PARTIAL DISCHARGE TESTING: A PROGRESS REPORT

RAPID DETERIORATION – PD TRENDS

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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 [4 - 18].

In the past few decades, trending of PD results has provided plant maintenance personnel with advanced notice as problems develop within their stator winding insulation. Though prediction of failure is never exact, increases in PD activity over time have shown to indicate advancing damage to the stator winding that could lead to premature failure. Rapid deterioration, defined as a "doubling of activity over six months", has become a common reference. This paper evaluates the trend patterns of thousands of results from data collected over the last 20+ years to determine the correlation between what is considered high levels of PD activity and advancing (rising) levels of PD. It seems that high levels of PD are correlated to a rapid increase in PD.

Calibration of on-line PD test results is impractical [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 2011 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 16,700 statistically independent new results. 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

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 6 months has been used as a "rule of thumb" to indicate rapid deterioration is occurring. 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:

- Test instrument bandwidth and noise separation techniques [2]
- Type of sensors [2, 5, 12, 15]
- Operating voltage of the machines [2, 11, 12]

- Operating gas coolant of the machines – PD is pressure dependent [2, 8, 12]
- PD levels appear to be influenced by the quality of design, manufacturing, and installation, and not solely operating hours or operating condition [6, 7, 10, 13, 14, 16]
- Impact of ambient conditions [18]

Not as significant are:

- Type of insulation system [6, 9, 12]
- Machine type [2,5,6,11]
- Winding type [2,5,6,11]

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, an instrument called the PDA-IV or TGA is temporarily 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 or TGA separates PD from system noise on the basis of 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.

3.3 2011 DATABASE

After the accumulation of all available test data through to 2011 with over 272,000 records, 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

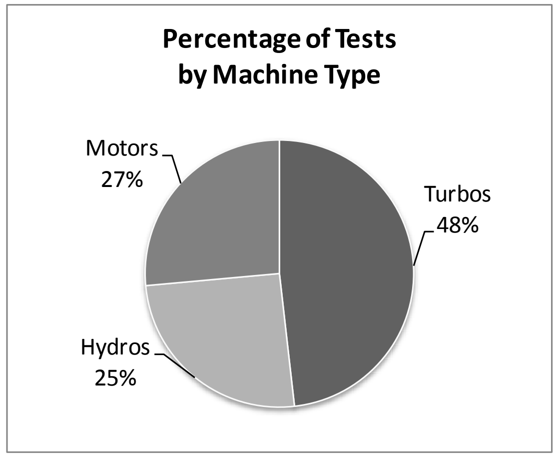
Once these criteria were applied, about 16,700 statistically independent test results were analyzed.

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	27%
Hydros	25%
Turbos	48%

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

The range in Qm from all the tests for the particular 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 hydrogenerators or pump-storage units, 25% of tests had a Qm below 35 mV, 50% (the median) had a Qm below 93 mV, 75% were below 193 mV and 90% of tests yielded a Qm below 376 mV. Thus if a Qm of 400mV is obtained on an 13.8 kV hydrogenerator, 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 [21].

Table 1. Distribution of Qm for Hydrogenerators with 80 pF Sensors

Oper kV	6-9kV	10-12kV	13-15kV	16-18kV	> 19kV
25%	12	19	35	37	67
50%	33	50	93	118	142
75%	72	111	193	334[1]	441[1]
90%	201	231	376	687	838[1]
95%	322	389	561	1016[1]	956

Table 2 illustrates the similar statistical distribution for motors and air-cooled turbo generators where the 80pF capacitors are installed at the machine terminals (rather than within the stator as in Table 1). Similar tables have also been prepared for hydrogen-cooled machines and those with other types of PD sensors and can be found in the appendix of this paper.

Table 2. 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%	8	29	34	50	41	40
50%	20	70	77	113	77	85
75%	63	149	172	239	151	136[2]
90%	228	288	376	469	292	497
95%	398	433	552	723	582	722

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

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

off-line tests and/or a visual inspection would be prudent. Continuous PD monitors should have their alarm levels set to the 90% level.

4 PD TRENDS

The first step of analysis is to compare the results of the current test with any previous test results. Trending of the Qm and NQN values can give you an indication of the *progression* of the aging mechanisms. A doubling of PD activity (Q_m values twice that of the previous test) every six months has been considered a strong indication of a rapidly developing failure mechanism [11].

There are two significant trends used in this analysis, the *short-term* and *long-term* trends. The purpose of the *short-term trend* is to discern whether there has been a sudden and significant change from the previous test. Changes in PD levels are usually slow to develop. Significant changes up or down over a short time period are cause for concern and indicate a need to retest as soon as possible to determine whether the change is permanent or intermittent. Maintenance decisions should not be made in isolation based on a single change in pattern – PD is stochastic in nature and can be highly influenced by variances in operating and ambient conditions as shown in Figure 1 [18-20, 22].

Caution: Erratic PD can cause wide swings in trends that may be misleading. Do not interpret these in isolation. Variations of some percent, say +/- 25%, are normal and the impact of operating/ambient conditions should also be considered as shown in Figure 1. [18.

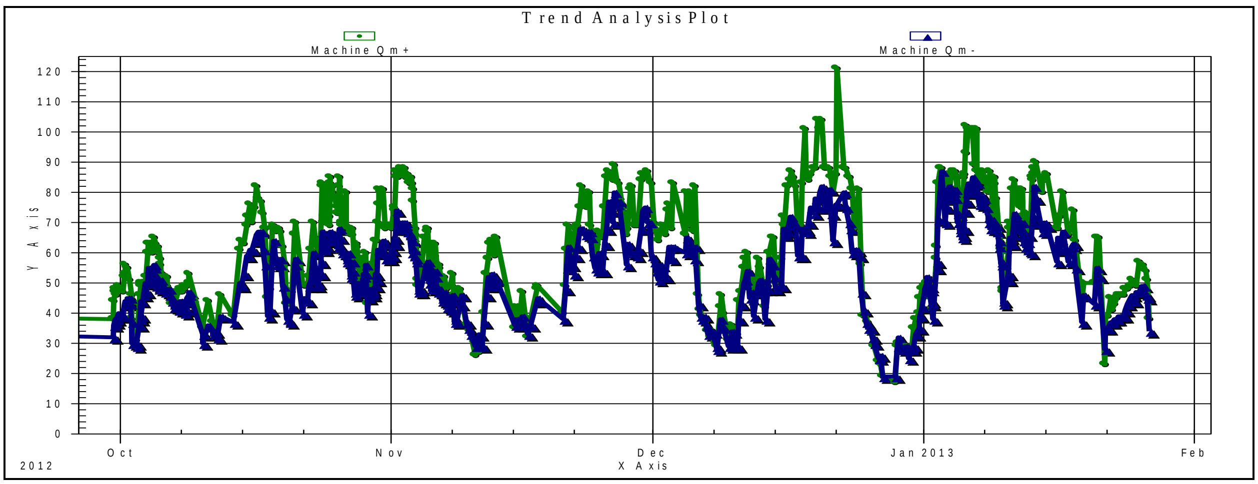


Figure 1. Actual PD Trend – surface PD highly influenced by ambient condition variations

The purpose of the *long-term trend* is to determine whether there is a notable long-term trend that is changing. The long-term trend analysis is a linear regression comparison to the "best" measurements from all relevant test dates within the database for a specific asset. Note that tests older than the winding itself are excluded (since a rewind has occurred) and data collected within the first 12-18 months of operation may be excluded if they highly influence the results. The latter is due to the common occurrence that PD behavior is often erratic for new windings as the winding settles-in and resins continue to cure. Long-term trends may not be possible if the current test results are outside of the norm, that is, judged to be unreasonably high or low values relative to the trend.

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 usually occurring over years, and sudden changes are not expected in the PD test results. Though the condition of the stator winding can be assessed, time to failure cannot be predicted [22]. The actual time of failure is normally the result of an unusual source of insulation stress such as lightning, out-of-phase synchronization, or severe overheating.

The typical PD life cycle of an asset as displayed in Figure 2 shows that on a new machine the PD will often start relatively high and then decrease as the winding settles over the first 12-18 months to "baseline" levels [**Error! Reference source not found.**]. Following that, there should be many years of relatively stable levels, with perhaps minor fluctuations due to the influence of variable ambient and operating conditions. Once a problem develops, the PD levels will increase quite rapidly, and then may stabilize at a high level [22].

Note PD may continue to increase or may not continue to increase until failure occurs.

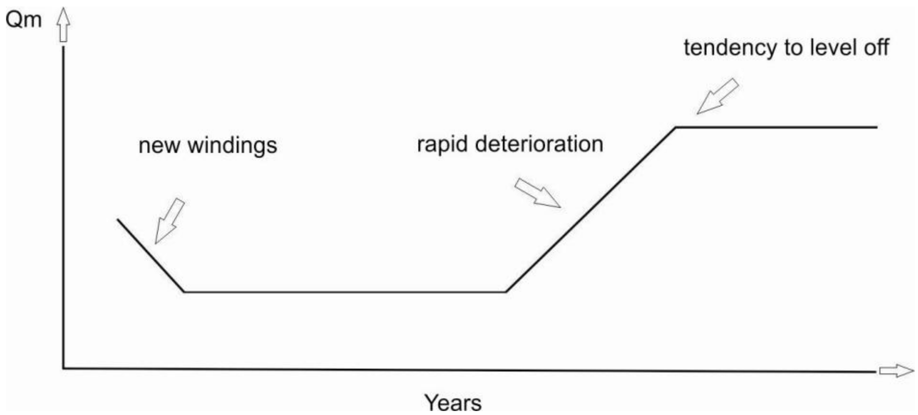


Figure 2. Overall PD Trend

Should it be possible to repair the damage, then the levels should decrease back to those observed prior to the onset of the problem, and the process repeats – with many years of relatively stable activity until the PD levels once again start increasing. 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 re-wedging, cleaning, dip and bake, and repairs to the voltage stress coatings. If the source of the PD is within the bulk of the insulation (usually due to poor manufacturing, thermal aging or load cycling) repairs may not be effective.

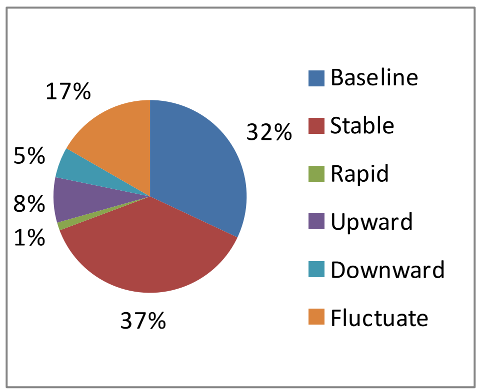
As previously stated, there is no way to predict when failure will occur, as failure normally happens when a compromised insulation system is exposed to an unusual, random stress. Based on the insulating materials, and nature of the deterioration, an inexplicable decrease or shift in the PD patterns may also be an indication of a rapidly developing problem.

Any significant change in activity, up or down should be investigated [Error! Reference source not found.**].**

4.1 DATABASE ANALYSIS FOR TRENDS

Several different analyses were done on the Iris database to determine whether there was a distinctive pattern between PD magnitude levels and PD long-term trends. Over 6000 long-term trends were evaluated from PD results collected using EMCs as the PD sensor. For this paper, there was no further separation based on voltage class and/or operating pressure.

Trend	Definition	% results
Baseline	Initial test	32%
Stable	Within ± 25%	37%
Upward	> 25%, but less than Rapid	8%
Rapid	> 100% in 6 months	1%
Downward	< 75% over 6 months	5%
Fluctuations	Influenced by ambient conditions [Figure 1]	17%



4.1.1 Breakdown of Trends based on PD Magnitudes

Table 3 below shows the percentages of the PD trends for each of the standard categories for PD magnitudes, that is, for PD results that would be considered "High" (≥ 90% Tables 1 & 2) there were 29% that were Baseline, 28% were Stable, 21% were Upward and 3% Rapid deterioration. In this table, it is apparent that the "Very High" (≥ 95% Tables 1 & 2) category has a higher percentage of results that are increasing rapidly. However, it should also be noted that if the "Upward" and "Rapid" trends are combined then both the "High" and "Very High" results have almost ¼ (23-24%) of the results that are increasing. This suggests a correlation between PD magnitude and PD trends.

Table 3. Breakdown of PD Trends based on PD Magnitudes

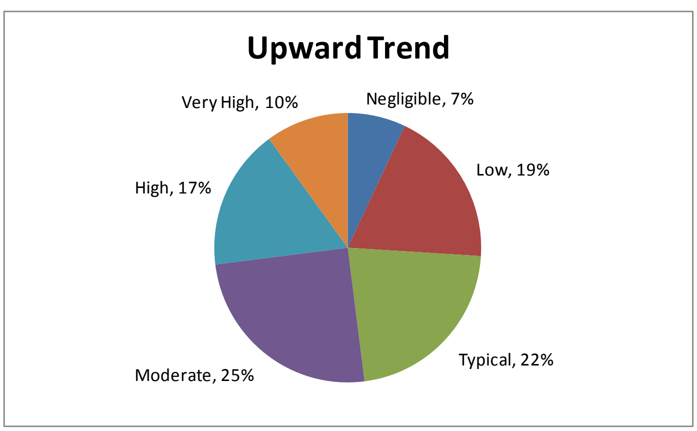
	Baseline	Stable	Upward	Rapid	Downward	Fluctuation
Negligible	37%	38%	2%	1%	6%	16%
Low	32%	41%	6%	1%	5%	16%
Typical	29%	40%	8%	1%	5%	17%
Moderate	28%	35%	13%	2%	5%	17%
High	29%	28%	21%	3%	4%	15%
Very High	38%	20%	14%	9%	2%	17%

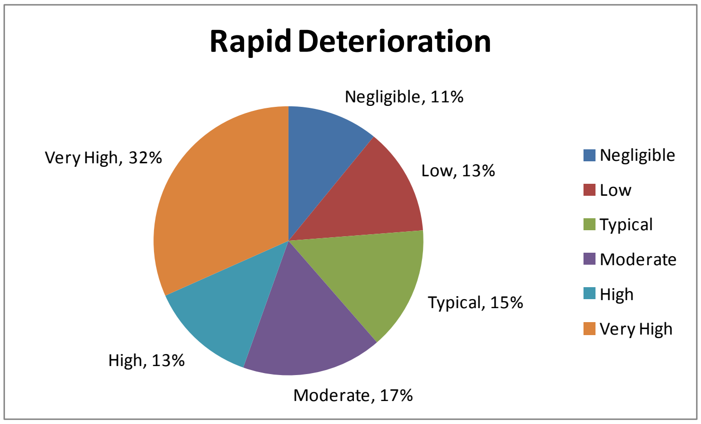
4.1.2 Breakdown of Magnitudes based on PD Trends

Table 4 below shows the percentages of the PD magnitudes for each of the standard categories for PD trends, that is, for PD results that would be considered "Upward" there were 7% that were Negligible, 19% were Low, 22% were Typical and 25% Moderate. In this table, it is apparent that the "Rapid" category has a higher percentage (32%) of results that are considered Very High. However, it should also be noted that as in Table 3, if the "Upward" and "Rapid" trends are combined then both the "High" and "Very High" results have ¼-½ (27-45%) of the results that are increasing. This supports a correlation between PD magnitude and PD trends.

Table 4. Breakdown of PD Magnitudes based on PD Trends

	Negligible	Low	Typical	Moderate	High	Very High
Baseline	**31%**	**25%**	**19%**	**13%**	**5%**	**6%**
Stable	**28%**	**28%**	**23%**	**14%**	**5%**	**3%**
Upward	**7%**	**19%**	**22%**	**25%**	**17%**	**10%**
Rapid	**11%**	**13%**	**15%**	**17%**	**13%**	**32%**
Downward	**32%**	**23%**	**22%**	**15%**	**4%**	**3%**
Fluctuations	**27%**	**24%**	**22%**	**15%**	**5%**	**6%**





When evaluating the PD magnitudes of the results that indicated an "Upward Trend" as shown above, there is no obvious correlation between magnitude and trend. That is, the Low, Typical and Moderate levels are just as likely to exhibit an upward trend as the High and Very High. However, the chart for "Rapid Deterioration" shown above clearly shows that those PD trends exhibiting a significant increase in PD over a fairly short time (6 months) tend to have Very High PD magnitudes.

5 CONCLUSION

Based on this limited database analysis, there appears to be a correlation between High (≥ 90% Tables 1 & 2) magnitude PD and those results that show an increasing trend (Upward or Rapid deterioration). Though this analysis does not fully substantiate the definition of "Rapid deterioration" as a "doubling of PD over a six-month interval", it does suggest that when "Rapid deterioration" exists, the PD magnitudes are likely to be High or Very High. As well, based on third-party analysis, it has been shown that when PD is High or Very High, there is a problem within the stator winding [21]. Whether or not that "problem" will lead to premature failure in mica-based insulation systems depends on the mechanism that is the source of the PD, not the PD itself.

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 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.

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7 APPENDIX – DATA ANALYSIS OF RESULTS THRU 2011

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 2011 with over 272,000 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.

7.1.1 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.

7.1.1.1 Directional Method

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**	
Avg	88	126	156	208	179	155	
25%	8	29	34	50	41	40	25% of the results have Qm levels below this value
50%	20	70	77	113	77	85	50% of the results have Qm levels below this value
75%	63	149	172	239	151	136[3]	75% of the results have Qm levels below this value
90%	228	288	376	469	292	497	90% of the results have Qm levels below this value
95%	398	433	552	723	582	722	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 172mV for machines rated less than 12kV, 239mV for machines rated 13-15kV, 151mV for 16-18kV 184mV for those >19kV.

Additionally, there is at least a doubling of the Qm levels between the 75% and the 90%. There are a few machines with PD much higher than the 90th percentile with Qm levels >220-500mV. These machines are suspected to have significant deterioration.

7.1.1.2 Differential Method

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. Thus, it is reasonable to assume the results obtained with the couplers at this location will be higher than when the couplers are located outside the machine housing typical of directional (TGA-BUS) installations. However, when comparing the directional (TGA) results to the

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

differential (PDA) results, though there are some minor variances, there is little significant difference between the statistical summaries for windings rated less than 19kV. Thus, it is safe to say that for a 13.8kV winding, regardless of installation type, the PD levels should be less than ~240mV 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**	
Avg	85	106	164	262	300	
25%	12	19	35	37	67	25% of the results have Qm levels below this value
50%	33	50	93	118	142	50% of the results have Qm levels below this value
75%	72	111	193	334[4]	441[4]	75% of the results have Qm levels below this value
90%	201	231	376	687	838[4]	90% of the results have Qm levels below this value
95%	322	389	561	1016[4]	956	95% of the results have Qm levels below this value

Capacitors – (gas-cooled)

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 of 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**			**16-18kV**				**> 19kV**		
H2 (psig)	**11-20**	**21-30**	**31-50**	**11-20**	**21-30**	**31-50**	**>50**	**21-30**	**31-50**	**>50**
Avg	163	87	138	148	222	103	56	105	60	125
25%	35	18	18	57[4]	31	25	9	43	20	9
50%	84	42	43	116	60	50	22	94	45	29
75%	172[4]	91	95[4]	188	182	110	38	172	77	87
90%	363[4]	173	277	313	891[4]	249	102[4]	217	132	255
95%	556[4]	370	648[4]	441	966	423	309[4]	246	159	732[4]

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 below 110mV and 90% generally below ~250mV, less than half of that observed on the air-cooled machines (TGA). At the lower operating pressures, the PD levels are much higher, with a few machines having extremely high PD of Qm levels >600mV, which would require more tests and investigation

[4] Fluctuations from previous years due to a low number of samples

7.1.2 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 (psi)	**11-20**	**21-30**	**31-50**	**11-30**	**31-50**	**> 50**	**11-30**	**31-50**	**>50**	**31-50**	**>50**
Avg	25	21	13	14	12	7	35	19	10	14	7
25%	1	0	0	0	0	0	1	0	0	0	0
50%	10	1	9	2	3	0	7	8	3	7	3
75%	25	13	19	15	14	6	20	22	11	16[5]	7
90%	47	63	31	45	37	15	83	50	22	29[5]	18
95%	49	92	50	78	53	22	198	67	37	41[5]	29

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. It should be observed that though the majority 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 is capable of discriminating 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 ~15mV. 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 (psi)	**11-20**	**21-30**	**31-50**	**11-30**	**31-50**	**> 50**	**11-30**	**31-50**	**>50**	**31-50**	**>50**
Avg	4	3	4	5	2	5	3	4	6	4	5
25%	0	0	0	0	0	0	0	0	0	0	0
50%	0	0	0	0	0	0	0	0	0	0	0
75%	3	0	6	2	0	2	1	3	5	1	0
90%	14	9	12	14	8	15	9	12	13	11[5]	4
95%	27	19	18	22[5]	14	35	25	19	26	12[5]	22[5]

Stator slot coupler – (air-cooled)

Qm values for air-cooled machines with SSC sensors

Slot PD		
Rated V	**13-15kV**	**16-24kV**
Avg	31	21
25%	0	1
50%	16	4
75%	35	14
90%	96	68
95%	135	105

Endwinding PD		
Rated V	**13-15kV**	**16-24kV**
Avg	14	5
25%	0	0
50%	0	0
75%	14	2
90%	44	7
95%	68	16

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. The majority of these machines have slot Qm levels less than ~30mV, but there are a few with extraordinarily high PD, >90mV, that would require further investigation.

[5] Fluctuations from previous years due to a low number of samples