IRIS
POWER ENGINEERING

Technical Overview

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Who Is Iris Power Engineering?

Iris Power Engineering is the world's largest supplier of on-line partial discharge monitoring systems for motor and generator stator windings. Iris has been at the forefront of bringing these new on-line partial discharge (PD) monitoring technologies to utilities, petroleum and refining plants, pulp and paper plants, mines and other industrial users of motors and generators. PD monitoring has now been accepted as a major component of any plants predictive maintenance program. The key reason for our success is a measurement method that:

- Explicitly separates stator winding PD from electrical noise that could cause false indications
- Allows for objective interpretation of test results by non-experts of PD, using the Iris database of test results
- Is reliable testing system with low risk of errors

Iris' head office is located in Toronto, Canada with branch offices near Manchester, England and Houston, USA. In addition, Iris has staff working throughout Canada and the USA, and is represented by agents located throughout the world.

Iris continues to spend almost 15% of its revenue on research and development to improve and expand its products for monitoring the condition of motor and generator windings, as well as associated electrical equipment. The contributions of Iris and its staff have been recognized by several industry awards conferred by the US Electric Power Research Institute, the IEEE, and several business magazines. Iris' commitment to quality and continuous improvement are demonstrated by its ISO 9001:2000 registration.

What are Partial Discharges?

Partial discharges (PD) are small electrical sparks that occur within the high voltage electrical insulation in stator windings. PD occurs whenever there are small air-gaps or voids within or on the surface of the stator winding insulation. These voids are the result of improper manufacturing, overheating, coil vibration or pollution. It is within these voids that partial discharge activity occurs. This is why manufacturers make every effort to prevent these insulation voids when making new or rewound high-voltage motors, generators, and switchgear. PD is a symptom of several stator winding problems caused by electrical, thermal, mechanical and environmental stresses. Monitoring PD can be useful addition to any company's test and inspection procedures.

Motor Stator Winding Failure

PD As A Symptom Of Failure Mechanisms

Since the 1940s, it has been known that the presence of partial discharges within the electrical insulation is a strong indicator that thermal, mechanical or environmental factors may be causing electrical insulation deterioration. As the magnitude and number of these partial discharges increases, the rate of electrical deterioration increases. If the problem is not addressed, these partial discharges can cause sufficient deterioration of the insulation's organic resins to result in catastrophic stator winding failure.

Examples of such failure mechanisms in medium and high voltage electrical equipment are:

Pollution on endwindings or bus bars
Overheated groundwall insulation
Loose windings
Degraded semi-conductive coating

Experience has shown that most of these problems take many years to result in failure of generators, and that PD testing can give as much as 5 years of warning that a failure is imminent. In 3.3-4.1 kV motors, there is less insulation, thus failure rates can be much faster so that warnings from PD tests may give advanced warnings of only a few months.

Partial Discharge Monitoring

Over 50 years experience has shown that measuring PD activity either during normal machine service (on-line monitoring) or when machine is out of service (off-line testing), can detect most stator winding failure mechanisms in high voltage electrical equipment rated 3.3 kV and above.

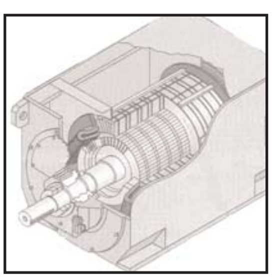
The PD is detected as current pulses by means of "couplers", either high voltage capacitors or specialized antennae called stator slot couplers (SSCs). With the generator or motor operating under normal service conditions, the operator connects the couplers to the test instrument. The instrument separates the partial discharges from electrical interference and determines the magnitude, phase position and number of partial discharges emanating from each coupler. Using a portable computer, the test instrument displays and permanently stores the test results for analysis.

On generators, tests are typically performed semi-annually with a portable instrument and take about 30 minutes to complete. Motors rated 3.3 and 4.1 kV produce PD often only a few months before failure and, therefore should be tested more frequently, monthly or continuously, depending on their age and service demands. In order to test, 80 pF capacitive sensors or SSCs are permanently installed either at the time of manufacture, or during a convenient equipment outage.

The test data can be analyzed for increases in PD activity over time (trending), or compared with other machines using Iris' unique database of over 60, 000 test results, to determine whether the activity indicates any cause for concern. The analysis can be done by trained plant personnel, or by Iris staff. For the best results, tests should be conducted regularly.

Stator Winding Design

To better understand how PD monitoring can help plan stator maintenance, a review of stator winding design insulation design is requested. The principal function of a stator winding coil or bar is to provide a conductive path for the currents induced in it by the rotating magnetic field. Winding designers have gone to great lengths to make sure that they put in as much copper and as little insulation as possible in each coil or bar. What construction they chose depended on the size of the machine that you wanted and the amount of money that you wanted to spend. Medium to high-voltage (>2300V) stators are made with form-wound coils, while lower voltage machines tend to be random-wound. Form-wound coils are designed such that the turn voltage stress is constant. These are different from random-wound motors where the turn voltage stress will vary considerably and can be the maximum phase-to-ground voltage. Only form-wound coils will be discussed here.



Rotating machine

Coil Structures

There are two widely used designs of form-wound stator windings:

A bar (half coil)
A multi-turn coil

Typically, machines rated less than about 75MW will have multi-turn coils, while those larger than 75MW will usually have bars.

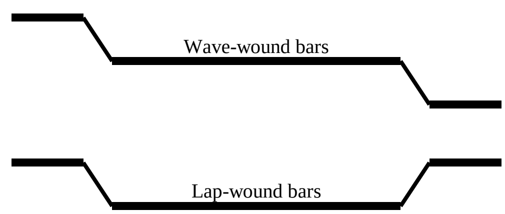


Figure 1. Bars (half coils)

Bars

If the lengths of the core slots are extremely long, or the bore diameter is not large, then it can be extremely difficult to install a multiturn coil. For these machines, the coils are frequently made in two half sections, called bars or half-coils. Further, they are often referred to by their relative positions within the stator slot, i.e. "top bar" for that one closest to the rotor and "bottom bar" for that one in the bottom of the slot. This sectional approach makes installation easier since each bar can be inserted by itself, and then later connected to the other half. A bar (half coil) is formed by taking a group of insulated copper strands equal to the cross-sectional area desired and applying groundwall insulation. Two types of bars are common: wave-wound and lap-wound, as shown in Figure 1. The only difference between the designs is that the end arm structures vary to accommodate the winding design.

Multi-turn Coils

A multi-turn coil is formed by taking a group of insulated copper strands to form the turn cross-section required and wrapping several layers of turn insulation around them. The bundle is then wrapped the specified number of turns around a jig and eventually pulled and formed into the final "diamond" shape. The entire coil is then insulated with multiple layers of groundwall tape.

Diamond Coil

Types of Insulation

There are three types of insulation in a multi-turn coil: strand, turn, and groundwall. As there are no turns in a bar (half-coil), there is only strand and groundwall insulation.

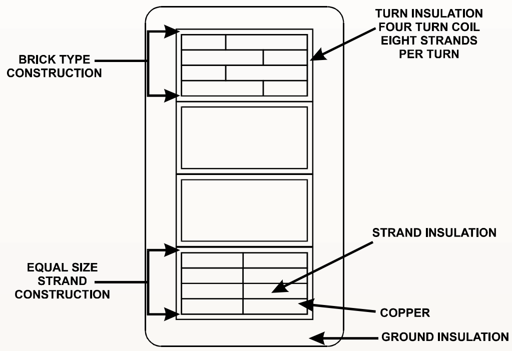


Figure 2. Insulation in a Multi-Turn Coil

The primary function of insulation is to separate the conductor from the stator core to allow a voltage difference to exist between the two. The most common taping materials used to provide this electrical separation are mica paper, and mica flakes. All of these products have excellent electrical insulating properties; however, they have terrible mechanical properties. Mica tend to shatter when exposed to the severe vibrations - 100/120Hz - present in a machine. To diminish the mechanical stress on the insulation, winding designers have chosen to impregnate the tapes with an organic compound. The organic compounds frequently used are asphalt, polyester, and epoxy. Which compound exists within your motor or generator is dependent on which company manufactured the winding and the year of manufacture.

Strand Insulation

The purpose of strand insulation is to insulate the individual strands that make up a turn bundle. Turns are made up of smaller strands to lower the skin effect and stray current losses from the axial magnetic fields. Strands have a larger surface area (skin) and can carry more current than a solid conductor. The voltage stress across the strand insulation is usually less than 1 V, that is, in the millivolt range. Because there is minimal stress, failure of the strand insulation normally only increases stray losses; however, if arcing is present, strand-to-strand shorts may eventually lead to coil failure.

The materials used for strand insulation vary with the manufacturer and age of the winding. Machines made prior to about 1960 will have strand insulation of varnish, enamels and cotton serving. Modern machines tend to have polyamide, polimide films, glass or dacron/glass, film and glass, and mica paper strand insulation. As stated before, the choice of material is normally based on the manufacturer's experience, machine requirements, and economics.

Turn Insulation

Since stator bar windings have only one turn, there is no turn insulation required on bars. Only multi-turn coils will have turn insulation. The presence or absence of dedicated turn insulation will depend on your winding specification or manufacturer.

The purpose of the turn insulation is to prevent shorts between turns and to provide sufficient dielectric strength to prevent insulation failure under the influence of high transient voltages imposed on the stator windings during starting, lightning strikes or IFD operation. The power frequency voltage stress across the turn insulation in a form-wound coil is constant and is a product of the machine design. It can be computed based on the phase-ground voltage of the machine, the number of coils in series in a parallel, and the number of turns in a coil. Typically, voltage stress across the turn insulation is 10 - 200V per turn.

If the turn insulation fails, there will be a tremendous amount of circulating current within the coil. This is caused by exposing a complete circuit path (closed loop) to the strong magnetic field yielding a high current through the turns with the short. The result is a very high I^2R thermal stress on the groundwall insulation adjacent to the position of the short and imminent failure of the groundwall. The time could be as short as a few seconds, depending on the impedance of the fault.

Typical materials used for turn insulation are large flake mica tape possibly with a cotton serving backing in the older windings and mica paper with glass or polyester glass backing in the newer windings. Some winding manufacturers have chosen to upgrade strand insulation, such as a single or double layer of Dacron glass over heavy enamel, to also serve as turn insulation. The presence or absence of dedicated turn insulation will depend on your winding specification or manufacturer. The turn insulation that is located on the sides of the turns will be subjected to higher groundwall electric stress. Also, since the turn insulation is located adjacent to the copper turns, it will operate at a higher temperature than the groundwall insulation itself.

Groundwall Insulation

The purpose of the groundwall insulation is to prevent shorts between the copper conductors and the grounded stator core. The thickness of the groundwall insulation is solely dependent upon the voltage rating of the machine and the volts/mm stress chosen by the manufacturer. For example, for the 13.8kV machine described above, the highest voltage to ground stress is 7967V. If the maximum volts/mm stress chosen by the manufacturer is 2.5kV/mm (65V/mil), then the groundwall insulation will be at least 3 mm (123 mils) thick. You don't need to be told, the thicker the groundwall the less copper in the slot, and the more thermal stress of the copper. However, the thinner the groundwall, the more voltage stress across it and the increased susceptibility to electrical breakdown.

The voltage stress across the thickness of groundwall insulation is based on the rated voltage of the winding and the coil position within the winding. The voltage stress on the groundwall insulation in the line-end coil will be the total phase-to-ground voltage, in our previous example: 7967V. However, as you move progressively away from the line-end coil towards the neutral or Y-point, the voltage stress across the groundwall decreases. Therefore, the line-end coils are more susceptible to failure. Failure of the groundwall insulation is machine failure and will lead to a relay operation and the inability to return the unit to service without repairs.

The primary material used in insulation is a partial discharge-resistant material called mica. Mica is electrically and thermally durable but an extremely brittle substance. Because of this brittleness, it is necessary to protect the mica from mechanical stresses by impregnating the tapes with an organic resin. Also, since the coil groundwall insulation can be impacted by in service electrical and thermal stresses, its layers are bonded together with organic varnish.

In older windings (before about 1970), the organic varnishes used were either asphaltic or shellac. Both of these varnishes deform or flow when under thermal stress, i.e., thermoplastic. These thermoplastic resins retain part of their distorted shapes when cooled. In newer windings, thermoset resins of epoxy or polyester are used. Thermoset windings are less affected by thermal stresses at normal winding operating temperatures, and usually do not deform until the glass transition temperature is exceeded.

Common Failure Mechanisms of Stator Windings

Failure Mechanism	Symptoms	Detection Tests	Insulation Types
Inadequate bonding	Partial discharge	PD, power factor, tip-up	Global VPI, resin-rich coils
Electrical slot discharge	Partial discharge, slot discharge, ozone	PD, visual inspection	Air-cooled machines
Semi-con/stress interface	Partial discharge, white powder, ozone	PD, visual inspection, power factor	Air-cooled with stress control paints
Loose windings	Partial discharge, slot discharge, ozone, loose wedges	PD, visual inspection, wedge tap, ozone	Hard systems - epoxy & polyester
Inadequate spacing	Partial discharge, white powder, ozone	PD, visual inspection	Air-cooled
Endwinding vibration	Loose blocking, white powder	Accelerometer, visual inspection	High voltage machines with long end arms
Surges	Turn-to-turn shorts	Surge test	Multi-turn coils, especially VSD
Thermal deterioration	Partial discharge, discoloration of insulation	PD, visual inspection, power factor	All stator winding types
Load cycling	Partial discharge, girth cracking	PD, visual inspection, power factor	All stator winding types
Contamination	Partial discharge, white powder, ozone	PD, visual inspection, power factor, IR, PI, Hi-pot, tip-up	High voltage coils

Basic Partial Discharge Theory

Partial discharge (PD) is a symptom of several stator winding problems caused by electrical, thermal, mechanical, and chemical stresses. Monitoring PD can be a useful addition to other tests and inspection procedure. Not only is PD a symptom, it is also damaging to the organic resins used in insulation materials. Fortunately, since most stator winding insulation systems for machines rated greater than 2300V contain a discharge-resistant material called mica, degradation of the groundwall is usually slow. It is because of this relatively slow aging process that periodic monitoring of the PD activity makes sense. A general rule of thumb regarding the length of time between detection of PD associated with a failure mechanism and insulation failure is:

For > 20kV machines	10 years
For 13.8kV machines	5 years
For 6kV machines	2-3 years
For 4kV machines	Several months

Partial Discharge or Corona

The terms partial discharge and corona are frequently used interchangeably in the industry. According to IEEE and IEC definitions, a partial discharge is an incomplete, or partial, electrical discharge that occurs between insulation and either insulation or a conductor. This is in contrast to a full discharge that spans the gap between two conductors, otherwise called insulation failure. Corona occurs when the gas adjacent to an exposed conductor ionizes and produces visible partial discharges. Corona does not involve insulation.

Void Formation

The first step of most failure mechanisms is the creation of gas-filled voids as shown in Figure 1. These voids are the result of degradation of the impregnated resin, and may be internal to the insulation system (thermal deterioration, load cycling, improper impregnation) or on the surface of the coil (loose coils, semi-con/grading deterioration, contamination, inadequate spacing). End-arm vibration and penetration of the insulation by a foreign object do not develop voids and thus these latter two mechanisms cannot be detected by PD testing.

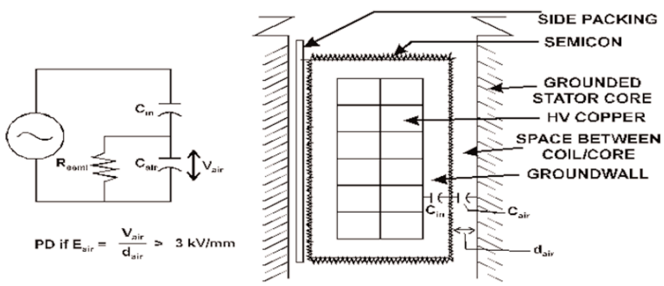


Figure 3. Electrical stress in an air space void between the coil and core

A discharge can only occur when the electric stress (V/mm) exceeds the electrical breakdown stress for the gas based on Paschen's law. Other issues besides the gap length that can affect the electric stress in a void are diameter, internal gas pressure, and the nature of the surface in the void. The product of the gap separation and the gas pressure establishes the voltage necessary to lead to a discharge, i.e., breakdown voltage.

The magnitude of the discharge is proportional to the volume of the air void, and the larger the volume, the bigger the discharge.

Voltage Dependence

Not only is the spark (partial discharge) an indication that a gas-filled void exists and thus a symptom of deterioration, but it also breaks down the carbon bonds of the organic resin and accelerates aging. Because the magnitude of the voltage stress across a void is dependent upon the applied voltage, most partial discharges only occur on high voltage (line-end) coils. Coils at the neutral end do not have sufficient voltage to ground stress to exceed the electrical breakdown stress for air or hydrogen.

Pulse Shape

The pulse from a partial discharge has an extremely fast rise-time and short pulse-width. The period of oscillation, the rise-times and magnitudes of subsequent peaks vary for each pulse. This normally depends upon the geometry of the machine, the location of the pulse and the insulation materials. Most partial detection devices only detect the initial pulse that has a rise-time of 1-5ns. Based on rise-time, to a first approximation, the actual frequency of a pulse is $f = 1/T = 1/(4*\text{rise-time})$. For example, a pulse with a rise-time of 3ns would have a period, $T = 4 * 3ns = 12ns$, and a frequency, $f = 1/T = 1/12ns = 83MHz$. Thus, the rise-time range of 1-5ns corresponds to the frequency range of 50-250MHz.

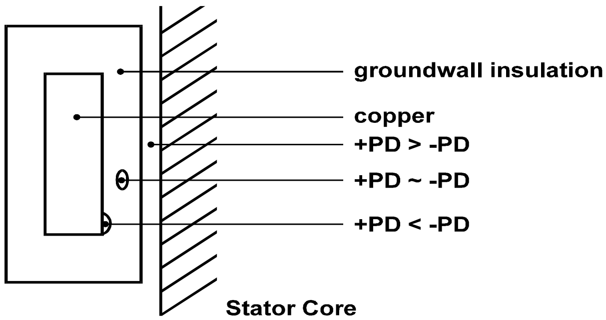
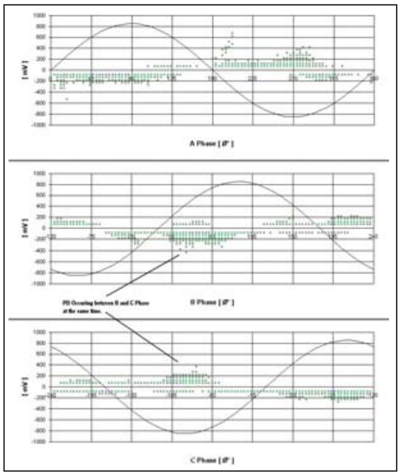


Figure 4. Pulse Polarity based on Void Location

Pulse Polarity



Modeling the actual characteristics of a pulse is difficult since the void dimensions, void gas and pressure, inductance, capacitance, geometry, among other issues can affect the magnitude and frequency of a pulse. However, there are some basic pulse characteristics, which can be predicted based on the void location:

Voids within the Insulation

Machines that have not been properly impregnated or that have been operated for several years at high temperatures tend to develop voids within the groundwall insulation. In theory there will be two observable PD pulses in each AC cycle of equal magnitude and opposite polarity per void within the bulk of the insulation. These pulses clump at the classic positions for phase-to-ground dependent pulses, that is, negative pulses near 45 and the positive pulses near 225 with reference to the 50/60Hz phase-to-ground voltage.

Voids Near the Conductors

A machine that is frequently load cycled or severely overheated develops voids near the copper conductors. A void bounded by the copper conductor and insulation, exhibits a different phenomenon than those within the bulk of the insulation. In this case, there will usually be an observable predominance of negative PD pulses clumped near 45 during the positive AC cycle.

Voids Near the Core Iron

Loose coils, poor semi-conductive coatings, and problems with the grading/semicon interface can all lead to surface discharge between the stator bar and the grounded core iron, called slot discharges. The observable PD pulses will be predominantly positive clumped near 225 .

Endwinding Discharges

Contamination or inadequate spacing in the end arm area can lead to partial discharge activity in this area. Unlike the previously described pulses that are phase-to-ground voltage dependent, these pulses are based on phase-to-phase voltages. Though these types of pulses tend to be very erratic, it is sometimes possible to distinguish these pulses from others by observing their location with reference to a phase-to-ground voltage. Typically, because of the phase-to-phase voltage dependence there is a 30 phase shift from the classic phase positions associated with pulses that are phase-to-ground voltage dependence. That is endwinding pulses tend to clump at 15 , 75 , 195 , and 255 , based on the location of the pulses and the phase rotation of the machine.

WHY USE EMCS AND SSCS?

Epoxy Mica Capacitors (EMCs)

The capacitive couplers used are 80pF +/- 3pF. These couplers block the 50/60Hz signal and pass the high frequency PD signal. This is obvious by comparing the impedance of an 80pF capacitor at a typical power frequency (60Hz) to a typical partial discharge frequency (83MHz).

$X_C(60\text{ Hz}) = 1/2\pi(60)80pF = 33\ M\Omega$
(High impedance - blocks)
$X_C(83MHz) = 1/2\pi(83M)80pF = 24\ \Omega$
(Low impedance - passes)

They are designed to close electrical tolerances and, of necessity, are discharge free well beyond voltage levels normally encountered in machine operation. These capacitors are permanently attached to the phase circuit ring or the isolated phase bus. By connecting the couplers to these high voltage points they are close to the points in the winding that have the highest partial discharge activity. Remember, partial discharge is dependent upon the applied voltage so that only the line-end coils are likely to have discharge activity.

Stator Slot Couplers (SSC)

On many large (>100-300MW) high-speed turbo generators there are PD-like pulses that occur because of core iron arcing. Because it is difficult to discriminate between these pulses and true (insulation) PD, it is recommended that an antenna type sensor be used. This antenna sensor, or stator slot coupler, is comprised of an electrode structure printed on an epoxy-glass laminate. The SSC is placed in the slot embedded either between the top and bottom coils or directly underneath the wedge. Like the capacitive couplers, the SSC blocks the low frequency pulses but passes the high frequency PD-like pulses. However, the SSC is only sensitive to PD occurring within the slot containing the sensor. Though this limits the amount of coverage for the sensor, it does guarantee that only PD from the slot and not noise will be detected.

Data Interpretation

The collection of data should be repeated at least every six months for machines rated 6kV and up. If a problem develops, then the frequency of collection may need to be increased. Due to the short-time frame between detection and failure for motors rated less than 4kV, it is recommended that PD testing be done more frequently on these machines. By using the summary variables, trending of data is straightforward. Collection of data at different operating parameters may also help in determining the condition of the stator winding.

Trend Analysis

The first step of analysis is to compare the results of the current test with any previous test results. If the unit operating parameters - voltage, load, winding temperature and gas pressure - are similar to those of the previous test, then a direct comparison can be made between the two test results. In order to compare tests it is best to maintain operating conditions within certain ranges.

When a trend line is established for PD tests taken over a period of time, it will be obvious that most show an up and down variation between successive tests. However, as an insulation system ages, there will be an easily discernible overall upward movement of PD with time. Aging is a very slow process and sudden increases are not expected in the PD test results. A doubling of PD activity (Qm values twice that of the previous test) every six months is a strong indication of a rapidly developing failure mechanism. Though the condition of the stator winding can be assessed, time to failure cannot be predicted. The actual failure is normally the result of an unusual source of insulation stress such as lightning, out-of-phase synchronization, or severe overheating.

Maintenance can often be done on a machine to lower the PD activity. Examples of maintenance that have been known to successfully reduce PD are rewedging, cleaning, dip and bake, and repairs to the voltage stress coatings. If the source of the PD is within the bulk of the insulation, then repairs may not be effective.

Comparison to Similar Machines

Data collected from the same machine operating under similar parameters using the same test setup are directly comparable and the most useful. It is also possible to roughly compare the results of one machine to those of similar machines. Based on statistical analysis, the type of machine does not appear to have a great impact on PD levels and though insulation types have different types of failure mechanisms, in these gross comparisons there does not appear to be much difference in the overall levels of PD activity. Tables like the one below, which are based on over 60,000 rest results enable stator windings in trouble to be immediately identified.

Detecting PD

Every partial discharge creates a current pulse. This current pulse can be detected by means of special 80pF capacitive sensors called Epoxy Mica Capacitors (EMCs), or by an antenna called the SSC, known as the stator slot coupler.

Noise

Electrical noise from power tool operation, corona from the switchgear, RF sources, etc., is easily confused with PD from the machine windings. This confusion can lead to healthy windings being misdiagnosed as deteriorated, which lowers confidence in the test results. An improved on-line PD test was developed which can significantly reduce the influence of noise, leading to a more reliable indication of machine insulation condition. The Iris system use several methods of noise separation:

Frequency

One of the most effective ways of separating noise is to test at frequencies high enough that only the high-frequency, partial discharge pulses will be detected and the lower frequency, <20MHz, electrical noise pulses will be attenuated. The key is to select an appropriate frequency range such that the signal-to-noise ratio (SNR) is so high that only PD signals and not noise pulses are counted.

The sensing device defines the low-level frequency limit. The 80pF sensors into 50 ohms impedance limit the lower frequency band of detection to 40MHz. At this frequency, the noise signal is is strongly reduced and therefore the SNR is extremely high. Limiting the sensor to only detect high frequency signals does somewhat reduce the total amount of PD energy that can be found, but it also eliminates the need for an expert to discriminate between noise and PD.

Impedance Mismatch

Another method of noise separation is to use the natural tendency of a high frequency pulse to distort when it traverses from a conductor of one surge impedance level to another, or through an impedance mismatch.

A pulse that originates in the winding will almost double in magnitude as it travels from a low impedance coil to a high impedance bus, while pulses from the system (noise) will halve in magnitude traveling from a high impedance bus to a low impedance coil. Because of this phenomenon, the high voltage leads of the sensing capacitors should be attached to the winding as close as possible (less than 1 meter) to the junction of the first coil and the circuit ring. Sensors at this position will have the maximum sensitivity to machine PD and the maximum attenuation of the noise.

Air-Cooled Machines with 80pF Capacitive Sensors - Qm Values (mV)						
Level	% Tile	2-4 kV	6-8 kV	10-12 kV	13-15 kV	16-18 kV
Negligible	< 25th	6	12	34	36	36
Low	< 50th	40	35	77	95	72
Typical	< 75th	136	143	188	220	260
Moderate	< 90th	262	267	414	477	2090
High	< 95th	389	339	665	760	2796
Very High	> 95th	389	339	665	760	2796
Avg		182	137	287	310	515
Max		3200	1626	3079	3200	3200

Time-of-arrival

Perhaps the most effective means of separating PD from noise is via the time-of-arrival method. Though this method does require extra effort during installation, it ensures that external pulses are classified as noise. Two different installation configurations can be used for time-of-arrival separation: differential and directional, which are described later.

Pulse Shape

Another noise separation method used by SSCs and 80pF couplers is to examine the shape of the pulse.

Hydro Generator PD Detection

In hydrogenerators, 80pF capacitive coupler pairs are placed on one phase and the length of the coaxial cables trimmed such that any system (noise) pulse detected by the two couplers arrives at the test instrument simultaneously. The test instrument will perform a differential comparison of arrival time along with the pulses' shapes, sizes, and polarities to separate noise from the machine PD.

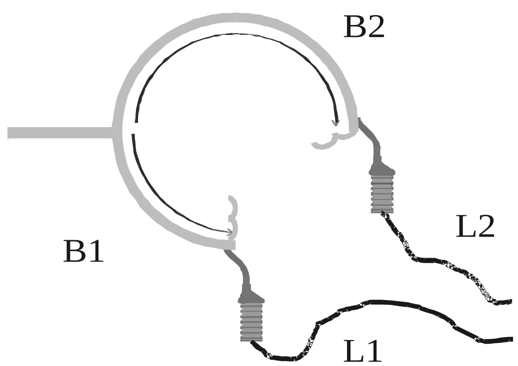


Figure 4. Differential Time-of-Arrival Noise Separation

During calibration, the coaxial cables are trimmed so that:

B1+L1 = B2 +L2

Noise pulses originating in the power system arrive at the same time at the end of the coaxial cables connected to each coupler and will be classified as noise. All other pulses (PD) will be assigned to the coupler that detects it first, and will be classified as PD. This is a differential time-of-arrival noise separation.

The locations of the optimum coupler placement in a generator are dependent on the layout of the stator winding. If certain physical requirements are not built into the winding design, there may not be the opportunity to install pairs of couplers in locations that assure the best opportunity to separate the effects of external noise. The differential style of coupler installation is preferred and can be done on hydro-generators that have at least 1 meter (3 feet) of circuit ring bus on each of the parallels to be monitored for a total distance between couplers of at least 2 meters (6 feet).

For machines of less than 100 MW, two couplers per phase are generally installed - one each at the line end of different stator parallel circuits. If a generator has more than two parallels per phase, it is possible to have a coupler on each parallel for extra winding coverage.

This is customarily reserved for large units (>100MW) or for very important smaller units where the extra cost is justified. When carrying out the calibration for machines with more than two couplers per phase, couplers are "paired" for calibration and data collection. This configuration is used with PDA-IV, HydroTrac and HydroGuard instruments or systems. The test instrument separates the pulses according to the following time-of-arrival criteria:

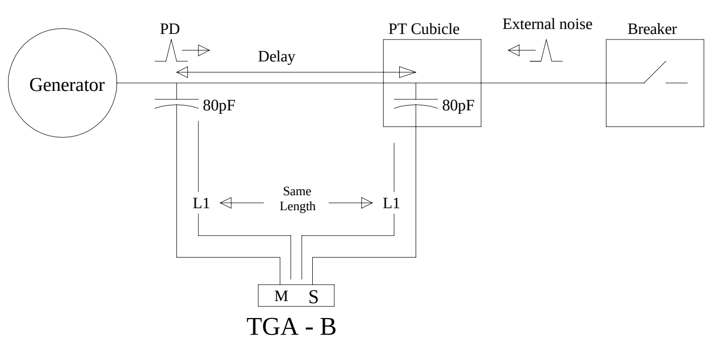
Classification	C1 sensor	C2 sensor
C1	L1	B1+B2+L2
C2	B2+B1+L1	C2
Noise*	B1+L1	B2+L2

*Calibrate so that B1+L1 = B2 + L2

Turbogenerator PD Detection

In most turbine generators, the circuit ring is not present or it is less than 2 meters (6 feet) long as required for the differential style, thus a directional installation is necessary. For a directional installation, one coupler (machine) is placed as close as possible to the junction between the line-end coil and the circuit ring. The second coupler (system) is placed on the incoming phase bus at a convenient location towards the system at least 2 meters (6 feet) from the first coupler. The coaxial cables are the same length.

Calibration involves measuring the delay time or the time it takes a fast rise-time pulse to travel between couplers. In a directional installation, instead of the system noise arriving at the couplers from opposite directions, it arrives from the same direction at the end of both coaxial cables.



Directional Time-of-Arrival Noise Separation

"L1" represents the time in nanoseconds that it takes a pulse to travel through the coaxial cables. For a directional installation, the coaxial cables are the same lengths; therefore, L1 is equal for both couplers. "Delay" is the time in nanoseconds it takes for a pulse to travel along the bus between the two couplers.

This configuration is used for TGA-B, BusTrac and BusGuard instruments and systems. The test instrument separates the pulses according to the following time-of-arrival criteria:

Classification	Machine	System Sensor
Unit PD	L1	L1 + delay
System	L1 + delay	L1
Bus Noise	L1 + <delay	L1 + <delay

** System and Bus Noise are displayed together as Total System Noise*

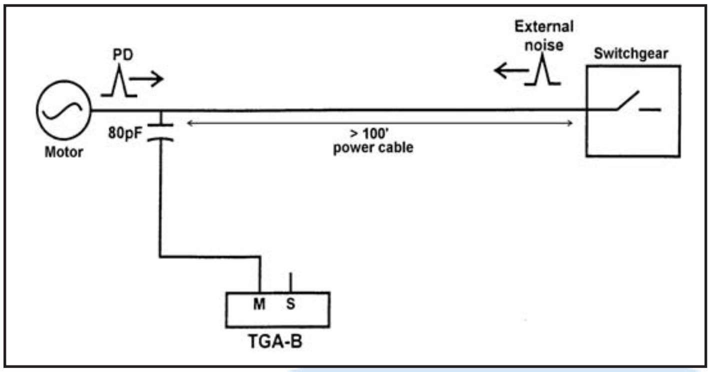
Large Turbine Generator PD Detection

Like the Directional (BUS) installation, the SSC installation has two sensors, one on each end of the antennae, and therefore categorizes pulses by direction of arrival. The delay time between pulse arrivals is a function of the sensor design and does not require calibration during installation. SSCs discriminate between PD and noise based on pulse shape.

Classification	EW Sensor	Slot Sensor
Endwinding	>8nS	N/A
Slot wide	N/A	>8ns
Noise	>20ns	>20ns

Single-Ended (80pF couplers)

In some installations, particularly motors, the unit is connected to the power system via a relatively long power cable. If the power cable is longer than about 30 meters (100 feet), the high frequency noise pulses from the power system may be severely dispersed and attenuated. If the pulse has a fast risetime, then it is probably PD. If the pulse has a long risetime, then it is likely noise. Thus, in these cases the system coupler is not necessary. In these cases only one coupler per phase, three per unit, should be installed. This is often referred to as a "single ended install".
There is no calibration required, though a sensitivity check is recommended. This configuration is used for PDTrac systems.



Single Ended Installation

About Iris Power Engineering

Four individuals who had worked at Ontario Hydro, the largest electric power utility in North America at the time, formed Iris Power Engineering in 1990. These individuals, Steve Campbell, Blake Lloyd, Greg Stone and Resi Zarb, have spent many years at the utility performing tests on motor and generator windings, as well as developing new on-line monitoring methods in research projects funded by Ontario Hydro, The Electric Power Research Institute (EPRI) and The Canadian Electricity Association (CEA). Iris was specifically formed by these pioneers, together with Ontario Hydro, to commercialize the new technology via an organization that shared the same interests as owners and operators of machines.

In the 1990s, Iris grew from four staff members to over 60, primarily as a result of the tremendous acceptance of its PDA and TGA on-line partial discharge monitoring products. By the year 2000, over 50% of large generators in American and Canadian utilities were equipped to use this technology for planning stator winding maintenance and replacements.

In 1998, a change of ownership occurred when Ontario Hydro and the four original partners sold their shares to Koch Engineering, Inc. Koch, based in Wichita, Kansas, is a major supplier of equipment and services to the petrochemical industry as well as operating refineries and pipelines. With over $30 billion in sales per year, Koch had the financial resources and local presence to continue to fuel the growth of Iris technology throughout the world.

ISO 9000:2001 Registered

Iris commitment to quality and continuous improvement are demonstrated by its ISO 9001-2000 registration in the Toronto facility, and ISO 9000: 2000 registration for the UK facility.

The Iris Advantage

- world-recognized expertise in testing and maintenance of motors and generators
- staff have extensive motor and generator experience from working for decades at Ontario Hydro, Ontario Power Generation, and other utilities, as well as machine manufacturers such as ABB, Westinghouse and GE
- intimate knowledge of CSA, IEEE and IEC standards - since we helped to write them
- one of the largest, non-OEM concentrations of machine expertise in the world
- unbiased, independent third party assistance
- wide range of test equipment, for HV and LV , on and off line tests available locally
- Iris knows machines
- cost effective solutions
- Iris with its utility background recognize the need of operators for reliable operating plant

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