Large Air Cooled Generator Failure

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2017 IRIS Rotating Machinery Conference
FM Global Basics

- Commercial/Industrial Property Insurer
- Mutual Co., founded in 1835 in USA
- 5,300 employees including 1,800 engineers
- Global – 66 offices serving clients in ~150 countries
- Clients – large organizations, 30% Fortune 1000
Zachariah Allen – Founder

Textile manufacturer, scientist, lawyer, writer, inventor and civil leader
FM Global Basics

- Chemical
- Pharma
- Mining
- Molten Materials
- Power Gen
- Pulp and Paper
- Semiconductor
FM Global Difference

- “The Majority of Loss is Preventable”
- Mutual with Specialty Focus
- Engineering Services
- Global Product Delivery
- Outstanding Claims Service
- Strong Client Partnerships
- Business Risk Consulting
Loss Prevention Resources

- Dedicated Client Service Team
- Data Sheets
- Specialist Loss Prevention Engineers
- Subject Matter Experts & Industrial Principle Engineers
- Research
- Training (on site, corporate)
- Approval
Outline - This Presentation

- Generator Failure Case Study
- FM Global Loss Prevention Strategy for Generators
Case Study-Generator Failure

- **Site Information**
  - 600 MW - 2x1 Combined Cycle Plant – (2) CT’s & (1) Stm Turbine
  - Cycled 7am to 11pm Monday thru Friday
  - Commissioned in 2005
  - Can operate 1X1 or bypass Stm Turbine @ reduced load
Case Study-Generator Failure

- The Unit
  - 255 MW, 21 kV - 2 pole, air cooled, 60HZ
  - Steam turbine driven
  - Satisfactory acceptance testing @ commissioning
  - Manufactured in 2005
  - 15,000 hours (625 days) of operation at the time of the incident with no significant previous issues
Case Study-Generator Failure

- Unit trips offline suddenly – reportedly differential relay trip (modern digital multi relay package installed)

- Condition assessed by operators and restart attempted three more times – relay tripped each time

- Turbine/Generator secured for damage investigation

- All vital parties notified (Management, OEM, Insurance etc.)
Severe arc fault damage top bar #4 at phase lead connection
Case Study-Generator Failure

- **Damage assessment:**
  - Stator arc fault damage to “B” phase top bar # 4 insulation noting cracked phase connection (exciter end) flashed over to ‘C” phase
  - Operator restart attempts caused more severe arc fault damage and end winding physical movement after the initial fault
  - Resulted in retaining ring, rotor forging & field coil overheating & metal loss damage
11 o’clock positon where initial arc flash over occurred
Other as found blocking & phase lead connection exciter end
Phase lead blocking - note poor taping and displaced wedge.
Stator Damage Map – Exciter End

- Bar 4 Failed
  - Loose Blocking
  - (Blocking showed long term signs of vibration)

- Bar 13
  - Blocking Tight
  - No Cracks Noted

- Bar 37
  - Top
  - Neutral

- Bar 28
  - Top
  - Neutral
  - Bar 49
  - Blocking Tight
  - No Cracks Noted

- Bar 40
  - Two Cracks
  - Loose Blocking
  - (Blocking could have some loose during fault)
  - Mixed Mode cracking
  - Intergranular and intragranular
  - ~50,000 amps fault current
  - Also known as CTL Sample

- Bar 43
  - Top
  - Neutral

- Bar 22
  - Top
  - Neutral
  - Bar 1
  - Top
  - Neutral
  - Bar 10

- Bar 31
  - Top
  - Neutral
  - Bar 31
  - Two Cracks
  - No Blocking
  - Single Mode cracking Intergranular
  - ~25,000 amps fault current
  - Also known as LPI sample

- Bar 4
  - Top
  - Neutral

- A (T1)
  - Top
  - Neutral

- B (T2)
  - Top
  - Neutral

- C (T3)
  - Top
  - Neutral

- Terminal

- Bot

- Bot
• Found 4 of 6 phase lead connections cracked in the strand braze area where loose or no blocking evident

• Phase lead connections with secure blocking were not cracked

• Long term insulation vibration wear at failed bar # 4 noted

• Bump test found signs of 120 HZ resonance present in end winding suggesting “High Cycle Fatigue”

• Suspect rotor/field & retaining ring arc fault damage (removed for off site evaluation - repair)
“Phase lead connection crack”
(copper lug brazed to the bar end - then trapezoidal intermediate piece & circular phase ring)
Stator - poor strand to phase lead braze connections
Retaining Ring Removed from Rotor at Repair Shop (exciter end)
Retaining Ring & Rotor damage assessment:

- The retaining ring on the exciter end sustained arcing damage at the taper end.

- Splatter debris was found throughout the rotor.

- Ground fault (arching damage) at exciter end through the damper winding to ground on the face of the slot tooth between coils 1 and 2 & on the same coil on the exact opposite side.

- Arc damage was also found on inboard pole coil Nos. 1 and 2 and outboard pole @ coil No. 1.

- Arc damage was found on a tooth on the forging.
Retaining ring inside surfaces

Severe arc fault metal loss & overheating damage – ring required replacement becoming long lead time item
Rotor coil and forging arc fault damage (exciter end)
Rotor Repair – off site

- The rotor weighed approximately 130,000 lbs. and was considered a “super load”.

- Regulations about transporting a super load are strict requiring special permits and caused delays.

- Rotor became the critical path in terms of reassembling the generator. (4 months & 5 days later)

- Locating a replacement retaining ring was critical long lead item
Case Study-Generator Failure - Cause

- Root Cause - High Cycle Fatigue due to 120 HZ resonance - induced end turn vibration damage

- Contributing Cause - Inferior strand to phase lead braze connections created crack initiation point and accelerated damage time line to failure.
New phase lead connections (H clip - more rugged design)

Original design
More robust end blocking design to reduce vibration
Case Study - Generator Failure

- Lessons learned
  - Validated benefit of
    - Modal Analysis – “Bump Testing” phase lead connections & end winding during acceptance test
  - Improvements:
    - Phase lead braze connections improved
    - End winding support blocking improved and eliminated 120 HZ resonance
    - PD monitoring installed
    - Continuous fiber optic end winding vibration monitoring installed (18 exciter end and 6 on drive end)
Generator Failures-Risk Factors

Environment
Operating conditions
Age/history
Maintenance
Operator training

Operator training, contingency plan, safety device
PM program

- Every generator is different
  - Design or Manufacturing Issues
  - Operating History
  - Base Load vs. Peaking
  - New versus Old
  - Etc…
Recent trend

Condition Based Approach vs Rotor Out Inspection
PM program

- FM Global recommends the following as appropriate:
  - Establish generator electrical testing frequency as well as test scope
  - Install on-line condition monitoring systems and consider robotic inspections
  - Closely manage findings (rate of degradation)
  - If test results or trends indicate high risk - plan remedial action & repairs before an in service failure.
# PM program

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# Generator Failures

## FM Global Property Loss Prevention Data Sheets

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### HYDROELECTRIC POWER PLANTS

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- Table 1: Recommended Protective and Alarm Devices for AC Generators
- Table 2: Analysis of Failures in Hydro-Turbines and Generators, 1971 through 1980
- Table 3: Resistance to Pitting of Different Runner Materials
Electrical Protection: The Defense Line

- **FM Global focus**
  - Adequate Relay Protection (ANSI / IEEE C 37.102)
  - Operational As A System (RELAYS, DC BATTERIES, CONTROL WIRING etc.)
  - Operator Response/Training
Conclusion

- **FM Global Loss Prevention Strategy for Generators**
  - Verify Adequate Electrical Protection
  - Emphasize Operating Training
  - Promote Condition Based PM - online monitoring (PD, End winding vibration, flux probe etc.)

*FM Global Data Sheet*
5-12: Electrical AC Generators
5-19: Switchgear and Circuit Breakers
5-20: Electrical Testing
5-3: Hydro Power Station
7-79: Fire Protection for Gas Turbine and Electric Generators
7-101: Fire Protection for Steam Turbines and Electric Generators