



*Pacific Gas and
Electric Company®*

Pacific Gas and Electric Company

EPIC Final Report

Program

Electric Program Investment Charge (EPIC)

Project

EPIC Project 1.09 – Test New Remote Monitoring and Control Systems for Existing T&D Assets

Sub-Project

EPIC Project 1.09A Close Proximity Switching

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Date

March 31, 2016

Version

Final

Table of Contents

1	Executive Summary	1
2	Introduction	3
3	Project Summary	4
	3.1 Issue/Problem Statement	4
	3.2 Project Overview and Objective	5
	3.3 Project Scope	5
	3.4 Project Tasks and Deliverables	5
4	Project Results and Key Findings	6
	4.1 Detailed Technical Results	6
	4.1.1 Individual Vendor Assessments	6
	4.1.2 Comparison of the Vendors’ Remote Switch Operator Tools	9
	4.2 Key Findings and Recommendations	13
	4.3 Technical Issues and Lessons Learned	14
	4.4 Value proposition.....	15
	4.4.1 Mandatory Guiding Principles of EPIC	16
	4.4.2 Secondary Principles of EPIC.....	16
	4.5 Technology/Knowledge Transfer Plan for Applying Results into Practice.....	16
	Information Sharing Forums Held.....	17
	4.6 Data Access	17
	4.7 Overall Results	17
5	Project Metrics	18
	Appendix A: Remote Controlled Switch Operator Engineering Specifications.....	19
	Appendix B: Summary of Results from Pilot Field Test.....	23
	Appendix C: Remote Switch Operator Pilot Survey Template.....	24

List of Tables

Table 1: Comparison of Vendors’ Prototype Switch Operators.....	10
Table 2: Performance Ranking by the Evaluation Team	13
Table 3: Comparison of Vendor Field Test Performance	23

1 Executive Summary

Pacific Gas and Electric Company's (PG&E) Electric Program Investment Charge (EPIC) Project 1.09A, Close Proximity Switching, successfully built and demonstrated tools that would allow PG&E workers to more safely operate certain subsurface or underground (UG) oil switches, and compared the results of these tools across the three vendors chosen to participate. The primary goals of this EPIC project were to increase system reliability and to improve the safe operation of three-phase Load Break Oil Rotary (LBOR) switches, which was achieved through this project.

As the assets of PG&E age, it is imperative to public and employee safety to develop a proactive replacement program while prioritizing safety for the current operations and maintenance of existing assets. This is especially critical for assets such as oil switches that use the older technology of solid blade in oil to break or make loads. These sub-surface LBOR switches manufactured prior to 1972 do not offer an oil level indicator. Switches manufactured after 1972 do include an oil level indicator; however, the condition of the oil inside of the tank (even with an oil level indicator) is unknown. Existing worker safety equipment includes an insulated tool, called a "hot stick", a shield, and a protective suit; however, despite the protective equipment, the employee is still left within close proximity to the switch and potentially at risk of being injured if the switch fails when being operated. While PG&E has a multi-year replacement program in progress to replace approximately 900 LBOR switches without oil level indicators, and another 1400 units, which are pre-1972 that are considered high risk due to their age and lack of data on a number of operations, they will be operated potentially thousands of times before the replacement program can be completed.

PG&E sought input from switch and tool manufacturers and from industry forums, like the National Electric Energy Technology and Application Research Committee (NEETRAC), looking for a solution to this shared industry problem which would allow the worker to either assess the condition of these legacy LBOR switches or move the employee a safe distance from the hazard during switching. No existing solution was identified. It was decided that the best approach would be to apply innovative technology to build a prototype remote controlled LBOR switch operator to allow a worker to operate the legacy switches from a safe distance. This Close Proximity Switching Project was the outcome of that decision.

The project scope was for vendors to develop prototype remote controlled units per PG&E requirements and submit the prototypes to PG&E for testing and evaluation. The goal at the end of this project was for PG&E to have selected one or more prototypes for purchase to be beta tested in PG&E's Mission, Diablo, and San Jose divisions where large numbers of these legacy switches are installed.

PG&E developed engineering specifications for the creation of a prototype remote controlled unit to operate these LBOR switches at a minimum distance of 25 feet from the switch. Invitations were then sent to potential vendors requesting proposals. Two were selected, Vendor A and Vendor B for development. In tandem, a third vendor, Vendor C, decided to independently develop a prototype remote controlled unit that was later added to the demonstration and testing phase.

Each of the three prototype units were both laboratory and field-tested. The laboratory tests were conducted under controlled, simulated field conditions by PG&E personnel at PG&E's Applied Technology Services (ATS) facility. The field tests were conducted on installed LBOR switches and

operated by workers who operate the legacy switches. The results of the laboratory and field tests allowed PG&E to comparatively evaluate the three prototypes. While each of the three prototypes met the RFP specifications and performed sufficiently once set up, each had strengths and weaknesses such that any selected would require modification:

- Vendor A: This prototype was the heaviest and experienced the most technical and usability issues during the laboratory tests, but ranked favorably in the field tests.
- Vendor B: This prototype ranked the best based on the Request for Proposal (RFP) selection criteria, but ranked the worst in the limited field tests. However, it was the lowest cost unit.
- Vendor C: This prototype was most preferred by PG&E workers in the field tests, but the unit cost far exceeded the first two prototypes.

The project concluded with the recommendation to move forward with both Vendors A and B for potential beta testing of production model units. Both vendors' tools require modifications to be fully functional in PG&E operations, which will be implemented before rolling out to production. The vendors were provided with the modification requirements identified during demonstration and testing. Additional cost negotiations will be necessary with Vendor C to make it competitive. Due to the successful results of this project, PG&E has implemented plans to transition the Close Proximity Switching Project, PG&E EPIC 1 Project 09A, into beta testing and ultimately to full deployment.

PG&E will be sharing the knowledge and experience gained from this project with the California Energy Commission and other California investor owned utilities, including knowledge sharing in industry meetings, such as National Electric Energy Technology and Application Research Committee (NEETRAC), the Western Underground Committee Spring Meeting, EPIC workshops and through web postings of this report.

In conclusion, this project was successful in addressing a safety and reliability risk that is shared across the industry by developing and testing multiple solutions that eliminate the need for personnel to manually open and close rotary vault switches. As an interim solution during a multi-year switch replacement program, this outcome proactively reduces public and employee safety risk, while also increasing reliability by enhancing the workers' ability to operate LBORs and reduce outage time should a circuit failure occur. This solution will also reduce the public exposure since the operator will have better visibility of the pedestrians when he/she is ready to execute the switching command remotely.

2 Introduction

This report documents the EPIC 1.09A Close Proximity Switching project achievements, highlights key learnings from the project that have industry-wide value, and identifies future opportunities for PG&E to leverage this project.

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this project. The CPUC initially issued Decision 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*¹, which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued Decision 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020*,² 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 technology demonstration as the installation and operation of pre-commercial technologies 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.

The decision also required the EPIC Program Administrators³ 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 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, 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 #1.09: Test New Remote Monitoring and Control Systems for Existing Transmission and Distribution (T&D) Assets. As indicated in PG&E's 2014 and 2015 EPIC Annual Reports, Project 1.09 was split into three projects. This project final report captures one of the three projects: 1.09A Close Proximity Switching. Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project.

The following is PG&E's final report on this project, which ultimately successfully built and demonstrated tools that would allow utility workers to more safely operate aging oil switches, and compared the results of these tools across the three vendors selected to participate.

¹ http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF

² http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF

³ Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), and the California Energy Commission (CEC)

3 Project Summary

3.1 Issue/Problem Statement

PG&E has over 20,000 oil filled sub-surface 200-amp, three phase Load Break Oil Rotary (LBOR) switches in its underground distribution system. The safe operation of these switches is crucial to avoid worker injury and to provide reliable electric service. Individual employees manually operate these switches by standing over the enclosure, and use an insulated tool, called a “hot stick”, to turn the switch nob off or on. Although the hot stick protects the employee from electric shock, the employee can still be potentially injured if a failure/explosion were to occur due to low oil, mechanical fatigue or dielectric integrity of the fluid, since the employee would be in close proximity to the switch. LBOR switches manufactured in 1972 and later are equipped with oil level indicator gauges that assists the operator in determining whether the switch can be safely operated based on the oil level. This oil level gauge can support validate the integrity of the switch for operation for when they are operated; however, the condition of the oil inside of the tank is still unknown. Sub-surface LBOR switches, manufactured prior to 1972, do not include an oil level indicator, which would allow the operator to determine whether the switch can be safely operated. PG&E has approximately 2,300 LBOR switches that were installed before 1976⁴. Currently, there are limited options to mitigate risk to switch operators beyond the hot stick, shield, and protective suit. None of these hazard controls, used individually or in combination, fully protects an operator from potential injury.

Failed oil switches have resulted in injury events, triggered customer outages, and/or caused property damages⁵. As PG&E’s assets age, it is imperative for public and employee safety to perform more comprehensive inspections (condition-based assessment) and to develop a more active replacement program. This is especially critical for assets such as older oil switches that do not have oil level indicator gauges. PG&E has a multi-year program to replace the approximately 2,300 LBORs installed prior to 1976. This replacement program will require workers to operate legacy LBOR switches thousands of times before they are all replaced, so PG&E has been seeking interim measures to ensure the safe operation of these legacy switches. PG&E had researched this issue and discussed it with switch manufactures in various industry venues. Since no existing solution was identified, it was decided the best way to resolve this issue was to leverage technology and develop a tool that could remotely operate these legacy LBOR switches.

⁴ LBOR records are maintained based upon year of installation, not year of manufacture. LBORs manufactured before 1972 could have been installed in later years. Therefore, for the purpose of this analysis, it is assumed that all switches installed prior to 1976 were manufactured without oil level indicator gauges.

⁵ Details of switch failures can be found in PG&E’s 2014 General Rate Case (Ch. 5)

3.2 Project Overview and Objective

The specific objectives of this project were to:

1. Evaluate alternatives to reduce possibility of injury to workers and public during switch operation
2. Help design and manufacture a robotic tool to allow remote operation
3. Develop the necessary parts/adaptors to be used on various types (manufacturer, brand, age, etc.) of UG switches
4. Test new tools and techniques for safe operations of UG oil filled switches

Ultimately, the goal was to collaborate with vendors and approve one or more jointly-developed prototypes of portable remote controlled LBOR switch operators for use in the PG&E system to accomplish this objective.

3.3 Project Scope

This project focused on application of new technology to improve worker safety and public exposure to a safety risk. The project's scope was to specify and deliver a prototype remote switch operator tool that would enable workers to operate legacy switches at a safe distance. The participating vendors implemented PG&E requirements for the tool, and their prototypes were then lab and field-tested by PG&E personnel.

3.4 Project Tasks and Deliverables

The project involved four tasks:

1. **Vendor selection:** This task developed a request for proposal (RFP), which was issued on July 18, 2014, to furnish and deliver a 12 kV through 21 kV oil filled sub-surface switch remote operator. The selected vendors were responsible for the design, fabrication, testing, and shipping of a complete remote switch operator assembly. The remote switch operators would be installed by PG&E employees in a laboratory and in various field locations for testing and evaluation. Following the acceptance of two vendors from the RFP process, PG&E invited a third vendor who had independently developed a similar prototype device to provide a demonstration and participate in the laboratory and field evaluations.
2. **Laboratory testing:** As part of this task, the remote switch operators were evaluated for ease of installation and operation in a laboratory environment at PG&E.
3. **Field testing:** In this task, once the remote switch operators were favorably evaluated in the lab, they were assessed for ease of installation and operation in actual field situations and conditions.
4. **Final prototype evaluation:** Following the laboratory and field evaluations, final evaluations were completed for each vendor, taking into account lab tests, field tests, PG&E operator preference, and unit cost.

The deliverables for Tasks 1-3 were the individual test results for each prototype. This final report is the deliverable for Task 4.

4 Project Results and Key Findings

4.1 Detailed Technical Results

PG&E developed an engineering specification for the remote controlled switch operator (Appendix A) and issued a Request for Proposal (RFP) to solicit bids from potential vendors, including diverse suppliers. Nine companies expressed interest during the RFP process, and of those, four continued with submissions after receiving the design requirements. Of the four companies that submitted proposals, PG&E selected two vendors (Vendor A and Vendor B) for technology demonstrations and testing of the vendors' remote switch operators. Later, Vendor C was invited to conduct a product demonstration because they had separately developed a prototype tool for underground sectionalizing three-pole oil filled rotary switches in tandem. Vendor C did not participate in the initial RFP because a pending patent made them unable to share the details of their design with PG&E. In order to test each of the vendor's remote switch operators, a demonstration platform was created in the High Voltage Dome at PG&E's Applied Technology Services (ATS) facility. The platform included a staircase and railings to simulate how a hand held remote controller can open and close a sub-surface load break oil rotary switch from a safe distance. Additionally, to simulate real field conditions of an underground environment, PG&E procured two types of enclosures, one round⁶ and one rectangular⁷. An underground three-pole rotary sectionalizing switch with no oil was placed into each enclosure, and elbow receptacles, insulated caps, and cable were also installed on the top of each switch.

PG&E worked with each of the selected vendors on the design elements of the remote controlled switch operator, and the final tool had to consist of the following foundational components:

- Remote switch operator that can open and close sub-surface oil filled rotary type switches;
- Mounting hardware to securely position the operator on top of the switch; and
- A hand held remote control device to open and close the switch at a safe distance of 25 feet.

The following sections describe the overall results of each vendor's demonstration and testing trial.

4.1.1 Individual Vendor Assessments

Vendor A

Vendor A's remote switch operator tool was tested on both the rectangular and circular enclosures. Initially, the tripod mounting assembly took longer than expected to set up on the rectangular enclosure. The set up time later improved through additional operating instructions. The tripod set up time was much shorter for the circular enclosure due to the smaller opening.

The switch operator assembly came with a snap on external battery similar to what PG&E personnel carry in their trucks for hand held power tools. The battery also included a charge status indicator, as well as AC backup power in case it was fully discharged during a switching task. During the design and initial testing phase, the following modifications to the tool were made:

⁶ 42 inch diameter by 39 inch height

⁷ 3 feet by 5 feet by 3 feet 6 inches

- A reflective flag was added to the unit to improve nighttime visibility and to indicate whether the switch has traveled from the open to closed position;
- The existing light on the overall unit was modified to be a flashing, strobe light to indicate caution to the public and personnel operating the unit;
- The enclosure mounting bracket was replaced with a redesigned bracket to facilitate the mounting and dismounting of the switch operator assembly on the tripod; and
- The round hold in the actuator drive was modified into a slotted hold to improve the pin snap-in action needed to lock the shaft to the hot stick drive linkage.

Additionally, green markings will be added to the tripod bracket and the enclosure mounting bracket to aid in determining the proper orientation of the brackets during the device setup.

Vendor A's remote switch operator tool includes a wireless, remote controlled hand held unit with a lanyard to prevent it from falling into the enclosure. Testing at Vendor A's facility indicated a communication range of up to 50 feet between the remote switch operator and the remote control. This range will vary depending on the ambient environment and the elevation difference between the remote switch operator enclosure and the remote control device.

Vendor B

The Vendor B assembly instructions were lengthy and complicated, but correctly following the instructions led to a proper installation and a successful operation. The remote switch operator assembly included a horizontal jack bar assembly, which produced a sturdy fit on the rectangular enclosure. The operator also included an extension bar to accommodate larger rectangular enclosures. While the horizontal jack bar assembly also fit well on the round enclosure, PG&E's territory contains round enclosures with smaller, 36-inch diameter openings, which will require modifications to the horizontal jack bar.

The battery on the demonstration unit is built-in, rechargeable, and watertight. Vendor C currently has no plans to provide an external snap on battery. The battery charger is a 13.6VDC, 4A continuous duty power supply and will operate the systems if the battery is fully discharged or removed from the operator. The battery charger also provides AC backup power for the operator in case the internal battery is fully discharged or removed from the operator.

The following modifications will be made for the final production model:

- Permanent pads made of vulcanized hard rubber will be placed on the mounting feed on the bracket at both ends of the horizontal jack bar to securely cushion and fasten the bar to the enclosure;
- Slide mount assembly will be modified to enable easier installation of the operator assembly;
- A low battery status indicator will be included on the hand held remote controller and made available by attaching the battery charger to the operator assembly; and
- Instructions for quick positioning of the horizontal jack bar to different enclosure sizes will be engraved or stenciled onto the bar.

During demonstration and testing, there were occasions when the hot stick slipped out of the switch operating ring while opening and closing the UG switch. For the production model, Vendor B will replace the demonstration hot stick with a modified Utility Solutions USSA-OHP Universal probe end to securely grip the switch ring and prevent slippage. A new scissor clamp assembly of the controller was also added and accepts 1- $\frac{1}{8}$ to 1- $\frac{3}{8}$ round and triangular hot sticks. Vendor B is also evaluating an alternate “clamp”-type hot stick end fitting which could be supplied with the switch operator to include a hot stick if desired. Additional modifications to the demonstration unit include:

- The flashing light sequence has been modified to two short bursts and one long burst per second to indicate caution to the public and personnel operating the unit;
- A green, 11 mm LED has been added to the top of the operator case that illuminates a “STOPPED” signal when the system has completed the switching operation;
- A slot has been added to the pivot foot assembly and the long extension assembly to accommodate a hook; and
- Rotation nomenclature has been changed to “CW” to indicate clockwise and “CCW” to indicate counter-clockwise on the hand held remote control and the operator unit.

Like Vendor A’s remote control operator device, the Vendor B device also included a wireless, remote controlled hand held unit with a lanyard to prevent the unit from falling into the enclosure. The maximum control range of the remote control is 300 feet and is not adjustable. Reducing the range could create problems in an obstructed view situation and was not recommended by the controller manufacturer.

Vendor C

Vendor C’s remote switch operator setup included a switch mock-up comprising a square pedestal with a switch hook eye at the top to simulate a rotary switch. The entire operator was packed into a single, hard plastic case, including the wired hand held remote control and the communication cable. The mounting tripod was stored in a separate, sling-on bag. Unlike the previous vendors’ operators, Vendor C’s unit is powered by 8 AA batteries (12VDC), which are readily available.

The operator was first demonstrated using the Standalone Local Operation with a standard hot stick, and successfully opened and closed the switch on the pedestal mockup. The operator has LED lights on the side that correspond to the rotation of the hot stick’s motion. During the demonstration, the clockwise and counter-clockwise operation on the operator was in sync with the LED light direction of travel. This visible indication of the rotation travel is an added benefit for this device that will aid in the visibility to indicate caution to the public and to the personnel operating the unit.

To simulate field conditions, the Vendor C’s tool was evaluated at PG&E’s ATS facility to conduct testing similar to that for the previous two vendors. A rotary sectionalizing switch was placed inside the round enclosure and the tripod was placed on top. The operator unit was then locked on top of the tripod to accept a hot stick for switch operation. Initially, there was a problem with the hot stick, which turns the switch for operation. The grip to hold the hot stick was too loose to hold it in place for the entirety of the rotational operation. Improvements to the grip would need to be improved if the unit uses the PG&E standard hot stick. Additionally, the timing on the operator was less than the travel time needed to complete the switch operation, though this was solved by re-programming the hand held controller to a longer timeframe.

A PG&E underground specialist also operated the unit and timed it for operation. It took on average approximately two and a half minutes to complete either a closing or an opening of a switch to complete the operation. It was determined that nine seconds was adequate to setup the switch timer for manual standalone operation providing the operator enough time to get clear from the switch enclosure. PG&E personnel performed both manual standalone and wired operations using the hand held device several times to open and close the rotary switch inside the enclosure.

PG&E suggested having a separate power cord using the 12VDC receptacle in PG&E trucks as an alternate source in the event the operator battery becomes fully discharged. This option would require the truck to be in close proximity to the operator to accommodate the power cord, but this setup may not be possible in some situations.

Vendor C has also explored developing a wireless handheld controller using Bluetooth low energy technology that would be paired to each device, thus preventing the operation of multiple devices. They are also considering an auto lock feature which would tighten the operator's grip on the hot stick as the motor rotates. PG&E will determine if these additional features need to be added in the future for the final production model.

4.1.2 Comparison of the Vendors' Remote Switch Operator Tools

Each of the vendor's final prototypes delivered various positive features as well as opportunities for improvement. Table 1 below summarizes each vendor's offering across various attributes that PG&E is interested in for the final remote switch operator tool.

Initially, the vendors' prototypes were assessed based on their qualitative attributes, with the comments seen in the summary table below (Table 1). Following the tests at the ATS facility, the three prototype units were field tested by a small sample of PG&E field operators. The field tests were conducted in operational environments on actual enclosures with live switches. Each vendor's tool was tested by three PG&E field operators on a round enclosure type. Vendor A's remote switch operator was also tested twice on a rectangular UCD TX Switch. While all prototypes met the requirements of the specifications in the RFP, the small number of field tests indicates that on average, Vendor C's tool was superior to the Vendor A and Vendor B units across all attributes except for operation (Appendix B). In this category, the Vendor B unit performed slightly better on the round enclosure, and the Vendor A unit performed better on the rectangular enclosure. The Vendor A and Vendor B remote switch operators displayed significant challenges in packaging and weight, instructions, and setup, indicating additional improvements can still be made. Overall, the Vendor C remote switch operator performed the best in the limited field tests, followed Vendor A's unit on the rectangular enclosure, Vendor A's unit on the round enclosure, and finally Vendor B's tool on the round enclosure.

Following the field tests, the project's evaluation team translated the qualitative comments and the field test survey results into a standardized set of quantitative rankings seen in the columns to the left of each vendor by device attribute (Table 1).

Table 1: Comparison of Vendors' Prototype Switch Operators

1 = Poor 2 = Acceptable 3 = OK 4 = Very Good						
Attribute	Vendor A	Numeric Evaluation	Vendor B	Numeric Evaluation	Vendor C	Numeric Evaluation
Remote Controller	Wireless	3	Wireless	4	Wired	2
	Up to 50 foot signal range		Up to 300 foot signal range		50 feet	
Battery	Interchangeable with most hand held rechargeable power tools in truck	3	Rechargeable battery that is not interchangeable.	2	8 AA batteries	3
Ergonomics / Ease of Use	Turning thumb screws to lock tripod requires bending and kneeling	3	Installation of mounting assembly, motor operator and hot stick requires bending and kneeling	2	Easy setup with tripod, motor operator, and hot stick , which does not require much bending/kneeling	4
	Hot stick assembly requires operator to lean out over enclosure, bending, and kneeling		Motor operator can be installed without leaning out over the enclosure; however leaning will be required to position motor and install hot stick		Ability to be operated manually or remotely using remote controller	
Cost	Intermediate unit cost	2	Lowest unit cost	3	Highest unit cost	1

1 = Poor 2 = Acceptable 3 = OK 4 = Very Good						
Attribute	Vendor A	Numeric Evaluation	Vendor B	Numeric Evaluation	Vendor C	Numeric Evaluation
Motor Operator	Ability to reverse motor operation using remote controller	3	Cannot be reversed without repositioning the hot stick	2	Ability to be operated manually or remotely using remote controller. Operation can be reversed while using the remote controller	4
					Operation can be time-programmed by manufacturer at PG&E's request	
Mounting Assembly	Requires thumb screws to lock tripod in place	3	Jack bar assembly components need to be assembled to fit enclosure size prior to installation.	2	Tripod legs do not lock into place	4
	Tripod- Potential to fall into enclosure during installation and removal				Tripod-Potential to fall into enclosure during installation and removal	
			Once installed, jack bar assembly is very secure.		Tripod use makes operator more visible to surroundings	
Weight	Heaviest unit	2	Intermediate weight	3	Lightest unit	4

1 = Poor 2 = Acceptable 3 = OK 4 = Very Good

Attribute	Vendor A	Numeric Evaluation	Vendor B	Numeric Evaluation	Vendor C	Numeric Evaluation
Package Design	Packaging needs improvement	3	Packaging needs improvement (too many pieces)	2	Compact packaging	4
Motor Operator Installation	Uses tripod to mount motor operator	3	Bending and kneeling required to position motor and hot stick	2	Rubberized foot for placing tripod on concrete surface	4
	Tripod operator motor mounting base exposed to damage				Handles for locking adjustable extensions in place (don't require thumb screws to tighten)	
Motor Operator Use / Performance	Occasional motor operations lag down	2	Motor operator opening can accept most available hot sticks	3	Motor operator opening does not work well with the universal hot stick	4
Hot Stick Handling	Hot stick assembly difficult to mount	2	Hot stick needs to be pre-loaded	2	Hot stick can slip from the motor operator grip after tightening	3
Backup Power	Yes	4	Yes	4	Yes	4
Instruction Manual	Needs improvement	2	Needs improvement	2	User friendly	3
Other	Wireless hand held remote controller is used to determine clockwise / counterclockwise travel	2	Travel direction must be determined during motor operator setup.	1	LED lighting system allows switch operation travel to mimic the direction of light rotation	4

While Table 1 provides a summary of the qualitative and quantitative metrics for each attribute category by vendor, Table 2 shows the relative ranking of each vendor by attribute. The highlighted attributes (i.e., Ergonomics / Ease of Use, Package Design, and Motor Operator Use/ Performance) represent the primary drivers for a unit’s overall ranking and are composed of the average score of the attributes below them. For example, Vendor C’s score of 2.5 under Ergonomics / Ease of Use is the average of its Remote Controller and Battery scores, two and three, respectively. A unit with a perfect score (and the highest ranking) would have a Total Average Score of four.

Table 2: Performance Ranking by the Evaluation Team

Attribute	Vendor A	Vendor B	Vendor C
Ergonomics / Ease of Use	3	3	2.5
Remote Controller	3	4	2
Battery	3	2	3
Package Design	2.7	2.3	4
Motor Operator	3	2	4
Mounting Assembly	3	2	4
Weight	2	3	4
Motor Operator Use / Performance	2.6	2.2	3.6
Motor Operator Installation	3	2	4
Hot Stick Handling	2	2	3
Backup Power	4	4	4
Instruction Manual	2	2	3
Other	2	1	4
Total Average Score	2.76	2.51	3.37

Based on the scoring above, Vendor C is the best ranked overall, followed by Vendor A and Vendor B. Table 2 only includes attributes related to the actual product design and usability, but does not include a score for cost. It is important to note that Vendor C’s unit costs nearly twice that of Vendor A’s or Vendor B’s units, respectively. Taking cost into consideration, Vendor A’s and Vendor B’s remote operators become much more attractive options relative to Vendor C’s tool, since each prototype met the specification requirements.

4.2 Key Findings and Recommendations

The results from the demonstrations and testing at the ATS facility show that each vendor’s products have strengths and weaknesses. This section highlights the key findings and recommendations for future actions. The recommendations are based on the assumption that the vendor moves forward to design the final production models.

Key Findings: Overall, each vendor’s remote operator unit performed successfully once set up properly, though each requires minor modifications and improvements to the products. Vendor B’s remote operator ranked the best based on the selection criteria established in the RFP (Appendix A), followed by the Vendor C operator; however, the Vendor C tool was favored by PG&E personnel during the limited field tests. Vendor C’s unit costs almost twice as much as the Vendor B unit, so the preference does not represent an operational advantage unless Vendor C reduced its unit cost.

- **Recommendation:** Below are key recommended modifications to support the improvements of the design and use of the device:
 - Make reflective lights more visible to the operator when operating from far away.
 - Use a thick plastic casing material to balance both weight and durability of the device.
 - Add a handle and similar components to improve ergonomics and safety while operating the tool.
- **Recommendation** Provide a case for each device so the components are protected from damage and wear.
- **Recommendation:** Identify and move forward with the lowest cost modifications that provide the greatest improvements to product design and performance.
- **Recommendation:** If costs allow, move forward with both Vendor A and Vendor B to design final production models.
- **Recommendation:** Negotiate with Vendor C to provide alternative pricing that will better balance both operational and field personnel preferences for safely operating sub-surface oil filled rotary switches.

4.3 Technical Issues and Lessons Learned

The Close Proximity Switching project aimed to develop a tool to remotely operate switches that did not already exist on the market to meet all of PG&E's needs. As such, the project experienced several technical issues around the performance of the vendor designed prototype tools. The following summarizes the technological issues, the key lessons learned, and recommendations for addressing the challenges.

Description of Issue #1:

- Vendor A's remote operator required the longest setup time for the tripod mounting assembly and was the heaviest unit of the three tools tested. The setup time was later improved through additional operating instructions and Vendor A has indicated that colored markings will be added to the tripod for easier orientation during mounting.

Lessons learned:

- Develop clear and easy to follow instruction manuals and provide corresponding employee training to demonstrate proper assembly and setup of the equipment.
- Identify detailed product specifications around packing and unit weight early in the project and directly communicated through the RFP or during the product design phase once vendors are selected.

Recommendations:

- Improve the instruction manual and add diagrams so the users better understand how to properly setup the device (e.g. to first set the two legs of tripod close to the user before placing or adjusting the third leg).
- Continue to collaborate with Vendor A on ways to reduce the overall weight of the unit without having to complete an entire redesign effort.

Description of Issue #2:

- The Vendor B remote operator cannot fit on round enclosures smaller than the 42-inch diameter enclosure on the demonstration platform. PG&E's service territory contains round enclosures with 36-inch diameters, which would require modifications to Vendor B's existing offering.

Lesson learned:

- Identify the number of different enclosure sizes in PG&E's territory early in the project and communicate dimension specifications through the RFP or during the design phase once vendors are selected.

Recommendation:

- Determine the number of 36-inch diameter enclosures that are in PG&E's territory and resolve the issues on a separate basis in the future as demand necessitates.

Description of issue #3:

- Vendor C's switch operator is programmable for a range of times for the operator, some of which are too short for the user to get clear from the switch enclosure.

Lesson learned:

- The wired remote controlled operator requires a minimum lead-time for the user to get clear from the switch enclosure.

Recommendation:

- Establish a standardized lead-time range for the operator to complete the switching operation using a PG&E standard hot stick.

4.4 Value proposition

The purpose of EPIC funding is to support investments in technology demonstration and deployment projects that benefit the electricity ratepayers of PG&E, San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE). The California Public Utilities Commission (CPUC) requires that each EPIC project advance at least one mandatory guiding principle and at least one complementary guiding principle.

4.4.1 Mandatory Guiding Principles of EPIC

The mandatory guiding principle of EPIC⁸ is to invest in clean energy technologies and approaches that provide benefits to electricity ratepayers by promoting greater reliability, lower costs, and increased safety. The Close Proximity Switching project advances two of the primary principles: (1) safety and (2) reliability.

1. **Safety:** By developing a hand held remote controlled tool to open and close underground rotary oil filled switches, workers and the public can be placed a safe distance away in the event of a failure.
2. **Reliability:** The project enhances system reliability by reduced outage time should a failure result, and also creates interim solution to maintaining the distribution infrastructure while PG&E implements its multi-year program to replace the approximately 2,300 LBOR switches installed prior to 1976 that have no oil level indicator.

4.4.2 Secondary Principles of EPIC

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 Close Proximity Switching project advances one of the secondary principles: producing societal benefits. By developing a remote controlled tool, this project increases public safety, in addition to guiding principles of enhancing employee safety, during sub-surface oil-filled switch operations. This solution reduces public exposure to the safety risk of an oil switch failure, since the operator of the switches will be securing the area (i.e. coning off) around the enclosure and will have better visibility of the pedestrians when he/she is ready to execute the switching command remotely.

4.5 Technology/Knowledge Transfer Plan for Applying Results into Practice

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within PG&E and across the other IOUs and the CEC. In order to facilitate this knowledge sharing, PG&E will share the results of the Close Proximity Switching 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 plan to be presented:

⁸ *Electric Program Investment Charge 2013 Annual Report*. April 2014. California Energy Commission. <<http://www.energy.ca.gov/2014publications/CEC-500-2014-009/CEC-500-2014-009-CMF.pdf>>.

Information Sharing Forums Held

1. National Electric Energy Technology and Application Research Committee (NEETRAC)
Georgia Institute of Technology, Atlanta, GA | January 27, 2016

Information Sharing Forums Planned

2. Western Underground Committee Spring Meeting
Tempe, AZ | March 23-25, 2016

In terms of applying the project's results into practice, the project was so successful that the project team recommends purchasing remote operator units to be deployed in three territory divisions with the highest sub-surface LBOR switch asset base and ultimately integrate the units into PG&E operations. The next step will be a beta test conducted in actual switch operations, which includes acquiring the improved devices between 2016 and 2018.

4.6 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.

4.7 Overall Results

This project planned and successfully executed the development and demonstration of a technology that would allow PG&E workers to more safely operate three-phase LBOR switches. The primary goals of this EPIC project were achieved, which were to increase system reliability and to improve the safe operation of certain sub-surface or UG switches in the PG&E territory by testing the devices and comparing the attributes of difference devices from three vendors for product improvements and potential integration in PG&E's operations.

Vendor B's remote operator was the ranked the best based on the selection criteria and has the lowest cost unit. The motor operator was the second heaviest, however unlike the setups for the Vendor A and Vendor C units, the installation of the operator did not require leaning out over the enclosure. While the assembly instructions were long and complicated, when followed correctly, they resulted in the proper setup of the tool over the enclosure and a successful switch operation. The primary issue for the Vendor B remote operator was the loose clamp; however, a modified clamping mechanism has been planned for the final production model.

The Vendor C tool was the most preferred by PG&E field operations personnel; however, it was also the highest in cost. Overall, the Vendor C unit was the lightest and the easiest to operate. It also offered an additional feature over the Vendor A and Vendor B models, which was the ability to provide manual standalone operations. The operator can also be installed and removed while the user remains in a standing position; however, the installation and removal of the components required the user to lean out over the enclosure. The primary issues with the tool were the lack of gripping on the hot stick and the inability to accommodate the standard PG&E hot stick.

The Vendor A remote operator was the heaviest and experienced the most technical and usability challenges during the demonstration phase. Additionally, the packaging was bulky and larger than that of the Vendor B or Vendor C offerings. The primary issues for the Vendor A unit were the difficulties in mounting the tripod over the enclosure, with larger enclosures potentially requiring the user to kneel,

and the installation and removal of the assembly components required the user to lean out over the enclosure.

Through extensive collaboration with PG&E, each vendor designed and developed a tool that could perform successful switch operation, though each had its own strengths and weaknesses. In order to be approved by PG&E, each of the vendors will need to make moderate to significant modifications and improvements to their products.

Based on the successful results of this EPIC project, the next step will be a beta test conducted in actual switch operations, which includes acquiring the improved devices between 2016 and 2018. One or more prototypes will be incorporated into PG&E's Mission, Diablo, and San Jose division areas where large numbers of these switches exist and ultimately integrate the units into PG&E operations.

In the end, this project was successful in addressing a safety and reliability risk that is shared across the industry by developing and testing a variety of devices that eliminate the need for personnel to manually open and close rotary vault switches. As an interim solution during a multi-year switch replacement program, this outcome proactively reduces both public and employee safety risks, while also increasing reliability by ensuring the workers' ability to operate LBORs and reduce outage time should a circuit failure occur.

5 Project Metrics

The project's metrics are those highlighted in Table 1 and Table 2 that were used to evaluate the three vendors' switch operator units. Below are two additional metrics that were identified for this project in PG&E's EPIC Annual Report⁹.

5a – Outage number, frequency, and duration

Any switch without a sight glass can be deemed inoperable by the technician. This has the potential to increase the duration of an outage because the clearance time is impacted. A remote operator tool would eliminate this issue. Additionally, if an LBOR failure results in an employee injury, care for the employee would supersede the restoration of electric service. The successful development of the remote operator will minimize the potential for an employee injury and the associated extended outage that would follow.

5e – Utility worker safety improvement and hazard exposure reduction

When an LBOR is operated, the operator is standing over the switch. Due to the age of some of the switches in PG&E's territory, there is the potential for a switch failure, which can expel hot oil or gases directly onto the operator. The development of the remote operator allows the operator to be a minimum of 25 feet from the switch during operation, thus greatly improving safety and minimizing a hazard exposure.

⁹http://www.pge.com/includes/docs/pdfs/about/environment/pge/epic/EPIC_2014_Annual_Report_PGE_20150227.pdf

Appendix A: Remote Controlled Switch Operator Engineering Specifications

This document describes the functional, non-functional requirements, and key deliverables in connection with the build out of the Remote Switch Operator Tool.

1. QUALITY, WORKMANSHIP, TESTING AND WARRANTY

- 1.1 A complete set of detail conception drawings with dimensions and schematic or wiring diagrams, including bill of materials, shall be furnished to PG&E after the contract is awarded, or in advance via standardized template drawings. PG&E shall review these drawings for major concerns to ensure that the supplier has not missed any key requirements, and appropriate comments shall be sent back to supplier for updates.
- 1.2 Concurrent with PG&E's review and commenting on the conception documents, the supplier shall prepare the detail drawings for fabrication. PG&E will not review the correctness of the drawings for fabrication. It is assumed that the supplier has thoroughly checked the drawings for accuracy and ready for fabrication.
- 1.3 Design Tests: Design testing on the production unit is not required if manufacturer's design test data are available. Supplier shall be prepared to submit certified copies of the manufacturer's design test report. PG&E is establishing mock switch installation facilities where supplier may test and/or demonstrate their units' capability.
- 1.4 Factory Acceptance Test (FAT). Supplier shall perform factory or Shop testing and PG&E shall have the option of witnessing the test provided that the PG&E inspector is notified well in advance of the product tests. See Section 9 of the General Conditions, Inspection and Tests.
- 1.5 Site Acceptance Test (SAT). An onsite field test procedure shall be developed by supplier and approved by PG&E to insure that the Remote Switch Operator assembly performs as specified. See Section 9.5 of the General Conditions, Field Tests.
- 1.6 Supplier shall warrant that when the Remote Switch Operator is placed in operation or used, it will perform in the manner set forth as specified. The Remote Switch Operator assembly shall have a warranty period not to exceed two years after delivery to PG&E. The Equipment Warranty of the General Conditions, Section 14, shall apply.

2. DOCUMENT REQUIREMENTS

- 2.1 Drawings shall be produced using the computer graphics program Micro station version 8.5, or latest version. Where possible, drawings shall be furnished in electronic format on CD
- 2.2 Lines shall be uniform in sharpness and density, with good line-to-background contrast, matching the ".seed" files provided by PG&E for CAD purposes.
- 2.3 PG&E's specification number, purchase order number shall be shown on each drawing, test report, and instruction book.

3. OPERATOR

- 3.1 Operator housing, shall be fabricated for all weather outdoor use.

- 3.2 The Operator shall be nonconductive.
- 3.3 Operator shall be connected to a closed ring connector on top of the sub-surface switch handle which shall be rotated in an open and close position. See Reference Drawing 039954.
- 3.4 Operator shall be design to operate several manufactured sub-surface oil filled switch as listed on Section 15 of this specification.
- 3.5 Operator motor shall be DC powered preferably by Lithium-ion rechargeable battery. One set of spare batteries and charger shall be included per order. Option: 120VAC power source, if DC rechargeable battery is not available.
- 3.6 Operator shall have torque limiter so as not to twist a non-anchored switch or apply undue torque to the switch.
- 3.7 Operator shall not impede the closing operation of the switch once the switch mechanism has reached the point of spring assisted closing.
- 3.8 Operator shall be self-calibrating so that the Operator can be utilized on the various manufactured switches without the need for adjustments. See Section 15 of this specification for sub-surface oil rotary switch manufacturers used by PG&E system wide.
- 3.9 Indicating light. An "ON-OFF" switch shall be on the Operator. An amber LED light shall indicate that the Operator is powered on and ready to receive command from the hand held remote control device. Indicating light on the Operator shall be visible at a distance of 25 feet from personnel using the hand held remote control device.
- 3.10 The Operator shall be capable of 1000 operations before failure.

4. MOUNTING HARDWARE

- 4.1 Mounting hardware shall be designed to fit sub-surface oil filled rotary switches and enclosure as shown on Drawings 039954, 062000, 066205 & 052676 (Table A for 600A Sectionalizing Oil Switches). Sub-surface oil filled switch Manufacturers are listed in Section 15 of this specification.
- 4.2 Provisions shall be considered for mounting hardware to be installed while sub-surface rotary oil filled switch is energized.

5. HAND HELD REMOTE CONTROL DEVICE

- 5.1 Hand held control device enclosure shall be suitable for all weather outdoor use.
- 5.2 A wireless hand held remote control device shall be preferred. This will eliminate the potential transfer from Operator to the hand held device when there is a fault in the sub-surface oil filled switch. The wireless hand held control device shall be equipped with a proximity sensor that will be located in the Operator to prevent the switch from being operated when the remote control device is less than 25 feet from the Operator. This will assure that personnel operating the wireless hand held remote device is at a safe distance from the sub-surface oil filled switch. An "Auto -Off" switch at the Operator shall control the proximity switch. The "OFF" position shall disable the proximity switch function while the "Auto" position shall enable it. Optional: The hand held remote control device shall be connected to the Operator via a 25ft control cable if wireless operation is not available.

5.3 Hand held control device shall have a safety feature built in that would prevent accidental operation if the unit is dropped.

6. PAINTING

6.1 If paint is required, apply to the interior and exterior metalwork: One coat of a suitable rust-inhibiting primer, plus one or more coats of urethane or epoxy paint. Minimum total dry film thickness of paint shall be 4 mils. Supplier is encouraged to quote as an alternate their suggested low maintenance or high-grade exterior paint or finish.

7. ASSEMBLY AND SHIPMENT

7.1 Lifting the complete assembly including spare battery and charger by a single person crew shall be provided. The overall weight of the assembly shall be less than 40 lbs. No part of the assembly shall be greater than 20 lbs.

7.2 The complete Remote Switch Operator Assembly shall be securely kept in a hard case enclosure with handles and wheels for ease in transporting.

7.3 The complete assembly shall be set up and ready for operation at the work site in 10 minutes or less.

7.4 All parts of the Operator mounting hardware shall be marked for ready identification and assembly at the job site to fit most sub-surface switch enclosure. See Reference Drawing 062000, 066205, 066207 & 052676.

7.5 Each shipping unit shall be adequately packed at the factory so that no damage will occur in transit or in the process of installation.

8. GROUNDING

8.1 The Operator shall be provided with stud for grounding to sub-surface oil field switch ground bar if power to Operator is through 120VAC.

9. NAMEPLATES

9.1 Operator assembly nameplate shall show PG&E's purchase order number; and the date of manufacture.

9.2 Nameplates shall be made from Formica with letters machine engraved through black (red where specified) facing to white opaque core, in accordance with PG&E's Drawing #027818, Nameplates for General Use.

10. Switch Manufacturers

10.1 The following switch manufacturers are installed system wide in PG&E sub-surface enclosures. Suppliers must adapt their prototype tool to meet the requirements of all variables included:

1. AB Chance
2. Allis-Chalmers
3. American Electric
4. Asea Brown Boveri (ABB)
5. Acme Tool
6. Elastic Stop Nut (ESNA)
7. Electric Equipment Co.
8. Elastimoid
9. Electric Service (ESCO)

10. Gardiner/PE/FP
11. General Electric (GE)
12. G&W
13. Kearny Company
14. Kuhlman
15. McGraw Edison
16. Nelson
17. RTE
18. Square D
19. Standard
20. TC
21. Trayer
22. Wagner
23. Westinghouse

Appendix B: Summary of Results from Pilot Field Test

The below Field Test Performance rating was utilized to provide feedback and enhanced the final motor design. The survey template that was filled out can be found in Appendix C.

Table 3: Comparison of Vendor Field Test Performance

1 = Poor 2 = Acceptable 3 = OK 4 = Very Good 5 = Excellent								
Vendor	Enclosure Type	Packaging & Weight	Instructions ¹	Setup	Operation	Removal	Time ³	Overall Score ²
Vendor A	Round	3	4	4	2	4	4	4
		2	3	2	1	3	3	3
		3	4	4	4	5	4	4
Average Score		2.7	3.7	3.3	2.3	4.0	3.7	3.7
Vendor B	Round	1	1	3	5	4	3	3
		3	1	2	4	2	3	2
		2	1	3	4	4	2	3
Average Score		2.0	1.0	2.7	4.3	3.3	2.7	2.7
Vendor C	Round	5	4	4	4	4	N/A	N/A
		5	N/A	4	4	5	5	5
		4	4	5	4	5	5	4.5
Average Score		4.7	4.0	4.3	4.0	4.7	5.0	4.8
Vendor A	#7 Box UCD TX Switch	4	N/A	4	5	4	4	4
		3	3	3	4	2	N/A	N/A
Average Score		3.5	3.0	3.5	4.5	3.0	4.0	4.0

¹N/A indicates that the crew did not have time to thoroughly review the written instructions due to time constraints. Instead, a quick demonstration was provided before the evaluation.

²N/A indicates that no score or comments were provided.

Appendix C: Remote Switch Operator Pilot Survey Template

Remote Switch Operator Pilot Survey

Load Break Oil Rotary (LBOR) Style switches

Unit being evaluated:

Evaluator Name: Lan ID:

Date: Enclosure type:

Score as indicated below

1=Poor, 2=Acceptable, 3=OK, 4=Pretty good, 5=Excellent

1. Tool Package and Weight: 1 2 3 4 5 (please provide comments below)

2. Instructions: 1 2 3 4 5 (please provide comments below)

3. Setup: 1 2 3 4 5 (please provide comments below)

4. Operation: 1 2 3 4 5 (please provide comments below)

5. Removal: 1 2 3 4 5 (please provide comments below)

6. Time: 1 2 3 4 5 (please provide comments below)

7. Overall Score: 1 2 3 4 5 (please provide comments below)

Additional Comments/Impressions: (please provide comments below)

In an effort to create a safer work environment for our employees, it is important that we continually look for ways to limit their exposure to potentially hazardous situations.

Your honest feedback and participation in this pilot is greatly appreciated.

Thank you,

EAM Distribution Standards