Jacobs Challenging today. Reinventing tomorrow.

I&C 101

Stephanie McGregor/Jacobs

Agenda

I&C 101

- Design drawings
- Hardware
- Software
- PIDs

Why I&C?

My I&C story

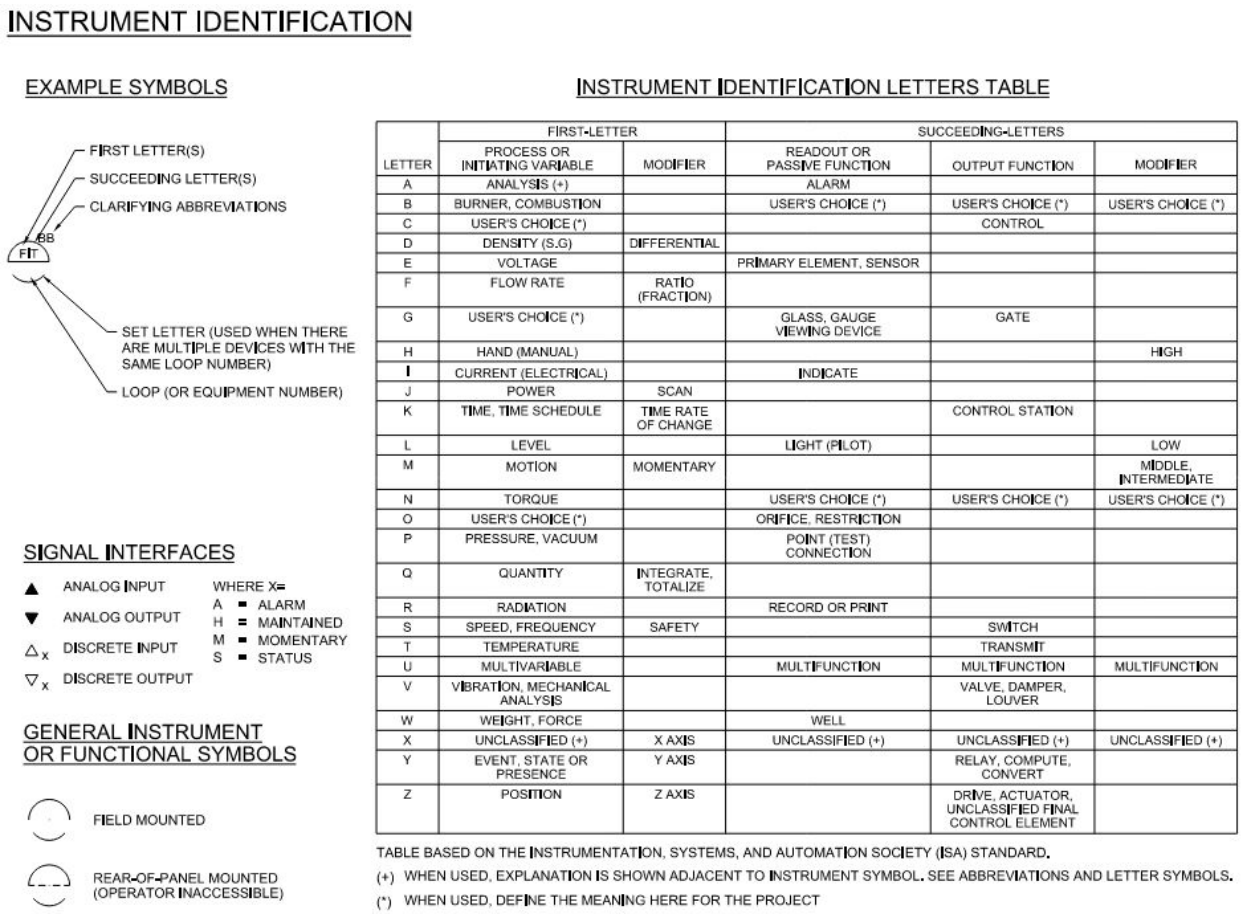
Starting up the Woodland Davis WTP in 2016

Lahaina WWRF commissioning in 2022

Design drawings

P&IDs – When in doubt, check the P&ID!

- Refer to project specific legend sheet
- If it's not captured correctly on the P&ID then don't expect it to get built correctly
- Shows
  - Equipment
  - Manufacturer provided equipment & cables
  - Tags
  - Power requirements
  - IO signals
  - Flow path



INSTRUMENT IDENTIFICATION

EXAMPLE SYMBOLS

SIGNAL INTERFACES

▲ ANALOG INPUT
▼ ANALOG OUTPUT
$\triangle_X$ DISCRETE INPUT
∇_X DISCRETE OUTPUT

WHERE X=
A = ALARM
H = MAINTAINED
M = MOMENTARY
S = STATUS

GENERAL INSTRUMENT OR FUNCTIONAL SYMBOLS

FIELD MOUNTED

REAR-OF-PANEL MOUNTED (OPERATOR INACCESSIBLE)

INSTRUMENT IDENTIFICATION LETTERS TABLE

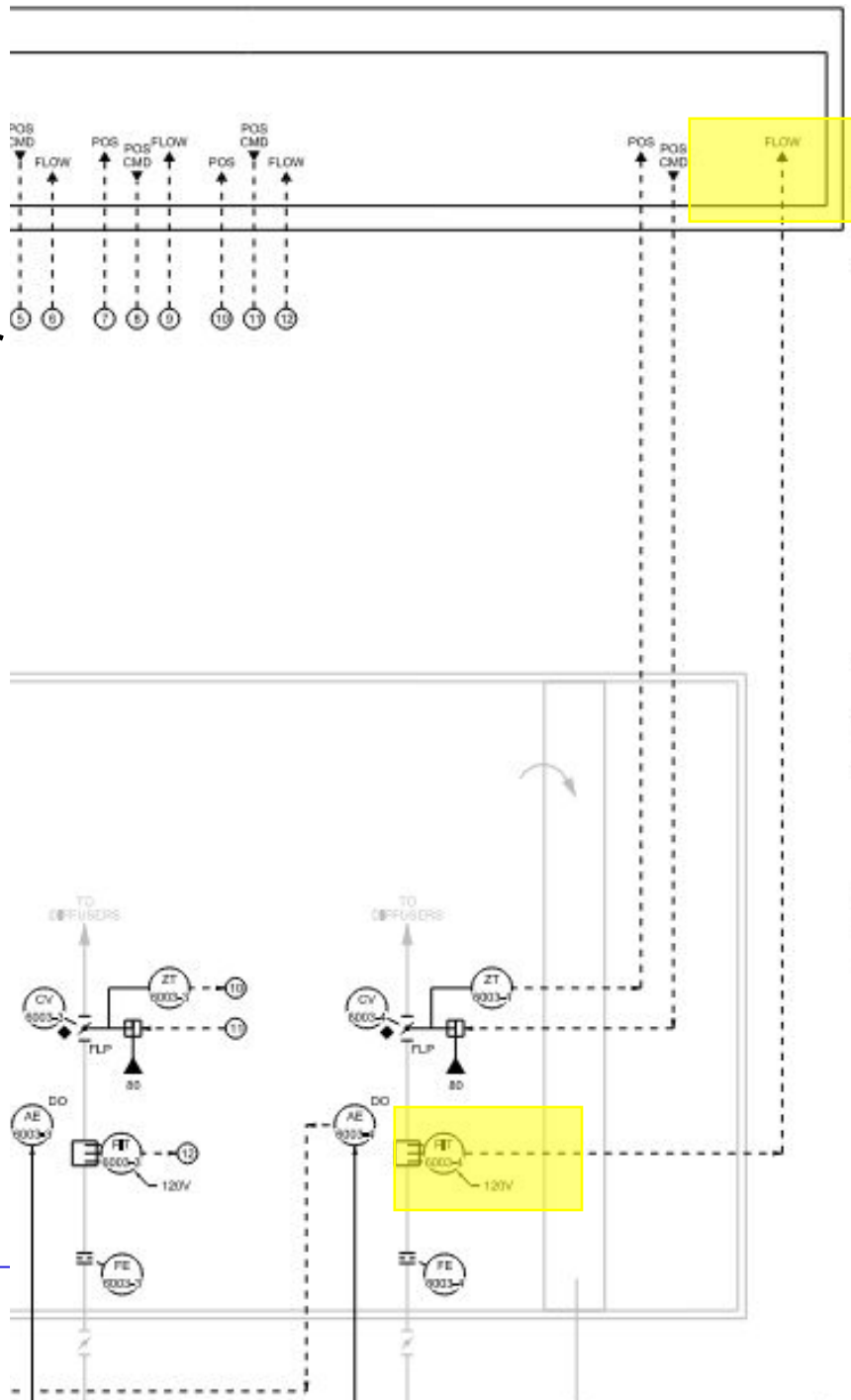
LETTER	FIRST-LETTER		SUCCEEDING-LETTERS		
	PROCESS OR INITIATING VARIABLE	MODIFIER	READOUT OR PASSIVE FUNCTION	OUTPUT FUNCTION	MODIFIER
A	ANALYSIS (+)		ALARM		
B	BURNER, COMBUSTION		USER'S CHOICE (*)	USER'S CHOICE (*)	USER'S CHOICE (*)
C	USER'S CHOICE (*)			CONTROL	
D	DENSITY (S.G)	DIFFERENTIAL			
E	VOLTAGE		PRIMARY ELEMENT, SENSOR		
F	FLOW RATE	RATIO (FRACTION)			
G	USER'S CHOICE (*)		GLASS, GAUGE VIEWING DEVICE	GATE	
H	HAND (MANUAL)				HIGH
I	CURRENT (ELECTRICAL)		INDICATE		
J	POWER	SCAN			
K	TIME, TIME SCHEDULE	TIME RATE OF CHANGE		CONTROL STATION	
L	LEVEL		LIGHT (PILOT)		LOW
M	MOTION	MOMENTARY			MIDDLE, INTERMEDIATE
N	TORQUE		USER'S CHOICE (*)	USER'S CHOICE (*)	USER'S CHOICE (*)
O	USER'S CHOICE (*)		ORIFICE, RESTRICTION		
P	PRESSURE, VACUUM		POINT (TEST) CONNECTION		
Q	QUANTITY	INTEGRATE, TOTALIZE			
R	RADIATION		RECORD OR PRINT		
S	SPEED, FREQUENCY	SAFETY		SWITCH	
T	TEMPERATURE			TRANSMIT	
U	MULTIVARIABLE		MULTIFUNCTION	MULTIFUNCTION	MULTIFUNCTION
V	VIBRATION, MECHANICAL ANALYSIS			VALVE, DAMPER, LOUVER	
W	WEIGHT, FORCE		WELL		
X	UNCLASSIFIED (+)	X AXIS	UNCLASSIFIED (+)	UNCLASSIFIED (+)	UNCLASSIFIED (+)
Y	EVENT, STATE OR PRESENCE	Y AXIS		RELAY, COMPUTE, CONVERT	
Z	POSITION	Z AXIS		DRIVE, ACTUATOR, UNCLASSIFIED FINAL CONTROL ELEMENT	

TABLE BASED ON THE INSTRUMENTATION, SYSTEMS, AND AUTOMATION SOCIETY (ISA) STANDARD.
(+) WHEN USED, EXPLANATION IS SHOWN ADJACENT TO INSTRUMENT SYMBOL. SEE ABBREVIATIONS AND LETTER SYMBOLS.
(*) WHEN USED, DEFINE THE MEANING HERE FOR THE PROJECT

Portion of example P&ID legend sheet

P&IDs

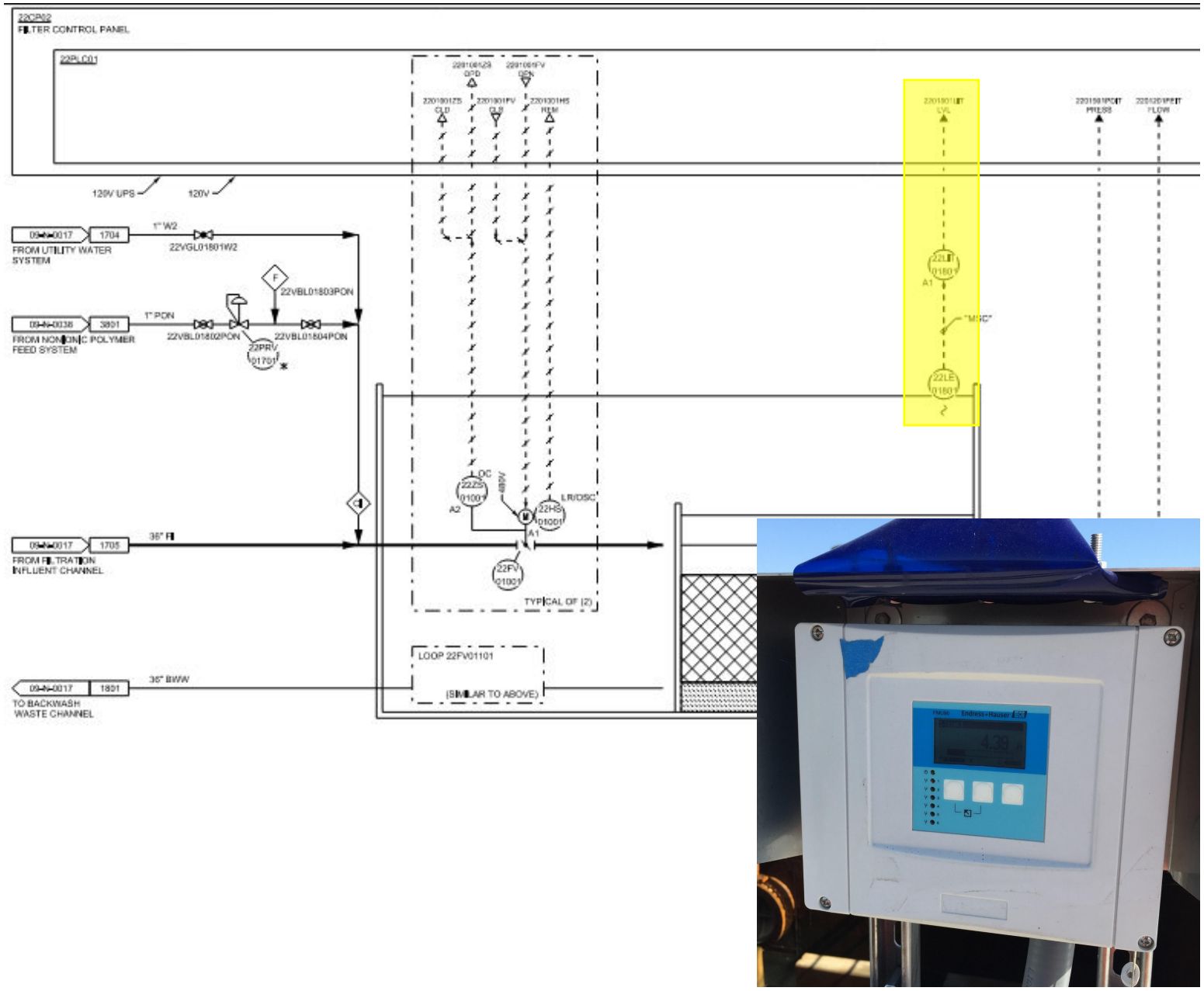
- FIT
  - Flow Indicating Transmitter



Air flow meter

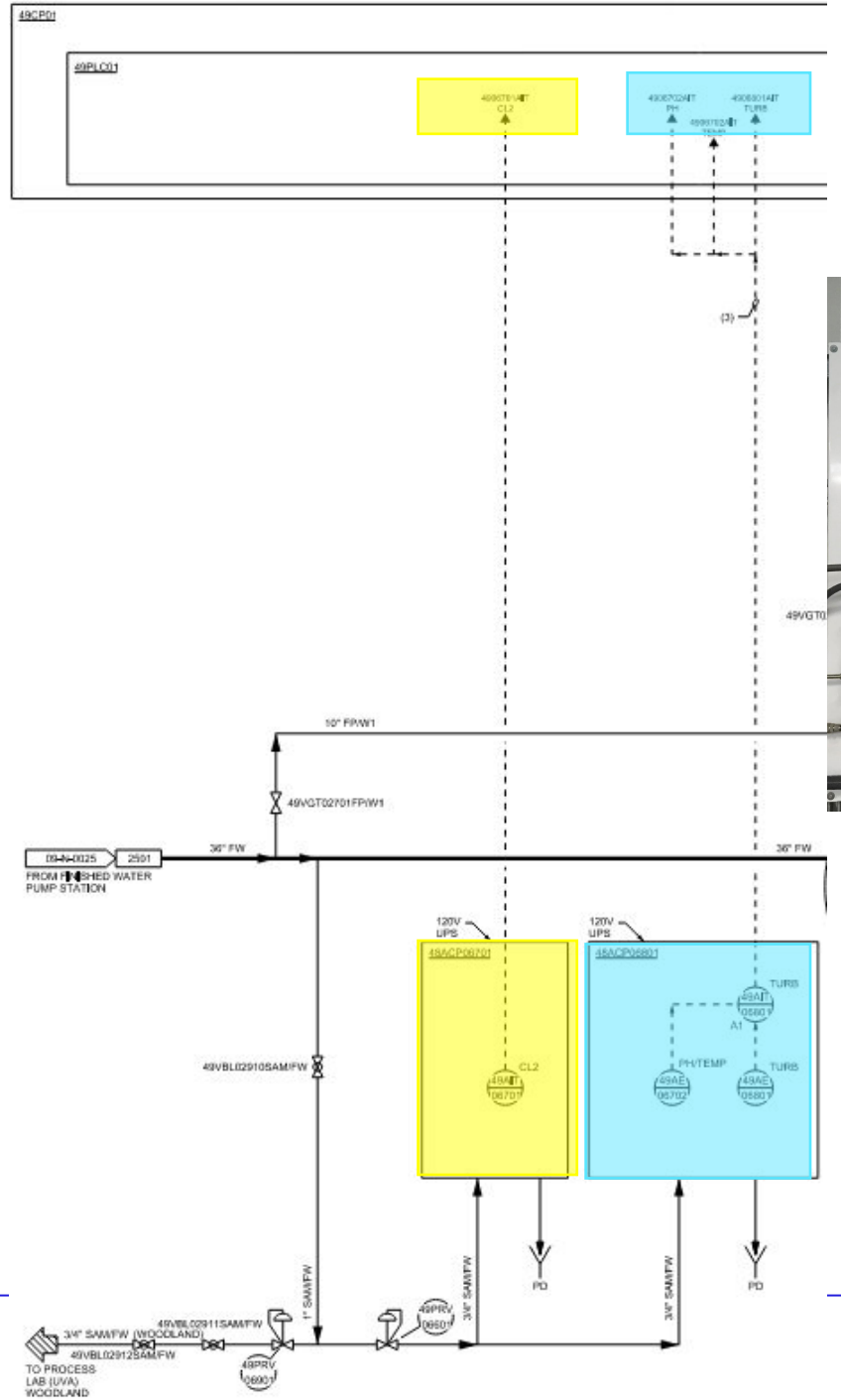
P&IDs

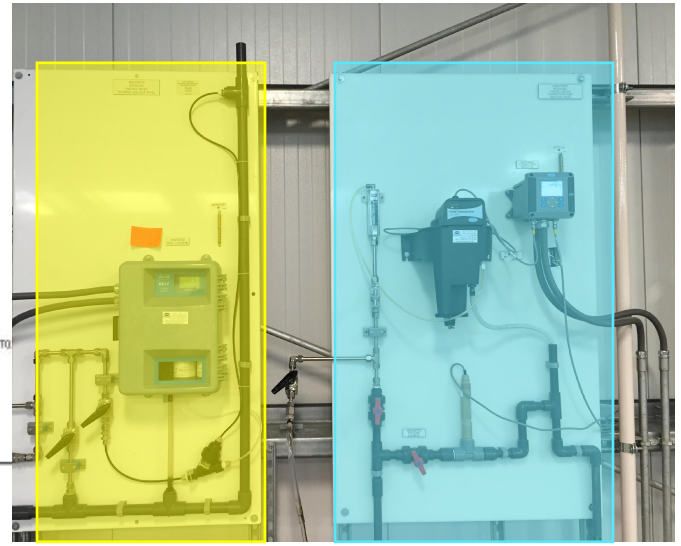
- LIT
  - Level Indicating Transmitter



P&IDs

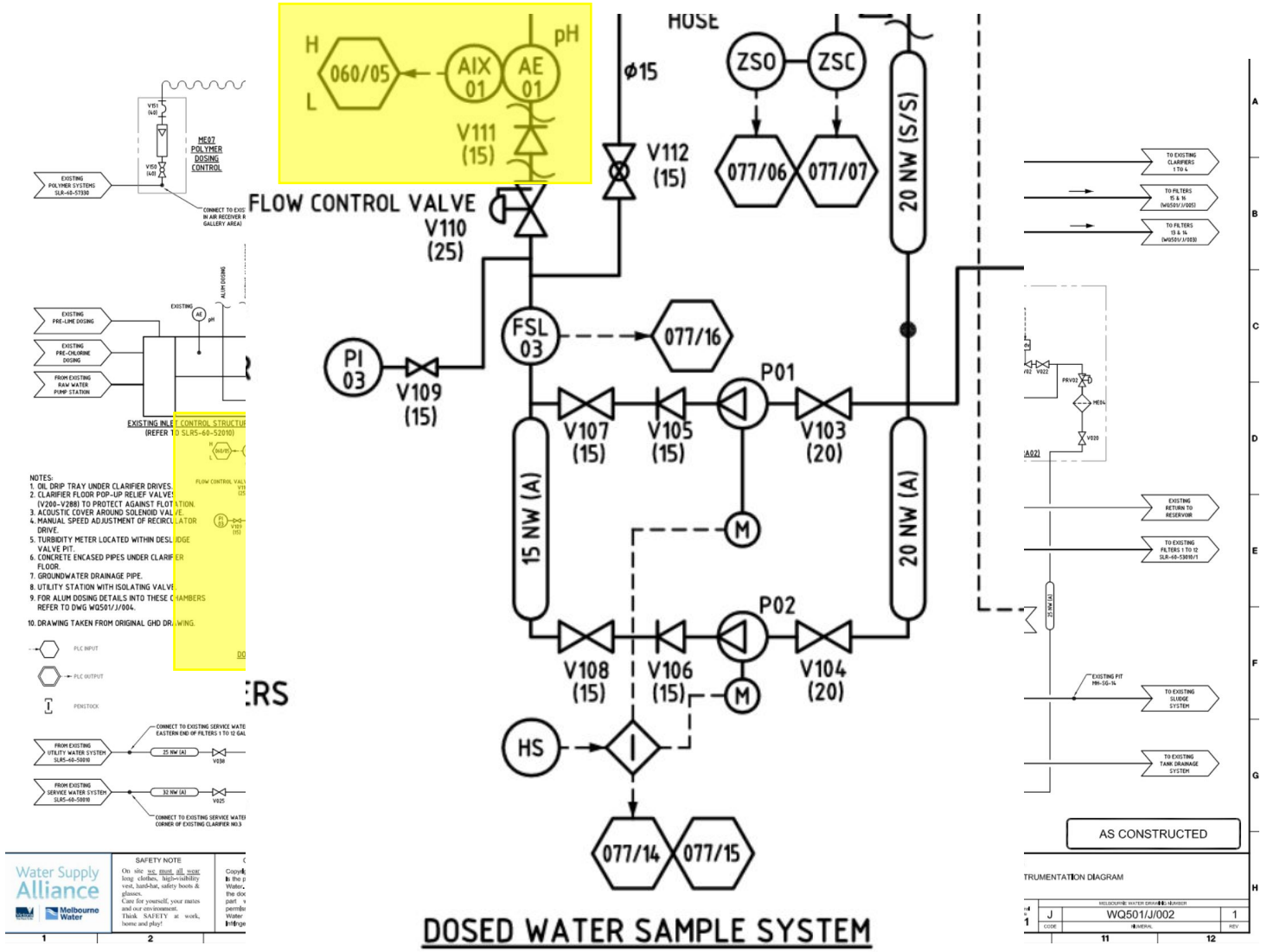
- AIT
  - Analyzer Indicating Transmitter
  - Subscript for type





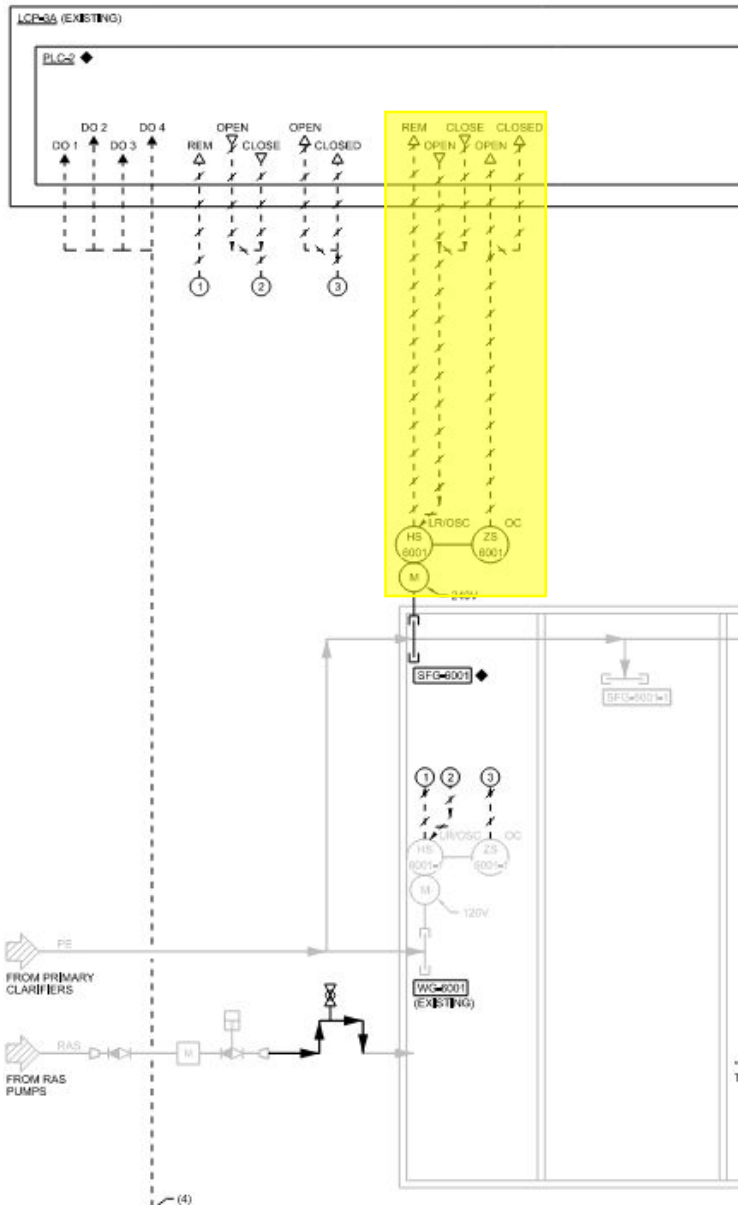
P&IDs

- Lots of different P&ID flavors, but they all communicate critical information



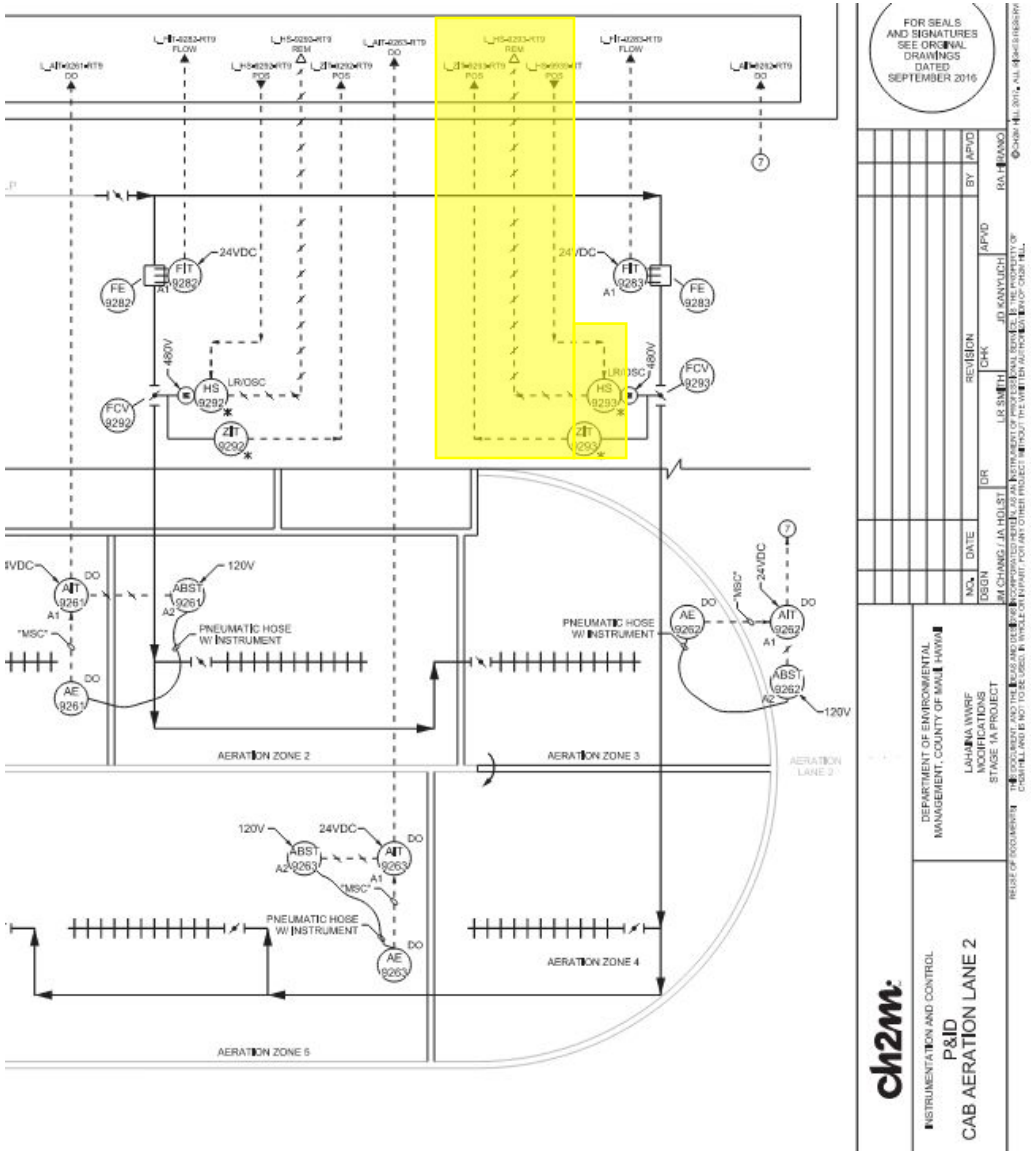
P&IDs

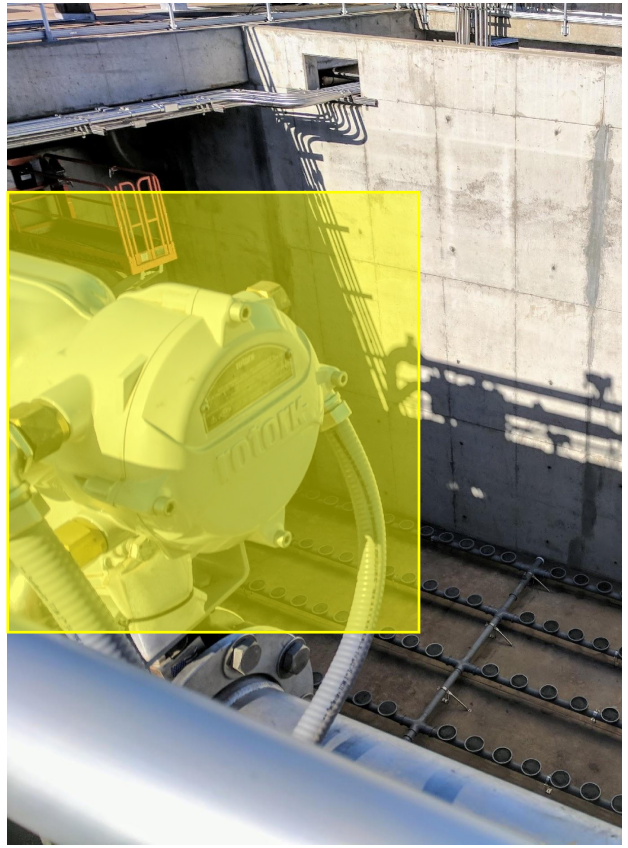
- Valve/gate actuators
  - Open Close (OC)
    - Discrete open/close command and feedback



P&IDs

- Valve/gate actuators
  - Modulating
    - Analog position command and feedback

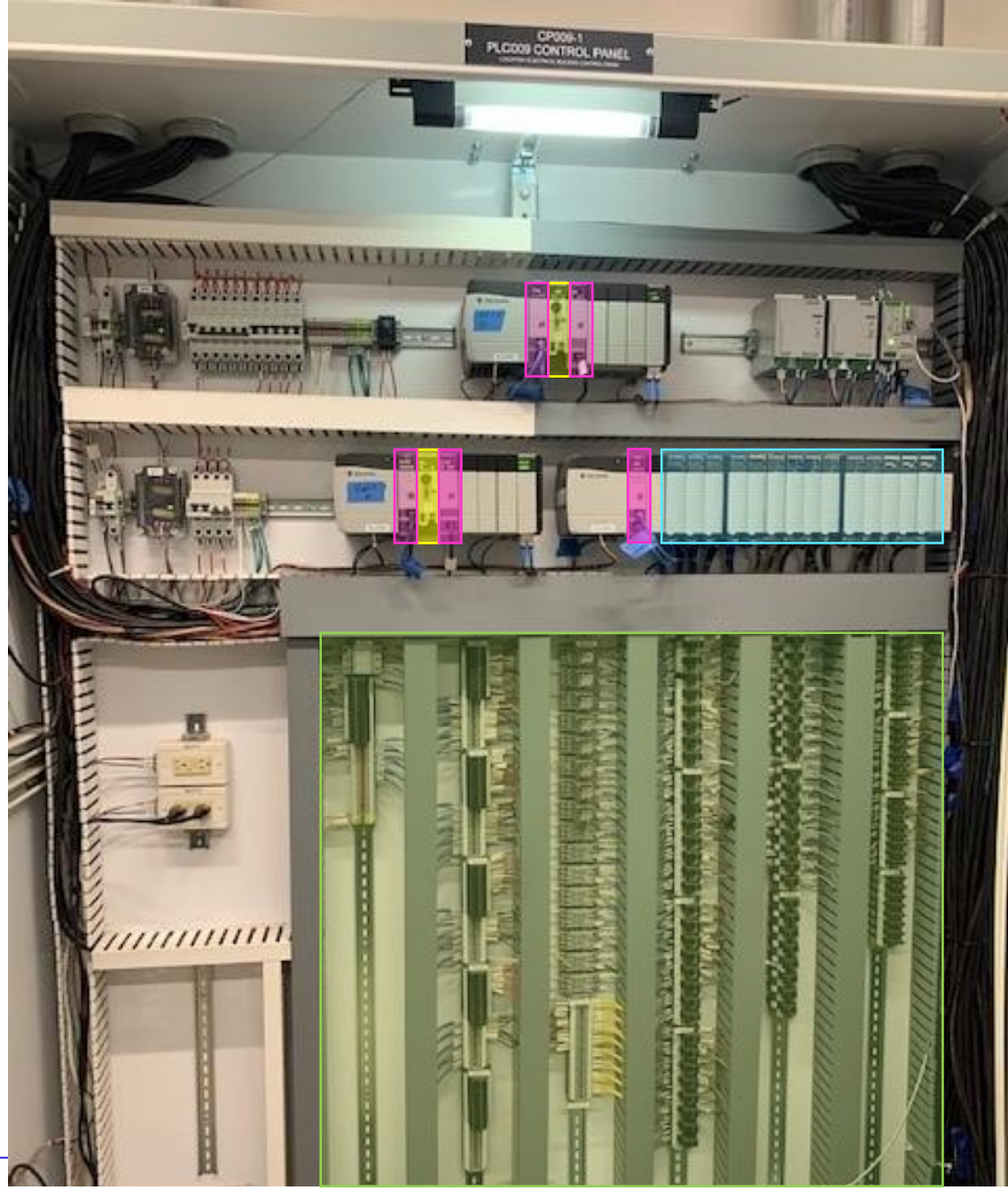




Hardware and associated drawings

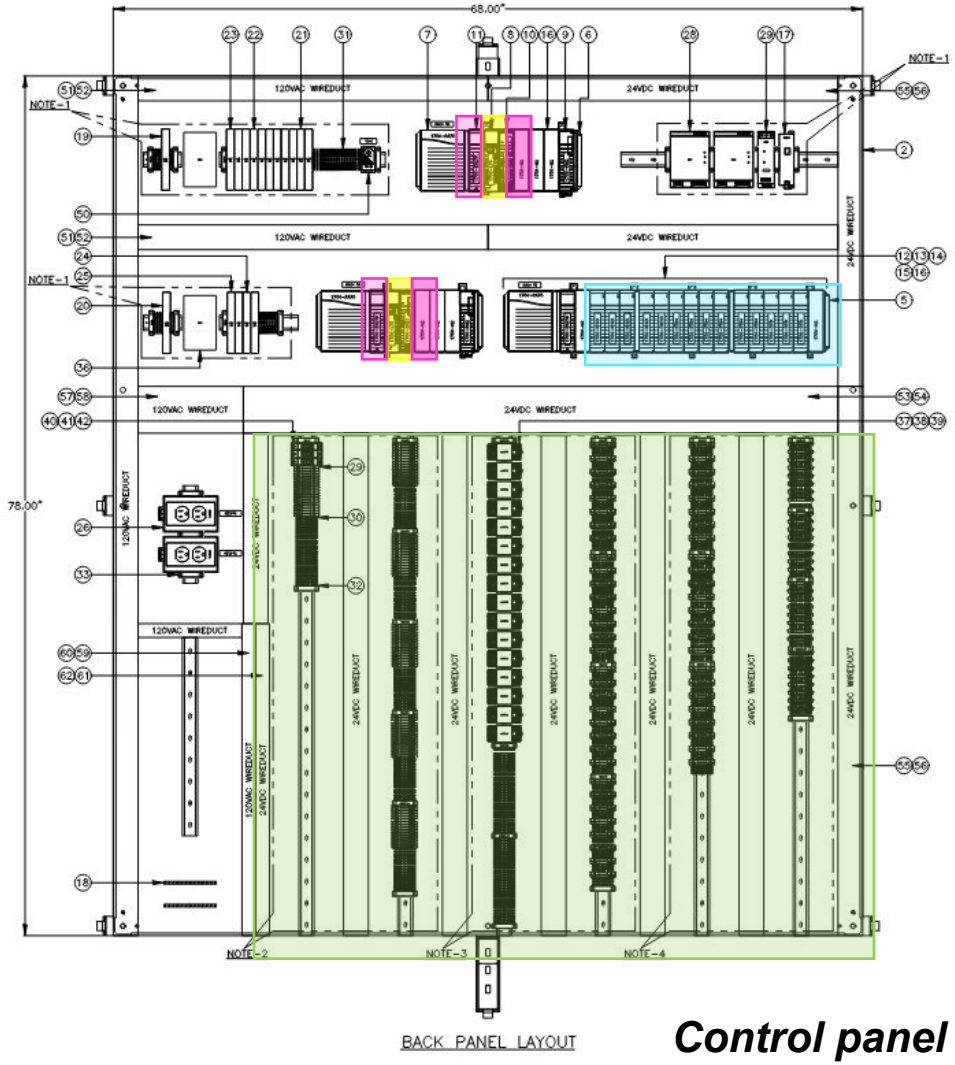
Control Panels

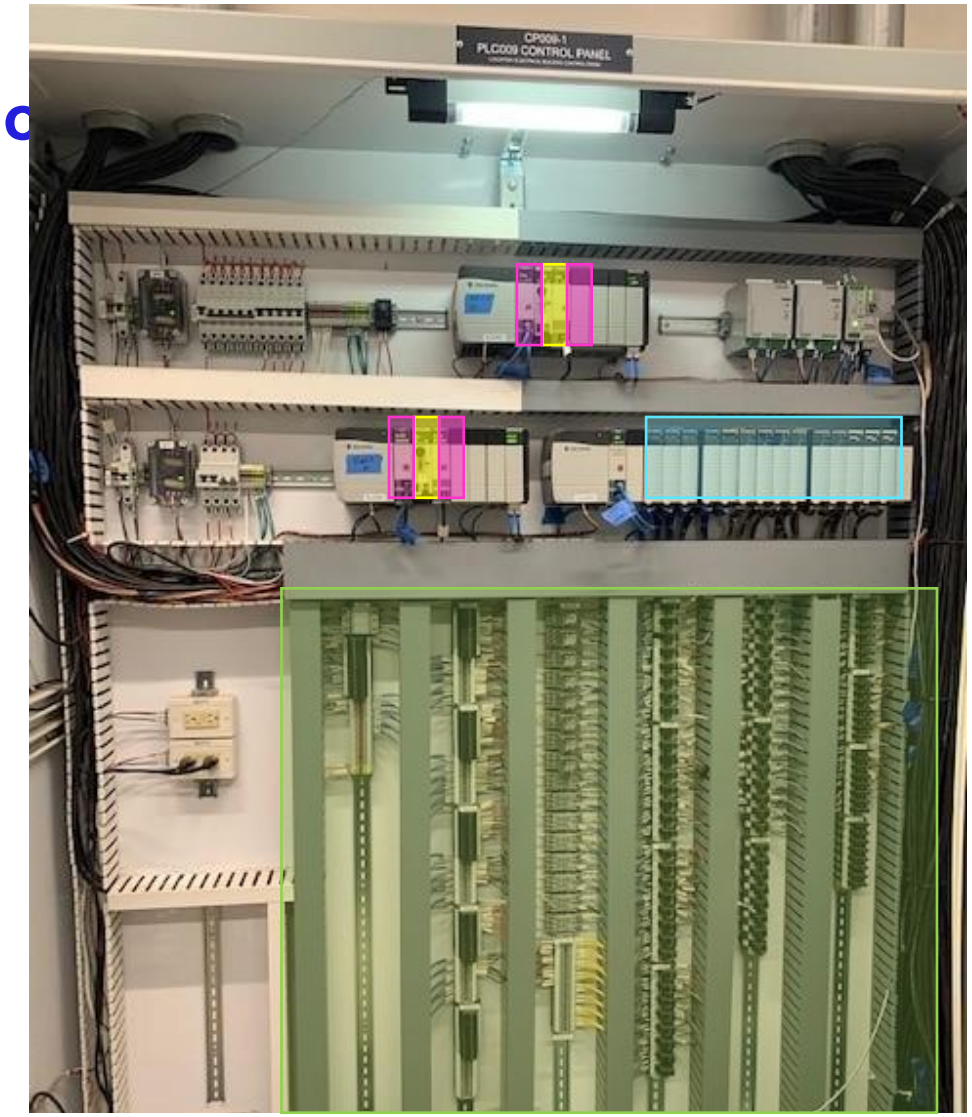
- PLC (Programmable Logic Controller)
  - Processor programmed to control equipment
    - Redundant PLCs in photo
- Communication cards
  - Connects PLC to SCADA
  - Connects remote IO racks
- IO cards (Input/Output)
  - Receive signals from terminal blocks and sends to PLC
- Terminal blocks
  - Where wires to/from the field are landed



Allen Bradley PLC hardware

Control Panels – Where do the IO signals go

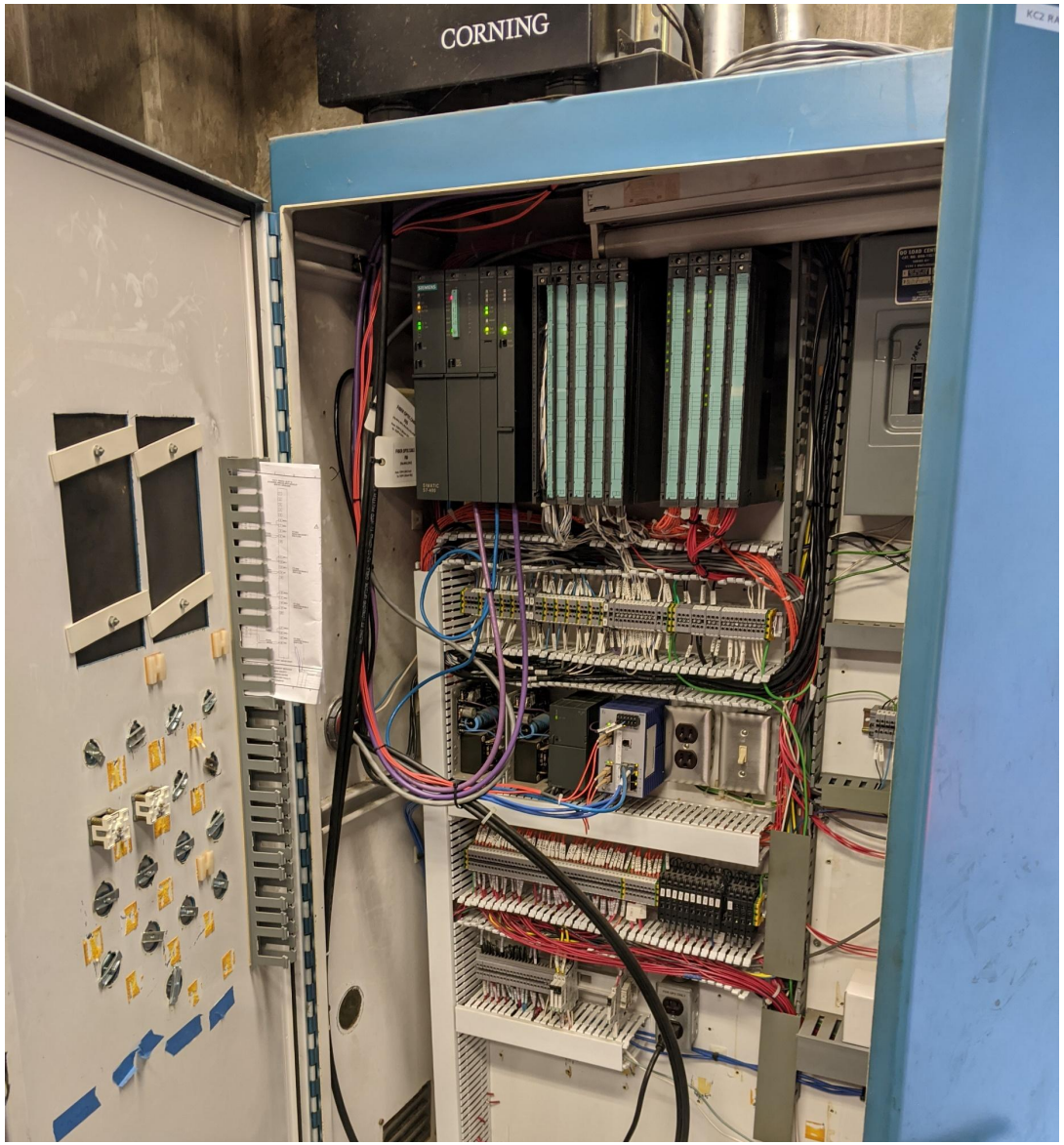




Control panel drawing and photo

Control panels

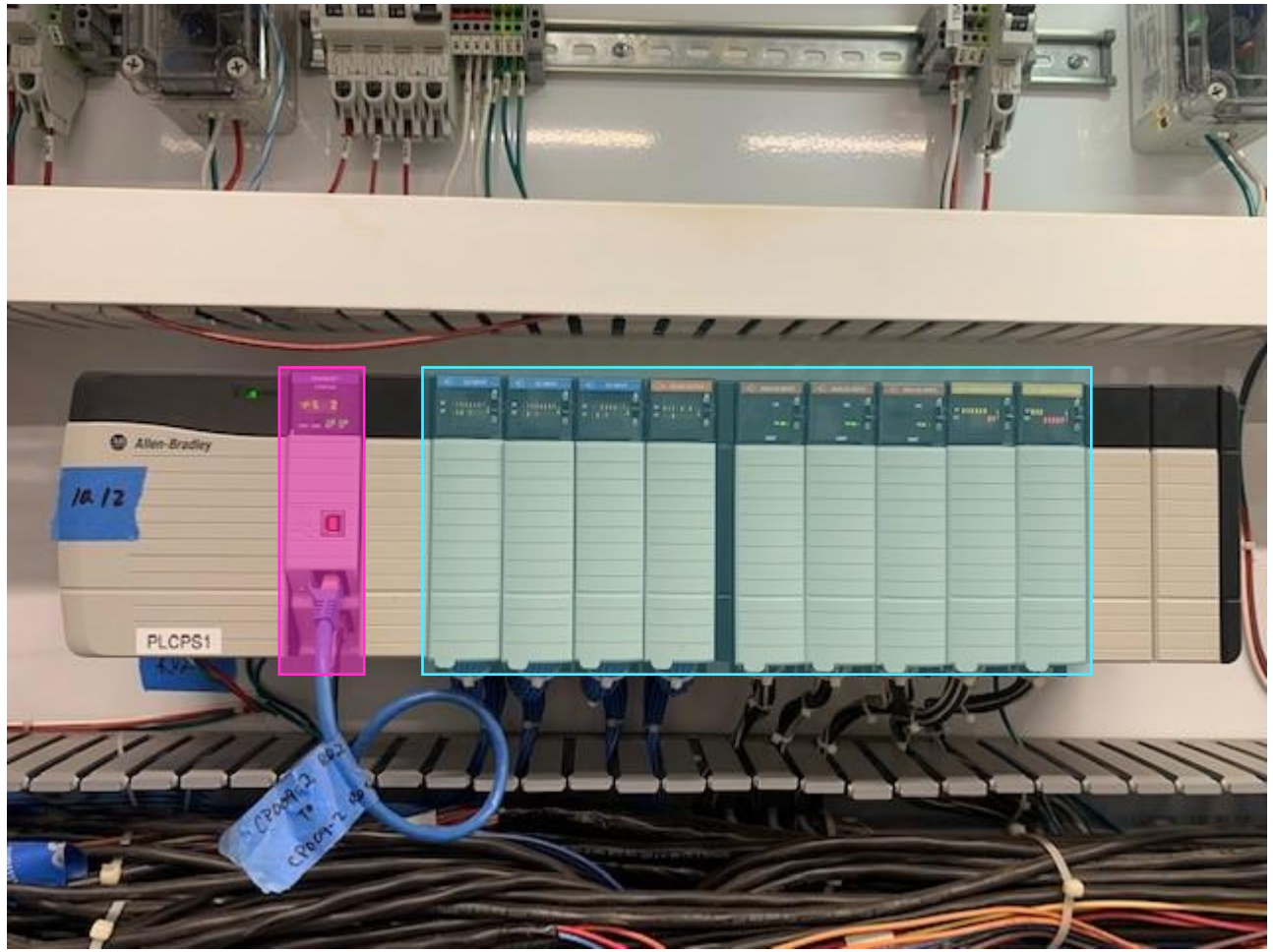
- Common PLC manufacturers
  - Allen-Bradley
  - Siemens
  - Schneider Electric (Modicon)
  - Honeywell
  - Emerson
- Common communication protocols
  - EthernetIP
  - Modbus
  - Profibus
  - HART



Siemens PLC hardware (prior to upgrade)

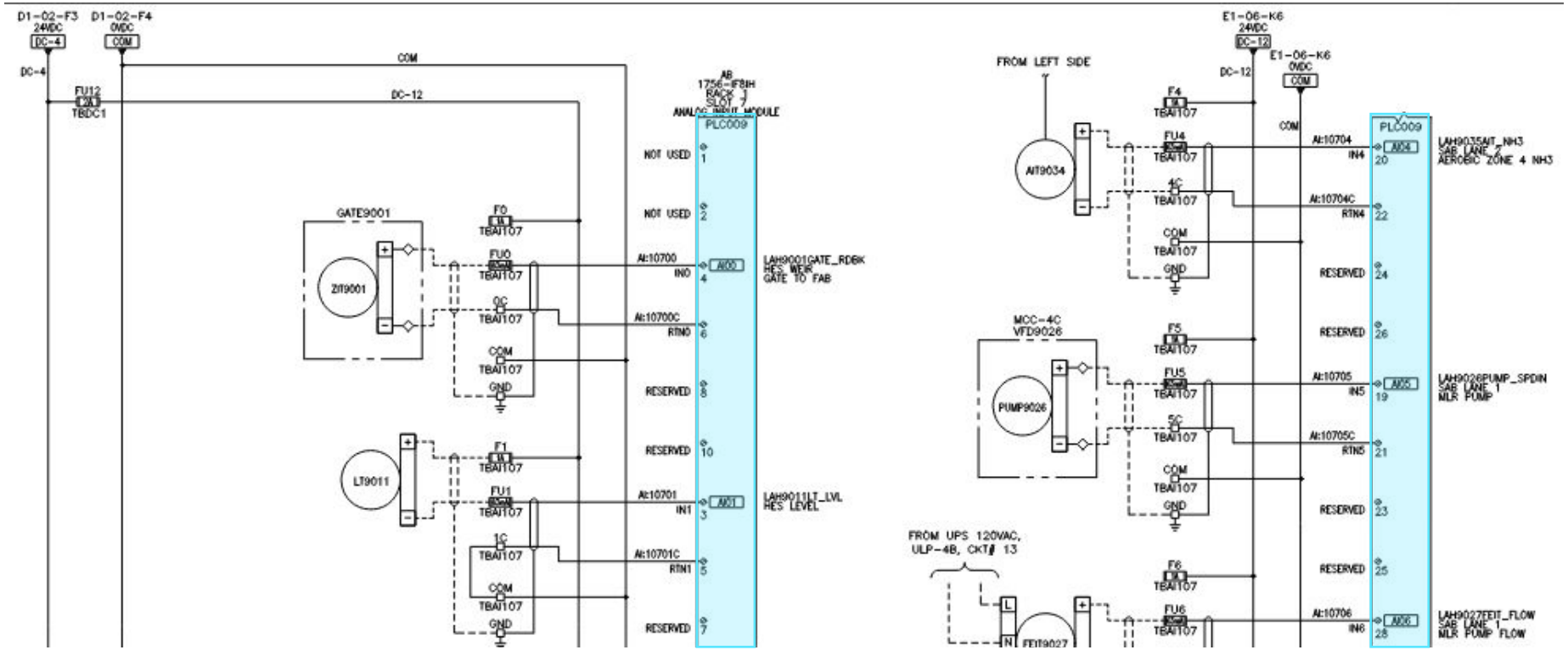
Types of IO

- Discrete Input (DI)
  - Input from field to PLC
  - 0 or 1
  - Ex: Open valve feedback where 1 = Opened
- Discrete Output (DO)
  - Output from PLC to field
  - 0 or 1
  - Ex: Open valve command where 1 = Open
- Analog Input (AI)
  - Input from field to PLC
  - 4 to 20 mA signal scaled to process value
  - Ex: Flow value
- Analog Output (AO)
  - Output from field to PLC
  - Process value scaled to 4 to 20 mA signal
  - Ex: Pump speed command



Allen-Bradley IO cards

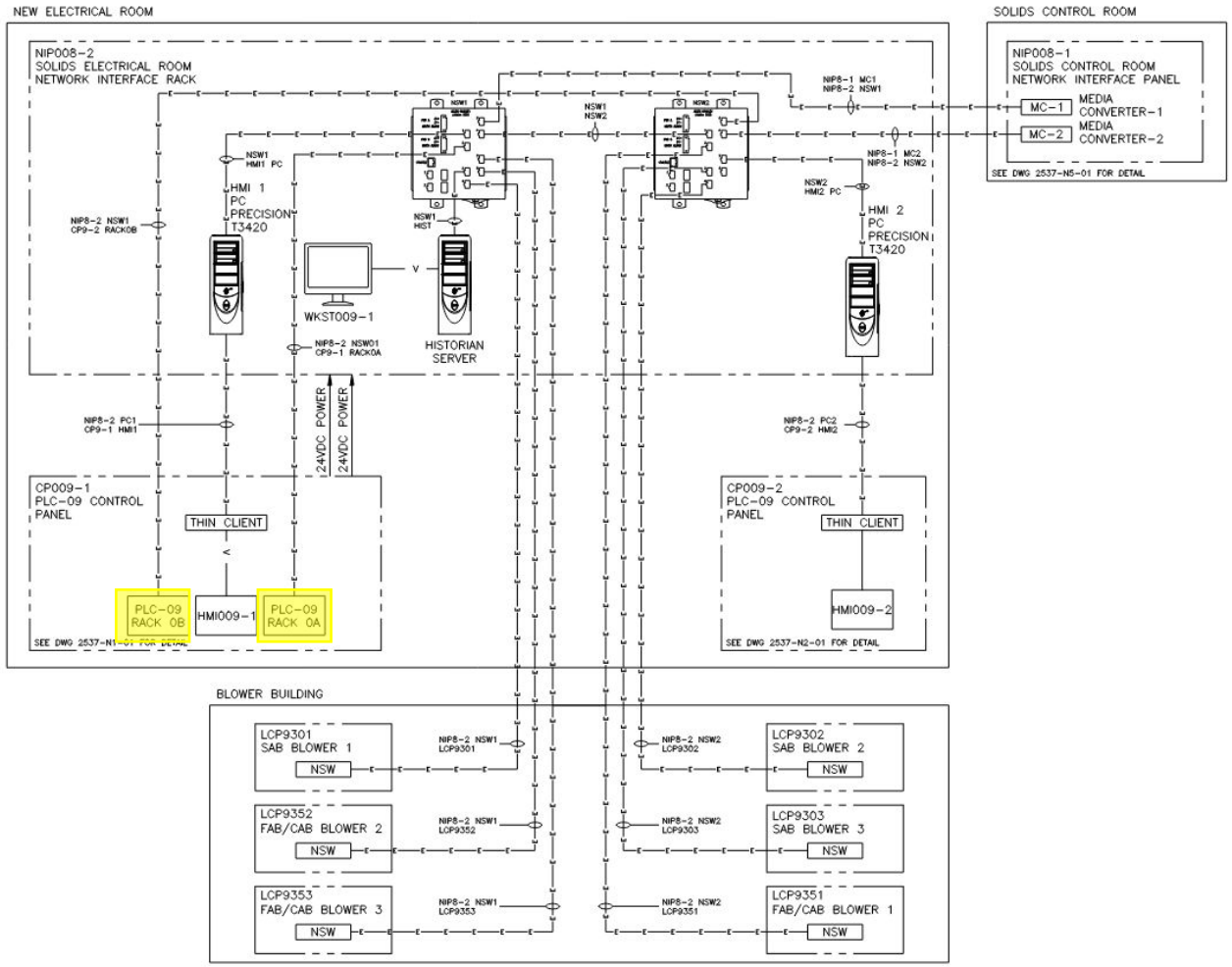
Wiring diagrams – How are the IO signals wired from the field to the control panel?



Analog Input (AI) wiring diagram – shows where field wires land on terminal blocks and wiring from terminal block to AI IO card

Network block diagrams – How does the control system communicate?

- PLC network stand alone and protected by firewall
  - Secure remote access via multi-factor authentication

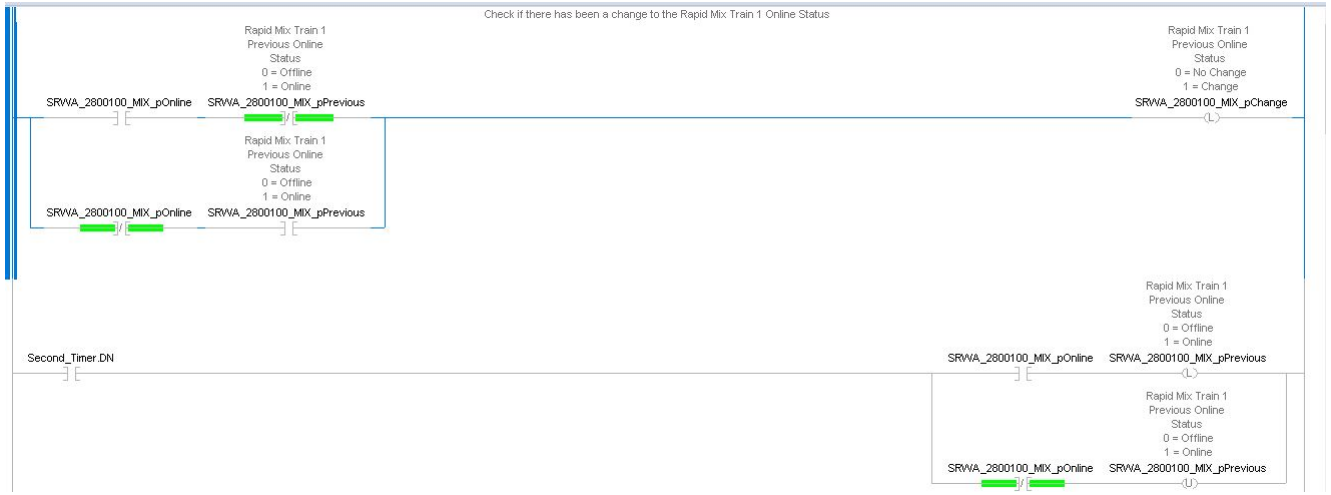


Network block diagram showing connectivity between master PLC, HMI, SCADA and blower P

Software

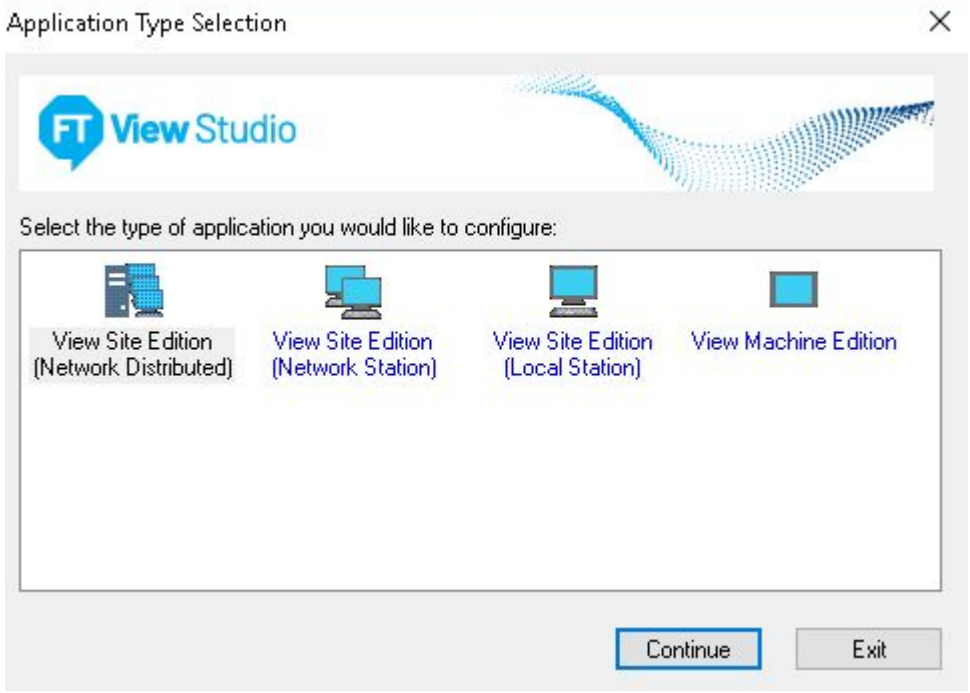
PLC

- Programmable Logic Controllers (PLCs)
  - Software to program how the plant is controlled
- Commonly used software used
  - Studio 5000 by Rockwell for Allen-Bradley PLCs
  - TIA Portal for Siemens PLCs
  - Concept for Modicon
- PLC programming languages
  - Ladder diagram
  - Function block diagram
  - Sequential function chart
  - Structured text

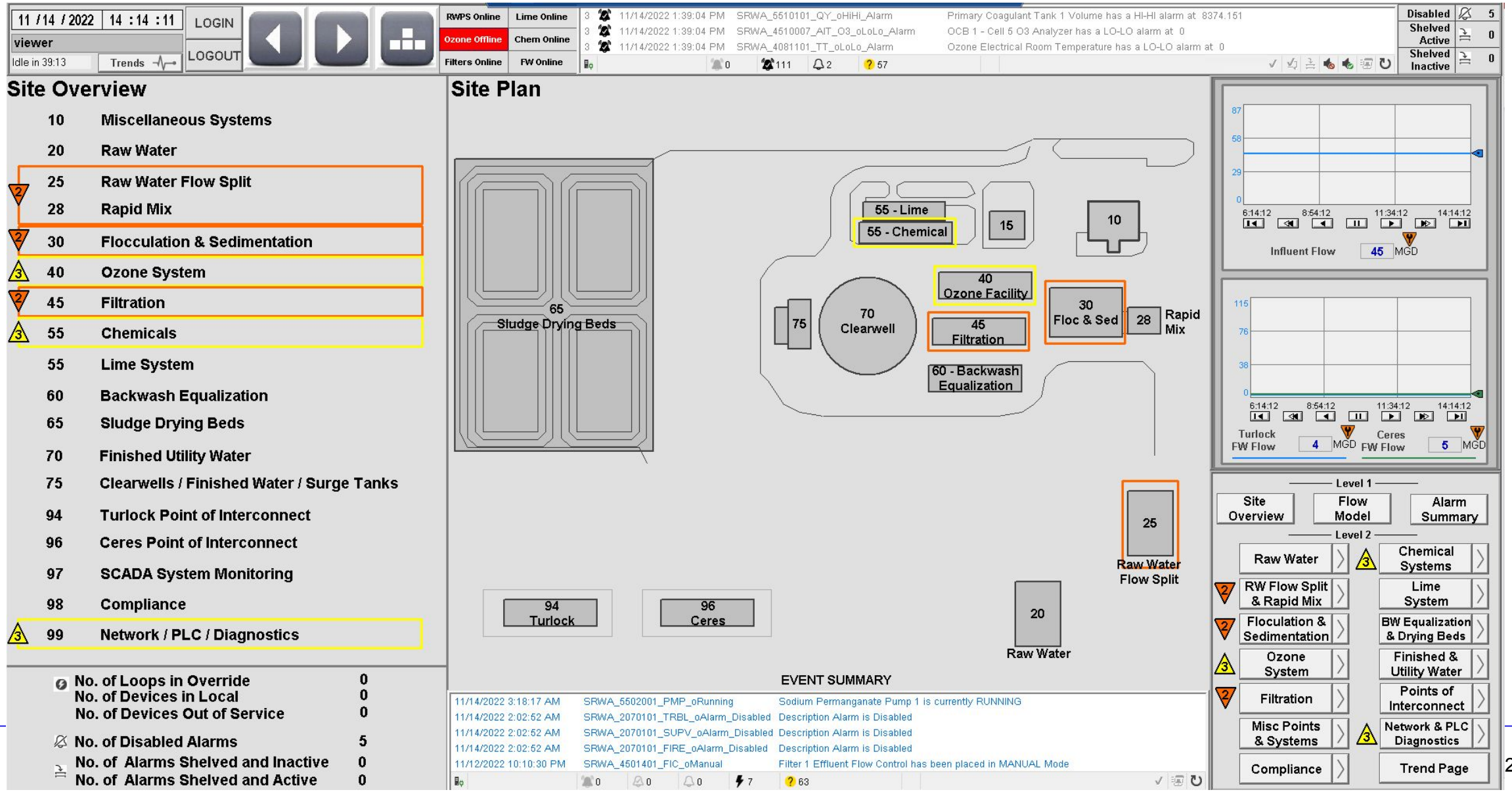


SCADA

- Supervisory Control and Data Acquisition
  - Plant wide control
  - Displays equipment status, process variables
  - Allows operations to change setpoints, start/stop equipment
- Common software used
  - Factorytalk by Rockwell
  - Ignition by Inductive Automation
  - System Platform by AVEVA (formally Wonderware)
  - Cimplicity by GE
- Alarming
  - Notifies operations of equipment faults, process variables too high or too low, communication failures etc
  - Typically, at SCADA and via text message/dial out



SCADA


11 / 14 / 2022
14 : 14 : 11
LOGIN
viewer
Idle in 39:13
Trends
LOGOUT
RWPS Online
Lime Online
Ozone Offline
Chem Online
Filters Online
FW Online
11/14/2022 1:39:04 PM SRWA_5510101_QY_oHiHi_Alarm Primary Coagulant Tank 1 Volume has a HI-HI alarm at 8374.151
11/14/2022 1:39:04 PM SRWA_4510007_AIT_O3_oLoLo_Alarm OCB 1 - Cell 5 O3 Analyzer has a LO-LO alarm at 0
11/14/2022 1:39:04 PM SRWA_4081101_TT_oLoLo_Alarm Ozone Electrical Room Temperature has a LO-LO alarm at 0
Disabled 5
Shelved Active 0
Shelved Inactive 0
Site Overview
10 Miscellaneous Systems
20 Raw Water
25 Raw Water Flow Split
28 Rapid Mix
30 Flocculation & Sedimentation
40 Ozone System
45 Filtration
55 Chemicals
55 Lime System
60 Backwash Equalization
65 Sludge Drying Beds
70 Finished Utility Water
75 Clearwells / Finished Water / Surge Tanks
94 Turlock Point of Interconnect
96 Ceres Point of Interconnect
97 SCADA System Monitoring
98 Compliance
99 Network / PLC / Diagnostics
No. of Loops in Override 0
No. of Devices in Local 0
No. of Devices Out of Service 0
No. of Disabled Alarms 5
No. of Alarms Shelved and Inactive 0
No. of Alarms Shelved and Active 0
Site Plan
65 Sludge Drying Beds
55 - Lime
55 - Chemical
15
10
40 Ozone Facility
75
70 Clearwell
45 Filtration
30 Floc & Sed
28 Rapid Mix
60 - Backwash Equalization
25 Raw Water Flow Split
94 Turlock
96 Ceres
20 Raw Water
EVENT SUMMARY
11/14/2022 3:18:17 AM SRWA_5502001_PMP_oRunning Sodium Permanganate Pump 1 is currently RUNNING
11/14/2022 2:02:52 AM SRWA_2070101_TRBL_oAlarm_Disabled Description Alarm is Disabled
11/14/2022 2:02:52 AM SRWA_2070101_SUPV_oAlarm_Disabled Description Alarm is Disabled
11/14/2022 2:02:52 AM SRWA_2070101_FIRE_oAlarm_Disabled Description Alarm is Disabled
11/12/2022 10:10:30 PM SRWA_4501401_FIC_oManual Filter 1 Effluent Flow Control has been placed in MANUAL Mode
87
58
29
0
6:14:12
8:54:12
11:34:12
14:14:12
Influent Flow 45 MGD
115
76
38
0
Turlock FW Flow 4 MGD
Ceres FW Flow 5 MGD
Level 1
Site Overview
Flow Model
Alarm Summary
Level 2
Raw Water
Chemical Systems
RW Flow Split & Rapid Mix
Lime System
Floculation & Sedimentation
BW Equalization & Drying Beds
Ozone System
Finished & Utility Water
Filtration
Points of Interconnect
Misc Points & Systems
Network & PLC Diagnostics
Compliance
Trend Page

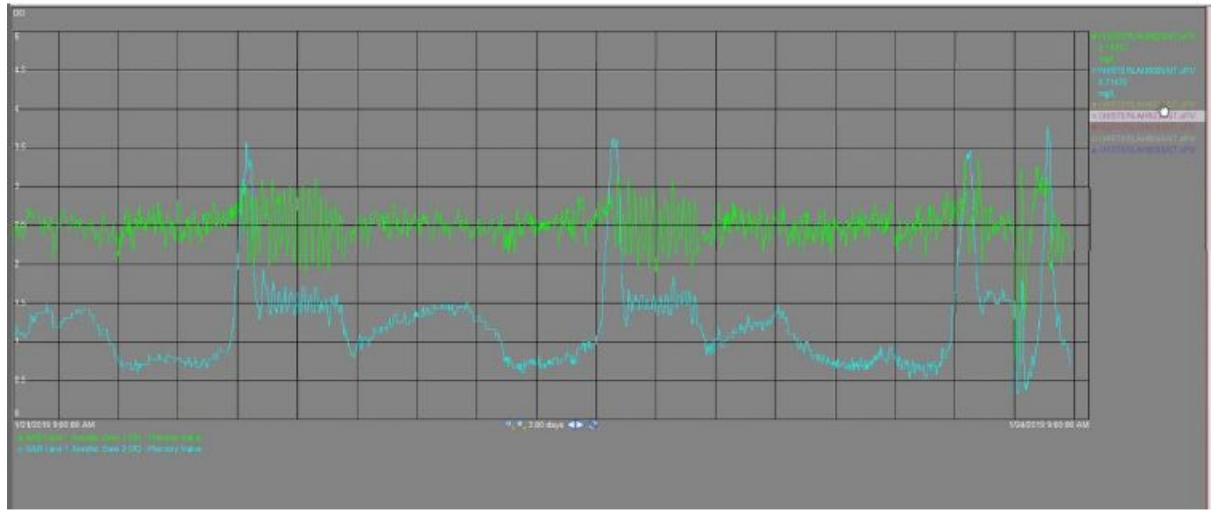
HMI

- Human Machine Interface
  - Control of particular process or facility
  - Displays equipment status, process variables
  - Allows operations to change setpoints, start/stop equipment
  - Typically provided with vendor packages

Historian

- Configured to store historical values relevant to plant operation
- Data accessible on PLC network via trending, reports and data exports

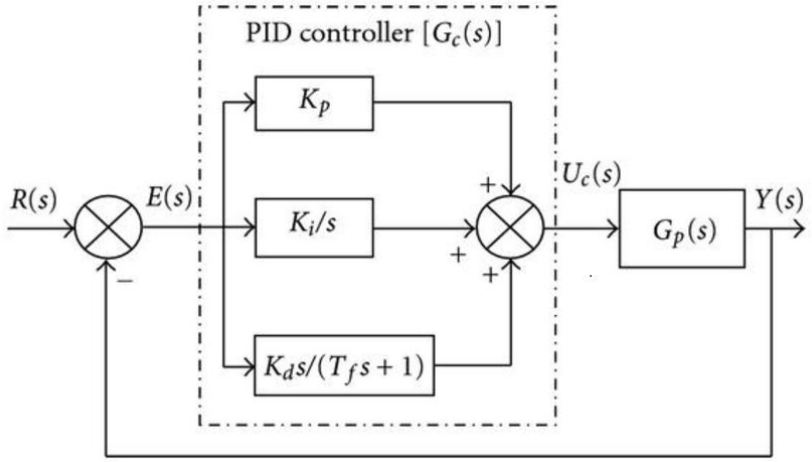
	Start Time	8/2/2022 8:30		
	End Time	8/6/2022 8:30		
			LAH9001FI.oPV	LAH9000FI.oPV
			Flow to FAB/CAB - Calculated Process Value	Total Plant Flow - Calculated Process Value
			MGD	MGD
	8:30:00 AM	02-Aug-22 08:30:00	5.26	5.31
	8:35:00 AM	02-Aug-22 08:35:00	5.56	5.31
	8:40:00 AM	02-Aug-22 08:40:00	6.34	5.41
	8:45:00 AM	02-Aug-22 08:45:00	4.72	5.41
	8:50:00 AM	02-Aug-22 08:50:00	5.70	5.41
	8:55:00 AM	02-Aug-22 08:55:00	4.75	5.41
	9:00:00 AM	02-Aug-22 09:00:00	6.35	5.41
	9:05:00 AM	02-Aug-22 09:05:00	6.01	5.52
	9:10:00 AM	02-Aug-22 09:10:00	5.32	5.62
	9:15:00 AM	02-Aug-22 09:15:00	5.73	5.62

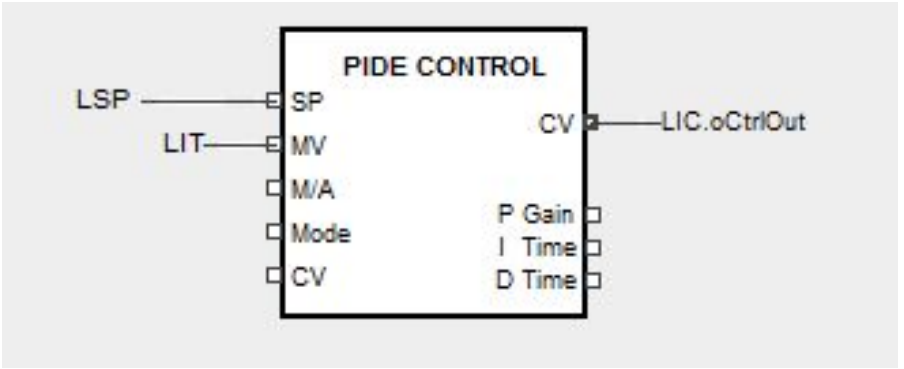


What is a PID?

PID Defintion

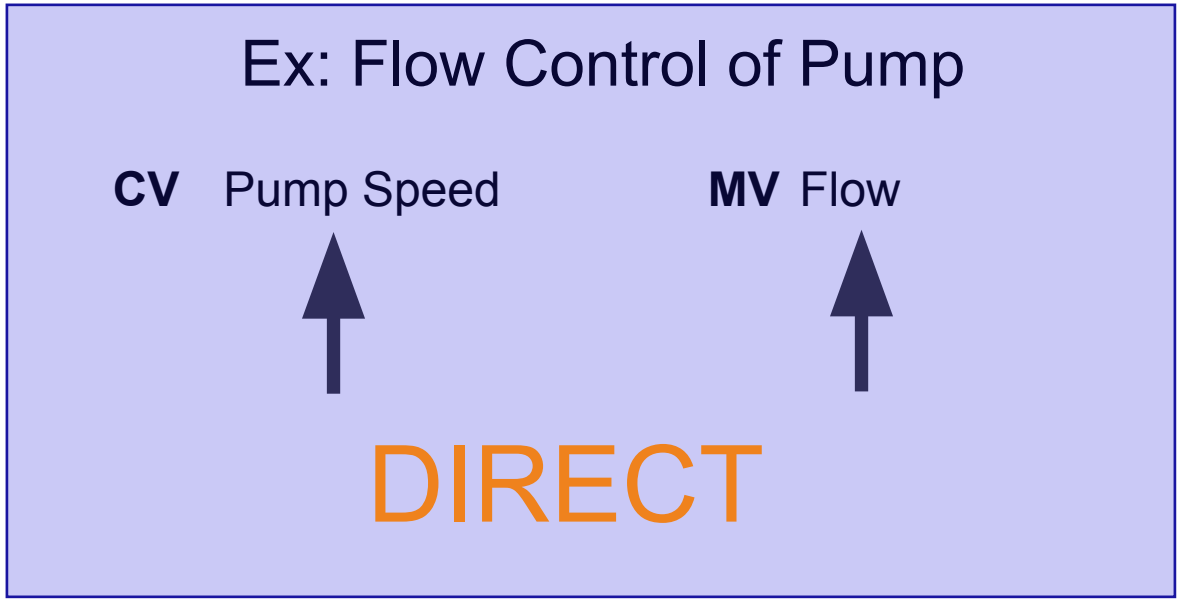
- **P**roportional-**I**ntegral-**D**erivative Controller
  - Proportional: changes output proportional to error
  - Integral: changes output according to the accumulated error
  - Derivative: changes output as the rate of change of error increases
- Inputs:
  - Setpoint (SP)
  - Measured Variable (MV) also called Process Variable (PV)
  - Flow, level, pressure
- Output:
  - Control Variable (CV)
  - Pump speed, valve/gate position, etc.





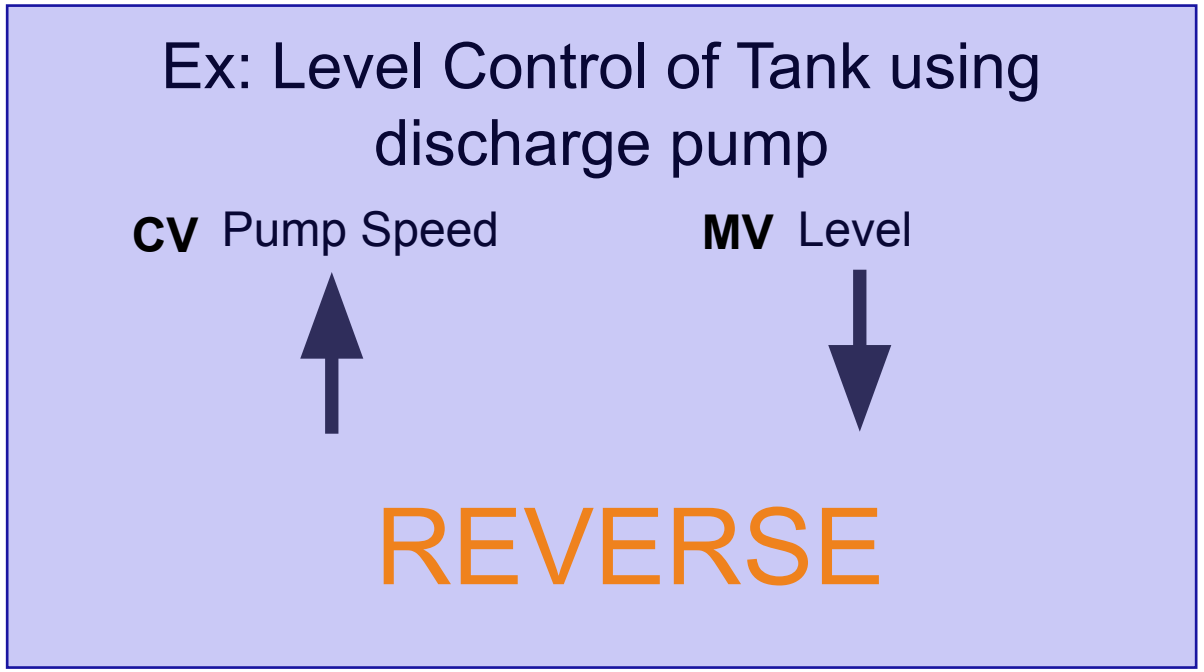
PID Definition

- Direct Acting: Controller output increases as measured variable increases



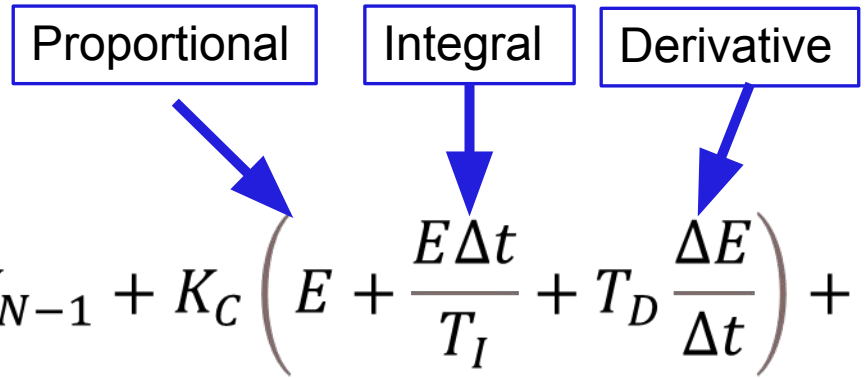
PID Definition

- Reverse Acting: Controller output decreases as measured variable increases



PID Equation

- Two forms of equation
  - **Dependent**
    - Controller gain effects action of all three terms (P, I and D)
  - Independent
  - Know what form your controller is using



CV_N = Control Variable at time step n

CV_{N-1} = Control Variable at time step n-1

K_C = Controller Gain

T_I = Integral time constant (seconds/repeat)

T_D = Derivative time constant (seconds)

E = Error

ΔE = Change in Error

Δt = Change in Time

Bias = Offset for CV calculation

Error Equation

- Calculation of Error depends on the minimum and maximum of the measured variable

$$Error = SP - MV \,/\, (Max\ MV - Min\ MV)$$

SP = Setpoint

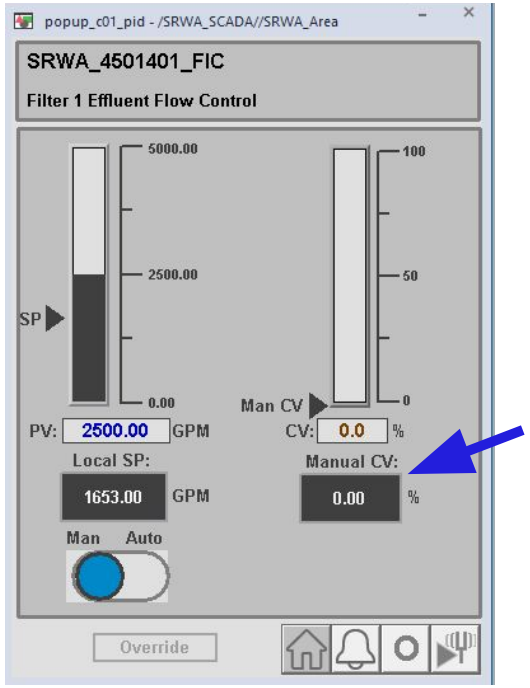
MV = Measured Variable

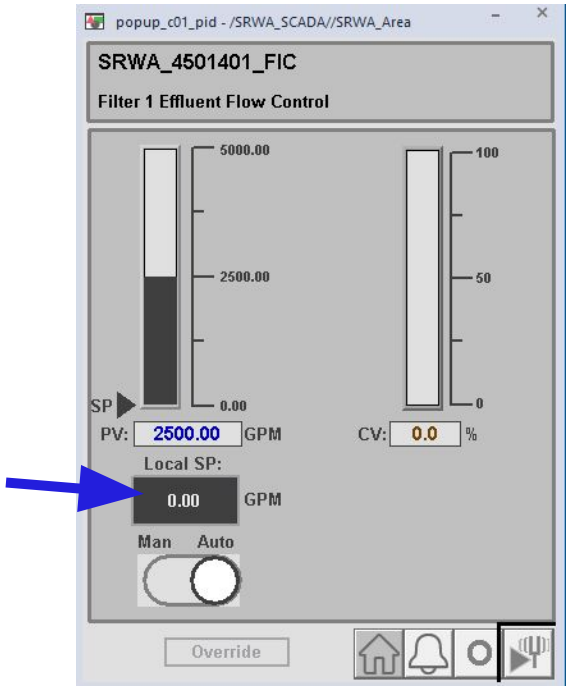
Max MV = Maximum Measured Variable

Min MV = Minimum Measured Variable

Manual versus Auto

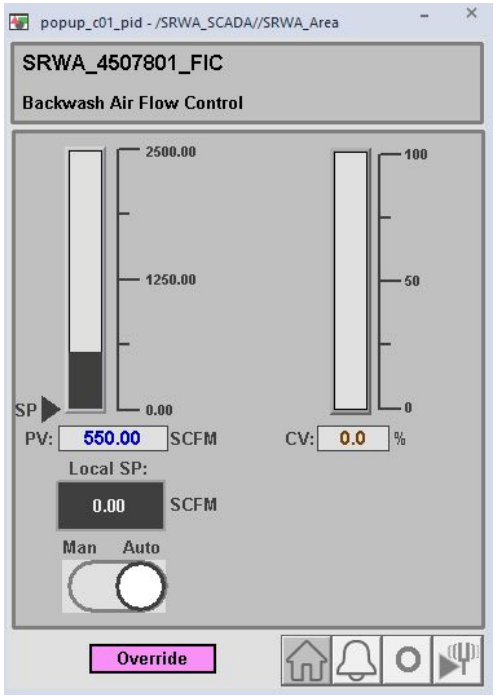
- Manual
  - Allows user to set CV output directly
- Auto
  - CV output set by PID equation to achieve SP

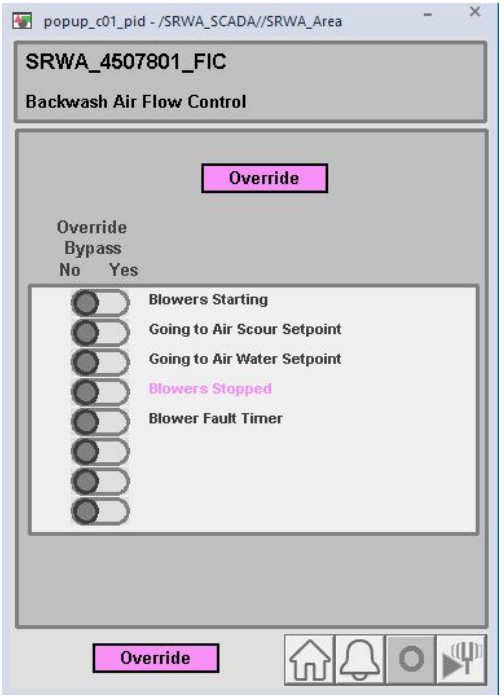




PID Overrides

- Used when making a significant process change
  - Ex: increasing or decreasing pump quantity
  - Ex: equipment not running
- CV output set to programmed override value
  - PID equation NOT used determine CV output

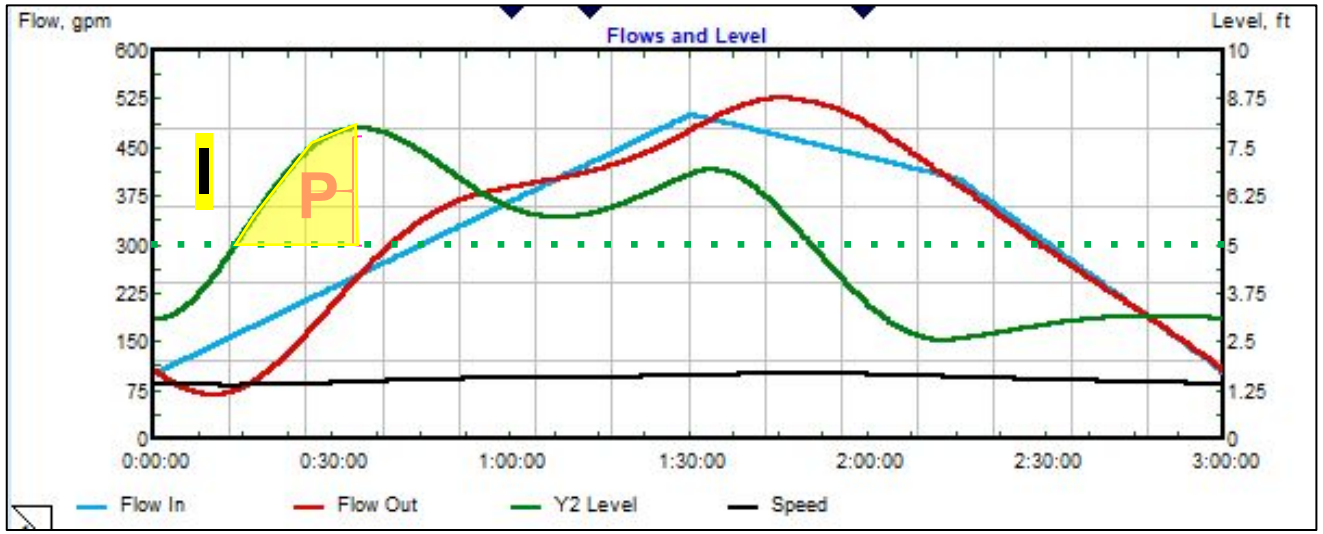




PID Tuning

PID Tuning

- Proportional
  - Acts on the Error
  - Proportional only tuning could end up with constant offset between SP and MV
- Integral
  - Acts on the change in Error
- Derivative
  - Acts on the rate of change of error
  - Not typically used in water

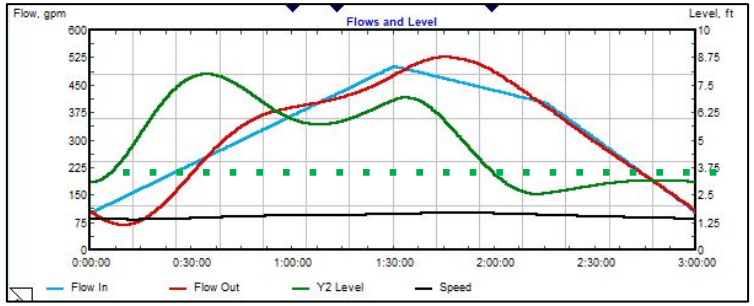


PID Tuning

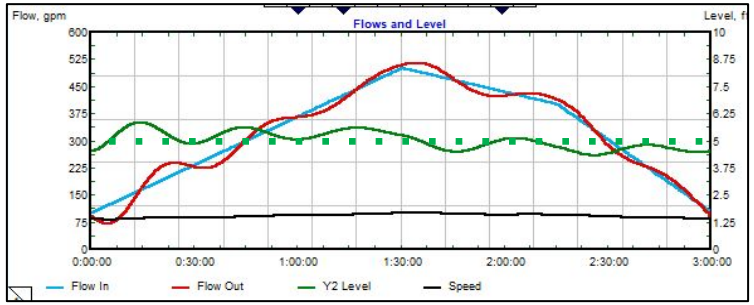
- Make one adjustment at a time, wait until you can see a result, and determine if it is better or worse
- Know the units: will a smaller or larger value result in more integral action
- Write down your tuning changes

$$CV_N = CV_{N-1} + K_C\left(E + \frac{E\Delta t}{T_I} + T_D\frac{\Delta E}{\Delta t}\right) + Bias$$

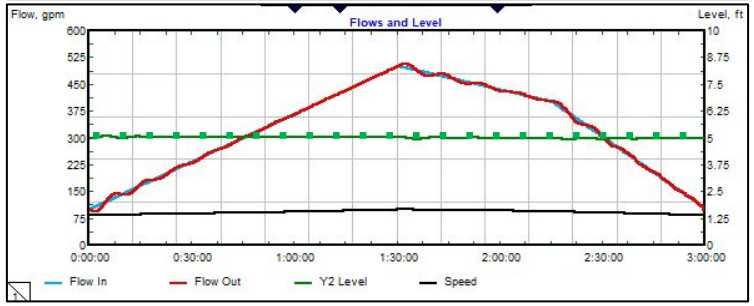
P = -1
I = 50s



P = -1
I = 10s



P = -10
I = 10s

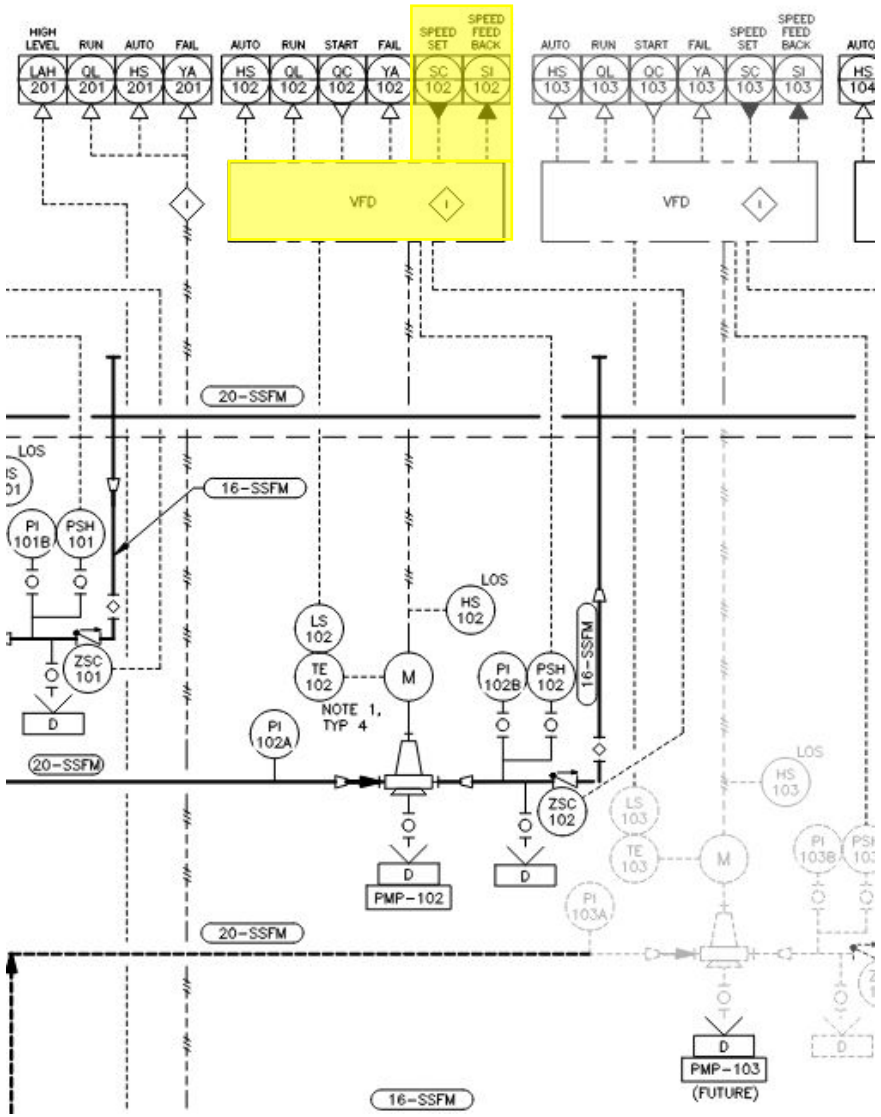


Questions?

stephanie.mcgregor@jacobs.com

P&IDs

- Pumps
  - Variable Frequency Drives (VFDs)
    - Analog speed command and feedback



P&IDs

- Pumps
  - Constant Speed (CS)
    - Discrete run command and feedback