PARTIAL DISCHARGE TESTING: A PROGRESS REPORT

PD – INDUSTRIAL VERSUS UTILITY APPLICATIONS

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1 ABSTRACT

It has long been known that comparing the partial discharge results obtained from a single machine is a valuable tool enabling companies to observe the gradual deterioration of a machine stator winding and thus plan appropriate maintenance for the machine [1]. In 1998, at the annual Iris Rotating Machines Conference (IRMC), a paper was presented that compared thousands of partial discharge (PD) test results to establish the criteria for comparing results from different machines and the expected PD levels [2]. At subsequent annual Iris conferences, using similar analytical procedures, papers were presented that supported and expanded upon the previous criteria [6 - 21]. This paper presents the most recent statistical analysis of the database.

Previous database analyses have only separated results based on voltage class, sensor type and cooling gas pressure. This paper looks deeper by comparing the results from utility-based assets to industrial-based assets. There are a few differences in these applications that might impact the partial discharge (PD) results, but most notably are operating history and the traditional usage of surge capacitors in industrial application, which are normally not used in utility applications.

Disclaimer: The classification of utility versus industry was based solely on the primary function of the plant. No effort was made to determine whether surge equipment was installed.

Calibration of on-line PD test results is theoretically not possible [3]; therefore, only results obtained using the same method of data collection and noise separation techniques are compared. For this paper, all the data were obtained with a PDA-IV, TGA, Trac or Guard test instrument. Data collected through to the end of 2017 was used; and, as in past papers, it is standardized for frequency bandwidth and pruned to include only the most recent full-load-hot (FLH) results collected for each sensor on operating machines. All questionable data or data from off-line testing or unusual machine conditions was excluded, leaving over 22,000 statistically independent new results collected from about 7,000 machines. The Appendix presents the statistical summary of the latest data to enable Trac, Guard, TGA, and PDA-IV test users to compare on a gross level their test results to those of similar machines.

2 INTRODUCTION

Partial discharges (PD) may occur in electrical insulation systems that operate at 3.3 kV and above. PD only occurs when gas-filled voids are present within the insulation or a gas (usually air) is present on the insulation surface when there is a high electric stress [24]. If the stress is high enough, the gas will experience electrical breakdown, creating a spark consisting of energetic electrons which will break molecular bonds in any organic polymer. Thus, PD will age the insulation and may eventually cause failure. PD occurs in a wide variety of high voltage electrical apparatus such as transformers, gas insulated switchgear, power cables and rotating machines. Since each discharge causes of a flow of charge, the PD can be detected by measuring the current pulses on the terminals of high voltage equipment. Off-line PD testing has been as a factory test for almost 100 years on equipment such as power cables. The purpose is to detect flaws created during manufacturing that lead to PD, and thus lead to insulation failure. In the past 40 years or so, owners of high voltage equipment are also measuring PD over time on installed equipment. Many aging processes can create voids that can lead to PD, and thus PD is often a symptom of thermal and thermo-mechanical aging processes. By monitoring the evolution of PD over time either in off-line tests or by on-line monitoring while the equipment is operating normally, equipment owners have a powerful tool for determining when maintenance or equipment replacement is needed. More commonly, machine owners have been using off-line and on-line PD testing to assess the condition of the stator winding insulation to determine if maintenance is needed. Problems such as loose coils in the stator slots, contamination leading to electrical tracking and thermal aging of the insulation are easily detected [25][26]

There are many different types of PD testing equipment that have been used for coils and stator windings. Most use a capacitor to detect the PD pulse currents in the presence of the 50/60 Hz high voltage. The instrumentation to measure the PD current pulses most commonly includes an analog to digital converter that determines the number, magnitude and phase position (with respect to the 50/60 Hz ac cycle) of the PD. However almost every brand of PD detector works in a different part of the frequency spectrum. Since each partial discharge pulse is the result of a brief flow of electrons lasting only a few nanoseconds, by the Fourier transform, frequencies from 0 Hz up to several hundred MHz are created by each discharge. Thus, PD can be detected in a very wide range of frequencies, and this will impact what is measured. Only instruments using very high frequency (VHF) bandwidths, 30-300MHz, are included in this paper [25].

2.1 PD - A COMPARISON TEST

Partial discharges (PD) are small electrical sparks that occur when voids exist within or on the surface of high voltage insulation of stator windings in motors and generators. These PD pulses can occur because of the manufacturing/installation processes, thermal deterioration, winding contamination or stator bar movement during operation. As the insulation degrades, the number and magnitude of PD pulses will increase. Although the magnitude of the PD pulses cannot be directly related to the remaining life of the winding, the doubling of PD pulse magnitudes approximately every 12 months has been used as a “rule of thumb” to indicate rapid deterioration is occurring [26]. If the rate of PD pulse activity increases rapidly, or the PD levels are high compared to other similar machines, this is an indicator that visual inspections and/or other testing methods are needed to confirm the insulation condition [4]. Furthermore, if the PD magnitudes by the same test method from several identical windings are compared, the windings exhibiting higher PD activity are generally closer to failure [1]. This paper examines the validity of this approximation.

2.2 PREVIOUS PAPERS

The conclusion of previous papers was that when comparing PD data results from different machines, the following parameters must remain constant: [2] [4][5][6]

- Test instrument bandwidth and noise separation techniques [1998]
- Type of sensors [1998, 1999, 2006, 2009]
- Operating voltage of the machines [1998, 2005, 2006, 2013]
- Operating gas coolant of the machines – PD is pressure dependent [1998, 2002, 2006, 2015]
- PD levels appear to be influenced by the quality of design, manufacturing, and installation, and not solely operating hours or operating condition [2000, 2001, 2004, 2007, 2008, 2010, 2014]
- Impact of ambient conditions [2012]
- Impact of resin penetration method, GVPI vs VPI [2018]

Not as significant are:

- Type of insulation system [2000, 2003, 2006]
- Machine type [1998, 1999, 2000, 2005]
- Winding type [1998, 1999, 2000, 2005]

Differences in operating loads and temperatures could also affect the results, but these were dependent on the condition of the stator winding and therefore, would only be applicable when comparing the PD results obtained from a single machine, not when comparing results from different machines.

3 COLLECTION OF DATA

3.1 PD TEST METHOD

During normal machine operation, the VHF instrument called the PDA-IV or TGA is temporarily connected or a Guard system is continuously connected to the previously installed sensors in each phase. The sensor blocks the power frequency voltage, and passes the high frequency voltage pulse accompanying partial discharge. To avoid any confusion with electrical noise from power tool operation, corona from the switchgear, RF sources, etc., the PDA-IV, TGA or Guard separates PD from system noise and disturbances based on time-of-arrival and pulse characteristics, and measures the number, magnitude and ac phase position of the PD pulses.

3.2 DATA PRESENTATION

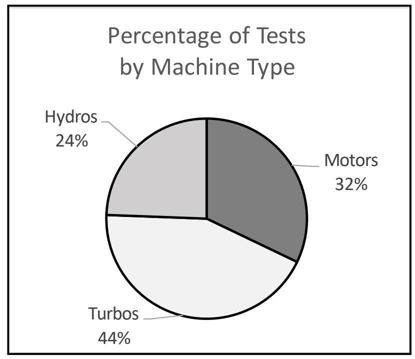
Two types of plots are generated for each partial discharge test. The first type of plot is two-dimensional (2-D), where the number of partial discharges per second versus PD magnitude is displayed. The greater the number of pulses per second, the more widespread is the deterioration in the winding. The higher the PD magnitude, the more severe is the deterioration. The second type of plot is three-dimensional (3-D), where the quantity (vertical scale) and magnitude (scale coming out of the page) of the PD versus the ac phase angle (horizontal scale) are displayed. Experience has indicated that such pulse phase analysis can be used to identify if multiple deterioration mechanisms are occurring, and what the mechanisms are.

The 2-D and 3-D plots are unwieldy for making comparisons amongst the machines. The PDA-IV or TGA summarizes each plot with two quantities: the peak PD magnitude (Qm) and the total PD activity (NQN). The Qm is defined to be the magnitude corresponding to a PD repetition rate of 10 pulses per second. Qm relates to how severe the deterioration is in the worst spot of the winding, while the NQN is proportional to the total amount of deterioration and is similar to the power factor tip-up. Since the Qm scalar quantity is more indicative of how close the winding is to failure, the peak magnitude (Qm) will be used throughout this paper for comparisons [25].

3.3 2017 DATABASE

After the accumulation of all available test data through 2017 with over 640,000 records from tests using portable instruments only, a database was carefully compiled using the following selection criteria:

- only on-line tests obtained during normal operation
- only one test result per sensor
- the most recent test at Full Load and Hot stator winding temperature (FLH)
- any test with questionable results was discarded
- Once these criteria were applied, over 22,000 statistically independent test results from over 7,000 assets were analyzed.



The following tables show the breakdown of the results that were retained once non-FLH and repeat tests were discarded.

Number of FLH Tests by Machine Type	
Motors	32%
Hydros	24%
Turbos	43%

The appendix shows the updated statistical distribution of peak PD magnitudes for various voltage classes and sensor types.

3.4 STATISTICAL ANALYSIS

The database was analyzed to determine the effect on Qm of several different factors, including:

- Sensor installation
- Voltage class
- Hydrogen Pressure

The range in Qm from all the tests for the operating voltage was established for each set of the above factors. A sample of the statistical distribution is shown in Table 1. For example, for 13-15 kV stators in turbine generators or motors, 25% of tests had a Qm below 55 mV, 50% (the median) had a Qm below 120 mV, 75% were below 258 mV and 90% of tests yielded a Qm below 507 mV. Thus, if a Qm of 500mV is obtained on a 13.8 kV motor or turbine generator, then it is likely that this stator will be deteriorated, since it has PD results higher than 90% of similar machines. In fact, in over two hundred cases where a machine was visually examined after registering a PD level >90% of similar machines, significant stator winding insulation deterioration was observed [23].

Table 1. Distribution of Qm for Air-Cooled Stators, 80 pF Sensors on the Terminals

Oper kV	2-5kV	6-9kV	10-12kV	13-15kV	16-18kV	> 19kV
25%	9	28	45	55	42	60
50%	22	71	100	120	80	106
75%	62	159	214	258	175	289
90%	216	318	436	507	338	664
95%	360	494	679	764	555	971

Table 2 illustrates the similar statistical distribution for hydrogen-cooled turbo generators where stator slot couplers (SSC) capacitors are installed. For these, both the operating voltage and gas pressure influence the results. Similar tables have also been prepared for air and hydrogen-cooled machines with other types of PD sensors and can be found in the appendix of this paper.

Table 2. Distribution of Qm for Gas-Cooled Stators using SSC sensors – Slot PD

Oper V	13-15kV			16-18kV			19-22kV			23-26kV	
H2 (kPa)	76-138	145-207	Over 207	75-207	214-345	Over 345	75-207	214-345	Over 345	214-345	Over 345
H2 (psi)	11-20	21-30	31-50	11-30	31-50	> 50	11-30	31-50	>50	31-50	>50
25%	0	0	8	0	0	0	0	0	0	0	0
50%	0	0	13	0	0	0	4	0	0	0	0
75%	20	12	21	19	8	0	19	9	4	6	6
90%	56	38	40	39	42	7	54	35	10	13	20
95%	183	60	58	69	68	15	69	53	22	31	37

With these tables, it is now possible, with only an initial test for motor and generator owners, to determine if the stator winding insulation has a problem. If the PD is higher than that found on 90% of similar machines, then off-line tests and/or a visual inspection would be prudent. Continuous PD monitors should have their alarm levels set to the 75% for 4kV rated and below and the 90% level for above 4kV rated assets.

4 INDUSTRIAL VERSUS UTILITY APPLICATION

The following tables and figures indicate the cumulative probability distributions for industrial vs utility PD levels as a function of voltage class. To determine if the cause of PD is different between utility and industrial machines, polarity predominance is also compared.

4.1 MAGNITUDES

3-5kV	Industrial	Utility
25%	10	14
50%	24	29
75%	53	108
90%	263	298
95%	449	394

For windings rated 3-5kV, Figure 1, there is very little difference between the two applications.

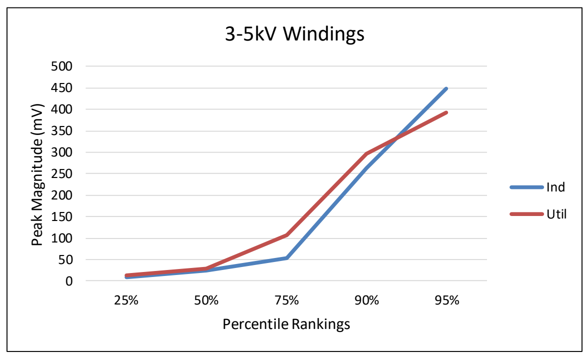


Figure 1. Comparison of the Industrial versus Utility applications with 3-5kV rated windings

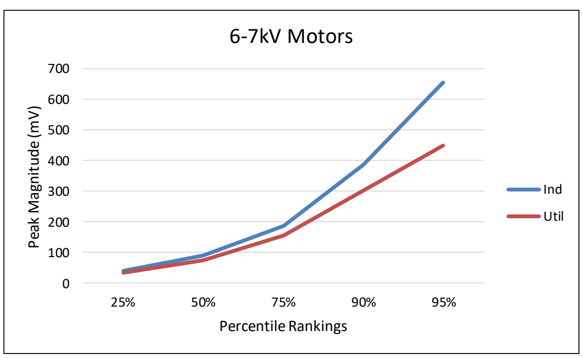


Figure 2. Comparison of the Industrial versus Utility applications with 6-7kV rated windings

6-7kV	Industrial	Utility
25%	39	33
50%	91	73
75%	184	147
90%	380	297
95%	654	440

For windings rated 6-7kV, Figure 2, there is a notable difference above the 75% indicating on average higher PD activity in industrial machines.

10-12kV	Industrial	Utility
25%	75	37
50%	173	77
75%	327	148
90%	618	332
95%	866	569

For windings rated 10-12kV, Figure 3, there is a significant difference between the two applications with the industrial application notably higher for all percentile rankings.

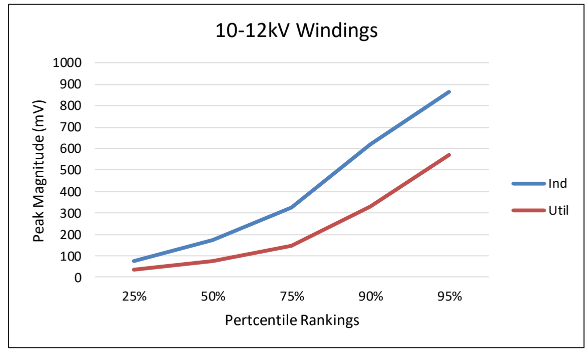


Figure 3. Comparison of the Industrial versus Utility applications with 10-12kV rated windings

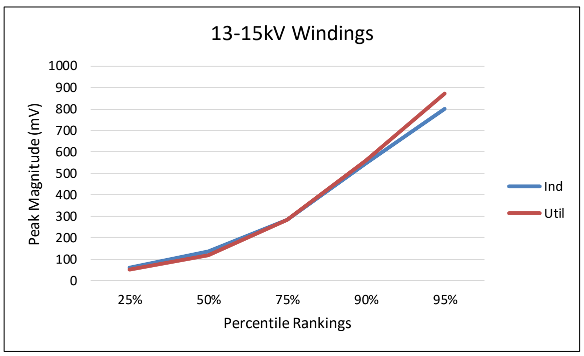


Figure 4. Comparison of the Industrial versus Utility applications with 13-15kV rated windings

13-15kV	Industrial	Utility
25%	59	53
50%	136	116
75%	283	283
90%	547	562
95%	799	871

For windings rated 13-15kV, Figure 4, there is little difference between the PD magnitudes between the two applications.

4.2 POLARITY PREDOMINANCE

The polarity of the classic pulses and their predominance tells a lot about the relevant failure mechanism as shown in Figure 5. Due to space charge effects, a pulse will occur in a specific direction based on the proximity of the void to a metallic substance. For this reason, it is possible to determine where the pulses originate, and therefore, the location of the voids in the insulation system. Several failure mechanisms produce voids predominantly at a certain location in the insulation. By observing the pulse polarity, it is often possible to determine which failure mechanism is dominant.

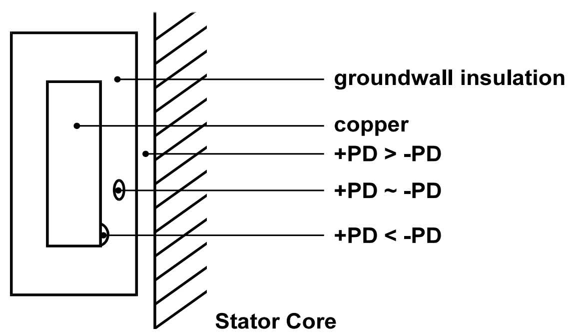


Figure 5. PD Polarity based on Void Position

Though comparing the peak magnitudes (Qm values) from each polarity for each winding is a simplistic method to hypothesize about the actual source of the PD activity, when comparing multiple machines, it does provide some insight. In this case, no predominance would be suggestive of voids within the bulk of the groundwall insulation, negative predominance suggests internal voids in proximity of the copper strands, and positive predominance suggests surface activity due to electrical slot discharge, coil/bar movement or contamination. Note that polarity predominance should be based only on the classic PD patterns, that is, clusters around 45° and 224° from PD sources that are phase-to-ground dependent. In the absence of classic PD, polarity predominance is not applicable.

When the occurrences of polarity predominance for assets within each voltage class are compared between utility and industrial applications, Figure 6, there is nominal difference. This suggests that the failure process that generates the voids, or the source of the PD activity is comparable regardless of the application.

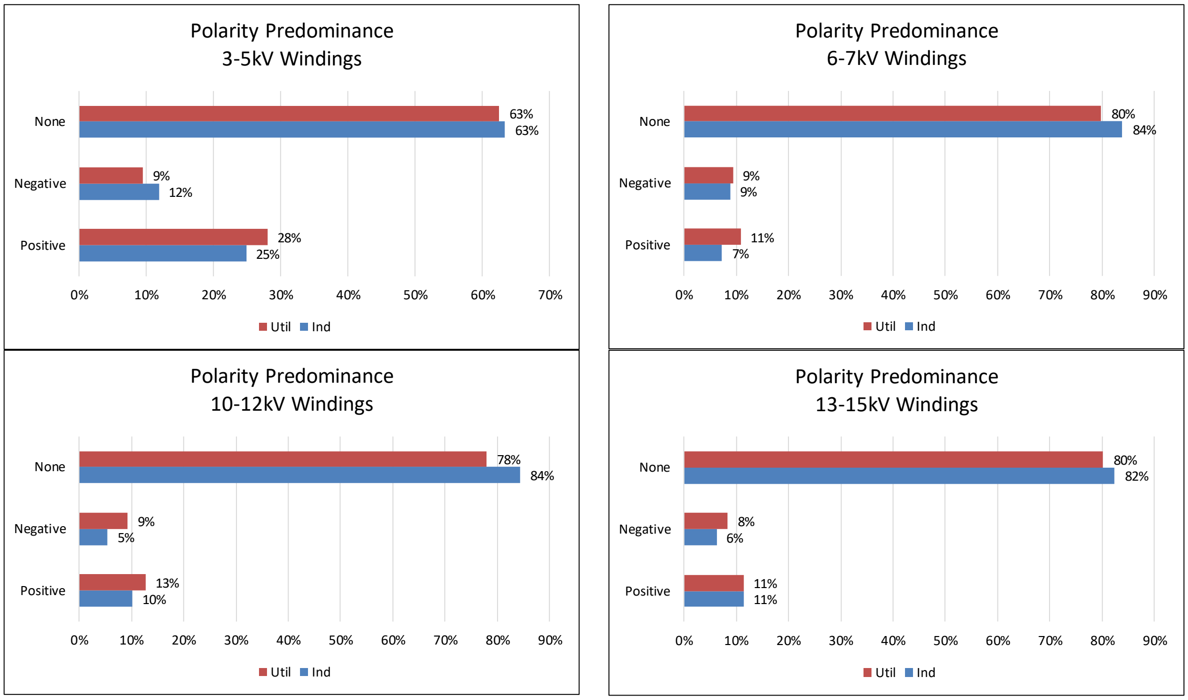


Figure 6. Charts comparing occurrences of polarity predominance between Utility and Industrial applications

5 CONCLUSION

Comparison of the PD results between assets that are in utility versus industrial applications point to some theories. In summary, the following possibilities are revealed in the data comparison:

- PD Magnitudes
  - There was little difference with the PD magnitude rankings at the various percentiles for the 3-5kV and 13-15kV assets. This suggests that regardless of application, there is little difference in the quality of manufacturing and the aging process of the stator windings.
  - In both the 5-7kV and 10-12kV comparisons, the industrial assets were notably higher. The reason for this is unknown, but may be due to either the manufacturing process or the differences in operating stress. In the PD Progress paper of 2018, it was in the 10-12kV range that some (1990-1990 and >2010) GVPI machines have higher PD activity than the conventional VPI process. Perhaps this contributes to the differences seen here. [6]
- Polarity Predominance
  - For all four (4) voltage class categories, there is minimal significant difference between the frequency of occurrence for negative, positive or no polarity predominance. This suggests that the failure processes, or sources of the PD activity, are comparable between industrial and utility applications.

Though it is always recommended that you trend the results for one machine over time and thus monitor the rate of degradation of the stator winding, it is also possible to compare results from similar machines. If the test instrument is a TGA, PDA-IV, Trac or Guard and the sensors are either 80pF capacitors, or stator slot couplers, then the tables contained within the appendix can be used to ascertain whether a machine warrants further tests and inspections or is operating within reasonable limits. Yellow flags should only be raised if the PD levels on a specific machine are above the 90th percentile (High). In all cases, raising the flag means increasing the frequency of PD testing to determine the rate of deterioration and when possible, conduct specialized tests, inspections and repairs as required. In mica-based insulation systems, PD is a symptom of a failure mechanism; action should be based on the severity of the failure mechanism detected by the PD, not the PD results. PD levels exceeding threshold alarms are warnings for further investigation to determine the cause of the high PD; however, be aware that PD levels can fluctuate with ambient and operating conditions. Maintenance should be based on the cause of the PD, not the overall levels. Continuous PD monitors should have their alarm levels set to the 75% or 90% level.

The time of winding failure is normally the result of a deteriorated winding being subjected to an extreme stress such as a lightning strike, out-of-phase synchronization, excessive starts, or system imbalance. As these are unpredictable, it is impossible to forecast when a failure will occur. However, by monitoring the PD characteristics of a stator winding, it is often possible to determine which machines are more susceptible to failure, and therefore which require maintenance.

6 REFERENCES

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[24] IEC 60270, "High Voltage Test Techniques. Partial Discharge Measurements.", 2015

[25] IEC TS 60034-27, "Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines", 2006

[26] IEC TS 60034-27-2 "On-line partial discharge measurements on the stator winding insulation of rotating electrical machines", 2012.

7 APPENDIX – DATA ANALYSIS OF RESULTS THRU 2017

The following summarizes the analysis of the PD levels, given by Qm number, for all data collected with Iris equipment up to the end of the year 2017 with over 640,000 results. Since it has been well established that it is ambiguous to compare PD results obtained using different types of sensors [3], data analysis requires separation of the database based on sensor type. The two basic types of sensors used in the data collection are: 80pF capacitors (cable-type and epoxy-mica type) and stator slot couplers (SSC). Furthermore, data will be separated based on gas cooling pressure and operating voltages.

7.1 CAPACITORS – (AIR-COOLED MACHINES)

The most widely employed sensors are the 80pF couplers used on motors, hydro-generators, and small turbine generators. There are two methods of sensor installation for the capacitive couplers, the directional (TGA) and the differential (PDA) methods.

7.1.1 Directional Method (TGA)

The directional method is used primarily on motors and small turbine generators and occasionally on small hydro-generators.

Qm values for air-cooled machines with directional capacitive couplers (TGA)

Rated kV	**2-5**	**6-9**	**10-12**	**13-15**	**16-18**	**≥ 19**	
25%	9	28	45	55	42	60	25% of the results have Qm levels below this value
50%	22	71	100	120	80	106	50% of the results have Qm levels below this value
75%	62	159	214	258	175	289	75% of the results have Qm levels below this value
90%	216	318	436	507	338	664	90% of the results have Qm levels below this value
95%	360	494	679	764	555	971	95% of the results have Qm levels below this value

As shown here, the majority, 75%, of the results obtained with the directional mode installation (BUS) of capacitive couplers are below 214mV for machines rated less than 12kV, 258mV for machines rated 13-15kV, 175mV for 16-18kV, and 289mV for those >19kV.

Additionally, there is almost a doubling of the Qm levels between the 75% and the 90%, which supports the definition of *rapid deterioration* as doubling over a twelve-month interval [26]. There are a few machines with PD much higher than the 90th percentile with Qm levels >500-650mV. These machines are suspected to have significant deterioration.

7.1.2 Differential Method (PDA)

The differential method is used primarily on large hydro-generators having an internal circuit ring bus.

There are two major differences in the directional and differential installations: one is the method of time-of-arrival noise separation and the second is the actual location of the couplers. Since both time-of-arrival noise separation techniques work similarly, this difference should have little impact to the test results.

However, the difference in the sensor locations can greatly affect the results. A differential (PDA) installation in a larger hydro-generator uses sensors normally placed within one meter of the junction between the incoming phase bus and the first coil/bar in the circuit. A sensor at this location will be extremely sensitive to any pulses originating within the coil/bar since the magnitude of the pulse will be amplified when it reaches the impedance mismatch between the bus and the coil/bar. When comparing the directional (TGA) results to the differential (PDA) results, there are some minor variances, there is little significant difference between the statistical summaries for windings rated less than 16kV. Thus, it is safe to say that for a 13.8kV winding, regardless of installation type, the PD levels should be less than ~250mV and those machines with PD higher than 500mV need further investigation.

Qm values for air-cooled machines with differential capacitive couplers (PDA)

Rated V	**6-9kV**	**10-12kV**	**13-15kV**	**16-18kV**	**≥ 19kV**	
25%	13	19	33	22	98	25% of the results have Qm levels below this value
50%	33	50	89	95	176	50% of the results have Qm levels below this value
75%	58	114	192	274	440	75% of the results have Qm levels below this value
90%	176	240	364	579	854	90% of the results have Qm levels below this value
95%	295	388	535	793	966	95% of the results have Qm levels below this value

7.2 CAPACITORS – (GAS-COOLED) (TGA)

Since the occurrence of PD is extremely dependent on the electrical breakdown point of the gas medium, PD results from air-cooled machines are typically higher than machines cooled with either hydrogen or pressure carbon dioxide. Therefore, it is not advisable to compare the results from machines using different gas mediums. Since most hydro-generators (PDA installations) are air-cooled, all the tests for gas-cooled machines with capacitors were obtained using a TGA instrument and directional sensor installation. Most of the hydrogen-cooled machines have high rated loads and frequently suffer from problems with the core iron arcing. PD or noise activity at the machine terminals, outside the hydrogen environment, can make stator winding insulation condition difficult to interpret. As a result, stator slot couplers (SSC) are the recommended sensors in these applications to avoid misdiagnosis resulting from the capacitive sensor detecting core-iron problems in addition to stator winding problems.

Qm values for non air-cooled machines with directional capacitive couplers (TGA)

Rated V	**13-15kV[1]**				**16-18kV**				**≥ 19kV[1]**		
H2 (kPa)	**76-138**	**145-207**	**214-345**	**Over 345**	**76-138**	**145-207**	**214-345**	**Over 345**	**145-207**	**214-345**	**Over 345**
H2 (psig)	**11-20**	**21-30**	**31-50**	**≥ 50**	**11-20**	**21-30**	**31-50**	**≥ 50**	**21-30**	**31-50**	**≥ 50**
25%	29	19	14	19	15	33	19	9	49	19	9
50%	77	48	35	69	86	72	37	18	89	53	24
75%	180	92	74	197	144	379	86	42	147	134	75
90%	365	172	225	547	268	905	224	292	187	213	357
95%	765	284	492	810	441	976	398	357	218	1371	1015

As expected, the PD results for gas-cooled machines are much lower than for the air-cooled machines. This is especially observable at higher pressures, where 75% of the tests for all operating voltages operated above 31psig are generally below ~100mV and 90% generally below ~300mV, less than half of that observed on the air-cooled machines (Section 7.1.1). At the lower operating pressures, the PD levels are generally much higher, with a few machines having extremely high PD of Qm levels >900mV, which would require more tests and investigation.

[1] Fluctuations from previous years due to a large influence by one or more manufacturers

7.3 STATOR SLOT COUPLERS (SSC) – (GAS-COOLED)

Qm values for non air-cooled machines with SSC sensors- Slot PD

Rated V	13-15kV				16-18kV			19-22kV			23-26kV	
H2 (kPa)	**76-138**	**145-207**	**214-345**	**Over 345**	**75-207**	**214-345**	**Over 345**	**75-207**	**214-345**	**Over 345**	**214-345**	**Over 345**
H2 (psi)	**11-20**	**21-30**	**31-50**	**> 50**	**11-30**	**31-50**	**> 50**	**11-30**	**31-50**	**>50**	**31-50**	**>50**
25%	0	0	0	0	0	0	0	1	1	0	0	0
50%	9	1	11	3	3	1	3	8	8	5	5	3
75%	31	14	23	7	14	16	8	23	21	13	14	8
90%[2]	48	63	37	27	47	37	13	95	47	24	43	19
95%[2]	60	92	60	46	64	53	19	225	71	38	64	30

The preferred sensor for turbine generators rated higher than 100MVA is a stator slot coupler (SSC). The sensor is placed within the slot of the highest voltage bar either directly beneath the wedge or between the top and bottom bars in the slot. There is little difference in the results obtained from the two installations [2]. Since these machines are operating in a hydrogen environment, the overall slot PD is quite low relative to the air-cooled windings. It should be observed that though most of the machines have slot Qm values less than ~30mV, there are a few with levels higher than 60-200mV. These should be subjected to further tests and inspections. The SSC is a high frequency antenna that detects the pulses and through pulse analysis, the TGA can discriminate between pulses originating in the high voltage insulation and those from core-iron arcing or external sources. Furthermore, the SSC/TGA test setup can identify whether the PD originates in the slot or in the endwinding [15]. The endwinding PD is slightly lower than the slot PD, with 90% of all the tests less than ~20mV. There are, however, a few machines with Qm levels higher than 25mV, and these machines require additional attention.

Qm values for non air-cooled machines with SSC sensors- Endwinding PD

Rated V	13-15kV				16-18kV			19-22kV			23-26kV	
H2 (kPa)	**76-138**	**145-207**	**214-345**	**Over 345**	**75-207**	**214-345**	**Over 345**	**75-207**	**214-345**	**Over 345**	**214-345**	**Over 345**
H2 (psi)	**11-20**	**21-30**	**31-50**	**> 50**	**11-30**	**31-50**	**> 50**	**11-30**	**31-50**	**>50**	**31-50**	**>50**
25%	0	0	0	0	0	0	0	0	0	0	0	0
50%	0	0	0	0	0	0	0	0	0	0	0	0
75%	0	0	5	0	2	0	5	1	3	5	0	1
90%	20	9	12	1	12	10	22	9	12	16	10	8
95%	34	19	19	26	19	19	44	28	19	43	61	18

7.4 STATOR SLOT COUPLER – (AIR-COOLED)

Qm values for air-cooled machines with SSC sensors

Slot PD		
Rated V	**13-15kV**	**16-24kV**
25%	0	1
50%	15	4
75%	40	15
90%	87	75
95%	126	123

Endwinding PD		
Rated V	**13-15kV**	**16-24kV**
25%	0	0
50%	0	1
75%	13	1
90%	44	8
95%	62	21

There are a few air-cooled machines being monitored with stator slot couplers. As previously described, because of the differences in the electrical breakdown points of the gas mediums, it is not recommended to compare results from air-cooled machines to those from gas-cooled ones. It is not surprising that the PD levels for the air-cooled machines with SSCs are generally higher than the gas-cooled ones. Most of these machines have slot Qm levels less than ~40mV, but there are a few with extraordinarily high slot PD, >120mV, that would require further investigation.

[2] Fluctuations from previous years due to a large influence by one or more manufacturers