Making Sense of Partial Discharge

This paper provides insight into the role of partial discharge monitoring as a practical metric in the IntelliSAW Critical Asset Monitoring (CAM) system with a specific focus on trending and alarm thresholds. While the examples included herein are specific to IntelliSAW measurements, the stated principles are widely applicable.

When it comes to asset health and predictive maintenance, contact temperature, humidity, and partial discharge are the three most important metrics indicative of asset health, and risk of failure.

Temperature and humidity are universally understood concepts, as is their effect on electrical equipment. At high temperatures plating on copper can oxidize, and the asset generally ages at an accelerated rate. ANSI and IEC have defined safe operating temperatures for different classes of electrical equipment. These standards can easily be used to set warning and alarm thresholds for a continuous monitoring system. Likewise, humidity and condensation are well understood to reduce or eliminate the effective insulation (air clearance or surface creepage). As the scale for humidity goes from 0% dry to 100% wet, it too has easy-to-define thresholds for a continuous monitoring system. In both cases, these measurements exist in an easy to understand absolute scale where high values indicate an undesired state of the asset itself.

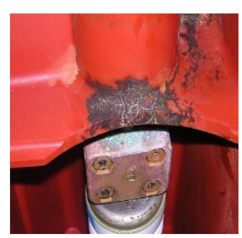
Partial discharge (PD) however does not have a comparable scale with easily defined thresholds, and while it is a key component of the aforementioned three most important indicators of asset health, it is perhaps the least well understood metric. Moreover, the variety of measurement units that can define PD, their respective scales, and most importantly – how PD data can be used in real world applications such as continuous monitoring and predictive maintenance, is not universally understood.

Partial discharge is a concept more familiar than you think.

Lightning is a form of electrical discharge familiar to most. As electrical charges increase in a cloud, it eventually reaches a level where the distance between the cloud and ground, the effective air-gap insulation, no longer acts as a sufficient insulator for a given voltage, and a flashover in the form of lightning neutralizes the existing electrical charge.

Given a high enough voltage any charged surface will demonstrate an electrical discharge in search of an oppositely charged surface. As noted above, this phenomenon is evident in lightning, and on a smaller scale with the static "shocks" we all experience in cold, dry weather when contacting a metal object/surface. The same principle plays out in microscopic airgaps that exist inside charged electrical power cables. When charged with enough voltage, a flash of electrons can occur from one charged side of tiny airgaps in insulation or cabling to the other charged side. When this occurs within electrical equipment it is referred to as partial discharge.

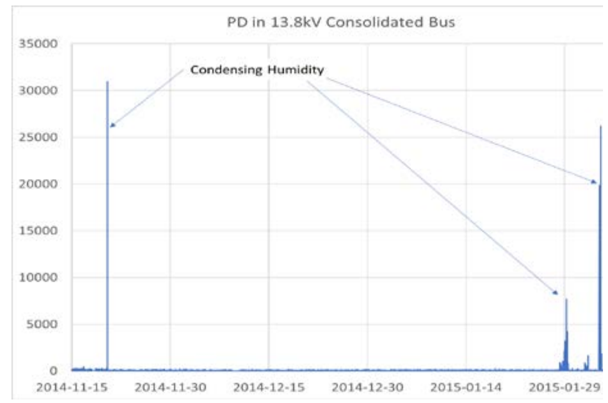
A similar effect occurs along the contaminated or imperfect surfaces of insulators. Prior to the full explosive flashover of lightning, electrons can creep over a given surface looking for a suitable path to ground. When this phenomenon occurs in energized electrical equipment, it creates surface discharge, also known as corona, and often can cause surface discoloration on, and breakdown of, an insulator. If left unaddressed, the damage caused by partial and surface discharge can exacerbate over time and ultimately lead to a catastrophic failure.



Common causes of partial discharge in electrical equipment, and what are we monitoring?

Partial discharge is constantly occurring in electrical assets, but its existence alone is not a cause for alarm. Airgaps and defects commonly exist in electrical cabling, and all electrical equipment is subject to internal and external factors that can create partial discharge. It is the continuously occurring partial discharge under normal operating conditions, this baseline of activity, that gives us the most important insights into asset health. More to the point, it is the rate of any increase of the continuously occurring discharges within an asset that is relevant to predictive monitoring and assessing asset health, not any individual occurrence.

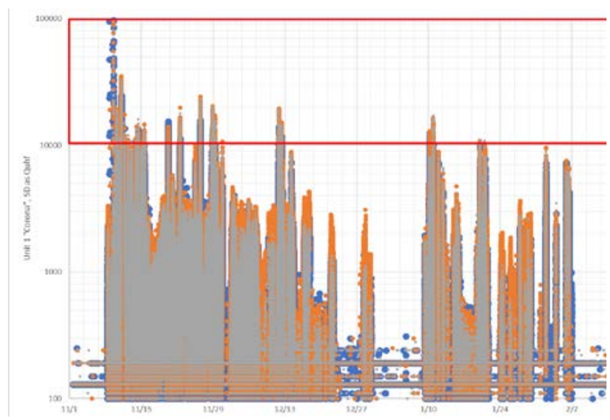
There are many external factors that create partial discharge, often in much larger magnitude than any given baseline. Common external sources, or externally induced partial discharge include voltage surges from inductive load switches, over-voltage conditions when a given load drops rapidly, and lightning strikes. These types of events can occur locally or at a distribution grid level, and the associated discharge magnitude can be very large and can last for a meaningful amount of time after the triggering event. Large, externally-induced discharges are not diagnostic of damage, but potentially causative.



Large PD events in a distribution substation with inadequate humidity control. Dew point rated spacers had no accumulated damage.

Graph 1

Environmental conditions of electrical assets can also create conditions that will generate large discharges. Extremes of humidity (Graph 1) or high levels of particulates (Graph 2) in the air can cause deposits on the surfaces of insulators that will lead to partial discharge and surface discharge until the pollution level of the surface is reduced – either by off-line cleaning or as a result of the discharges vaporizing the contaminants. These sudden bursts of partial discharge, like those of externally induced discharges, are of little diagnostic value for asset health, but they can signal an environmental problem.



Large PD events in a generator iso-phase bus duct during start-up resulting from dust after major construction.

Graph 2

Externally or environmentally-caused discharges are not diagnostic of damage, but they can cause permanent tracking damage to the surface. Until damage has occurred there will be little to no increase in baseline discharge activity between the externally induced events. Adding value to calculated baseline activity, there are also interfering RF signals that can be hard to distinguish from partial discharge. This interference may fluctuate daily and seasonally but will trend differently than partial discharge diagnostic of a failure.

Due to the above factors, it is best to monitor the baseline levels of partial discharge, to see if any large external factor has caused damage that would reveal itself in an elevated baseline of partial discharge. What is most important to derive information on asset health from partial discharge is the overall trend in activity, not the absolute value of partial discharge at any given point. In summary:

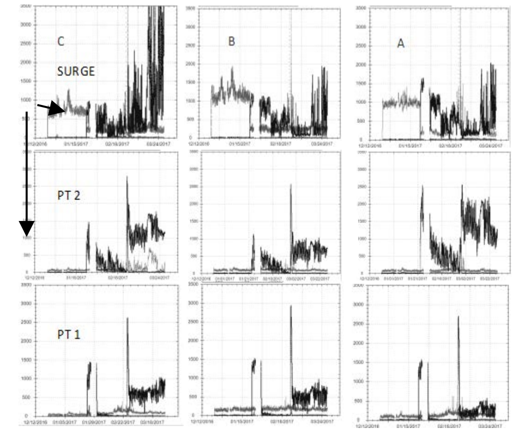
1. Partial discharge induced by external events: Can be large, is short lived, and is not diagnostic.
2. Interfering signals: Can vary daily or seasonally but do not show long term growing trend.
3. Partial discharge from defects: Exhibit long term exponential growth on baseline activity since stronger discharges inflict new damage. Growth rate is more important than magnitude.

Discharges Caused by, and Diagnostic of, Damage

The true goal of partial discharge monitoring is to detect when an external event induced partial discharge that causes real and progressive damage to the asset. Partial discharge can degrade an insulator and cause increased levels of partial discharge under normal operation conditions as that insulator fails. In this way, partial discharge can create a feedback loop that will cause asset failure if not addressed.

For a very real example, in the plots (Graph 3) the three columns represent three phases (phases C, B, A), each with a surge arrestor (top) and two PT's (middle and bottom). Two externally induced events are observed. These external events caused significant partial discharge levels in all nine points of measurement. The first surge caused some permanent damage and the second surge made the damage worse. The second surge is off the charts in the surge arrestor section.

After the second surge there were continual and growing levels of partial discharge in the baseline measurements. These would have led to complete failure if the component had not been repaired. The increased levels of partial discharge are visible in adjacent compartments, but comparative analysis localized the faulty component.



Embedded analytics data from nine compartments in a generator PT, as they are physically arranged. Partial discharge activity was seen in multiple locations and was localized by comparing responses.

Graph 3

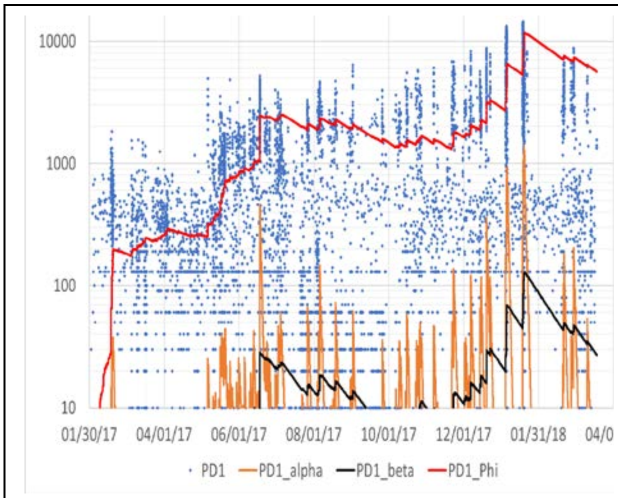
In this example, the data used IntelliSAW's embedded analytics to compress the data from multiple power cycles into very concise data describing the cumulative partial discharge over the time. It is noteworthy that the externally induced discharges were significantly higher than those resulting from the damage. The key takeaway here is that it is not the absolute magnitude of partial discharge at any given time that is valuable for understanding asset health, rather it is monitoring the baseline levels of partial discharge, and trending how that baseline level changes over time that reveals the true health of the asset. In this case the impending failure was observed before levels that would typically be recommended for alarms; however, the induced event exceeded those levels.

Advanced Trending in the CAM-5 Platform

The CAM-5 HMI monitoring system plots the rolling average of raw partial discharge data to enable trending creating a baseline measurement for advanced alarming. The fast (daily) average trendline, labeled α, allows warnings and alarms to be set based on short-term activity.

As an example, the power plant depicted (Graph 4) shows the daily average has a cyclic behavior that appears to be related to load power. This could be brush noise – which is a form of partial discharge and can be indicative of a need to clean or replace brush contacts – or it could be that the load current is raising temperature and that partial discharge levels are temperature dependent.

For dB scale measurement systems, it could also simply indicate a load dependent electromagnetic interference (EMI) condition that is not completely filtered from the sensor. While the IntelliSAW system's embedded analytics remove most interference, it also can see interference in high noise environments.



PD data from 800MW ISO-phase bus ducts (22kV) (blue), 1-day α average (orange), 14-day β average (black), and the trend, Φ, x 10^4 (red).

Graph 4

A longer average, called β, is taken over a 14 to 60 day period – in Graph 4 a 14-day average is shown. This trend function is also plotted in the CAM-5 and is available as a source for warnings and alarms. This function does a good job of rejecting transient events that are typically externally induced. For a variable-load generator, this function varies with long-term average load. It also varies seasonally. It is noted that the deterioration of the partial discharge surge arrestor occurred over a four to five-week period, so a two-week average should capture such an event.

Both the α and β trends are simple averaging functions that should be available in most data historians. The CAM-5 also offers another function, φ, which represents the rate at which the raw partial discharge values are exceeding the long term β baseline. This delta of SD or PD above β is treated as an indicator of damage, and the accumulated damage is plotted as φ. In the event that the level of SD or PD is not escalating then the baseline average (β) will eventually stabilize to reflect this increased baseline and the function φ will not increase.

Alarm Strategies

IntelliSAW recommends setting warnings and alarms based on the trended baseline data from the CAM-5 HMI. As these trendlines are asset specific and are created over time, it is necessary to observe data from an energized system first before setting an alarm level. **IntelliSAW recommends setting warnings at 1.5X the baseline levels of PD, and alarms at 2X baseline levels of PD.**

External and environmental sources may induce PD at levels well above the baseline, but the baseline is the true indicator of asset health. These levels (1.5X and 2X) will provide an early warning indicator of any issue, as baseline values expected with asset failure are orders of magnitude above that of those of a healthy asset. Note that when setting alarms based on trended averages, a user will miss the absolute magnitude of large partial discharge events but this will be averaged into the trendline and available as raw data stored on the CAM-5. In most cases this is precisely the desired behavior for providing functionable and actionable information on asset health.

If no data is available, it is suggested to initially use 10,000 Q_{UHF} for warnings and 20,000 Q_{UHF} for alarms. Experience has demonstrated these values to be well suited for typical 13.8kV to 33kV switchgear affording a reasonably low rate of nuisance alarms.

The IntelliSAW CAM-5 family have default warning and alarm thresholds of 5,000 Q_{UHF} and 10,000 Q_{UHF}, respectively. These are set to avoid missing important partial discharge events and are intended to be raised (or lowered) after having obtained baseline data. If not adjusted to actual system performance, these thresholds could generate alarms that are not diagnostic of an asset health condition where no damage has occurred, and no action is needed.

Note that, in the case of a 13.8KV consolidated bus (Graph 1), levels of 30,000 Q_{UHF} were exhibited during the condensation-induced discharges. The iso-phase data for the 13.8KV generator (Graph 2) was initially 100,000 Q_{UHF} and decreased to a range of 1,000 to 10,000 Q_{UHF}. Meanwhile the actual component failure in the 22KV PT cabinet's (Graph 3) surge arrestor was diagnosed by trending at about 3,000 Q_{UHF}, while the externally induced surges exceeded 10,000 Q_{UHF}. If the trendline had not indicated progressing damage, then eventually the levels would have grown until an absolute alarm on the raw data was reached.

Summary

1) Using partial discharge as a health indicator in electric power assets is somewhat like using heart rate or blood pressure monitor in human health. While high levels can be diagnostic of a problem, they need to be looked at in context and trended over time.

2) While partial discharge analysis is not easy and is often confusing, it provides early warning on asset failure, and as such, should be included in any comprehensive asset health monitoring program.

3) There is a tradeoff between very expensive and complicated diagnostic tools and more simple, low-cost sensor devices. The simple, low-cost devices are:

    a. Intended for deployment in ***every*** MV and HV asset.

    b. Require some form of confirmation before action is taken.

    c. Are best used to signal a need for professional diagnostic services, unless an obvious root cause is found on visual inspection.

4) Partial discharge alarms are informative, should NOT be a distraction to operations, and should be routed to asset management teams.

Visually confirmed PD in a 13.8KV generator.

For more information, please visit www.IntelliSAW.com