EPRI's SF_6 Management Program

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Introduction

Sulfur hexafluoride (SF_6) gas is widely used in circuit breakers and gas-insulated substations, but its use presents safety and environmental challenges when maintenance is needed. Utilities using SF_6 gas have a variety of needs, including best practices for handling SF_6, new tools for detecting and mitigating leaks, and information on assessing gas purity.

In recent years, EPRI has conducted research and developed tools to meet these needs. The tools will assist utilities in adopting handling procedures that are safe, economical, and environmentally sound; detecting leaks cost-effectively and reducing the cost of replacement gas; and evaluating gas quality.

Background

SF_6 gas has a number of qualities that make it useful as a dielectric medium for electric utility applications. It has a high dielectric strength, is not corrosive to metals at ambient temperatures, and is chemically and thermally stable, nontoxic, and nonflammable.

Utility applications of SF_6 began in the United States in the 1950s. Since that time, the gas has progressed to be the main dielectric and insulator for circuit breakers, disconnect switches, gas-insulated busbars, and distribution equipment. Several million SF_6-filled units are estimated to be currently in service. Annual SF_6 production is approximately 8 million kg.

Although pure SF_6 is chemically inert and safe to handle, many of its decomposition products are corrosive and toxic. Their accumulation in SF_6 equipment raises concerns about equipment reliability and personnel safety during maintenance procedures and cleanup of faulted equipment.

SF_6 also has properties that may impact the environment. The Kyoto Accord identified it as a greenhouse gas whose emissions should be reduced to combat global warming. As a result, many governments have set policies to reduce SF_6 emissions, and the U.S. government has instituted a plan to encourage emissions reduction on a voluntary participation basis.

Beyond these environmental concerns, added attention has been focused on SF_6 gas during the last few years because its price has increased substantially. In addition, the environmental and economic aspects of SF_6 may converge in the future if regulatory measures provide credits for actions to reduce greenhouse gas emissions in advance of mandated reductions.

Because it is unlikely that a replacement gas could be found that would match SF_6 gas' insulation and interruption capabilities without also presenting environmental or other concerns, it is important for utilities to improve their current maintenance practices and minimize gas leaks.

Handling Practices

Given the challenges involved in using SF_6, a key need for utilities is a summary of the best procedures and policies related to the handling of the gas. To meet this need, EPRI approached utilities that were already active in formulating their own guides and procedures. These utilities generously shared material and provided cooperative assistance. EPRI combined and edited these guides and procedures, selecting the most broadly applicable information from each. EPRI also sought the advice of experts from utilities, laboratories, and manufacturers. In addition, information from three national conferences organized by EPRI on SF_6 handling practices was compiled and added.

Figure 1. *Peter Ng, Bjorn Holm and Pat Gillam of BC Hydro, seen here beside a gas cart, were some of the important contributors to the EPRI handling practices guide.*

The resulting guide suggests procedures and policies related to the handling of SF_6 gas. The document does not constitute a standard, but is intended for use as a reference for formulating customized utility-specific policies that will improve SF_6 handling practices. The contents should be used in conjunction with manufacturers' recommendations, and where applicable, with national, state or provincial, and local regulations.

The guide applies to electrical equipment employing SF_6 gas and mixtures of SF_6 with N_2 or CF_4 gas as an insulating and/or interrupting medium. It defines handling procedures that include SF_6 gas filling of equipment and the storage or disposal of clean or contaminated gas under normal and abnormal conditions. It also outlines requirements for safe working conditions and describes the degrees of protection to be provided for personnel and the environment.

The guide specifically addresses the following six areas. Sample results are described below for each of the areas.

- **Equipment Classifications.** The type of SF_6 equipment and its operating environment determine the level of risks, handling procedures, and protection to be taken. Equipment types may be either switching, such as circuit breakers, or nonswitching, such as gas-insulated transmission lines or bus ducts.

- **Risks, Warning Signs, and Written Instructions.** Risks of handling SF_6 gas may be categorized as low, medium, or high. A low-risk situation would include working around new or existing equipment that has been problem free. In these cases, harmful SF_6 breakdown products are not expected to be present. Safe working practices include working only in well-ventilated areas, refraining from smoking in designated areas, and controlling arc welding. An intermediate risk situation would include routine maintenance when a switching device is opened for inspection. In these cases, by-products of SF_6 gas may pose hazards. Safe working practices include wearing protective clothing. A high-risk situation would include cleanup after an arcing fault. In these events, decomposition products that are highly toxic may be released, and work areas should be evacuated if the SF_6 alarm is activated.

  Warning signs should be posted at strategic locations and should carry emergency instructions, identify vital controls and equipment locations, and display evacuation maps and plans. Written instructions should be developed for abnormal operating conditions, including response to gas pressure and density alarms, response to detection of SF_6 and decomposition products, and re-entry following an evacuation order.

- **Handling Procedures.** Normal, safe handling procedures include not dropping or rolling cylinders, not applying heat, not storing in sunlight, and not allowing cylinder temperature to exceed 50°C. Procedures for commissioning of equipment include use of a gas cart that meets performance factors and is equipped with a storage vessel, compressor, vacuum pump, and filtering system. Safety procedures must be followed for filling or topping up cylinders with SF_6. Normal equipment maintenance practices include periodic measurement of pressure, moisture content, and leakage. Test procedures and recommendations have been developed for these measurements and for detection of SF_6 decomposition products. Equipment failures include ruptures of pressure relief devices and burn-through of the enclosure. Following an equipment failure, procedures should be followed for cleanup of indoor or outdoor areas.

- **Personal Protective Equipment.** Workers exposed to gaseous and/or solid SF_6 decomposition products should wear clothing and devices for protection from these contaminants. Protective clothing should be worn by all personnel removing or handling solid SF_6 by-products, entering a building where a fault has occurred, and working with solvent cleaning. Clothing includes overalls, footwear, rubber gloves, and goggles. Respiratory devices include dust masks, cartridge filter masks, supplied air respirators, and self-contained breathing apparatuses (SCBA). SCBA should only be worn by personnel trained in their use and only for special emergency conditions, including during fire fighting, and for entrance to an indoor substation in which a major burn-through has just occurred.

- **Disposal and Environmental Protection.** Clean SF_6 gas has a minor impact on the environment. However, federal and state regulations on release limits must be observed, and routine equipment leakage should be kept as low as possible. Contaminated SF_6 gas should not be released to the atmosphere. If contamination occurred during normal operation of equipment, the SF_6 can be reclaimed through normal recycling. If the contamination occurred during abnormal operation of equipment, the contaminated gas should be evacuated into a storage vessel and held in storage until it can be shipped to a purification center. Solid decomposition products must be treated in neutralizing agents before disposal in an approved landfill.

- **Transportation and Storage.** Electric utilities need to be aware of regulations and appropriate precautions for moving gas carts containing gas from one substation to another. There are elaborate U.S. federal regulations covering rules for transporting materials that are hazardous or pressurized. Most significant for substation equipment maintenance people are the segments relating to highway transport. During cylinder transport, precautions should be observed, including not lifting by the protective cap, storing away from heat, and storing in upright and secured position. During cylinder storage, procedures should be followed, including storing cylinders in a safe, well-vented location, and storing away from flammable substances and heat sources.

Leak Detection

New tools are needed to improve detection of SF_6 leaks in order to meet the requirements of voluntary emission reduction programs, reduce the cost of detection, reduce the cost of replacement gas, avoid service outages, and improve gas recycling efficiency.

The conventional method of leak location involves use of a soaplike solution, which, when spread over a suspected leak, bubbles at the leak point. Effective in small areas, it is impractical for large pieces of equipment if the general area of the leak is not already known, and it cannot be used on hard-to-reach equipment such as rupture disks. The method is also time-consuming and costly because it requires de-energizing equipment during inspection.

In 1996, EPRI purchased a custom-built version of a real-time SF_6 gas leak visualization system normally used for assembly line leak testing. The technology, known as “GasVue,” uses an infrared laser camera to visualize SF_6 gas, which is transparent in visible light but can be seen with infrared light.

Since its introduction, the GasVue camera has been successfully demonstrated by utilities in the U.S. and abroad. Unlike conventional leak detection methods, the camera allows maintenance personnel to inspect large areas for leaks. More precise than other methods, the camera can be used to spot pinhole leaks that are invisible to the unaided eye or other optical detection equipment and to determine leak location to within about half an inch. The camera can also be used to detect leaks without taking equipment out of service, thereby avoiding loss of revenue and simplifying the procedure. In addition, use of the GasVue camera for leak detection is faster than other available approaches. It ensures all significant leaks are found and can be used to prove that a leak repair was successful.

In 2000, EPRI participated in the development of a new field-hardened version of the GasVue camera. The new camera—which is smaller, lighter, and more rugged than the earlier version—was designed specifically for use by field technicians. The camera's compact size and toughness make it easier to maneuver and position to locate leaks. The reduced size was achieved by using an electronic system, in place of circulating water, to maintain the laser's temperature.

Figure 2. *The first of the new-generation laser cameras is undergoing a field trial at Consolidated Edison Co. The operator holds the shoulder unit while the remainder is atop the shipping case.*

Gas Condition Assessment

The condition of SF_6 must be understood for its safe and effective use in utility applications. To assist utilities in better understanding how to evaluate SF_6 gas, EPRI conducted a study of methods and equipment for laboratory and field assessment of the gas, and reviewed techniques for reclamation of air-contaminated gas.

The condition of SF_6 needs to be assessed for numerous reasons, including acceptance testing of new gas for compliance with specifications, quality control for continued use of in-service equipment, and contamination monitoring following repairs and refilling operations. The extent of the condition assessment depends on the source and function of SF_6. Sources of the gas include new SF_6 as supplied by the manufacturer, gas from in-service equipment, and gas from SF_6 gas-handling and recycling equipment.

Contaminants originating from the manufacturing process and during storage and handling are oxygen, nitrogen, and carbon tetrafluoride. Decomposition products caused by arcing, corona discharge, and thermal faults include thionyl fluoride (SOF_2), sulfuryl fluoride (SO_2F_2), and carbonyl sulfide (COS). Another key contaminant is moisture within gas-insulated substations.

In the laboratory assessment of SF_6, four separate sensors are used to determine purity or percent content of SF_6, oxygen content, moisture content, and presence of decomposition products. Multiple component detection is also possible through gas chromatography. For field assessment of SF_6, commercially available kits are available for detecting decomposition products. Air content is usually measured with oxygen sensors, and moisture content is determined by hygrometer. However, a single field device capable of assessing purity, oxygen, moisture, and decomposition products is highly desirable.

In the EPRI study, the project team improved and field-hardened a previously developed EPRI prototype SF_6 decomposition products detector (DPD) developed at Powertech Labs. The DPD consists of a flow controller, catalytic reaction tube, and gas detector. The instrument is portable and is designed for quick and accurate measurement of SF_6 decomposition products in the field. Improvements to the DPD included battery operation and a novel method for heating the detector catalyst tube. The DPD was successfully field-tested by three EPRI member utilities.

The project team also evaluated methods for decontamination and reclamation of SF_6 gas. Tests on the use of hollow-fiber membranes to remove air from contaminated SF_6 gas showed that such membranes are capable of extracting air from contaminated gas, and in one test, a 10% fraction of air was reduced to less than 1% with minimal losses of SF_6.

Results of the condition assessment project give utilities the tools they need for field assessment and potentially the means to reclaim contaminated gas. Such procedures, when implemented, will assist utilities in maintaining their equipment in good condition and will result in reduced operating costs and SF_6 consumption.

References

Practical Guide to SF_6 Handling Practices, EPRI, Palo Alto, CA: 1999, TR-113933.

SF_6 Gas Condition Assessment and Decontamination, EPRI, Palo Alto, CA. 10000131.

For More Information

For more information about the EPRIsolutions SF_6 Leak Location Service, contact Ken Loynes, 413/499-5712, kloynes@epri.com.