Build on Your Knowledge.
2010 Emerson Global Users Exchange

Control Loop Foundation Batch and Continuous Processes

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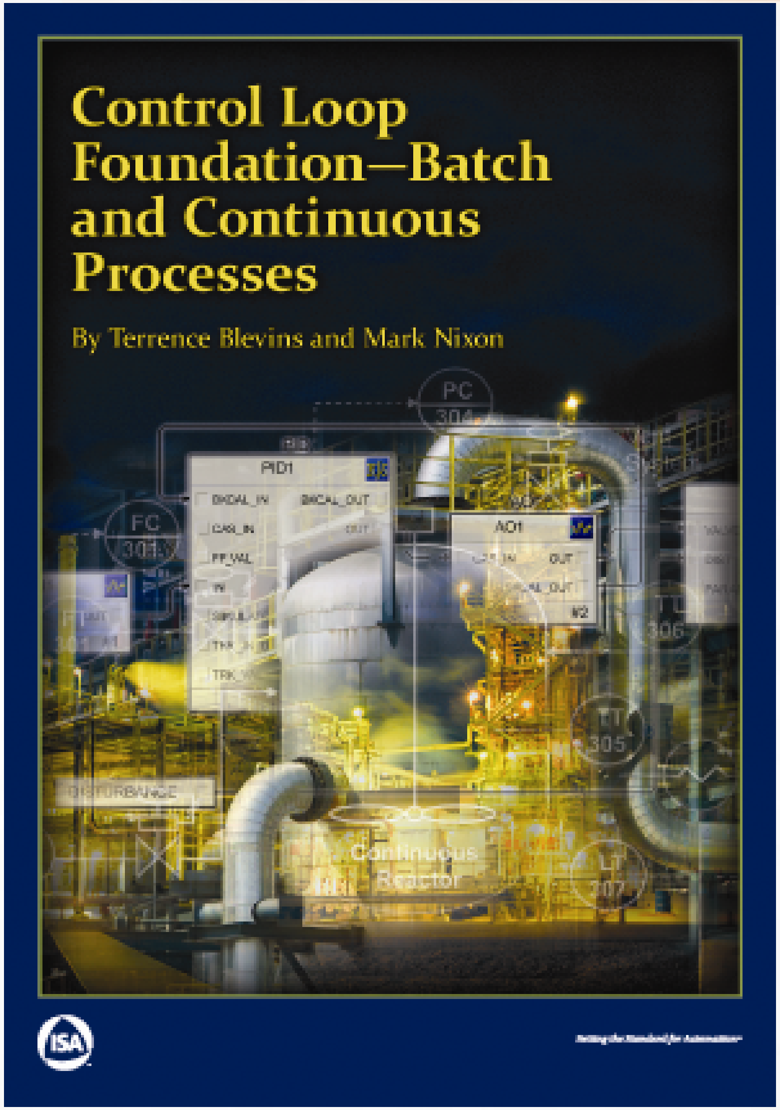
EMERSON GLOBAL USERS EXCHANGE

Control Loop Foundation Short Course

Introduction	
Background	– Historic Perspective
Measurement	– Basic Transmitter Types, Limitations
Analyzers	– Examples of On-line Analyzers
Final Elements	– Valves and Variable Speed Drives
Field Wiring and Communications	– Traditional, HART, FF , WirelessHART
Control Strategy Documentation	– Plot Plan, Flow Sheet, P&ID, Loop Diagram
Operator Graphics and Metrics	– Considerations in Display Design
Process Characterization	– Identifying process dynamics and gain
Control Objectives	
Single Loop Control	– PID basics, selecting PID structure, action
Tuning and Loop Performance	– Manual and automated tuning techniques
Multi-loop Control	– Feedforward, Cascade, Override, Split-range
Model Predictive Control	– Addressing Difficult Dynamics, Interactions
Process Modeling	– Process simulation for Checkout/Training
Applications	– Continuous, Batch, Combustion, Distillation
Accessing the book web Site	
Open Discussions book drawing & Wrap-up	

Control Loop Foundation Short Course



- Short Course will provide a summary of key points and examples from Control Loop Foundation
- All workshops and application examples in the book are based on DeltaV control capability. This book is available at www.isa.org and this week at the ISA booth.
- The application section is designed to show how control techniques may be combined to address more complex process requirements
- The book web site may be accessed to perform the workshops and to obtain hands-on experience using application example. Copies of the modules and trends may be downloaded from the web site and imported into a DeltaV system.
- A new class, Control Loop Foundation - **Course 9025,** Is available through the education department.

Introduction

- Control Loop Foundation address the concepts and terminology that are needed to work in the field of process control.
- The material is presented in a manner that is independent of the control system manufacturer.
- Much of the material on the practical aspects of control design and process applications is typically not included in process control classes taught at the university level.
- The book is written to act as a guide for engineers who are just starting to work in this field.
- Experienced control engineers will benefit from the application examples on process control design and implementation of multi-loop control strategies.

Background - Different Construction Techniques

Figure 2-1. Plant with Enclosed Construction

Figure 2-2. Plant with Open Construction

Wiring Practices

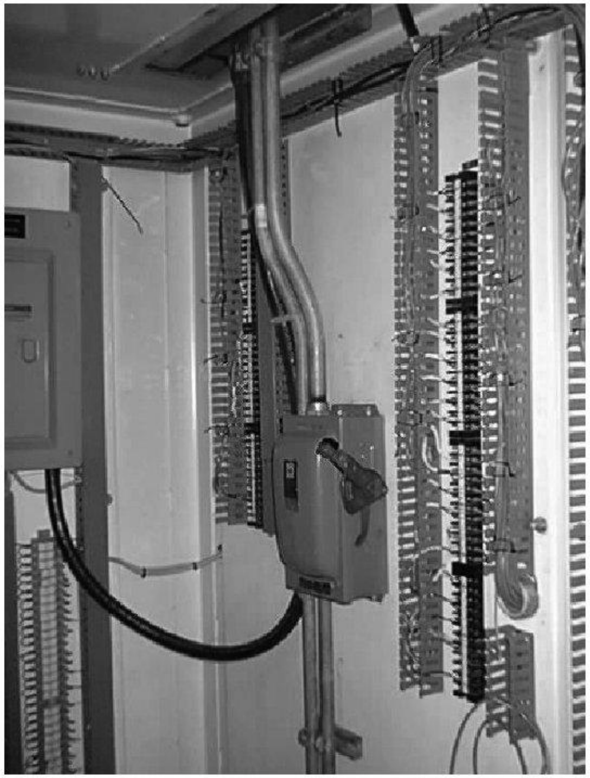


Figure 2-15. Junction Box for Field Wiring

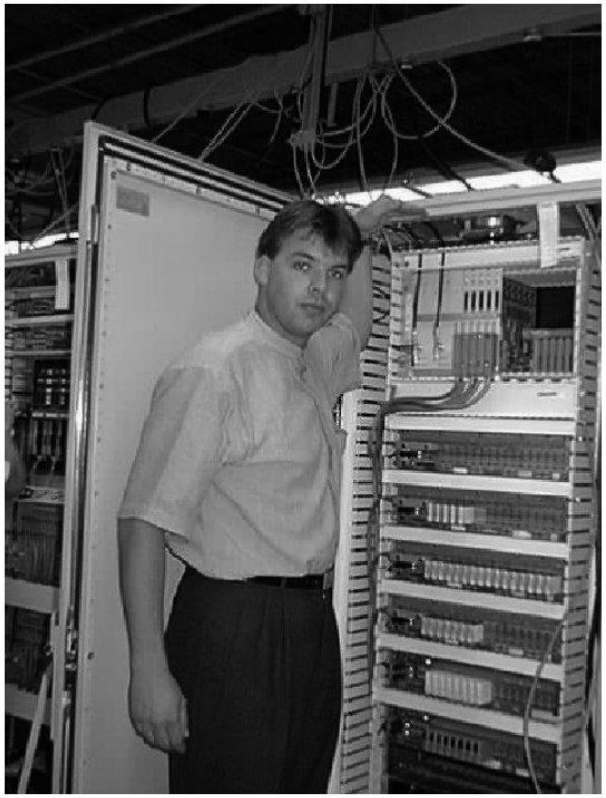


Figure 2-14. Controller Termination Boards

Figure 2-3. Cable Tray and Conduit for Instrumentation Wiring

Plant Organization

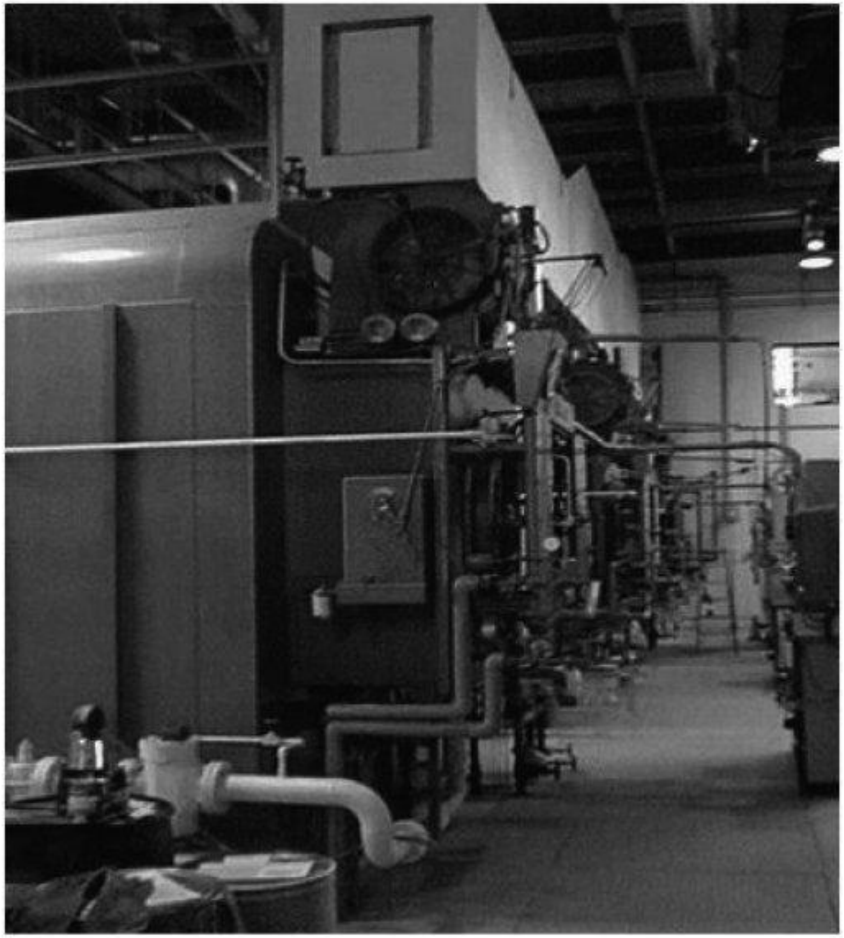


Figure 2-4. Multiple Power Boilers in the Powerhouse Area

- Common terms used to describe plant organization are introduced.
- Plant Area – classification by name and area number
- Units within a process Area

Lab, Control Room, Lab and Rack Room

Figure 2-5. Lab Used to Provide Analysis of Quality-related Parameters

Figure 2-12. Custom Furniture Used in a Control Room

Figure 2-13. Rack Room for Distributed Control Equipment

Existing System – Electronic and Pneumatic

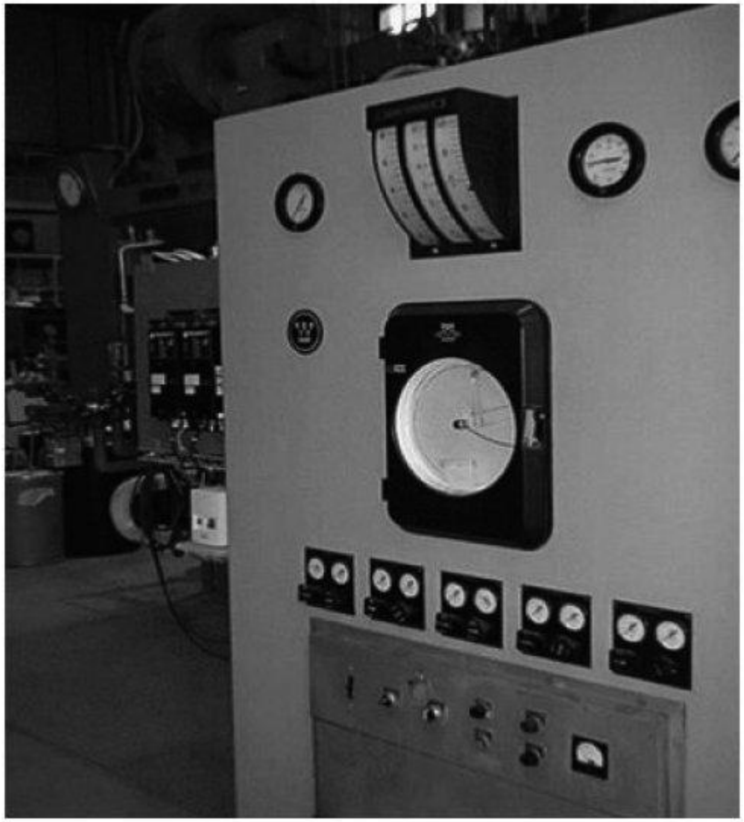


Figure 2-7. Circular Chart Recorder in a Control Panel

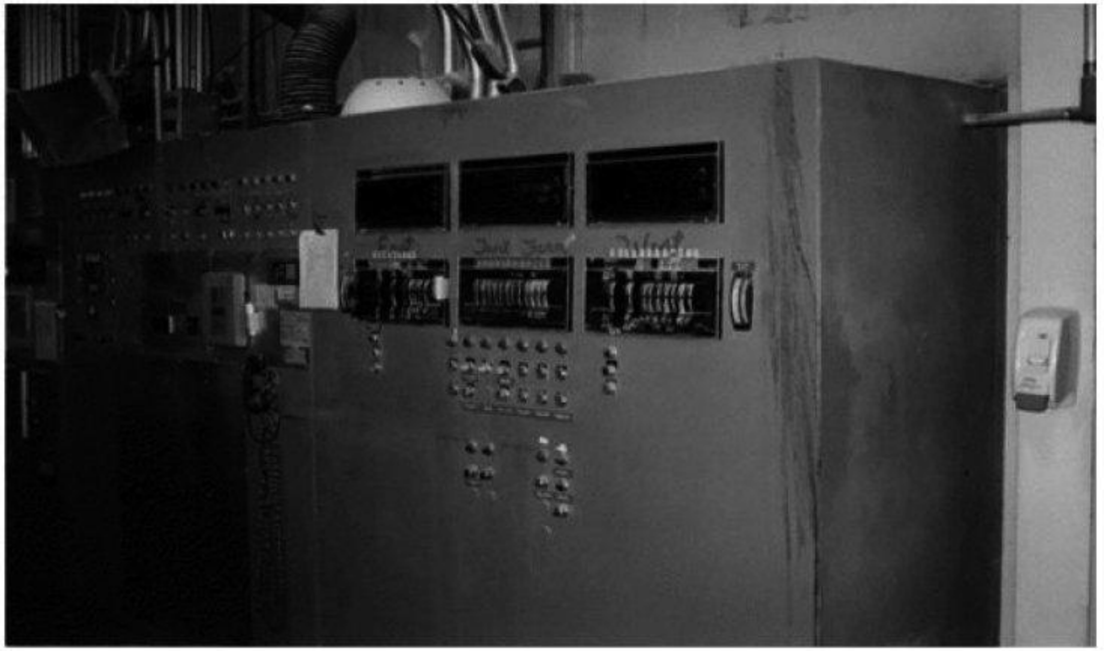


Figure 2-6. Panel-based Analog Electronic Control System

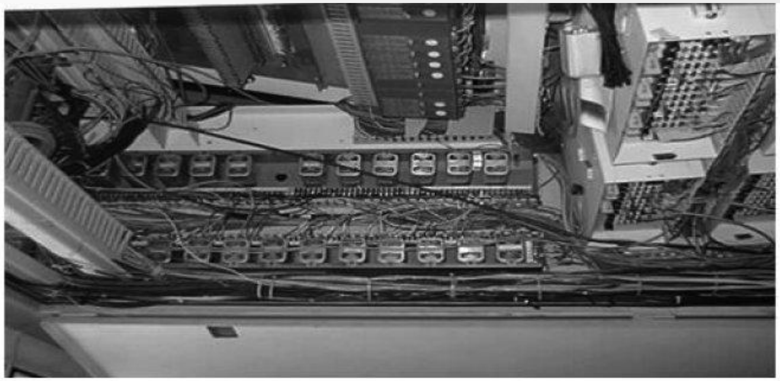


Figure 2-8. Control Panel Wiring

Impact of DCS Systems

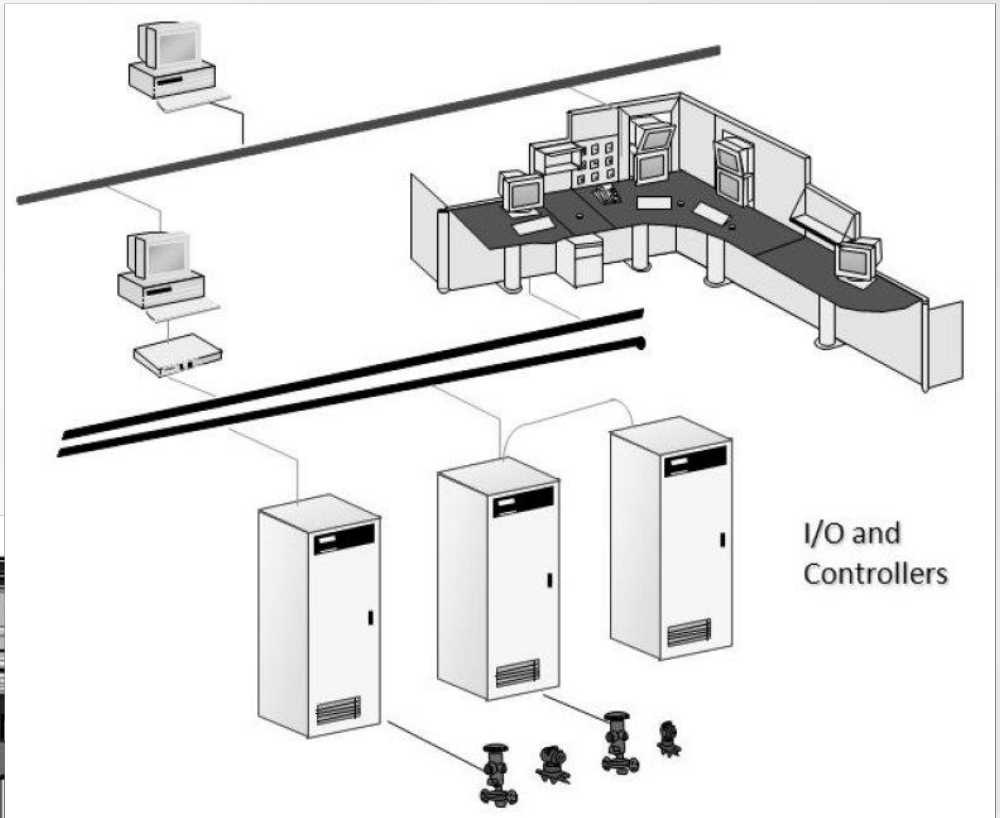


Figure 2-9. Distributed Control System Overview

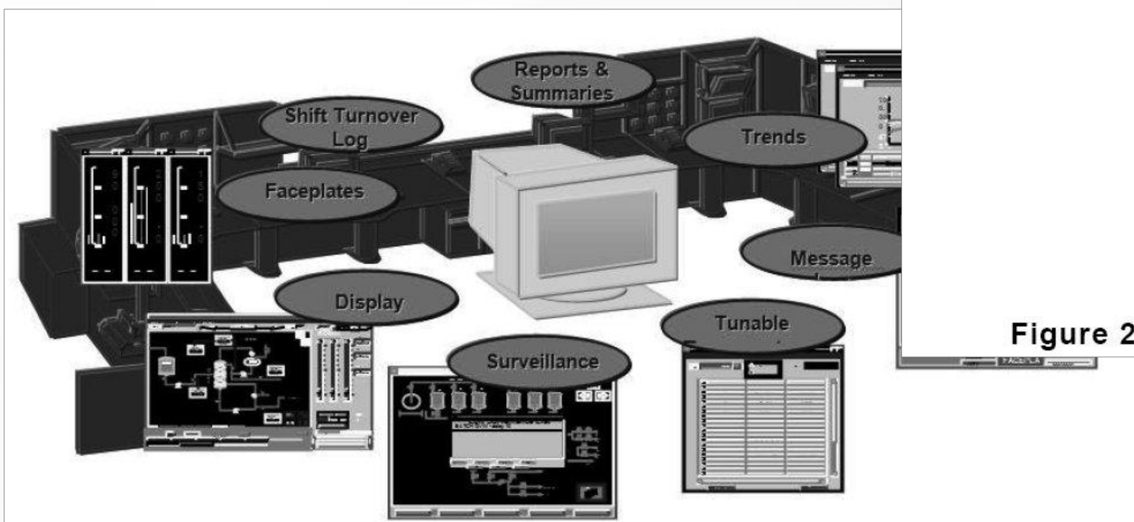


Figure 2-10. Operator Interface Graphical Displays

Integration of External System/Interface

Figure 2-16. Addressing Specialized Applications with a PLC

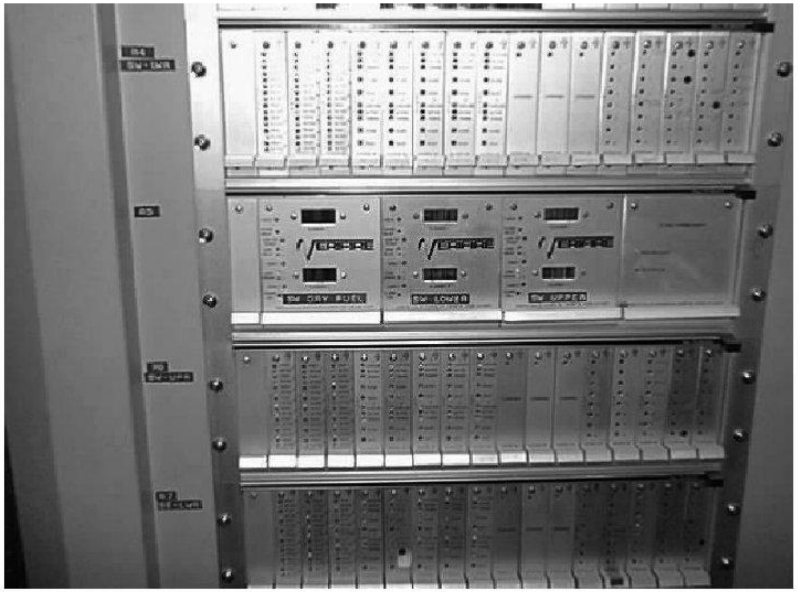


Figure 2-17. Vibration Monitoring System

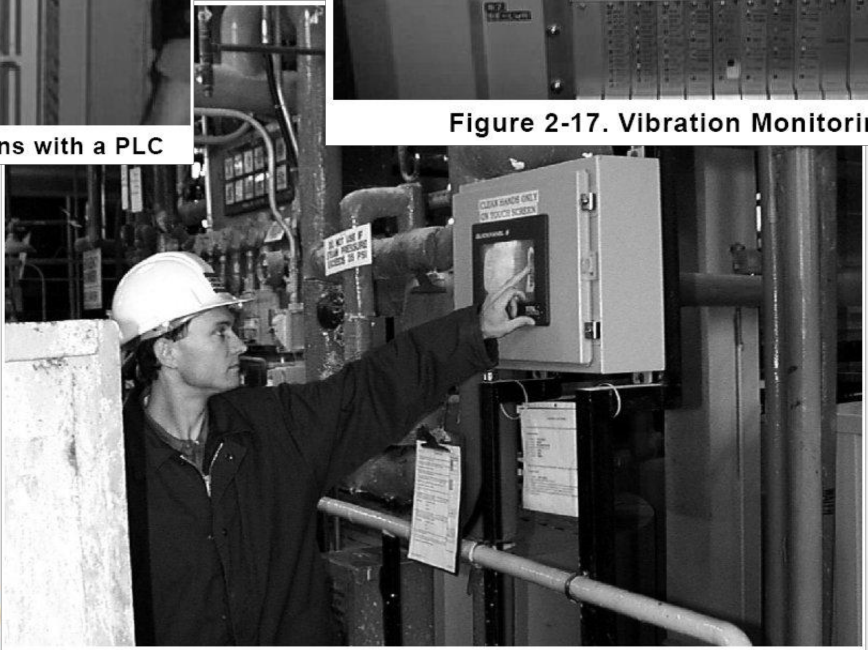


Figure 2-18. Local Interface

Modern DCS Controller

Figure 2-20. Field Wiring and Terminations

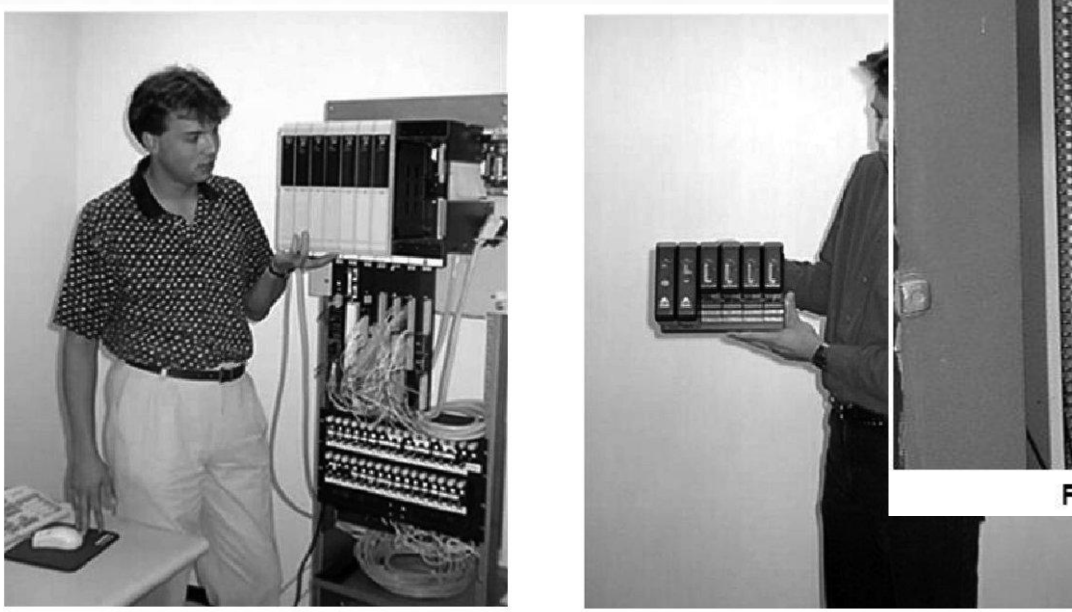


Figure 2-19. Comparison of Multi-loop Controller Designs

Impact of Digital Communications

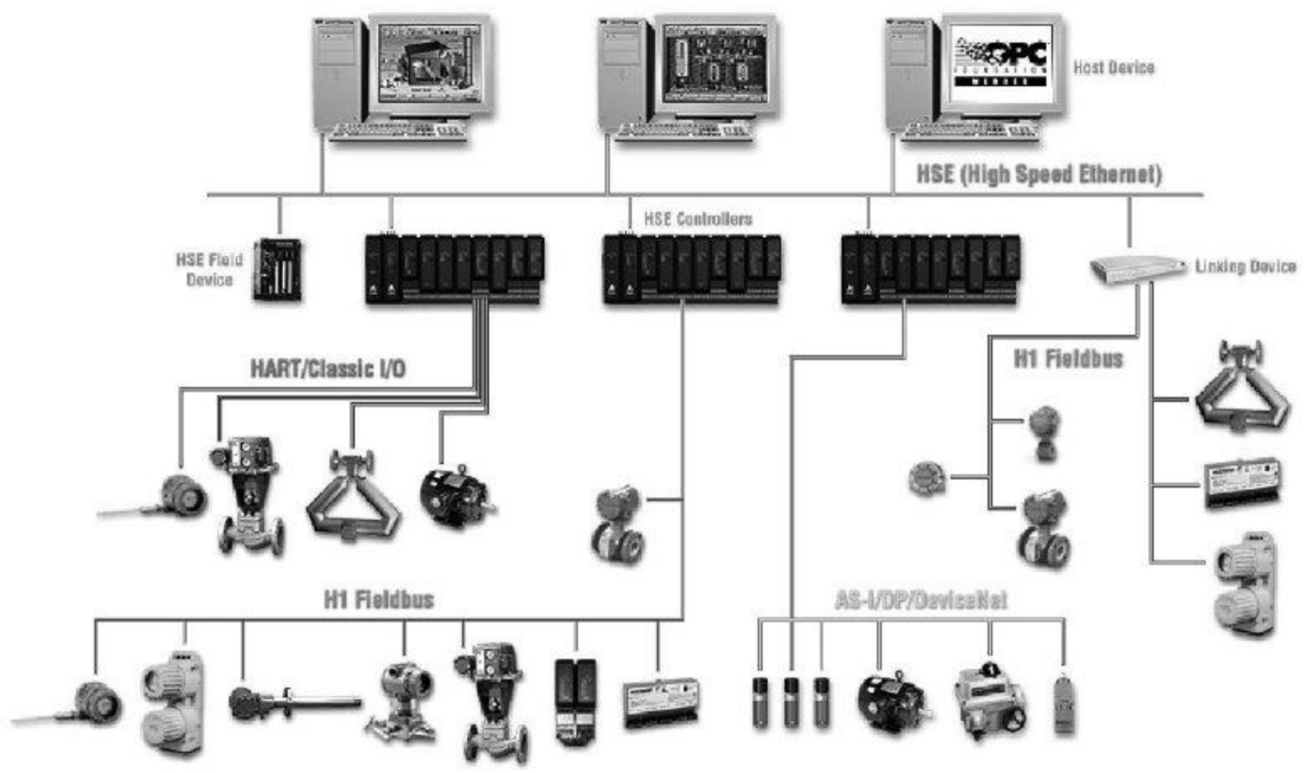


Figure 2-21. Field Wiring Using Bus Technology

- Ethernet
- Fieldbus – Foundation Fieldbus, Profibus
- Wireless - WirelessHART

Wireless Impact

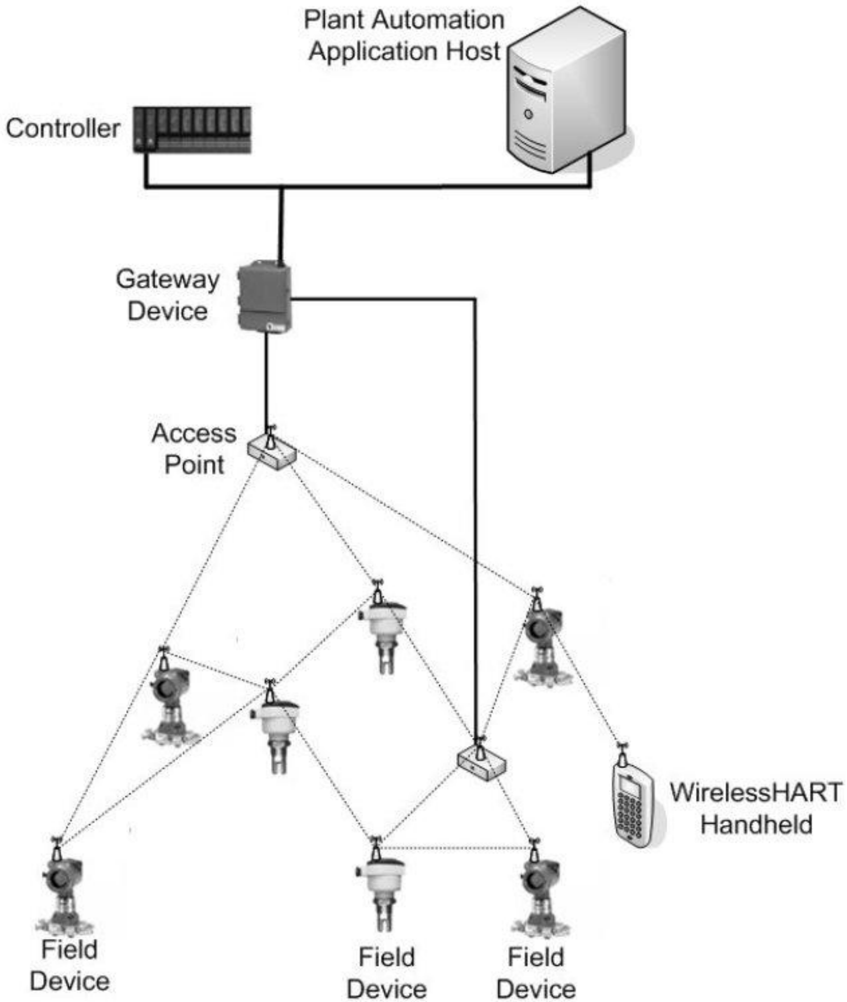


Figure 6-5. WirelessHART Installation

- Wireless Field Devices
- Relatively simple - Obeys Network Manager
- Gateway and Access Points
- Allows control system access to WirelessHART Network Gateways
- Manages communication bandwidth and routing

WirelessHART Objectives

- Satisfy the end users concerns

  Reliable & Secure

  Fit for Industrial Environments

- Keep it simple

  As simple as 4-20mA HART

  Instruments should be Intelligent and easy to use

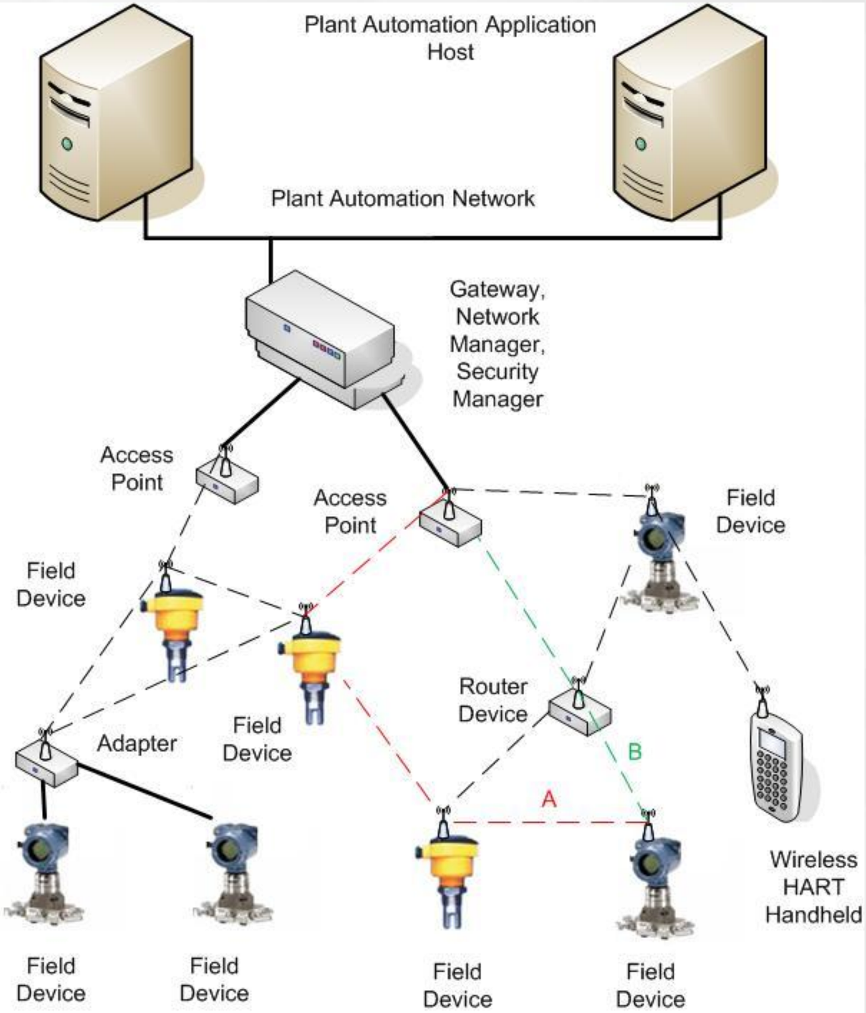
- Use Existing tools

  Update DD for Handheld and Asset Management applications

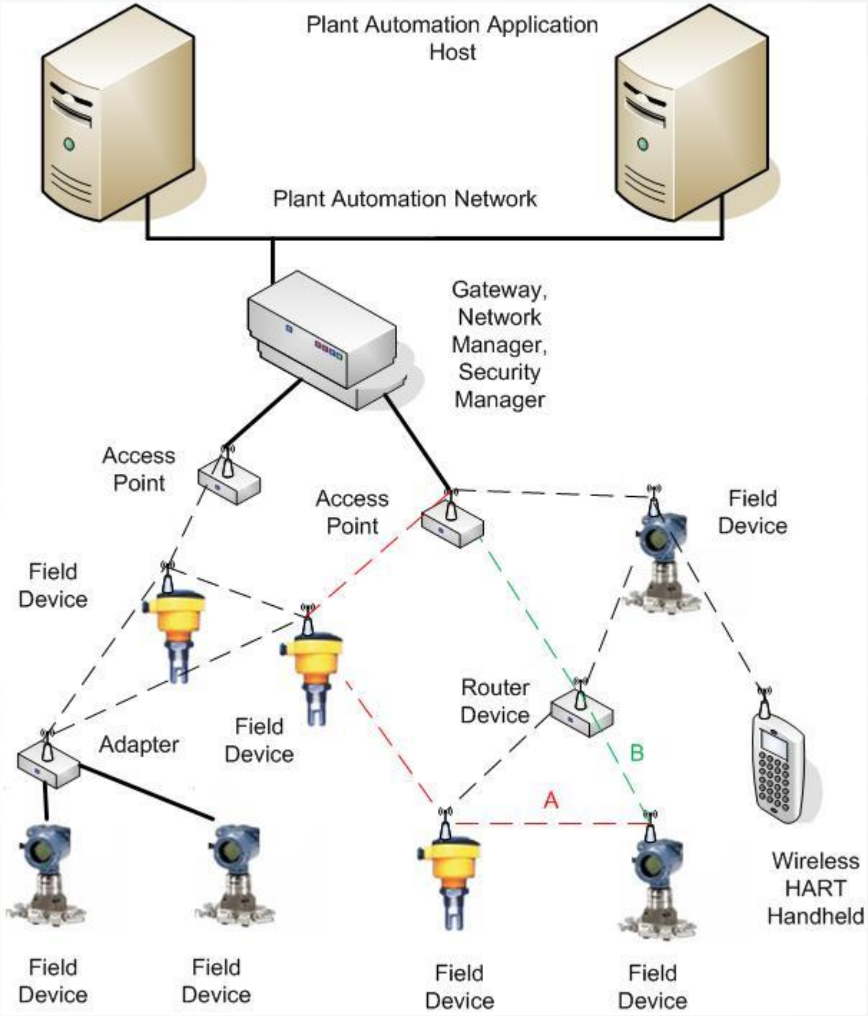
  Same tools – same procedures

Satisfy the end users concerns

- **Reliable**
  - Use Mesh for redundant paths (A – B)
  - Redundant Gateway to the Host
  - Multiple Network Access Points
  - Coexistence with neighbouring networks
    - Channel hopping
    - TDMA
    - Low Power
- **Secure**
  - Device Authentication
  - AES128 Encryption
  - Anti-Jamming
    - Channel Hopping
  - Verification at MAC Layer
  - Key Management



Device Types



- Wireless Field Devices
  - Relatively simple - Obeys Network Manager
  - All devices are full-function (e.g., must route)
- Adapters
  - Provide access to existing HART-enabled Field Devices
  - Fully Documented, well defined requirements
- Gateway and Access Points
  - Allows access to WirelessHART Network from the Process Automation Network
  - Gateways can offer multiple Access Points for increased Bandwidth and Reliability
  - Caches measurement and control values
  - Directly Supports WirelessHART Adapters
  - Seamless access fro existing HART Applications
- Network Manager
  - Manages communication bandwidth and routing
  - Redundant Network Managers supported
  - Often embedded in Gateway
  - Critical to performance of the network
- Handheld
  - Supports direct communication to field device
  - For security, one hop only communication
- All devices compatible with existing DD-enabled Applications

Impact of Standard on Control

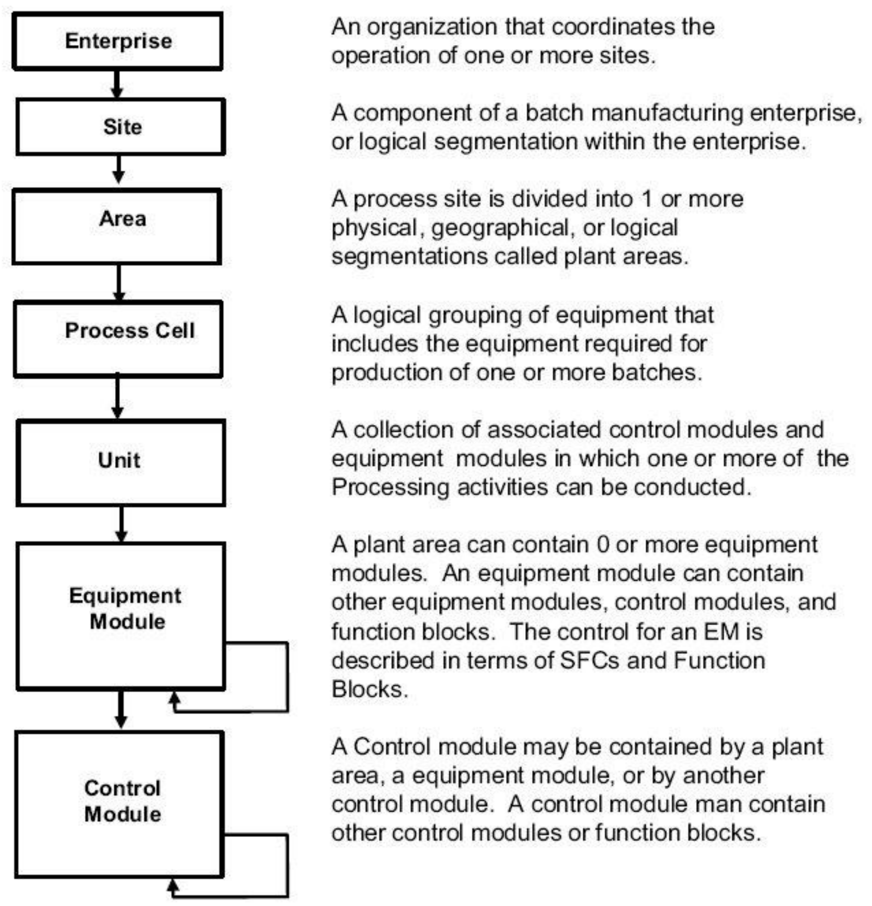


Figure 2-22. Overview of ISA-88 Terminology

- ISA88 – Batch terminology
- IEC 61131 – Function blocks, Ladder Logic, Structured Text, Sequential Function Charts.
- IEC 61804 – Function blocks for the process industry,

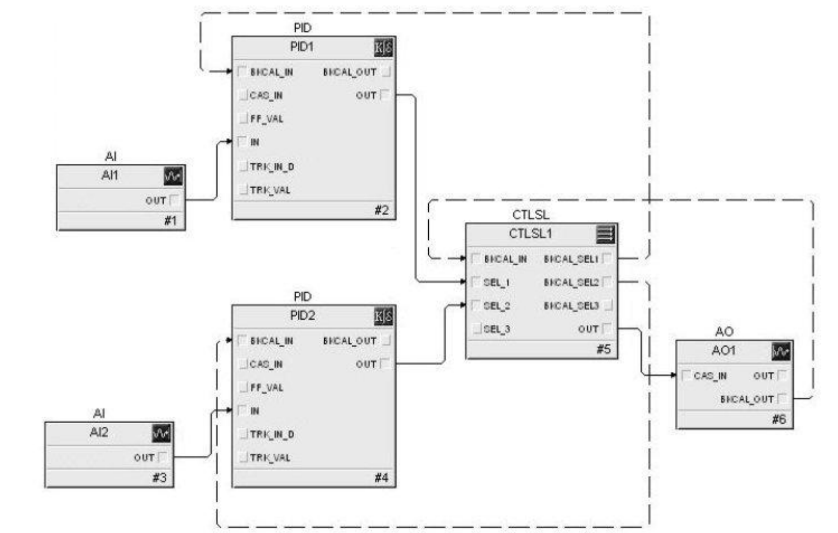


Figure 2-23. Function Blocks in Control Applications

Measurement

Figure 3-1. Magnetic Flowmeter

Figure 3-2. Vortex Flowmeter

Figure 3-7. Temperature Transmitter

Figure 3-6. Pressure Transmitter

Figure 3-9. Radar Level Measurement

Figure 3-8. Level Measurement Based on Pressure

Figure 3-3. Flow Measurement Based on Differential Pressure and Orifice

Figure 3-5. Coriolis Mass Flowmeter

- Introduction to devices used for basic measurement
  - Magnetic flow meter
  - Vortex flow meter
  - Differential pressure for flow measurement
  - Corilois flow meter
  - Absolute and gauge pressure
  - Temperature – RTD, thermocouple
  - Level based on pressure/differential pressure
  - Level - Radar

Device Calibration

Figure 3-4. Hand-held Device to Check and Set Transmitter Calibration

- Concept of devices calibration and configuration is introduce.
- Role of hand held devices and EDDL is addressed

Analyzers

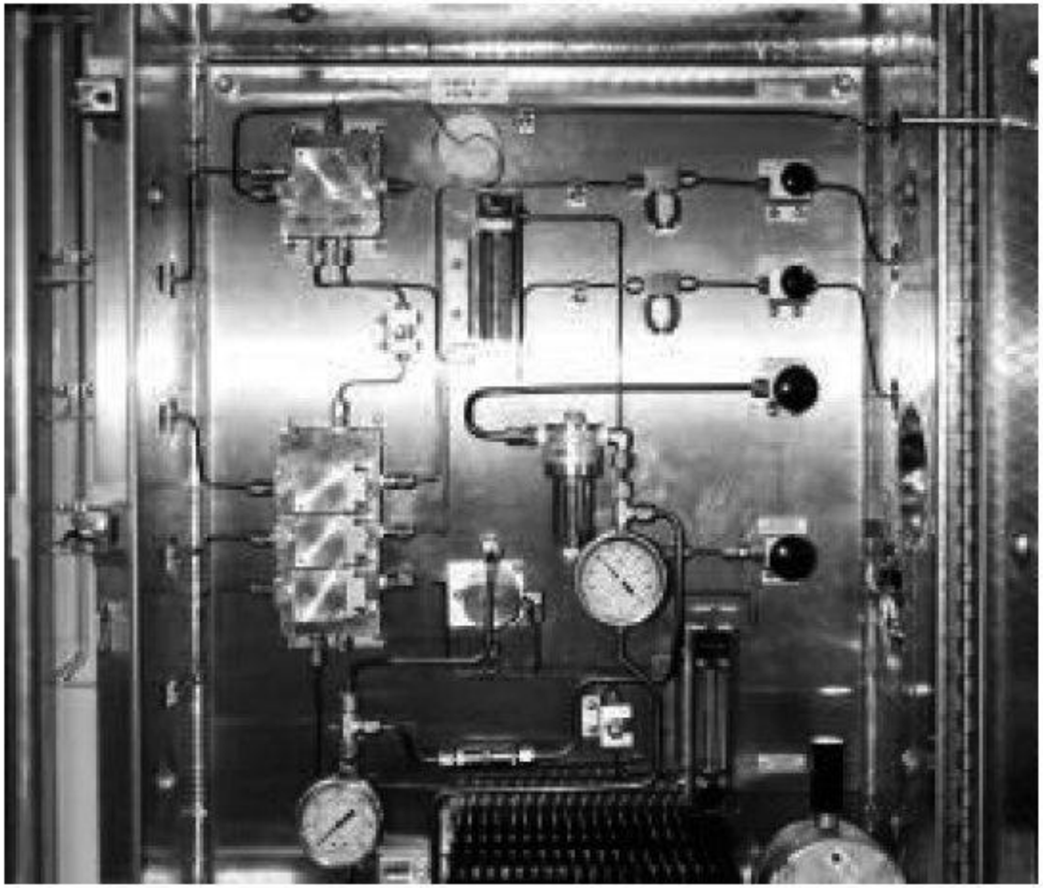


Figure 4-1. Example Sampling System

- Difference between sampling and situ analyzers is addressed
- Impact of sampling system on maintenance and measurement delay is highlighted

Analyzer Example

Figure 4-2. In-Situ Flue Gas Oxygen Analyzer

Figure 4-3. pH/ORP Transmitter

- A couple of common situ analyzers are addressed to show features and options
  - Flue Gas O2
  - pH/ORP
- Calibration of analyzer and role of sample/hold when used in control is addressed.

Final Control Element

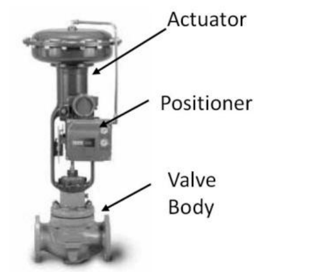


Figure 5-1. Components of a Sliding Stem Valve

Figure 5-4. Valve with Electro-Pneumatic Transducer

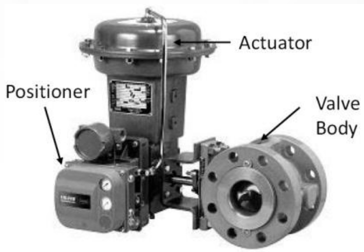


Figure 5-2. Example of a Rotary Valve

Figure 5-5. Damper Drive

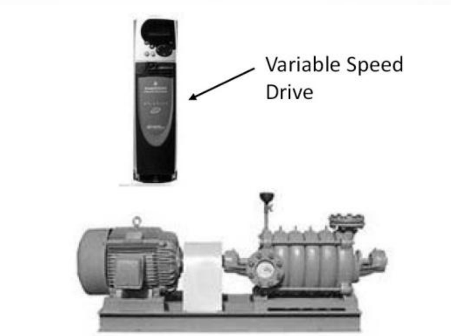


Figure 5-6. Variable Speed Drive and Pump with Electric Mot

Figure 5-7. Blocking Valves

- Basic final control elements are addressed:
  - Sliding stem valve
  - Rotarty valve
  - Damper drive
  - Variable speed drive
  - Block valve
- Advantages and limitations are discussed

Final Control Element Terminology

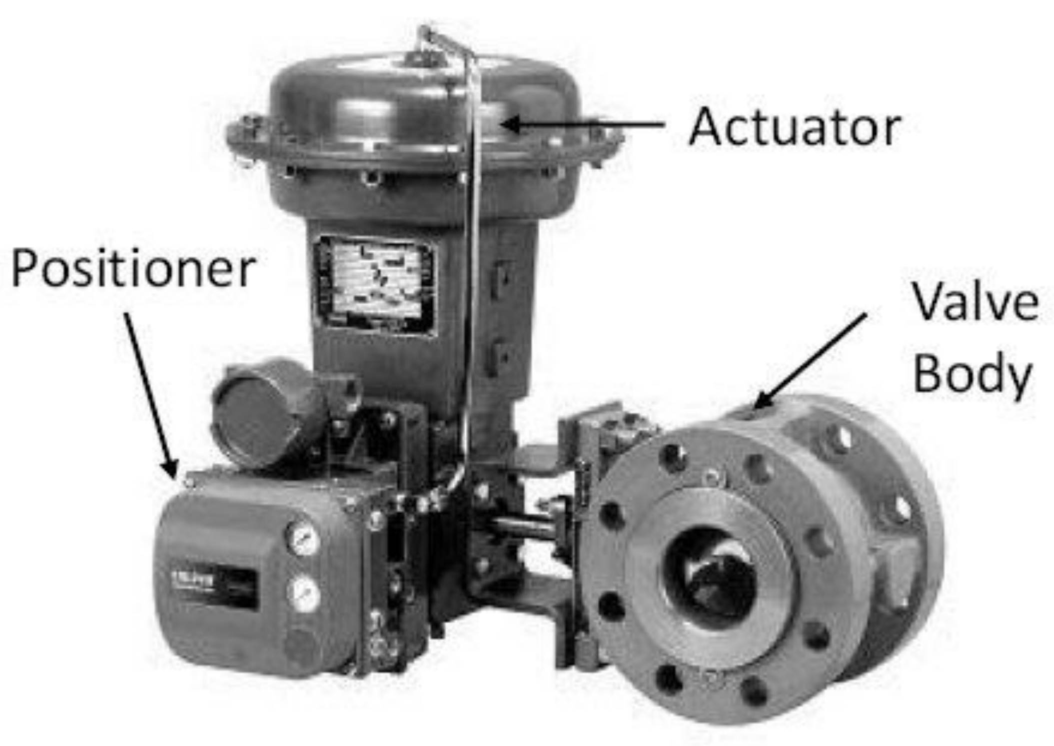


Figure 5-2. Example of a Rotary Valve

- Common terms associated with final control elements are defined
  - Positioner
  - Actuator
  - Valve Body

Installed Characteristics

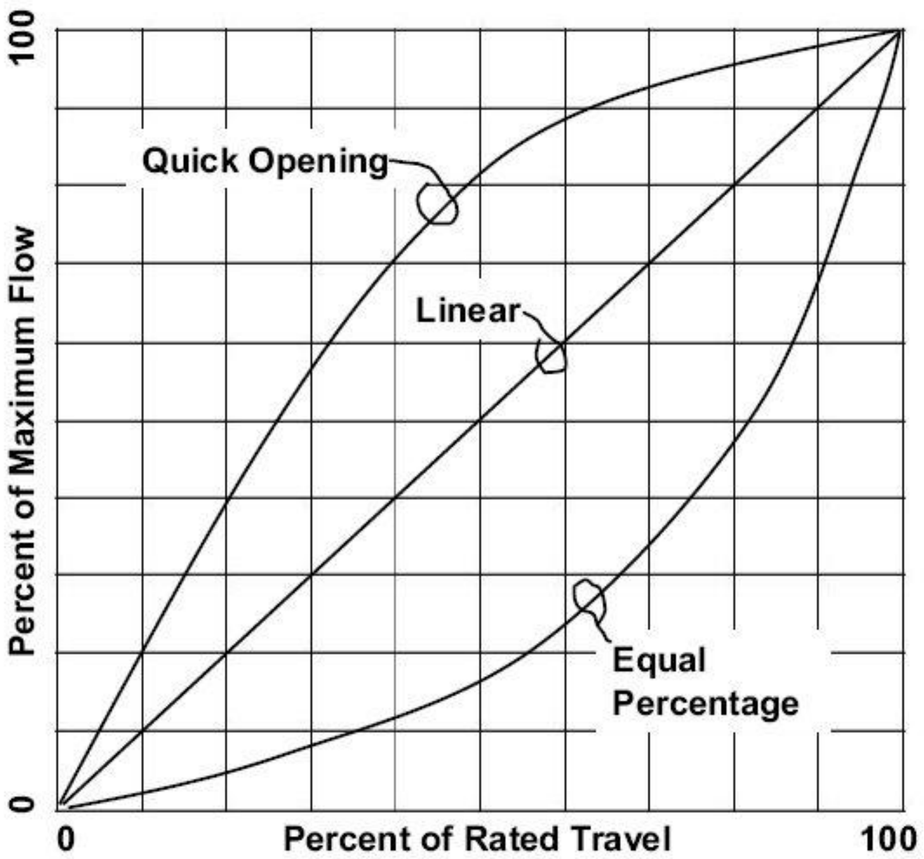


Figure 5-3. Valve Characteristic

- Types of valve characteristics and their impact on installed characteristics is addressed

Field Wiring and Communications

- Installation of 2-wire vs 4-wire devices is addressed
- Common problems are address e.g. need for electric isolation when utilizing a 4-wire device

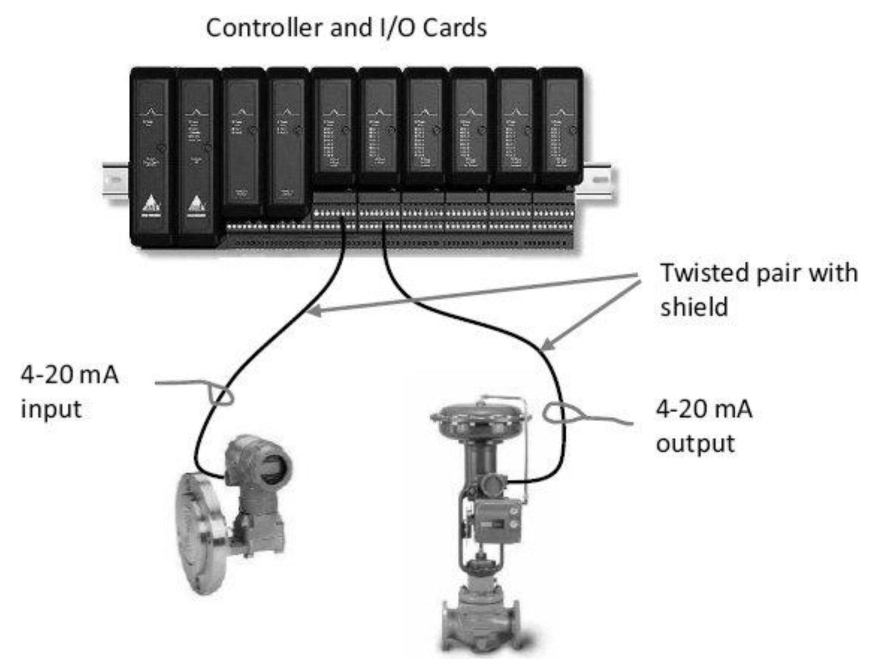


Figure 6-1. Wiring for Traditional Installation

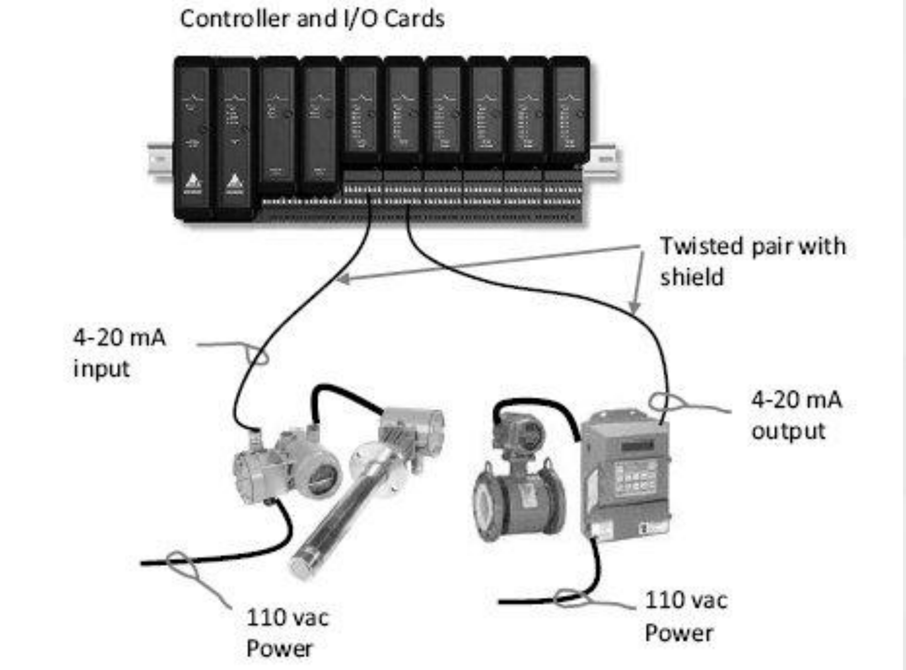


Figure 6-2. Wiring for Four-wire Transmitters

Fieldbus Installation

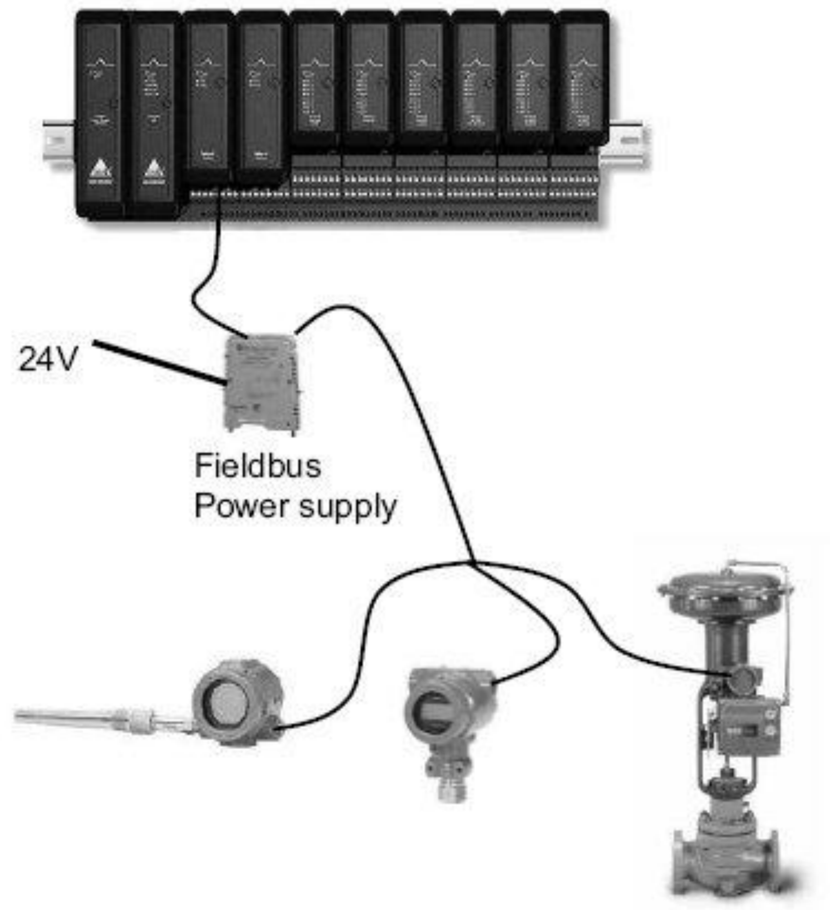


Figure 6-4. Foundation Fieldbus Segment

- Special requirements for a fieldbus installation are addressed
- Common terminology is defined:
  - Multi-drop
  - Power conditioner
  - Terminator

Control System Documentation

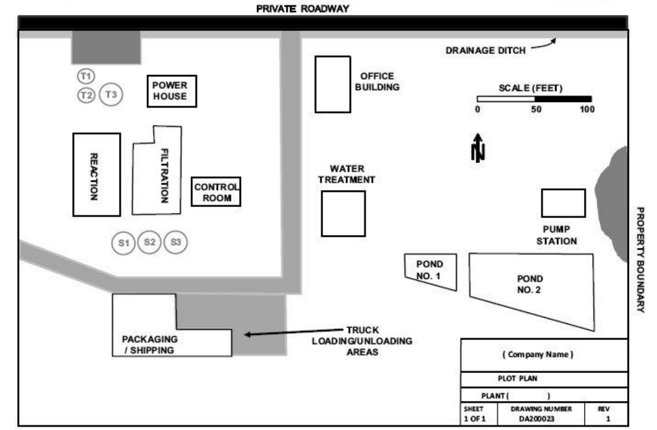


Figure 7-1. Plot Plan

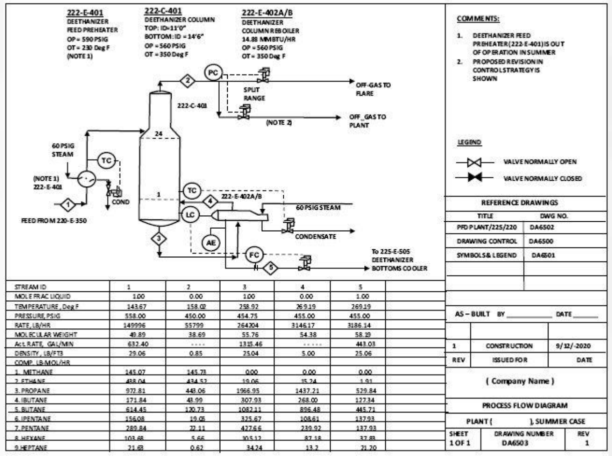


Figure 7-2. Process Flow Diagram

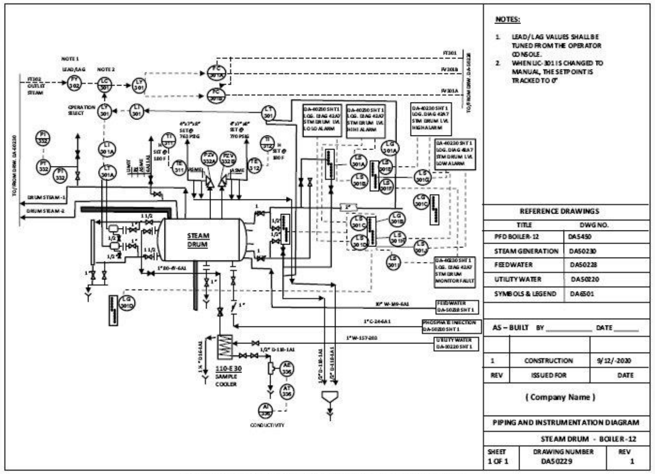


Figure 7-3. Piping and Instrumentation Diagram

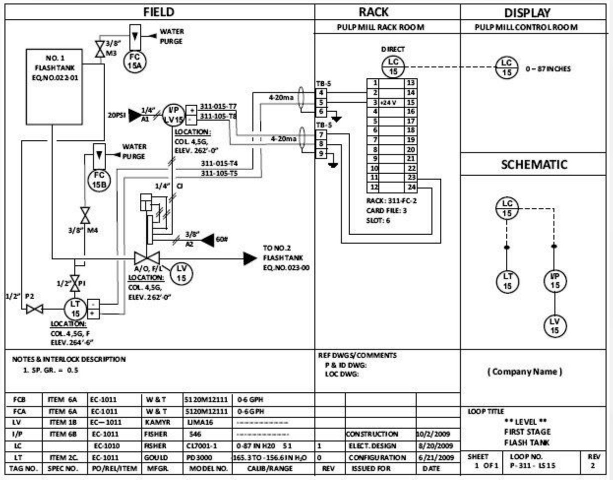


Figure 7-4. Example Loop Diagram—Level Control

- Documentation that is typically generated for a control system installation are addressed.
- The purpose of each document is explained.
- Reference provided to ISA-5.4 standard for Instrument Loop Diagrams

Tag Convention – ISA S5.1

TYPICAL TAG NUMBER

TIC 103 - Instrument Identification or Tag Number
T 103 - Loop Identifier
103 - Loop Number
TIC - Function Identification
T - First-letter
IC - Succeeding-Letters

EXPANDED TAG NUMBER

10-PAH-5A - Tag Number
10 - Optional Prefix
A - Optional Suffix

ISA S5.1 Tag Number Convention

	First Letters		Succeeding Letters		
	Measured/Initiating Variable	Variable Modifier	Readout/Passive Function	Output/Active Function	Function Modifier
A	Analysis		Alarm		
B	Burner, Combustion		User's Choice	User's Choice	User's Choice
C	User's Choice			Control	Close
D	User's Choice	Difference, Differential			Deviation
E	Voltage		Sensor, Primary Element		
F	Flow, Flow Rate	Ratio			
G	User's Choice		Glass, Gauge, Viewing Device		
H	Hand				High
I	Current		Indicate		
J	Power	Scan			
K	Time, Schedule	Time Rate of Change		Control Station	
L	Level		Light		Low
M	User's Choice				Middle, Intermediate
N	User's Choice		User's Choice	User's Choice	User's Choice
O	User's Choice		Orifice, Restriction		Open
P	Pressure		Point (Test Connection)		
Q	Quantity	Integrate, Totalize	Integrate, Totalize		
R	Radiation		Record		Run
S	Speed, Frequency	Safety		Switch	Stop
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	
V	Vibration, Mechanical Analysis			Valve, Damper, Louver	
W	Weight, Force		Well, Probe		
X	Unclassified	X-axis	Accessory Devices, Unclassified	Unclassified	Unclassified
Y	Event, State, Presence	Y-axis		Auxiliary Devices,	
Z	Position, Dimension	Z-axis, Safety Instrumented System		Driver, Actuator, Unclassified final control element	

Figure 7-9. ISA-5.1 Identification Letters

Representation of Signals and Instruments

- Instrument supply
  or connection to process
- Pneumatic Signal
- Electric Variable or Binary
- Communication Link

Figure 7-10. Excerpt from ISA-5.1 Instrument Line Symbols

Discrete Instrument,
field mounted

Discrete instrument,
accessible to operator

Visible on video Display

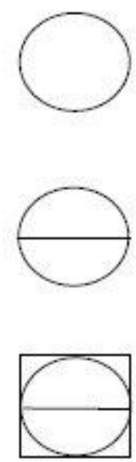


Figure 7-11. Excerpt from ISA-5.1 General Instrumentation or Symbol Function

Symbols for Field devices and Elements

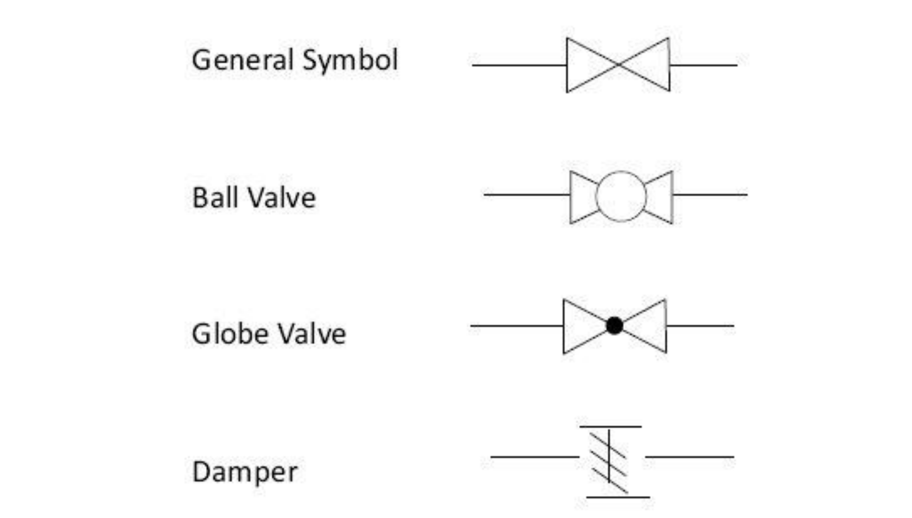


Figure 7-12. Excerpt from ISA-5.1 Valve Body and Damper Symbols

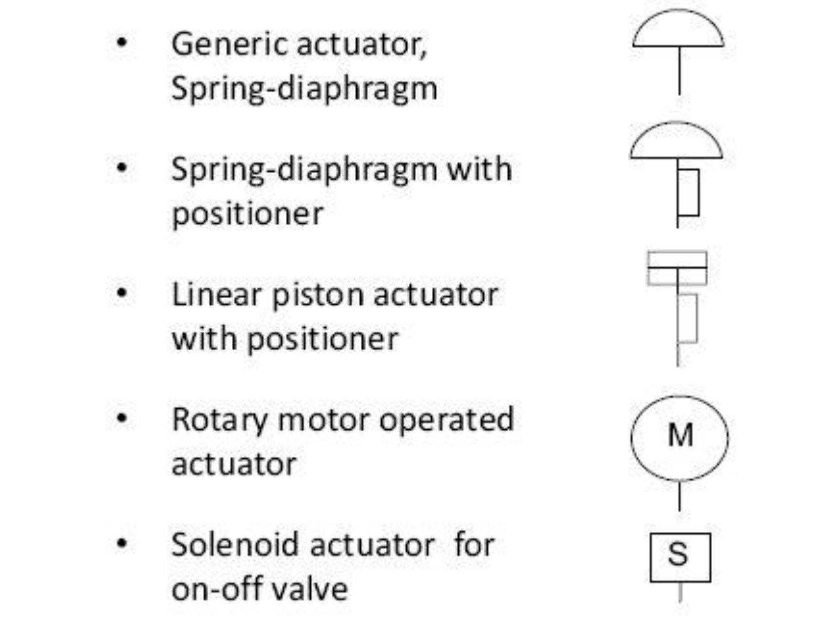


Figure 7-13. Excerpt from ISA-5.1 Actuator Symbols

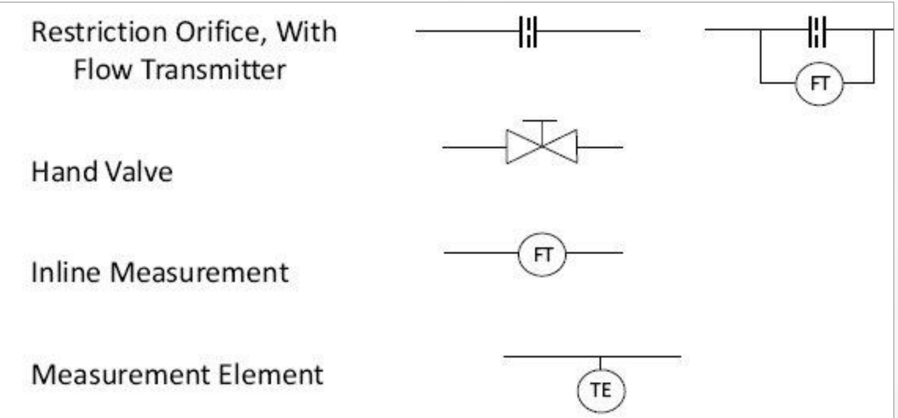


Figure 7-14. Excerpt from ISA-5.1 Symbols for Other Devices

Process Symbols

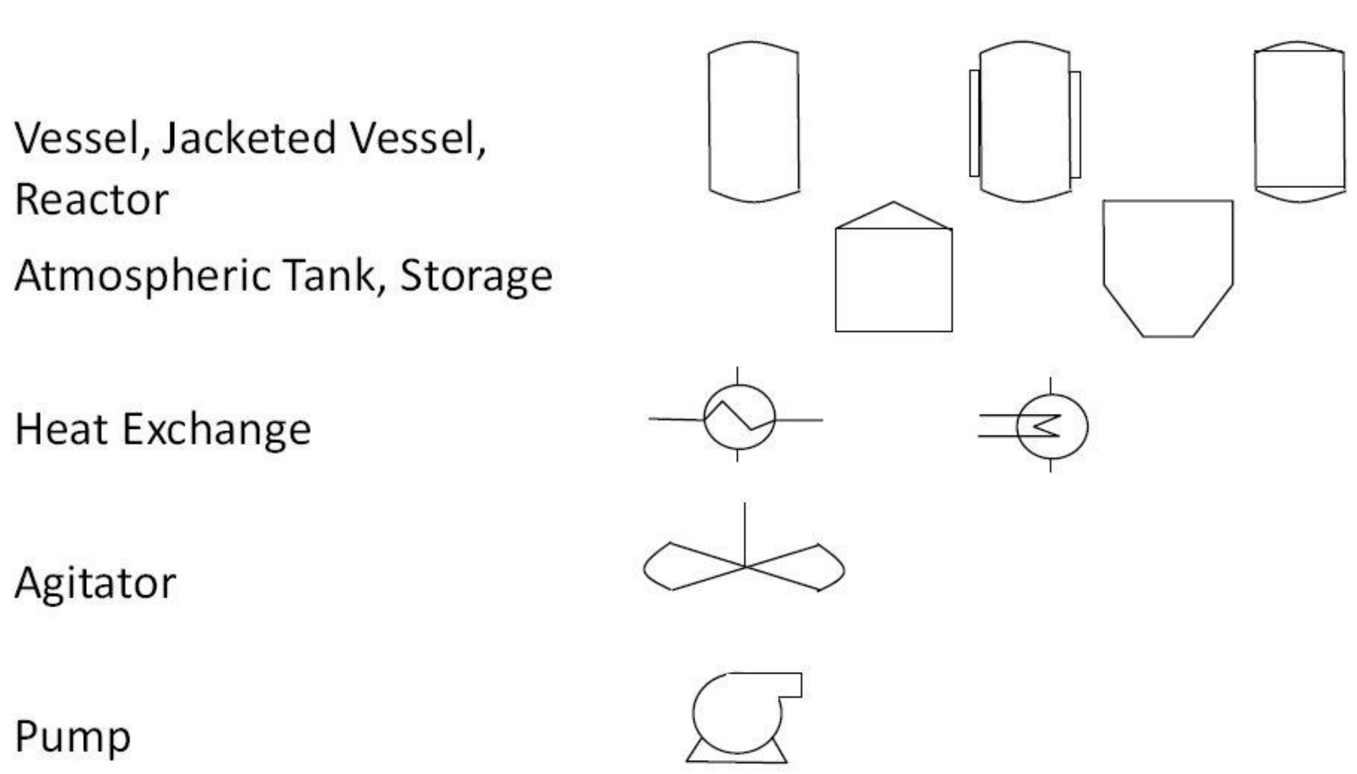


Figure 7-15. Examples of Process Equipment Symbols

Symbol Example – P&ID Drawing

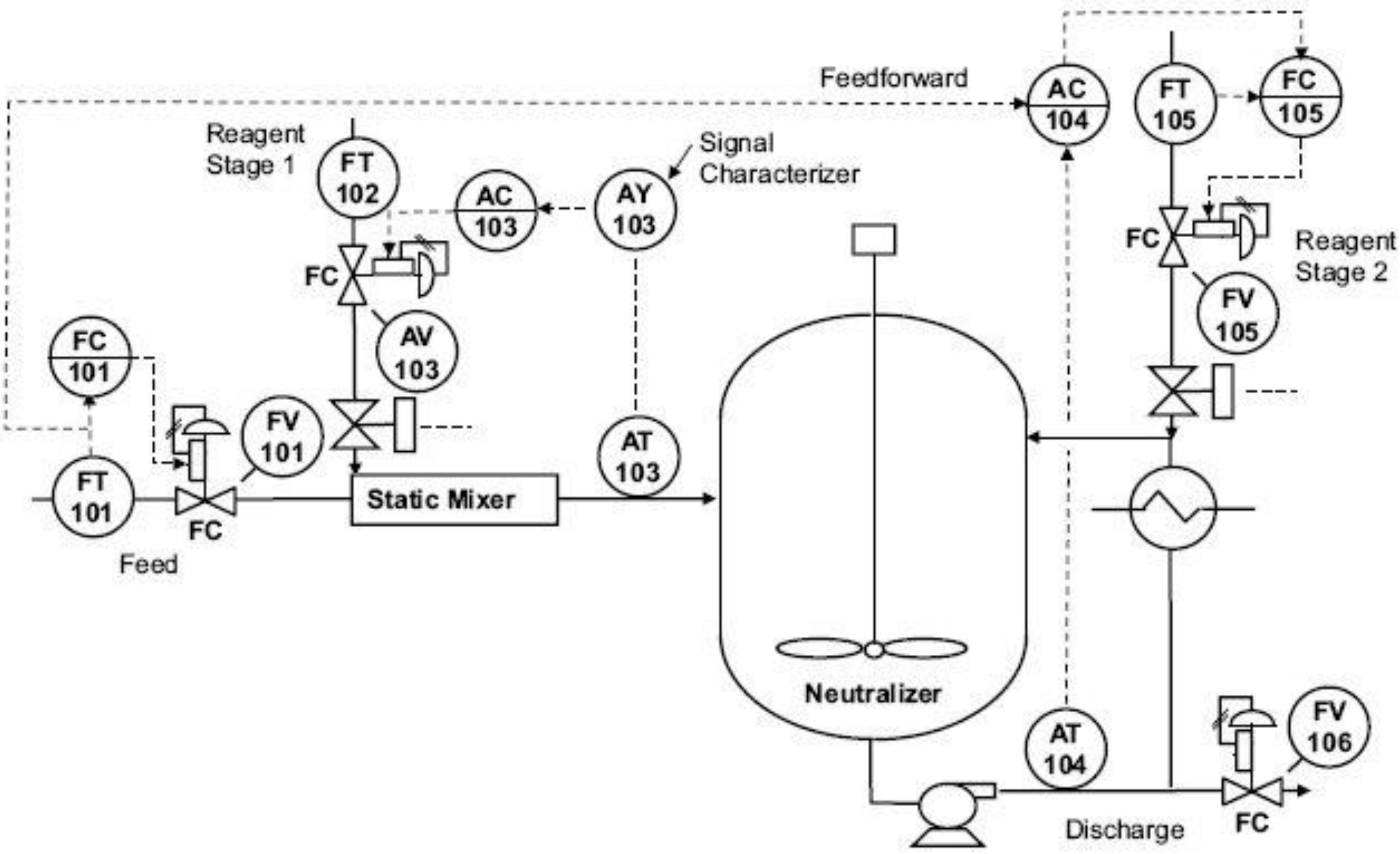


Figure 7-16. Example – Basic Neutralizer Control System

Symbol Example(Cont.)

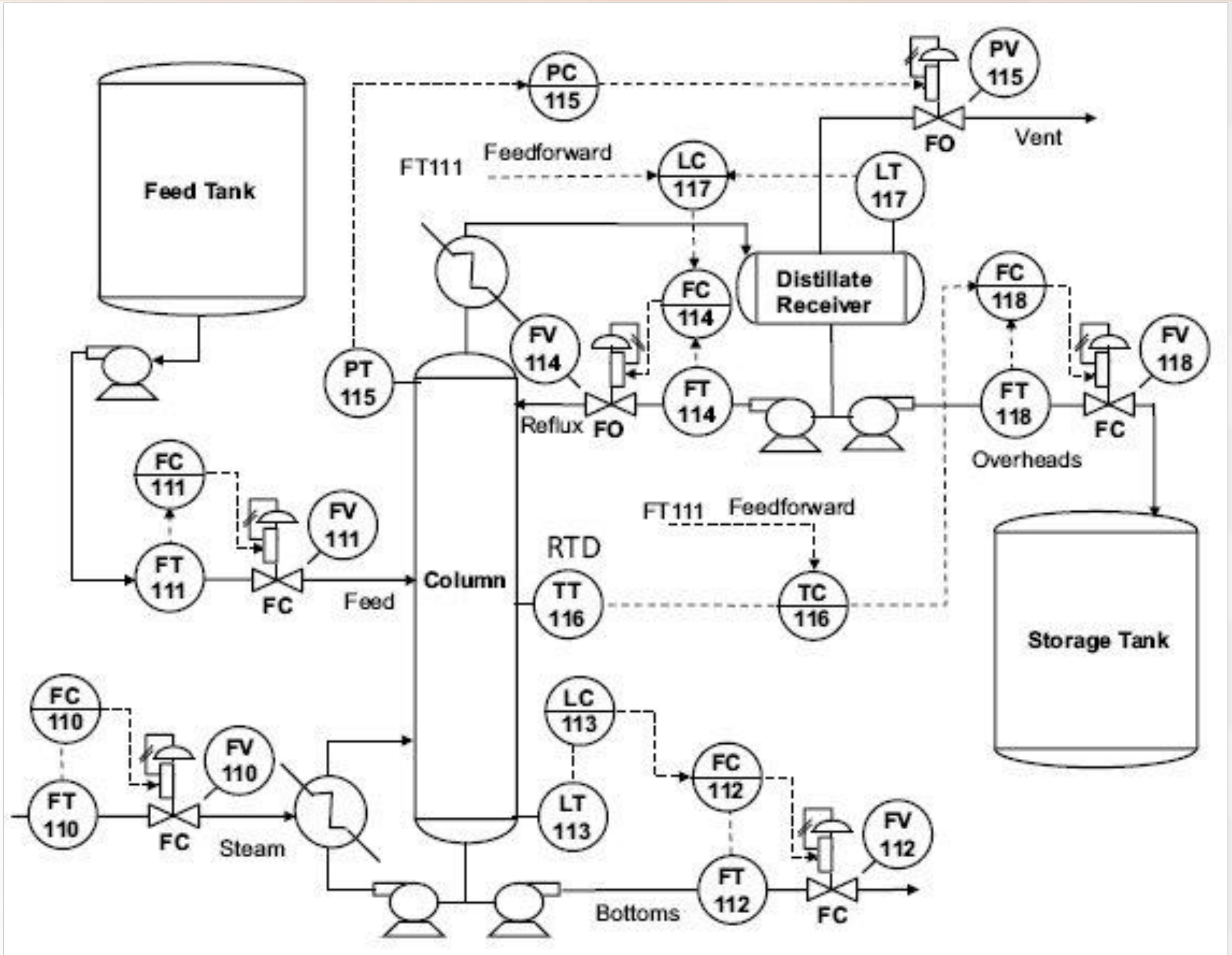


Figure 7-17. Basic Column Control System

Symbol Example(Cont.)

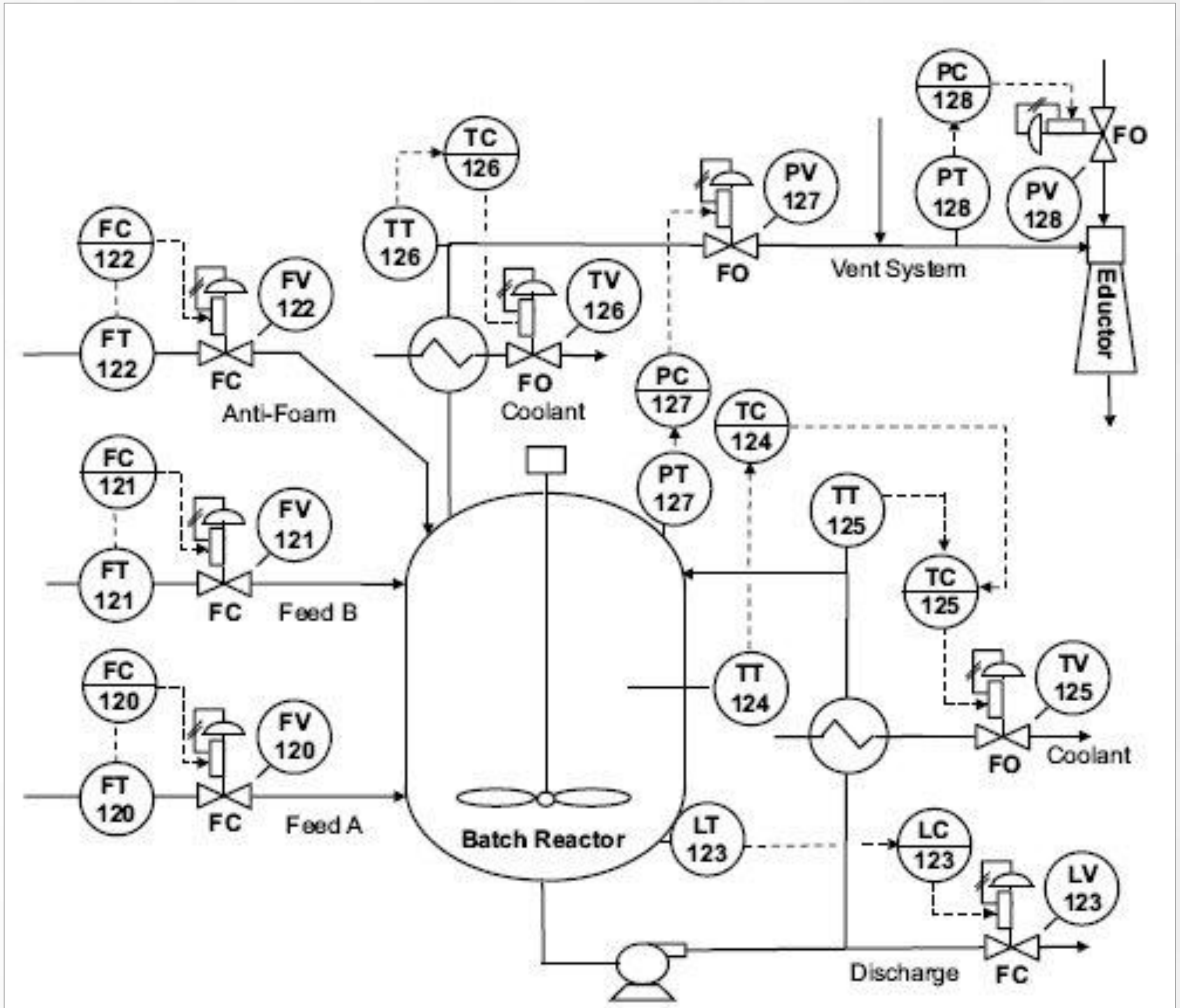


Figure 7-18. Example – Batch Reactor Control

Symbol Example(Cont.)

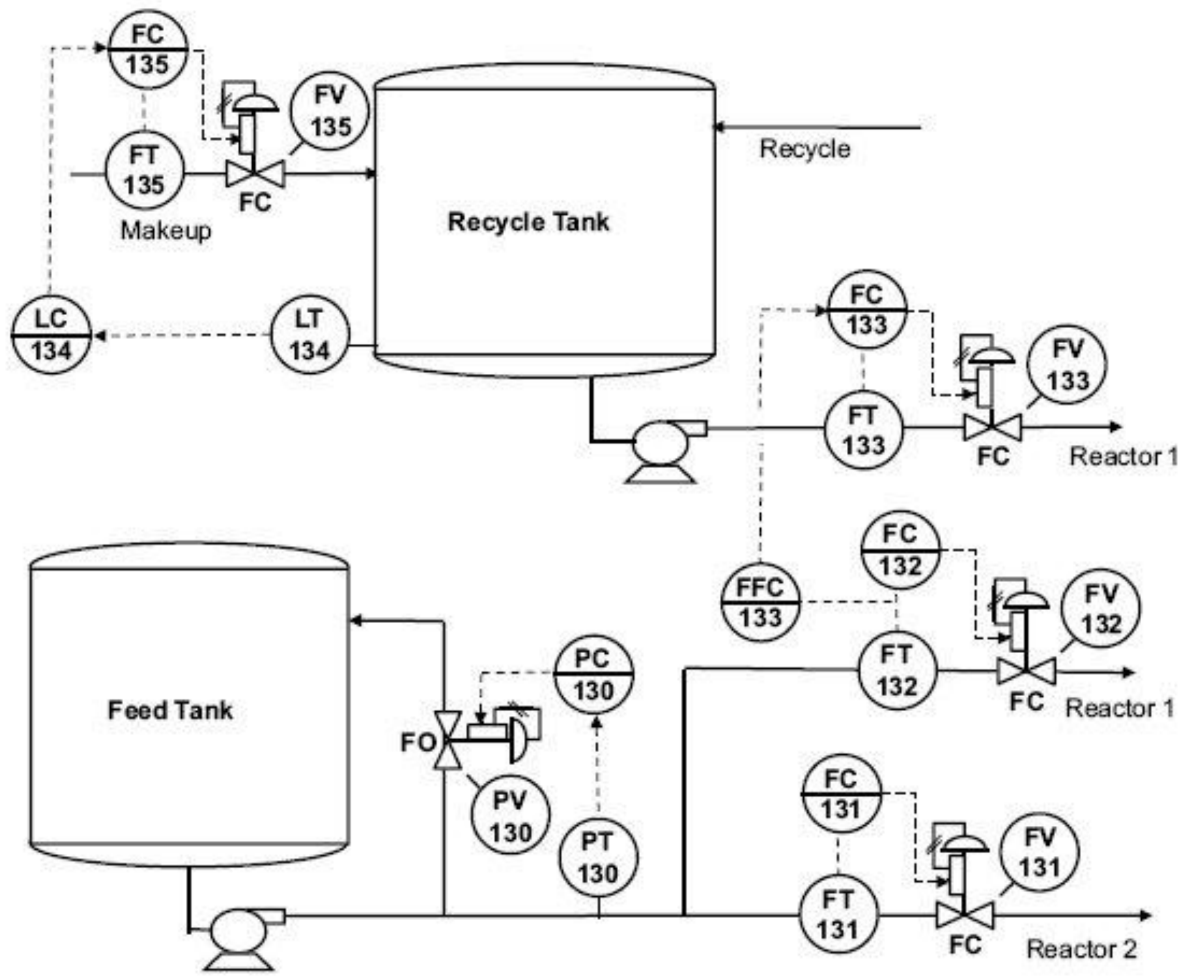


Figure 7-19. Example – Continuous Feed and Recycle Tank

Operator Graphics and Metrics

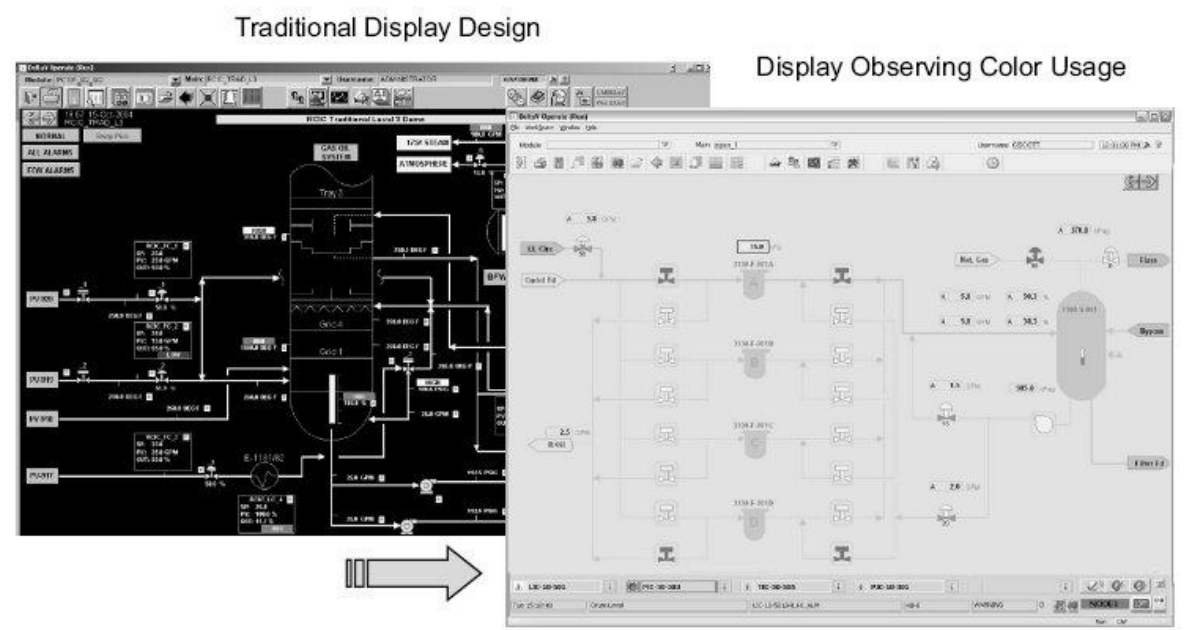


Figure 8-2. Impact of EEMUA 191 on the Use of Color in Displays

- An operator interface design is addressed by Alarm Standard EEMUA 191
- Advocates that alarms should be in alarm color. Pipes, pumps, valves, etc. should not be in alarm colors, or any other bright color.

Display Observing Color Usage

Display Tools

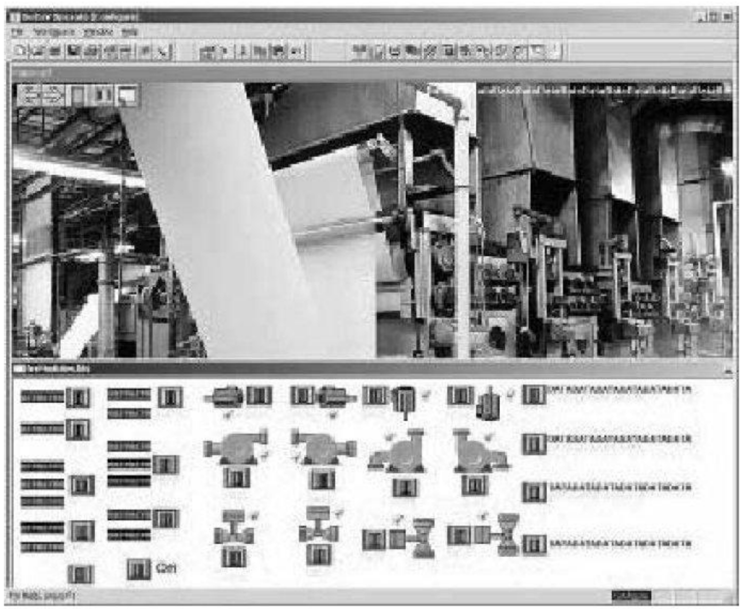


Figure 8-3. Dynamo Examples for Display Building

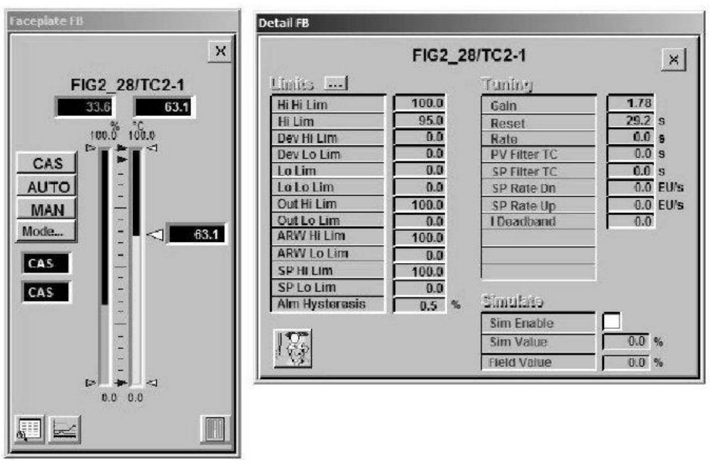


Figure 8-4. Faceplate and Detail Display

- Basic tools for construction a display are discussed
  - Dynamos, dynamic elements, faceplates, links for creating a display hierarchy

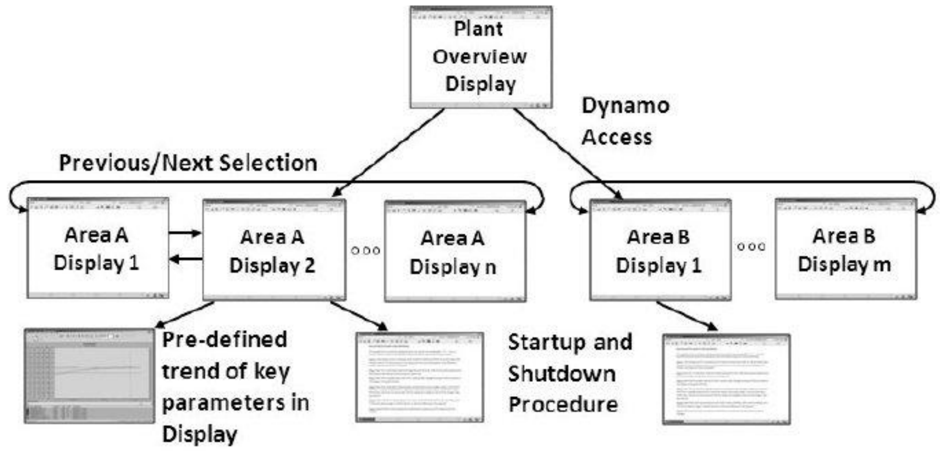


Figure 8-5. Example of Typical Display Hierarchy

Performance Metrics

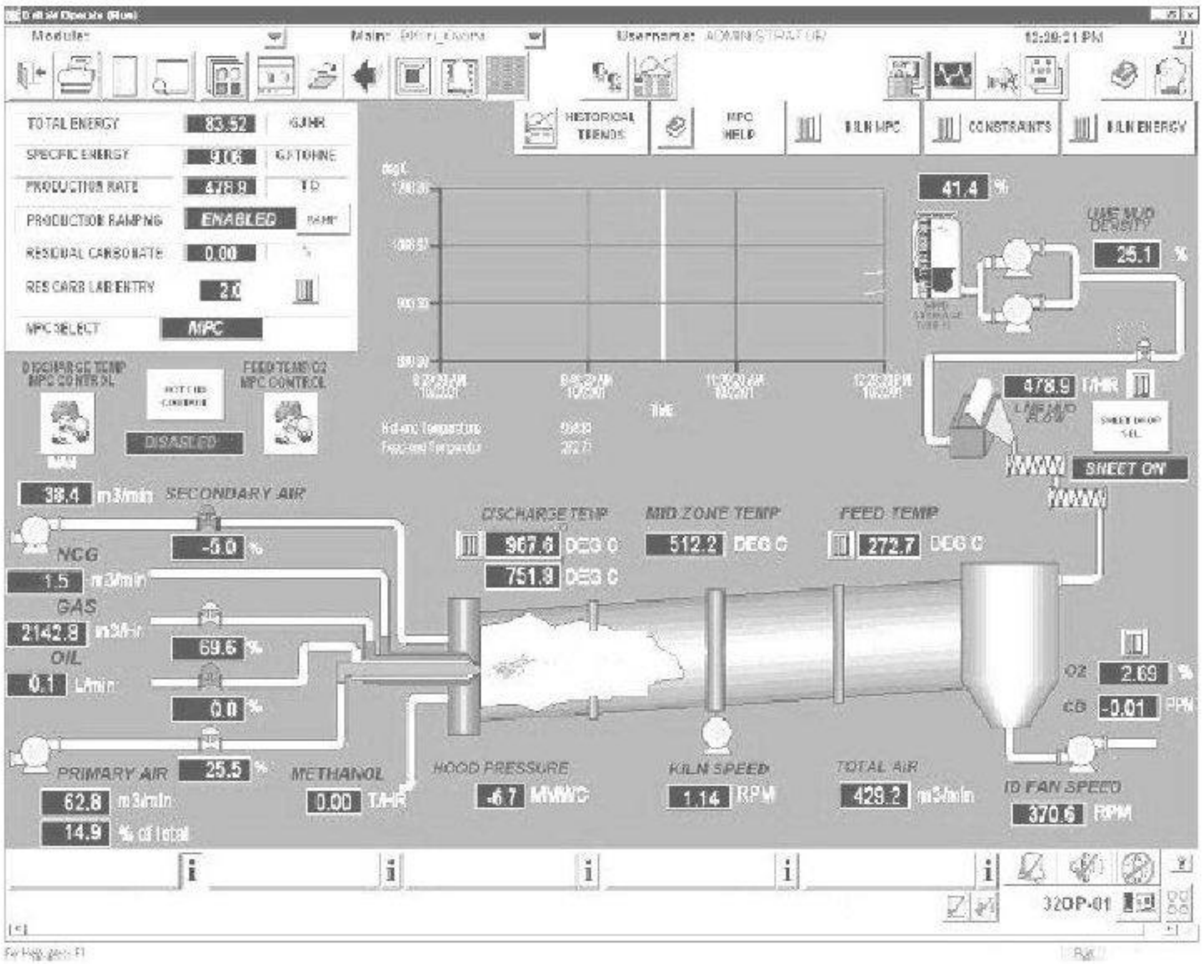
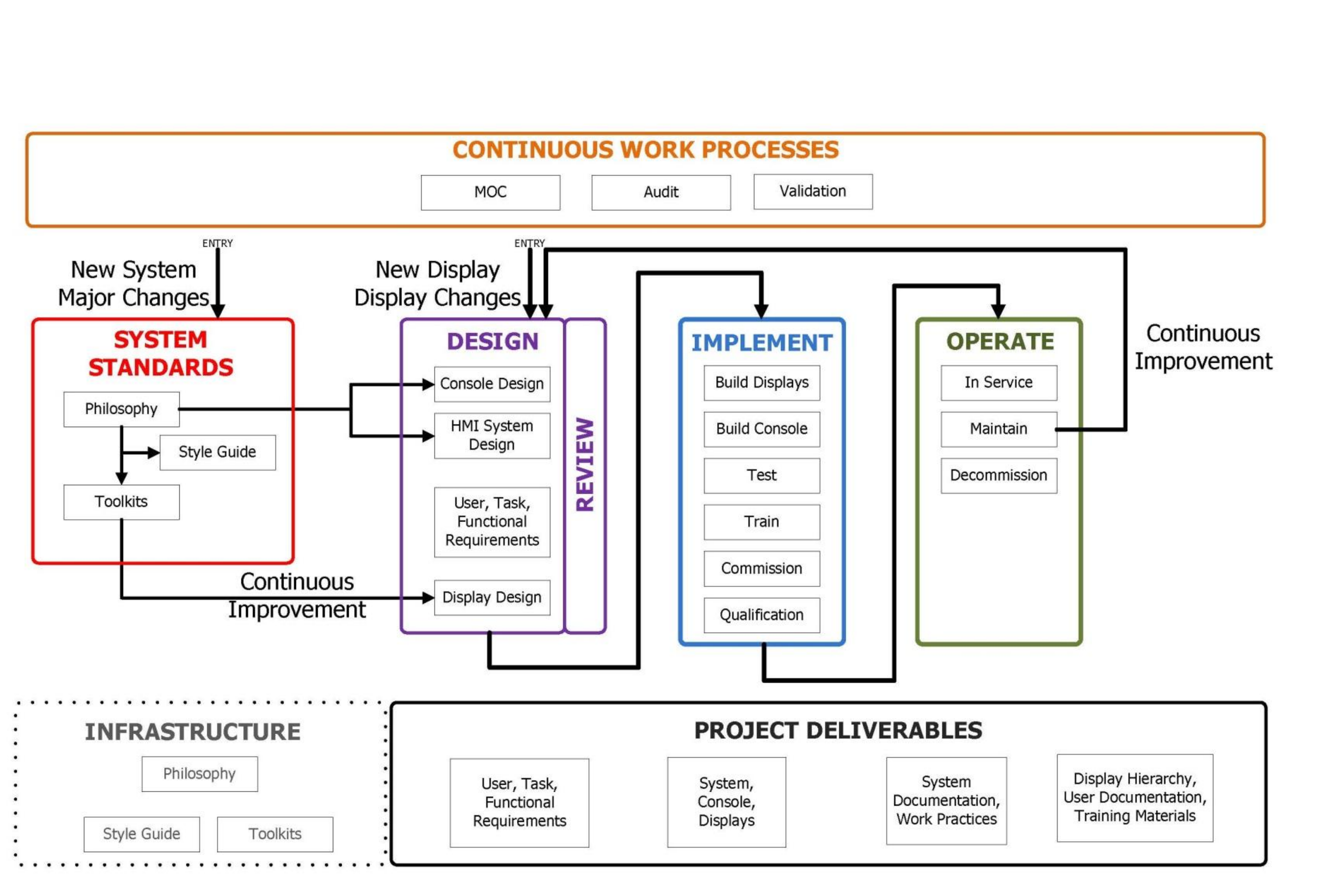


Figure 8-6. Display for Monitoring Performance Indicators

- Example used to illustrate how operation metrics may be added to an operator display
- Benefits of integrating this type of information into the operator interface

ISA 101 - Human Machine Interfaces for Process Automation Systems



Center for Operator Performance

http://www.operatorperformance.org/

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Research Programs

- Completed
  - Nature of Expertise
  - Decision Making Exercises
  - Simulator Usage
  - Color Usage/Display Design
  - Alarm Rate & Presentation Impact
- Current
  - Quantify alarm actuation rates that operators can handle
  - Develop & evaluate effectiveness of decision-based operating graphics
  - Develop systematic approach to documenting “expertise? of senior operators before they walk out the door
  - Evaluate methods of early detection of off-normal operations
  - Data Mining of Near Miss Process Incidents
  - Human Performance Metrics

Process Characterization

- A plant may be thought of as being made up of a series of processes.
- A good understanding of these processes is required to design a control system for the plant.

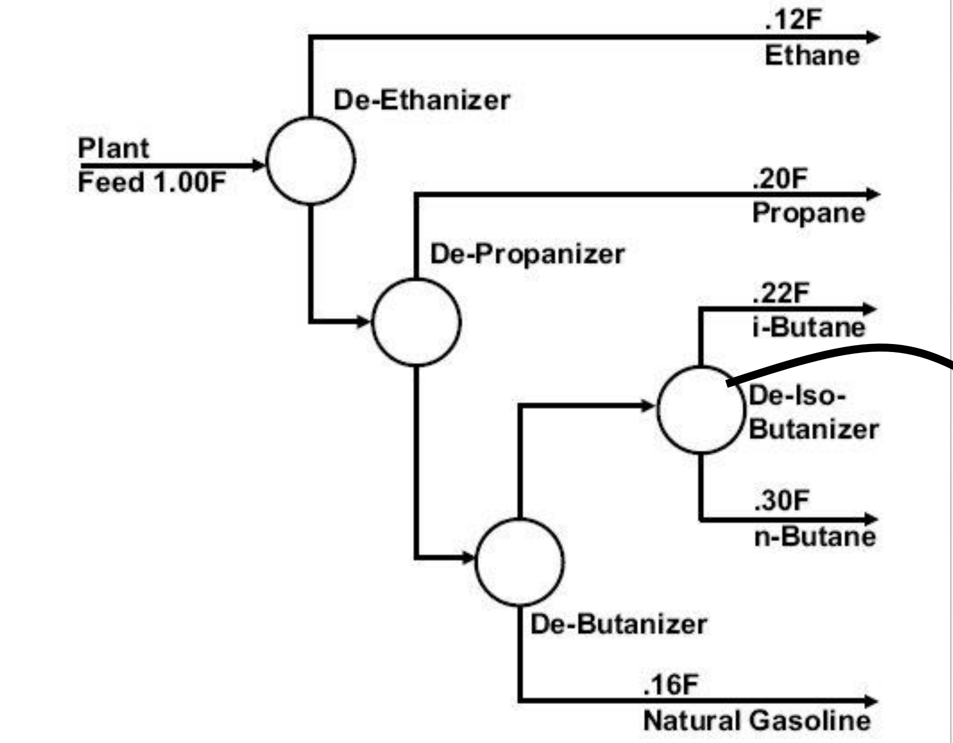


Figure 9-1. Example – Gas Plant Process Flow Diagram

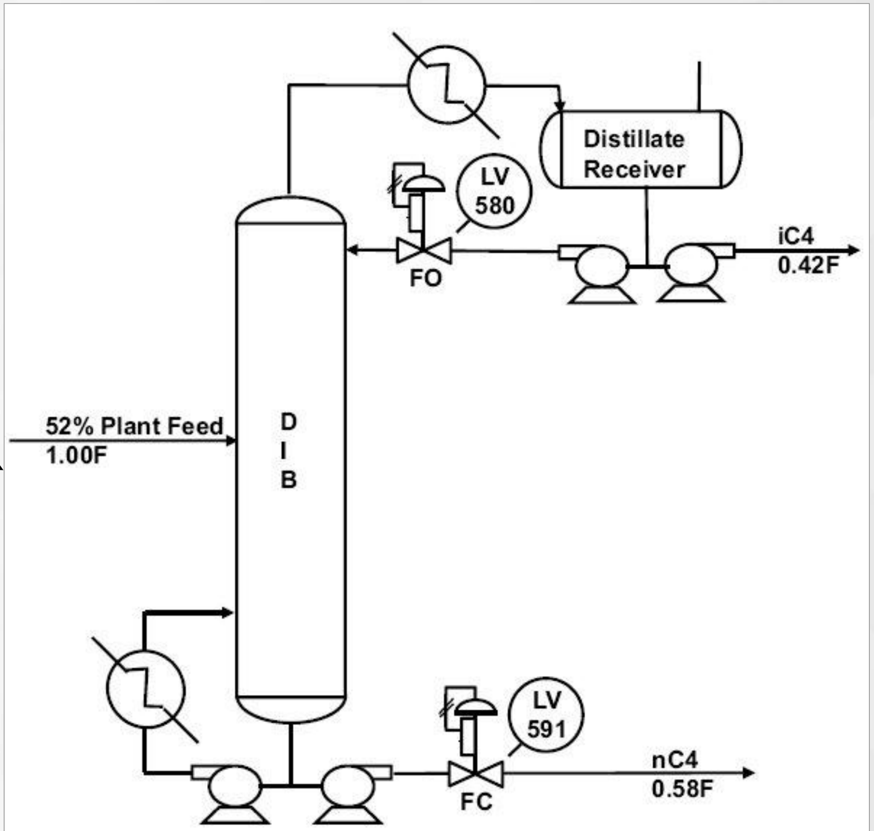


Figure 9-2. De-Iso-Butanizer Process Detail

Process Definition

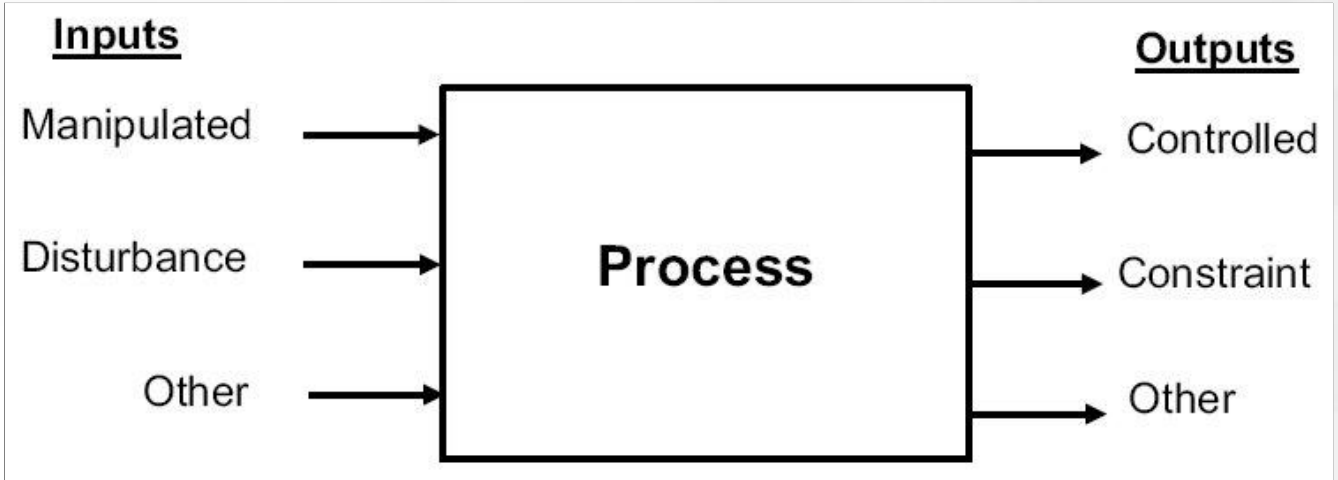


Figure 9-3. Process Representation

Process – Specific equipment configuration (in a manufacturing plant) which acts upon inputs to produce outputs.

Process Terminology

- **Controlled output (controlled parameter)** – Process output that is to be maintained at a desired value by adjustment of process input(s).
- **Setpoint** – Value at which the controlled parameter is to be maintained by the control system.
- **Manipulated input (manipulated parameter)** – Process input that is adjusted to maintain the controlled parameter at the setpoint.
- **Disturbance input** – Process input, other than the manipulated input, which affects the controlled parameter.
- **Constraint output (constraint parameter)** – Process output that must be maintained within an operating range.
- **Constraint limit** – Value that a constraint parameter must not exceed for proper operation of the process.
- **Other input** – Process input that has no impact on controlled or constraint outputs.
- **Other output** – Process output other than controlled or constraint outputs.

Example – Application of Terminology

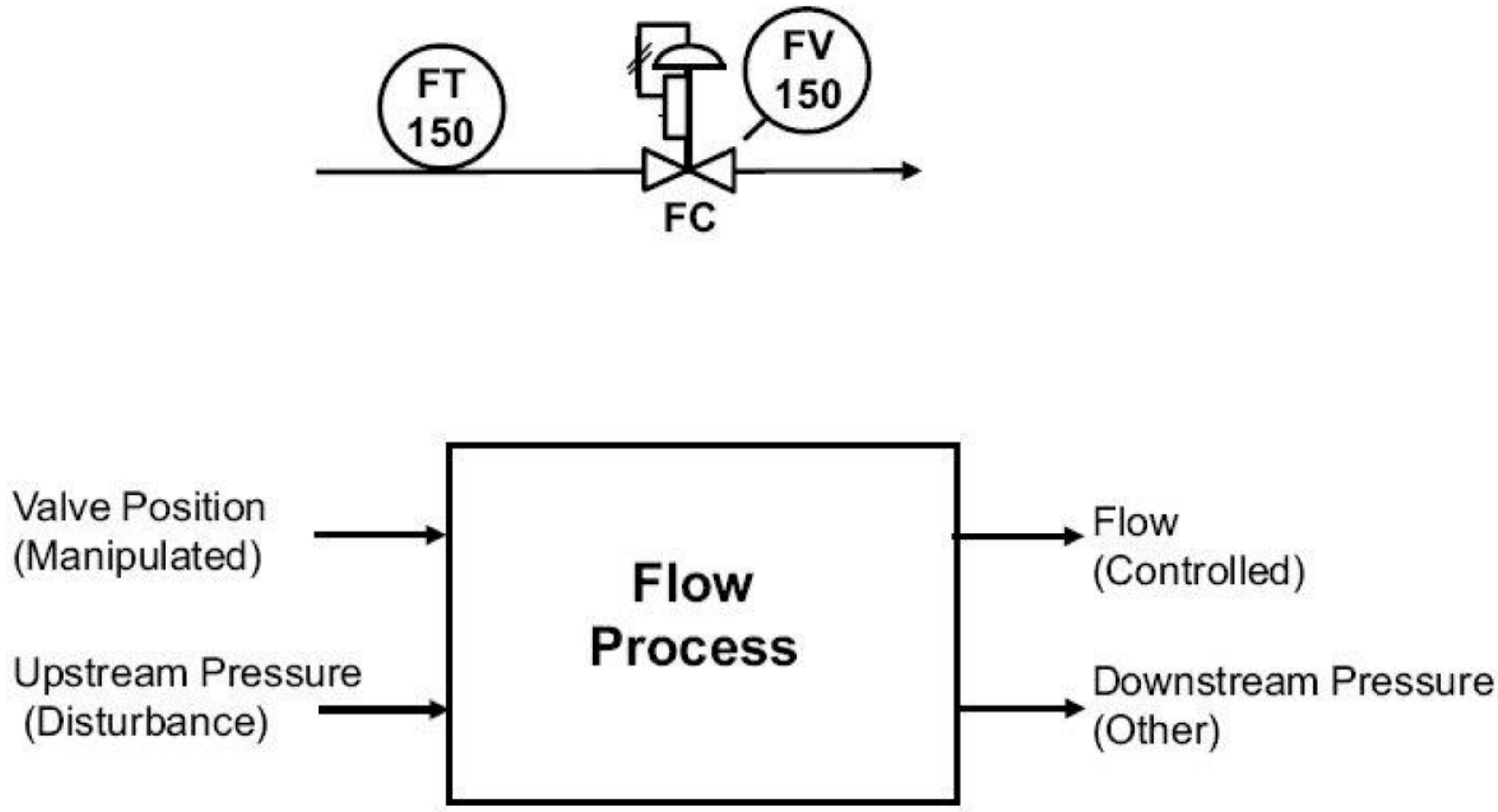


Figure 9-4. Example – Flow Process

Impact of Disturbance Input

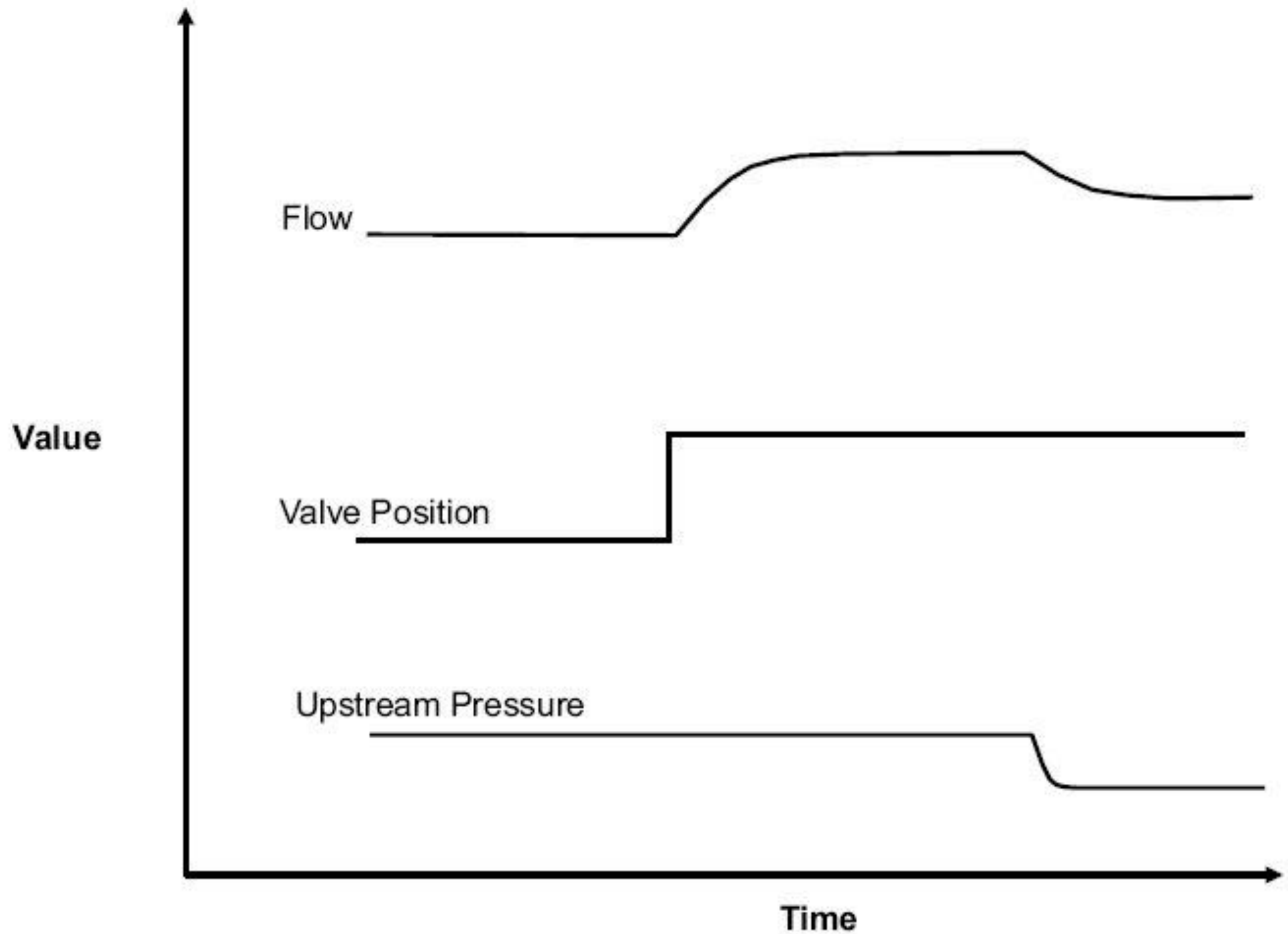


Figure 9-5. Flow Process – Response to Input Change

Example – Lime Mud Filter Process

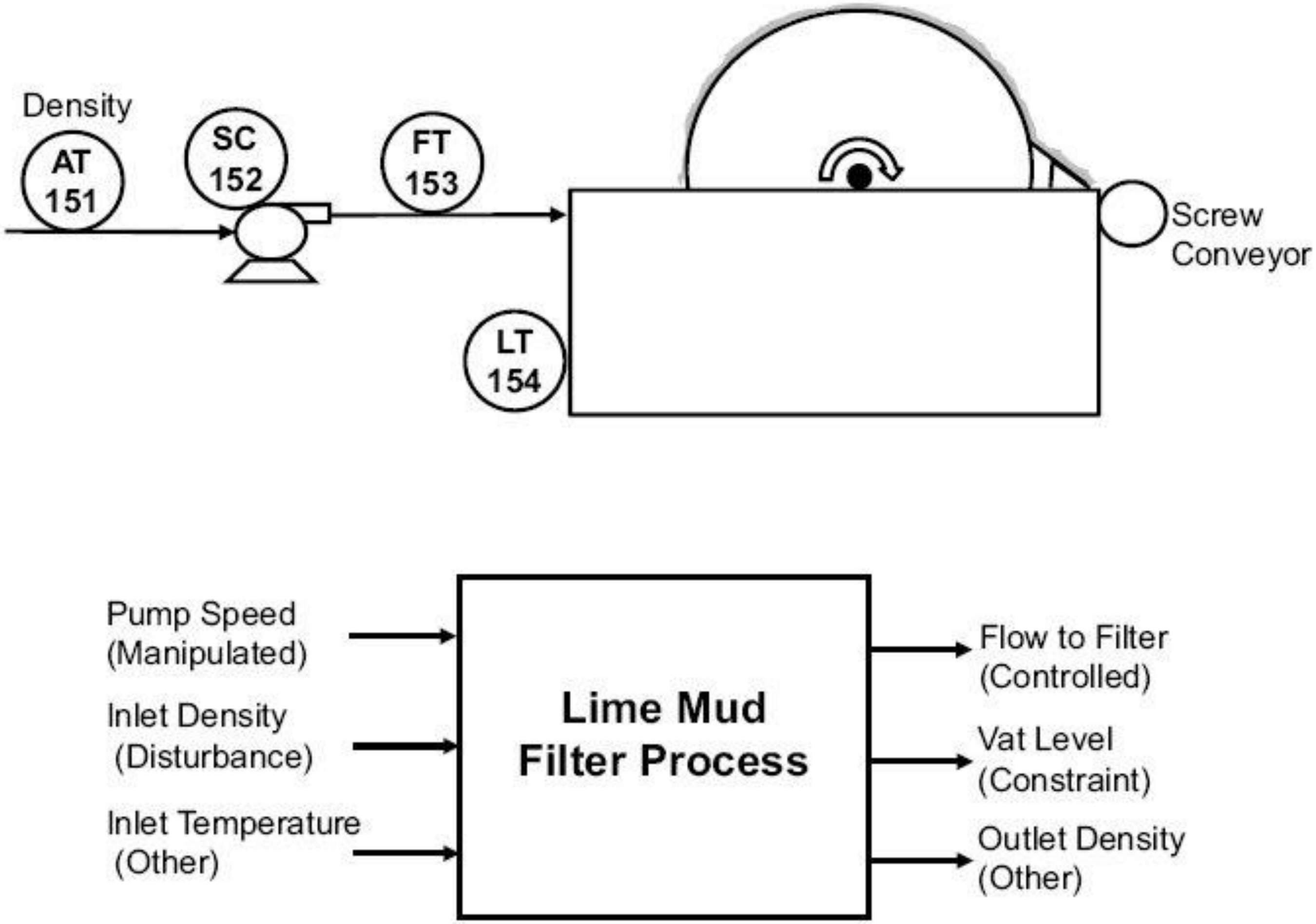


Figure 9-6. Process Example – Lime Mud Filter

Example – Lime Mud Filter (Cont.)

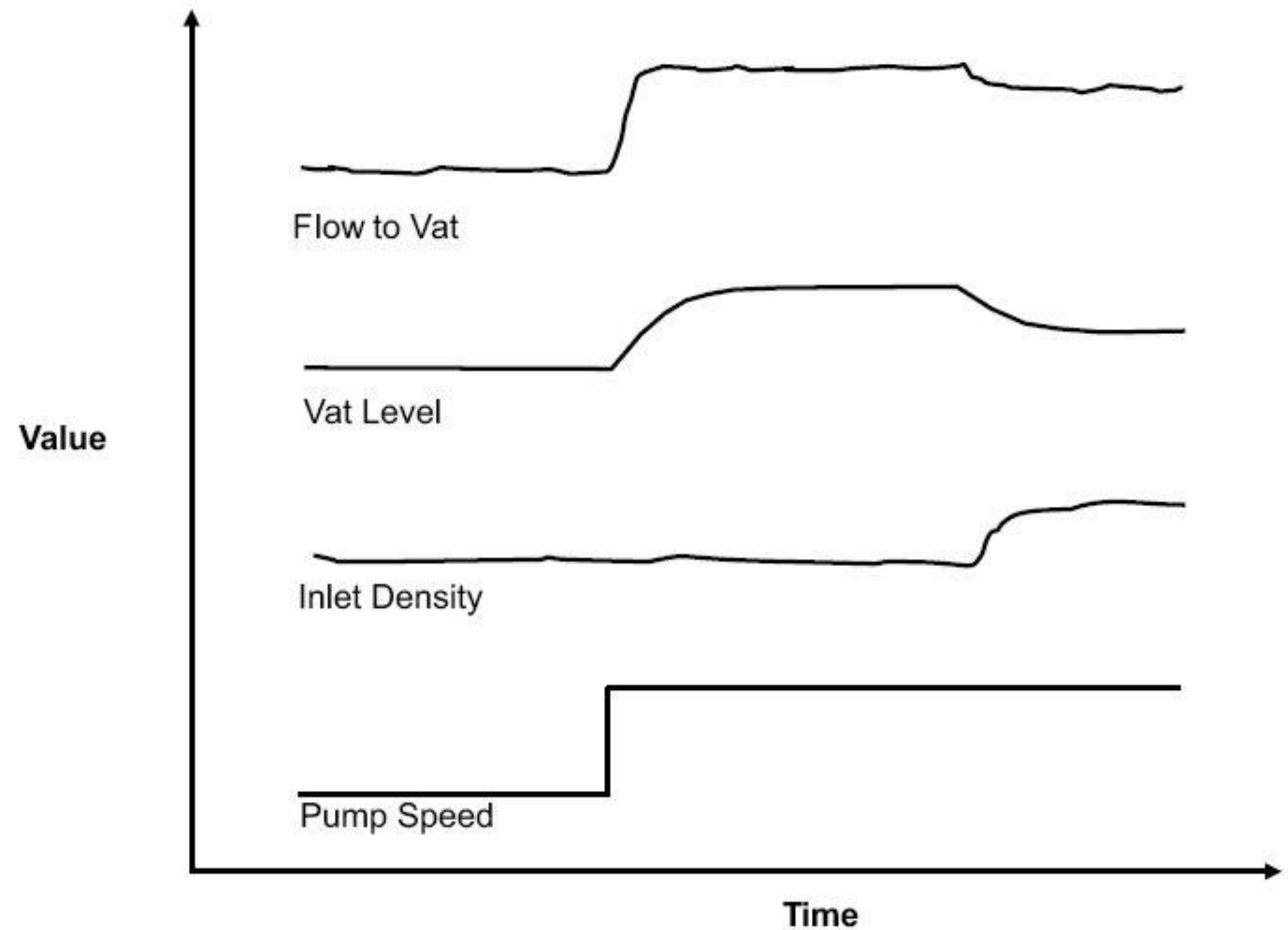


Figure 9-7. Lime Mud Filter – Response to Input Change

Pure Gain Process

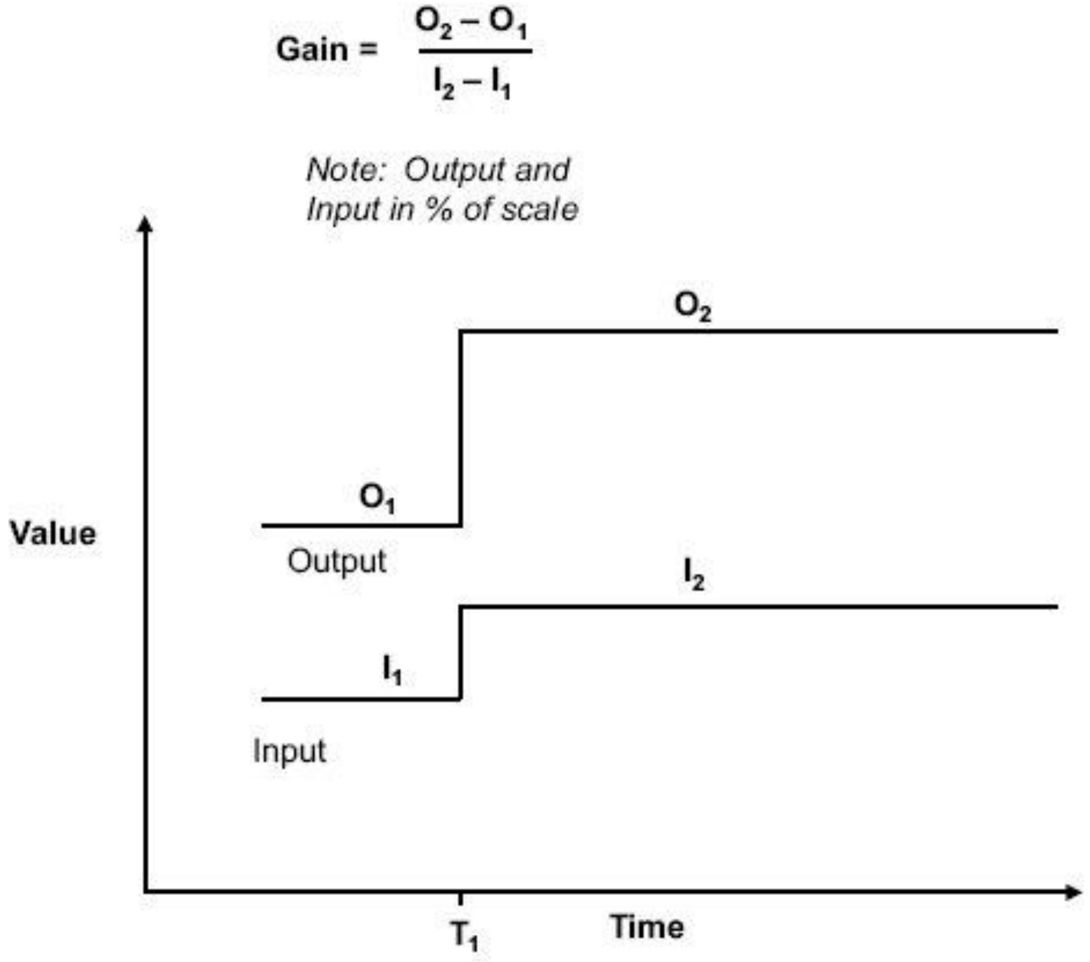


Figure 9-8. Pure Gain Process Response

- When the process output tracks the process input except for a change in signal amplitude, the process is known as a pure gain.
- The change in signal amplitude is determined by the process gain.
- For a step change in process input, the process gain is defined as the change in the process output divided by the change in process input

Example – Pure Gain Process

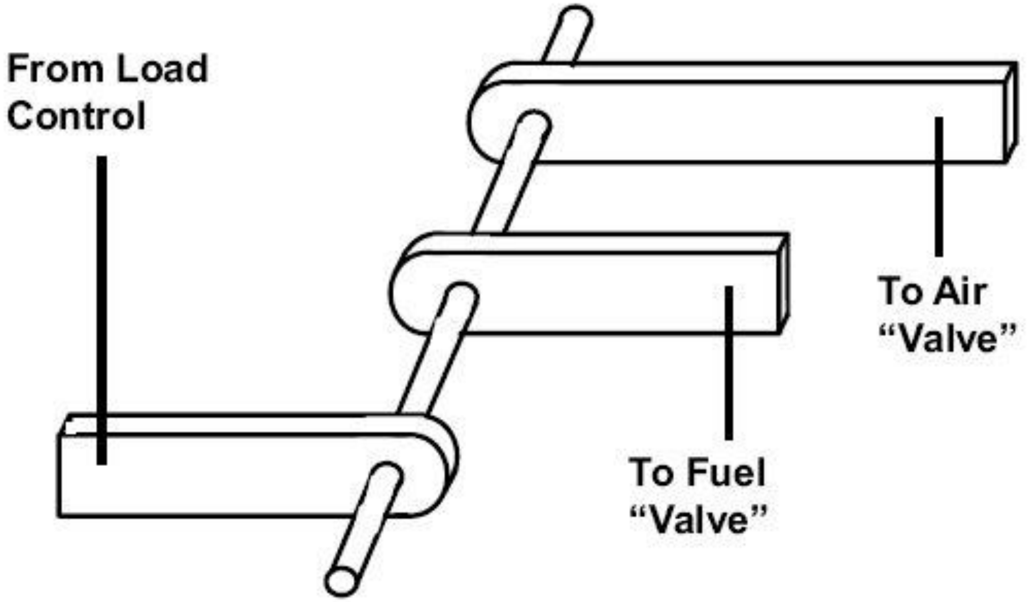


Figure 9-9. Pure Gain Process Example

- An example of a pure gain process is the jack shaft used in some boiler combustion control systems.
- Gain is determine by the length of the lever arms attached to the jack shaft.

Pure Delay Process

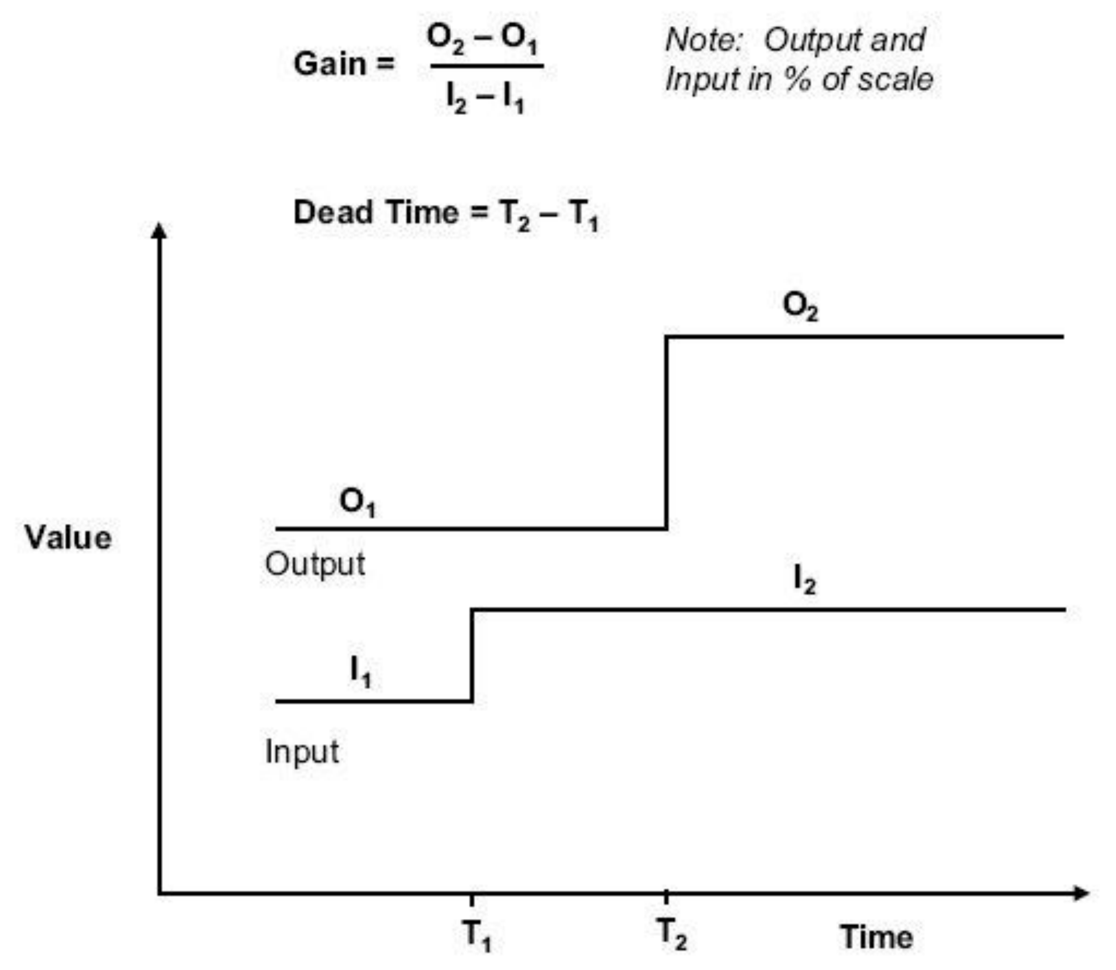


Figure 9-10. Pure Delay Process

- When the process output tracks the process input except for a delay in the output signal, the process is know as a pure delay process.
- For a step change in the process input, process deadtime is defined as the time from the input changing until the first affect of the change is seen in the process output.

Examples – Pure Delay Process

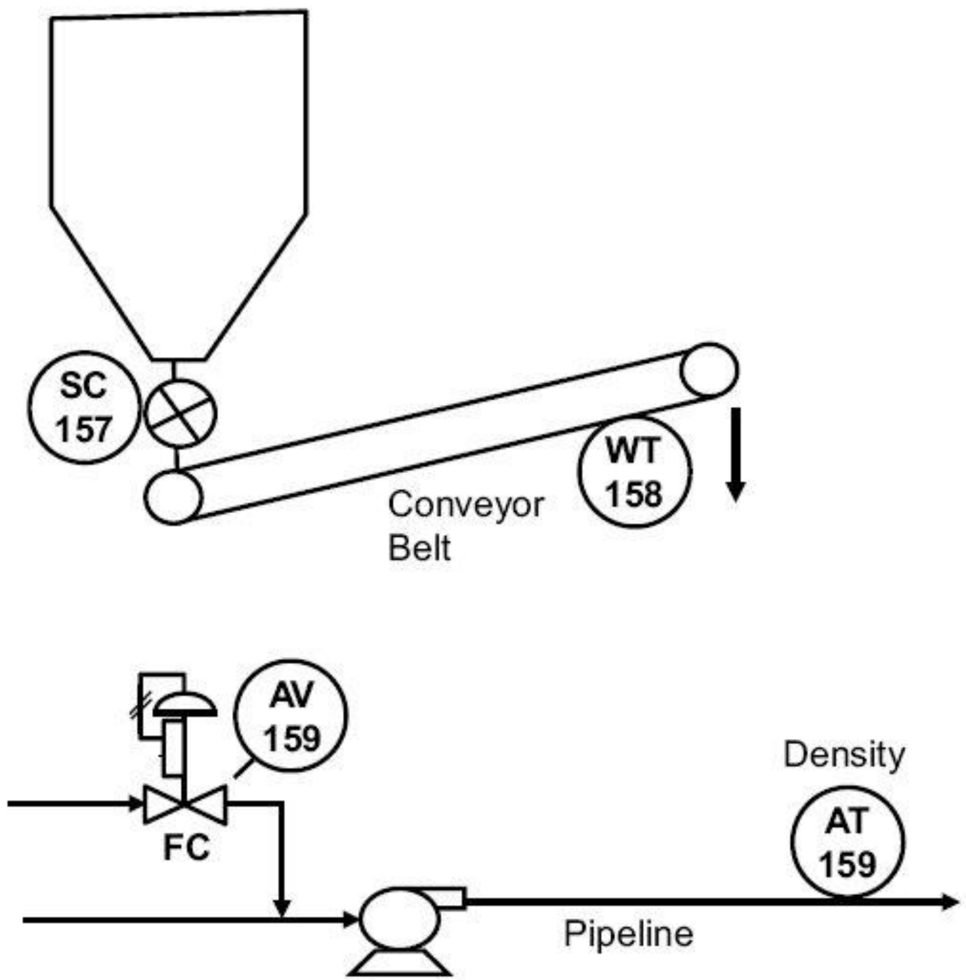


Figure 9-11. Example – Pure Delay Process

- Example of pure delay processes are a conveyor belt and a pipeline.
- Delay is the result of transport time and will vary with the speed of the belt or the flow rate through the pipe.

First Order Process

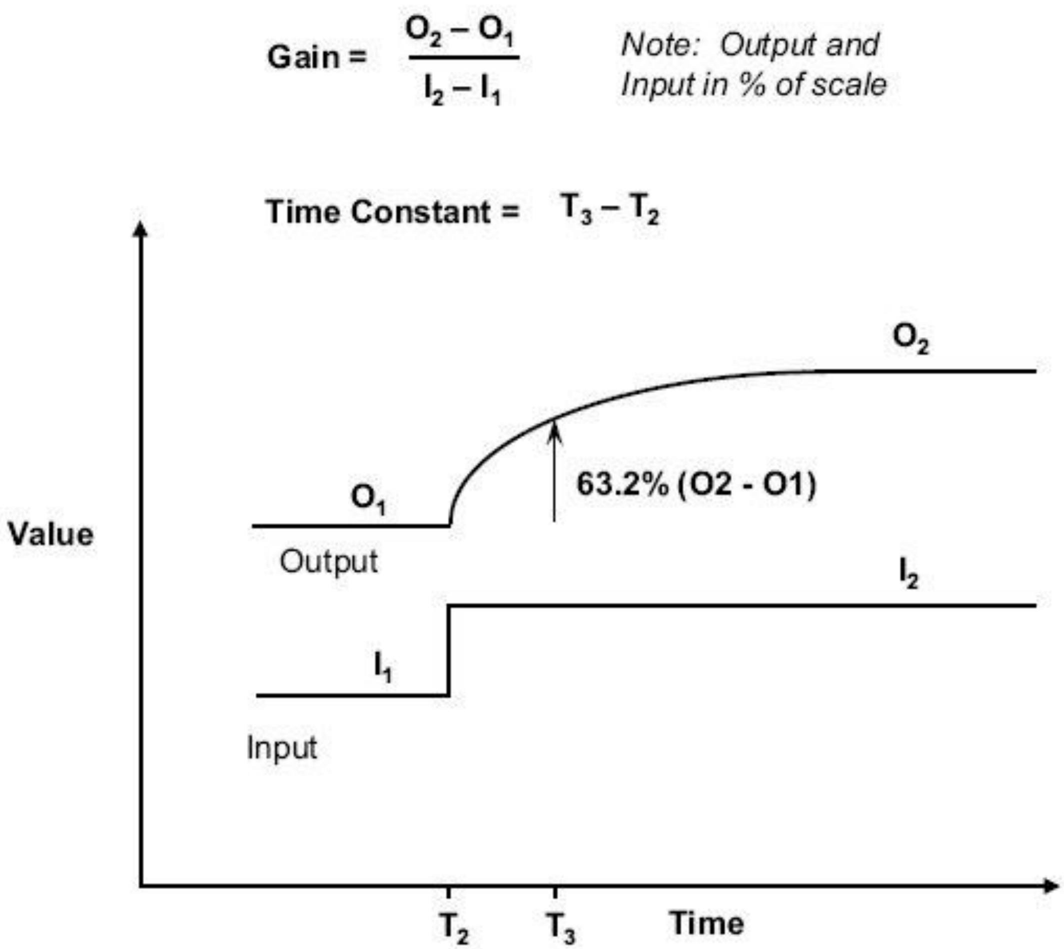


Figure 9-14. Pure Lag (First-Order) Process Response

- When process output immediately begin to respond to a step change in a process input and the rate of change is proportional to its current value and the final value the output will achieve, the process is know as a first order process.
- The dynamic response is fully captured by identifying the process gain and the process time constant.

Example – First Order Process

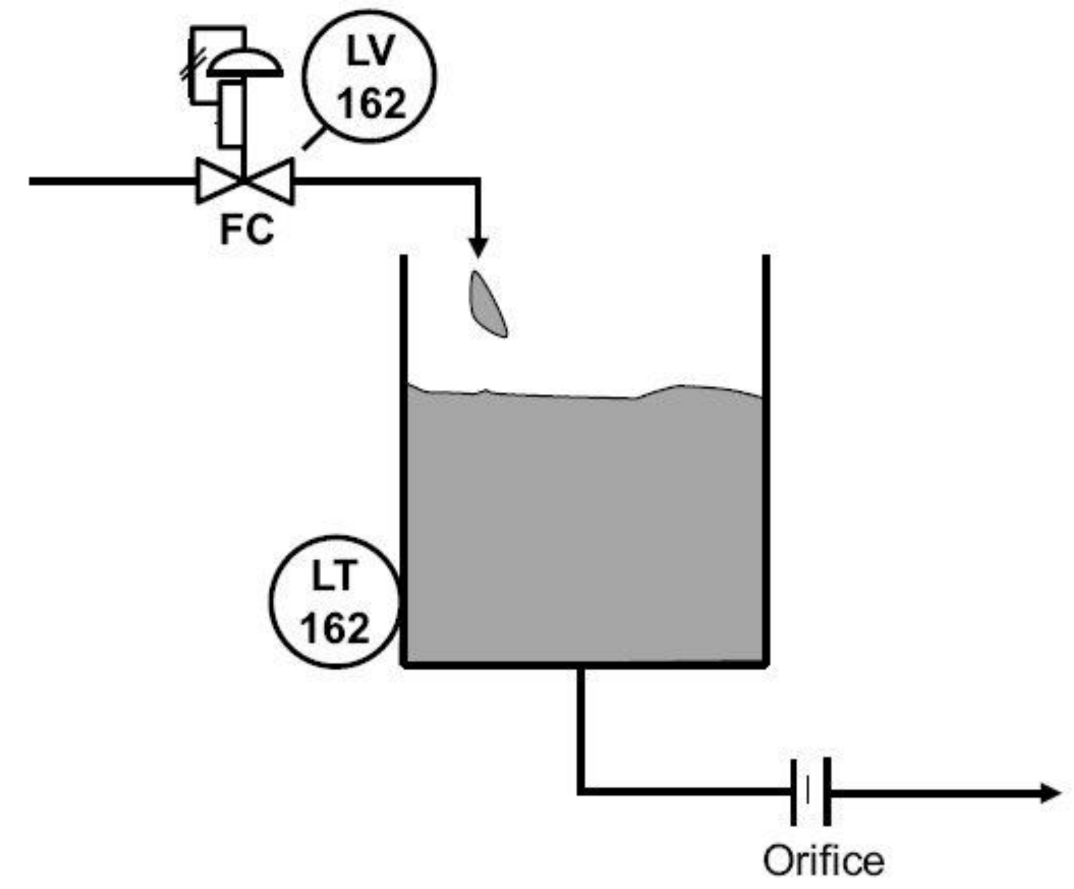


Figure 9-15. Example – Pure Lag Process

- An example of a pure lag process is a tank with outlet flow determined by tank level and the outlet flow restriction caused by the orifice.
- The level will settle at a value which results in an outlet flow that matches the inlet flow.

First Order Plus Deadtime Process

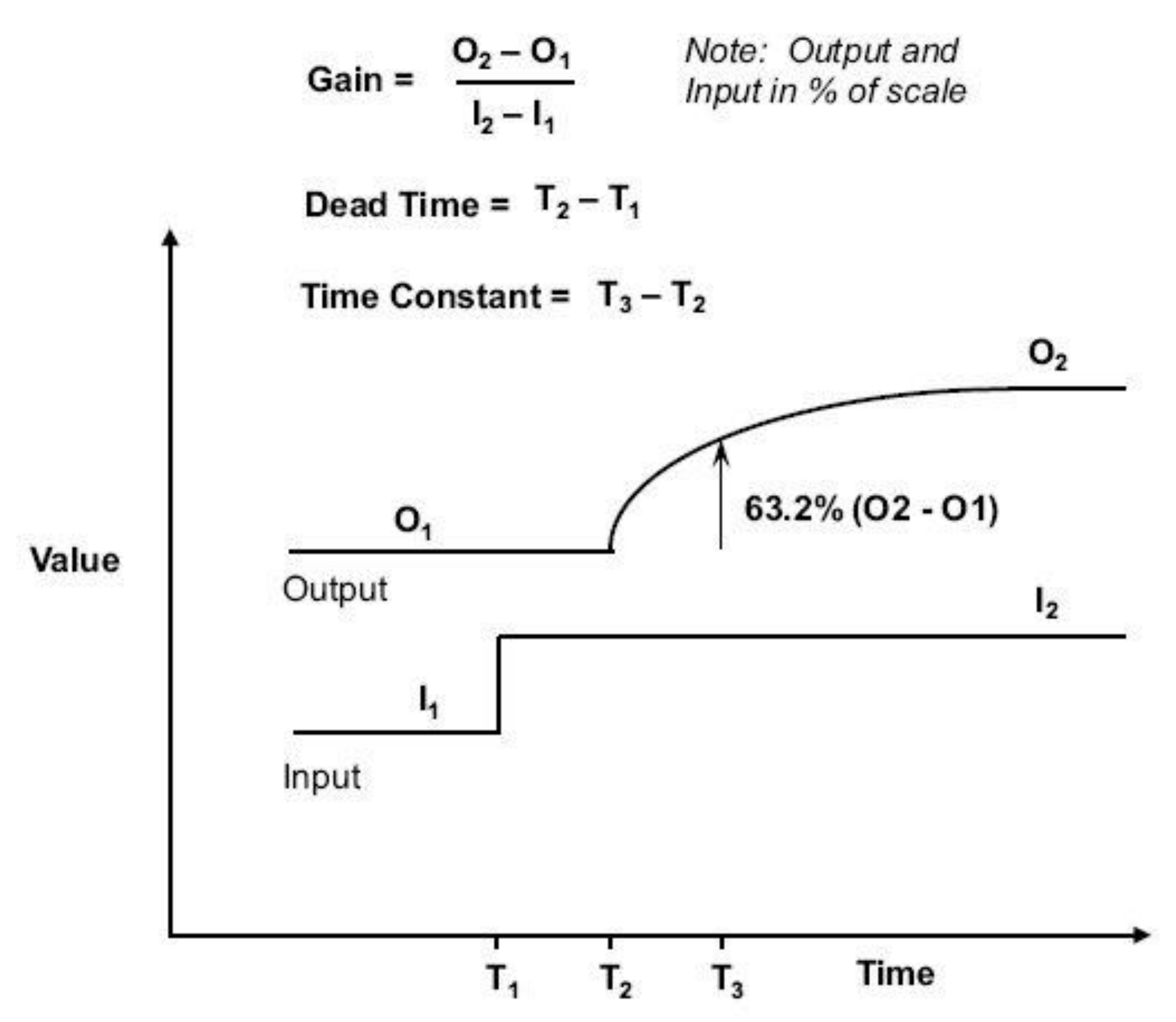


Figure 9-16. First Order Plus Deadtime Process

- Most process in industry may be approximated as first order plus deadtime processes.
- A first order plus deadtime process exhibits the combined characteristics of the lag and delay process.

Example – Steam Heater

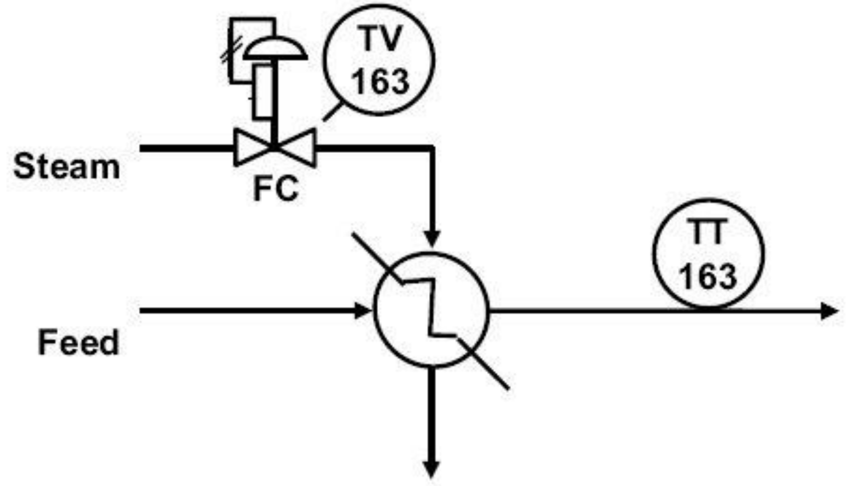


Figure 9-17. Heater Example – First Order Plus Deadtime Process

- An example of a first order plus deadtime process is a steam heater.
- The process lag is caused by the heating process
- The process deadtime is caused by transport delay

Higher Ordered Systems

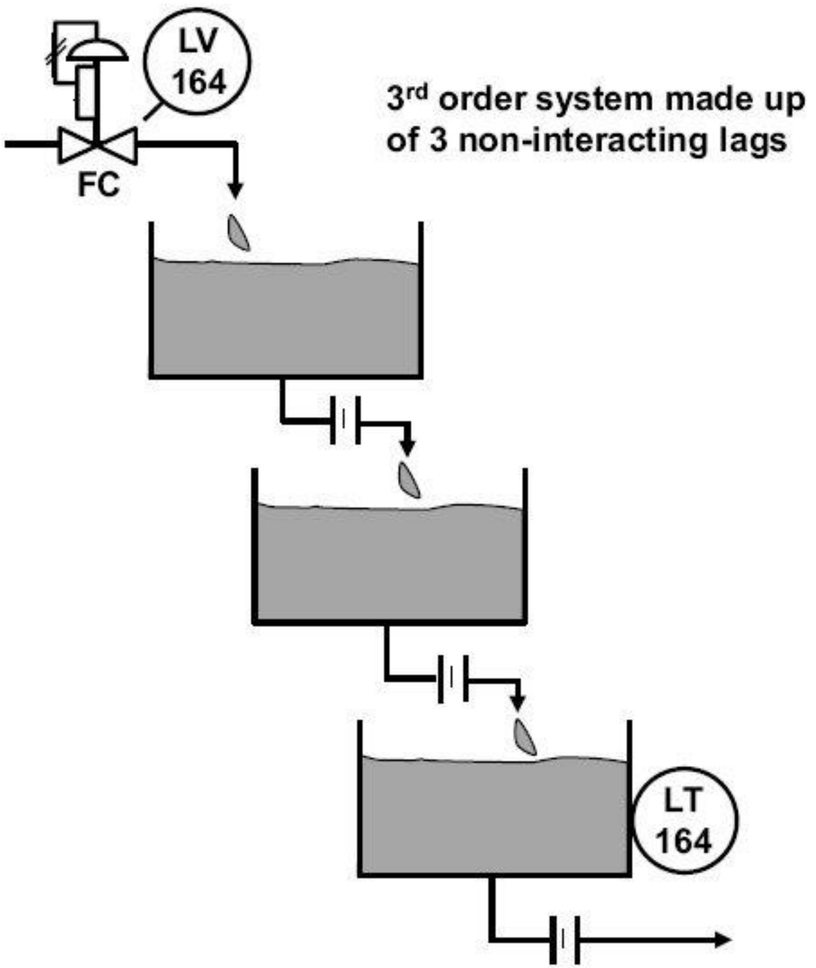


Figure 9-18. Addressing Higher Order Systems

- The dynamic response of a process is the results of many components working together e.g. I/P, Valve actuator, heat or fluid/gas transport, etc.
- The net process response of these higher order systems can be approximated as first order plus deadtime.

Combined Impact of Process Dynamics

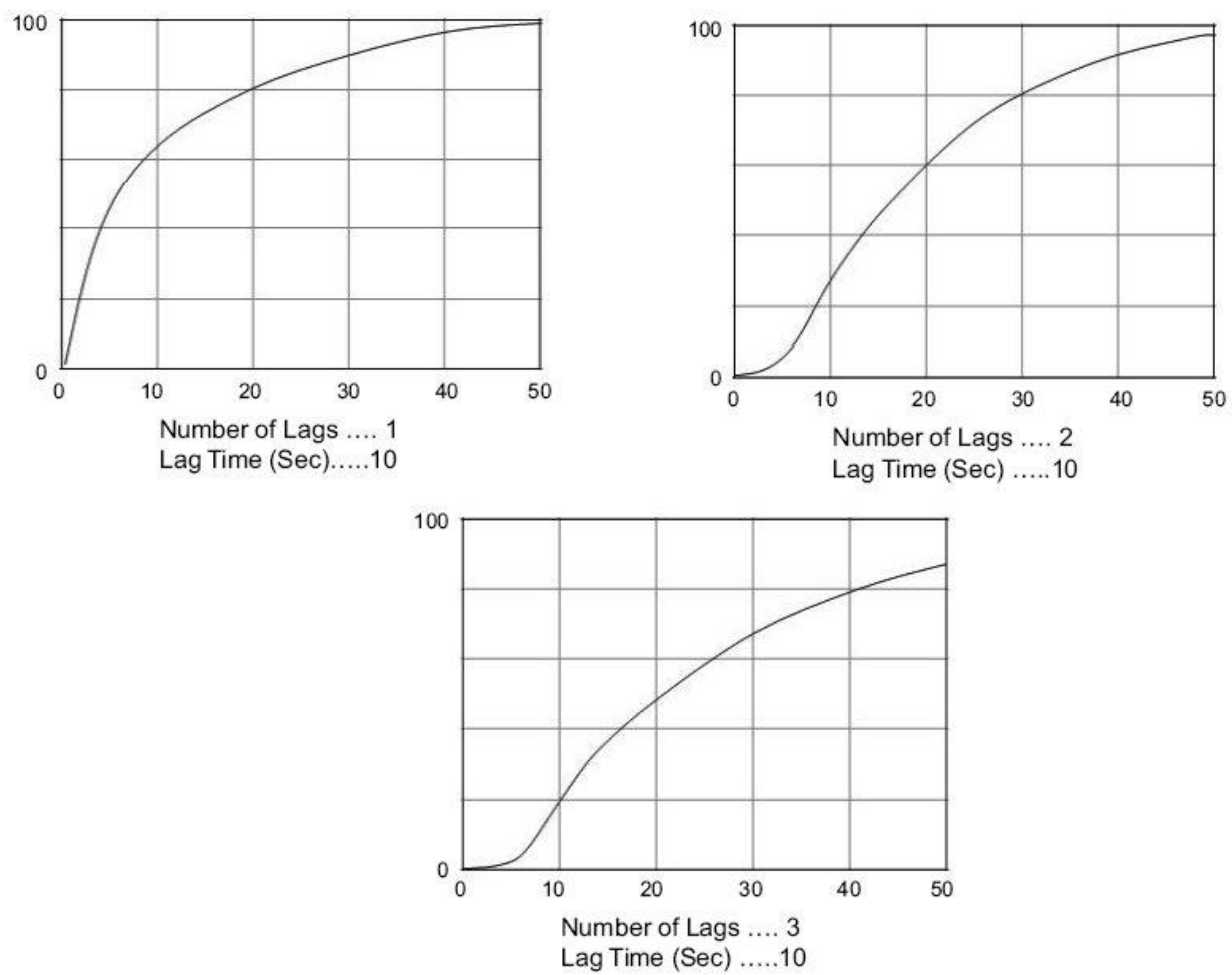


Figure 9-19. Approximating Higher Order Systems

Integrating Process

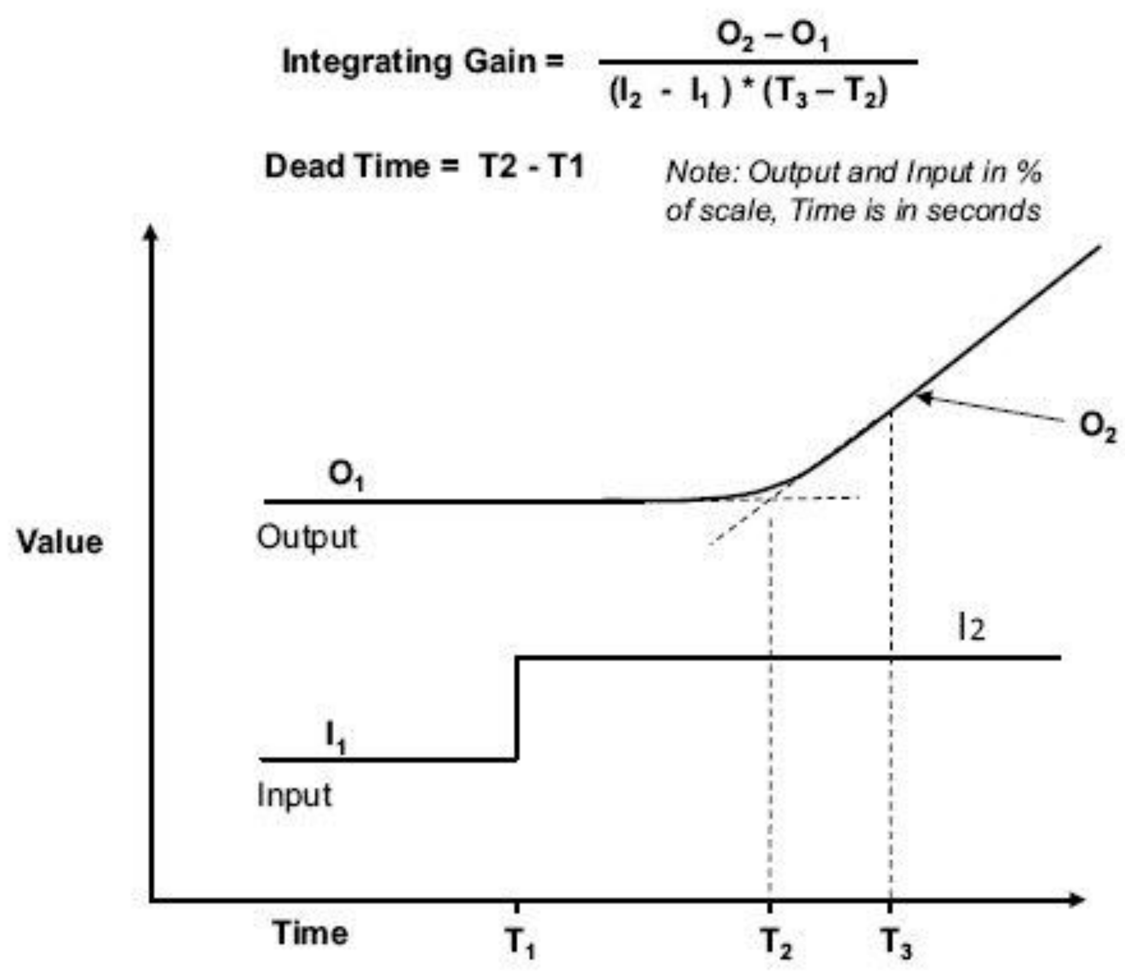


Figure 9-20. Integrating Process Response

- When a process output changes without bound when the process input is changed by a step, the process is know as a non-self- regulating or integrating process.
- The rate of change (slope) of the process output is proportional to the change in the process input and is known as the integrating gain.

Example – Integrating Process

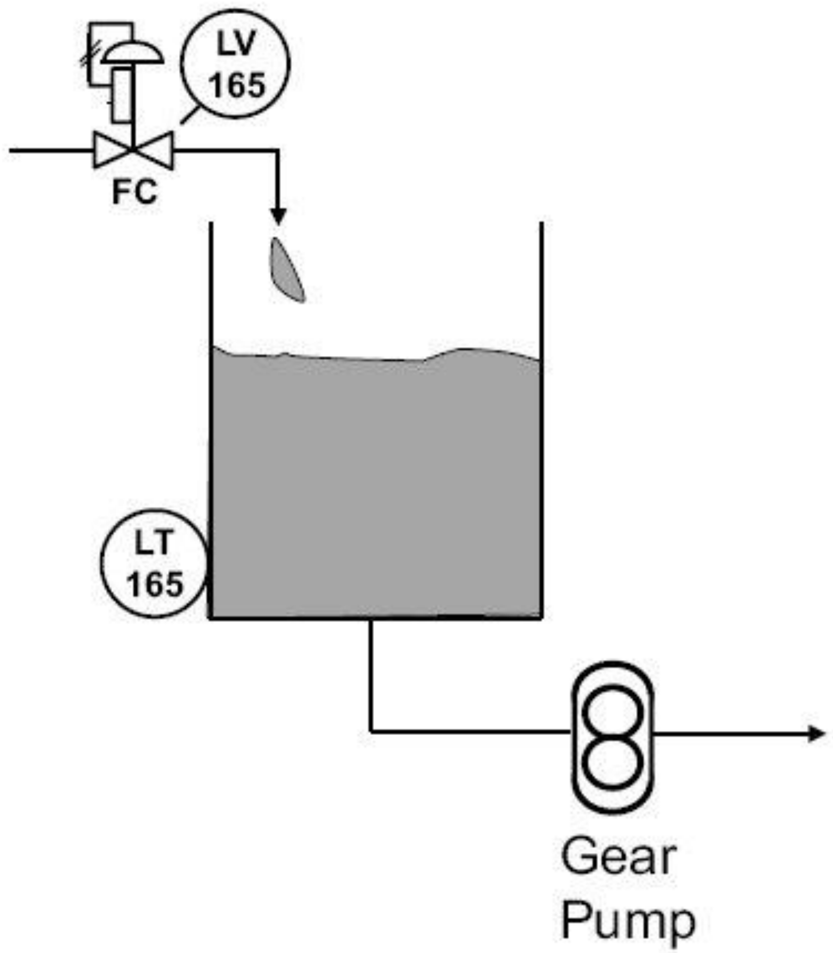


Figure 9-21. Example – Integrating (Non-self-regulating) Process

- An example of a non-self-regulating process is tank level where outlet flow is established by a gear pump.
- If the inlet flow does not match the outlet flow, then level will continue to change until the tank overflows or runs dry.

Inverse Response Process

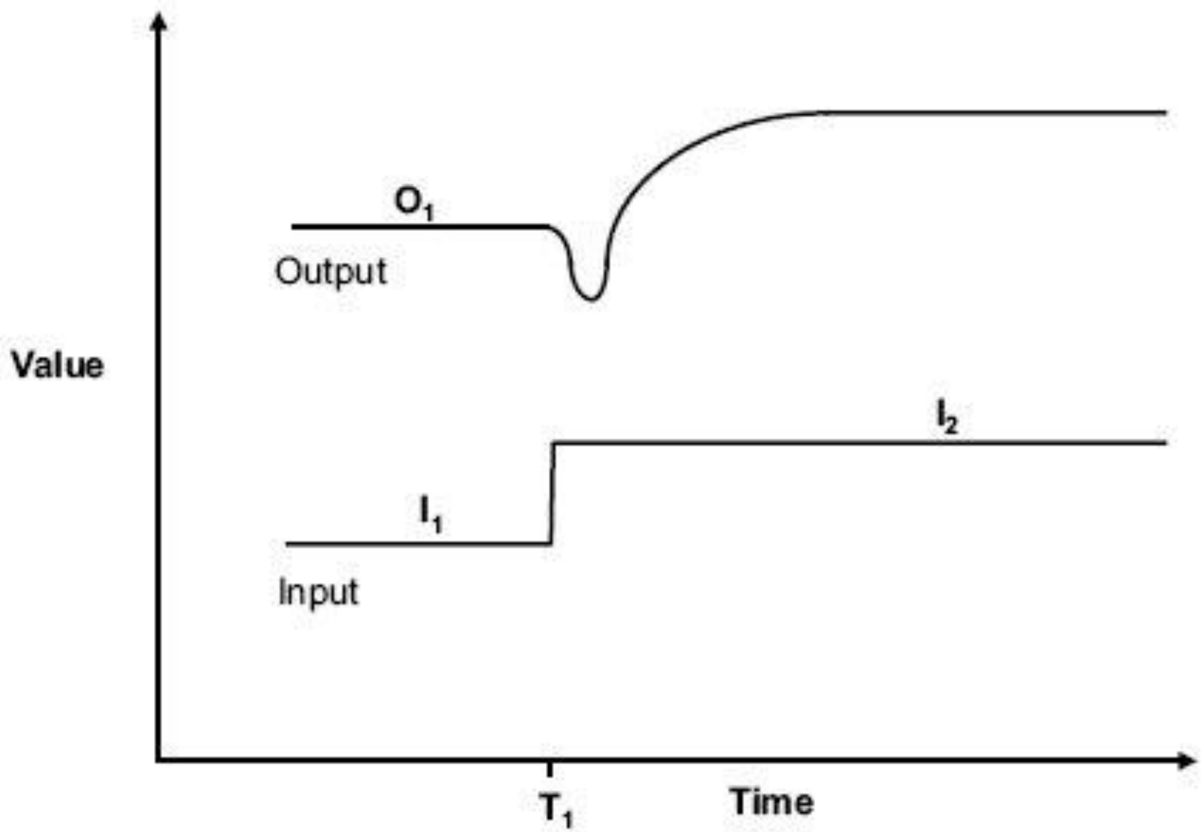


Figure 9-22. Inverse Response Process

- For a few processes, the initial change in the process output to a step change in a process input will be in the opposite direction of the final output change.
- Processes exhibiting this characteristic are said to have an inverse response.

Example – Inverse Response Process

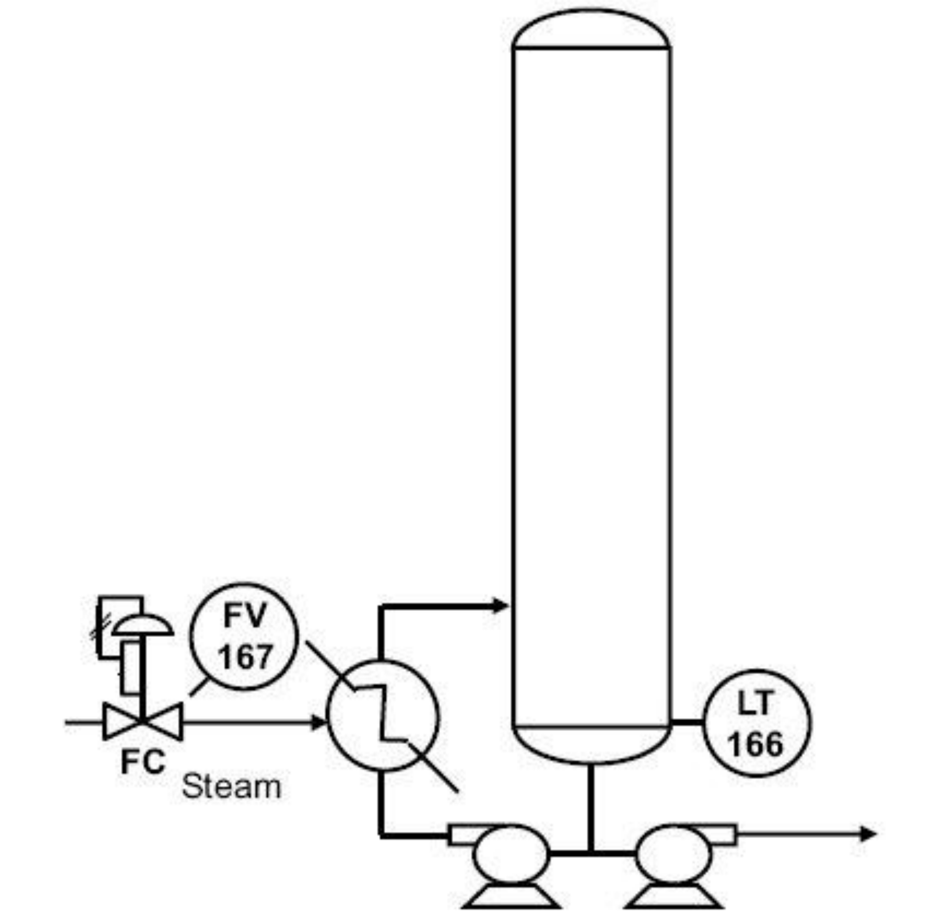


Figure 9-23. Example – Process with Inverse Response

- The level of a vertical thermosiphon reboiler in a distillation column may exhibit an inverse response to a rapid increase in heat input.
- The size or direction of the change in heat input may determine if an inverse response is obtained.

Process Linearity

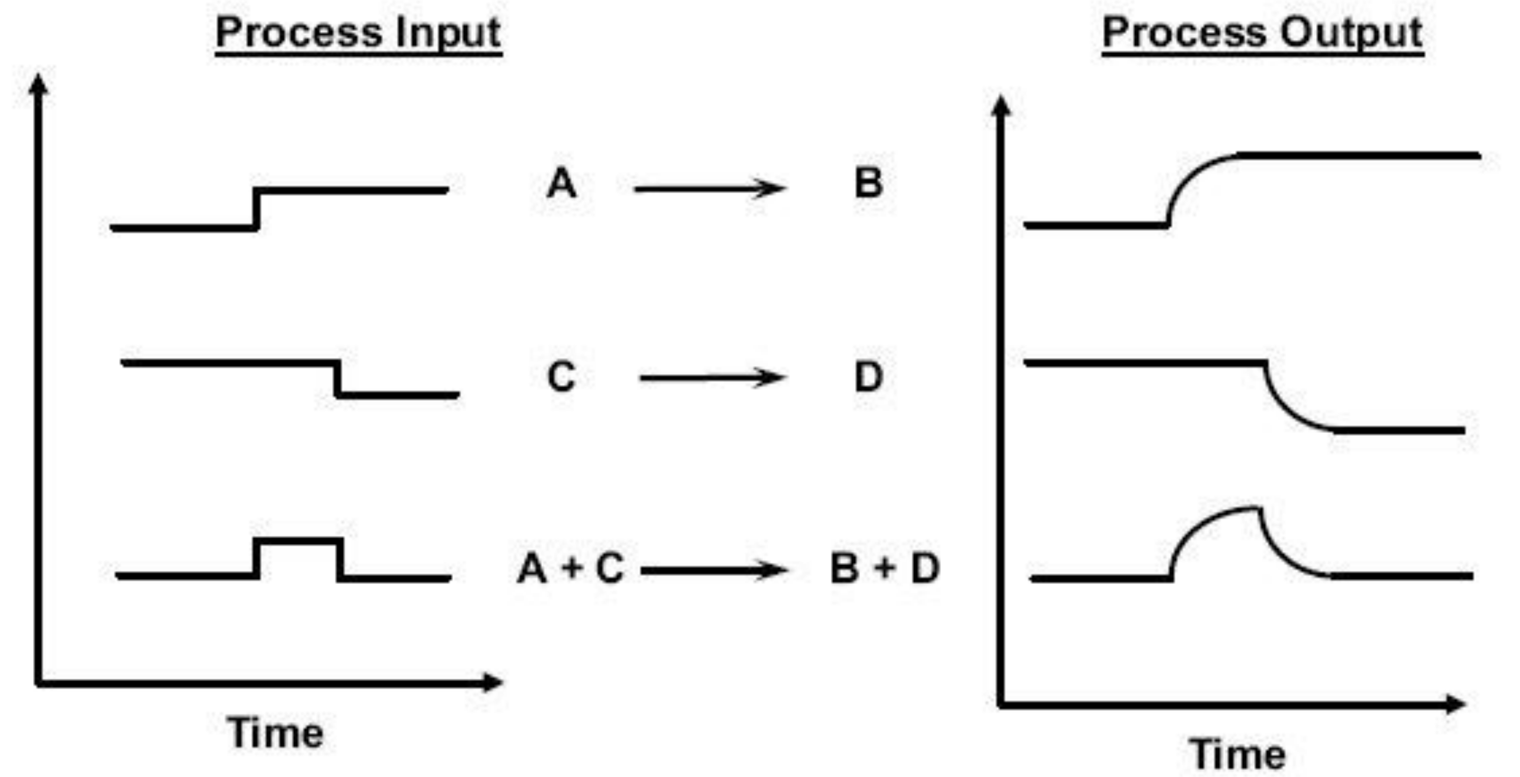


Figure 9-24. Linear Process Criteria

Example – Non-linear Process

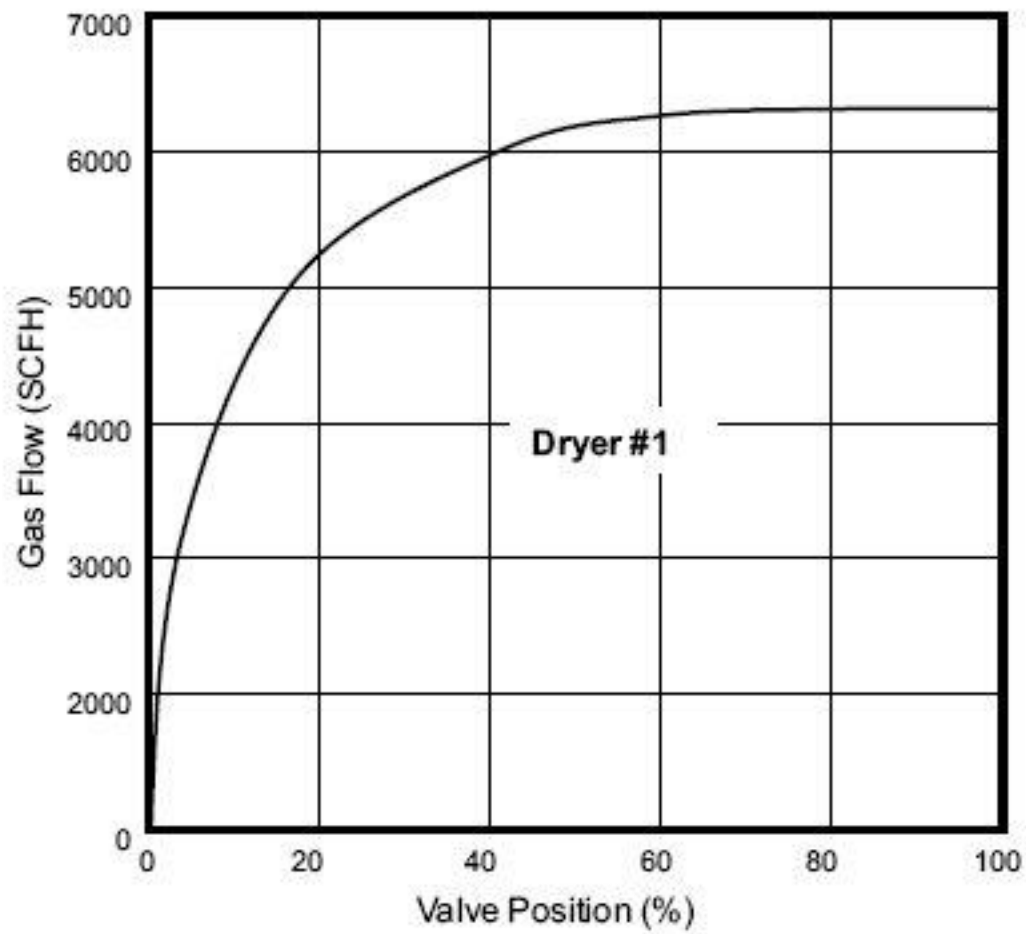


Figure 9-25. Example – Process Non-linearity

- Most processes may be approximated as linear over a small operating range. However, over a wide range of operation, processes may exhibit some non-linearity.
- A common cause of non-linearity is a change in process gain – reflecting the ***installed characteristics of the final control element*** i.e. valve acting with the other equipment making up the process, as illustrated in this example.

Workshop – Use of Process Simulation

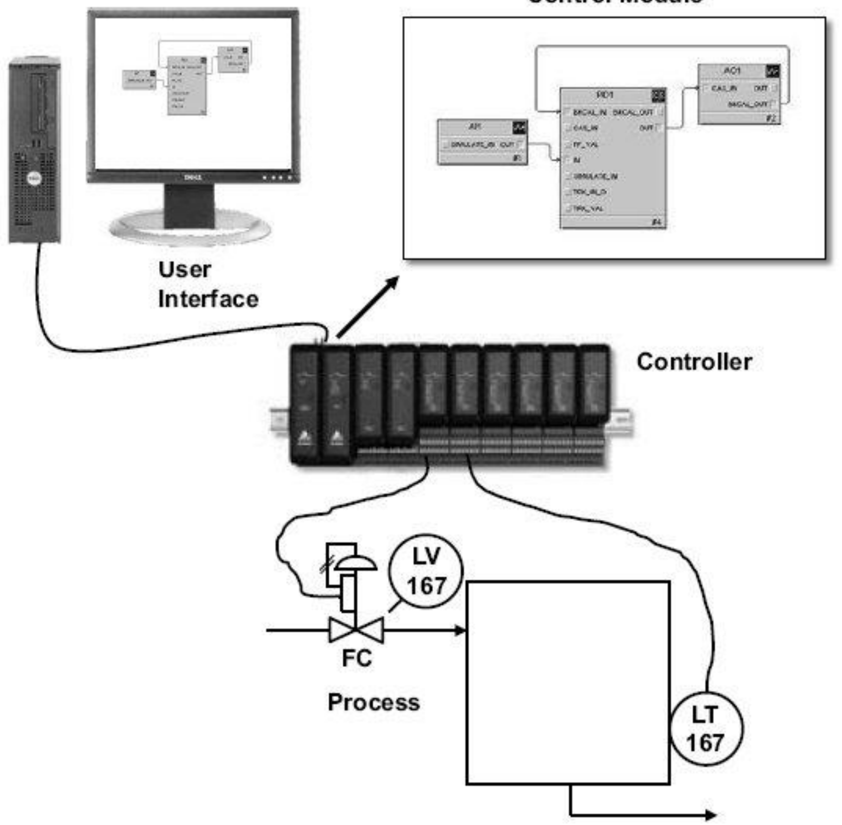


Figure 9-26. Typical Control Loop

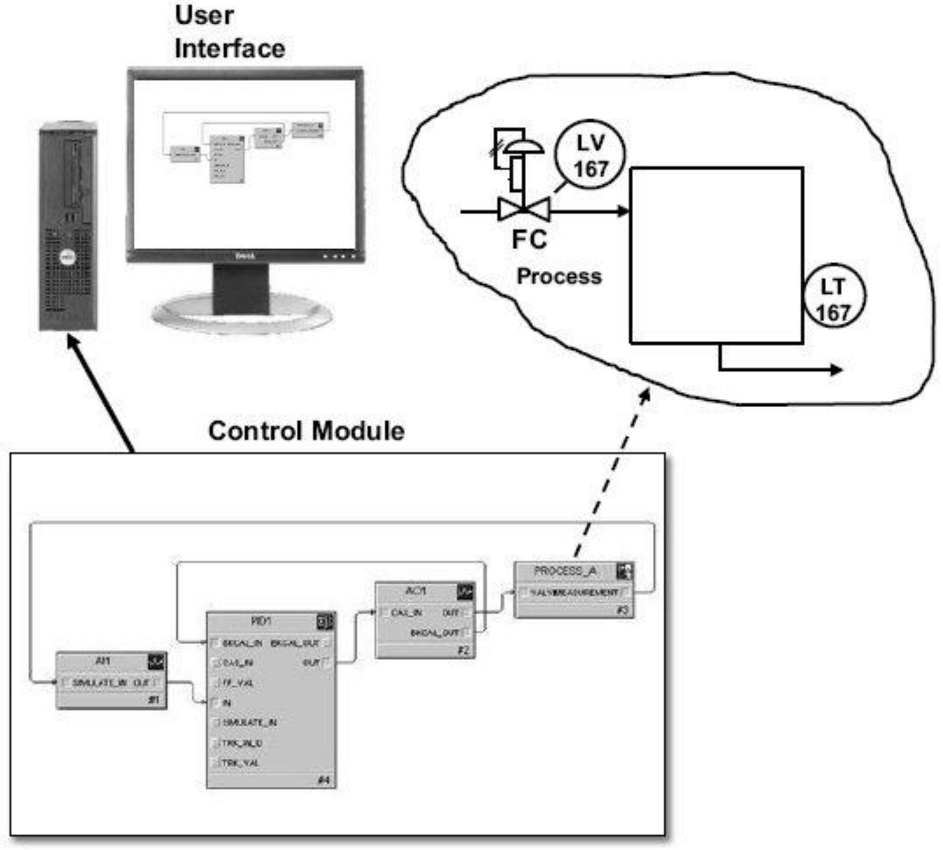


Figure 9-27. Simulated Process for Workshop Exercises

Workshop - Process Characterization

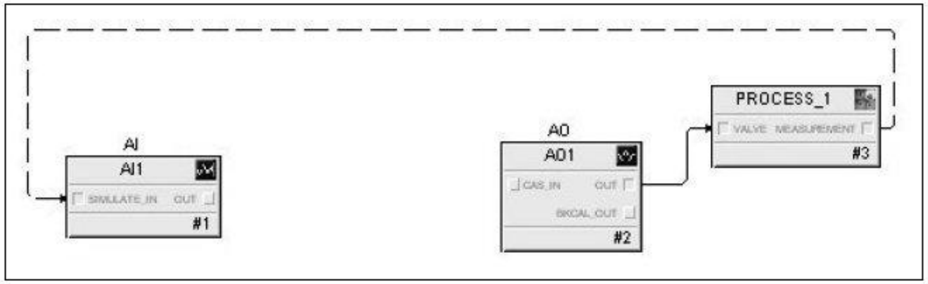


Figure 9-28. Process Characterization-1 WorkShop Module

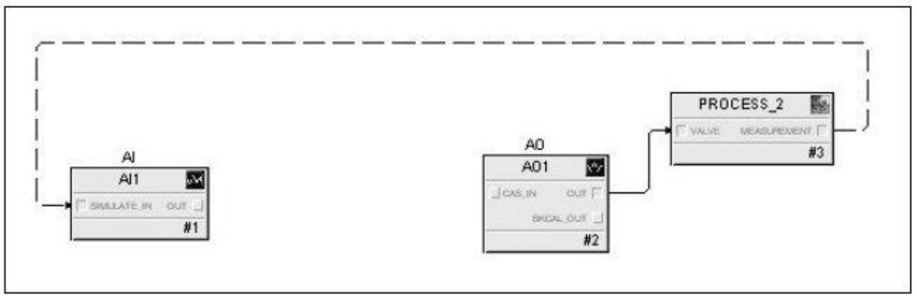


Figure 9-29. Process Characterization-2 Workshop Module

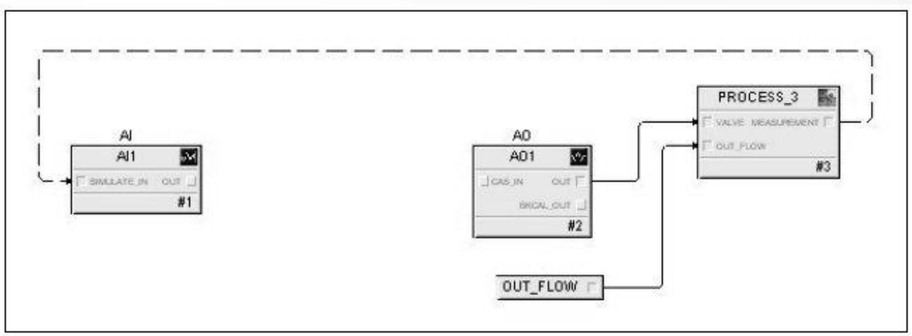


Figure 9-30. Process Characterization-3 WorkShop Module

- Three example processes are include in workshop
  - First order plus deadtime
  - Integrating
  - Inverse response
- Web site is accessed to perform step test. Only a web browser is needed – no software to install.

Control Objective

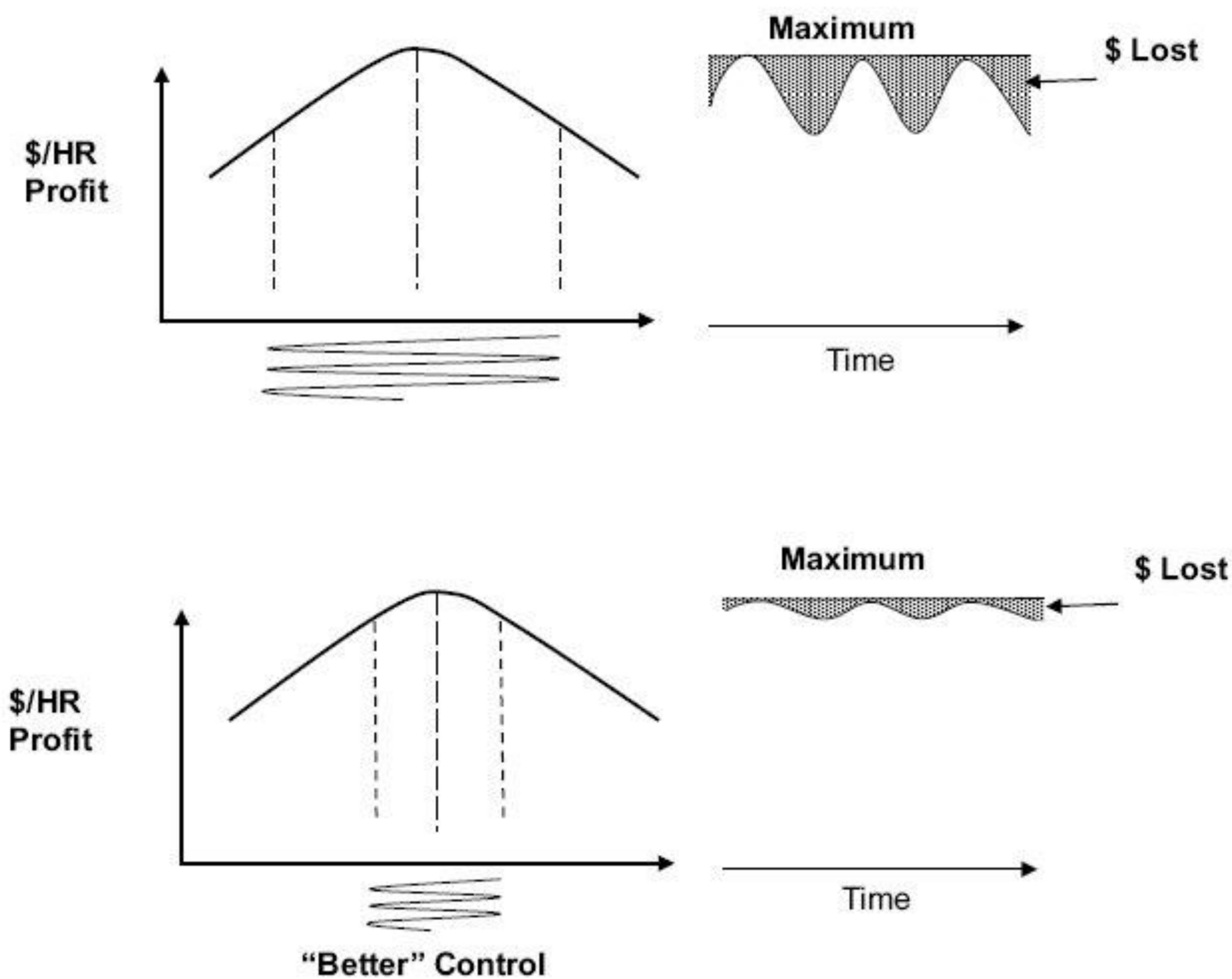


Figure 10-1. Operating at Global Production Maximum

- For the case, production is greatest when the band of variation is reduced to zero and the process parameter is maintained at the value corresponding to maximum production

Impact of Operating Target

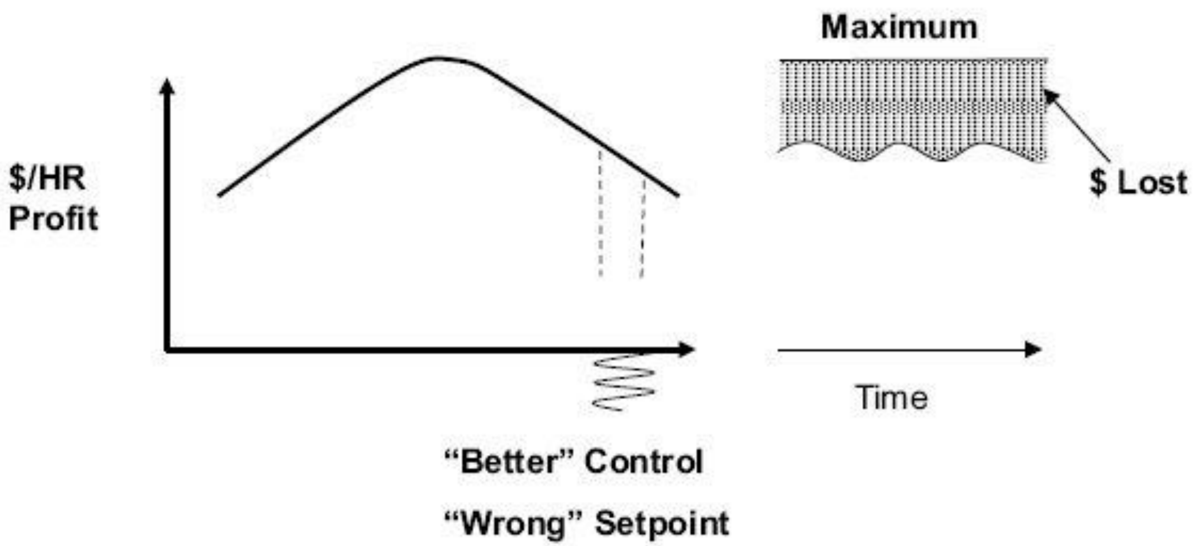


Figure 10-2. Operating Away from the Global Production Maximum

- To benefit from improvement in control, the loop must operate at the target that provides maximum production.
- The plant design conditions may be used as a guide in establishing setpoints for best operation

Operating at a Limit

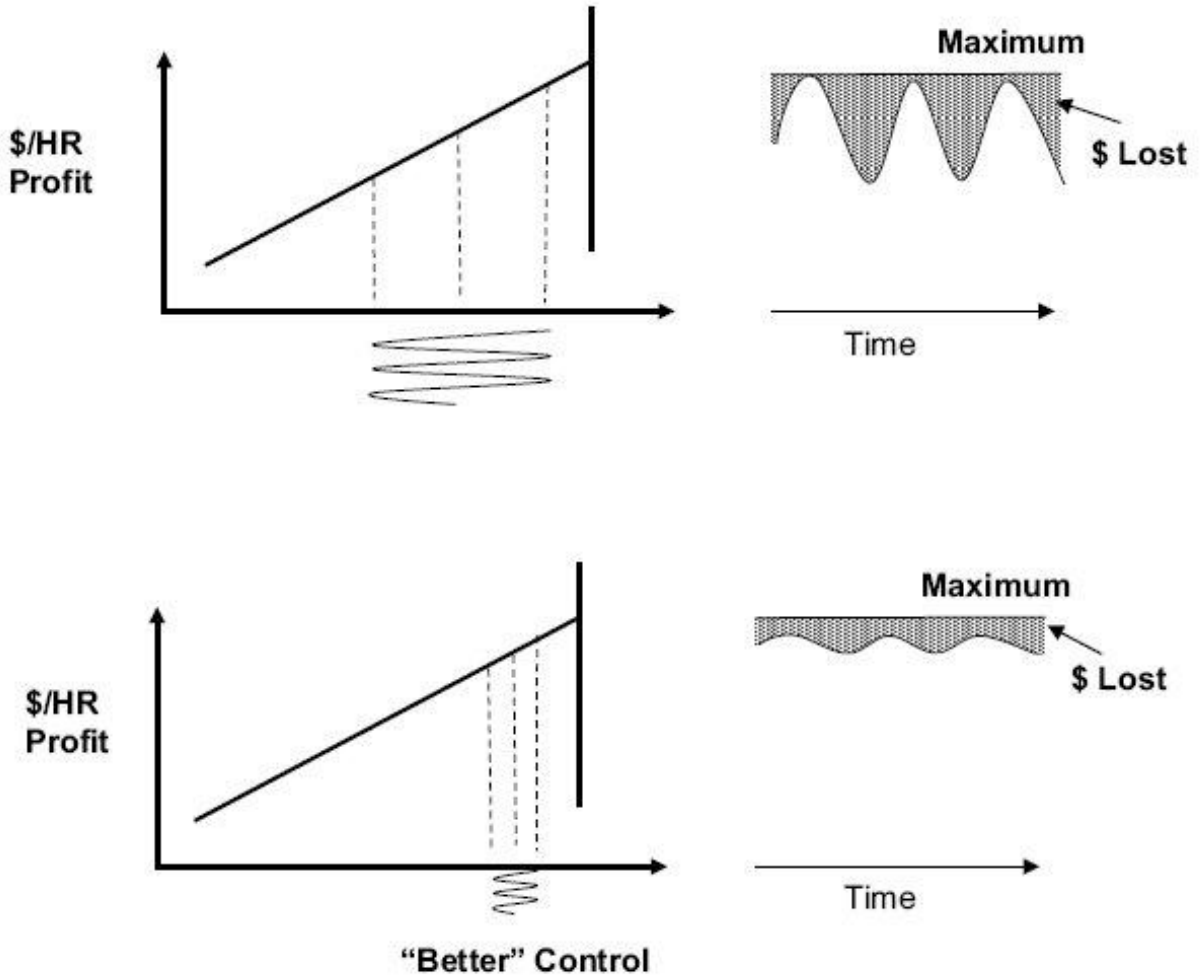


Figure 10-3. Production Maximum at Equipment Physical Limit

- For this case, maximum production is obtained by maintaining the process parameter at a limit determined by some plant limitation.
- How close to the limit you can operate is determined by the quality of the control

Impact of Reduced Variability

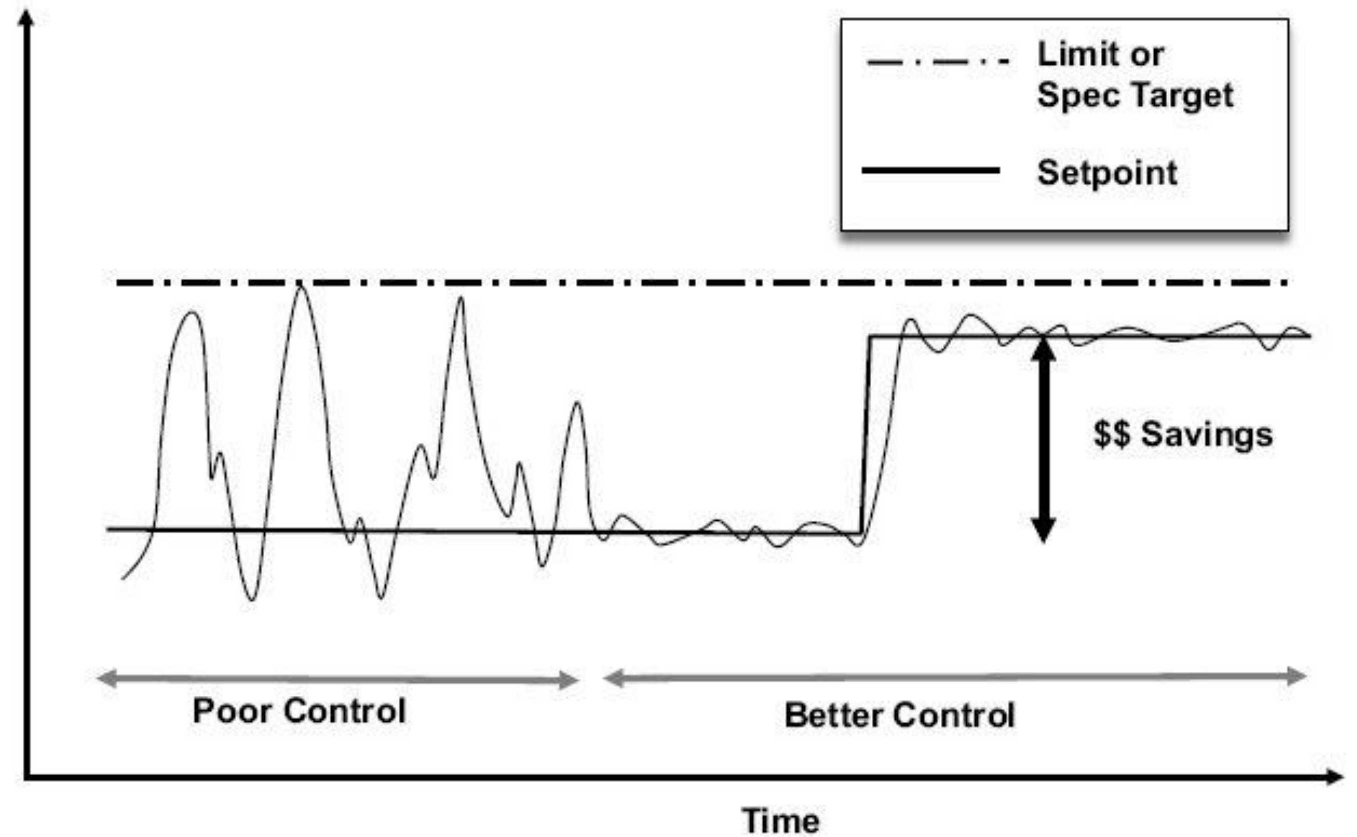


Figure 10-4. Production Maximum at Limit

- Production improvement is obtained by operating closer to product specification or operating limit.

Example - Ammonia Plant

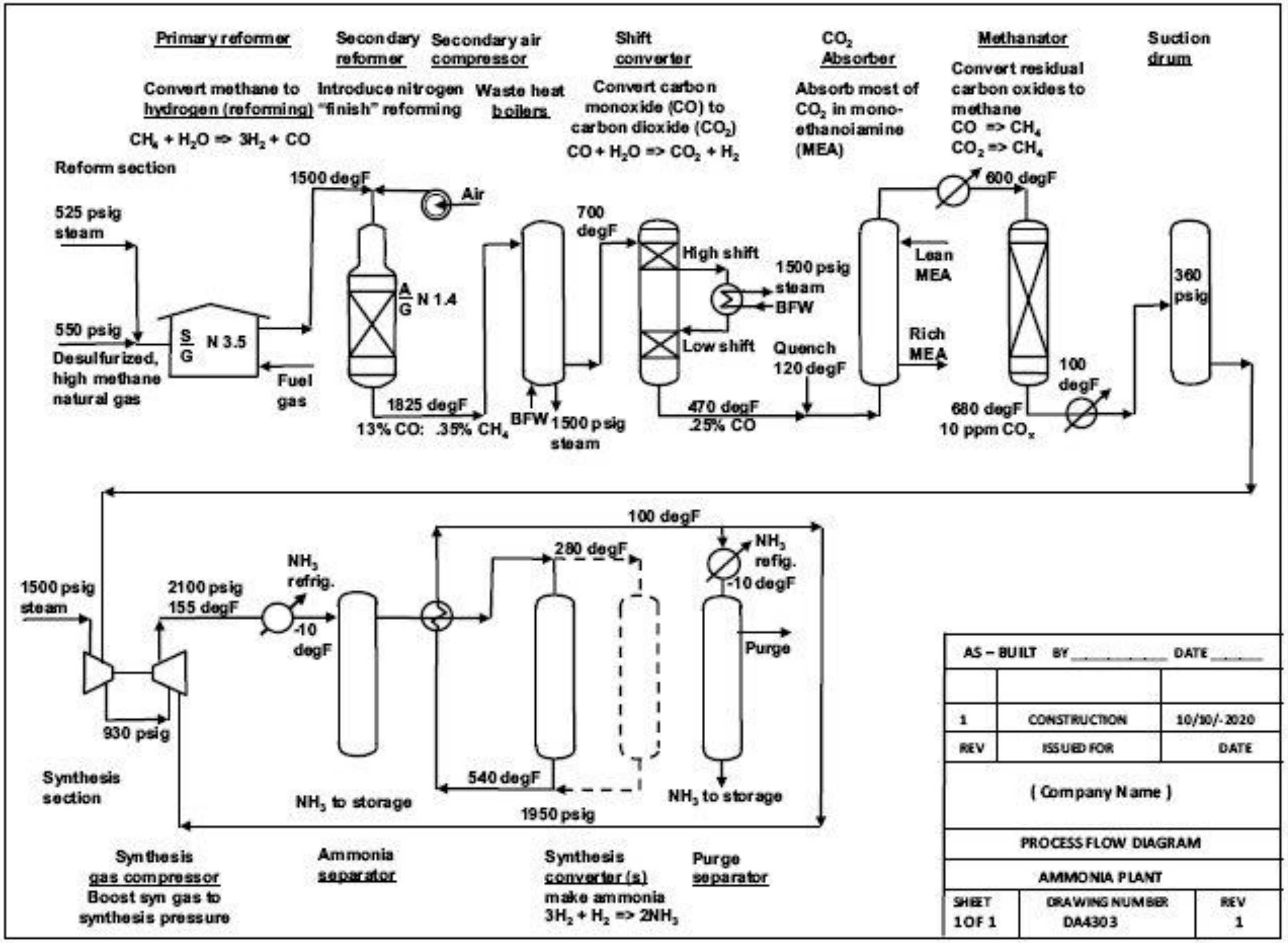


Figure 10-5. Ammonia Plant Example

Example - Ammonia Plant (Cont.)

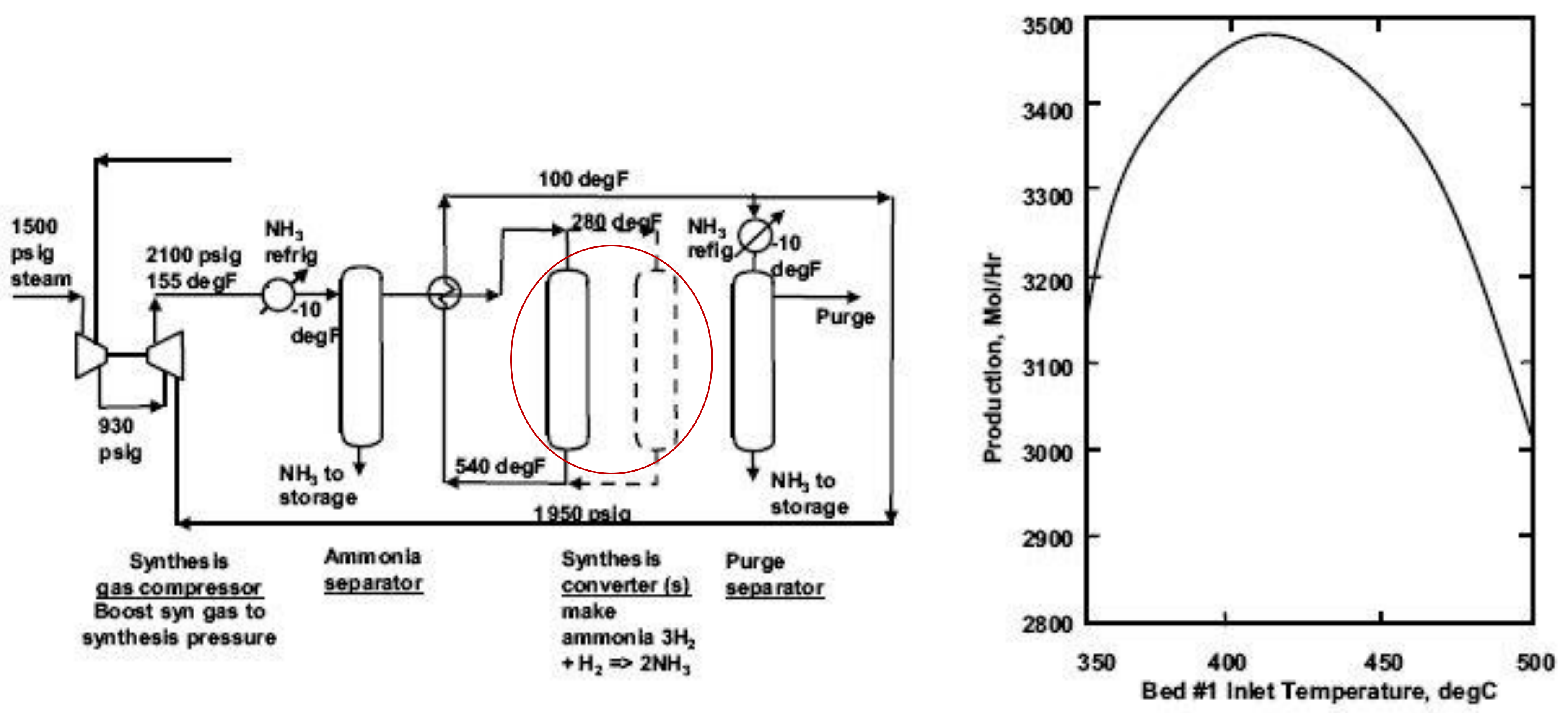


Figure 10-6. Impact of Synthesis Bed Temperature on Plant Production

Example - Ammonia Plant (Cont.)

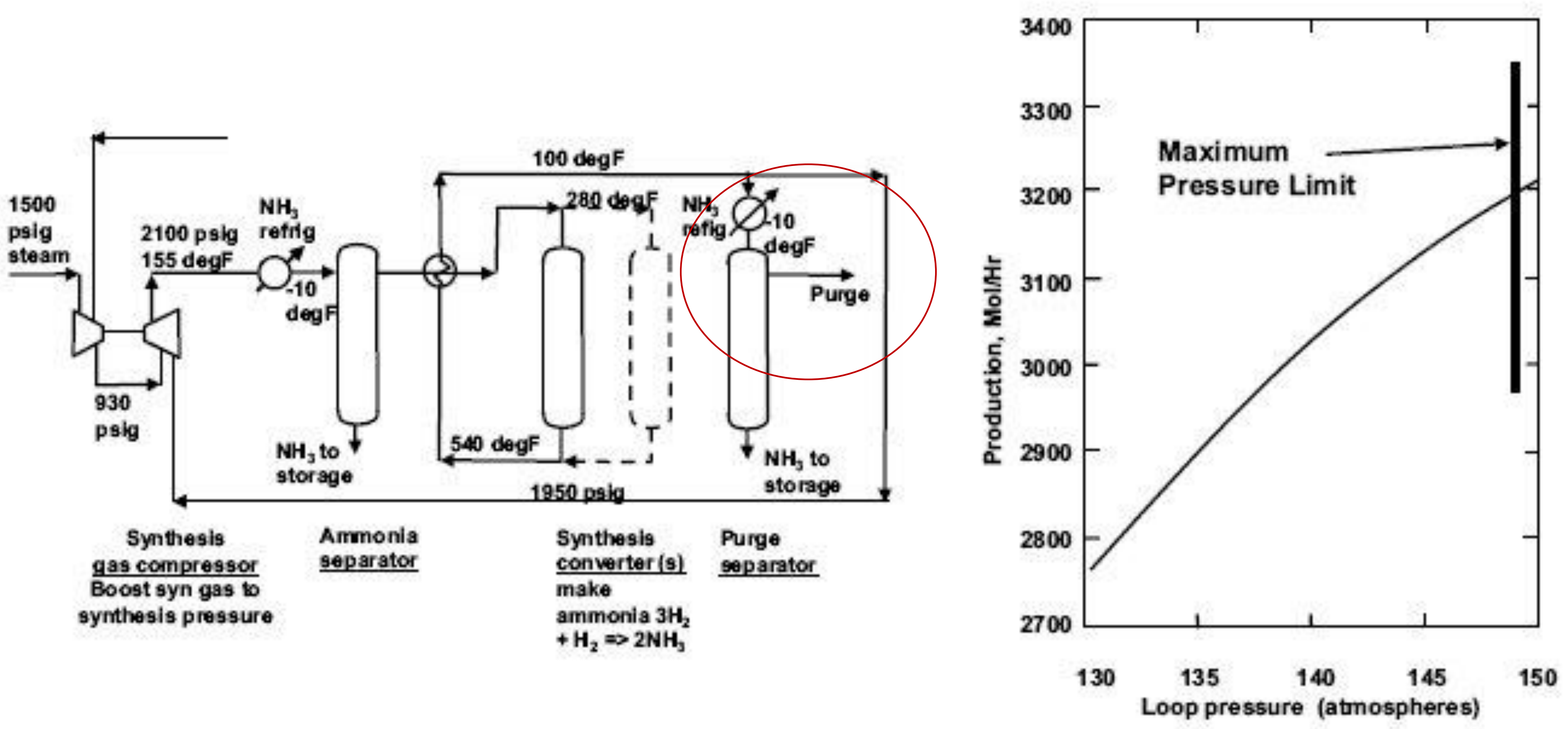


Figure 10-7. Synthesis Loop Pressure Control at a Limit

Other Control Objectives

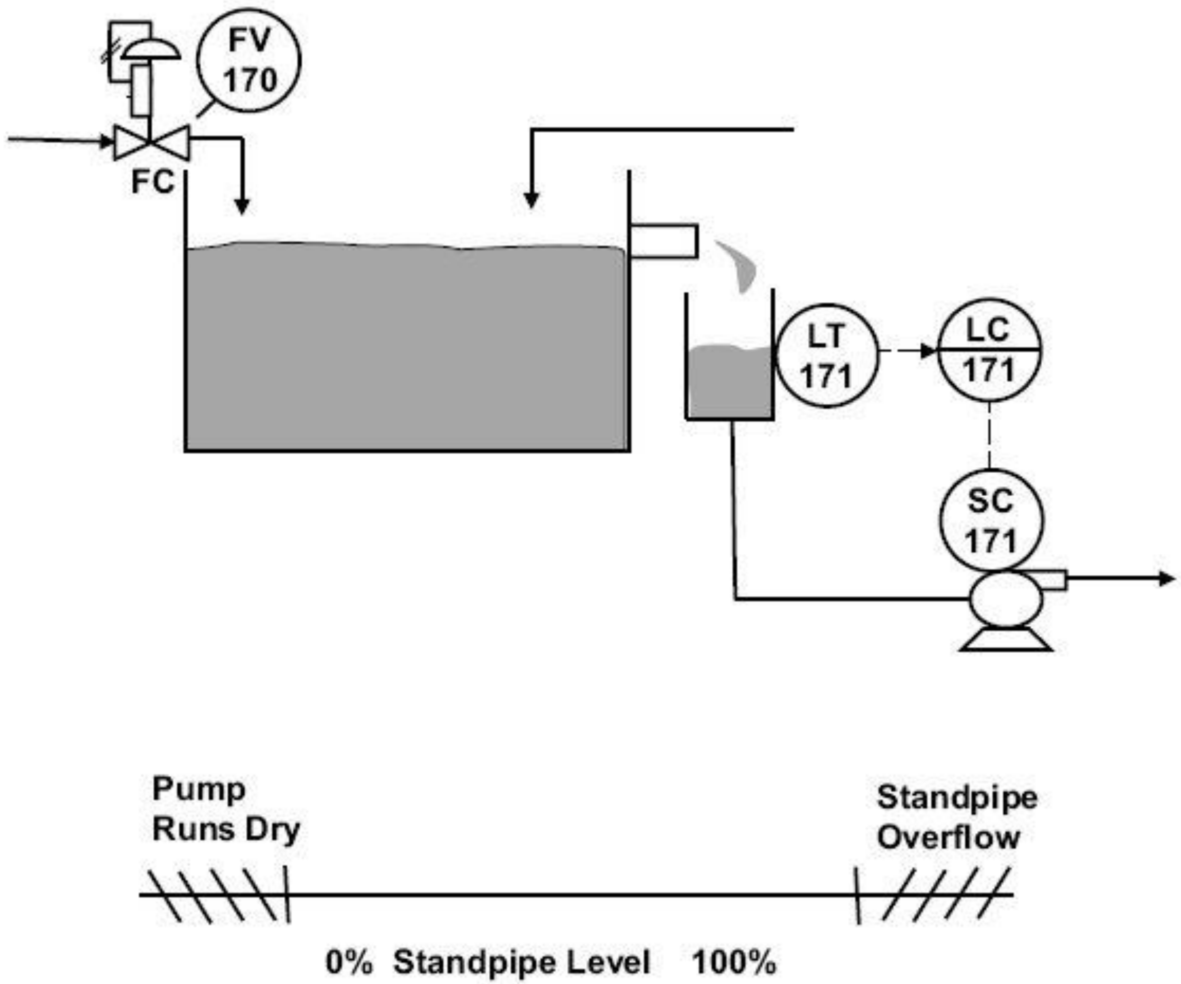


Figure 10-11. Equipment Protection – Standpipe Level Control

Balancing Control Complexity and Benefits

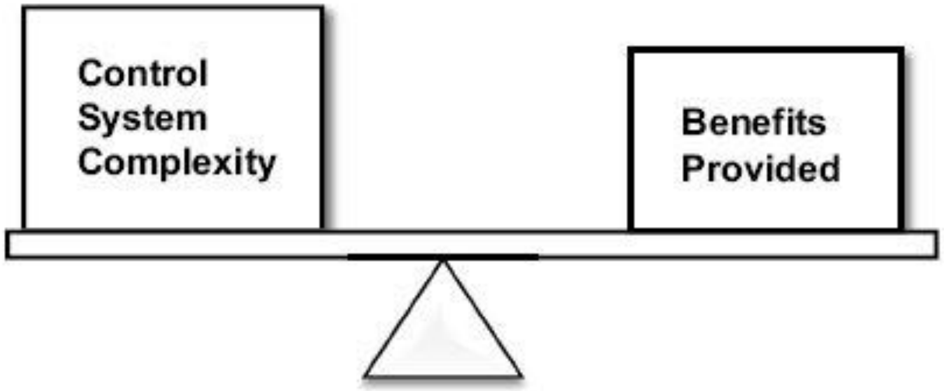


Figure 10-12. Control System Benefits Balance

- Various techniques may be used to improve the control of a process
- As the complexity of the control system increases, so does cost for operator training and maintenance
- The complexity (cost) of the control system should be balanced with the benefits provided
- The benefits of control improvement may be influenced by market conditions i.e. value of product, cost of feedstock, energy cost

Single Loop Control

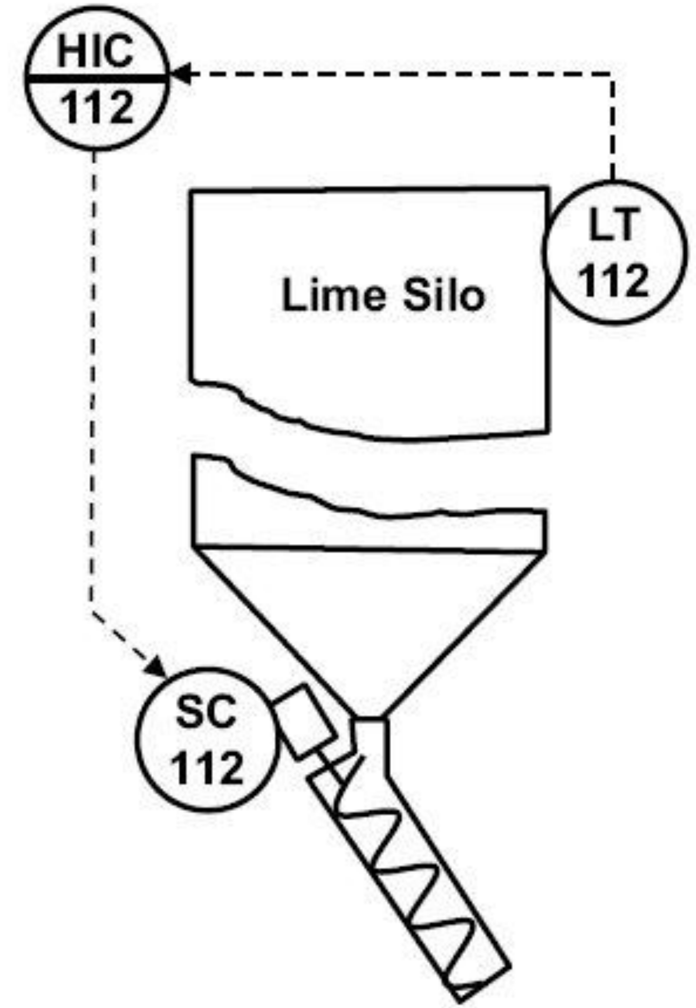


Figure 11-1. Example – Hand Indicator Control

- In some cases manual control may be appropriate
- Manual Loader Block may be used to implement manual control

Manual Control Implementation

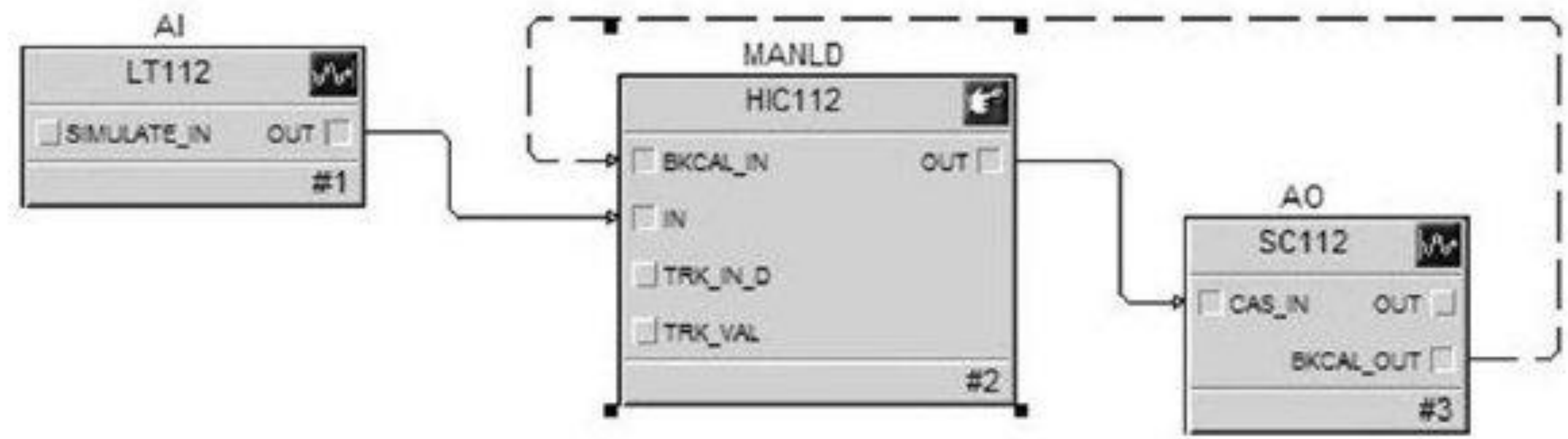


Figure 11-2. Function Block Implementation of Hand Indicator Control

Processing of Analog Input Signal

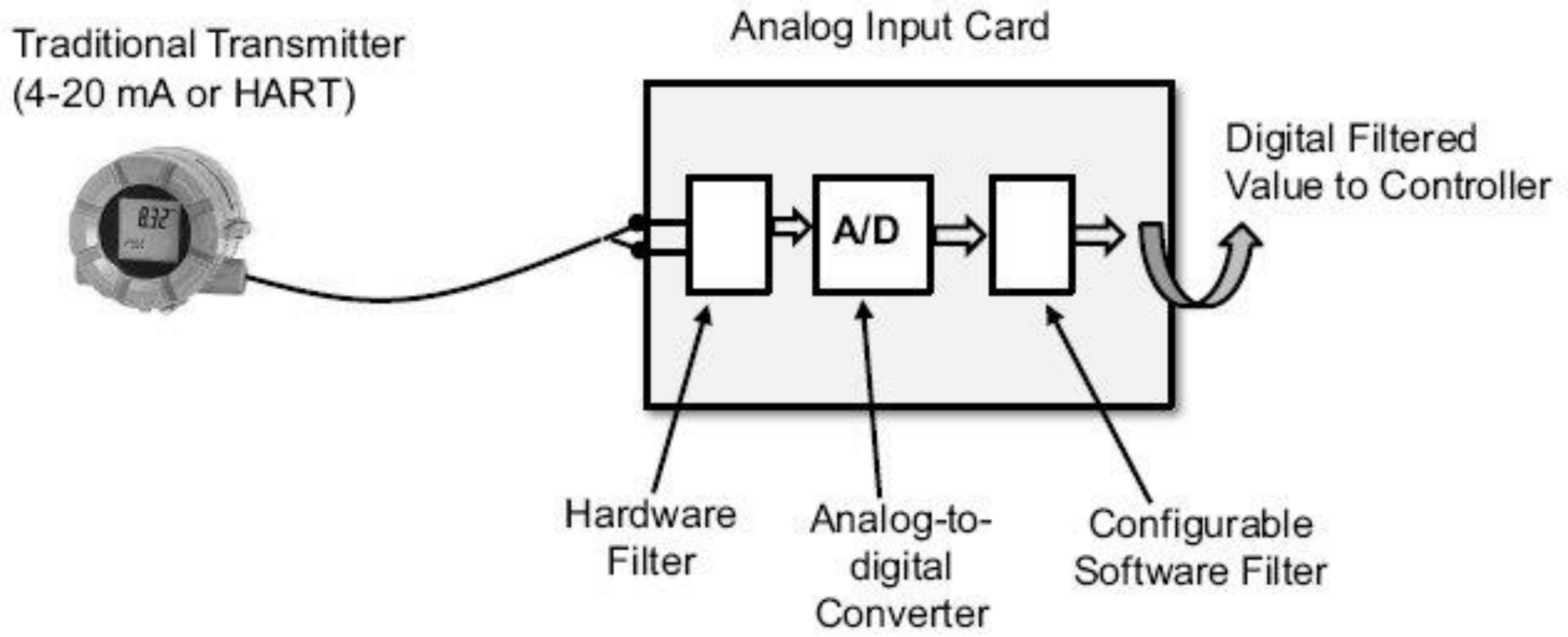


Figure 11-3. Analog Input Card Processing

Impact of Aliasing

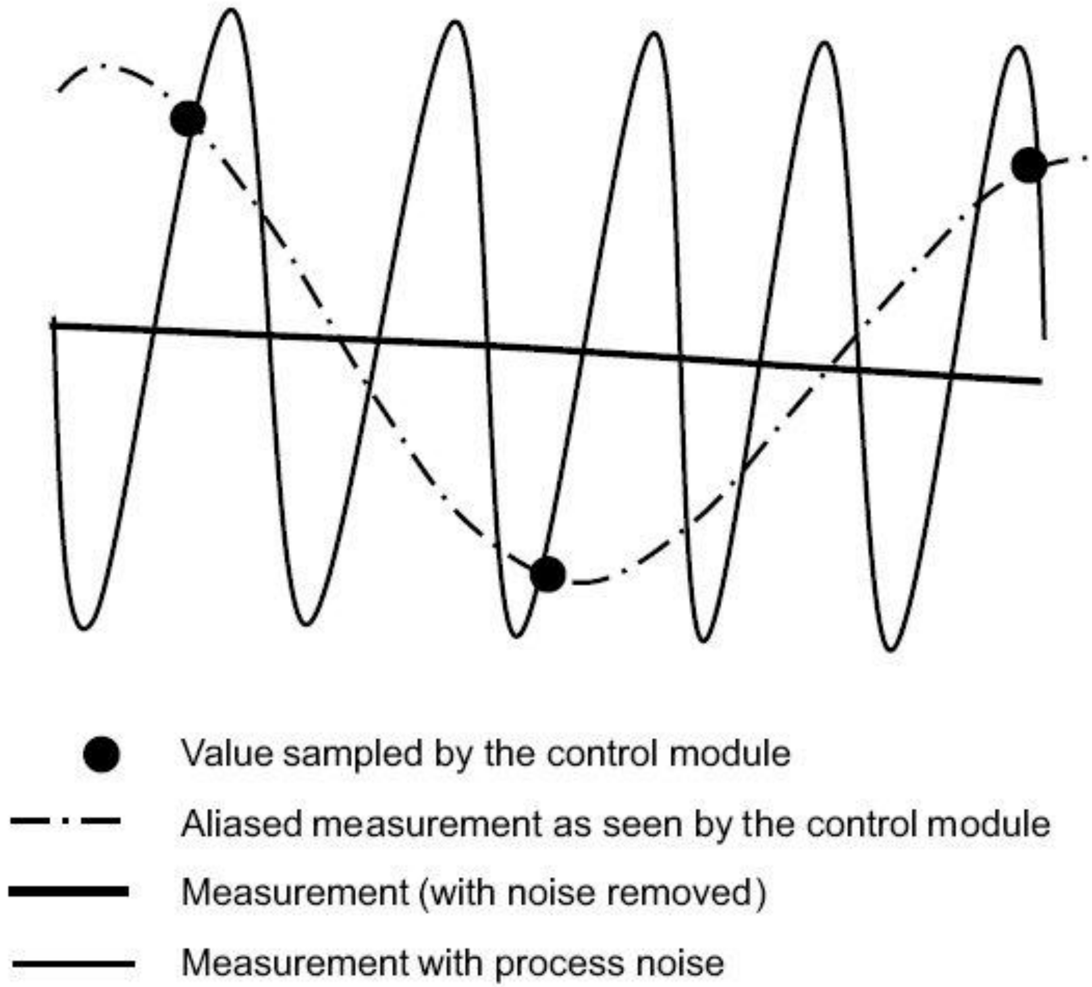


Figure 11-4. Aliasing of Measurement

Setup of Anti-aliasing Filter

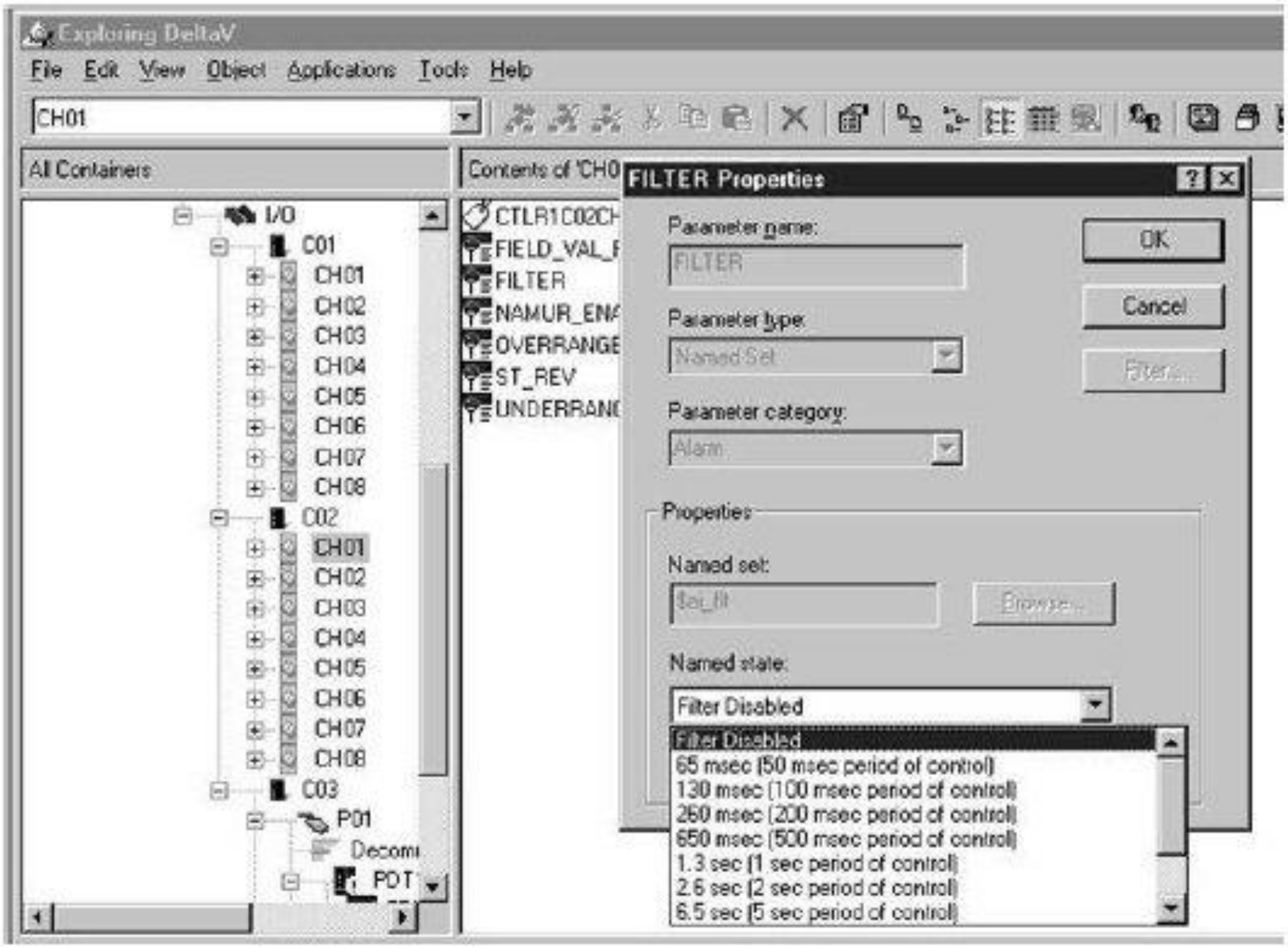


Figure 11-5. Anti-aliasing Filtering at the Analog Input Card

Processing by Analog Input Block

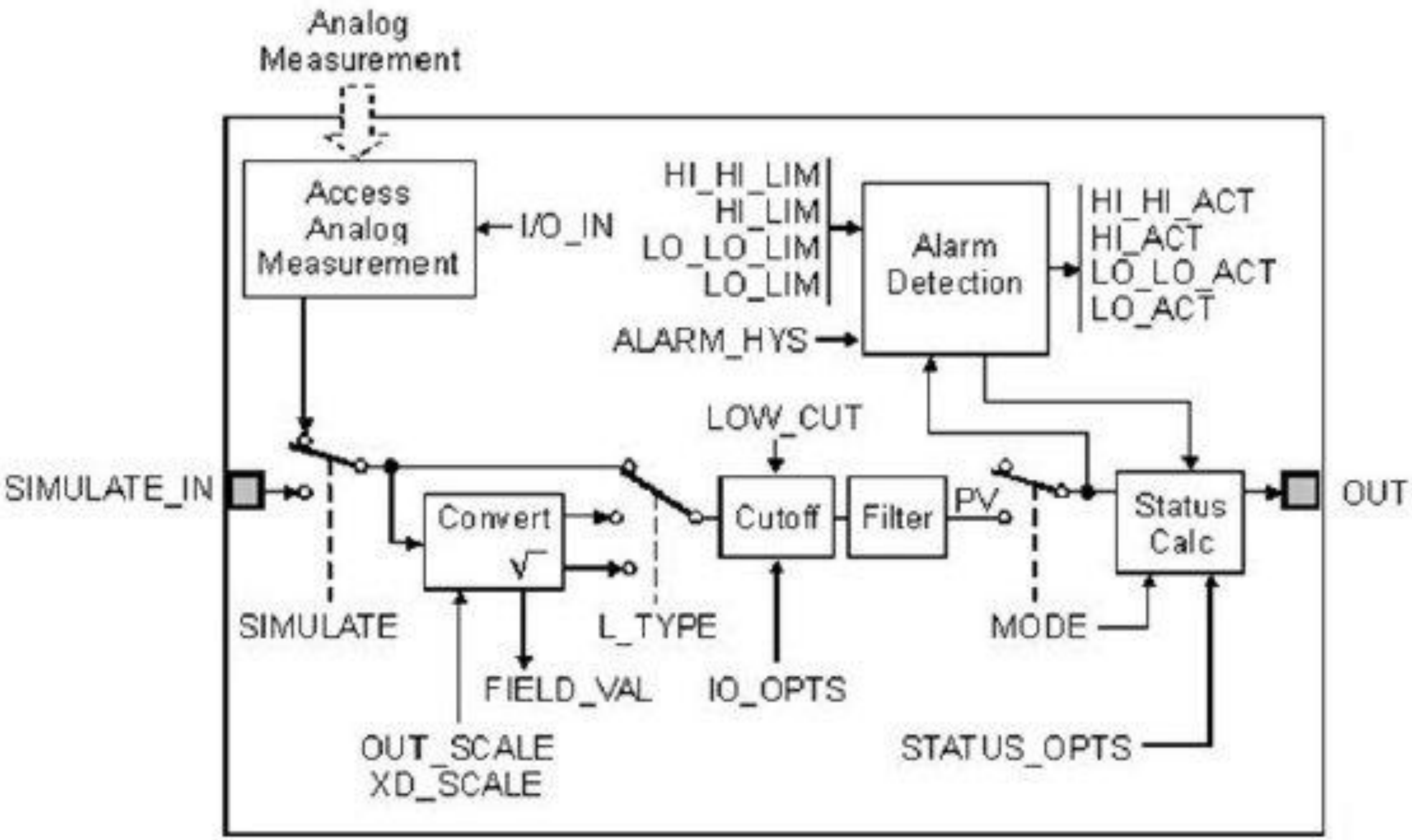


Figure 11-6. Analog Input Block

Filtering Provided by Analog Input Block

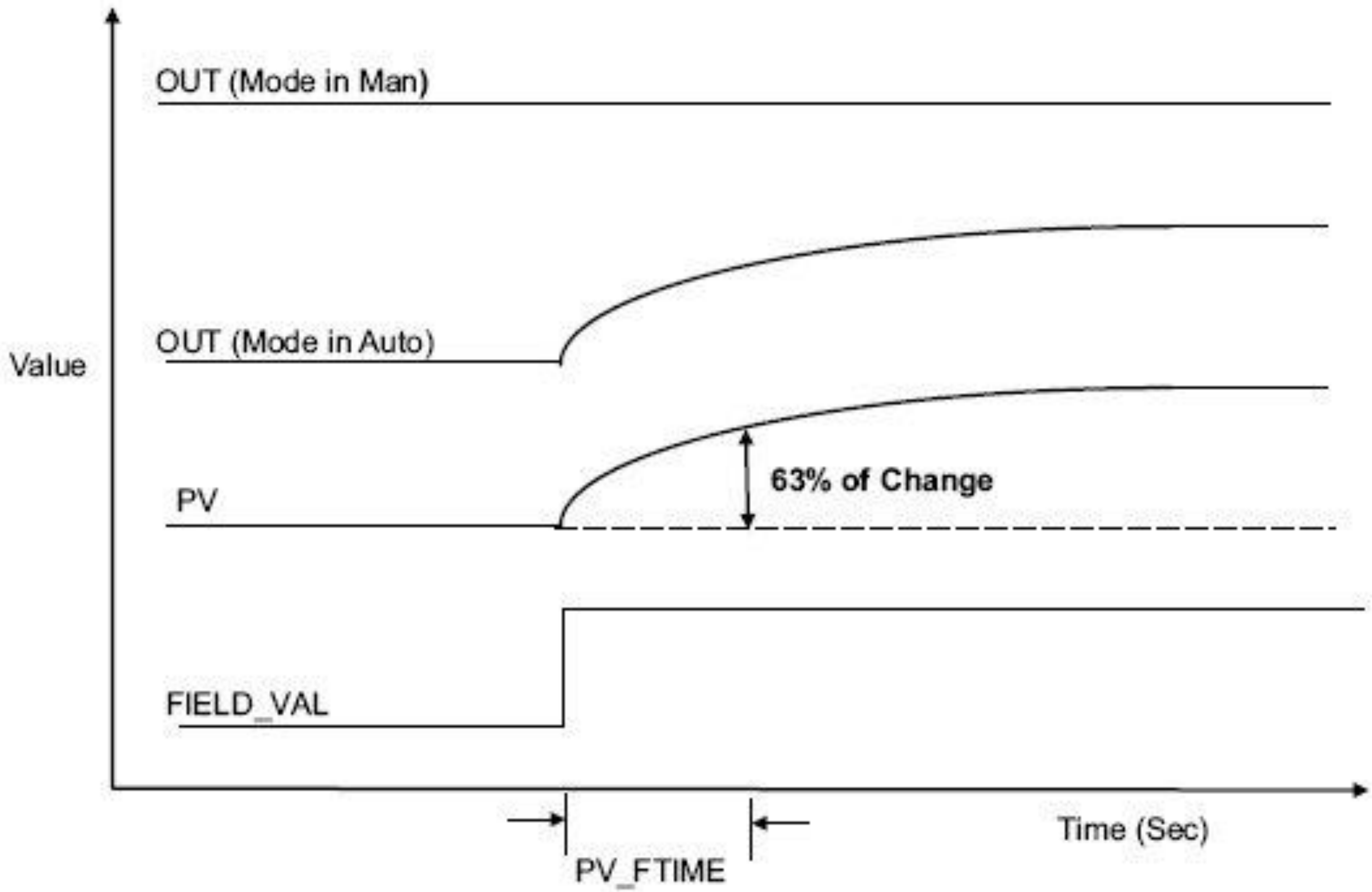


Figure 11-7. Analog Input Filtering

Manual Loader Block

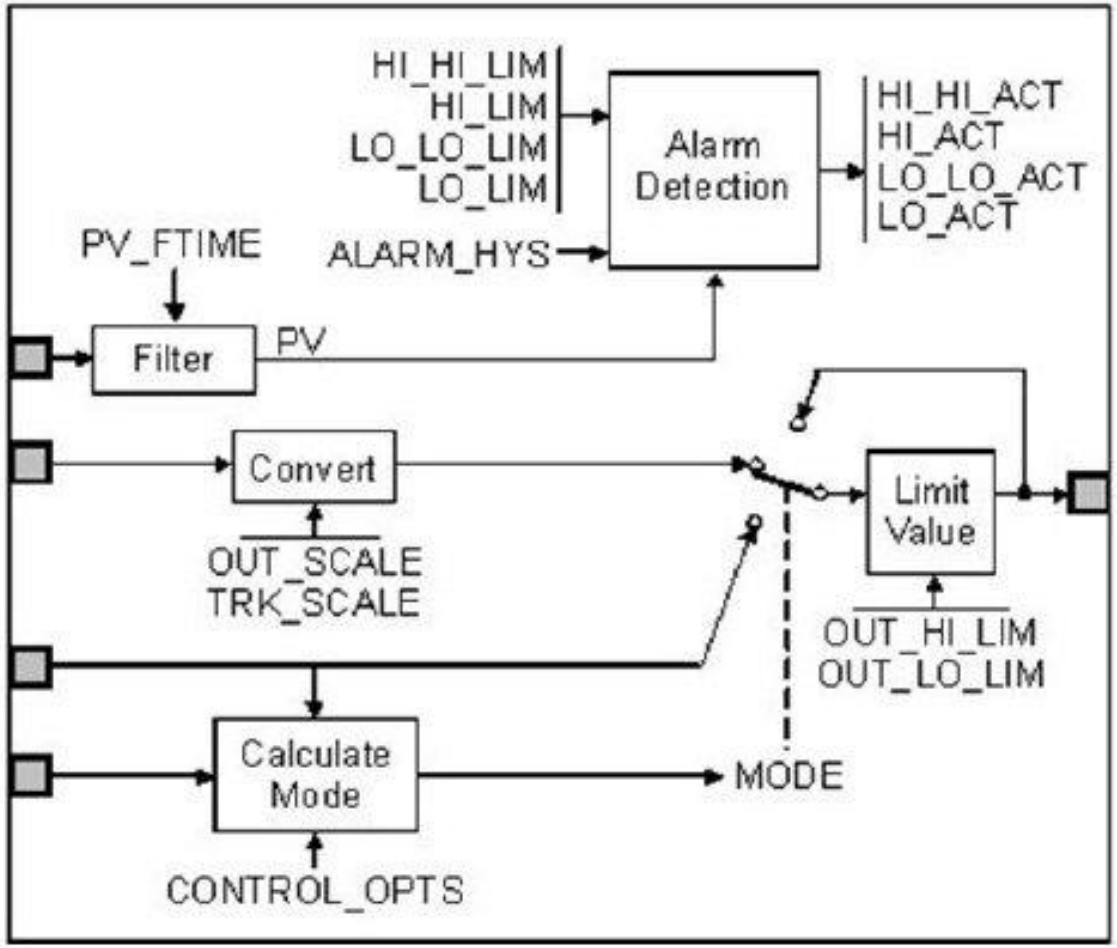


Figure 11-9. Manual Loader Function Block

Analog Output Block

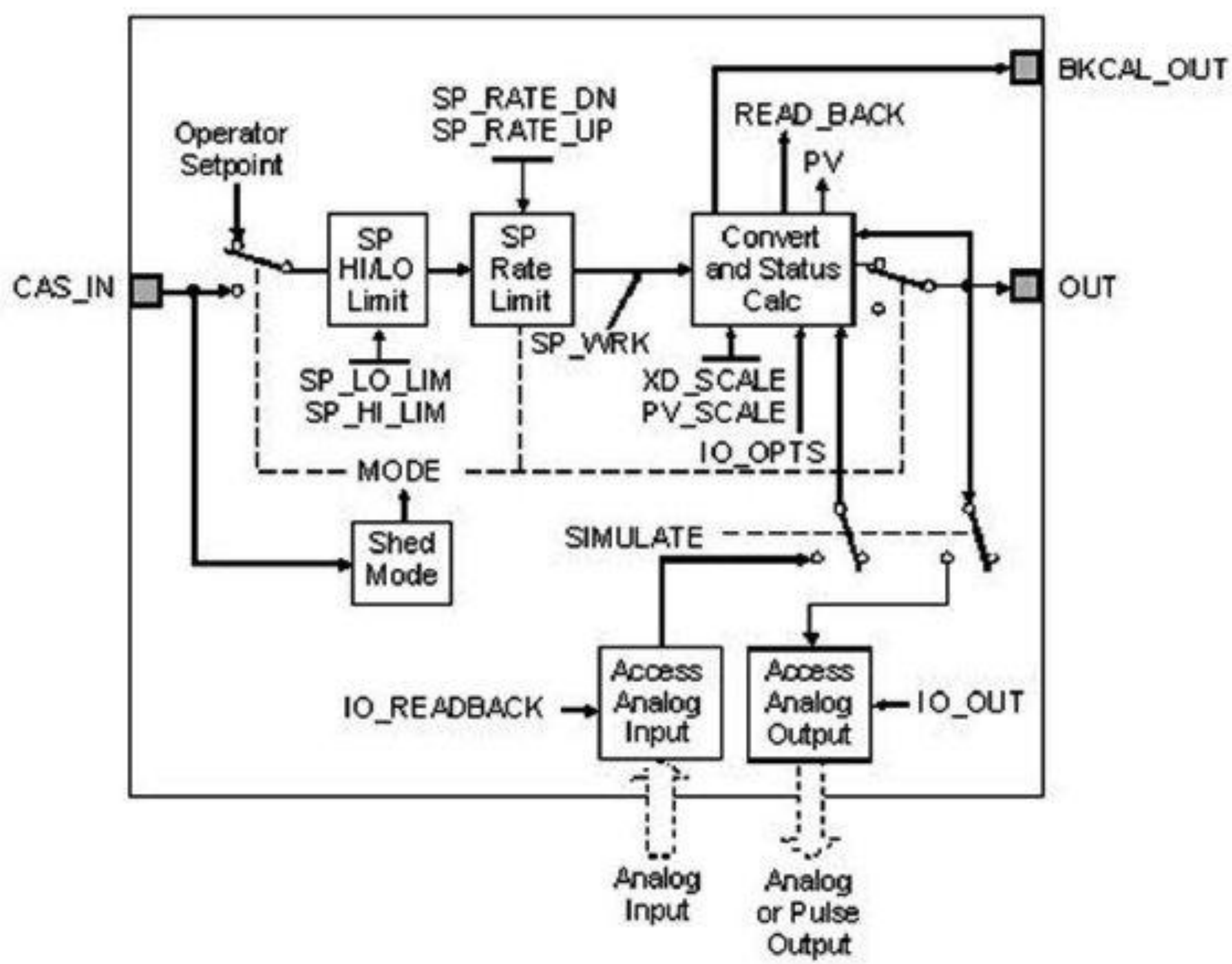


Figure 11-10. Analog Output Block Rate Limiting of Analog Output

Analog Output Block - Rate Limiting

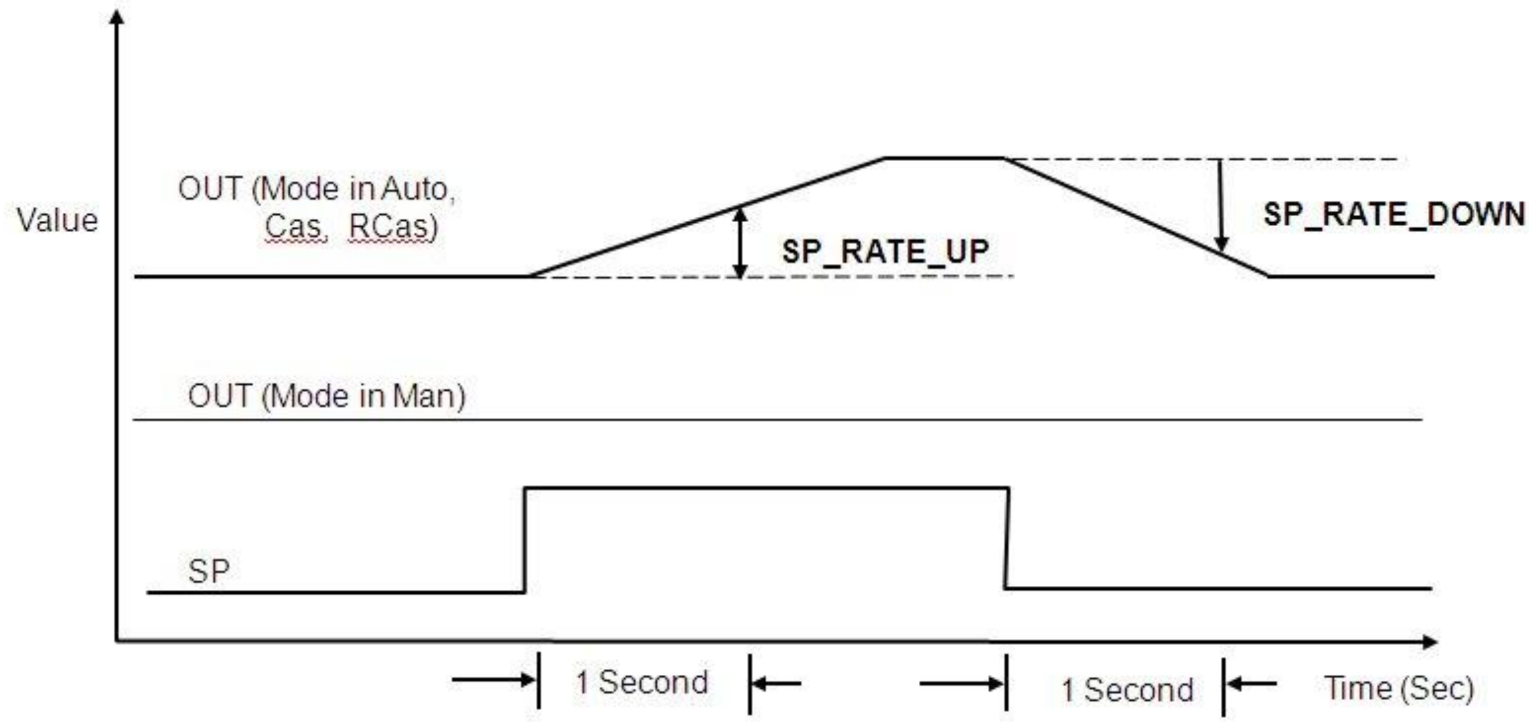
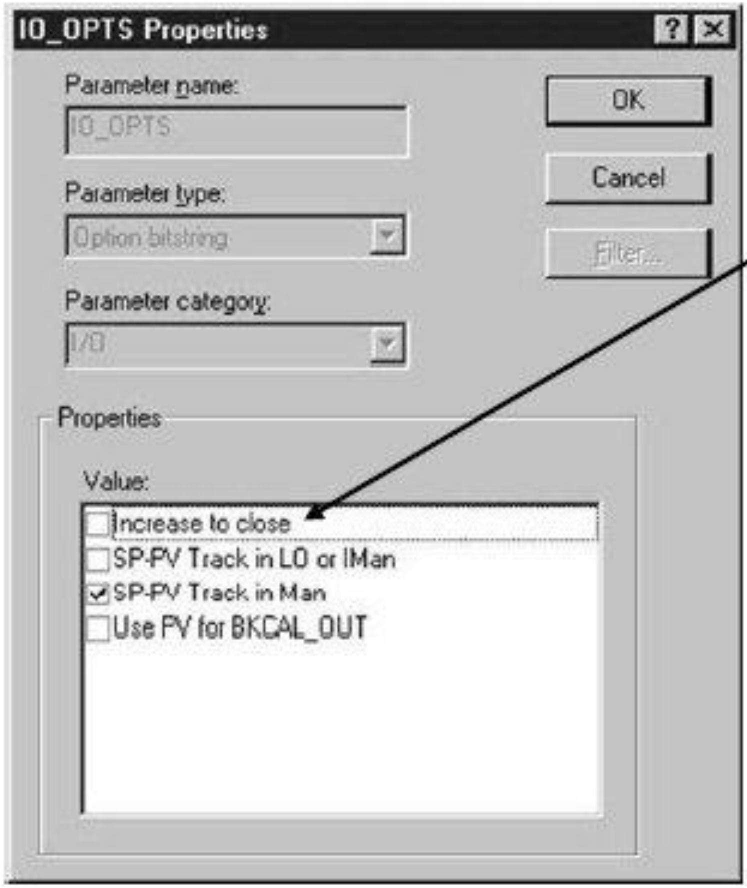


Figure 11-11. Rate Limiting of Analog Output

Analog Output Block – Increase to Close Option



The **Increase to close option** should be *set to account for field reversal* (I/P, actuator) so that the SP value always indicates “implied” valve position.

Figure 11-12. IO_OPTS Parameter

Feedback Control

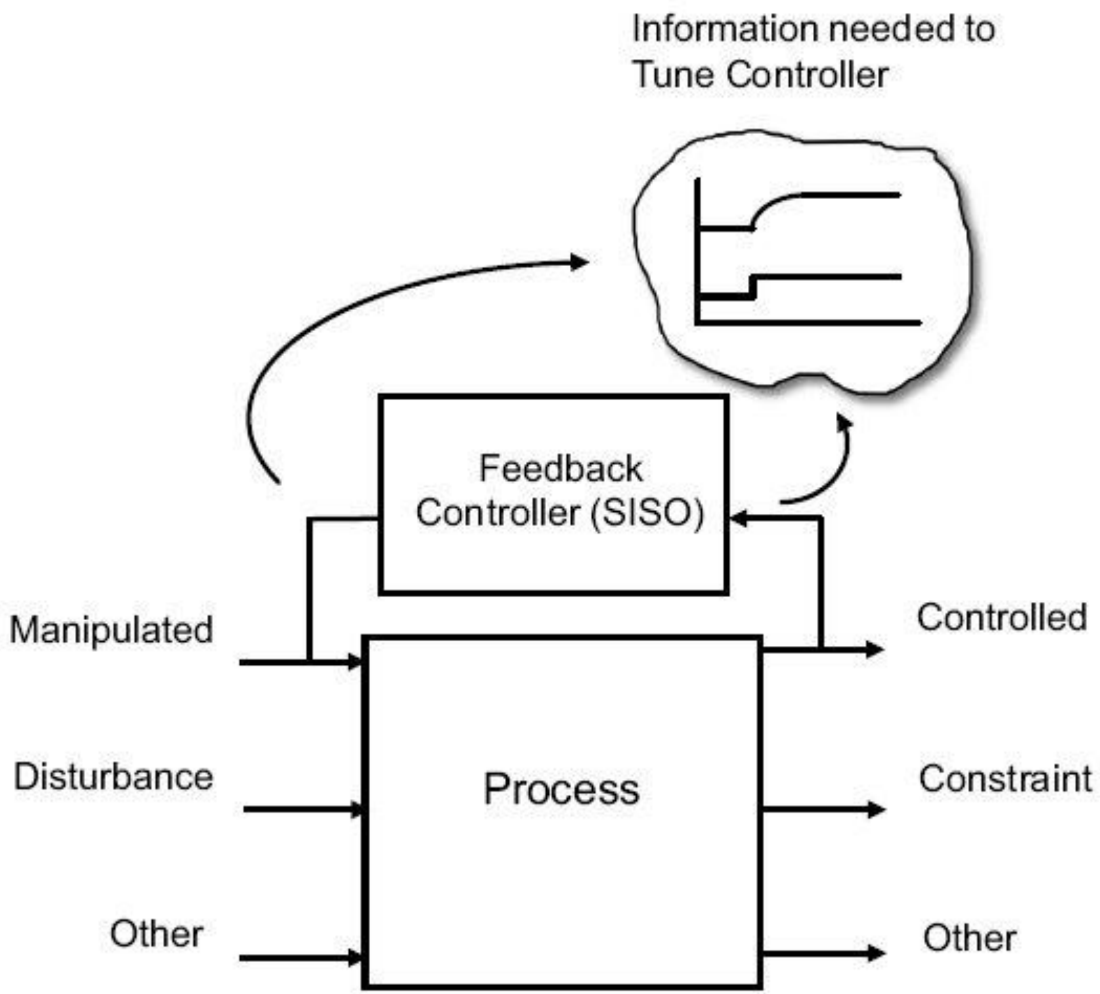


Figure 11-13. Basis of Feedback Control

Proportional Only Control

$$OUT = K_P * Error + BIAS$$

Where

OUT = Output of Controller

K_P = Proportional Gain

Error = Different between the Setpoint and the controlled parameter

BIAS = bias value, also known as manual reset

P-Only

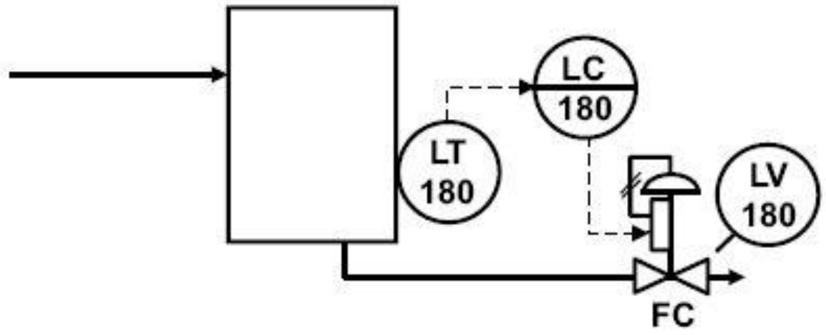


Figure 11-14. Proportional-Only Control

Proportional Plus Integral (PI) Control

$$OUT = K_P\left(Error + \frac{1}{K_I}\sum Error * \Delta t\right)$$

Where

OUT = Output of Controller

K_P = Proportional Gain

Error = Different between the Setpoint and the controlled parameter

K_I = Reset time, second per repeat

Δ**t** = Period of execution (sec)

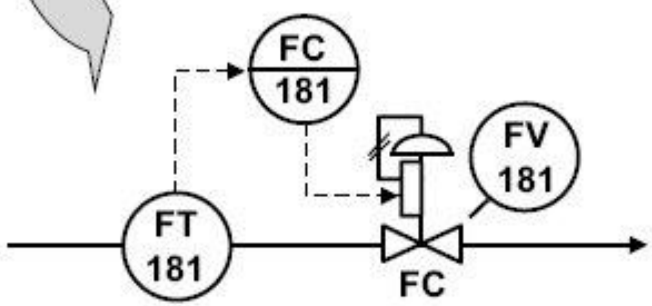


Figure 11-15. Proportional-Integral Control (PI Control)

Proportional, Integral, Derivative (PID) Control

$$OUT = K_P\left(Error + \frac{1}{K_I}\sum Error * \Delta t + K_D * Rate\ of\ Change \right)$$

Where

OUT = Output of Controller

PV = Control measurement

K_P = Proportional Gain

Error = Different between the Setpoint and the controlled parameter

K_I = Reset time, second per repeat

K_D = Rate, seconds

Δ**t** = Period of execution (sec)

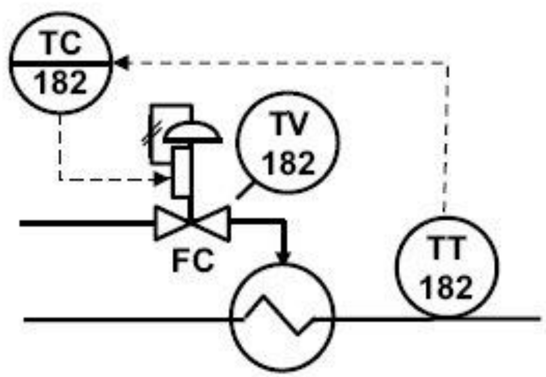


Figure 11-16. PID Control

PID Structure Selection

The selection of **PID structure** should be based on the process i.e. how the controlled parameter reacts to a change in the manipulated parameter.

I-Only - When the response of the controlled parameter to a change in the manipulated parameter is instantaneous – the process is a pure gain.

PI - The process can be adequately represented as a first-order lag. *The majority of industrial process fall into this category*

PID - The process is best represented as a second-order system and the control parameter contains little noise.

P-Only - If the process is best represented as an integrator.

Figure 11-17. Guidelines in Selecting PID Structure

PID Direct/Reverse Selection

A direct/reverse selection is normally provided with the PID to compensate for the relationship of the manipulated parameter to the controlled parameter

1. Select ***direct*** if the manipulated parameter must be increased to correct for an increasing controlled parameter
2. Select ***reverse*** if the manipulated parameter must be decreased to correct for an increasing controlled parameter

Note: The OUT parameter of the PID is normally considered to be the manipulated parameter.

Figure 11-18. Setting Controller Action

PID Function Block

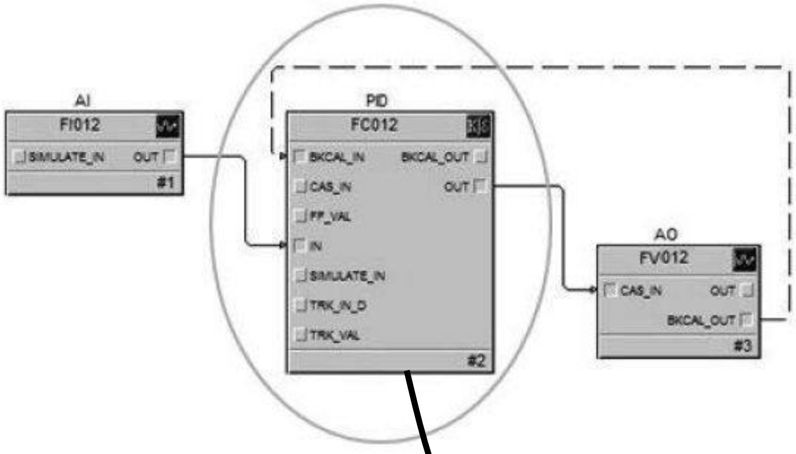


Figure 11-19. Feedback Control Connections

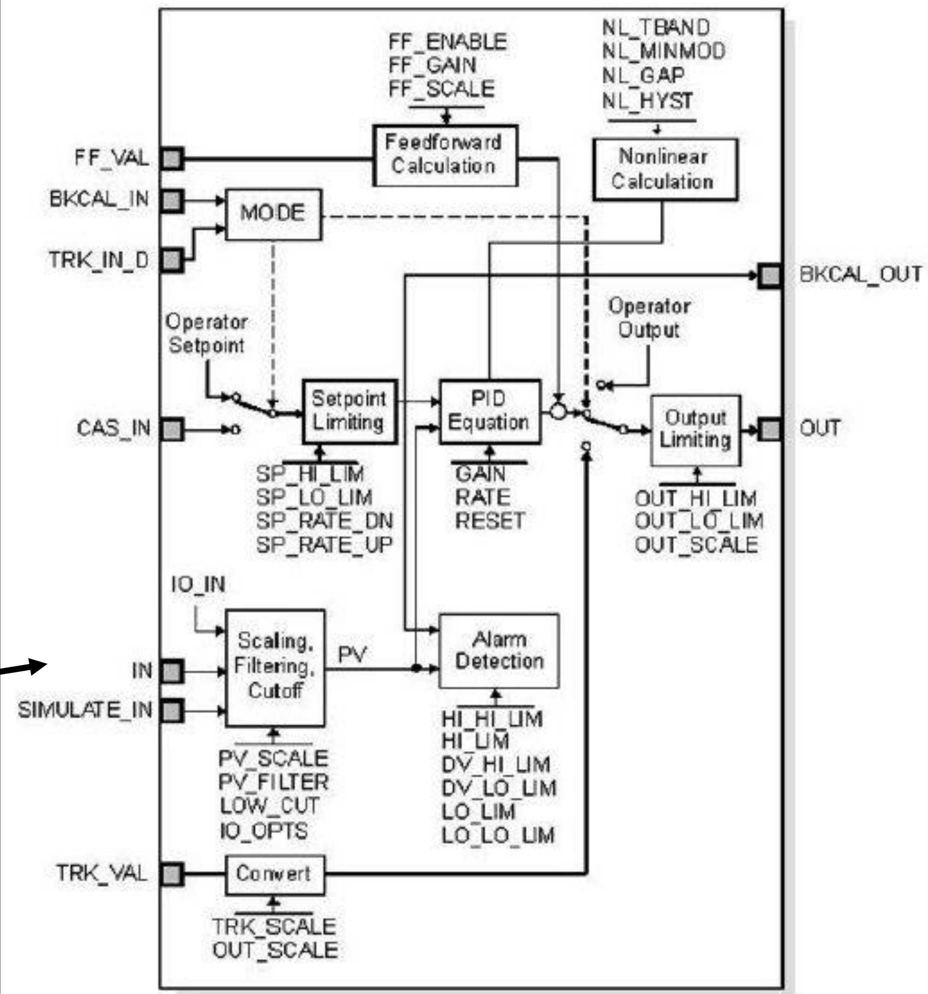


Figure 11-20. PID Block Implementation

PID Form – Standard and Series

Conventional Standard PID with feedforward – Laplace (s domain) representation.

$$OUT(s) = GAIN * \left(1 + \frac{1}{T_r s} + \frac{T_d s}{(\alpha T_d s + 1)}\right) * E(s) + F(s)$$

Series PID with derivative filter applied only to derivative action, with feedforward – Laplace (s domain) representation.

$$OUT(s) = GAIN * \left(1 + \frac{T_d s}{(\alpha T_d s + 1)}\right) * \left(\frac{T_r s + 1}{T_r s}\right) * E(s) + F(s)$$

where:

$GAIN = \text{Proportional gain}$

$T_r = \text{Reset time, seconds per repeat}$

$T_d = \text{Rate, seconds}$

$E(s) = \text{Error}$

$F(s) = \text{Feedforward contribution}$

Figure 11-21. PID Form

Setting PID Form and Structure

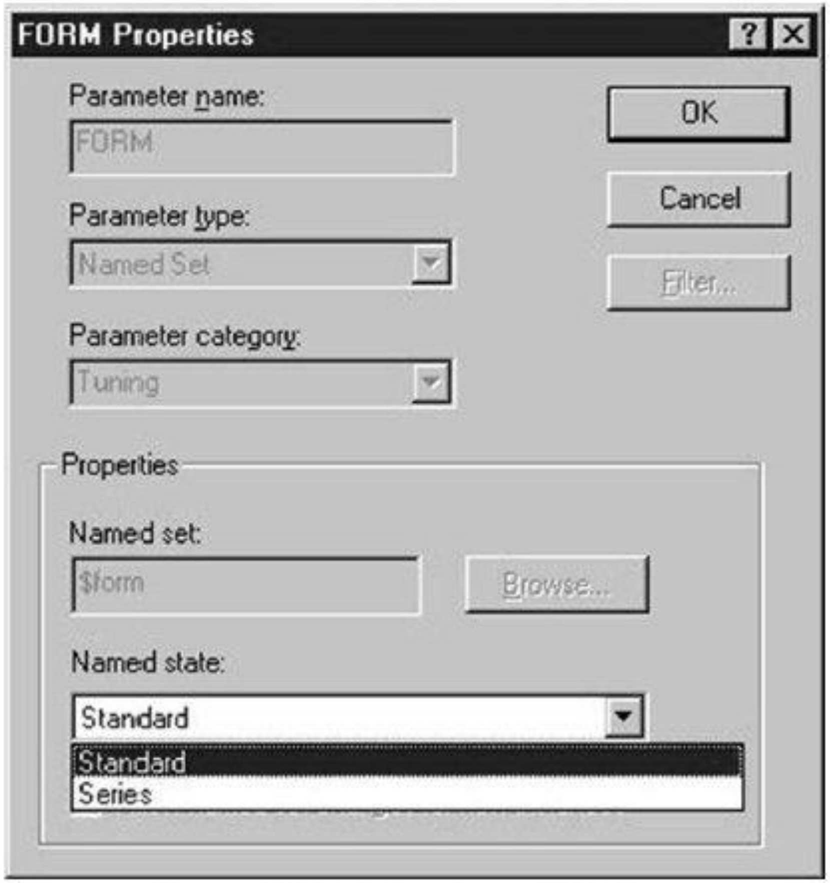


Figure 11-22. Selection of PID Form

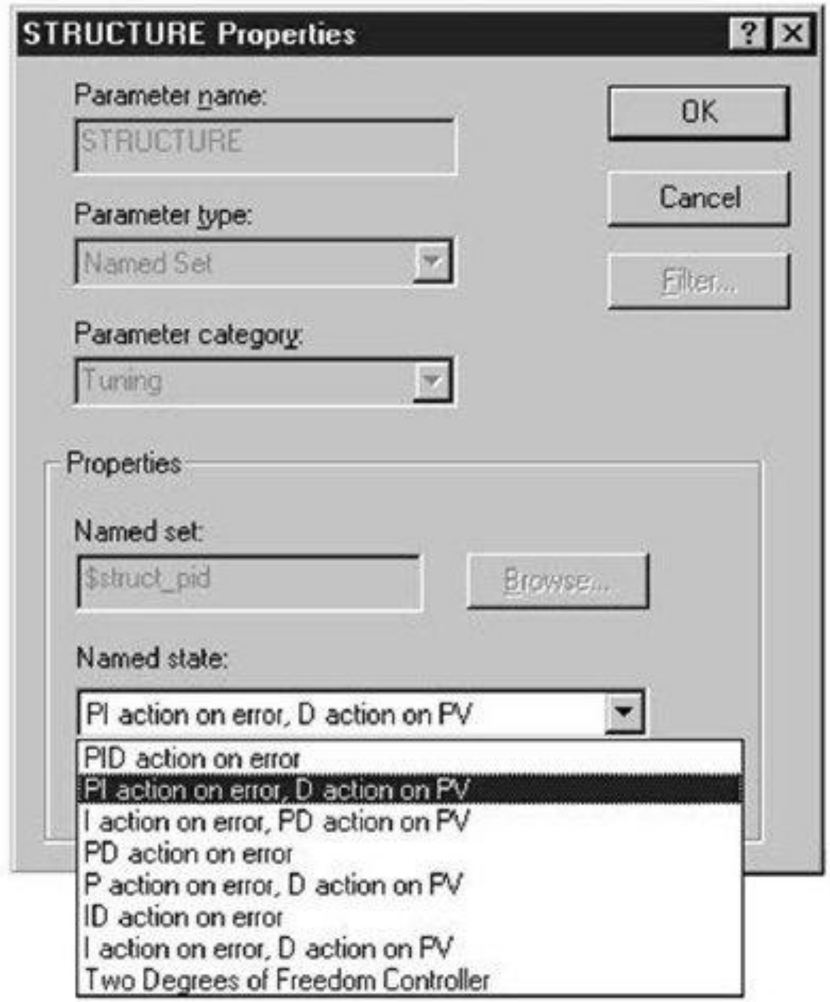


Figure 11-23. Selection of PID structure

Block Mode – Selection of Source of SP and OUT

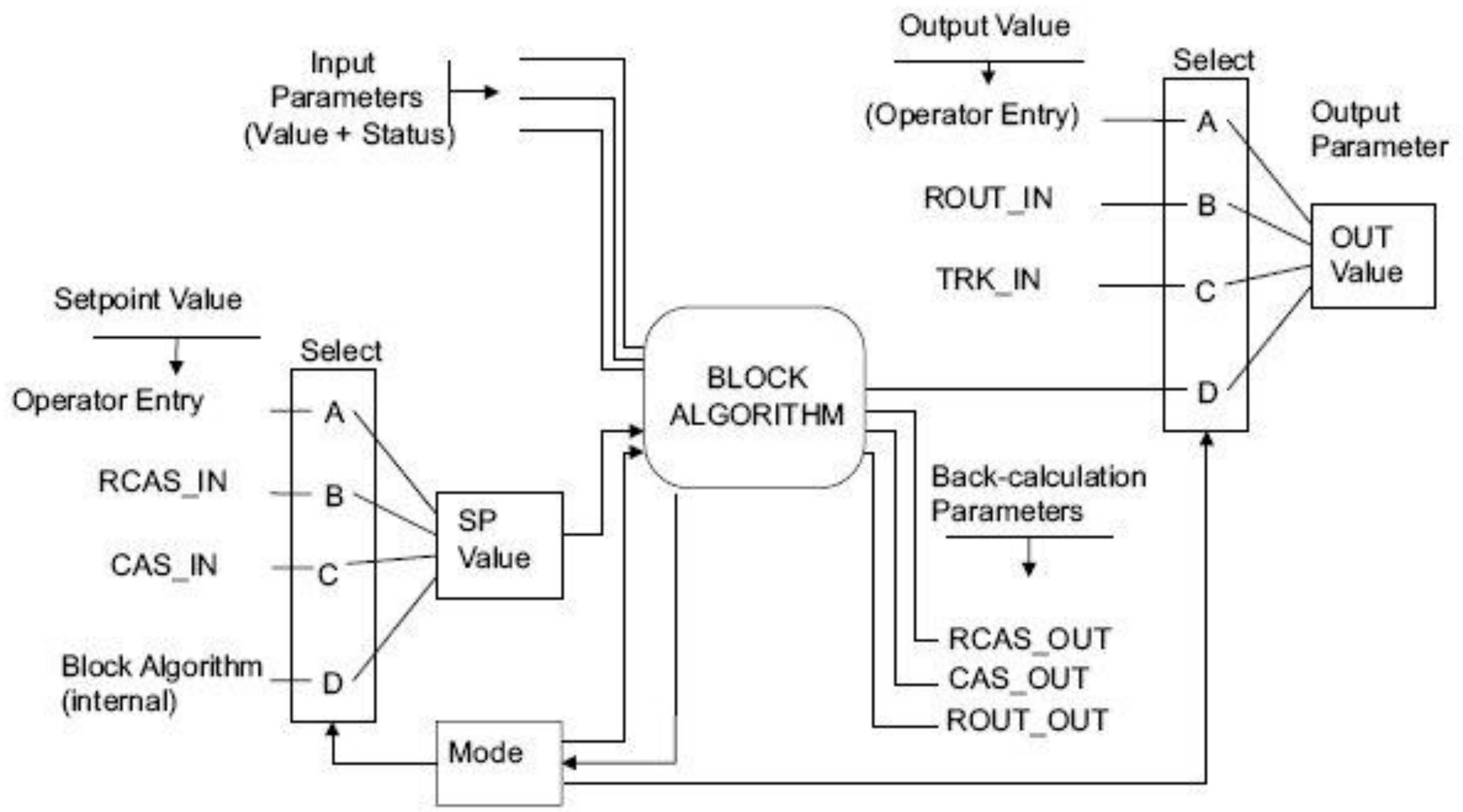


Figure 11-24. PID Mode Parameter

Target Modes of Block

Mode	Source of SP	Source of OUT
Out-of-Service(O/S)	Operator	Operator
Manual (Man)	Operator	Operator
Automatic (Auto)	Operator	Block
Cascade (Cas)	CAS_IN	Block
Remote Cascade(Rcas)	RCAS_IN	Block
Remote Output (Rout)	Operator	RCAS_OUT

Control and output blocks

Figure 11-25. Supported Operator Modes

Other Actual Modes of Block

Actual Mode	What it means
Local Override (LO)	Track or Auto-tuning is active and in control of the output value
Initialization Manual (IMAN)	The forward path to a physical output is broken and the output is tracking the downstream block

Figure 11-26. Other Actual Modes

Duty Cycle Control

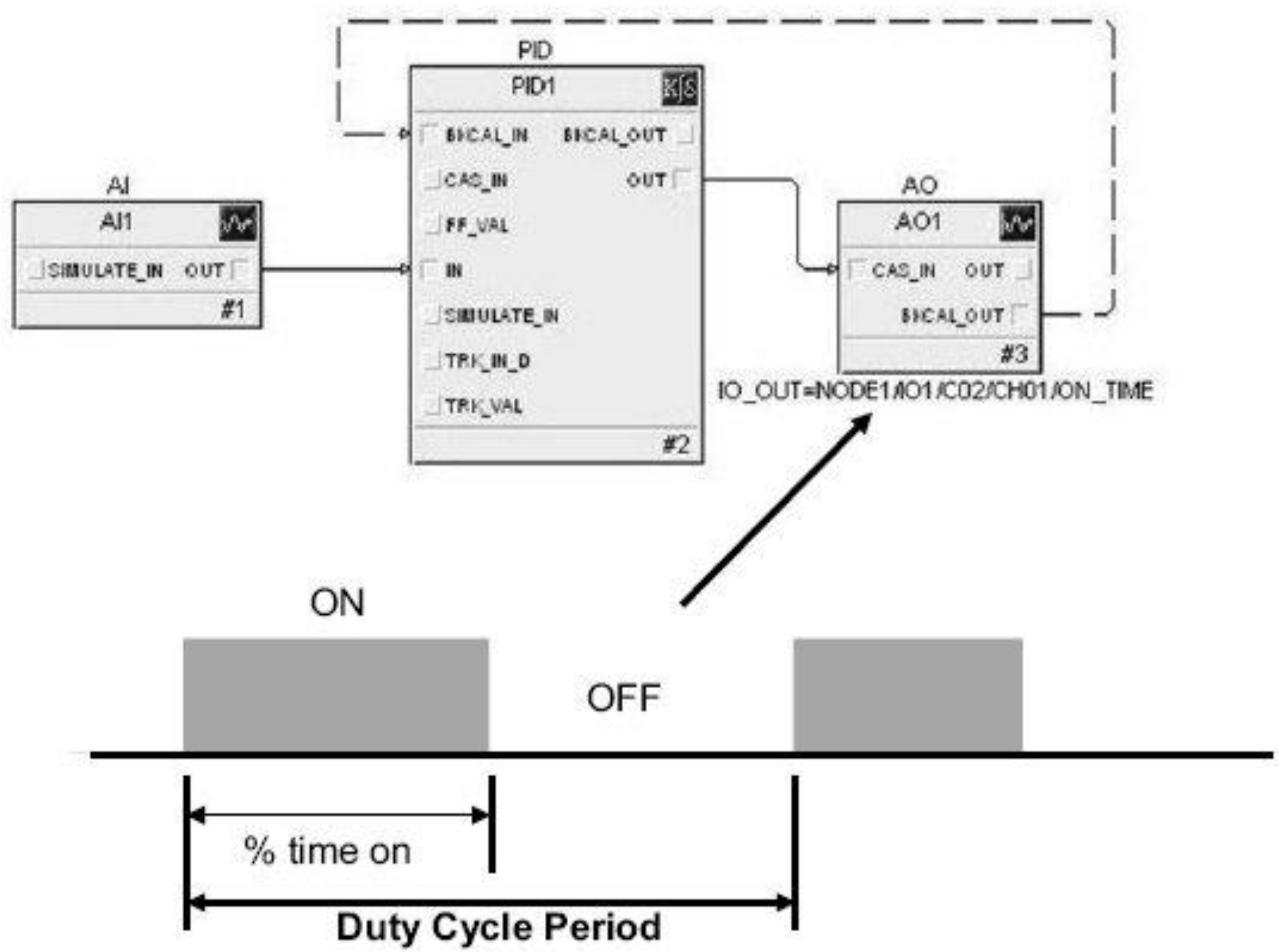


Figure 11-27. Duty Cycle Control

Duty Cycle Control (Cont.)

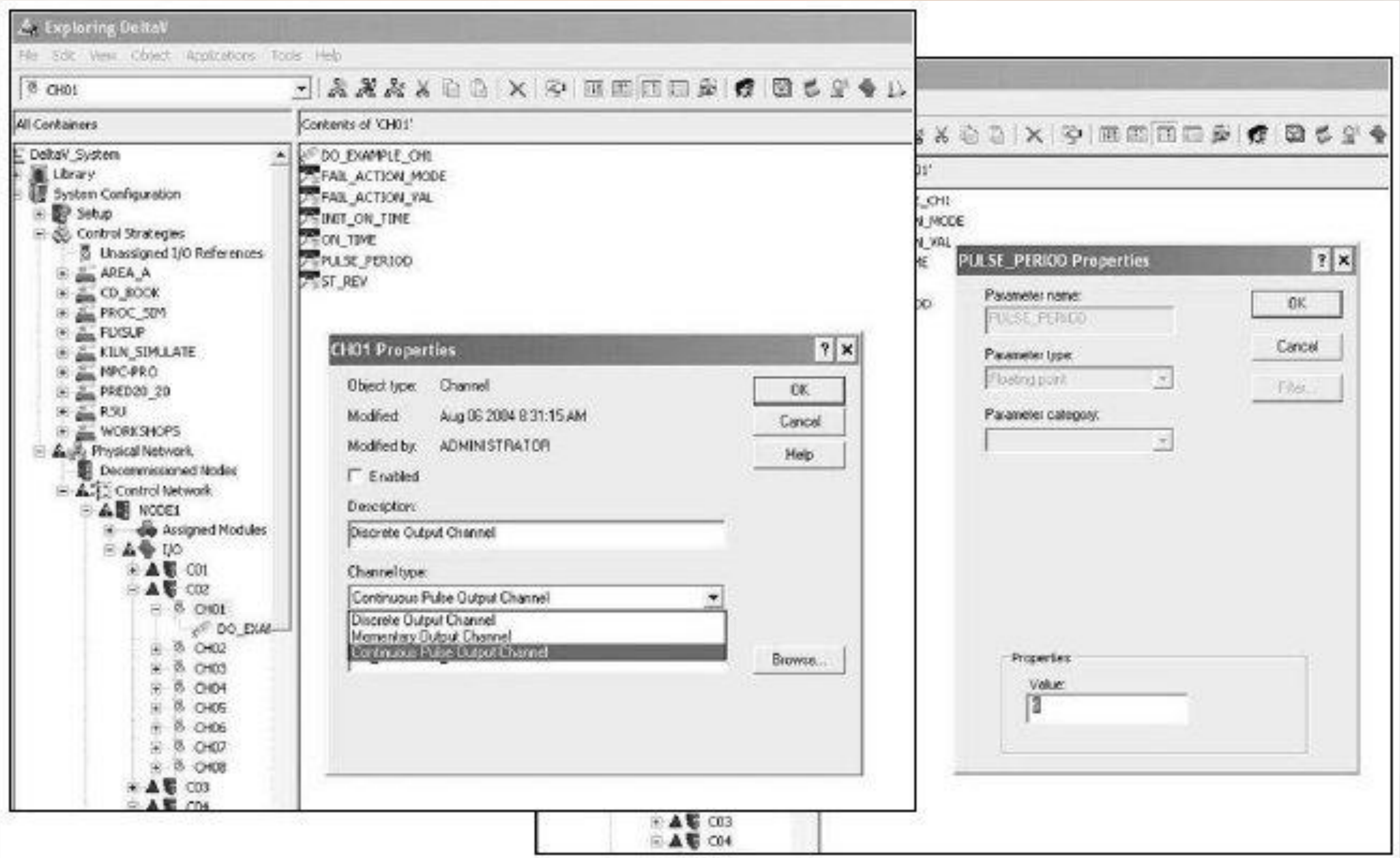


Figure 11-28. Discrete Output Setup for Duty Cycle Control

Increase-Decrease Control – Motor Driven Actuator

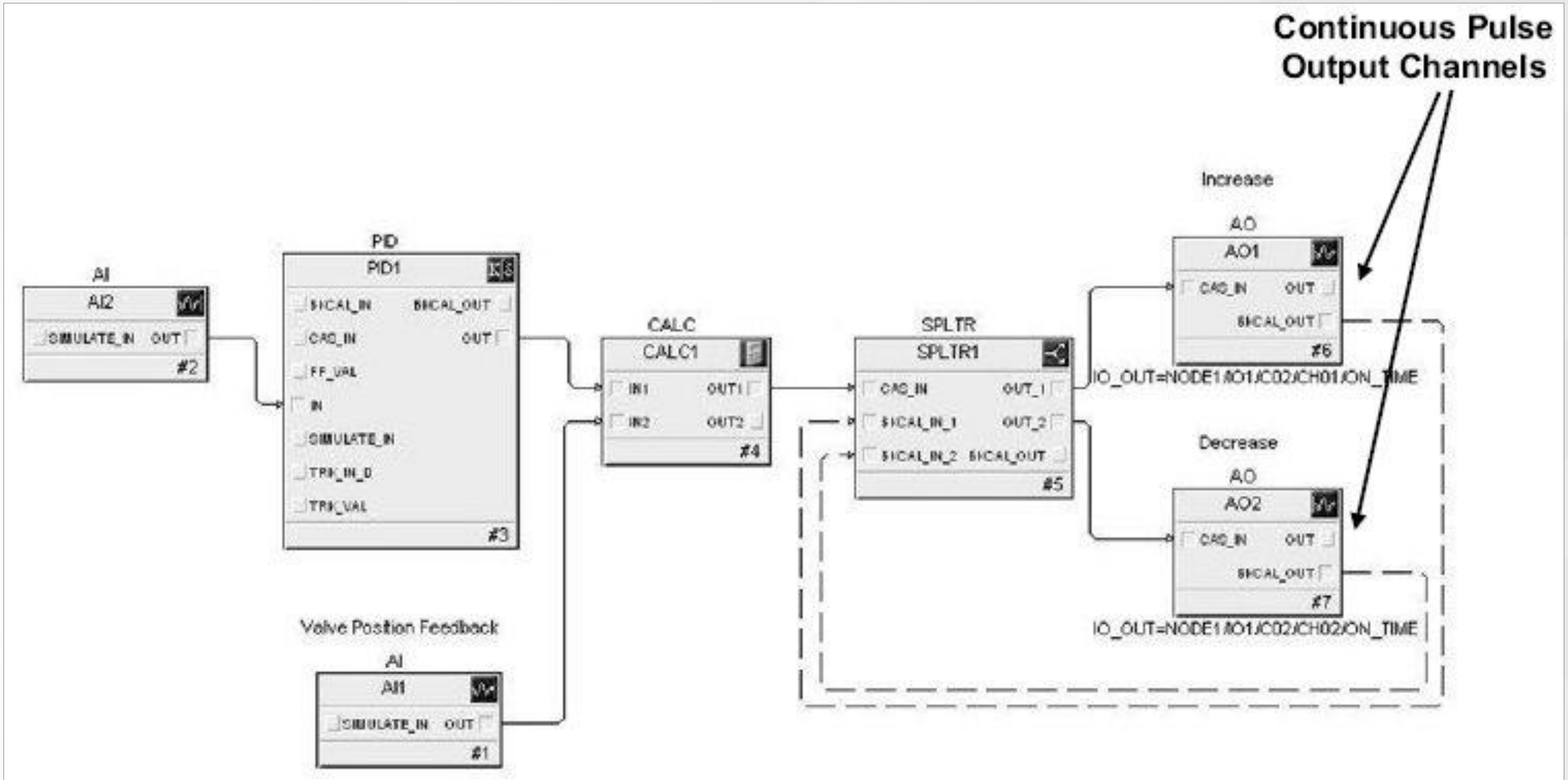


Figure 11-30. Interfacing to Increase-Decrease Actuators

Workshop – Feedback Control

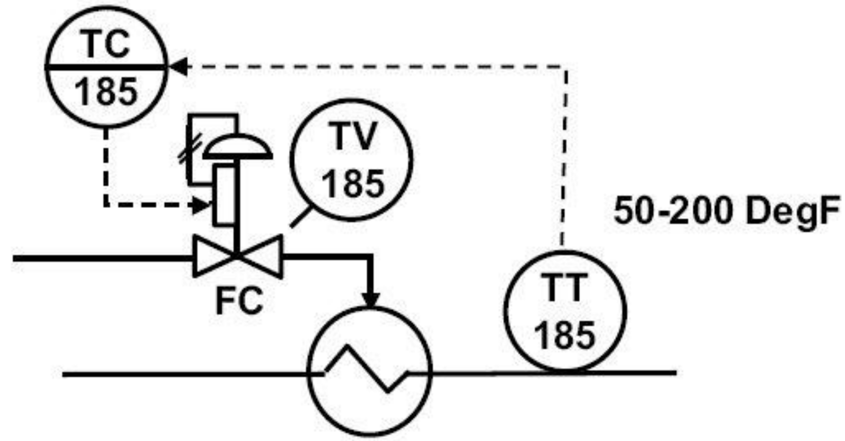


Figure 11-32. Process for Feedback Control Workshop

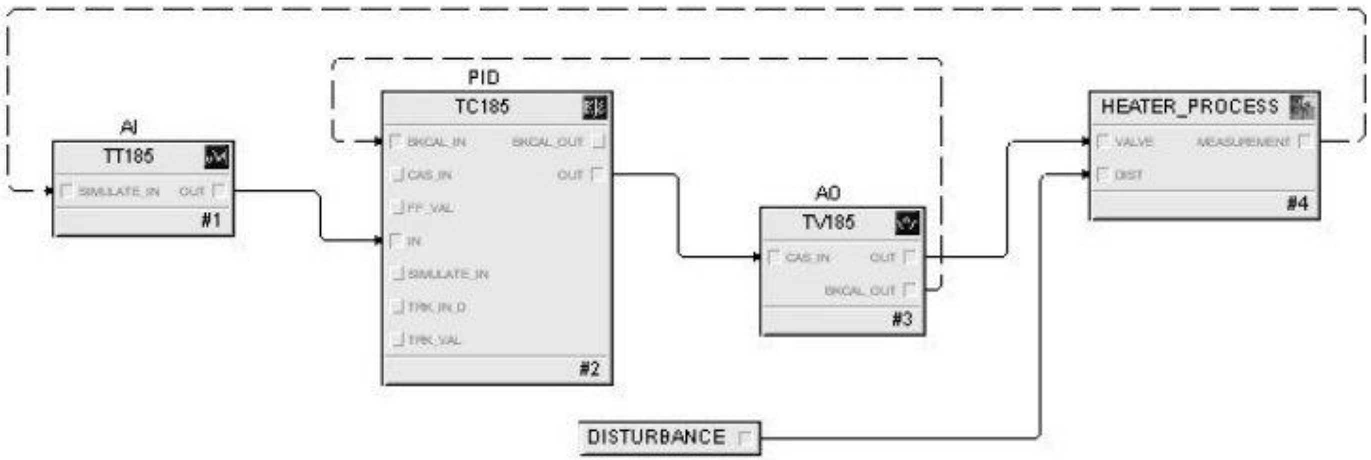


Figure 11-33. Feedback Control Workshop Module

Tuning and Loop Performance – Default Setting

	Gain	Reset	Rate
Flow	0.3	5	--
Temperature	1.3	300	60
Level	2	600	--
Gas Pressure	3	600	--

Figure 12-1. Initial PID Tuning

Manual Tuning Technique

Tuning of a PI controller applied to a self-regulating process can be quickly establish as follows:

1. Place the controlled and manipulated parameters on trend.
2. Place the controller in manual and allow the process to reach steady state.
3. Impose a step change in OUT and observe the response.
4. Set the RESET to match the sum of the process deadtime plus the time constant.
5. Place the loop on automatic control using conservative GAIN.
6. Make small changes in Setpoint and observe the response. Adjust only the GAIN to achieve the desired response.

Figure 12-2. Manual Tuning Technique

Tools to Automate Tuning

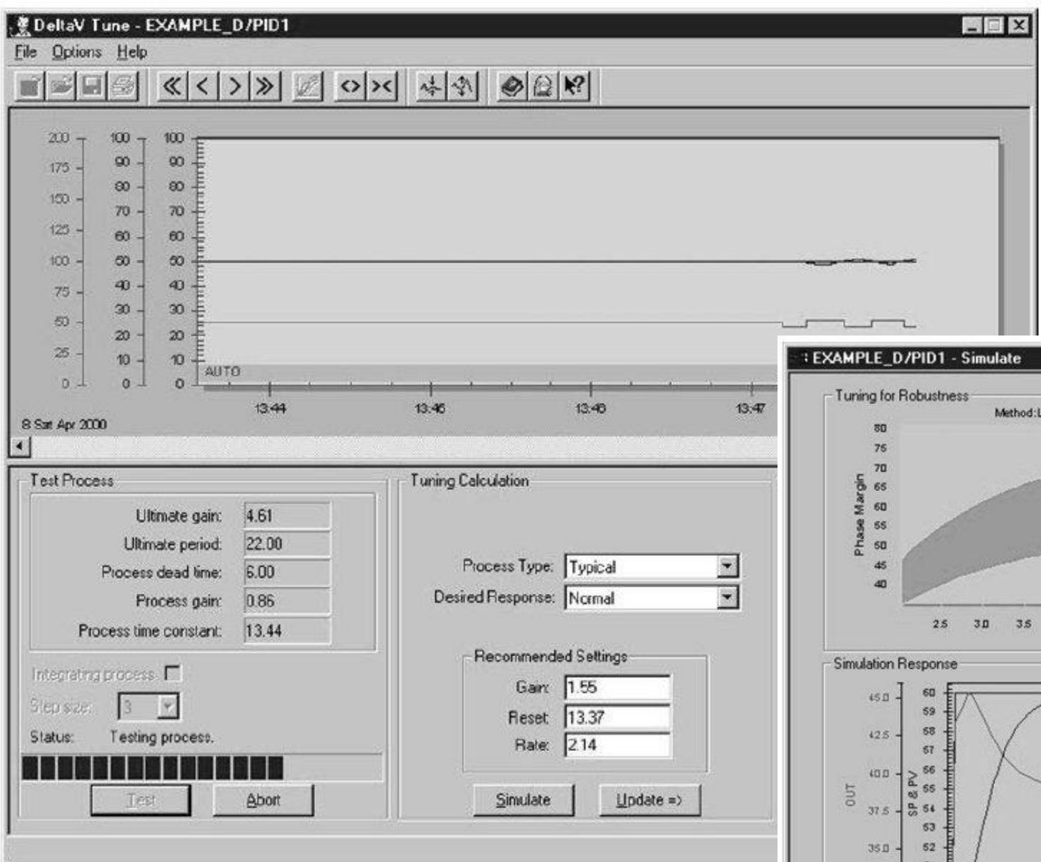


Figure 12-3. Auto-Tune Interface

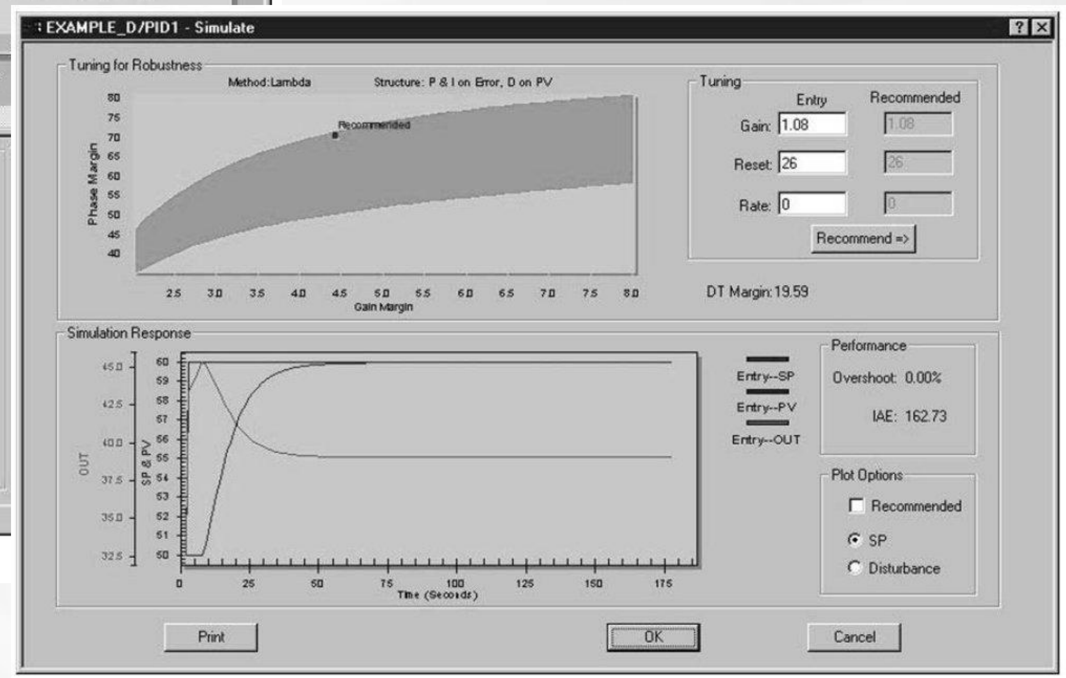


Figure 12-4. Simulation of Loop Response

- Example base on DeltaV Insight On-demand Tuning

Impact of Sticky Valve

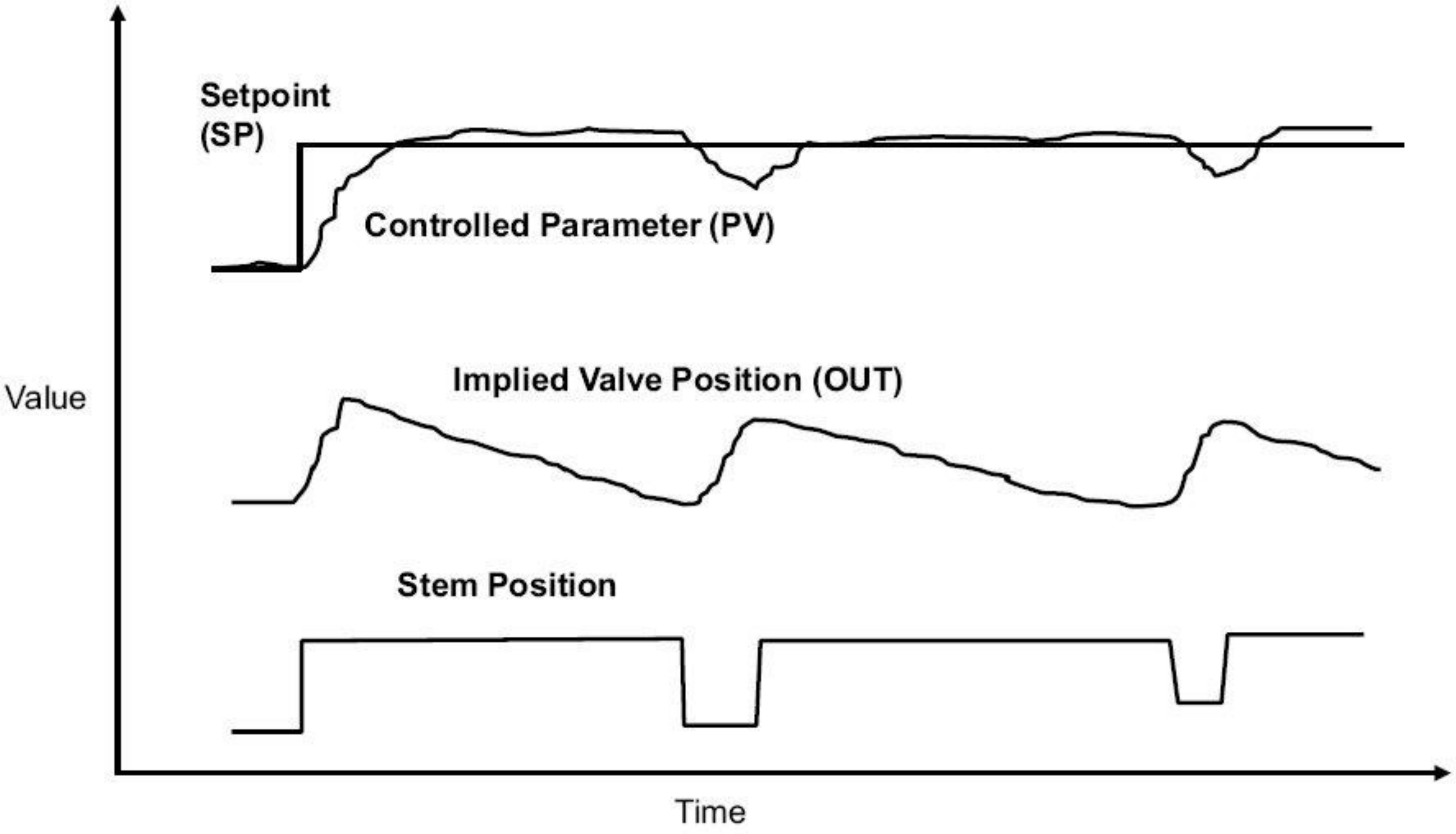


Figure 12-5. Impact of Sticky Valve on Automatic Control

Use of Signal Characterizer to Compensate for Non-linearity

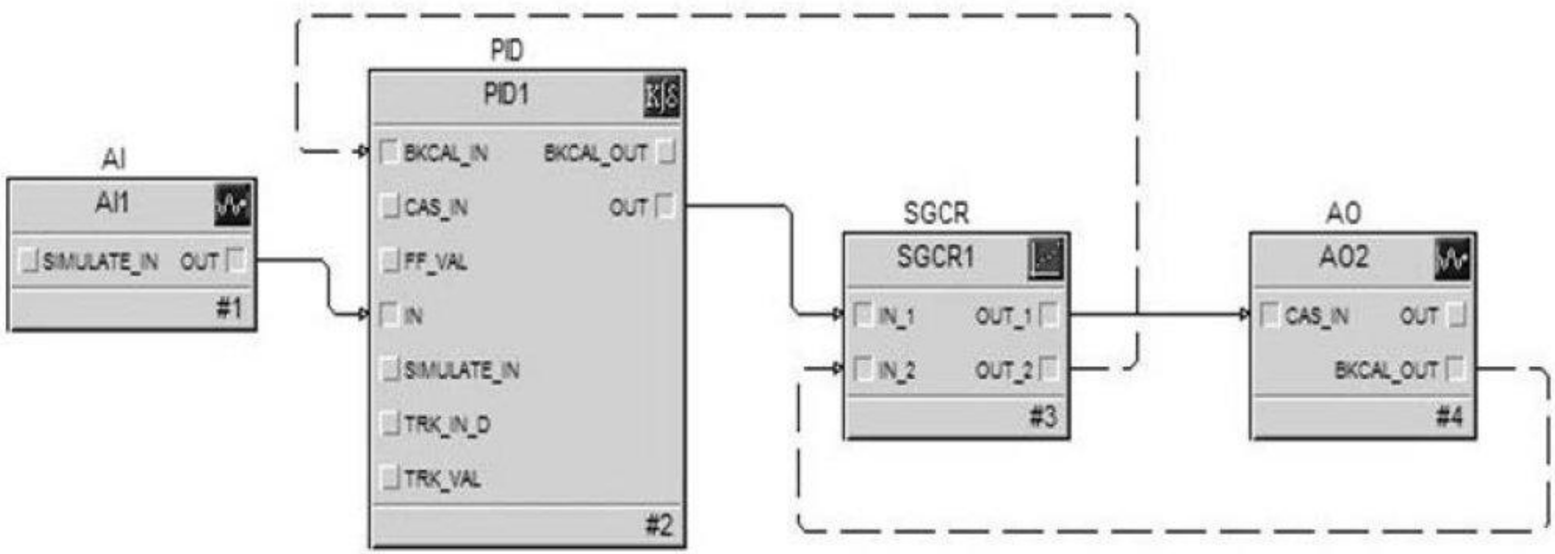
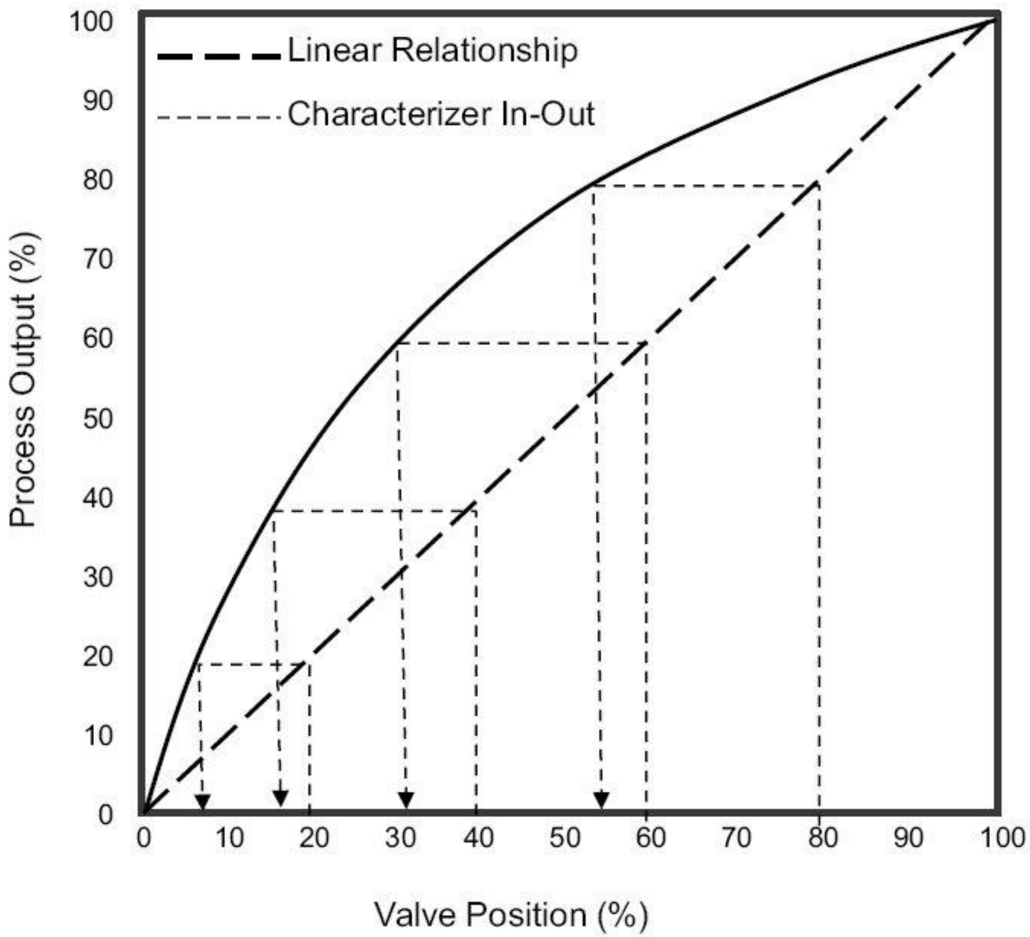


Figure 12-7. Signal Characterization in Control Path

Characterizer Setup



Characterizer IN	Characterizer OUT
0	0
5	1.5
10	3
15	5.5
20	8,5
25	10
30	11.5
35	13
40	17
45	20
50	22
55	26
60	31
65	36
70	42
75	48
80	54
85	63
90	74
95	86
100	100

Figure 12-8. Example of Characterizer Setup

Multi-loop Control - Feedforward Control

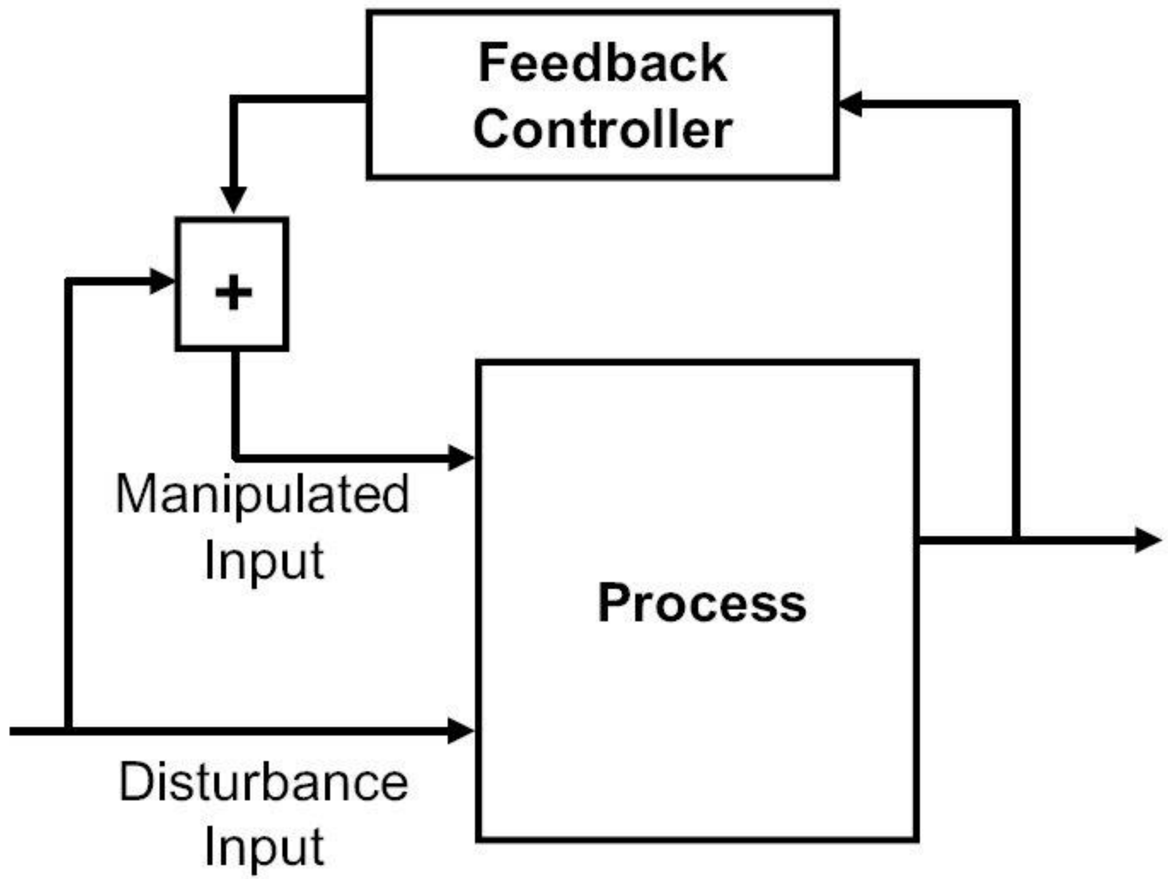


Figure 13-1. Basis of Feedforward Control

Feedforward Control Implementation

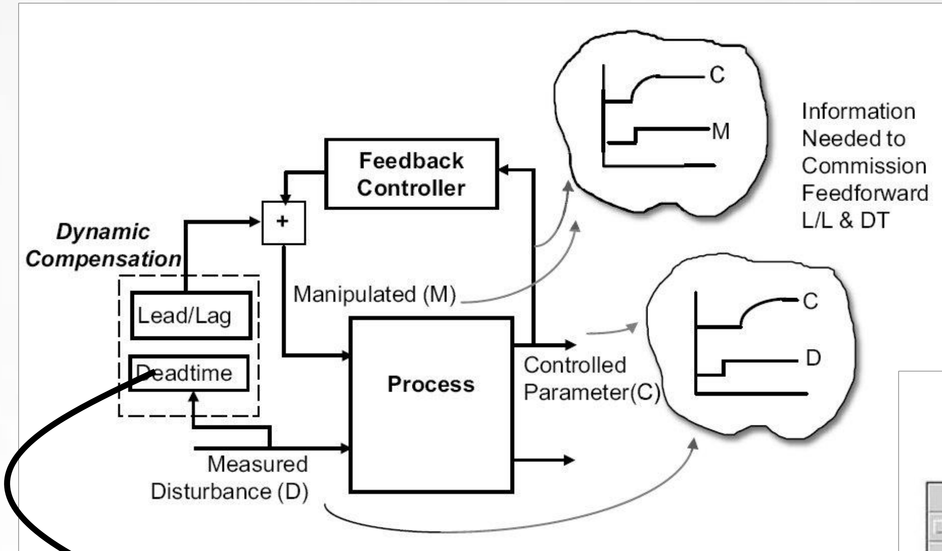


Figure 13-2. Feedforward Dynamic Compensation

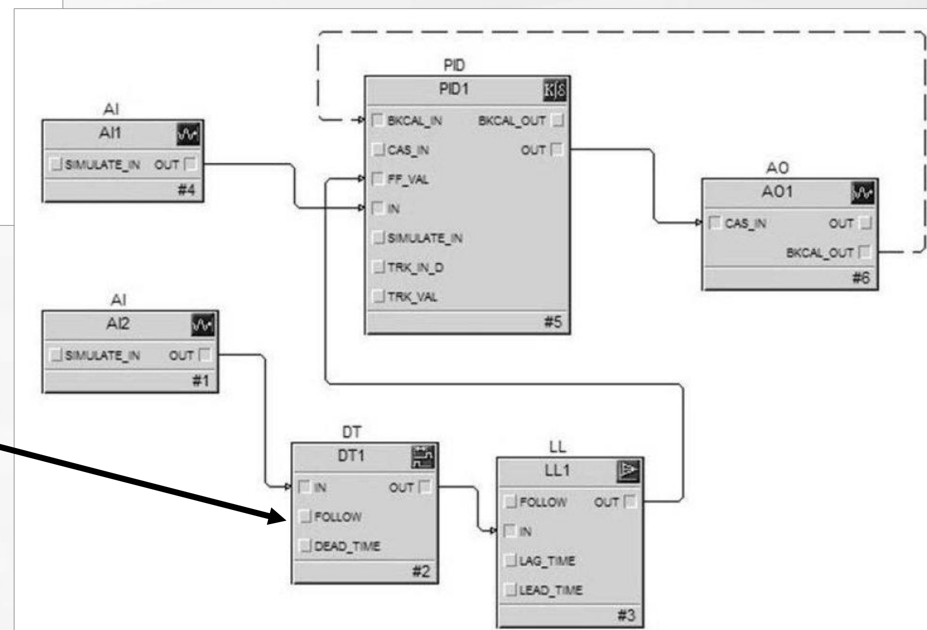


Figure 13-3. Dynamic Compensation in Feedforward Path

Commissioning Dynamic Compensation

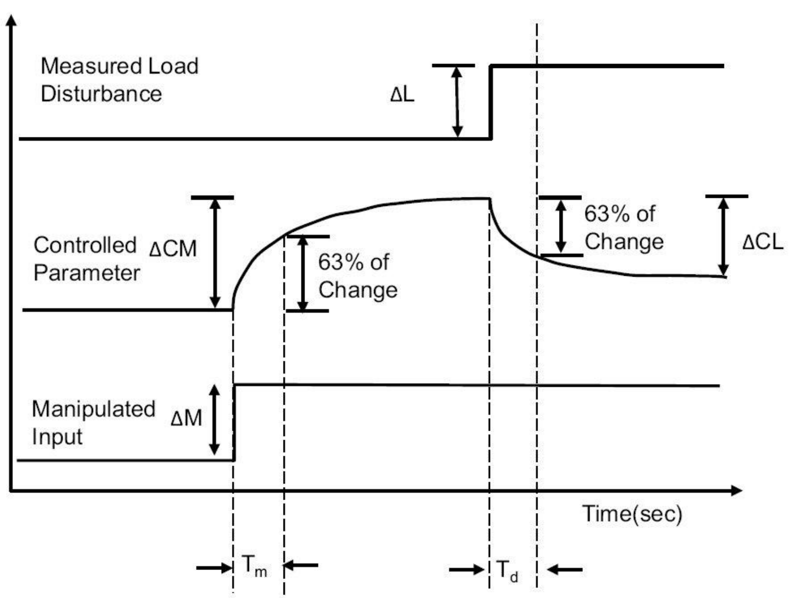


Figure 13-4. Step Test to Determine Process Dynamics

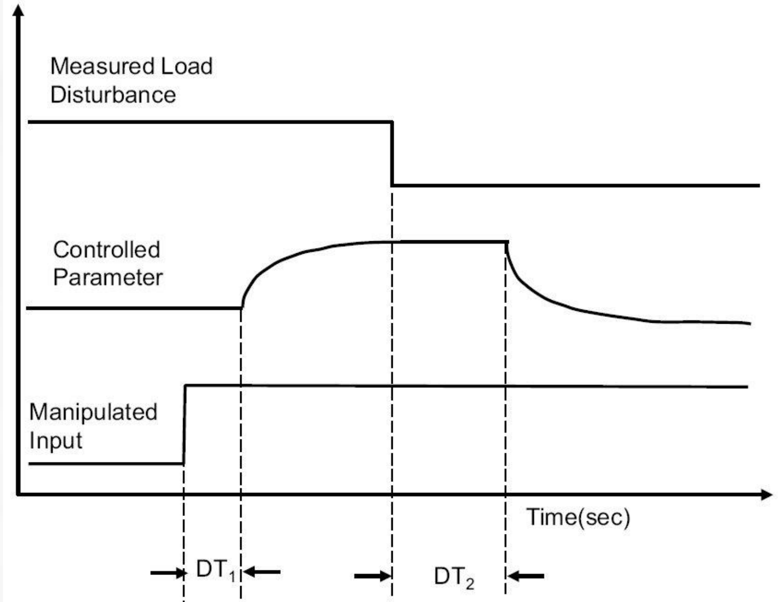


Figure 13-5. Step Test to Determine Process Deadtime

$$FF_{lead} = T_m$$

$$FF_{lag} = T_d$$

$$FF_{gain} = -\left(\frac{Gain_{disturbance\ input}}{Gain_{manipulated\ input}}\right)$$

$$FF_{dt} = DT_2 - DT_1$$

Workshop – Feedforward Control

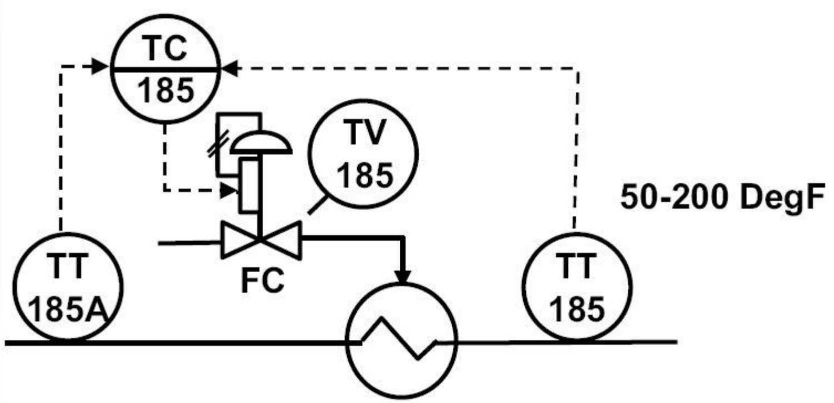


Figure 13-9. Process for Feedforward Control Workshop

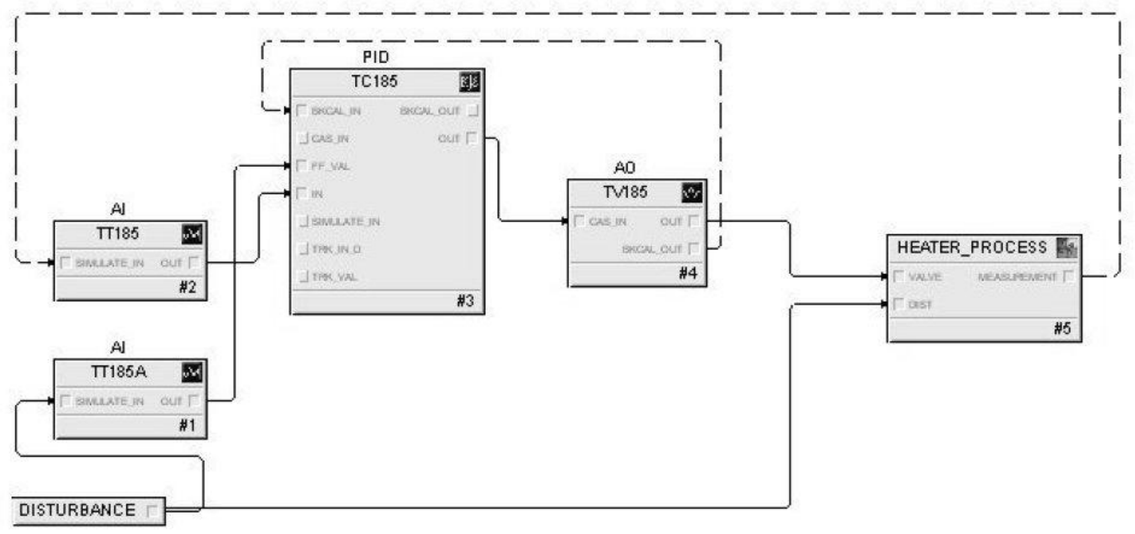


Figure 13-10. Feedforward Control Workshop Module

Cascade Control

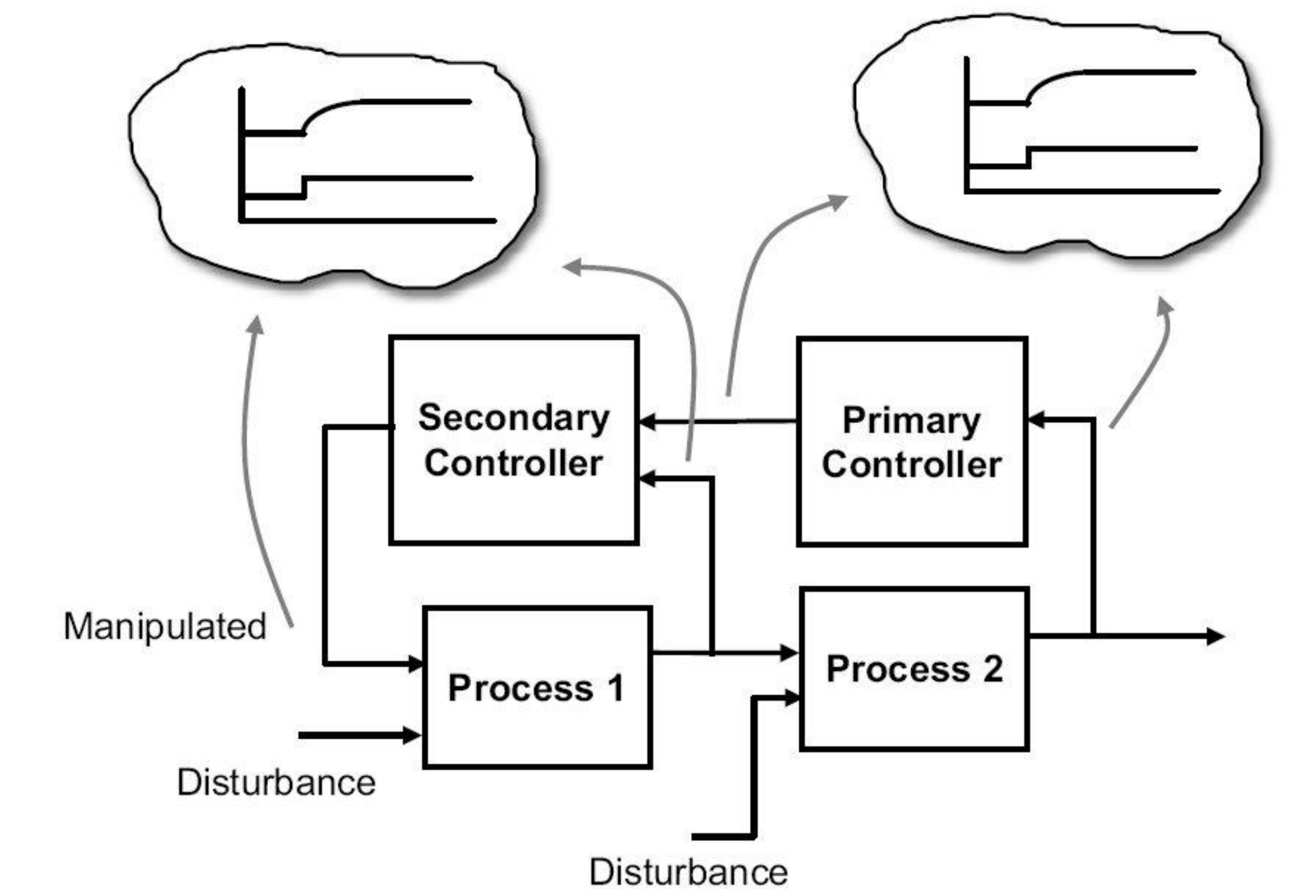


Figure 13-11. Basis of Cascade Control

Example – Boiler Steam Temperature

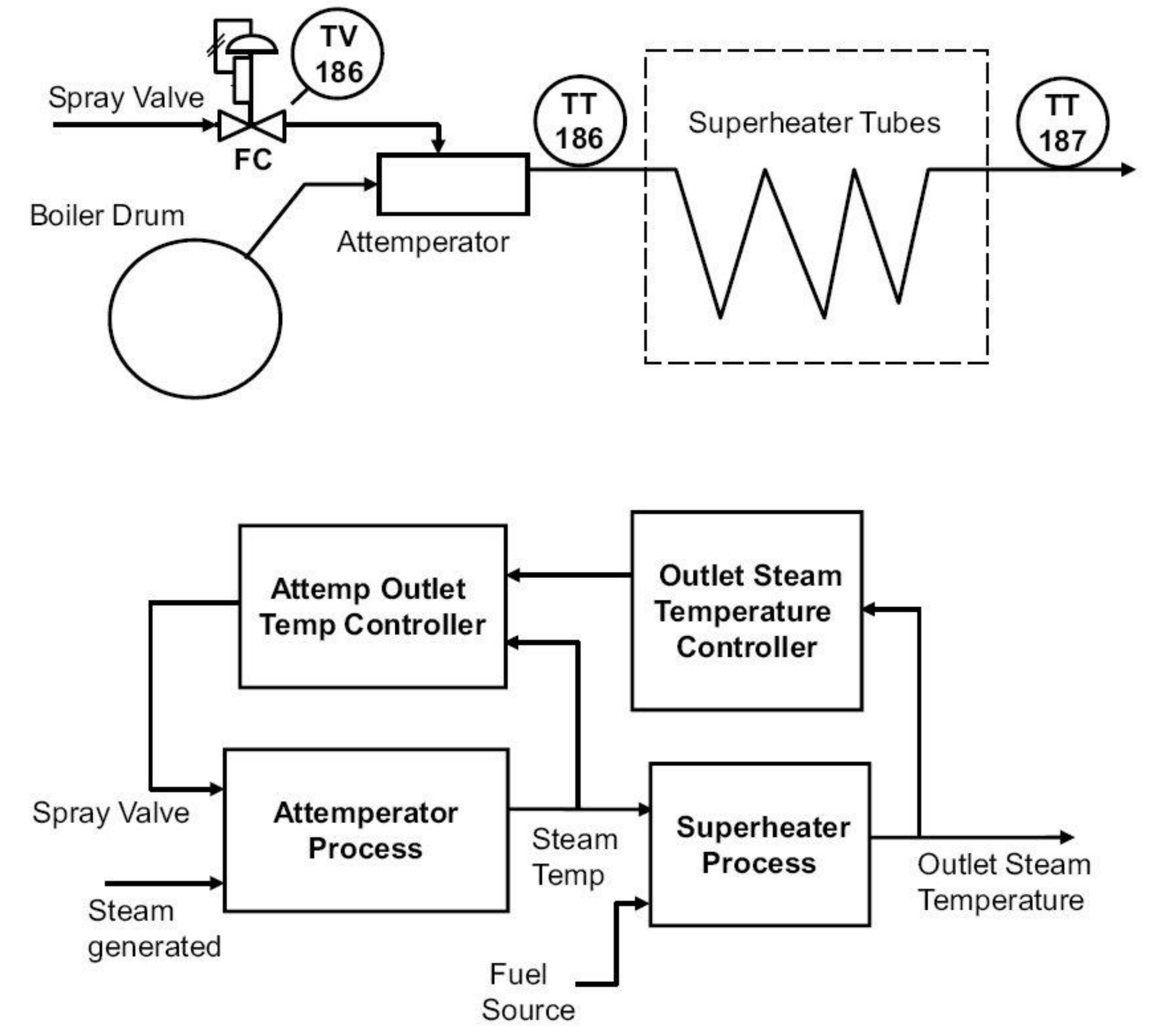


Figure 13-12. Example – Control of Outlet Steam Temperature

Cascade Control Implementation

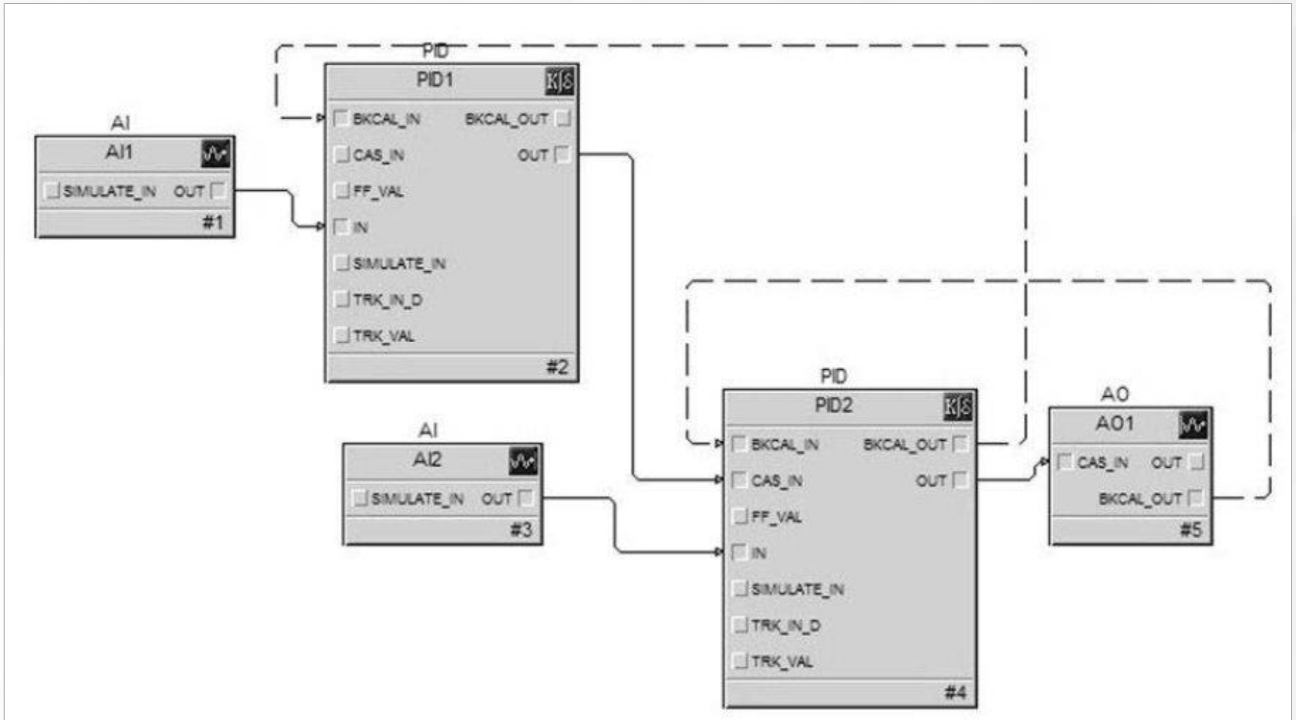


Figure 13-13. Cascade Control Implementation

- Selecting FRSI_OPT for dynamic reset in primary loop and CONTROL_OPTS for Use PV for BKCAL_OUT in secondary loop can often improve dynamic response.

Workshop – Cascade Control

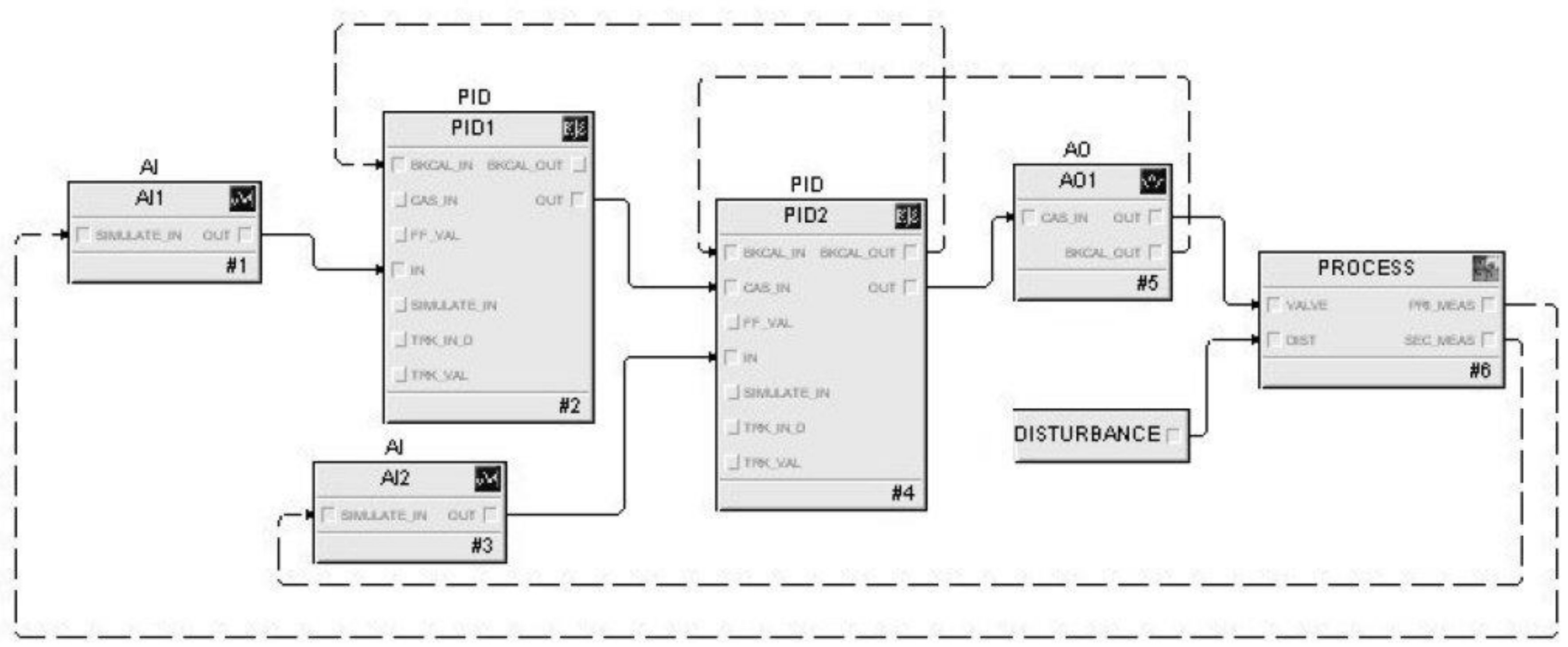


Figure 13-15. Cascade Control Workshop Module

Override Control

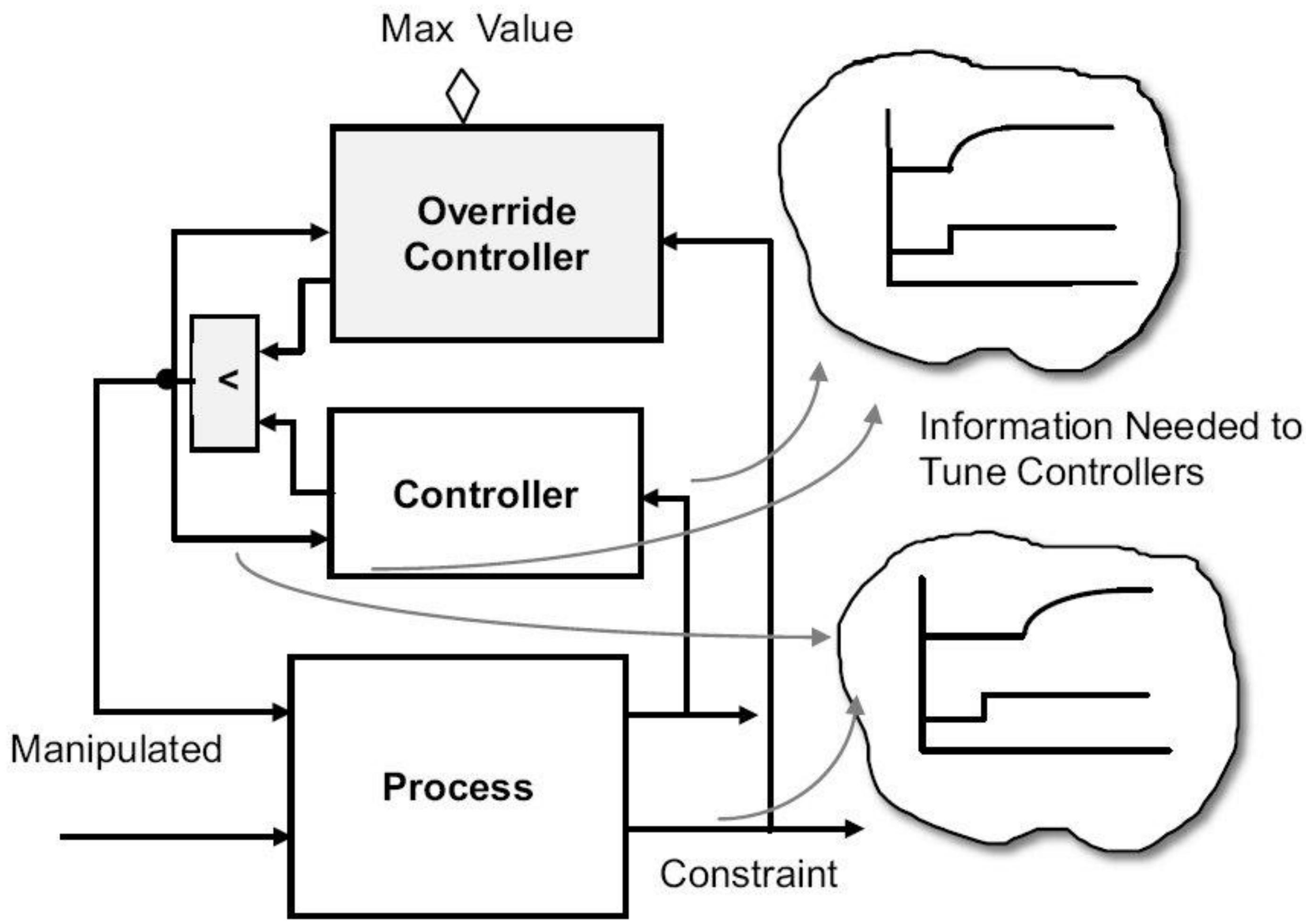


Figure 13-16. Basis – Override Control

Example – Override Control

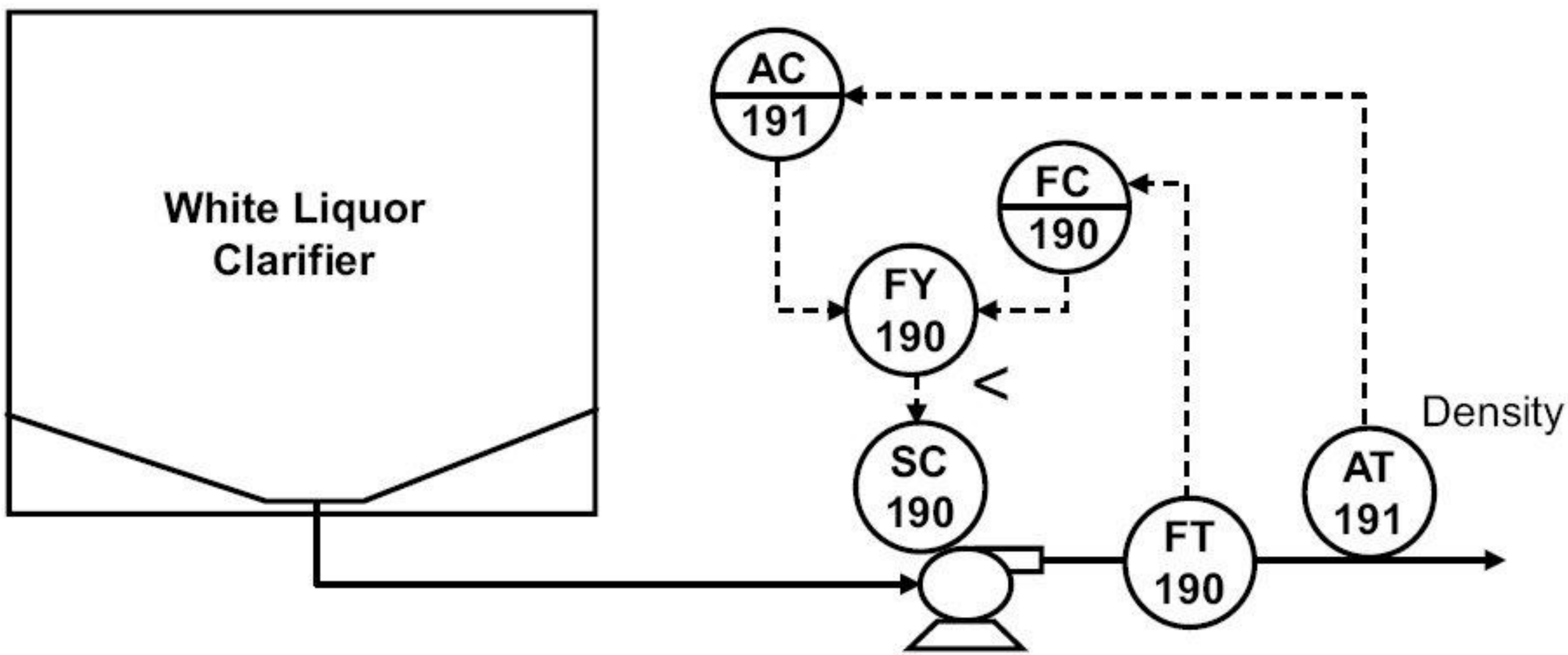


Figure 13-17. Example – Clarifier Control

Override Control Implementation

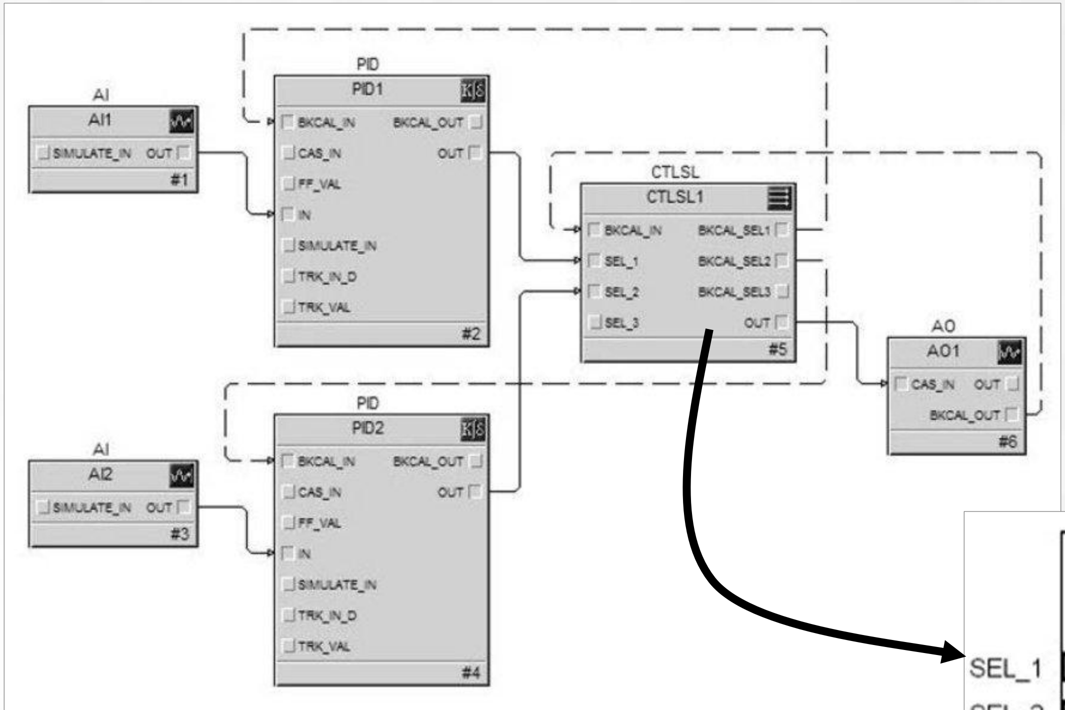


Figure 13-19. Typical Override Control Implementation

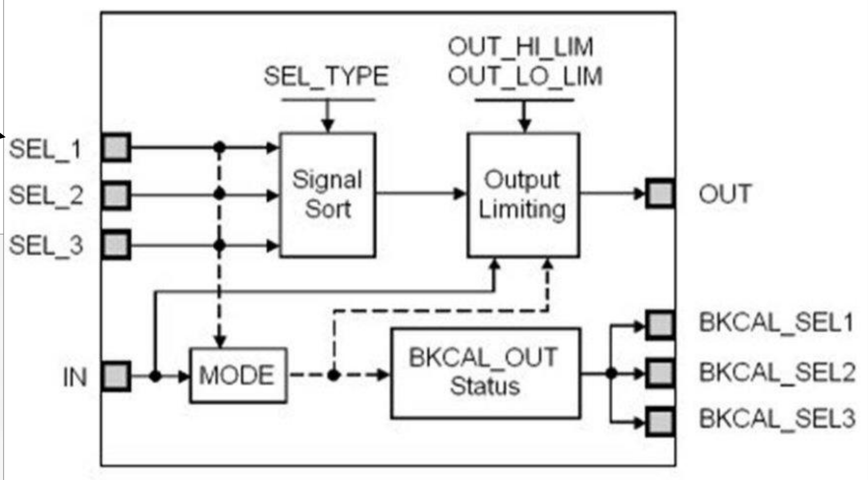


Figure 13-20. Control Selector Block

Workshop – Override Control

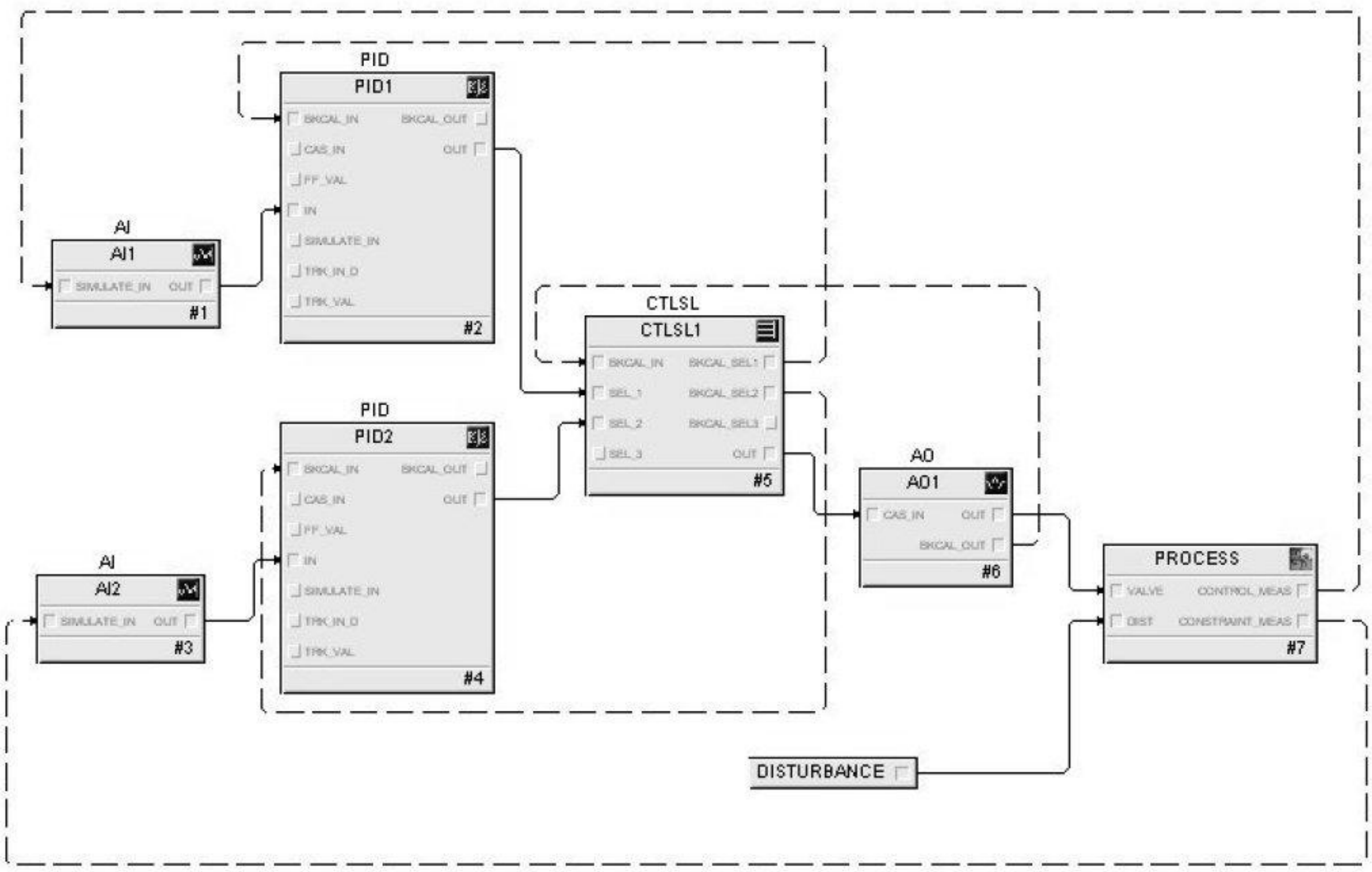


Figure 13-21 Override Control Workshop Module

Control Using Two Manipulated Parameters

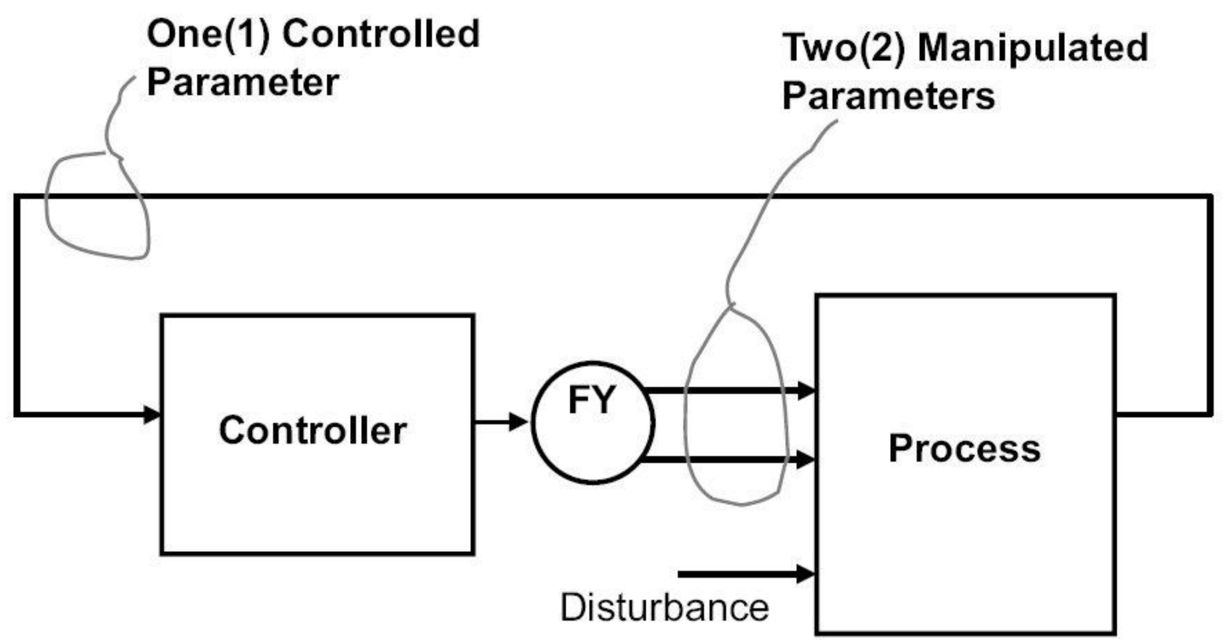


Figure 13-22. Control Using Two Manipulated Parameters

Three methods Addressed:

- Split Range Control
- Valve Position Control
- Ratio Control

Split Range Control Implementation

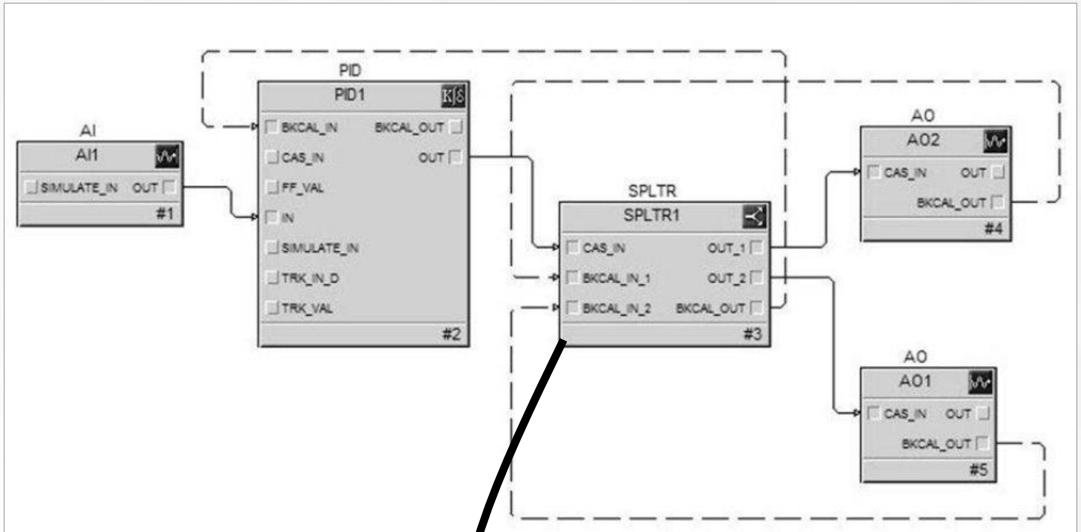


Figure 13-29. Split-range Control Implementation

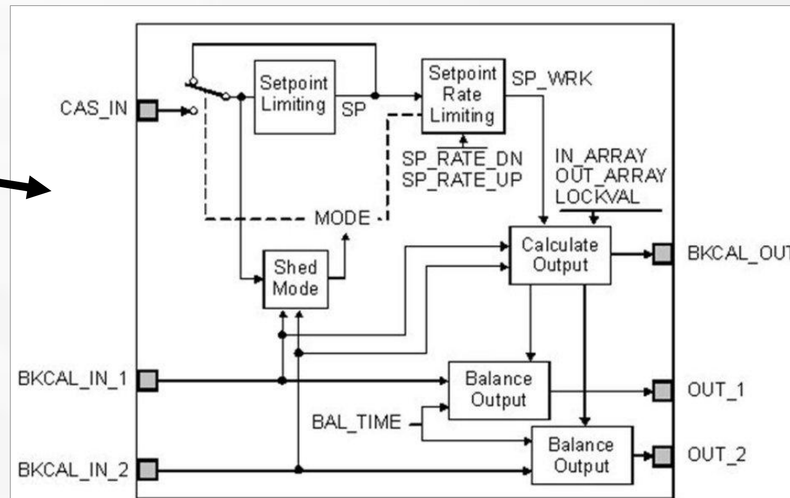


Figure 13-30. Splitter Block Calculation

Split Range Setup

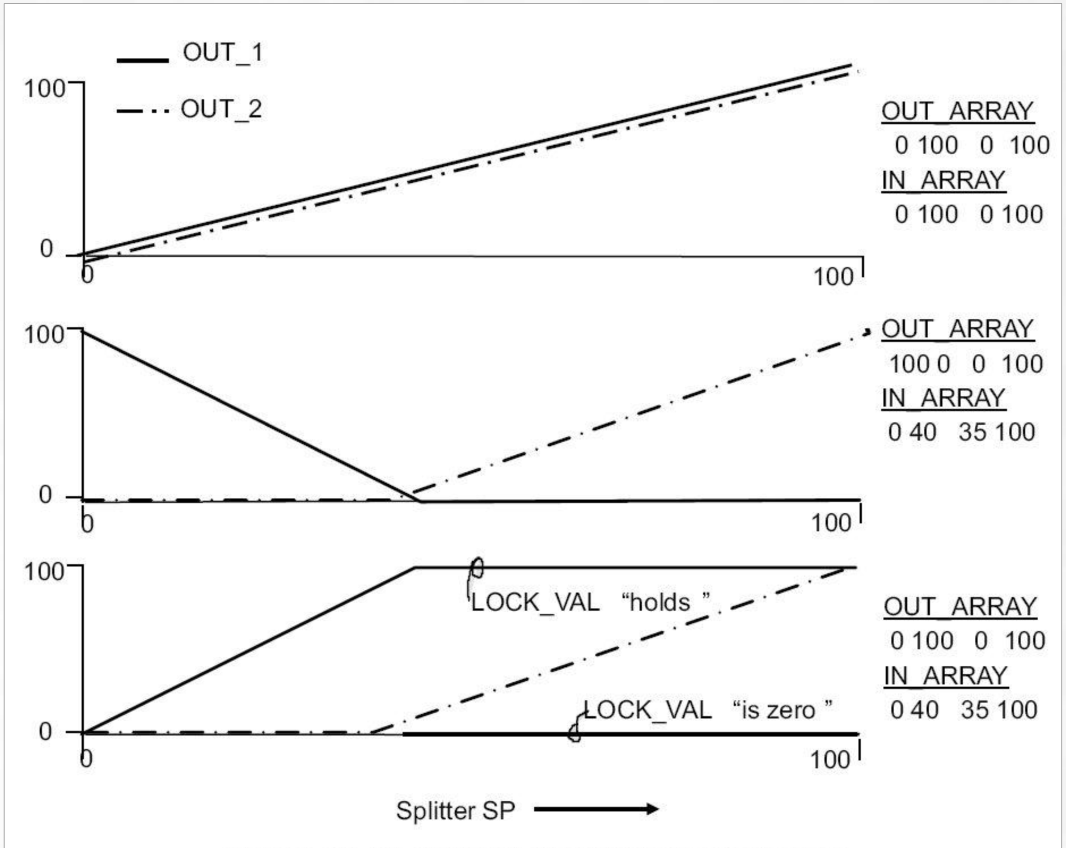


Figure 13-31. Splitter Block Characterization

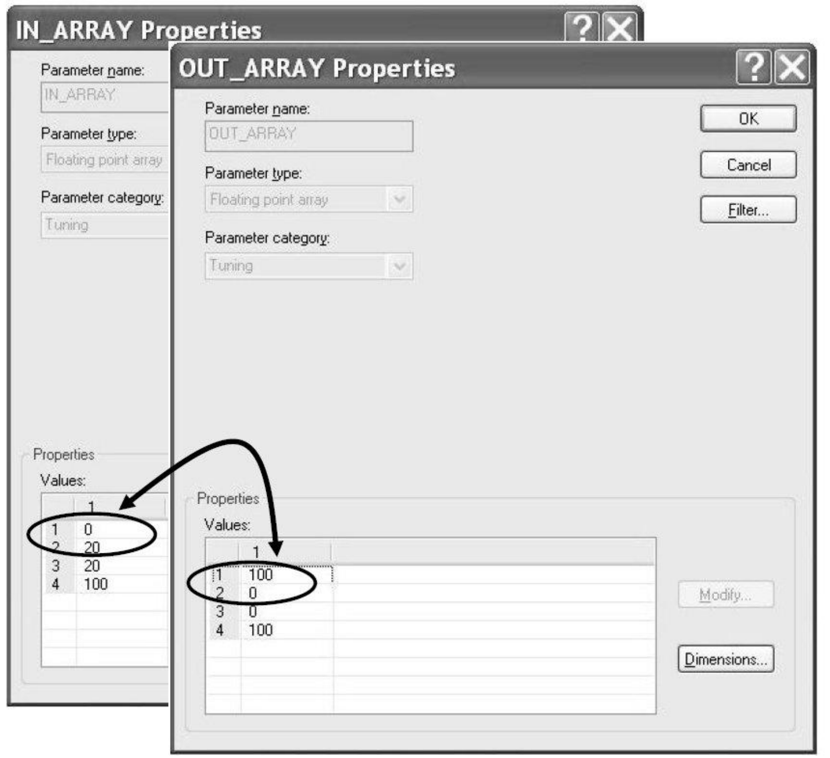


Figure 13-32. Configuring the IN_ARRAY and OUT_ARRAY

Example – Split Range Control

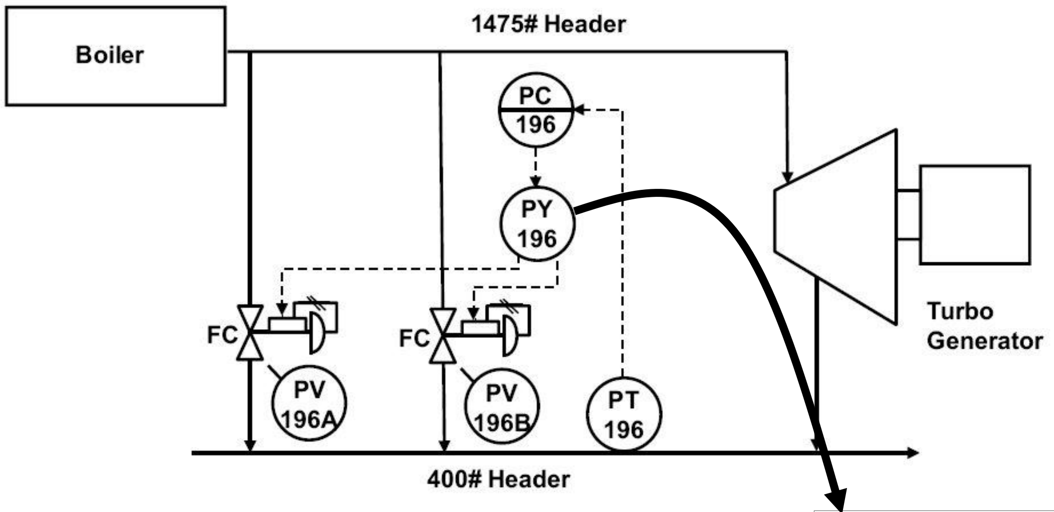


Figure 13-24. Steam Header Example

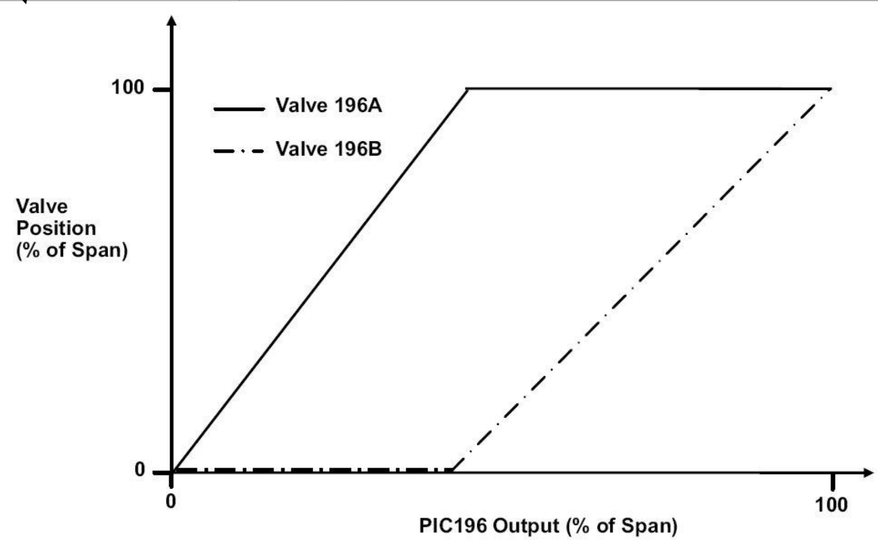


Figure 13-25. Split-range Output (FY196)

Workshop – Split Range Control

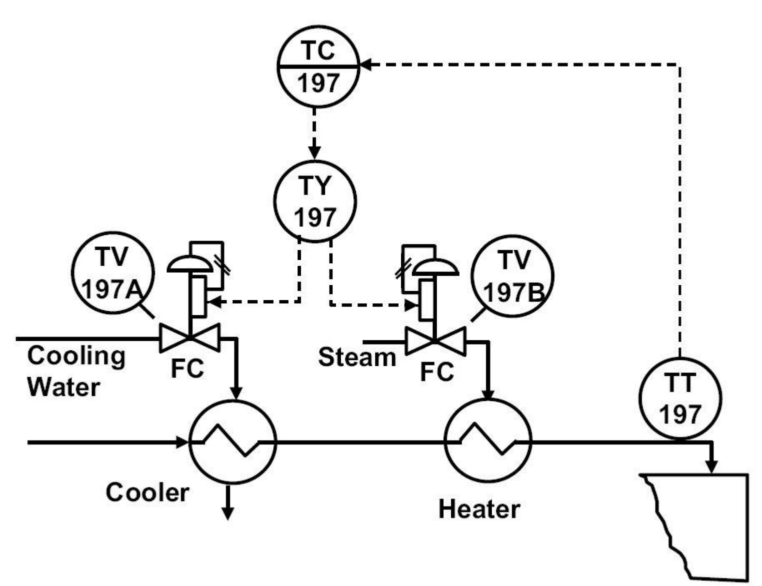


Figure 13-35. Process for Split-range Control Workshop

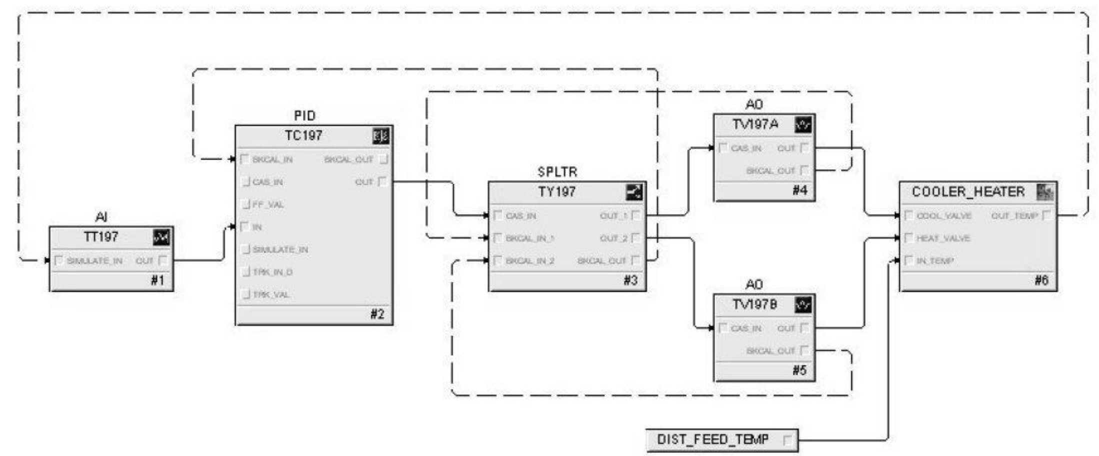


Figure 13-36. Split-range Control Workshop Module

Valve Position Control

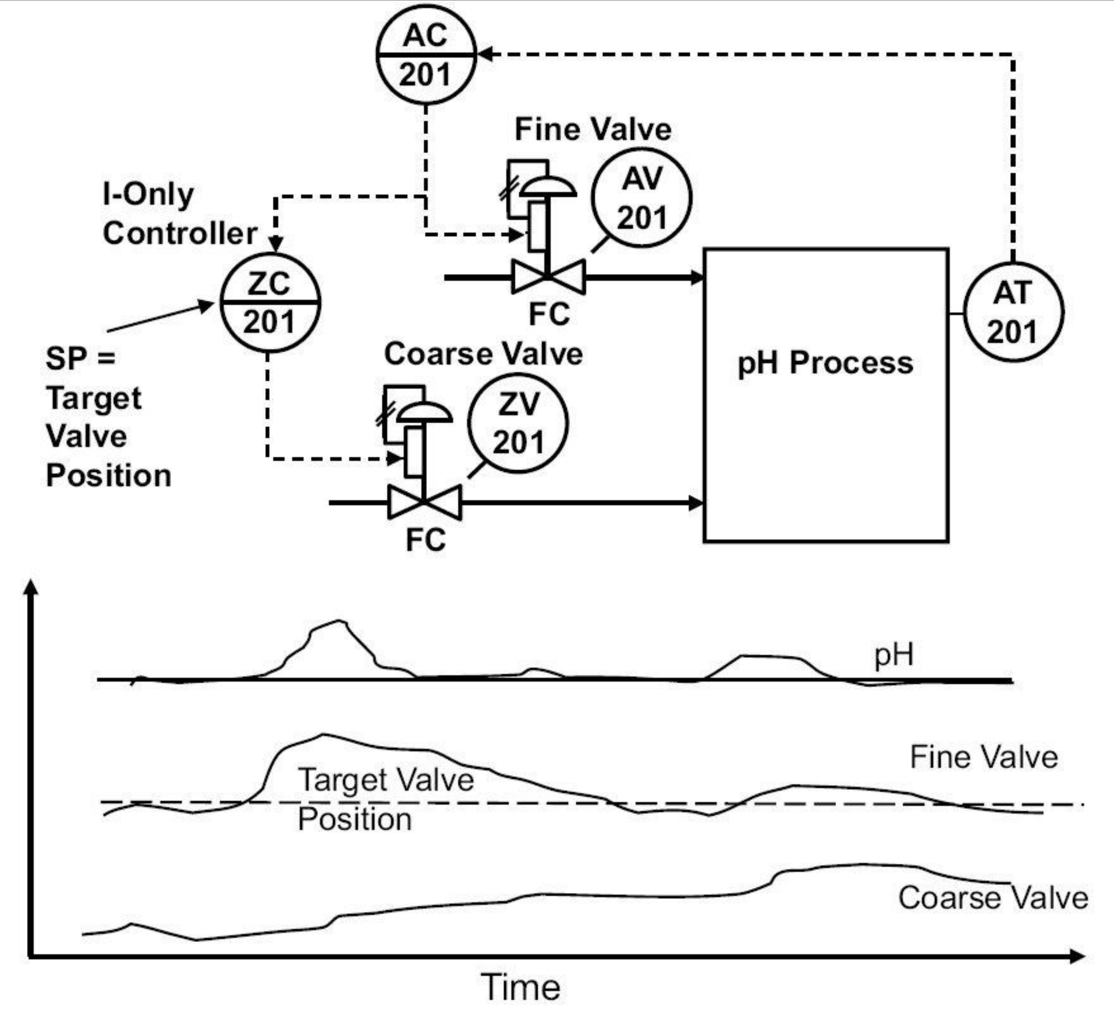


Figure 13-37. Valve Position Control

Valve Position Control Implementation

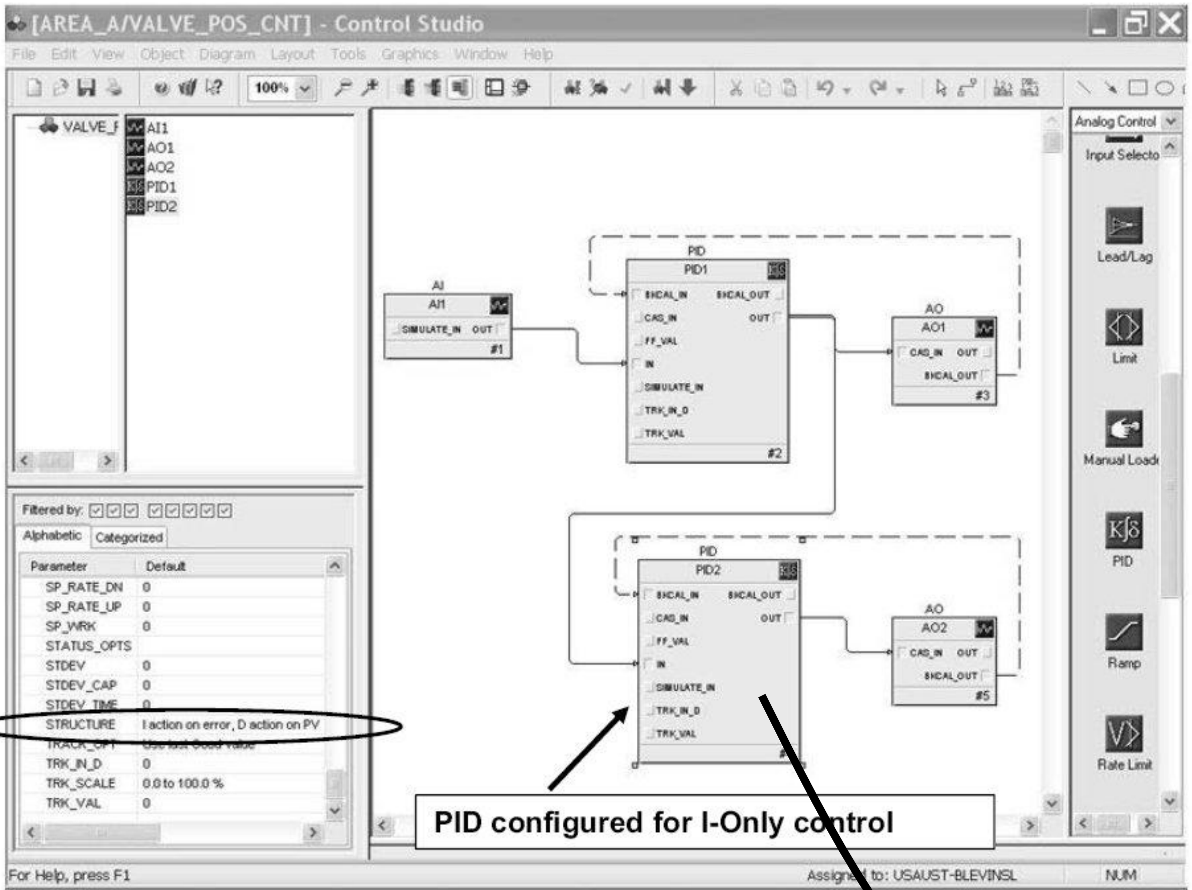


Figure 13-40. Valve Position Control

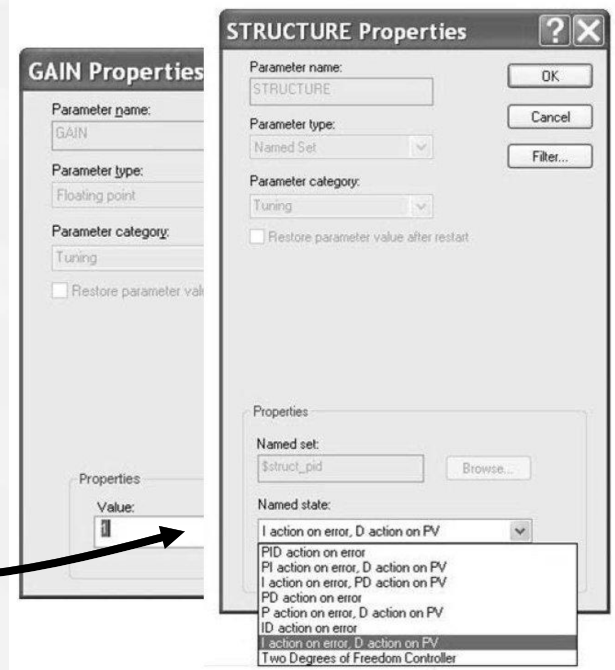


Figure 13-41. Configuring PID for I-only Control

Example – Valve Position Control

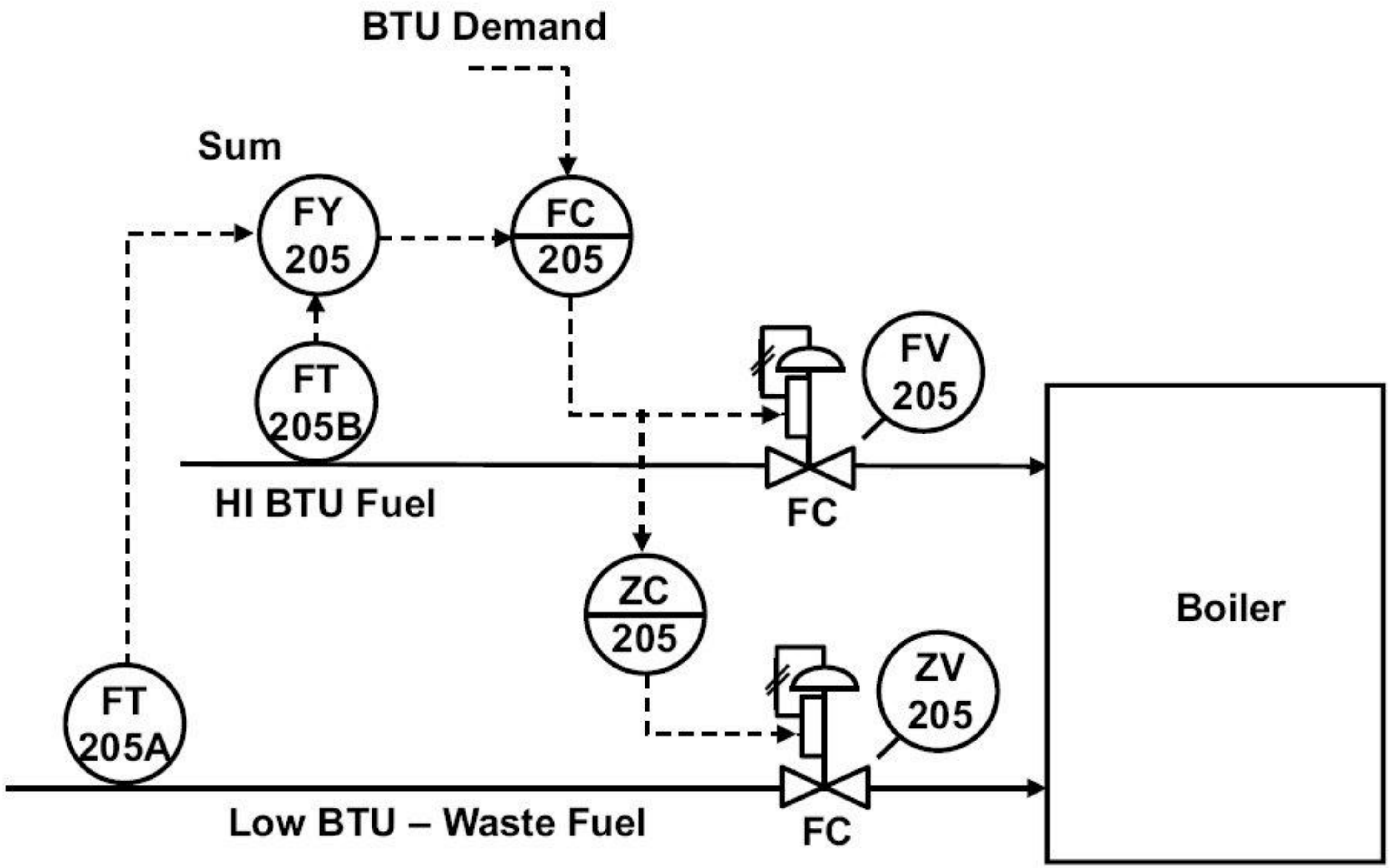


Figure 13-38. Example – Boiler BTU Demand

Workshop – Valve Position Control

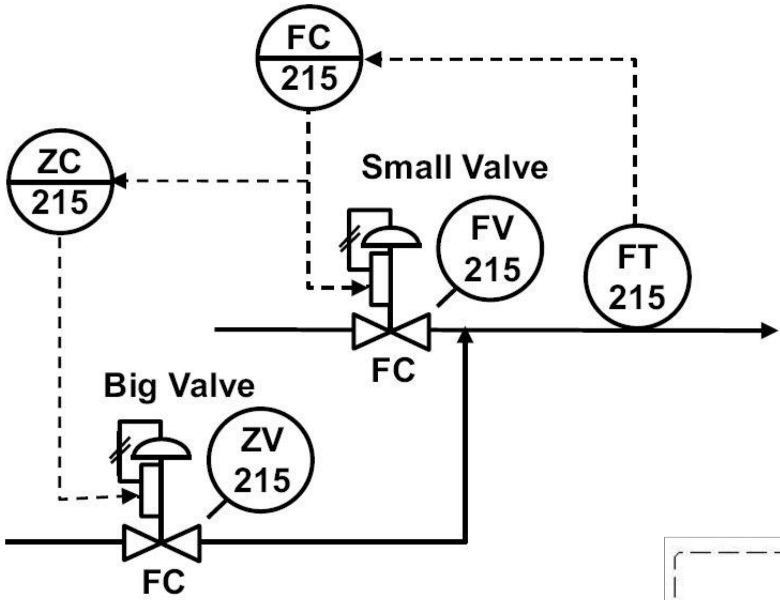


Figure 13-42. Process for Valve Position Control W

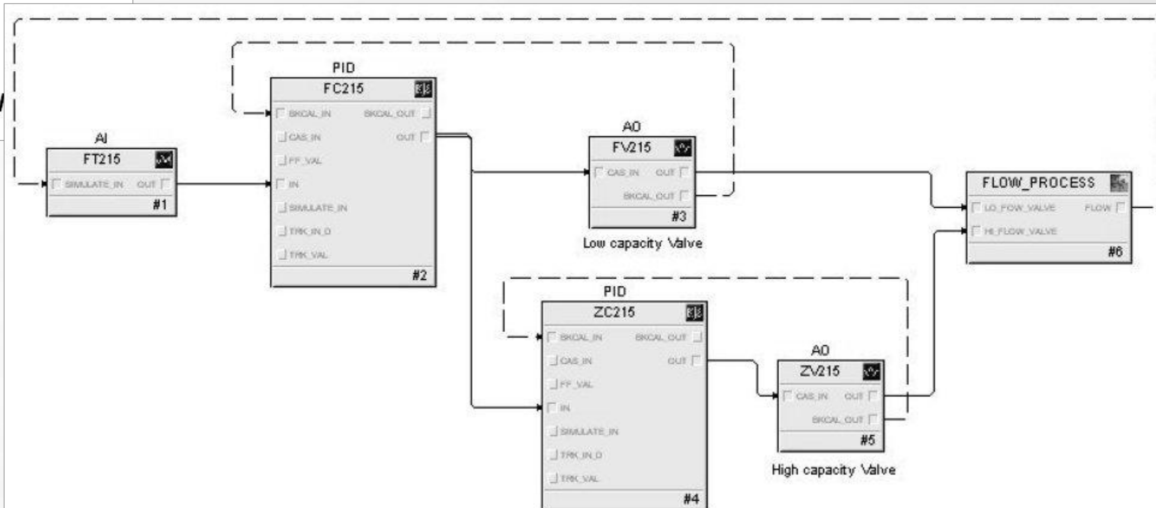


Figure 13-43. Valve Position Control Workshop Module

Ratio Control

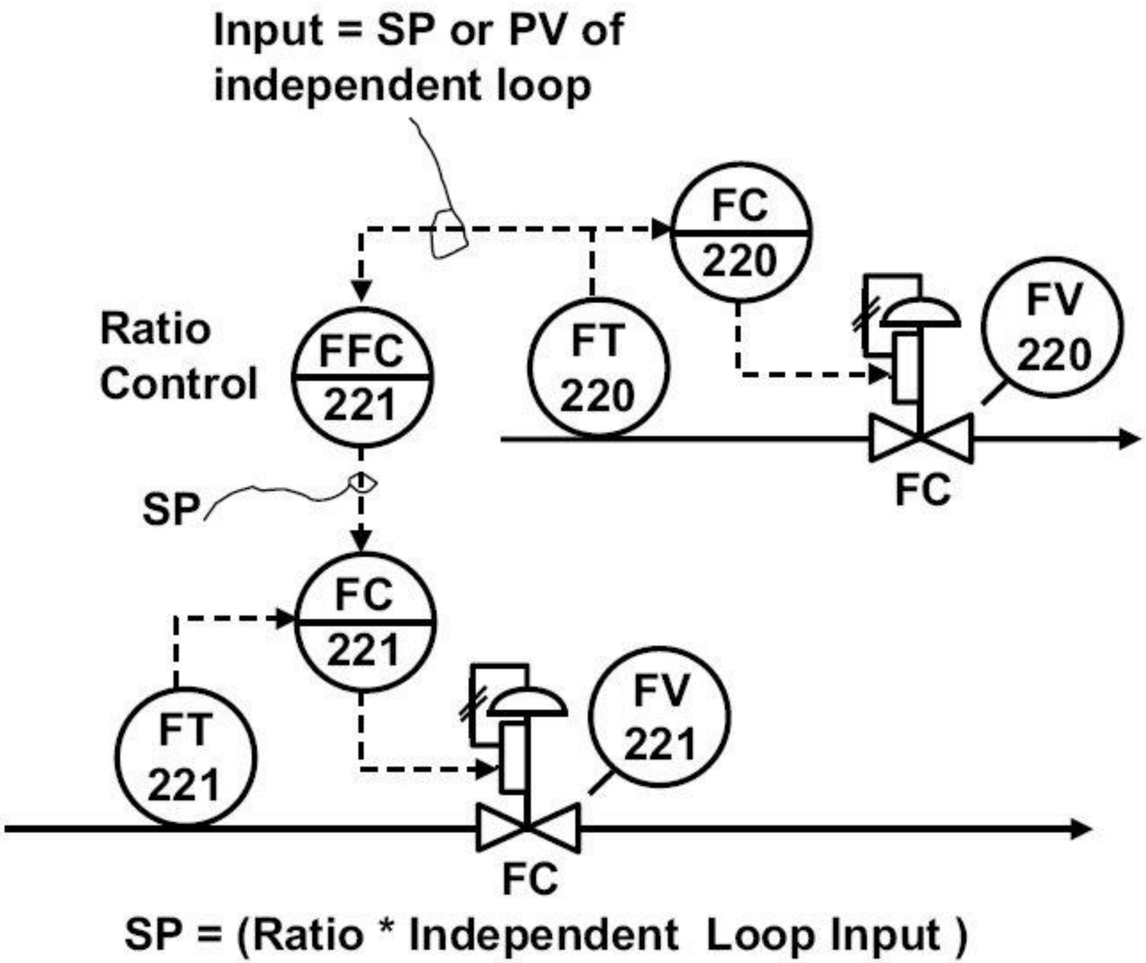


Figure 13-44. Basis – Ratio Control

Ratio Control Implementation

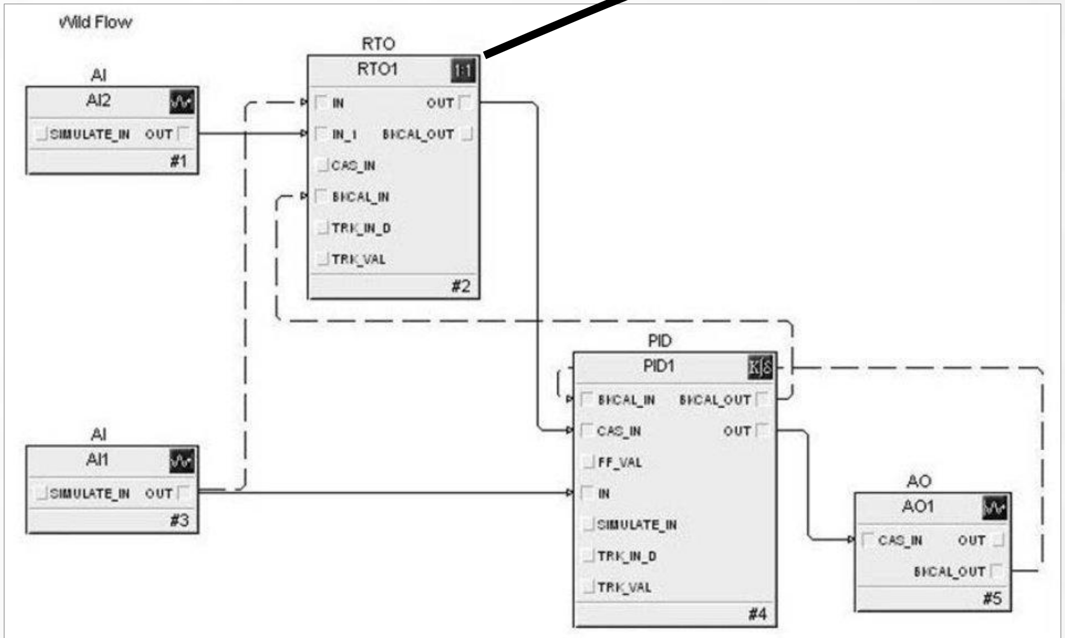


Figure 13-48. Ratio Control

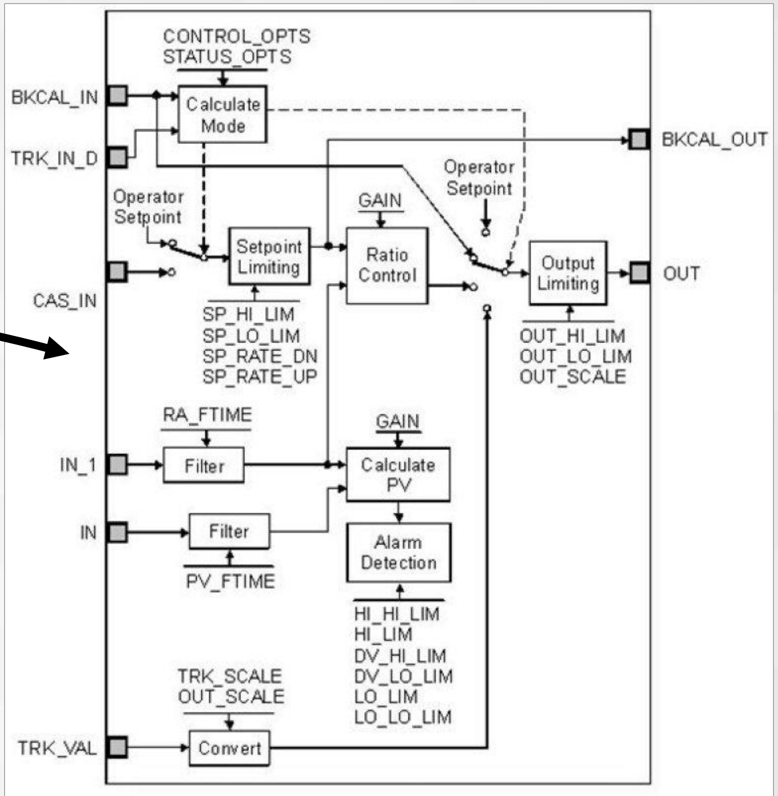


Figure 13-49. RATIO Block Function

Example – Ratio Control

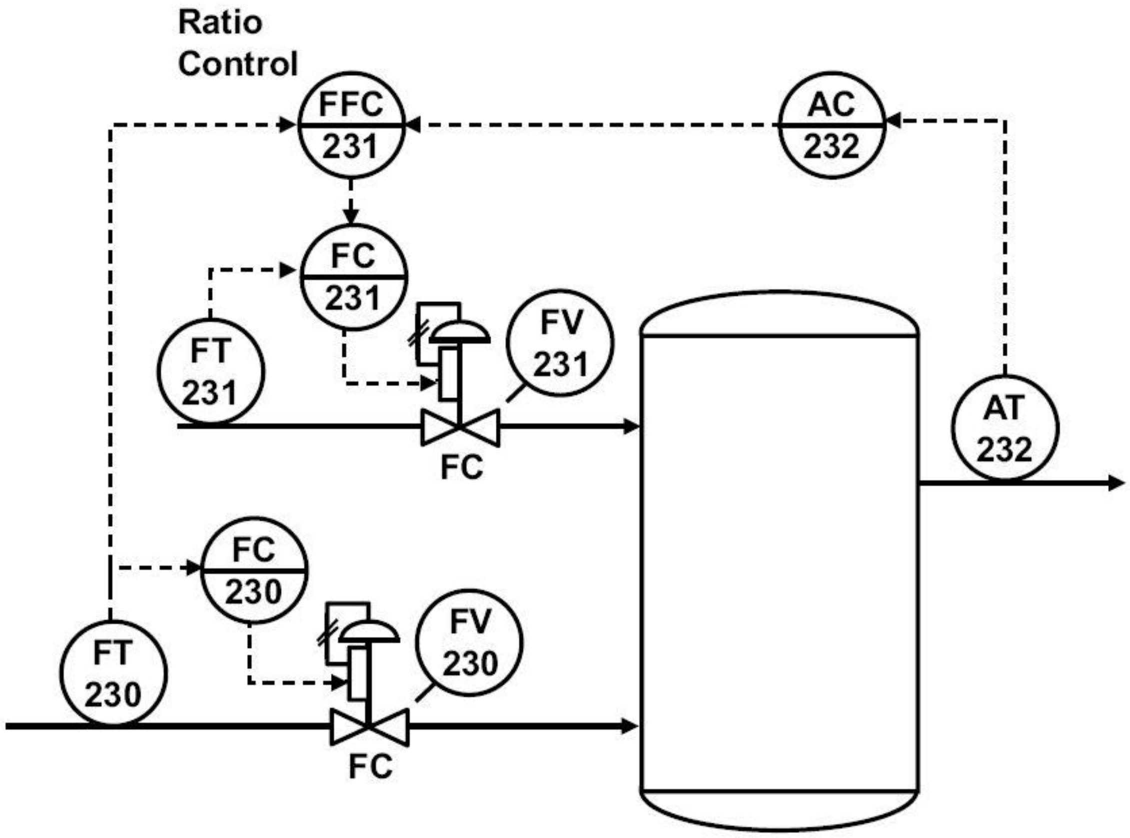


Figure 13-46. Automatic Ratio Adjustment

- In this example the ratio setpoint is adjusted using feedback control based on a downstream analysis of the blended material

Workshop – Ratio Control

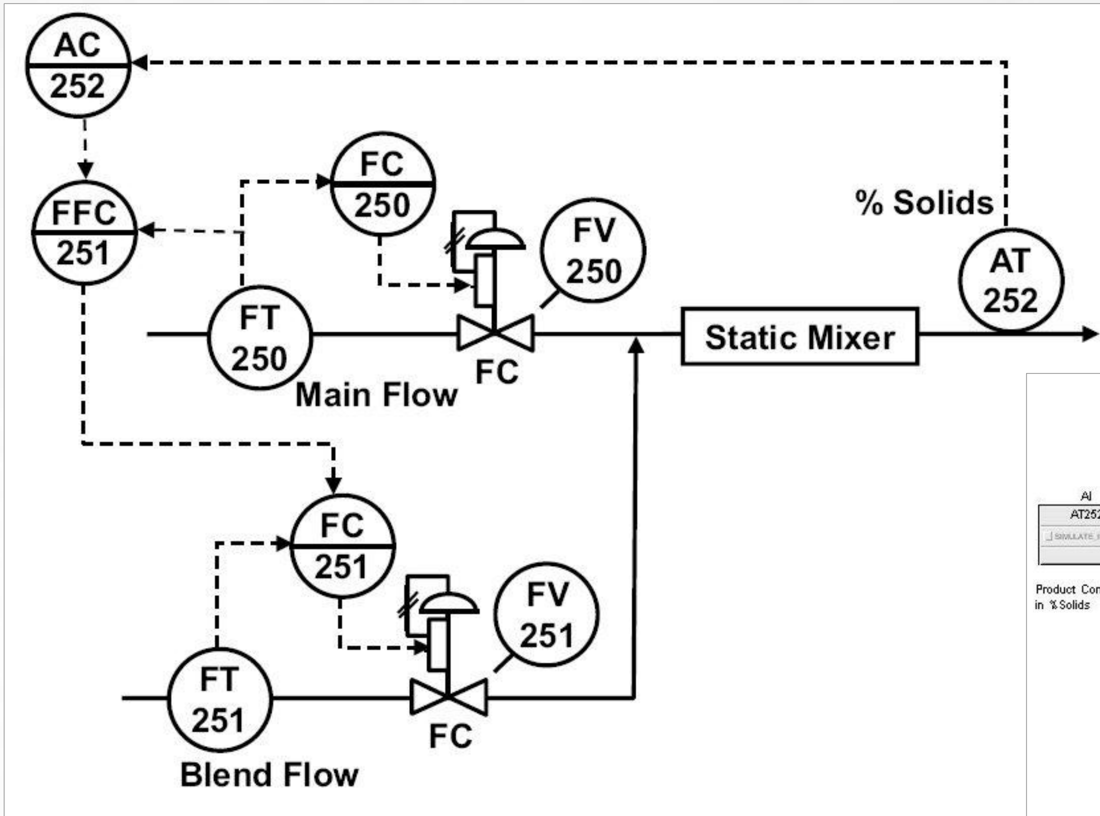


Figure 13-50. Process for Ratio Control Workshop

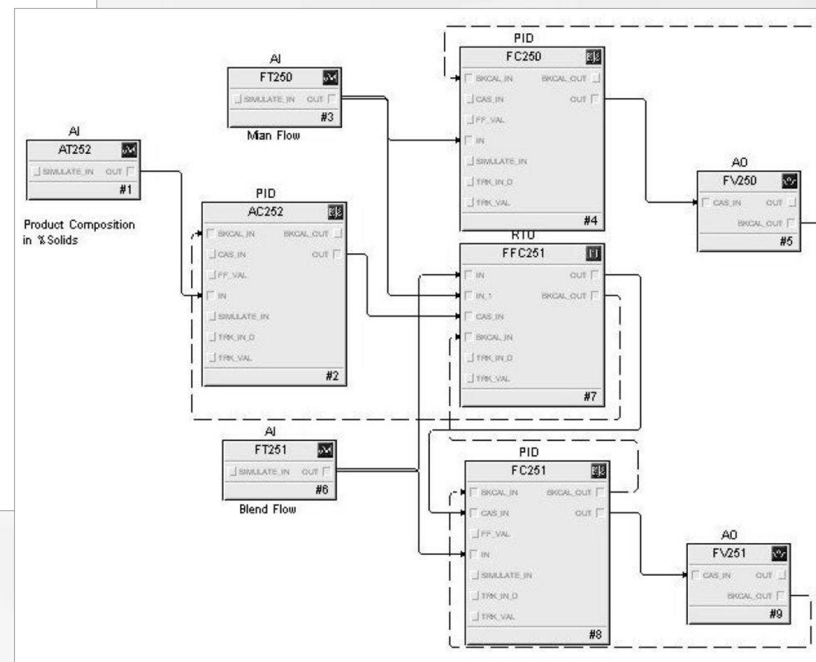


Figure 13-51. Ratio Control Workshop Module

Process Simulation for Ratio Workshop

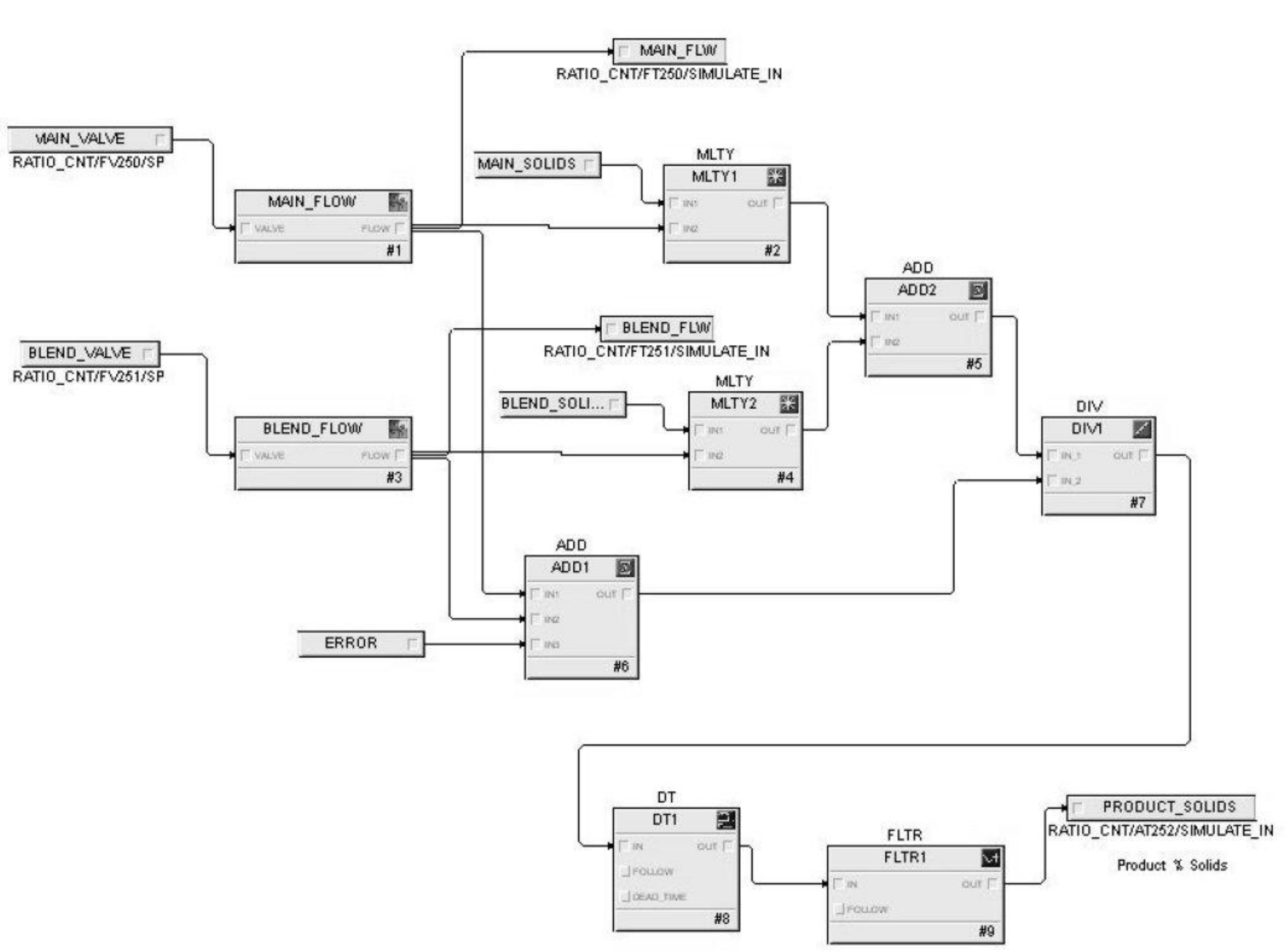


Figure 13-52. Process Simulation for Ratio Control Workshop

Model Predictive Control (MPC)

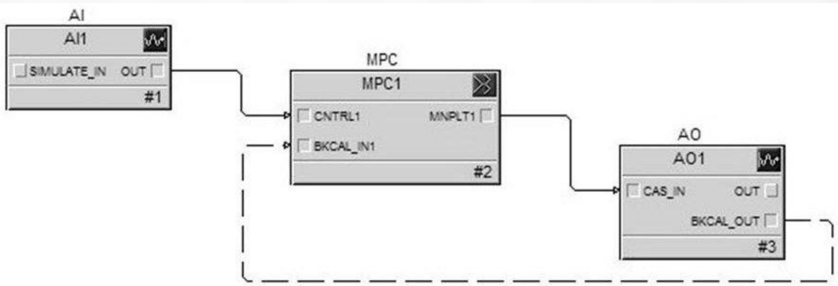


Figure 14-2. MPC Configuration for Single Loop

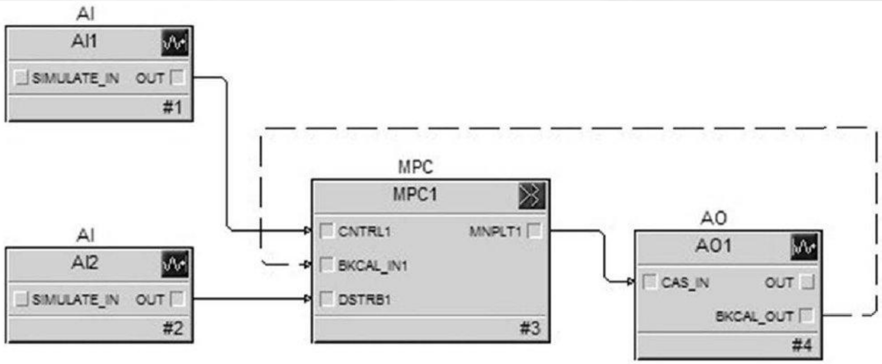


Figure 14-10. Example MPC Implementation for One Measured Disturbance Input

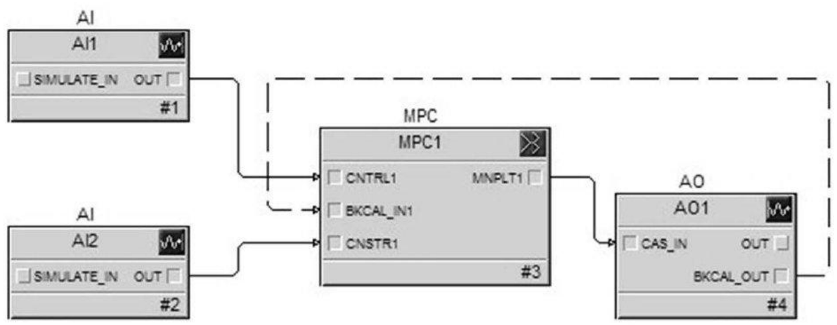


Figure 14-12. MPC Constraint Control

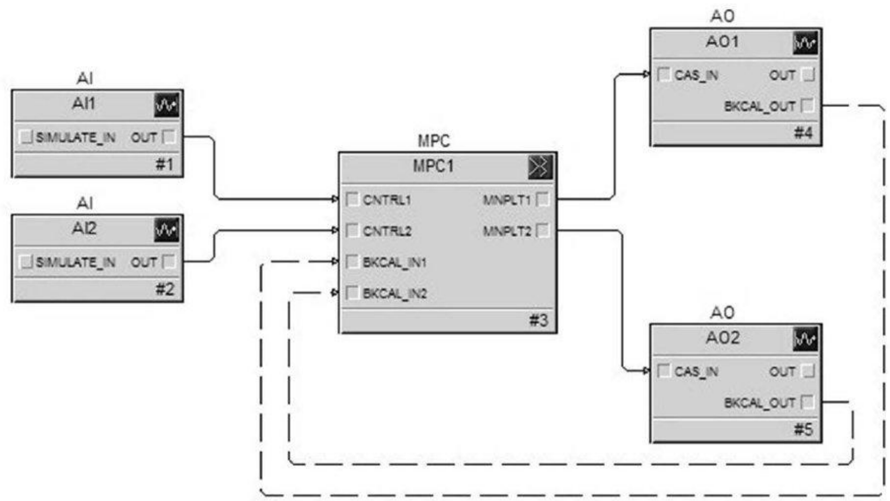


Figure 14-14. MPC Implementation for Interactive Process

MPC May be Layered on Existing Control

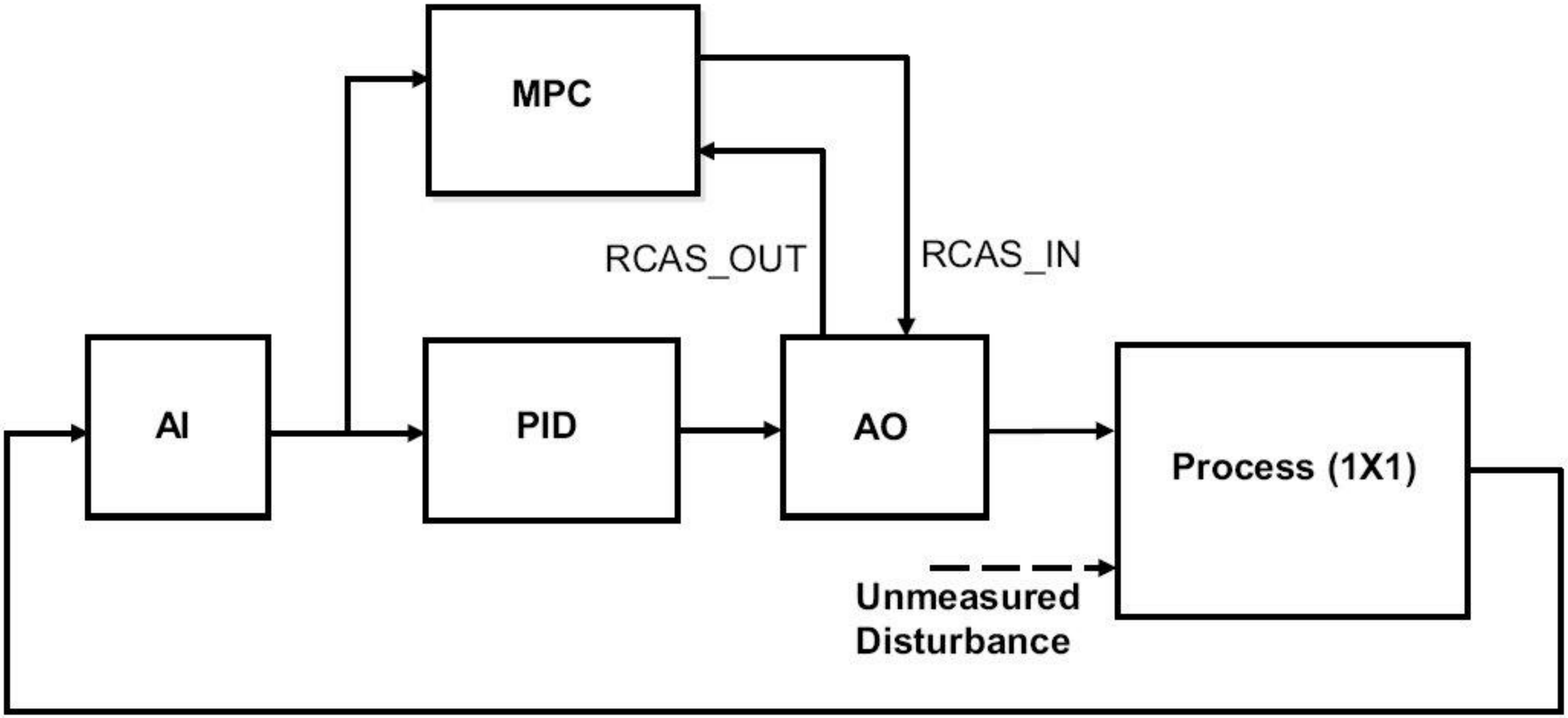


Figure 14-16. Layering MPC onto an Existing Strategy

Workshop – Model Predict Control

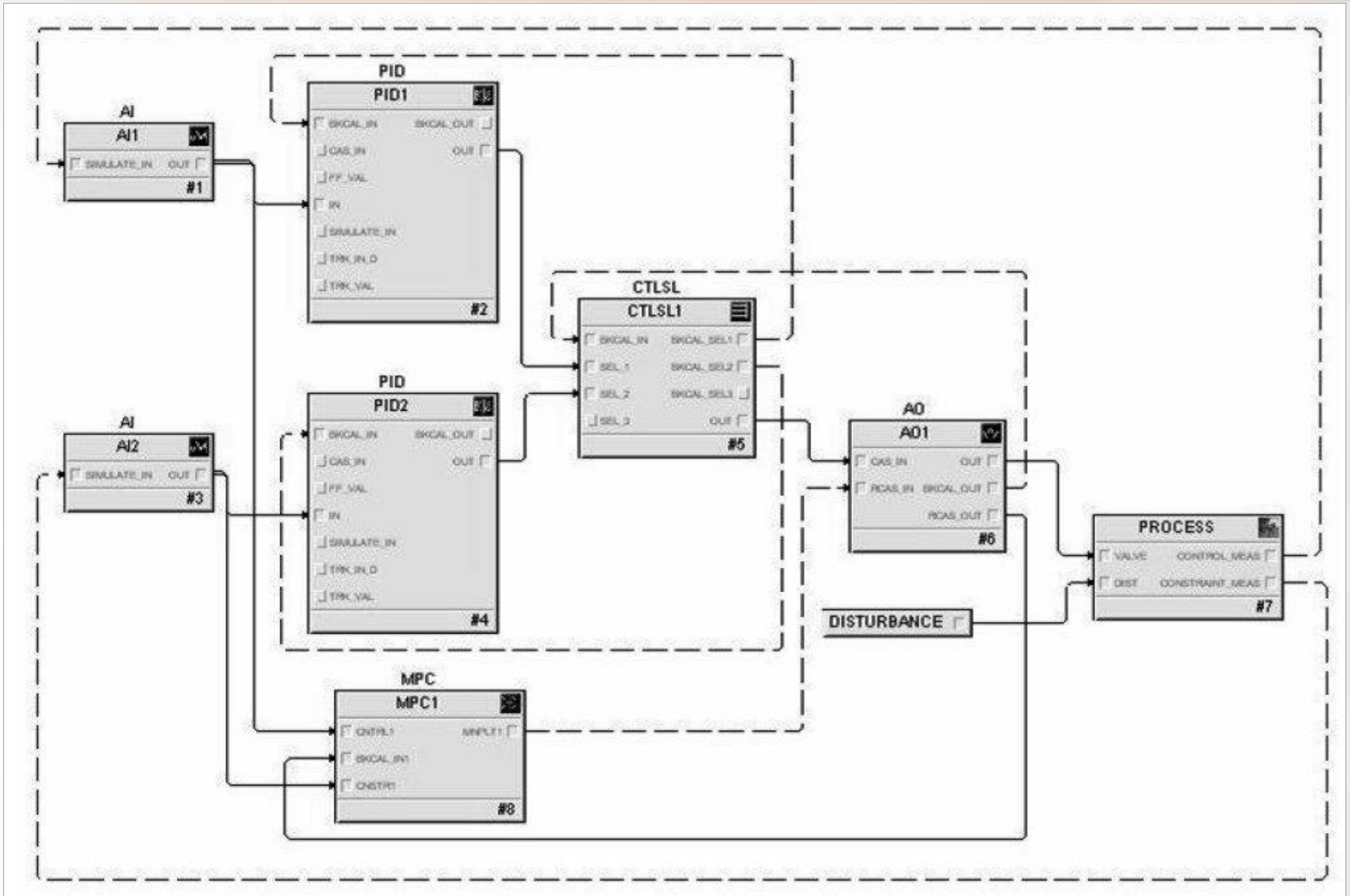


Figure 14-19. Module MPC Workshop – PID versus MPC

Process Modeling

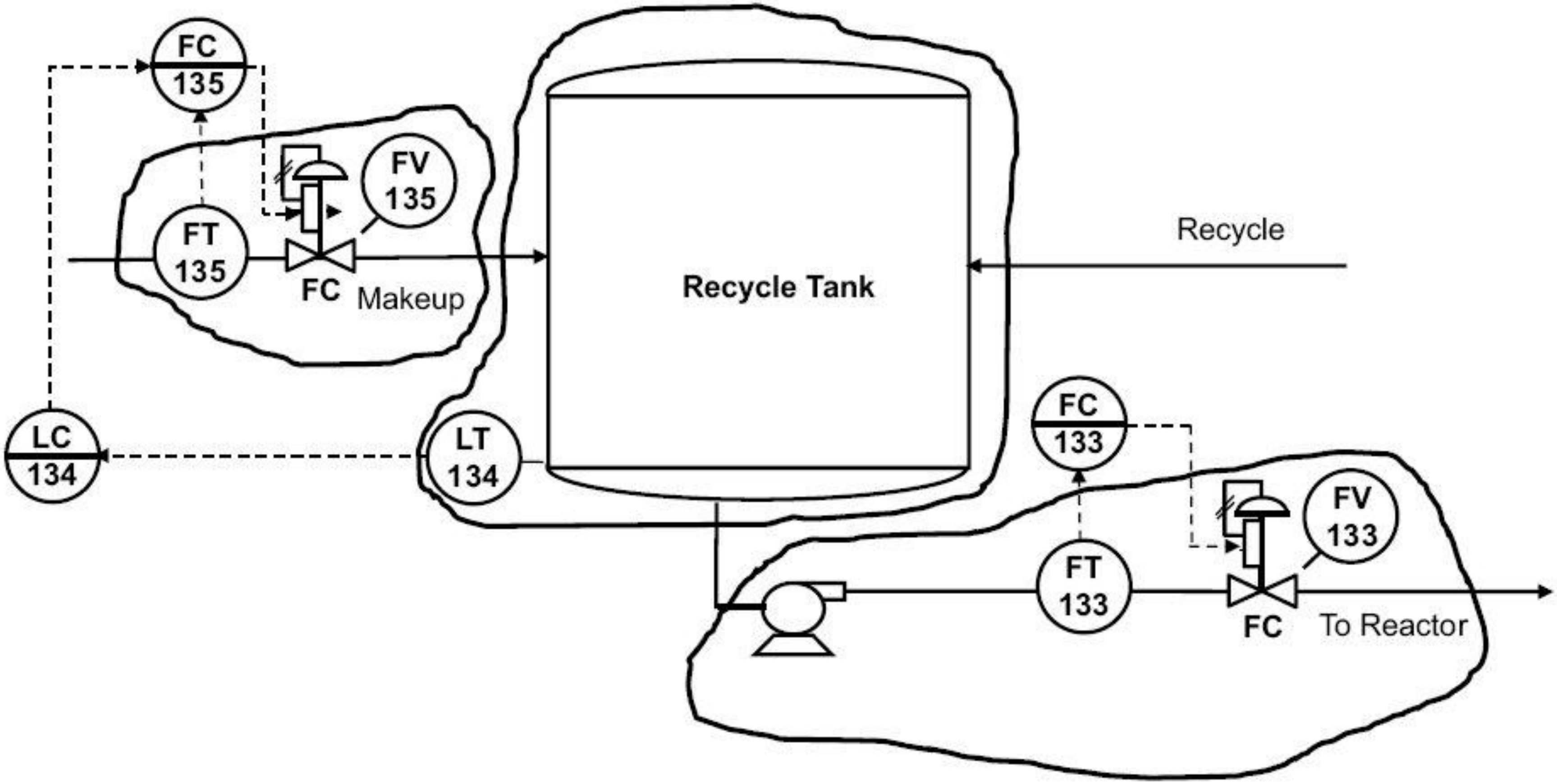


Figure 15-4. Breaking P&ID into Small Processes

Simulation Diagram

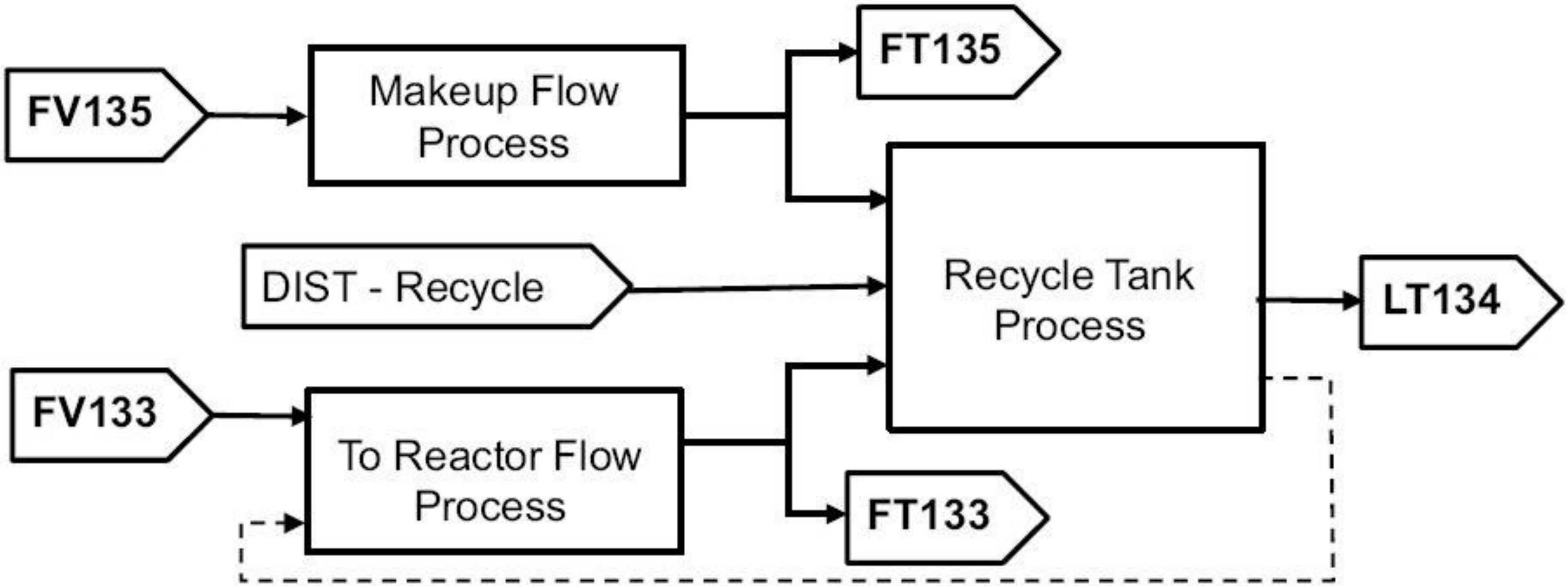


Figure 15-5. Diagram Showing Processes for Recycle Tank

Simulation Module

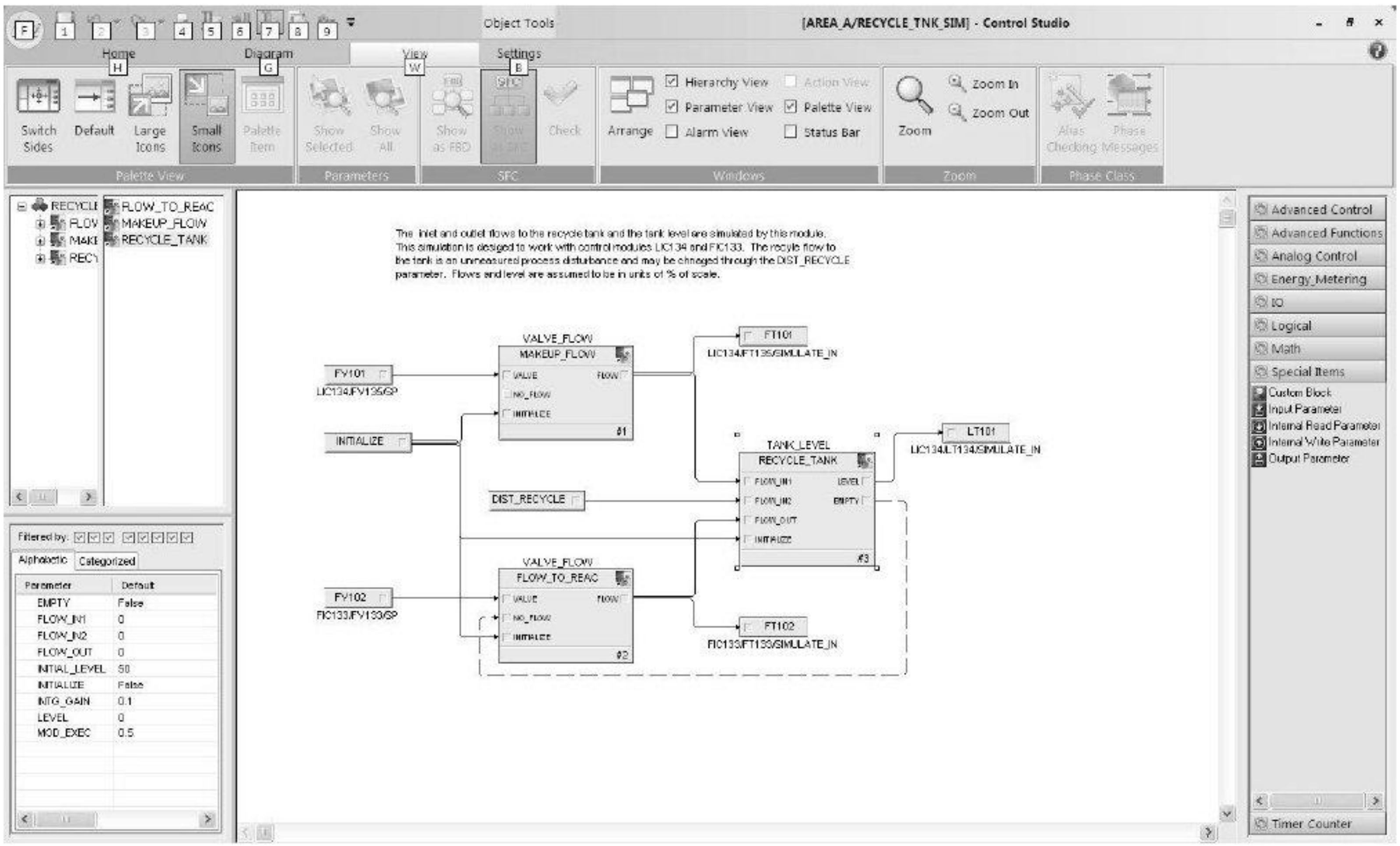


Figure 15-6. Simulation Module

Example – Process Simulation Composite

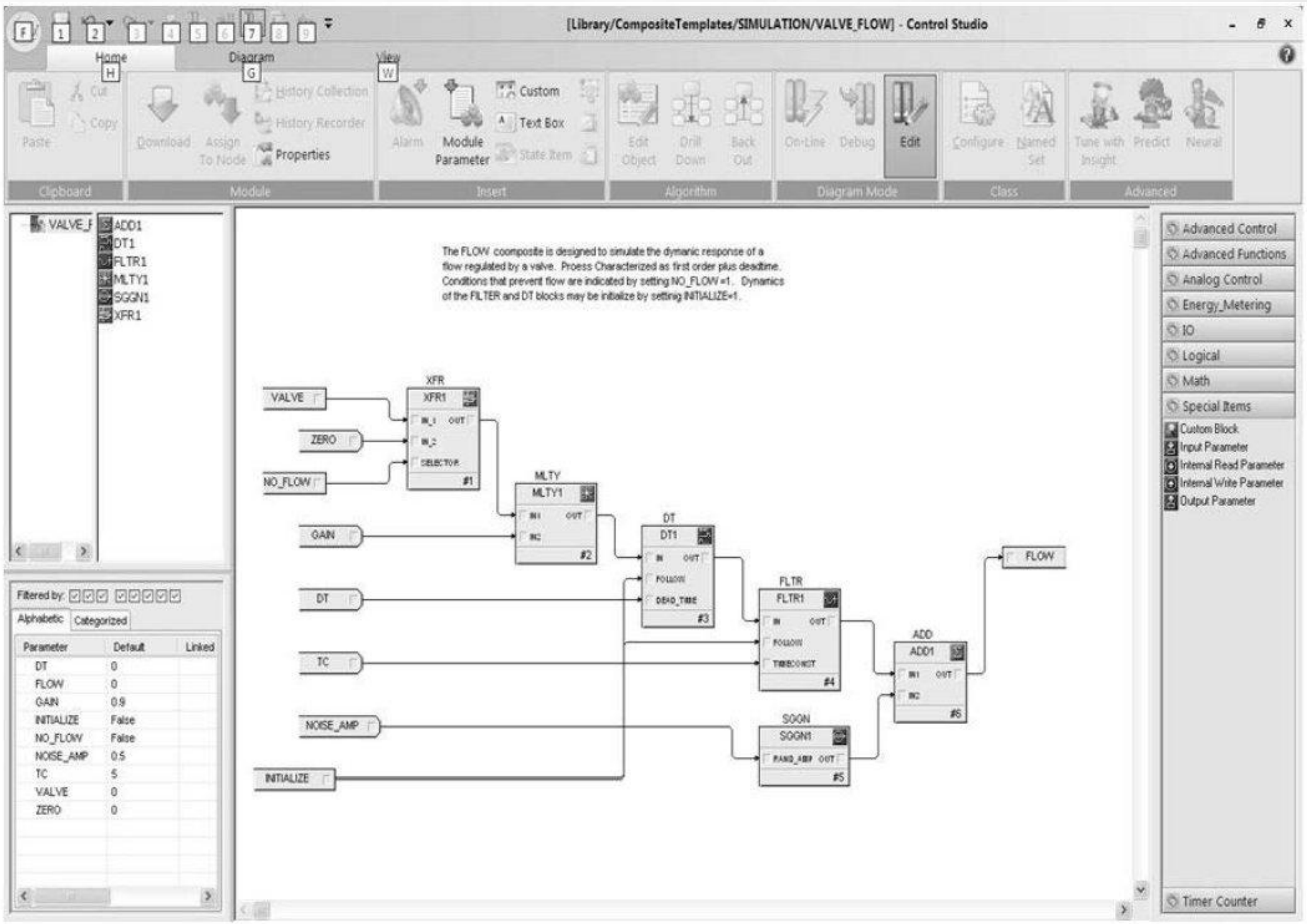


Figure 15-9. FLOW_VALVE Composite

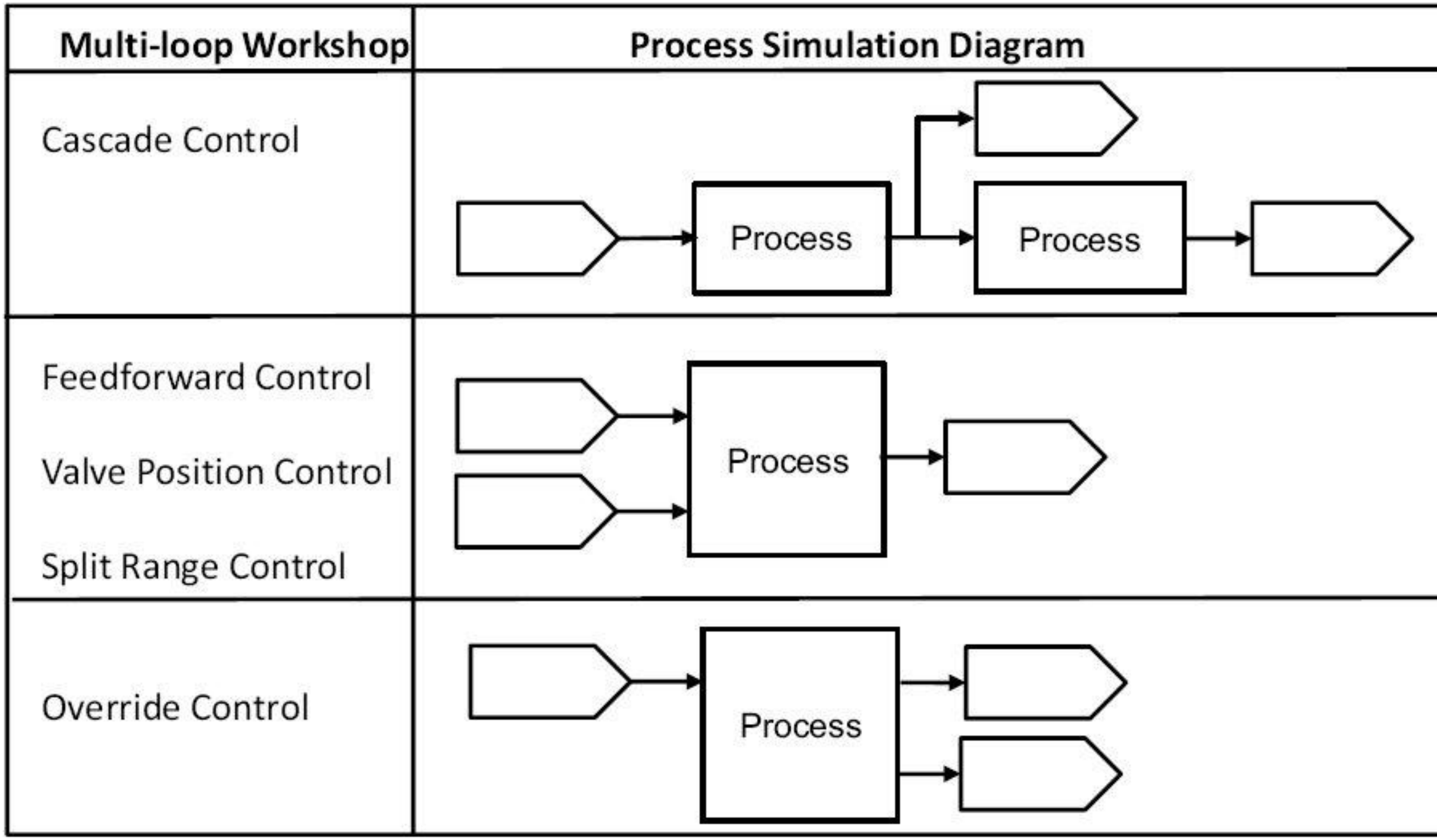


Figure 15-11. Simulation for Multi-loop Workshop

Workshop – Process Modeling

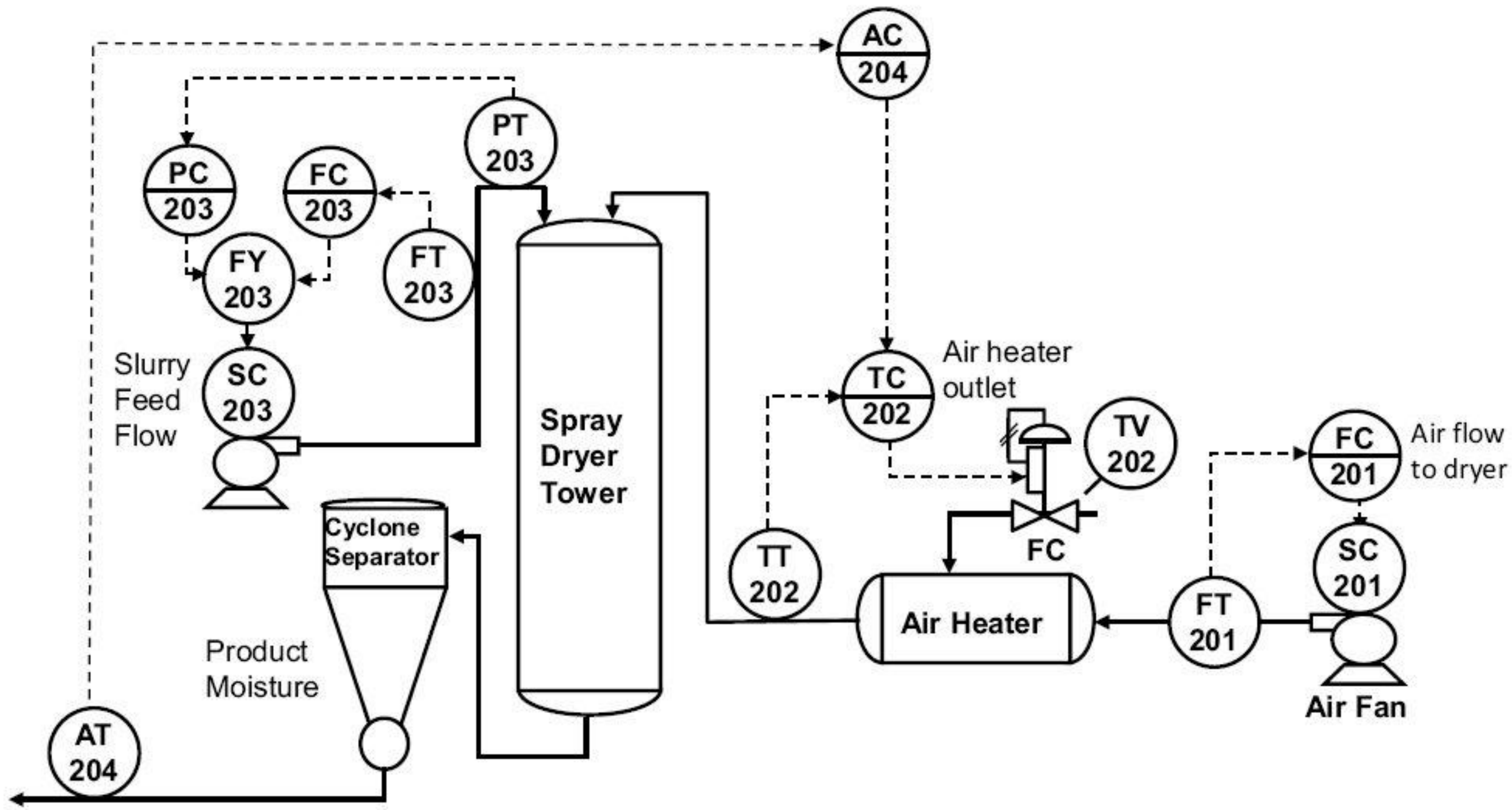


Figure 15-19. Spray Dryer Process

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Application – Boiler Drum Level

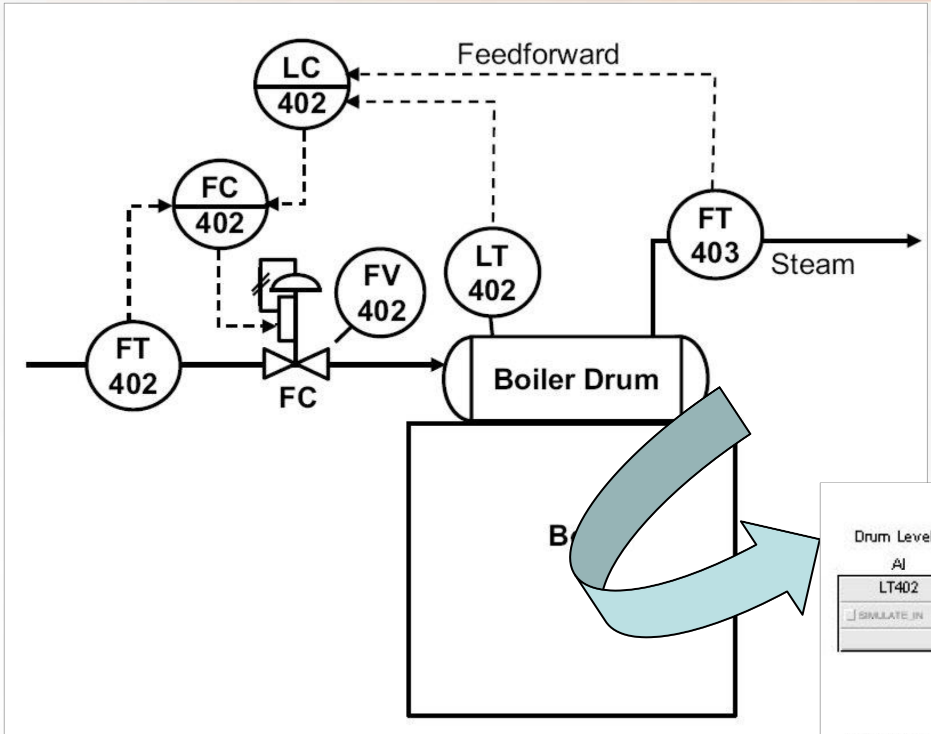

Figure 16-4. Three Element Drum Level Control

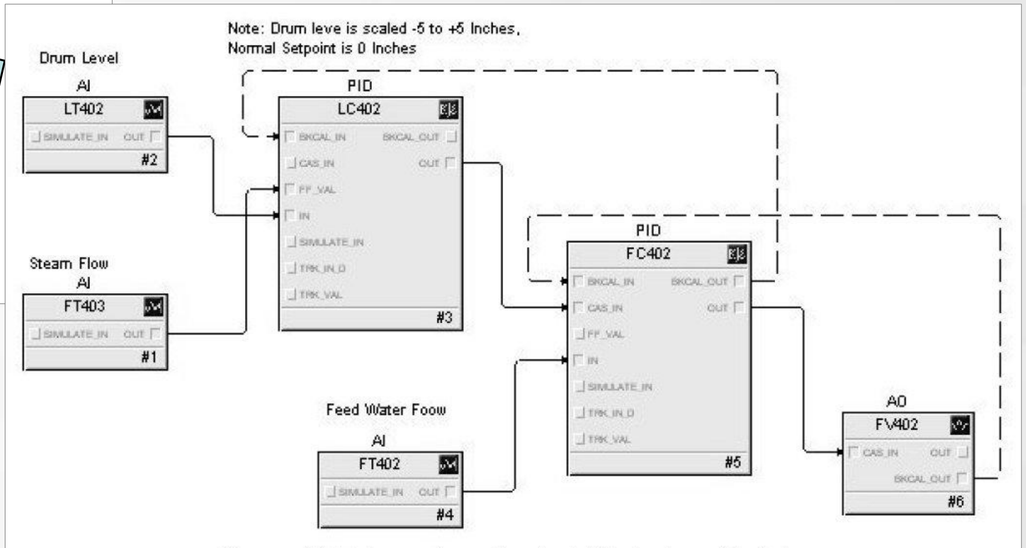

Figure 16-5. Inventory Control Workshop Module

Batch Reactor

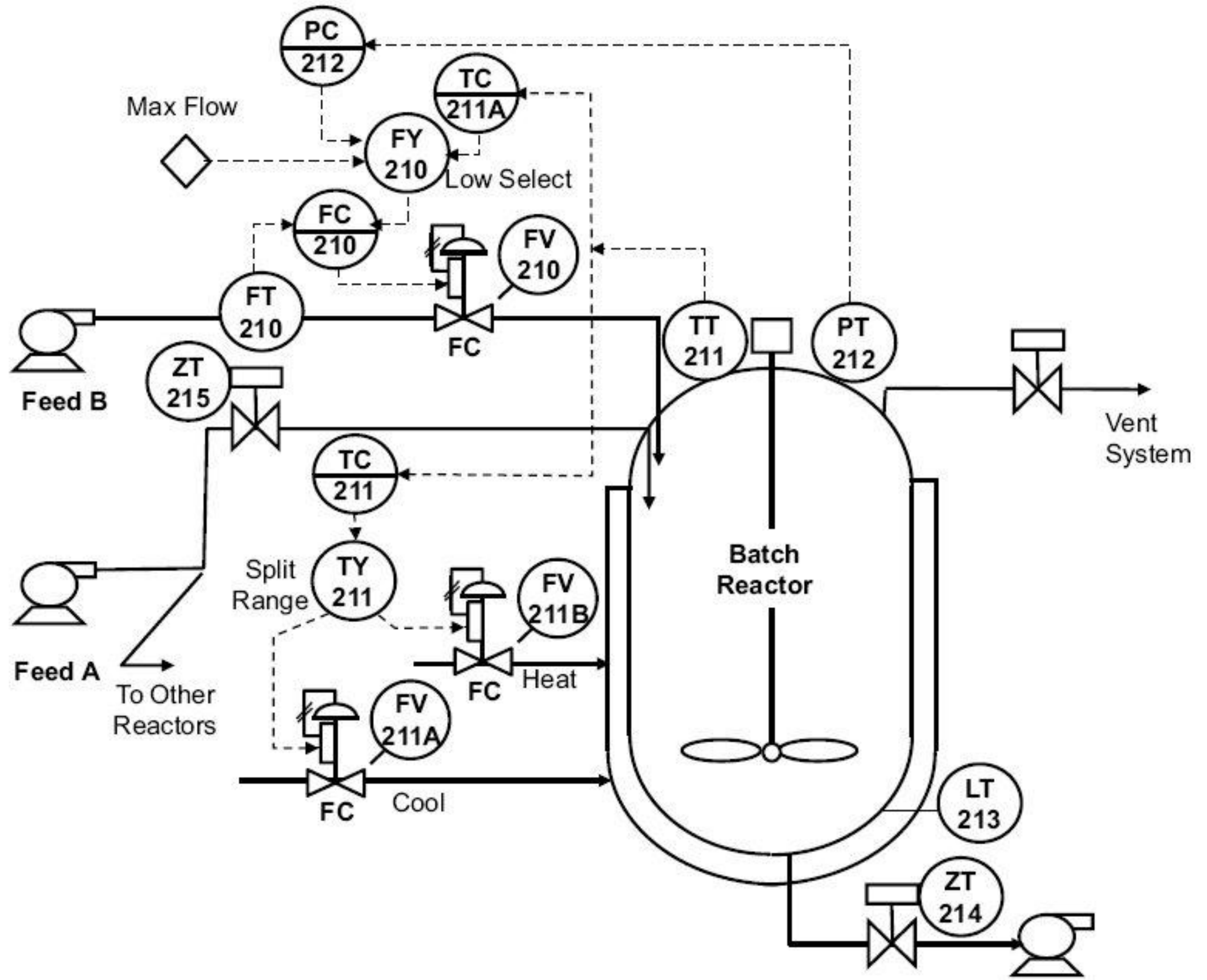

Figure 16-8. Batch Chemical Reactor Control

Batch Reactor- Processing

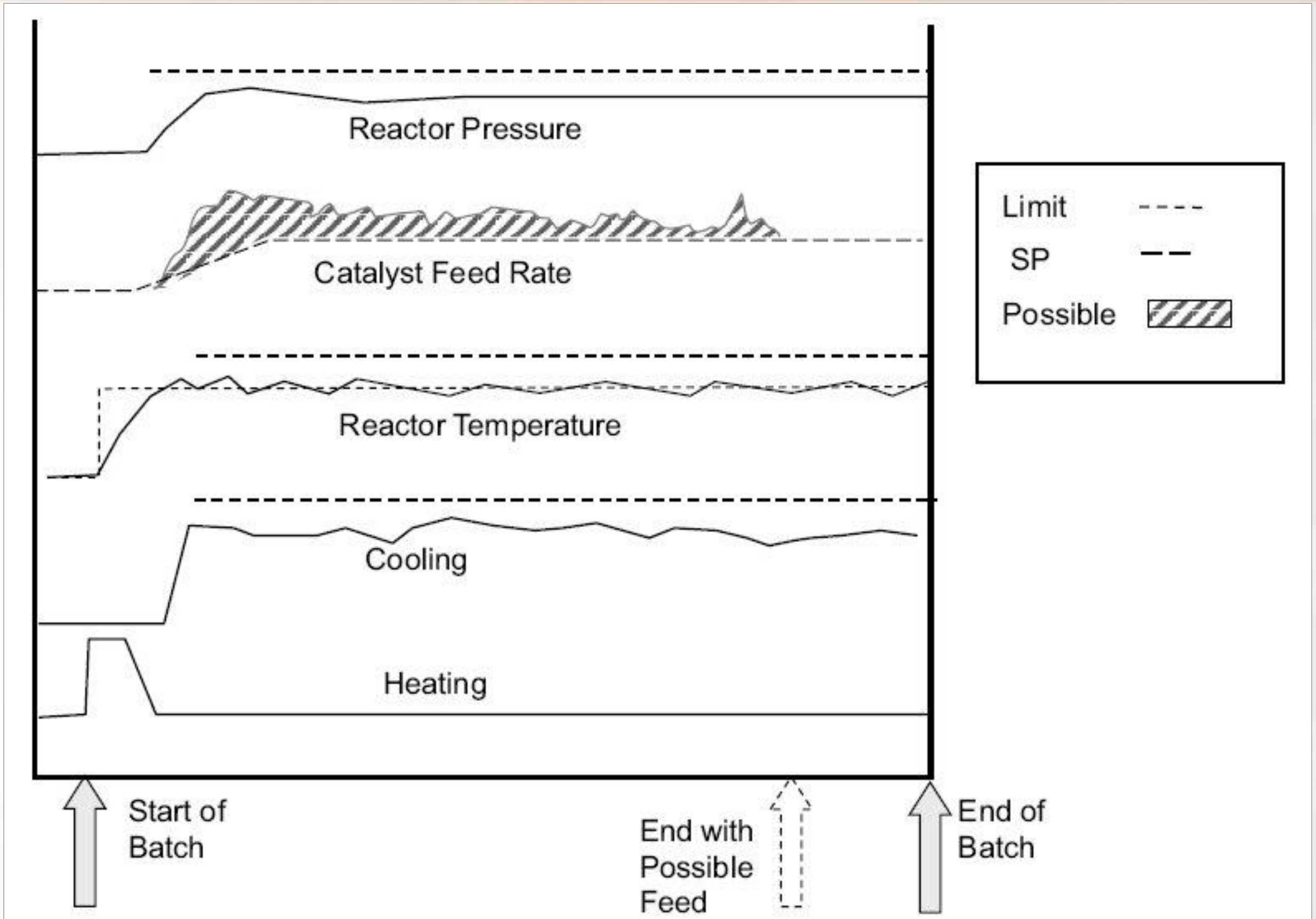

Figure 16-9. Batch Chemical Reactor Cycle

Batch Reactor - Control

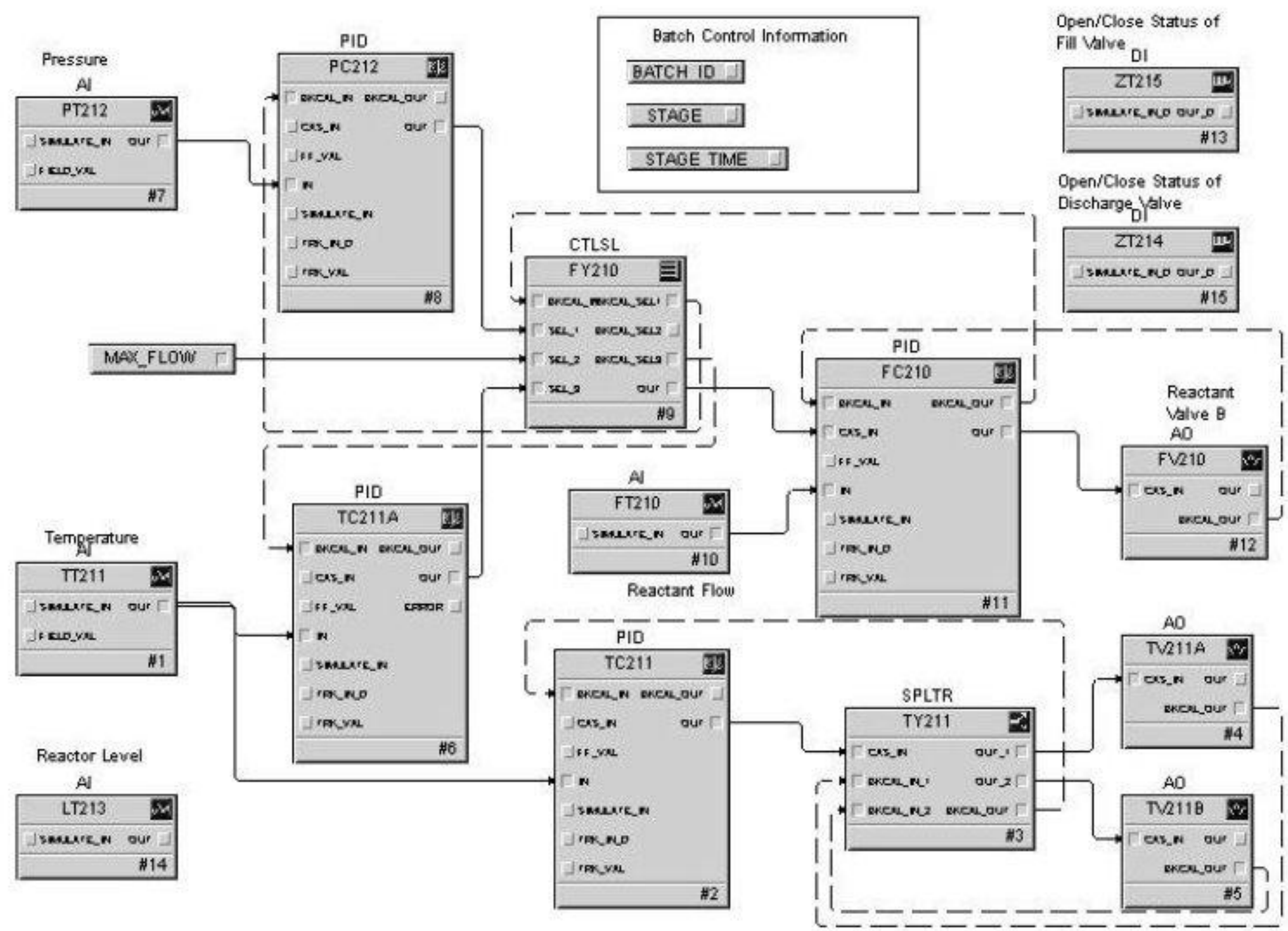

Figure 16-13. Batch Control Workshop Module

Continuous Reactor

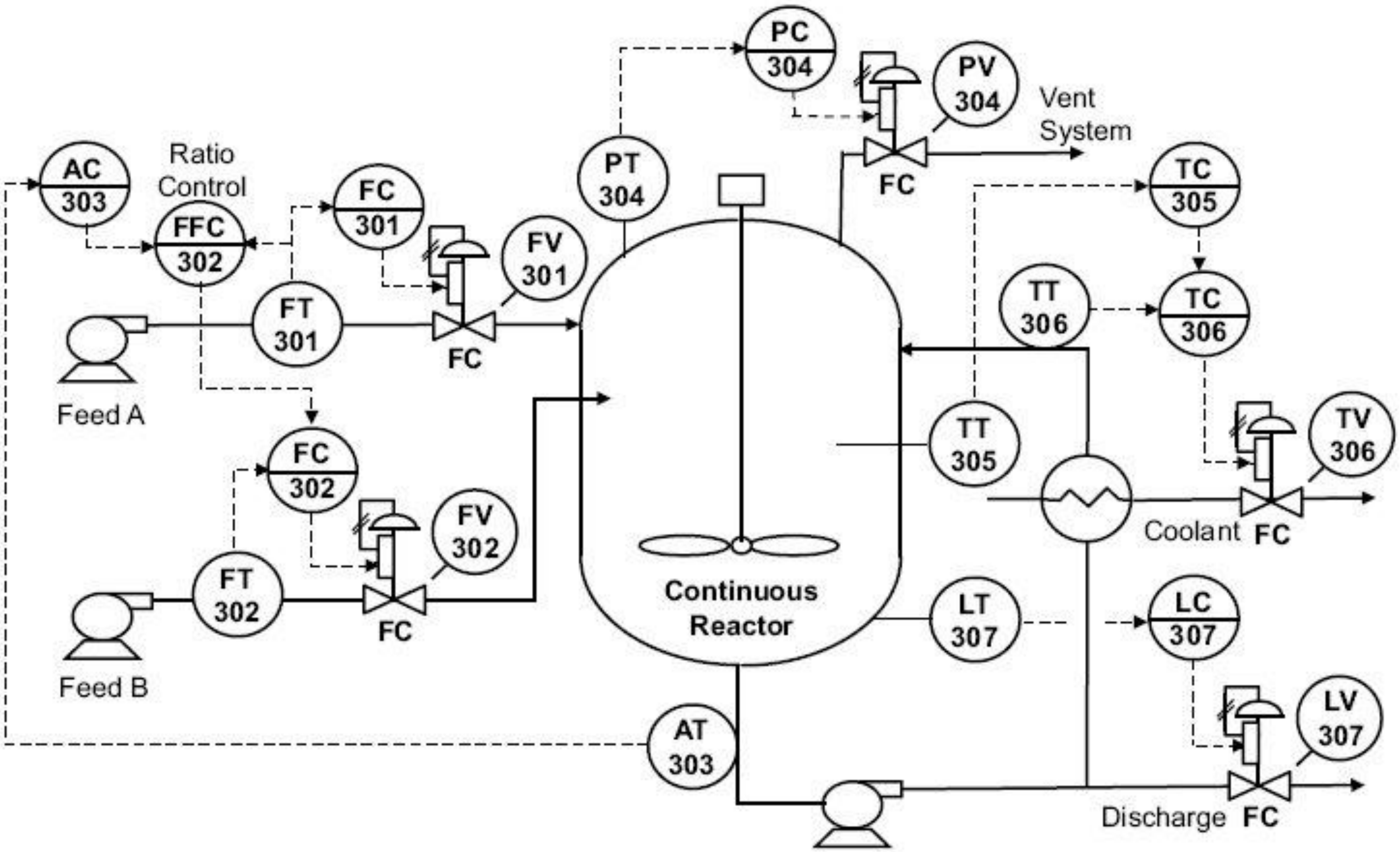

Figure 16-14. Continuous Chemical Reactor

Continuous Reactor - Control

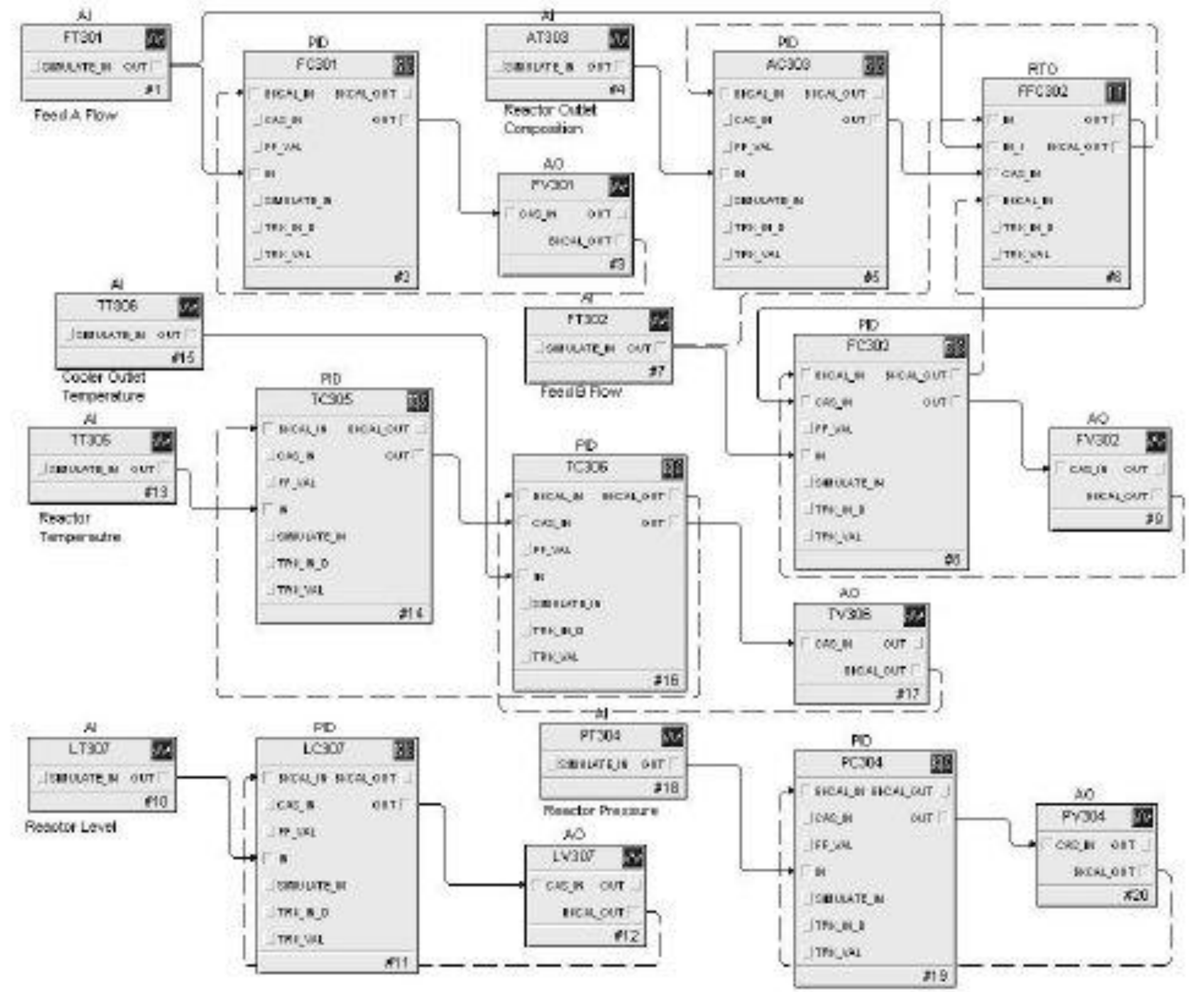

Figure 16-17. Continuous Control Workshop Module

Single Fuel Power Boiler

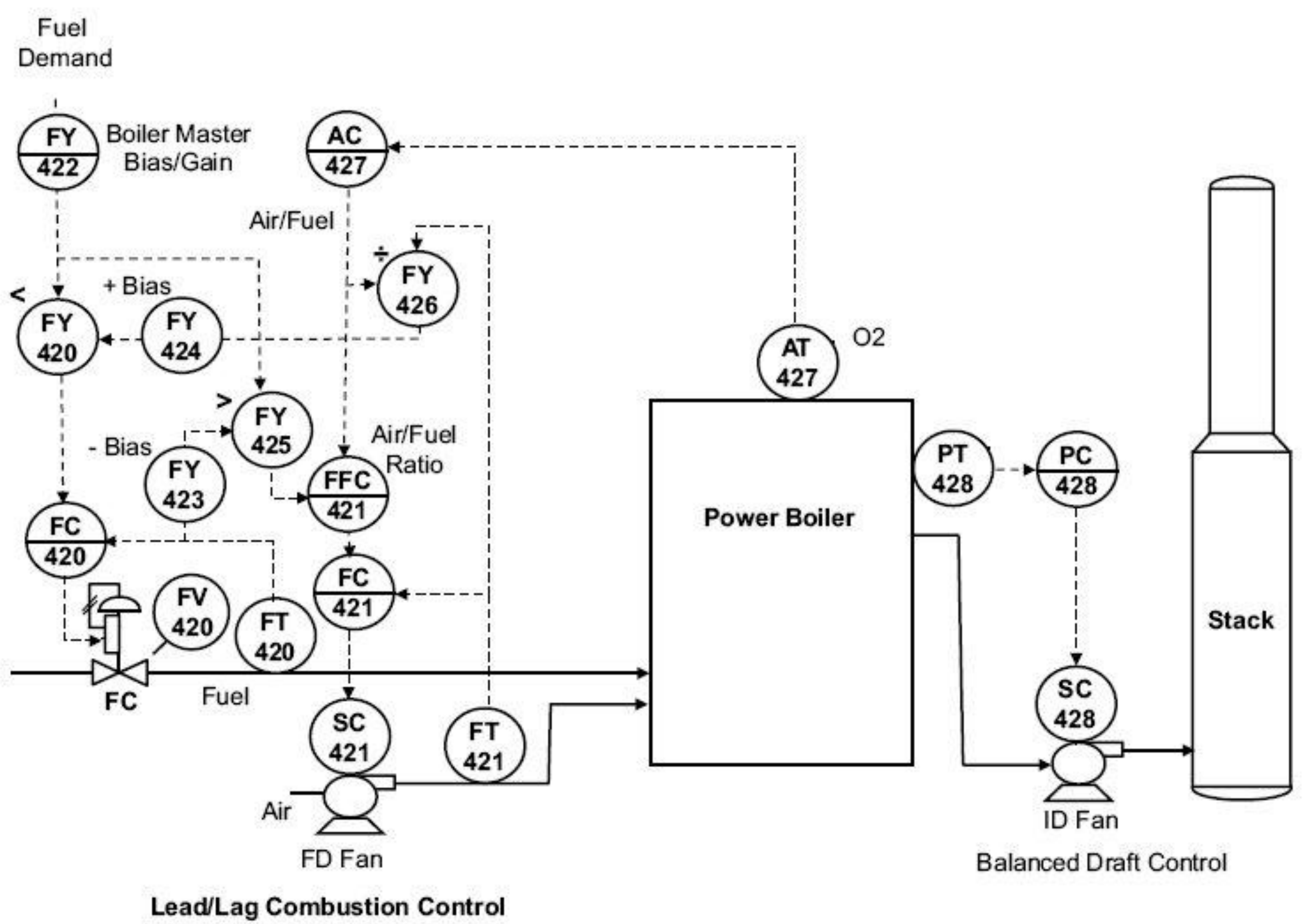

Figure 16-20. Power Boiler – Single Fuel

Power Boiler Combustion Control

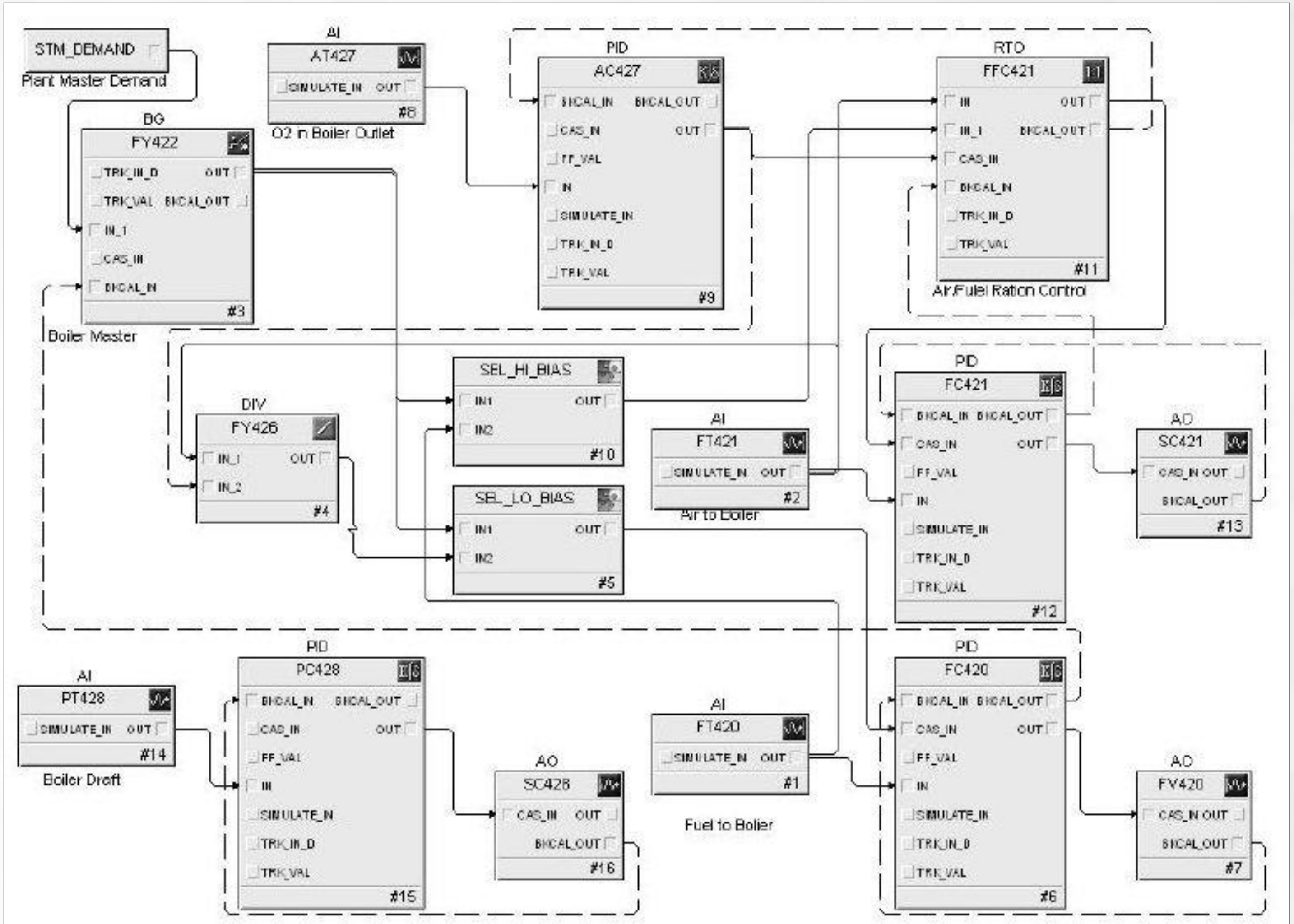

Figure 16-22. Combustion Control Workshop Module

Distillation Column

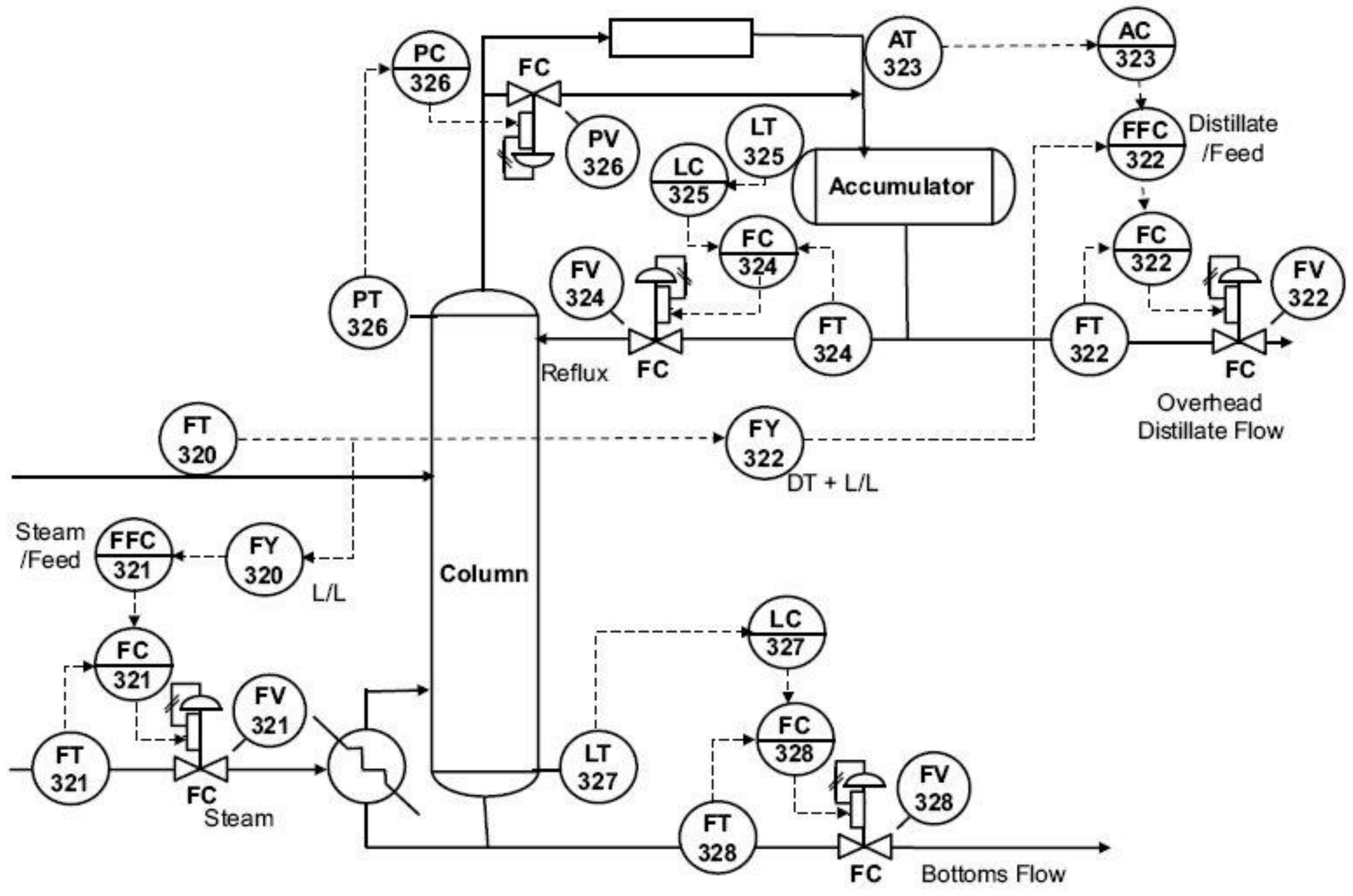

Figure 16-23. Distillation Column Control

Distillation Column Control

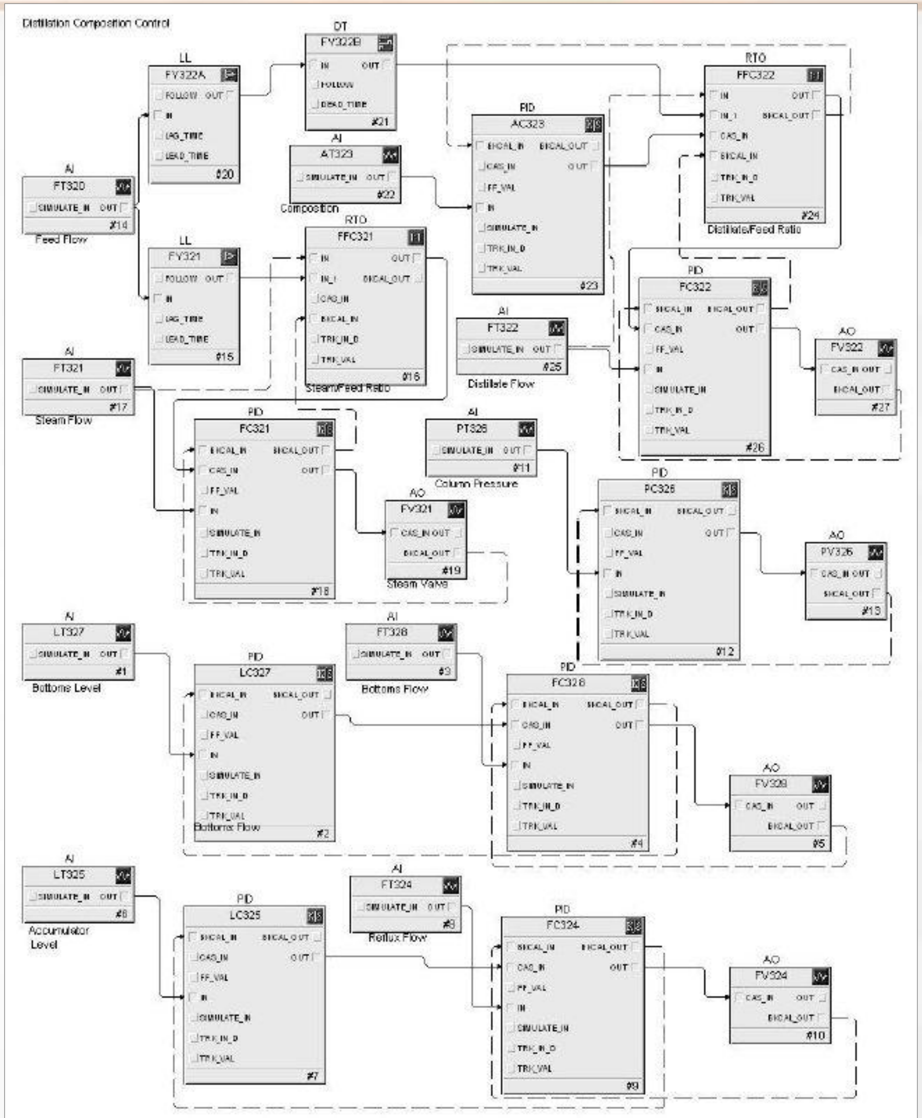

Figure 16-24. Distillation Control Workshop Module

Ammonia Plant H/N Ratio Control

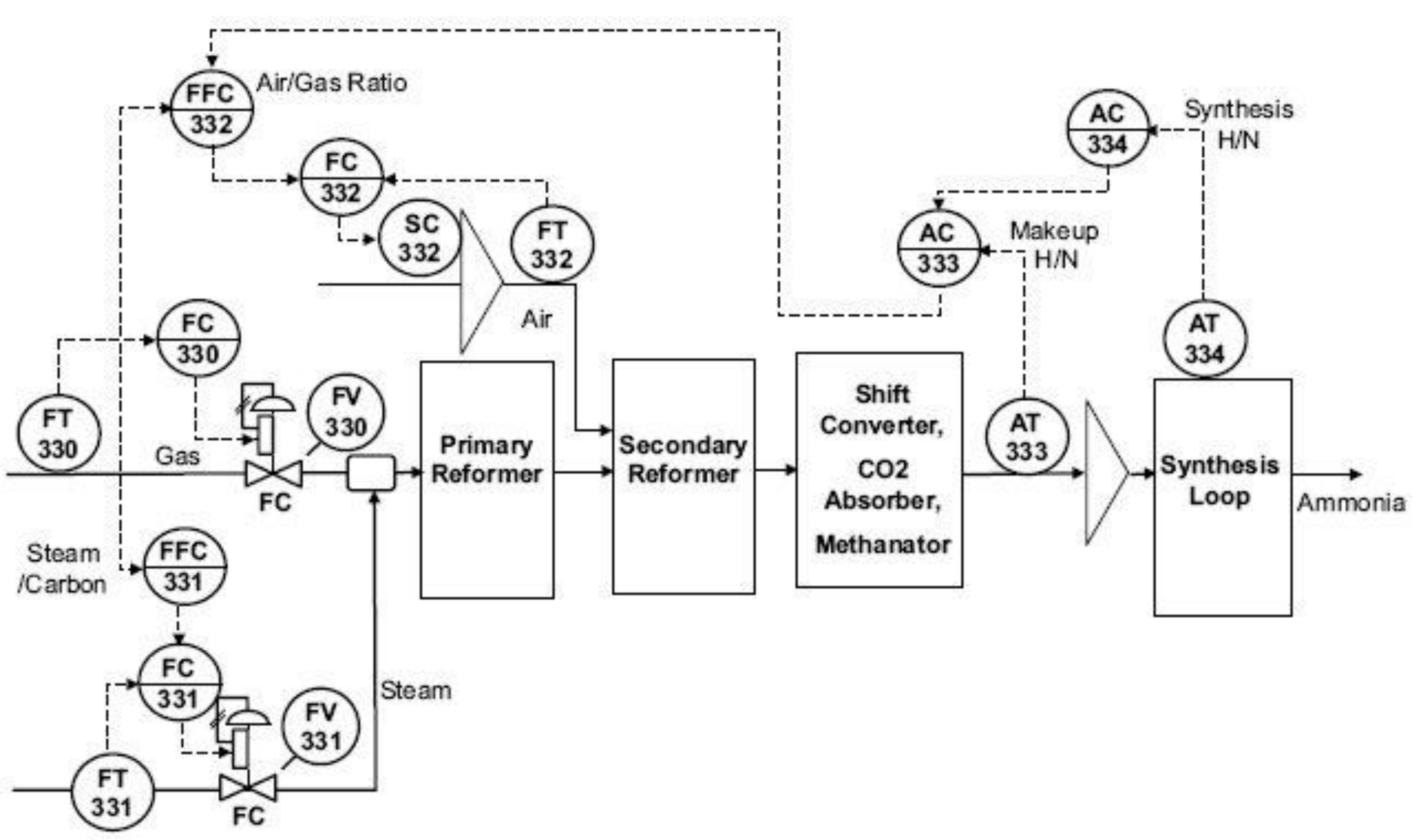

Figure 16-25. Ammonia Plant H/N Control

Ammonia Plant H/N Ratio Control (Cont.)

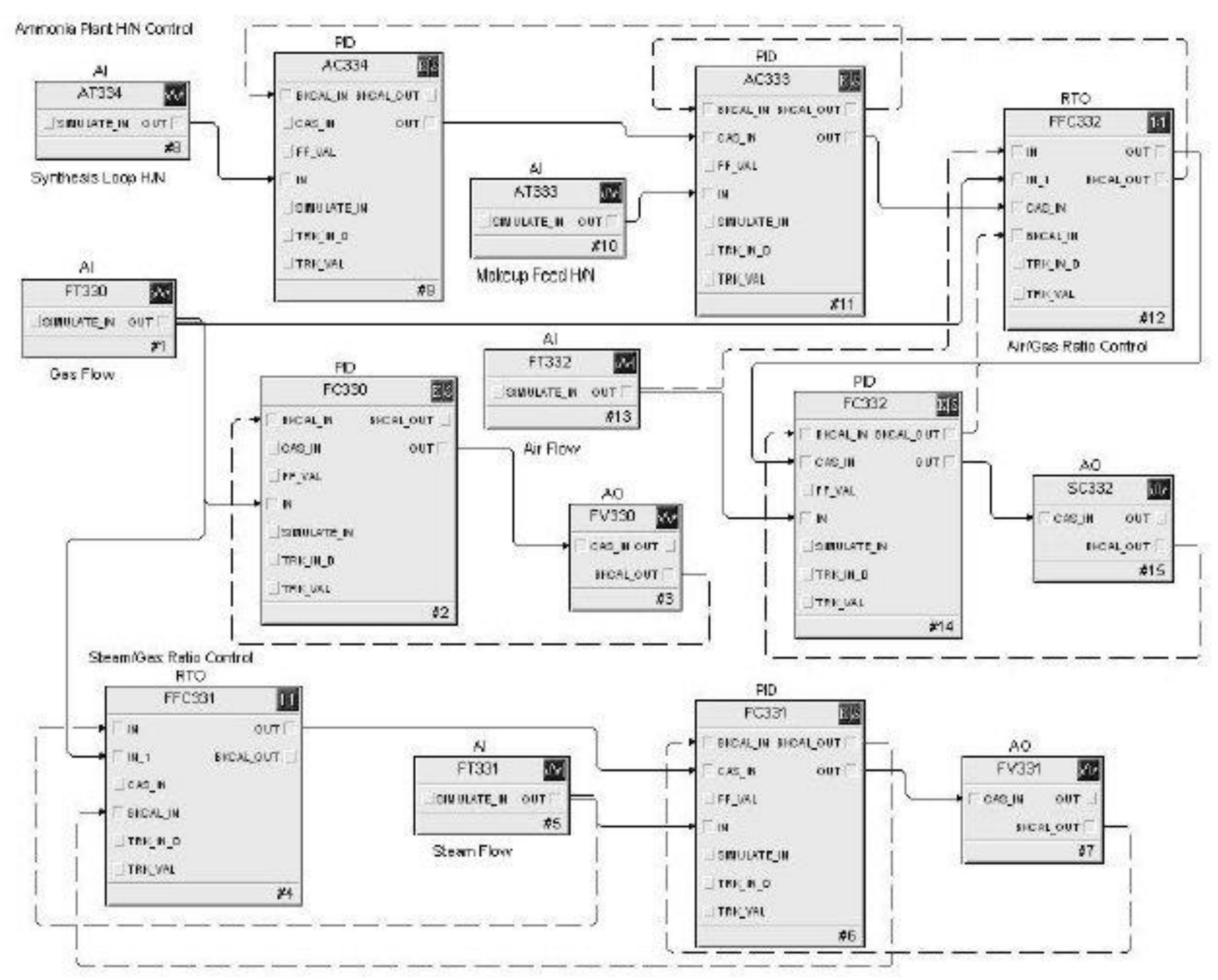

Figure 16-27. Unit Coordination Workshop Module

Control Loop Foundation Web Site

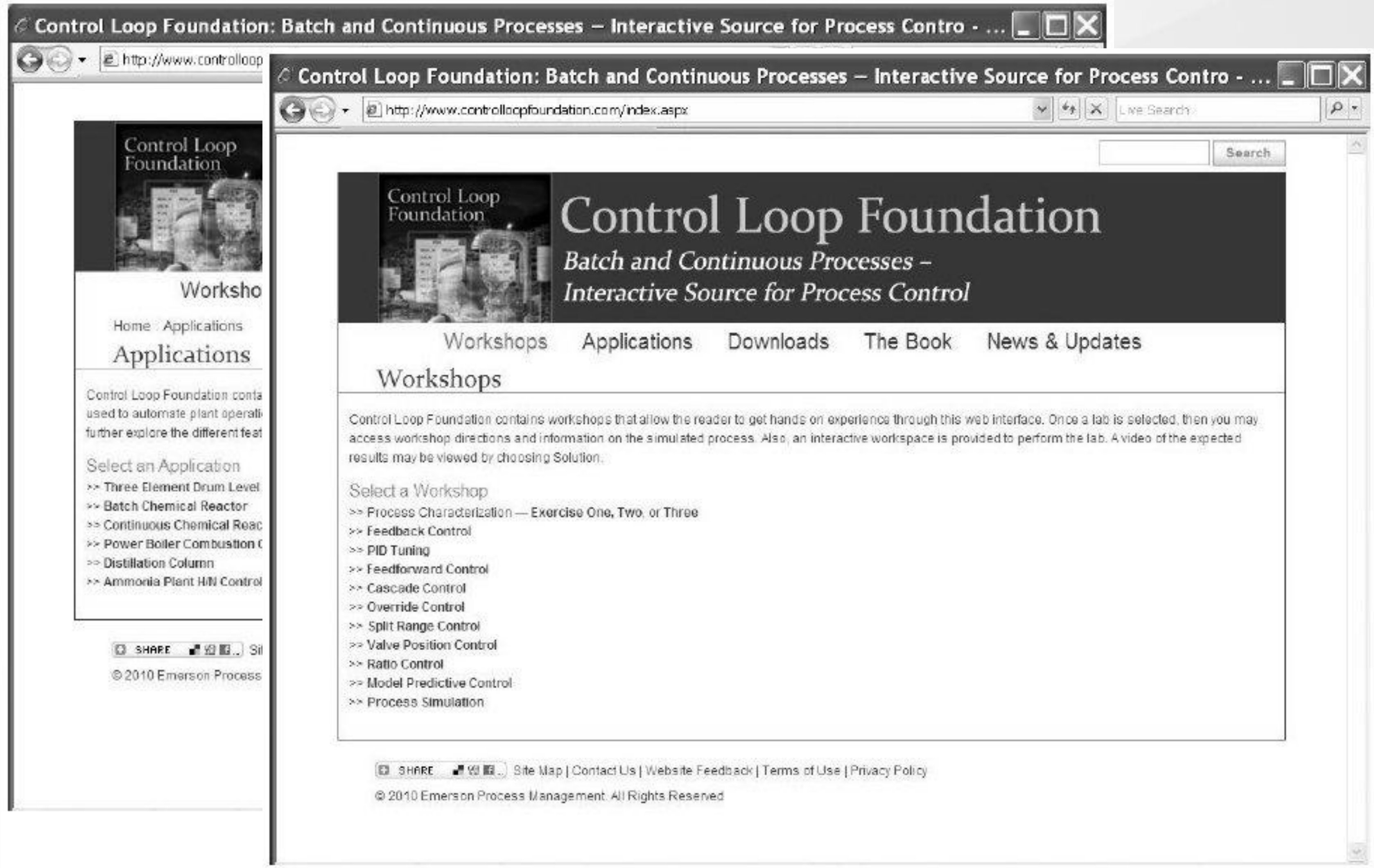

Figure A-1. Web Site Home Page

Exercise and Process Information

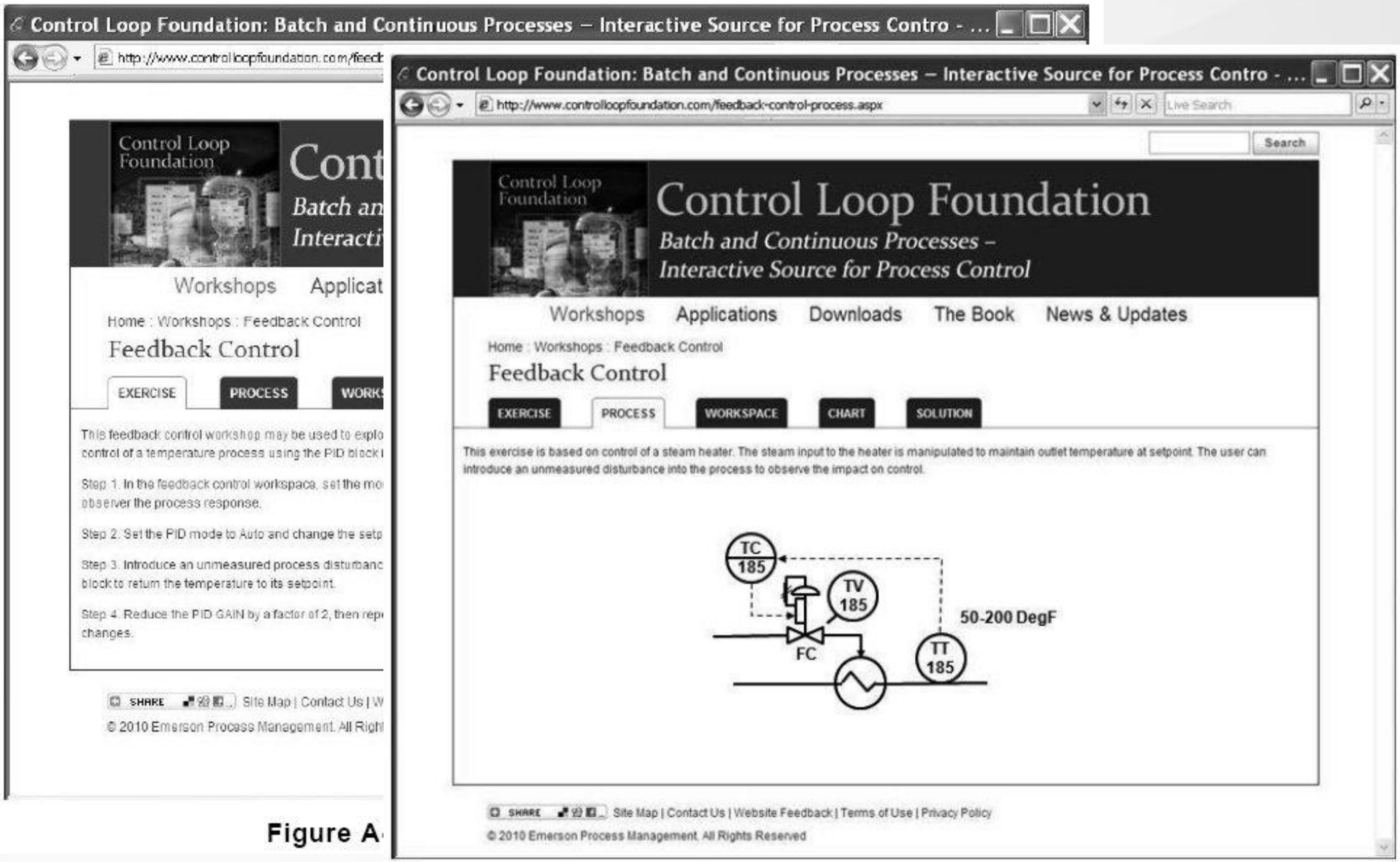

Figure A-

Figure A-4. Process – Feedback Control

Workspace –Dynamic Simulation/Control

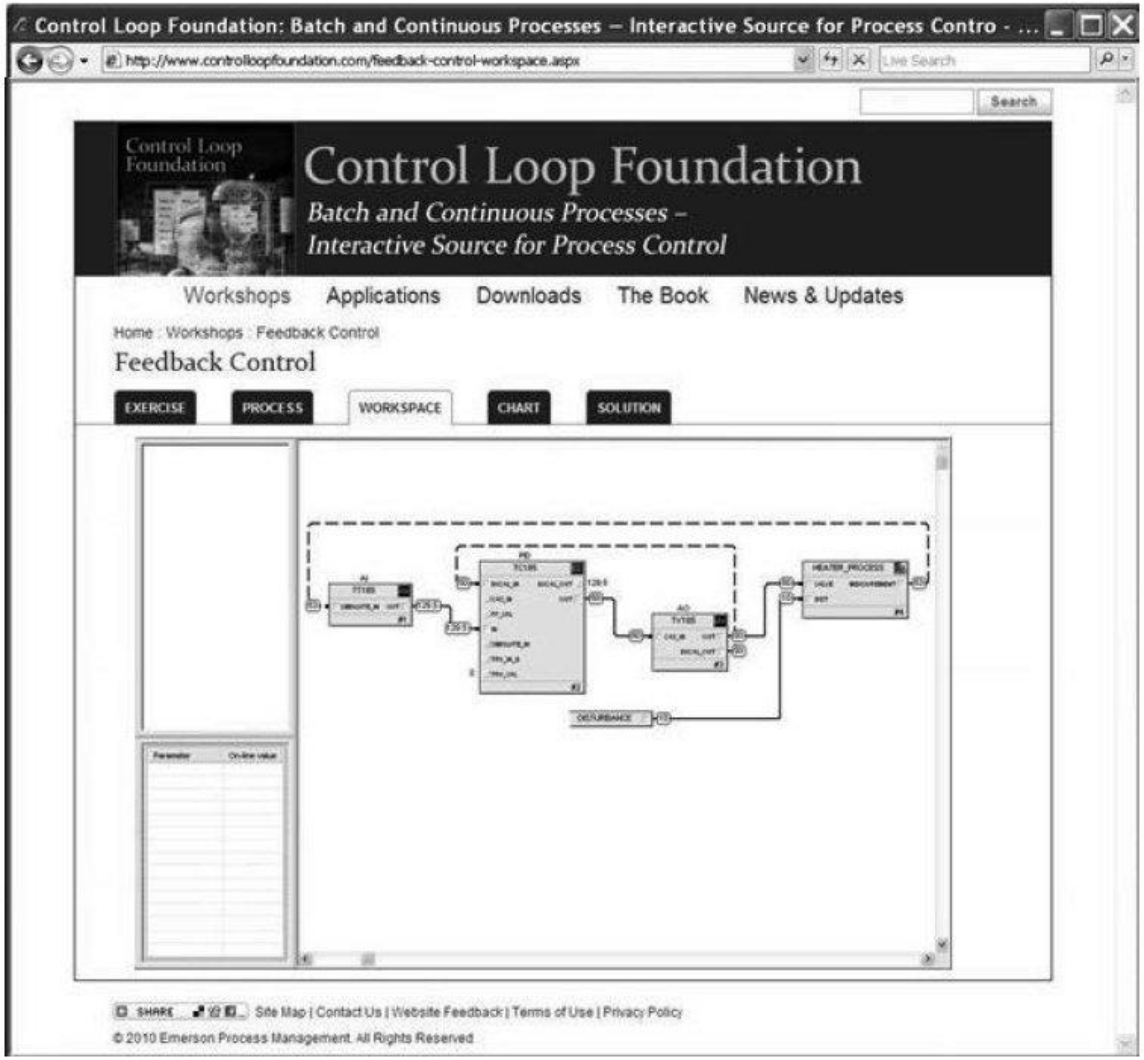

Figure A-5. Workspace – Feedback Control

Chart and Solution Selections

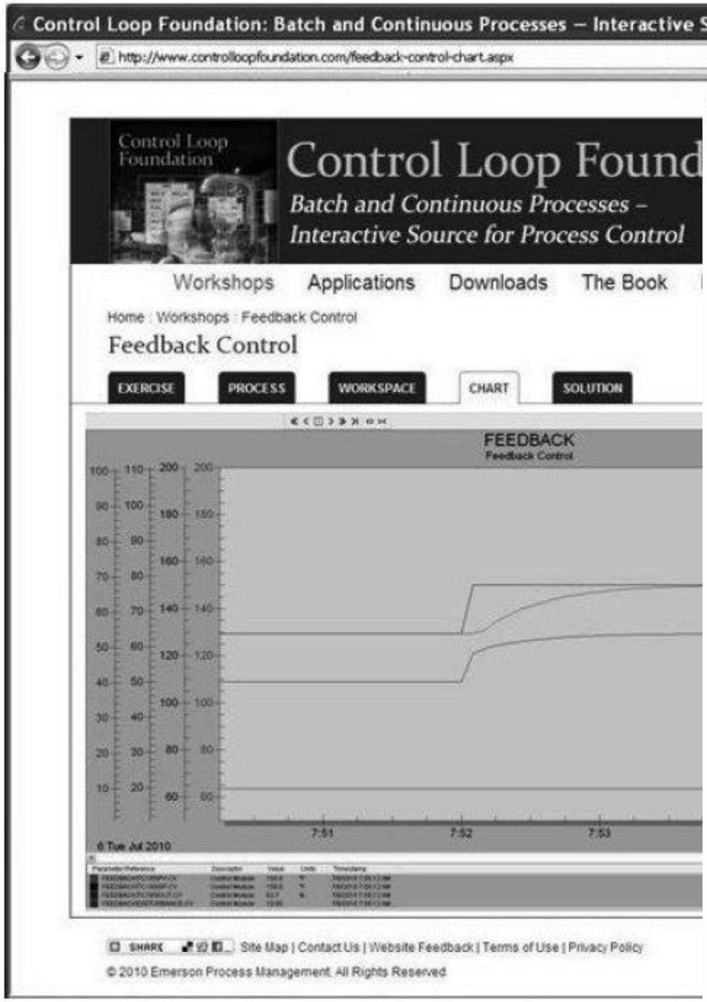

Figure A-9. Chart – Feedback C

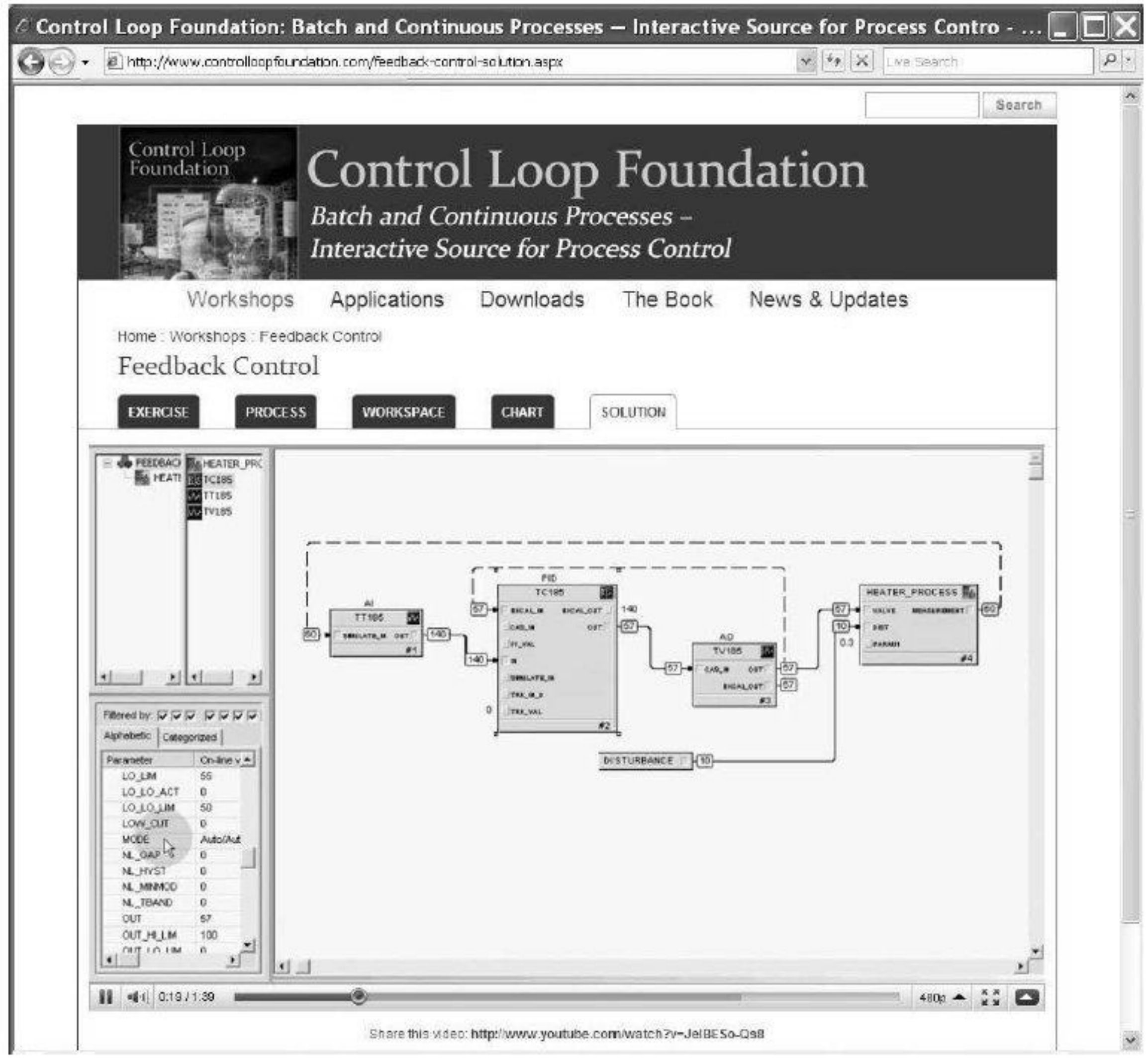

Figure A-10. Solution – Feedback Control

Summary

- Feedback on the book can be provide through the Control Loop Foundation website
- Questions?
- Drawing for books

How to Get More Information

- **Emerson Education Class**
  - **Control Loop Foundation, Course 9025   CEUs: 3.2**
  - This course is for engineers, managers, technicians, and others that are new to process control or need a refresher course. This course includes the practical aspects of control design and process applications that course developers personally learned through years of hands on experience while designing and commissioning process control applications.
    Overview
  - This 4-1/2 day course covers the concepts and terminology that are needed to understand and work with control systems. Upon completion of this course the student will be able to effectively work with and commission single and multi-loop control strategies. Interactive workshops allow the student to apply what they learn in the class.
    Prerequisites
  - Windows experience.
- **Control Loop Foundation - ISA Book**
  - May be purchase through the ISA web site - http://www.isa.org/
- **Book Web Site**
  - Explore book workshops - http://www.controlloopfoundation.com/