

Predictive Diagnostics for Switchgear

White Paper

Switchgear Reliability and Personnel Safety Solutions

Advances in materials science, designing and manufacturing process made medium voltage switchgear much more reliable. In spite of this, insulation failures continue to happen often resulting in catastrophic equipment damage.

Periodical maintenance tests can still leave switchgear in virtually unknown condition. Insulation defects and deterioration may very well develop in service within maintenance cycle. These defects are often not detectable with traditional off-line tests.

Continuous on-line insulation monitoring is a proven solution to assess switchgear condition in real time and keep the risk of failure and workplace safety under control.



Degradation of Insulation in Switchgear

Electrical insulation is subjected to electrical and mechanical stress, elevated temperature and temperature variations, and environmental conditions especially for outdoor applications. In addition to normal operating conditions, there are a host of other factors that may trigger accelerated aging or deterioration of insulation. Switching and lightning surges can start ionization in an already stressed area. Mechanical strikes during breaker operation can cause micro cracks and voids. Excessive moisture or chemical contamination of the surface can cause tracking. Any defects in design and manufacturing are also worth mentioning.

Both normal and accelerated aging of insulation produce the same phenomenon in common — Partial Discharge (PD). PD is a localized electrical discharge that does not completely bridge the electrodes. PD is a leading indicator of an insulation problem. Quickly accelerating PD activity can result in a complete insulation failure.

PD mechanism can be different depending on how and where the sparking occurs:

- Voids and cavities are filled with air in poorly cast current transformers, voltage transformers and epoxy spacers. Since air has lower permittivity than insulation material, an enhanced electric field forces the voids to flashover, causing PD. Energy dissipated during repetitive PD will carbonize and weaken the insulation.
- Contaminants or moisture on the insulation induce the electrical tracking or surface PD. Continuous tracking will grow into a complete surface flashover.
- Corona discharge from sharp edge of a HV conductor is another type of PD. It produces ozone that aggressively attacks insulation and also facilitates flashover during periods of overvoltage.

Features of partial discharge activity, such as intensity, maximum magnitude, pulse rate, long-term trend, are important indications of the insulation's condition. Healthy switchgear has very little or no PD activity. If PD activity is significant, it will eventually deteriorate insulation to a complete failure. Higher voltages produce higher intensity partial discharges, thus PD detection in gear with higher voltages (13.8 kV and up) is more critical.



PD on Bus



PD Between Bus and Cubicle Wall



Surface Tracking on Primary Stab



Insulation Damage on Voltage Transformer

Photos on Page 2 and to the right show damages resulting from partial discharge activity. Complete failure of the insulation in these examples can be prevented by PD monitoring.

Possible locations of partial discharge in switchgear:

- Main bus insulation
- Breaker insulation
- Current transformers
- Voltage transformers
- Cable terminations
- Support insulators
- Non-shielded cables in contact with other phases or ground



PD Damaged Insulation on Current Transformer



Tracking on a Support Insulator

Usually in insulation, the deterioration process is relatively slow and the problem can be detected, located and fixed.

Why is Continuous On-line Monitoring PD Necessary?

Traditionally, on-line or off-line PD tests have been performed on a periodic basis commonly twice a year. Continuous PD monitoring has the following advantages over periodic PD testing:

- Periodic on-line PD test could miss significant PD activities since PD activities vary by time. On-line continuous monitoring eliminates the inherent flaw of interval-based testing.
- Trending of PD activity is one of the most important parameters for predictive diagnostics. Periodic tests will not be able to provide sufficient information for diagnostics based on trending.
- On-line monitoring provides more accurate information than off-line testing since off-line testing conditions can differ greatly from real operating conditions.
- Continuous on-line monitoring effectively reduces labor costs. In addition, the PD data saved in the instrument can be accessed anytime, anywhere with modern communication means.

What's the Difference Between PD Systems?

Partial discharges are very short pulses with rise time from fraction of nanosecond to several dozens of nanoseconds. PD pulses have a very broad frequency spectrum from DC to hundreds of megahertz.

Different PD analyzers are designed to use different frequency bands depending on the application and noise environment.

High frequency PD systems (above 100 MHz band) have better inherent noise rejection due to a high signal to noise ratio. These systems will not, however, sense distant PD signals as high frequency components attenuate quickly as the signal travels from its origin to a PD sensor.

In contrast, low frequency measurement technology within an industrial noise environment will make on-line PD measurements almost impossible.

Selection of a suitable measurement frequency band does not guarantee complete noise suppression. Noise sources include sparking in surrounding equipment, radio station operation, operation of power control electronics, welding, etc. A combination of noises from different sources can be very complex and there is no single procedure to reject all types of noises at one time.

Usually PD measuring systems are equipped with different kinds of noise cancellation tools, such as analog filters, digital filters and special noise identification sensors. PD pulse identification algorithms can be implemented in hardware and software.

Another important feature of the PD instrument, especially for switchgear, is the number of measuring channels on a single PD monitor to acquire PD signals. Since switchgear lineups often include a number of cubicles, fewer channels means more PD monitors are required at higher cost.

A higher number of channels with simultaneous synchronous acquisition increases the quality of measured PD data. It also allows the use of more noise cancellation algorithms.

What Additional Parameters Should be Monitored?

There are several dynamics that can significantly affect partial discharge. The most important ones are temperature, humidity and voltage.

Correlation between PD and these factors provides valuable information for diagnostics of an insulation problem in switchgear.

PD Sensors for Switchgear

There are two major types of partial discharge sensors for switchgear lineups — coupling capacitors and radio frequency current transformers (RFCT). Besides, Eaton is also capable of using epoxy bottle on switchgear as an effective PD sensor.

Coupling capacitor PD sensors are a high voltage device that directly connects to an energized high potential bus.

The capacitance of the couplers is usually in the range of tens to hundreds of picofarads. The 80 pF capacitor is the most popular due to its advantages of good sensitivity to high frequency signals, compact volume, etc. Each sensor is able to detect PD occurring in a limited zone because of signal attenuation while traveling from place of the origin. Commonly, one set of coupling capacitors per three vertical sections is enough for reliable detection of PD activity.

RFCT sensors are usually installed over feeder shield grounding cables and sense pulse currents produced by partial discharges.



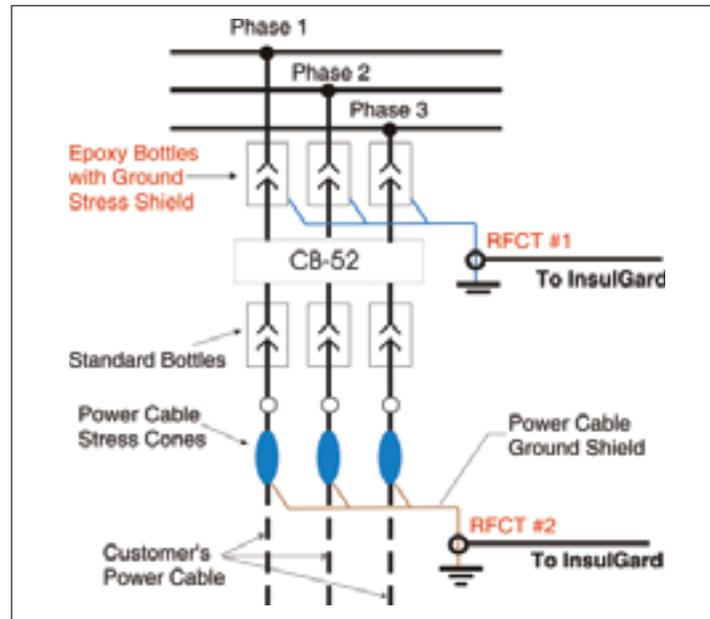
An Example of Installation of a Set of Coupling Capacitors



An Example of RFCT Installation

Coupling capacitors have an advantage of being more immune to noise vs. an RFCT, however, RFCTs can see further into a feeder because they are more sensitive to lower frequencies which travel further. As each coupling capacitor is connected directly to high voltage terminal of each phase, the PD signals are large and it is easy to tell in which phase the PD happens. RFCT is a more economical solution, but it does not have as high sensitivity as a coupling capacitor does. Three RFCTs installed on separate phase shield grounds can distinguish phase information of PD much easier than one RFCT on common ground of three phases. In some applications, RFCTs are the only option; for example, if there is no room for capacitors. In general, coupling capacitors and RFCTs can compliment each other.

A unique approach for PD measurement on switchgear manufactured by Eaton is to make use of the epoxy bottles with molded-in grounded stress shields and RFCT as PD sensor. Capacitance between stress shield and the HV bus works the same way as coupling capacitors do which eliminates the need for coupling capacitors and decreases the cost of PD monitoring system. This space-saving solution has been well tested and verified. PD signals acquired this way are comparable to those of coupling capacitors. An example of typical built-in PD sensor configuration is presented to the right.



A Section of Eaton Medium Voltage Switchgear With Built-in PD Sensors



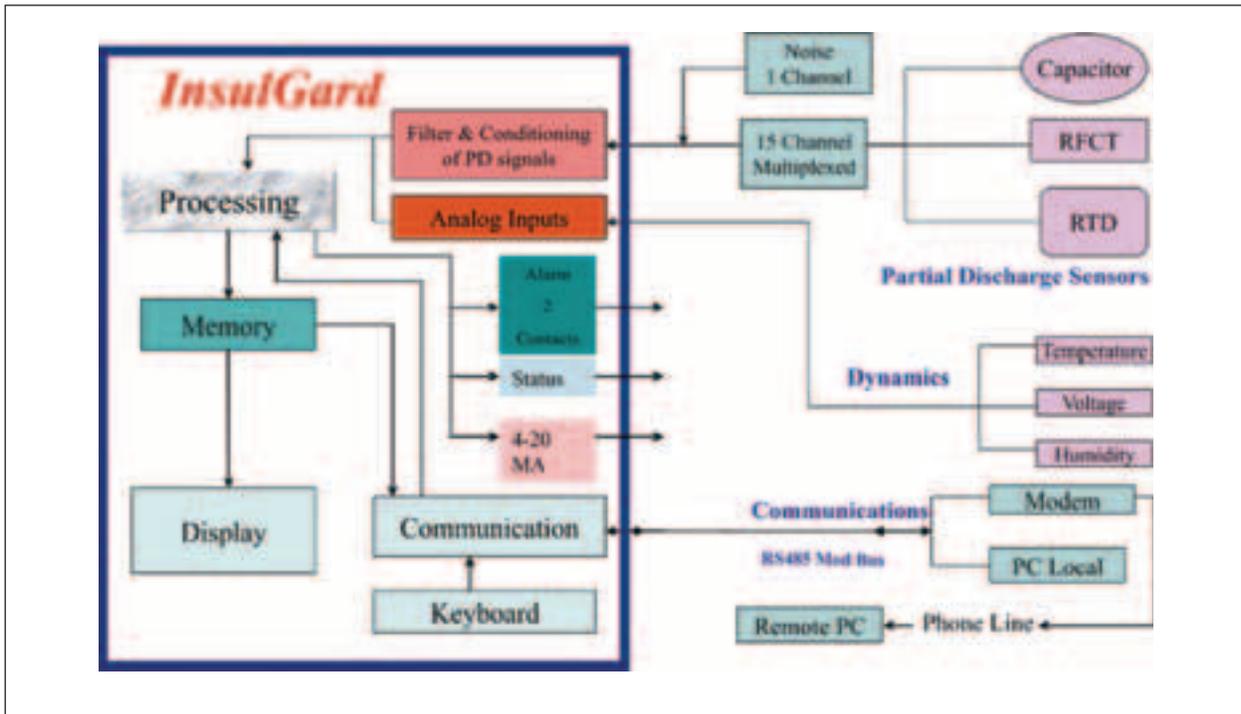
Why InsulGard™ from Eaton?

The InsulGard, a continuous on-line PD monitor by Eaton, has been successfully implemented on hundreds of switchgear of medium voltage range throughout the world. The application includes metal-clad switchgear, metal-enclosed switchgear and medium voltage motor control centers with applied voltage over 4 kV.

InsulGard makes measurements in the optimized frequency band of 1 MHz to 20 MHz and is equipped with advanced technology for noise suppression. When used with permanently installed noise immune PD sensors, the InsulGard can be applied even in very electrically noisy environments.

InsulGard unit has 15 PD measurement channels and one extra noise cancellation channel.

The dynamic parameters such as humidity and temperature can be monitored in-sync with PD measurements.



InsulGard's Components and Functions

What is a Partial Discharge Monitor System from Eaton?

The diagram below shows the principal components of an on-line PD measurement system.



A complete partial discharge monitor system consists of four major components:

- **Sensors:** They efficiently acquire PD signals.
- **Intelligent monitoring unit:** This is the core component of the system. It is responsible for filtering, conditioning and analyzing PD signals. A microprocessor controls the PD measuring process, data storage and communication.
- **Communication:** InsulGard is equipped with an RS-485 port allowing integration into a Modbus® network. Various converters allow for communication through an RS-232 or USB port of a local PC, remote link with a modem or Ethernet networking via secure connections.
- **Software:** InsulGard can be adjusted to local conditions as each and every switchgear lineup and sensor configuration is unique. Other software functions include data downloading, remote settings, visualization, reporting and analysis. This picture to the right shows the trend screen.
- **Installation:** InsulGard PD monitor can be door-mounted or panel-mounted inside switchgear or placed in a weatherproof enclosure. The following photos to the right show examples of InsulGard installed in a switchgear lineup.



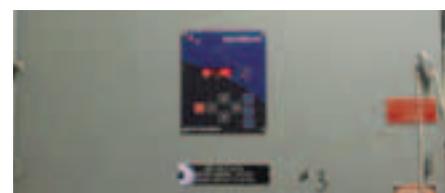
InsulGard Software Trend Screen



Panel-Mounted InsulGard



InsulGard in an Enclosure

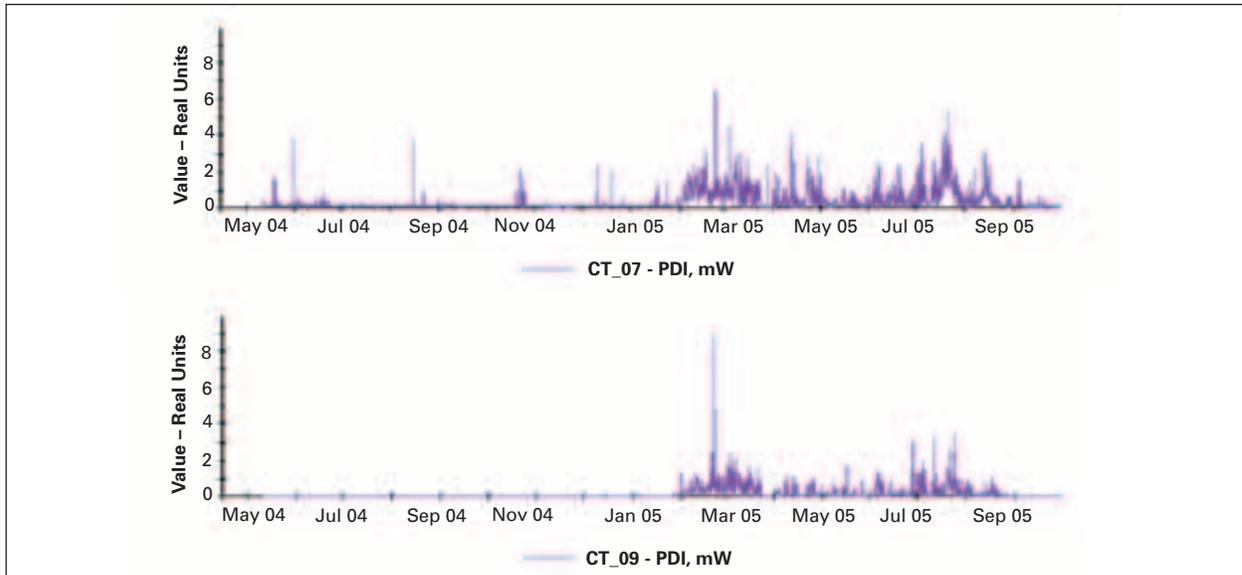


Door-Mounted InsulGard

Case Studies

A. 34.5 kV Substation — Voltage Transformer

Warning light on InsulGard front panel and audible “corona” noise triggered the investigation. Data analysis revealed continuously increasing sporadic PD activity in two vertical sections #7 and #9 next to the section #8 with Voltage Transformer (VT). PD activity was above Warning but below Alarm set points.



Trend Graph for PD Intensity on Two Sensors in Sections #7 and #9

Corresponding Phase Resolved Partial Discharge Distribution revealed evident PD patterns in both sections — VT compartment was not equipped with PD sensors.



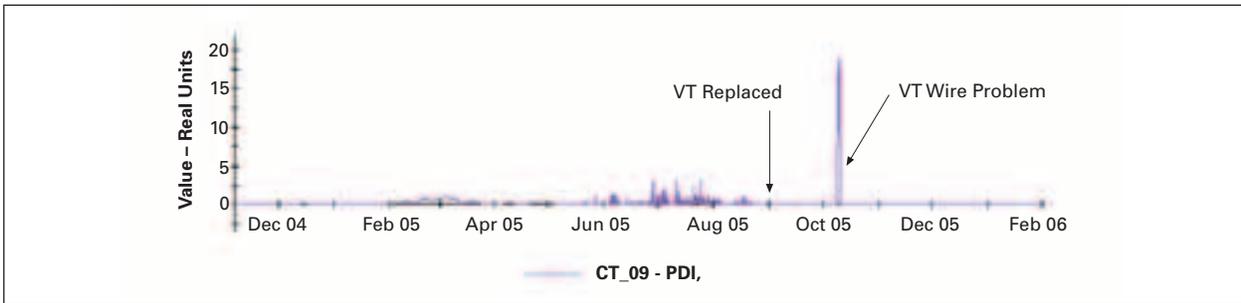
Phase Resolved Distribution Diagrams Created by InsulGard Software



Surface Tracking on A Phase VT

Subsequent inspection revealed significant surface tracking on A phase VT as shown in photo to the left.

After VT was replaced, corresponding PD activity disappeared. However, in a short period of time, Alarm set point was exceeded and the line was inspected again. The source of outburst of PD activity was evident — #12 AWG wire from VT to HV bus came into contact with contaminated fiberglass barrier. Proper wiring eliminated that problem and no dangerous PD activity has been detected since then.

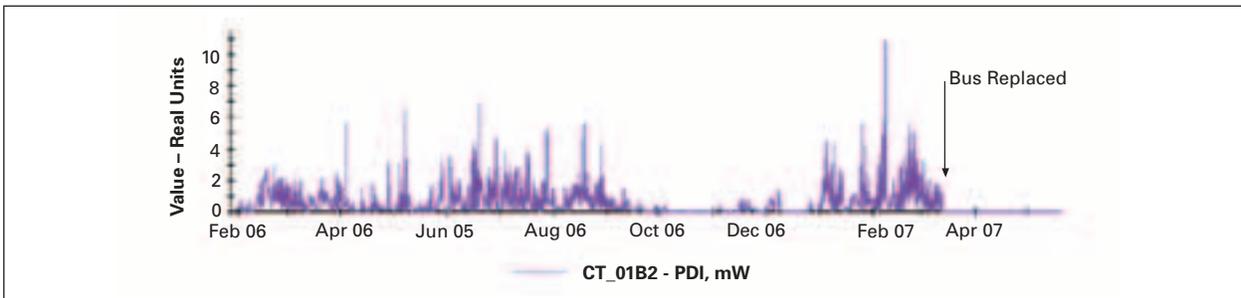


PD Activity Variations

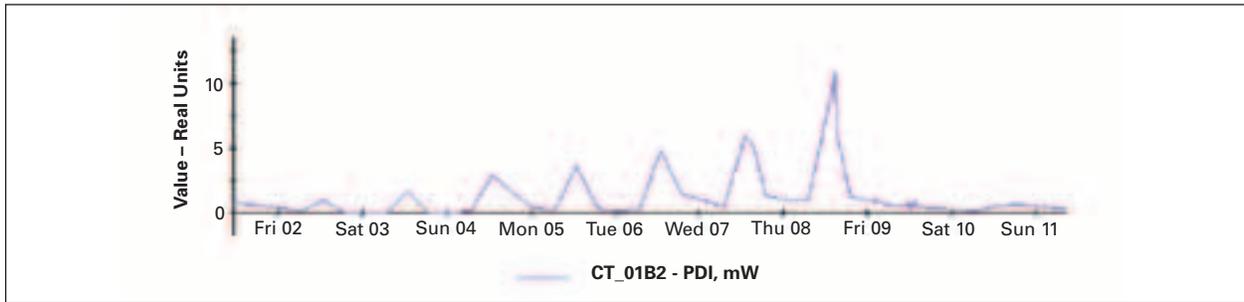
B.13.8 kV Substation in Texas — Outdoor Bus With Water Intrusion

Substation was equipped with three sets of coupling capacitors in every third vertical section, including Incoming Main from outdoor transformer. Substantial unstable PD activity above Alarm set point was detected only in the incoming section. Seasonal and daily variations pointed to the outdoor part of the system. Data analysis and manually initiated additional measurements revealed that PD activity was significant only in the rainy season around mid-day when outdoor temperature was high. It was determined that water penetrated into the bus duct volume, began to evaporate and ultimately increased relative humidity. Seasonal and daily variation of PD intensity for the B phase sensor in section #1 can easily be seen on trend graphs below.

PD patterns corresponding to phase-to-phase and phase-to-ground PD activity were detected only by PD sensors in incoming section.



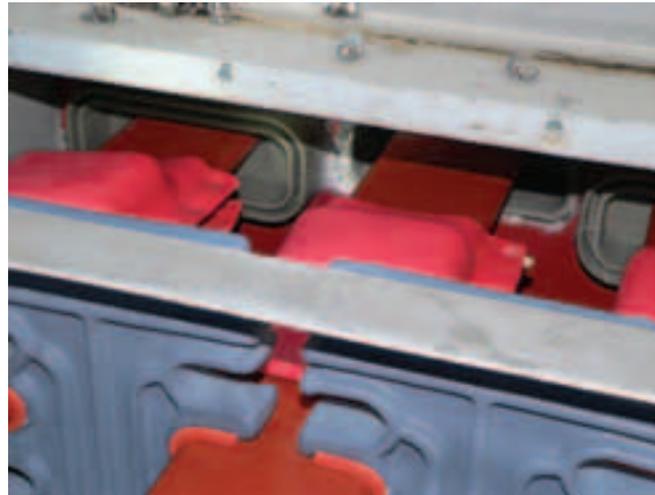
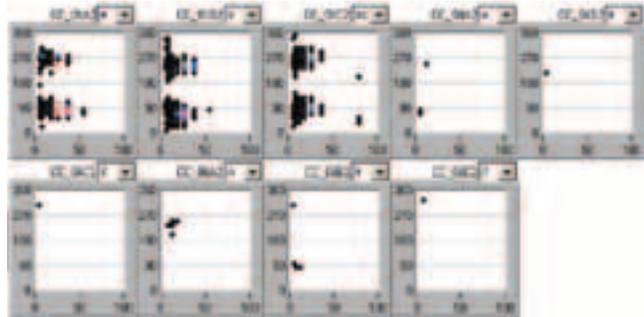
Seasonal Variations



Daily Variations With Maximum PD Activity Occurring Around Noon

Substation was taken out of operation, inspection revealed signs of water penetration into outdoor bus duct and multiple sites with insulation damage by partial discharge as seen in the picture.

Bus was replaced and no PD activity has been detected since then. If not replaced, bus failure would abruptly halt the entire unit and lost production cost could be huge compared to investment made in the PD monitoring system.



Summary

Continuous on-line partial discharge monitoring technology is an efficient way to maximize the uptime and reliability of switchgear. It overcomes the inherent flaw of traditional periodic PD measurements. The advantage is especially dominant when the facility maintenance method is switching from TBM (Time-Based Maintenance) to CBM (Condition-Based Maintenance), or Eaton's patent-pending PBM (Performance-Based maintenance). For more information, please visit our website at <http://www.partialdischarge.com>.

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