Twin Falls Hydro Project

13 MW 13.8 kV Generator Failure

NWHA Technical Workshop

June 2002

Enel Group

Project Facts

- Located on the SF Snoqualmie River east of North Bend, Washington
- Commissioned in late 1989
- Underground powerhouse
- Two horizontal Francis turbines direct coupled to synchronous generators
- Run of river operation

History

- 1990 Project license amended to allow production at full nameplate capacity
- Routine maintenance carried out annually on generators
- 1996 Noted first indications of corona damage
- 1997 PDA couplers installed & found loose/missing wedges
- 1999 Both generators cleaned and corona damage repaired
- 2002 Unit #1 failure due to a turn to turn failure

Generator Data

- Manufactured by Brush Electric Machinery
- Each unit 13 MVA 13.8 kV
- Class F stator coils – partial length wedges
- Open fan cooled
- At rated output coil temperature ~225 F (107 C) with ~103 F (39 C) ambient air
- Brushless excitation

Maintenance History

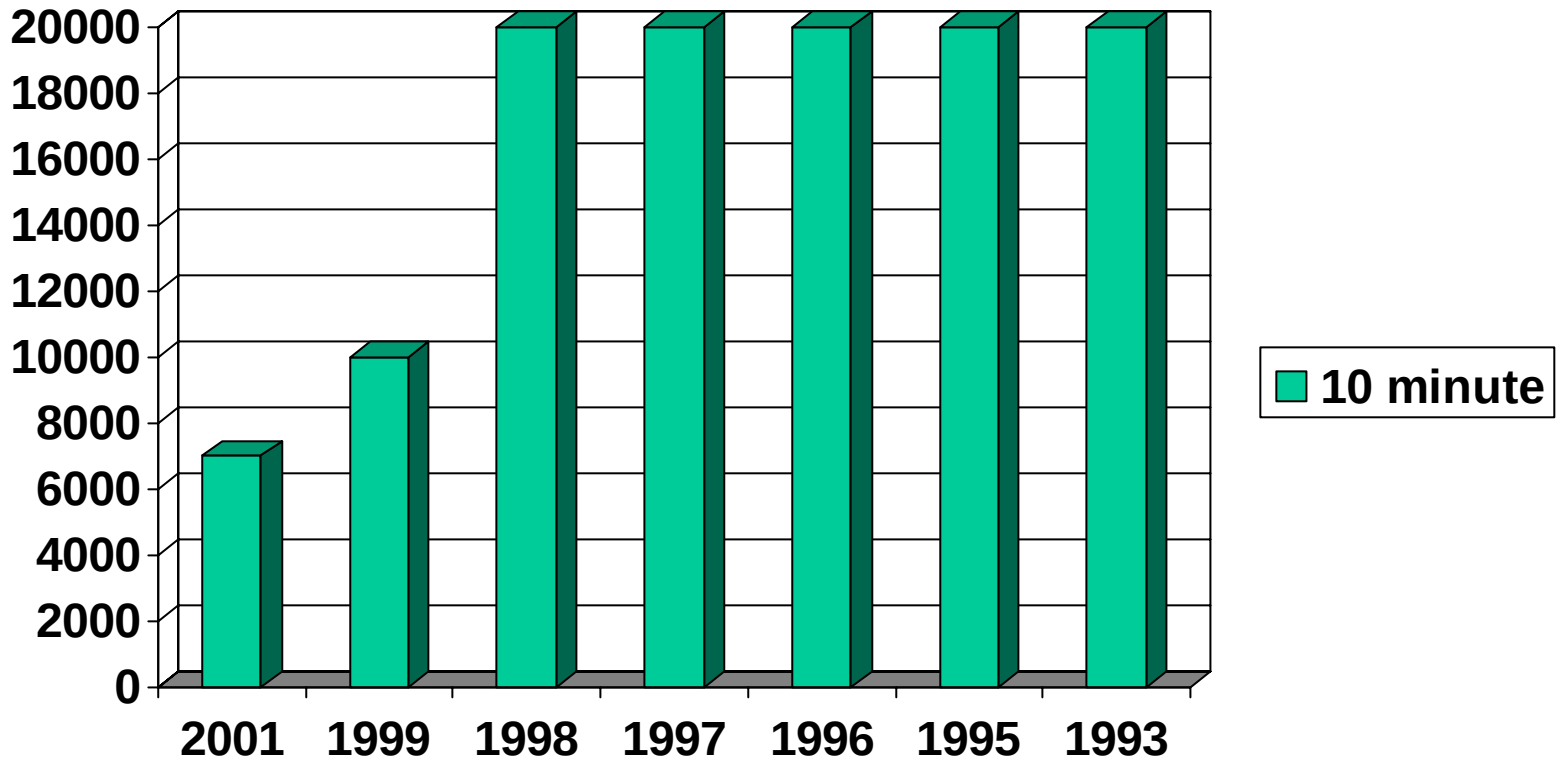
- Annual scheduled preventative maintenance program, included:
- Megger tests and PI
- Visual inspection with end covers removed
- Exciter checks
- PDA testing (not on an annual basis)

Megger Tests

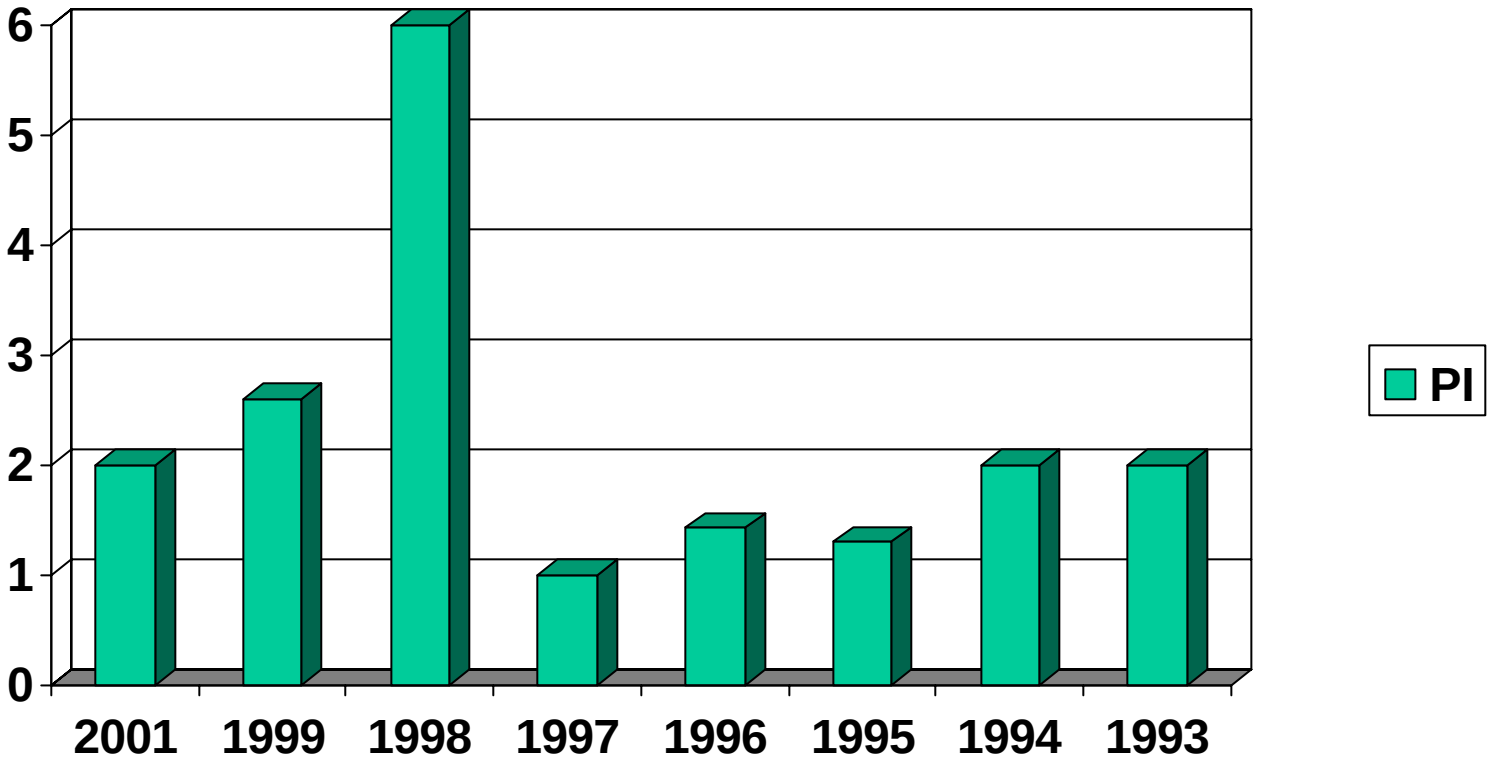
- Megger tests performed annually
- Some scatter in results
- Typically megger tests taken in summer when unit off-line during annual maintenance and low river flows
- Damp environment

Megger Tests

Mega ohms



Polarization Index

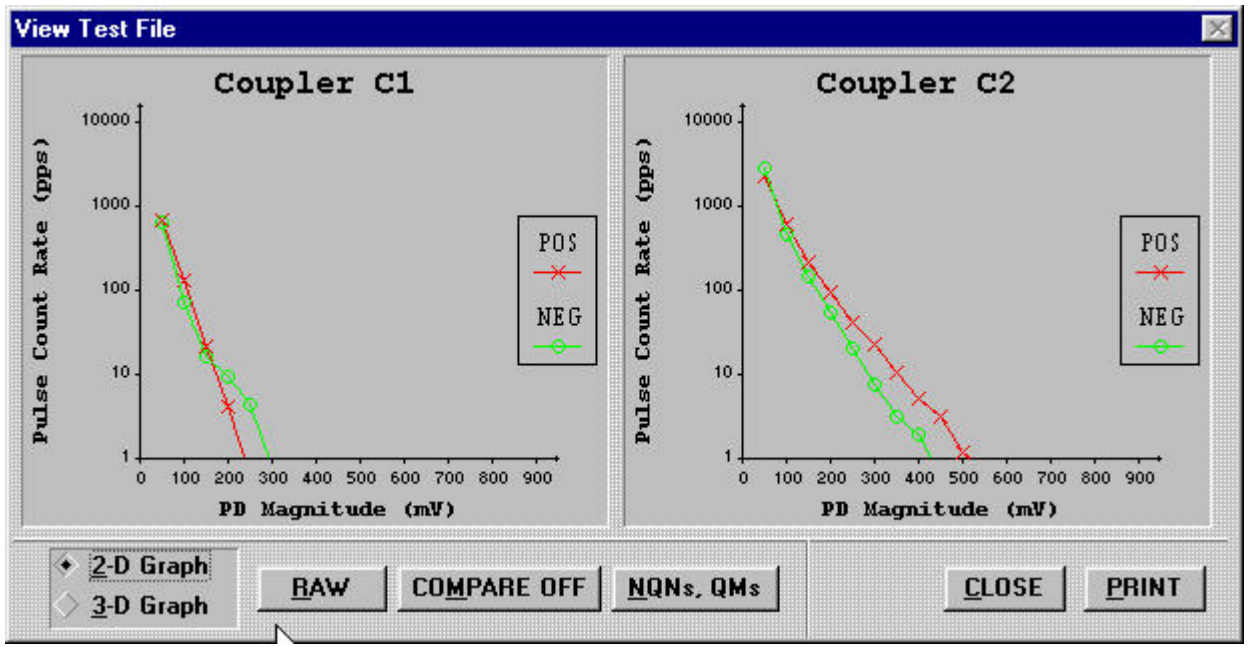


1997 PDA Testing

- With the recognition of potential problems PDA couplers were installed in 1997
- IRIS Power Engineering PDA
- Baseline run in 1997 indicated high partial discharge activity (typical values in the 100 mV range these units run ~300 mV)
- Interpretation of PDA results indicated thermal delamination, coil looseness and end-winding contamination

1997 PDA Testing (Cont'd)

Unit #1, phase A, 8 MW



1998 Generator Repair

- 1997 found loose wedges & corona damage
- No ripple springs – packing/coil deterioration allowed wedges to loosen
- 1998 contracted NEC to clean unit, replace wedges and repair corona damage
- Repair work done with rotor in place and one pole removed for access

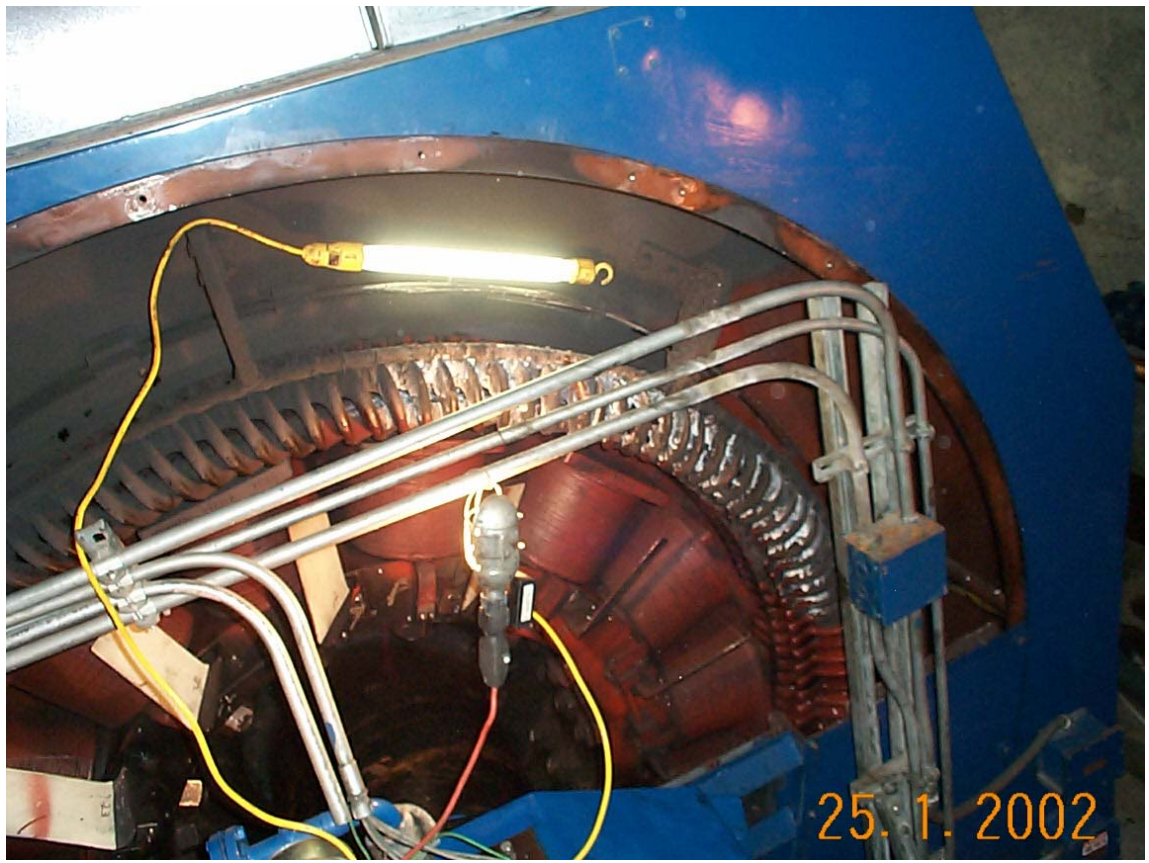
1998 Generator Repair (cont'd)

- Corona damage to coils where coils exit iron
- CO_2 ice pellet cleaning
- Repainted gradient paint and tried to re-establish ground between coil and iron
- Painted end turns

2002 Unit #1 Failure

- January 25, 2002 Unit #2 generator fire while unit running at full load
- Operator called out at 02:30 when unit tripped off due to fire alarm and 86E ground fault
- Operator found dense smoke and burning coils

2002 Unit #1 Failure



2002 Unit # 1 Failure

2002 Unit #1 Failure

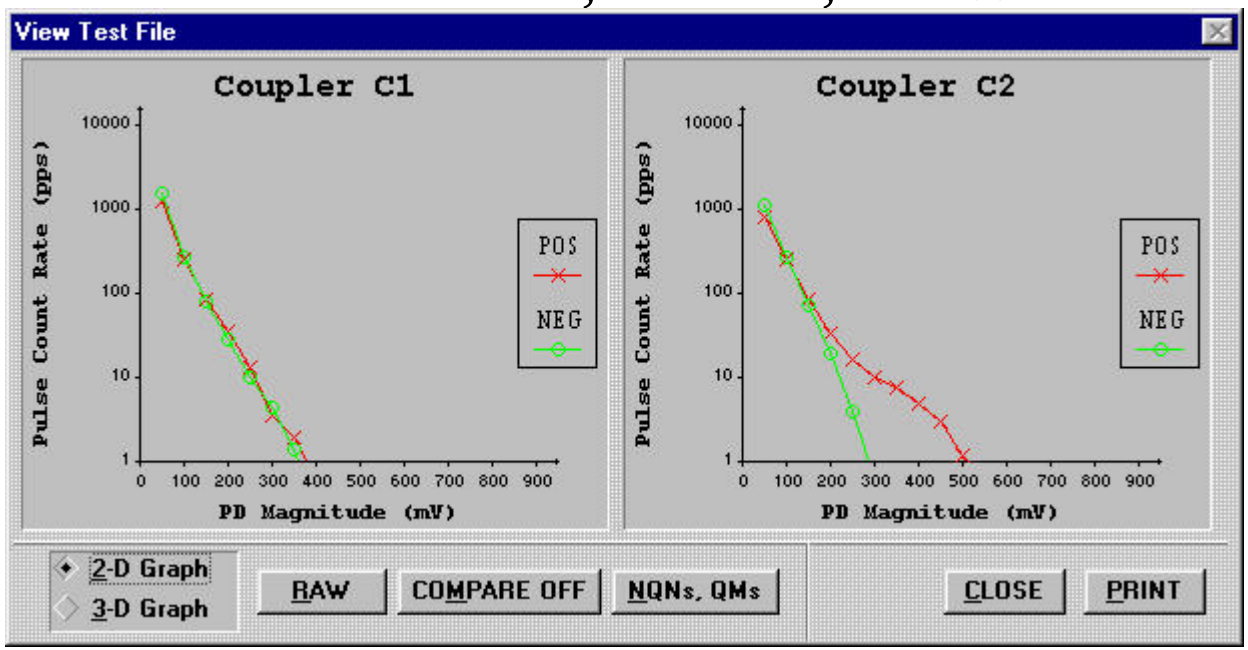
- Forensic inspection indicated a turn-turn failure in the end winding area
- Marginal design on insulation thickness (~75 volts/mill)
- Marginal strand insulation
- Sectioning indicated delamination of original windings

2002 PDA Testing

- PDA tests performed on Unit #2 following failure of Unit #1
- No PDA testing performed since 1997
- Interested in current condition of remaining generator
- PDA tests indicate delamination of windings and some slot discharge

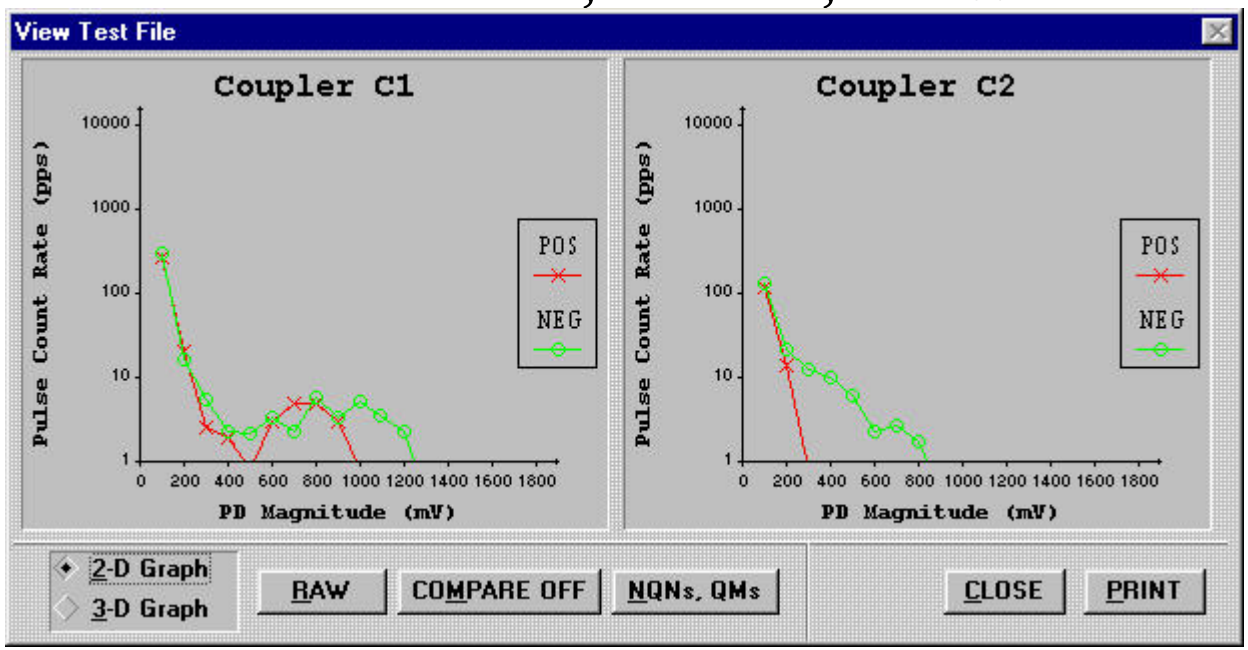
PDA Testing (Cont'd)

1997 Unit #2, Phase C, 2 MW



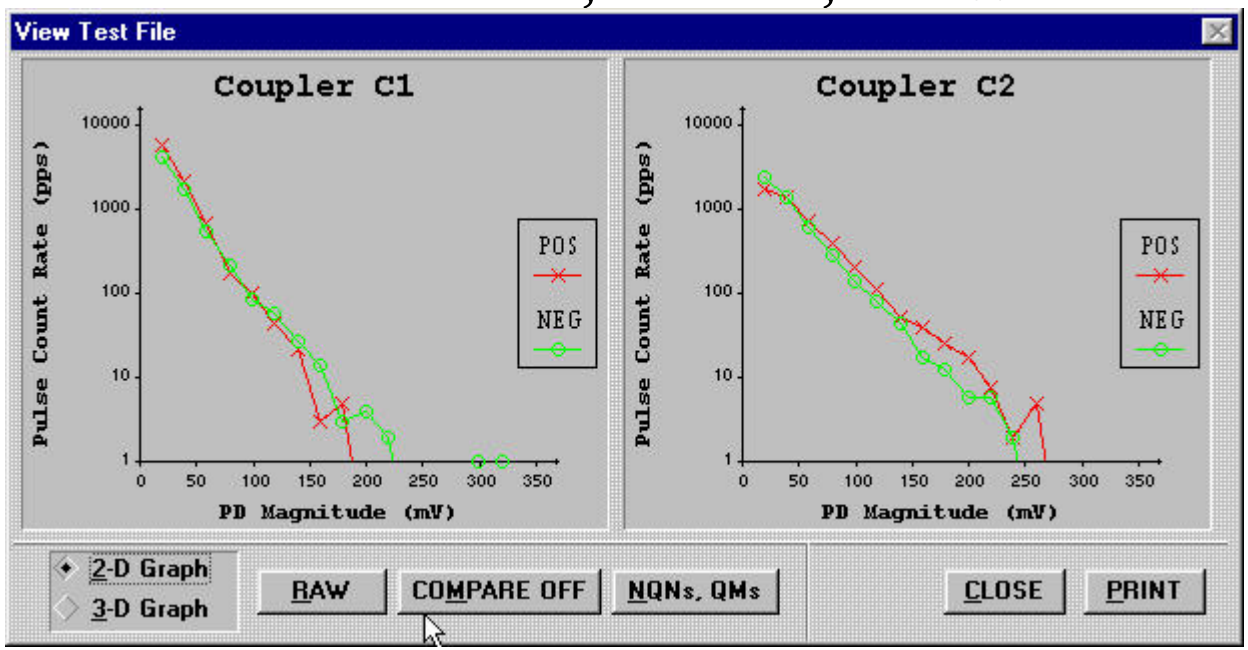
PDA Testing (Cont'd)

1997 Unit #2, Phase B, 2 MW



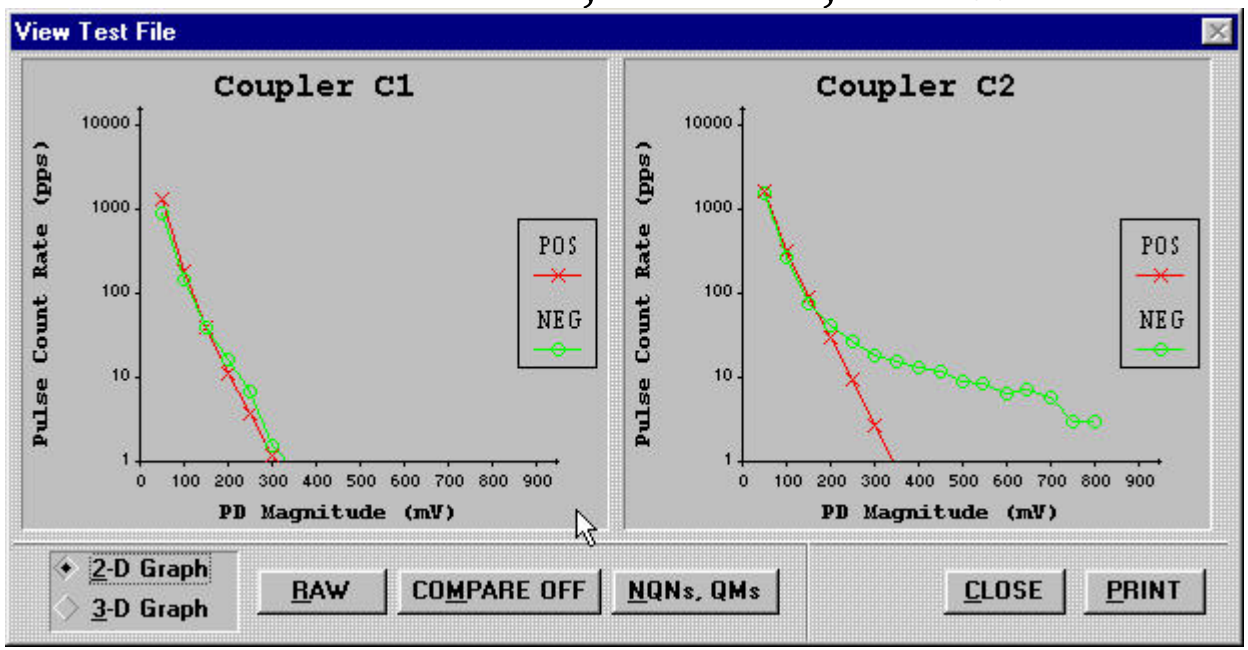
PDA Testing (Cont'd)

2002 Unit #2, Phase C, 5 MW



PDA Testing (Cont'd)

2002 Unit #2, Phase B, 5 MW



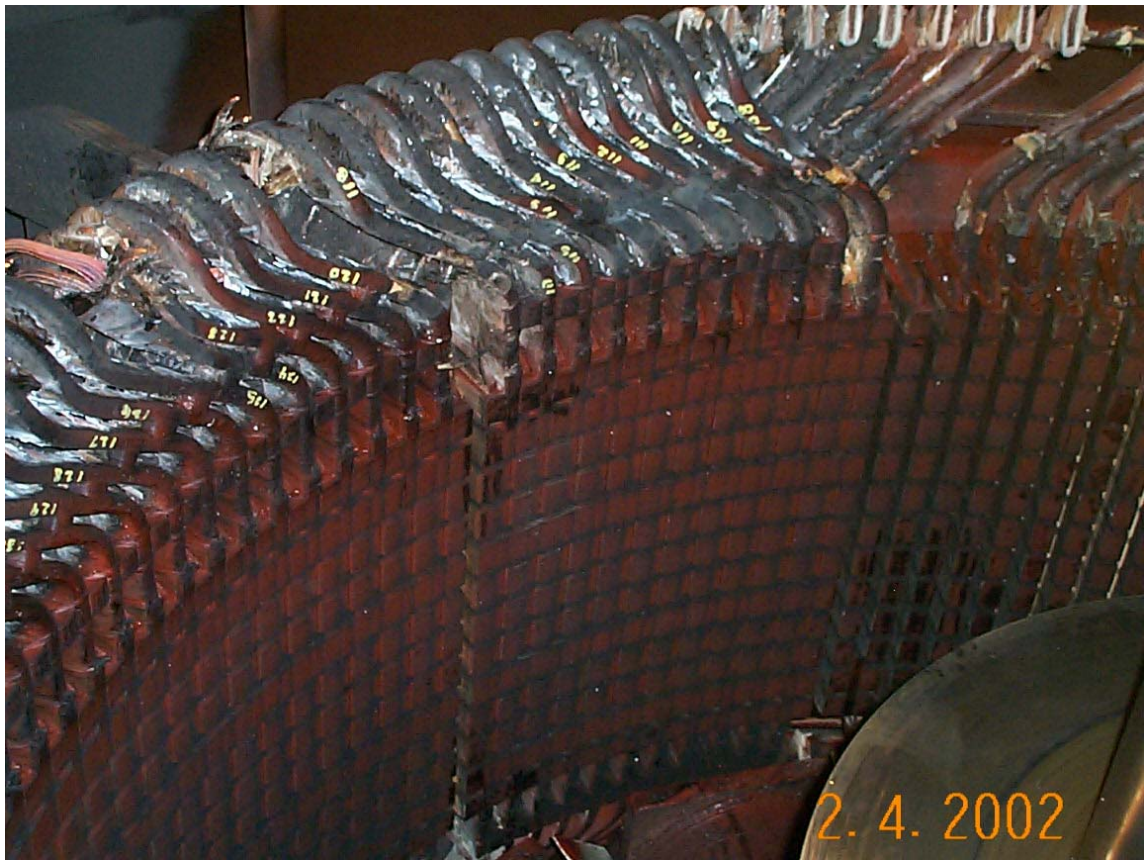
Unit #1 Rewind

- GE Hydro selected to rewind generator
- New coil design will be more conservative (65 volts/mill)
- Utilize B-stage epoxy mica Class F insulation
- Will utilize full wedges with ripple springs
- Interlaminar test performed to verify integrity of core
- Core cleaned (walnut shell)

Unit #1 Rewind (Cont'd)

- Rotor removed to allow access
- Rewind contract allows ~12 weeks to complete rewind
- Hired consultant with high voltage coil rewind experience to develop specifications and perform QA at factory and on-site

Unit #1 Rewind (Cont'd)



Unit #1 Rewind (Cont'd)

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Summary

- High voltage coils need to be purchased with tight specification requirements for design manufacture, testing and installation
- Carefully monitor condition of unit over time with visual, megger and PDA