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SF_6 Monitoring in the United States T&D Market

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SUMMARY

Sulphur Hexafluoride (SF6) management is a large part of breaker and/or Gas Insulated Substation (GIS) maintenance. In an effort to combat climate change, the California Air Resources Board has released amended requirements governing both the management of existing Gas Insulated Equipment (GIE), as well as the purchasing of new GIE, effective in the State of California in January 2022. These requirements are two-fold: 1. To set target cut-off dates for the purchase of new GIE with Global Warming Potential values greater than one; and 2. To consolidate and regulate the appropriate methods for handling the insulating gas of existing and future GIE. California GIE owners must prove that their SF6 fleet meets these new requirements, including reducing emissions of SF6 and meeting annual leakage rate limits, otherwise they face annual penalties which increase on a yearly basis[1,2]. Furthermore, the United States Environmental Protection Agency (EPA) requests yearly SF6 inventory tracking from all North American SF6 users per equations based on the weight of SF6 bottles before and after gas handling has occurred. No nationwide penalty for leakage rates has been established as of yet, but it is anticipated that the CARB penalties, or similar, will be enacted in the future across the country.

Using cost-effective ways of ensuring that GIE is running within acceptable reliability and compliance parameters prevents the need to replace equipment prematurely due to new environmental restrictions. Monitoring SF6 insulated equipment provides:
1. Visibility of leaks as small as 0.1% mass/year, identifying costly SF6 emissions.
2. Data processing to minimize false alarms that can plague users.
3. Auto refill detection and other reporting tools that can be used as part of a comprehensive SF6 management plan.
4. A flexible platform: a centralized monitoring system that can include breaker monitoring, partial discharge, and other parameters.

KEYWORDS

Gas Insulated Substations, GIS, SF6 Monitoring, T&D Monitoring, non-SF6 Alternatives

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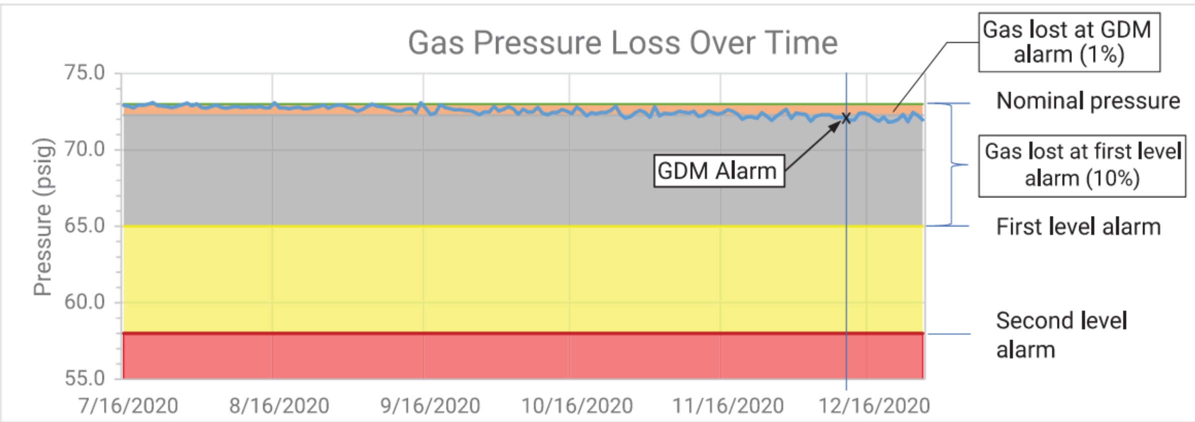
The Problem

SF6 is the dominant gas found in circuit breakers and is used in large quantities in gas insulated substations. Recent legislation enacted in January 2022 by the California Air Resource Board (CARB) establishes significant fines for SF6 losses. Negligent emissions penalties are now set at a maximum cost of over $400,000 per day per pound of SF6 above the established yearly limit.
Shifting away from the use of greenhouse gasses in high voltage equipment is already underway, however, both older and newer equipment containing SF6 are expected to remain in service longer because of the unfavorable economics related to early retirement or replacement.

Traditional gas pressure alarms are not designed to minimize SF6 emissions. Alarms meant for safe operation (≈10% loss) don't provide fast notifications to minimize SF6 loss. Therefore, systems that can detect leakages all the way down to 0.1% of SF6 mass loss/year are required.

The Solution

SF6 monitoring is essential for lowering electric utilities' environmental risk profile:



Other industries (including power generation) have been taking full advantage of monitoring technology for decades to quickly react to problems. Using proper instrumentation and a computer to continually process data, modern monitoring systems can recognize problems faster than before. These systems greatly reduce costly manual inspection and enable true condition-based maintenance and replacement planning.

Responsible utilities recognize the need for automated systems to monitor SF6 for protecting the environment and their bottom line. These systems are the best way to manage the environmental and financial liability, and system reliability by providing quick notification of leakage and the priority for scheduling repairs.

What is SF6 Monitoring Used For?

Use #1: Leak prediction
Any potential leaks are reported immediately based on predictive analytics. This use case eliminates the need to wait for alarms to inform the user of an SF6 leak.
Use #2: SF6 Inventory double check
SF6 monitoring system can be used to double-check the bottle-in/bottle-out method tracking of SF6 on at the substation level.

Use #3: Easy Access to SF6 gas data offsite
Gas weight & pressure data available for observation or for double-checking bottle weight records. This data can be exported and incorporated into utility-wide enterprise monitoring package

Features of a Monitoring System
Monitoring systems are comprised of two parts: the instrumentation and the computer. Instrumentation is fundamental to the system while the computer handles the processing of the data and serves as the interface between the equipment, the operator, and other business or enterprise-wide systems.

Instrumentation
Instruments, otherwise known as sensors, transmitters, or transducers, are available for a wide range of applications. The most common measurement for SF6 monitoring is density, but another measurement gaining popularity recently is moisture.

Traditionally, the output of an instrument is measured by the amount of current the instrument draws from its power source[3]. More recently, however, measurements can be obtained from multivariable instruments using a communications protocol, such as Modbus. In both cases, the instruments are low-power devices typically powered with 24 VDC.

Since the gas pressure varies disproportionately to temperature, much consideration is given to instrument placement, distance of the instrument from gas insulated equipment, and using insulation to keep the instrument the same temperature as the high voltage equipment. Additionally, the gas pressure is expressed in terms of a temperature compensated value (i.e., at 20 °C or 68 °F) for simplicity[4].

Both pressure and temperature instruments have their advantages and disadvantages when ultimately producing a compensated gas pressure measurement. Both measurement techniques suffer from the inability to measure the gas from within the gas-insulated chamber.
Having to install the instrument outside the chamber results in an occasional temperature difference between the instrument and the chamber where most of the gas is contained. Thus, installing the instrument as close to the chamber as possible and adding insulation produces the most accurate measurement.

Due to the relative nature of condition monitoring, instrument precision is more important than accuracy. Condition monitoring identifies differences over time regardless of how the measurement compares to that of another instrument measuring the same gas.

Computer and HMI
The HMI is a crucial part of the system as it is the how operators can visualize the data, statuses, and other information on the system. HMI best practices are centered around human performance best practices, which include:
• Hierarchical structure (General » Area » Specific Equipment » Detail)
• An easy-to-read alarm list
• Display elements and colors that are familiar to the user (system/site drawings, diagrams, and alarm colors)
• Adherence to standard symbols (ISA, IEEE, etc.)
• Background colors that minimize eye strain
• Symbols and static element colors that contrast well
with background
Other features, such as a touchscreen and/or computer speakers, enhance the operator's experience as well. All data for the substation can be viewed in one centralized location which eliminates the need to walk around the entire substation.

Alarms
The alarm list is a critical component that conveys alarm status efficiently and effectively. It is important that alarm text are clearly understandable so that the operator can respond appropriately to any given situation. Further, alarms are shown with timestamps so that multiple alarms can be viewed

in sequence, and in the same colors that are used on displays for consistency and to eliminate confusion.

Historian
The purpose of the system historian is to store data for extended periods of time for retrieval at a later time. Data is stored on the computer's local hard drive, and the duration of storage is typically limited to drive storage capacity. Rapidly changing data is usually logged by the historian once every few minutes, whereas data that is slow to change (or doesn't change at all) is usually logged once per day.

This data can then be used in:
• Situations where historical recollection of events is required (i.e., confirming gas handling activities)
• Confirmation of reporting (gas weight data can backup gas handling records made manually)
• Reviewing and analyzing past data to look for trends, such as leaks

Analytics
The HMI is also capable of analyzing historical data on a set interval (daily, weekly, etc.), or on-demand for ad hoc re-porting. The objective of the analyses is to find trouble with the equipment before problems arise. An automated analysis can be as simple as looking for a day-over-day change in equipment parameters, or as complicated as using the least squares method to predict when any parameter will reach an alarm limit (potentially even 1-2 years in advance). Additionally, analytical methods can be used for detecting gas handling events, such as refills.

Like other automated processes, analytical methods are first prototyped manually and then tested against actual historical data to ensure that the analysis methodology is sound and capable of finding the problems they are de-signed to find.

Where are SF6 Monitoring Systems Installed?

New GIE
Vast majority of North American utilities are including mandatory requirements for real-time SF6 Monitoring Systems on new GIS substation purchases.

Existing GIS
Existing GIS Substations can be retrofitted with an SF6 monitoring system.
System can be installed on unlimited gas zones

AIS Equipment (GIE)
Consists of instrumentation for circuit breaker gas zones, cable to a marshalling cabinet which houses the rugged computer with software
Can be implemented with Breaker Monitoring

OEM Independence
Instrumentation connected to standard gas ports (DN20). Does not require any network communication with existing OEM's equipment.
Interface to customer's existing communication architecture (DNP, IEC)

Data Filtering
The Mitsubishi Electric Gas Monitoring and Analytics System reduces noise (caused by uncontrollable external conditions) found in the raw data using several noise suppression techniques. Once normalized, the data are analysed, alarms are generated, and accurate reports can be produced.

False alarms are also mitigated through the use of a time-dependent alarm threshold. For example, a smaller analysis period will have a coarser alarming criterion, such as a 1% loss. A larger analysis period, however, can be more closely scrutinized and therefore a 0.1% threshold can be applied for alarming gas loss.

Architectures

The monitoring system is flexible enough to be installed in a variety of ways:
On-site (on-premises or on-prem) Standalone: HMI computer installed in substation. The data can only be taken from the system by removable storage (ex. USB flash drive).

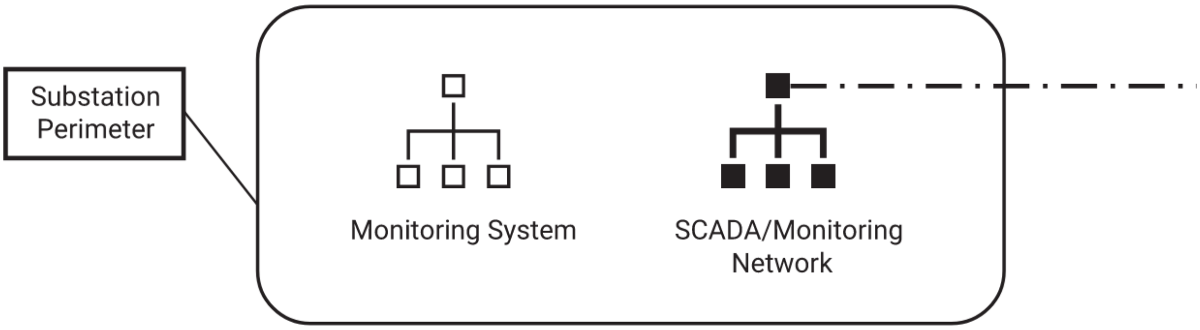


Figure 4: Islanded monitoring network topology

On-site with external connectivity: A computer is installed in the substation and integrated with SCADA or monitoring system. Data can be stored both locally and on user's enterprise-wide data historian. The system would be connected to the user's SCADA or monitoring network through either a firewalled ethernet or direct serial data connection for security.

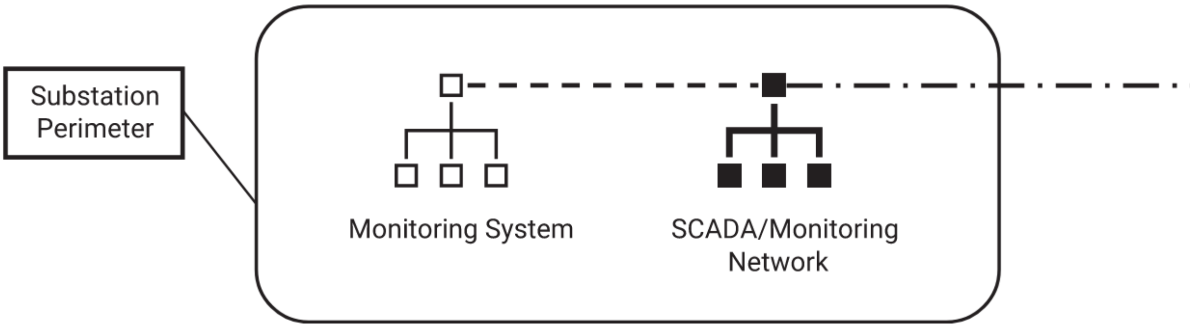


Figure 5: Connection with on-site monitoring network

Remotely Connected: A remote computer (i.e., in user's datacenter) receives data from on-site instruments. The entire monitoring system would reside on user's existing SCADA or monitoring network infrastructure.

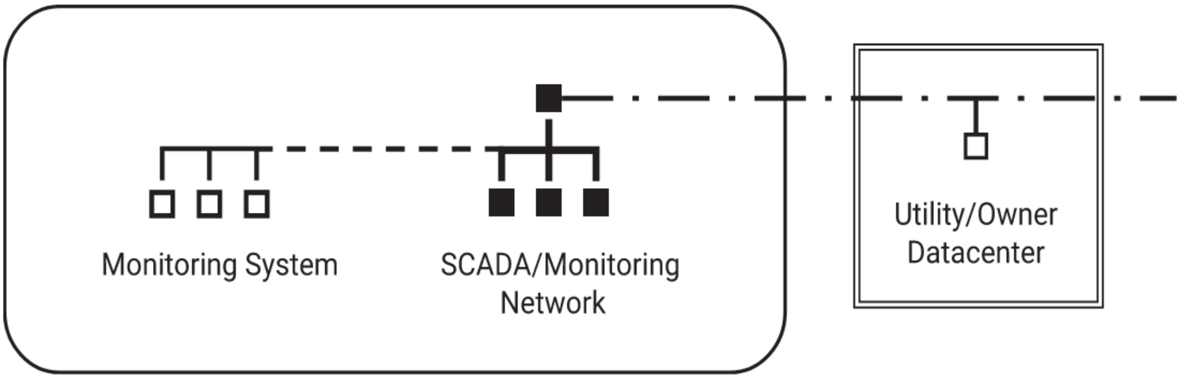


Figure 6: Monitoring system with off-site computer

Case Study for SF6 Monitoring

In 2020, Mitsubishi Electric installed its SF6 Gas Monitoring and Analytics System on over 200 gas zones on 245kV & 500kV GIS Equipment in Western USA. The GIS equipment was 15 years old.

The customer utilized the substation SCADA connection to receive raw SF6 data directly from the SF6 Monitoring System.

Two months after installation, the SF6 data was shared with Mitsubishi Electric, and a leak was found on the 2nd largest gas zone on the substation property - - 1100 pounds in the gas zone total. The non-critical gas zone was so large that it would have only alarmed after 1 year at its current leak rate. Mitsubishi Electric notified the customer of Its leak, and the SF6 monitoring system limited the leak to 20 pounds of SF6 lost. Had the leak occurred until alarm, approximately 100 pounds of SF6 would have been emitted.

100 pounds of SF6 CO2 equivalency:

- 225 passenger vehicles driven for one year (2.6M miles)
  Or
- 125 homes' energy use for one year

CARB penalties in effect January 2022 are tied directly to any emissions of SF6 over 1.0% of a utility's SF6 system capacity, with potential for >$400k/day penalties for just one pound of SF6 over the 1.0% yearly emission allowance. At these penalty levels, the value of understanding where SF6 leaks are occurring on GIS or AIS equipment as soon as possible is immense.

Future of Substation Monitoring: Power-I Computer-Vision Based System

1. Visible light cameras continuously check and alert for changes in equipment condition, oil leaks, vegetation, animal activity, criminal acts, intrusion, and analog gauges.
2. Thermographic cameras continuously monitor and identify thermal changes of substation equipment that are outside of their normal operating ranges. In addition, these cameras identify thermal incidents such as wildfires around the substation
3. Microphones identify acoustic anomalies of equipment and analytics to identify the signature of events such as gunshot detection.
4. Provide real time visual and thermal access to a substation and its equipment 24x7 without the need to roll a truck.

Conclusion

W. Edwards Deming once stated, “If you can’t measure it, you can’t manage it.” Monitoring systems make what is invisible now manageable, and in today’s world, that’s more important than ever. Real-time monitoring systems facilitate digital transformation and harness modern computing power, resulting in changes for the better.

End of text

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