Table 5.1: EPIC Primary and Secondary Guiding Principles

Primary Principals			Secondary Principals				
Reliability	Lower Costs	Safety	Loading Order	Low-Emission Vehicles / Transportation	Safe, Reliable & Affordable Energy Sources	Economic Development	Efficient Use of Ratepayers Monies
✓	✓	✓	✓		✓	✓	✓

The Visualization and Situational Awareness Project covers the following primary EPIC principals:

- **Reliability:** This project developed tools that give the ability to monitor, visualize, and analyze information which help reduce number of outages, as well as their frequency and duration, giving a higher reliability. Transmission fault location use case is particularly useful for this purpose.

- **Lower Costs:** Given the ability to visualize occurring events in near real time to operators, helps deploy maintenance crews more efficiently and effectively. The imagery management use case, for example, aim is to be able to see the data sources visually, in a geographic context, as opposed to searching for the data via file and folder names. This should save time and effort in organizing huge amounts of data.

- **Safety:** As mentioned, the ability to monitor events and historical trends, like transmission faults or voltage issues, gives the departments and crews that depend on this information, to have a better assessment on how to approach an occurring issue, or based on trends, evaluate on how to safely plan a future activity.

6 APPENDIX: FOUNDATIONAL COMPONENTS

6.1 Esri GIS Components

This section provides very basic information about the Esri GIS components that have been used in this project. The source of the information is largely from Esri's extensive web-help site http://resources.arcgis.com/en/help/ (following the contained links).

Esri provides various solutions to meet its clients' GIS needs. Figure 6-1. Esri ArcGIS Enterprise Components shows the main components of ArcGIS Enterprise, which is the version used by SDG&E® in this project. The diagram shows the main functional groups of components. Subsequent sections contain a brief summary of these groups.

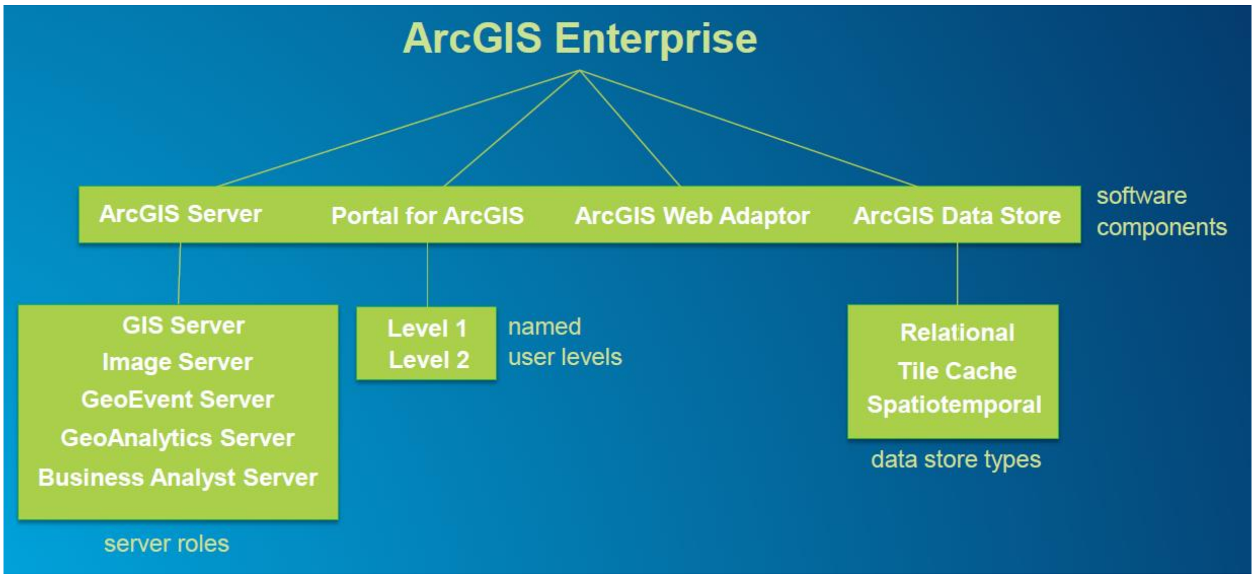


Figure 6-1. Esri ArcGIS Enterprise Components

In the following subsections, each of the functional groups of the ArcGIS Enterprise suite of applications is briefly overviewed based on the information provided on the Esri Web Site.

6.1.1 ArcGIS Servers

There are five different kinds of servers: GIS Server, Image Server, GeoEvent Server, GeoAnalytics Server, and Business Analyst Server. A brief overview of each of these servers is provided in the following subsections.

6.1.1.1 Image Server

ArcGIS Image Server provides serving, processing, analysis, and extracting business value from collections of imagery, rasters, and remotely sensed data. Figure 6-2. Esri Image Server shows, pictorially, Esri's depiction of the main roles of its Image Server. In this project, Image Server is primarily used to support Use Case 4, Imagery Management.

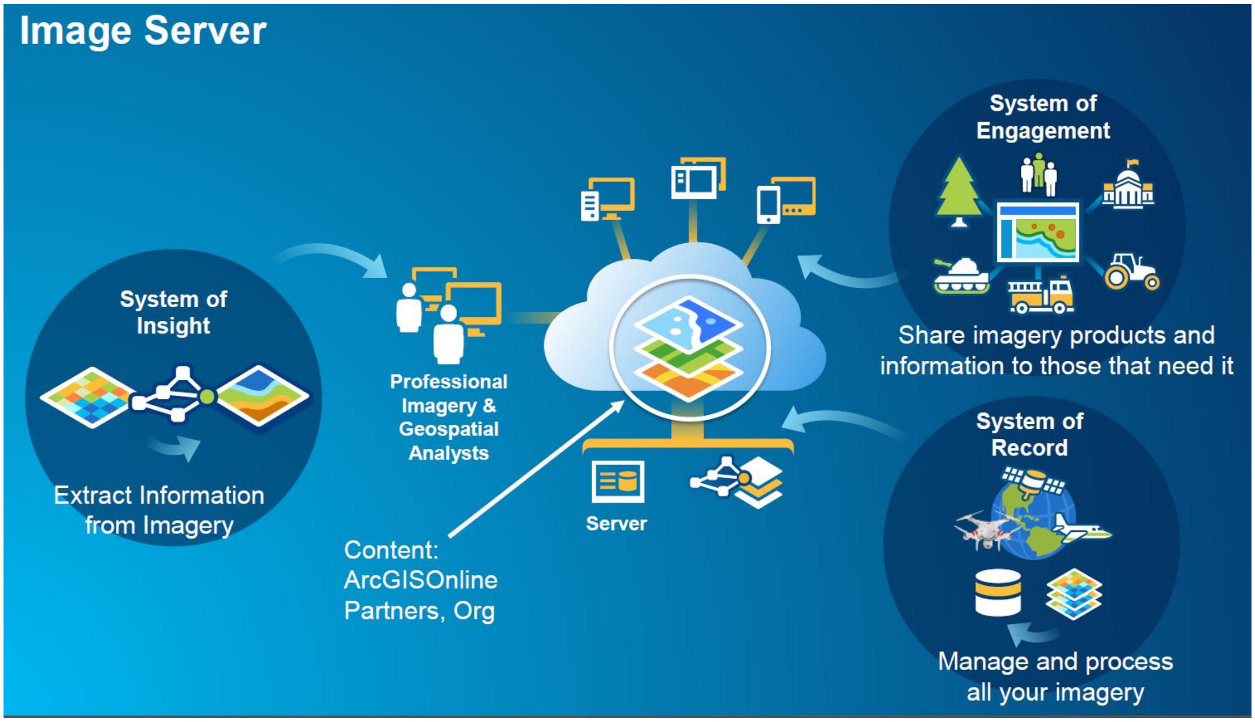


Figure 6-2. Esri Image Server

6.1.1.2 GeoEvent Server

The main role of GeoEvent Server (Figure 6-3) is to facilitate updates of geospatial feature of GIS maps based on dynamic data. Within this project, the role of providing dynamic data updates is filled by OSISoft PI Esri Integrator for the dynamic data that resides in PI Historians, and by GeoEvent Server for all other kinds of dynamic data (e.g., weather, fire, etc.).

6.1.1.3 GeoAnalytics Server and Insights

GeoAnalytics Server (Figure 6-4) supports Big Data analytics on the server side.

Insights provides visual programming capabilities to end-users, allowing them to specify sophisticated data analysis and display results on maps within portal for ArcGIS. Insights blends spatial and non-spatial data to bring together spreadsheets, databases, and ArcGIS data.

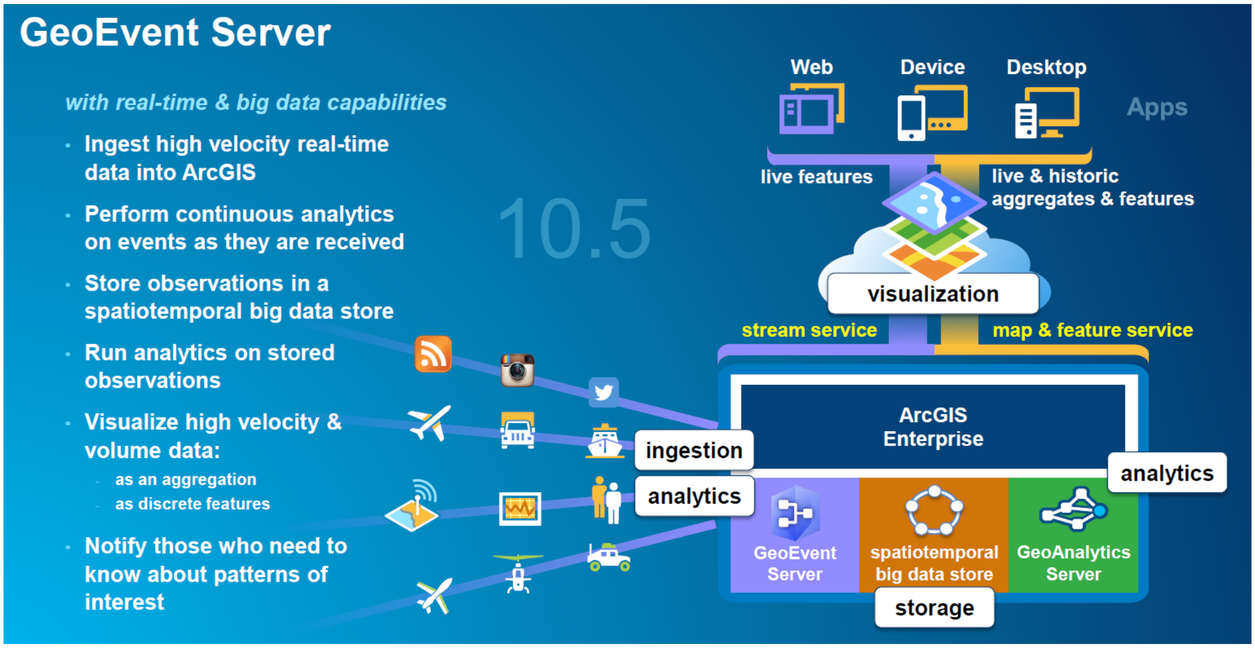


Figure 6-3. Esri GeoEvent Server

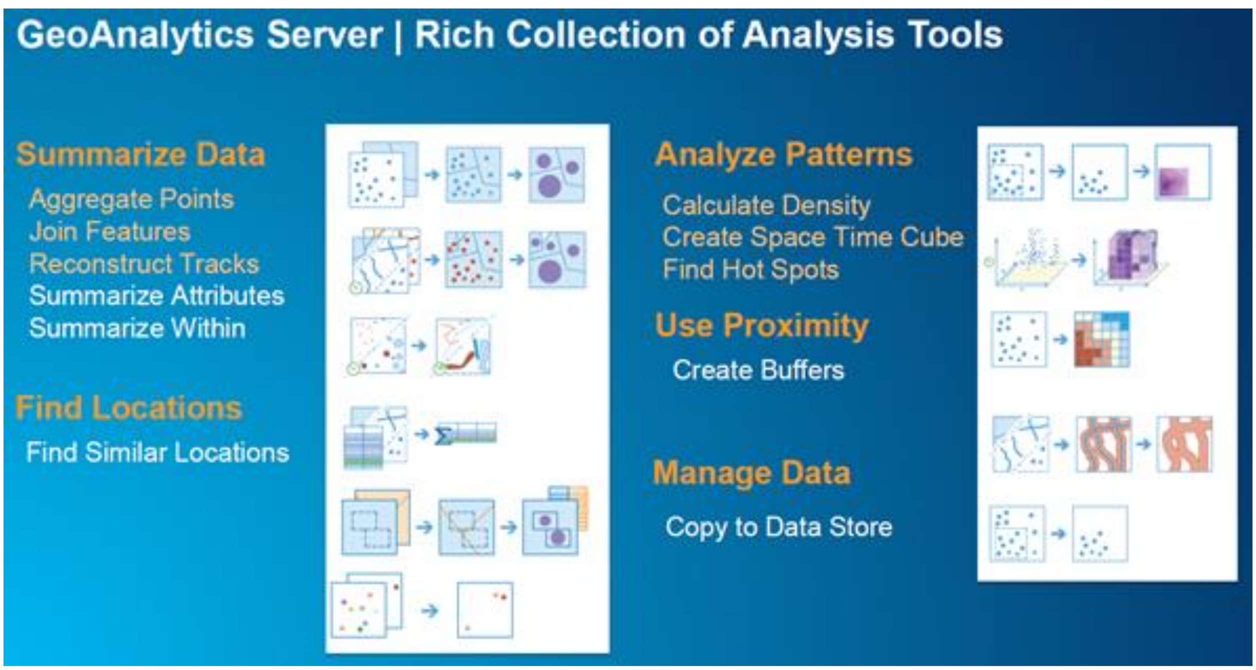


Figure 6-4. Esri GeoAnalytics Server

6.1.2 Portal for ArcGIS

This component was heavily used in this project. Portal for ArcGIS allows sharing of maps, scenes, apps, and other geographic information with other people in the organization. The shareable content is delivered through a website. The website can be customized to the organization's visual standards.

Portal for ArcGIS brings together all the geographic information in the ArcGIS platform, and it shares it throughout the organization. For example, with Portal for ArcGIS it is possible to:

- Create, save, and share web maps and scenes.
- Create and host web mapping apps.
- Search for GIS content within the organization.
- Create groups for sharing GIS information with coworkers.
- Share links to GIS apps.
- Share map and layer packages to use in ArcGIS Desktop.

Portal for ArcGIS includes geographic viewers designed for those who are just beginning with GIS. Experienced GIS users can connect to Portal for ArcGIS from ArcGIS Desktop, developer APIs, and other applications.

6.1.3 ArcGIS Web Adapter

The Web Adaptor provides the following features:

- Allows integration of *Portal for ArcGIS* with the organization's existing web server. Inclusion of a web server with ArcGIS Web Adapter provides the ability to host web applications that use GIS services.
- The organization's identity store and security policies can be used at the web-tier level. For example, when using IIS, it is possible to use Integrated Windows Authentication to restrict who enters the portal. It is also possible to use Public Key Infrastructure (PKI) or any other identity store for which the web server has built-in or extensible support. This allows provision of a single sign-on or other custom authentication experience when logging in to use services, web applications, and Portal for ArcGIS.
- Portal for ArcGIS functions can be exposed through a site name other than the default ArcGIS.

The Web Adaptor is platform independent of Portal for ArcGIS, and hence, the Web Adaptor does not have to match the operating system platform of the portal. For example, if the portal is running on Linux, it is possible to deploy ArcGIS Web Adaptor (IIS) or (Java Platform) to work with Portal for ArcGIS. Conversely if the portal is running on Windows, an ArcGIS Web Adaptor (Java Platform) on Linux can work with the Portal for ArcGIS.

After installing and configuring the Web Adaptor, the URL used to access the portal will be in the format https://webadaptor.domain.com/arcgis/home. For example, if the machine hosting the Web Adaptor is named *webadapter* with the domain *sdgeorg.net*, and the portal is named *arcgisportal*, the portal is accessed using the URL https://webadapter.sdgeorg.net/arcgisportal/home.

6.1.4 ArcGIS Desktop and Server

ArcGIS for Desktop – Comprehensive software used by GIS professionals on Windows PCs for a range of GIS activities including data compilation, mapping, modeling, spatial analysis, and geoprocessing. ArcGIS for Desktop extensions provide additional functionality such as 3D visualization, network analysis, schematics, and geostatistics. Desktop is the starting point and foundation for deploying GIS in organizations. It is used by professional GIS staff for desktop mapping, reporting, and analysis. It is also used by data compilation staff to create and maintain critical foundational data layers that fuel other GIS applications. This role for data stewardship is quite significant.

ArcGIS for Server – GIS back-office software that enables centralized, enterprise-level geodatabase management and server-based publication of maps and geographic information services throughout the enterprise and on the Internet as web services. ArcGIS Server supports the leading enterprise database management systems (DBMS): Oracle, SQL Server, DB2, Informix, and PostgreSQL. It is available on Windows or Linux servers on-site or in cloud configurations. This project uses on premises installations.

ArcGIS Server provides the core technology for implementing large-scale GIS in organizations and businesses worldwide.

6.1.5 Esri Utility Network

A utility network is the main component used for managing utility and telecom networks within ArcGIS. Combined with a service-based transaction model, attribute rules, editing tools, and more, it allows users to completely model and analyze their complex network systems for water, gas, electric, telecom, sewer, storm water, and other utilities.

The capabilities to manage and analyze network data are delivered through the ArcGIS Utility Network Management extension to ArcGIS Enterprise. The extension provides the ability to access all capabilities through a service-based architecture callable from any device or application that supports web services.

A utility network is a comprehensive framework of functionality in ArcGIS for modeling utility systems such as electric, gas, water, storm water, wastewater, and telecommunications. It is designed to model all of the components that make up utilities system—such as wires, pipes, valves, zones, devices, and circuits—and allows you to build real-world behavior into the features you model. The key elements of the Utility Network platform are shown in Figure 6-5

Figure 6-5. Esri Utility Network System Components

6.1.6 ArcGIS Data Store

ArcGIS Data Store is an application supporting configuration of data stores for hosting and for federated servers used with the Portal. The following different types of data stores can be configured:

- Relational data store: stores Portal's hosted feature layer data, including hosted feature layers created as output from spatial analysis tools running in the portal
- Tile cache data store: stores caches for Portal's hosted scene layers
- Spatiotemporal big data store: archives real-time observation data that can be used with an ArcGIS Server running ArcGIS GeoEvent Server that is federated with the portal; also stores the results generated using ArcGIS GeoAnalytics Server tools

A more comprehensive list of ArcGIS data store features includes:

- Publish large numbers of hosted feature layers.

  When publishing large numbers (thousands) of feature layers to Portal, it is recommended to use ArcGIS data store to create a relational data store. Hosted feature layers that rely on the relational data store require a smaller memory footprint to run, making it possible to publish many services with fewer hardware resources.
- Publish hosted scene layers to the Portal.

  When the Portal's hosting server is registered with a tile cache data store, it is possible to publish hosted scene layers from ArcGIS Pro to Portal.
- Publishing hosted scene layers also creates a hosted feature layer. Esri recommends use of ArcGIS data store to create a relational data store to support this functionality; other managed databases registered with the hosting server can be used instead if preferred.
- Archiving high volume, real-time observation data
- When using ArcGIS GeoEvent Extension to stream high volumes of real-time data, it is possible to create a spatiotemporal big data store to archive the GeoEvent observation data in it
- Create automatic backups of relational data stores
- Backups support recovery of feature data in the event of a disaster such as data corruption or hardware failure
- Configure a failover data stores for feature layer data and scene caches
- ArcGIS data store allows a setup of primary and standby relational data store machines, and primary and standby tile cache machines. Hosted feature layer and hosted scene layer tile cache data is replicated from the primary machines to the standby machines
- Configure highly available spatiotemporal big data stores
- Configure multiple spatiotemporal big data stores to balance data loads over multiple machines and ensure availability of spatiotemporal data in the event of a machine failure.
- Analyze the Portal for ArcGIS map viewer
- Spatial analysis functionality in Portal requires that the portal hosting servers use an ArcGIS relational data store
- GeoAnalytics Tools require the hosting server to be configured with a spatiotemporal big data store.

6.2 OSIsoft PI

OSIsoft PI was originally developed to efficiently capture and store real-time data, especially time series data. Through addition of functions, and a widespread deployment in the industry, it has grown to now include a comprehensive set of functions to capture, process, analyze, store, and visualize any form of real-time data. PI is used extensively at SDG&E®.

The key elements of the PI platform are shown in Figure 6-6. A standard installation is shown in Figure 6-7.

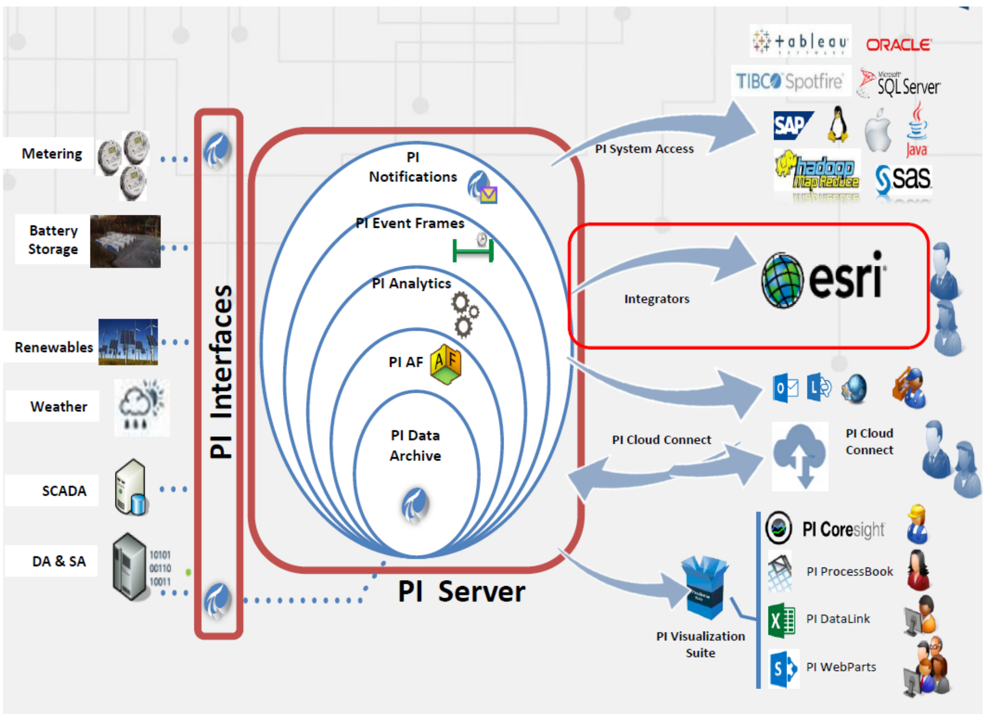


Figure 6-6. OSISoft PI System Components

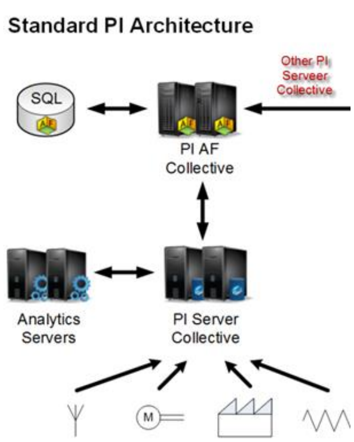


Figure 6-7. OSISoft Standard PI Architecture

A generic on-premises installation of PI systems in combination with ArcGIS is shown in Figure 6-8 and the specific configuration at SDG&E® is shown towards the beginning of this document in Figure 1-1. Main Components of Visualization and Situational Awareness DemonstrationFigure 1-1

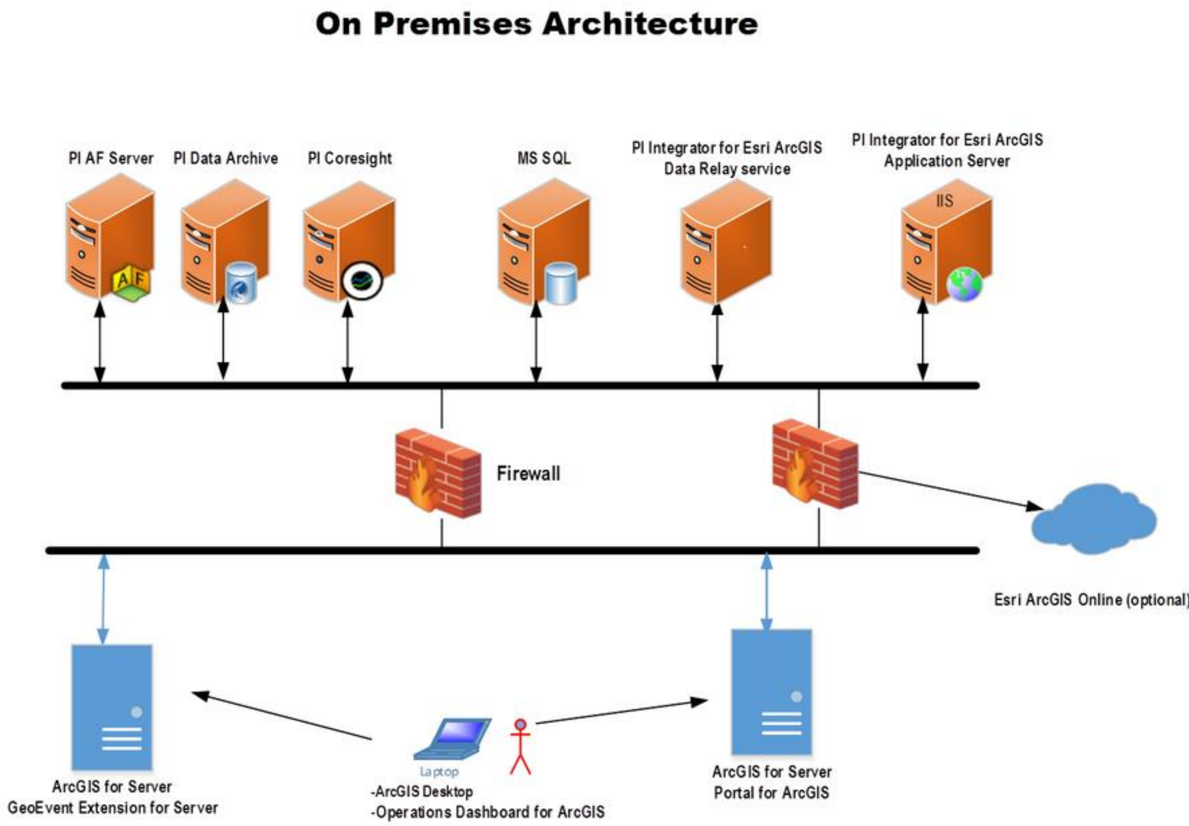


Figure 6-8. OSISoft Generic On-Premises Architecture

6.2.1 PI Integrator for Esri® ArcGIS® Overview

PI Integrator for Esri® ArcGIS® is the OSISoft product that enables a PI System to be connected with an ArcGIS Platform to first define geospatial feature services and layers in ArcGIS, and once defined, to dynamically update these with the data from PI[4]. The whole process of dynamically updating ArcGIS feature services and layers requires two components from Esri and two components from OSISoft:

- Esri
  - Esri ArcGIS for Server: manages feature services and layers
  - GeoEvent Extension for Server: provides GeoEvent Service to update real-time data, as well as Input and Output (the difference between the input and output is that additional processing can be performed on Input data within the GeoEvent Service, e.g., filtering, processing, geofencing, to produce Output)
- OSISoft
  - PI Server, containing PI Data Archive and PI Asset Framework data stores

[4] https://www.youtube.com/watch?v=7iTPdVHZkWM

- PI Integrator for Esri ArcGIS, containing Application Server and Data Relay

The integration process starts by using Application Server wizards to setup GeoEvent Services and Inputs and Outputs in GeoEvent Extension for Server. A simple setup is when Output = Input, but manual changes in GeoEvent Extension for Server can be made to institute additional transformation of Input data to Output. Here, one service is defined for each PI AF Template used.

Once the GeoEvent Service is defined, at certain periodicity, the service issues HTTP (or HTTPS) to Application Server, which in turn relies on Data Relay to retrieve data from PI Data Archive referenced by an AF Template, provides it to Application Server, which in turn responds to GeoEvent Service with the requested data, which then traverses through Input to Output within GeoEvent Extension for Server, and finally updates the Feature Service on ArcGIS for Server.

The Data Relay component sends metadata and real-time information to Application Server of Esri ArcGIS.

6.3 Power BI

Power BI is a Microsoft suite of tools for efficient data analysis, which enables users to connect with many data sources to extract, analyze, and visualize the extracted data in many different ways. Once a connection to data sources is established, even the end users – without any programming skills – can specify through a Graphical User Interface (GUI) the type of analysis to be performed, and how to visualize the data and the results. Enhanced capabilities for these tasks are also available through high-level languages supported by the various Power BI sub-components.

Esri provides a component that enables display of Power BI results on geo-spatial maps, giving additional options for presenting results in addition to Excel-like tables and graphs that are available in the Power BI itself. This component, however, does not work in mixed environments, where Esri products run on premises and Power BI in the cloud, as is the case at SDG&E®. To overcome this difficulty, SDG&E® resorted to Java-based programming to allow Power BI widgets to be displayed on geospatial maps.

Major sub-components of Power BI (with yes/no indication of if used in this project):

- Power Query (yes): Data mash up and transformation tool.
- Power Pivot (yes): In-memory tabular data modelling tool
- Power View (yes): Data visualization tool
- Power Map (no): 3D Geo-spatial data visualization tool
- Power Q&A (no): Natural language question and answering engine
- Power BI Desktop (yes): A development tool for building Power BI reports and dashboards

There are other components, such as PowerBI.com Website that is used to share Power BI data analysis as cloud services; and Power BI Mobile Apps on Android, Apple, and Windows mobile devices.