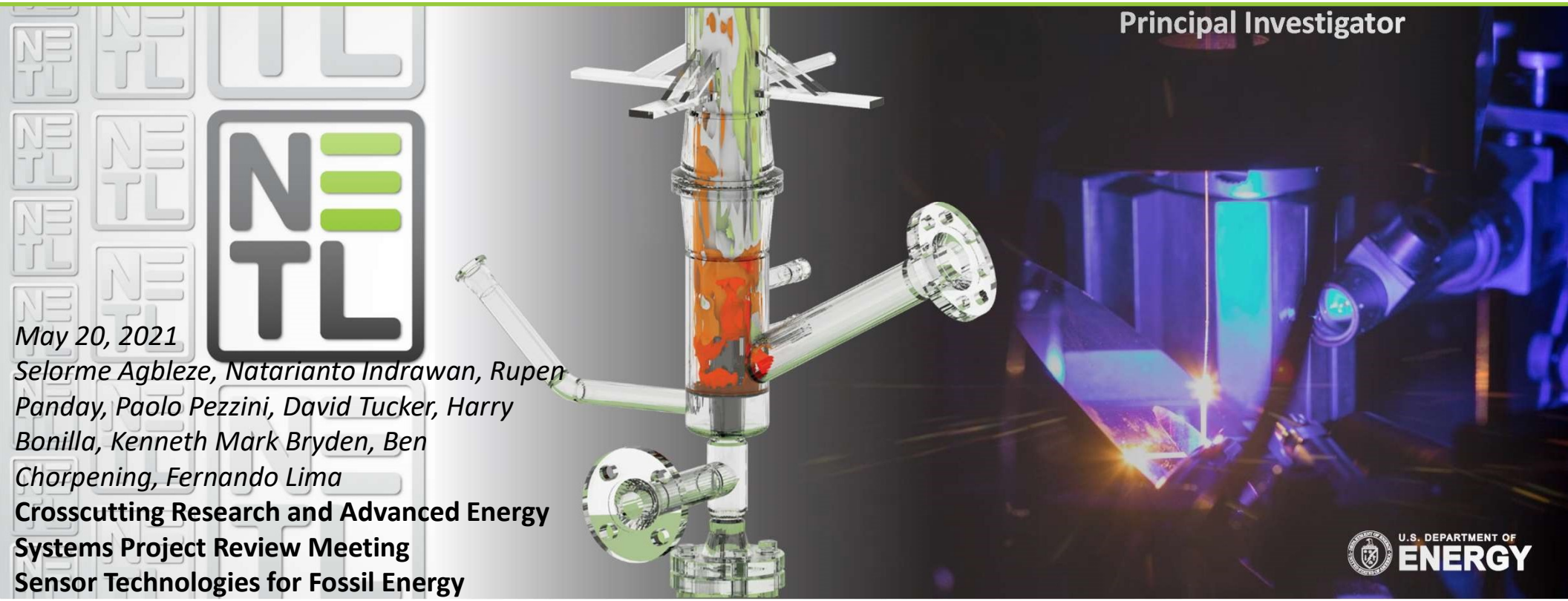
Online System ID for Predicting Power Plant Performance Throughout Cycling Operations

Larry Shadle
Advanced Sensors and Controls
Principal Investigator



May 20, 2021

Selorme Agbleze, Natarianto Indrawan, Rupen Panday, Paolo Pezzini, David Tucker, Harry Bonilla, Kenneth Mark Bryden, Ben Chorpening, Fernando Lima

Crosscutting Research and Advanced Energy Systems Project Review Meeting
Sensor Technologies for Fossil Energy

MISSION

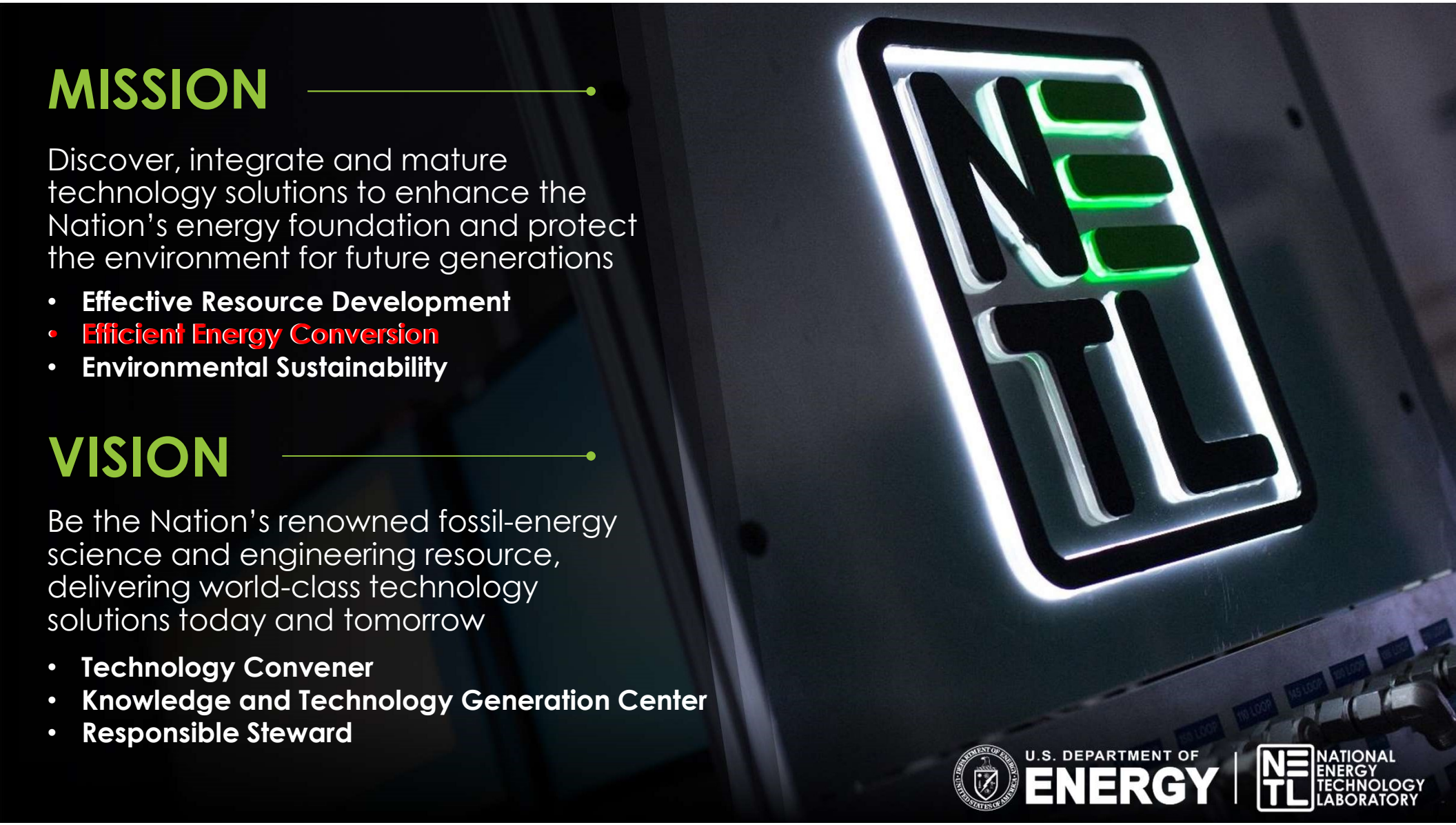
Discover, integrate and mature technology solutions to enhance the Nation's energy foundation and protect the environment for future generations

- **Effective Resource Development**
- **Efficient Energy Conversion**
- **Environmental Sustainability**

VISION

Be the Nation's renowned fossil-energy science and engineering resource, delivering world-class technology solutions today and tomorrow

- **Technology Convener**
- **Knowledge and Technology Generation Center**
- **Responsible Steward**



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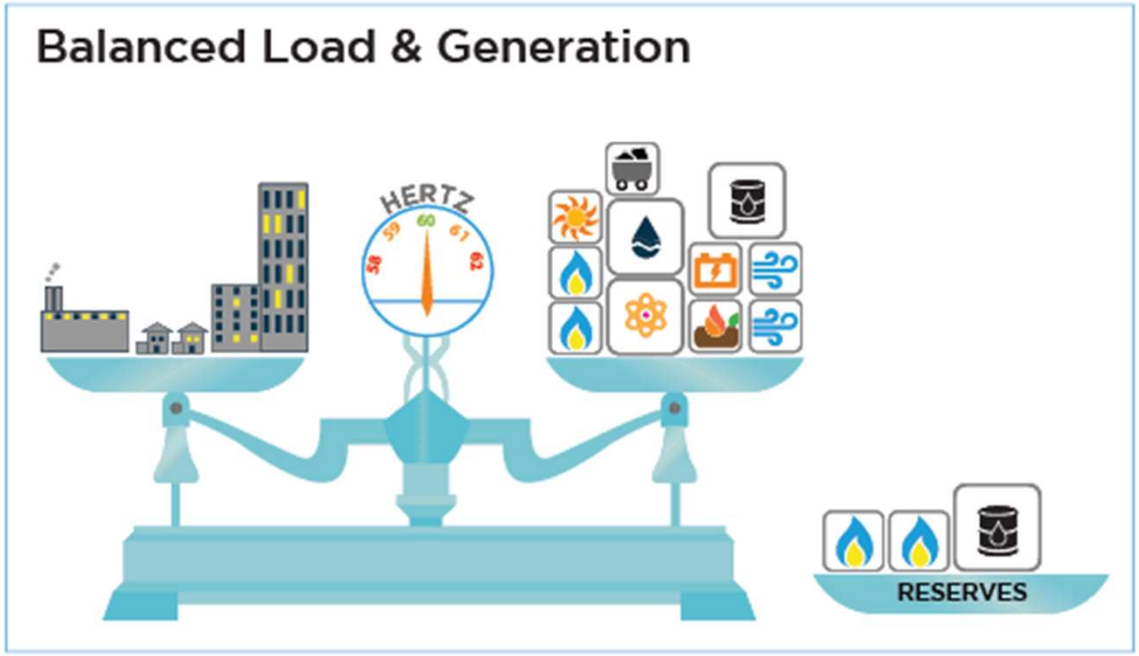
Integrated Energy Systems

The Grid is Changing – big impact on FE fleet

- **Fossil Energy - the foundation for reliable, resilient power generation**
  - Derived from system capacitance (**dispatchability**) - spinning inertia + turndown
  - Capacitance is shrinking
    - Retirement of base generation assets (lower dispatchability)
    - High renewables penetration (higher variability)



Responsibility to maintain reliability in the face of these changes

Permission pending from PJM Interconnection https://learn.pjm.com/three-priorities/buying-and-selling-energy/ancillary-services-market.aspx

Advancing Systems Readiness
Integrated Energy Systems – Integrated R&D

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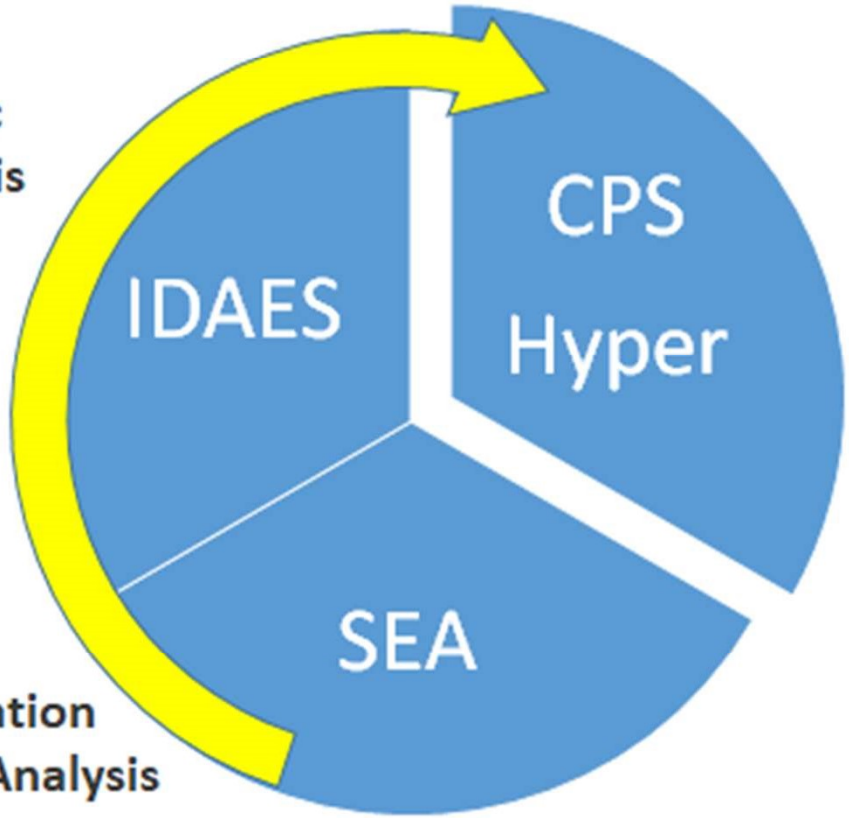
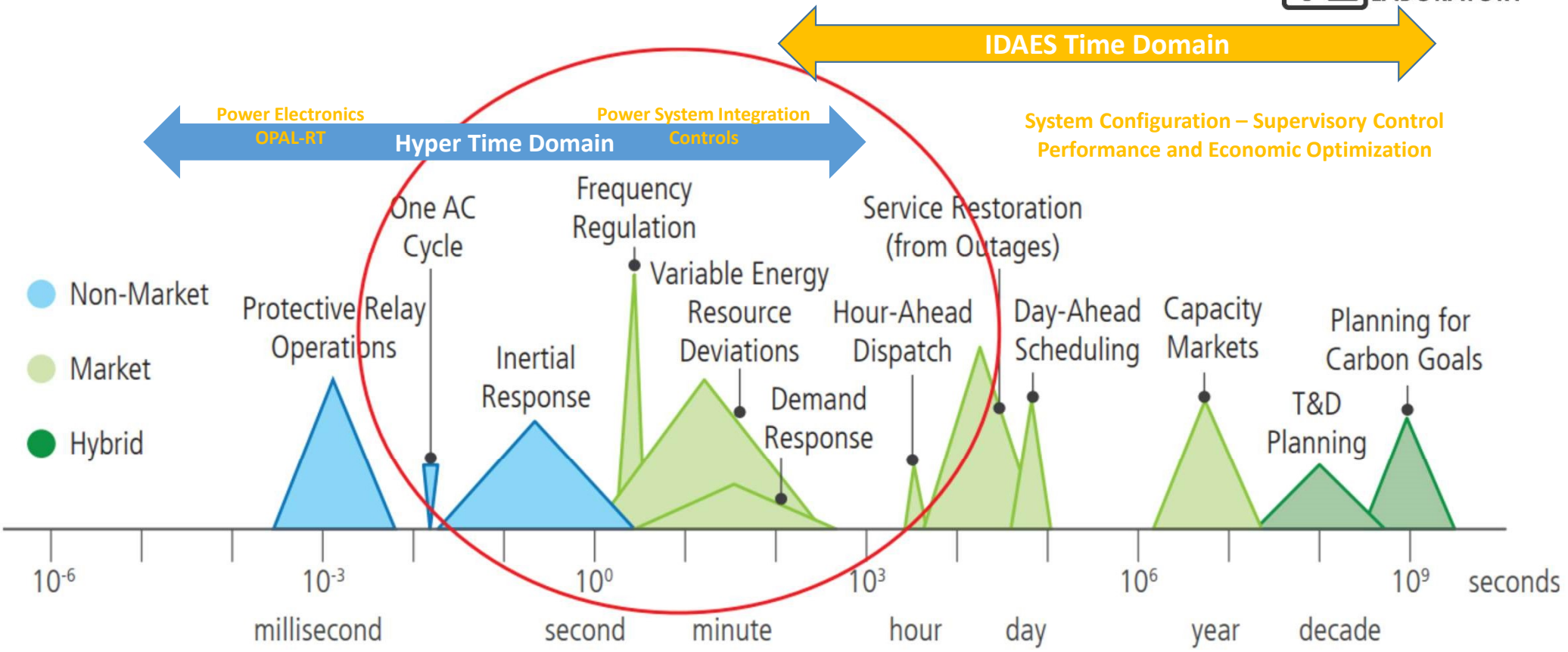
Optimization – Dynamic
Techno-Economic Analysis
Supervisory Control



Dynamic Operability
Start-up, Load Following
Integration and Control

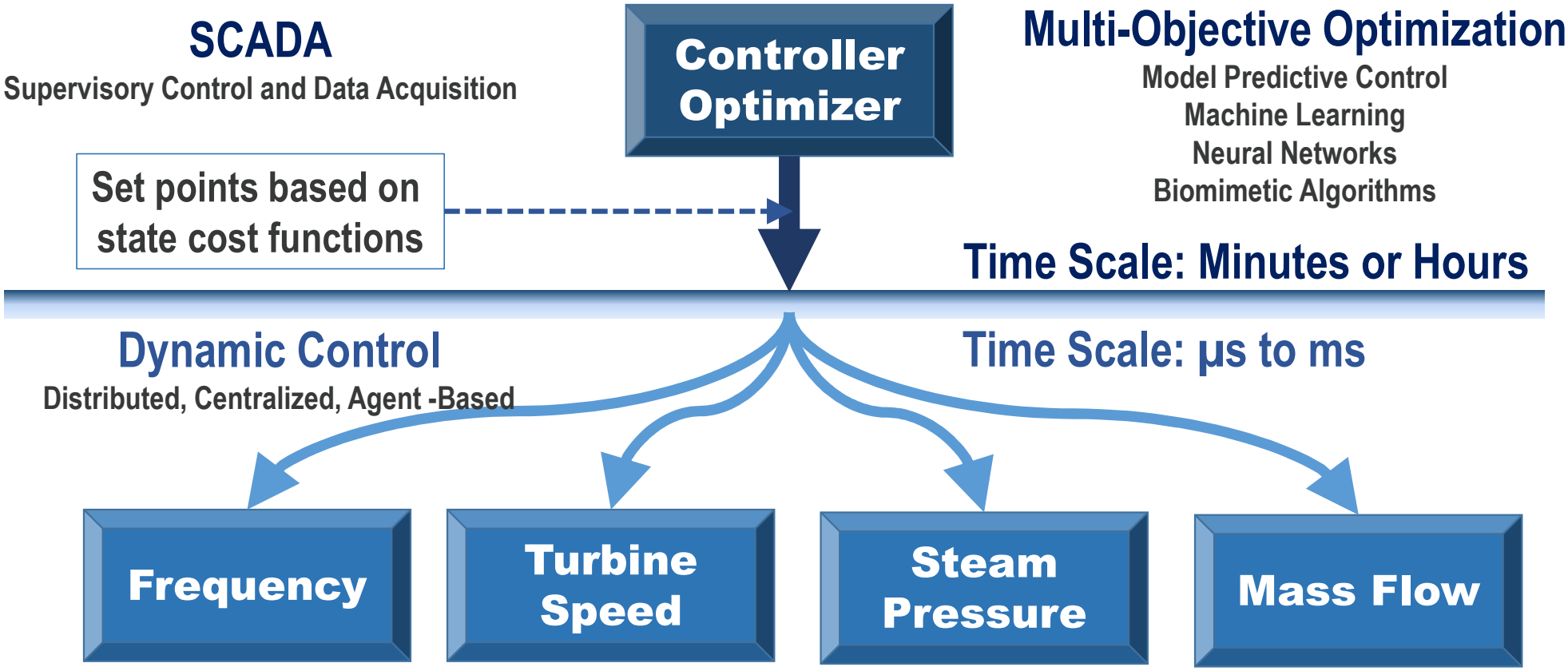
System Identification
Integration and Analysis

Reliability – optimization and control



Source: DOE (2017). Quadrennial Energy Review, Second Installment. https://www.energy.gov/policy/downloads/quadrennial-energy-review-second-installment

Technology Development Hyper Focus



Testing of Online System Identification for Fault Detection

Advanced Sensors and Controls Task 53

Product/Task Objective

- Demonstrate utility of online system identification for detection of tube leaks, and support technology transfer to industry.

Problem Statement

- Availability Boiler tube leaks - 54% of total outages[1].
- Maintenance - typical repair costs range from $2–$10 million per leak[2]

Approach

- Early detection of such leaks can reduce forced outages.
- Online System Identification to evaluate abnormal process dynamics.

[1]Kokkinos, A., "Coal R&D Beyond 2020," DOE-NETL-EPRI) Technical Exchange Meeting, Pittsburgh, PA (2019).

[2]Lang, F.D., et al.., "Detection of Tube Leaks and Their Location Using Input/Loss Methods," ASME 2014 Power Conference, Baltimore, MD, (2008), pp. 10.

State-of-the-art tools for fault detection

Advanced Sensors and Controls Task 35

- Artificial neural networks, Fuzzy logic, Bayesian networks, tube failure models, and multivariable statistics.
  - Evaluate leak detection rates in terms of days.
  - Input/loss method used for early detection ~two days prior to failure[3].
  - Dynamic principal component analysis (PCA) flagged leaks 72hr later[4].
- NETL researchers investigated various approaches (TTNEP Task4)
  - Fisher Discriminant Analysis
  - Kalman Filter with varia le threshold, and
  - Online System ID

[3]Lang, F.D., et al. "Detection of Tube Leaks and Their Location Using Input/Loss Methods," ASME 2004 Power Conference, Baltimore, MD,, pp. 10.

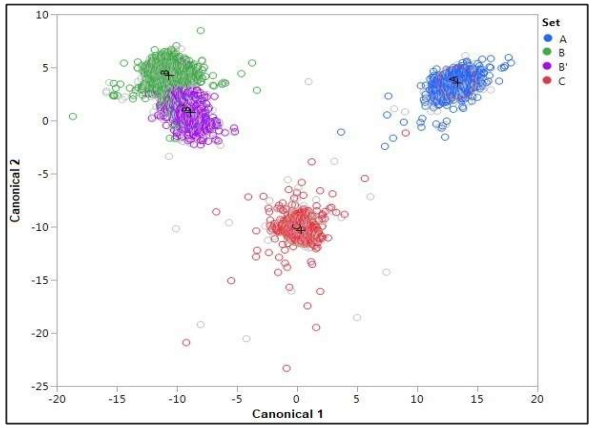
[4]Sun, X, et al., "Efficient Model-Based Leak Detection in Boiler Steam-Water Systems," *Computers & Chemical Engineering*, Vol 26 (11) (2002), pp. 1643–1647.

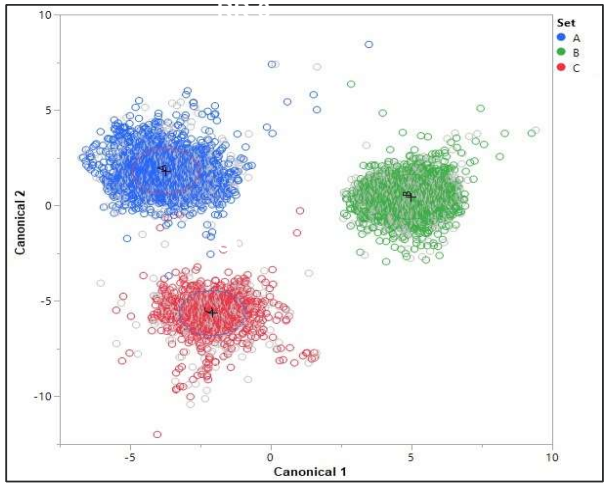
Data Analytics for Fault Detection in Commercial Plants

Five different plants of pulverized coal, subcritical and supercritical steam power plants experienced leaks during 2007-2009.

Plant	Comm. Year	Nominal Size, MW	Type	Nom. Opr. Conditions	Leak Location
Plant 1	1984	650	Subcritical	1013°F and 2460 psi.	Waterwall
Plant 3	1947	350	Subcritical	1063°F and 2655 psi.	Radiant superheater
Plant 6	1961	325	Subcritical	1077°F and 2436 psi	Economizer
Plant 9	1968	550	Subcritical	1000°F and 2520 psi.	Waterwall
Plant 2	1973	800	Supercritical	1024°F and 3545 psi.	Economizer

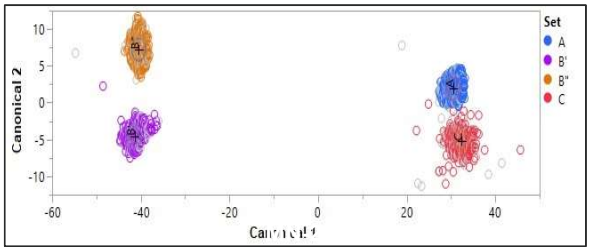
Canonical Plots and Fisher Discriminant Analysis

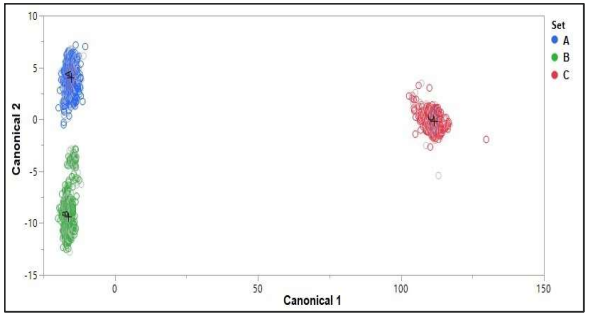


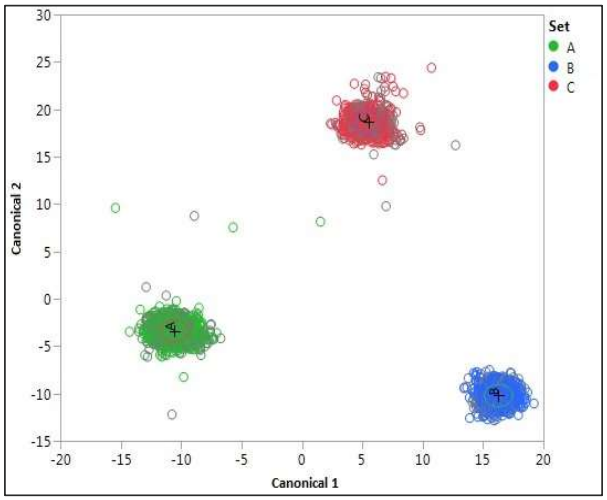


Effect of Power levels on Clustering Accuracy

Power level	Count		Misclassified observations: Nominal and leak sets		Misclassified observations: Leak or no leak	
	Total	Leak	No.	%	No.	%
All	7565	931	254	3.358	40	0.529
>90% full load	5054	372	12	0.237	1	0.020
80-90% FL	476	79	2	0.420	1	0.210
60-70% FL	1526	502	9	0.590	4	0.262

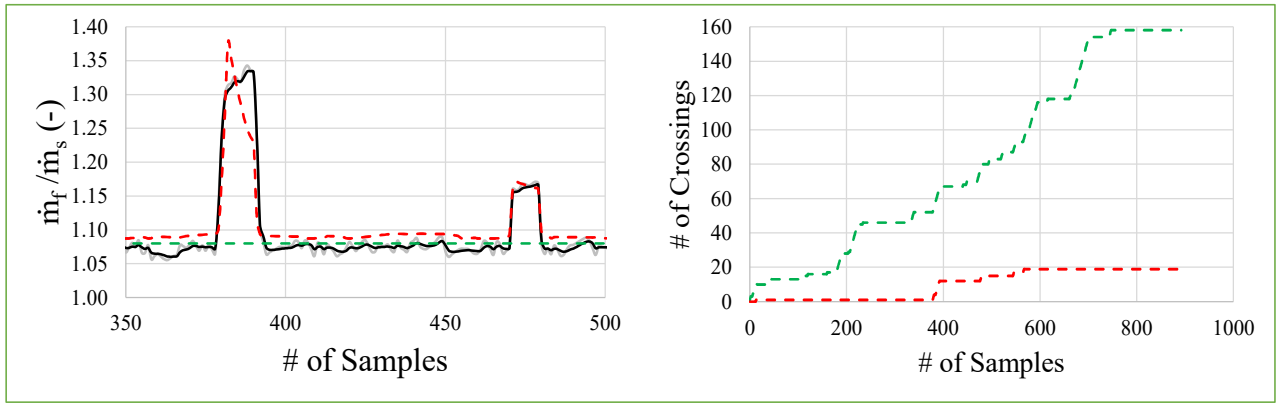


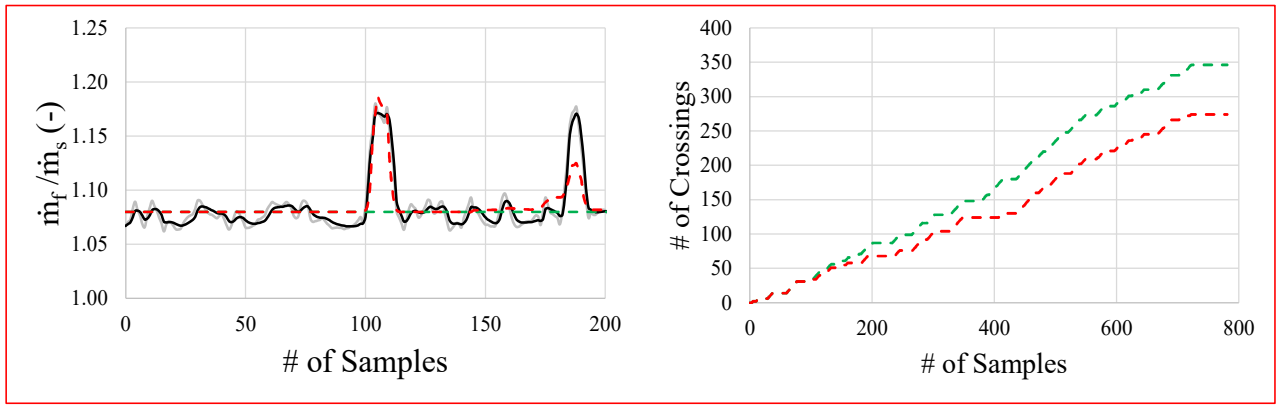




Variable Threshold on Leak Detection

Threshold Fixed (3σ) vs Threshold Scaled with Power Load





Normal Operations

SetA: # of Samples (Total) = 893

Fixed threshold crossing = 18%

Variable threshold crossing = 2%

Signal/Noise improved from **2.44** to **17.5**

Operations with Steam Leak

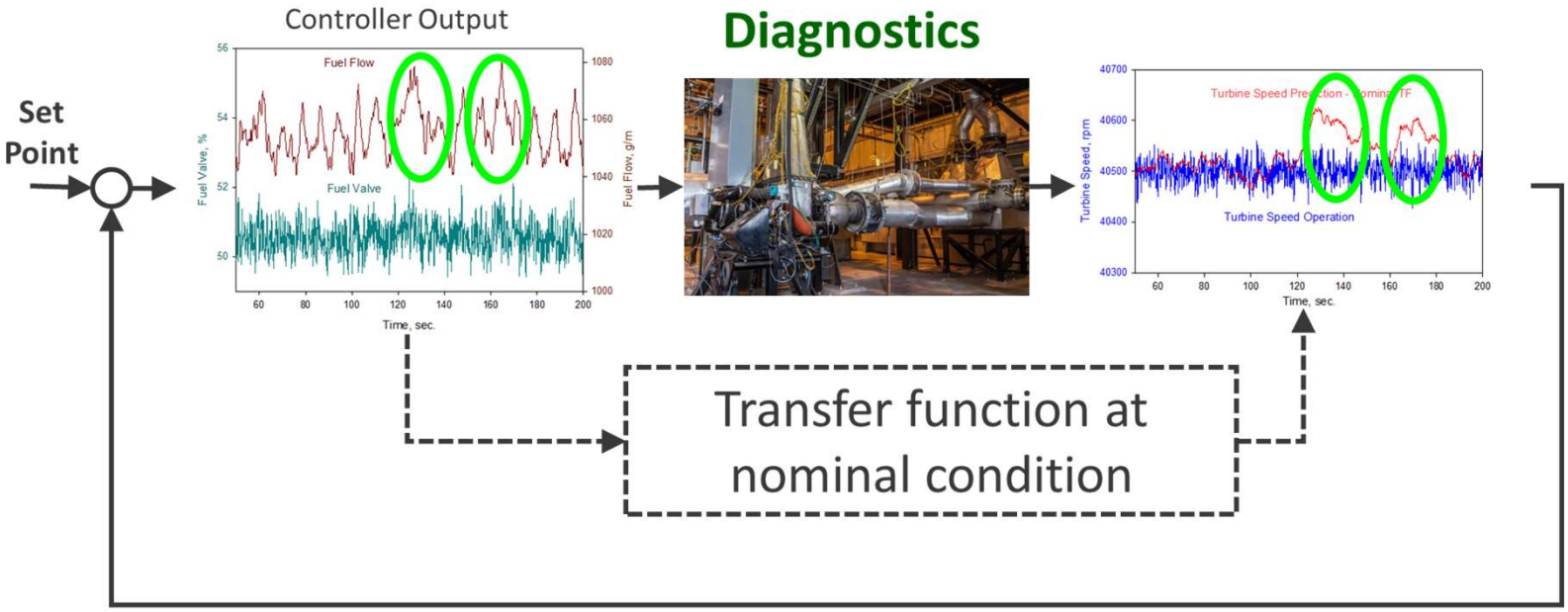
SetC: # of Samples (Total) = 782

Fixed threshold crossing = 44%

Variable threshold crossing = 35%

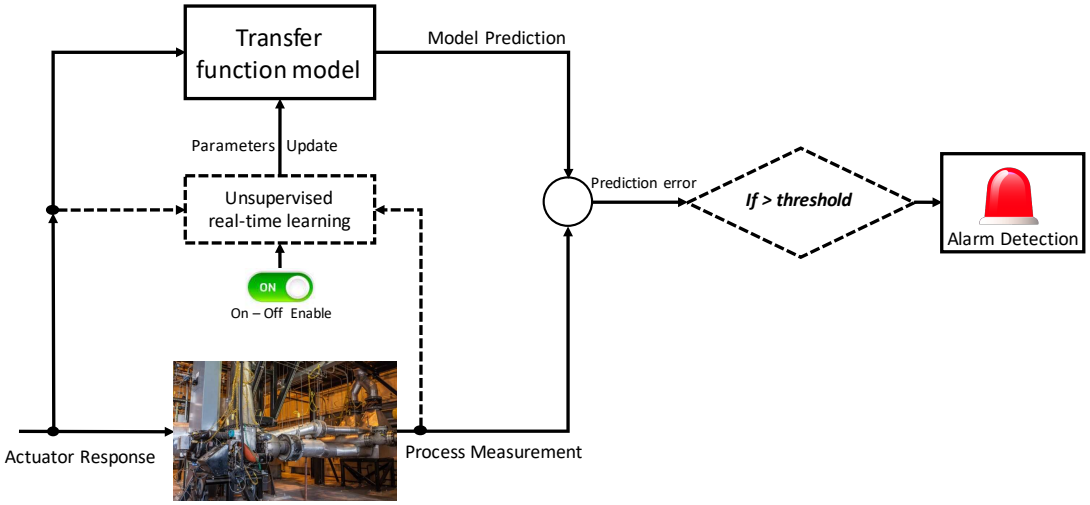
Fault detection based upon On-line System ID

Advanced Sensors and Controls *Task 51 Online System ID*



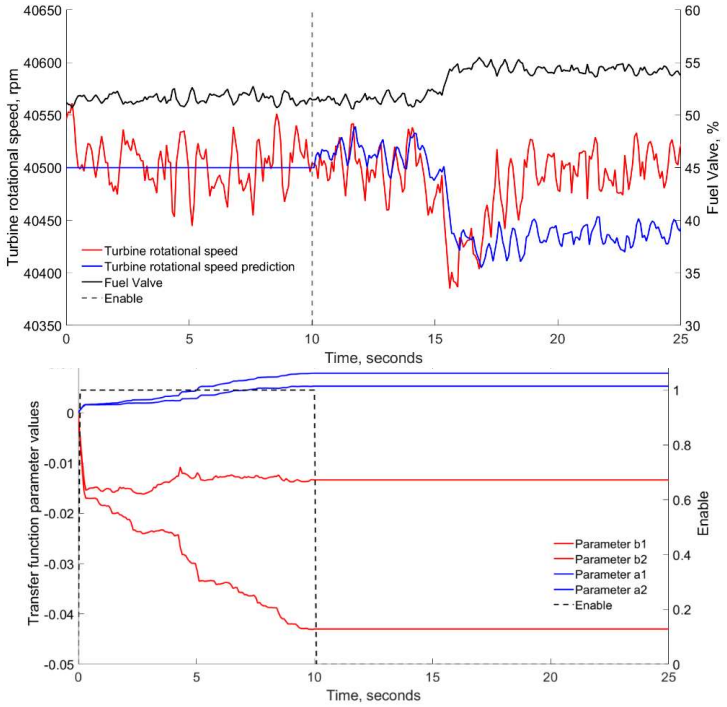
Continuously Adaptive Gain Scheduling

Online System Identification to detect abnormal operations



How it works

- An empirical transfer function implemented in parallel
- During automated control, controller output and measurements used in a recursive algorithm.
- New parameters used for online prediction.



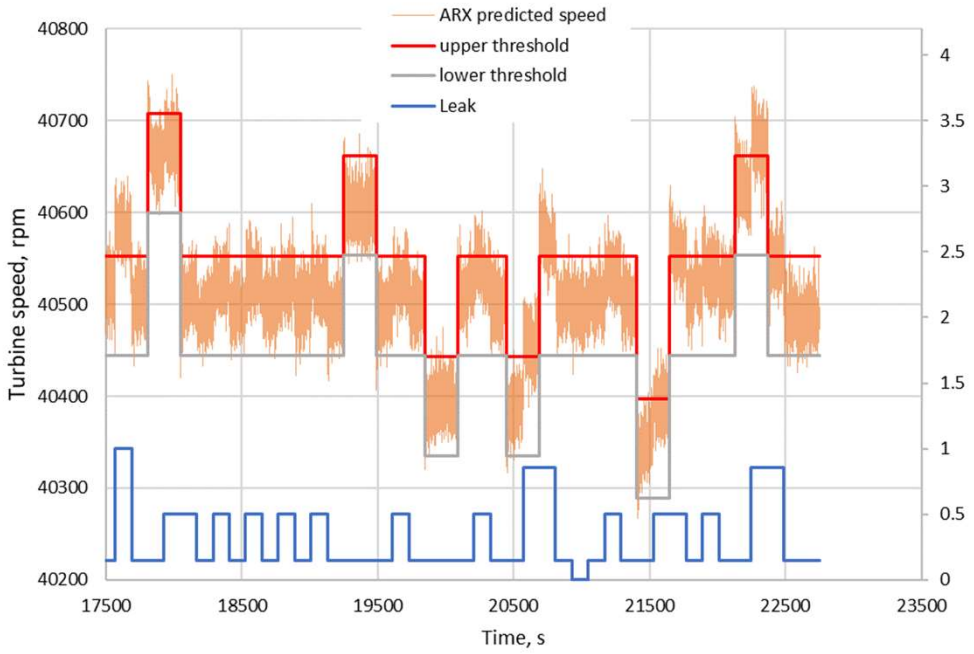
Test Results

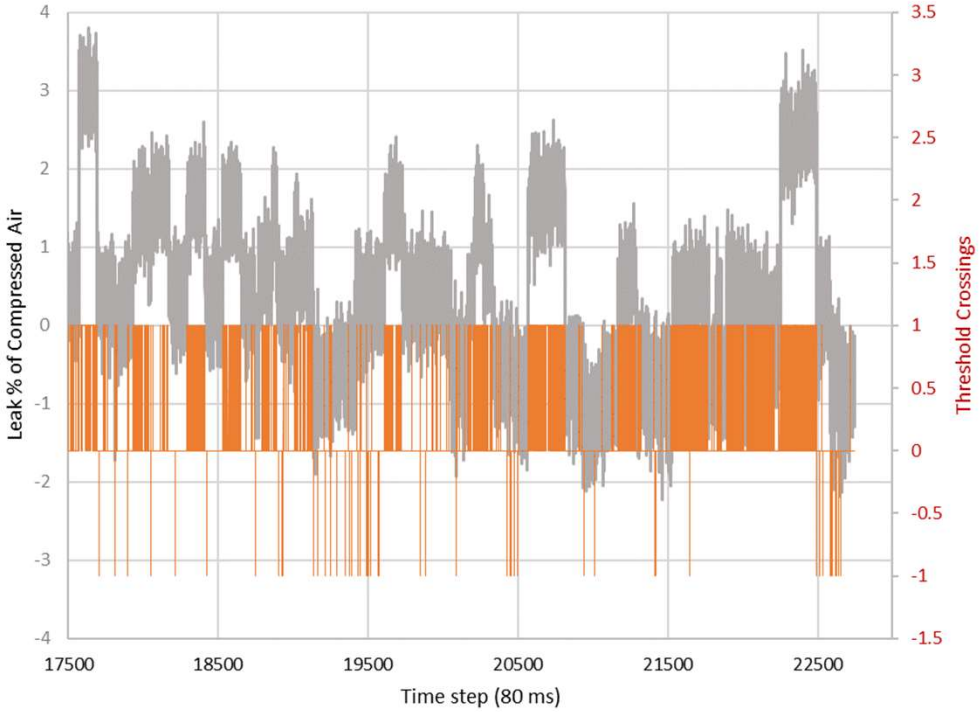
- A 10% leak reproduced in the working fluid
- Fuel flow increased to maintain normal operation
- The leak was detected 7s after it occurred

H. Bonilla-Alvarado et al. "Development of realtime system identification to detect abnormal operations in a gas turbine cycle," Journal of Energy Resources Technology, July 2020, 142, 070906-1.

Results using on-line system ID

Leak detection during load following operations





Milestones

AS&C Task 53

No.	Type	Date	Description
A	Project	05/28/2021	Joint statement of work with CRADA partner
B	Project	07/30/2021	CRADA agreement approved and initiated with industrial partner
C	Project	10/29/2021	Obtain normal and faulty data from target power plant, Identify critical sensors and controls, verify data resolution and S/N for System ID.
D	Go/No-Go	02/15/2022	Develop online system ID fault detection with historical data. No-go: Obtain higher time resolution data or additional control system data to improve system ID fault monitoring.

THANK YOU

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