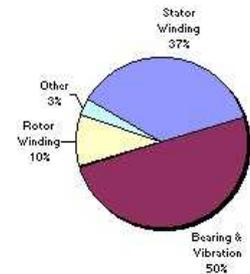


APPLICATIONS & BENEFITS

PARTIAL DISCHARGE TESTING FOR HYDROGENERATORS

Introduction

Partial Discharge testing is a predictive maintenance tool for motor and generator stator windings. It is the only on-line electrical test that correctly identifies and warns of pending stator winding failure mechanisms such as loose windings, contamination, thermal deterioration, poor manufacture, problems due to load cycling and more! The test can be applied to any stator winding 3kV to 26kV. Industry statistics by IEEE and EPRI (Electrical Power Research Institute) indicate that approximately 40% of all rotating machine failures occur due to failure of the stator winding insulation. (See chart to right)



Defining Partial Discharge

Partial Discharges (PD) are basically tiny sparks that occur inside motors and generators. They occur within voids and on the surface of the stator winding insulation and out in the endwinding between phases. What we want to do is count the number of partial discharges inside the machine and quantify them. Essentially, if we see the PD activity increasing (more pulses and bigger pulses) over time, then we know that the stator winding insulation is aging. Knowing this, one can predict the severity of the insulation condition well in advance of a catastrophic failure. All this information is coming to you while the machine is running (on-line).

The reason it is called a "partial" discharge is simply because it's not a complete discharge (breakdown). It is not a breakdown from HV to ground, but rather a breakdown between some intermediate voltage and another intermediate voltage within the insulation. At 1 atmosphere (psig) the dielectric strength of air is ~3kV/mm. Hence the reason for not being able to PD test machines operating under ~3kV.

Iris Power Engineering is the worldwide leader in employing Partial Discharge monitoring techniques for predictive maintenance on rotating machines (motors and generators) rated 3kV and above. Iris sensors are installed on more than 5,000 machines around the world!

Benefits of Partial Discharge Testing

Partial Discharge testing WILL provide users a huge benefit in the form of one or more of the following:

- Avoid unnecessary rewinds on older machines by maximizing the operating hours from a stator winding
- Avoid unexpected in-service failures of the stator winding; and extend up-time between outages
- Find a problem and correct it before it has a chance to fail the winding
- Find problems on new machines which may still be under warranty
- Assess the quality of maintenance repairs and/or rewinds with before and after readings
- Compare results from similar machines to focus maintenance on those with higher levels of PD
- Identify specific failure mechanisms in the stator winding to allow for corrective action prior to an outage
- Some insurance companies recognize the PD test and may give rebates
- Improve the overall reliability of motors & generators
- Accomplish all this while the machine remains in operation (On-Line)

In some cases, users have replaced such offline tests as Doble and HiPot testing with the on-line Partial Discharge test. We don't normally market our test with the intention to replace other forms of electrical testing as most are good tests to perform when given the chance. However, why take an operating machine out of service or extend an outage to do these tests when on-line Partial Discharge testing indicates a healthy stator winding. Iris does recommend that if a problem is identified with the on-line PD testing that users perform various off-line tests (Corona Probe, Megger, etc...) to confirm the problems existence. This will provide a solid "second opinion" for which to base future maintenance.

Studies show that most stator windings are very reliable (about 95%) at any given time. Knowing this, it is important for users of large machines to know or at least have an idea if they are one of the 5% or not. There are advantages to knowing that there are no problems. Some machines are known to be more reliable than others because of their design and how they are operated. However, eventually these machines will fail, if for no other reason, due to gradual thermal aging of the stator winding insulation. Users of the partial discharge test will be able to find problems while on line and also identify machines that are in good condition enabling them to extend the time between major outages. On-line Partial Discharge testing is the only electrical test that allows you to do this.

On-Line PD Testing Applications

The Partial Discharge technology Iris offers was designed with plant staff in mind. That is, anyone can use it. Users don't have to rely on some expert with a PhD to come to site and interpret the signals shown on the screen. The way the system works is by creating a 'user friendly' environment where unwanted noise signals are separated, but not discarded, from machine Partial Discharge.

In accomplishing this, Iris offers its clients several options:

1. Purchase their own portable **PDA-IV™** or **TGA-B™** instrument for routine periodic testing;
2. Rent a portable **PDA-IV™** or **TGA-B™** instrument and have Iris do the analysis;
3. Purchase a Continuous On-Line Monitor (**HydroTrac™**, **BusTrac™** or **PDTrac™**) to operate in either stand alone mode with alarm or analog outputs, remote control mode or automated mode;
4. Testing Services – Have Iris come to site and perform periodic routine testing



In any of the above cases, permanently installed PD sensors, 80pF capacitive couplers (shown to the left) specifically designed to work with partial discharge frequencies (50MHz-250MHz typically) need to be installed. These high voltage capacitors create a high pass filter to allow PD signals through for measurement. Iris has sold over 25,000 of these sensors around the world. Worthy of mention is that not one has ever failed. In fact, the IEEE has specified a theoretical operating life of about 60,000 years!!! We'll all be retired by then...

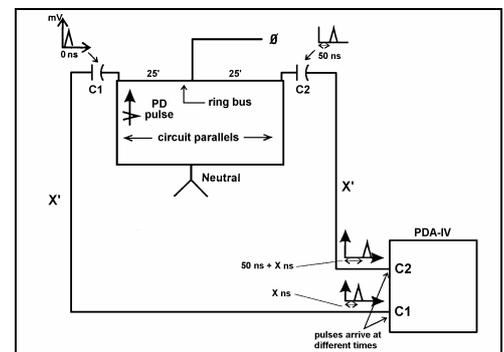
With only 2 days worth of training, clients can become their own "expert" on partial discharge testing and interpretation. It's that easy. The reason is simple. Iris's patented noise separation techniques that are built into the system (sensor installation and instrument) objectively separate signals based on where they originate. Thus, eliminating false indications. Here's how 2 of Iris' technologies work:

1. PDA Installation - Differential Noise Separation

The Iris PDA technology works simply on pulse arrival time. We need to separate noise signals from stator winding PD. To explain how it works, we will look at it in two stages: *PD Detection* and *Noise Separation*.

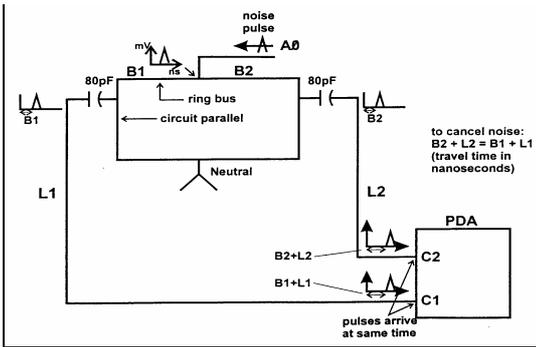
PD Detection:

The figure shown to the right schematically describes how the PDA technology detects partial discharge signals from the generator stator winding. As PD pulses originate from within the winding they travel out to the circuit ring bus. A minimum of two sensors per phase are installed on the circuit ring bus. C1 in this case, will detect a PD pulse from the first parallel right away. The pulse will then travel along the circuit ring bus towards the second sensor C2. However, it arrives some time after C1 first detected it. In the example to the right, the PD pulse had to travel through 50 feet of bus to get from C1 to C2. Since PD travels at 1 ft/ns, it arrives at C2 about 50ns after C1 first detected it. The signal cables from both sensors are of the same electrical length such that the pulses will arrive at our **PDA-IV™** with a time delay equal to the length of bus between the two sensors. In this case, since it arrived at C1 first, it is detected as PD originating from the first parallel, or the parallel closest to C1.



Noise Separation:

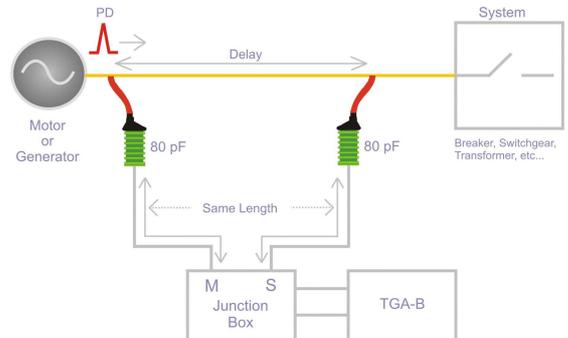
When PD testing, it is essential that noise be eliminated or separated. If it is not, then there can be a misdiagnosis of the stator winding in question. Since we are dealing with High Frequency signals (>40MHz) the only noise that will cause grief originates from the system. In a large hydrogenerator winding there is a circuit ring bus to connect multiple parallels to one point. Somewhere in between, there is a connection to the outgoing bus. This is where the noise signals will enter. They are relatively harmless pulses, but make PD testing a little more difficult to the inexperienced. The PDA technology eliminates this difficulty by accurately separating these noise signals. In the figure to the left, noise will enter from the connected bus, split and go towards both C1 and C2. In this example the noise signal must travel through 25 feet of circuit ring bus before being detected by either sensor (C1 and C2).



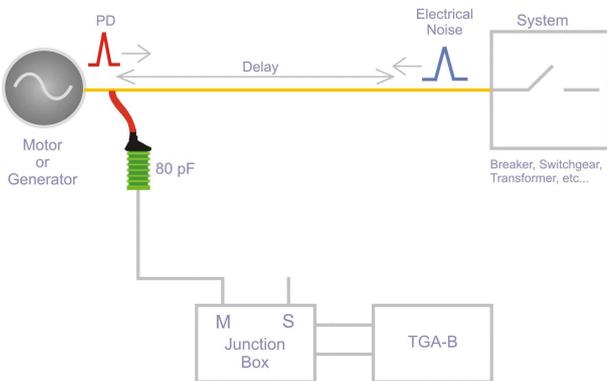
The signals then travel towards the **PDA-IV™** instrument that determines if the pulses are of the same magnitude, and rise-time arrived at the same time. If this is true, the instrument then classifies them as noise signals originating from the system.

2. Bus Coupler Installation - Directional Noise Separation

The figure shown here describes how our Bus Coupler system works in separating noise signals from the system and partial discharge signals from a generator. The portable **TGA-B™** instrument is able to tell which direction the signals originate from, thus also giving the unique benefit of being able to see any PD activity from the connected system. It determines if the PD detected came from the generator, between the bus coupler pair, or from the connected system.



Bus couplers are installed in pairs: 2 sensors per phase with at least 6' but no more than 50' of bus between them. A typical installation takes two days to complete per generator. Iris offers installation supervision and calibration services to clients who prefer assistance.



In cases where the machine is connected to the system (breaker, switchgear, etc.) using power cable, AND there is at least 100 feet (straight run, no taps) of power cable between the machine terminals and connected system, one bus coupler per phase can be used. This type of installation is very typical for motors, but on occasion is applied on generators. The reason for only needing one bus coupler is that any High Frequency (HF) electrical noise signals traveling from the system will be significantly attenuated by the >100' of power cable. Since Iris' bus couplers operate at HF (>40MHz), noise signals don't pass through the bus couplers. If they were to operate at lower frequencies, more

electrical noise would enter the system and make it difficult to separate the PD from electrical noise. Thus, PD testing at high frequencies provides a high Signal-To-Noise Ratio (SNR).

Iris Recommends

As a basis for new clients, Iris recommends PD testing every 6 months for the first 2 years. This will provide a good solid baseline trend for future comparison. From there, depending on the levels of Partial Discharge and how it is changing, Iris recommends, as a minimum, testing no less than once per year.

Alternatively, some clients opt to purchase a continuous on-line monitor to continually “track” and trend the PD activity. This eliminates the need for on-site visits. Our Trac instruments **HydroTrac™**, **BusTrac™** & **PDTrac™** will provide maximum warning of increasing PD activity in order for maintenance personnel to act accordingly. They come equipped with alarm relays and optional analog (4-20mA) signal outputs for connection to a DCS or SCADA. Users can also remotely communicate with the Trac monitors via Ethernet, RS485, fibre-optic or wireless. **PDTrac™** also comes equipped with analog input modules to allow condition based triggering on stator winding temp, ambient temp, or humidity.



The **HydroTrac™** is used with 6, 9 or 12 differentially installed PDA couplers while the **BusTrac™** is used with 6 directionally installed bus couplers. The **PDTrac™** is used when there are only 3 bus couplers installed. The Trac instruments make life that much easier since the user knows that PD measurements are always being collected.

The Iris Partial Discharge Database

Iris has an extensive statistical PD database of results. Currently, there are over 47,000 records in the database. Each year Iris breaks it down and summarizes it in various ways making it more practical. To date, comparisons by type of sensor, stator voltage, type of machine, vintage, hydrogen pressure and OEM have been completed with very interesting conclusions. Having such an extensive database provides the following benefits:

- Allows the comparison of similar machines, focusing maintenance time and expenditure on machines with excessive deterioration (higher PD magnitudes)
- Informs users of what a good, and bad level really are when it comes to PD levels, rather than guessing
- Indicates further that Iris Power Engineering is the leader in partial discharge theory and application

Iris Profile – (brief)

Iris Power Engineering’s roots stem from the utility industry. The PD test we market today was developed in conjunction by Ontario Hydro (now Ontario Power Generation) the Canadian Electrical Association and EPRI. The key personnel involved in the research and development of this on-line PD testing system from Ontario Hydro left in 1990 to form Iris Power Engineering, Inc. Their goal: To provide users of large motors and generators with high-quality products and services to improve maintenance capabilities. As an ISO9001 registered company, Iris customers can expect to receive quality products and continued professional service. Currently Iris employs 75 people with continued growth in mind. Iris Power’s extensive client list contains customers from around the world.