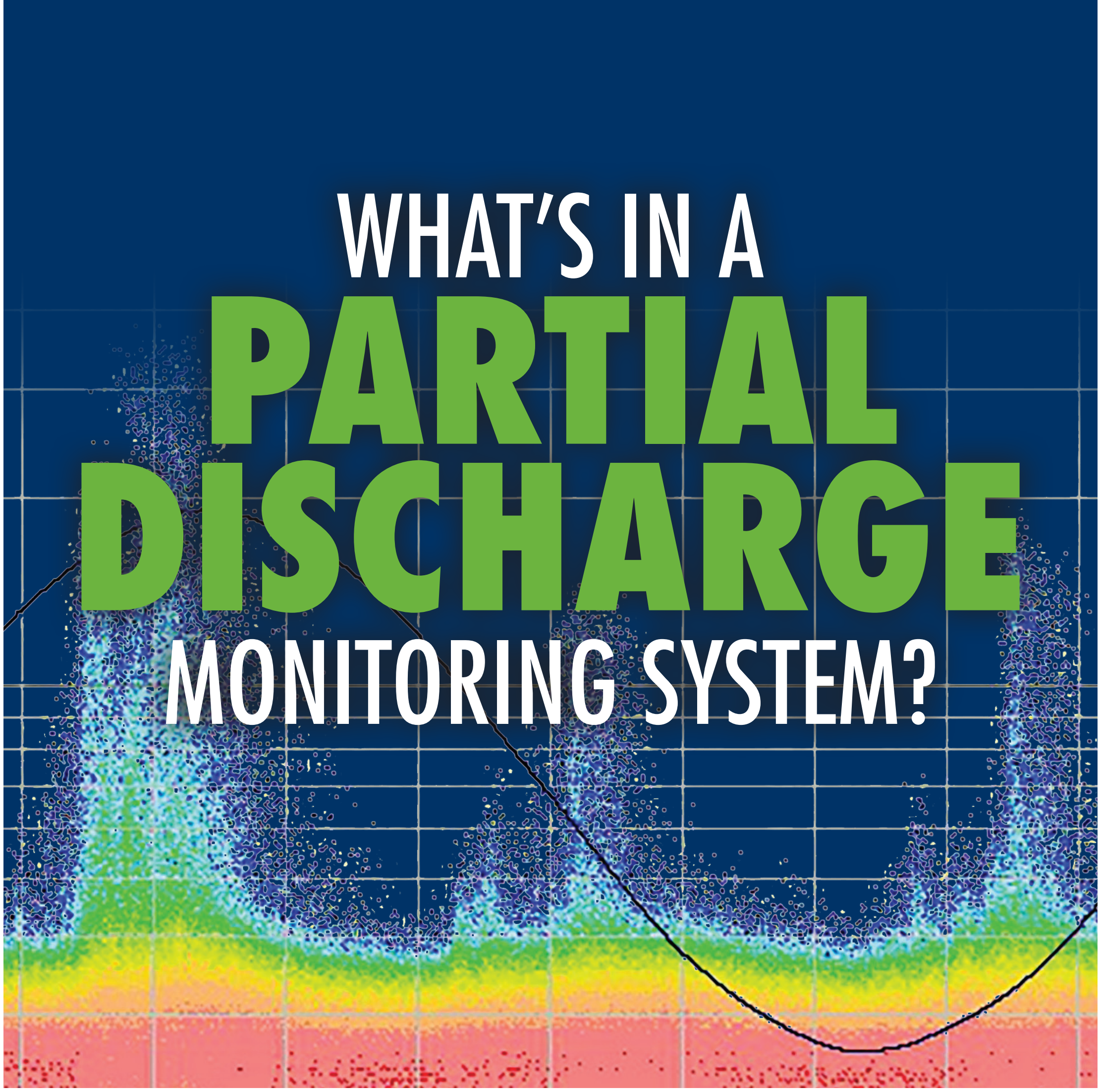
FEATURE



WHAT'S IN A PARTIAL DISCHARGE MONITORING SYSTEM?

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Partial discharge (PD) testing is becoming common in U.S. industrial systems and is gaining acceptability in U.S. utilities. Testing in the form of periodic surveys can provide valuable insight into asset condition. Beyond periodic surveys, full-time system monitoring is the state of the art in PD detection, offering additional capabilities that:

- Warn of rapidly evolving PD situations that might go from inception to failure faster than a periodic survey interval.
- Allow trending of slowly evolving data to better confirm real degradation.
- Allow trending with external events such as load charges or environmental changes.
- Provide better data than periodic surveys through additional sensors or time-of-flight fault location.

A permanently installed full-time monitor with dozens of sensors is a larger commitment in capital, effort, and expertise than a periodic survey tool. This article explains the technology involved in full-time monitoring.

OFFLINE VERSUS ONLINE TESTING

Offline testing for PD has been around for several decades. IEC 60270 defines how it is to be done, and several IEEE/ANSI standards discuss and clarify offline testing. A VLF PD-free power source energizes an electrical asset by measuring impedance. Any discharge current that is present in the sample causes a drop in voltage across the impedance that is proportional to the discharge current. The sample is disconnected from the power system, and the voltage is supplied by the external source. This process requires quite a bit of effort and expertise.

During online testing, the asset is in service and is energized by the power grid. A variety of sensing techniques can be used to detect PD in normal operation. Online testing has advantages and disadvantages. For example, the system voltage cannot be varied to determine where the PD starts and where it extinguishes. However, online tests are done at system frequency and real operating conditions, so they are more representative of real-world conditions. All full-time monitoring is online.

Monitoring systems are made up of hubs and sensors. Hubs are the access points for users. The sensors are connected to the hubs via cables and fibers. Sensors can be connected to the hub through intermediate nodes (Figure 1) or directly to the hub. Connecting hundreds of sensors directly to one hub requires significant wiring.

Monitor Hubs

Called different names by various manufacturers, the hub is the brain of the system. The hub puts all the sensor data into a format for the user to see, stores the data, applies algorithms and filters, and provides the user interface. Hubs are mounted outside the high-voltage compartments, connected to the sensors via cables, and usually accessed by Ethernet or cellular connection, which allows the user to see the data from anywhere at any time. Hubs can generate alarms and emails alerting the user to degrading conditions.

Some hubs store all the data locally; others stream it to the cloud. Cloud-based systems allow users to get to the data even if the hub is temporarily offline. User interfaces vary, but many are graphical and allow visualizations of the data over time. Simple systems that do not provide sufficient data may not allow the user to differentiate noise from real PD.

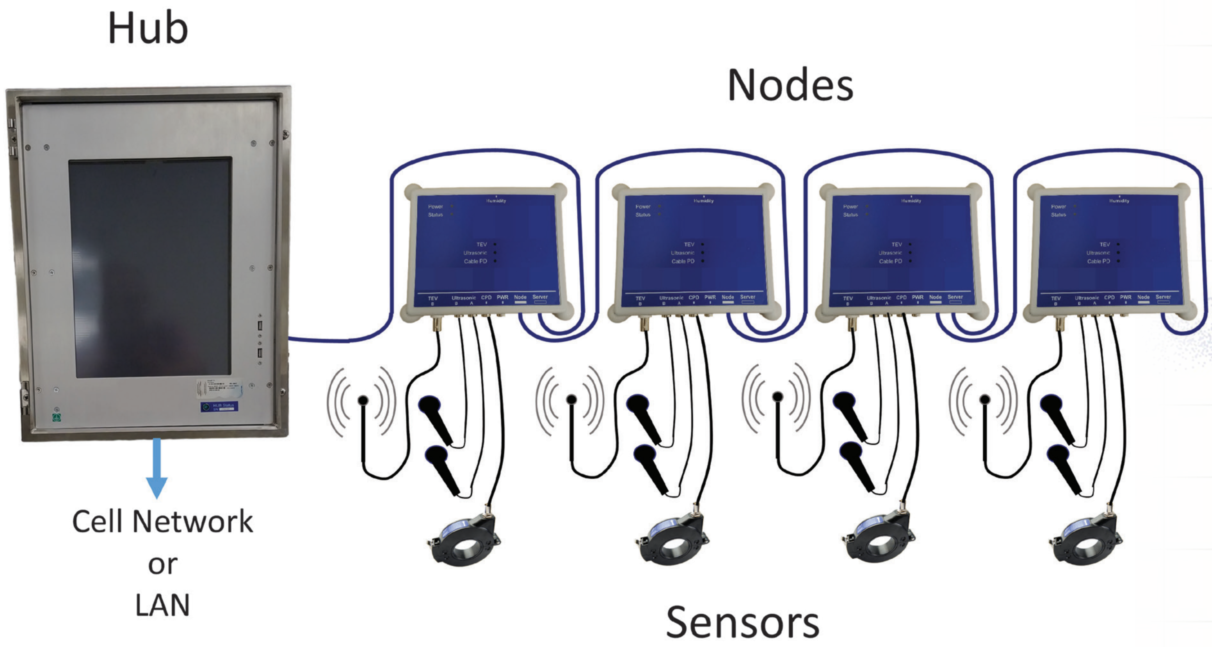

Figure 1: *Typical Online Monitor with Hub, Nodes, and Sensors*

DIRECT CONNECT VERSUS NON-INVASIVE METHODS

Online monitoring can be further broken down into direct connect and non-invasive methods. In direct connect systems, voltage sensors (coupling capacitors) are connected to bus bars and connection points. Radio frequency current sensors are sometimes added to cables. These sensors require the system to be de-energized and are usually installed prior to initial commissioning.

Non-invasive sensors pick up side effects of the discharge such as airborne acoustic energy, transient earth voltage, EMI emissions, ultraviolet (UV) light, and cable ground strap current. These sensors do not provide direct readout of PD discharge current, but they don't require direct connection to HV conductors. This allows these systems to be retrofitted, sometimes without even de-energizing.

Direct Connect Sensors

Voltage sensors containing a capacitive voltage divider connect directly to bus bars, breaker spouts, joints, etc. This device spans the phase-to-ground voltage, so it requires high power frequency voltage withstand capability. For safety, the voltage and basic insulation level (BIL) ratings of the sensor must equal the ratings of the switchgear. The sensor consists of two capacitors in series forming a divider ratio such as (1:2000). The smaller capacitor is attached to ground; a surge limiter across this capacitor is often used to protect the monitoring circuitry. These sensors must be installed with the same care as all other high-voltage components. Poor installation can cause PD or even catastrophic failure.

Another direct connect sensor is a radio frequency current transformer (RFCT) placed around the core conductor of a cable. This is typically installed on a portion of the cable after the shield is removed to avoid potential cancellation of the PD current. Cable insulation is still present, but the RFCT typically provides little or no insulation. This means the RFCT is in a potentially hazardous area and must be placed carefully. Poor placement can cause PD or catastrophic failure just like the voltage sensor.

Once these sensors are properly installed and routed through signal cables outside the switchgear, the gear can be commissioned and monitoring placed into service. A full-voltage hi-pot test is required because the insulation of the sensors to ground must be confirmed prior to energization.

Non-Invasive Sensors

Non-invasive monitors use different sensing technology. These sensors are termed non-invasive because they are not directly connected to or placed around the conductor. They do not require insulation, and they do not provide insulation of system voltages. Many of these sensors can be placed with the system energized and the cubicle doors closed. This allows monitoring systems to be retrofitted either online or with a brief outage.

- **Airborne ultrasonic.** Surface discharge tends to generate significant acoustic energy in the ultrasonic band. Under the right conditions, an airborne sensor can pick this up even before visible damage is present. An airborne sensor requires an air path from the source of the discharge to the sensor. The sensor can be placed inside the cubicle but far away from the HV equipment, or it can be placed outside the cubicle (Figure 2) provided it is aimed at an airpath to inside such as a louver, vent, or bolt hole.

Figure 2: *Ultrasonic Sensor Mounted Outside Cubicle*

- **Contact ultrasonic.** In the event no airpath exists, as might be the case in well-sealed gear, a contact sensor outside the cubicle can be used. A contact sensor detects s the vibration of whatever it is attached to. A sensor mounted on the outside of a door can detect airborne ultrasonic energy impinging on the door. For this to work, the sensor must be very sensitive. The downside is that the sensor is non-directional; ultrasonic noise from outside the cabinet or inside the cabinet will both cause the door to vibrate. This tends to result in a higher noise floor and less distinct sounds. Contact sensors should only be used where airborne sensors cannot be installed.
- **Transient Earth Voltage.** Transient earth voltage (TEV) is a by-product of partial discharge inside grounded conductive enclosures such as metalclad switchgear. Discovered by EA Technology in the late 1970s, TEV results in a short-duration (1–5 microseconds) unipolar voltage pulse on the outside surfaces of such an enclosure. The sensor, which is typically a flat plate 1–3 inches in diameter with some type of fixing arrangement such as magnets, uses a capacitive connection to the surface to detect the voltage. Because the pickup is capacitive, it can work through paint. The TEV sensor is placed on the outside surface of the switchgear; placement near the center of each panel is ideal, but not critical. Every high-voltage compartment should have a sensor. For example, if the bus bar compartment is separate, a sensor on its end plate would be helpful.
- **RF Antenna.** RF antennas can serve two functions in non-invasive monitoring: They can detect PD or noise. If placed where PD detection is desired (for example, inside the cubicle), they can act as a source of signal to the monitor (Figure 3, lower left). These types of antennas vary greatly in size and shape. Ideally, the antenna is sensitive, omnidirectional, and tuned for a range of frequencies common to PD. The second use of antennas is to pick up noise. TEV sensing, in particular, is subject to radio frequency interference. While it might not be mistaken for PD, radio noise can swamp the desired signal and make analysis difficult. If external antennas are used, the monitor can detect the noise and use time of flight to determine whether the signal originates outside the switchgear.

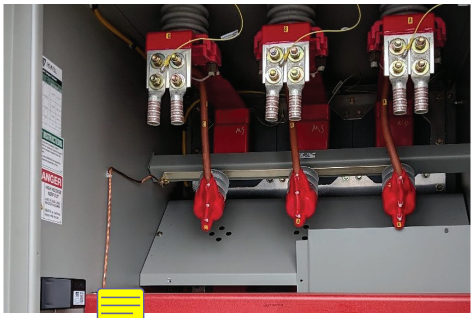

Figure 3: *RF Antenna Mounted Inside Cubicle*

- **Radio Frequency Current Transformer.** RFCTs are used in direct connect and non-invasive systems, but they tend to be used differently. In a non-invasive system, RFCTs are placed on the ground straps of shielded cables (Figure 4), where they can detect the PD current pulse that typically travels down the conductor, through the defect, to the shield, and down the shield. Placing the RFCT on the shield ground is inherently safe as long as the ground remains intact. It is the installer's responsibility to ensure the ground wire will not fail under any fault condition. If the RFCT is on the high side of the break, failure of the ground wire could lead to

Figure 4: *RFCT Sensors Installed on Ground Straps*

disastrous results. In IEC-type switchgear, ground straps tend to be outside the box, allowing easy installation while live. The ground is typically inside the HV compartment in U.S. switchgear, and it cannot be installed live.

Other Sensors

Any monitoring system can use additional sensors to provide more input to the analysis process.

- **Environmental.** Since surface PD is related to humidity, ultrasonic and humidity trends can be matched. This can rule out other sources of ultrasonic noise.
- **System Frequency.** As all PD occurs in specific spots on the power system voltage cycle, knowing the exact frequency of the power system is important. Direct connect systems inherently obtain that information from the voltage sensors. A separate ac sensor (typically plugged into a wall outlet) provides that information to a non-invasive system.
- **Temperature.** Sensing the temperature of cabinet doors or busbar connections can help indicate severe problems. Many monitors include mechanisms to measure the temperature of panels and/or bus bar connections. Fiber connections from the bus bar provide the isolation. The yellow fibers in Figure 3 are temperature sensors.

MONITORING FUNCTIONS AND ANALYSIS

It is beyond the scope of this article to cover all the functions of a monitor and how to analyze the results. However, the major functions of PD monitors include:

- Phase-resolved plots that relate impulses from any sensor to the voltage wave provide a critical means to eliminate noise. PD occurs synchronously with the power system frequency; noise typically does not (Figure 5).
- Listening to audio/ultrasonic sound clips is a common way to detect PD. Listening remotely can avoid a site visit.
- Using multiple synchronized RF sensors to measure time of flight can locate the source by determining which sensor triggers first.
- PD is usually a slowly developing phenomenon, and long-term trending over months can highlight issues that might escape detection in a survey.
- False alarms are a nuisance and reduce customer confidence. Using complex alarming algorithms to look at a variety of factors can result in fewer trigger-happy alarms.

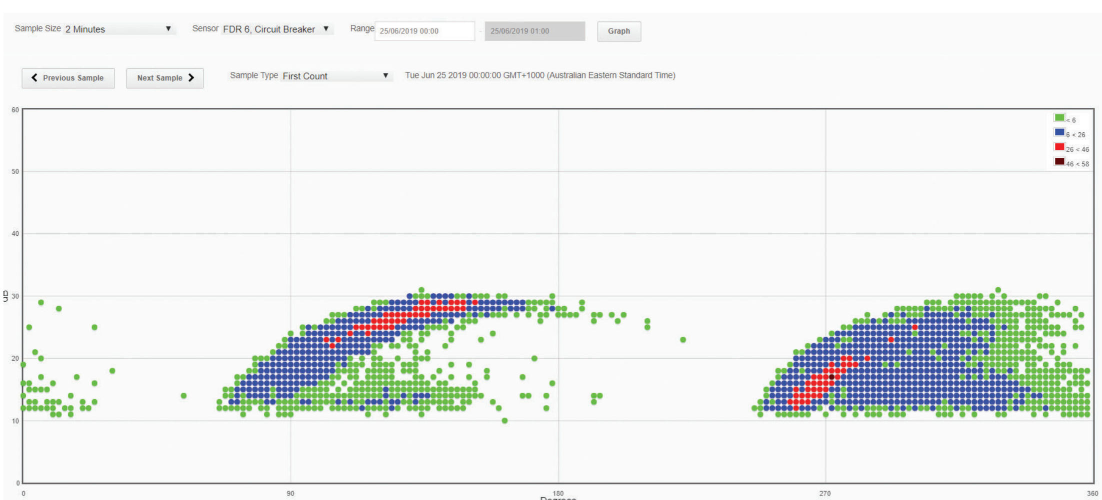

Figure 5: *Phase Resolved Plot Showing Significant PD*

CONCLUSION

Online monitoring systems provide the ultimate in PD detection. They can be seemingly complex and daunting for a new user, but they are merely extensions of the periodic test technology technicians already know. Configured, installed, and commissioned by a skilled tech, online monitoring can be a new source of revenue for testing firms while offering substantial benefits to their customers.

If you are interested in this topic and want to learn more, please plan to attend Bill Higinbotham's seminar at PowerTest 2020.

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