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How Can Dynamic Analysis Improve Gas Turbine Feed System Reliability and Availability?

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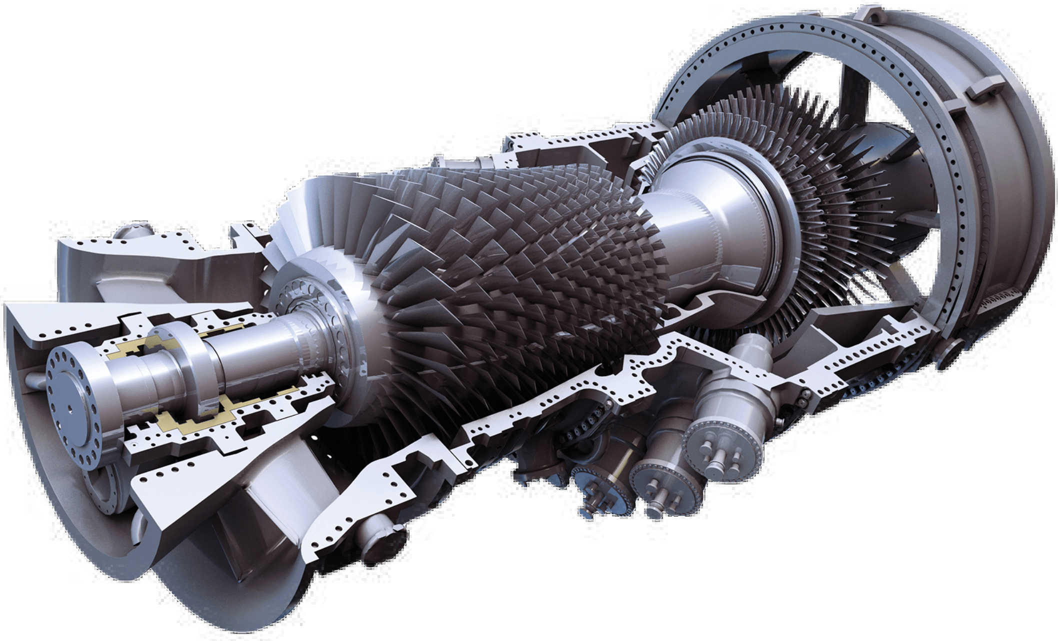


This technical paper presents an in-depth analysis of gas turbine feed gas systems in power plants, focusing on dynamic process simulations to enhance reliability and availability. Gas turbine power plants are vital assets that require high availability, often exceeding 90%. The minimization of unit trips is critical to achieve this goal. This paper outlines the key characteristics of these systems, the dynamic analysis procedure, and the significant benefits of employing dynamic simulations in the engineering design phase. The cost-effectiveness of dynamic analysis is also discussed, emphasizing its potential to prevent costly process trips.

Introduction

Gas turbine power plants are indispensable components of modern power generation, providing a substantial portion of the electricity required to meet the ever-growing demands of today's grids. These power plants must not only deliver high reliability but also maintain maximum availability, typically exceeding 90%. Achieving this level of performance involves minimizing unit trips and cascade failures affecting both power plant operation and the stability of the broader electricity grid. This paper explores the use of dynamic process model simulation to analyze gas turbine feed gas systems ensuring their robustness and reliability, emphasizing their main importance in the context of power generation.

Gas turbines are at the heart of many power generation systems due to their efficiency, quick startup times, and ability to operate at varying loads. They play a critical role in supporting grid stability by rapidly responding to fluctuations in demand. As such, gas turbines are instrumental in providing essential services such as peaking power and grid balancing. The high availability and reliability of gas turbines are prerequisites for ensuring grid resilience and meeting dispatch requirements, especially during periods of peak demand or unexpected load variations.

A unit trip in a gas turbine power plant can have critical consequences and the extend will depend on the plant and feed system configuration, how many Gas turbine and feed units (compressors and pressure reduction station) are working in parallel. The effects are in the following areas:

- Power Supply Disruption: A trip results in an immediate loss of power output, affecting not only the plant's internal operations but also the electricity supply to consumers.
- Grid Instability: The sudden loss of a gas turbine's output can destabilize the electricity grid, leading to voltage and frequency fluctuations. This, in turn, can trigger protective relays and potentially lead to further generation units tripping offline.
- Economic Costs: Trips can result in substantial economic losses, not only in terms of lost revenue from electricity sales but also due to potential fines for failing to meet contractual obligations with grid operators.

- Mechanical Stress: Frequent trips and starts can subject gas turbine components to mechanical stress, potentially reducing their operational lifespan.

The gas turbine feed gas system analysis is characterized by several main aspects:

- Hard Constraints: Gas turbine manufacturers impose strict limits on flow and pressure variations in the fuel gas supply.
- Pressure Reduction Station: Pressure reduction stations and compressors are commonly used in these systems, often with complex arrangements to feed one or more gas turbines.
- Pressure System Dynamics: Understanding the dynamics of the pressure system is crucial in optimizing the feed system.
- Measurement Analysis: Passive and active measurement methods are essential to minimize the possibility of unit trips during the design phase.

Dynamic Analysis

Typically, the application of simulation analysis in gas turbine projects at the design level lies in the often insufficient consideration of dynamic simulations and comprehensive process modeling. While gas turbine designs are engineered in detail for high availability and reliability, there is a tendency to focus primarily on steady-state conditions, overlooking the complexities of transient behavior and response to disturbances. This gap becomes apparent in the following areas:

- **Transient Performance Analysis:** Many design processes place significant emphasis on steady-state conditions and nominal operation. However, the dynamic behavior of gas turbine systems during startup, shutdown, load variations, and disturbances is equally critical. The gap lies in not adequately assessing and optimizing the transient performance of these systems, potentially leading to unexpected operational challenges.
- **Comprehensive Dynamic Simulation:** While steady-state simulations are commonly employed in the design phase, there is often a lack of comprehensive dynamic simulations that consider various operating scenarios and disturbances. These simulations can provide valuable insights into how the system behaves under different conditions and help identify vulnerabilities that might lead to trips or performance issues.
- **Interaction with Other Systems:** Gas turbines are typically part of larger power generation systems that interact with various components, such as electrical grids, heat recovery systems, and control systems. The gap exists when designers do not thoroughly analyze how these systems interact dynamically, potentially leading to suboptimal performance or instability in the broader context.
- **Risk Mitigation:** Gas turbine projects may not adequately assess and mitigate risks associated with transient conditions. This includes insufficient consideration of safety margins, the need for additional buffer capacity, and the optimization of control strategies to prevent trips and maintain system stability.

The shift toward a more comprehensive and dynamic approach to gas turbine feed system design includes the integration of advanced dynamic simulations, consideration of transient behavior, and a focus on the dynamic and challenging scenarios that can occur in plant operation.

Procedure

The dynamic analysis of gas turbine feed systems follows a structured procedure, as outlined in the previous section, ensuring the robustness of the system against potential disturbances:

Step 1: Select the most conservative case for protection analysis and assess sensitivity to key parameters, such as header volumes.

Step 2: Examine volume distribution feasibility based on the current pipe configuration and constraints.

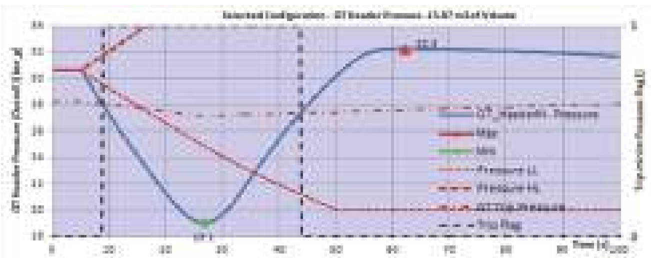
Step 3: Explore additional mitigation measures, such as control system enhancements or adding backup units.

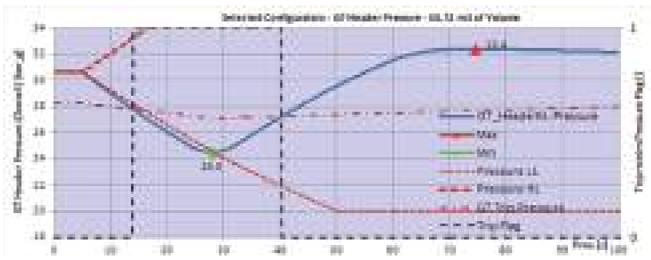
Step 4: Verify the system's resilience against other disturbances.

The dynamic analysis assesses the transient behavior of the system providing detailed

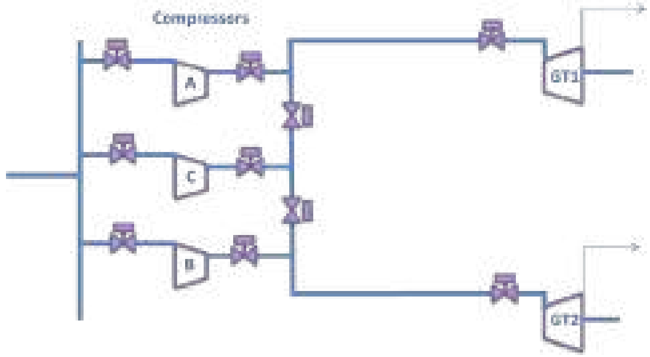
knowledge of the system and the necessary recommendations to implement the design modification to guarantee the system availability. The evaluation includes the piping system between the gas distribution pipelines, the pressure reduction station if any and the fuel gas compressor to the inlet of the gas turbines. The result of this analysis allows evaluating the safety margin to reach the manufacturer limits and make the recommendations to modify the piping system if required to increase the buffer capacity and improve the compressor control.
The dynamic analysis granting to:

- Evaluate the transient conditions and determine if more gas inventory is required (pipe volumes or buffer tank) between the compressor and gas turbine to reduce the pressure variation rate to achieve the turbine manufacturer limit, as shown in the following figures. The analysis calculates the additional volumes if required (pipeline volume or buffer tank) to avoid trip in case of upset in the gas feeding and contribute to guarantee the process availability.

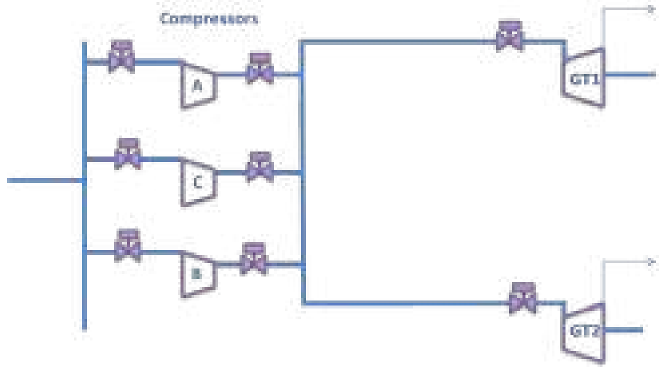




- Answer questions about the best arrangement that meets the requirement and shows higher availability. For example: A system with 3 fuel gas compressors that operates at 3x50% and 2 gas turbines at 2x50%. This can be arranged as one dedicated compressor for each turbine and the third in standby (Configuration A) or the two compressor operates in parallel discharging to the common gas header (Configuration B).



Configuration A



Configuration B

Which is the best configuration in terms of availability? This question can be answered by the dynamic analysis providing details of the system behavior to take the best decision.

- Assess the impact of the addition of a new turbine to an existing gas supply system (feeding other gas turbines).
- Is the compressor control operating fast enough during typical operation, i.e. compressors switchover?

Benefits and conclusions

In a power plant the average cost of the piping is around 3% of the total direct cost of the plant. The benefit of performing dynamic analysis at the engineering design phase is significant considering the cost of a process trip:

Process Application	Spurious Trip Cost
Oil & Gas Platforms	Up to $2 million/day
Power Generation	$100k/MW hour

Source: Miller, Curtis, Win/Win: A Manager's Guide to Functional Safety, 1st Edition, 2008

Comparing the cost of the mitigation measurement and the possibility to prevent trip of the process has a marginal cost. Moreover, the dynamic analysis allows verifying the design in the early phase of the engineering project and set up the proper requirement of the equipment like compressor units in terms of reaction time.

- Early Design Verification: Dynamic analysis allows for design verification in the early engineering project phase, reducing the likelihood of costly design flaws going unnoticed until later stages.
- Optimized Equipment Requirements: It helps establishing precise equipment requirements, such as compressors and pressure reduction stations, in terms of reaction time and capacity.
- Cost-Effectiveness: By comparing the cost of mitigation measures with the potential cost savings from preventing process trips, dynamic analysis proves its cost-effectiveness.
- Enhanced Safety Margin: Detailed safety margin assessments help preventing system trips, ensuring greater operational reliability.
- Early-Phase Design Validation: Verifying the design in the early engineering phase reduces the risk of costly modifications and rework during construction.

In conclusion, dynamic process simulation based on first-principles simulation models is instrumental in bridging the gap in gas turbine project analysis at the design level. It offers a comprehensive understanding of transient behavior, system dynamics, and responsiveness, leading to more reliable and available gas turbine feed systems, ultimately contributing to the success of high-availability power generation plants.

References:
Miller, Curtis. "Win/Win: A Manager's Guide to Functional Safety, 1st Edition." (2008).