ADVANCED REACTORS AND THE NEED FOR ADVANCED CONTROL SYSTEMS, JULY 12-14, 2023, LEMONT, IL

Argonne NATIONAL LABORATORY

DIGITAL TWINS FOR HEALTH MONITORING TO SUPPORT ADVANCED CONTROL

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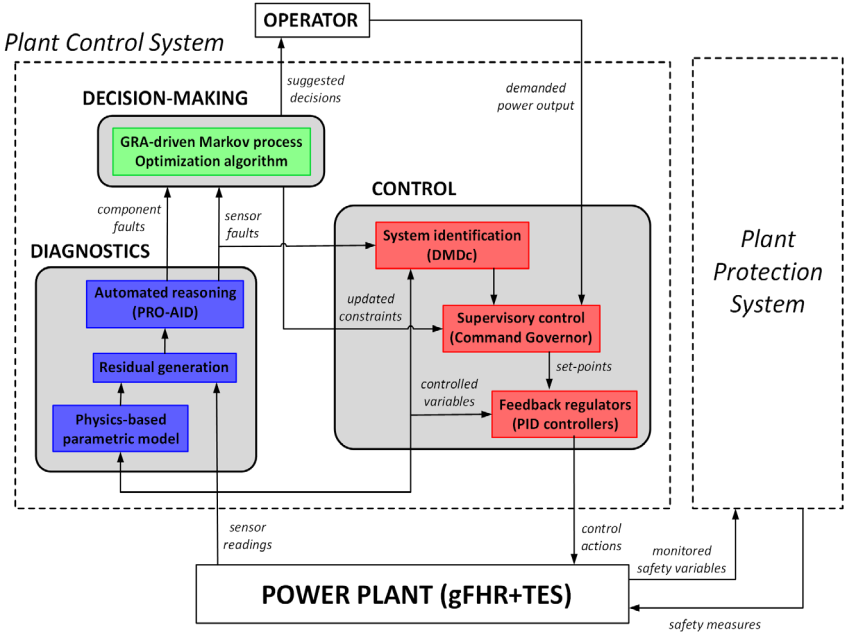
OUTLINE

- Overview
- Digital Twins for Fault Diagnostics
- Examples
- Conclusion

OVERVIEW

- Diagnostics is an integral part of advanced control:
  - Equipment health for O&M decision
  - Instrument health for control

- Desired capabilities:
  - Differentiate component and sensor faults
  - Provide explainable diagnoses to operator

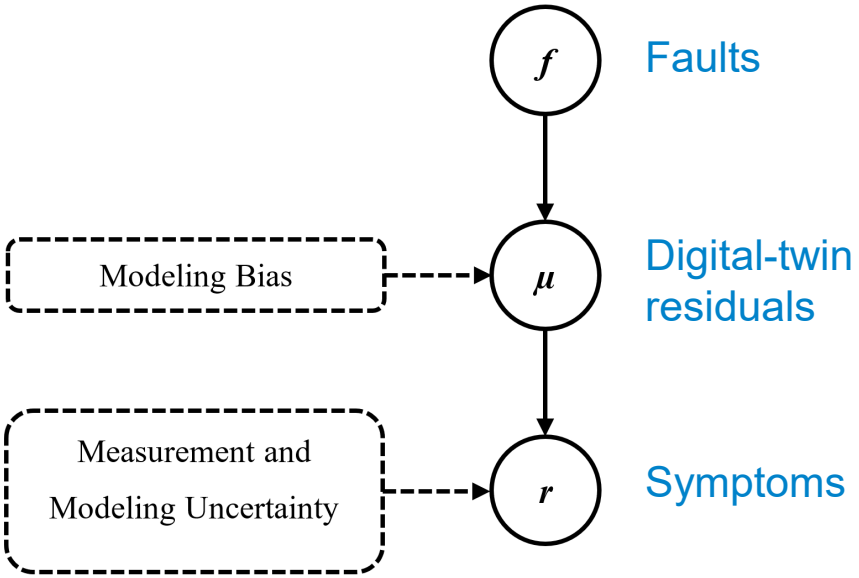


Structure of a proposed autonomous control system architecture (Ponciroli et al.)

DIGITAL TWINS FOR DIAGNOSTICS

- Utilized in model-based diagnosis:
  - Enable detection and diagnosis of component and sensor faults
  - Allow robust treatment of uncertainty in reasoning process

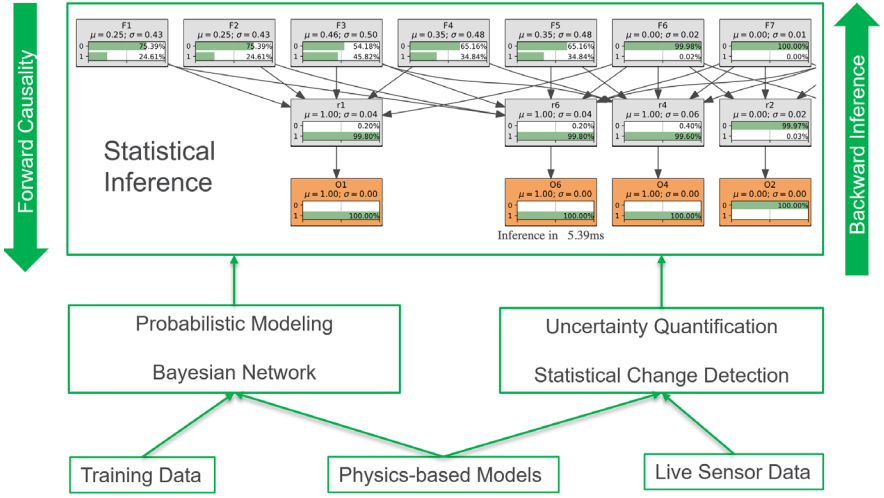
- Facilitate explainable diagnosis:
  - Clear cause-effect relations between faults and symptoms



IMPLEMENTATION IN PRO-AID

- Under development at Argonne
  - Featured in a live demo on 7/14

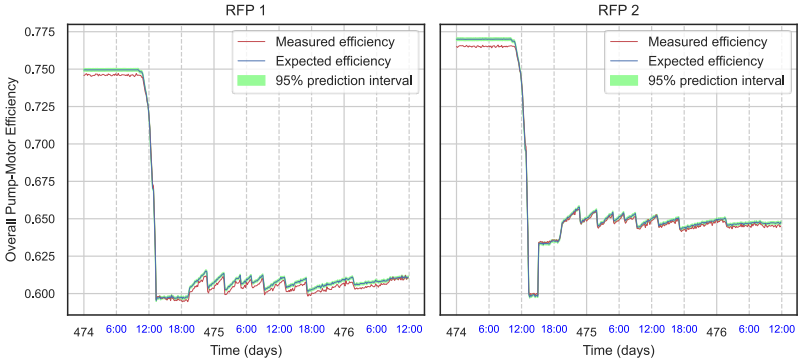
- Prioritized capabilities:
  - Detection of equipment and sensor faults
  - Robust uncertainty treatment
  - Explainable, actionable diagnoses
  - No design parameters, configurable to generic systems

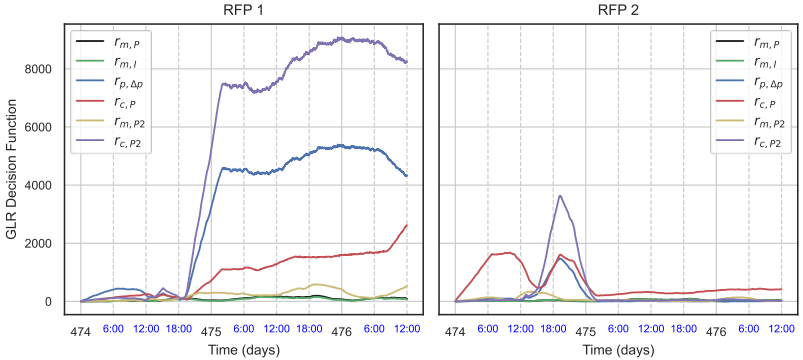


EXAMPLE 1: MONTICELLO BWR FEED PUMPS

Results

- Diagnostic results:
  - Symptoms: Non-zero residuals for RFP 1
  - Diagnosis: Pump fault in RFP 1
- Confirmed by Xcel:
  - Flow straightener failure in RFP 1 at approx. 15:00 on day 474



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-----------------------------------------------------------------
                      DIAGNOSTIC RESULT
-----------------------------------------------------------------
Reasoning method: Probabilistic
Faults, ranked by posterior probability:
-----------------------------------------------------------------
|Rank|Fault Name                                |Probability|
-----------------------------------------------------------------
|1   |Pump-rfp11                                |   0.73359 |
|2   |SensorFault-rfp11:vflow:in                |   0.16370 |
|3   |Bearings-rfp11                            |   0.14803 |
|4   |SensorFault-rfp11:press:in                |   0.13371 |
|5   |SensorFault-rfp11:press:out               |   0.13371 |
|6   |Motor-rfp11                               |   0.07776 |
|7   |SensorFault-rfp11:power:mid               |   0.00149 |
|8   |SensorFault-rfp11:current:mid             |   0.00023 |
|9   |SensorFault-rfp11:rspeed:mid              |   0.00004 |
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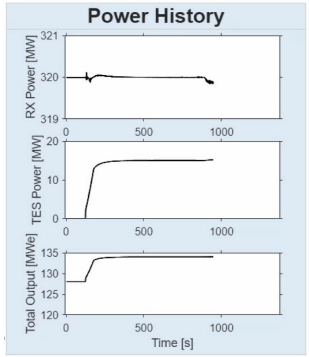
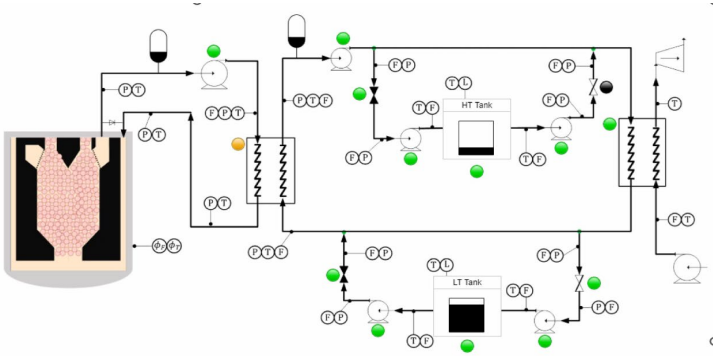
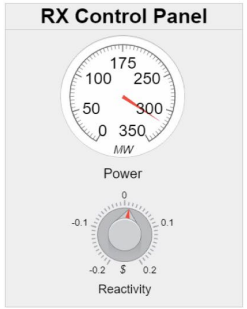
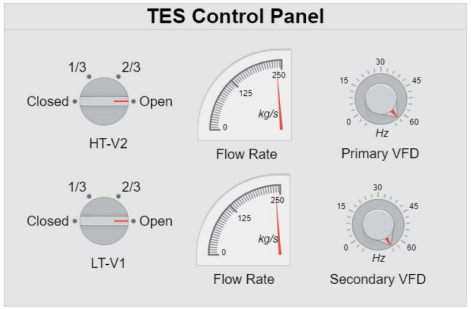
EXAMPLE 2: THERMAL STORAGE SYSTEM

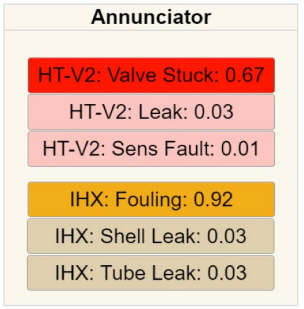
- Fault scenario:
  - HT-V2 valve stuck
  - IHX Fouling











CONCLUSION

- Essential role of diagnostics in advanced control:
  - Detection of sensor faults to ensure proper control
  - Monitor equipment health to support O&M decision

- Benefits of digital-twin-based approach:
  - Utilize physics-based diagnosis information to supplement sensor data
  - Enable detecting and differentiating both component and sensor faults
  - Facilitate explainable diagnoses

THANK YOU