EPIC 1 Program Report 2013086

Outage Management and Customer Voltage Analytics

SOUTHERN CALIFORNIA EDISON®

An *EDISON INTERNATIONAL®* Company

Report Prepared by: Southern California Edison

Report Prepared for: The California Public Utilities Commission

February 18, 2016

Executive Summary

SCE successfully demonstrated the use of meter data for Distribution grid benefits in this EPIC I[1] project. The project consisted of a scaled pilot demonstration and a feasibility study.

The scaled pilot consisted of approximately 20,000 customers' historic meter data (meter events and hourly voltage and consumption) on 14 distribution circuits of 12 substations. 14 use case were developed and successfully demonstrated. These use cases addressed voltage deterioration along a circuit, voltage of a strategic node (fuse, switch, etc.), identification of Distribution system assets outside of user defined voltage threshold limits, transformer load evaluation and overloading conditions with loss of life estimation using the IEEE standard C57.91-195, load aggregation to a strategic node upstream of several transformers, outage reconstruction and reporting models utilizing voltage data and meter exceptions/event data, etc.

The demonstration occurred in an isolated lab environment and included installation of a vendor's analytics platform. The platform consumed the historic meter data to provide metrics, graphics and circuit visualization overlaid on SCE's comprehensive geographic information system (cGIS). An easy to understand user interface provided the necessary information for Distribution planners, engineers, outage reporting analysts and customer service representatives to make quick and informed decisions. It enabled planners and engineers to perform quick assessments for Transformer Load Management and engineering analysis in finer detail than was previously possible. The project provided valuable insight into the technical requirements for an enterprise-wide implementation of a similar analytics and visualization tool.

The demonstration concluded with user testing/evaluation by Distribution system engineers and planners and outage reporting analysts to educate them of the value, test the functionality of this tool and to receive feedback on opportunities for improvement. The demonstration of the use cases with the analytics platform was so successful that SCE is proceeding with an enterprise-wide deployment of a platform with similar functionality that uses smart meter data.

The feasibility study was on the potential use of meter outage events in SAIDI/SAIFI metric calculation. It included an evaluation of the existing outage analysis process and the changes and benefits of using meter outage events with time stamps. The study concluded with comparison/validation testing between using the existing method versus meter events time stamps in calculating Customer Minutes of Interruption (basis for System Average Interruption Duration Index/System Average Interruption Frequency Index) values on a single area outage as well as for an entire District. The general conclusion from the comparison testing was that

[1] EPIC I: Electric Program Investment Charge established by the California Public Utilities Commission in Decision 12-05-037 for Rulemaking 11-10-003 on May 24, 2012. EPIC I represents SCE's first Triennial Investment Plan application A12-11-004filed for approval November 1, 2012, pp37-39.

using meter event data can be an efficient and accurate method for calculating CMI values. The study also made recommendations. These included (i) automation of some steps of the outage analysis process, (ii) implementation of interfaces between databases including Outage Management System (OMS), Outage Database and Reliability Metrics (ODRM) and Edison Smart Connect Data Warehouse (ESCDW) to enable sharing of data and (iii) conduct a study to capture outages of meters that do not generate (i.e. non-smart meters) or communicate meter events.

The demonstrated capability to leverage smart meter data with SCE existing tools and data systems opens the way to fundamentally change how distribution engineers and planners approach Distribution system asset and system management. These disciplines would literally have a broad view of the Distribution network or circuit by circuit, enabling them to pinpoint problem Distribution system assets in a minimum amount of time, readily perform comparative analysis, and to efficiently prioritize Distribution system asset maintenance and replacement. It also has the potential to improve the outage analysis process in reliability indices reporting.

Contents

List of Figures

List of Tables

1 Project Background

Smart meter data presents a valuable opportunity to provide analytics tools that benefit the T&D system. However, it was first necessary to demonstrate that data collected from smart meters could be integrated into an outage management and analytics solution. This project was a first step towards that massive undertaking. It was a crucial step, based on the sheer magnitude of the data available, the complexity of the system being managed and the process transformation expected. A sweeping paradigm shift of T&D analytics and OMS fully integrated to the smart meter level, without certainty as to the viability of the application, would be impractical and potentially flawed.

The SCE system includes five million customer smart meters generating voltage and usage data at 60 minute intervals around the clock, seven days a week. The SmartConnect™ platform polls the meters once per day, then transmits that data to the Edison SmartConnect™ Data Warehouse (ESCDW) for storage. The sheer magnitude of the data necessitated the project confine itself to a sample of customers and electric infrastructure.

With the deployment of smart meters throughout its service territory, a significant amount of data was being collected and stored. The concept of using the meters as sensors on the distribution network had been envisioned and specified years ago in Edison SmartConnect™ design specification. It is only in the last few years that analytics applications using smart meter data were starting to be marketed by software development vendors.

The availability of energy consumption, service interruption, and voltage data presented the opportunity for a distribution system analytics application, furthering SCE's drive toward customer service excellence. This project demonstrated that capability through installation of an Integrated Analysis Platform (IAP) data model. The IAP Data Model was implemented through a partnership between SCE and its third-party vendors using historical meter data.

14 use cases on voltage analytics, customer and transformer load analysis, outage reconstruction and a simulated circuit model were demonstrated in a scaled pilot. The scaled pilot demonstration with approximately 20,000 smart meters was integrated with SCE's GIS electrical network model. These meters were distributed across SCE's service territory and associated with 14 distribution circuits. The analytics and visualization solution utilized 90 days of historic customer meter hourly consumption and voltage data and meter events and exceptions. The demonstration was performed in an isolated environment using a database and server in SCE's Advanced Technology laboratories. The meter data was extracted from the ESCDW and stored on the lab database along with the related GIS, infrastructure and Distribution system asset data for the 14 circuits.

Separately, the idea of using smart meter data in service reliability indices reporting was also identified. The existing indices calculation process is time and labor intensive in researching and validating reportable outages from one or more databases, field maintenance records, etc. It was speculated that meter outage events could be used in the indices calculation process to eliminate /reduce some time consuming steps. A feasibility study would be needed before any changes to the existing process could be implemented. The feasibility study would include an analysis of all the existing process steps, identification of areas where meter event data could be beneficial and the potential for automation of some of the process steps.

This project was funded by the Electric Program Investment Charge (EPIC). The California Public Utilities Commission (CPUC) established the EPIC program May 31, 2012 in Decision 12-05-037[2]. SCE, as one of the four program administrators, submitted its first three-year investment plan November 1, 2012[3] pursuant to the requirements set out in the Commission's EPIC Program Decision. This project, Outage Management and Customer Voltage Data Analytics, was specified in the filing within Section 6.3 Customer-Focused Products and Services Enablement and Integration[4].

2 Project Objective

There one key objective of this project. It was to demonstrate how SCE's smart meter data could benefit the distribution grid. To achieve that objective a technology demonstration and a feasibility study were conducted. The technology demonstration included using smart meter data in an analytics and visualization solution at scale. This project achieved the objective by demonstrating 14 Distribution system use cases in an analytics and visualization application using approximately 20,000 meter data associated with 14 circuits.

The feasibility study was on using smart meter outage data to improve or enhance the reliability indices calculation process. More specifically, the study was conducted to determine the benefits that the meter outage events and/or exceptions data could provide to the reliability indices (SAIDI/SAIFI) calculation process.

3 Issues Addressed

CPUC mandated the California investor owned utilities (IOUs) to report on service reliability i.e. the frequency and duration of both sustained and momentary outages. This decision directed the IOUs to compute service interruption statistics: 1) including transmission, substation and distribution outages, and 2) excluding planned outages. These statistics are reported annually as three indices:

1. System Average Interruption Frequency Index (SAIFI): this index indicates the average number of sustained outages per customer per year, where a sustained outage is defined as an outage lasting five minutes or more.
2. System Average Interruption Duration Index (SAIDI): this index reflects minutes of sustained outages per customer (on average) per year

[2] State of California, California Public Utilities Commission, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2012* (Decision 12-05-037, May 31, 2012)
[3] State of California, California Public Utilities Commission, *Application of Southern California Edison Company (U 338-E) for Approval of Its Triennial Investment Plan for the Electric Program Investment Charge Program,* Application 12-11-004, Sacramento, CA, November 1, 2012, 1-180
[4] *Application of Southern California Edison Company (U 338-E) for Approval of Its Triennial Investment Plan for the Electric Program Investment Charge Program,* 37-39

3. Momentary Average Interruption Frequency Index (MAIFI): this index reflects the average number of outages lasting less than 5 minutes per customer per year.

The current process used to calculate the indices requires significant human intervention, decision making and calculation. Currently, outages must be manually researched and validated against standard criteria to be counted. Intuitively, the SmartConnect™ platform has the potential to perform these calculations with greater accuracy and in a more efficient manner than the existing manual process. A feasibility study was conducted to evaluate whether smart meter data could provide the benefits of improved accuracy and efficiency.

Lastly, SCE, as with other electric utilities, is required to deliver on demand, 100% of consumer electrical watt (load) requirements within a predefined voltage range. The utilities must, at the same time, deliver that power at an optimum power factor[5] to conserve energy and control costs. The inherent complexity of the electrical network combined with the dynamics of consumer demand make meeting these tasks highly challenging. The means to manage these tasks in the electric distribution system is Voltage/VAR[6] control. Due to the cost, traditional technology limited Voltage/VAR monitoring to substations and feeder lines where high-level adjustments could be made. SCE did not have the ability to track voltages at the end of every distribution circuit—much less at each customer meter—without deploying a field technician. The smart meters virtually upended data and visualization capability, by allowing visualization of voltage deterioration along a circuit based on smart meter voltage data. With this type of application, SCE would have the capability to diagnose problems, develop strategies to conserve energy and review Voltage/VAR with system visualization.

Meeting each of these challenges would result in enhanced customer service excellence; but the approach had to be demonstrated as viable, effective and efficient before systemic changes could be implemented.

4 Project Scope

The scope of this project was to demonstrate that smart meter data could provide T&D operational and reliability indices reporting benefits. The project consisted of (a) a scaled pilot demonstration of an analytics and visualization solution and (b) a feasibility study on using smart meter outage events for calculating reliability indices (SAIDI/SAIFI).

a. The scope of the analytics and visualization solution project was to demonstrate 14 electric distributions system use cases by using historic smart meter data from approximately 20,000 customer meters on 14 circuits. 90 days of historic meter (meter events, and hourly voltage and consumption) data was converted and merged into a standard database format for consumption by the analytics solution to demonstrate the use cases.

[5] The power factor is the ratio of true power to apparent power.
[6] Volt-Ampere Reactive or VAR is a unit used to measure reactive power in alternating current.

The analytics and visualization application was required to demonstrate the following functionality:

1. Device and transformer monitoring, replacement and identification of overloaded transformers.
2. An interactive simple circuit visualization model with key devices and nodes.
3. Historical outage visualization.
4. Ability of a user to receive intelligent feedback from voltage data on a circuit to make dispatch decisions about an outage.

The following were deliverables of the analytics and visualization part of the project:

i. Solution Architecture and Design document.
ii. Step-by-step instruction manual/user guide with detailed product descriptions of all features.
iii. Showcase of application functionality that met the 14 use cases
iv. Written assessment of the ability to receive intelligent feedback from voltage data on a circuit and input from collected voltage data at specific points to make dispatch decisions on an outage.
v. Feasibility assessment on using near real-time data (including outage and voltage-based meter exceptions), identifying network traffic impact, latency of data, etc., for determining near real-time state/status of key devices on a circuit.
vi. Onsite product demonstration and walk-through of the use cases
vii. User training/testing sessions (UATs), materials and documentation.
viii. Technical assessment of alternate options for reliability indices reporting.
ix. White paper on the ability to export data into a format for a software program, such as Microsoft Excel and power flow modeling such as CYME.

b. The feasibility of using smart meter events data in the calculation of CMI for SAIDI/SAIFI was explored by SCE engineers and staff. The scope included an analysis of:
   1. Eight types of outage scenarios,
   2. Data flow of meter events to ESCDW,
   3. Current outage analysis process
   4. Accuracy of the meter events
   5. Completeness of the data sets,
   6. Integration of current and proposed SAIDI/SAIFI/MAIFI calculation criteria,
   7. Layout of outage CMI calculation methodology and
   8. Potential increase in efficiency and accuracy of the SAIDI/SAIFI/MAIFI calculation.

   The deliverable of this feasibility study was a report documenting the findings of the scope elements above, challenges and recommendations.

5 Major Tasks

The major tasks for this project were approached in two separate efforts: (1) demonstration of smart meter data for T&D analytics and circuit visualization and (2) a feasibility study of using smart meter data in calculating the service reliability indices.

5.1 Demonstrate application of smart meter data for T&D analytics and circuit visualization

5.1.1 Define Demonstration Parameters

Distribution system assets selected: SCE determined this demonstration project would include a cross section of substations and range of circuits to ensure a solid cross section of both Distribution system assets and customer meters would be included. SCE's comprehensive Geographic Information System (cGIS) project is where all Distribution system assets is available to engineers and planners on a geospatial map of the distribution network. Since the cGIS data base was one of the crucial data bases for this demonstration it was decided to follow that implementation pattern and select substations and Distribution system assets from areas where cGIS was operational. Circuits from those substations were then selected for inclusion in this demonstration to provide a geographical representation of SCE's customers and Distribution system assets. The result was a selection of twelve distribution substations and fourteen circuits as shown in Table 1.

Table 1, Substations and Circuits in Demonstration

Substation Name	Circuit Names
Duarte	Spinks
Goleta	Ace
Harvard	Bragdon
Haveda	Sump
Hesperia	Mesquite
Lancaster	Crowder and Oban
Little Rock	Calli Valli and Sun Village
Lucerna	Sky Hi
Modoc	Lauro
Monrovia	Alta
Palmdale	Caliber
Tortilla	Huevos

The approximately 20,000 customer SmartConnect™ meters included in this demonstration were served by the fourteen listed circuits. A subset of these customer meters on each side (i.e. line and load) of strategic Distribution system nodes (junction box, switch, fuse, etc.) were identified and designated to be "bellwether meters." Bellwether meters specifically identified the location of outages and provided other operational data such as voltage deterioration along a circuit.

Analytics selected: Only analytics currently used by SCE distribution engineers, planners and outage reporting analyst were considered for inclusion in this demonstration. The demonstration offered, for the first time, data at the customer meter level at a level of accuracy not previously available. The T&D analytics selected for this scaled pilot demonstration project were:

1) Evaluate load on an existing transformer,
2) Detect transformer overload conditions,
3) Detect and analyze voltage anomalies and complaints,
4) Perform load switching calculations,
5) Recreate and visualize circuit voltage profiles,
6) Graphically view each circuit to determine the states of Distribution system assets,
7) Visually reconstruct an outage and its restoration,
8) Assess the state of key circuit devices on geospatial maps and,
9) Data export to report applications and for other analysis not included in this project.

5.1.2 The IAP Data Model and Preexisting SCE Databases

IAP Data Model Demonstration

This demonstration required a front-end software platform to integrate SmartMeter™ data with SCE operating data bases (e.g. the electric distribution network GIS). This software, called an integrated analysis platform (IAP), was intended to enable engineers and planners to aggregate smart meter data to the circuit or feeder level, or to "drill down" to individual meter locations, depending upon the analytics being performed. The IAP achieved the goal and provided engineers and planners with visualization and dashboard data presentations.

In this scaled pilot, the IAP demonstration was performed using historical meter data from approximately 20,000 customer meters connected to fourteen circuits in SCE's service territory. The data was loaded onto SCE's Advanced Technology lab servers along with the circuit layouts from cGIS. Three months of customers' historic hourly consumption, voltage and meter events data was used. The IAP was preconfigured to accept and utilize this data.

The IAP was also configured to recognize two types of events: meter events and analytic events. Meter events are created by the meter such as an outage or a high or low voltage threshold is exceeded. Analytic events are generated by the IAP as the result of analyzing incoming readings plus meter events and recognizing patterns in the data. Analytic events were defined by the engineers and planners over operating ranges with upper and lower limits. Much of the reporting in the IAP dashboards was based on analytic events.

Simulated Circuit Model (SCM):

The visualization capability of the IAP was used to overlay smart meter data on the electric network cGIS, giving distribution engineers and planners a geospatial tool to rapidly:

1) Visualize the state of key devices on a distribution circuit segment using historic voltage data and meter events/exceptions from bellwether SmartConnect™ meters;
2) Assess the status of key devices using voltage data from bellwether meters and generate an area-wide heat map and view of key device states; and
3) Reconstruct outages and restoration timing, and then generate outage reports utilizing voltage and meter events/exceptions data.

5.1.3 Conduct User Acceptance Tests (UATs) on the Analytics and the SCM

The analytics included in this project were grouped into three categories: voltage analytics for power quality, customer and transformer load analysis and the SCM. UATs were developed as test controls, reflecting the typical analysis performed by distribution system engineers, planners and grid operations analysts ranging from adding new load to a transformer, voltage degradation along a circuit to reconstructing outage timelines for reporting purposes. The IAP data model was tested for performance against this set of use cases that reflected T&D analytic tools, circuit visualization and outage management needs. The UATs were the actual step-by-step tests to determine capability of the model to use smart meter data for T&D analytics. Distribution engineers and planners in these tests:

- Evaluated the voltage data at the end of a circuit and at several strategic node locations along a circuit. The data was then analyzed to demonstrate the types of proactive decisions planners and engineers will make on power flow and quality analytics, including potential capacitor bank location(s) at strategic points along a circuit.

- Evaluated the energy consumption data starting with the end-point customers and aggregating it to the transformer and circuit level. The data was then analyzed to:
  1) Assess the Distribution system asset loading conditions of the electrical network,
  2) Provide comparisons to nameplate ratings, and
  3) Present loading status in the form of heat map visualization.

- Visually reviewed the status indication of distribution circuits based on strategically selected bellwether meter data being collected, analyzed and integrated with the electric network GIS.

Some UAT examples included:

Use Case Category: Voltage analytics for power quality

Use Case 2, Analytic: Identify overloaded transformers to determine if a service transformer is causing high or low voltage at the customer level.
Expected Result 2a: The user (distribution engineer or planner) viewed historical voltage data generated by smart meters connected to a transformer. This

enabled the user to identify any pattern of high or low voltage readings which could point to an overloaded transformer.

Use Case Category: Customer and transformer load analysis

Use Case 6, Analytic: Evaluate unplanned additional load at the transformer level (e.g. new electric vehicle load).

Expected Result 6c: The user viewed customer connected load profiles for a selected transformer to determine aggregated kWh load on that transformer.

Use Case Category: Simulated Circuit Model (SCM)

Use Case 11, Visualization: Review the operating status of key devices on the distribution network using bellwether meter voltage data, displayed as an overlay to SCE's electrical network GIS.

Expected Result 11a: The SCM, for a selected circuit, displayed a single-line diagram with key device locations and previous day voltage profiles for each device.

The UATs, in total, included 12 analytics and visualizations with 30 expected results**.**

This demonstration was conducted using SmartConnect™ customer meter data and SCE operating Distribution system circuit information. Since publication of the full documents in this project would potentially compromise the privacy of SCE customers and security of SCE Distribution system assets they are not included in full. All graphics included in this report have been altered to obscure customer specific and Distribution system asset specific location information.

5.2 Reliability Indices: Conduct a Feasibility Study Using SmartConnect™ Meter Event Data

Whenever a smart meter experiences an outage, a primary power down event is created and stored in the meter. Likewise, when power is restored, a primary power up event is created and stored in the meter. Each meter event is date and time stamped along with its unique meter identifier. Meter events are retrieved once a day (when power is restored) and stored in ESCDW. Given the availability of meter event data from each meter it would be possible to calculate customer minutes of interruption (CMI) of an outage. Using smart meter data to calculate CMI could potentially improve accuracy and efficiency in the current methodology. A feasibility study was needed to evaluate the validity of these potential benefits.

The feasibility study included five steps:

1) Post-outage analysis process improvement study

   Document the current post outage analysis process to identify potential efficiency and/or accuracy improvements.

2) Meter outage events data flow improvement study and meter time stamp accuracy

   Verify the accuracy of both meter events data and the meter time stamp (as to the timing of the service interruption event)

3) Layout the CMI calculation methodology using smart meter data

Provide the CMI calculation process using smart meter data.

4) Test Case 1:

Compare previously verified single incident CMI values to CMI values calculated by meter time stamps and identify the back-end changes needed with different types of outages.

5) Test Case 2:

Demonstrate scalability of the methodology changes in Test Case 1 using the district of Santa Barbara.

6 Results

The T&D analytics and SCM demonstration project and the reliability indices feasibility study proved smart meter data can be used to increase data management efficiency, increase reliability and improve report accuracy. The integration of smart meter data and ability to visualize the distribution network will fundamentally transform voltage analytics, customer and transformer load analysis, outage management and reliability reporting.

6.1 UAT Results: T&D Analytics and the SCM

The UAT stepped demonstrations were conducted in the SCE Advanced Technology laboratory. This provided a controlled environment to ensure each step was consistently followed.

6.1.1 Voltage Analytics for Power Quality

There were four voltage analytics selected for the demonstration. Each of the four was identified as a sequentially numbered Use Case.

Use Case 1: Review the voltage profile of strategic nodes[7] along a distribution circuit to evaluate capacitor bank placement requirements based on voltage deterioration. As proof that smart meter data can be used to demonstrate voltage deterioration along a circuit two specific Expected Results were specified that, in combination, allowed the user to a) review the voltage of selected bellwether meters on either side of a key device on a circuit, and thus b) determine the voltage profile and any deterioration from the substation to the end point. The expected results were successful in every instance of the test. Fig. 1 shows the screen available to the user for determining the Expected Results. All the graphics are interactive and so clicking on an icon, a bar on a graph, etc. will take you to another screen with more details. Starting from the top, the blue lightning bolt icon indicates a transformer with low voltage located on the cGIS map. The second graph shows the secondary voltage profile over time where maximum (red), minimum (blue) and average (green) voltage of the transformer. The second graph from the bottom shows maximum (red), average (green) and minimum voltage operating bounds. The bottom bar graph is the number of service points (meters) with low

[7] A strategic node is defined as selected electrical connections on a circuit, typically a fuse, switch, junction box etc.

voltage alarms. The same exercise can be performed for high secondary voltage (red icons) alarming transformers.

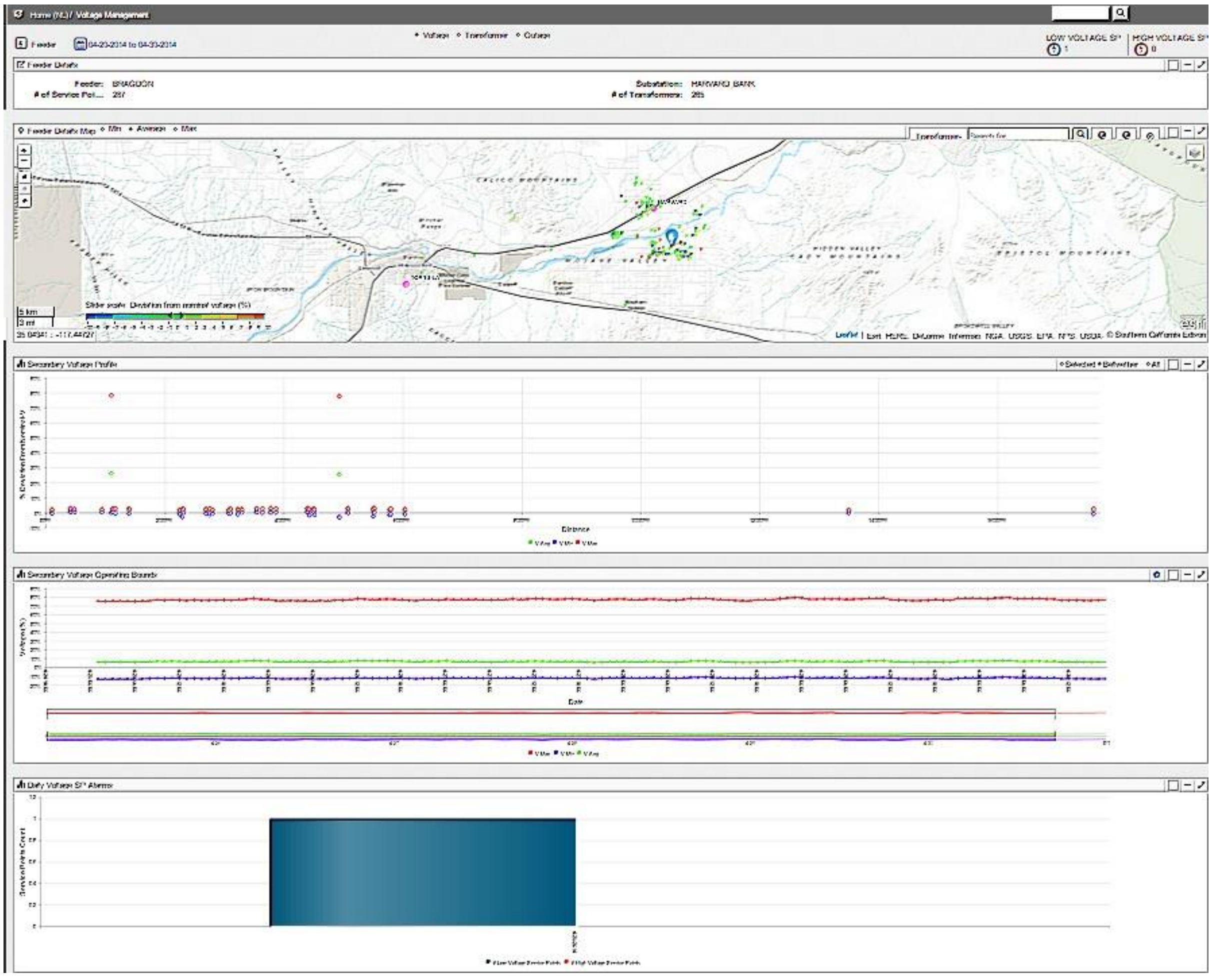

Figure 1, Feeder Detail Screen (Voltage Context)

Use Case 2: Determine if a service transformer load is contributing to high or low voltage at the customer level: identify transformers that are overloaded in the system and compare the voltage of customers connected to a selected transformer for potential power quality issues. There were, three Expected Results that allowed the user to: a) view, on a system wide basis, historical data from smart meters connected to a transformer to identify any pattern of high/low voltage readings to locate overloaded transformers, b) identify overloaded transformers within a region by entering high and low voltage thresholds, and c) select individual transformers and review voltage profiles of all customers attached to the selected transformer to identify high or low voltage abnormalities at the customer level. The Transformer Management Dashboard (Fig. 2) provided data that allowed users to complete their analysis for all three Expected Results in Use Case 2. Starting from the top, the numbers in the red and amber icons on the map represent the number of transformers experiencing peak utilization of over

150% (red) to within 80% - 120% (amber) of name plate rating. The color bar in the bottom of the window indicates the percent peak utilization. The bar graph in the middle indicates percent peak utilization of each transformer. Each bar represents a transformer. The third graph is a histogram of percent utilization versus the number of transformers. From left to right, the range is from 5% peak utilization to more than 200% peak utilization.

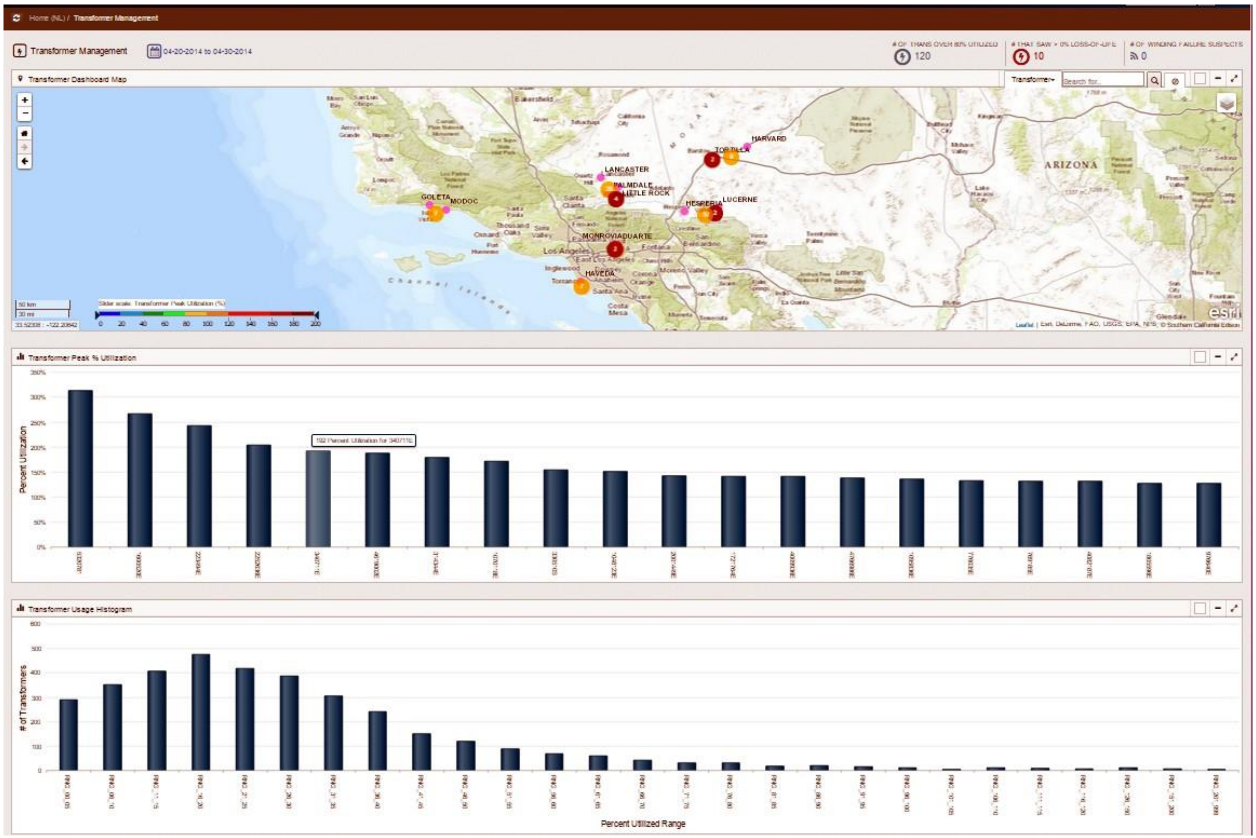

Figure 2, Transformer Management Dashboard

Use Case 3: Identify Distribution system assets operating outside of user-defined voltage limits through the GIS data visualization tool (i.e. the SCM). Two specific Expected Results were selected to demonstrate proof smart meter data would provide the user with visualized voltage data: a) on a historical basis for comparative time periods for any customer, and other customers in the vicinity on the same circuit, and b) as a color heat map (green, orange, or red) based on voltage thresholds entered by the user. Users affirmed both these Expected Results were met using Feeder Details Screen, Fig. 1.

Use Case 4: Demonstrate the ability to export data in the proper format for data manipulation in other power and non-power analysis tools. There were two Expected Results for this straightforward test: a) user can export data into a format that can be manipulated in a software program, such as Microsoft Excel, to generate additional reports and analysis for purposes other than power analysis, and b) user can export data into a format that can be manipulated in a power flow modeling software such as CYME. This functionality was displayed on the Service Point List (Fig. 3) where the user entered a query; the results were displayed on a map with a list/data table and the ability to export the data in various format.

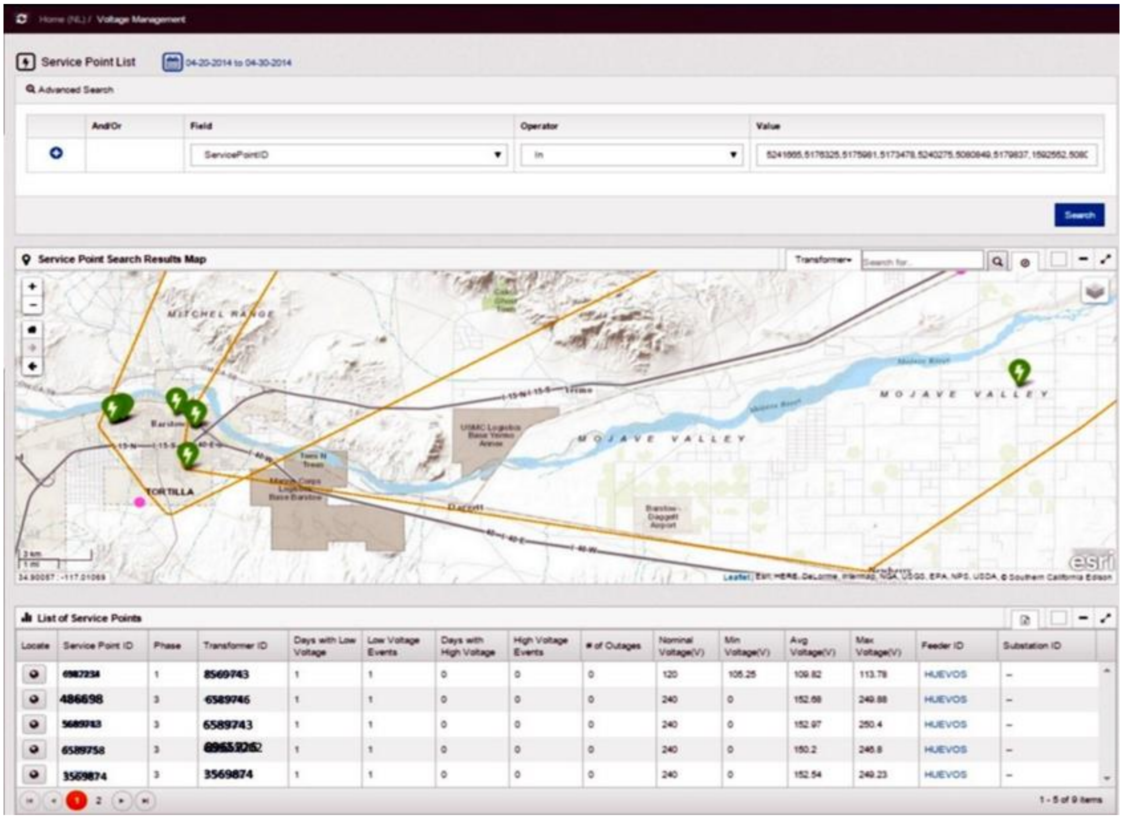

Figure 3, Service Point List

Note: This figure has been altered from the original to obscure specific customer and Distribution system asset information

6.1.2 Customer and Transformer Load Analysis

The second Use Case Category, Customer and Transformer Load Analysis, included four analytics for demonstration. As with the Voltage Analytics Use Cases, each was a sequentially numbered (continued from the Voltage Analytics Use Case numbers) Use Case.

Use Case 6[8]: Provided the ability to evaluate load addition at the transformer level. This analytic had six Expected Results: a) user was able to identify a specific transformer on SCE's GIS electrical network, b) user was then able to query the transformer to verify all the customers connected to the transformer, c) then viewed the cumulative load (aggregated customer load profiles from smart meter data) on the transformer in kWh, d) and then viewed the transformer load profiles for a 24-hour period, as well for a given historical duration up to a year, and e) viewed the same data converted to a kVA load profile, also for a 24 hour period and a given historical duration up to a year; lastly, f) the user hypothetically added kVA (i.e. for new service) to evaluate impact of additional load on the transformer. The Transformer Details displayed in Fig. 4 enabled users to complete their analysis. Starting from the top left is the transformer (green icon) location on circuit map with its associated meters (green squares). On the top right is transformer rating (horizontal line) with customer (amber lines) and aggregated load (green line) profiles over time. Similarly, below is the customer and aggregated voltages with user defined limits (horizontal lines). The pie chart indicates percentage of individual customer loads contributing to the total load on the transformer.

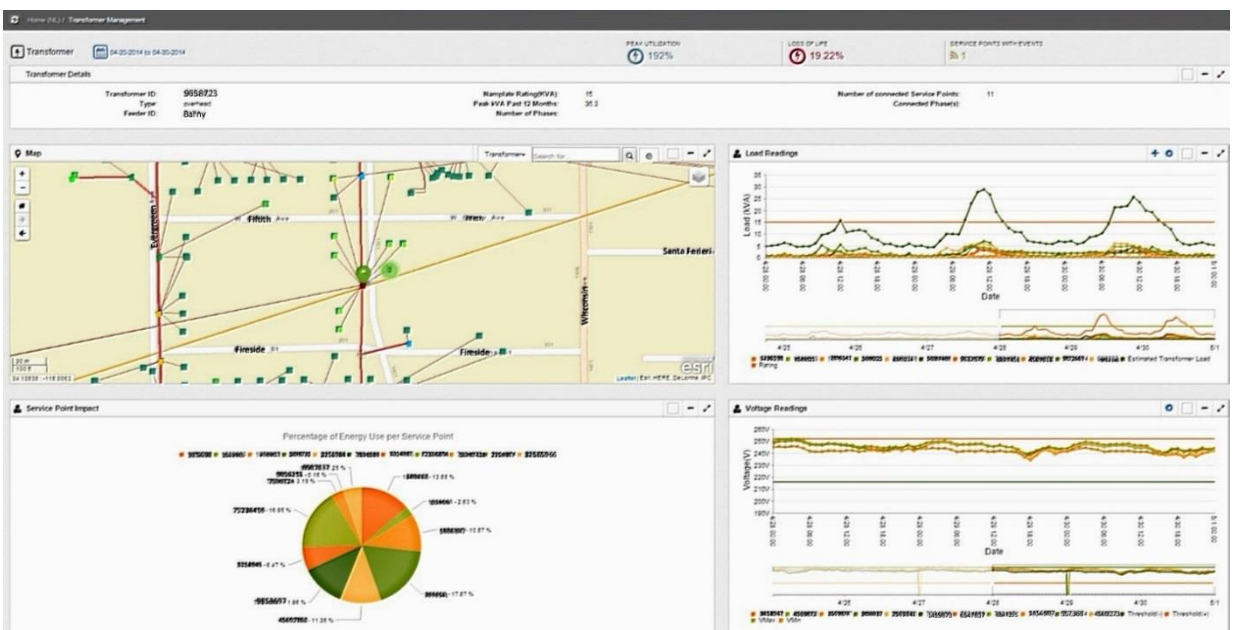

Figure 4, Transformer loading details.
Note: Figure has been altered from the original: street names were redacted to preserve customer privacy

---

[8] Use Case 5 was deleted and the Expected Results were incorporated into other Use Cases.

Use Case 7: Provided the ability to view aggregate load and generate load profiles of strategic nodes upstream of multiple transformers by aggregating load from the customer meter to the transformer to the strategic node along the same feeder. This Use Case included four Expected Results to demonstrate this use case. The user, in each expected result, was able to: a) identify strategic nodes (red arrow) along any given distribution circuit on SCE's cGIS electrical network, b) aggregate the customer loads and generate load profiles for the transformers connected to the strategic node along a selected circuit, c) view the load profiles for a 24-hour period as well for a given historical duration, but no more than a year, and then d) view the same data converted into a kVA load profile, again for either a 24-hour period or a historical duration exceeding a year. The Feeder Details Screen (Distribution system asset Context version) page, Fig. 5, depicts the view used to demonstrate this Use Case.

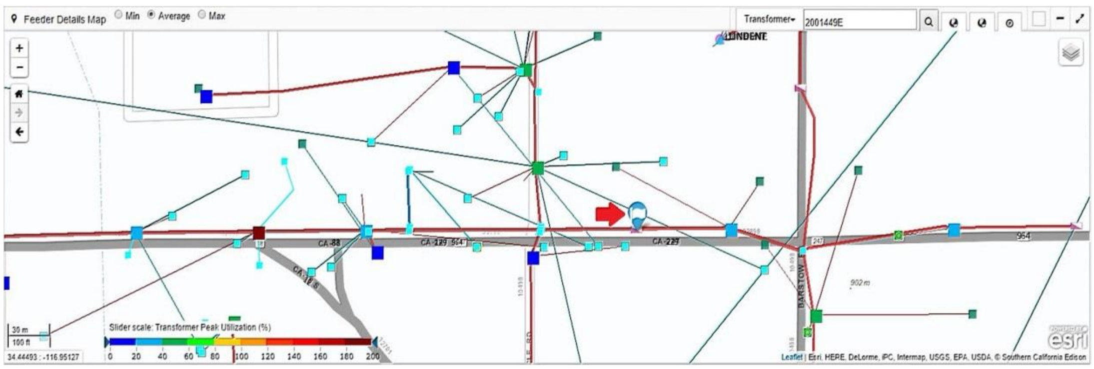

Figure 5, Feeder Details with transformers (big squares) and meters (small squares) identified. Transformers are color coded to indicate percent utilization.

Note: Figure has been altered from the original: street names and transformer ID were redacted to preserve customer privacy.

Use Case 8: Identify transformers at risk of overload based on a comparison of aggregated peak kVA load and transformer nameplate rating. There were three Expected Results to prove this Use Case. The user, in the three tests: a) reviewed transformer load profiles at a given point in time to determine if the rating (15kVA – horizontal green line) of the transformer is adequate to handle the current load profile, b) compared the load profile to an acceptable load threshold based on SCE distribution loading standards, and c) compared the load profile to an acceptable load threshold based on the transformer nameplate rating. The Transformer Details Screen Load Readings Chart, Fig. 6, shows the graphical presentation for the load readings and the data details.

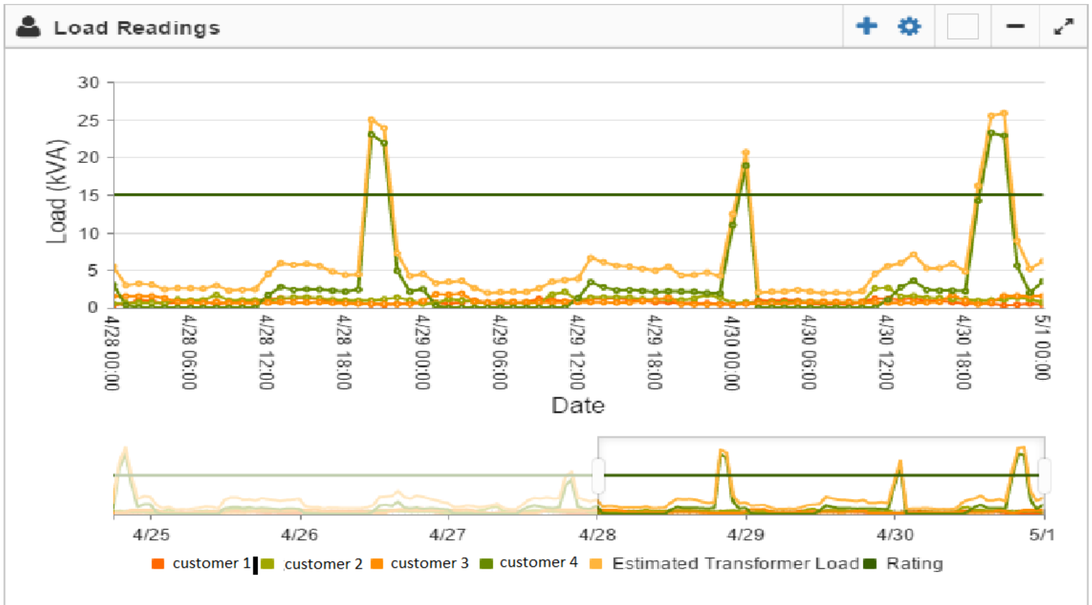

Figure 6, Transformer Loading details at an individual customer and aggregated level

Use Case 9: Generate an area wide heat map visualization to identify potential Distribution system assets at risk based on the load profiles at the transformer and circuit level. Expected Results for this demonstration test stated the User would be able to: a) enter user defined criteria similar to that used for Use Cases 1-3 to identify potential transformers at risk, and b) generate a transformer heat map layered on SCE's GIS electrical distribution network to visually identify all transformers in normal, at risk, or abnormal load conditions (green, yellow or red status indicators). The visual display was shown as the Distribution system asset Management Dashboard, Fig.7.

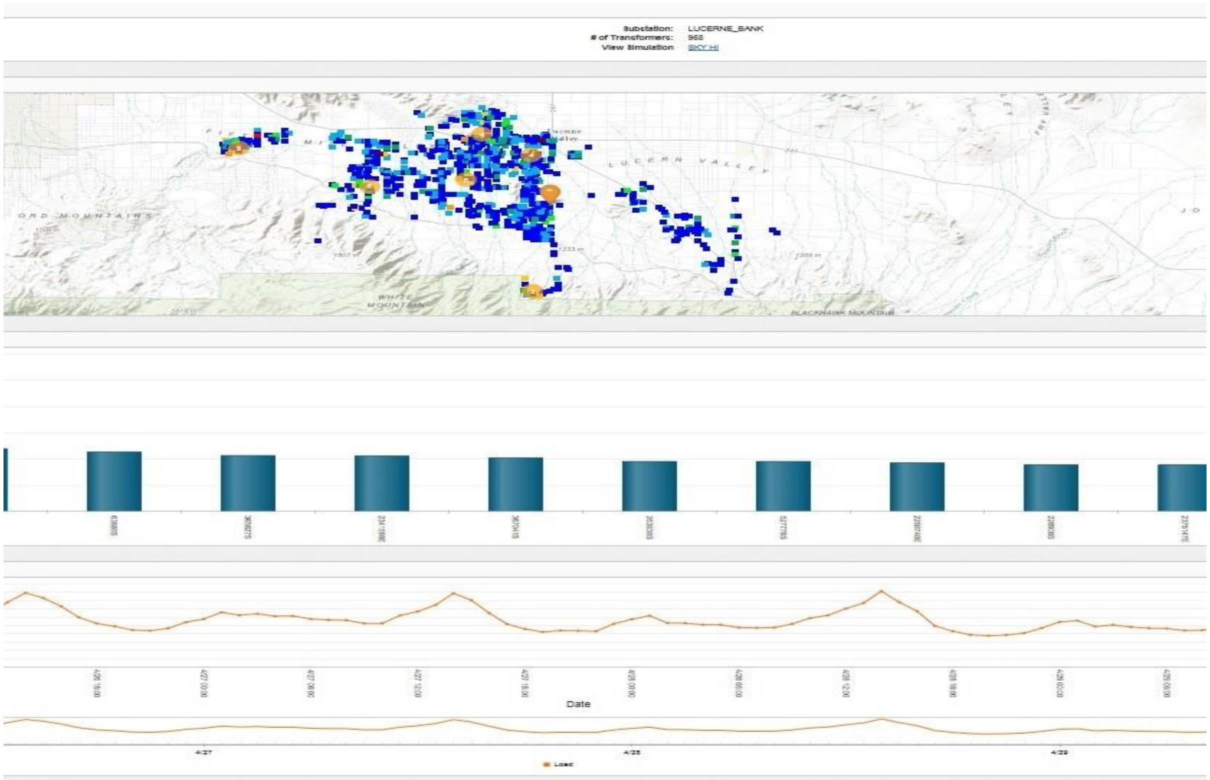

Figure 7, Transformer Dashboard Map overlaid on electrical distribution network GIS to visually identify all transformers

Use Case 10: Demonstrate the ability to export data in the formats for data manipulation in other power and non-power analysis tools. There were two Expected Results for this straightforward test, parallel to the Expected Results in Use Case 4: a) user can export data into a format that can be manipulated in a software program, such as Microsoft Excel, to generate additional reports and analysis for purposes other than power analysis, and b) user can export data into a format that can be manipulated in a power flow modeling software such as CYME. The Transformer List View provided an export option, including nameplate kVA, peak kVA, percent loss of life over the date range number of service points and number of phases observed, among other fields, as shown in Fig. 8, List of Transformers. This View also allowed selection of formats.

List of Transformers

Transformer ID	Nameplate KVA	Peak KVA	Peak % Load	% Loss of Life	Top Oil Temp	# of Service Points	Number of Phases	# HV SP Violations	# LV SP Violations	# of SP Outage Violations
16[redacted]E	5	40.66	813	1672886687477.04	334.08	3	3	0	0	0
2[redacted]6E	10	27.95	279	17950.19	90.66	3	1	0	0	0
3[redacted]S	15	36.73	245	9746.76	99.71	11	1	0	0	0
5[redacted]	1	7.09	709	1607748287625.33	484.25	2	3	0	0	0

1 - 4 of 4 items

Figure 8, List of Transformers View

6.1.3 The Simulated Circuit Model

The SCM's strength was in the visualization of electrical network through smart meter data at a high level view with the ability to drill down to the smart meter level. This Use Case Category included three visualizations to test the application of smart meter data to T&D operations, including outage management. The Use Cases here are sequentially numbered, continuing from the previous Use Case Category.

Use Case 11: Visually display the state of key devices on a distribution circuit segment using historic voltage data and meter events or exceptions from bellwether SmartConnect™ meters. There were five Expected Results for this visualization: a) the SCM overlaid a single-line diagram of a circuit with key devices and their respective voltage profiles for the previous day over the GIS electrical network, b) user selected a date range for voltage profiles, c) system analyzed and processed the voltage data from the bellwether meters (previously identified for each circuit) along with the geographical boundaries the meters were in, and determined the status of the geographical area for the time period selected, then d) the user was able to play back the last 30 days to visually notice the change of the status of the geographical areas during the time period, and e) the user was able to then play back the last 30 days to visually notice the change of the state of the devices during the time period. These tests were performed using the Feeder Details (SCM Context) screen, Fig. 9.

Use Case 12: Graphically represent the status of key devices on the GIS electrical network using voltage data from bellwether meters. Based on the voltage profiles at the transformer and circuit, generate an area wide heat map visualization to identify state of key devices. There were four Expected Results to demonstrate this capability: a) the application interacts with the GIS electrical network and loads a single-line diagram of the circuit with key devices and their respective voltage profiles for the previous day, b) user selected a time period for the modeling (e.g., last 30 days), c) the system analyzed and processed the voltage data for the bellwether meters (previously identified for each circuit) along with the geographical boundaries the meters were in and determined the status of the geography for the time period selected, and then d) the user was able to play back the last 30 days to visually notice the change of the status of the geographical areas during the time period. These four Expected Results also were proven using the screen shown in Fig. 9, Feeder Details (SCM Context)

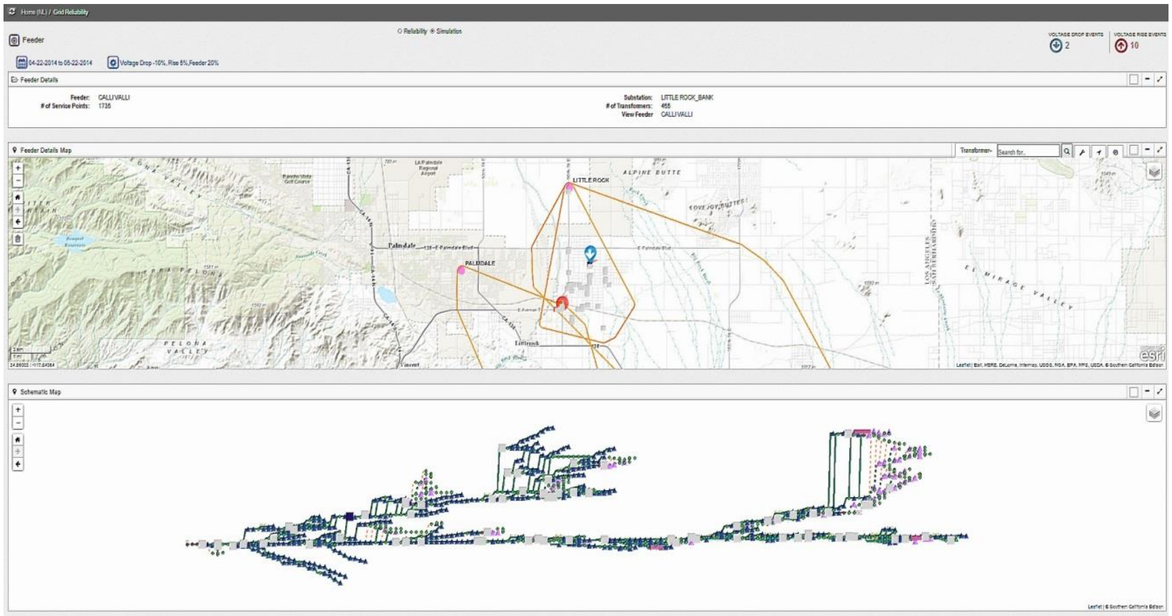

Figure 9, Feeder Details (SCM Context)

Use Case 13: Provide outage reconstruction and reporting models utilizing voltage data and meter exceptions/event data. The IAP was able to recreate outages, restoration timing, and customer counts then associate that data on a visual display. There were four Expected Results associated with this function: a) The IAP was able to retrieve meter outage and restoration events from the database (Teradata or others); provided a visualized replay of the outage sequence using outage start and restoration time stamps; displayed that data on the GIS map with heat map functionality, which allowed b) the user to view the outage on a single-line circuit map, along with the energized status of all distribution system assets by virtue of their associated bellwether meters, enabling c) the user to scroll through the outage event to see timeline of the start of the outage to the time individual devices were re-energized, and finally allowed the d) user to export restoration timing and customer counts for a selected outage, which can be used for outage reporting metrics, including the reliability indices. These tests also were performed using the screen shown above in Fig. 9, Feeder Details (SCM Context).

6.2 Feasibility Study: Use SmartConnect™ Meter Events in Reliability Indices Calculation

The feasibility study was laid out as a five step process as described under Major Tasks in section 5.2. The study focused on a single index (SAIDI) to perform the analysis and conduct the two test cases.

1) Post outage analysis process improvement study
   Analysis of the current Post-Outage CMI Validation process (Fig. 10) showed the process to be highly labor intensive; using analyst time. The Simulate, Update and Confirm steps

below are the most labor intensive steps. It was believed these laborious steps could be replaced and made more efficient by using smart meter data, but it was necessary to first confirm the accuracy of the meter data and identify any conflicts between data systems before recommending process changes.

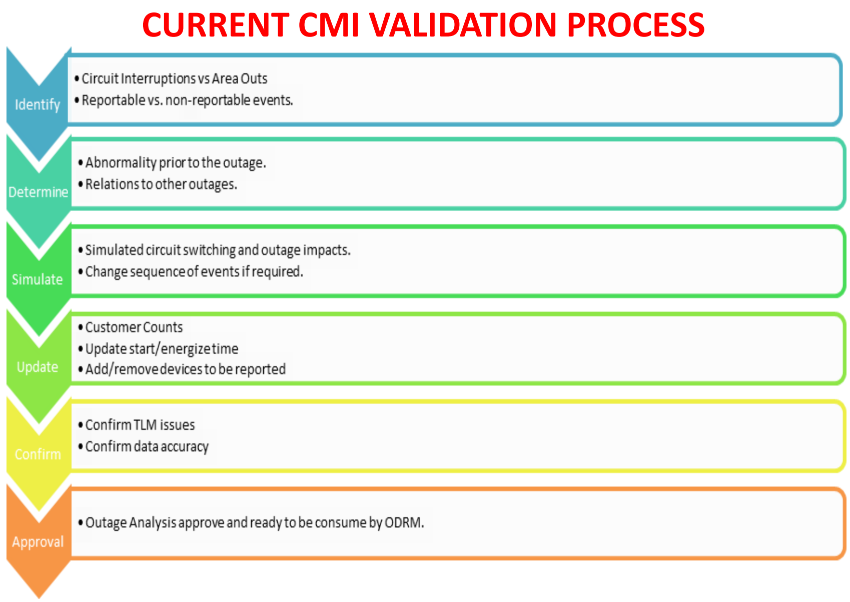

Figure 10, Existing CMI Post-Outage Validation Process

2) Meter outage events data flow improvement study and meter time stamp accuracy:
The smart meter event time stamps and records proved to be accurate, dependable and consistent. The integrated systems, however, presented challenges that required engineering intervention to resolve.

3) Develop CMI calculation methodology using smart meter event data:
Initially, it was anticipated smart meter data would readily enable CMI calculation automation. Systematic analysis of the CMI calculation process and the various data systems accessed for input made it clear that full automation would require a more extensive investment than anticipated for work on major systems (i.e. OMS, ESCDW and ODRM).

A hybrid alternative to full automation was identified. It would use smart meter event data and would not require full integration of the databases. While it would remove the most labor intensive (simulate & update) steps, this alternative would require reconstruction of the current meter outage events reporting tool. After analysis of the two Test Cases was completed, this became the recommended CMI Validation Process change.

Recommended Solution: The hybrid solution would generate an outage report based on meter events with manual input of reportable events information. As shown in Fig. 11 below, this solution has the potential to reduce engineering intervention.

RECOMMENDED CMI VALIDATION PROCESS

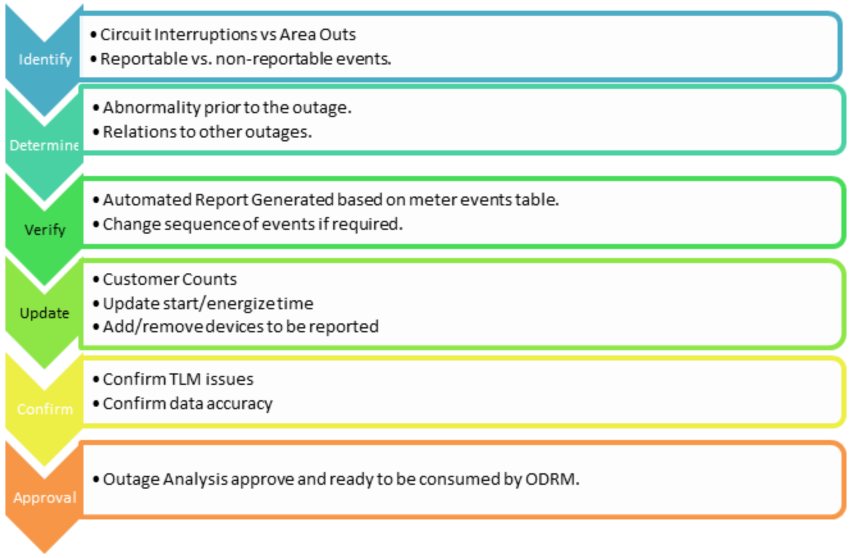

Figure 11, Recommended CMI Post-Outage Validation Process
Includes the verify and update steps automated; manual input of outage information

4) Test Case 1: comparison of verified single incident CMI values to CMI values using meter event time stamp
   This step of the Feasibility Study compared the CMI calculations made through the ODRM versus the SmartConnect™ meter events. The results of this analysis are shown in Table 2 below. Eight single outages and the calculated SAIDI index were included in the analysis. In six of the outages the calculated CMI differences were within 0.1% concluding that individual meter outage events calculated SAIDI values very close to the ODRM SAIDI values. Note that columns 1 – 3 are based on non-use of smart meter data (1) to complete use of smart meter data (3). Also note that "3-Normalized" are meter counts adjusted to account for discrepancies between databases.

Table 2, Single Line Outage Analysis and Results

	Customer Minutes of Interruption (CMI)							
Outage - Incident #	**1**	**2**	**3**	**Delta (2:3)**	**3 - Normalized**	**Delta(2:3-n)**	**SAIDI(ODRM)**	**SAIDI (3-N)**
1. SEWELL (#113092530)	167749.50	167403.50	162380.78	5022.72	167479.82	-76.32	0.03331	0.03220
2. WARRIOR (#113092417)*	148774.00	155740.50	131960.52	23779.98	156760.45	-1019.95	0.03082	0.03055
3. MENIFEE (#112874277)~	13368.05	21057.78	8982.65	12075.13	10956.09	10101.69	0.00422	0.00219
4. IBEX (#1130947393)	119580.53	121679.37	95765.25	25914.12	97106.26	24573.11	0.02436	0.01944
5. CANAL (#113000883)	210626.10	210626.10	187102.18	23523.92	211160.64	-534.54	0.04210	0.04214
6. DOGWOOD (#111878051)^	94955.10	97330.60	68470.20	28860.40	98928.81	-1598.21	0.01910	0.01903
7. BREN (#113091134)	94257.68	93690.22	81337.40	12352.82	93875.18	-184.97	0.01876	0.01879
8. ALLEGRA	52442.33	52296.13	42074.40	10221.73	52311.08	-14.95	0.01047	0.01047
Santa Barbara District - (April to July) New Datalab	NA	3997933.82	2745940.58	1251993.23	2998697.21	999236.61	0.80041	0.58665

*Missing half of events, used OMS start/end time instead.
~ Menifee experience a shorter than expected outage for half of the circuit.
^ Dogwood experience a longer than expected outage for half the circuit.
Use Case 4 difference could be attributed to the lack of gap fil in the months of April and May

A negative delta signifies a Use Case 3 has a higher CMI.

5) Test Case 2: demonstrate scalability of the methodology performed in Test Case 1 with the district of Santa Barbara.
   The individual outage meter events were deemed very close to the ODRM SAIDI values on a network wide basis. When expanded to the district level, however, the impact of legacy meters is much larger due to the effect of commercial and industrial customers on a smaller customer base. Outage analysis using smart meter data can be scalable and able to cover a majority of all outages at the district level. Even considering the impact of commercial and industrial customers on the district level analysis, there was still a 17% improvement in the SAIDI metric using smart meter data compared to ODRM calculations as shown in Fig. 12.

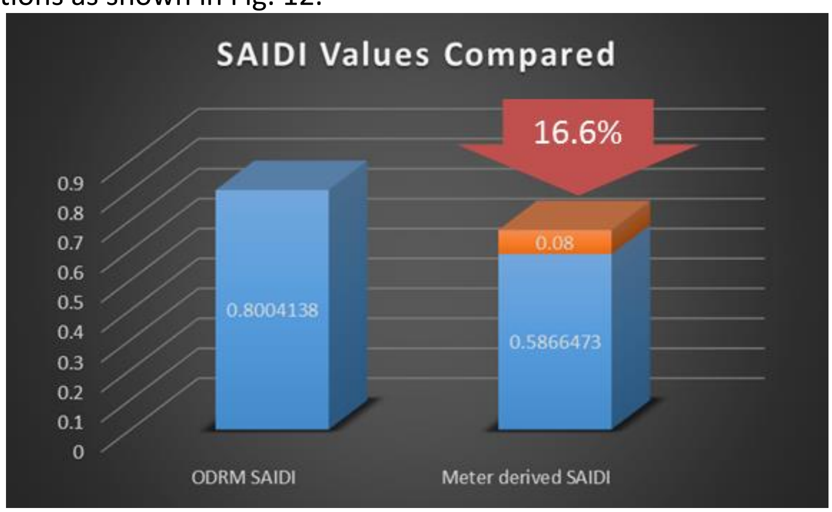

Figure 12, SAIDI Values Compared

Note: A total of 1634 Unique Customers were missing due to non-ITRON and non-communicating meters, accounting for 10.1% of the total 26.70% difference between Meter Events CMI and ODRM CMI.

The feasibility study demonstrated that expanding use of smart meter data to other applications will require additional effort. While immediate labor efficiencies can be captured and reporting accuracy potentially increased, other systemic changes will typically be necessary to achieve full integration of smart meter data into reliability reporting. Communications timing between data bases, dissimilar smart meter configurations, and divergent uses of shared data are examples of challenges that must be overcome to fully obtain the benefits of automated reliability reporting.

6.3 Special Implementation Issues (particular to the technology)

This demonstration project brought into clarity two challenges that will need to be addressed by SCE, and any electric utility, and intends to integrate smart meter data with T&D operations and management.

First, T&D systems and processes have typically been developed over the years for different purposes. Smart meter data has a lot of potential but would require a reassessment of these processes and systems to absorb and correctly utilize the data. Additionally, any differences in the systems being integrated or the data being used must be equalized to avoid conflicts.

Second, the challenge to integrate a working electric distribution GIS system with smart meter data cannot be understated. It required a significant time investment by SCE third party vendors to make this aspect of the demonstration workable.

6.4 Value Proposition

This project demonstrated that smart meter data can be used to provide T&D operational and reliability benefits. It may also have the potential to increase the efficiency and accuracy in reliability report calculations. Electric service reliability has the potential to dramatically increase as applications using smart meter data are made available. Approaches to address voltage fluctuations, transformer loss of life, outages, and unplanned load increases or decreases will change from reactive to proactive. The project demonstrated tools that engineers and planners can utilize to visualize and analyze electric demand and take action to protect the Distribution system assets from unplanned failure and outages. As an example, the IAP demonstrated the transformer load analysis tool. This tool has the potential to improve reliability by identifying all severely overloaded transformers. A proactive planned approach can then be taken to replace these transformers before failure. This planned approach also has the potential to also reduce cost, incurred from failures during non-business hours or environmental and safety benefits derived from preventing catastrophic failure. Additionally, it will also enable engineers and planners to optimize transformer operation to achieve the return on investment that was initially planned when the transformer was placed in service.

There are also societal economic benefits anticipated as this new generation of tools is incorporated into Distribution operations. The economic impact of service interruptions on customers is generally not measured unless the outage is pervasive. That is not to say the societal costs of service interruptions are not incurred, only that they are difficult to measure. Unplanned outages disrupt commerce at all levels, interrupt the continuous flow of society and create unsafe public conditions. Reducing service interruptions and improving voltage stability will have a direct, positive impact on society.

7 EPIC Program Metrics

The EPIC Metrics for this project were selected as shown in Table 3.

Table 3, EPIC Metrics

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement (as applicable to a specific project or investment area in applied research, technology demonstration, and market facilitation)	
3. Economic benefits	
a. Maintain / Reduce operations and maintenance costs	See 7.1
5. Safety, Power Quality, and Reliability (Equipment, Electricity System)	
c. Forecast accuracy improvement	See 7.2
f. Reduced flicker and other power quality differences	See 7.3
6. Other Metrics	
a. Enhance Outage Reporting Accuracy and SAIDI/SAIFI Calculation	See 7.4
8. Effectiveness of information dissemination	
b. Number of reports and fact sheets published online	See 7.5
f. Technology transfer	See 7.6
9. Adoption of EPIC technology, strategy, and research data/results by others.	
c. EPIC project results referenced in regulatory proceedings and policy reports.	See 7.7

7.1 Reduce operations and maintenance costs

The utility will have much to gain as Distribution system asset life will be extended through voltage and transformer load management. Unplanned outages which are currently highly labor intensive processes may be avoided. Operating and maintenance costs will be lower as Distribution system asset lives are optimized and extended through improved planning. As demonstrated in the Use Case Category - customer and transformer load analysis, engineers and planners would be able to use these tools to identify and visualize overloaded transformers and take targeted corrective action.

7.2 Forecast Accuracy Improvement

The voltage analytics demonstrated use of smart meter data to enhance T&D engineers and planners tool set. Using the voltage profiles and system visualization tools in this demonstration, engineers could identify overloaded transformers enabling them to direct corrective actions before equipment failure would have occurred.

7.3 Reduced flicker and other power quality differences

This project targeted voltage analytics for power quality. It successfully demonstrated the ability to evaluate capacitor bank placement based on voltage deterioration along a circuit. Engineers were able to demonstrate the IAP's capability to review and visualize voltage profiles, and deterioration from a smart meter at the end of the circuit to the substation. Engineers were also able to visualize the locations of overloaded transformers on a GIS map; enabling them to target voltage problems and take action before a failure occurred.

7.4 Enhance Outage Reporting Accuracy and SAIDI/SAIFI/MAIFI Calculation

Application of smart meter data to the reliability indices calculations can improve CMI metrics. The level of accuracy and efficiency may improve from the existing methodology.

7.5 Number of reports and fact sheets published online

This report is the first publication of the demonstration results.

7.6 Technology transfer

The results of this IAP demonstration have applicability to any electric utility interested in integrating smart meter data with T&D analytics and outage management. The demonstration successfully displayed the utilization of smart meter data to enhance T&D operations and maintenance toolset. SCE is in the initial stages of procuring and implementing a similar tool enterprise-wide for its T&D engineers and planners.

During 2015 SCE presented an overview of the project at two industry meetings:

- 4th Annual Utility Analytics conference, Phoenix, March 5th 2015, session 201 – presentation entitled "Advanced Analytics for Voltage Management"
- EPIC Innovation Symposium, December 3, 2015, presentation on "Outage Management and Customer Voltage Analytics"

7.7 EPIC project results referenced in regulatory proceedings and policy reports.

This report represents the first release of project results.

7.8 Project Objectives: Met

The objectives of this project were met. Users demonstrated the benefits of using smart meter data for enhanced analytics and the capability to visualize circuit state clearly will someday streamline the outage recovery process. The feasibility study identified the potential for smart meter data to improve the process of calculating CMI for reliability reporting. The study also pointed out the need to align data bases when implementing these new tools.

7.9 Measurement and verification results

The results of this demonstration were measured by the stepped control process implemented during the User Test. The users were T&D engineers, planners, outage reporting analysts and IT engineers. The Tests were conducted under laboratory conditions and users were provided a manual to follow each of the steps that demonstrated the use case. The user then was required to report on the success or failure of the technical requirements of the use case. The users found the results successful and proposed implementation of the analytics and visualization tools to their respective management.