VAISALA / WHITE PAPER

Online Dew Point Monitoring of SF6-Gas-Insulated Equipment

In recent years, online monitoring of SF6 dew point has become increasingly common. However, the factors that affect the reliability of online measurement in an environment where there is no gas flow, are not so well known. This paper explains water vapor and moisture transient behaviour and examines their fundamental impact on the installation process, installation design and the selection of connector and sealing materials.

In order to maintain the insulation properties of SF6 and to reduce the formation of corrosive by-products from SF6 decomposition, the amount of water vapor in gas-insulated high-voltage equipment must be kept to a minimum. Although initially filled with dry gas and being closed equipment at elevated pressure with no external gas flow, the high penetration ability of water molecules may increase the moisture level, especially as equipment ages.

Traditionally, moisture level has been checked using periodically taken gas samples, but in recent years condition-monitoring systems that incorporate online instrumentation for measuring the dew point of SF6 have become increasingly common. However, it has become apparent that this type of application presents challenges that are quite different to those experienced in more typical industrial dew point measurement or the measurement of basic parameters such as pressure and temperature in SF6-insulated equipment. In particular, the method of installation, the materials used in the measurement system, and the connector types are critical in determining whether the measurements really do provide the intended valuable data for asset management. Furthermore, remote equipment location often sets demanding requirements for stability and the length of the maintenance period of instrumentation used for condition monitoring of high-voltage assets.

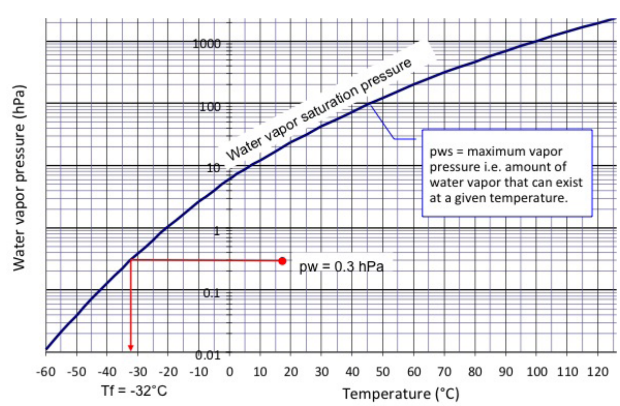

Figure 1. Example: water vapor pressure 0.3 hPa (mbar) vs. dew point.

+20°C		
	SF6 @ 4 BAR	AMBIENT AIR
Dewpoint	-40 °C	+9.3 °C
Relative humidity	0.6 %RH	50 %RH
Vapor pressure (pw)	0.13 mbar	11.7 mbar
+35 °C		
Dewpoint	-40 °C	+31 °C
Relative humidity	0.2 %RH	80 %RH
Vapor pressure (pw)	0.13 mbar	45 mbar

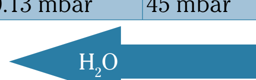

Table 1. Examples of dew point, relative humidity, and vapor pressure in a gas tank and in ambient air at two different temperatures (+20 and +35°C) and in ambient humidity conditions (50 and 80 %RH). Water molecules (H_2O) tend to move from high vapor pressure to low vapor pressure in order to reach equilibrium.

Water Vapor Pressure and Dew Point

Water vapor exists everywhere, and it is always part of total gas pressure – for example, atmospheric (barometric) pressure or system pressure in gas-insulated equipment (GIE).

Dew point/frost point ($T_{d/f}$) is defined as the temperature at which the partial water vapor pressure (p_w) of a gas is equal to the vapor saturation pressure (p_{ws}). In other words, dew point is the temperature to which a gas must be cooled in order for the water vapor to condense into dew or frost → $p_w = p_{ws}(T_{d/f})$

Dew point is not a temperature-dependent parameter, thus it can be measured by taking a gas sample at a temperature different than system temperature. Dew point is, however, highly dependent on pressure, so it is crucial to confirm that it is being measured at the same pressure as the main gas volume, or to know the exact pressure values, in order to be able to carry out the correct conversion for the values – for example, dew point at 4 bar or dew point at atmospheric pressure.

Vapor Diffusion

In the vapor phase (gas), water molecules are not bound, and due to their small molecular size they can move about easily. Water vapor tends to reach equilibrium between different phases, thus water molecules tend to migrate from higher vapor pressure to lower, even through polymeric materials like sealing rings or along metal surfaces at connection points. This behavior also occurs from lower total gas pressure to elevated system pressure, for example in the case of ambient air vs. SF6 in high-voltage equipment. So pressure-tight does not necessarily mean water-vapor tight. The diffusion effect is very slow and is only visible through online measurement of small volumes of static gas.

Moisture Transients

Water vapor pressure inside a sealed gas system does not remain exactly constant, even if diffusion does not occur. Temperature variations in the system drive moisture (vapor) transients between the two phases, i.e. gas and solid materials in contact with the gas. When temperature increases, solid materials release vapor to the gas because the two different phases tend to reach moisture equilibrium, i.e. equilibrium-relative humidity; with decreasing temperature the inverse occurs. The moisture sources inside gas insulated equipment (GIE) systems can be the pores of metal surfaces and organic materials such as spacers and sealing rings. The larger the surface area of solid materials, versus volume of gas, the greater the effect of vapor transients on dew point.

Figure 2: Outdoor installation into a "sensor block".

Figure 3 shows the effect of vapor transients in an on-site installation in Finland during fall 2010. Due to the fact that the sensor is installed in a small block with both long tubing from the main gas volume and multiple connection points, the gas around the sensor area does not necessarily represent the true dew point conditions inside the main gas tank.

It was not clear whether the detected moisture transients were occurring solely in the main gas volume or just along the gas sampling line where the sensor was located. It was not possible to take any reference measurement directly from the main gas volume because there was no available connection point for an additional sensor.

One other important factor with such installations is temperature. If the sensor is installed in a remote location, it is possible that at some point the temperature at the sensor location will be significantly different than in the main gas volume, thus the moisture transients in the main gas volume and along the gas line result in the gas having significantly different moisture levels. Due to the fact that vapor diffusion in static gas is a very slow process, the measured dew point values may not be representative of the main gas volume. This is especially likely to happen in the case of constant temperature variations, which result in continuous dynamic moisture transients, i.e. equilibrium is not achieved.

This kind of setup would not be problematic in the case of pressure or density measurements, but with dew point measurement such installations may result in incorrect conclusions. The volume of water vapor relating to the transients in the gas line is extremely small, but it becomes visible during online measurement in a small volume of static gas.

Installation of an Online Dew point Sensor

When designing an online measurement setup for a dew point sensor in SF6-insulated equipment, the basic principles of water vapor behavior described earlier should be taken into account in order to ensure correct measurement and thus to enable valid conclusions to be drawn. Traditionally the dew point of SF6 has been measured by taking a gas sample from the tank, meaning that there has always been gas flow to account for during these measurements. Gas flow conceals the effect of very slow diffusion and vapor transients between gas and solid materials.

To date it has been quite common for dew point sensors to be installed in the same sensor block as pressure relays or density sensors. In addition, these blocks are often not directly attached to the main gas tank, but connected to the tank with either polymeric or metal tubing. These various connection points and tubing are likely to introduce space for vapor diffusion and provide a medium for moisture transients. In a relatively small volume of static gas, these effects begin to play a dominant role, thus installing a dew point sensor in the manner described above would likely result in measurements that do not necessarily provide the intended valuable data for asset management.

In order to ensure the best possible online dew point measurement in an SF6-insulated system, the sensor should be installed as close to the main gas volume as possible, preferably directly onto the tank wall. Minimizing the number of connection points and avoiding the use of plastic or rubber materials close to the measurement cell is also highly beneficial. Metal-to-metal sealing should be preferred whenever applicable.

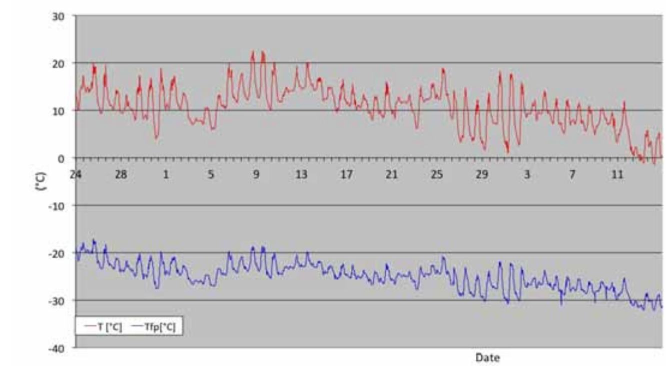

Figure 3. *Measured dew point (Tfp) vs. temperature of an SF6-insulated switch in Finland (fall 2010).*

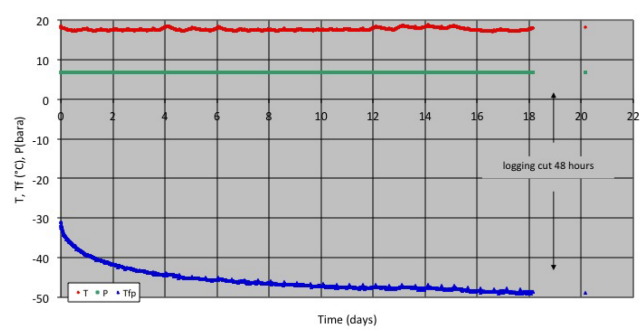

Figure 4. *Measurement data (dew point, pressure, and temperature) from an indoor system.*

System Response After Sensor Installation

The response time of dew point measurement in GIE is not defined by the response time of the sensor itself, which is typically measured in seconds or minutes. The dominant factor is the system response after installation. When installing the sensor, some initial moisture from ambient air is also introduced into the system's connection point. Considering the total SF6 volume, this amount of vapor is negligible; however, from the point of view of the sensor inside the measurement cell, the effect is clearly visible and measureable. It will take quite some time for the vapor pressure in the measurement cell to reach equilibrium with the main gas volume. Even if the sensor is installed very close to the main tank, it can take hours or even a few days until the vapor pressure, and therefore the dew point, are equal in both gas volumes.

The system response time is determined by how quickly the measurement cell dries to the same vapor pressure as the main SF6 volume after the installation, meaning how quickly water molecules move from solid materials to the gas in the cell and then diffuse from the cell to the tank, finally reaching equilibrium. The drier the gas, the longer the drying of the solid materials and surfaces takes, especially in static gas. The distance between these two volumes and the dryness of the SF6 affects the diffusion rate from the cell back to the tank. The longer the distance and the dryer the gas, the longer it takes to achieve a 100% correct response. If there is too much diffusion through the tubing or contact points, it is also possible that the vapor pressure inside the measurement cell will never reach equilibrium with the main gas volume, and thus the measurement will not be representative of the true conditions inside the tank.

Figure 5. Installation of a dew point-pressure-temperature sensor (DPT145) directly to the main gas tank (25.3– 14.4.2010).The gas volume in the measurement cell is roughly 20 ml.

It is therefore very important to minimize the introduction of initial moisture during installation. In order to avoid water droplets getting into the sensor connector, installation should not be carried out during rainy weather conditions. Great care should also be taken to ensure that no dust or dirt particles remain on the sealing surfaces, because these may later act as a medium for the diffusion of water molecules, ruining the measurement and, in the worst case, cause wetting of the SF6. In outdoor installations, a rain shield should be used to prevent water from gathering on the connection points and increasing vapor diffusion.

System Response During Operation

It is reasonable to ask how the sensor responds if the dew point of the main SF6 gas volume starts to increase, as the system response is rather slow directly following sensor installation.

The most dominant factor determining this slow initial response is that the drying of solid material surfaces (pores) takes a long time even when gas flow is involved; in static gas drying takes significantly longer. This phenomenon only has a marginal effect when gas containing more moisture diffuses from the main tank into the drier measurement cell, where dew point is measured.

A second factor to take into account is that in a high volume of SF6, dew point increase by diffusion through sealing materials or along metal surfaces is a very slow process. It is evident that when dew point starts to increase in the main tank, it also starts to increase in the measurement cell and is detected by the sensor more or less at the same time – assuming that the sensor is sufficiently close to the main tank.

Whether the dew point values are exactly the same at the same point in time (100% response) is not really relevant because it is the increasing trend that highlights the fact that corrective action needs to be taken.

Any quick, dramatic change in dew point indicates a leak that should be detected by both dew point and pressure measurement.

Summary

In order to ensure that an online measurement system provides reliable and valuable dew point data with minimized uncertainty, it is crucial to pay careful attention to both the design of the dew point sensor installation and the installation process itself. The quality and long-term stability of the sensor being used is also a critical factor. The best measurement results will be achieved when the sensor is installed directly to the main gas tank. Only high-quality metallic materials should be used, both for the connectors and the sealing close to the sensor. By ensuring that the sensor reading reaches the dew point value of the main SF6 volume after installation, it is possible to confirm that any excess diffusion occurring via connections and/or tubing is not disturbing the measurement and that the data received is reliable in the long term, thus avoiding any false alarms.