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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial / Agricultural / Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Trenchless Burial Equipment project, one of six projects conducted by San Diego Gas & Electric This project contributes to the Strategic Energy Research program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

This project demonstrates three systems applicable to underground electric distribution systems.

- Obstruction detection technology (SafeNav™) integrated onto an existing power and control module (AccuNav®) for horizontal drilling operations.
- Digital inspection system to facilitate inspection of subsurface facilities.
- Radio-based fault indicators.

SafeNav™

Open trenching is the traditional way to replace or expand underground utility distribution systems. Underground boring techniques, designed to replace traditional trenching, are an emerging technology which will expedite construction and reduce costs. It requires only small holes at the inlet and outlet of the trench compared to open trenching. It has several advantages over open trenching:

- More environmentally friendly
- Fewer outages
- Improved safety
- Reduced construction costs
- Faster installation time
- Less disruption to consumers.

SafeNav is an underground horizontal drilling technology that detects underground metallic obstacles. When integrated with the AccuNav System, a power and control module, it alerts the driller when obstructions are located within the bore's path. This integrated system would reduce damage to existing underground utilities.

The AccuNav device was developed by the Electric Power Research Institute (EPRI) to provide information to the driller on the location of the drill tip relative to the bore path.

Objectives

- Integrate the SafeNav device with the AccuNav power and control module.
- Improve and test SafeNav, technology's potential in underground utility operations by:
  - Bench testing hardware development
  - Verifying system operations
  - Conducting preliminary bench test of modified systems
  - Completing system modifications.

Outcomes

- Integrated the SafeNav device with the AccuNav power and control module.
- Modified software based on calibration tests to successfully estimate the separation distances between detected utilities and the SafeNav sensors assembly.

- Bench tested hardware and software with positive results relative to design parameters.
- Completed a surface field test where the SafeNav system was able to detect:
  - Ferrous pipes and structures
  - Energized AC/DC power cables
  - Fiber optic cables and plastic pipes installed with tracer signals
  - Sewer and other non-metallic pipes inserted with Radio Frequency (RF) transmitters.

Conclusions

- The SafeNav device can be readily integrated with standard/conventional rigs currently used in horizontal drilling.
- The potential is high for SafeNav to detect obstructions in the drill path real-time during horizontal drilling.
- Anticipated cost savings of the SafeNav System over open trenching is estimated at $300,000 annually.

Recommendations

- Verify bench test results by demonstrating SafeNav device during field drilling operations.

Digital Imaging System

Entry to subsurface structures for inspection requires elaborate procedures to render these spaces safe. The procedures include water pumping and atmosphere purging and usually involve crews of at least three people.

A digital inspection system allows access to underground facilities through an existing opening on a manhole or handhole cover. A probe is lowered into the vault to image the surrounding walls and map the vault configuration.

Digital imaging system enables one person to perform the inspection without entering the underground structure. This results in substantial savings in labor costs and reduced exposure to hazardous conditions. The images can be digitized and analyzed at a workstation, and then integrated into the utility's Geographic Information System (GIS).

Objectives

- Integrate and demonstrate a digital imaging inspection system that would allow mapping and inspection of subsurface facilities such as electric transmission and distribution vaults. System development would:
  - Determine knockout positions inside a subsurface structure such as a manhole or handhole without opening the cover.
  - Digitize the facility for use on a desktop computer.
  - Eliminate need for traffic control and reduce the labor costs.
  - Improve the safety aspect of subsurface facility inspection.

Outcomes

- Demonstrated the advantage of examining subsurface facilities without physical entry of structures.
- Provided the basis for its application into utility operations to improve the electric system's reliability, safety and integrity.
- Field test determined system requirements for later analysis at engineering workstations.
- Required hardware was available but software needed to be developed for a prototype system.

Conclusions

- The digital imaging system proved flexible in its use. It has potential for inspecting hard-to-access facilities.
- Initial software proved to be of value in recording data needed by planners for analysis of facilities.
- Field test results were disappointing because of the orientation of the probe was uncertain and the computer screen difficult to see in daylight.
- Image of underground facilities need to be sharper.

Recommendations

- Improve software to allow orientation of the probe.
- Recommend orientation mapped according to street side and property side.
- Mark the probe to determine a physical orientation reference.
- Test different lenses to determine sharpness of images.

Radio Based Fault Indicator

Wireless radio based fault indicator (RBFI) technology allows the location of underground cable faults with a hand-held radio device. Crew personnel poll (query) the fault indicator unit with a hand held reader that displays the condition of the fault.

The radio based fault indicator units shows promising benefits in the areas of labor reduction, timesaving and improved system reliability and personnel safety by avoiding opening vaults and traffic control. Anticipated benefits include savings of nearly $350,000 annually.

Objectives

- Develop use of RBFI to remotely determine the status of underground distribution conductors and locate system faults without opening underground facilities by performing the following tasks:
  - Verify hardware development
  - Provide bench test
  - Test system operations
  - Perform preliminary field testing

– Conduct field demonstrations.

Outcomes

- Communications between the FI and the handheld polling units were established and correct programming confirmed.

The contractor successfully:

- Established hardware requirements.
- Tested and verified communication between the ERT and FS/2.
- Selected underground locations for the first 40 – 60 sites
- Designed total 120 RBFI sites.
- Forty underground locations were installed with RBFI devices and tested for six months.

Conclusions

- The concept of using a radio based device to detect conductor faults proved feasible and worked well.
- No fault was detected in the circuits in which the 40 devices were placed, but field test results indicated a potentially significant reduction in the labor required to locate a fault if one had occurred.
- After nearly six months the radio transmitting devices lost their power. Further investigation concluded that the units failed because of the installation environment.
- The radio devices were removed and we worked with the supplier to improve the housing for better protection in the installation environment. The supplier did not pursue this development because of other business priorities.

Recommendations

- Continue to identify other radio-based technology to replace the failed devices.
- Revisit supplier to promote development of a housing that would withstand the underground environment of the vaults.
- Perform more detailed cost analysis to better determine other potential economic benefits related to improved operation improvements and reduction in outage times.

Abstract

Improving system reliability and lowering costs to ratepayers is important in today's utility market. This project demonstrates three emerging technologies relevant to underground distribution applications. Obstacle detection technology (SafeNav™) for horizontal drilling operations promises to minimize damage to existing underground utilities and lower the occurrence of outages and associated safety hazards. Digital imaging systems allow the inspection of subsurface facilities by planning engineers without them actually entering the facility. And radio based fault indicator technology remotely determines the status of underground distribution conductors and locates system faults without having to open underground facilities.

Underground distribution applications promise to cut labor time, minimize environmental hazards and disruptions, and improve safety of the operations over conventional methods, thus allowing for faster service restoration. The California ratepayer would benefit from a reduction in operations and maintenance costs and the risk associated with the traditional means of installing, inspecting and troubleshooting underground facilities.

1.0 Introduction

1.1 Project Overview

Open trenching is the traditional way to replace and expand underground utility distribution systems. Open trenching literally cuts into the surface, while in comparison, underground boring techniques like SafeNav™ and AccuNav® systems leave only small holes behind. They represent a much more environmentally friendly, cost effective and labor saving technique.

1.2 Project Objectives

This project demonstrated three systems relevant to underground distribution applications:

- Obstruction detection technology (SafeNav) integrated onto an existing power and control module (AccuNav) for horizontal drilling operations.
- A digital inspection system to facilitate inspection of subsurface facilities
- Radio-based fault indicators.

1.3 Report Organization

The report is divided into three sections:

- Section 2.0 — SafeNav
- Section 3.0 — Digital Control System
- Section 4.0 — Radio-based fault indicators

Each section discusses the objectives, outcomes, conclusions, and recommendations for the applicable system.

2.0 SafeNav

2.1 Introduction

Utilities employ horizontal directional drilling equipment to install a substantial portion of their underground distribution systems. As the use of this directional drilling has increased, so has the number of utility strikes by the drill head. Strikes occur when the drilling tool hits or strikes underground structures such as water or gas mains, communication lines or other obstacles. Strikes cause damage to property and people and are costly to the consumer.

The development of sensing technology that can scan axially in front of and radially around the bore path to detect obstacles would enable the operation to be stopped or modified before a strike occurred. The SafeNav and AccuNav systems are smart boring drilling systems that minimize existing underground utility damages, outages, and safety hazards during construction.

AccuNav, an Electric Power Research Institute (EPRI) product, is a self-contained unit that electronically locates the position of the boring tool. It is equipped with a metal rod and a sensing device that is guided by a locator who controls the direction of the boring tool.

SafeNav is a subset of AccuNav that San Diego Gas & Electric developed in collaboration with EPRI. It detects underground obstructions and alerts the drill operator. It will be a self-contained unit that can be mounted on the AccuNav boring head, using existing on-board systems (power, control and communications). Figure 1 shows SafeNav mounted on the AccuNav boring head.

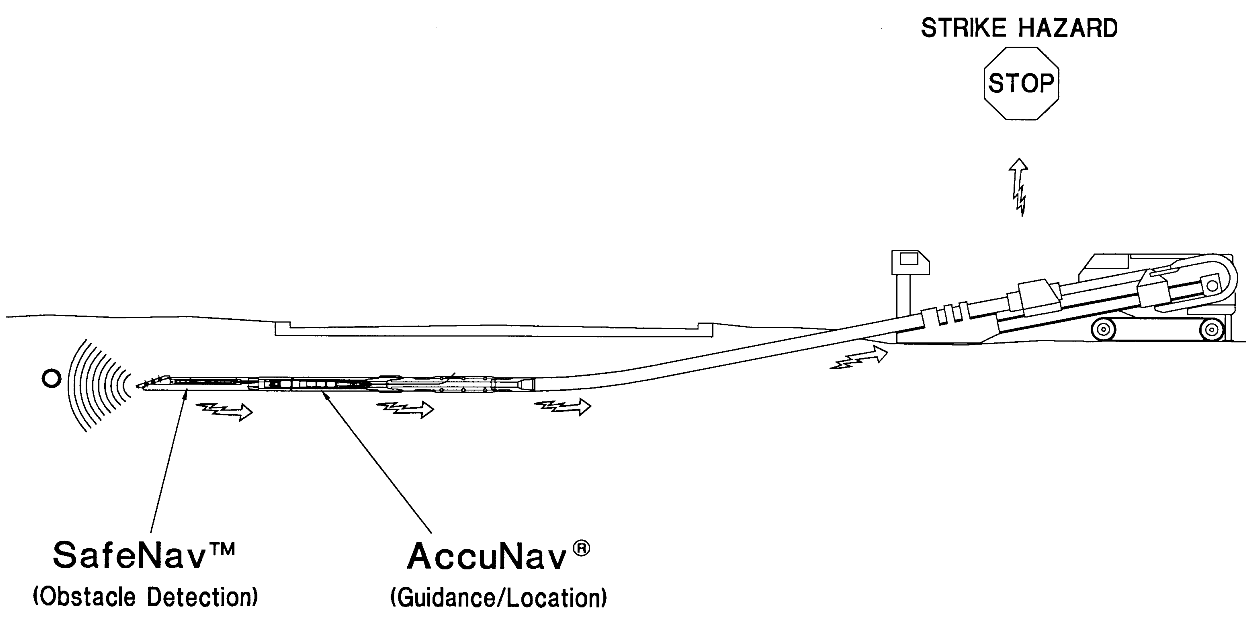

Figure 1. SafeNav Mounted on the AccuNav Boring Head

SafeNav is projected to have promise in identifying metallic and magnetic obstacles. Successful demonstration of SafeNav would provide the basis for its application in utility operations, improving the electric system's reliability, safety and integrity.

Potential benefits include:

- Improved safety
- Fewer hazardous waste spills
- Less surface disruption and restoration
- Less utility damage
- Lower costs.

2.2 SafeNav Project Objectives

This project tested and demonstrated obstruction detection technology for horizontal drilling operations. It evaluated hardware development and verified system operations. A preliminary field test to determine the system's effectiveness and to deploy modifications to the SafeNav housing before in ground testing was completed.

The objectives were to:

- Integrate the SafeNav detection device with the AccuNav drilling power and control module.
- Improve and test detection technology's potential in underground services by:
  - Providing a bench test of hardware development
  - Verifying system operations
  - Conducting preliminary bench testing
  - Completing system modifications.

2.3 SafeNav Concept Development

The preliminary research associated with SafeNav™ technology has been ongoing since early 1997, detailing the system requirements for obstacle detection. The basic hazards associated with underground construction of any kind are other buried utilities. These hazards include energized AC and DC power cables, telecommunications lines (wire and fiber optic), steel and plastic gas piping and potable water and sewer lines made from various materials including clay and concrete. To avoid striking these utilities, it is necessary to combine several different sensor technologies.

To maximize SafeNav's effectiveness, the detection sensors must be designed to search in front of and radially around the bore head. Forward looking is necessary to prevent possible strikes, while radial scanning assures sufficient area exists for back reaming (enlargement of the pilot hole through congenital pulling techniques) capabilities. In each case, the sensors must penetrate the soil at a distance that provides enough reaction time to prevent a strike from occurring.

Maurer Engineering, designed the following criteria to select SaveNav's sensor's system requirements:

- *Sensitivity and range*: How responsive is the sensor when positive recognition of an obstacle is confirmed?
- *Alarm ratio:* Is the device capable of distinguishing differences between diversions (such as background noise and environment) and true obstacles?
- *Reliability:* Does the device exhibit long-term benefits and dependability when subjected to applications?
- *Cost benefit:* Can the technology be marketed at a price, which supports commercialization, and would the anticipated savings be realized?

Phase II objective will be to facilitate development of an acoustically based obstacle detection system and assist in prototype development.

2.4 SafeNav Testing

System verification included refining the communication process between the AccuNav and SafeNav systems. SafeNav is designed to use the onboard guiding system and electronics located in the AccuNav system. SafeNav cannot act as a stand-alone unit; therefore proper communication between the two units is crucial for the success of the underground obstacle detection technology. Communications consist of processors passing data back and forth to record the location of the drilling unit.

The contractor successfully confirmed the process by:

- Verifying that all data values are being passed correctly
- Modifying the user interface with our handheld computer software.

The testing followed these procedures:

- Bench testing at VFL Energy Technologies prior to SDG&E field testing
- Completed SafeNav assembly and pressure testing
- Algorithm development and testing
- In-house field experiments performed at Maurer Engineering
- System modifications
- Second series of field testing at SDG&E

2.4.1.1 SafeNav Preliminary Field Testing

In June of 1998, a preliminary field test of the SafeNav unit was conducted at the SDG&E skills training center. The test successfully gathered empirical field data, but was not intended as a demonstration of the SafeNav system. The SafeNav components were not housed in the drilling tool, but used to verify communication and gather data needed to verify system components and its communication capabilities with the AccuNav unit.

This preliminary testing was necessary to improve the performance of the RF detection aspects of the SafeNav system.

2.4.1.2 SafeNav Assembly and Pressure Testing

We successfully retrofitted the SafeNav prototype with improved RF receiver coils.

2.4.1.3 SafeNav Algorithm Development and Testing

We wrote computer codes and algorithms that successfully estimated the separation distances between detected utilities and the SafeNav sensors assembly. The software is still in evaluation. Empirical equations needed for this data are frequently encountered in directional drilling applications and must be tested continuously.

2.4.1.4 SafeNav In-house Field Experiments Performed at Maurer Engineering

Week long testing at Maurer Engineering verified that the SafeNav system is operational. It provided data to refine the performance of the detection sensors and supporting mathematical logarithms. This initial testing also provided the requirements for the field-testing.

2.4.2 SafeNav Project Test Results

Phase II of the SafeNav project facilitated several testing producers in assisting in the demonstration of obstruction detection technology. Since December of 1997, the SafeNav prototype has undergone numerous preliminary testing both at SDG&E skills training center, located in San Diego, California, and in house testing at Maurer Engineering (Maurer), located in Houston, Texas.

Currently, SafeNav possess the sensors capable of detecting the following hazards:

- Ferrous pipes and structures
- Energized ac / dc power cables
- Fiber optic cables and plastic pipes installed with tracer signals
- Sewer and other non-metallic pipes inserted with RF transmitters.

2.4.3 SafeNav Prototype System Modifications

Maurer retrofitted the SafeNav Prototype with improved RF receiver coils based on the results of in-house field experiments. They are still working to verify that all data channels are operating properly. A high ambient offset appeared on two of the channels that hadn’t appeared there before.

Work on the SafeNav unit focused on finalizing the packaging and assembly techniques for the sensor head. During this process, Maurer found and remedied two problems that caused excessive background noise to the sensors; both were assembly and packaging related. Due to successful modifications, background noise levels are below 1000 counts. With a 16-bit system, where there are 65,535 possible counts, this is exceptionally good. In addition, Maurer finalized the format of the surface software for the SafeNav unit.

2.4.4 Second Series of SafeNav Field Testing at SDG&E

Before the scheduled field test and demonstration took place, the SafeNav microprocessor was damaged at the contractor’s facility during a bench test. This caused fluctuations in the performance of the RF tracer sensor system outputs. The SafeNav unit produced background noise levels that were not consistent and that changed unpredictably. In addition, the sensitivity of the coils (i.e. the useful range of detection) seemed to be reduced.

To correct the problem, Maurer verified that all data channels on the SafeNav unit operated properly. When the power was applied incorrectly to the entire unit, which caused the microprocessor damage, it is possible that other components could have sustained damage.

Due to monetary and scheduling constraints, we were unable to perform the in ground field testing under this contract.

2.5 SafeNav Outcomes

The following were accomplished:

- Integrated the SafeNav device with the power and control module AccuNav.
- Modified software based on calibration tests.
- Bench tested hardware and software with positive results relative to design parameters.
- Completed a surface field test where the SafeNav system was able to detect:

– Ferrous pipes and structures
– Energized AC / DC power cables
– Fiber optic cables and plastic pipes installed with tracer signals
– Sewer and other non-metallic pipes inserted with Radio Frequency transmitters.

2.6 SafeNav Economic Analysis

Initial SafeNav / AccuNav unit costs are estimated at $75,000, and are expected to decrease with increased production.

Using underground horizontal drilling technology saves an estimated $15 per foot, compared to open trenching. If we consider an average of 500 ft per drilling job, that would equate to $7,500 savings per job. However, taking ten actual typical drilling jobs performed SDG&E, demonstrates average costs saving $ 37,872 per job or over $300,000 annually by using HDD alone, adding SafeNav (obstacle detection technology) could provide an additional 25% in savings.

In taking these broad averages, a utility could conceivably pay for the capital costs of SafeNav Technology within the first year of applying SafeNav technology in horizontal drilling applications.

The potential benefits of commercialization of SafeNav justifies the high costs associated with its research costs. With the rising need for horizontal drilling, the need for detection technology increases. SafeNav offers improved safety, reduced drilling costs, faster installation time and lower labor costs, and less disruption to consumers. In addition, SafeNav offers accurately navigated boring to the drilling tool, making it an integral part of the drill rig.

The need for underground obstacle technology will continue to grow as electric, telecommunication, sewer and waterlines continue to be moved underground. As this trend toward underground lines increases, so will the use of directional drilling because of its environmental and safety benefits over traditional trenching methods. This new need for directional drilling will open the market for applied obstruction detection technology.

2.7 SafeNav Commercialization Potential

The use of guided directional drilling systems began in the early 1980's. It is estimated that the current market exceeds 5000 active rigs worldwide. These rigs support a utility directional drilling industry market of US$1 billion annually, which continues to grow at a healthy rate. Figure 2 shows the dramatic increase in the use of guided drilling systems.

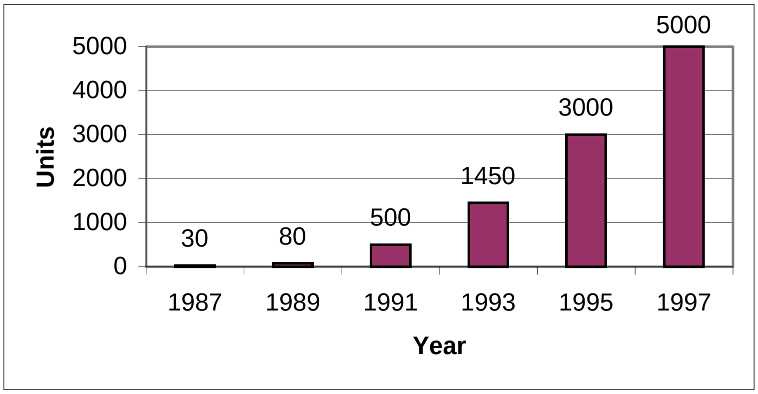

Figure 2. Approximate Number of Drilling Rig

Today the market for AccuNav to guide horizontal drilling rigs is about 40 units per year. This is expected to grow along with the growing number of employed drill rigs. The SafeNav system with its ability to detect metallic obstruction and provide drilling tool location information should increase the value of the AccuNav technology.

As SDG&E moves forward with the development and commercialization of the SafeNav system, it anticipates an increase in the sales, services and leases of the integrated AccuNav / SafeNav products to an estimated 80 units per year. Sales increases are estimated at as much as 50 to 100 percent higher than just the AccuNav system alone.

This anticipated increase is due to the additional benefits the SafeNav system offers in detecting metallic and magnetic obstructions. New requirements for trenching product disposal and zoning restrictions by cities will result in an increased demand for the SafeNav technology. It is conceivable that the market could double the first year after introduction. Currently the commercialization of the SafeNav product is targeted for early 2001.

2.8 SafeNav Benefits to California Ratepayer

SafeNav type technology, would promote more effective use of trenchless technology, lowers the risk of damage to existing technology, and provides accurately navigated boring, and better personal safety. Its benefits include:

- Fewer delays in the drilling cycle
- Faster assessment of drilling demands
- Safer working environment
- Minimize risk of accidents and litigation
- Increased production of manpower and equipment by minimizing chance of hitting unknown obstacle
- Reduction in hazardous waste removal from trenching

SDG&E proposed that SafeNav will enable guided directional drilling to be more efficient in the use of time and labor. We calculate that horizontal drilling to provide cost savings exceeding $300,000 a year over open trenching

Table 1 provides a cost breakdown.

Table 1. Cost Benefits: Open Trenching Vs. Directional Drilling

Job Type	Open Trench	Drill Job		VALUE
1GC	$ 13,636	$ 9,087		$ 4,549
1GN	$ 37,543	$ 53,602		$ (16,059)
1UG	$ 7,964	$ 8,271		$ (307)
2GC	$ 338,401	$ 229,224		$ 109,177
2GN	$ 297,366	$ 257,918		$ 39,448
2UA	$ 11,262	$ 7,411		$ 3,851
2UC	$ 12,925	$ 9,702		$ 3,223
2UN	$ 32,382	$ 17,224		$ 15,158
3GC	$ 657,423	$ 456,293		$ 201,130
3GN	$ 371,457	$ 352,900		$ 18,557
Total	$ 1,780,359	$ 1,401,632		$ 378,727

Note: SDG&E 1/1/95 - 4/30/96

Drill costs based on SDG&E drill equipment

SDG&E Process Concepts:

GC Gas Company work: all costs
GN Gas Company new business: customer billing
UA Underground conversion: underground conversion budget
UC Underground discipline company work, all SDG&E expenses
UN Underground new business: customer billing

Southern California Gas estimated costs for guided drilling which compare favorably to traditional open trenching:

- $ 30 / ft open trenching
- $ 20 / ft horizontal drilling
- $ 15 / ft directional drilling

Guided directional drilling has established fieldwork only in the last three years. It is estimated that cost savings will continue to grow with increasing advancements in the technology, and familiarity with it in the field.

2.9 SafeNav Conclusions and Recommendation

2.9.1 SafeNav Conclusions

- The SafeNav device can be readily integrated with standard / conventional rigs currently used for horizontal drilling.
- The potential is high for SafeNav to detect obstructions in the drill path on horizontal drilling real-time
- Anticipated cost savings for the SafeNav System over open trenching is estimated at $300,000 annually (Table 1).

2.9.2 SafeNav Recommendation

The SafeNav project estimates a cost savings over open trenching of $300,000 annually. The potential is high for SafeNav to detect obstructions in the drill path on horizontal drilling real-time. It can be readily integrated with standard / conventional rigs currently used for horizontal drilling. SDG&E recommends that:

- Further demonstration of this technology be completed to help realize its full potential.

3.0 Digital Imaging System

3.1 Discussion

This project demonstrated the advantage of examining subsurface facilities without physical entry of structures and provided the basis for its application to improve the electric system's reliability, safety and integrity.

Current design procedures for underground vaults require designers to meet with a field crew and access subsurface facilities to physically map the vault configuration by sketching it. This conventional process, normally used by SDG&E and other utilities, is time consuming and labor intensive.

Access and evacuation to underground utility vaults requires that a qualified maintenance crew of at least two persons open the manhole and evacuate water and any gases that may be present and present a danger to anyone accessing the vault. Gases are removed by circulating fresh air into the vault for a determined amount of time.

This may require additional disturbance of traffic diversion during the time equipment is set up and for the duration of the vault inspection. A typical evacuation and inspection process takes an average of one hour per structure and a crew of three persons including the designer and crew.

A digital imaging system (DIS) would determine the existing configuration of conduits and conductors in an underground vault or manhole. It allows the designer to map underground facilities such as electric transmission and distribution vaults in a fraction of the time using a pen-based lap top computer.

The engineer or planner could access underground facilities through an existing orifice on a manhole. A probe would be lowered into the vault to record a digital image of the surrounding walls and equipment. The digital images would be analyzed at the individual's workstation. The engineer or planner could inspect and map at least five times more facilities in the same period of time than when using today's conventional methods

3.2 DIS Project Objectives

- Develop and demonstrate a digital imaging inspection system that would allow the mapping and inspection of subsurface facilities such as electric transmission and distribution vaults which would determine knockout positions inside a subsurface structure such as a manhole or handhole without opening the cover
- digitize the facility for use on a desktop computer
- eliminate need for traffic control and reduce the labor costs
- improve the safety aspect of subsurface facility inspection

3.3 DIS Selection

VFL Energy Technologies, under contract to SDG&E, investigated the different types of available digital imaging technology to provide a system that would meet the requirement.

VFL investigated several products from the petroleum, medical, and optical industries and identified several potential systems.

The selected device, either optical or acoustical, had to be capable of capturing images in dark environments that might be totally or partially flooded with water. It had to be maneuverable and capable of fitting through manhole cover openings, which are typically less than ¾ inch in diameter. It should be able to reach the limits of underground structures, which range from 4'(w) x 6'(l) x 4'(d) to 8'(w) x 21'(l) x 10'(d).

Because of gases that might be trapped inside the vault, the device had to operate safely in potentially flammable atmospheres. The light source at the tip of the probe needed to be well below the temperature range that would ignite flammable gases in a substructure. The temperature at which these gases ignite should be considered to be the same temperature at which natural gas ignites.

The image signal from the device would be digitized and linked via fiber optics, or an equally reliable connectivity, to a monitor during the inspection process and stored in a personal laptop computer. The stored data should be available for later retrieval, display and analysis.

The imaging system had to have the capability of storing the image data in a software file along with documentation to describe the image. Software to perform this activity may need to be developed. In the case of an existing product, it might be necessary to modify the software to meet the requirements for this effort.

Devices commonly used in other industries, such as oil and gas inspection of pipes, were anticipated to be appropriate for development for our purposes.

The available technology in fiber optics were limited to the type of environment (high temperature, high moisture) the equipment could tolerate. The flexibility required to meet the specifications was limited because of the type of probe available and the location of the camera.

Following the product search, VFL developed a short list of promising devices. It discussed the progress with SDG&E to obtain feedback and for guidance of the effort in the appropriate direction.

VFL acquired several devices including a camera, fiber optic probe and a light source and incorporated them into a preliminary bench test device. This device was discussed with SDG&E to fine-tune our progress.

From this preliminary effort, VFL successfully established further requirements for a long (greater than three feet) probe. Potential safety issues with the light source were identified. Other requirements, such as the capability of storing the image data in a software file with documentation to describe the image, were also identified.

3.4 DIS Prototype Testing

The first bench testing of a digital imaging system for mapping underground facilities began in June 1998.

The bench test of possible existing equipment types and of the first alpha design equipment demonstrated that the assembled device must meet the following parameters:

- Must be maneuverable and capable of fitting through manhole covers openings.
- Should be able to reach the limits of underground structures that range from 4'(w) x 6'(l) x 4'(d), to 8'(w)x 21'(l) x 10'(d).
- Must operate safely in potentially flammable atmospheres.
- Be digitized and linked by fiber optics, or an equally reliable connectivity, to a monitoring station for the inspection process.
- Information storage for later retrieval, display and analysis in a laptop computer was desirable.

These parameters were used in hardware selection. It was found that existing hardware could be applied to the digital imaging systems package. This would be more economical, saving time and money, and permit testing the system concept before individualized manufacturing began.

The hardware package consisted of a Xenon light source unit, fiber optic light, a hand control, viewing mask, and laptop computer for informational viewing (Figure 3).

Figure 3. Digital Imaging Hardware Package

A probe (Figure 4) would be lowered into the vault to image the surrounding walls thus mapping the vault configuration. A handheld device controls the probe. The attached fiber optic cable is longer than three feet and is movable and can be guided around the vault. (Figure 5 and Figure 6)

Figure 4. Probe

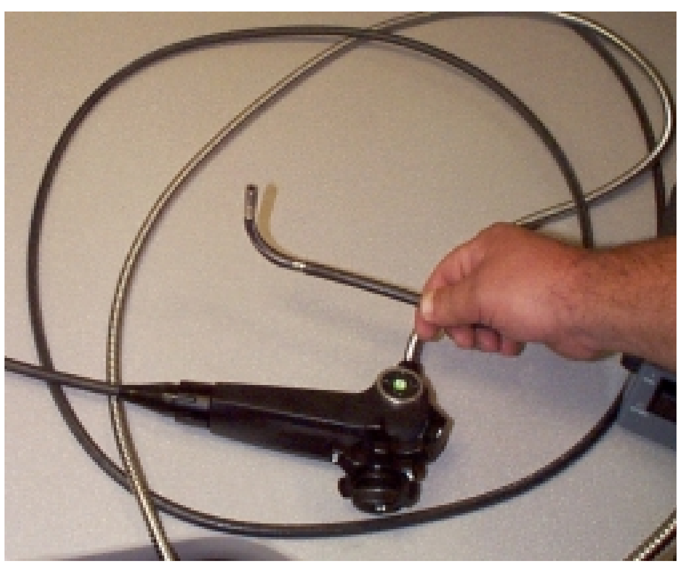

Figure 5. Fiber Optic Light Source and Hand Control

Figure 6. Fiber Optic Light Source

The planner can instantaneously view the images through the viewing mask (Figure 7). The planner decides which images to capture and digitize. These can be see upon the laptop and stored for later analysis at the planner's workstation. The images can be integrated into the utility's Geographic Information System (GIS).

Figure 7. Viewing Mask

This permits a rapid map out of the interior of structures including cables, conduits, and knockout connections to determine if additional connections and conduits can be housed within the existing structure.

3.4.1 DIS Field Demonstration

SDG&E conducted a preliminary field demonstration of the VFL digital imaging system alpha unit on February 25, 1998. The demonstration showcased the alpha unit mapping and viewing a 14-foot manhole.

3.4.1.1 Main Issues addressed in DIS demonstration

The following operational issues were identified in the demonstration, and addressed:

- Orientation
- Visual Resolution
- General digital imaging function and design
  - Controls: quickness of response
  - Keyboard functions
  - Current compass doesn't meet manhole design needs
  - Cable security at manhole entry

Orientation

Orientation is considered the biggest obstacle in the implementation of the digital imaging unit in the field. We believe that orientation be mapped according to street side and property side. This would allow the fiber optics head to rotate at a 90-degree angle to view the manhole rather than up and down which flips the views from one side to the other.

Visual Resolution

The primary concern here are the shadows and dark areas produced at the end of the manholes. Manholes are designed in 14 foot, 20 foot and 26 foot lengths. In the field demonstration, a 14-foot manhole was used. Cable knock-off, capped off, or open ends could not be seen because of the shadows at the end of the manhole.

Possible solutions included:

- Fish eye lens
- Bigger lens and light source
- Existing lens size with additional light source.

General digital imaging function and design adjustments

Hand controls that move the fiber optic eye, were developed by equipment designers to allow the operator to change keyboard frames for optimal viewing of the manhole. Display command keyboard functions (directional arrows) were also developed by software designers as a result of needs identified by field testing. Additionally, software designers developed a new compass to be seen on the laptop; rather than the common circular shape, this compass had a configuration conforming to the manhole shape of 14 feet long, 6 feet high, and 4 feet wide); this compass shape aided in viewer orientation to the manhole. Finally, the .5 inch fiber optics cable was fitted with a stopper to enable a controlled slide when inserted into the 2 inch diameter manhole, thereby providing cable security at manhole entry.

3.5 DIS Outcomes

- Demonstrated the advantage of examining subsurface facilities without physical entry of structures
- Provided the basis for its application into utility operations to improve the electric system's reliability, safety and integrity.
- Demonstration successful in determined system requirements for later analysis at engineering workstations.
- Required hardware was available but software had to be developed for a design prototype system.

3.6 DIS Economic Analyses

The project demonstrated the advantage of examining subsurface facilities without physical entry of structures. Digital imaging allows a single individual to access a subsurface vault and determine the existing configurations of conduits while retaining needed information at an engineering station. It is anticipated that utilities could realize labor savings of $125,000 annually as well as improved productivity of fault locating crews.

Additional benefits include:

- Cost reduction in operations
- Safer operating conditions
- Faster design process.

Current design procedures require the designers to meet with a crew in the field to access subsurface facilities. This process is tedious because the subsurface structure has to be evacuated (of water) and ventilated prior to the designer entering the substructure. The process takes an average of one hour per structure and a total crew of three persons, designer and fault van crew. Average crew costs of three people amounts to $ 250/hr including the crew van, and the cost of a designer is approximated $50/hr.

Digital imagining systems are designed to allow the mapping of existing configurations of conduits and conductors in underground facilities, without the need for removing the man-hole cover. This project developed and demonstrated a DIS system for mapping subsurface facilities without physical entry, which allowed the engineer/designer to digitize the facility for later analysis on a desktop computer, eliminated needs for traffic control and improved the safety aspect of subsurface facility inspection. A preliminary field demonstration conducted on the DIS alpha unit, was successful in showcasing mapping ability, software analysis, and viewing capacity of a 14-foot manhole of a DIS system. This process allowed the engineer/planner to complete the task alone and improved productivity by inspecting and mapping at least five times more facilities in the same period of time of conventional methods.

At $300 per structure, a typical utility could save an estimated $125,000 per year. The system offers potential savings of $125,000 per year in labor costs and reduced exposure to hazardous conditions. Additional savings can be expected, as city ordinances are imposing environmental standards on vault de-watering.

Utilities will also benefit from labor and cost reductions for Public Utility Commission inspections. It is estimated that the inspection process would be preformed in a fraction of the time with a pen-based lap top computer and one field person, rather than a crew of three, cutting the cost of these inspections in half.

We expect the DIS to cost about $45,000, have an average life span of 10 years and have O&M costs of $500 per year. Amortized over 10 years at a nominal interest rate, DIS cost to the utility equates to $5,200 per year. Annual savings predicted at $125,000 promises cost savings in the area of mapping underground facilities.

3.7 DIS Commercialization Potential

The current digital imaging prototype is a small collection of hardware, consisting of a laptop, penlight and visual eyeware that can be easily used by the on-site utility field team. With its simple design and labor savings exceeding $125,000 annually, the digital imaging units are expected to have a high commercialization rate to the utility industry.

3.8 DIS Benefits to California Ratepayer

The California ratepayer would benefit from the digital imaging system through anticipated labor savings of $125,000 annually as well as improved productivity of fault locating crews. Additional benefits include cost reduction in operations, safer operating conditions, and faster design process.

3.9 Digital Imaging System Conclusions and Recommendations

3.9.1 Conclusions

- The Digital Imaging system proved to be flexible in its use. It has potential for inspecting other hard-to-access facilities.
- Initial software proved to be of value in recording data needed by planners for analysis of facilities.
- Field test results were disappointing because of the orientation of the probe was uncertain and the computer screen was difficult to see in daylight.
- Image of underground facilities need to be sharper.

3.9.2 Recommendations

- Improve software to enable orientation of the probe.
- Recommended orientation mapped according to street side and property side.
- Mark the probe to determine a physical orientation reference.
- Test different lenses to determine sharpness of images.

4.0 Radio Based Fault Indicator

4.1 RBFI Program Discussion

SDG&E has implemented a Radio Based Fault Indicator (RBFI) program designed to reduce the time required to restore service after an underground cable fault has occurred. Currently, when an underground fault occurs, utilities send trouble crews to visit different subsurface switches looking for fault indication status.

The crew uses the information from the fault indicator monitors in each location to determine the direction of the fault. The crew must set up at each location, maintain traffic control, and open the switch enclosures. Each crew may have to open dozens of holes, typically taking between one and three hours. This process is labor intensive, time consuming and costly.

SDG&E designed RBFI in its underground electrical distribution system to improve outage response times. A wireless RBFI technology would allow SDG&E crews to locate underground cable faults with a hand-held radio device instead of physically opening vaults to inspect fault switches.

RBFI application was derived from the need to improve operations performance and improve safety. Adapting radio frequency technology to existing electromechanical fault indicators facilitates locating of faults in a fraction of the time, leading to faster service restoration.

4.2 RBFI Benefits

- One person operation versus a fault locating crew.
- Saves time in locating cable faults with a hand-held radio device.
- Low cost option to supervisory control and data acquisition (SCADA) fault detection devices.
- Improves system reliability and personnel safety by avoiding opening vaults and traffic control.

4.3 Fault Indication Background

Trouble crews are immediately dispatched when underground electric distribution circuits experience a sustained outage due to a cable or other underground system fault. In the absence of reports regarding explosions, fire, smoke, or other events, a divide and conquer switching scheme is usually implemented, starting with a switch at or near the circuit midpoint.

Typical fault locations take between one and three hours. During this time the repair crew is on stand-by at a cost of $250 / hour. Combined with locating crew's time at $150 / hour, the combined costs can be $400 / hour or higher.

Through a series of switch and test operations, the fault is isolated, usually within an hour and a half, to a relatively small segment. During this time, customers may experience one or more additional interruptions as a result of this testing. At least half of circuit outage time is spent in crews locating the cable fault.

Fault Indicators (FI) permanently installed on most SDG&E circuits provide a visual target that turns bright orange when the initial fault current passes through them. When inspected at the beginning of an outage, these indicators provide valuable data that significantly enhances the divide and conquer scheme.

The utility dispatches a repair crew to the closest possible fault location. The crew then systematically locates the actual fault by use of the FI, which indicates that either the cable is in a normal condition or has sustained a fault current condition. To read the FI, the crew must open up the structure (manhole, handhole, or vault), take a visual read, and then proceed to the next possible location until the faulted cable is located.

By comparison, a Radio Based Fault Indicator (RBFI) is installed in the manhole or handhole. When an outage is investigated, the crew dispatched to the probable cable fault location queries the RBFI with a hand held device (reader) capable of communication with the RBFI without removing the handhole or manhole cover.

4.4 RBFI Project Objectives

Project overall objective was to develop use of RBFI to remotely determine the status of underground distribution conductors and locate system faults without opening underground facilities.

RBFI could increase overall benefits to underground trenching procedures and projects and increase the underground distribution value two-fold by improving system restoration in case of outage and by reducing overall customer costs.

Specific Objectives included:

- verification of hardware development
- provide bench test
- test system operations
- perform preliminary field testing
- conduct field demonstrations

4.5 RBFI Technology Concept Development

The Encoder Receiver Transmitter (ERT) device connected to the RBFI can be polled by a hand held (FS/2 unit) device nearby. When polled, the RBFI responds with the status, normal or tripped.

Each ERT unit must be programmed with a unique designation so the reader knows which ERT unit it is responding to. After several in-house bench tests, successful communication between these units was established and correct programming confirmed. This programming is currently underway on an as needed basis as the ERT units are being installed in the underground locations.

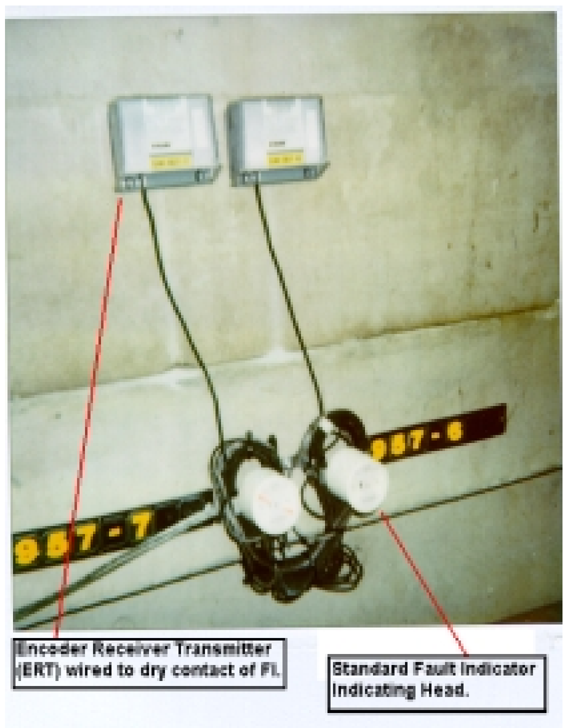

Figure 8. ERT Mounting

4.6 RBFI Operation

- Field crewmembers operate hand-held devices to read status of Fault Indicator without removing manhole cover.
- Fault indicator is connected to radio unit.
- Hand-held programmer is used to assign unique identity to each radio unit.

Figure 9. Typical RBFI Installation

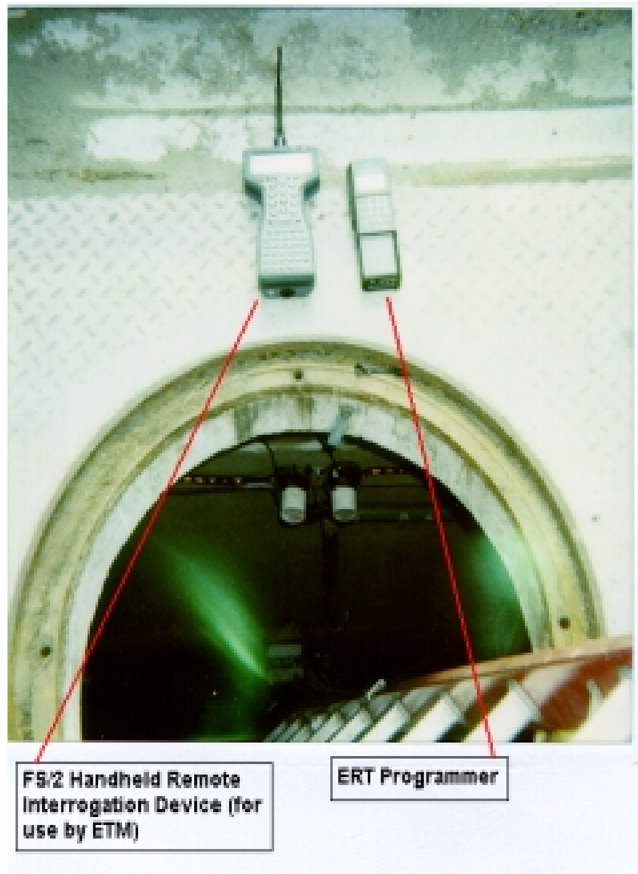

Figure 10. Handheld Remote Interrogation Device & ERT Programmer

Several manufactured equipment types were tested and hardware selected. Itron, a global provider of data acquisition and wireless communication solutions for collecting and analyzing electric, gas, and water usage data, was chosen as the sub-contractor to provide the ERT and FS/2 units.

The contractor performed bench testing of the hardware development and verification of the system communications.

4.7 RBFI Prototype Testing

Sixty locations around San Diego County were submitted for the RBFI study in June of 1998. The following criteria was used to determined the locations:

- Subsurface switches with unjacketed cables were selected as the priority.
- Location of incoming feed switch, due to environment, causes switch operations to require monitoring.
- Tie positions on switches recently required rearrangement to non-tie positions.

The installation of the first batch of 40 ERT units began and continued through July 1998.

4.7.1 RBFI Test Results

Starting installation of the second batch of ERT units in July, the field crews and engineer returned to interrogate the previously installed batch of ERT units (approximately 40). Out of 40 only 2 responded.

When the non-operational ERTs were removed, it was found that dead batteries caused the problem. The batteries were designed to have a 10 to 15 year life span.

Itron surmised that SDG&E had received a defective batch of ERT units. Itron said the original ERT units had a bad outboard pin on the main board. Another problem was due to "silver migration" --a tracking of the laser etched silver on the ceramic board-- most likely due to contamination or moisture prior to sealing.

Itron hypothesized that the two units found with the bad batteries may have been drained by a silver migration short in the board. With this new development several additional ERT units were rushed to Itron for evaluation of the problem.

Along with the warranted investigation, further installation was halted. It later prove that the ERT units are sensitive to moisture and high temperatures. This sensitivity causes the silver migration in the board. Since ERT units would be installed in manholes for this study, typically partially water filled and subject to summertime high temperatures, installation of current ERT units was discontinued.

SDG&E contacted the sub-contractor to find an alternate solution to the ERT problem. Itron is in the design stages of a water product that may do the same job as the ERT unit, but the unit is still in the experimental stages.

Both SDG&E and Itron feel that the current ERT technology is valid and can successful fulfill the requirements of the RBFI package with minor modifications, such as sealing, to the ERT unit. But Itron was not willing to provide the needed changes in the ERT unit in time to be included in this study. They were not interested in pursuing the ERT modifications because of financial constraints.

After a through investigation into an alternate solution to the environmental problems of the ERT unit, we found that no current technology is available. Itron believes that they may be able to create the needed technology, but it would a year before a preliminary design was available.

Our goal was to solve the technology failure and instrument all 120 designed sites by late third quarter of 1998 to use the tool in finding faults. This could not be completed within the timeframe specified under the contract, so further installation was abandoned.

4.8 RBFI Outcomes

SDG&E successfully:

- Established hardware,
- Tested and verified the communication between the Encoder Receiver Transmitter (ERT) and the Hand-held FS/2 programming units, confirming their correct programming
- Designed 120 RBFI sites
- Selected underground locations for the first 60 sites
- Installed 40 ERT units within forty underground locations
- Tested the RBFI devices for six months.

4.9 RBFI Economic Benefits

RBFI technology helps reduce outage duration and speed service restoration by allowing the field crews to immediately detect faults. It is estimated that using RBFI units will allow crews to locate faults 30 to 60 minutes faster than conventional methods.

Estimated costs are $165,000 per year for the pilot project, when amortized over seven years. Anticipated costs for the implementation of the1998 RBFI target are as follows:

100 circuits (6sw/circ.) ($500/sw) =	$300,000
8 hand-held radio devices ($1,800/ea) =	$14,400
Annual O&M costs per RBFI unit is $200/ea (x 600 units) =	$120,000
Total costs	$434,400

In estimating that RBFI units will locate faults 30 minutes faster, an annual labor saving is expected to be $60,000. (Labor = $400/hr (300)(.5hr)) However, the key financial impacts are realized through the reduction of outage duration resulting in SAIDI savings to the utility.

Faults are anticipated to be located and repaired 30 minutes faster. Results would be reduction of outage duration experienced by customers, and the utility will receive revenue of $ 675,000 per year in energy sales; (Energy Value = (.5 hours)(300 outages)(6MW)($750/MWh)= $675,000).[**]

[**] Anticipated savings included above were estimated taking the following assumptions:

– 300 outages per year. 3 Failure times per year of 100 subsurface circuits (based on circuit outage statistics of nearly 1000 SDG&E distribution circuits).

– Average circuit capacity is 6 MVA

– Average cost of locating and repair line crew is $400 per hour

– Typical fault location time is 3.5 hours

The cost to benefit ratio from straight revenue saved by reducing overall outages by an average of 30 minutes is estimated from benefit divided by cost equates to 1.6.

Ratio of revenue saved = 675,000 / 434,400 = 1.6

In addition, this technology would improve utility SAIFI and SAIDI that constitutive in added value.

4.10 RBFI Technology Commercialization Potential

Promising a higher dispatching efficiency during troubleshooting events, this technology could be expanded for use by the utility industry nationwide. However, since the available technology does not currently meet the design specifications a working prototype could not be evaluated for future commercialization.

4.11 RBFI Benefits to California Ratepayer

RBFI technology helps reduce outage time and speed service restoration by allowing field crews to immediately detect faults. By locating faults 30 minutes faster, RBFI would help restore service more quickly after an outage, improving electrical service to our customers. The California ratepayer could realize savings of nearly $350,000 annually by locating faults 30 minutes faster.

RBFI enables existing technology to contribute significantly to the reliability of electric distribution. Additional savings can be provided through a higher dispatching efficiency during troubleshooting events, as a reduction in the system average interruption duration index (SAIDI) by minute. SAIDI is a utility industry term used to assess system reliability by evaluating past performance data (e. g., outage data; equipment failure rates; equipment loading; circuit, and substation and transmission configurations) against industry standards.

4.12 RBFI Conclusions and Recommendations

4.12.1 Conclusions

A wireless radio based fault indicator (RBFI) technology would allow SDG&E crews to locate underground cable faults with a hand-held radio device instead of the conventional manual way by physically opening vaults to inspect fault switches. Although the field study could not be completed, the theory was proved to be technically valid. Initial installation showed promising results in the operation of a Radio Based Fault Indicator system.

- The concept of using a radio based device to detect conductor faults worked well. Additionally, SDG&E operations personnel were responsive to the integration of the new field unit and liked the application.
- No fault was detected in the circuits the 40 devices were placed, but the field test results indicated a potentially significant reduction in labor requirements to locate a fault if one had occurred.
- After nearly six months the radio transmitting devices lost their power. Further investigation concluded that all units failed because of the installation environment.
- The radio devices were removed and worked with the supplier to improve the housing for the type of installations to be used. The supplier did not pursue this development because of other business priorities.

4.12.2 Recommendations

- Pursue development of packaging of low cost RBFI system
- Investigate a fully automated system to bypass utility FI manual operations.
- Continue to identify other radio-based technology to replace the failed devices.
- Revisit with supplier to promote development of a housing that would withstand the underground environment of vaults.
- Perform more detailed cost analysis to better determine other potential economic benefits related to improved operation improvements and reduction in outage times.

5.0 Summary of Conclusions and Recommendations

5.1 Conclusions

Underground distribution applications are being employed by utilities to minimize damage to underground facilities and lower the occurrence of outages and associated safety hazards.

The three technologies tested in this project contribute to the reliability of electric distribution systems and would provide delivery cost savings to the California ratepayer. Each technology described in this report identifies labor saving devices designed to assist utilities to reduce the overall Operations and Maintenance costs, safety, and risk associated with troubleshooting underground facilities.

5.2 SafeNav

5.2.1 Conclusions

SafeNav underground obstacle detection technology is an important emerging tool in the advancement of underground horizontal guided drilling. Preliminary field testing at SDG&E demonstrated SafeNav's successful detection of hazards including: Ferrous Pipes and Structures, Energized AC / DC Power Cables, Fiber Optic Cables and Plastic Pipes Installed with Tracer Signals, Sewer and Other Non-Metallic Pipes Inserted with RF Transmitters. In addition, this project completed system modifications and packaging for SafeNav prototype. This project verified the ability of this new technology to provide California ratepayers with a reliable, safe, environmentally accepted, and cost effective way to expand and maintain underground utility services. SafeNav exhibited benefits including improved safety, reduced drilling costs, faster installation time, and less disruption to consumers. Anticipated savings of this project are estimated to exceed $300,000 annually (comparing actual horizontal drilling to open trenching costs per fiscal year).

5.2.2 Recommendations

The SafeNav project estimates a cost savings over open trenching of $300,000 annually. The potential is high for SafeNav to detect obstructions in the drill path on horizontal drilling real-time. It can be readily integrated with standard / conventional rigs currently used for horizontal drilling. SDG&E recommends that:

- Further demonstration of this technology be completed to help realize its full potential.

5.3 Digital Imaging System

5.3.1 Conclusions

The digital imaging system product integrated and demonstrated in this project would minimize the need for entry to subsurface structures for inspections and mapping. The system allows one person to perform the inspection, saving labor costs and reducing exposure to hazardous conditions. The cost to benefit ratio from straight revenue saved by reducing overall outages by an average of 30 minutes (benefit divided by cost) equates to a 1.6 advantage of implementation.

5.3.2 Recommendations

The Digital Imaging system proved to be flexible in its use and has the potential for inspecting hard-to-access facilities. Considering its cost-effectiveness, SDG&E recommends that:

- The software be improved to allow orientation of the probe, sharper images of underground facilities, and orientation mapping tools.

5.4 Radio Based Fault Indicator

5.4.1 Conclusions

RBFI technology would allow SDG&E crews to locate underground cable faults with a hand-held radio device instead of the conventional manual way by physically opening vaults to inspect fault switches. Although the test equipment failed prematurely, the theory is technically valid. With adaptation of the existing technology to endure the environmental conditions, the RBFI units may provide promising benefits in the areas of labor reduction, timesaving, and improved system reliability.

5.4.2 Recommendations

SDG&E recommends the following tasks for further RBFI study:

- Identify other radio based technology to replace the failed device.
- Develop a housing that would withstand the underground environment of the vaults.
- Perform a a more detailed cost analysis to better determine other economic benefits related to improved operationalimprovements and reduction in outage times.

6.0 Glossary

Bore path	A cylindrical hole by boring or digging away material by the drilling tool
Conduit position	Industry term for the position where conduit enters a subsurface structure
Digital Inspection System (DIS)	System which allows one engineer to access underground facilities through an existing orifice on a manhole by a probe to map the vault configuration
Mapping	Which is a physically drawn map of the interior of structures, which includes cables, conduits, and conduit connections for the purpose of finding out if additional connections and conduits can be housed within the existing structure
Encoder Receiver Transmitter (ERT)	Used to wire dry contact of Fault Indicator and communicate with the hand held Interrogation device
Fault Indicator	Permanently installed circuits, an indicator, which turns bright orange when the initial fault current passes through them. These indictors provide the crew with an indication that either the cable is in normal condition or has sustained a fault current condition
FS/2 Unit	Hand held programmer used to assign unique identity to each radio unit
Polled	A query of transmitted messages from the Fault Indicator to the Hand Held FS unit
Open trenching	The traditional way to replace and expand underground utility distribution systems through open cutting the ground surface
Radio Based Fault Indicator (RBFI)	Hand held radio device used to locate underground cable faults
SAIDI minute	Utility industry term used to assess system reliability by evaluating historic performance data (e.g., outage data; equipment failure rates; equipment loading; circuit, substation and transmission configurations) and analyzing it against industry standards
SafeNav	Obstruction detection technology for horizontal drilling operations