WHITE PAPER · OPERATIONAL THERMODYNAMICS INTELLIGENCE

OPERATIONAL THERMODYNAMICS INTELLIGENCE

A Historian-Derived Framework for Thermal-State Interpretation in Thermal Power Generation

YBGGlobal.com · ControlAlign™

EXECUTIVE SUMMARY

The thermodynamic transfer environment between fuel and output

Modern thermal power plants generate vast quantities of operational data.

Distributed control systems, historians, APC environments, emissions systems, and instrumentation networks continuously monitor:

- combustion conditions,
- steam parameters,
- load behaviour,
- emissions,
- fuel flow,
- and equipment status.

Yet despite increasingly data-rich operational environments, many plants continue experiencing:

- heat-rate drift,
- rising fuel intensity,
- operational instability,
- and progressive thermal-performance deterioration over time.

> **These conditions often develop while the unit continues appearing operationally stable. Generation remains acceptable. Dispatch obligations are met. Combustion conditions remain within expected ranges.**

However, progressively more fuel becomes required to sustain equivalent electrical output.

This paper explores an emerging operational perspective:

> *“Thermal performance may increasingly depend not only on combustion-state management — but on understanding the thermodynamic transfer environment operating between fuel input and electrical output.”*

This includes improving visibility into:

- thermal-state behaviour,
- radiative heat-transfer effectiveness,
- thermal coupling stability,
- operational drift,

- and fuel-to-steam conversion effectiveness.

THE OPERATIONAL COMPRESSION PROBLEM

Thermal plants continuously operate within highly dynamic thermodynamic environments.

Between fuel entering the furnace and electrical output leaving the generator exists an interacting thermal-transfer system involving:

- combustion kinetics,
- flame geometry,
- radiative heat transfer,
- convective transfer,
- thermal absorption behaviour,
- working-fluid enthalpy rise,
- load-transition dynamics,
- furnace-state stability,
- and continuously evolving operating conditions.

Historically, much of this complexity becomes operationally compressed into a relatively small number of KPIs:

- heat rate,
- specific fuel consumption,
- emissions,
- output,
- and steam conditions.

These KPIs remain operationally important. However, they primarily describe outcomes — rather than the evolving thermodynamic operating state that produced those outcomes.

> **Plants may observe deteriorating heat rate, rising fuel intensity, or reduced thermal efficiency, without a sufficiently interpretable view of why the drift developed, which thermal-state conditions evolved, or which operating conditions correlate with superior historical performance.**

HEAT RATE AS A THERMODYNAMIC OUTCOME

> *Heat rate is generally defined as: "The amount of fuel energy required to produce one unit of electrical output."*

Operationally, heat rate is often treated as the primary thermal-performance KPI. Commercially, this is understandable because heat rate directly influences:

- fuel cost,
- operating margin,
- and emissions intensity.

> **However, heat rate itself is not directly controlled. It is an operational outcome produced by the thermodynamic operating state of the unit over time.**

This distinction is important because two operating periods may:

- produce identical MW output,
- satisfy dispatch conditions,
- and remain within acceptable combustion ranges,

while exhibiting materially different thermal performance.

This suggests that stable operation does not necessarily imply stable thermodynamic transfer effectiveness.

OPERATIONAL DRIFT

Thermal environments are not static. Their operating state continuously evolves due to interacting operational variables such as:

- excess O_2 variation,
- air–fuel imbalance,
- burner-condition drift,
- pulverizer variation,
- fuel-quality variability,
- slagging and fouling,
- air ingress,
- sootblower influence,
- load-transition instability,
- furnace pressure variation,
- and radiative transfer changes.

Over time, these interacting conditions influence:

- flame behaviour,
- thermal-state stability,
- heat-transfer effectiveness,
- and the efficiency with which released thermal energy reaches the working fluid.

> **The unit may continue operating within apparently normal operational ranges while this thermodynamic transfer environment progressively deteriorates. This is operational thermal drift.**

THE IMPORTANCE OF RADIATIVE HEAT TRANSFER

In pulverized-coal thermal environments, a substantial portion of useful heat transfer occurs through radiation.

Radiative transfer strongly influences:

- waterwall absorption,
- furnace heat absorption balance,
- steam generation behaviour,
- and overall thermal performance.

Historically, many operational systems primarily focus on:

- combustion stability,
- emissions control,
- load following,
- and process regulation.

While essential, these systems do not always explicitly interpret:

- radiative coupling behaviour,
- thermal-state stability,
- or the effectiveness with which thermal energy is transferred throughout the furnace environment.

> **This creates a potential interpretive gap between combustion management and thermodynamic transfer effectiveness.**

HISTORIAN-DERIVED OPERATIONAL INTELLIGENCE

As historian environments become increasingly sophisticated, an emerging opportunity is developing: using existing operational data to reconstruct thermal-state behaviour over time.

This includes improving visibility into:

- operational drift development,
- thermal-state stability,
- fuel-to-steam conversion effectiveness,

- load-band performance behaviour,
- and the operating conditions associated with superior historical thermal performance.

This approach does not require:

- pressure-part modification,
- major hardware replacement,
- or operational disruption.

Instead, it involves improving interpretation of the operational thermodynamic environment already existing within the plant.

DETERMINISTIC THERMAL-STATE INTERPRETATION

One of the emerging challenges in industrial analytics is maintaining:

- operational traceability,
- engineering interpretability,
- and deterministic consistency.

In thermal infrastructure environments, operational interpretation must remain:

- reviewable,
- engineering-grounded,
- operationally contextualized,
- and traceable to plant historian conditions.

> **This creates growing interest in historian-derived deterministic operational intelligence frameworks.**

The objective is not replacing:

- plant operators,
- APC systems,
- DCS environments,
- or combustion controls.

The objective is improving visibility into the thermodynamic operating conditions influencing thermal-performance outcomes.

AN EMERGING OPERATIONAL LAYER

Historically, thermal operations have focused heavily on:

- combustion management,

- equipment reliability,
- emissions,
- and generation stability.

An emerging operational perspective suggests that the next layer of thermal-performance management may increasingly involve understanding the thermodynamic transfer environment itself, including:

- thermal-state behaviour,
- radiative coupling effectiveness,
- operational drift development,
- and fuel-to-steam conversion stability.

CLOSING OBSERVATION

Thermal plants do not always lose efficiency through catastrophic failure.

In many cases: performance deterioration develops gradually through operational drift.

The unit remains online. Generation continues. Combustion remains acceptable.

Yet progressively more fuel becomes required to sustain the same electrical output.

> **Could the next evolution in thermal-performance management involve improving visibility into how effectively thermal energy is transferred, absorbed, and sustained throughout the thermodynamic operating environment itself?**

YBGGlobal.com · Operational Thermodynamics Intelligence