Pacific Gas and Electric Company

# EPIC Final Report

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| **Program** | ***Electric Program Investment Charge (EPIC)*** |
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## Table of Contents

## List of Tables



## List of Figures



## Table of Acronyms

| | |
|---|---|
| A. | Application |
| AMI | Advanced Metering Infrastructure |
| ANSI | American National Standards Institute |
| AP | Access Point |
| API | Application Programming Interface |
| CC&B | Customer Care and Billing |
| CEC | California Energy Commission |
| CPU | Central Processing Unit |
| CPUC | California Public Utilities Commission |
| CSVS | Cloud Solutions Vendor Service |
| D. | Decision |
| DER | Distributed Energy Resource |
| EPIC | Electric Program Investment Charge |
| EV | Electric Vehicle |
| FAS | Field Automation System |
| GB | gigabyte |
| GHG | greenhouse gas |
| GIS | Geographic Information System |

| | |
|---|---|
| GPS | Global Positioning System |
| Hz | Hertz |
| ID | Identification |
| IEEE | Institute of Electrical and Electronics Engineers |
| IOU | Investor-Owned Utility |
| IP | Internet Protocol |
| IT | Information Technology |
| KPI | Key Performance Indicator |
| kVARh | kilovar-hour |
| kWh | kilowatt-hour |
| LTE | Long-Term Evolution |
| MB | megabyte |
| MDM | Meter Data Management |
| MDMS | Meter Data Management System |
| MHz | Megahertz |
| NGM | Next Generation Meter |
| NIC | Network interface card |
| PG&E | Pacific Gas and Electric Company |
| PV | Photovoltaic |
| RF | radio frequency |
| SCE | Southern California Edison Company |
| SD | Secure Digital |
| SDG&E | San Diego Gas & Electric Company |
| TOU | Time-of-Use |
| U.S. | United States |
| V | Volts |

# 1 Executive Summary

This report summarizes the project objectives, technical results and lessons learned for Electric Program Investment Charge (EPIC) Project 2.29 Mobile Meter Applications as listed in the EPIC Annual Report. The EPIC 2.29 Project is also referred to as the Next Generation Meter (NGM).

**Project Summary**
EPIC 2.29 designed, built, and tested the core circuitry of the NGM. This revenue-grade electricity meter has the potential to:

1) Be installed in a wider range of locations beyond traditional customer premises (e.g., Electric Vehicle (EV)/photovoltaic (PV) submetering, PG&E substation meters as grid monitoring, SmartPole metering),
2) Reduce meter maintenance and replacements costs,
3) Improve the grid operator's situational awareness during outages, and
4) Provide additional services and applications as grid-edge technology evolves

The NGM can provide these benefits due to a compact, modular design that takes advantage of a host of new technologies including faster microprocessors, expanded memory, and multiple communications pathways—all contained in a hardware package that is the size of a credit card.

First, the size, configuration, and power requirements of the current generation of SmartMeters™ limits how and where they can be installed. In contrast, the NGM's small size and minimal power requirements allow it to be installed in space-restricted locations (e.g., a micro-cell tower or SmartPole, a small electrical room), in locations with limited power, or even in mobile EVs.

Secondly, if a component in the current generation of meters requires service, the entire unit must be removed from the premise's service panel and a new unit must be installed. This creates time-consuming, costly, and disruptive service connections.

In contrast, the NGM core unit, which contains the electronics, is designed in order to mate to a future base unit that would contain the connections to the service panel. Thus, if there is a problem with an NGM, in most cases a technician merely replaces the NGM core unit and does not have to remove the electrical components within the base. This greatly lowers service and replacement costs and eliminates the few minutes of no power (outage) that a customer's premise would experience today.

Thirdly, the NGM uses advanced sensors to provide high-resolution, real-time data on electrical grid conditions, which in turn can help reduce outages. Because the NGM features multiple communications pathways, including a cellular modem, it can continue to send critical data to grid operators during under-voltage conditions. The combination of advanced sensors and improved electronics allows the NGM to transmit critical grid data (e.g., voltage, temperature) at voltage conditions as low as 22 Volts (V). Such grid data can potentially help grid operators with a faster restoration of the normal grid conditions and improve safety and reliability.

Finally, because the NGM uses open communications standards,[1] the new meter design is far more interoperable. This will allow utilities to add new functionality to existing meters without being dependent on

[1] NGM utilizes the ANSI C12.19 meter data format standard and the ANSI C12.22 cellular communication protocol.

proprietary vendor solutions. For instance, possible future applications of the NGM could include submetering of Distributed Energy Resources (DER) such as EVs, solar systems, and battery storage.

In summary, the NGM project will enable PG&E and other utilities to reduce costs, improve service to customers, and provide additional benefits that take advantage of grid-edge innovation after further development and demonstration of the base unit allowing for installation on the appropriate service item.

**Objectives**

The project's primary objective was to develop a new electricity meter technology that:

- is small enough to fit in constrained places,
- can be modular to facilitate submetering of EVs and solar roof top applications with the appropriate base unit(s),
- is less expensive to install and service,
- provides more useful analytics data during outages and other critical grid events, and
- uses open standards to interoperate with other devices and accommodate future innovations.

**Scope and Project Tasks**

The scope of work for this project included tasks that supported the NGM's core electronics hardware and software development. These tasks focused on building prototype NGMs that are flexible, modular, and use open standards.

<u>Task 1: NGM Hardware and Software Requirements Development</u>

This task focused on establishing the requirements around mobility, power, sensors and applications, communication pathways, and compliance with national standards.

<u>Task 2: NGM Prototype Development</u>

Prototype development included the design of the NGM's hardware, firmware, and software based on the requirements developed in Task 1. This included procuring off-the shelf technology and working with a vendor to integrate components and develop a prototype meter. American National Standards Institute (ANSI) C12.19 tables and C12.22 communication protocol code was also required to demonstrate the ability to transmit data through the network to a cloud-based head-end, which was required to test the meter functionality and to demonstrate that the NGM was capable of providing real-time data.

<u>Task 3: NGM Hardware and Software Functional Testing</u>

This task focused on testing the electrical accuracy of the meter, and testing communication between the processing module and a mock-base. EV & Charger, Inverter, and SmartPole use cases were tested in a lab setting to demonstrate revenue-grade accuracy and the NGM capability of communicating high-resolution data using ANSI Standards.

**Project Results**

The following are the task results:

<u>Task 1: NGM Hardware and Software Requirements and Development</u>

The project team developed design requirements for NGM development. Key requirements included:

- Demarcation of high and low voltage components.

- Flexibility for multi-applications such as single residential, multi-dwelling units, EVs, DERs and SmartPoles with the appropriate yet-to-be-developed base unit(s).
- Higher resolution grid analytics data to enable future grid analytics for predictive and preventative maintenance and support of safety and grid reliability.
- Multiple communication pathways (AMI and cellular) to send data back to PG&E
- Multiple communication pathways (Bluetooth, Zigbee, Wi-fi, etc.) to allow for the interaction and management of edge devices
- Accelerometers to collect seismic data to support predictive analytics of earthquakes
- Compliance with national standards of revenue grade and accuracy (ANSI C12.1 and C12.20)
- Open standards for data structures (ANSI C12.19/C12.22) to support interoperability and enable future integration of customer devices and other products

Task 2: NGM Prototype Development

The project procured all hardware, sensors, and communications components to build the NGM, with the exception of the electric AMI network interface card (NIC) currently used for billing. The AMI NIC was not available for this demonstration as the NIC vendor was not ready to participate during the EPIC 2.29 project timeframe. However, a vendor was selected to develop the NGM and successfully integrated all hardware needed for the NGM Core into a small circuit board with the size of a credit card, which could then be tested over other non-AMI communications medium.

The criterion for the NGM footprint was that it be no bigger than 8” x 6.” The design targets for the internal NGM were that all sensors must fit on one printed circuit board and that wireless interfaces and associated hardware (e.g., antennas) would work as specified and would limit radio frequency (RF) interference. The finished prototype version must meet ANSI C12.1 and ANSI C12.20 Standards, which set the performance criteria and physical standards for electricity meters. ANSI C12.19 tables and C12.22 communication protocol code was developed along with a cloud-based head-end to test meter functionality in Task 3.

Task 3: NGM Hardware Functional Testing

Functional testing included testing the NGM core for 1) adherence to national standards (ANSI C12.1 and C12.20) for a revenue grade meter, 2) the ability to communicate C12.19 data tables to head-end using ANSI C12.22 network communication protocol; and 3) testing the NGM core in a lab environment for the three use-cases of EV charging stations, smart poles and smart inverter. These three use-cases were identified and selected by the project team to evaluate the NGM for interoperability and the ability to collect and transmit real-time data.

The test results demonstrated that the NGM is revenue grade compliant, able to communicate and transmit over 4G Long-Term Evolution (LTE), Wi-Fi and Bluetooth, able to record power consumption and seismic data, able to store high resolution data (voltage, temperature) for grid analytics, and able to provide this data in near real-time. For instance, the project demonstrated that the seismic data could be acquired and transmitted in 0.48 millisecond (ms) intervals.

**Challenges and Resolutions**

The largest challenge in hardware development was RF interference due to the various wireless functionalities. The project team had to go through multiple iterations of antennae placement within the NGM enclosure before all communication interfaces worked as expected.

Another challenge was firmware development of the NGM to meet national standards, which needed very specialized skills in firmware code writing and knowledge of American National Standards and relevant standards to handle high resolution data for the accelerometer, various communications, power measurements and grid data delivery in specified and real-time mode.

Also, there is a challenge in connecting the NGM core meter to and transmitting the meter data over the existing AMI system. The AMI system is a proprietary technology and requires discussion and collaboration the AMI vendor to integrate NGM core into the AMI technology. PG&E knows such task would take time and resources, and plans to work toward such integration.

Since this NGM core serves as the foundation for potential future EPIC 3 Project use cases as approved in PG&E's EPIC 3 application[2], additional work to address these challenges is being evaluated as part of these potential EPIC 3 projects.

**Recommendations**

Below are the key recommendations from this project:

Meter Development and Deployment: The NGM developed can potentially reduce meter installation and replacement costs. However, a critical path to deployment for the NGM is to obtain the AMI NIC so that the meter can cost effectively integrate into the existing billing system. The absence of this card would require creation of a new infrastructure of systems interface and integration to support new communication pathways. If the NIC can be integrated, the next steps would be to build a docking station for single and multi-tenant applications to complete the integrated NIC and NGM meter, and to further enhance as well as interface the NGM head-end application into PG&E systems for grid operations.

Grid Analytics Data Applications: The AMI network is not designed for real-time data. In order to leverage the NGM for grid-analytics, a cellular communication pathway is needed to deliver this data to a head-end system that can manage the data and meter operations. Typical solutions for utility head-end systems are proprietary vendor solutions, which the utilities depend on to add functionality and upgrade their SmartMeter network. Further industry support for open communication protocols to enable new products and offerings from different vendors is needed to unlock additional advancements in this space.

**Key Takeaways**

- The NGM core was designed and built with multiple interfaces, communication protocols, and various other features currently not available from existing meters.
- The NGM was able to use multiple wireless protocols, and draw data from multiple sensors, at the same time: 4G, Wi-Fi, Bluetooth; Global Positioning System (GPS) and accelerometer.
- The NGM demonstrated that it could fit all of its necessary components into a very small footprint (size of a credit card and less than ¼ inch thick).
- A demonstration-grade head-end application was developed to operate and function with a new NGM, however additional development would be needed to fully leverage the cellular communication functionality at scale.
- PG&E demonstrated that it was possible to interface the new externally-developed headend application into existing PG&E applications such as field application tool, meter data management application and billing application. Additional work in enhancement and interface of the head-end application with other PG&E systems is being planned for in the potential EPIC 3 projects.

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[2] On April 28, 2017, PG&E filed its Application in the Third Triennial EPIC 2018-2020 proceeding [Application (A.) 17-04-xxx] on 41 EPIC 3 Projects. On October 25, 2018, the California Public Utilities Commission (CPUC) approved PG&E EPIC 3 filing.

- The NGM demarcation design that separated high and low voltage components could support replacement of a failed solid-state component (instead of the entire meter), which should help reduce costs. Furthermore, this could be an opportunity to eliminate redundant metering components in multi-tenant applications.

**Intellectual Property**

Because of the ground-breaking nature of the EPIC 2.29 Mobile Meter Applications Project, a final patent application was filed with the U.S. Patent Office. The "Application of Resource Meter System and Method" (Application Number 16143295) outlines the first of its kind solution that demonstrated a small NGM core with a size of the credit card and with a capability of metering and submetering multiple use cases such as EV, EV charger, SmartPole, solar roof top. This NGM core serves as the foundation for potential future EPIC 3 Project use cases as approved in PG&E's EPIC 3 application

PG&E looks forward to working with the other California utilities, and the industry at large, to realize the benefits of this approach. This intellectual property is owned and held by Pacific Gas and Electric Company (PG&E or the Company), and can be commercialized for the Company's commercial benefit, in accordance with all appropriate laws and regulations (including Decision (D.) 13-11-025).

**Conclusions**

The project successfully designed, built, tested, and demonstrated the NGM to incorporate open standards (e.g., ANSI C12.1, C12.20, C12.19, and C12.22) and communicate meter data to a head-end system. This work resulted in an NGM Core with all electronic components on a single board the size of a credit card. The NGM was proven to be revenue-grade, have multiple communication paths to networks and edge devices (Bluetooth, Wi-Fi, 4G LTE, GPS), have an accelerometer to support potential earthquake prediction use cases, have real time capability, and provide high resolution data for potential future grid analytics use cases. The project successfully tested EV & Charger, Smart Inverter and SmartPole use cases in a lab setting.

Evolving customer needs require utilities to have a new compact metering solution that can easily fit into any application (i.e., Smart Pole, Smart inverter, EV chargers, etc.). This NGM technology was demonstrated to enable utilities meter and submeter energy consumption of non-traditional devices, such as EV, EV chargers, solar roof top; as well as to provide a lower cost alternative to traditional metering (with further development). This new technology design could reduce meter installation, replacement and maintenance costs with further development of future use cases in EPIC 3.

# 2 Introduction

This report documents the EPIC 2.29 – *Mobile Meter Applications* project tasks and accomplishments; highlights key learnings from the project that have industry-wide value; and identifies future opportunities for PG&E to leverage this project.

The CPUC passed two decisions that established the basis for this demonstration program. The CPUC initially issued D.11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*[3], which established the 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*[4], which authorized funding in the areas of applied research and development, Technology Demonstration and Deployment (TD&D), and market facilitation. In this later decision, 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 appraisal of the operational and performance characteristics and the financial risks associated with a given technology."[5]

The decision also required the EPIC Program Administrators[6] 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, PG&E filed its first triennial EPIC Application at the CPUC, requesting $49,328,000 including funding for 26 TD&D. On November 14, 2013, in D.13-11-025, 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: *2.29, Mobile Meter Application* project. Throughout the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project. The following information is PG&E's final report on this project.

3 http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF.

4 http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF.

5 D.12-05-037, p. 37.

6 PG&E, San Diego Gas & Electric Company(SDG&E), Southern California Edison Company (SCE), and the California Energy Commission (CEC).

# 3 Project Summary

*EPIC 2.29 Mobile Meter Applications* was initiated to address the need to create a highly functional meter that could serve multiple current uses cases. This new meter was demonstrated in the three use cases of EV, Smart Pole, and distributed generation/smart inverter, while using open standards to ensure flexibility for additional grid-edge technologies.

The focus of this project was to develop a *NGM* core that could 1) reduce the operating and replacement costs of existing meters and support meter-to-cash applications, 2) demonstrate the ability for the NGM to communicate real-time grid analytics data using ANSI standards, and 3) provide multiple communication pathways for the NGM to communicate to utility networks and edge devices.

This project demonstrated that NGM technology could serve evolving customer needs by using open standards. This would provide both customers and utilities with the flexibility of developing necessary functions promptly to meet utility needs without being tied to a vendor's communication protocol solution.

The NGM could provide utilities with these benefits due to a compact and modular design. This design takes advantage of a host of new technologies including faster microprocessors, expanded memory, and multiple communications pathways—all contained in a hardware package that is the size of a credit card. This enabled PG&E to develop a small meter that could be installed in a variety of space restricted and/or mobile applications. The meter was designed to have multiple wireless communication pathways to transmit data, connect to edge devices, and enable the visibility of various loads, such as EVs, PV cells, and other distributed generation assets such as battery storage.

The meter's modular structure was designed to allow for addition of future sensors to meet evolving utility needs and reduction of components to reduce costs. Decreasing the number of redundant components in the meters would help reduce meter maintenance and operating costs.

The NGM was capable of providing high-resolution analytics data (e.g., voltage, temperature) to support grid operations. Its cellular antennae would provide a reliable pathway to transmit electric grid data in real time for grid operators to monitor conditions of electric grids during an outage, provide faster restoration, and improve safety and reliability.

Current SmartMeters do not provide real-time data because the AMI network is a mesh network and designed for billing purposes. Leveraging the cellular communication in the NGM would enable the ability to procure grid analytics data for predictive and preventative maintenance and faster response to support safety and grid reliability.

## 3.1 Issue Addressed

***Meter Costs and Installation***

PG&E has over 5.4 million SmartMeters currently deployed in the field. Over the next 10 years, approximately 1.6 million meters will be replaced for purposes of maintenance and new business connections based on the current replacement and installation rate of 160,00 meters/year. The replaced meters may have one failed component but have other components still fully functional. However, due to the current meter design, the entire meter will need to be replaced. In many cases, existing SmartMeters must be replaced due to relatively small issues such as failure of an LCD display, a component of the metrology board, or an AMI NIC. Such replacement/removal of an entire meter wastes other working components in SmartMeter or incurs costs to utilities.

The existing SmartMeters can be inefficiently duplicative in some instances. As an example, in multi-dwelling and commercial applications, metering rooms may have hundreds of SmartMeters installed. In these settings, SmartMeters include many redundant metering components, which drive up costs.

There is also a growing need for submetering and installation of meters in areas with space restrictions such as EVs, DERs, SmartPoles, appliances. Existing SmartMeters are too large to be used in these applications.

The EPIC 2.29 Project addresses these issues by developing a meter with a small, modular interchangeable footprint. The NGM does this by separating high and low voltage components so that only the low voltage (NGM Core) or high voltage (housing/docking station for NGM core) is replaced as necessary. Also, by separating the high voltage side of the meter, there is an opportunity to reduce redundant components, which will help reduce the manufacturing cost of meters for these applications.

Furthermore, separating the low voltage components from high voltage improves safety for field technicians by reducing their exposure to high voltage during replacement. These attributes will make field maintenance easier and will reduce truck rolls.

It should be reiterated that the scope of the EPIC 2.29 Mobile Meter Applications was to develop the NGM core and functionality. The docking station concept was planned to be developed and demonstrated in EPIC 3. Therefore, the EPIC 2.29 project does not have a meter readily available for deployment, and the design and demonstration to make the NGM meter complete for deployment is being evaluated for the potential EPIC 3 projects.

***Grid Data, Communication Pathways and Interoperability***

Utilities have a growing need to provide grid analytics data for predictive and preventative maintenance and faster response to support grid reliability and safety. Existing SmartMeters are unable to provide this data and functions because the AMI network creates latency due to the inherent nature of mesh technology, does not fully operate during wire down events, and does not operate at all during outage conditions. During such critical grid outage and conditions, the grid operators will need the grid data and information (voltage, temperature) the most and in real time to provide faster restoration and ensure safety and reliability. An alternative cellular communication path is necessary to provide this information in real-time.

Another issue is that PG&E’s gas and electric AMI networks are not currently interoperable. Each system consists of proprietary hardware, software and firmware. This creates substantial costs, time restrictions, and vendor dependencies for PG&E to configure meters to collect grid analytics data. PG&E’s experience has shown that being tied to a vendor’s proprietary network head-end application introduces costly problems and delayed resolutions for utilities and customers.

EPIC 2.29 addresses these issues by demonstrating a meter that can collect high-resolution grid data, provide alternative communication pathways, and improve interoperability with open standards and protocols.

## 3.2 Project Objectives

The objectives of EPIC 2.29 NGM were to:

- Reduce lifecycle costs of meter materials, maintenance and replacements
- Develop a meter core that is compact, modular, and interchangeable on space-restricted applications
- Demonstrate the ability to provide high-resolution grid analytics data in real-time using cellular networks
- Meet national standards for metering (ANSI C12 Series)

## 3.3 Scope of Work and Project Tasks

The scope of work for this project included tasks of development of NGM's hardware and software, design of prototypes, and use of various open standards for meter data table format (ANSI C12.19) and cellular communications protocol (ANSI C12.22). To complete the Scope of Work for the project, the following tasks were developed:

Task 1: NGM Hardware and Software Requirements Development

This task included establishing the requirements for the design, mobility, power requirements, additional sensors and applications, communication pathways to networks and edge devices, industry standards compliance, and software head-end requirements to test the NGM.

The hardware requirements development started with leveraging PG&E's existing electric SmartMeter specification and adding additional hardware components that that were needed for new functionalities and capabilities. These electronic components were off the shelf and hardened using the latest printed circuit board design and technologies. As a result, these components were interfaced and laid out on one board with fast processing power, an open source operating system, and a modular design.

The minimum measurement data required was to be comparable with the existing data available in PG&E's SmartMeters used to support utility business functions. In addition, more emphasis was placed on power quality measurements, tamper detection, asset recovery, and seismic research studies, all of which could be used for grid analytics. Grid analytics would include both predictive and prescriptive analytics. Finally, all measurement data must meet the ANSI C12.19 Utility Industry End Device Data Table standard.

The software development was to use existing cloud-based applications and open source or standard communication protocols rather than to develop a new proprietary application. The user interface would be web browser based and need to be friendly and allow users to maneuver through various functions easily. All measurement data should be presented in a dashboard format. Communication protocol for bringing data back to the cloud-based server application should meet ANSI C12.22 Protocol Standard for Interfacing to Data Communications Networks.

Task 2: NGM Prototype Development

Prototype development included the design of the hardware, firmware, and software meeting requirements in Task 1. This included procuring off-the shelf technology and working with a vendor to integrate components and develop a prototype meter.

The major criteria was for the NGM footprint to be no bigger than half the size of the existing notebook computer. The internal design was determined such that all sensors would fit on one printed circuit board, wireless interfaces and hardware and associated antennae would work as specified.

The finished prototype version was targeted to meet ANSI C12.1 and ANSI C12.20 Standards described in the "NGM Specification" document. In addition to building a prototype, ANSI C12.19 tables and C12.22 communication protocol code was required to be programmed to format sensor data into readable tables and transmit this data through the network to the cloud-based head-end. This head-end interface was developed to access the meter functionality and prove that the NGM can provide real-time data.

Task 3: NGM Hardware and Software Functional Testing

Functional testing included testing the accuracy of the meter to ensure that it is revenue grade (ANSI C12.1 and C12.20). The ANSI C12.19 meter data tables and ANSI C12.22 cellular communication protocols were used in the functional testing to demonstrate the NGM would communicate data to a head-end system. Three use cases of EV & Chargers, Inverters, and SmartPoles were tested in a lab setting to demonstrate revenue grade accuracy, interoperability, and the ability for the NGM to transmit real-time data using C12.19 and C12.22 standards.

The vendor provided NGM prototypes along with associated software and firmware versions for functional testing.

# 4 Project Activities, Results, and Findings

Below is a description of the NGM hardware and Software requirements development. This section provides details on the capabilities and functionality of the NGM Core.

## 4.1 NGM Hardware and Software Requirements Development

### 4.1.1 Demarcation of the SmartMeter

A requirement for the meter was to create a demarcation point between the high and low voltage components within the NGM. Low voltage components would be included in the NGM Core, and the high voltage components would be included in the docking station, which is being planned for in the potential EPIC 3 projects. There were several reasons for the requirement to separate the docking station from the NGM. This design would improve safety by reducing exposure to high voltage during installation of meters, improve service reliability by allowing components of the meter to be replaced, and improve cost effectiveness by eliminating redundant components in multi-tenant applications.

### 4.1.2 Mobility

The requirement of the NGM was to build a meter with mobility and interchangeability, so that it could measure and communicate power from anywhere network access is available, and be easily repurposed by moving it from one location to another. The meter would be able to operate any time while connected to any devices with energy consumption or generation. This could be achieved by creating an NGM core with a small form factor that would allow the NGM to be inserted into a docking station for easy replacement and removal. By creating a mobile core unit, the NGM can be integrated with several devices such as: Electric vehicles, EV charging stations, residential/commercial meters, battery storage units, and smart inverters.

### 4.1.3 Modular Structure

The intent of the design was to build a meter with a modular structure. The modular approach would support multiple product applications such as multiple communication pathways and sensors. A module was built in a hardware structure that could be added to the NGM with a full connectivity and support of power, interfaces, processing, and mechanical provisions. This modular structure would allow for a flexibility to add or remove new tools to the NGM core based on existing and future needs. When paired with the high-power processor and flexible power system of the NGM, the modular structure would make the device more flexible and configurable for future use cases.

### 4.1.4 NGM Power Supply

The NGM required power supplies to various modules. The goal was to design a meter with minimum voltage and current input requirements comparable to or better than PG&E’s existing meter. The power supply was required to be a stabilized, high efficiency, low ripple product. The auto-ranging flexibility of the power supply within the NGM would allow the meter to be connected from a low level of 120V to high level of 305V power source.

### 4.1.5 Power Metering

**Billing and Grid Data**

The primary purpose of an electrical meter was to accurately measure electric usage so that the utility could bill a customer for the delivered electricity. The EPIC 2.29 achievement reached beyond this primary purpose. NGM metering was able to produce data in the form of both accurate billing data and grid data. The measured parameters for billing data included +/- real power component (Watts) and reactive power component (Vars). The measured parameters for grid data were magnitude and phase angle of voltage and current, voltage and current harmonic distortion, and percent harmonic distortion. The NGM could log

several events such as sag/swell, undervoltage, and overvoltage conditions. It generated a phasor diagram of the meter installation and identified a phase using both single and three phase power sources.
Requirements included:

- 1-phase AC with a range of voltage from 85V to 305V. Supporting multiple phase-neutral/Phase-phase combinations such as Phases A and C to neutral, Phases A, B and C to neutral, Phase A to Phase B, Phase A to Phase B to Phase C, etc.
- 3-phase AC with a range of voltage from 85 to 305V. Supporting multiple phase-neutral/Phase-phase combinations such as Phases A and C to neutral, Phases A, B and C to neutral, Phase A to Phase B, Phase A to Phase B to Phase C, etc.

**Standards and Certifications for Power Metering**

Since electricity meters are used to measure a customer's power consumption, NGM development should be subject to utility level meter standards and certification procedures. Table 4-1 shows the relevant ANSI standards that the meters are required to comply with in order to qualify as revenue-grade.

**Table 4-1 Utility Level Power Meter Standards for Electric Meters**

| ANSI Standard | Description |
|---|---|
| ANSI C12.1 | This standard establishes acceptable performance criteria for new types of AC watthour meters, demand meters, demand registers, pulse devices and auxiliary devices. It describes acceptable in-service performance levels for meters and devices used in revenue metering. |
| ANSI C12.20 | This describes an ANSI standard for solid state Electricity Meters – accuracy and performance. |

### 4.1.6 Other Sensors

**Temperature Sensors**

The design requirements included incorporating a temperature sensor into the NGM core to measure circuit board and Central Processing Unit (CPU) temperatures. This would enable utilities to better assess meter health and meter panel conditions in real-time.

**Accelerometer**

The design requirements included an accelerometer to measure seismic activity. By gathering earth movement data from certain points within the PG&E service territory, the NGM can support seismic research and earthquake prediction. An ongoing collaboration between PG&E and the geoscience community was looking at ways to use this new data source, assess earthquake hazards, and predict earthquakes.

**Global Positioning System**

The design requirements included incorporating a sensor for asset tracking and tamper detection. Basic and affordable GPS technology was integrated into the NGM Core. Such technology would aid field service crews in locating the NGM quickly and accurately.

### 4.1.7 Memory and Processing Power

The NGM was required and later designed to include sensors and have a high-speed central processing unit suitable for multiple applications. In addition, 8 Giga-Bytes memory was chosen to hold data for longer periods of time compared to existing meters (i.e., multiple years vs. 60 days).

The performance parameters were specified to support:

- A 32-bit quad-core 800 megahertz (MHz) processor using Advanced RISC Machine (ARM) technology
- Analog-to-digital converter (ADC) channels (6) with multiplexing capabilities, with Δ-Σ built in support, 10 kilobytes per second sampling rate per channel
- Flexible analog input assignment
- Better than 0.1% accuracy over a wide dynamic range of current
- Dedicated core cryptographic and control engine supporting Advanced Encryption Standard 256 (AES-256) and other encryption standards.
- High accuracy real-time clock
- Built-in energy saving and wake-up mechanisms

### 4.1.8 Communication Pathways

The inclusion of multiple communication methods within the NGM provided a flexibility and allowed the NGM to communicate information back to PG&E under various conditions (e.g., outages, wires down). Additionally, with multiple systems, the NGM would connect to and communicate with current and future edge devices using the capability to remotely switch from one communication path to another. The NGM could also act as a node and move from “real-time” to a “scheduled” C12 read job device and vice versa. Such function of switching modes should be a design of the NGM firmware and software.

The different communication requirements were split into two categories: 1) Network Access, and 2) Hardware Interfaces as described below:

**Network Access (AMI and Cellular)**

PG&E currently utilizes the AMI network to send meter data back to PG&E systems for billing. This network has a limited throughput and a relatively high amount of latency. The AMI system delivers metered data back to PG&E in 4-hour batches and is not a design for real-time analytics. To utilize NGM grid data for grid analytics, a more reliable, faster communication pathway is required such as the cellular technology. Table 4-2 shows network interfaces and communication pathways

**Table 4-2 Network Interfaces and Communication Pathways**

| Communication | Description | Pros | Cons |
|---|---|---|---|
| **AMI Networks** | Currently PG&E owns and operates the 900 and 450 MHz system for meter-to-cash applications | • Fewer devices that use cellular service back-haul (900 MHz collector nodes ~1600) | • Vendor proprietary protocol dependency<br>• Not designed for high resolution real-time data |
| **Cellular (4G) Networks** | Cellular can be used a communication gateway to deliver real-time data to utility systems and meter-to-cash applications as needed | • Reliable pathway for high resolution real-time communication | • Will require infrastructure development and systems interface to ingest real-time data for utility applications<br>• Cost of cellular services per end device may be cost prohibitive. However, controlled activation of cellar communication functions during critical electric grid conditions can mitigate cost (e.g., less than 1% of the time). |

**Hardware Interfaces**
An additional feature of the NGM is its ability to communicate with other hardware devices. This enables the opportunity for different network devices, such as EVs, solar panels, HVAC (heating ventilation, air conditioning) equipment, and appliances, to interact and be managed by the NGM. Below is a list of the different communication paths the NGM will use to connect to devices at the physical level. These communication pathways generally support the IoT (Internet of Things) space.

**Table 4-3 Hardware Interfaces and Communication Pathways**

| Communication Pathway | Potential Applications |
|---|---|
| **Wi-Fi (Institute of Electrical and Electronics Engineers (IEEE) 802.11):** | • Is a gateway interface of the meter to other systems in use-cases where a Wi-Fi router is available (Distributed Generation installation or residential charging station) |
| **Zigbee (IEEE 802.15.4)** | • Used to be the communication standard to connect with DERs. This standard is being superseded by IEEE 2030.5 or Wi-Sun Protocol |
| **Bluetooth** | • Has a short-range application<br>• Permits phone applications to view meter read<br>• Communicates with sensors and possible household devices |
| **GPS** | • Is a GPS to pinpoint the location of the NGM |
| **Serial** | • Enables laptops to connect to meter for troubleshooting of meters<br>• Has an ability to update firmware locally |
| **Ethernet** | • Allows to hardwire to internet if WI-FI is not available. This can be configured as a serial connection. |
| **USB (universal serial bus)** | • Enables laptops to connect to meter to download SmartMeter Data |
| **Expandable Secure Digital (SD) Memory Card** | • Provides additional capacity to store meter data<br>• Communicates with sensors and possible household devices |

### 4.1.9 Software and Cloud-Based Head-end (HE) Interface Requirements

In order to access, verify, and test the NGM functionality, it was necessary for the NGM to use cloud-based software with a user interface. The network communication pathway was 4G/LTE since the AMI NIC was not available for this demonstration.

Through the UI, the operator could view the NGMs connected to the network, see associated data, and have the ability to perform various functions shown below:

- Configure NGM functionality (i.e., turn high resolution data on and off, configure interval periods, polling and pushing frequency, program what data is required at a specific location or batch, etc.)
- Communicate through a cellular network
- Access real-time visual displays for monitoring meter assets
- Monitor and control grid-edge devices
- Upgrade software and firmware
- Access data and control features as fast as the LTE network can provide

**Standards and Compliance**
A primary focus for the NGM was compliance with open standards. The NGM used a variety of ANSI standards including data table format (ANSI C12.19) and communication protocol format (ANSI C12.22). However, the network communication protocol to transport meter data to a head-end is typically a vendor proprietary solution. Due to the evolving need for real-time grid data and alternative communication

pathways, PG&E chose to pursue the use of C12.22 for head-end development. This would enable interoperability and eliminate dependency on a given vendor's proprietary equipment.

**Challenges and Resolutions**

The largest challenge for the hardware and software requirements development was to have the complete set of requirements upfront without future modifications. The project team had to go through a few updates of requirements, collaborations with and discussions between the vendor design engineers and PG&E engineers. This task took time and ensured that all key stakeholder input was incorporated in the requirements.

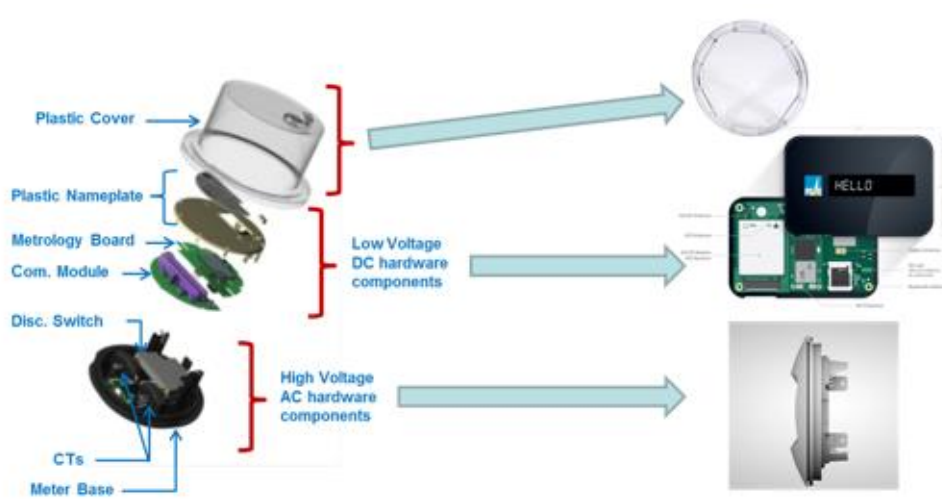
## 4.2 Task 2: Prototype Development and Set-Up

### 4.2.1 Prototype Development

Prototype development included the design of the hardware, firmware, and software meeting requirements in Task 1. This included procuring off-the shelf technology and working with a vendor to integrate components and develop a prototype meter.

Figure 1 is a conceptual drawing comparing an existing SmartMeter vs. the new NGM. High voltage components in the NGM included the power supply, current transformers, disconnect switch and associated surge protection devices. Low voltage components included the main CPU, power meter, 4G LTE, GPS, micro-SD card slot, various interfaces, accelerometer and temperature sensor chipsets, and associated communications antennas. The low voltage components were known as the NGM core and were developed as part of the EPIC 2.29 Project. The high voltage components (docking station) for future and actual use cases will be developed as part of EPIC 3.

**Figure 1: Existing SmartMeter Design vs. NGM**



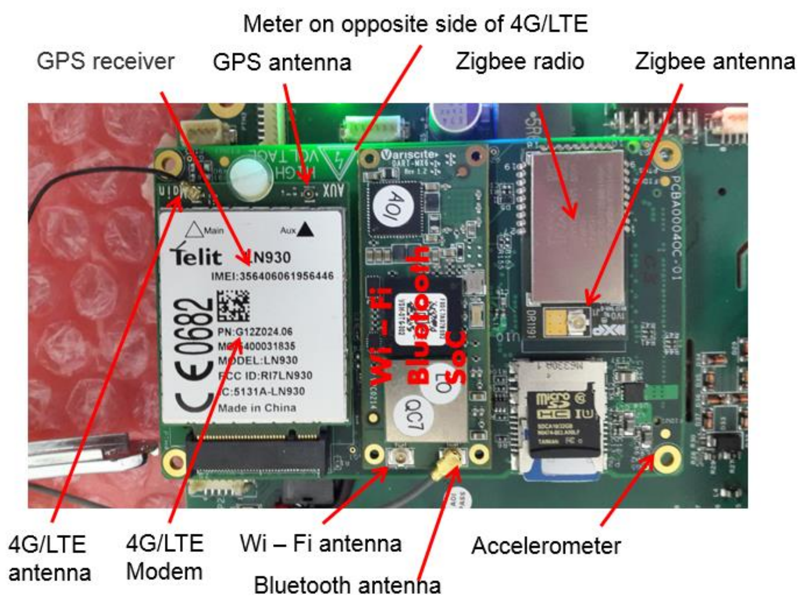

After all the requirements were identified and finalized, PG&E worked with a vendor to deliver a prototype of the NGM. Product development included three official iterations of the NGM (alpha, beta, and prototype units). The result was the successful development of NGM prototype meters and successful test results for accuracy against ANSI C12.1 and ANSI C12.20 Standards.

Figure 2 shows the NGM core circuit board and related components. This figure shows the highly-integrated design and small size of the circuit board (approximately the size of a credit card).

**Figure 2: NGM Core the Size of a Credit Card**


Figure 3 highlights the different components and modules integrated into the circuit board. Determining the best location for these components was a challenging aspect of the project, and thus EPIC 2.29 generated substantial learnings for future development of NGM prototypes.

**Figure 3: NGM Meter Components**




### 4.2.2 NGM-C12 (C12.19/C12.22)

The NGM project made use of open standards to ensure interoperability. The NGM used the C12.19 data table format, which is the industry standard for meter data. The NGM also used the C12.22 communication protocol, which is standard for delivering data through a cellular network. Both protocols were used to transport data tables from the NGM to the cloud-based head-end server application. This head-end application was necessary to demonstrate that the NGM can provide useful information using open protocol.

Additional work in enhancement and interface of the head-end application with other PG&E systems is still needed in the future EPIC projects.

NGM-C12 would measure, calculate and process usage data, and then store it in a set of ANSI C12.19-formatted Tables into the NGM memory. Data stored in this format would then be encrypted, retrieved, packetized and communicated using ANSI C12.22. In addition, the NGM cloud-based server application provided a range of advanced capabilities (including periodic data transfer and high-resolution transmission), supported remote display, configuration and control, and was able to use a standards-based user interface to present NGM-C12 parameters.

The following tables were developed as part of this project:

- Meter information (i.e. configuration, nameplate, status, etc.)
- Billing meter data
- Power measurement data
- Time of use data

### 4.2.3 NGM Cloud Based Server Application

A vendor cloud-based solution and head-end application was necessary to operate the NGM, verify the functionality, and test its ability to transmit data. The inclusion of a cloud-based head end application was found to be more efficient and cost effective than developing a new application from scratch. The server application was used to test:

- Bi-directional communication
- Simple file storage, accessible as a web service
- Additional processing procedures

The server application was successfully tested and proven effective in transferring the data from the NGM to a cloud server. The transfer time interval could be set from 1 second to 24 hours. This cellular connection was also used for NGM software and firmware upgrades, configuration changes, and for resetting various sensor registers and polling high resolution data. However additional development of the NGM cloud base server application would be needed to fully leverage the cellular communication functionality at scale.

**Challenges and Resolutions**

The largest challenge for the hardware development was RF interference due to the various wireless functionalities. The project team had to go through multiple iterations of antennae placement within the NGM enclosure before all communication interfaces worked as expected.

Another challenge was firmware development of the NGM to meet national standards. This task required both specialized skills in firmware code writing and knowledge of the national standards and relevant standards.

Also, there is a challenge in connecting the NGM core meter to and transmitting the meter data over the existing AMI system. The AMI system is a proprietary technology and requires discussion and collaboration the AMI vendor to integrate NGM core into the AMI technology. PG&E knows such task would take time and resources, and plans to work toward such integration.

Since this NGM core serves as the foundation for potential future EPIC 3 Project use cases as approved in PG&E's EPIC 3 application, additional work to address these challenges is being evaluated as part of these potential EPIC 3 projects.Task 3: Functional Testing

### 4.2.4 Revenue Grade Meter Testing

**ANSI C1 and C20 Testing**

ANSI C12.1 and C12.20 are national standards for in-service accuracy of revenue-grade electricity meters. The ANSI standards require meters to maintain an accuracy of 0.2% with voltage ratings between 96-144V (+/-20% range for a nominal voltage level of 120Vac).

The NGM was tested to be compliant with the ANSI accuracy standard and proven to be revenue-grade. This would enable PG&E to provide the latest, most advanced meter technology to its customers. It would also provide utility companies and customers with application features far beyond the current SmartMeter technologies. Testing results for voltage and accuracy performance is described below.

**Accuracy Performance**

The results of the accuracy test demonstrated that the meter provided acceptable accuracy (within 0.2%) for nominal voltages (120V). The success criteria of energy measurement was an accuracy standard of 0.2% average, which the NGM was tested and proven to be accurate within. Accuracy is a very critical component for utilities to ensure to meter and bill the customer's energy usage correctly.

Most of PG&E's current SmartMeters adhere to the ANSI standard 0.2% accuracy. Therefore, a metering chipset with 0.2% accuracy was selected for the NGM. To ensure that the NGM was accurate to a revenue-grade standard, accuracy tests were performed on the NGM at various loads. A sample of the test results is shown in the Table 4-4.

**Table 4-4: NGM Accuracy Tests**

| ACCURACY TESTING at Various Load | | | | | | |
|---|---|---|---|---|---|---|
| **Device Name** | **Voltage** | **Current** | **PF** | **AWS (Wh)** | **RD-20 (Wh)** | **% Error** |
| HV41_CORE23 | 120V | 0.5A | 1.0 | 30 | 30.0255 | 0.085 |
| HV41_CORE23 | 120V | 5.0A | 1.0 | 60 | 60.1705 | 0.283 |
| HV41_CORE23 | 120V | 10.0A | 1.0 | 90 | 90.0333 | 0.036 |
| HV41_CORE23 | 120V | 20.0A | 1.0 | 150 | 150.2901 | 0.193 |

**Voltage Performance**

The results of the voltage test demonstrated that the NGM provided acceptable accuracy for voltages below the threshold of what existing meters could tolerate (below the minimum 96V). NGM prototypes were tested at different voltages to determine the starting operating voltage which would be used to test the accuracy of the energy measurement. More importantly, the NGM was tested to find the lowest level of operating voltage that the NGM could still measure energy usage accurately and communicate with the head-end. This was determined to be 22V—significantly lower than standard meters that shut down the meter operations below 96V. This would help PG&E identify possible wire-down scenarios and take actions to ensure public safety.

**Table 4-5: Minimum Voltage Performance**

| MINIMUM VOLTAGE ACCURACY TESTING | | | | | | |
|---|---|---|---|---|---|---|
| **Device Name** | **Voltage** | **Current** | **PF** | **AWS (Wh)** | **RD-20 (Wh)** | **% Error** |
| HV41_COR236 | 21.95V | 5A | 1.0 | 60.00 | 60.0474 | -0.08% |
| HV41_CORE36 | 21.95V | 10.0A | 1.0 | 15.00 | 15.07 | -0.46% |
| HV41_CORE36 | 21.95V | 10.0A | 1.0 | 105.00 | 105.0897 | -0.08% |

### 4.2.5 Lab Testing for Use-Cases (EV Chargers, Smart Inverters, and Smart Poles)

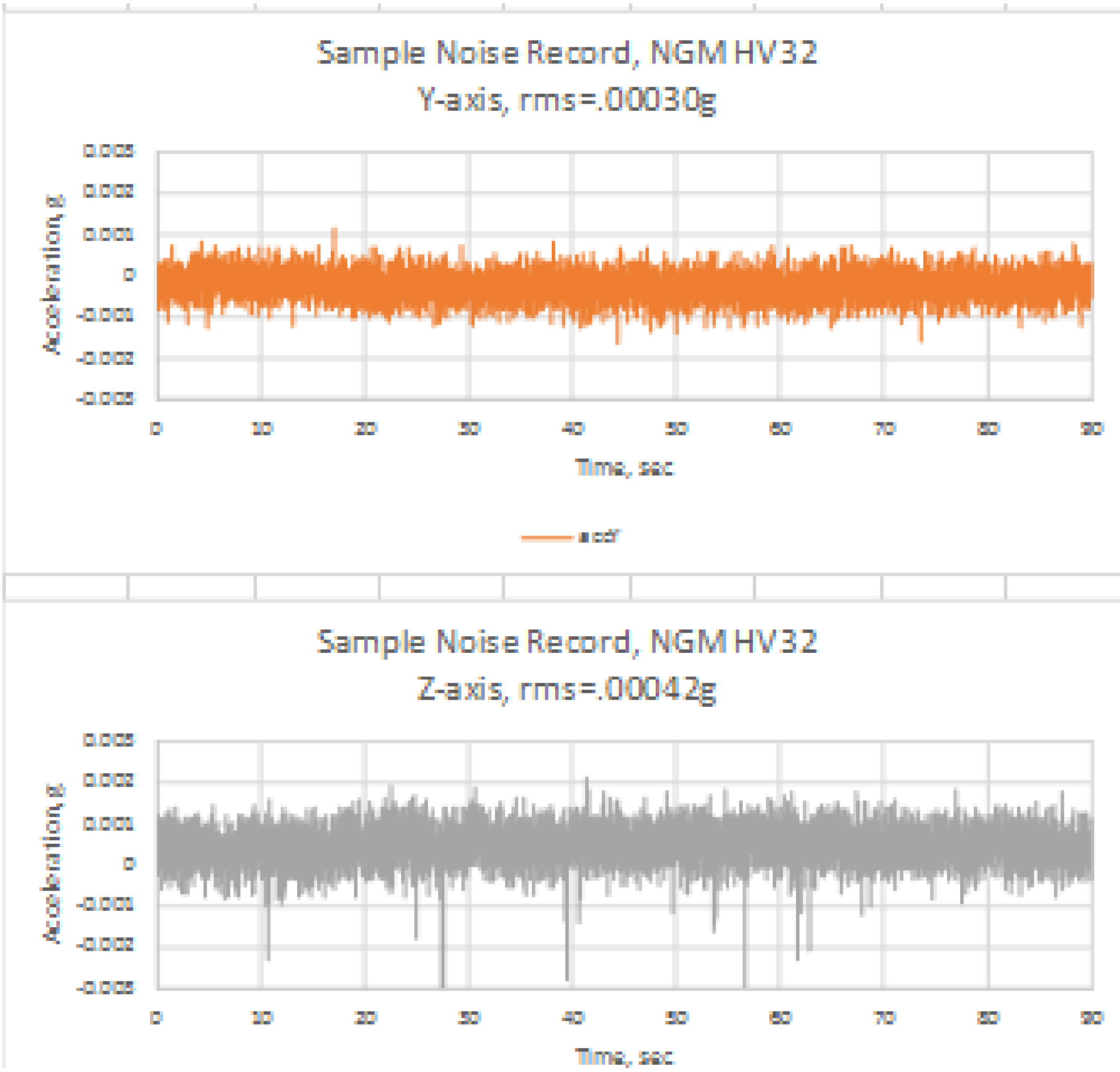
The functional testing involved three use cases covering EV metering, smart inverters, and smart poles. The use cases were identified and selected by PG&E's project team to evaluate the NGM for interoperability, and the ability to collect and transmit real-time data. Overall, regardless of the application, these use cases demonstrated that the NGM be a revenue-grade meter and able to provide data such as voltage, current, and kilowatt-hour (kWh) in seconds. For additional details on the value of these use cases and lab setup, refer to Appendix C.

### 4.2.6 Accelerometer Testing

The addition of an accelerometer to the NGM created the opportunity to support seismic research and the development of an earthquake warning system. When deployed in production meters, this seismic sensing had the potential to greatly increase knowledge of earthquake behavior and hazard. Ongoing collaboration between PG&E and the geo-sciences community was looking at ways to use this new potential data source for refinement of a Northern California earthquake hazard warning system.

Two micro-electro-mechanical systems accelerometers were included in the NGM prototype hardware, one on the sensor board, and the other on the core board. Testing included amplitude accuracy, timing accuracy, noise level, and simulated earthquake measurement. Results are shown in Figure 4.

**Figure 4: Real-Time Meter Collection using Accelerometer Data**




The results demonstrated that seismic sensing capability in the NGM prototype met the initial expectation of accuracy and performance. In addition, the meter was capable of providing high resolution seismic data in milliseconds (0.48 ms). However, there were challenges with the firmware as the real-time high-speed data created heavy demands on the cloud-based head-end system. Although not in-scope of this project, additional firmware development and evaluation of communication protocols would later be required to determine how to develop a head-end that would manage an enormous amount of grid data in real-time.

**Challenges and Resolutions**

One of biggest challenges for the NGM functional testing was knowledge and skills in earthquake science. To overcome this, the project team needed to collaborate with a geoscience consultant who is subject matter expert in accelerometer devices and earthquake science. The challenge was overcome by successfully completing the test plan, performing shake tests, and collecting the simulated-earthquake data in the NGM.

# 5 Value proposition

The purpose of EPIC funding is to support investments in TD&D projects that benefit the electricity customers of PG&E, SCE, and SDG&E. EPIC 2.29, Mobile Meter Application successfully developed and executed the design requirements, functionality, and testing of a NGM core to meet ANSI revenue grade standards and communication protocols.

## 5.1 Primary Principles

The primary principles of EPIC are to invest in technologies and approaches that provide benefits to electric ratepayers by promoting greater reliability, lower costs, and increased safety. This EPIC project contributes to these primary principles in the following ways:

- **Greater reliability:** The ability to obtain high-resolution grid analytics data from the NGM will enable future grid analytics for predictive and preventative maintenance and faster response to support safety and grid reliability.
- **Increased safety:** The design of NGM separates high and low voltage metering components of a SmartMeter. This separation reduces the exposure of field technicians to high voltages during maintenance and repair of meters.
- **Lower costs:** The design of NGM separates high and low voltage components which can reduce both maintenance and operating costs. This includes the capability to replace only failed components.

## 5.2 Secondary Principles

EPIC also has a set of complementary secondary principles. This EPIC project contributes to the following three secondary principles: societal benefits, greenhouse gas (GHG) emissions reduction, the loading order, low-emission vehicles/transmission, economic development; and efficient use of ratepayer funds.

- **Societal benefits:** The NGM is equipped with an accelerometer to support research and prediction of earthquakes.
- **GHG emissions reduction:** By providing the ability to communicate and control DERs, these resources will be used more efficiently, thereby reducing GHG emissions.
- **Low-emission vehicles/transmission:** The NGM will have the capability to consolidate metering of EV's energy usage/charges at public locations/stations, or at home. This will enhance EV ownership and encourage the use of low-emission vehicles.

## 5.3 Accomplishments and Recommendations

## 5.4 Key Accomplishments

The following summarize some of the key demonstration and accomplishments of the project over its duration:

- Successfully developed and executed design requirements, functionality, and testing of the NGM to meet national standards
- Designed a revenue grade power meter that fully meets both ANSI C12.19 and C12.22 standards and communicate over the 4G LTE network
- Incorporated all specified electronic components of NGM onto a credit-card-sized circuit board
- Demonstrated NGM capability of communicating high resolution real-time data (voltage, current, phase ID, kWh) using open communication protocols.
- Designed and built an NGM with multiple interfaces, communication protocols, and various other functions currently not available from the existing SmartMeters.

- Demonstrated multiple wireless protocols of 4G, Wi-Fi, and Bluetooth, along with data polled from multiple sensors such as GPS and accelerometer.
- Developed and demonstrated a demonstration-grade head-end application to operate and function with a new NGM.
- Demonstrated that the interface of the new headend to existing PG&E applications such as field application tool, meter data management application and billing application be feasible. However, additional work in enhancement and interface of the head-end application with other PG&E systems is needed in the future EPIC projects.
- Design separating high and low voltage components would lead to replacement of a failed solid-state components, instead of wasting the entire meter, which will help reduce costs.

## 5.5 Key Recommendations

Meter Development and Deployment: Development of the NGM demonstrated that it was possible to reduce installation and replacement costs of meters. A critical path to deployment for the NGM is to obtain the AMI NIC so that the meter can easily integrate into PG&Es current billing system. The absence of this card requires creation of a new infrastructure of systems and application interfaces to support new communications pathways and thus increases costs. If the NIC can be integrated, the next steps will be to build a docking station for single and multi-tenant applications to complete the SmartMeter.

Grid Analytics Data Applications: The AMI network is not designed for real-time data. To leverage the NGM for grid-analytics, a cellular communication pathway is needed. Typical solutions for head-end systems are based on proprietary vendor equipment. The recommendation is that the industry support open communication protocols and promote interoperability to facilitates new product interfaces and enable product offerings from different vendors.

## 5.6 Technology Transfer Plan

### 5.6.1 IOU's Technology Transfer Plans

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. 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 will be presented:

**Information Sharing Forums Planned**

- DistribuTECH in 2020-2022
- Edison Electric Institute Conference in 2020-2022
- Utility Benchmarking Meetings in 2020-2022

**Path to Production**

The NGM developed and demonstrated in the lab through EPIC 2.29 is fully operational as designed and specified, however this does not mean this solution can now simply be plugged into our standard metering infrastructure to begin being used as a replacement for our SmartMeters. Additional development and demonstration is needed to adapt the NGM core to residential and/or commercial metering use. PG&E has filed EPIC 3 projects to conduct the technology development and demonstration needed including grid monitor meter functions and multipurpose meter functions.

The potential EPIC 3 projects will be developed with a full head end application enhancement, systems interface and integration to fully demonstrate the metering system. Through this further development, PG&E will be able to evaluate how the NGM can be utilized for the complete end-to-end solutions that take data from NGM to the headend applications for both billing and grid operation purposes. This will also allow PG&E to further evaluate how the NGM may be able to provide new submetering functions and capabilities to future applications such as EVs, EV chargers, solar roof top DERs, SmartPoles, and appliances.

Through these additional demonstrations, PG&E would like and plan to develop an NGM technology for the utility industry that will enable utilities to more efficiently meter and submeter energy consumption of more devices beyond the traditional homes and buildings, connect to the grid and provide grid operators with useful data for faster restoration while ensuring safety and reliability, and achieve affordability by reducing metering equipment installation and maintenance costs.

### 5.6.2 Adaptability to Other Utilities and Industry

The following findings of this project, upon the additional demonstrations described above, are relevant and adaptable to other utilities and the industry:

- NGM is revenue grade power meter, meets national standards, and facilitates interoperability.
- Multiple communications of 4G LTE, Wi-Fi and Bluetooth provides flexibility in metering operations.
- NGM core is as small as a credit card, which facilitates submetering and meets customer needs.
- High resolution real-time data of voltage, current, and temperature is useful data for grid operations during critical grid conditions.
- A head-end application and systems interface and integration are needed to manage end-point NGMs.
- NGM design separates high and low voltage components. Such design reduces high voltage exposure, improves safety for field personnel and supports low replacement costs in materials and labor by replacement of only failed solid-state components, instead of the entire meter.

## 5.7 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

# 6 Intellectual Property

Because of the ground-breaking nature of the EPIC 2.29 Mobile Meter Applications Project, a final patent application was filed with the U.S. Patent Office. The “Application of Resource Meter System and Method” (Application Number 16143295) outlines the first of its kind solution that demonstrated a small NGM core with a size of the credit card and with a capability of metering and submetering multiple use cases such as EV, EV charger, SmartPole, and solar roof top. This NGM serves as the foundation for potential future EPIC 3 Project use cases as approved in PG&E’s EPIC 3 application.

PG&E looks forward to working with the other California utilities, and the industry at large, to realize the benefits of this approach. This intellectual property is owned and held by PG&E, and can be commercialized for the Company’s commercial benefit, in accordance with all appropriate laws and regulations (including D.13-11-025).

With this EPIC final report, which is required by the CPUC, PG&E and its subsidiaries do not undermine, waive or relinquish any ownership, title, exclusivity or any intellectual property or proprietary rights, of claims made by PG&E or its subsidiaries with respect to such new functionalities of NGM for providing grid data and information in real time and at the time of need for electric grid operational purposes in the EPIC 2.29 Mobile Meter Applications Project.

# 7 Metrics

The following metrics were identified for this project and included in PG&E's EPIC Annual Report as potential metrics to measure project benefits at full scale.[7] Given the proof of concept nature of this EPIC project, these metrics are forward looking.

**Table 7-1: 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) | Reference |
|---|---|
| **1. Potential energy and cost savings** | |
| e. Peak load reduction (megawatts) from summer and winter programs | Section 5.2 |
| f. Avoided customer energy use (kWh saved) | Section 5.2 |
| h. Customer bill savings (dollars saved) | Section 5.2 |
| **3. Economic benefits** | |
| a. Maintain / Reduce operations and maintenance costs | Section 3.1 |
| b. Maintain / Reduce capital costs | Section 3.1 |
| e. Non-energy economic benefits | Section 3.1 |
| f. Improvements in system operation efficiencies stemming from increased utility dispatchability of customer demand side management | Section 3.1 |
| **4. Environmental benefits** | |
| a. GHG emissions reductions (MMTCO2e) | Section 5.2 |
| **5. Safety, Power Quality, and Reliability (Equipment, Electricity System)** | |
| d. Public safety improvement and hazard exposure reduction | Section 3.1 |
| e. Utility worker safety improvement and hazard exposure reduction | Section 3.1 |
| d. Public safety improvement and hazard exposure reduction | Section 3.1 |

# 8 Conclusion

The NGM was demonstrated to be the first revenue grade, high resolution real time power meter that fully met national standards for metering including ANSI C12.1 and ANSI C12.20 (accuracy), ANSI C12.19 (meter data table format) and C12.22 (cellular communication protocol format) standards. The NGM had a small, modular design that leveraged cutting edge technologies. The NGM could communicate over multiple channels including 4G LTE network, Wi-Fi, and Bluetooth to support improved analytics and future use cases.

[7] 2015 PG&E EPIC Annual Report. February 29, 2016. http://www.pge.com/includes/docs/pdfs/about/environment/epic/EPICAnnualReportAttachmentA.pdf.

PG&E successfully developed and demonstrated a fully functional NGM prototype in accordance with the requirements and designed specification. For example, the NGM could provide real-time data with the appropriate additional investment in the communications backhaul. During critical grid conditions such as outage, high/low grid voltage, wire downs, this real-time meter data would be useful information for the grid operators to achieve a faster response and restoration of the electric grids. Such NGM capability, in turn, would support the delivery of safe, reliable, and affordable service to utility customers.

The NGM was successfully tested in the three use cases of EV and Charger, Smart Inverter, and SmartPole in the lab. Through demonstration, NGM could fit into and submeter these use cases. It would satisfy the evolving customer need for a compact metering solution.

This technology could enable utilities to more efficiently meter and submeter energy consumption of more devices connected to the grid while reducing equipment installation and maintenance costs with further development as outlined in PG&E's EPIC 3 filing.

# 9 Appendix A: Electric Meter Technology Measurement Data

Below listed are the billing, grid, and seismic data available on the NGM.

**Table 9-1: NGM Billing, Grid, and Seismic Data**

| Channel | Channel Description | Channel | Channel Description |
|---|---|---|---|
| 1 | Delivered Energy kWh | 41 | % Voltage Harmonic Value 1 thru 24, Phase C |
| 2 | Received Energy kWh | 42 | Harmonic Voltage Angle Value1 thru 24, Phase C |
| 3 | Total Energy (Del+Rec) | 43 | % Current Harmonic Value 1 thru 24, Phase A |
| 4 | Net Energy (Del-Rec) | 44 | Harmonic Current Angle, Value 1 thru 24, Phase A |
| 5 | Instantaneous Voltage | 45 | % Current Harmonic Value 1 thru 24, Phase B |
| 6 | Instantaneous Power | 46 | Harmonic Current Angle, Value 1 thru 24, Phase B |
| 7 | Reactive Energy, Lag (kilovar-hour (kVARh) | 47 | % Current Harmonic Value 1 thru 24, Phase C |
| 8 | Reactive Energy, Lead kVARh | 48 | Harmonic Current Angle, Value 1 thru 24, Phase C |
| 9 | Net Reactive Energy (Del– Rec) | 49 | Distortion Power (Volt-Ampere (VA)) Phase A |
| 10 | Tamper Switch | 50 | Distortion Power (VA) Phase B |
| 11 | Power Factor | 51 | Distortion Power (VA) Phase C |
| 12 | Apparent Power Factor | 52 | Distortion Power (VA) Total |
| 13 | Displacement Power Factor | 53 | Distortion Power Factor Total |
| 14 | Distortion Power Factor | 54 | Total Harmonic Distortion (THD) Voltage % |
| 15 | 4 Quadrant Metering | 55 | THD Current % |
| 16 | Multi-Dwelling Flag | 56 | Voltage Sag Counter |
| 17 | Maintenance Info (Dates, Names, Work Done) | 57 | Minimum Voltage during Sag Event, Phase A |
| 18 | Frequency, Hertz (Hz) | 58 | Minimum Voltage during Sag Event, Phase B |
| 19 | Outage Monitor-Voltage - 30 Min | 59 | Minimum Voltage during Sag Event, Phase C |
| 20 | Voltage Phase A to Neutral, F+H | 60 | Duration of Sag Event (cycles) |
| 21 | Voltage Phase B to Neutral, F+H | 61 | Voltage Swell Counter |
| 22 | Voltage Phase C to Neutral, F+H | 62 | Maximum Voltage during Swell Event, Phase A |
| 23 | Voltage Phase A to Phase B, F + H | 63 | Maximum Voltage during Swell Event, Phase B |
| 24 | Voltage Phase B to Phase C, F + H | 64 | Maximum Voltage during Swell Event, Phase C |

| Channel | Channel Description | Channel | Channel Description |
|---|---|---|---|
| 25 | Voltage Phase C to Phase A, F + H | 65 | Duration of Swell Event (cycles) |
| 26 | Current Magnitude Phase A | 66 | Latitude/Longitude |
| 27 | Current Magnitude Phase B | 67 | Accelerometer, Acc X axis |
| 28 | Current Magnitude Phase C | 68 | Accelerometer, Acc Y axis |
| 29 | Current Magnitude Neutral | 69 | Accelerometer, Acc Z axis |
| 30 | Voltage Angle, Phase A | 70 | Accelerometer, Gyro X axis |
| 31 | Voltage Angle, Phase B | 71 | Accelerometer, Gyro Y axis |
| 32 | Voltage Angle, Phase C | 72 | Accelerometer, Gyro Z axis |
| 33 | Current Angle, Phase A | 73 | RF Data* - 460 MHz |
| 34 | Current Angle, Phase B | 74 | RF Data* - 900 MHz |
| 35 | Current Angle, Phase C | 75 | RF Data* - 4G LTE |
| 36 | Diagnostic Counters | 76 | RF Data* - Bluetooth |
| 37 | % Voltage Harmonic, Value 1 thru 24, Phase A | 77 | RF Data* - Wi Fi |
| 38 | Harmonic Voltage Angle, Value1 thru 24, Phase A | 78 | RF Data* - Reserved |
| 39 | % Voltage Harmonic, Value 1 thru 24, Phase B | 79 | Data Usage (megabyte (MB)/ gigabyte (GB)) |
| 40 | Harmonic Voltage Angle, Value1 thru 24, Phase B | 80 | 4G LTE Signal Strength |

# 10 Appendix B: Data Comparison of NGM vs. Existing SmartMeter

Appendix B compares the data provided by the existing SmartMeters against the data available from the NGM. Table 10-2 shows that the NGM adds a tamper switch, maintenance info, ability to monitor outages, geolocation information, an accelerator and data streams relating to the many communications systems in the NGM.

**Table 10-1: Comparisons of NGM Meter Data and Existing SmartMeter Data**

| Channel | Channel Description | Existing SmartMeter | Next Gen Meter |
|---|---|---|---|
| 1 | Delivered Energy kWh | X | X |
| 2 | Received Energy kWh | X | X |
| 3 | Total Energy (Delivered + Received) | X | X |
| 4 | Net Energy (Delivered – Received) | X | X |
| 5 | Instantaneous Voltage | X | X |
| 6 | Instantaneous Power | X | X |
| 7 | Reactive Energy, Lag kVARh | X | X |
| 8 | Reactive Energy, Lead kVARh | X | X |
| 9 | Net Reactive Energy (Delivered – Received) | X | X |
| 10 | Tamper Switch | | X |
| 11 | Power Factor | X | X |
| 12 | Apparent Power Factor | X | X |
| 13 | Displacement Power Factor | X | X |
| 14 | Distortion Power Factor | X | X |
| 15 | 4 Quadrant Metering | X | X |
| 16 | Multi-Dwelling Flag | X | X |
| 17 | Maintenance Info (Dates, Names, Work Done) | | X |
| 18 | Frequency, Hz | X | X |
| 19 | Outage Monitor-Voltage - 30 Min | | X |
| 20 | Voltage Phase A to Neutral, F+H | X | X |
| 21 | Voltage Phase B to Neutral, F+H | X | X |
| 22 | Voltage Phase C to Neutral, F+H | X | X |
| 23 | Voltage Phase A to Phase B, F + H | X | X |
| 24 | Voltage Phase B to Phase C, F + H | X | X |
| 25 | Voltage Phase C to Phase A, F + H | X | X |
| 26 | Current Magnitude Phase A | X | X |
| 27 | Current Magnitude Phase B | X | X |
| 28 | Current Magnitude Phase C | X | X |
| 29 | Current Magnitude Neutral | X | X |
| 30 | Voltage Angle, Phase A | X | X |
| 31 | Voltage Angle, Phase B | X | X |
| 32 | Voltage Angle, Phase C | X | X |
| 33 | Current Angle, Phase A | X | X |
| 34 | Current Angle, Phase B | X | X |
| 35 | Current Angle, Phase C | X | X |

| Channel | Channel Description | Existing SmartMeter | Next Gen Meter |
|---|---|---|---|
| | | | |
| 36 | Diagnostic Counters | X | X |
| 37 | % Voltage Harmonic Value 1 thru 24, Phase A | X | X |
| 38 | Harmonic Voltage Angle, Value1 - 24, Phase A | X | X |
| 39 | % Voltage Harmonic Value 1 thru 24, Phase C | X | X |
| 40 | Harmonic Voltage Angle, Value1 - 24, Phase C | X | X |
| 41 | % Current Harmonic Value 1 thru 24, Phase A | X | X |
| 42 | Harmonic Current Angle, Value 1 - 24, Phase A | X | X |
| 43 | % Current Harmonic Value 1 thru 24, Phase B | X | X |
| 44 | Harmonic Current Angle, Value 1 - 24, Phase B | X | X |
| 45 | % Current Harmonic Value 1 thru 24, Phase C | X | X |
| 46 | Harmonic Current Angle, Value 1 - 24, Phase C | X | X |
| 47 | Distortion Power (VA) Phase A | X | X |
| 48 | Distortion Power (VA) Phase B | X | X |
| 49 | Distortion Power (VA) Phase C | X | X |
| 50 | Distortion Power (VA) Total | X | X |
| 51 | Distortion Power Factor Total | X | X |
| 52 | THD Voltage % | X | X |
| 53 | THD Current % | X | X |
| 54 | Voltage Sag Counter | X | X |
| 55 | Minimum Voltage during Sag Event, Phase A | X | X |
| 56 | Minimum Voltage during Sag Event, Phase B | X | X |
| 57 | Minimum Voltage during Sag Event, Phase C | X | X |
| 58 | Duration of Sag Event (cycles) | X | X |
| 59 | Voltage Swell Counter | X | X |
| 60 | Maximum Voltage during Swell Event, Phase A | X | X |
| 61 | Maximum Voltage during Swell Event, Phase B | X | X |
| 62 | Maximum Voltage during Swell Event, Phase C | X | X |
| 63 | Duration of Swell Event (cycles) | X | X |
| 64 | Latitude/Longitude | | X |
| 65 | Accelerometer, Acc X axis | | X |
| 66 | Accelerometer, Acc Y axis | | X |
| 67 | Accelerometer, Acc Z axis | | X |
| 68 | Accelerometer, Gyro X axis | | X |
| 69 | Accelerometer, Gyro Y axis | | X |
| 70 | Accelerometer, Gyro Z axis | | X |
| 71 | RF Data* - 460 MHz | | X |
| 72 | RF Data* - 900 MHz | | X |
| 73 | RF Data* - 4G LTE | | X |
| 74 | RF Data* - Bluetooth | | X |
| 75 | RF Data* - Wi Fi | | X |
| 76 | RF Data* - Reserved | | X |
| 77 | Data Usage (MB/GB) | | X |
| 78 | 4G LTE Signal Strength | | X |

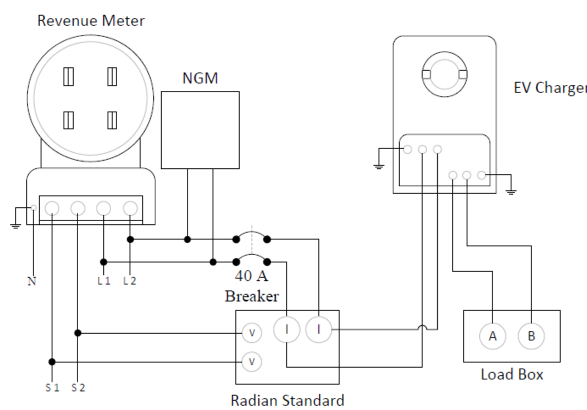
# 11 Appendix C: Lab Test Field Set-Up

**Electric Vehicle Charger Use-Case**

There was a significant load increase due to a number of EVs being charged from PG&E's grid. This triggered the team to research and develop a mobile meter which could be used metering not only customer's home energy usage but also the EV chargers and the EVs. This would provide utility companies with huge benefits to reduce cost of upgrading their current infrastructure and have a way to monitor and provide necessary EV usage data for EV load consumption and forecast.

NGM was envisioned to have an ability to provide real-time data to users in such a way that it would automatically identify the EV, be able to charge, and add fees onto the existing electric bills. This would simplify and consolidate the customer billing transactions at the end of each month. The set-up shown in Figure 5 was used for this test.

**Figure 5: NGM Test Set-up - With Simulated EV Charging Station Load**

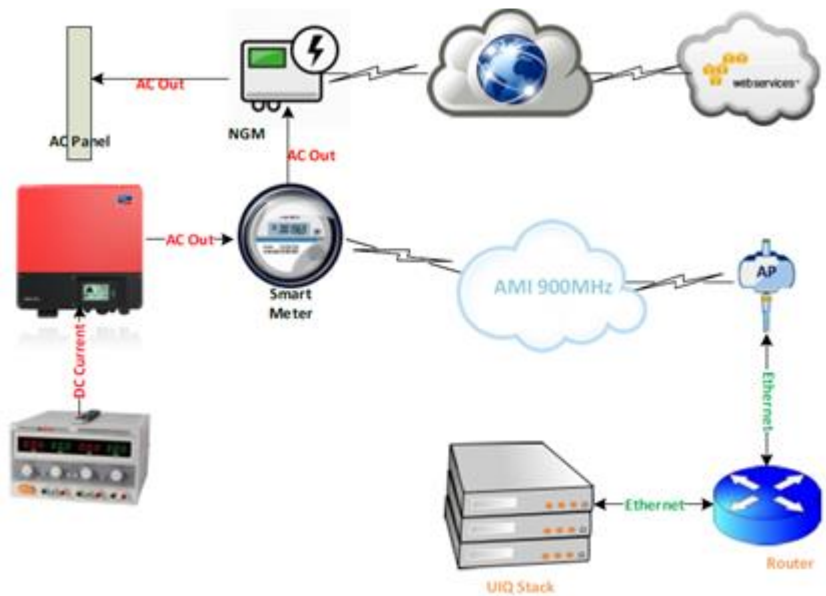



**Smart Inverter Use-Case**

The utility industry is looking for a way to monitor and control the Smart Inverters to ensure power quality (i.e., stable voltage) is delivered to the customers. Utility companies need to monitor smart inverter outputs and be able to turn ON/OFF accordingly to ensure the voltage on the grid is stable and within +/-5% per Rule 2 set forth by CPUC.

A Smart Inverter was used for this test with a system architecture drawing for the testing shown on Figure 4. As of today, the gross generation output of all Smart Inverter/PV systems is not visible to PG&E. As shown in Figure 4, by connecting the output of the Smart Inverter/PV system to the NGM, the gross generation output became visible in real-time.

**Figure 6: Smart Inverter Testing Architecture**




## SmartPoles

*EPIC 1.14 – Next Generation SmartMeter™ Telecom Network Functionalities* designed a low-profile meter that reduced installation costs by eliminating the need for meter panel and pedestal installations for streetlight applications. The SmartPole developed in EPIC 1.14 with an AMI NIC. This 2.29 Project installed the NGM Core for testing the SmartPole use case. This application would provide an alternate mean to deliver data using the ANSI C12.22 open architecture system.

# 12 Appendix D: C12.19 Table Development

**Table 122-1: C12.19 Tables in NGM**

| Table # | Name | Access |
|---|---|---|
| **0** | General Configuration | R |
| **1** | General Manufacturer Identification | R |
| **2** | Device Nameplate | R |
| **3** | End Device Mode Status | R |
| **5** | Device Identification | R |
| **6** | Utility Information | R |

Table creation of meter information

**Decade 1: Data Source Tables**

| Table # | Name | Access |
|---|---|---|
| **11** | Actual Data Sources Limiting | R |
| **12** | Units of Measure Entry | R |

Table creation of billing meter data

**Decade 2: Register Tables**

| Number | Name | Access |
|---|---|---|
| **21** | Actual Register Limiting | R |
| **22** | Data Selection | R |
| **23** | Current Register Data | R |
| **27** | Present Register Selection | R |
| **28** | Present Register Data | R |

Table creation of power measurement data

**Decade 5: Time and Time-of-Use Tables**

| Number | Name | Access |
|---|---|---|
| **51** | Actual Time and Time-of-Use (TOU) Limiting | R |
| **52** | Clock | R |
| **53** | Time Offset Table | R |

Table creation to define TOU data in relation to power data – for billing data