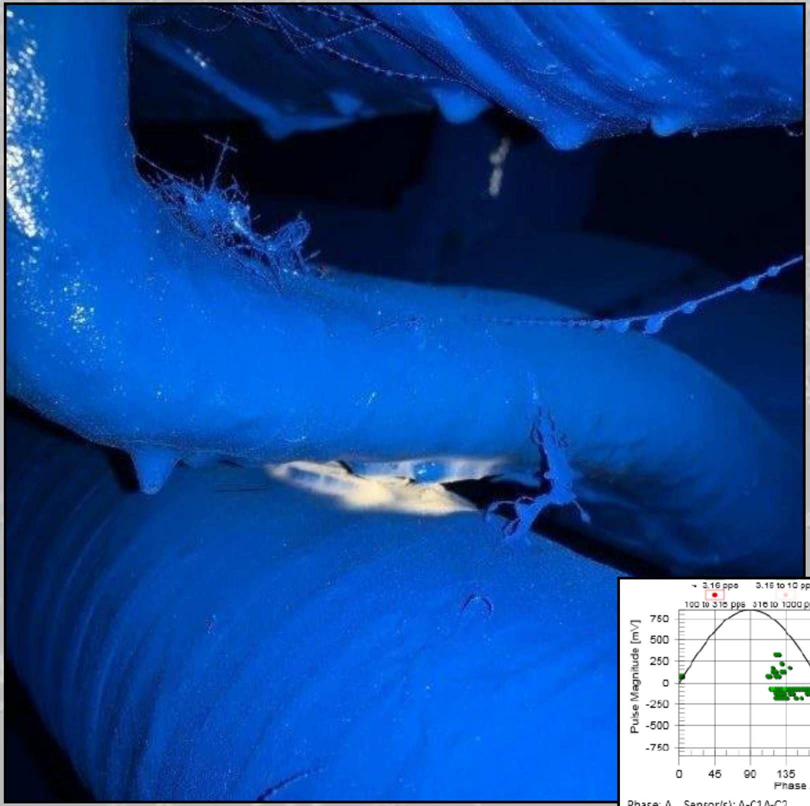
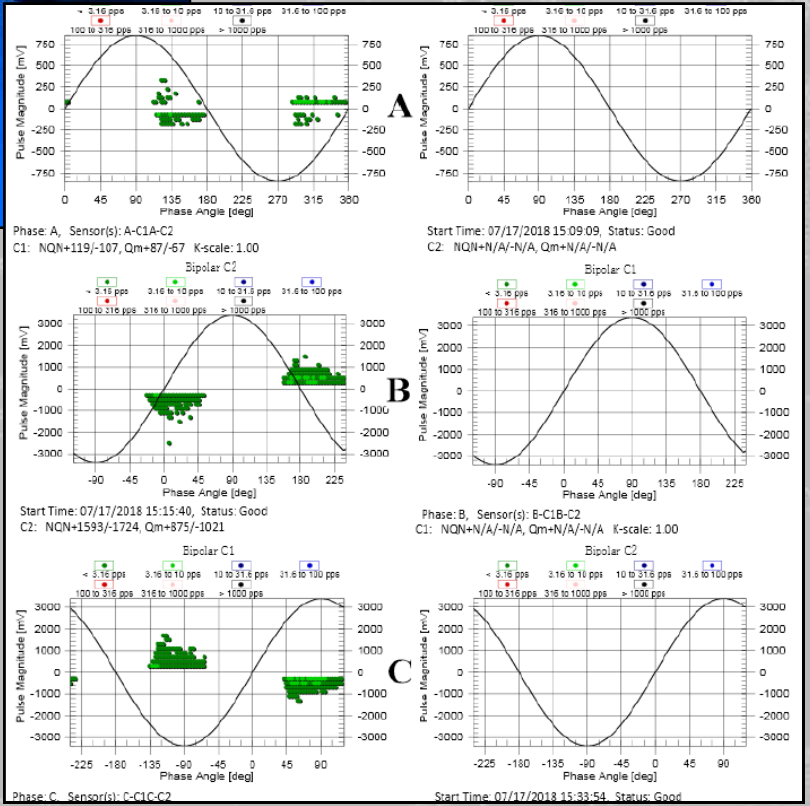
# DISCOVERING / RESOLVING REWIND PROBLEMS

## USING PDA BASELINE DATA ANALYSIS

## IRIS ROTATING MACHINE CONFERENCE 2021







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Date: 22 June 2021

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# OUTLINE

1. Basic PDA concept and use
2. Testing and inspections during a rewind
   - How testing during rewinds relates to possible PDA findings
3. Case studies in PDA baseline data following rewinds
4. Conclusions

# BASIC CONCEPT OF PDA



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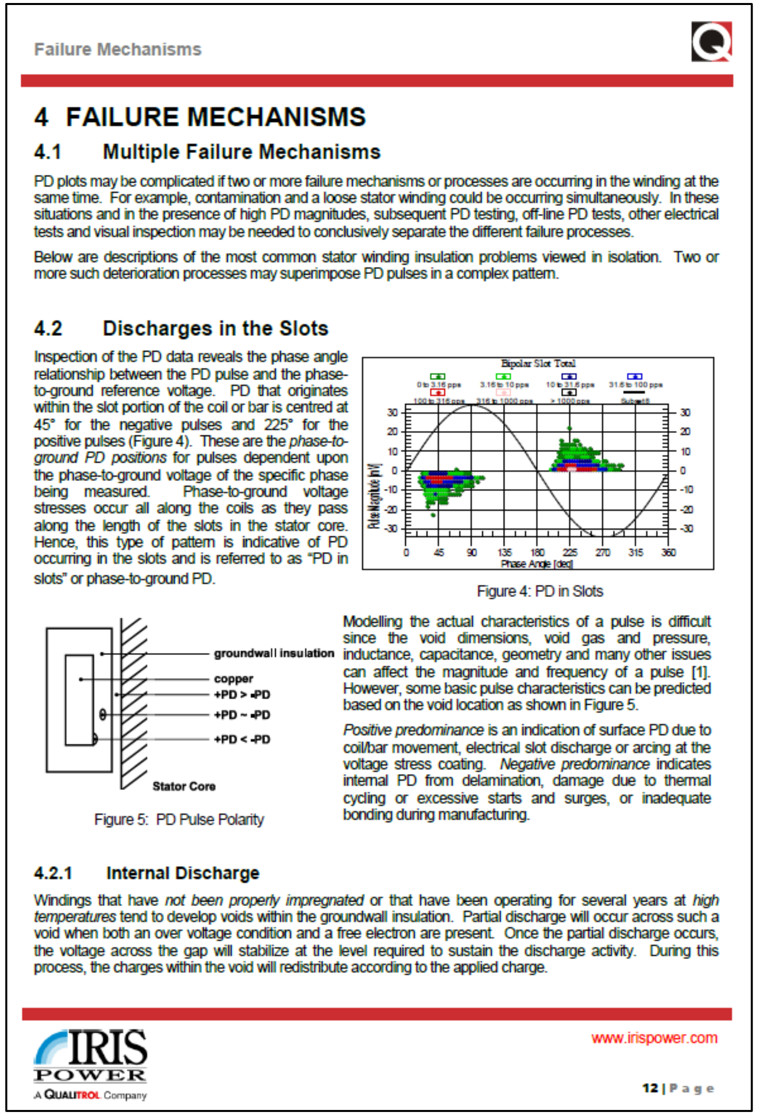
Partial Discharge Analysis (PDA) uses electrical measurements during machine operation to detect electrical discharge activity.

By analyzing specific discharge pulse activity, the nature of the discharge (including general location and possible severity) may be estimated.

- General location inside groundwall insulation
- On external surface of bar
- End-winding, grading system, etc.

Over the lifespan of a stator winding, regular monitoring and trending of this data (when collected under similar conditions!) can give indication as to condition and any problems.


Failure Mechanisms

4 FAILURE MECHANISMS

4.1 Multiple Failure Mechanisms

PD plots may be complicated if two or more failure mechanisms or processes are occurring in the winding at the same time. For example, contamination and a loose stator winding could be occurring simultaneously. In these situations and in the presence of high PD magnitudes, subsequent PD testing, off-line PD tests, other electrical tests and visual inspection may be needed to conclusively separate the different failure processes.

Below are descriptions of the most common stator winding insulation problems viewed in isolation. Two or more such deterioration processes may superimpose PD pulses in a complex pattern.

4.2 Discharges in the Slots

Inspection of the PD data reveals the phase angle relationship between the PD pulse and the phase-to-ground reference voltage. PD that originates within the slot portion of the coil or bar is centred at 45° for the negative pulses and 225° for the positive pulses (Figure 4). These are the *phase-to-ground PD positions* for pulses dependent upon the phase-to-ground voltage of the specific phase being measured. Phase-to-ground voltage stresses occur all along the coils as they pass along the length of the slots in the stator core. Hence, this type of pattern is indicative of PD occurring in the slots and is referred to as "PD in slots" or phase-to-ground PD.



Figure 4: PD in Slots



Figure 5: PD Pulse Polarity

Modelling the actual characteristics of a pulse is difficult since the void dimensions, void gas and pressure, inductance, capacitance, geometry and many other issues can affect the magnitude and frequency of a pulse [1]. However, some basic pulse characteristics can be predicted based on the void location as shown in Figure 5.

*Positive predominance* is an indication of surface PD due to coil/bar movement, electrical slot discharge or arcing at the voltage stress coating. *Negative predominance* indicates internal PD from delamination, damage due to thermal cycling or excessive starts and surges, or inadequate bonding during manufacturing.

4.2.1 Internal Discharge

Windings that have *not been properly impregnated* or that have been operating for several years at *high temperatures* tend to develop voids within the groundwall insulation. Partial discharge will occur across such a void when both an over voltage condition and a free electron are present. Once the partial discharge occurs, the voltage across the gap will stabilize at the level required to sustain the discharge activity. During this process, the charges within the void will redistribute according to the applied charge.

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# PDA TRENDING AND BASELINE DATA

Typical assessment of PDA data over a winding's life may include recording the data under staged conditions approximately every 6 months, starting ~1 year after installation. Data may also be taken immediately upon completion of rewind, after first going online.

## IRIS:

*"Figure 3 shows that on a new machine the PD will often start relatively high and then decrease as the winding settles* ***over the first 12 months to "baseline" levels.****"* ("Interpretation of Partial Discharge Results", Iris Power)

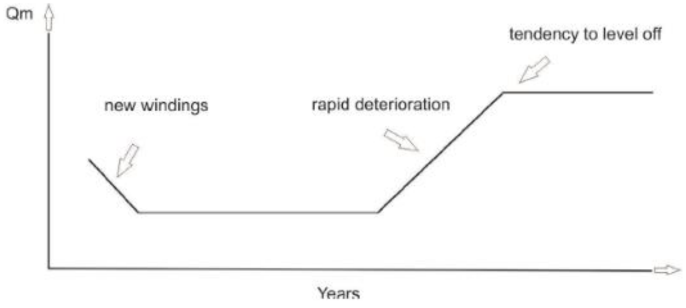


Figure 3: PD Life Cycle

## IEEE 1434:

*"There may be merit in performing PD tests on individual stator coils/bars and completed newly installed windings as a quality control check."*

*"Although off-line testing is more time-consuming and expensive to perform, it can form a good complement to on-line testing if there is concern over trendable machine readings. It is convenient to make the initial offline tests when the machine winding is new." (Advantages of offline testing at such a time are also discussed)*

## CEATI:

TESTS DURING OPERATION

*To verify winding design claims regarding capability and temperature rises, a heat run is necessary, as follows:*

The generator is to be operated at rated ____ MVA at ____ power factor (generator mode) and the following are to be monitored every 30 minutes until temperature stabilization is reached (i.e., less than 1°C increase in any monitored temperature in a 30 minute period).

- Record MW, MVAR, line-to-line voltage line currents, rotor field winding voltage and current every 30 minutes.
- Stator winding RTD temperatures – *Temperature rise on any RTD not to exceed 60°C (or the agreed to rise) above cooling air inlet temperature.*
  ***Note:*** *If equipped with on-line partial discharge measurement capability, specific conditions or expectations may be inserted as shown below. Keep in mind that there are no current standards for what is an acceptable level.*
- On line Partial Discharge test results – to IEEE 1434 [23]. Once stabilized, PD levels should be lower than those obtained during the off line stator winding acceptance tests and certainly no greater than Typical for a PDA ≥ ___ kV air-cooled winding per *the relevant database for the equipment used.*

# TESTING AND INSPECTIONS DURING REWINDS

During winding installation:

- Bar-to-slot contact resistance
- High potential testing

After winding completed:

- IR/PI Tests
- Corona probe tests of each slot
- Blackout test (or corona scope)

After generator reassembly:

- Final winding high potential test – each phase individually
- DC Ramp Test
- Special field testing/heat run/etc.

Failure Mechanisms

## 4 FAILURE MECHANISMS

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Below are descriptions of the most common stator winding insulation problems viewed in isolation. Two or more such deterioration processes may superimpose PD pulses in a complex pattern.

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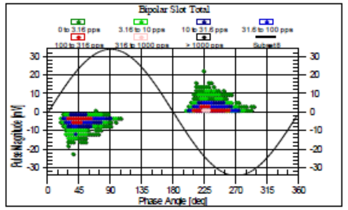

Figure 4: PD in Slots

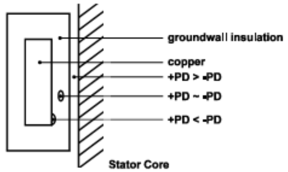

Figure 5: PD Pulse Polarity

Modelling the actual characteristics of a pulse is difficult since the void dimensions, void gas and pressure, inductance, capacitance, geometry and many other issues can affect the magnitude and frequency of a pulse [1]. However, some basic pulse characteristics can be predicted based on the void location as shown in Figure 5.

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#### 4.2.1 Internal Discharge

Windings that have *not been properly impregnated* or that have been operating for several years at *high temperatures* tend to develop voids within the groundwall insulation. Partial discharge will occur across such a void when both an over voltage condition and a free electron are present. Once the partial discharge occurs, the voltage across the gap will stabilize at the level required to sustain the discharge activity. During this process, the charges within the void will redistribute according to the applied charge.

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During winding installation:

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- High potential testing

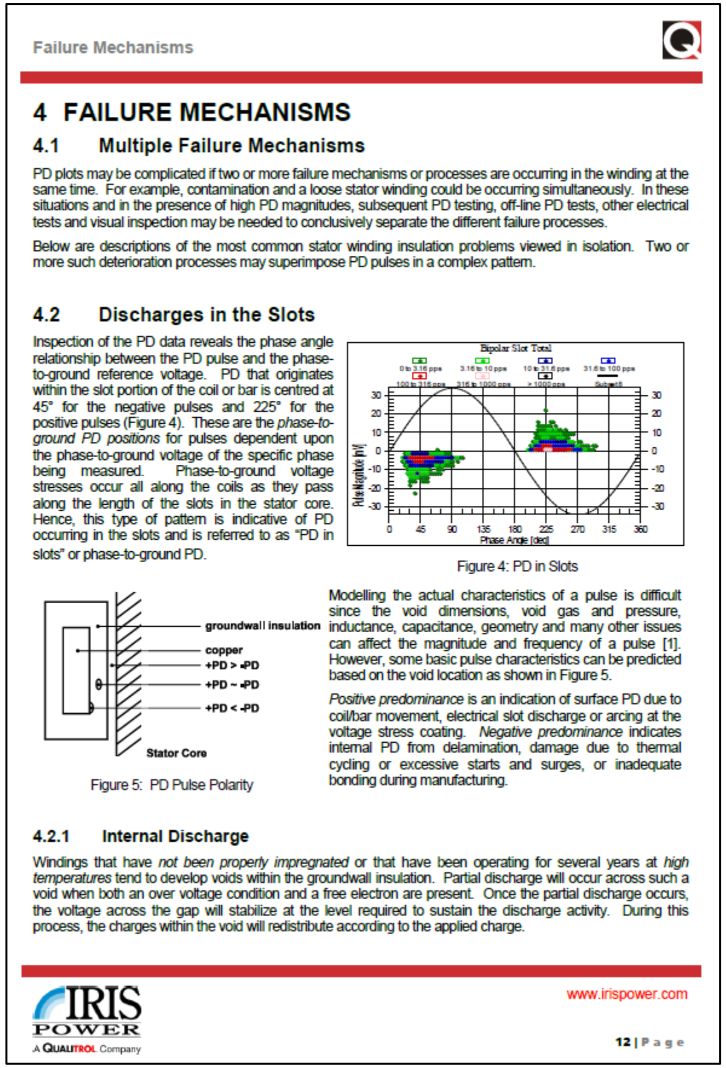
After winding completed:

- **IR/PI Tests**
- **Corona probe tests of each slot**
- Blackout test (or corona scope)

**These could find bulk insulation issues**

After generator reassembly:

- Final winding high potential test – each phase individually
- **DC Ramp Test**
- Special field testing/heat run/etc.



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During winding installation:

- **Bar-to-slot contact resistance**
- High potential testing

After winding completed:

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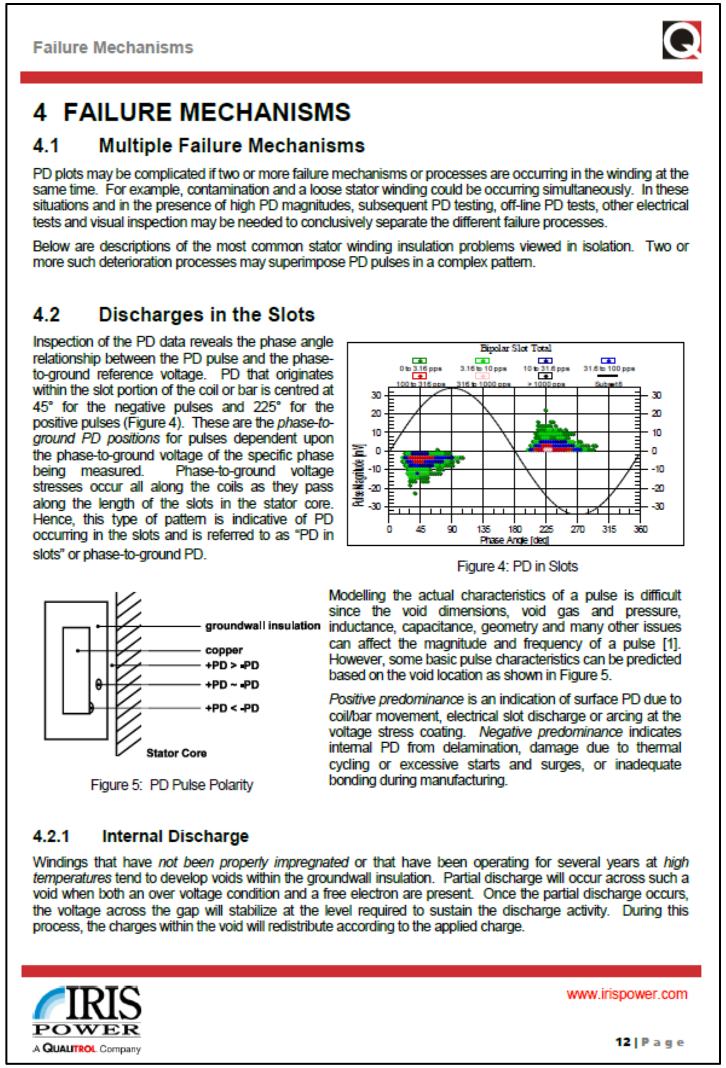
- **Corona probe tests of each slot**
- Blackout test (or corona scope)

**These could find bar-to-slot contact issues (slot discharge)**

After generator reassembly:

- Final winding high potential test – each phase individually
- DC Ramp Test
- Special field testing/heat run/etc.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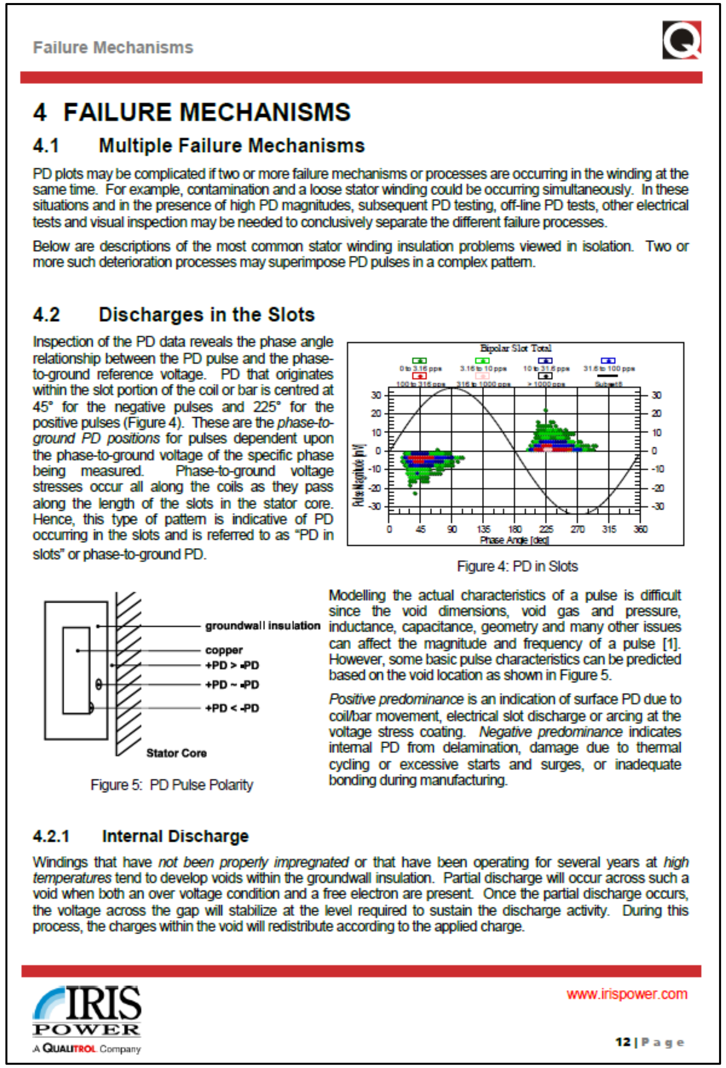
During winding installation:
- Bar-to-slot contact resistance
- High potential testing

After winding completed:
- IR/PI Tests
- Corona probe tests of each slot
- **Blackout test (or corona scope)**
  - **Test voltages and application have implications on what can be seen!**
  - **IEEE 1799 provides guidance on these considerations.**

**These could find end-winding and circuit ring clearance issues:**

After generator reassembly:
- **Final winding high potential test – each phase individually**
- **DC Ramp Test**
- Special field testing/heat run/etc.



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Bipolar Slot Total

Phase Angle [deg]

Figure 4: PD in Slots

groundwall insulation

copper

+PD > -PD

+PD ~ -PD

+PD < -PD

Stator Core

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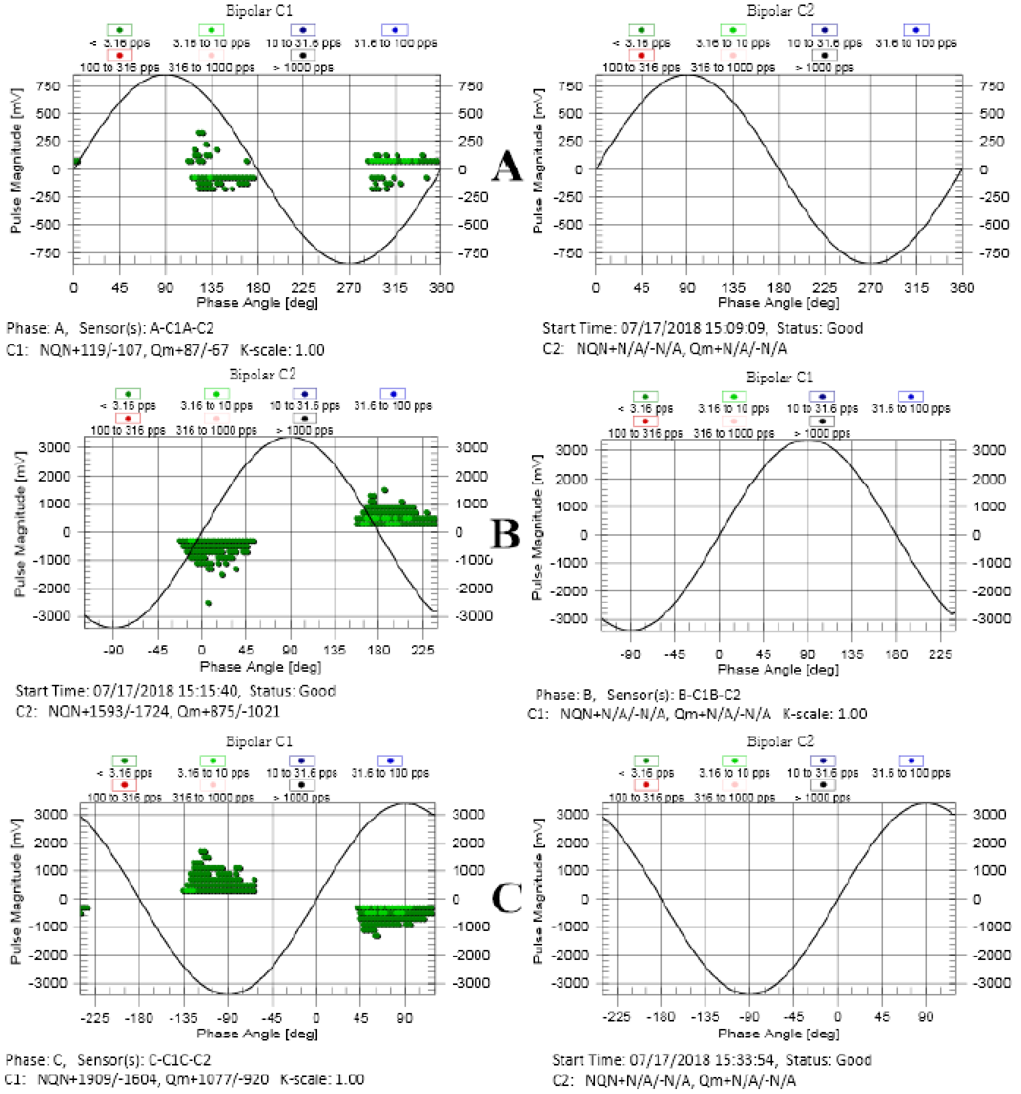
# CASE STUDY 1

Initial ("baseline") PDA data was recorded during commissioning following generator rewind.

All previously mentioned testing had already taken place prior.

PDA "baseline" report which was provided indicated:

- High inter-phase PD in end-winding (B and C phases)
- Some cross-coupling on A phase (not indicative of problem, though can obscure other issues)



# CASE STUDY 1

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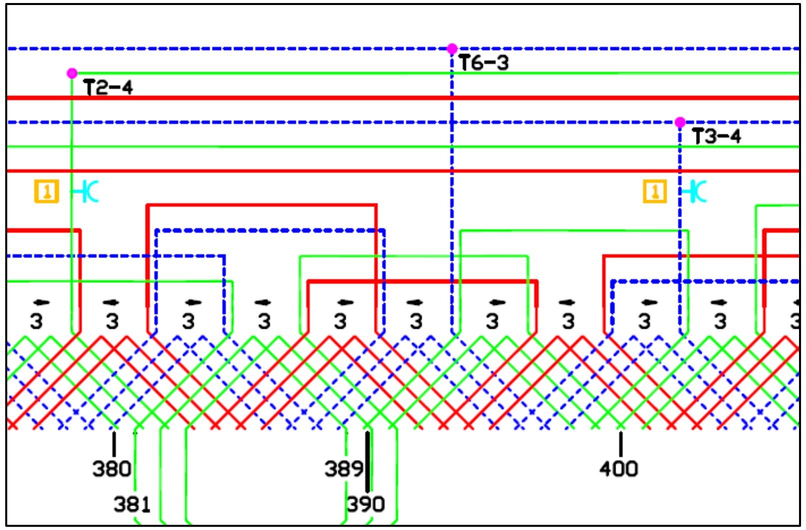
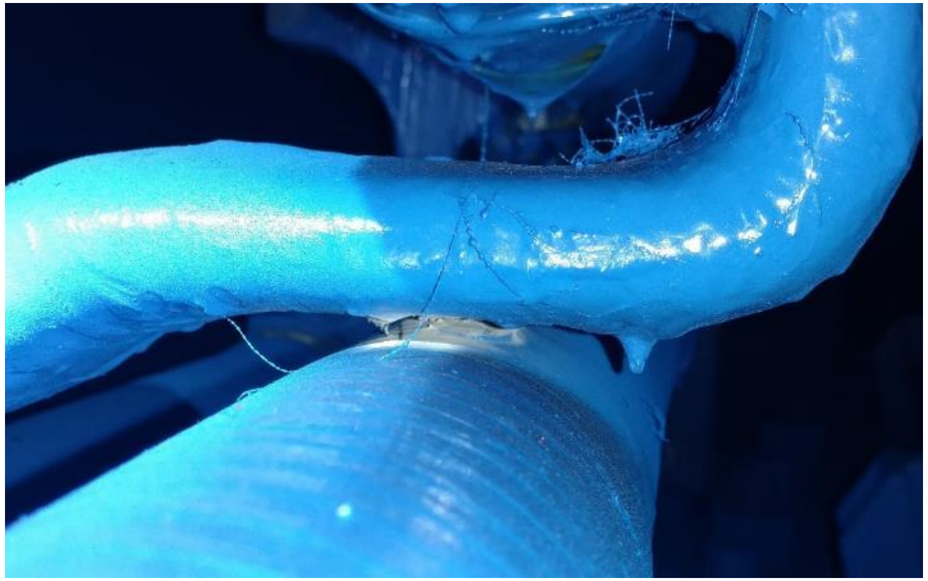
Review of physical location of the couplers along with the winding diagram indicated the likely location of the problem.




Physical inspection and blackout test confirmed the location of the inter-phase corona activity

- Voltage at which the activity was observed was higher than original blackout test for the involved phase(s) achieved. One possible reason it wasn't seen – though access and visibility is also a challenge!

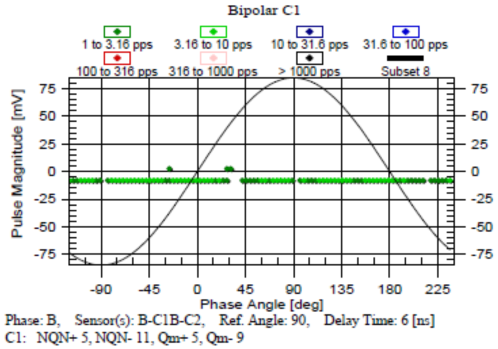
The second blackout test, conducted with rotor in, provided greater access to end-winding to see the issue.

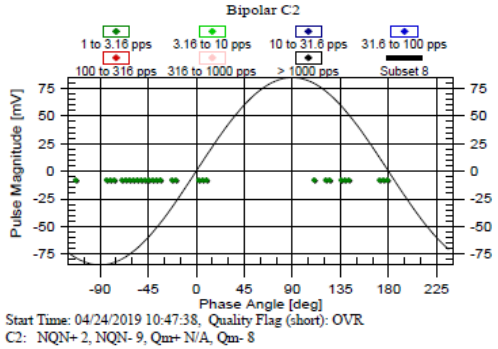


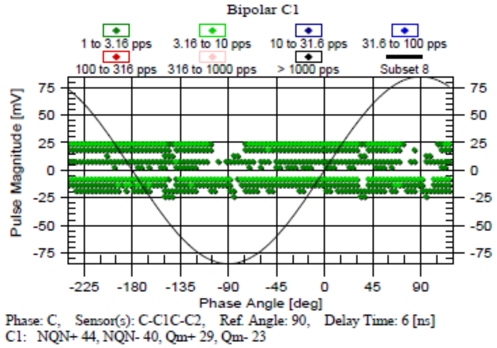
# CASE STUDY 1

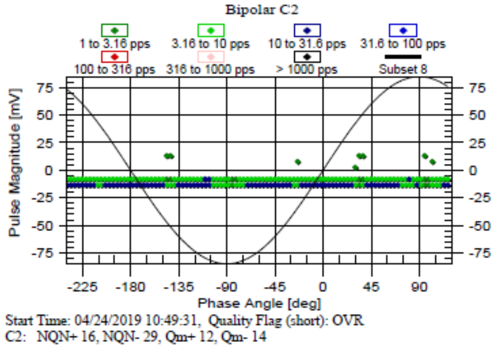
Using garnet paper, sanded varnish drips and loose material to clean the area. Filled the narrow gap with 100% silicone, injected to completely fill the gap.

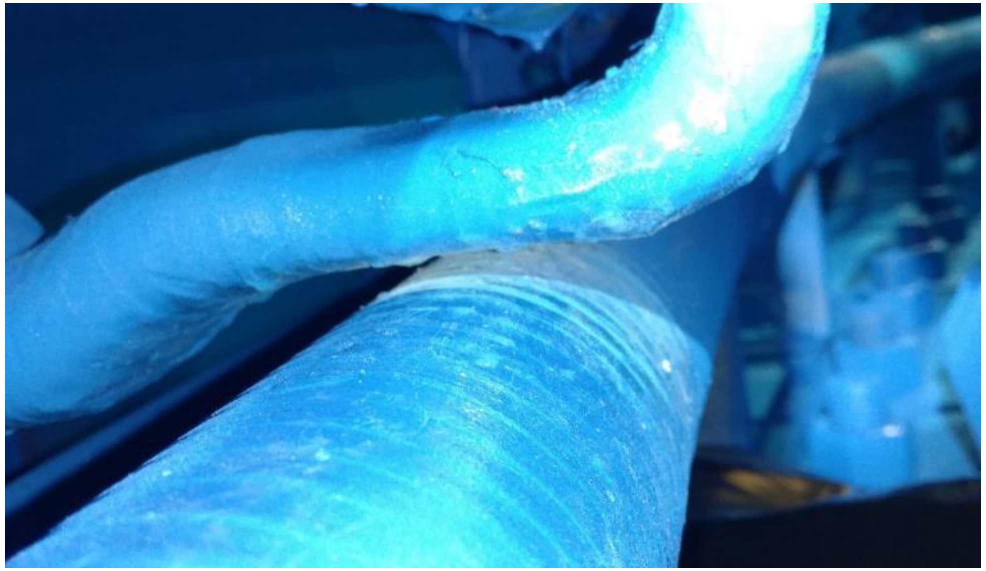
PDA results taken afterwards show no remaining activity (low level broadband clusters only)



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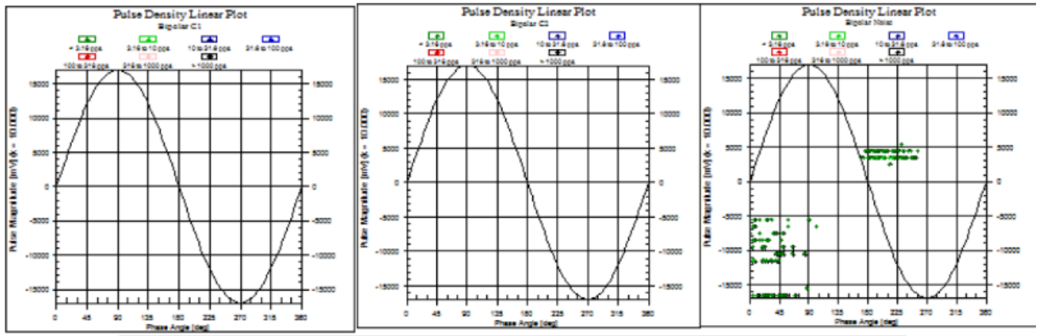
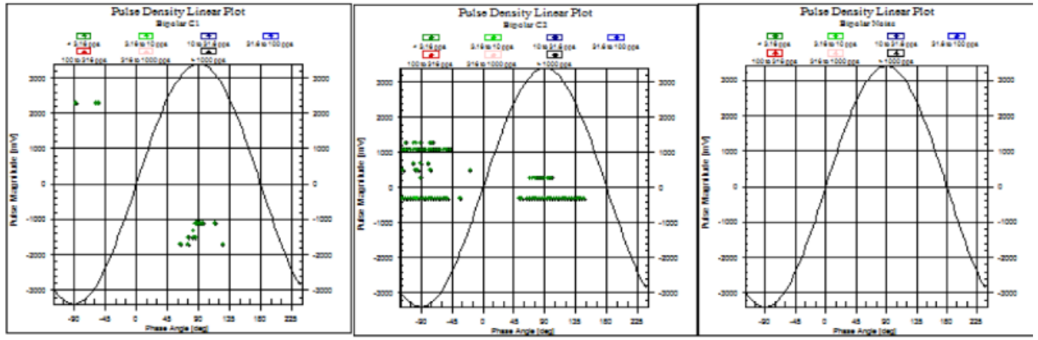
# CASE STUDY 2

Again, initial PDA data was recorded following commissioning after a rewind was performed. The report indicated potentially numerous issues which were considerably less straightforward to interpret than the first Case Study example. Significant noise (gap discharge) was present, likely cross-coupling, some evidence of slot-exit PD, etc.

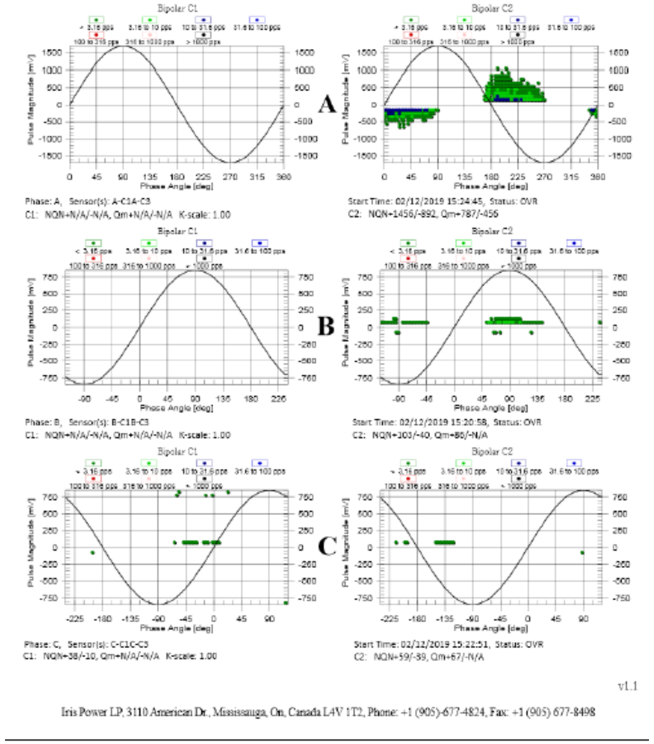
A detailed inspection and repeated blackout test with access to the end-winding was performed.



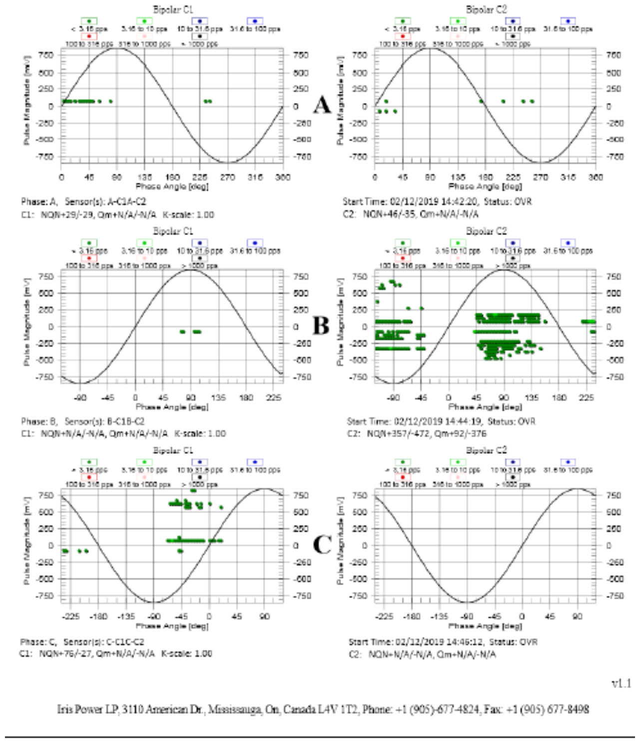

Phase: A Start Time: 02/12/2019 15:03:13, Delay Time: 6 [ns], Freq. (Test Duration): 60 Hz, (1 sec.)




Phase: B Start Time: 02/12/2019 14:56:23, Delay Time: 6 [ns], Freq. (Test Duration): 60 Hz, (5 sec.)




Plot 2: ABC report of pair C1-C3 at high load

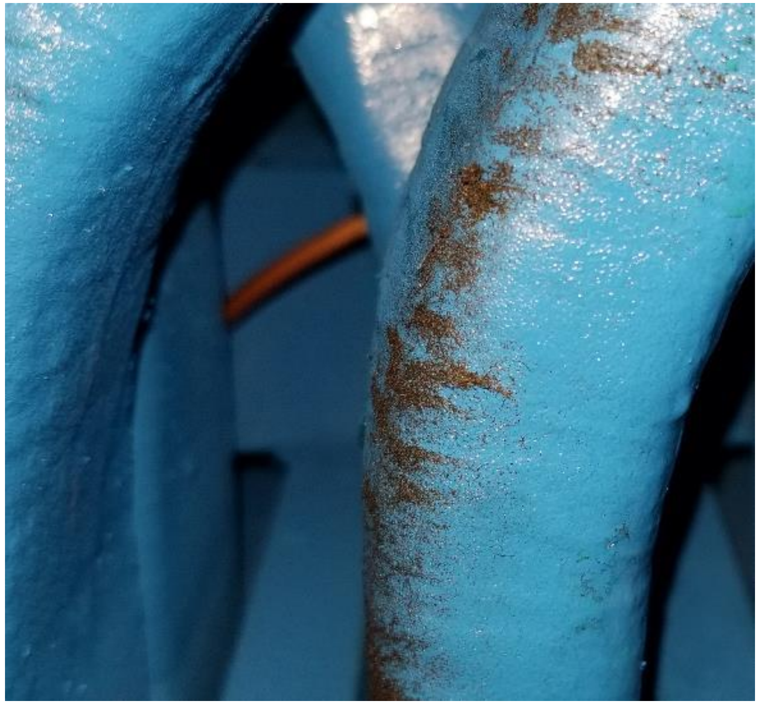



Plot 1: ABC report of pair C1-C2 at high load

# CASE STUDY 2

General findings during inspection and blackout testing were low clearances between some circuit connections, as well as air gap sensor leads which were loose and relatively far from the core end.

Resolving some of these items through securing leads and filling gaps removed the noted corona locations during repeated blackout testing.



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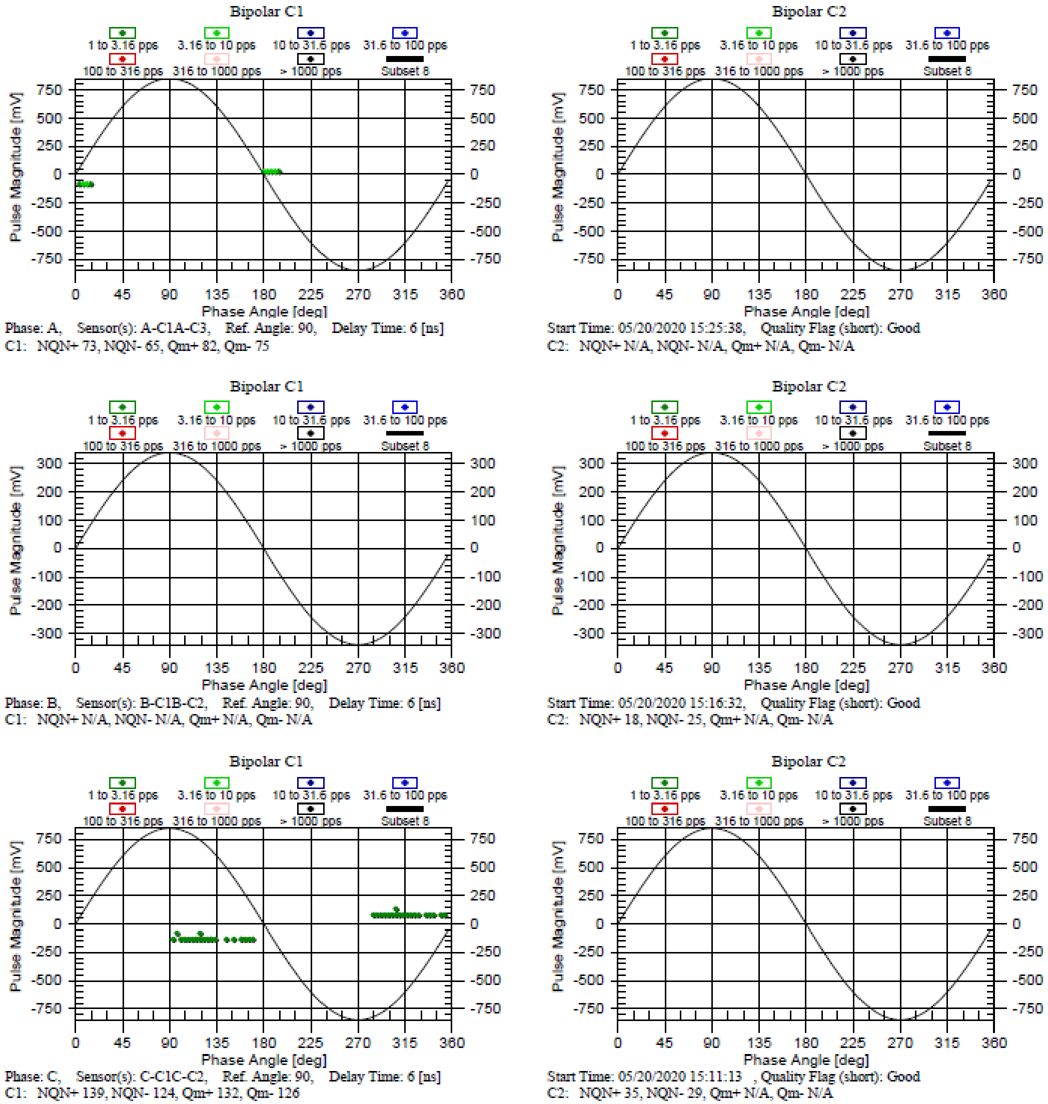
PDA Analysis performed afterwards showed greatly improved results, with previous issues resolved.



# CONCLUSIONS

1. Some problems can be missed during typical winding testing (including blackout and corona-scope testing) – especially when they are occurring in areas which are hard to access with windings energized and rotor removed.
2. Magnitude of applied voltage should be considered for blackout/corona scope testing – higher voltages may be needed to observe possible inter-phase activity.
3. PDA systems can detect some winding installation problems using off-line (with separate voltage supply) and/or on-line testing.
4. Immediately upon return to service, as part of commissioning, can be an opportune time to collect PDA data and look for issues.
   - Interpreting levels of PD immediately upon return to service should be done with great care, knowing PD will likely decrease over first 6-12 months of operation.
5. Careful on-site quality assurance and witnessing of winding installation and finish treatment can go a long way in preventing some of these issues as well.