Gas Insulated Substation Control and Monitoring

An Online Continuing Education Course for Engineers

Course Number: E-2050

Credit: 2 Hours / 2 PDH / 2 CPD

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This course includes GIS monitoring topics including gas monitoring, partial discharge tests, and circuit breaker monitoring. The control topics of bay controllers and control diagrams are also discussed. The fundamentals of gas monitoring including the related alarms are described and gas monitoring routines are presented. The partial discharge monitoring paragraph also includes the types of faults causing partial discharges and provides details on partial discharge measuring procedures, where electric, acoustic, chemical-specific routines of partial discharge monitoring with GIS are presented.

Local control cabinet paragraph provides details on different types of GIS technology that is currently used. Current and voltage transformer wiring including mimic schemes are presented. The function of the bay controller with all its basic elements is presented. Control diagrams of different mode selections and interlockings are provided and examples are presented.

Paragraphs related to digital communication show the impact of digital communication to GIS, which is based on IEC 61 850. Fundamental digital communication standards are presented and their relations to other standards are discussed. Switchgear related communication standards of GIS are presented and the locations of the controls in the GIS and their timing operations are given. Procedure to measure and test digital communication in GIS is also provided.

GIS Equipment Monitoring

GIS equipment can be supervised in several ways and for different purposes needs. Many of these techniques are not unique to GIS equipment and can also be found on other switchgear and breaker elements. The most frequent monitoring arrangement is typically gas monitoring. Gas monitoring will exist on almost every device that uses SF_6 gas, including GIS bus and breakers. Another typically used monitoring arrangement involves the circuit breakers. Breaker supervision is not restricted to GIS equipment and there are a number of commercially available products, both from OEMs and third-party suppliers. The easiest form of breaker supervision (e.g., monitoring the number of operations) will exist on almost every circuit breakers. Nevertheless, more advanced monitors are also available and are widely used, even though all of the available functions are not used by some users. Lately, partial discharge (PD) monitoring has earned interest as it promises to have the possibility to warn of developing insulation problems in the GIS installations. There are just a few commercially available solutions since data assessment typically requires expert interpretation.

Gas Monitoring

In GIS installation, the SF6 gas gives electrical insulation and, in the breakers, arc-quenching capability. These characteristics depend on the SF6 gas density. Nevertheless, gas pressure is typically quoted in lieu of density. For instance, different documents frequently use terms such as "fill pressure" or "normal working pressure." Pressure is used because it can be easily measured and is intuitive, but it is gas density that is the crucial parameter. Pressure is strongly dependant on temperature, but density is not (in the case a state change is not involved).

Gas monitoring is primarily used to make sure that a sufficient quantity of SF6 gas is provided to meet the equipment's requirements. This typically involves some form of gas density monitoring. Nevertheless, gas density measurements have limitations. Gas density is observed at one point within the GIS installation, typically at the enclosure. While it can be considered that the gas pressure is constant throughout the gas enclosure, there may be density differences resulting from variations in temperature. For instance, for GIS installation under load, the gas temperature may be greater closer to the central conductor as opposed to at the enclosure, where the gas density monitor is typically placed. Therefore, a measure of density at the enclosure may tend to overrate the density at GIS live parts. In some situations, there may also be problems such as convective flow within the cylinder, solar gain (in the case of outdoor installations), that may impact the temperature and density distribution within the equipment. In most situations, these density differences are considered secondary and SF6 density thresholds are based on adequate margins to consider these secondary impacts. In reality, gas density monitoring systems can be set up to give one or two types of outputs:

1. Permanent output signal. These signals can be used for trending for diagnostic requirements. For example, previous records could distinguish between a slow leak happening over a long period of time in comparison to a recently developed leak of bigger severity. Trending data can also be used to observe SF6 emissions to help meet environmental requirements and standards. Since the SF6 gas is a considerable greenhouse gas, the importance of monitoring emissions cannot be understated.

2. Threshold alarms. An alarm signal is started when the gas density decreases below a certain predefined limit. Normally, two thresholds are used. The first threshold is a warning to signal low gas. The second level is typically a control signal used to block switchgear service or, in some situations, to disconnect the affected equipment completely. The second signal is typically tied to the minimum density needed to ensure adequate equipment operation. Different technologies are available to complete these functions. These technologies include:

1. Simple pressure switches. Since pressure is not density, this technology is only used in certain equipment with inherently big design margins where the threshold pressures, given the expected temperature change, still ensures adequate gas density for proper service. Certain medium voltage equipment uses such switches, calibrated to one or both above-discussed threshold levels.

2. Temperature compensated pressure gauges. A separate temperature signal is used to change the response of a pressure sensor. These sensors typically have a visible gauge (set to read true pressure or compensated pressure), but the signaling is accomplished via relays or switches set to the two density threshold levels.

3. Gas monitor with reference gas. Reference gas in a sealed enclosure interfaces with the relevant gas via mechanical bellows. Since temperature variations equally affect both the measured and reference gas, variations in pressure also equally affect them and the effect of temperature is eliminated. The bellows will react to differential pressures that would be related to density and cause microswitches to function.

4. Direct density measure. Sensors equipped with tuning forks change their resonant frequency when gas density changes. These sensors give a permanent signal, which tracks density. Nevertheless, the signal is also interfaced to relays to give the threshold alarms.

It is important to note that advanced monitoring systems that measure pressure and temperature separately could use state equations to calculate density. Sometimes, it is also feasible to include thermal models to give better indications of gas density at various parts of the GIS equipment. Such installations have the potential to monitor and quantify small gas leakages more precisely. Nevertheless, at the moment, this method is not used in commercially available systems.

Gas Monitoring Methods

Most gas density monitors installed as part of the GIS are of the "relay" type. They use contact closures to signal that defined gas density thresholds have been reached. Visual displays on the devices themselves typically consist of color-coded status indicators but do not give a quantified density value. With this equipment type, low-gas alarms are typically the only available form of monitoring. Manual observation of the indicator status can also be completed during regular inspections. With these installations, SF6 loss is done by tracking the gas quantity added when low gas is detected. More accurate tracking of SF6 loss is only possible if SF6 quantified values of density are recorded at defined intervals. Even though such records could be manually kept, the process makes sense only with automated systems.

Partial Discharge

Partial discharges (PDs) are small electrical discharge processes that happen in some types of electrical insulation systems. In some situations, particularly with advanced multicomponent setup, PD is almost considered a normal occurrence. Nevertheless, in many situations, PD is an indication of an insulation defect and its presence shows some form of deterioration. Generally, GIS fits into this category – GIS should be PD free. In reality, detection sensitivity limitations factor into this analysis. Also, some types of low-level PD might not be of consequence within the anticipated equipment lifetime. Therefore, for acceptance testing, upper bounds on PD levels are typically adopted. Any PD lower than this level is typically considered to be of little consequence to the overall equipment health.

Nevertheless, from a monitoring perspective, the objectives are slightly different. Monitoring is used to determine if major insulation deterioration is developing over time and to assist in analyzing this situation. Ideally, monitoring is used to assist in addressing the following:

- Is there a developing insulation issue?

- Where within the device is this problem happening? What elements are suspected?

- How serious is the problem? What are the effects?

- How much time is needed to resolve the problem?

The first question refers to detection. Since GIS, needs to be PD free, any detection of PD above a minimum threshold is construed to be reading of a developing problem. Nevertheless, reading has to be followed up with the second issue of location, particularly if the sources of the PD can be found. PD from different elements need to be differently interpreted and analyzed. If the PD source is found, an assessment can typically be done. The last question referring to the available time would be very useful to many end users (since it allows for planning) but is the most challenging to answer, particularly as random processes are involved. For example, some insulator defects types that create PD can cause failure almost instantly but might also last for many months or years without causing any issues. For most monitoring plans, practical objectives would focus on detection and location, from which analysis can follow with proper and educated interpretation.

Failure Types

In GIS installation, there are different defect types that could create PD.

1. Metallic particles. Metallic particles are, by far, the most defect type found in GIS installation. Nevertheless, metallic particles are mostly the problem during commissioning since they are typically introduced during the assembly process. For in-service monitoring, metallic particles are less of an issue. Nevertheless, particles in relatively harmless areas could be physically moved into more active locations through vibration and other mechanical forces that are created by breaker operation. Also, enclosures with moving parts will occasionally create their own particles over time through wear, particularly if some mechanical deficiency exists. Particles "free" to move inside the GIS installation are relatively simple to detect. Movement due to acquired charges in the applied electric field will cause the particles to "bounce" along the GIS cylinder, creating both acoustic and electrical signals on contact. Nevertheless, metallic particles that become adhered to an insulator surface are especially dangerous. These metallic particles can, start surface tracking on the insulator and lead to failure. However, the PD related to such development in the early stages can be very low and challenging to detect.

2. Floating elements. M… otect specific high-stress
locations. These shie… own potential, whether it
is the main high volt… situations, the contact is
made using low force … mage or contamination,
electrical contact coul… . Partial discharges will
typically happen betwe… onductors. In the early
stages, the PD could … ess, when completely
realized, the floating ele… asily both electrically
and acoustically. Floatin… rather hazardous and
could cause damage in a … ging can create local
SF6 gas decomposition - … arby insulators and
may cause them to collaps… also create conducting and
non-conducting particles, … wears away.