GasVue and the Magnesium Industry: Advanced SF_6 Leak Detection

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INTRODUCTION

Concerns about atmospheric emissions of greenhouse gases and operation costs are converging to increase incentives for both the electric utility and magnesium industries to rapidly locate and repair equipment leaks (Irwin, 1997). The primary culprit is sulfur hexafluoride (SF_6), an invisible, non-hazardous, inert gas with near-perfect dielectric properties that is used as an insulating gas in high-voltage switchgear and circuit breakers, as well as a cover gas during magnesium processing. It is also an extremely efficient absorber of infrared radiation, making it one of the most potent of all known greenhouse gases. Although its atmospheric concentration is less than 0.1% of that of the major greenhouse gas (CO_2), SF_6 was among the six greenhouse gases targeted for emissions reduction at the 1997 Kyoto Japan Summit. On an equivalent basis of global warming potential, SF_6 accounts for 14% of the greenhouse gas emission reductions that the U.S. and 150 other nations agreed to make by 2012. It is commonly estimated that, directly or indirectly, the electric power industry purchases about 80% of all SF_6 produced. Although the magnesium processing industry uses much less SF_6 than the electric power industry, its use as a melt protection gas means an inevitable release into the atmosphere.

In October 1998, the U.S. Environmental Protection Agency (EPA) began promoting voluntary emissions prevention agreements with both the electric power and magnesium industries. Under a memorandum of understanding, these industries are being asked to report annually on their SF_6 use and emissions and establish corporate policies that will reduce emissions to the extent economically and technically feasible. The EPA is also pursuing similar agreements with other industrial users of SF_6.

Detection of SF_6 leaks in both of these industries is an ongoing, labor-intensive process usually consisting of spraying a soap film on, or passing the intake of a SF_6 gas sensor (or sniffer) over, the suspect area. A promising alternative to the soaping and sniffing leak detection methods is a laser-based remote sensing technology known as Backscatter Absorption Gas Imaging (BAGI). The BAGI technique is different from other laser-based, remote detection techniques in that it is designed for the sole purpose of locating leaks or tracking gas clouds (McRae, 1993). It should not be confused with other laser-based gas detection techniques that are capable of measuring gas concentration data. These other laser remote sensing techniques generally require two or more laser wavelengths, whereas the BAGI technique only requires one wavelength. The BAGI technique is inherently a qualitative three-dimensional vapor visualization scheme that makes a normally invisible gas leak "visible" on a standard video display of the region of interest. The image of the escaping gas allows the operator to quickly identify the source of the leak. As will be discussed later, the technique is capable of detecting gaseous leaks and displaying them in real-time in a standard TV format. Laser Imaging Systems, Inc. (LIS) holds an exclusive license for the manufacture and sales of the patented BAGI technology (US patent #4,555,627) and is currently marketing this new technology under the registered trademark "GasVue".

DEVELOPMENT HISTORY

The first GasVue systems were designed and built at the Lawrence Livermore National Laboratory (LLNL) under funding from the Naval Sea Systems Command (NAVSEA/OOC). The design purpose for these systems was for the initial surveillance of disabled marine vessels for the presence of toxic or flammable vapors. In these cases, it is desirable to know if there is a leak on board and, if so, where it originates. This information is crucial to the safety of the men who must board and secure the vessel (McRae, 1986). The first two phases of the LLNL program were completed in 1985 and involved studies of hazardous gas absorption properties and the laser power requirements necessary to meet the desired system range. The 1986 Phase III effort consisted of laboratory proof-of-principle experiments. In 1987, a system was constructed for field evaluations of the GasVue technique. This first unit was a short-range shoulder-mount version, as the Navy was also interested in the possibility of a man-portable GasVue system. The goal of the 1988-1992 effort was the fabrication and evaluation of a long-range, multi-wavelength GasVue system involving both laboratory and field trials. This work has since been transferred to the Sandia National Laboratory (SNL) in Livermore, CA, where development has continued (Kulp, 1991).

In recent years, the Electric Power Research Institute (EPRI) has been actively working to find methods to assist the electric utility industry with their SF_6 leak detection and repair programs. Current leak location technologies involve soaping or the use of handheld sniffers. However, because of the high voltages involved with the SF_6 insulated components, the equipment must be taken out of service during these leak surveys. As a result, EPRI too has been keenly interested in alternative technologies allowing for “stand-off” or remote leak detection and was a willing partner in the design and evaluation of the GasVue technology for use in the electric utility industry (Moore, 1999).

TECHNOLOGY DESCRIPTION

The concept of the GasVue technique is to make gases that are not visible to the human eye visible on a standard video image. In order to keep the system economical, operator-friendly, and field-reliable, the current system design does not provide quantitative concentration information. However, for leak location applications the operator does not need to actually know the gas concentration. A system that allows him to see the gas at concentrations of interest is sufficient, and a GasVue system provides the operator with this information in a real-time video format.

The GasVue technique produces a video image of the area under inspection using backscattered laser light at a laser wavelength that is strongly absorbed by the gas of interest. The result is that the normally invisible gas becomes visible on the TV display. An artist’s interpretation of this concept is shown in Figure 1. The GasVue laser camera illuminates the objects under inspection, producing an infrared image from the backscattered laser light much in the same way that backscattered sunlight produces an image for a conventional TV camera. The detector in the laser camera is filtered so that it responds primarily to the wavelength of the laser light and ignores essentially all of the background thermal emission. Because there is no SF_6 gas in the top view of Figure 1, the TV image produced by the GasVue camera is just of the background objects. However, when SF_6 gas is present within the GasVue camera field-of-view as shown in the bottom view of Figure 1, it absorbs the laser light making the gas appear as a dark cloud emanating from the leak source. The higher the gas concentration, the greater is the absorption, and the darker is the gas cloud. In this manner, the normally invisible gas becomes visible on the TV monitor, and its origin, size, and direction of movement are easily determined. Although the gas cloud of Figure 1 is shown in contact with the background, this is not required. The background objects may be well behind the gas cloud just so long as they are within the operational range of the laser camera.

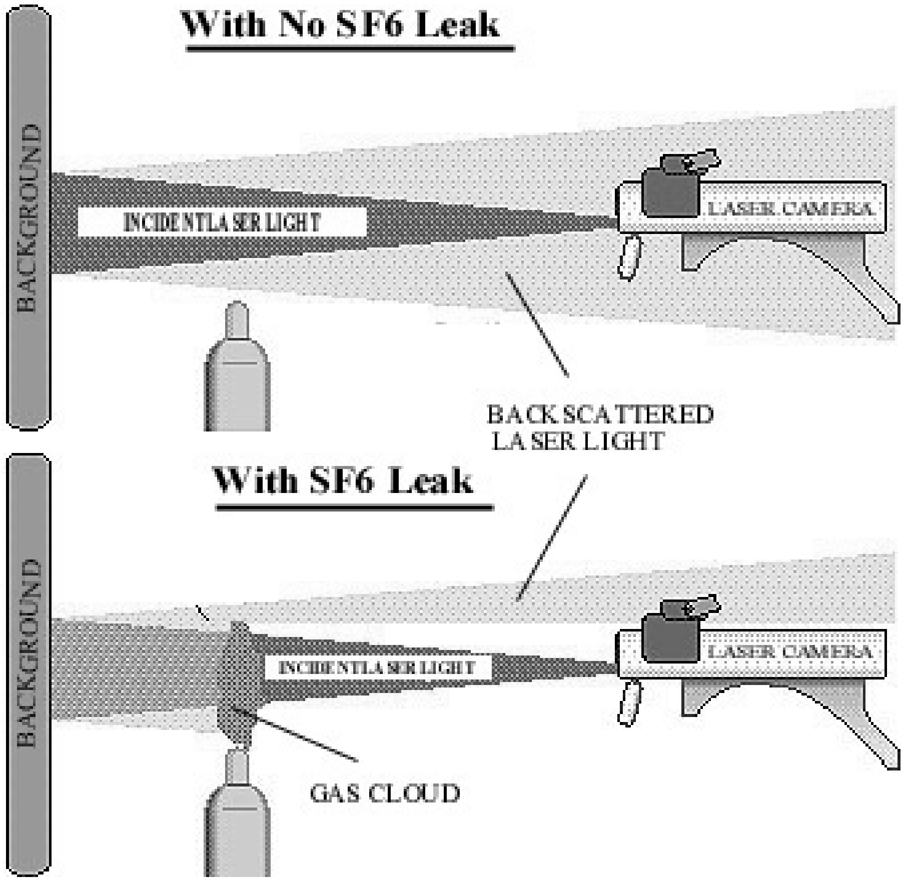

FIGURE 1. Artist's Interpretation of the GasVue Technology

The photo of Figure 2 shows the inspection of an SF_6 circuit breaker with a GasVue TG-20 system. The infrared image of the area under inspection is shown as the black-and-white inlay of Figure 2. This inlay is the same image presented to the operator by the laser camera's viewfinder. For illustrative purposes, the leaking SF_6 gas in Figure 2 has been enhanced. In the actual GasVue image, it is the motion of the leaking gas plume that makes it so noticeable. As shown here, the GasVue technology is able to rapidly inspect entire gas-insulated equipment while in service, and can pinpoint extremely small SF_6 leaks. Furthermore, leak inspection results are easily documented by video recording.

Critical performance parameters for the GasVue technology are range and detection sensitivity. For the GasVue technology to visualize a leak, there must be a reflective or backscattering surface behind the leak. It is not possible to visualize a gas plume against the sky. This is generally not a real problem for detection of fugitive emissions from electrical substation switchgear because the leaking component itself serves as the background for the gas image. Range limitations are exceeded when the GasVue system no longer produces a useable image of the component under inspection. The amount of laser light backscattered to the detector of the laser camera depends strongly on the backscatter coefficient of the illuminated surfaces, which can vary by several orders of magnitude. With the CO_2 laser power (2.0-2.5 watts) and optical design of the current GasVue systems, useful ranges of 20 to 30 meters are realized in typical electrical substation applications.

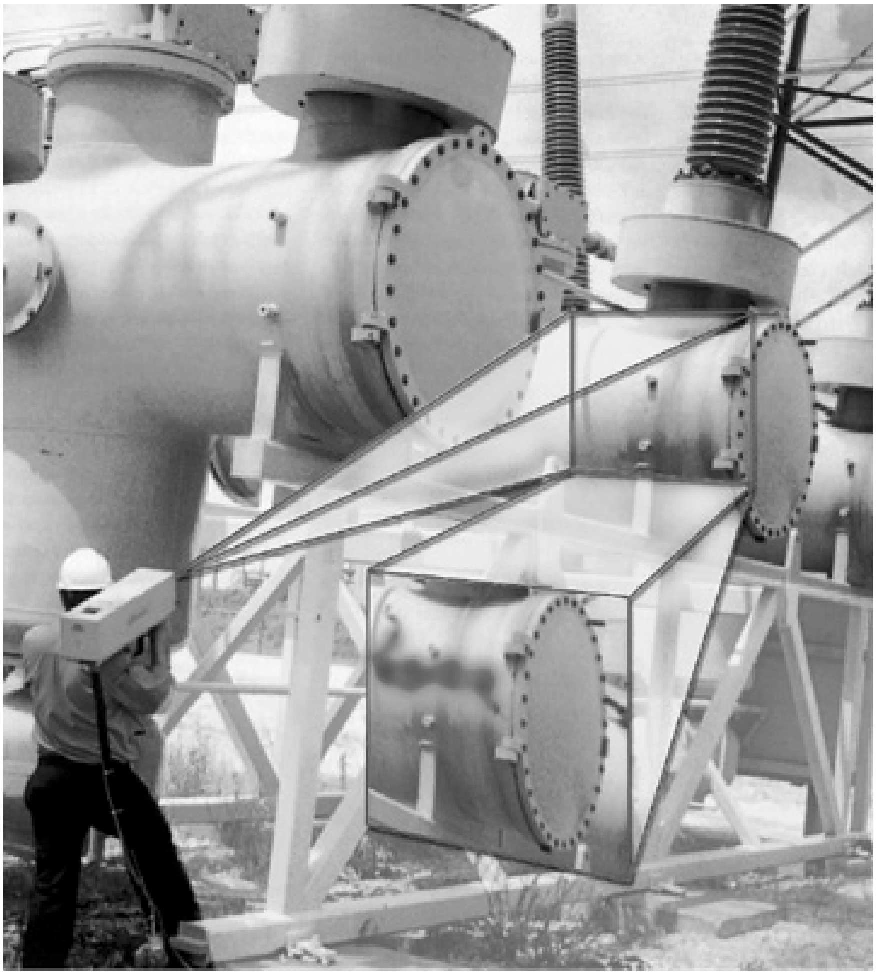

FIGURE 2. Leak Location Using a GasVue System

The detection sensitivity depends most strongly on a match-up between the laser wavelength and the wavelength of strongest absorption by the gas of interest. In general, the gas leakage plume must attenuate the laser beam power by at least 8% for the leak to be visible. Use of the CO_2 laser allows spectral operation between 9.2 and 10.8 microns at about 40 discrete laser lines. For the match-up of SF_6 and the CO_2 laser line at 10.55 microns, leaks as small as 10^{-4} cc/sec (100 gm/year) can be detected. However, the noble gases (He, Ne, Ar, Kr, Xe) and symmetrical diatomic molecules (H_2, N_2, Cl_2, etc.) are IR inactive and are not detectable by the GasVue technology. Estimates of GasVue detection sensitivities for about 80 other gases are available. Recent development of lasers operating in the 3-4 micron region has opened up numerous other gas detection possibilities, in particular natural gas and the VOCs (McRae, 1999).

Numerous other parameters such as wind speed, optical resolution, and gas plume motion are also known to affect GasVue leak detection. However, their impact on detection sensitivity is not fully understood to date. The higher the wind speed, the more quickly the gas is dispersed as it leaves the leak source and the less visible it becomes on the GasVue display. The effect of optical resolution actually appears as a range effect on the leak detection sensitivity. The optical resolution of the current GasVue design is about 0.11 degrees, which gives a "resolvable spot" of about 2 cm at a distance of 10 m. In order to be detectable, the gas leakage plume must produce observable laser attenuation in at least four or five *adjacent* resolvable spots in the imaged scene. A leak occupying only one resolvable spot will appear only as a gray-scale structure of the illuminated background. Consequently, a visible leak occupying five spots at a range of 2 m would not be visible at a range of 10 m because it would occupy only one spot at that distance. And motion of the leakage plume is essential. A stationary gas cloud is very difficult to distinguish against a non-uniform background.

Another important parameter is the angle at which the leak is viewed. The most sensitive viewing angle is when the gas comes directly toward the laser camera. This is the more sensitive viewing angle because the absorption path through the gas is greatest. Consequently, the most favorable leak detection conditions are to view the leak source as close as possible, under low wind speed conditions, and with the escaping gas coming directly at the laser camera. Under these conditions, and with a fairly uniform background surface, the GasVue technology is capable of visualizing SF_6 leaks down to $1x10^{-4}$ cc/sec.

FIELD TEST RESULTS

A photo of the GasVue TG-20 system is shown in Figure 3. The first TG-20 system was built for EPRI in 1997 and initially evaluated by Consolidated Edison of New York and Public Service Electric and Gas of New Jersey. A one-inch viewfinder and all system controls are provided with the shoulder-mount laser camera. The camera is tethered to the power and cooling unit of the system by a 25-foot cable. The size of the power and cooling unit and the thickness of the laser camera cable are a result of the use of a water-cooled CO_2 laser. To date, about one dozen TG-20 systems are currently being used in the electrical utility industry as part of their SF_6 fugitive emissions reduction program. Leaks as small as 2 lb/year, and at distances out to 50 feet, have been located with this new technology. Just recently, in less than four months, Roberts Transformer (under contract to Florida Power & Light) was able to inspect over 460 circuit breakers for leaks (Fischer, 2000). In many cases, the GasVue technology was able to locate leaks "previously undetected using traditional techniques."

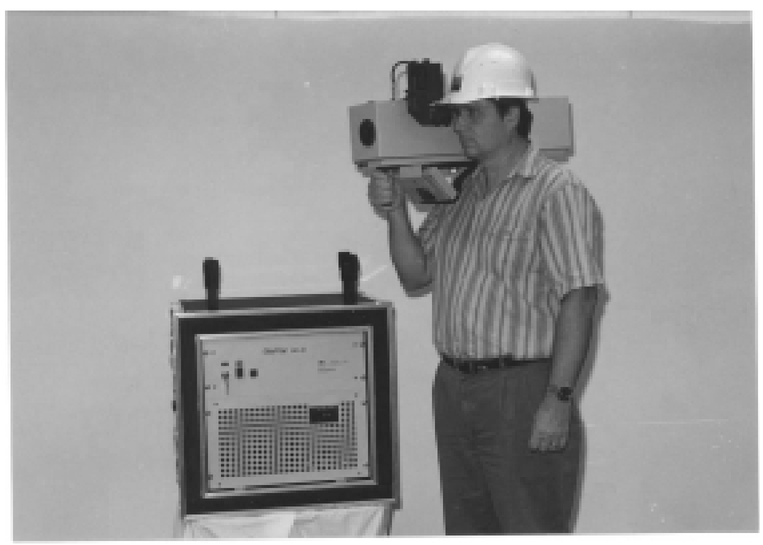

FIGURE 3. The GasVue TG-20 System

Although the TG-20 has been quite successful in locating SF_6 leaks from gas insulated switchgear, there were numerous complaints about the system size and weight and the quality of the video image. Through the support of a U.S. Air Force SBIR contract, and with design input from TG-20 system users, LIS was able to make significant improvements to the GasVue technology. Use of a higher resolution detector module with a smaller air-cooled laser made the system considerably smaller without sacrificing detection range performance. A photo of the prototype air-cooled GasVue TG-30 system is shown in Figure 4. Although the TG-30 laser camera is about the same size as for the TG-20 system, the cable and power unit are much smaller. A prototype TG-30 system was delivered to ConEd of NY in March 2000 for pre-production evaluations. Design changes suggested by ConEd were incorporated, and a second TG-30 was delivered to the New York Power Authority in September. To date, both systems have been performing as expected.

FIGURE 4. The New Air-Cooled GasVue TG-30 System

Although to date the GasVue technology has not been used for SF_6 leak inspections in the magnesium industry, there is no reason to suspect that it will not perform as successfully as it has for the electric power industry. The TG-30 system was designed for the harsh outdoor leak inspection conditions existing in electrical substations, and should have no trouble rapidly surveying the SF_6 plumbing and storage areas of a magnesium processing plant. The portability and 90-foot range of the new TG-30 system should allow inspection of even the most inaccessible SF_6 components in the plant. And finally, videotape leak documentation allows for rapid and accurate repairs to the faulty equipment.

SUMMARY & CONCLUSIONS

The basic operation of the GasVue SF_6 leak detection technology is explained, including important operational parameters that affect the performance of the technology. The state-of-the-art of the GasVue equipment is described, and its successful application as an SF_6 emission reductions tool for the electric power industry is summarized.

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