HYBRID ANALYTICS SOLUTION TO IMPROVE COAL POWER PLANT OPERATIONS

DE-FE0031753

2021 Integrated Project Review
Joint Artificial Intelligence Session

May 13, 2021

Randy Bickford
Expert Microsystems, Inc.

PROJECT TEAM AND COAUTHORS

Randy Bickford
Principal Investigator (PI)
President & CTO
Expert Microsystems

Dr. Rodney Gay
President & CTO
MapEx Performance Monitoring

Rahul Palnitkar
Vice President, Engineering
Expert Microsystems

Scott Affelt
President
XMPLR Energy

PROJECT OBJECTIVE & DESCRIPTION

OBJECTIVE

Align with DOE's Fossil Energy Objective to create innovative solutions that integrate physics-based models with data-driven analytics and machine learning techniques to improve coal fired power plant operations

(DE-FOA-0001989 Topic 3A)

DESCRIPTION

New technology is developed to integrate an existing heat-balance modeling product with an existing advanced pattern recognition, machine learning and artificial intelligence product to create a hybrid online monitoring solution

- Completed solution is demonstrated at a utility-owned coal fired plant
- New Technology Elements are taken from TRL 2 to TRL 7

IMPROVING POWER PLANT OPERATIONS

ENABLING EARLIER INTERVENTION TO PREVENT PROBLEMS

Improve Equipment Reliability

- Early detection of equipment issues
- Higher equipment availability
- Insights into issue causes
- Estimate of remaining time to act

Improve Plant Flexibility

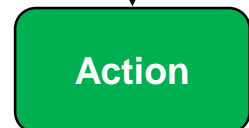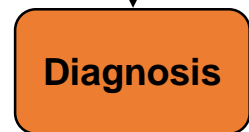- Expand operating envelope to accommodate renewables
- Safe and compliant transients

Improve Process Performance

- Early detection of performance issues
- Enhance/maintain optimal performance

Problem Detected

Time to Act Determined

Cause Identified

Problem Corrected
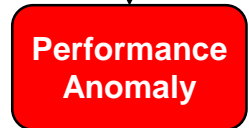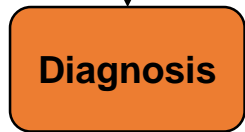
SERVICE INTERRUPTION

DAMAGING FAILURE

TYPICAL UTILITY M&D CONFIGURATION
SEPARATE PERFORMANCE AND RELIABILITY TEAMS / PRODUCTS

Performance

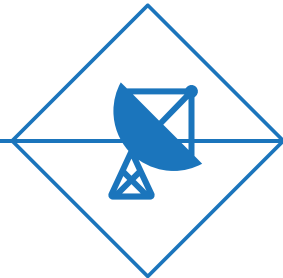| Heat Balance |
| Performance Anomaly |
| Diagnosis |
| Action |

Reliability

| APR |
| Reliability Anomaly |
| Diagnosis |
| Action |
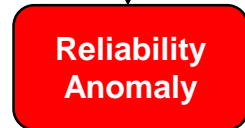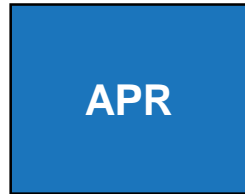
First Principles Methods

- Thermal analysis & heat balance models
- Generally focused on performance
- Anomaly detection limited by model fidelity

Advanced Pattern Recognition (APR)

- Generally focused on reliability
- Good at detecting small changes
- Uses mostly measured values

Diagnostics

- 1st principles can provide insight on cause
- Simple IF/THEN rules
- Rarely used, even if available
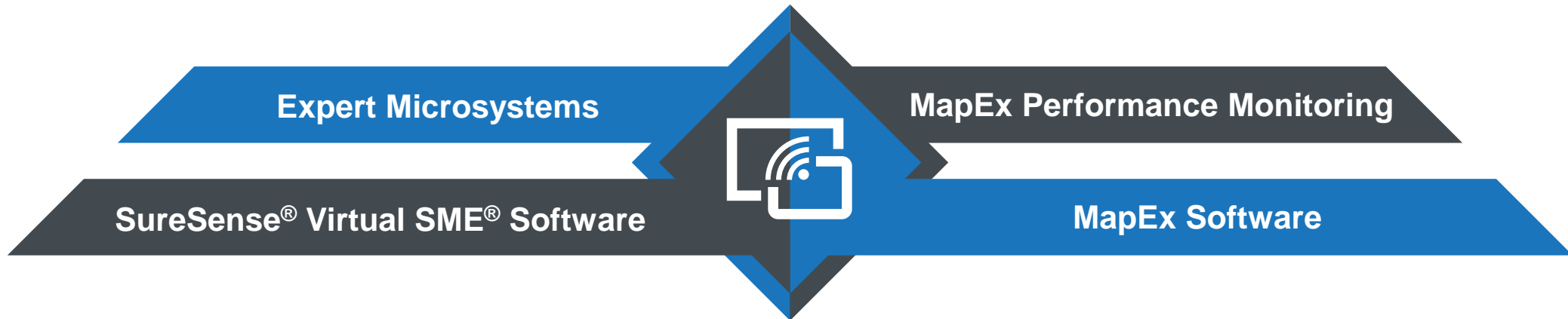
Prognostics

- Generally, NO prognostics available
- Single parameter trending (vibration)

NEW HYBRID ANALYTICS SOLUTION
INTEGRATION OF TWO PROVEN TECHNOLOGIES

Expert Microsystems | **MapEx Performance Monitoring**

SureSense® Virtual SME® Software | **MapEx Software**

- **SureSense® Software**
  - Advanced pattern recognition (APR) and machine learning
  - Online problem detection and alerting
  - Automated AI diagnostics and remaining time to act estimates
- **Broad power generation user base**
  - Over 50GW of power assets monitored
    - Coal, nuclear, gas/CC, hydro & renewable
  - Comprehensive IT integration

- **MapEx Software**
  - Detailed heat balance analysis
  - Online data reconciliation
  - Equipment performance analysis
- **Led by Dr. Rodney Gay**
  - Original developer of GE GateCycle
    - (acquired by GE in 1999)
  - Author: "Power Plant Performance Monitoring"
- **Installed at more than 25 sites globally**

HYBRID HB/APR MODELS
COMBINE ADVANTAGES & REMOVE LIMITATIONS

HEAT BALANCE MODEL

Advantages
- Based on physics of process
- Calculates values not directly measured
- Can use model to explain cause
- Includes upstream & downstream impacts
- Can model infrequent operating conditions

Limitations
- Difficult to setup & configure
- Less accurate predictions
- Sensitive to model & sensor errors
- Limited anomaly detection

APR (DATA-DRIVEN) MODEL

Advantages
- Very easy to setup & configure
- More accurate predictions
- Highly sensitive anomaly detection
- Detects all types of abnormal behavior
- Learns historical relationships

Limitations
- Normal state defined by training dataset (operating envelope)
- No inherent basis to explain cause
- No consideration of upstream or downstream impacts

## Improving Performance & Reliability
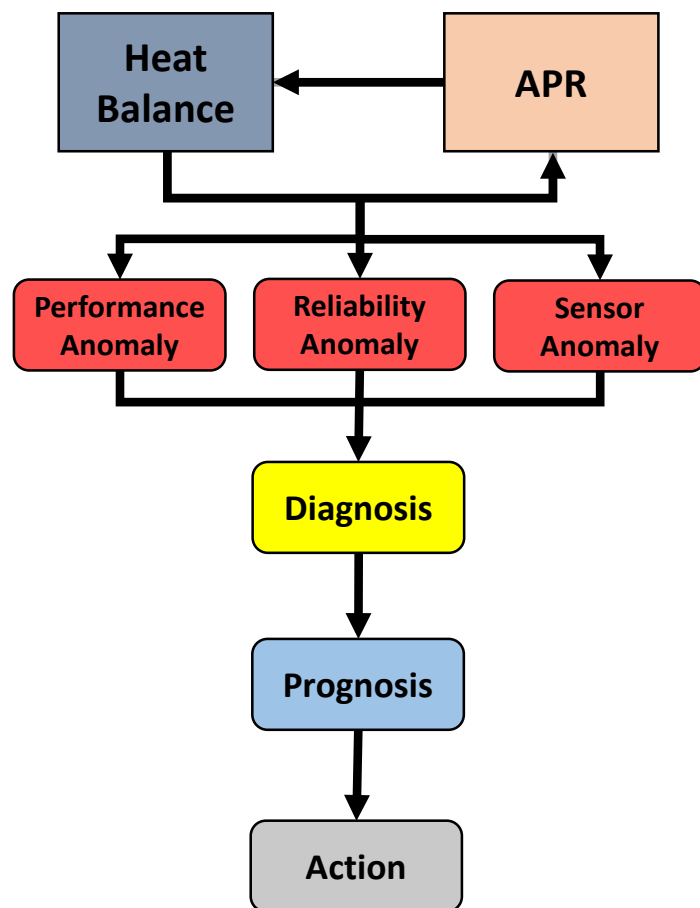
- **Heat Balance (HB) Methods**
  - Calculates "virtual" sensor information
  - APR models "calibrate" HB models
- **Advanced Pattern Recognition (APR)**
  - Uses both measured and calc HB data
  - Compares *Current State* to *Normal State*
- **Advanced Anomaly Detection**
  - Early and accurate anomaly detection
- **Online Diagnostics**
  - Rules-based **PLUS** model-based
  - Use symptoms from both HB and APR
  - Considers upstream/downstream info
- **Online Prognostics**
  - Calculates remaining time to act
  - Automatically updates with new information

HYBRID MODELS DETECT PROBLEMS SOONER
MODEL RESIDUALS ARE MINIMIZED FOR NORMAL BEHAVIOR
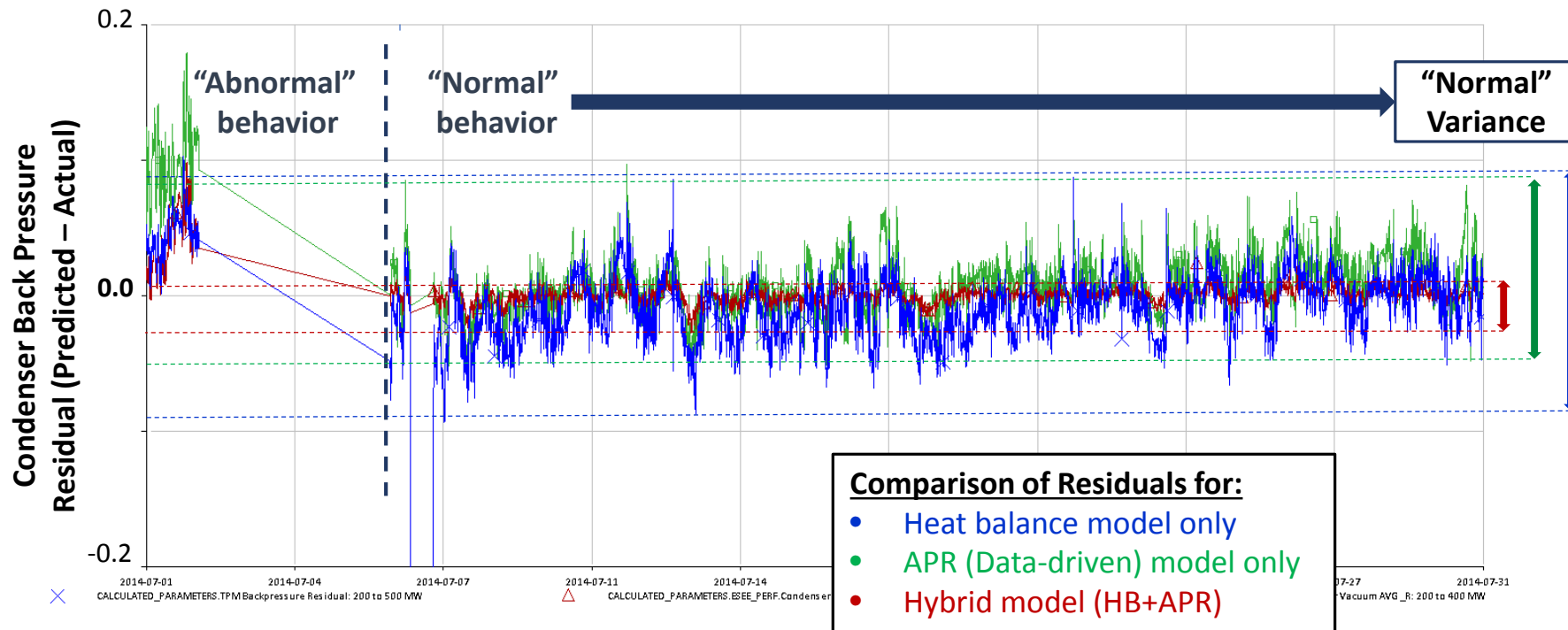
Heat balance models have modeling error/noise that makes it difficult to clearly detect an anomaly through the "normal" noise or variance.

Data-based APR models have lower "normal" residuals & therefore can detect anomalies easier & earlier.

Hybrid models (APR+Heat Balance) have the lowest residuals and most accurate anomaly detection

Comparison of Residuals for:
- Heat balance model only
- APR (Data-driven) model only
- Hybrid model (HB+APR)

RESIDUAL DISTRIBUTION COMPARISON
HYBRID MODEL HAS BEST RESIDUAL DISTRIBUTION

Distribution of Residuals

Normal Operation

	TPM	APR	HYBRID
Mean	-0.012	0.009	0.000
Standard Deviation	0.027	0.024	0.007
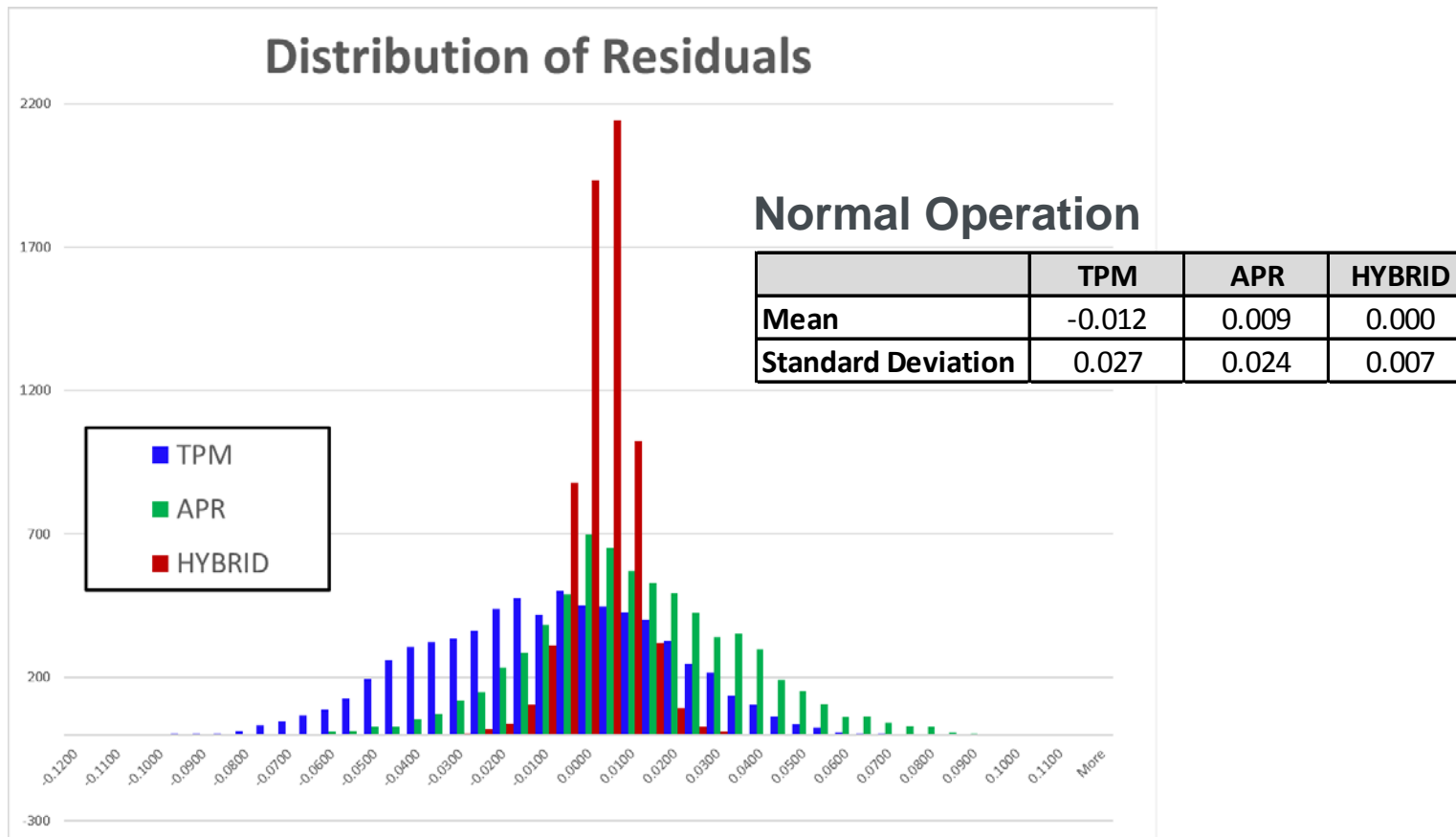
HYBRID MODEL
- Less Bias (lower mean)
- Lower Standard Deviation

BENEFITS
- Tighter Thresholds
- More Sensitivity
- Earlier Detection
- Fewer False Alarms

CURRENT STATUS OF PROJECT
FOUR TECHNICAL TASKS (MONTH 18 OF 24)

Develop & Integrate Physics-based Models

Develop & Integrate Hybrid-Analytics Framework

Verify Hybrid-Analytics Solution

Demonstrate Hybrid Analytics Solution

- MapEx HB modeling engine rewritten as SureSense plug-in
- MapEx user interface plugin for SureSense in progress
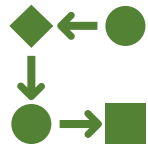
- First generation MapEx HB modeling engine integrated
- Iterative analytics framework completed

- Agile development and test sprints ongoing
- Framework elements deployed at customer sites for user feedback
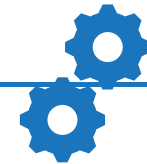
- Coal-fired boiler and steam system heat balance model in progress for utility site demonstration testing

UTILITY SITE DEMO ARCHITECTURE

Monitoring Server
- Deploy Projects
- 24/7 Monitor Projects

Database Server
- Data Stores (results)
- Project Stores

Studio Client
- Create Projects
- Monitor Projects

Web Server
- Company-wide Access
- 24/7 Monitor Projects

Historian Server
- Source for Plant Operating Data

Web Clients
- View Results on All Device Types

Monitoring Server

Database Server

Web Server

Historian Server

Network LAN/WAN

Studio Client

Web Client

Web Client

COAL-FIRED PLANT STEAM CYCLE MODEL
HEAT BALANCE MODEL DESIGN VIEW
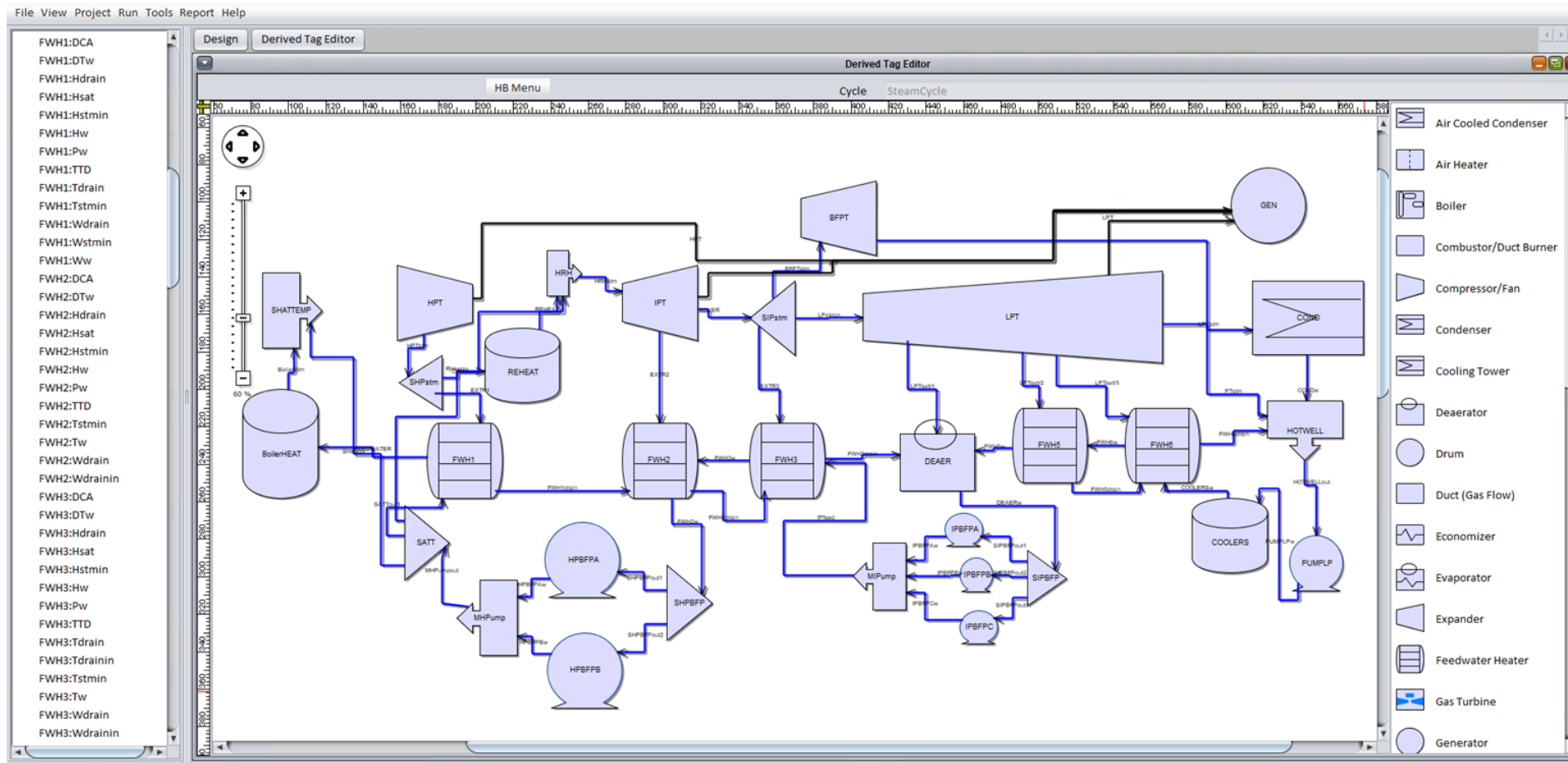
COAL-FIRED PLANT STEAM CYCLE MODEL
INPUT – OUTPUT MAPPING EDITOR

Connect real-time plant data to the MapEx model plugin

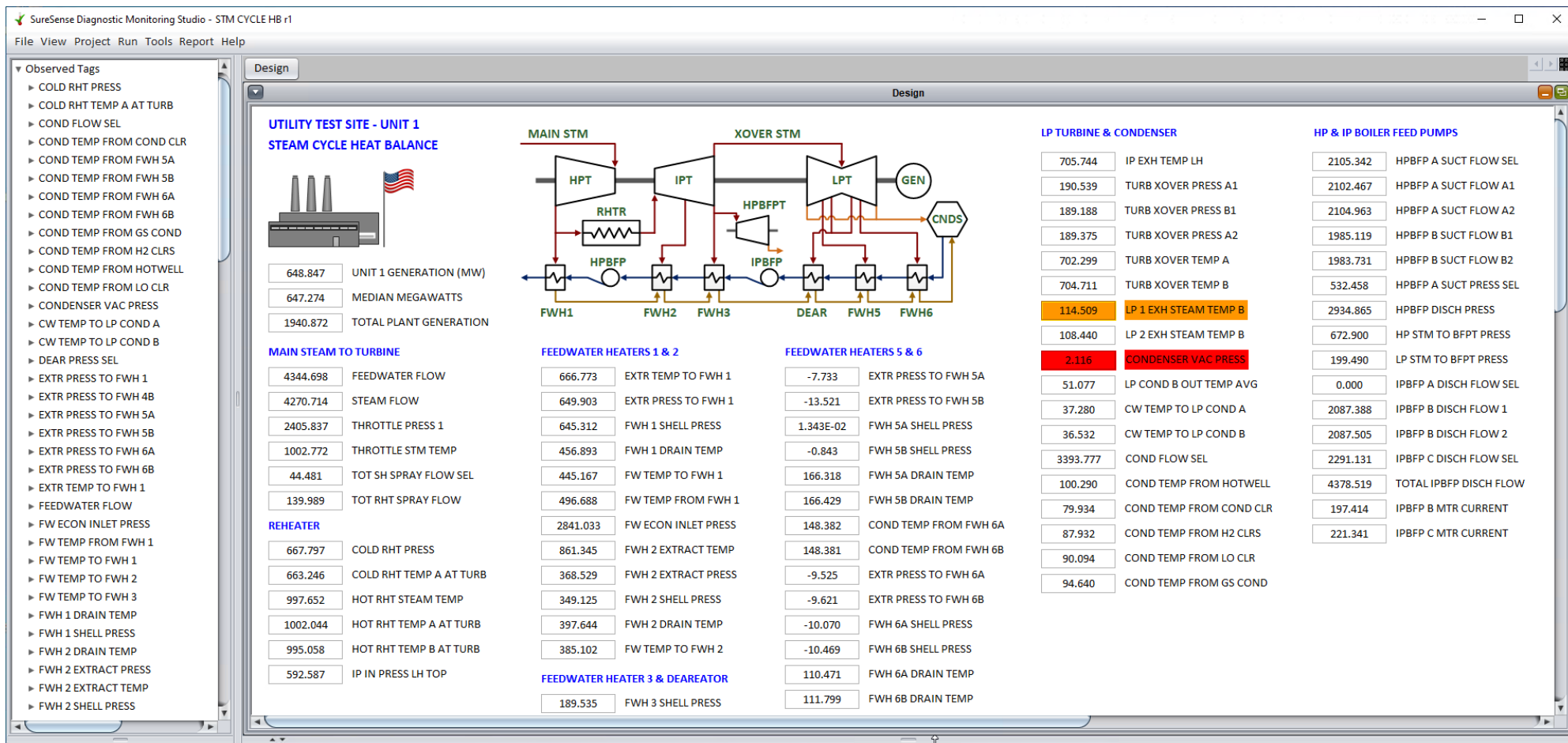Model adjusts to use the available input tags

Heat Balance outputs are available as SureSense derived tags

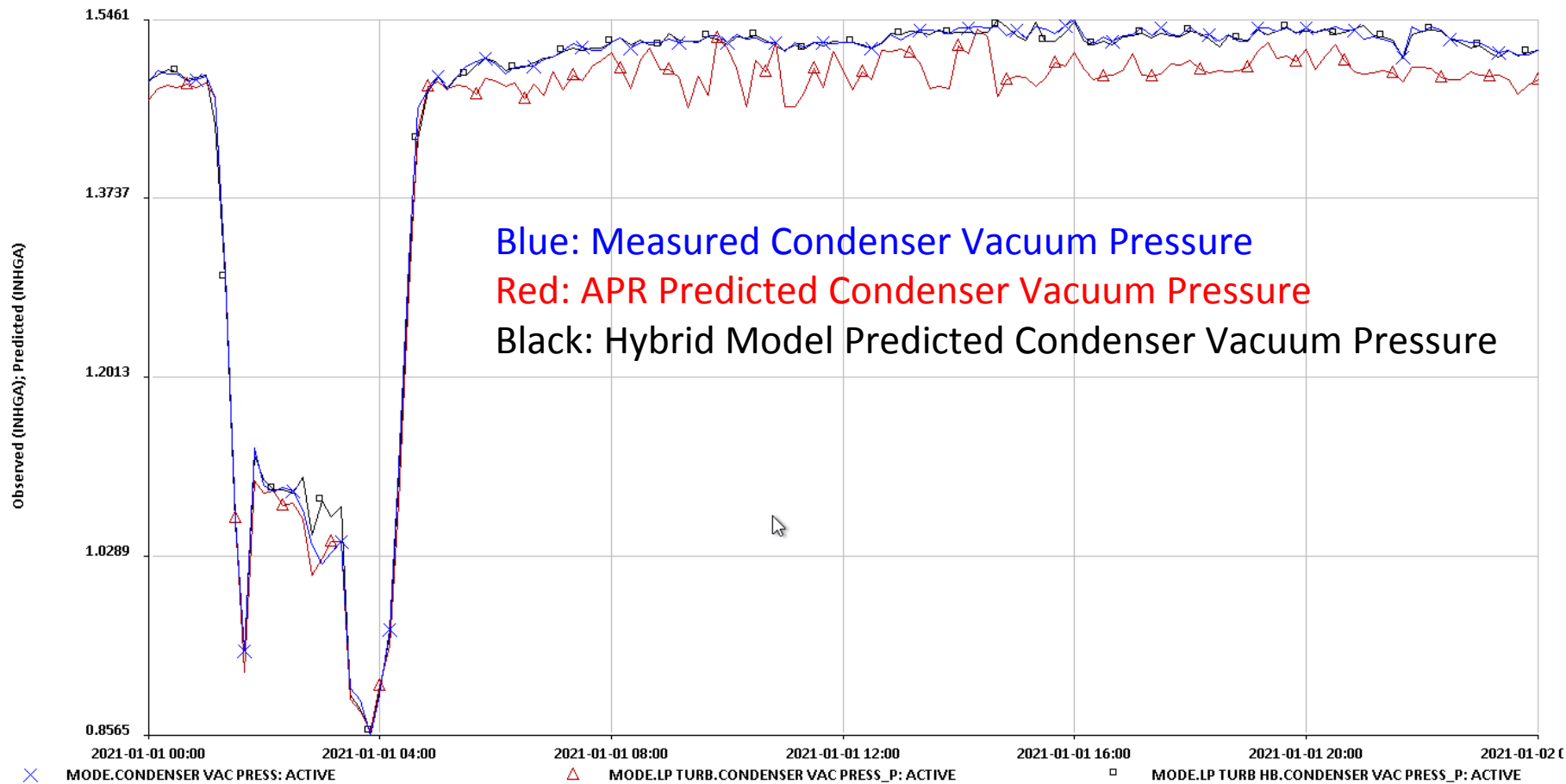Available for use in data-driven models, diagnostics & prognostics

COAL-FIRED PLANT STEAM CYCLE MODEL
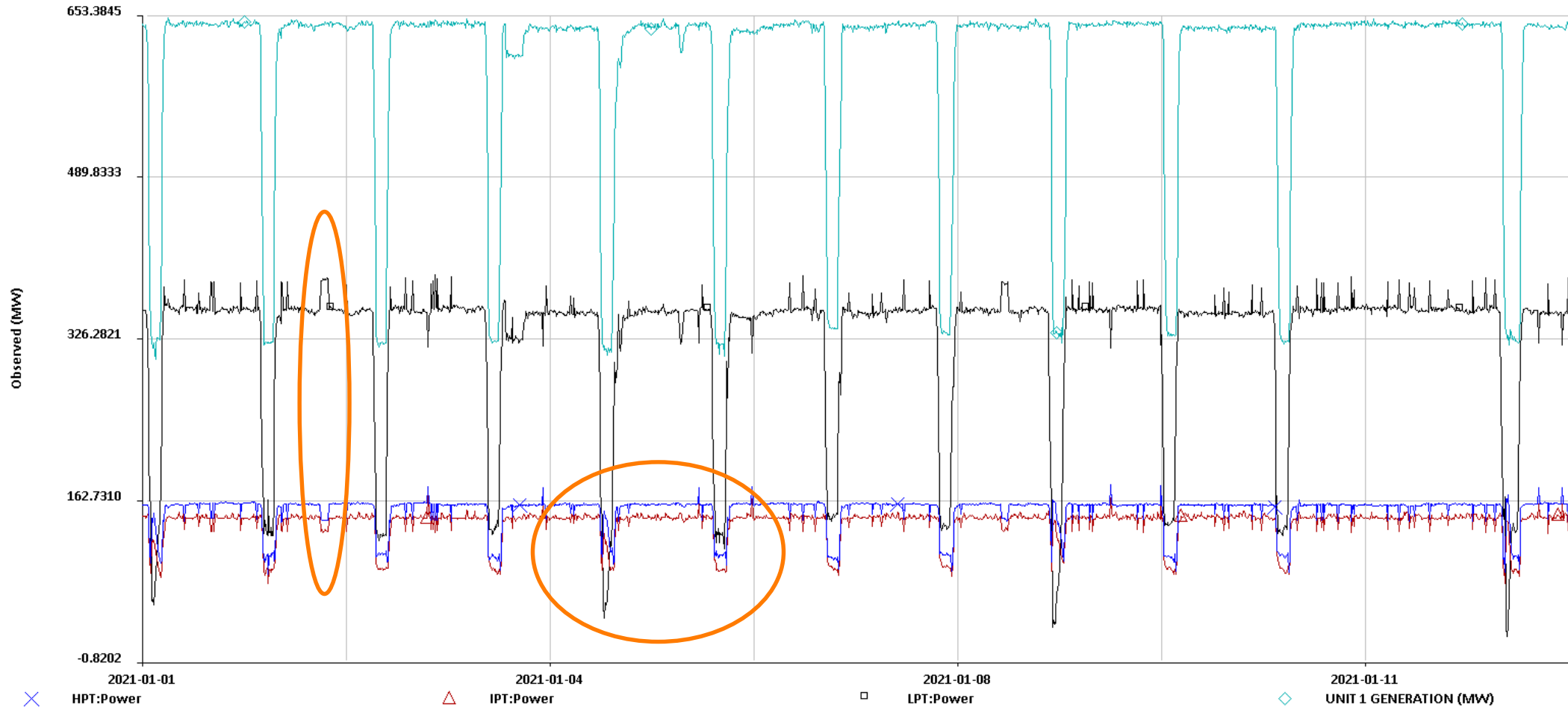## *ONLINE MONITORING VIEW*

HYBRID MODEL IMPROVES PREDICTIONS

Blue: Measured Condenser Vacuum Pressure
Red: APR Predicted Condenser Vacuum Pressure
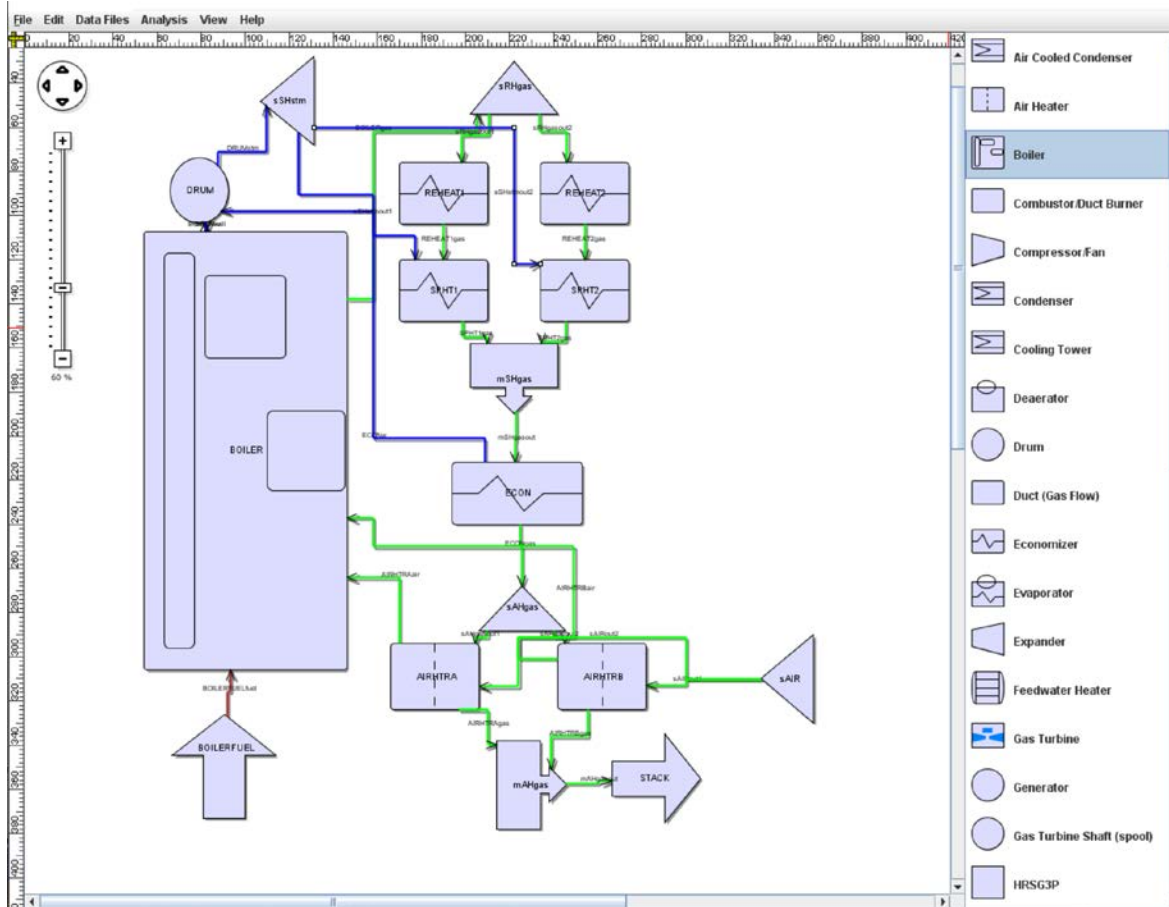Black: Hybrid Model Predicted Condenser Vacuum Pressure

HYBRID MODEL PROVIDES NEW INFORMATION
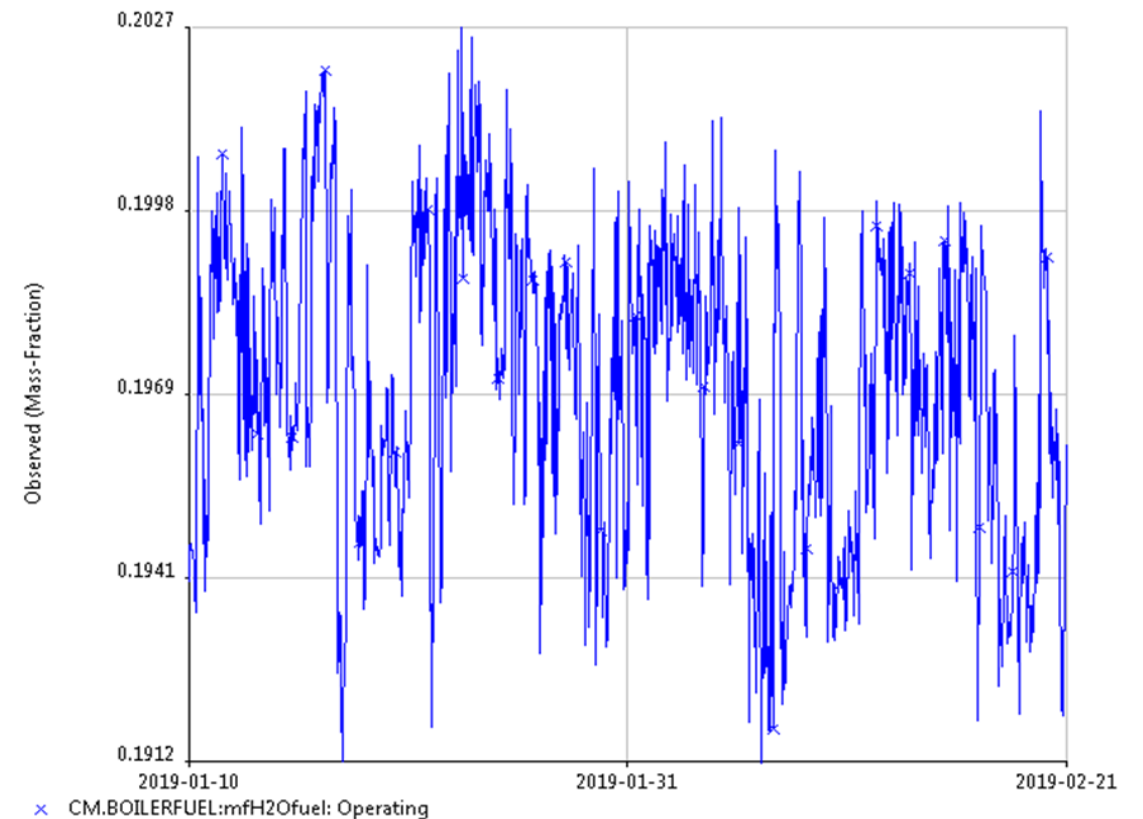## *TURBINE POWER CONTRIBUTIONS*

COAL-FIRED PLANT BOILER MODEL

Calculated Fuel Moisture Content

FUTURE GOALS AND OPPORTUNITIES

- **The Hybrid Analytics Platform** offers an unprecedented opportunity to automate diagnostics and remaining life prognostics for all types of power generation equipment

- **Model-Based AI Methods** can learn complex diagnostic relationships and capture subject matter expertise

  - Probability-based decision graphs (belief networks)
  - Ideal for complex & multi-symptom failure modes
  - Use performance AND reliability symptoms for holistic diagnosis
  - Use upstream and downstream symptoms for diagnosis

Q&A

DEPARTMENT OF ENERGY
ACKNOWLEDGEMENT & DISCLAIMER

- This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.