PARTIAL DISCHARGE TESTING: A PROGRESS REPORT

STATISTICAL EVALUATION OF PD DATA

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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 - 15].

In order to further evaluate the industry trends of PD magnitudes, this paper tracks the results for different types of air-cooled machines (Motors 6-8kV, Hydros 13-15kV, Motors 13-15kV, and Turbos 13-15kV) from various manufacturers. This paper evaluates if manufacturing and/or design issues lead to high PD, or if high PD requires long-term operation, that is, whether newer machines have higher PD than older machines. Data collected through 2009 was used; and, as before, 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 15,000 statistically independent results.

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 either a PDA-IV or TGA test instrument. 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.

INTRODUCTION

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 indicates 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].

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]

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.

COLLECTION OF DATA

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 bases of time-of-arrival and pulse characteristics, and measures the number, magnitude and ac phase position of the PD pulses.

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.

2009 Database

After the accumulation of all available test data through to 2009 with over 225,000 records, a database was carefully compiled using the following selection criteria:

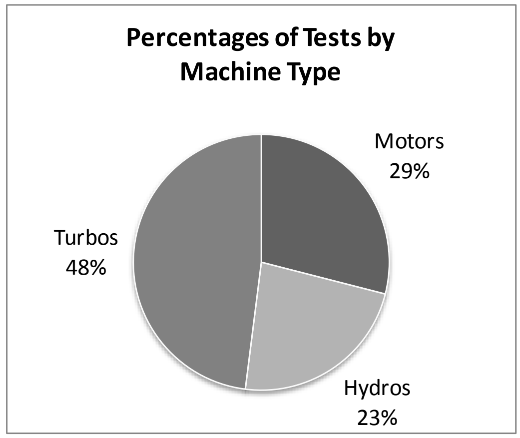
- only on-line tests obtained during normal operation
- only one test result per sensor
- the most recent test at Full Load and Hot stator winding temperature (FLH)
- any test with questionable results was discarded

Once these criteria were applied, about 15,000 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	29%
Hydros	23%
Turbos	48%



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

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 91 mV, 75% were below 189 mV and 90% of tests yielded a Qm below 372 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.

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

Oper kV	6-9kV	10-12kV	13-15kV	16-18kV	> 19kV
25%	13	19	35	36	76
50%	34	48	91	110	137
75%	70	102	189	278	255
90%	236	229	372	588	718
95%	364	376	560	768	861

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	28	30	53	43	34
50%	20	70	70	119	77	79
75%	63	147	160	242	153	205
90%	230	277	341	454	287	454
95%	437	404	525	701	556[1]	776

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 90% level.

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

MANUFACTURERS AND AGE

Because PD results are dependent on the machine type and voltage class, to properly evaluate the industry trends four of the most common air-cooled machine types and voltage classes were selected: Motors 6-8kV; Turbos 13-15kV; Motors 13-15kV; and Hydros 13-15kV.

For each machine and voltage category, the results were separated based on manufacturer (labeled A-I in the charts). There was no attempt to evaluate type or method of manufacturing, or to extend the breakdown the machine types beyond the general categories listed. In addition, for all manufacturers trends based on year of winding installation are also presented.

Though the 90th percentile is recommended as the level for further investigation of a specific winding, the 75th percentile is a better measure of manufacturing design and process, so the 75th percentile is used in this evaluation.

Motors 6-8kv

Chart 1 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for each and all of the manufacturers. It is apparent by the chart that for manufacturers D and F, the PD values are higher than typical (ALL), especially for the machines with measured PD levels in the 90th and 95th percentiles. This indicates that for these two manufacturers, the highly PD-active machines are substantially more active than similar machines from other manufacturers.

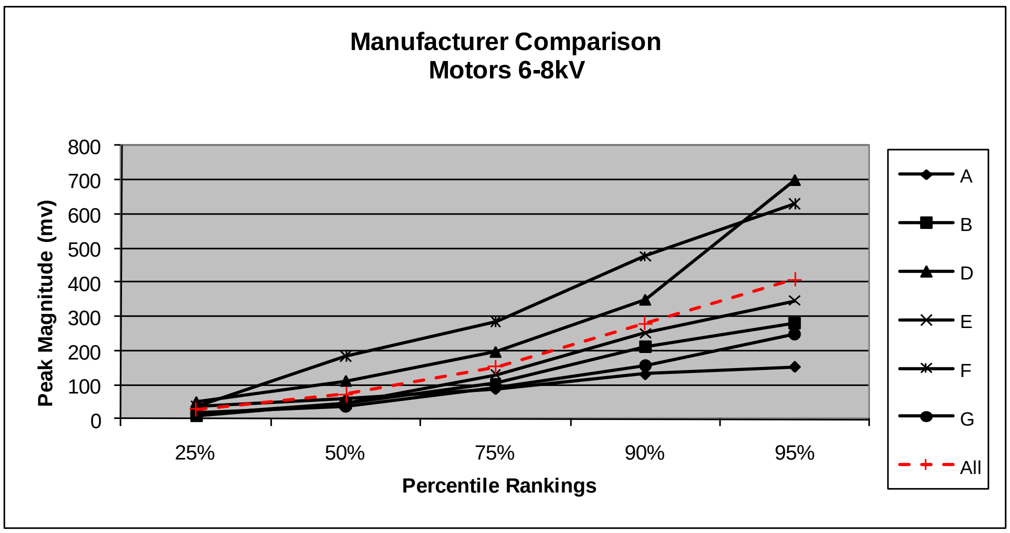


Chart 1. Motors 6-8kV by OEM

Chart 2 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for all manufacturers based on date of winding installation (<1981, 1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2005, and 2006-2010). Note that only the most recent test data is displayed, that is, even if a winding was installed in 1986, only the PD results the 2009 tests are included. In this presentation, it is expected that due to aging, the older machines in the 2009 test results would have higher PD results than the newer ones. In other words, there should be a noticeable downward trend from those manufactured before 1981 to those installed in 2006-2010.

However, it is apparent that this is not the case. Instead, the newer windings manufactured from 2006-2010 actually have higher PD for the 75th, 90th and 95th percentiles than the previous decade of 1996-2005. This suggests that across the industry there is a trend in some of the newer windings of this voltage class to have problems that result in PD activity that was not present in the past decade, but perhaps was present in earlier machines.

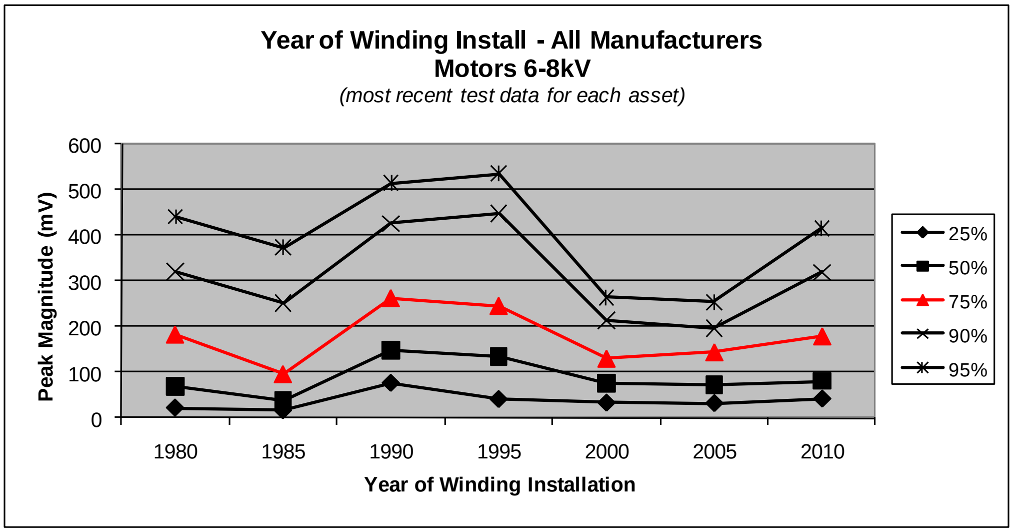


Chart 2. Motors 6-8kV by Year of Install (test results of 2009)

Turbos 13-15kv

Chart 3 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for each and all of the manufacturers. It is apparent by the chart that for manufacturers B, F and J, the PD values are higher than typical (ALL), especially for the machines with measured PD levels in the 90th and 95th percentiles. This indicates that for these three manufacturers, the highly PD-active machines are substantially more active than similar machines from other manufacturers.

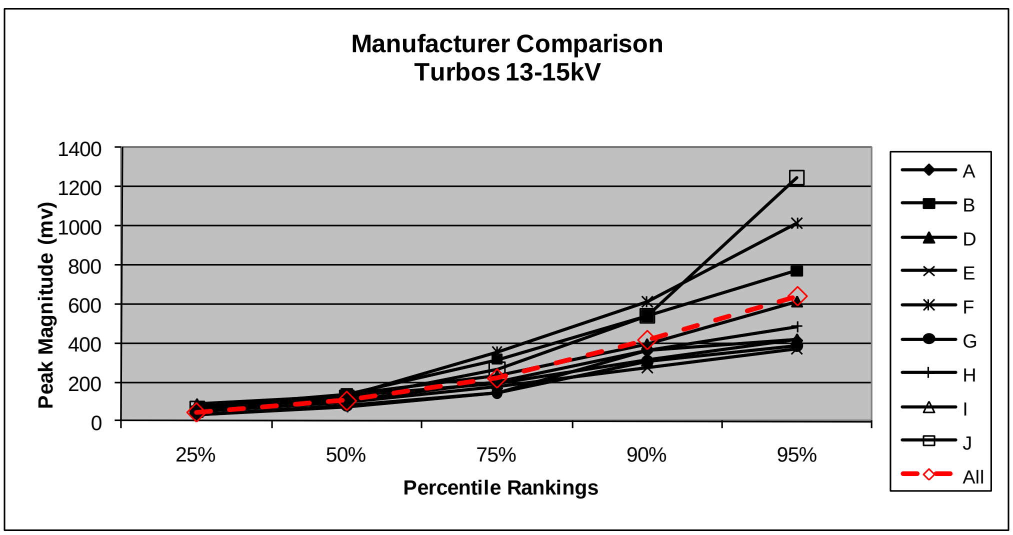


Chart 3. Turbos 13-15kV by OEM

Chart 4 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for all manufacturers based on date of winding installation (<1981, 1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2005, and 2006-2010). Note that only the most recent test data is displayed, that is, even if a winding was installed in 1986, only the PD results the 2009 tests are included. In this presentation, it is expected that due to aging, the older machines in the 2009 test results would have higher PD results than the newer ones. In other words, there should be a noticeable downward trend from those manufactured before 1981 to those installed in 2006-2010.

However, it is apparent for turbine generators, 13-15kV, the PD levels are relatively stable. This suggests that older windings and newer windings are in about the same condition. And with the exception of the top 10% (90th percentile), the manufacturer's quality control and durability of the windings with respect to problems that produce PD have been consistent over the past 3-4 decades. Based on tests in 2009, the newer windings are about the same as the older ones.

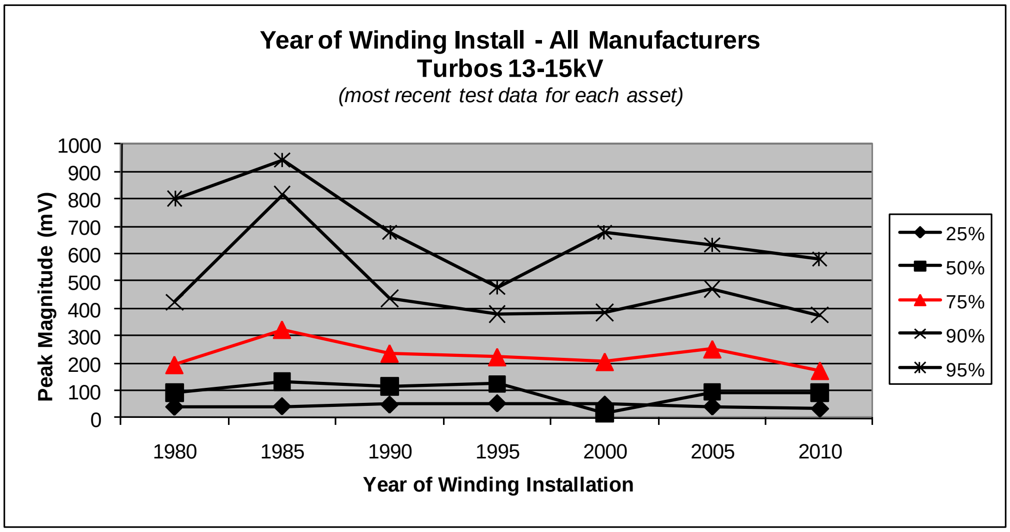


Chart 4. Turbos 13-15kV by Year of Install (test results of 2009)

Motors 13-15kv

Chart 5 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for each and all of the manufacturers. It is apparent by the chart that for manufacturers D and F, the PD values are higher than typical (ALL), especially for the machines with measured PD levels in the 90th and 95th percentiles. This indicates that for these two manufacturers, the highly PD-active machines are substantially more active than similar machines from other manufacturers.

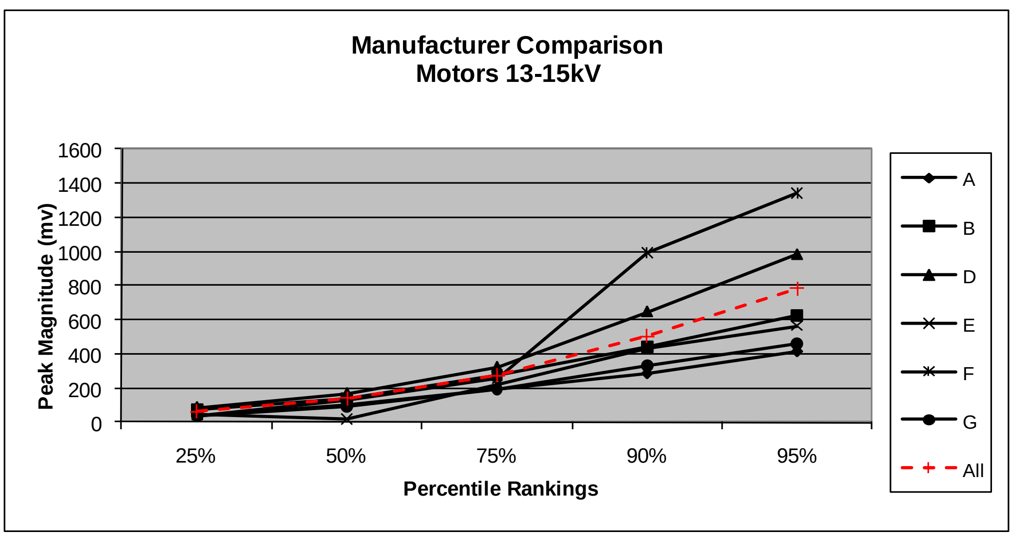


Chart 5. Motors 13-15kV by OEM

Chart 6 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for all manufacturers based on date of winding installation (<1981, 1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2005, and 2006-2010). Note that only the most recent test data is displayed, that is, even if a winding was installed in 1986, only the PD results the 2009 tests are included. In this presentation, it is expected that due to aging, the older machines in the 2009 test results would have higher PD results than the newer ones. In other words, there should be a noticeable downward trend from those manufactured before 1981 to those installed in 2006-2010.

However, it is apparent for motors, 13-15kV, that this is not the case. Instead, like with the 6-8kV motors, the newer windings manufactured from 2006-2010 actually have higher PD for the 75th, 90th and 95th percentiles than the previous decade of 1991-2005. This suggests that across the industry there is a trend in some of the newer windings of this voltage class to have problems that result in PD activity that was not present in the past decade, but perhaps was present in earlier machines.

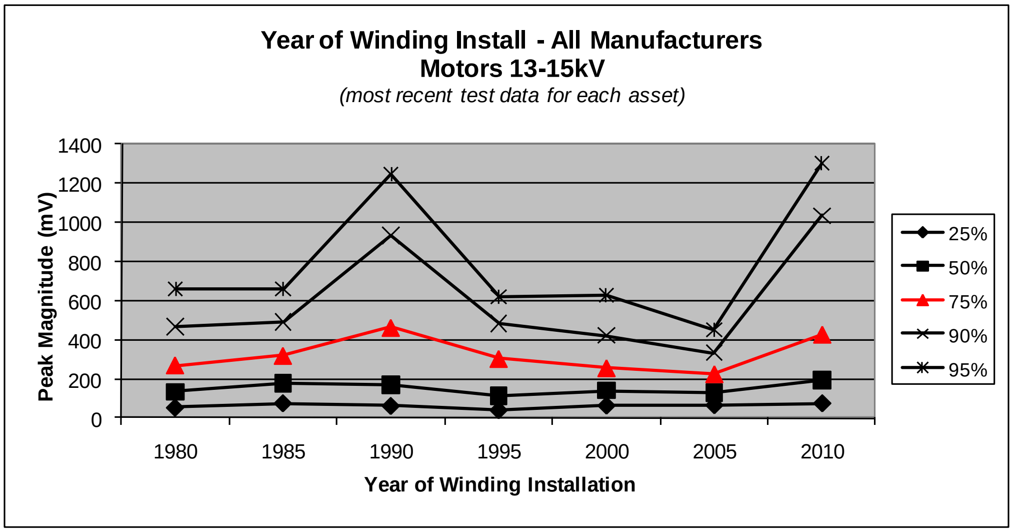


Chart 6. Motors 13-15kV by Year of Install (test results of 2009)

Hydros 13-15kv

Chart 7 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for each and all of the manufacturers. It is apparent by the chart that for manufacturer F, the PD values are higher than typical (ALL), especially for the machines with measured PD levels in the 90th and 95th percentiles. This indicates that for this manufacturer, the highly PD-active machines are substantially more active than similar machines from other manufacturers.

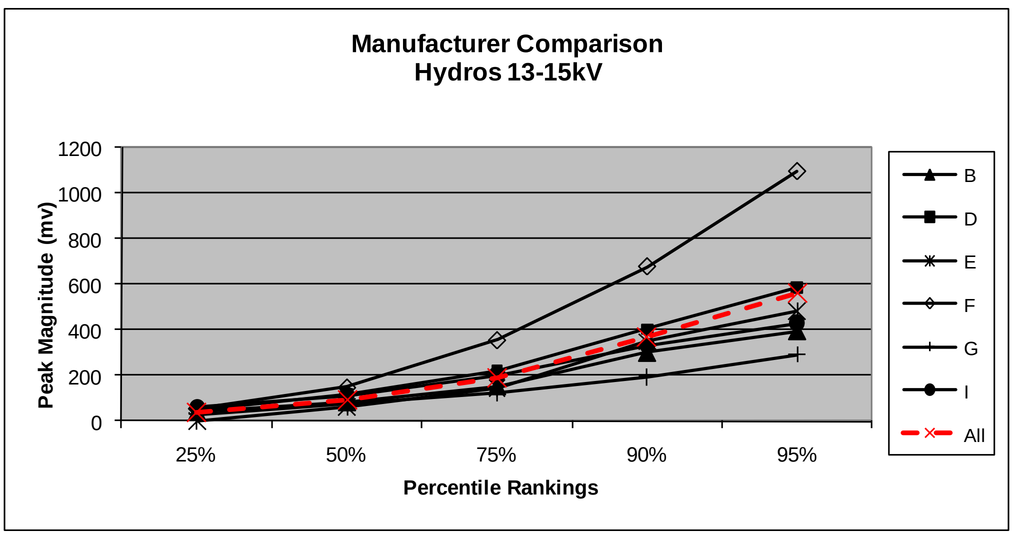


Chart 7. Hydros 13-15kV by OEM

Chart 8 below depicts the 25th, 50th, 75th, 90th and 95th percentiles for all manufacturers based on date of winding installation (<1981, 1981-1985, 1986-1990, 1991-1995, 1996-2000, 2001-2005, and 2006-2010). Note that only the most recent test data is displayed, that is, even if a winding was installed in 1986, only the PD results the 2009 tests are included. In this presentation, it is expected that due to aging, the older machines in the 2009 test results would have higher PD results than the newer ones. In other words, there should be a noticeable downward trend from those manufactured before 1981 to those installed in 2006-2010.

For hydro generators, 13-15kV, the PD levels exhibit this pattern. This suggests that older windings have thermally aged, while the newer windings have not.

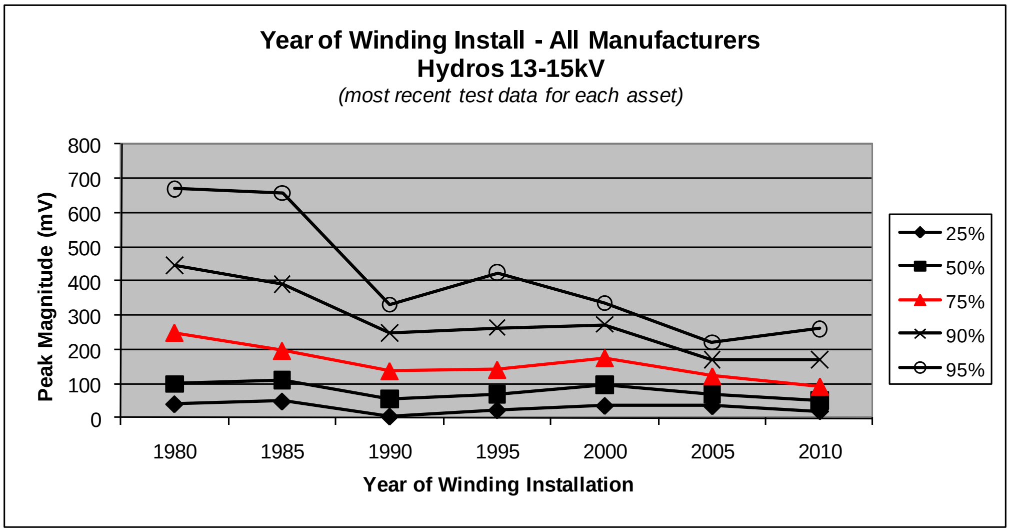


Chart 8. Hydros 13-15kV by Year of Install (test results of 2009)

DISCUSSION

Motors 6-8kV

- The overall trend of the 2009 data separated by date of winding for all manufacturers has emerged with an upward trend to indicate that newer machines have more PD activity than older machines, and thus a PD-source problem has developed within the industry.
- Machines from manufacturers, D and F, have higher PD activity than everyone else.

Turbos 13-15kV

- The overall trend of the 2009 data separated by date of winding installation for all manufacturers has been stable to indicate that the older machines do not possess more PD-related problems than the newer machines. This is unexpected, as it is assumed that older machines would have higher PD due to long-term thermal aging.
- Machines from manufacturers, B, F and J, have higher PD activity than everyone else.

Motors 13-15kV

- The overall trend of the 2009 data separated by date of winding for all manufacturers has emerged with an upward trend to indicate that newer machines have more PD activity than older machines, and thus a PD-source problem has developed within the industry.
- Machines from manufacturers, D and F, have higher PD activity than everyone else.

Hydros 13-15kV

- The overall trend of the 2009 data separated by date of winding for all manufacturers has emerged with a downward trend. This is the expected pattern, where older machines have higher PD levels in 2009 than the newer ones due to long-term thermal aging.
- Machines from manufacturer F have higher PD activity than everyone else.

CONCLUSION

For Hydros 13-15kV, there appears to be an overall industry trend that newer windings have lower PD levels than older ones, which implies that in general the manufacturing and design process of newer machines is good while the older machines have some signs of thermal aging. For Turbos 13-15kV, there appears to be little difference in the PD levels between older machines and newer machines, which suggests that the older machines were well made and are well maintained, or that the newer windings are not as well made or maintained. For Motors 6-8kV and Motors 13-15kV, new windings manufactured since 2006 tend to have higher PD levels than the previous decade. The reason for this has not been examined, but has been speculated that smaller frames are being used for higher power output, and therefore spacing in the endwinding may be an issue.

For each category, there are 1 to 3 manufacturers for whom the PD levels of their machines are higher than the typical levels for all machines.

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. Red flags should only be raised if the PD levels on a specific machine are doubling over a six-month interval, or if they are above the 90th percentile and steadily rising. In all cases, raising the red 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. 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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APPENDIX – DATA ANALYSIS OF RESULTS THRU 2009

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 2009 with over 225,000 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.

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.

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	87	118	146	208	163	186	
25%	8	28	30	53	43	34	25% of the results have Qm levels below this value
50%	20	70	70	119	77	79	50% of the results have Qm levels below this value
75%	63	147	160	242	153	205	75% of the results have Qm levels below this value
90%	230	277	341	454	287	454	90% of the results have Qm levels below this value
95%	437	404	525	701	556[2]	776	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 160mV for machines rated less than 12kV, 242mV for machines rated 13-15kV, 153mV for 16-18kV and 205mV 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 90^{th} percentile with Qm levels >230-450mV. These machines are suspected to have significant deterioration.

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

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

machine housing typical of directional (TGA-BUS) installations. However, when comparing the directional (TGA) results to the 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 13kV winding, regardless of installation type, the PD levels should be less than ~275mV 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	98	98	162	224	230	
25%	13	19	35	36	76	25% of the results have Qm levels below this value
50%	34	48	91	110	137	50% of the results have Qm levels below this value
75%	70	102	189	278	255	75% of the results have Qm levels below this value
90%	236	229	372	588	718	90% of the results have Qm levels below this value
95%	364	376	560	768	861	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[3]**	**21-30**	**31-50**	**11-20**	**21-30**	**31-50**	**>50**	**21-30**	**31-50**	**>50**
Avg	218	104	119	140	178	103	36	105	68	146
25%	43	19	17	15	31	19	9	43	18	15
50%	106	41	39	93	58	51	16	94	45	35
75%	255	83	77	161	163	110	28	172	98	87
90%	503	193	201	327	667	251	54	217	152	353
95%	901	408	537	457	966	355	104	246	201	879

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 >800mV, which would require more tests and investigation

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

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	26	20	12	167	11	3	42	19	10	12	7
25%	0	0	0	0	0	0	1	0	0	0	0
50%	8	0	9	7	3	0	9	8	3	0	3
75%	29	14	17	20	14	4	24	22	10	0	8
90%	47	57	27	55	37	9	97	50	23	13	19
95%	55	81	45	81	53	15	232	67	36	113	31

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 will detect 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 portion of the bar or in the endwinding area [15].

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	6	2	5	4	4	6	3	3
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%	0	0	6	6	0	1	1	3	3	0	0
90%	20	9	12	14	8	12	11	12	12	0	3
95%	34	19	17	32	16	42	31	19	25	2	8

The endwinding PD results are slightly lower than the slot PD results, with 90% of all the tests less than ~20mV. There are, however, a few machines with Qm levels higher than 30mV, and these machines require additional attention.

Stator slot coupler – (air-cooled)

Qm values for air-cooled machines with SSC sensors

Slot PD		
Rated V	**13-15kV**	**16-24kV**
Avg	31	17
25%	0	0
50%	16	0
75%	40	10
90%	92	57
95%	119	97

Endwinding PD		
Rated V	**13-15kV**	**16-24kV**
Avg	12	5
25%	0	0
50%	3	0
75%	16	0
90%	42	5
95%	56	12

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 ~40mV, but there are a few with extraordinarily high PD, >90mV, and some with high endwinding PD that would require further investigation.