ELECTRIC POWER RESEARCH INSTITUTE

SF_6 Leak Location and Sealing Solutions: 2013 Update

3002000801

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Technical Update, December 2013

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Hoffman Power Consulting

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

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This report describes research sponsored by EPRI.

EPRI would like to gratefully acknowledge the contributions of the following utility personnel:

- Rod Sauls, Alabama Power Company
- Steve Lowder, Bonneville Power Administration
- Thomas Fryer, CPS Energy
- Rick Burnett, Duke Energy Corporation
- Bob Sicker, FirstEnergy Corp.
- Dale Schoening, Nebraska Public Power District
- Mark Goff, Tennessee Valley Authority
- Jim Hackett and Liisa Colby, The Colt Group

This publication is a corporate document that should be cited in the literature in the following manner:

SF_6 Leak Location and Sealing Solutions: 2013 Update. EPRI, Palo Alto, CA: 2013. 3002000801.

ABSTRACT

The goal of this technical update is to document best practices for locating and sealing common SF_6 gas leaks. The owners or operators of electric utility substations that contain SF_6 insulated equipment are the intended audience.

SF_6 leak detection and sealing is not currently mandated. However, there are several benefits of locating and sealing leaks that make such a practice beneficial. This technical update examines the primary locations for the bulk of SF_6 leaks and identifies common makes and models of devices that experience a majority of SF_6 leaks. This technical update also summarizes leak-detection and leak-sealing methodologies. There are a wide variety of leak detection methods and technologies and a more limited range of leak sealing methods, each with their own advantages and disadvantages.

This update examines the real-world experiences of seven utilities in locating and sealing SF_6 gas leaks and provides a number of recommendations for utilities in managing leak detection and leak sealing practices. Recommended next steps for research in the general area of SF_6 tracking and reporting, leak sealing and repair, and SF_6 capture are outlined. This report updates EPRI report 1024223 (2012).

Keywords

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Gas-insulated switchgear
Greenhouse gases
SF_6 detection
SF_6 leak sealing
Sulfur hexafluoride

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1
INTRODUCTION

This section summarizes the objective, approach, and organization of this technical update, as well as provides summary background on SF_6.

Objective of this Report

The objective of this technical update is to document best practices for locating and sealing common SF_6 gas leaks. While the term "best practice" is subjective, EPRI offers these recommendations to help utilities address their SF_6 leaking detection and sealing needs.

Approach

To gather the information in this technical update, the research team first conducted a literature review. To gather further information on best practices, the project team conducted first-person interviews with industry-leading utility representatives and vendors who are directly involved in SF_6 operations, leak detection, or leak sealing. The team then organized and synthesized this information into the present technical update. This report updates a 2012 report (#1024223) on this subject.

Organization of this Report

Section 1 of this technical update describes the report objective, approach, and organization, as well as important background information on SF_6 and its use in the industry. Section 2 describes the importance and benefits of leak detection and sealing. Section 3 covers some of the most common leak locations and otherwise characterizes these leaks. Section 4 covers leak detection methodologies, and section 5 covers leak sealing methodologies. Section 6 examines seven utilities' real-world experiences in locating and sealing SF_6 gas leaks. Section 7 includes conclusions and recommendations. Section 8 outlines recommended next steps, including a more engaging, interactive method of conveying information on SF_6 management to members. Section 9 includes references for more information, and Appendix A lists acronyms.

Background on SF_6

SF_6 is a non-hazardous, inert gas that is used both as an arc quenching and insulating medium in high-voltage switchgear, circuit breakers, and gas-insulated substations. SF_6-insulated equipment is predominantly used in the transmission system that manages the high voltages carried between the generating stations and customer load centers. The largest use of SF_6 occurs in high-voltage circuit breakers. Here, in addition to providing insulation, SF_6 is used to quench the arc formed when an energized circuit breaker is opened [1].

Disconnectors and ground switches primarily use SF_6 for insulation; individually, they contain only slightly less SF_6 than a circuit breaker. These devices are used to isolate portions of the transmission system where current flow has been interrupted (using a circuit breaker). Gas-insulated substations also use a significant amount of SF_6. These installations house SF_6-insulated circuit breakers, busbars, and monitoring equipment [1].

SF_6-insulated switchgear is currently used world-wide. It is estimated that an average of about 80% of high voltage equipment manufactured today contains SF_6 [2]. The most common use for SF_6, both domestically and internationally, is as an electrical insulator in high voltage equipment that transmits and distributes electricity. SF_6 is essential to the utility industry – no known substitute currently exists [1].

Like all gases, SF_6 tends to leak from containers and equipment. SF_6 is the most highly potent greenhouse gas known to-date. Over a 100-year period, SF_6 is 23,900 times more effective at trapping infrared radiation than an equivalent amount of carbon dioxide (CO_2). SF_6 is also a very stable chemical, with an atmospheric lifetime of 3,200 years. As the gas is emitted, it accumulates in the atmosphere in an essentially un-degraded state for many centuries. Thus, a relatively small amount of SF_6 can have a significant impact on global climate change [1].

Although the present share of SF_6 from the electricity industry in man-made greenhouse gas emissions is considered low, concern over the long-term impact of SF_6 on global warming is significant. SF_6 handling, use, and emissions are under increasing regulatory scrutiny. On November 9, 2010, the U.S. Environmental Protection Agency (EPA) issued a rule for the mandatory reporting of greenhouse gases (GHGs). SF_6 is one of the fluorinated greenhouse gases required to be reported under that program. (For more information, see EPRI reports #1024225 and #3002000800: Industry Practices on SF_6 Tracking and Reporting: 2013 Update.)

The EPA SF_6 tracking and reporting program does not yet require GHG emissions reduction. Instead, it informs future policy decisions and provides comprehensive and comparable GHG data to external stakeholders for a variety of purposes. Nevertheless, some utilities are adopting release abatement procedures via better SF_6 handling, as well as leak detection and sealing.

2
BENEFITS OF LEAK DETECTION AND SEALING

This section summarizes the benefits of leak detection and sealing.

Inevitably, a certain percentage of utility equipment that contains SF_6 will fail or be damaged each year. The EPA may ultimately set a limit on SF_6 emissions. For this and other reasons, a utility should aim to reduce SF_6 leaks.

Leak detection is essential to minimizing SF_6 gas releases. According to an analysis of SF_6 leaks conducted by the EPA between 1998 and 2005, an average of 7.3% of circuit breakers leaked, for a total of 3407 lbs (1545 kg) emitted [3].

Locating and sealing SF_6 gas leaks offers a range of benefits (see Figure 2-1), including improving equipment reliability and reducing the chance that a piece of equipment will fail prematurely. A deliberate and comprehensive approach to reducing leaks also plays a large part in controlling costs. Leaking equipment is costly in terms of personnel time required to continuously top-off the equipment.

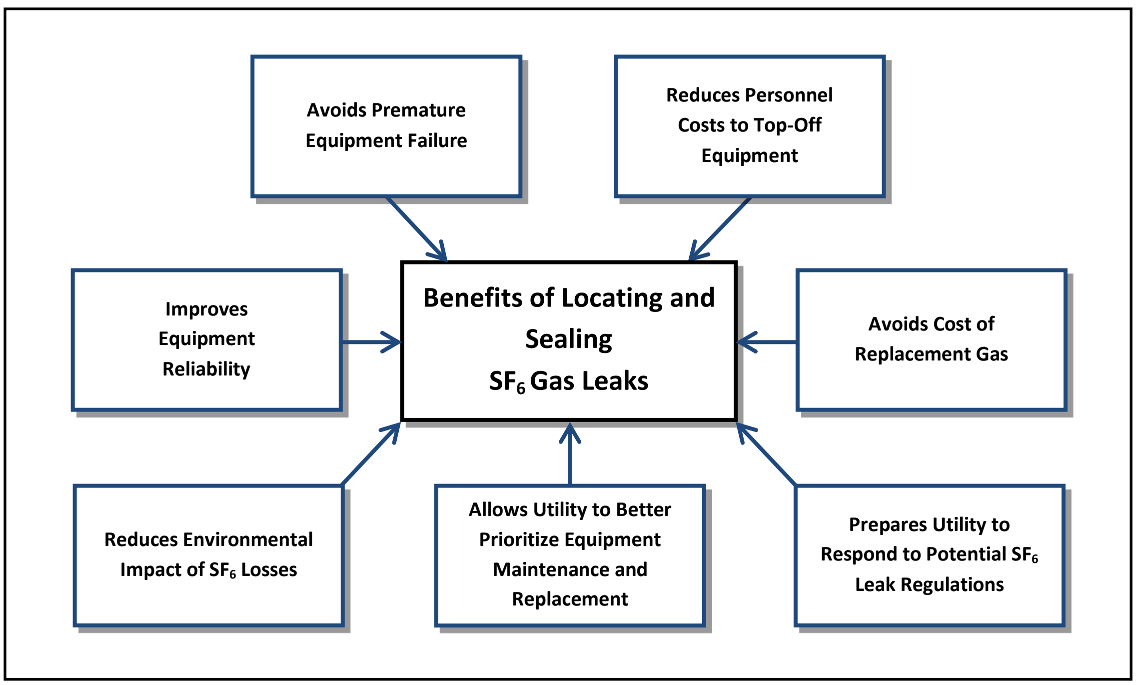

Figure 2–1
Benefits of locating and sealing SF_6 gas leaks.

Because SF_6 is odorless, a low-pressure alarm is commonly the best indication of a leak. Often, a utility worker responding to a low-pressure alarm will add gas to the breaker to clear the alarm. Some utilities recommend an enhancement to this practice. Rather than simply adding SF_6 to raise the pressure on the breaker and clear the alarm, actively investigate the source of the leak. If the source cannot be identified or a repair be made, escalate the issue so personnel dedicated to making repairs can further investigate the problem. Track such incidences and create a leaker list so common sources of leaks can be more intensively targeted for repair or replacement. Developing a “leaker list” is a good practice.

Newer equipment typically leaks much less than older equipment, making replacement an attractive option. But replacing breakers is costly, and securing an outage to change equipment is problematic.

Perhaps most importantly, locating and sealing SF_6 leaks allows utilities to address the environmental impact of SF_6 losses. A recommended best practice is to regularly assess usage and inventory data to identify equipment that may be leaking. Maintenance and replacement can then be prioritized according to the severity of leaks.

The major issues a utility faces regarding SF_6 leak detection and repair are:

- Minimizing potential environmental issues.
- Minimizing or eliminating equipment outages. The extended outages required for conventional repairs are difficult to accommodate. Leak repairs can be done in areas with limited access and require shorter outage durations. In some instances, the repairs can be made with the equipment energized.
- Resource availability. Utility resources are often limited and utilities need to maximize these resources (people, time, and money).
- Availability of replacement parts. As with any aging infrastructure, original equipment parts are often scarce, difficult to locate, expensive, or simply no longer available.
- Long delivery times. Along with the availability issue, parts that are available or need to be custom manufactured often have long lead times.

Several utilities have instituted Infrastructure Improvement Programs to focus on replacement of leaking gas-insulated switchgear (GIS). One utility’s transmission system recently acquired five in-service GIS sites manufactured between 1970 and 1972. The utility determined these substations were a significant source of SF_6 emissions. The leaks and intensive maintenance required for each site prompted the decision to replace the aging GIS with new equipment.

In 2005, the utility initiated a plan to replace the leaking installations over a period of four to six years. The GIS replacement project at one site alone enabled the company to eliminate approximately 104 personnel-hours of labor in the winter and 24 personnel-hours in the summer to maintain leaking breakers. Additionally, the company eliminated the need to purchase approximately 16 cylinders of SF_6 gas annually (about 1840 lbs/835 kg) to replace losses from the leaking equipment. Since then, approximately 12,000 lbs (5443 kg) of SF_6 have been captured, purified, and returned to inventory, while also resulting in a significant reduction in emissions [4].

Furthermore, if gas is leaking out, air and moisture can, and often does, get in. Moisture can migrate into transformers through several methods. One of the most common methods is through aged, leaking gaskets. Even though a transformer is at positive pressure, capillary action can draw moisture and air into a transformer, even when it is leaking gas in the opposite direction. Rapid pressure changes attributed to cold weather operation and sudden removal from service (transformer switched out or de-energized) can increase the rate at which water is introduced into the transformer. Wherever gas is seen leaking from a transformer, those leaks should be repaired, as they are also areas where moisture and oxygen can infiltrate the unit [5].

3
CHARACTERIZING LEAKS

This section characterizes SF_6 leaks in the electric utility industry in summary form.

Utilities interviewed for this report found the predominant number of leaks at flange seals, gas mechanisms, bushings, and gas tanks. Leaks may be due to poor installation, disturbance during planned maintenance, or failure of the sealing parts due to age. They also reported that the majority of leaks they located occurred with early generation equipment (i.e., equipment manufactured in the 1960s, 1970s, or 1980s). Domestic companies dominated early generation electrical equipment manufacturing. Therefore, the majority of leaks were found in equipment manufactured by domestic companies such as Westinghouse, ITE, and GE. These early generation breakers also require a higher quantity of SF_6 gas than breakers manufactured today and have more moving parts, providing additional opportunities for leaks. Leak sealing is often difficult on old equipment. The utilities interviewed for this report stated that such equipment is often disassembled and rebuilt or replaced in order to completely contain a leak. Table 3-1 summarizes the key findings in this area.

Table 3–1
Characterizing leaks: key findings.

Characterizing Leaks: Key Findings	
Locations	Flange seals, gas mechanisms, bushings, gas tanks
Predominant Cause	Corrosion or long-term degradation
Equipment Affected	Primarily early generation equipment
Reasons for Leakage	More moving parts, few opportunities for leak sealing
Result	Affected equipment is often disassembled and rebuilt or replaced

Several factors affect SF_6 emissions from electric power systems, such as the type and age of the SF_6 containing equipment (e.g. older circuit breakers can contain up to 2000 lbs [900 kg] of SF_6, while modern breakers usually contain less than 100 lbs [45 lg]), and the handling and maintenance procedures practiced by electric utilities [1].

Additionally, industry standards recommend that new equipment be built to low leakage limits.

The International Electrotechnical Commission (IEC) recommends allowable leakage rates of 0.5% per year [3].

4

LEAK DETECTION METHODOLOGIES

Leaks do not get better over time. To reduce SF_6 leaks, a utility must first locate them. This section summarizes two classes of leak detection methods:

- Methods that require close proximity to the leak
- Methods that enable remote detection

Methods that Require Close Proximity to the Leak

The detection of leaks from SF_6-filled equipment was traditionally restricted to the proximity of the leaking equipment. Detection involved determining the presence of a leak at the source and required actual contact with the equipment at or near the leak source. Today, additional methods of proximity detection exist. Table 4-1 summarizes the leak detection methods that require close proximity to the leak.

Table 4–1
SF_6 leak detection methods requiring close proximity to leak.

Proximity Method	Detection Method	Advantages	Disadvantages	Additional Notes
Pressure Drop, Density Alarm, or Fill Records	Utility Procedure	Most basic and common method of leak detection	Exact location of the leak must still be determined, and significant gas is lost before alarming Does not provide information about the leak rate	Primarily for indication of low gas pressure
Soap Bubbles/ Thin Films	Visual	Requires little training (no equipment is involved) Inexpensive but labor intensive High sensitivity	Leak can only be detected directly at the source Does not provide information about the leak rate	Commercially available solutions are superior to simple soap and water, but choose the correct one for the application
Handheld Leak Detectors	Overall	Do not require the operator to identify the leak source	Not always accurate Can be difficult to use	Bagging can be used to avoid wind issues and pinpoint leak location
	Thermal Conductivity	Compact Requires no external power supply	Not as sensitive Not specific to any gas – other gases can interfere	Quite effective for locating leaks

Table 4–1 (continued)
SF_6 leak detection methods requiring close proximity to leak

Proximity Method	Detection Method	Advantages	Disadvantages	Additional Notes
Handheld Leak Detectors (Continued)	Ionic Discharge	Cell design and electronics help eliminate interference from electric fields, increasing sensitivity	Console containing the power supply can weigh up to 20 lbs (9 kg)	Detects halogens
	Radioactive (Electron Capture)	Extremely sensitive	Radioisotopes strictly regulated, requiring licenses and annual testing	Based on the principle of electron capture detection
Ultrasonic Detection	Acoustic	Useful in narrowing in on leaks	Subject to interference	Uses the sound produced by small leaks for detection
Mass Spectrometer	Mass Spectrometry	Extremely specific and able to detect extremely low leak rates	Complex Expensive	Most commercially available instruments are for helium leak testing but can be customized to detect SF_6

Pressure Drop/Density Alarm/Fill Records

This is the most basic and common method of leak detection and is useful in locating equipment with the greatest SF_6 losses. Low-density alarms from density monitors installed on gas compartments are often the first indication of a leak. Prior to the increased focus on SF_6 loss prevention, pressure gauges, and density monitors were used as an indication for topping up rather than determining leak rates. Today, many utilities monitor fill records in order to calculate a leakage rate. Accurate fill records require determination of the mass of gas used for topping up the compartment. This requires the ability to weigh the cylinder on-site before and after filling. If a leak repair is warranted using this method, the utility must then pinpoint the exact location of the leak.

Soap Bubbles/Thin Films

Soap bubbles or thin film leak testing is a common method of pinpointing SF_6 leaks. The main drawback to this method is that the leak can only be detected directly at the source. This means that personnel need to gain access, which can be difficult with live equipment or inaccessible areas.

This method of leak detection is also labor intensive because only small areas can be checked at a time. However, it is easy to use, requires little training, and is inexpensive. No equipment is involved, and this method is relatively sensitive. Leak rates as low as 0.001 cc/sec (0.44 lb/ year or 0.2 kg/year) can easily be seen [6].

Commercially available solutions are superior to simple soap and water as they incorporate surfactants and other additives that help the bubbles hold their form without drying, bursting quickly, or blowing off with larger leaks. And unlike soapy water, these solutions contain corrosion inhibitors so they are less corrosive. It is important to choose the correct product, as there are different inhibitors for different applications.

Handheld Leak Detectors

Handheld leak detectors use three different methods to detect leaks: thermal conductivity detection (TCD), negative ionic discharge (NID), and electron capture detection (ECD).

Handheld leak detectors use a probe that must be located at or near the leak for detection. Therefore, these detectors have limitations similar to the soap bubble method. But unlike soap bubbles, they do not require the operator to identify the leak source. Instead, the handheld leak detector can be used to reach in to inaccessible points.

Handheld leak detectors work best in low-wind areas. The dilution of leaking gas even in the slightest breeze requires location of the probe much closer to the source [6]. Some utilities utilize a well-known technique called bagging to enhance a handheld detector's ability to locate a leak. Enclosing an area of interest in a plastic sheet and sealing the edges with tape, the probe is inserted through a small hole in the plastic and sealed with tape. By successively enclosing smaller areas, the leak can be pinpointed to a precise location. Challenges reported with the use of handheld leak detectors are that results are not always accurate and they can be difficult to use.

Handheld Thermal Conductivity Detectors (TCD)

A handheld detector that uses TCD usually consists of an electrically heated wire or thermistor, a pump, and an inlet probe to draw a sample of gas over the thermistor. The temperature of the thermistor depends on the thermal conductivity of the gas flowing around it. Changes in thermal conductivity, such as when SF_6 gas displaces some of the air, cause a temperature change in the thermistor that is sensed as a change in resistance. This change in resistance is proportional to the concentration of the SF_6 and is often displayed by a row of LEDs accompanied by a variable pitch audible alarm [6].

The response is fairly linear through the detectable range but is not as sensitive as other detectors. It is also non-specific, so other gases, which have a different thermal conductivity to air, will interfere. However, because little interference from other types of gases is encountered in substations, handheld TCD detectors can be quite effective for locating leaks. The detectors are also compact, operate on batteries, and require no external power supply [6].

Handheld Ionic Discharge Detectors

Other types of handheld detectors use negative ionic discharge or corona discharge detection. These detectors are sensitive to halogen-containing compounds (e.g., chlorine, fluorine, bromine) and are more specific than a TCD.

A sample of gas is drawn into the detector, which usually contains a partially evacuated cell in which a corona is created using high voltage. The materials used and shape of the electrodes are specifically designed for this application. Halogen containing compounds are electrophilic, meaning they have a strong affinity for electrons; when introduced into the corona, they attract electrons, causing a change in voltage of the cell and producing a signal. Cell design and electronics help eliminate interference from electric fields; the sensitivity is claimed to be less than 0.000002 lb/year (0.000001 kg/year) for ideal circumstances [6].

Many handheld ionic discharge detectors have a handgun attached to a power supply. The handgun weighs between one and two lbs (0.45–0.9 kg). The console containing the power supply can weigh up to 20 lbs (9 kg) [6].

Handheld Radioactive Detectors

Handheld radioactive detectors are based on the principle of electron capture detection. The electron capture detector contains a low energy-ray source that is used to produce electrons for capturing by appropriate atoms. The radioisotope 63Ni is generally the energy-ray source. A small potential (usually only a few volts) is applied across the cell that is just sufficient to collect all the electrons available and provide a small standing current [3].

If an electron capturing molecule such as SF_6 enters the cell, the molecule captures the electrons, and the molecules become charged. The mobility of the captured electrons is much smaller than the free electrons, and the electrode current falls dramatically. Because this detection method is extremely sensitive to SF_6, which has six fluorine (the most electronegative element) atoms, the detector can become saturated even with the smallest leaks. A factor to consider with handheld radioactive detectors is the radioisotope, because they are strictly regulated and require specific licenses from governmental agencies and annual leak tests [6].

Ultrasonic Leak Detectors

Ultrasonic leak detectors use the sound produced by small leaks for detection. While large leaks are audible, small leaks produce sound frequencies too high for the human ear.

As a gas passes from a high pressure to a low pressure, turbulence is created at the leak source that produces ultrasonic frequencies. A process called heterodyning converts this high frequency sound to a lower range that is heard through a set of headphones attached to the detector. Because the detector is focused on a particular range of ultrasonic frequencies, normal background sounds such as wind, voices, or traffic are not detected. This method is directional and can be useful in narrowing in on leaks in the absence of interference. The downside to ultrasonic leak detectors is that electrical substations can pose considerable sound interference that limits the usefulness of this technique in SF_6 leak detection.

Mass Spectrometer

Traditionally used as laboratory instruments, mass spectrometers are increasingly employed as a field instrument tuned to detect specific compounds. These instruments are extremely specific and are able to detect leak rates as low as 10^{-8} cc/sec (4.4 x 10^{-6} lb/year or 2 x 10^{-6} kg/year) [6].

The detection of compounds by mass spectrometry is accomplished by bombarding the molecule with an electron beam that has sufficient energy to fragment the molecule. Positively charged fragments are produced that are then accelerated in a vacuum through a magnetic field and are sorted on the basis of mass-to-charge ratio by varying the magnetic field. Most of the fragments created carry a single positive charge, so this mass-to-charge ratio is equivalent to the molecular weight of the fragment [6].

The downside of mass spectrometers in SF_6 leak detection is that these devices are complex and require training. They also require high vacuums and elaborate vacuum systems. Most commercially available instruments are for helium leak testing but can be customized to detect SF_6.

Remote Detection

Remote detection strategies can also be employed to locate SF_6 leaks. The most significant benefit of detecting SF_6 remotely is that leaks can be detected at a distance, and almost all components of a piece of equipment can be checked for leaks without an outage. Additionally, a wider area can be examined simultaneously, and leaks can be located in less time. The downside is that pinpointing a leak can be challenging. Potentially, both proximity and remote detection can be used together. Remote detection can identify an area of concern, while proximity detection using portable sniffers and/or soap bubbles can then be used to pinpoint the leak source.

Remote detection technologies primarily involve infrared (IR) cameras, which may employ either passive or active detection techniques. Active infrared detection utilizes a laser as the source of infrared radiation required for detection, while passive infrared detection relies on background or natural light as the source of infrared radiation. Table 4-2 summarizes remote leak detection methods.

Table 4–2
Remote SF_6 detection methods.

Remote Method	Detection Method	Advantages	Disadvantages
Active Infrared (BAGI)	Utilizes a laser as the source of infrared radiation required for detection	Can pinpoint extremely small leaks and visualize the intensity of the leak Equipment can remain in service while being tested and testing time is greatly reduced Results can be documented on video	Accurate determination of volume is not possible Must be a "reflective or backscattering surface" behind the leak Detection can be limited by weather Range is limited to 66–98 ft (20–30 m)
Passive Infrared (IR)	Relies on background or natural light as the source of infrared radiation	Equipment can remain in service while being tested Results can be documented on video	Must be a "reflective or backscattering surface" behind the leak Detection can be limited by weather

Leak Detection and Camera Technology

High-tech cameras allow for the visualization of SF_6 leak sites using video detection. The two main benefits are the ability to perform leak detection without taking equipment out of service and the dramatic reduction in time necessary to detect and locate a leak site.

FLIR is a primary producer of infrared cameras, which are able to visualize gas by utilizing the physics of fugitive gas leaks. The camera produces a full picture of the scanned area and leaks appear as smoke on the camera's viewfinder or LCD, allowing the user to see fugitive gas emissions. The image is viewed in real time and can be recorded in the camera for easy archiving.

According to FLIR, one advantage to the cameras is that systems do not have to be shut down during inspection, measurements can be carried out remotely and rapidly, and – most importantly – problems can be identified at an early stage. An inspector using an infrared camera system can complete an inspection regime of more than one hundred objects an hour [7].

The long wave gas detection camera has proved to be effective at detecting very small leaks. The pressures used in switchgear and transformers are relatively low, which results in very small leak rates. In addition, the operating temperature of the equipment is generally close to ambient. The result is a low thermal contrast between the leak and the background. Despite this, the camera is capable of detecting leaks as small as 0.55 lb (0.25 kg) per year and has had success in both indoor and outdoor substations, according to FLIR [7].

However, the cameras can be expensive. One utility purchased two thermal FLIR cameras at a cost of $100,000 per camera to facilitate the detection of SF_6 leaks on energized equipment where the use of liquid or sniffer detectors would be dangerous. The utility uses the cameras to survey the worst performing SF_6 gas breakers in their system. The camera is particularly helpful in finding leaks in energized locations such as bushings, where a shutdown is often necessary in order to examine a potential leak. The camera also helps detect minor/intermittent leaks.

Passive Infrared Technology

The properties that make SF_6 a powerful greenhouse gas are exploited in the passive infrared detection of the gas. Background radiation from the sun can be compared to blackbody radiation. The power density of this radiation when plotted against frequency yields a curve. The curve shifts to shorter wavelengths with increasing temperature and can enter the visible spectrum. This can be seen as objects, when heated hot enough, become red hot, then white hot. This is one of the factors, along with its long lifetime in the atmosphere, which makes SF_6 such a potent greenhouse gas [6].

Methods of gas detection that require close or near contact are often time consuming and run a risk of missing gas leaks. They may expose inspectors to invisible and potentially harmful chemicals, and do not allow for wind and weather factors that can produce inaccurate measurements. In addition, they can only provide information about the test points that have been previously identified and only provide readings within the immediate vicinity of the inspector.

Active Infrared Technology (BAGI)

Backscatter absorption gas imaging (BAGI) is an active remote sensing technique that uses a low power (approximately three watts) carbon dioxide laser tuned to the adsorption wavelength of SF_6 as the source of infrared radiation. The technique requires a background surface for the laser beam to reflect back towards the camera. This laser is scanned in the view field by using mirrors and the camera detects the reflected or backscattered radiation. If the backscattered radiation passes through SF_6, the light is absorbed and appears as a black cloud on the gray scale image. The technique will not work when the background is the sky as the there is no reflection of the laser radiation [6].

5
LEAK SEALING METHODOLOGIES

After SF_6 leaks are located, the leaks need to be sealed. Because outages are difficult to schedule, sealing typically is done while the equipment is energized and under pressure. This section summarizes various SF_6 leak sealing methodologies.

Utilities typically seek common characteristics in a leak sealing methodology, including:

- An effective temporary seal of the leak
- A seal that is easy to remove if needed with minimal damage to the original equipment
- A seal that can be applied while gas compartments are at full pressure and, where clearances allow, can be applied while equipment is in service
- A solution that is cost effective
- A solution that can seal even large leaks while the gas is leaking

In the past, it was common practice to take leaking equipment out of service, drain the gas, re-gasket all potential leak points, refill the unit, and hope that the problems were corrected. In some cases, a leak would recur and the whole process would have to be repeated. Today, leaks can be repaired without draining or depressurizing the equipment by means of hydraulically injecting compatible sealants to stop the leak.

There are three main types of leak sealing methodologies, including caulks and sealants, leak sealing clamps, and epoxy coating systems. Table 5-1 summarizes these leak sealing methodologies.

Table 5–1
Common SF_6 leak sealing methodologies.

Method	Advantages	Disadvantages	Additional Notes
Caulks and Sealants	Can be applied while equipment in service Low mechanical loading on GIS	Requires a two-day process	Can seal weld and seam leaks Exact source of the leak must be determined first
Leak Sealing Clamps	Fast Can be applied while equipment in service	Must be formed to fit configuration of the leaking part	Can be utilized on leaking transformers as well as leaking circuit breakers
Two-Part Epoxy Coating Systems	Short repair times and low cost compared to caulking	Epoxy ages over time and may become less effective	Must be applied in dry conditions

Caulks and Sealants

Caulks and sealants can seal weld and seam leaks. The exact source of the leak must be determined first so the caulk or sealants are applied in the correct location. Caulks and sealants can commonly be applied while equipment is in service. They are predominantly made of resin and plastic, so they place a low mechanical loading on the gas-insulated switchgear (GIS). Application of caulks and sealants normally requires a two-day process, which includes surface preparation, sealant pouring, and curing.

Leak Sealing Clamps

Clamps are another leak sealing solution. Once a leak is identified, a clamp can be bolted around a leak and injected with sealant. The clamps are most often used with a silicone-based sealant. Clamps are a fast solution that can commonly be used while equipment is in service. Clamps are specifically made to eliminate arcing and corona action. They are nonmetallic and made from composites designed specifically for electrical applications. They can be formed to fit any configuration and can be utilized on leaking transformers as well as leaking circuit breakers.

SF_6 gas 345-kV breaker bushing terminal ends are notorious for leaking where the porcelain enters the aluminum terminal end. The clamp in Figure 5-1 is made of cast nylon, and would be one style of clamp made for this repair. The clamp and cured sealant are easily removed later.

Figure 5–1
A typical cast nylon fabricated clamp used to repair a high voltage bushing leak. The two rubber seals close on either side of the leak and sealant is injected between the rubber seals.

The cast nylon clamp with rubber seals is designed to close on the outside diameter (OD) of the aluminum terminal end then drop down and close on the porcelain OD. This creates a barrier around the entire leaking area that can then be injected with sealant.

Figure 5-2 shows an aluminum hub clamp installed over an SF_6 gas leak on a 345-kV breaker bushing. The leak was located where the porcelain bushing goes through the flange. The custom-fabricated clamp has a rubber seal on the inside diameter (ID), which closes on the OD of the bushing. The clamp also has a rubber seal on the inside face. This seal is pulled up against the outside face of the existing bushing flange by using six of the existing flange bolts. This creates seals on each side of the leaking area (where the bushing goes through the flange) that encapsulate the leak. Sealant is hydraulically injected between the clamp seals for maximum penetration and compaction around the entire leaking area.

Figure 5–2
Aluminum hub clamp installed over an SF_6 gas leak on a 345-kVb breaker bushing.

Two-Part Epoxy Coating Systems

Specially-formulated epoxy coatings are another option for sealing SF_6 leaks. A significant benefit to epoxy coatings is that repair times and costs can be lower than with the caulking method. This solution must be applied in dry conditions. A disadvantage is that epoxy mechanical integrity degrades as the epoxy ages over time and may become less effective.

6

UTILITY CASE STUDY EXAMPLES: EXPERIENCES IN SF_6 DETECTION AND SEALING

The following section describes the experiences of seven utilities in locating and sealing SF_6 leaks and examines practices they have employed to manage such processes.

Utility Case Study One: More Consistent Solutions

Over ten years ago, an electric transmission and distribution utility began utilizing outside specialists to seal gas leaks in their transformers and circuit breakers. Previous attempts using epoxy had yielded less than acceptable results. Use of a special epoxy mixture was attempted to seal leaks at seams, pinholes, cracks, and pipe connections. This option was easy to perform and inexpensive; however, the results were inconsistent. With proper preparation, the epoxy repairs were effective only about 50% of the time. In addition, removal of the epoxy for re-gasketing or replacement was extremely labor intensive. Figures 6-1 and 6-2 show two examples of in-house repairs.

Figure 6–1
In-house repair utilizing epoxy.

Figure 6–2
In-house repair utilizing epoxy.

The utility's equipment was aging, and the engineers at the utility were interested in finding a better solution. The utility began working with an outside contractor on a leaking circuit breaker they knew they were soon removing from service. They decided to test out a different leak repair technique as a temporary fix until they changed the unit out. They were very pleased with the results and began using the approach elsewhere and soon realized that the time savings was substantial.

The utility has now worked with the outside contractor for seven years in a proactive leak repair program. What began as an intensive series of repairs at multiple sites matured into a more limited but ongoing inspection and maintenance routine. Some of the repairs have serendipitously become long-term solutions, while other repairs were short-term fixes until the utility could properly schedule and complete permanent repairs. Although the repairs are guaranteed for two years, many are still in place and working effectively many years later.

The SF_6 leak repair methodology involves a custom-fabricated clamp or enclosure. This creates a barrier around the leaking component; injecting the cavity of that piece of hardware obtains a seal. This special hardware allows the sealant to be injected under pressure to successfully seal the leaks.

In Figure 6-3, an enclosure of nylon composite was fabricated to seal a leak at the top of a bushing. Two outages were required – on the morning of Day One, a 1-hour outage was needed for the leak seal technician to obtain precise measurements for the enclosure. The device was fabricated and overnighted to the client. A second outage of 4–6 hours was then taken to install the enclosure. Sealant is injected into a channel inside the clamp to seal the leak. The clamp remains in place and can be easily removed when needed.

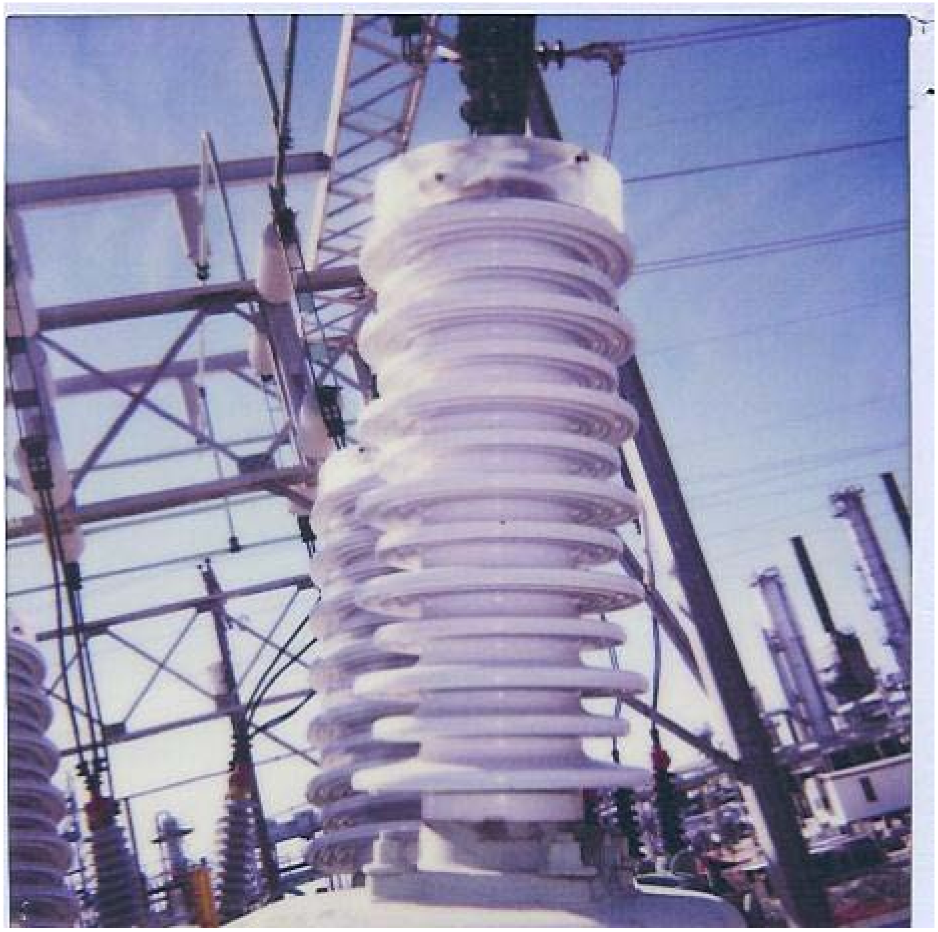

Figure 6–3
An enclosure of nylon composite was fabricated to seal a leak at the top of a bushing.

The sealant used is not an epoxy. Specially formulated for use with high voltage electrical apparatus, the sealant is flexible and easily removed. It maintains a “memory” that allows for expansion and contraction as needed due to temperature changes and vibration. The substance has excellent dielectric properties as documented by test results from an independent laboratory. Figures 6-4 to 6-7 show another example from the utility.

Figure 6–4
Leak is identified.

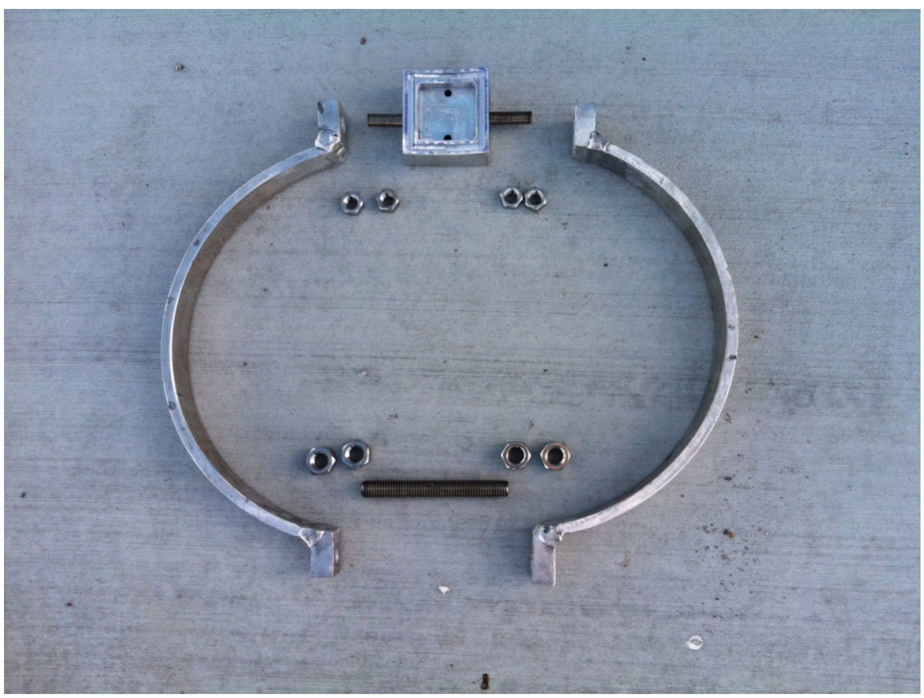

Figure 6–5
Clamp is manufactured.

Figure 6–6
Clamp is installed over the leak with injectors to facilitate sealant injection.

Figure 6–7
Injectors are removed and pipe plugs are installed.

The utility has found sealants and clamps to be viable leak repair solutions due to the following criterion:

- A minimal outage is required
- Leaks can often be repaired within one hour
- No need to drain gas
- Reduced labor needs
- Generally, only a single "safety observer" is required
- Personnel are available to work on capital projects
- Replacement parts are not required
- Immediate cost savings
- Work can be scheduled almost immediately [5]

Utility Case Study Two: Lower-Cost Solutions

A large utility had completed a number of successful gas leak repairs working with an outside contractor. A significant SF_6 leak was identified in a breaker at a substation. The first option was to re-gasket the breaker, but the time required to remove the breaker from service was an issue, as it would have required five days of down time, loss of transmission, and $20,000 due to the placement of the breaker. Instead, the utility determined the optimal solution was to repair the breaker by installing a custom clamp and injecting sealant (see Figures 6-8 to 6-10). This approach resulted in just one day of downtime and approximately $21,000 to fix all of the leaking components.

Figure 6–8
Precise measurements are taken prior to designing the clamp.

Figure 6–9
The clamp is designed and manufactured.

Figure 6–10
The clamp is installed over the leak.

Utility Case Study Three: Cameras and Equipment Refurbishment

One utility that EPRI interviewed found the majority of SF_6 leaks in older, two-pressure Westinghouse breakers. Most leaks occurred at the base of columns, in bushings, and in plumbing. The utility employs SF_6 cameras as its main leak detection methodology. The utility favors cameras for leak detection because equipment does not have to be de-energized in order to locate leaks. However, because they only have one camera per geographic region, technicians also use handheld SF_6 detectors and soap bubbles for proximity detection of leaks.

The utility reports that it has tried many methods of leak sealing, with mixed results depending on the situation. Some sealing solutions have been successful, while others provided only temporary fixes and the equipment was eventually found to leak again.

The utility's philosophy is that refurbishing breakers is the only viable long-term solution. All other solutions are viewed as short-term. In the case of Westinghouse equipment, they install new bushings, which successfully eliminates most leaks.

The utility praised breaker manufacturers that take time to seal and properly prepare surfaces during the manufacturing process, stating that taking extra precautions to reinforce common leak locations from the beginning can save utilities significant time and expense later.

Utility Case Study Four: Breakers with Porous Tanks

Another utility found most leaks in fittings for plumbing, at the bottom of flanges, and bushings. Leaks typically occur in equipment made from 1990 through 1997. After 1997, the utility reports that one of the main manufacturers it procures equipment from began placing silicon outside the O ring of new equipment, which helped reduce leaks.

The utility also struggled with leaks from breakers with porous tanks when a particular manufacturer provided poorly constructed castings. The manufacturer eventually replaced most of the tanks. In another instance, a breaker with a porous tank was overlooked. After a leak appeared and the source was narrowed down to the tank, the manufacturer came to the facility, located the leak, used a grinder to smooth out the tank, and applied a sealant. The solution has proven successful thus far.

The utility employs a commercial liquid leak detector and soap bubbles as their primary method of leak detection. They also contract with a company that utilizes laser leak detectors. The company visits the utility once or twice a year to visit all the stations and pinpoint leaks.

If leaks occur in fittings or gaskets, the utility tightens or replaces fittings or changes bushings. To date, the utility has not explored other methods of leak sealing.

Utility Case Study Five: Primarily New Equipment

Another utility found the majority of leaks at bushings, flange connections to bushings, and at the top and the base of breakers. They have also witnessed a number of leaks in the piping or manifold system from the tank frame into the control panel. The utility is currently involved in a three-year replacement program so that much of its equipment inventory is new.

The utility primarily uses soap bubbles for proximity leak detection. SF_6 cameras are desired, but because the utility resides in a state with consistently high winds, the cameras are not a viable solution. Primarily, the utility changes bushings or replaces fittings to mitigate leaks. Beyond that, they have not adopted a particular leak sealing methodology. Because the majority of their breakers are new, the utility has experienced few leaks thus far.

Utility Case Study Six: Cameras Recommended

Another utility experienced leaks from porcelain bushing flanges, tubing, and porous castings or O rings. The utility primarily uses soap bubbles or sniffers to detect leaks, although they purchased an SF_6 camera within the last four years. The camera has been helpful in finding small leaks while equipment is in service. The utility reports that the primary benefits of the camera are that leaks are easy to see, find, and repair.

When the utility identifies a corrosive flange issue, their most common repair approach is to disassemble the breaker and repair or replace all 12 bushings, assuming that if one bushing is failing, the rest will eventually fail as well. They then install new O rings and seal the interior with grout to prevent moisture penetration. For porous castings, they simply replace the equipment. They have tried several methods to repair porous castings in the past but none worked satisfactorily.

The utility highly recommended SF_6 cameras due to ease of use and the ability to locate leaks effortlessly in the right conditions (no wind). The cameras also allow documentation so that repair crews can easily find and repair leaks.

Utility Case Study Seven: Prevention

Another utility is reducing its SF_6 gas emissions through two key programs:

- A preventive maintenance program, which targets equipment repair
- An infrastructure improvement program, which addresses equipment replacement

The utility has an ongoing circuit breaker replacement project that began in 2003. The utility tracks the frequency of maintenance of its gas breakers to help prioritize which ones should be replaced. In making the decision to replace equipment, maintenance costs and performance records of leaking breakers are reviewed and compared to the costs to replace the breakers. The utility also considers other benefits associated with new breakers, such as greater equipment reliability and environmental benefits.

Tracking the costs associated with repair operations including replacement gas and labor, as well as the costs associated with installing new equipment, together with the environmental aspect of emissions, facilitates decision-making at the utility. Leaks are first identified using the low-gas density alarm included with the circuit breaker. The utility's field personnel respond to the alarm and attempt to locate the leaks using commercially available and inexpensive electronic leak detectors. A work request is subsequently issued to personnel to either locate the leak source (if not discovered) or repair it, thus avoiding future refill visits and associated costs. The utility pays particular attention to the potential for gas leaks from new equipment installed since 2003, for which leaks should be minimal.

Various types of repairs are then made, including installing bolted-on clamp/seal rings around leaking gas breaker bushings, repairing gas breaker tube fittings, replacing seals at interrupter flanges, etc. There is constant communication between the asset management team and the equipment operators regarding problem breakers and leak identification and repair efforts. In addition, prior to any scheduled preventive maintenance breaker inspection, the history is carefully reviewed so that any issue related to possible gas leaks is identified. This allows the inspection team to plan accordingly so as to identify the area of the leak and conduct any necessary repairs while the unit is out of service.

Since beginning the circuit breaker replacement project, the utility has replaced or decommissioned 81 leaking circuit breakers. With the new circuit breakers installed, the manufacturer conducts periodic checks to verify that gas system pressure, quality, and moisture are normal. In the event of a low-pressure alarm signal, the manufacturer investigates any evidence of leaks under warranty. As a result of these replacement efforts, the utility reduced its SF_6 gas emissions [4].

7 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes report conclusions and recommendations.

Conclusions

Even though leak detection and sealing is not currently mandated, several benefits of locating and sealing leaks make such a practice recommended. These include improving equipment reliability and reducing the chance that a piece of equipment will fail prematurely. A deliberate and comprehensive approach to reducing leaks also plays a large part in controlling costs. Leaking equipment is costly in terms of personnel time required to continuously top-off the equipment. A full set of these benefits is summarized in Figure 2-1.

- Most leaks occur at flange seals, gas mechanisms, bushings, and gas tanks, and are caused by corrosion or long-term degradation.
- Most leaks occur in older equipment, and newer equipment is typically constructed in compliance with recommended low leak rates.
- A wide variety of leak detection methods and technologies exist, and a more limited range of leak sealing methods exist – each with their advantages and disadvantages.
- Clamps are a fast solution that can commonly be used while equipment is in service.

Recommendations

- A preventive maintenance program, which targets equipment repair, is recommended.
- An infrastructure improvement program, which addresses equipment replacement, is recommended.
- Tracking the costs associated with repair operations including replacement gas and labor, as well as the costs associated with installing new equipment, together with the environmental aspect of emissions, can facilitate decision-making.
- Use of soap bubbles/thin films for leak detection was cited in four utility case studies.
- Based on a limited sampling of utilities, infrared cameras seem to be a popular choice for leak detection, despite their limitations due to wind and range.
- Once leaks are detected, equipment replacement is often an option considered, especially if the equipment is nearing the end of its useful life.
- Leak sealing methods exist and were successfully employed at several utilities.
- Potentially, both proximity and remote detection can be used together. Remote detection can identify an area of concern, while proximity detection using portable sniffers and/or soap bubbles can then be used to pinpoint the leak source.

8
NEXT STEPS

This section summarizes recommended next steps.

- **SF_6 Capture.** Replacement of equipment that leaks SF_6 in substations may not be possible due to the need to maintain the substation online. While some SF_6 leaks can be effectively sealed during operation, others cannot. Methods of capturing leaking SF_6 are needed until equipment repair or replacement is possible. Several methods of SF_6 capture have been tested, with a range of results. In collaboration with utilities, EPRI has conducted analysis and testing of various methods of SF_6 capture and is conducting additional research in this area in 2014. Providing the industry a detailed best practices guide on leak capture would complement the work described above.
- **SF_6 Management White Paper.** SF_6 leak tracking and reporting, leak detection and repair, and leak capture are all inter-related areas. Together, these areas could be termed "SF_6 management." Consolidating the highlights of best practices in these three areas in a holistic way into a single concise document, such as a white paper, would help utilities seeking to enhance their SF_6 management programs. This document would integrate best practices from EPRI and industry research in the last three years. This document would be targeted at utilities that are not far along in their SF_6 management programs, but that are seeking recommended first steps.

9
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BAGI	Backscatter Absorption Gas Imaging
CO_2	Carbon Dioxide
ECD	Electron Capture Detection
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GHG	Greenhouse Gases
GIS	Gas-Insulated Substations
ID	Inside Diameter
IEC	International Electrotechnical Commission
IR	Infrared
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
NID	Negative Ionic Discharge
OD	Outside Diameter
SF_6	Sulfur Hexafluoride
TCD	Thermal Conductivity Detection

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