Special Risks for Steam Turbine Operation due to changed energy markets

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Claims, Allianz Zentrum für Technik (AZT) and the Allianz Risk Consultants Network (ARC)

- Common support for underwriters, clients and loss adjusters with pre- and post loss expertise and services.
- ARC Global network of more than 260 engineers, specialists and industry experts.
- AZT services include in-depth failure analysis, failure prevention and evaluation of prototypical technologies.

AZT is an independent service provider within the ARC network. Services are provided to AGCS clients and independently via the Allianz Risk Consulting GmbH.

AZT Services facilitate Claims Adjustment
AZT Services facilitate Insurance Solutions
“Our perspective on damage and risk”

It’s a Fan!

It’s a Wall!

It’s a Rope!

It’s a Snake!

Wear and Tear
“Our perspective on damage and risk”

Design

Operation Conditions

Handling

Material Issues

Lifetime Consumption

Wear and Tear

Multiline Interdisciplinary
Why the changed energy markets lead to new risks for steam turbines

Can you mitigate these risks?
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Steam Turbines, Some Key Facts

Largest single steam turbine set: ~1650 MW
Max. Lengths of rotor trains: ~ 65 m
Weight of a LP rotor: 300 t
Max. LP Exhaust Area: 30 sqm
Min. radial clearance: 0,3 mm
Value up to: 200 Mio €
Steam Turbines, Some Key Components

- Last stage blade
- Rotor
- Vanes

Source: Siemens
Steam Turbine Evolution (1)

Development Steam Turbines in Fossil Fired Power Plants in Germany

- **Life Steam Temperature (°C)**
  - Subcritical
  - Supercritical
  - Mature Technology

- **Max. Unit Capacity (MW)**
  - 1100
  - 1000
  - 900
  - 800

- **Time**
  - 1970
  - 1980
  - 1990
  - 2000
  - 2010
  - 2020

- **R&D ongoing Ni-base materials**
- **Current market introduction**
- **Supercritical**
  - Neurath F, G
  - Lippendorf R,S
  - Niederaußem K
  - Heyden
  - Scholven G
Steam Turbine Evolution (2)

Length of Last Stage Blade (LSB), development steps 3000 rpm

- **Steel**: 1990 - 2005
  - 1000 mm in 1990
  - Steady increase to 1200 mm by 2005

- **Titanium**: After 2010
  - Steep increase from 1200 mm to 1500 mm
  - Note: 48 inch longest LSB of many manufacturers, 2005 - 2012

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**Key Points**
- **1990-2000**: Gradual increase in LSB length for both steel and titanium materials.
- **2005-2012**: Significant leap in LSB length, with specific emphasis on titanium due to its exceptional properties.
Risk Evaluation for Steam Turbine operation

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<th>Loss Experience</th>
<th>Operation Parameters</th>
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Transfer into standardized risk assessment tool

- identical and consistent for all lines of business
- providing qualitative and quantitative results
- Global network management, Expert Teams and Lessons Learned provide best practice and consistency

Local risk information captured by ARC engineers

.. transformed into risk quality describing..

.. and processed to the business

Portfolio
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In 2012 the renewable share generated was 22% of which 11.3% are solar + wind.

Electricity generation in Germany 2012:
617 MRD KWh

- Hard coal: 11%
- Gas: 6%
- Oil, pump storage, others: 19%
- Renewables: 22%
- Nuclear: 26%
- Lignite: 16%
- Waste: 0.80%
- Solar: 4.60%
- Hydro: 3.30%
- Biomass: 5.80%
- Wind: 7.30%

Quelle: BDEW 2012
In 2012 the renewable share generated was 22% of which 11.3% are solar + wind.

Electricity generation in Germany 2012: 617 MRD KWh

- Hard coal
- Gas
- Oil, pump storage, others
- Renewables
- Nuclear
- Lignite

However: Steam Turbines stand for 2/3 of generation.

Quelle: BDEW 2012, and AZT estimates
The first day in Germany with Green energy production peaking over conventional generation

Electricity Generation in Germany on ?

Your guess ?

Source : IWR 2013
high wind and solar production mainly impacts hard coal based production

nuclear and lignite with moderate and hard coal with high load variation
Balancing PVs

Technical min. Load during nights

No operation on weekends

No operation 26th to 29th October due to strong wind
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1. Specific costs and contracts determine usage

2. Profitability difficult to maintain
→ Maintenance budgets and periods under question

3. Primary and Secondary power operation mode

4. Operation as consumer for capacity power (Gt’s, pump storage, NPP Biblis)
New *operation* for power plants (hard coal, CCPP)

1. Decreased low and minimum loads
2. Increase of operation in low and minimum loads
3. Increased number of starts
4. Increased load gradients
5. Increased number and longer time of outages

How does this work and what are the upcoming risks out of this challenging boundaries for the steam turbines?
Additional Aspect:
The German Capacity of hard coal Power Generation is 36 Years old

The average power plant and steam turbines were designed for base load and middle load (night stand still, daily starts)
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Change of load situation

Flexibility: load ramp and no. of starts

max. capacity

min. load

load range

time
Increased Risks due to changed loads (1)

Minimum Load

1. Increased HP-IP vibrations (partial arc admission)
2. Expected Higher Nozzle and Valve Erosion Rates
3. More water droplet erosion due to lower live steam temperatures
4. Increased Exhaust Temperatures due to LP ventilation,
   → different axial expansion
   → increased spray flow and erosion
   → reduced clearance and potential rubbing
5. Excitation of LP blades due to ventilation
6. HP ventilation
7. IP valve vibrations
8. Changed frequency band of feed water pump turbines

Increase of wear and tear and damage risk
Increased Risks due to changed loads (2)

1. Increased HP valve vibrations
2. Higher Nozzle, Valve and LP section Erosion Rates
3. Increased Exhaust Pressure
   → critical in air condenser applications
   → increased load on LP blades at trips
4. Excitation of LP blades due to Flutter Vibration
5. Changed frequency band of feed water pump turbines

Increase of wear and tear and damage risk
Increased Risks due to changed loads (3)

Flexibility:

1. Hot Components with higher Low Cycle Fatigue (thermal)
2. LP blades + rotors with higher Low Cycle Fatigue (mech.)
3. Increased risk of crack propagation especially of precracked or prefatigued rotating components
4. LP blades: extended operation times with high cycle fatigue
5. Valve seat and sealing wear
6. Stand still corrosion
7. Drainage Issues in case of manual drainage

Increase of wear and tear, corrosion, fatigue and damage risk
Increased Risks due to changed loads (4)

- wear and tear
- corrosion
- fatigue
- damage risk
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What do you need to expect out of this

- based on damage cases where turbines already operated under respective load conditions
- based on proven engineering know how and
- average ability of engineers to predict ;-)
Max Capacity
Example: Blade Failures on feed water pump turbines

Detachment after 80,000 to 130,000 operation hours

First free standing blade row
Damage Causes

Fatigue fracture caused by periods of resonance due to modified speed range (load uprate of main turbine)

+ pitting corrosion due to stand stills

+ corrosion fatigue
Example: Flutter Vibrations

- Occurring at high steam flows
- Self exciting mechanism
- High effort to calculate
- Measurable

→ Potential blade failures
Increased Flexibility
Example: LCF in Rotor groove cracks

Even with former moderate start/stop sequences rotor grooves and blade roots require attention and special maintenance efforts.

Increase of starts will reduce years of component usage.
Optimizing a 40 year old mid size power generation turbine for secondary load control

Normal Operation
„4“ closed, 3 MW/min

Optimization for 12 MW/min: „4“ rapid open and closing,

550°C
180 bar

Did the additional load cycles of optimization cause the cracks in the valve inlet section of the outer casing?
Data Acquisition

Geometry
→ no drawings or CAD
→ optical 3 D scan
→ FE model

Boundary Conditions
→ analysis of operational data
→ estimation of heat transfers
→ determination of a load cycle
Results: Temperature Differences

Diff. Temp of load cycle, Valve 4
Resulting stress

Location of highest stress matches with observed crack location

→ Optimization of operation leads to crack growth,
→ But: Value of stress amplitude shows that additional factors need to increase the stress locally.
→ Stress amplification can be caused by low casting quality
Other consequences of increased load ramps

The consequences are:

- Increased maintenance costs and outage time for repair
- Reduced remaining lifetime

LCF-cracks at an HP-Casing

LCF-cracks at stationary blading of IP-turbine
Reduced minimum loads
Blade Failures caused by low load
The problem with low loads

“This is like diving your car in 1st gear only“

The problem with low loads: excitation by ventilation

- Rule of thumb: below 25% nominal flow ventilation must be expected
- CFD calculation: vortex area depending on individual exhaust cone

Source: Abgenommener Stromlinienverlauf in einer ND-Teilturbine bei extremer Schmidt '99
Identifying low load failures: Fatigue Fracture

- Low load
- Ventilation
- Random blade excitation
- Fatigue Fracture
- Danger of rotor failure
Identifying low load failures:
Droplet erosion at the trailing edge close to the root

Abb. 2.1: Angenommener Stromlinienverlauf in einer ND-Tellturbine bei extremer
Schmidt '99

Low load

ventilation

Backflow with saturated steam

Droplet erosion

Increased notch factor and risk of crack growth
Identifying low load failures: Tip rubbing

Blade Row L-1:
- fractured
- tip rubbing
- ok

Low load

ventilation

Local temperature increase

Local temperature increase

Additional Elongulation of blades
Identifying low load failures:
Discoloration and / or build up of scale
Identifying low load failures:
Analysis of operational data

=> Pressure ratio over last stage below 1 (at load over 200MW)
Other consequences of low load operation

- Erosion of casing splitting
- LP-Last stage blading drop erosion

This is not easy and not fast to repair

- LP-Last stage stationary blading erosion
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Increased range and flexibility of load

Ageing of turbine fleet

Base/Middle Load Design

Budgets constraints

Risk Increase
Changed Risk Balance…

Risk Balance

Risk Increase
- Wear and Tear
- Corrosion
- Fatigue
- Material Damage
- Business Interruption
…requires individual and joint approach…

Risk Balance

Risk Increase
- Wear and Tear
- Corrosion
- Fatigue
- Material Damage
- Business interruption

Risk Mitigation Measures
- Individual plant analysis
- Appropriate Operational Measures
- Tailor Made concepts of Manufacturers
- Awareness
- Risk Control

Development needs not only to consider efficiency and costs but also flexibility and reliability!

…to mitigate new risks
Loss Control programs help mitigate the new risks

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<td>- Monitoring and coordination CRM programs</td>
<td>- Loss analysis &amp; support</td>
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<td>- Risk improvements and loss mitigation concepts</td>
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Core Service/Portfolio protection

Additional Services bundled / unbundled

Prototype Evaluation
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