PARTIAL DISCHARGE TESTING: A PROGRESS REPORT

PD – GLOBAL VPI PROCESS

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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.

In addition to presenting the most recent analysis of the database, in this paper we also reviewed the influence of winding impregnation method on the PD levels. There are three primary manufacturing processes used for resin penetration: resin-rich (B-stage) tapes, batch vacuum pressure impregnation (VPI) and global VPI. Over the past several years, the global VPI process has been more widely used as it accelerates the manufacturing process. Since the presence and magnitude of PD are well-established indicators of resin penetration and insulation consolidation, this paper compares the PD results for non-global and global VPI processes. Previous papers have determined that voltage and test configurations highly influence the results, thus the comparisons are made for assets within the same voltage classes and data gathered using identical test specifications.

Disclaimer: The analyses contained within assumes that the operating voltages, year of manufacturing and manufacturing process are correctly entered into the database at the time of the test.

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 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]**Error! Reference source not found.**.

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:

- Test instrument bandwidth and noise separation techniques [2]
- Type of sensors [2, 5, 12, 15]
- Operating voltage of the machines [2, 11, 12, 19]
- Operating gas coolant of the machines – PD is pressure dependent [2, 8, 12, 21]
- 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, 20]
- 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, 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

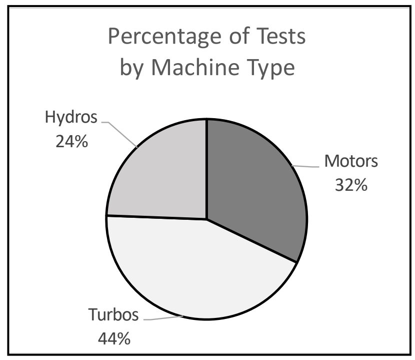
Two types of plots are generated for each partial discharge test. The first type of plot is two-dimensional (2-D), where the number of partial discharges per second versus PD magnitude is displayed. The greater the number of pulses per second, the more widespread is the deterioration in the winding. 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 590,000 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.

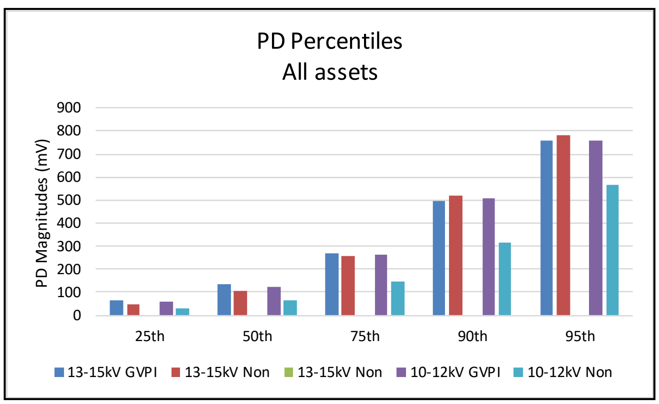
4 GVPI PROCESS AND PD

4.1 MAGNITUDES

Many end-users have wondered if the GVPI process is as good as the individual coil VPI process or resin rich process for impregnating mica paper tapes with epoxy resin. If there is poor impregnation with any impregnation method it will generally result in voids within the groundwall insulation, and thus produce high PD levels. For the first time we have tried to compare the PD activity between GVPI and non-GVPI methods. Although when PD data is collected with the PDA-IV or TGA-B instruments, the user is encouraged to enter if the winding under test has a GVPI or other winding. Often endusers may not know this information, and thus this field is often blank. However, we do know that most motors made since 1980 are made with the GVPI method. In addition, we know that certain brands of air-cooled turbine generators made after 1990 were most often made using the GVPI process. Thus, we used such nameplate information as a substitute means to determine if a winding was GVPI or not. This of course may not always be true and should be kept in mind.

Table 1. Global VPI (GVPI) and Non-GVPI from all the data

All	13-15kV		10-12kV	
	GVPI	Non	GVPI	Non
25th	62	45	59	29
50th	133	103	125	67
75th	270	257	264	144
90th	494	520	509	314
95th	758	780	761	563



Based on the data within the database, there is more overlap for non-global and global VPI processes for machines rated 10-12kV and 13-15kV categories. Table 1 shows the percentile ranges for the two categories of resin penetration process for each of these voltage range categories. For 13-15kV range, there is little difference; however, for the 10-12kV the global VPI results are noticeably higher for each percentile rank. This suggests that for the 10-12kV range, there are more issues with insulation consolidation due to manufacturing process or insulation aging for the global VPI method.

4.2 TRENDS

The plots below [Figure 1-Figure 4] show the PD results additionally separated based on year of manufacturing. The trend for the 75th percentile, which is the lower range for what is considered moderate PD and the trend for the 90th percentile, which is the lower range for what is considered high PD are both shown. For the 13-15kV range [Figure 1 and Figure 2], the overall trend indicates that the newer machines have slightly less PD than the older ones. This suggests that the primary source of PD is age-related, that is, long-term thermal aging. On the other hand, for the 10-12kV range [Figure 3 and Figure 4], the newer assets have significantly higher PD than the older assets. This is common for both the global and non-global VPI processes; however, the rate of increase for the global VPI is higher. This suggests that the design or manufacturing process is a contributing factor to the PD and that more recent processes have different design attributes or more problems with resin penetration and/or insulation consolidation for all machines, but more so for the global VPI method.

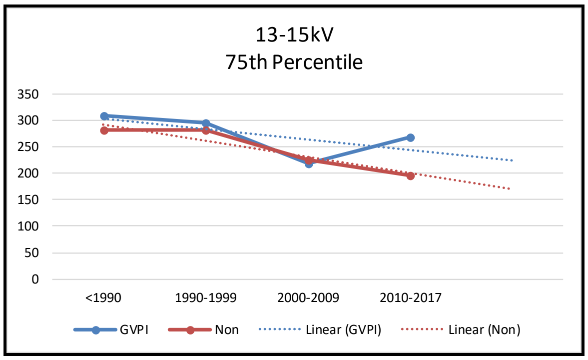


Figure 1. 13-15kV 75th Percentile

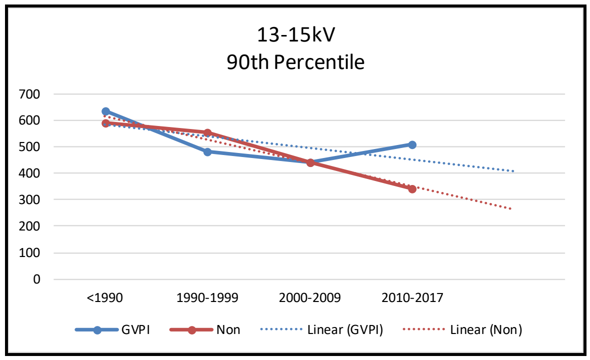


Figure 2. 13-15kV 90th Percentile

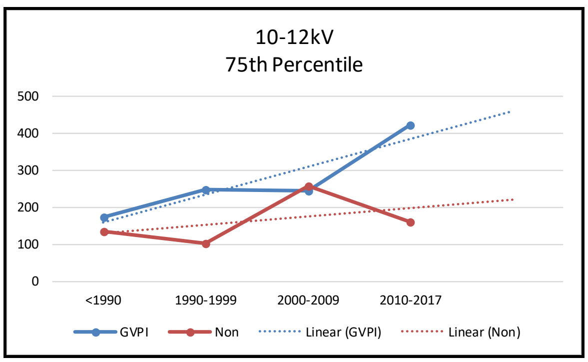


Figure 3. 10-12kV 75th Percentile

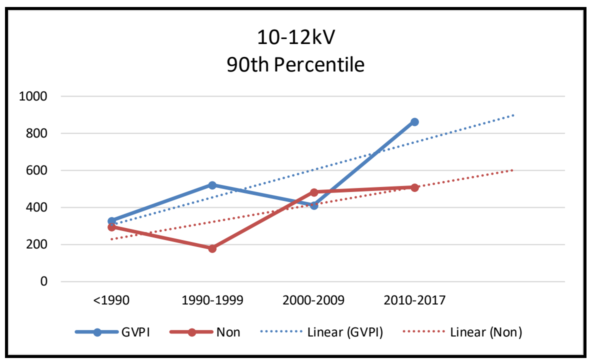


Figure 4. 10-12kV 90th Percentile

4.3 GENERATIONS

The following plots are a closer examination of the PD results based on decades of the winding manufacturing year. For the 13-15kV assets, windings manufactured before 2009 the global and non-global VPI results were similar [Figure 5], whereas, for the more recent machines the global VPI is noticeably higher [Figure 6].

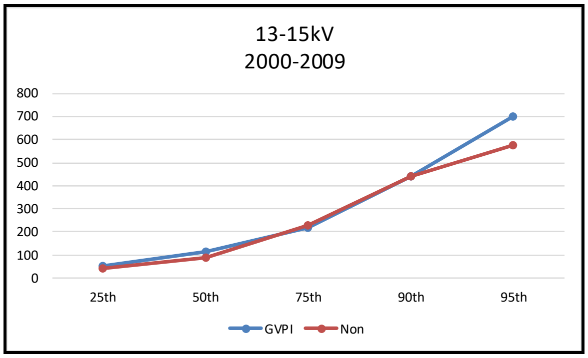


Figure 5. 13-15kV 2000-2009 Manufacturing Year (similar results for <1990 and 1990-1999 generations)

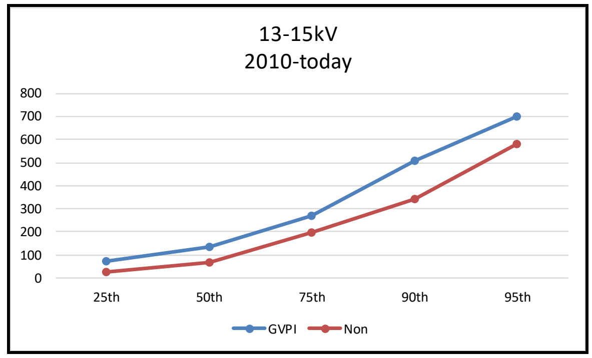


Figure 6. 13-15kV 2000-2009 Manufacturing Year

The percentile plots for the generations of the 10-12kV have unusual variability. For the older machines, manufactured before 1990 [Figure 7] and from 2000-2009 [Figure 9], the results between the global and non-global VPI results are basically the same. However, for the 1990-1999 [Figure 8] and 2010-today [Figure 10] decades, the global VPI results are significantly higher than the non-global results. The reason for this variability is not obvious, but suggests that during these eras there may have been issues with the manufacturing process for global VPI machines of this voltage class.

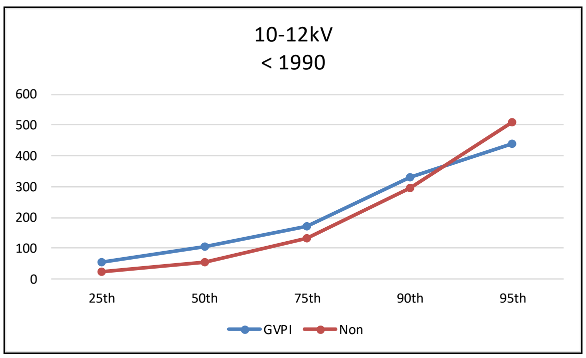


Figure 7. 10-12kV < 1990 Manufacturing Year

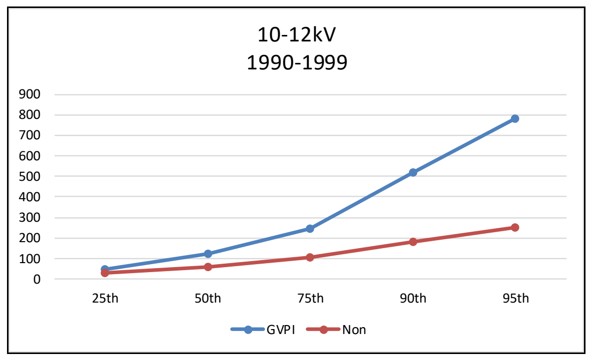


Figure 8. 10-12kV 1990-1999 Manufacturing Year

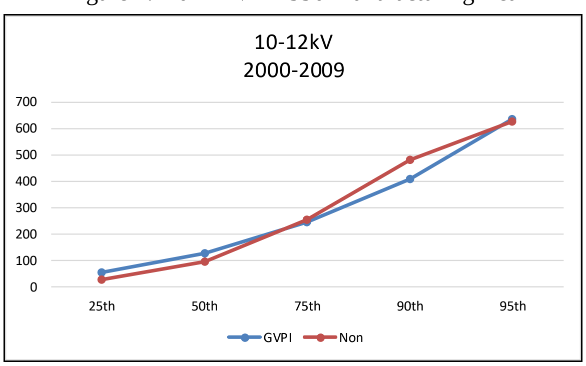


Figure 9. 10-12kV 2000-2009 Manufacturing Year

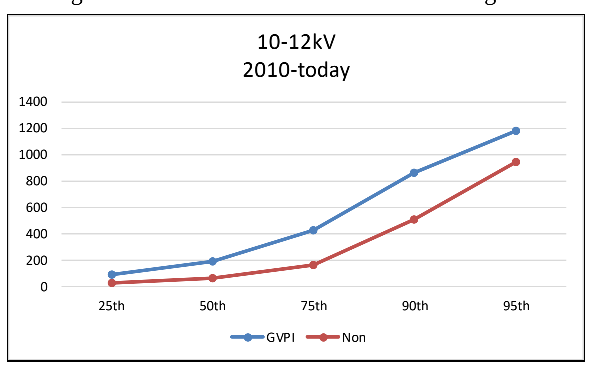


Figure 10. 10-12kV 2010-present Manufacturing Year

5 CONCLUSION

Comparison of the PD results between global and non-global VPI processes discloses different patterns, suggesting a difference between the two processes. In summary, the following possibilities are revealed in the data comparison:

- 13-15kV range
  - Little difference in magnitude between global and non-global VPI
  - Trends for both global and non-global VPI is downward versus age of machine, newer is lower.
    - Suggests that the primary source of PD for 13-15kV is age-related, that is, long-term thermal aging
  - Machines manufactured before 2009 have similar results between the global and non-global VPI
  - Machines manufactured from 2010 to present, the global VPI have higher PD levels

        - Suggests that for newer machines, there may be some manufacturing issues for this voltage class
- 10-12kV range
    - The global VPI results are noticeably higher than the non-global VPI for each percentile rank
        - Suggests there are more issues with insulation consolidation due to design, manufacturing process or insulation aging for the global VPI method
    - Trend for both global and non-global VPI is upward versus age of machine, newer is higher.
        - This suggests the manufacturing process is a contributing factor to the PD and that more recent processes have a different design or more problems with resin penetration and/or insulation consolidation for all machines
        - The higher rate of increase for the global VPI suggests a more prevalent problem with this resin penetration process in recent years
    - Machines manufactured before 1990 and from 2000-2010 have similar results between the global and non-global VPI
    - Machines manufactured from 1990-1999 and 2010 to present, the global VPI have higher PD levels
        - Suggests that for these eras, there may be some manufacturing issues for this voltage class

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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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 590,000 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 90^{th} 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