Cost/Benefit Analysis For
Using Partial Discharge Testing

Partial Discharge Testing

Partial Discharges (PD) are electrical discharges that occur within gaseous voids in high voltage insulation systems. Partial discharges occur as symptoms of a number of failure mechanisms related to motors, generators and switchgear. As a result, partial discharge testing may be used as a predictive maintenance tool. The test can be applied to equipment rated 4kV to 25kV. Testing can correctly identify and warn of active failure mechanisms such as:

- Loose stator windings
- Contamination
- Thermal deterioration
- Poor manufacturing

Benefits and Economic Justification for Partial Discharge Testing

Industry statistics by IEEE and EPRI (Electrical Power Research Institute) indicate that approximately 40% of all air-cooled high voltage motor and generator failures occur due to failure of the stator winding insulation. Partial discharge testing will provide users with benefits such as:

1. Avoidance of unnecessary rewinds on older machines by maximizing the operating hours from a stator winding. Most windings, if well designed and maintained, are reliable, however, OEMs and/or repair shops stress the need for a stator rewind after a specified number of years of operation. It is beneficial for a user to have objective evidence from an independent source to justify rewinding the machine. If a rewind is not needed, the user saves on the large capital cost of such maintenance. The benefit is easy to calculate especially for older generators. For example, there are documented cases in the following companies where rewinds were delayed:
    a. Florida Power & Light – Turkey Point (400 MVA generator)
    b. Kansas City Power & Light – Montrose Unit 1 (170 MW)
    c. Ontario Hydro – Lakeview Units 5 & 6 (300 MVA each)
2. Lower the risk of in-service failures.
3. Find problems on new machines that may still be under warranty. There are many examples, unfortunately, where the plant cannot be identified, where rewinds, and extended warranties were obtained for motors of compressed-air companies, refinery motors, steel plant motors and hydro-generators.
4. Focus maintenance efforts on machines with higher levels of PD by comparing to similar machines. Quick comparisons can be made with the Iris Database, which has over 60,000 test results on a wide variety of machines.
5. Identify specific failure mechanisms to determine the appropriate corrective action prior to a forced outage.
    a. ***Example of FP&L:*** On-line partial discharge tests identified loose windings in a 400 MVA generator. The windings were severely degraded therefore a rewind was necessary. Off-line tests and inspections confirmed the partial discharge test results.

b. ***Example of Ontario Hydro***: Lambton Generating Station Unit 4 (500 MVA): On-line partial discharge tests identified loose windings. The windings were in the early stage of degradation therefore a rewedge was sufficient to restore the generator. Off-line tests confirmed the on-line test results.

6. Increase overall safety within a plant.
7. Determining what corrective action needs to be done prior to an outage.

   Example of Nevada Power: PD testing was implemented after a generator failure. The repair cost was in excess of $1M. In a different generator at the same plant, on-line PD test identified problem with a 94 MVA, 13.8 kV generator prior to an outage during which a corrective action was performed.
8. Improve the overall reliability of generators, motors and switchgears thereby reducing the risk of unexpected failure (if performing hipot test).
9. Low cost of testing (see comparisons with PF Tip-Up Test in paper written by Nevada Power Company).
10. Testing while machines are in normal operation.
11. Ensuring the effectiveness of corrective maintenance. Cleaning and re-wedging are common maintenance practices for high voltage machines. After completing such work, it is important that their effectiveness be assessed. By performing a partial discharge test "before" and "after" maintenance, the effectiveness of that maintenance can be ensured. If "after" maintenance partial discharge tests yield poor results, there might be a need to plan additional maintenance or rewind to avoid in-service failures. The following examples demonstrates this:
    a. Ontario Hydro – Hearn Plant (200 MVA)
       Partial discharge levels decreased 5-fold after a re-wedge.
    b. Ontario Hydro – Nanticoke Generating Station, Unit 8 (600 MVA)
       This unit had a core fault that burned the external insulation. The damaged coils were removed and the machine refurbished. All the slots have low PD with the exception of one that has severe PD levels.

12. Extend the time between major outages. Major outages on hydrogen-cooled generators involving rotor pulls are often recommend every 5 to 7 years. For large generators, some outages may last up to 6 weeks and costs $100k in labor and materials alone (loss of production is extra). There is also the possibility of machine damage during major outage activities. If the machine condition can be assessed on-line, operators can scientifically extend the time between outages. This may eliminates 2 or more major outages over the expected life of the machine. This advantage is one of the main reasons owners of hydrogen-cooled generators adopt on-line PD testing, even though the stators in such machines are very reliable.

    The following is an example:
    KCPL Montrose Unit 1. Savings of $100k.

Customer supplied data on cost benefit analysis:
Cost/Benefit Evaluation of PD Testing/Monitoring
Kansas City Power & Light, Montrose Unit #1

Machine Properties: 170 MW, 1958, asphaltic-mica insulation
In 1991 an OEM recommended rewind, based on a DC leakage test. Rewind was put into plant budget for 1999. In 1993, Iris' partial discharge monitoring was implemented and indicated a relatively low and constant partial discharge level. The rewind budget was cancelled, based on the assessment that the winding insulation was sound and suitable for further reliable service.

Benefit Assessment:

Benefit: ***Avoided future capital cost of a rewind and interest on borrowed capital.***

Remaining Plant Life: estimated 20 years from 1998 (total life cycle of 60 years)
Costs: TGA Instrument, PD sensors and installation = $65 000.00
Periodic testing: 20 years @ $500.00/year = $10,000.00
Total: $75,000.00

Rewind cost:

- 170 MW Hydrogen-cooled generator, probably at 30 psig
- Size would be similar to 230 MW Atikokan machine, ~ 4.5m, ~ 54 slots for rewind need 120 bars (including spares)
- Cost/bar = $10k to $15k

Material cost: $1.2M to $1.8M
Installation cost: $300,000 to $500,000

Estimated Rewind Capital Cost:	$ 1,500,000.00
	$ 2,300,000.00
Benefit/Cost Ratio:	1,500,000 / 75,000 = 20
	2,300,000 / 75,000 = 30.7
Payback period:	1 year 8 months

**The avoided cost due to lost unit production has not been evaluated (assumed zero).*

The Iris Advantage

- Easy to use technology: a large number of companies, after minimal training, perform their own testing.
- Database of approximately 60,000 test results on a wide range of machines.
- Effective and proven noise separation techniques: this is one of the most important aspects of partial discharge testing. Noise-free data can be reliably interpreted and trended over time. Users can perform the test and do basic interpretation of results with only 2 days of training as a result of the noise separation methods.
- Expertise: Iris Power Engineering is home to some of the world's leading experts in partial discharge testing.
- Objectivity: Iris Power Engineering maintains an objective outlook for your machine since we are an independent, third party company.
- Industry acceptance: over 50% of North American utility generators (>20 MW) already use the Iris technology. Its use is expanding rapidly in Europe and Asia.