Pacific Gas and Electric Company

Program	*Electric Program Investment Charge (EPIC)*
Project	*EPIC 1.19 – Pilot Enhanced Data Techniques and Capabilities via the SmartMeter^{TM} Platform*
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Table of Contents

List of Tables

List of Figures

List of Equations

List of Acronyms

AEIC   Association of Edison Illuminating Companies

AMI   Advanced Metering Infrastructure

ANSI   American National Standards Institute

AP   Access Point

ATS   Advanced Technology Services

CEC   California Energy Commission

CPUC   California Public Utility Commission

EPIC   Electric Program Investment Charge

HAN   Home Area Network

IPv6   Internet Protocol version 6

LOS   Line of Site

MDC   Mobile Data Collector

NLOS   No Line of Site

PQ   Power Quality

SCE   Southern California Edison

SDG&E   San Diego Gas and Electric

TD&D   Technology demonstration and deployment

TOU   Time of Use

VVO   Volt/VAR Optimization

Executive Summary

PG&E has invested over $2 billion in a robust Advanced Metering Infrastructure (AMI) network, one of the largest IPv6 networks[1] in the world with more than 9 million AMI devices (also referred to as the SmartMeter[TM]). Data collection and messaging has so far been constrained to the direct benefit generating features supported in the California Public Utility Commission's (CPUC) Decisions approving PG&E's SmartMeter[TM] deployments, including *D. 06-07-027[2] Final Opinion Authorizing Pacific Gas and Electric Company to Deploy Advanced Metering Infrastructure* and *D. 09-03-026[3] Pacific Gas and Electric Company's Proposed Upgrade to the SmartMeter[TM] Program*. The benefits of the SmartMeter[TM] highlighted in the decisions focused on meter reading operations savings, Home Area Network (HAN) functionality, etc.

In order to contribute to maximizing the value of SmartMeters[TM] for customers, PG&E proposed and the CPUC approved PG&E's Electric Program Investment Charge (EPIC) Project 1.19 - "Pilot Enhanced Data Techniques and Capabilities via the SmartMeter[TM] Platform" to demonstrate new and improved data collection techniques and capabilities that could potentially expand the benefits from the AMI network system.

Objectives

EPIC 1.19 successfully met the following project objectives:

1. Demonstrate additional types of data that can be collected via PG&E's SmartMeter[TM] platform, both by converting meter formats and by exploring new data channels in the existing format.

2. Demonstrate various data collection network improvement or endpoint devices with longer range or enhanced data rates or other data collection improvements. Examples include new methods of collection for meters in remote areas and new power theft methodologies using meter data to identify energy diversion cases.

Major initiatives

To achieve the above objectives, EPIC Project 1.19 executed four initiatives that contributed to improving data collection techniques and capabilities of the SmartMeter[TM] network.

- **Initiative 1 – C12.19 Format and Power Quality Data**

  Demonstrate the ability to convert meters from the AMI vendor proprietary original format to the ANSI Standard C12.19 format, which provide more granular voltage and power quality data that may enable PG&E to more easily and automatically access a myriad of data elements previously only available through on-site troubleshooting field visits. This data could potentially provide the ability to proactively, virtually monitor electric distribution circuits and correct voltage issues prior to an issue occurring, and could be leveraged by high usage / large

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[1] Internet Protocol version 6 (IPv6) is the most recent version of the Internet Protocol (IP), the communications protocol for devices across the SmartMeter[TM] network.
[2] http://docs.cpuc.ca.gov/word_pdf/FINAL_DECISION/58362.pdf
[3] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/98486.PDF

customers to save energy and maintain operations productivity by managing sensitive equipment. Additionally, this data can be leveraged to identify energy diversion as described in Initiative 4.

- **Initiative 2 - Explore New Data Channels from existing AMI meters**

  Investigate obtaining new data channels from existing AMI meters that could be used to support safety and reliability goals and investigate whether it's possible to obtain the desired channels in the original (non-C12.19) format.

- **Initiative 3 - Mobile (Remote) Data Collector (MDC)**

  Demonstrate that AMI two-way communications can be successfully transmitted using a radio bridging technology to close the gap between stranded meters that aren't communicating and the headend operating system, which can enable PG&E to communicate with hard-to-reach customers that currently require monthly, in-person visits to read the meters for billing purposes.

- **Initiative 4 - Identifying Energy Diversion**

  Demonstrate the ability to predict 'Line Side Taps' by identifying mismatches between customer voltage drops and corresponding usage to enable PG&E to more easily and quickly identify suspected energy diversion cases.

Key Project Findings

EPIC Project 1.19 concluded with the following key takeaways:

- PG&E determined through lab testing that the current AMI electric meters can be converted to the industry standard ANSI C12.19 protocol, by installing batteries and necessary firmware to maintain time synchronization, which enabled the collection of additional power quality data that is not currently available.

- The proprietary, original meter data format showed gaps in data channels (missing or not complete) from the new meter models that are being developed and added to the AMI network. PG&E may evaluate ways to collaborate with vendors in developing and improving on-shelf products in order to best meet PG&E needs and improve vendor response to product challenges.

- Radio equipment with directional antennae can extend the range of the AMI network in hard-to-reach areas of PG&E's territory.

- The collection of interval voltage readings, in addition to customer usage data, can be used to identify unsafe energy diversion using the 'Line Side Tap' detection technique.

Next Steps

Based on the results of this project, PG&E has taken multiple next steps and will explore several others:

- **Initiative 1 - C12.19 Format and Power Quality Data:** Explore alternative methods for maintaining the clock without the need for a field visit to install batteries and firmware, such as

synchronizing the meter time to AMI network time. Explore the possibility of conducting an end-to-end test to ensure the data can be successfully retrieved in the billing system without negative impact. Pending that an alternative method for maintaining time can be established and that converted meters have no adverse impact on billing, explore rolling out meter data conversion to the ANSI C12.19 format to provide additional visibility into voltage data. For new meter installations, consider purchasing ANSI C12.19 formatted polyphase meters with super-capacitors (no batteries).

- **Initiative 2 - Explore New Data Channels from existing AMI meters:** Collaborate with the AMI vendor to correct the defects of leading kVARh for original format meters. In order to incorporate large commercial and industrial customers in to PG&E's AMI metering solution, this data is needed. This effort is currently underway in collaboration with the vendor. Additionally, PG&E will explore the use of new meters manufactured with C12.19 format in scenarios where the business case shows value.

- **Initiative 3 - Mobile (Remote) Data Collector (MDC):** Apply remote data collection technologies at locations that are proven to be economical, practical, and feasible, to connect as many meters to the AMI network as possible. This demonstration has now led to the successful use of a low-cost antennas only solution. It was found that this was all that was needed for most applications. An antenna will connect to a single meter that can then act as a hub to be connected to multiple meters. PG&E has tested and rolled out antennas to over 55 remote locations, and plans to continue this roll out to additional sites.

- **Initiative 4 - Identifying Energy Diversion:** The demonstration of the 'Line Side Tap' diversion condition has proven to be accurate. As such, PG&E now leverages the algorithm in an automated in-house tool. Users can select the regions/ cities and meter types that best suit the user's workload and priorities. Customer data is incorporated in to the tool in order to take the necessary action. The Line Side Tap Tool relies on interval voltage data available from the AMI meters. As such, the scope of the tool is limited to only those meters that currently have interval voltage data. As described in Initiatives 1 and 2, PG&E will explore the expansion of interval voltage data to the rest of the electric meters and continued conversion to ANSI C12.19 format in order to leverage this data for the Line Side Tap Tool as well as other grid operations.

Conclusion

EPIC Project 1.19 successfully demonstrated ways to leverage SmartMeters^{TM} to provide greater visibility and granularity to additional data, which could potentially assist in improvements, such as more efficiently meeting voltage requirements and proactively addressing customer satisfaction concerns related to voltage variability more quickly. The project also connected difficult to reach meters to the AMI network to potentially reduce meter reading operation and maintenance costs. Finally, the project improved the ability to identify 'Line Side Tap' scenarios to improve the efficiency and effectiveness of investigating energy diversion cases and to mitigate safety hazards with customers, the public or PG&E.

As a result of this project, PG&E is planning to leverage these findings by pursuing the conversion of existing meters to C12.19 format when cost-effective, leveraging additional data collection in existing original format, deploying radio/antenna communication devices for hard-to-reach meters, and rolling out a 'Line Side Tap' tool. In the end, this EPIC project provides industry value by demonstrating new ways to leverage AMI data and platform to advance the foundational utility principles of safety, reliability and affordability.

1.   Introduction

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this project. The CPUC initially issued D. 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*[4], which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued D. 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020,*[5] which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. In this later decision, the CPUC defined TD&D as "the installation and operation of pre-commercial technologies or strategies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments, to enable the financial community to effectively appraise the operational and performance characteristics of a given technology and the financial risks it presents."[6] The decision also required the EPIC Program Administrators (PG&E, SCE, SDG&E, and the CEC) to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020.

On November 1, 2012, in A.12-11-003[7], PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application at the CPUC, requesting $49,328,000, including funding for 26 Technology Demonstration and Deployment Projects. On November 14, 2013, in D.13-11-025[8], the CPUC approved PG&E's EPIC plan, including $49,328,000 for this program category. Pursuant to PG&E's approved EPIC triennial plan, PG&E initiated, planned and implemented the following project: Project #1.19 - "Pilot Enhanced Data Techniques and Capabilities via the SmartMeter™ Platform." Through the annual reporting process, PG&E kept the CPUC staff and stakeholders informed of the progress of the project.

This is PG&E's final report on this project, which successfully demonstrated new and improved data collection techniques and capabilities from our electric meters using the existing AMI infrastructure. This report documents the EPIC 1.19 project achievements, highlights key findings and next steps from the project that have industry-wide value, and identifies future opportunities for PG&E and other stakeholders to leverage this project.

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[4] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF
[5] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF
[6] Decision 12-05-037 pg. 37
[7] http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M031/K735/31735305.PDF
[8] http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M081/K773/81773445.PDF

2. Project Summary

2.1. Project Objective

The overall purpose of the EPIC 1.19 project is to demonstrate new and improved data collection techniques and capabilities that could greatly expand the use from various types of data collected via the SmartMeter™, also referred to as the AMI network system.

EPIC 1.19 successfully met the following project objectives:

1. Demonstrate additional types of data that can be collected via PG&E's SmartMeter™ platform, both by converting meter formats and by exploring new data channels in the existing format.

2. Demonstrate various data collection network improvement or endpoint devices with longer range or enhanced data rates or other data collection improvements. Examples include new methods of collection for meters in remote areas and new power theft methodologies using meter data for identifying meter diversion cases.

2.2. Issue Addressed

PG&E has invested over $2 billion in a robust Advanced Metering Infrastructure (AMI) network, one of the largest IPv6 networks[9] in the world with more than 9 million AMI devices, also referred to as the SmartMeter™. Data collection and messaging has so far been constrained to the direct benefit generating features supported in the California Public Utility Commission's (CPUC) Decisions 06-07-027[10] *Final Opinion Authorizing Pacific Gas and Electric Company to Deploy Advanced Metering Infrastructure* and 09-03-026[11] *Decision on Pacific Gas and Electric Company's Proposed Upgrade to the SmartMeter™ Program* approving PG&E's SmartMeter™ deployments, which focused on meter reading savings, outage notification, faster restoration following outages, power theft identification, and Home Area Network (HAN) functions.

In order to contribute to maximizing the value of AMI meters for customers, PG&E proposed and the CPUC approved PG&E's Electric Program Investment Charge (EPIC) Project 1.19 - "Pilot Enhanced Data Techniques and Capabilities via the SmartMeter™ Platform" to demonstrate new and improved data collection techniques and capabilities that could potentially expand the benefits from the type of data collected via the AMI network system.

In addition to providing PG&E with critical information to allow it to more effectively and efficiently monitor and manage the grid, enhanced data could support new information-based services aimed at better addressing customer energy management needs. This, for example, could allow customers to understand and react to their consumption, and provide them with the opportunity to more closely manage costs, and to respond to alerts and grid conditions, should they choose to do so. The drive for

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[9] Internet Protocol version 6 (IPv6) is the most recent version of the Internet Protocol (IP), the communications protocol for devices across the SmartMeter™ network.
[10] http://docs.cpuc.ca.gov/word_pdf/FINAL_DECISION/58362.pdf
[11] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/98486.PDF

new services also may include demonstrating and deploying new technologies that improve network connectivity in order to further enhance the customer experience and improve the reliability of our grid services.

2.3.   Project Initiative Overview

EPIC Project 1.19 completed four major initiatives:

- **Initiative 1 - C12.19 Format and Power Quality Data**

  Demonstrate the ability to convert meters from the AMI vendor proprietary original format to the American National Standards Institute (ANSI) Standard C12.19 format, which may enable PG&E to more easily and automatically access a myriad of data elements previously only available through on-site troubleshooting field visits.

- **Initiative 2 – Explore New Data Channels from existing AMI meters**

  Investigate obtaining new data channels from existing AMI meters that could be used to support safety and reliability goals and investigate whether it's possible to obtain the desired channels in the original (non-C12.19) format. Visibility to additional voltage data could assist in proactively addressing customer satisfaction concerns related to voltage variability more quickly.

- **Initiative 3 - Mobile (Remote) Data Collector (MDC)**

  Demonstrate that AMI two-way communications can be successfully transmitted using a radio bridging technology to close the gap between stranded meters that aren't communicating and the headend operating system.

- **Initiative 4 - Identifying Energy Diversion**

  Demonstrate the ability to predict 'Line Side Taps' by identifying mismatches between customer voltage drops and corresponding usage to enable more efficient identification of suspected energy diversion cases.

PG&E also considered other additional initiatives in this project, but these initiatives were adjusted for efficiencies or put on hold when identifying a duplicative effort.

- **Initiative 5 - Multiple Data Feed from One Meter Using GMI and C12.19 Format**

  This project was combined with Initiative 2 – Explore New Data Channels from Existing AMI Meters. Both initiatives aimed to gather data from existing AMI meters in a new and novel way: one exploring new data channels and the other collecting multiple data points from these channels. Combining the initiatives provided synergy in achieving the objectives.

- **Initiative 6 - New Meter Health Event Data**

  This objective of this initiative was to determine the ability to obtain new meter health events that could provide useful data for detecting and trending additional conditions, such as meter internal high temperature, meter inaccuracy, and meter internal disconnect switch problems. Prior to the initiative's launch, PG&E uncovered that another utility (Pepco Holding Inc.) had been able to obtain additional health event data in the manner that this initiative had proposed.

In an effort to avoid unnecessary duplication per the EPIC guidance in Decision 13-11-025,[12] PG&E decided to not proceed with executing this initiative, as the premise has been proven elsewhere.

3. Project Initiatives: Overviews, Results, Findings and Next Steps

The sections below describe the overview, milestones and tasks, results, findings, and next steps for each of the project's four key initiatives.

3.1. Initiative 1 - C12.19 Format and Power Quality Data

3.1.1. Overview

To determine the ease and feasibility of accessing a myriad of data elements previously only available through on-site troubleshooting field visits, Initiative 1 converted AMI meters from the AMI vendor proprietary original format to ANSI Standard C12.19 format. The ANSI Standard C12.19 meter data format is the national-standard data format for meter communications and provides the ability to access additional meter data, such as power quality data and more granular voltage data, which is not available in the original format.

Collecting more granular voltage information may support PG&E's ability to more accurately locate and proactively resolve electric line fault conditions. Also, the C12.19 standard meter is capable of providing power quality data, which is information that may benefit high usage/large commercial customers in two ways: 1) energy savings and, 2) manufacturing operations. Customers may save energy by leveraging the available power quality data to replace inefficient equipment and install additional capacitors to compensate VAR, stabilize voltage supplied to the load and reduce heat generation during operation. For manufacturing operations, the power quality data may help these customers set up equipment, increase equipment efficiency and longevity and maintain operations and productivity.

The original and ANSI C12.19 formats are two different methods of communicating meter data and commands between the headend operating system and the meter. The original AMI meter data format is proprietary to the AMI network provider. In this original format, the radio interface card that is mounted in the meter acts as an interface between the headend operating system and the meter. A few channels of metering interval data and logs are stored in the radio interface card. The meter itself has a simple program based on total kWh as opposed to Time of Use (TOU) data.

For the national standard ANSI C12.19 meter data format, the radio interface card passes the commands and meter data directly between the headend operating system and the meter. Metering interval data and logs are stored in the meter and are limited only by the meter programming and memory size. The meter itself has a more complex program.

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[12] http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M081/K773/81773445.pdf

Objectives

Converting the meter data format to the ANSI C12.19 standard allows for additional power quality data and more granular voltage data to be collected, which would support the benefits noted above. This initiative had three main objectives that contributed to determining if the conversion to ANSI C12.19 format may provide these additional benefits to PG&E and our customers:

1) Convert polyphase AMI meters from the original AMI vendor proprietary meter data format (original format) to the national standard ANSI C12.19 meter data format (ANSI C12.19 format).

2) Schedule and execute on-demand reads to retrieve additional interval data channels.

3) Schedule and execute an on-demand power quality data reads to retrieve power quality (PQ) data.

Tasks

To achieve the objectives of this initiative, the following tasks were executed and results identified:

1) **Task: Converted meters to ANSI C 12.19 format:** Four meters, two self-contained Form 16S and two transformer rated Form 9S, were converted from the original format to ANSI C12.19 format. To complete the conversion, the following steps were performed:

    a) Installed batteries and the necessary firmware options into the meters to enable advanced functions:

    - kVA/kVAR Measurement
    - Power Quality Measurements
    - Expanded Load Profile Recording
    - Time of Use (TOU) so the meter may be programmed for self-reads at midnight and other TOU operation.
    - Voltage Event Monitor
    - Event Log to track the most recent 500 events with date and time stamps.

    b) Performed the conversion process from original format to ANSI C12.19 format using the headend operating system.

    c) Reprogramed the meters using the headend operating system with new Time of Use (TOU)/Load Profile meter programs to enable load profile recording.

2) **Retrieve Interval and Register Reads for New Data Channels:** On-demand interval and register reads for the new channels were retrieved using the headend operating system. The data was compared to the values pulled directly from the meter.

    a) Lab Test: The test was performed one time for each of the four meters in a lab setting.

    b) Field Test: The test was performed on one of the converted meters on-site at one location in San Francisco.

3) **Retrieve Power Quality Data:** On-demand power quality (PQ) data reads were retrieved using the headend operating system. The data was compared to the values pulled directly from the meter.

a) Lab Test: The test was performed one time for each meter in a lab setting.

b) Field Test: The test was performed on one of the converted meters on-site at one location in San Francisco.

3.1.2. Technical Results

Through completing the above tasks, Initiative 1 demonstrated the following results:

Through lab testing and field testing, two self-contained Form 16S and two transformer-rated Form 9S meters were successfully converted from the original format to the ANSI C12.19 format and tested. Figure 1 below depicts the test meters that were used in the lab and field testing.

Figure 1. Initiative 1 - Test Meters (green arrows indicate test meters)
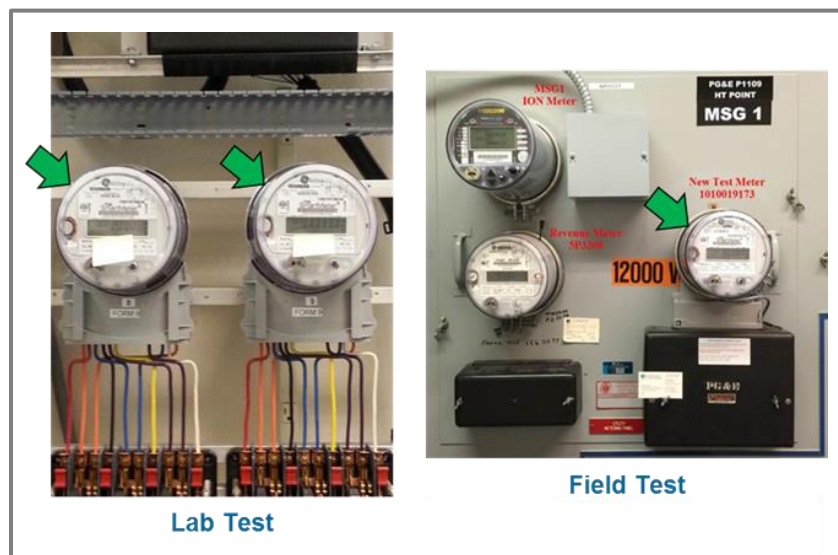
4) On-demand interval usage and register reads were requested and successfully received using the headend operating system. There was no delay in receiving the data. The data received matched the expected values within revenue meter class standards, which can be leveraged for billing and planning purposes. With visibility into all of these data elements, PG&E can potentially leverage SmartMeter^{TM} building capability for all customers. The additional data channels include:

- kWh Total Delivered Only Fundamental + Harmonics
- kVARh Total Lag Only Fundamental + Harmonics
- kWh Total Received Only Fundamental + Harmonics
- kVARh Total Lead Only Fundamental + Harmonics
- Phases A, B, C Line to Neutral Voltages Fundamental + Harmonics
- Phases A, B, C Line to Line Voltages Fundamental + Harmonics

5) On-demand Power Quality (PQ) data reads were successfully received using the headend operating system. There was no delay in receiving the data and the data received matched the expected values that were pulled directly from the meters. This additional PQ data could assist in meeting voltage requirements and proactively addressing customer satisfaction concerns related to voltage variability. The PQ data included:

- Phases A, B, C Voltage Magnitudes and Phase Angles
- Phases A, B, C Current Magnitudes and Phase Angles
- Distortion Power Factor
- Meter Specific Diagnostic Flags and Counters
- Previous Interval and Momentary Demands
- Phases A, B, C kW Demand Fundamental + Harmonics
- Phases A, B, C kW Demand Fundamental Only
- Phases A, B, C kVAR Demand Fundamental + Harmonics
- Phases A, B, C kVAR Demand Fundamental Only
- Phases A, B, C Distortion kVA Demand
- Phases A, B, C Apparent kVA Demand
- Phases A, B, C Line to Neutral Voltages Fundamental + Harmonics
- Phases A, B, C Line to Neutral Voltages Fundamental Only
- Phases A, B, C Line to Line Voltages Fundamental + Harmonics
- Phases A, B, C Line to Line Voltages Fundamental Only
- Phases A, B, C Currents Fundamental + Harmonics
- Phases A, B, C Currents Fundamental Only
- Imputed Neutral Current
- Power Factor
- Frequency
- Phases A, B, C Total Demand Distortion
- Phases A, B, C Current Total Harmonic Distortion
- Phases A, B, C Voltage Total Harmonic Distortion
- Phases A, B, C Register Distortion Power Factor
- Total Register Distortion Power Factor

Scheduled reads and export of power quality data were executed successfully and generated export files, including the data fields noted above. These export files are suitable for data analysis and database storage in a production environment.

3.1.3. Findings and Next Steps

Findings: The initiative successfully demonstrated the conversion of meters from the original, vendor-proprietary data format to the ANSI C12.19 format. In lab and field settings, four meters were converted from original format to ANSI C12.19 format and the desired data was successfully and accurately retrieved. This may enable PG&E to more easily and automatically access a myriad of data elements, which was previously only available through on-site troubleshooting field visits. This data can be leveraged for electric operations and power quality purposes to troubleshoot issues without needing to deploy metering equipment into the field.

While the conversion was successful, an in-person visit was required for each meter to install a battery and enable numerous firmware functions in order to have time synchronization for the data collected. Additionally, further testing is required to ensure that the billing system is not impacted.

Next Steps: As an outcome of these findings, PG&E will explore the following next steps:

- **Explore alternative timing methods:** During the project, if an in-person visit was required for each meter to install a battery for the meter clock and enable numerous firmware options in order to have time synchronization for the data collected. PG&E will explore alternative methods for maintaining the clock without the need for a field visit, such as synchronizing the meter time to AMI network time.

- **Conduct end-to-end test for converted meters:** This initiative tested the ability to collect this data in the meter headend. Following this project, PG&E will explore the possibility of conducting an end-to-end test to ensure the data can be successfully retrieved in the billing system without negative impact.

- **Conduct conversions in phases:** Pending that an alternative method for maintaining time can be established and that converted meters have no adverse impact on billing, PG&E will explore rolling out meter data conversion to the ANSI C12.19 format to provide additional visibility into voltage data. This can be performed in waves, but PG&E will potentially explore first deploying this new format to customers on the commercial / industrial, agricultural customers, and water districts, as they will see the highest benefits from these power quality troubleshooting improvements. Pending the results of this roll-out, PG&E will then explore converting meters to the ANSI C12.19 format with medium and large commercial/industrial customers.

- **Leverage standard format for new installations:** For new meter installations, replacements and maintenance, PG&E will consider purchasing ANSI C12.19 formatted polyphase meters with super-capacitors (no batteries) and/or with a capability of synchronizing the meter time to AMI network time.

3.2. Initiative 2 – Explore New Data Channels from Existing AMI Meters

3.2.1. Overview

As AMI technology improves over time, new data becomes available that could potentially be leveraged to support safety and reliability goals. For instance, visibility to additional voltage data could assist proactively addressing customer satisfaction concerns related to voltage variability more quickly.

The main deliverables of Initiative 2 involved programming meter communication interface cards to retrieve new data channels from the AMI meters to investigate what new data channels could be provided from existing AMI meters, demonstrate whether it is possible to obtain these channels from the original AMI proprietary format, and demonstrate the impact of receiving these new data channels into PG&E systems.

Objectives

This initiative had three main objectives:

1) Investigate new data channels (existing or still to be developed) from original/existing AMI single phase and polyphase meters that could be used to meet safety and reliability goals.

2) Demonstrate the ability to obtain desired channels from the original format.

3) Demonstrate that receiving additional data channel in the headend operating system does not negatively impact business critical systems and operations.

Tasks

This initiative conducted the following three tasks:

1) **Investigate Data Channel Options:** The project team investigated what potential new data channels could be extracted from existing AMI meters in the AMI vendor original format.

2) **Demonstrate Data Retrieval:** Eight meter communications interface cards (from 3 different manufacturers, in 4 different forms, and in 3 different meter models) were programmed to retrieve the new data channels. The additional data elements were then extracted from forms 2S[13], 9S[14], and 12S[15] meters.

3) **Assess Impact of Additional Meter Data Channels:** The project team analyzed and confirmed the data being retrieved from the additional meter channels.

3.2.2. Technical Results

To achieve the first objective, the project demonstrated that many additional meter data elements are now available from AMI meters in the original AMI vendor-proprietary format than in previous versions of the headend operating system and meter communications firmware.

To achieve the second objective of demonstrating the ability to retrieve the data, the project extracted several data elements from four AMI meters and tested to confirm that the data was being retrieved as expected. The project, however, identified several gaps in the ability of the current PG&E AMI system to provide the available data in the original format. This is due to the limited capabilities of the radio interface card mounted in the meter that acts as an interface between the headend operating system and the meter.

The most critical of these measurement channels is "kVARh, Total Lead". This channel is required to meet our 4-channel AMI metering solution of +/- kWh/kVARh, or more widely known as "Watt/VAR/Watt/VAR," meter programming for some of PG&E's large commercial and industrial customers.

Table 1 illustrates the data channels that are available from meters from three vendors and indicates which are not available for retrieval using the original format.

- Vendors 1 to 3 are different meter manufacturers.
- The source channel designations are from the AMI vendor.
- The references in the table refer to the notes found directly below the table.
- Cells in GREEN indicate data successfully provided.
- Cells in RED indicate data is missing or can't be retrieved in the original format.

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[13] ANSI Meter Form 2S: Self-contained and commonly used on 240v, single phase three wire service
[14] ANSI Meter Form 9S: Instrument rated meter type most commonly used in 4 wire service
[15] ANSI Meter Form 12S: Self-contained meter used on either three phase or single phase services

- Blank cells are not applicable.

Table 1. Initiative 2 - Available Data Channels in Original Format

Source Channel	Channel Description	Single-phase		Three-phase	
		Vendor 1	Vendor 2	Vendor 3	Vendor 1
2	Delivered Energy kWh	X	X		
3	Received Energy kWh	X	X		
4	Total Energy (Delivered + Received)	X	X		
5	Net Energy (Delivered – Received)	X	X		
6	Energy Health counters: Inversion, PF, Sag, Swell	X	X	X	X
7	Instantaneous Voltage	X	X		
8	Instantaneous Power	X	X		
9	Meter Health Flags	X	X	X	X
25	Delivered Energy kWh			X [6]	X [1, 4]
26	Received Energy kWh			X [6]	X [1, 4]
27	Total Energy (Delivered + Received)			X [6]	X [1, 4]
28	Net Energy (Delivered – Received)			X [6]	X [1, 4]
29	Reactive Power, Lag kVARh			X [6]	X [2, 4]
NA	Reactive Power, Lead kVARh			[3]	[3]
30	Reactive power VARh, Lag – Lead			X [6]	X [2, 4]
31	Voltage Phase A to Phase C				[5]
32	Voltage B to Neutral				[5]
33	Voltage Angle, Phase A				X
34	Voltage Angle, Phase B				X
35	Voltage Angle, Phase C				X
36	Voltage Magnitude, Phase A			X	X
37	Voltage Magnitude, Phase B			X	X
38	Voltage Magnitude, Phase C			X	X
39	Current Angle, Phase A				X
40	Current Angle, Phase B				X
41	Current Angle, Phase C				X
42	Current Magnitude, Phase A				X
43	Current Magnitude, Phase B				X

Source Channel	Channel Description	Single-phase		Three-phase	
		Vendor 1	Vendor 2	Vendor 3	Vendor 1
44	Current Magnitude, Phase C				X
49	Voltage Phase A to Neutral, F + H				X
50	Voltage Phase B to Neutral, F + H				X
51	Voltage Phase C to Neutral F + H				X
52	Voltage Phase A to Neutral, Fundamental Only				X
53	Voltage Phase B to Neutral, Fundamental Only				X
54	Voltage Phase A to Neutral, Fundamental Only				X
55	Voltage Phase A to Phase B, F + H				X
56	Voltage Phase B to Phase C, F + H				X
57	Voltage Phase C to Phase A, F + H				X
58	Voltage Phase A to Phase B, Fundamental Only				X
59	Voltage Phase B to Phase C, Fundamental Only				X
60	Voltage Phase C to Phase A, Fundamental Only				X

Notes: See references in Table 1**.**

1. Energy fundamental frequency only measurement or fundamental frequency + harmonics measurement is determined by the meter program.
2. Reactive Power (fundamental only or fundamental + harmonics) is determined by meter program.
3. Reactive Power, Lead is not available with the source channel noted as "NA".
4. A total of only 5 Energy plus Reactive Power measurements are allowed by the meter.
5. A "CHANNEL_SOURCE_NOT_READY_ERROR" is received for these channels. Other channels duplicate these.
6. Energy and Reactive Power are fundamental + harmonics.

To achieve the final objective of this initiative, demonstrating the new data channels do not negatively impact business critical systems and operation, the project executed an end-to-end certification test. This test is a pre-defined set of automated scripts that are run to ensure there is no impact to the systems. The test results indicated no negative impact on the headend operating system, meter data management system, or billing system from the addition of new channels and the conversion from original data format to ANSI C12.19 data format.

3.2.3. Findings and Next Steps

Findings

Test results show that a lot of additional meter information is now available from our AMI meters in the original AMI data format than in previous versions of the headend operating system and meter communications firmware. The meters themselves contain useful data, such as kVARh data, as well as

phase voltage and current magnitudes and angles. This data can potentially be leveraged for electric operations and power quality purposes to troubleshoot issues without needing to deploy metering equipment into the field.

The project's test results, however, also identified there are still several gaps in the type of data that can be retrieved and reported. For instance, there is no consistent delineation of the various channels by meter type (e.g. Polyphase meters from two different vendors have similar functionality and capability, but one meter has fewer channels available for retrieval in the original format). Additionally, other data channels, like temperature, power factor, diagnostics counters, and related PQ metrics are currently not available in original AMI data format on several meters, and are not currently in the AMI vendor's firmware road map to execute. This shortcoming is due to the limited capabilities of the radio interface card mounted in the meter that acts as an interface between the headend operating system and the meter.

Next Steps

Due to the limitations of retrieving the additional data channels in the original AMI data in the vendor's proprietary format, PG&E will explore the following next steps:

- Collaborate with the AMI vendor to correct the defect of not retrieving the leading kVARh channel for original format meters.

- Conduct further testing to ensure new data channels do not negatively impact the meter data management or billing systems.

- Pursue using the new C12.19 format meters in the field for new installations and maintenance, and in limited cases convert original format meters to C12.19 meters, when the business case shows value.

These actions are all planned to be underway at PG&E, including collaborating with the AMI vendor to correct the defect noted above, conducting further end-to-end testing, and pursuing the use of new C12.19 format meters if the business case is cost-effective.

3.3.   Initiative 3 – Mobile (Remote) Data Collector (MDC)

3.3.1. Overview

The goal of Initiative 3 is to extend the AMI network to remotely read analog meters for hard-to-reach customers that currently require monthly, in-person visits to read the meters for billing purposes. Initiative 3 demonstrated the ability of a radio bridging technology to provide two-way communications to meters that have no network connection. Extending the AMI network can provide access to meters for remote customers, which can potentially reduce manual meter reading operation and maintenance costs.

Objectives

This initiative had three main objectives:

1) Demonstrate that AMI two-way communications can be successfully transmitted using a bridging technology to close the gap between stranded meters that are not communicating and the headend operating system.

2) Compare three vendors for radio and antenna technologies using bench and field testing of multiple radio frequencies or ranges to determine if advantages or disadvantages exist for the various frequencies.

3) Measure throughput and latency for each type of AMI transaction.

Tasks

To achieve the above stated objectives, this initiative performed the following three tasks:

1) **Selected Radio Devices for Comparison:** Three radios devices were selected to represent different frequencies and technology types. Table 2 below provides more detail on the differences between each device.

Table 2. Initiative 3 - Radio Types Tested

	Vendor 1	Vendor 2	Vendor 3
Technology	5.8GHz Unlicensed	900MHz FHSS* Unlicensed	220MHz (Shared Use) Licensed
Performance Capability	Up to 100Mbps	125kbps to 1.25Mbps	10/20kbps with 12.5/25kHz Channel

*FHSS = Frequency Hopping Spread Spectrum

2) **Completed Bench Testing:** Before the devices were released for field testing, the three vendor radios were "Bench Tested" to assess the performance of the two-way communications between the headend operating system and edge devices (meters) at PG&E's Advanced Technology Services (ATS) lab. Between two and four meters were connected to a special isolated instance of the headend operating system via an access point, a pair of radios, and the isolated network during all of the tests.

3) **Completed Field Test:** Command functionality and performance field tests were then completed for two of the three vendor radios. Vendor 3 was not included in the field test due to its failure to retrieve data in the bench test. Figure 2 is a diagram that depicts the Access Point communications field test design.

Figure 2. Initiative 3 - Access Point (AP) Communications Test Setup Diagram
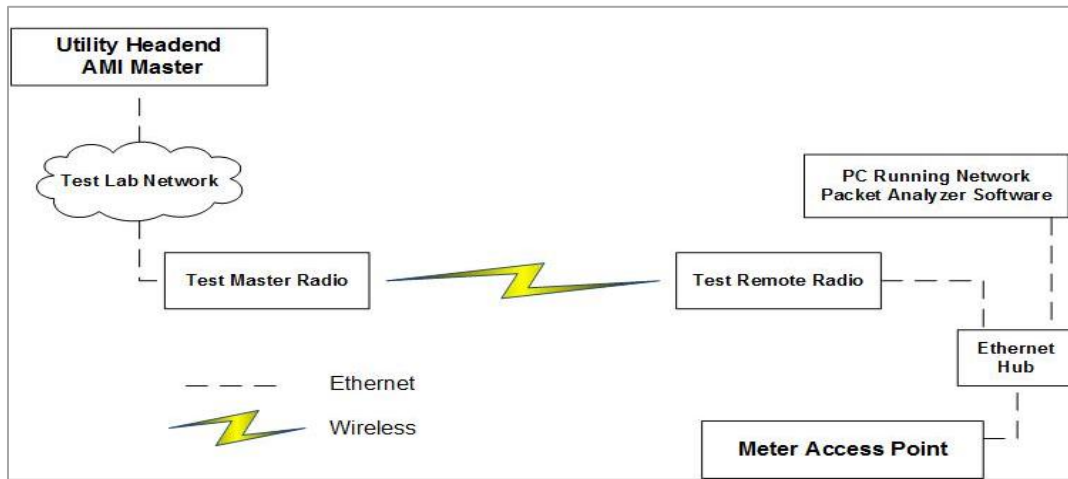
The field tests were conducted at 16 remote locations. The radios were tested at varying distances to determine viability over varying distances and with varying line-of-site impediments, such as trees, buildings, etc. The same isolated instance of the operating system was used for the field test. An antenna array was constructed on the roof of the Advanced Technology Services (ATS) communication lab in San Ramon, a mobile antenna tower was constructed on a PG&E vehicle with a telescoping mast. Figure 3 depicts the radio set-up of the vehicle for field testing.

Figure 3. Initiative 3 - Image of Mobile Test Vehicle

The appropriate antenna types were installed on each array for the Field Test. One radio was connected at the communications lab, the other radio was connected at the mobile array. One meter and an access point were installed at the mobile array and the access point was connected to the radio via Ethernet cable.

3.3.2. Technical Results

Bench Test

Table 3 summarizes the high-level pass/fail results for all operating system functions in the bench test. A "**PASS**" indicates that the meter was effectively read at the access point. A "**FAIL**" indicates that the meter data could not be received at the access point. The results varied based on the radio system used.

It was concluded from the "Bench Test" that radio technology could be used to bridge stranded meters and the headend system. Vendors 1 and 2 passed all headend application and command tests. Vendor 3 failed almost all tests aside from meter pings, on demand meter read, and scheduled internal meter reads.

Table 3. Initiative 3 Bench Test Pass/Fail Summaries

	Tests	Vendor 1	Vendor 2	Vendor 3
	Headend Application Tests			
1	Access Point (AP) Pings	**PASS**	**PASS**	**FAIL**
2	Meter Pings	**PASS**	**PASS**	**PASS**
3	On Demand Meter Read	**PASS**	**PASS**	**PASS**
4	Scheduled Interval Meter Reads	**PASS**	**PASS**	**PASS**
	Headend Command Line Tests			
5	AP Pings (64 byte)	**PASS**	**PASS**	**FAIL**
6	AP Pings (108 byte)	**PASS**	**PASS**	**FAIL**
7	AP Pings (1208 byte)	**PASS**	**PASS**	**FAIL**
8	AP Pings (1408 byte)	**PASS**	**PASS**	**FAIL**
9	Meter Pings (64 byte)	**PASS**	**PASS**	**FAIL**
10	Meter Pings (108 byte)	**PASS**	**PASS**	**FAIL**
11	Meter Pings (1208 byte)	**PASS**	**PASS**	**FAIL**
12	Meter Pings (1408 byte)	**PASS**	**PASS**	**FAIL**
13	AP Firmware Image Upload	**PASS**	**PASS**	**FAIL**
14	AP Firmware Image Upload with Offset	**PASS**	**PASS**	**FAIL**
	Headend Command Line Tests (cont.)			
15	DNS Update Logs	**PASS**	**PASS**	**FAIL**
16	Network Reachability Logs	**PASS**	**PASS**	**FAIL**
17	Periodic DNS Update Logs	**PASS**	**PASS**	**FAIL**
18	Meter NIC FW Image Upload	**PASS**	**PASS**	**FAIL**
19	Meter NIC FW Upload with Offset	**PASS**	**PASS**	**FAIL**

	Tests	Vendor 1	Vendor 2	Vendor 3
20	Network Reachability Extended Pings	**PASS**	**PASS**	**FAIL**

Field Test

Based on the Bench Test results, the project moved forward with Field Testing for Vendors 1 and 2. Table 4 depicts the high-level pass/fail summary for the headend operating software functions tested. A "**PASS**" indicates that the meter was effectively read at the access point. A "**FAIL**" indicates that the meter data could not be received at the access point. The results varied based on the radio system used, terrain, and obstacles.

Table 4. Initiative 3 Field Test Results

Test Locations					Vendor 1			Vendor 2			
Location	Condition	Distance (mile)	Altitude (ft.)	Note	RSSI@ 5.8GHZ	Speed MBPS	Test Result	RSSI@ 915MHZ	Speed MBPS	Antenna	Test Result
ATS											
ATS Base Location	NLOS	0	464	1			**PASS**		0.125	Yagi	**PASS**
Ground Zero Test Site at ATS	LOS	0.15	433		25/-44.5	2.41/12	**PASS**	-44	0.125	Yagi	**PASS**
Testing Locations - South of ATS											
South #1A	LOS	5.94		3			**N/T**				**N/T**
South #2A	LOS	6.24					**N/T**				**N/T**
South #2B	NLOS	9.39					**N/T**				**N/T**
South #2C	LOS	11.11					**N/T**				**N/T**
South #2D	NLOS	8.95	316	2, 4	NG	NG	**FAIL**	NG	0.125	Yagi	**FAIL**
South #3A	NLOS	13.01	291	5	NG	NG	**FAIL**	NG	0.125	Yagi	**FAIL**
South #3B	NLOS	15.12					**N/T**				**N/T**
South-Parking Structure	NLOS	5.94	347	6	NG	NG	**FAIL**	NG	0.125	Yagi	**FAIL**
South-Sunol Peak	NLOS	11.41	2165	7, 8	NG	NG	**FAIL**	-75	0.125	Yagi	**PASS**
Testing Locations - West of ATS											
West #1A	LOS	0.99	517		27/-54.5	5	**PASS**	-68	0.125	Yagi	**PASS**
West #2A	NLOS	2.37	687		NG	NG	**FAIL**	NG	0.125	Yagi	**FAIL**

Test Locations					Vendor 1			Vendor 2			
Location	Condition	Distance (mile)	Altitude (ft.)	Note	RSSI@ 5.8GHZ	Speed MBPS	Test Result	RSSI@ 915MHZ	Speed MBPS	Antenna	Test Result
West #3A	LOS	1.42	292		NG	NG	**FAIL**	-77	0.125	Yagi	**PASS**
West #3B	NLOS	2.59	827	9	27/-59	7.19	**PASS**	-83	0.125	Yagi	**PASS**
West #4A	NLOS	3.71					**N/T**				**N/T**
Testing Locations - North of ATS											
North #1N	NLOS	10.2	566				**N/T**		0.125	Yagi	**FAIL**
North #2N	LOS	7.2	707				**N/T**	-77	0.125	Yagi	**PASS**

Table 4 Notes:

1	NOS / NLOS = Line-of-sight / No Line-of-sight.	2	RSSI = Radio Signal Strength in dBm. Send/receive or receive-only.
3	N/T - Grey highlight indicates not tested.	4	Might be blocked by tall buildings along Highway 580.
5	Noise is OK.	6	30 ft. from cell tower.
7	Reference only.	8	Tilted radio, too much noise on 5 GHz.
9	Had to lower the mast to 3rd section only due to tilted elevation.		

Field Test Results Discussion

Vendor 1 was able to communicate only from two locations:

- West #1A (LOS, a short distance (0.99 miles)).
- West #3B (NLOS, a moderate distance (2.59 miles) at a moderately higher elevation (827 ft.)).

Vendor 2, however, was able to communicate from five locations:

- South-Sunol Peak (LOS, a great distance (11.41 miles), but at a much higher elevation (2165 ft.))
- West #1A (LOS, a short distance (0.99 miles)).
- West #3A (LOS, a moderate distance (1.42 miles) at a slightly higher elevation (292 ft.)).
- West #3B (NLOS, a moderate distance (2.59 miles) at a moderately higher elevation (827 ft.)).
- North #2N (LOS, a great distance (7.2 miles at a moderately higher elevation (707 ft.)).

The project found that Vendor 1 radio requires a higher degree of line-of-site than the Vendor 2 radio. The radio is more sensitive to tree obstructions for Vendor 1 than Vendor 2, and the radio for Vendor 1

is also sensitive to high interference in its frequency range (~5.8GHz). The Vendor 1 radio is not built for ground level installation with rolling hills and trees. Neither radio from Vendor 1 nor Vendor 2, however, could overcome structure obstructions, like a building or dense trees.

In general, the radio from Vendor 2 performed better than the Vendor 1 radio, because the Vendor 2 radio operates at a lower frequency. Lower frequency radio communications can successfully communicate at longer distances and are less affected by terrain, line-of-sight, vegetation, and elevation differences.

3.3.3. Findings and Next Steps

Finding: Mobile (Remote) Data Collector (MDC) initiative demonstrated that stranded, remote meters can communicate with the headend system using radio bridging technologies. Radios from two vendors successfully communicated and transmitted AMI meter data from a remote location at distances up to 2.5 miles with no line-of-sight or up to 11 miles with line-of-sight (i.e. no physical obstructions in the way).

Next Steps: PG&E will explore applying these radio communication methodologies at locations that are proven to be economical, practical, and feasible to connect as many meters to the AMI network as possible. This demonstration has now led to the successful use of a low-cost antennas-only solution. It was found that this was all that was needed for most applications. An antenna will connect to a single meter that can then act as a hub to be connected to multiple meters. PG&E has tested and rolled out antennas to over 55 remote locations, and plans to continue this roll out to additional sites.

3.4.   Initiative 4 – Identifying Energy Diversion

3.4.1. Overview

PG&E has identified instances where the user of electricity at a utility service point is diverting energy in a manner that prevents or avoids the usage from being metered and therefore the usage is not billed. One method of diverting this energy is by "tapping" into the electric lines on the utility side of the meter. This method of diversion is commonly called a 'Line Side Tap.' Figure 4 illustrates the common approach that is used to conduct a 'Line Side Tap.'

Figure 4. Initiative 4 - 'Line Side Tap' Illustration
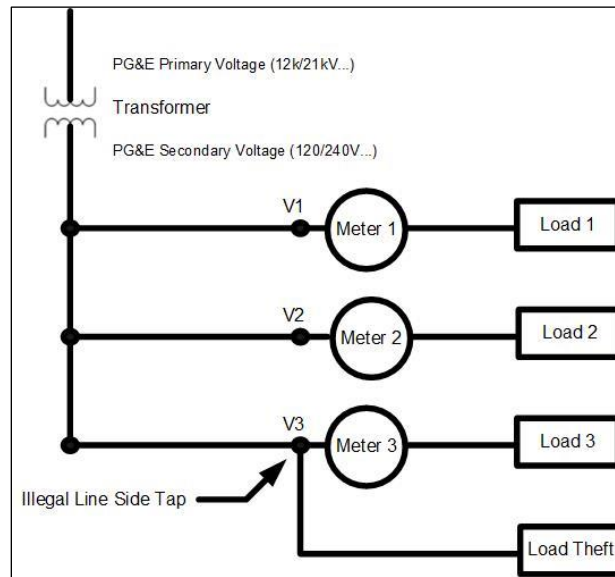
'Line Side Tap' energy diversion cases have been identified as a potential safety risk due to the potential exposure of energized lines to sources of combustion, bypassing of circuit breakers that are designed to protect the consumer and consumer's equipment, and increasing the risk of electrocution to the consumer, 3rd party contractors, and utility employees.

'Line Side Tap' energy diversion cases may also put service reliability at risk because it may prevent the utility from identifying the need to upgrade circuits and transformers when consumer load increases or may cause transformers to fail due to overloading situations.

Large electrical loads lower the voltage on the line near the large load. Under normal circumstances, a decrease in voltage is accompanied by a corresponding increase in the energy usage measured at the meter. In the case of 'Line Side Taps,' the load is diverted to the customer's equipment before it can be measured by the meter; hence, the decrease in voltage is not accompanied by an increase in measured usage.

Prior to this demonstration, PG&E used this knowledge to attempt to identify 'Line Side Tap' conditions; however, the collection of data and its analysis was largely a manual and time consuming process due to lack of commercial solutions to identify the 'Line Side Tap' conditions.

Initiative 4 demonstrated that 'Line Side Tap' conditions can be detected by leveraging voltage information, events, and energy usage data from the headend operating system. Using an algorithm to detect these conditions may reduce manual work and improve the efficiency of energy diversion investigations. It may also enable PG&E to mitigate potential safety hazards presented by 'Line Side Tap' conditions.

Objectives

To address the above stated challenges, this initiative had two main objectives:

1) Utilize interval voltage information, events, and energy usage (kWh) to detect 'Line Side Tap' conditions by cross-checking voltage and energy usage data with neighboring meters that are connected to the same transformer.

2) Provide a detailed list of meters with voltage below their neighbors. Populate a Graphical User Interface (dashboard) with a summary of meters with voltage below their neighbors.

Tasks

To achieve the above stated objectives, this initiative performed the following five tasks:

1) **Programmed a Sample of Meters to capture Voltage Data:** A sample of 35,000 meters was programmed to capture, store, and send interval voltage readings in parallel with the meters' standard kWh interval usage readings. If the meter's standard usage readings collection interval was 15 minutes, voltage readings were captured every 15 minutes. If usage readings were collected every 60 minutes, voltage readings were captured every 60 minutes.

2) **Extracted Data:** An internal voltage data extract from the AMI database was created to deliver data to two vendor analytic applications.

3) **Developed Algorithm:** An algorithm to detect line side tab conditions was developed in-house to calculate and analyze the data in these applications. The following equation is the algorithm used to identify the diversion condition.

Equation 1. Initiative 4 Diversion Condition Algorithm

$$IF\ Load\ 1 = Load\ 2 = Load\ 3$$
$$THEN\ V1 = V2 = V3$$
$$IF\ V3\ < V2\ \&\ V1\ AND\ Load\ 3 \leq Load\ 2\ \&\ Load\ 1$$
$$THEN\ Meter\ 3\ has\ high\ lotential\ for\ 'Line\ Side\ Tap'$$
$$(Diversion\ Condition)$$

4) **Developed Application:** Two vendors developed analytic applications with dashboards to calculate and display the results of the algorithm.

5) **Conducted Tests:** PG&E conducted ten day user acceptance tests of application functionality and performance. The team reviewed results based on a defined list of requirements (further detailed below in Section 3.4.2 Technical Results). In addition, a controlled data loading and indexing exercise was conducted with the vendors to ensure that the process of getting data into the applications was able to be done in a timely fashion and that the process was scalable to a much larger population of meters.

3.4.2. Technical Results

Out of the sample of 35,000 meters, the demonstration found 20 confirmed energy diversion cases that were studied in one area. Unless a tip was received, these cases would not have been found otherwise.

In response, PG&E was able to take action in these cases and prevented possible safety hazards from occurring that could impact the consumer, the general public, or PG&E employees.

A field check was conducted for each potential case found by the algorithm. There were two false positives, due to meter-transformer mismatch. There were no known false negatives as compared to manual investigations, but that would be expected, given the difficulty in detecting 'Line Side Taps' by traditional methods.

User Acceptance Testing

The team conducted ten day user acceptance tests of application functionality and performance leveraging the requirements listed below. In addition, a controlled data loading and indexing exercise was conducted with the vendor to verify these requirements were met.

There were 6 requirements expected of the applications:

1) Utilize voltage interval voltage information, events, and energy usage (kWh) from headend system

2) Capable of selecting and filtering a list of meter with different voltage drop range (i.e., 1%, 2%, 3%, 4% and 5%) from normal voltage (i.e., 120/208V or 120/240V for typical residential)

3) Capable of cross-checking voltage and energy usage data with neighbors meters that are connected to the same transformer

4) Populate a dashboard with a summary of meters with 1%, 2%, 3%, 4% and 5% voltage below their neighbors depending on the users selection

5) Capable of providing a detail list of meters with voltage data different 1%, 2%, 3%, 4% and 5% lower than their neighbors

6) Capable of selecting up to 10 neighbor meters to compare their voltage and energy usage against the suspected tamper condition for up to 10 day worth of data.

Vendor Comparison Summary

Both Vendors satisfied the primary requirements, which were to correctly calculate and identify the 'Diversion Condition' cases. Table 5 provides a comparison of the functionality results between the two vendors.

Table 5. Initiative 4 Vendor Functionality Comparison[16]

Feature	Vendor 1	Vendor 2	Comment	Rank V 1	Rank V 2
R1 - Utilize interval voltage and energy usage (kWh) from headend system	Yes	Yes	Both satisfy requirement equally	1	1
R2 - Capable of selecting and filtering a list of meters with different voltage drop ranges from nominal voltage	Yes	Yes	Both satisfy requirement equally	1	1
R3 - Capable of cross-checking voltage and energy usage data with neighboring meters	Yes	Yes	Both permit comparison but Vendor 2 combines Volts and kWh on 1 chart.	2	1
R4 - Populate dashboard with summary of meters with voltage below their neighbors depending on user selection	Yes	Yes	Both satisfy requirement equally	1	1
R5 - Capable of providing a detail list of meters with voltage lower than their neighbors	Yes	Yes	Both satisfy requirement equally	1	1
R6a - Capable of selecting up to 10 neighbor meters to compare their voltage and energy usage against the suspected tamper condition for up to 10 days' worth of data.	Yes	Yes	Both satisfy the meter selection requirement but Vendor 2's method is less cumbersome	2	1
R6b - Capable of selecting up to 10 neighbor meters to compare their voltage and energy usage against the suspected tamper condition for up to 10 days' worth of data.	Yes	Yes	Both satisfy the date selection requirement but Vendor 2's method has more options *(date range, last x days, last x weeks)* Vendor 1 is *(start date for x days)*	2	1
Functionality Provided but Not Required					
NR1 – Provide a map with pins designating the meters on a transformer	Yes	Yes	Both provide the functionality but Vendor 2's method is less cumbersome	2	1
NR2 – Provide a selection criteria for Transformer Id, Meter Badge Number	Yes	Yes	Both provide the functionality	1	1
NR3 – Provide a selection criteria for Voltage variance range	Yes	Yes	Vendor 1 allows a range whereas Vendor 2 is =>	1	2
NR4 – Look and feel – (1-10)	8	8		1	1
NR5 – Easy Navigation – (1-10)	7	9		2	1
Functional Requirements					
FR1 – time to load/index 30,000 60 Min. interval records average	3 min 7 sec	37 sec		2	1

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[16] The rankings in the V1 and V2 columns are only meant as relative comparisons between the two vendors. A ranking of 1 indicates that the project team determined that the vendor was better at the stated functionality than the other vendor. The rankings do not reflect requirement importance weighting. The ranks should not be used in their totality but only to reflect differences for individual functionality.

Feature	Vendor 1	Vendor 2	Comment	Rank V 1	Rank V 2
FR2 – time to load/index 5,000 15 Min. interval records average	8 min 50 sec	11 min 27 sec		1	2
Maintainability					
Ability to enhance with in-house or Third Party resources	Yes	Limited	Vendor 1 has developer tools and developer network, Vendor 2 is only configurable	1	2
Vendor availability for enhancements	Yes	Yes		1	2

Each vendor provided some useful additional functionality, including providing an online map of the meters on a selected Transformer Line and additional ways to select meters/transformers to analyze (Transformer ID, Meter Badge Number).

Vendor 1 provided a Diversion Signal calculator intended to make it easier to identify diversion cases; however, the users found it to be of limited use. Vendor 2 provided a combined Voltage/kWh chart for the voltage and usage profiles to be overlaid on one graph. The users found this useful, but cluttered, when there was more than 1 meter selected for the graph.

The vendors had opposite results when loading/indexing 15 minute interval records vs. 60 minute interval records (290 columns vs 75 columns). However, when load/index rates were extrapolated over 3 hours, both vendors loaded a satisfactory number of records for daily analysis.

From a navigation standpoint Vendor 1 was adequate but was more cumbersome when selecting/deselecting small numbers of meters to display and when selecting the map tool. Vendor 2 was generally less cumbersome, particularly with the selection of small numbers of meters and with the map tool.

From a user interface perspective, the project team determined that both vendors were similar, but with Vendor 2 holding a slight advantage.

3.4.3. Findings and Next Steps

Findings

Initiative 4, Identifying Energy Diversion, demonstrated the ability to predict 'Line Side Taps' by identifying mismatches between customer voltage drops and the corresponding usage. Out of the 35,000 meters that were studied, the initiative found 20 confirmed energy diversion cases, PG&E was able to take action on these identified, unsafe locations and prevented possible injury to the consumer, the general public, and utility employees. The execution of this initiative resulted in the following findings:

1) Using data analytics and graphical presentation tools, the customer voltage and usage data can be presented to the user in an easy and intuitive way that enables the user identify suspected energy diversion cases.

2) The data to support the analysis is available in our existing AMI meters.

3) Using the headend operating system to automatically collect the customer interval voltage data, in addition to the customer usage data, has a very minor effect on the AMI network.

4) The collection of the additional data for this project has already enabled other projects to move forward with studies that benefit customers in other ways. For example, the Volt/VAR Optimization (VVO)[17] project is leveraging interval voltage data collected by the headend system and stored in the AMI database to support its efforts.

Next Steps

Based upon the successful results of this initiative, PG&E has implemented or will explore the implementation of the following next steps:

- **Implemented - Automated 'Line Side Tap' Tool:** The demonstration of the 'Line Side Tap' diversion condition has proven to be accurate. As such, PG&E now leverages the algorithm in an automated in-house tool. Users can select the regions/ cities and meter types that best suit the user's workload and priorities. Customer and meter data is incorporated in to the tool in order to take the necessary action.

- **Next Step – Continue rollout based on available voltage data:** The Line Side Tap Tool relies on interval voltage data available from the AMI meters. As such, the scope of the tool is limited to only those meters that currently have interval voltage data. As described in Initiatives 1 and 2, PG&E will explore the expansion of interval voltage data to the rest of the electric meters and continued conversion to ANSI C12.19 format in order to leverage this data for the Line Side Tap Tool as well as other grid operations.

4.   Data Access

Upon request, Pacific Gas & Electric Company will provide access to data collected for these initiatives that is consistent with the CPUC's data access requirements for EPIC data and results.

5.   Value Proposition

The primary guiding principles of EPIC are to invest in clean energy technologies and approaches that provide benefits to electricity ratepayers by promoting greater reliability, lower costs, and increased safety. EPIC also has a set of complementary secondary principles that include: Societal benefits; Greenhouse gas (GHG) emissions reduction and adaptation in the electricity sector at the lowest possible cost; the loading order; low-emission vehicles/transmission; economic development; and efficient use of ratepayer funds. The project's contributions to these guiding primary and secondary principles are listed below by each Initiative.

Initiative 1 & 2: C12.19 Format and Power Quality Data & Explore New Data Channels from Existing AMI Meters

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[17] The VVO project implements an algorithm that uses AMI voltage data to calculate set points for the Load Tap Changer, line regulators, and capacitors on a bank where the VVO scheme is enabled.

By proving that additional data elements can be accessed, these initiatives addressed the EPIC principles of "Greater Reliability" and "Increased Safety" by:

- Giving access to additional power quality data helps PG&E address potential power quality issues such as voltage sags, transients, harmonics and events, which is critical knowledge for high usage/large customers.

- Giving visibility to more granular voltage data than was previously available assists in meeting CPUC Electric Rule 2 voltage service requirements for both line-to-line and line-to-neutral voltages. Meeting the voltage requirements allows the customer and utility equipment to operate properly and reduces potential damage from over- or under-voltage.

- Giving visibility to more voltage data also assists in meeting CPUC Electric Rule 2 voltage imbalance requirements - as close as practical to 2.5% maximum deviation from the average voltage between three phases. This allows the customer to operate properly.

- Giving visibility to more granular voltage data assists in proactively and more quickly addressing potentially customer satisfaction concerns, while also helping to avoid equipment damage or incorrect operation.

Initiative 3 – Mobile (Remote) Data Collector (MDC)

By proving that two-way AMI communications can be successfully transmitted using a radio bridging technology, this initiative addressed the EPIC principles of "Greater Reliability," "Lower Costs" and "Efficient Use of Ratepayer Monies" by:

- Demonstrating radio communications technologies that provide the AMI network with a longer range. This allows over-the-air operations rather than field visits for those meters that were outside of the AMI network coverage.

- Eliminating the need for monthly manual meter reading for those meters that were outside of the AMI network coverage. Since many of the meters outside of the AMI network coverage are in remote locations, the savings could be significant.

- Connecting hard-to-reach meters to the network permits accurate planning of AMI network equipment requirements, preventing unnecessary equipment installations and replacement.

- Permitting meter operations to more effectively and efficiently utilize the meter field work force by reducing field visits to meters in remote locations.

Initiative 4 – Identification of Energy Diversion

By proving that potential energy diversion cases can be identified, this initiative addressed the EPIC principles of "Lower Costs" and "Increased Safety" by:

- Enabling PG&E to more efficiently concentrate investigation efforts on suspected energy diversion cases with a higher likelihood of success.

- Permitting PG&E to more efficiently review more potential energy diversion cases than before and possibly increasing the number of mitigated cases.

- Mitigating dangerous (fire hazard, electrocution hazard) situations caused by 'Line Side Tap' conditions.

- Helping distribution planning personnel to properly size distribution equipment for the actual load on the line, which can prevent dangerous equipment failure and its consequences (loss of service to Medical Baseline customers, fire hazard and explosion hazard).

6.   Adaptability to Other Utilities / Industry

Initiative 1 – C12.19 Format and Power Quality Data

This demonstration was specific to the original, proprietary data format of PG&E's AMI network. The conversion of original format meters to C12.19 format meters is easily transferrable to other utilities that have implemented an AMI network using the original protocol and formats.

The results and next steps of Initiative 1 would also be useful to utilities that have implemented a network using the C12.19 protocol format because this Initiative confirmed that other useful data can be read from the meters and accepted in to the headend system.

Initiative 2 – Explore New Data Channels from existing AMI meters

For utilities that have not implemented the standard C12.19 format from the beginning of their implementations, Initiative 2 demonstrates that retrieving all the desired data elements from original format meters is not currently possible. However, meters can be converted to the standard C12.19 format as demonstrated by Initiative 1 – C12.19 Format and Power Quality Data. For utilities that have C12.19 format implemented, this initiative proves that additional data can be received into the headend system without issue.

Initiative 3 – Mobile (Remote) Data Collector (MDC)

The initiative results can be transferred to other utilities using AMI technologies with minimal effort. The concept and equipment are consistent with the techniques used by most electric utilities utilizing an AMI network for meter reading. Other Utilities could contract with 3rd party vendors or use internal resources to build a similar solution.

Initiative 4 – Identification of Energy Diversion

The initiative results can be transferred to other utilities using AMI technologies with minimal effort. The concept and algorithm are consistent with the techniques used by most electric utilities utilizing an AMI network for meter reading. Other Utilities could contract with either of the vendors the initiative used or build a solution themselves.

7.   Technology Transfer Plan

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within PG&E, and across the other IOUs, the CEC, and the industry. In order to facilitate this knowledge sharing, PG&E will share the results of this project in industry workshops and through public reports published on the PG&E website. Specifically, below is information sharing forums where the results and lessons learned from this EPIC project were presented or may be presented:

Information Sharing Forums Held:

1. Edison Electric Institute and Association of Edison Illuminating Companies (AEIC)
   Conferences
   October 3, 2016 | Seattle, WA

Potential Information Sharing Forums:

1. DistribuTECH
   January 31-Feb.2, 2017 | San Diego, CA

2. Bi-annual California IOU Metering Services Managers Info Sharing Sessions - Alternates between PG&E, SCE, SDGE
   To be scheduled

8.   Metrics

EPIC Project 1.19 was a technology demonstration project and, as such, did not calculate specific metrics related to each technology. Table 6 below lists potential metrics that could be developed and tracked when the technologies are deployed at full scale.

Table 6. List of Proposed Metrics and Potential Area of Mesurement

Metrics as identified in D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement.	See the following Section/ Initiative
1. Potential energy and cost savings	
f. Avoided customer energy use (kWh saved)	3.1 – Initiative 1
h. Customer bill savings (dollars saved)	3.1 – Initiative 1
3. Economic benefits	
a. Maintain / Reduce operations and maintenance costs	3.2 – Initiative 2 3.3 – Initiative 3 3.4 – Initiative 4
b. Maintain / Reduce capital costs	3.3 – Initiative 3 3.4 – Initiative 4
5. Safety, Power Quality, and Reliability (Equipment, Electricity System)	
d. Public safety improvement and hazard exposure reduction	3.4 – Initiative 4
e. Utility worker safety improvement and hazard exposure reduction	3.4 – Initiative 4
f. Reduced flicker and other power quality differences	3.1 – Initiative 1 3.2 – Initiative 2
i. Increase in the number of nodes in the power system at monitoring points	3.1 – Initiative 1
7. Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy	
b. Increased use of cost-effective digital information and control technology to improve reliability, security, and efficiency of the electric grid (PU Code § 8360)	3.1 – Initiative 1 3.2 – Initiative 2
f. Deployment of cost-effective smart technologies, including real time, automated, interactive technologies that optimize the physical operation of appliance and consumer devices for metering, communications concerning grid operations and status, and distribution automation	3.1 – Initiative 1 3.2 – Initiative 2

9.   Conclusion

EPIC Project 1.19 successfully demonstrated ways to leverage SmartMeters^{TM} to provide greater benefits to our customers and the industry through new and improved data collection techniques and capabilities that could greatly expand the type of data collected via the AMI network system.

In the first initiative of this project, PG&E verified the current electric meters can be converted to the industry standard ANSI C12.19 protocol, which can enable the collection of additional, more granular power quality data that is not currently available. This allows PG&E to proactively correct voltage issues prior to customer satisfaction concerns arising or reliability issues ensuing. Meeting the voltage requirements allows the customer and utility equipment to operate properly and reduces potential damage from over- or under-voltage requirements.

In the project's second initiative, non-standard data format showed gaps in data channels (missing or incomplete) when new meter models are developed and added to the AMI network. These gaps impede our ability to deploy metering solutions for all of our customers. PG&E will consider collaborating with vendors in developing and improving on-shelf products in order to best meet industry needs and improve vendor response to product challenges.

In the third project initiative, it was determined that radio equipment with directional antennae can extend the range of the AMI network in hard-to-reach areas of our territory. As a result, PG&E is now fully deploying a low cost antenna solution to expand AMI network coverage.

The final initiative of this project collected interval voltage readings and developed a repeatable algorithm that can be used to identify unsafe energy diversion cases using the 'Line Side Tap' detection technique. As a result, a lower-cost, in-house solution has been successfully implemented and PG&E is utilizing the tool to address instances of 'Line Side Tap.'

Finally, on-going benchmarking and industry collaboration avoided duplicate efforts on the collection of the interval temperature data in SmartMeters^{TM} and other projects.

In the end, this EPIC project identified a multitude of ways to leverage SmartMeter^{TM} data to take actionable measures upon identifying safety or reliability risks or opportunities. Some risks are addressed by gaining visibility to more granular voltage data to proactively address voltage variability concerns or identifying instances of energy diversion. Opportunities are captured by leveraging a low cost solution to read meters for hard-to-reach customers through an antenna, which expands PG&E's AMI network coverage and reduces costs to manually read meters. Ultimately, this EPIC project provided industry value by demonstrating new ways to leverage AMI data and platform to advance the foundational utility principles of safety, reliability and affordability.