PD Monitoring – 3-5kV Medium Voltage Motors

CONTENTS

1 SUMMARY

This paper describes the effectiveness of PD testing for condition-based maintenance of stator windings in 3-5kV motors. Determination of usefulness is based on the results of almost 1000 results in the Iris Database [7] and various case studies [Section 5, [11], [12], [13]].

Common failure mechanisms of 3-5kV motor stator windings and whether PD testing is known to be beneficial in advanced detection:

Failure mechanism	PD Pattern	Database	Case Studies
Inadequate Impregnation	Section 3.2.4		5.6
Thermal cycling	Section 3.3.4		5.4
Internal delamination	Section 3.4.4		5.6
Coil movements	Section 3.5.4		5.3
Electrical slot discharge	Section 3.6.4		5.3
Contamination or Electrical tracking	Section 3.7.4		5.1
Inadequate End-Winding Spacing	Section 3.8.4		5.6
Gap-type discharge (Leads)	Section 3.9.4		5.2 and 5.3

2 BACKGROUND

2.1 PUBLISHED PAPERS

- Almost twenty years ago at the IEEE PCIC conference, a paper was presented that concluded that most 4.1kV motors do not have significant PD activity; however, those with deteriorated insulation do, though at a much lower magnitude than in 6.6kV motors [11]. It also stated that for some failures there may be little time between PD detection and failure.

  "The conclusion from the off-line PD tests is that 4 kV stator windings in good condition may have no or very low levels of partial discharge. Secondly, the PD magnitudes for machines with significant deterioration are much smaller at rated line-to ground voltage for 4 kV machines than for 6 kV and above windings. Furthermore, since the groundwall insulation is relatively thin when compared to higher voltage motors, less insulation material needs to be digested in a 4 kV stator to result in winding failure. Thus if large magnitude PD does occur in a 4 kV stator, then the insulation will take less time to fail due to the thinner groundwall". [11]

  "3. Both on-line and off-line results indicated that, at least for some types of failure processes, the time between the occurrence of very active PD and failure may be only a few weeks. [11]

- At the 2008, Iris Rotating Machine Conference (IRMC), a case study was presented about a 4kV induction motor with the following history [12]. Initial testing in Nov 2006 and maximum PD levels of +136mV/-151mV on one phase were considered Moderate, but also twice as high as the other phases.

Six months later in July 2007, the results were now +909mV/-1880mV with a strong negative predominance indicative of internal voids due to a potentially damaged interturn insulation. Three months later in Oct 2007, the levels were still increasing at +1120mV/-2317mV. The motor was removed from service and shipped to a rewind shop. At the rewind shop, it passed the surge test and it passed the DC hipot at 9.3kV. During the AC hipot, at 2000V the PD was visible and audible, increasing in intensity at 3000V and finally catching on fire at 4000V.

- A case study was presented about a 3.3kV induction motors for one utility. [13] The findings were:
  - *"Original manufactured machines (some of them older than 20 years), have PD values lower than 90 mV. Most of these machines are operating at low temperatures and appear to be in good condition.*
  - *Recently rewound machines displayed high PD levels and are suspected of going through poor VPI processes. We expect these PD levels to decrease after going through normal thermal cycling.*
  - *Contamination levels can successfully be monitored with PD equipment."*

2.2 SINGLE-ENDED INSTALLATION

For each phase, one PD sensor, or EMC, is mounted at the motor, generator, switchgear or transformer terminals and is referred to as the "machine" coupler. This EMC measures the partial discharge (PD) originating within the machine stator winding or high voltage apparatus. It is desirable that there be no feeders, splits, CTs, PTs, or similar devices located between the machine terminals and the machine sensor on any given phase. The presence of such can lead to signal distortion and imperfect noise reduction.

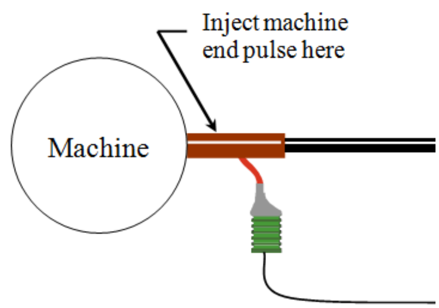
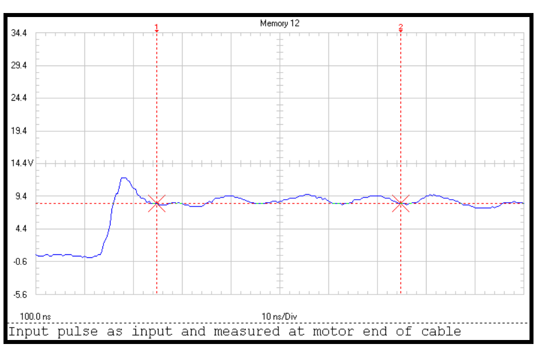


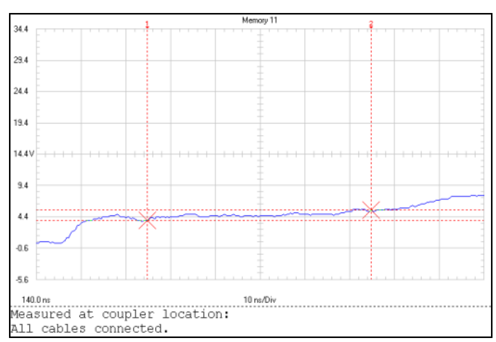
Figure 1. Coupler Response

In some cases, surge capacitors are present near the machine terminals. In this situation, it may be necessary to install the PD sensor on the bus near the surge capacitors. The EMC should be connected directly to the bus closer to the winding than to the surge capacitor and at least 1 m away from the surge capacitor. If the separation is less than 1 m, *a coupler response comparison with and without the surge capacitor is recommended*.

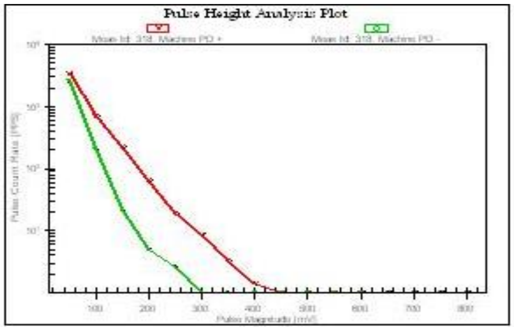
The impedance mismatch of surge arrestors and cables connections can attenuate a signal. In the final analysis this reinforces the point we stress – install the "machine" coupler as close to the machine terminals as possible. Installing couplers downstream from this point can, depending on bus/cable arrangements have a dramatic impact on the on-line PD data gathered and can lead, as in this case, to an incorrect assessment of winding condition.



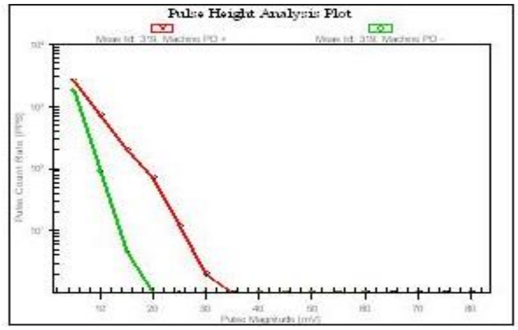
Measured at the motor leads. (10ns/ Div) Maximum PD signal at 12V.



Measured after Cables/Arrestors connected. (10ns/ Div) Maximum PD signal about 4 volts.



Qm+ 205mV, Qm- 185



Qm+ 26mV, Qm- 12

As is seen above, when the PD sensors (EMCs) are connected away from the terminals with cable and/ or arrestors connected between the stator winding and the terminals, the PD results can be greatly impacted. Though this does not impact trends, it will impact the overall PD magnitudes.

2.3 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 (Qm values twice that of the previous test) every six months has been considered a strong indication of a rapidly developing failure mechanism [6].

When a trend line is established for PD tests taken over a period, 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 [Figure 2]. 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 [10]. 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. 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.

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 [Figure 2]. 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 [10].

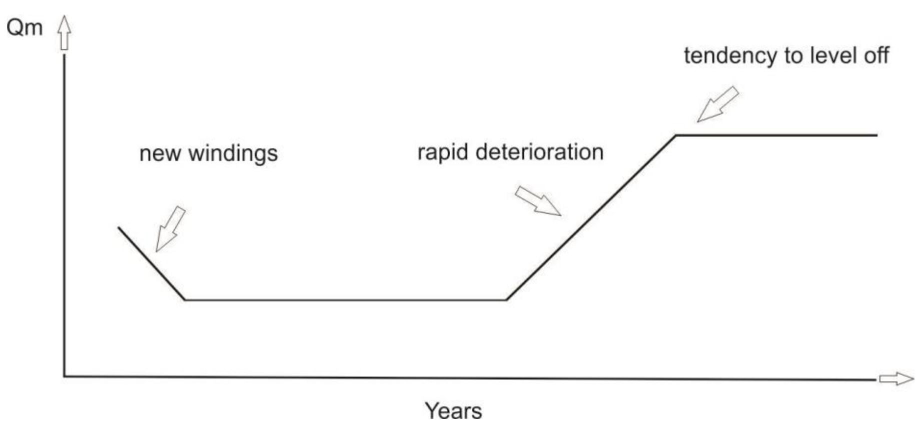


Figure 2. Overall PD Trend

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.

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 10. [7]

3 COMMON FAILURE MECHANISMS

Medium voltage motors are frequently load-cycled and operated in unique environments, that include wide swings in ambient conditions, exposure to extensive mechanical vibration, and variability of voltage. Most probable failures and other problems found in the type of windings commonly are described below. [10]

3.1 INTERTURN INSULATION

A common failure mechanism of motors is failure of a deteriorated interturn insulation due to a system surge. [3] Due to pulse behavior, negative predominance normally indicates PD originating near the conductor surface inside the insulation system. Such PD may be the result of voids created due to either improper manufacturing thermal aging or thermal cycling that has stressed the bonds between the conductor and the first layers of insulating tape, the interturn insulation. Eventually, after many years of service, even well-made windings will start to show signs of distress in this area. Because of the location of the voids, that is, near the copper conductors, there are no reliable repair mechanisms for this problem. *Although there may be voids and other defects in the insulation between the turns, if they are not on the outside surface of the copper stack (and adjacent to the ground insulation), PD will not be a symptom of turn failure due to voltage surges. If they are also on the outside surface, which is common, then negative PD predominance is an indicator.*

3.2 INADEQUATE IMPREGNATION (TURN-TO-TURN FAILURE)

3.2.1 Impact:

Sometimes during the impregnation process, small voids are inadvertently left within the groundwall. These can occur because of inadequate vacuum or pressure, incorrect resin viscosity, improper temperatures, tape wrinkling or foreign objects imbedded in the tapes. In the presence of voltage stress, partial discharges can occur across these voids and attack the organic resin. The attack may lead to strand or turn shorts in multi-turn coils if the voids are near the copper conductors, and eventually failure of the coils can occur.

If the voids are in the center of the groundwall insulation thickness, they are more benign and low magnitude, so failure can take many years to happen. An additional problem from manufacturing defect is that the internal voids create a thermal barrier inhibiting the transfer of heat from the copper to the core resulting in higher thermal stresses. See Case Study 5.6.

3.2.2 Probability:

Due to the complexities present during the impregnation process with global VPI (vacuum pressure impregnation), this problem has a quite high probability.

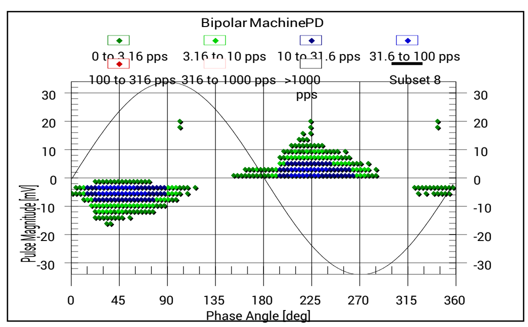


Figure 3. No Polarity Predominance 45°/225°

3.2.3 Risk to the winding:

This attack may lead to strand or turn shorts if the voids are near the copper conductors, and eventually multi-turn coil failure will occur within 2 to 5 years. If the voids are in the center of the groundwall insulation thickness, they are more benign and, as any discharges that take place within them are of low magnitude, failure due to this can take many years.

3.2.4 PD Pattern

Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location
Inadequate Impregnation	No or Negative predominance	None	Inverse	45° and 225°

Symptoms	Detection Tests	Machine types
Partial discharge	PD, power factor, tip-up, tan δ, capacitance	Global VPI, resin rich coils

3.3 THERMAL CYCLING (TURN-TO-TURN FAILURE)

3.3.1 Impact:

A machine that is frequently thermal-cycled or severely overheated develops voids near the copper conductors. The negative impact of frequent changes to the machine load is the cyclical shear stresses placed on the insulation due to different linear coefficients of thermal expansion in the stator winding materials. As the copper expands from increased temperature due to I^2R losses, the insulation, which is glued to the copper and wedged tightly between the conductor and the core, cannot expand due to a lower coefficient of thermal expansion and lower temperature. Repetitive stresses from sudden load changes strain the mechanical bond between the groundwall and either the strand or turn insulation, causing the bond to eventually weaken and break. Motors with long stator cores probably suffer the worst damage from thermal cycling because of surges from repetitive starts and stops.

Thermal cycling also causes movement of the stator coil or bar insulation groundwall with respect to the stator iron. Over a long period of time, these small movements can damage areas of the semiconducting surface of the coils/bars. Internal delamination problems develop quicker with faster load changes and higher operating temperatures. See Case Study 5.4.

3.3.2 Probability:

Due to the number of starts and frequent load-cycling, internal voids near the conductors have a high probability to develop over time.

3.3.3 Risk to the winding:

This attack may lead to strand or turn shorts if the voids are near the copper conductors, and eventually multi-turn coil failure will occur within 2 to 5 years.

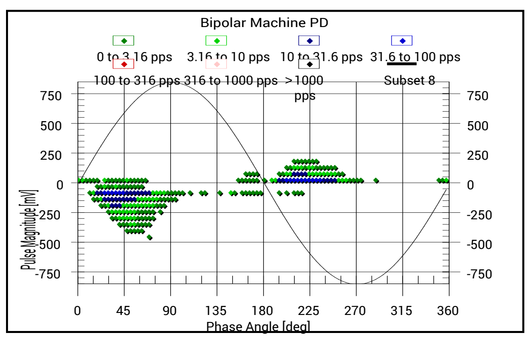


Figure 4. Negative Predominance (45°)

3.3.4 PD Pattern

Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location
Thermal Cycling Surges/Starts	Negative	None	Inverse	45°

Symptoms	Detection Tests	Insulation types

Partial discharge, Girth cracking, Shorted turns	PD, tan δ, power factor, surge test, visual inspection, hi-pot	All stator winding types Multi-turn coils, motors (VSD/IFD)

3.4 INTERNAL DELAMINATION (TURN-TO-TURN FAILURE)

3.4.1 Impact:

Internal Delamination can occur because of long periods of overloads, defective cooling, unbalanced phase voltages and poor design. As with most insulation systems, the damage is cumulative, non-reversible and results in decreased ability of the resin binder to mechanically bond the layers of insulation together. This loss of mechanical bonding allows the formation of voids within the layers of tape that make up the insulation thickness. As the tape layers separate, PD is created in the voids and the conductors can become free enough to vibrate.

Insulation breakdown from simple thermal overheating may take years depending on the temperature, insulation class and thickness of the insulation. The heat slowly destroys the organic resins, which bond the insulation layers together, but do not materially affect the real insulation, the mica flakes or splittings. Problems are less likely to occur with epoxy resin windings since these constructions can normally withstand higher thermal stress. Internal delamination can occur because of overloads, defective cooling, unbalanced

phase voltages, and poor design.

When operating a unit based on maximum indicated temperature, it is important to remember that the insulation immediately adjacent to the copper conductors may be at a significantly higher level than the temperature from the RTD's displayed in the control room. Where a margin was thought to exist, there may in fact be no margin at all. Resin damage is cumulative and non-reversing. Visible discoloration of the insulation system may be an indication of excessive thermal stress. In an older asphaltic stator winding system, it is not unusual to see the actual black asphalt material "oozing" out of the lower ends of the coils. See Case Study 5.6.

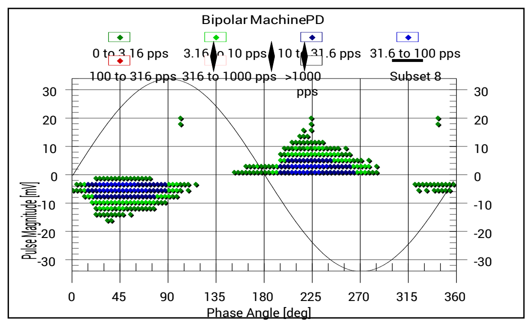


Figure 5. No Polarity Predominance (45°/225°)

3.4.2 Probability:

If properly consolidated during manufacturing, internal voids from thermal aging would be rare since it requires years of operation at high temperatures for these to form.

3.4.3 Risk to the winding:

The PD, along with possible mechanical abrasion, may lead to strand or turn shorts if the voids are near the copper conductors, and eventually multi-turn coil failure will occur within 2 to 5 years. If the voids are in the center of the groundwall insulation thickness, they are more benign and, as any discharges that take place within them are of low magnitude, failure due to this can take many years.

3.4.4 PD Pattern

Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location
Internal Delamination	No or Negative predominance	None	Inverse	45° and 225°

Symptoms	Detection Tests	Insulation types
Partial discharge,	PD, tan δ, power factor, capacitance,	All stator winding types

insulation discoloration	visual inspection	(Asphaltic mica)

3.5 COIL MOVEMENT FAILURE

3.5.1 Impact:

If properly installed, the wedges and side packing should prevent winding looseness. However, some insulation resins shrink when they are cured or thermally aged, coils may get smaller and so become loose in the slot. Also, some of the wedging and packing materials may become brittle and shrink over time, allowing the coils to become loose. In the presence of oil, side packing and ripple springs will soften faster because of the lubricating medium.

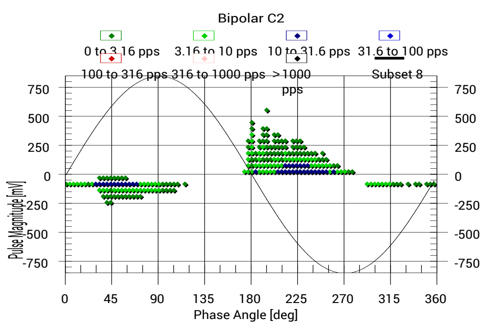
When windings become loose in the slot, the immediate problem is that, if left unattended, the looseness and vibration will quickly allow the laminated rough stator core surface to damage the semi-conductive coating on the surface of the coils. Damaged coil surfaces create discontinuities on the surface and allow voltage stresses to build up across these isolated locations, or between these and the stator core. If the voltage stress exceeds the electrical breakdown point of the gas medium, a discharge will occur. See Case Study 5.3.

3.5.2 Probability:

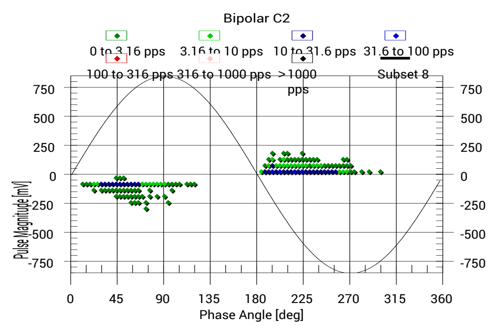
In a global VPI, coil movement normally has a low probability; however, when deterioration of the semi conductive coating occurs the probability increases due to the chemical attack on the resin securing the wedges in place.

3.5.3 Risk to the winding:

Eventually, a ladder-effect develops where the groundwall is thinner at the point of contact with the core, but maintains normal thickness at the core air vents. Though the absolute time between detection and failure is unknown, it can be as short as two years in many thermoset (hard) windings, especially those with a high electric stress across the groundwall.



High Load with Positive Predominance



Low Load

3.5.4 PD Pattern

Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location
Coil Movement	Positive	Direct	Inverse	225°

Symptoms	Detection Tests	Machine types
Partial discharge, ozone, loose wedges	PD, visual inspection, wedge tap, ozone monitoring	Hard groundwall systems – epoxy and polyester

3.6 ELECTRICAL SLOT DISCHARGE

3.6.1 Impact:

Slot discharge is the term given to discharges that occur between the surface of the coil and the stator core. It can be said that PD caused by a loose winding creates slot discharges, but not all slot discharges are due to winding movement. Some of them are due to problems with the semi-conductive coating and called electrical slot discharges. If the semi-conductive layer on the coil surface deteriorates, it results in the development of electrical slot discharge (a form of PD) and the production of ozone. Both PD and ozone will accelerate the decomposition of the organic epoxy or polyester resin binders. Due to this decomposition of the resins, the coils will decrease in size and may become loose. If allowed to become loose, the semi-conductive surfaces of the coils are the first to be damaged causing areas of high electric stress. If the semi-conductive coating is poorly made, especially if paint was used, it may become non-conductive at high temperatures and result in high electric stresses. However, if the coils remain tight in the 300 slots, electrical breakdown to failure may take decades. Thus, machines with slight damage to the coil surfaces can still provide many years of reliable operation provided movement is stopped by re-wedging. Once damaged, it is difficult to restore the semi-conducting surfaces - so prevention is paramount. Windings with severely damaged surface coatings may require replacement because of the high production of ozone. Slot discharge occurs primarily in air cooled machines

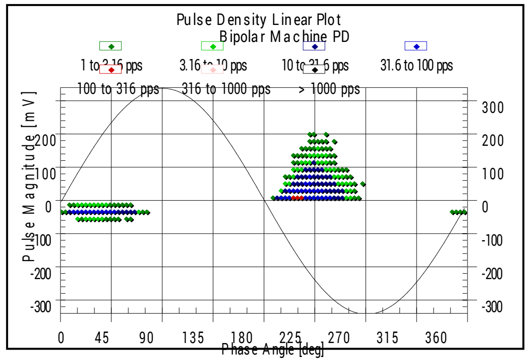


Figure 6. Positive Predominance (225°)

Windings with severely damaged surface coatings may require replacement because of the high production of ozone. Slot discharge occurs primarily in air-cooled machines. See Case Study 5.3.

3.6.2 Probability:

Because of the low voltage stress across the groundwall, this problem occurs rarely; however, it may be more pronounced in VFD motors.

3.6.3 Risk to the winding:

If allowed to become loose, the semicon surfaces of the coils are the first to be damaged causing areas of high electric stress. If the semicon coating is poorly made, especially if paint was used, it may become non-conductive at high temperatures and result in high electric stresses. However, as long as the coils remain tight in the slots, electrical breakdown may take decades.

3.6.4 PD Pattern

Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location
Electrical Slot Discharge	Positive	None	Direct	225°

Symptoms	Detection Tests	Machine types
Partial discharge, white powder, ozone	PD, visual inspection, ozone monitoring, coil-to-ground resistance, side clearance	Air-cooled machines

3.7 CONTAMINATION

3.7.1 Impact:

When any kind of conductive contamination from moisture or oil mixed with dust/dirt pollutes a machine, it is possible for electrical tracking (treeing) to develop across the blocking or along the end arms. Electrical tracking occurs because the pollution introduces a conductive path between two adjacent coils of different potential, and often from different phases. Because of the tracking, PD can arise and attack the groundwall insulation on the surface. Moisture condensation in the slot section can lead to problems if a machine has been idle. Oil tends to dissolve and loosen insulation system components and can attract dust that diminishes heat transfer from the winding surface thus reducing insulation life. In open enclosure machines, oil, in combination with dust, can clog up cooling air passageways to cause overheating. Conductive particulate contamination could produce a strong local concentration of partial discharges that could produce small perforations

3.7.2 Probability:

Oil and/or water, in combination with dust can clog up stator cooling air passageways to cause winding overheating. Considering the high moisture environments that machines are exposed to, the probability is moderate that problems from contamination will occur.

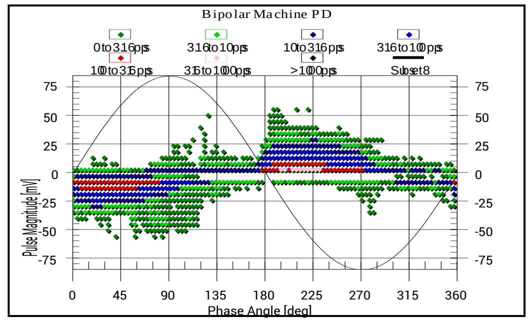


Figure 7. Mixed phase-to-ground and phase-to-phase discharges

3.7.3 Risk to the winding:

Permanent phase-to-phase or phase-to-ground deterioration may occur and eventual failure of the groundwall is possible. Failure process from contamination is often longer than 5-10 years, although faster in windings with a groundwall thickness of greater (>) 3 kV/mm design stress.

3.7.4 PD Pattern

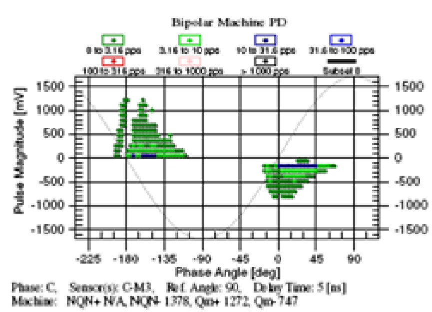
Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location
Contamination	No predominance	None	Unpredictable	15°, 75°, 195°, 255° (Can be erratic)

Symptoms	Detection Tests	Insulation types
PD, combination of oil/grease/dust, white powder	PD, IR, PI, Hi-pot, power factor, tan δ, tip-up, visual inspection	All stator winding types (High voltage coils)

3.8 INADEQUATE END-WINDING SPACING

3.8.1 Impact:

To reduce the size of the coils and to save copper or reduce losses, manufacturers occasionally fail to leave adequate clearance between the coils in the endwinding area or the ring bus connections. If two adjacent components from different phases do not have sufficient spacing between them, it is highly likely that partial discharge activity will occur between the two. In air-cooled machines, this leaves a white powder residue. The discharges will slowly erode the groundwall and eventually puncture it. However, if this activity is occurring between jacketed cable leads in the machine main terminal box, it can cause rapid insulation failure since such cable insulation has a



lower PD withstand capability. The combination of inadequate spacing and a polluted operating environment can provide a fertile condition for PD activity.

If you have two adjacent coils or ring buses from different phases with insufficient spacing between them, it is highly likely that partial discharge activity will occur between the two and in air-cooled machines leaving a white powder residue. These discharges will slowly erode the groundwall and could eventually puncture it. See Case Study 5.6.

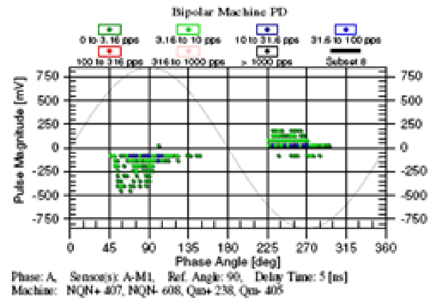


Figure 8. Phase-to-phase Discharges

3.8.2 Probability:

This is a relatively rare occurrence except when contaminated.

3.8.3 Risk to the winding:

The closer the coils, the faster the failure will occur. Generally, these phase-to-phase faults take years to develop, but produce high quantities of ozone in air-cooled machines.

3.8.4 PD Pattern

Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location	Pulse Polarity
Phase to Phase Discharges	No predominance	None	Unpredictable	15°, 75°, 195°, 255°	Opposite in the two phases

Symptoms	Detection Tests	Machine types
Partial discharge, white powder, ozone, insulation discoloration	PD, visual inspection, ozone monitoring	Air-cooled

3.9 GAP-TYPE DISCHARGES (LEADS)

3.9.1 Impact:

A gap-type discharge can occur when there is a constant space between two components at different potential. This type of activity will occur between two coils in the winding overhang, or between leads, or a lead and ground cluster that occurs at constant magnitudes without any lower magnitude pulses as shown in Figure 8. The “cloud” may be clustered around the positions associated with phase-to-phase or the phase-to-ground sources according to the location of the gap-type discharge location. When the problem is at the end of the coils or cables, then a rabbit ear pattern occurs.

See Case Studies 5.2 and 5.4

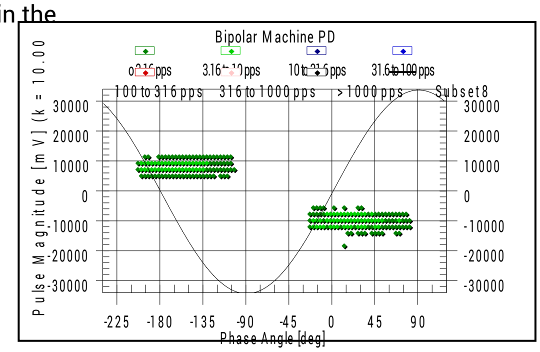


Figure 9. Gap-type Discharges

3.9.2 Probability:

This is a relatively rare occurrence as the routing of leads is normally done correctly.

3.9.3 Risk to the winding:

If the arcing is occurring at the leads, then this is a high risk as there is no mica within the lead cable insulation to protect it from electrical arcing (PD).

3.9.4 PD Pattern

Failure mechanism	Polarity	Load Effect	Temperature Effect	Phase Location
Gap-type Discharges	No predominance	None	Unpredictable	Variable (“Cloud”) or “rabbit ears”

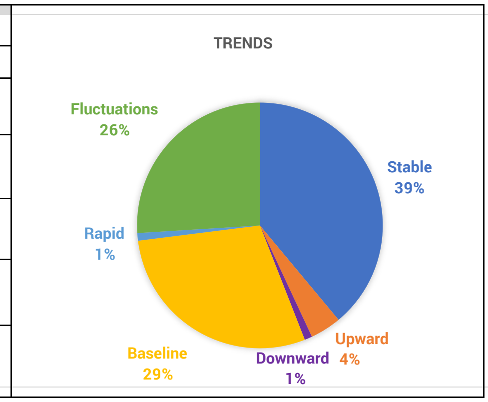
Failure mechanism	Symptoms	Detection Tests	Machine types
Inadequate cable spacing	PD, white powder, insulation discoloration	PD, visual inspection	Switchgear, motor leads

4 DATABASE ANALYSIS

4.1 TRENDS

Several different analyses were done on the Iris database to evaluate the long-term trend. Over 200 long-term trends were evaluated from PD results collected using EMCs as the PD sensor on machines rated 3-5kV. It is interesting to note in the table below that almost 26% of the results indicate fluctuations with ambient and/or operating conditions. It is also notable that 5% show an increase in the trend.

Trend	Definition	% result
Baseline	Initial test	29%
Stable	Within ± 25%	39%
Upward	> 25%, but less than Rapid	4%
Rapid	> 100% in 6 months	1%
Downward	< 75% over 6 months	1%
Fluctuations	Influenced by variable conditions [Figure 10]	26%



4.1.1 Continuous Monitors

Because of the potential for variability with ambient and/or operating conditions, it is recommended that to avoid misdiagnosis for this voltage class the stator winding insulation, when practical, should be monitored with a continuous instrument [Figure 10]. This instrument can be connected to plant DCS and or periodically examined for changes in PD. When data is obtained it is important to evaluate both the maximum levels of PD over the timeframe and the overall trend. Any significant change in activity, up or down should be investigated [Figure 11] is a trend of Very High PD relative to the Iris database; however, it is relatively stable, exhibiting a recent slow upward trend.

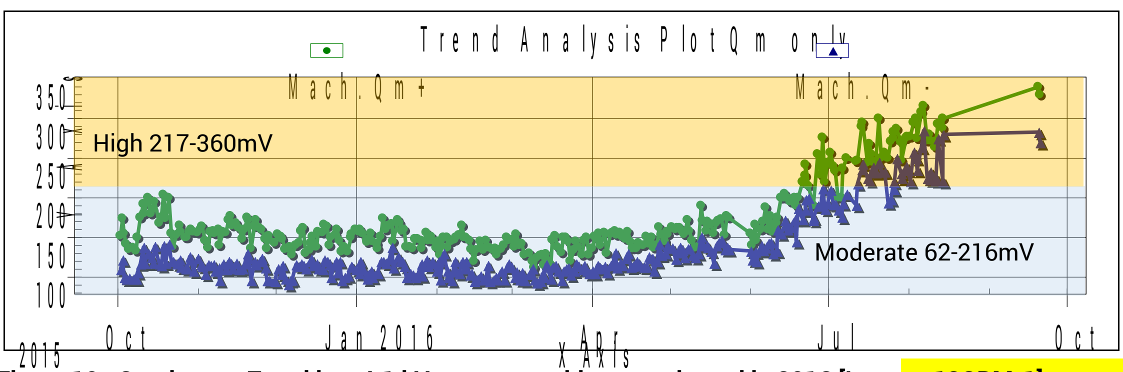


Figure 10. Continuous Trend in a 4.1 kV motor- notable upward trend in 2016 [Lemont 13GBM-1]

Figure 11. Continuous Trend - High, but Stable with a developing slow upward trend

4.1.2 Periodic Testing

Though continuous monitoring is recommended, it some cases periodic testing is more practical. In Figure 12, the PD is at Moderate to High levels but has been stable. It is too early to evaluate the overall trend to suspect a rapidly developing problem, though there is an indication of some activity. On the other hand, Figure 13 signifies data that is originally low, but because of the increasing, rapid trend should be closely monitored.

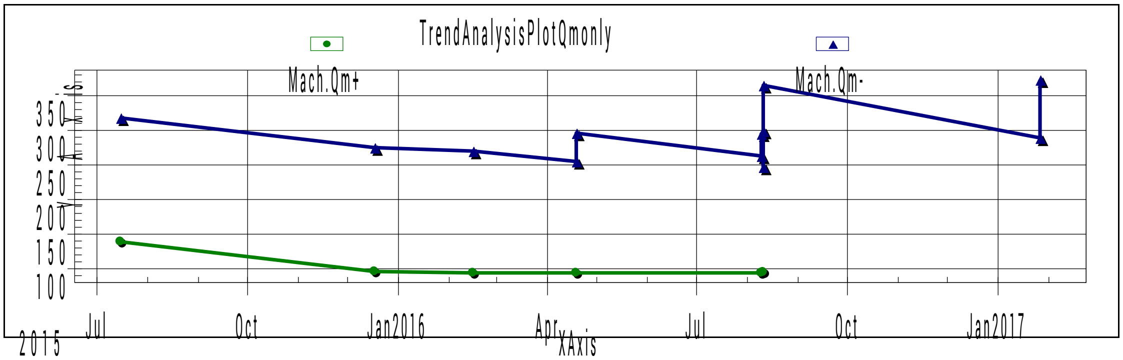


Figure 12. Periodic Test – High, but stable [Koch-UAN-M08]

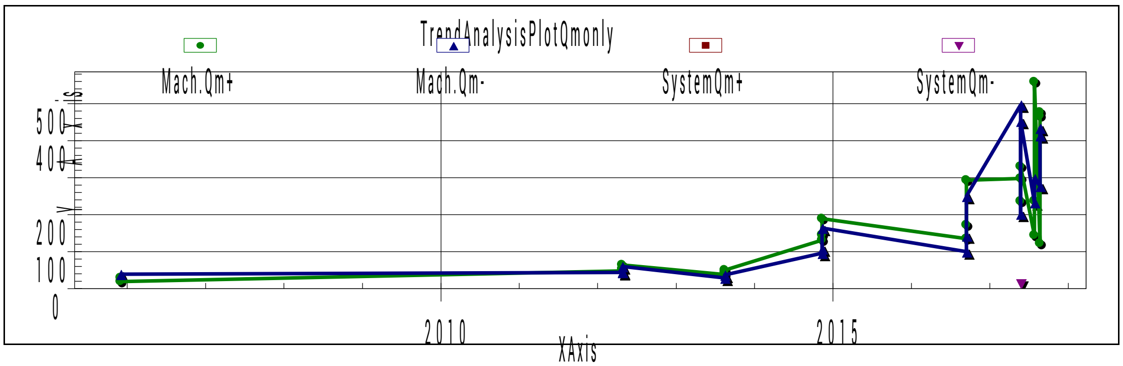


Figure 13. Periodic Test – High but Increasing trend [Marathon Detroit – 14MDC3]

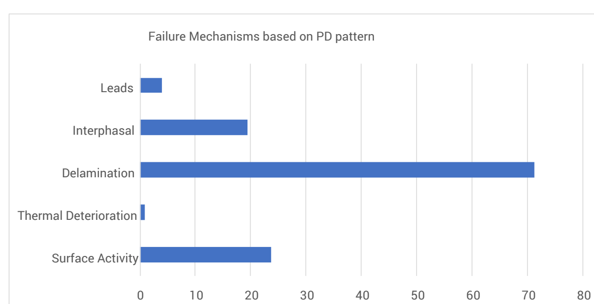
4.2 DATABASE ANALYSIS FOR PD MAGNITUDES

From the database, here are the statistics based on over 300 motors. [7]

	Rated kV	2-5	
Negligible	**25%**	9	25% of the results have Qm levels below this value
Low	**50%**	22	50% of the results have Qm levels below this value
Typical	**75%**	62	75% of the results have Qm levels below this value
Moderate	**90%**	216	90% of the results have Qm levels below this value
High	**95%**	360	95% of the results have Qm levels below this value

4.3 FAILURE MECHANISM PD PATTERNS

Failure Mechanism	Definition	Results out of 200
Leads	Clouds or Zero crossings	4
Interphasal	Phase-to-phase	19
Delamination/ Impregnation+	Negative Predominance	71
Thermal Deterioration	No Predominance	1
Movement/ Slot discharge+ +	Positive Predominance	24



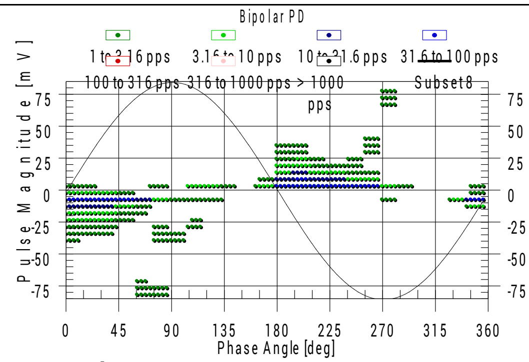
+ The difference between thermal delamination and inadequate impregnation (resin penetration) is the age of the winding. If it is a new winding, then it is a manufacturing defect. If it is an older winding, then it is more likely thermal deterioration. In either case, because of the risk to the turn insulation in multi-turn coils, this pattern is indicative of a high failure risk situation.

++ The difference between the two activities with surface activity, coil movement and electrical slot discharge, is whether the PD also changes in direct correlation with load. Unfortunately, for most of the results in the database, the load is not recorded with the PD data, so it is not possible to differentiate between the two. If the surface activity is strictly due to electrical slot discharge, then this is a slow process; whereas, if the problem is coil movement it is a high failure risk situation.

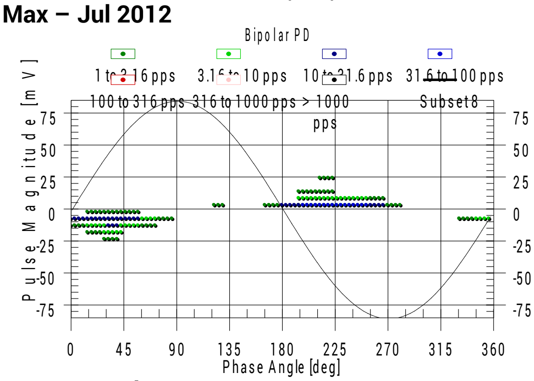
5 CASE STUDIES

5.1 ERRATIC PD

Plant: 4kV Induction Motor, 8000hp
Original test date was: Jun 2012 (continuous)
Max PD Values: Qm+ 85mV, Qm- 85mV
Pulse phase analysis: primarily internal PD but high magnitude around the peaks
Follow-up monitoring: continuous [Figure 10]
Comparison of Jul 2012 to Feb 2013 showed higher activity in July with sporadic clusters often indicative of contamination which would be highly sensitive to variable ambient and/or operating conditions
New PD Values: Qm+ 26mV, Qm- 20mV
Current situation: continue to monitor, be alert to erratic behavior



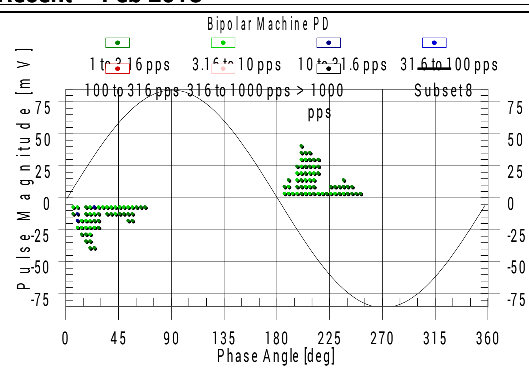
Max – Jul 2012



Recent – Feb 2013

5.2 LOW BUT INCREASING

- Plant: 4kV Induction Motor, 1250hp
- Original test date was: May 2009 (periodic)
- PD Values: Qm+ 9mV, Qm- 7mV
- Pulse phase analysis: negligible PD
- Follow-up monitoring: increase in Oct 2013 [Figure 13]
- Emergence of a narrowband cluster, indicative of a source at or near the terminals
- Decision: continue to monitor
- New PD Values: Qm+ 23mV, Qm- 27mV
- Current situation: minor problem developing

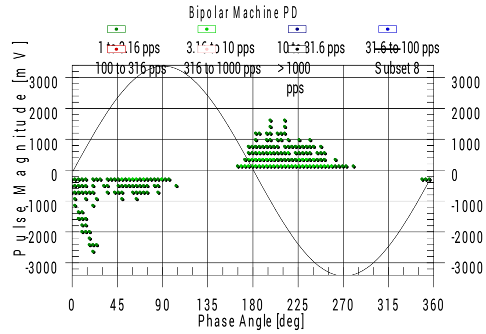


Oct 2013

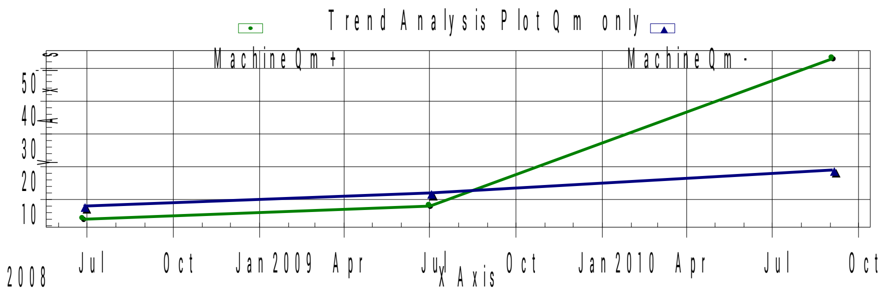
5.3 IMMEDIATE REWIND

- Plant: 4kV Induction Motor, 1250hp
- Original test date was: Apr 2008 (portable instrument)
- PD Values: Qm+ 1368mV, Qm- 1466mV
- Pulse phase analysis: arcing at the motor terminals combined with both internal and surface voids
- Decision: rewind motor immediately in 2008

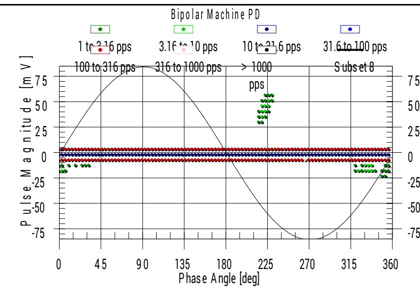
- PD Values: Qm+ 8mV, Qm- 4mV
- Follow-up monitoring: slight upward trend since Jul 2009, new PD values Qm+ 53mV, Qm- 19mV Current
- situation: isolated source of arcing at motor terminals indicated by a narrowband pulse near 225°



Apr 2008



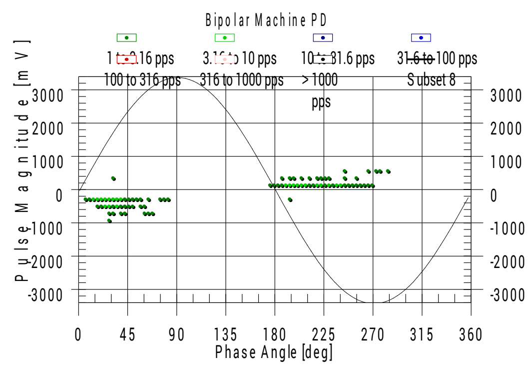
Post-rewind



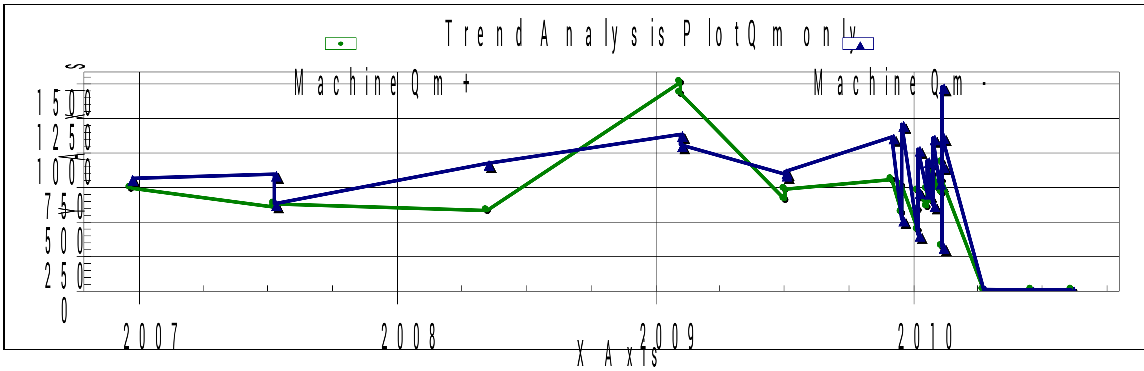
Sep 2010

5.4 HIGH PD MONITORED THEN REWOUND

- Plant: 4kV Induction Motor, 3000hp
- Original test date was: Dec 2006 (periodic)
- PD Values: Qm+ 746mV, Qm- 817mV
- Pulse phase analysis: primarily internal PD
- Follow-up monitoring: mostly stable, but increase in negative PD Feb 2009, new PD values Qm+ 798mV, Qm- 1120mV. Negative predominance is a concern for multi-turn coil construction. (see below)
- Decision: rewound motor in 2010
- New PD Values: Qm+ 8mV, Qm- 9mV
- Current situation: no problems indicated

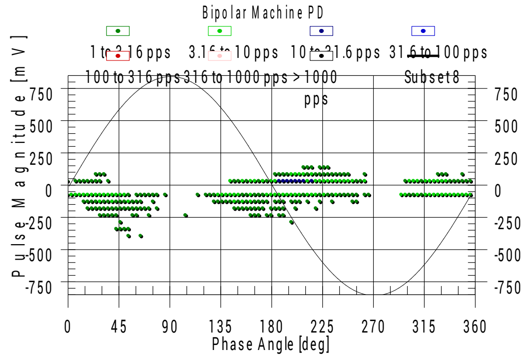


Dec 2006

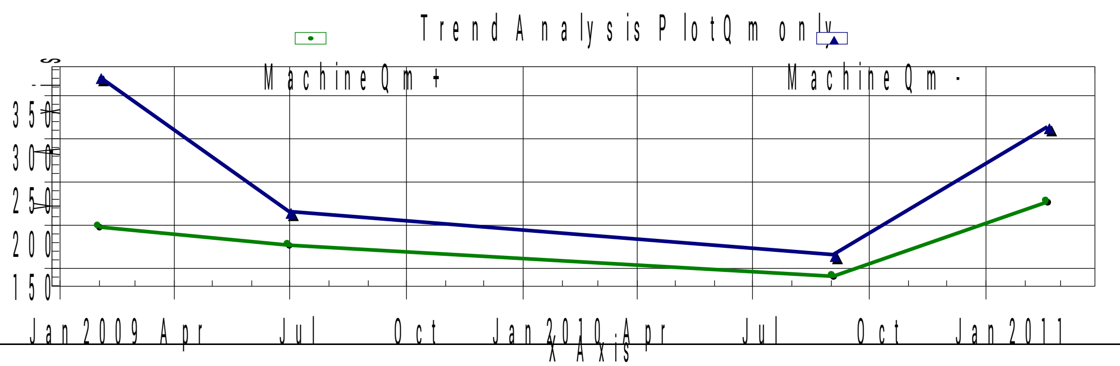


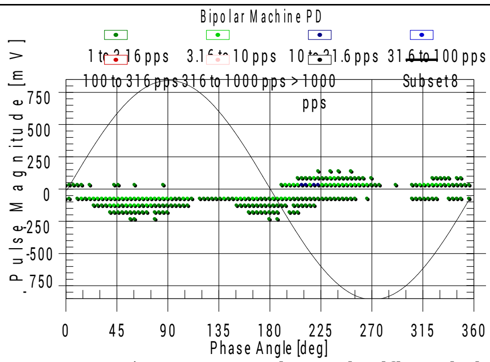
5.5 SEASONAL PD

- Plant: 4kV Induction Motor, 1250hp
- Original test date was: Mar 2009 (periodic)
- PD Values: Qm+ 198mV, Qm- 372mV
- Pulse phase analysis: High primarily internal PD
- Follow-up monitoring: initial decrease followed by an apparent increase (see below)
- Comparison of Mar 2009 to Feb 2011 showed no change in magnitude or pattern, but the Jun 2009 levels were lower in magnitude (see below)
- Decision: continue to monitor
- New PD Values: Qm+ 227mV, Qm- 314mV
- Current situation: no problems indicated

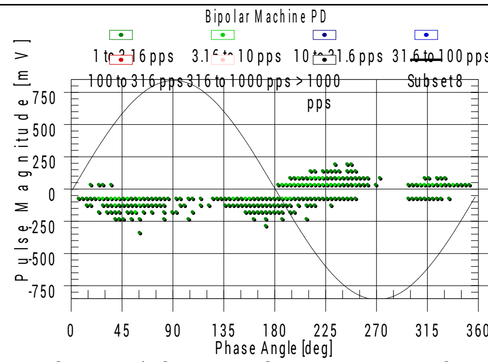


Mar 2009





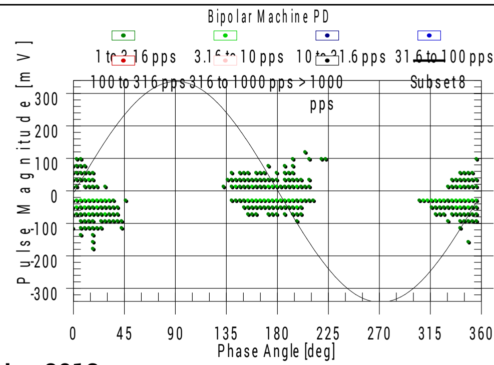
Jun 2009 (summer results – significantly less)
Qm+ 177mV, Qm- 216mV



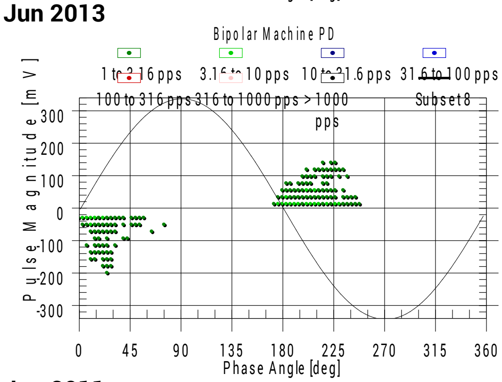
Feb 2011 (winter results – same as Feb 2009)
Qm+ 227mV, Qm- 314mV

5.6 MODERATE BUT CHANGE IN PATTERN

Plant: 4kV Induction Motor, 1250hp
Original test date was: May 2009 (periodic)
PD Values: Qm+ 95mV, Qm- 125mV
Pulse phase analysis: primarily internal PD, but may be interphasal
Follow-up monitoring: initial increase but since Jun 2011 primarily stable [Figure 12]
Comparison of Jun 2011 to Oct 2013 showed similar magnitudes but a significant change in PD pattern
New PD Values: Qm+ 132mV, Qm- 161mV
Current situation: continue to monitor, but consider additional testing because of the change in PD pattern



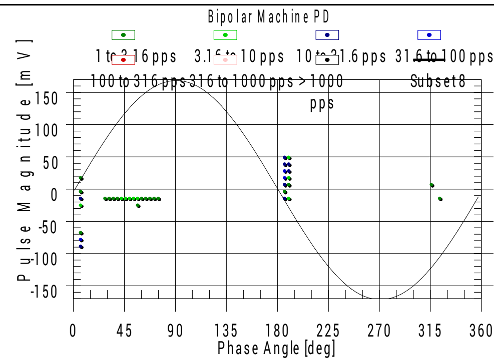
Jun 2013



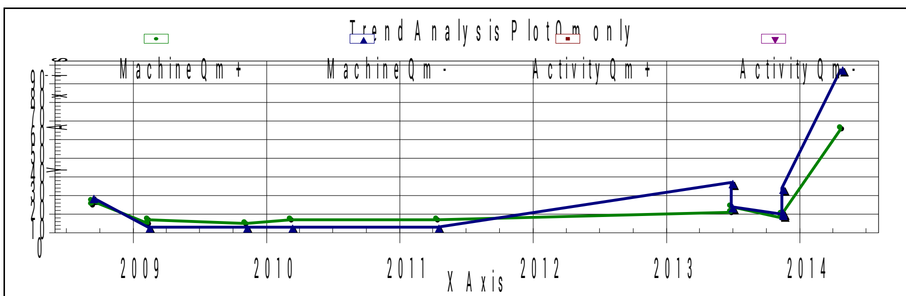
Jun 2011

5.7 INCREASE BUT NOT PD

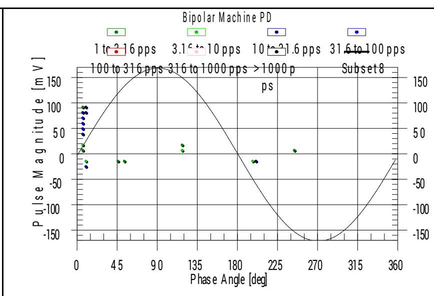
- Plant: 4kV Induction Motor, 1.865MW
- Original test date was: Sep 2007 (periodic)
- PD Values: Qm+ 16mV, Qm- 8mV
- Pulse phase analysis: negligible PD
- Follow-up monitoring: increase in Apr 2014 (see below)
- Comparison of Nov 2013 to Apr 2014 shows a single source at or near the zero crossings that has reversed polarity. This is not PD.
- Decision: continue to monitor
- New PD Values: Qm+ 56mV, Qm- 88mV
- Current situation: no problems indicated



Apr 2014



Long-term Trend



Nov 2013

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6 CONCLUSION

Using on-line PD monitoring as part of the condition-based assessment for medium voltage 3-5kV machines is possible and practical with several success stories. Trends and comparison to the Iris database is feasible; however, there are some issues to be considered:

1. Correct coupler installation at the machine terminals [Sections 2.2]
2. Periodic monitoring may be suitable, but once notable PD (>75%) is detected, or any change in PD magnitude up or down, or change in pattern, then continuous monitoring should be considered since at least for some failure mechanisms time of detection to failure may be just a few weeks, whereas for others it may be several months or years [Sections 2.1 and 5]
3. One common failure mechanism – surges to a damaged interturn insulation – may not have PD as a symptom [Section 3]

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.

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