Digital Transformation:

Enabling Predictive Maintenance Using Wireless Gauge Readers

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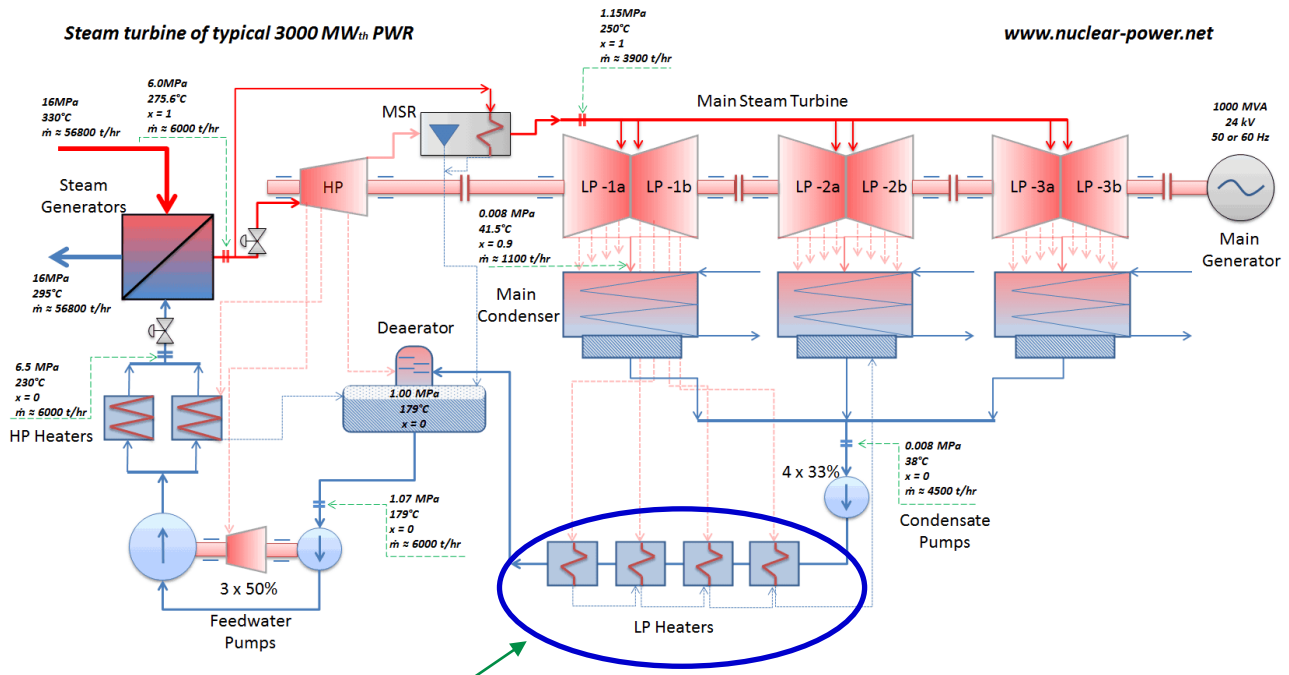
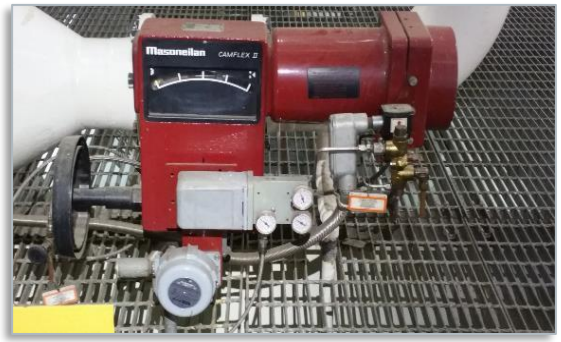
Exelon Generation®

Background: Air Operated Valves in Feedwater Heating Loop





- Feedwater Control Valves control tank water level for feedwater heaters (8 cascading stages).
- Existing valves are Air Operated – no motor, no voltage, no networking. Mechanical gauges display air pressure, but there is no remote monitoring or control.
- Cannot perform predictive analytics, automated fault detection, implement condition-based monitoring – no Predix, no Prism.
- Labor consuming (manual rounds).

Feedwater Drain Valve – Failure Modes and Impact

Typical Failure Modes	Process Impact	Labor/Repair Impact
• Ruptured diaphragm • Worn actuator cam – stuck positioner • Supply air leak • Mis-calibration	• **Water level too low:** May require makeup water which reduces water temperature going to steam generator. > 5MW impact • **Water level too high:** May trigger high level dump to empty tank. Water temperature to steam generator significantly reduced. >> 5 MW impact • **Power Spike:** In severe case, reactor power will spike to compensate for water temperature, may result in warning or plant trip.	• Emergency/overtime work • Expedited costs for parts • Potential unit downtime

Need to Digitize Legacy Air Operated Valves to Enable Automated Fault Detection and Predictive Maintenance

Non-Invasive Digitization of Pressure Gauges

Air Operated Valve (AOV)

- Valve has manual indicators:
  - Supply Air Pressure Gauge
  - Input Air Pressure Gauge
  - Output Air Pressure Gauge
  - Valve Position Indicator Window
- No remote data collection or trending
- No interface to ADR / Predix

Wireless Gauge Reader Non-Invasive Retrofit

"Electronic Eyeball" clamps onto existing gauge, Install in under 30 minutes

Digitized AOV

- Digitized valve with Wireless Gauge Readers
- Data sampled every 15 minutes
- Ability to store, trend and alarm
- Connection to PI Historian
- Data available for ADR Predictive Maintenance

Required Only Two Weeks to Digitize 36 Valves at Calvert Cliffs No Disruption to Plant Operations, Outage Not Required

Actual Fault Detection at Calvert Cliffs

- February 2019: Diaphragm rupture on valve positioner – slow leak causing drain valve to open more than commanded, resulting in lower water level in feedwater tank.

- June 2019: Worn cam on valve positioner – groove on cam caused valve actuator to be stuck in certain positions, resulting in erratic water level control.

- In both cases, data from WGR's allowed early detection before process was impacted and allowed maintenance to be scheduled in orderly manner.

- Planned expansion of Non-Invasive Monitoring system at Calvert Cliffs:
  - Tank Water Level Indication
  - Transformer Trace Gas Monitoring
  - Radiation Resistant WGR
  - Temperature and Humidity Monitoring
  - Condenser Cooling Flow Measurement
  - Circ Pump Water Level Sensor
  - Cooling Water Intake (from Chesapeake Bay) Radar Level Transmission

WGR Current Deployments – Nuclear Generation

- Exelon:
  - Calvert Cliffs (180 units)
  - Braidwood (1 unit)
  - Nine Mile Point (125 units in-progress)
- Duke Energy: Fleetwide 11 Reactors (280 units)
- Xcel Energy: Fleetwide 3 Reactors (20 units)
- Ontario Power Generation: Pickering (8)

Appendix – Fault Detection Data*

*Data recreated based on records – not original time series data collected at Calvert Cliffs

AOV parameters captured by the Wireless Gauge Readers

Supply Pressure:
The pressure of the air from the air compressor. Normally the pressure is at a fairly constant 100 psi.

Output Pressure:
This pressure is used to open/close the valve, and ranges from 0 psi (valve fully open) to 100 psi (valve fully closed).

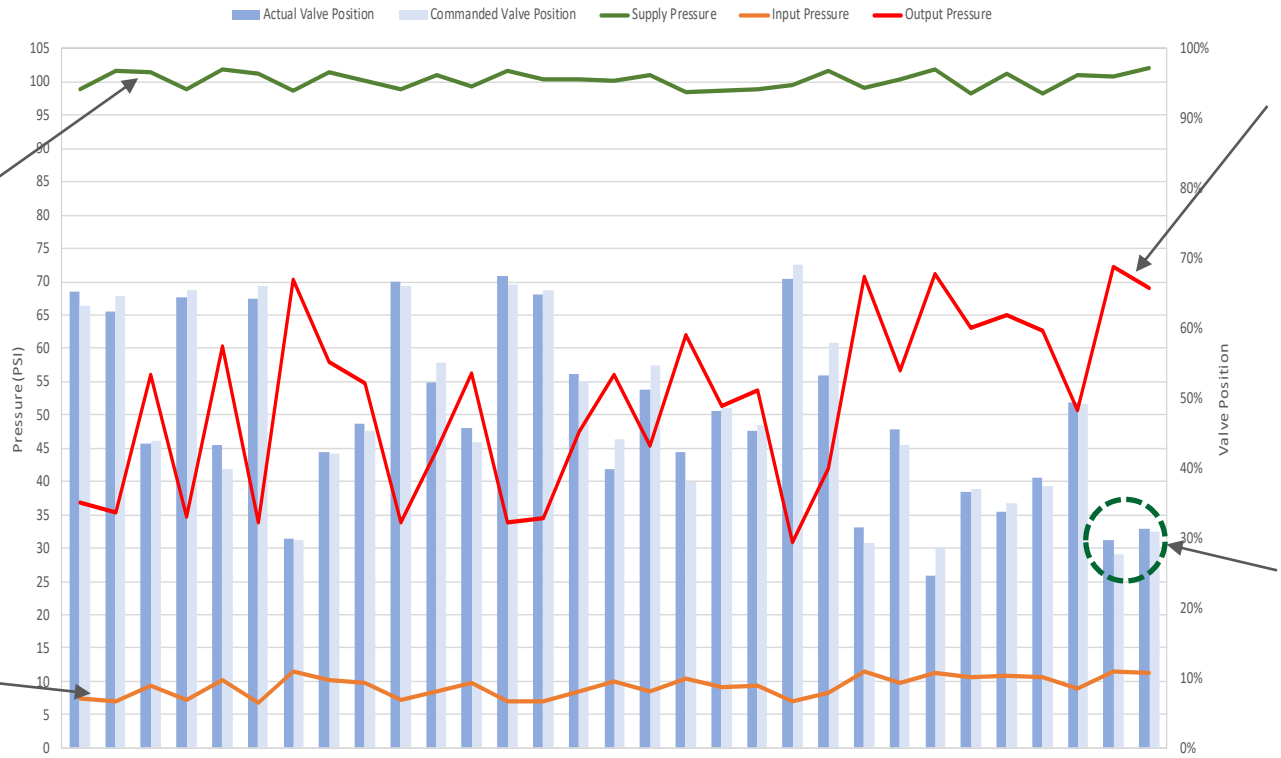
Input Pressure:
This is the control signal from the level controller to command the valve to the proper position. It ranges from 3 psi (valve fully open) to 15 psi (valve fully closed).

Valve Position:
This is the actual position of the valve actuator, seen through the view port. 0% is fully closed. 100% is fully open.

Normal Operation

1. Supply Pressure at 100 psi

2. Input Pressure is received from level controller – modulating between 3 psi and 15 psi depending on water level.



3. Output Pressure is responding to Input Pressure signal – 3 psi Input Pressure equates to 0 psi Output pressure. 15 psi Input Pressure equates to 100 psi Output pressure.

4. Actual Valve Position matches Commanded Valve Position (blue bars)

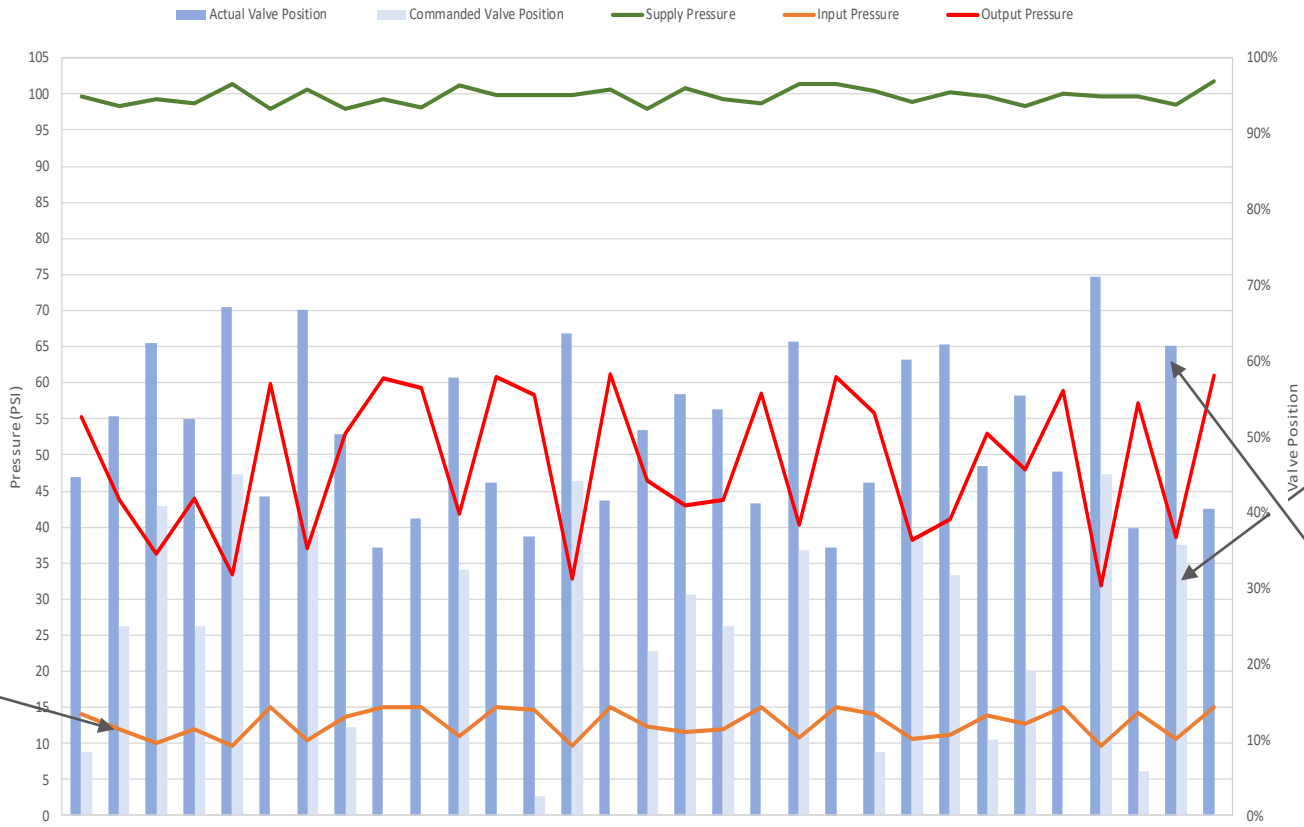
Time	5:15	5:30	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45
Supply Pressure	99	102	101	99	102	101	99	101	100	99	101	99	102	100	100	100	101	98	99	99	100	102	99	100	102	98	101	98	101	101	102
Input Pressure	7.5	7.0	9.4	7.2	10.1	6.8	11.4	10.1	9.8	7.3	8.5	9.7	6.9	7.1	8.5	9.9	8.5	10.5	9.2	9.3	6.9	8.2	11.4	9.8	11.2	10.6	10.9	10.6	9.0	11.4	11.3
Output Pressure	36.9	35.3	56.0	34.6	60.2	33.8	70.3	58.0	54.7	33.9	44.8	56.2	33.8	34.6	47.5	56.0	45.4	62.0	51.4	53.8	30.8	42.0	70.8	56.7	71.2	63.0	64.9	62.6	50.7	72.3	69.1
Actual Valve Position	65%	62%	44%	64%	43%	64%	30%	42%	46%	67%	52%	46%	67%	65%	53%	40%	51%	42%	48%	45%	67%	53%	32%	46%	25%	37%	34%	39%	50%	30%	31%
Commanded Valve Position	63%	65%	44%	65%	40%	66%	30%	42%	45%	66%	55%	44%	66%	65%	53%	44%	55%	38%	49%	46%	69%	58%	29%	43%	29%	37%	35%	37%	49%	28%	31%

Failure Mode: Ruptured Diaphragm

Failure Sequence and Indicators (small rupture):

- A ruptured diaphragm will introduce an air leak which will cause the Output Pressure to be lower than normal.
- As a result, the drain valve will *open* more than it should, and the tank water level will decrease.
- The level controller (which sends the Input Pressure to the AOV) will try to compensate for the lower water level and increase the Input Pressure to try to close the drain valve and maintain the water level setpoint.
- The Output Pressure will respond to the higher Input Pressure signal to close the valve - but because of the leak, it is *less closed* than normal.
- Unlike a normally operating valve where the ***actual*** valve position corresponds closely with the ***commanded*** valve position, the valve with a diaphragm rupture tends to be more open i.e. draining more water, than nominal.

Ruptured Diaphragm – Failure Signature



1. Mean Input Pressure is higher than normal to try to compensate for lower tank level.

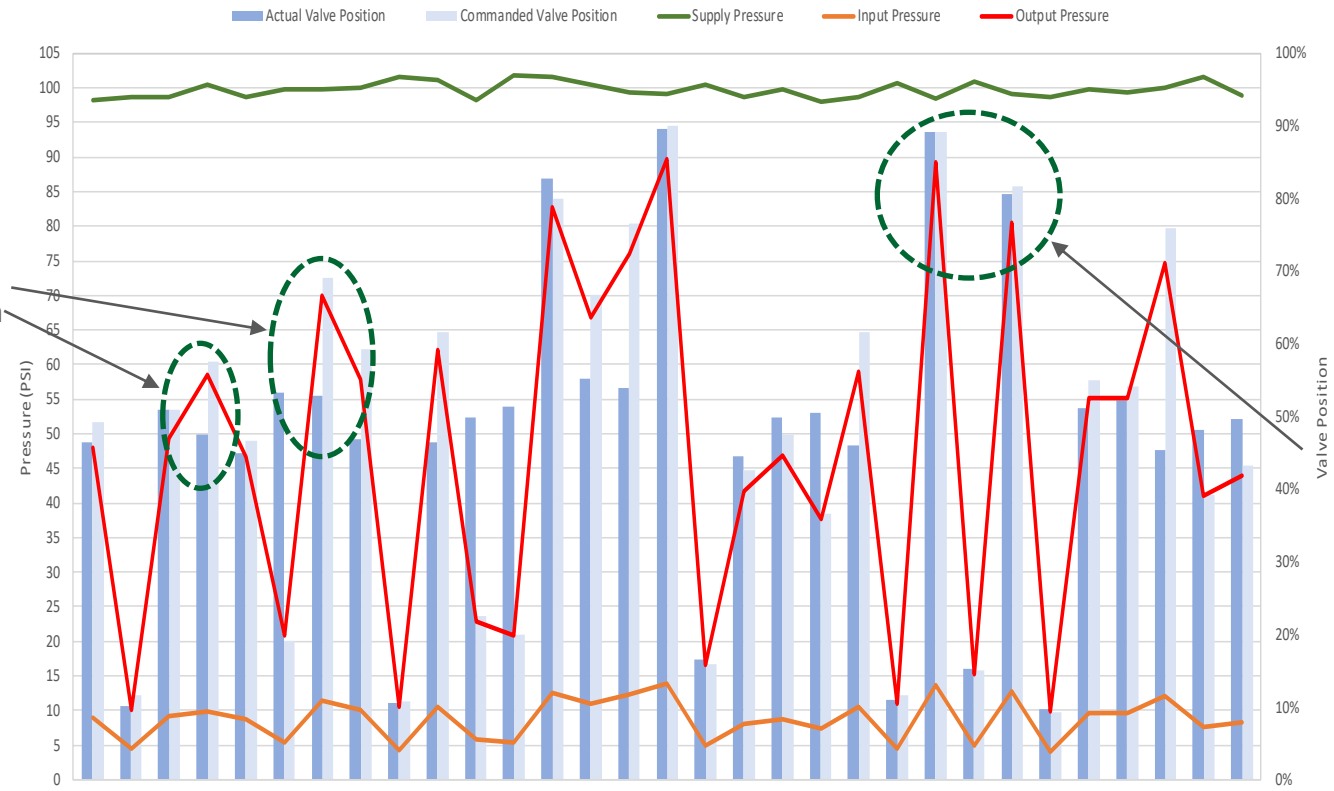
3. ***Commanded*** Valve Position (based on Input Pressure) is more closed than normal.

4. But ***actual*** valve position is more open vs. Commanded valve position, due to air leak.

Time	5:15	5:30	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45
Supply Pressure	100	98	99	99	102	98	101	98	99	98	101	100	100	100	101	98	101	99	99	101	102	100	99	100	100	98	100	100	100	99	102
Input Pressure	14.0	12.0	10.1	12.0	9.6	15.0	10.5	13.6	15.0	15.0	11.1	15.0	14.7	9.7	15.0	12.4	11.5	12.0	15.0	10.8	15.0	14.0	10.6	11.2	13.8	12.7	15.0	9.6	14.3	10.7	15.0
Output Pressure	55.2	43.7	36.4	43.9	33.4	59.8	37.1	52.9	60.7	59.3	41.8	60.7	58.4	32.8	61.2	46.4	42.9	43.8	58.5	40.4	60.9	55.8	38.2	41.1	52.9	47.9	58.8	31.9	57.1	38.7	61.1
Actual Valve Position	45%	53%	62%	52%	67%	42%	67%	50%	35%	39%	58%	44%	37%	64%	42%	51%	56%	54%	41%	63%	35%	44%	60%	62%	46%	55%	45%	71%	38%	62%	41%
Commanded Valve Position	8%	25%	41%	25%	45%	0%	38%	12%	0%	0%	33%	0%	3%	44%	0%	22%	29%	25%	0%	35%	0%	8%	37%	32%	10%	19%	0%	45%	6%	36%	0%

Worn out Cam (groove) – Failure Signature

1. Valve tends to get stuck in middle range (around 50% open) where groove is, and does not respond to Output Pressure.



Time	5:15	5:30	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45
Supply Pressure	98	99	99	101	99	100	100	100	102	101	98	102	102	100	99	99	101	99	100	98	99	101	98	101	99	99	100	99	100	102	99
Input Pressure	8.9	4.4	9.1	9.9	8.6	5.3	11.3	10.1	4.3	10.4	5.7	5.4	12.6	11.0	12.2	13.8	4.9	8.1	8.7	7.4	10.4	4.4	13.7	4.8	12.8	4.1	9.6	9.5	12.1	7.7	8.2
Output Pressure	47.9	10.1	49.3	58.5	46.7	20.7	70.0	57.9	10.5	62.1	22.8	20.8	82.8	66.7	76.0	89.7	16.5	41.7	46.9	37.6	59.0	11.0	89.2	15.3	80.5	9.7	55.1	55.1	74.6	41.0	44.0
Actual Valve Position	47%	10%	51%	47%	45%	53%	53%	47%	11%	47%	50%	51%	83%	55%	54%	90%	17%	45%	50%	51%	46%	11%	89%	15%	81%	10%	51%	52%	45%	48%	50%
Commanded Valve Position	49%	12%	51%	58%	47%	19%	69%	59%	11%	62%	23%	20%	80%	67%	77%	90%	16%	43%	48%	37%	62%	12%	89%	15%	82%	9%	55%	54%	76%	39%	43%

2. When Output Pressure is sufficiently high (or low), the force is enough to enable the cam follower to “jump” out of the groove and modulate correctly.