PROBABILISTIC RISK ASSESSMENT · POWER GENERATION

Reliability and Risk Assessment of a Combined-Cycle Gas-Fired Power Plant Fleet

From component degradation to plant-level forced-outage risk, with a prognostic monitoring program and an outage and overhaul plan

CLIENT
Independent power producer operating a fleet of combined-cycle gas turbine plants

SERVICE LINES
Probabilistic Risk Assessment, Decision Support Tools

SCOPE
Gas turbines, HRSGs, steam turbines, generators, and balance of plant across four sites

DURATION
10 months

4	60+	~35%	Weeks to months
combined-cycle plants assessed	critical components with degradation and failure models	of modeled forced-outage risk traced to five failure modes	advance warning targeted by the prognostic monitoring program

THE CHALLENGE

Forced outages were costly in lost energy and capacity revenue and in replacement power, and they were becoming more frequent as the units cycled harder to follow renewable generation. Maintenance followed OEM intervals and inspection findings, but the operator had no plant-level view of which failure modes drove the most outage risk, or of whether a scheduled overhaul could be safely deferred.

Leadership wanted a ranked list of the failure modes that mattered most, a monitoring program that would catch them before they caused an outage, and a defensible outage and overhaul schedule that balanced risk against cost and market opportunity.

WHAT WE DID

1. **Failure mode and criticality analysis.** We led FMECA sessions with plant engineers across the gas turbine (hot gas path, combustion, compressor, bearings, controls), HRSG (tube leaks, drum and header cracking, attemperators), steam turbine, generator, and balance-of-plant systems, linking each failure mode to its detectability, repair time, and outage consequence.
2. **Degradation and failure probability modeling.** For more than sixty critical components we built degradation models (creep, thermal-mechanical fatigue, oxidation, erosion, insulation ageing) driven by operating hours, starts, load profile, and ambient conditions, and calibrated them to inspection and failure records. Where records were sparse, OEM and industry reliability data were blended with plant data using Bayesian updating.
3. **Plant-level risk aggregation.** Component failure probabilities were aggregated through fault trees to plant-level forced-outage probability and expected lost production, with repair time, spares availability, and market price scenarios carried into the consequence. This identified the failure modes with the largest expected cost, not just the highest frequency.
4. **Prognostic health monitoring design.** For the top failure modes we specified condition indicators (vibration, exhaust temperature spread, combustion dynamics, HRSG tube metal temperatures, generator partial discharge), detection thresholds, and remaining-useful-life estimation methods, and set out which signals existing monitoring already captured and which needed new sensors or analytics.
5. **Outage and overhaul optimization.** Overhaul and inspection intervals were evaluated against risk and cost over five years, including shifting outages into low-price periods, producing a fleet outage plan with the risk of each deferral quantified.

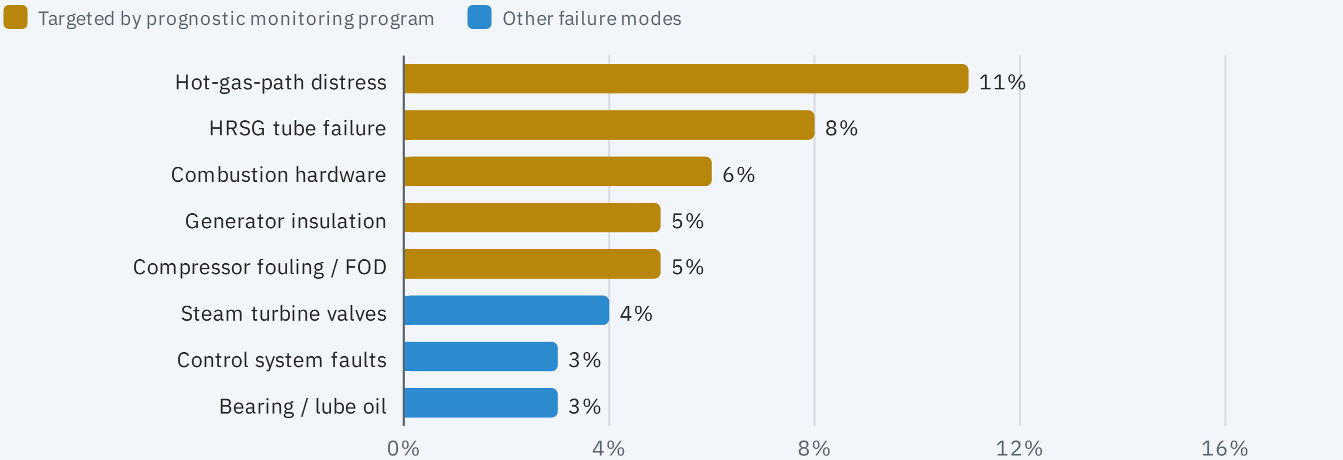
RESULTS

Five failure modes accounted for roughly 35% of modeled forced-outage risk across the fleet, led by hot-gas-path component distress from increased cycling and HRSG tube failures at two of the four sites. These had been treated as routine inspection items rather than as the fleet's dominant outage drivers.

The prognostic monitoring program targeted weeks to months of advance warning for the top failure modes, and early implementation on one unit identified a developing hot-gas-path issue that was addressed in a planned outage rather than as a forced event.

The optimized outage plan allowed one major overhaul to be deferred by a season with a quantified and accepted increase in risk, and moved two inspections earlier where the analysis showed deferral risk was not worth the savings.

Share of modeled fleet forced-outage risk by failure mode (top eight)



Illustrative. Expected lost production weighted by market price; the top five modes are the focus of the prognostic monitoring program.

IMPACT FOR THE CLIENT

Maintenance and capital decisions are now argued in terms of forced-outage risk and expected lost revenue, giving operations and commercial teams a shared basis for outage timing.

The fleet has a repeatable process: as cycling patterns and inspection findings change, the degradation models and outage plan are refreshed rather than rebuilt.

WHAT WE DELIVERED

- FMECA registers for major plant systems at four sites
- Degradation and failure probability models for 60+ critical components
- Plant-level fault tree models and forced-outage risk ranking
- Prognostic health monitoring specification and implementation roadmap
- Five-year risk-optimized outage and overhaul plan

METHODS AND STANDARDS

- FMECA
- Degradation and remaining-useful-life modeling
- Fault tree analysis
- Bayesian reliability data blending
- Prognostic health monitoring design
- Risk-based outage optimization