— CITY OF PORTLAND —
ENVIRONMENTAL SERVICES

Columbia Boulevard Wastewater Treatment Plant

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City of Portland • Bureau of Environmental Services
Engineering Services Group • Treatment & Pumping Systems Division

TPSD Design Guidelines
Chapter 9: Instrumentation and Control Design

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External References

- Equipment Naming Guidelines
- Instrument Preferences
- P&ID Templates (future)
- Control Schematic Templates (future)
- Loop Diagram Templates
- PLC Network Architecture Diagram Template (future)
- Instrument Standard Details
- I/O Terminal Block Standard Details (future)
- I/O Table Template
- Control Narrative Package Template
- Control Narrative Package Template Instructions

Selected Abbreviations

AI	analog input
AO	analog output
AST	Automation Support Team
AWG	American Wire Gauge
BDS	City of Portland Bureau of Development Services
BES	City of Portland Bureau of Environmental Services
BTS	City of Portland Bureau of Technology Services
CBWTP	Columbia Boulevard Wastewater Treatment Plant
CCTV	closed-circuit television
CNP	control narrative package
DI	discrete input
DLR	device level ring
DO	discrete output
E-stop	emergency stop
FHSS	frequency-hopping spread spectrum
GND	ground
HMI	human-machine interface
HVAC	heating, ventilation, and air conditioning
HYDRA	HYdrological Data Retrieval and Alarm
I&C	instrumentation and control
I/O	input/output
IT	information technology
LCP	local control panel
LED	light-emitting diode
LEL	lower explosive limit
L-O-R	local-off-remote
MCC	motor control center
OL	overload
OT	operational technology
PCS	process control system
P&ID	piping and instrumentation diagram
PID	proportional-integral-derivative
PLC	programmable logic controller
R/S/P	rack/slot/point
RTD	resistance temperature detector
SCADA	supervisory control and data acquisition
SCCR	short-circuit current rating
TB	terminal block
TCWTP	Tryon Creek Wastewater Treatment Plant
TSP	twisted shielded pair
TST	twisted shielded triad
UPS	uninterruptible power supply
Vac	volts alternating current
Vdc	volts direct current
VFD	variable-frequency drive

9. Instrumentation and Control Design Guidelines

9.1. Control System Design Principles

BES instrumentation and control (I&C) systems are designed according to a unified set of guiding principles to ensure reliable operation and ease of maintenance:

Safety

I&C systems employ safety interlocks to protect personnel and equipment in the event of failure or unexpected conditions. Emergency stop (E-stop) devices are installed near exposed equipment hazards as dictated by risk assessments and/or equipment manufacturer recommendations. Potentially hazardous process conditions are monitored and alarmed.

Automation

Treatment plant and pump station processes are designed for fully automated operation under normal conditions, with minimal operator intervention required.

Centralized Monitoring

Operators supervise treatment plant and pump station operations from a small number of centralized control stations, allowing each operator to efficiently view and respond to process data from many different instruments and devices.

Decentralized Control

Each process area is managed by one or more distributed programmable logic controllers (PLCs), located near the process inside space-conditioned facilities whenever possible. The use of many decentralized local controllers and backups provides resiliency by minimizing the impact of a single PLC failure.

Resiliency

I&C systems are engineered to a high standard of reliability and resiliency, with the goal of maintaining process health and permit compliance at all times. Critical systems employ redundant components where practical and cost-effective. Equipment and enclosures are appropriately rated for the areas they are installed in, ensuring reliable long-term operation in hazardous, wet, or corrosive locations. Most equipment can be operated with manual controls in the event of PLC failure.

9.1.1. Codes and Standards

Instrumentation and control system designs must comply with the most current versions of applicable codes and standards in Table 9-1. A project’s basis of design report must cite the versions of all codes and standards used on that project.

Table 9-1: Codes and Standards

Code/Standard	Description
DIN VDE 0611-4	Terminal blocks for connecting copper conductors; distribution terminal blocks up to 6 mm²
ANSI/ISA-5.1	Instrumentation Symbols and Identification
ISA-5.4	Instrument Loop Diagrams
ANSI/ISA-50.00.01	Compatibility of Analog Signals for Electronic Industrial Process Instruments
ISA-TR20.00.01	Specification Forms for Process Measurement and Control Instruments
IEEE C62.41	IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits
ANSI/NEMA 250	Enclosures for Electrical Equipment (1,000 Volts Maximum)
NEMA ICS 1	Industrial Control and Systems: General Requirements
UL 508A	Industrial Control Panels
ISO/IEC 11801-1	Information technology — Generic cabling for customer premises
NFPA 70	National Electrical Code (with Oregon amendments – Oregon Electrical Specialty Code)
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 72	National Fire Alarm and Signaling Code
NFPA 79	Electrical Standard for Industrial Machinery
NFPA 101	Life Safety Code
NFPA 820	Standard for Fire Protection in Wastewater Treatment and Collection Facilities

The BES Design Guidelines take precedence over the codes and standards in Table 9-1 whenever there is a conflict.

Installations must also comply with the International Building Code, State of Oregon Building Codes, City of Portland Codes, and local electrical inspections. Additional codes and standards of the following organizations may apply:

- American National Standards Institute (ANSI)
- American Society for Testing and Materials (ASTM)
- Electronic Industries Alliance (EIA)
- Institute of Electrical and Electronic Engineers (IEEE)
- Illuminating Engineering Society (IES)
- International Society of Automation (ISA)
- National Fire Protection Association (NFPA)
- Occupational Safety and Health Administration (OSHA)
- Telecommunications Industry Association (TIA)
- Underwriters Laboratories (UL)

9.2. Control System Equipment

9.2.1. Overview

BES treatment plants and pump stations are monitored, automated, and controlled by a complex network of sensors, computers, operator control stations, pumps, valves, and many other types of electrical and telecommunications equipment. Working together, these devices form a complete process control system (PCS).

The following are some of the major networks and subsystems of the PCS, and BES preferences for their hardware and implementation. This list is not comprehensive. Other types of equipment are discussed in more detail elsewhere in this chapter.

9.2.2. Fiber-Optic Network

The Bureau of Technology Services (BTS) maintains a large fiber-optic ring network along the Willamette River in Portland. Both BES treatment plants (CBWTP and TCWTP) and some critical pump stations and drop shafts communicate on this network. All BTS fiber is single-mode OS2.

Each treatment plant has multiple fiber network rings which are owned and managed by BES. All new fiber installations at the treatment plants use 24-pair single-mode loose-tube OS2 fiber cables, except some PLC hot standby systems that continue to use multi-mode fiber or coax. Legacy sections of the plant automation fiber network use 12- and 24-pair multi-mode cables.

Treatment plant PLCs communicate on a Modbus TCP (ethernet) device level ring (DLR). Other ring networks include a SCADA human-machine interface (HMI) workstation ring and a business information technology (IT) ring.

All new PLC installations at the treatment plants connect to the plant operational technology (OT) network. Major process areas at CBWTP have dedicated network cabinets. When a new PLC cabinet is being constructed and an existing network cabinet is not accessible, BES prefers for a new standalone network cabinet to be constructed near the new PLC cabinet to house the fiber patch panel. If space is limited, the fiber patch panel can be housed inside the PLC cabinet in a dedicated section.

9.2.3. Radio System

BES operates dual redundant radio systems to monitor pump stations and other remote sites not served by the fiber network. Data from the radio systems is integrated into the PCS for monitoring, trending, and alarming.

The HYdrological Data Retrieval and Alarm (HYDRA) system uses Modbus TCP radios. The Poller system uses serial radios. All BES radios transmit on a licensed 900 MHz band using frequency-hopping spread spectrum (FHSS) technology.

Most pump stations transmit to one of five repeater stations throughout the city, which multiplex the messages and retransmit to a master station on the roof of the Dodd building at CBWTP. A few pump stations transmit to Dodd directly.

Radios at the individual pump stations and other collection system elements transmit using directional Yagi antennas, which require line of sight to their respective receivers. Receivers use omni antennas.

Table 9-2: Radio Call Signs and Frequencies

Call Sign	BES Freq (MHz)	Repeater Station	Assigned to	Radio Service
WNEU520	952.28750 928.28750	Willalatin Tank	Poller iFIX	Microwave Public Safety Pool
WNTK282	952.36875 928.36875	Willalatin Tank	HYDRA	Microwave Public Safety Pool
WNTU776	952.76875 928.76875	Willalatin Tank	HYDRA	Microwave Public Safety Pool
WNTR429	952.23125 928.23125	Mt. Scott	HYDRA	Microwave Public Safety Pool
WPNM874	952.83125 928.83125 941.44375 932.44375	Prune Hill	HYDRA	Microwave Public Safety Pool
WPNN328	952.41250 928.41250	Tabor	Poller iFIX	Microwave Public Safety Pool
WQSK988	952.10625 928.10625	Council Crest	HYDRA	Microwave Public Safety Pool
WQNY523	941.46875 932.46875	Mt. Scott	HYDRA	Microwave Public Safety Pool

9.2.4. SCADA Workstations

Supervisory control and data acquisition (SCADA) workstations allow operators and other BES personnel to monitor and control process equipment remotely. SCADA workstations are installed in the field near process areas, in operations control rooms, and in offices at the treatment plants and pump stations. SCADA workstations use GE Proficy iFIX software. All workstations are provided with mice, keyboards, and full-size monitors.

SCADA workstations communicate with process PLCs to display, record, and trend process data and alarms. Workstations are synchronized with an atomic clock and all data is timestamped. Process information is displayed using a standardized system of graphical symbols and color codes. Most equipment that is normally automated by the PLCs can also be controlled remotely by operators in iFIX.

There are two primary types of SCADA workstation and one unique workstation:

Control Nodes

- Require operator login
- Process-specific control stations with full operator control
- Located in control rooms near the process area
- Some control functions are password-protected

View Nodes

- Require general login
- Allow for process monitoring, but no control access
- Typically located in offices
- Redundant/interchangeable
- Limited number of licenses, so sessions time out without user input

Historian Workstation

- Dedicated workstation configured for long-term data storage and reporting
- Historical data is stored in a SQL database
- Reports are generated using GE Dream Reports

9.2.5. Programmable Logic Controllers

Each process area and pump station is monitored and automated by a PLC. Some large pump stations and complex process areas have multiple PLCs, or one PLC with several remote I/O racks. Each PLC is capable of operating its associated equipment independently of the SCADA system in the event of a SCADA outage, though many programs depend on process data from other PLCs on the fiber network to function.

BES uses Modicon X80 platform PLCs for all new installations. New PLCs connected directly to the fiber network must use M580 processors, but M340s may be used for standalone systems. Many legacy Modicon Quantum, Momentum, and Square D SY/MAX PLCs remain in service at the treatment plants and pump stations. The Automation Support Team (AST) prefers to perform all PLC programming in-house, using EcoStruxure Control Expert software.

PLCs are housed in dedicated enclosures along with the auxiliary devices required to support their operation, including a managed network switch:

- Treatment plant PLCs use Hirschmann Bobcat BRS40 switches.
    - (4x) Uplink SFP (100/1000 Mbit/s)
    - (8x or 16x) 10/100/1000 BASE TX (Copper RJ45)
- PLCs outside the treatment plants use Hirschmann Bobcat BRS50 switches.
    - (4x) Uplink SFP (100/1000/2500 Mbit/s)
    - (8x or 16x) 10/100/1000 BASE TX (Copper RJ45)

9.2.6. Vendor-Packaged Control Systems

BES prefers for all equipment to be controlled by Modicon X80 PLCs programmed by the BES Automation Support Team. Occasionally, a project requires equipment that is only available as part of a vendor package with a pre-programmed PLC. Vendor-packaged equipment can be approved by individual written exception, but the vendor is requested to comply with the following preferences:

- The supplied PLC is a Modicon M340 or M580.
- The vendor programs the supplied PLC according to BES guidelines.
- The vendor, designer, and/or integrator supplies a control narrative package (CNP) in BES format.
- Operator controls consist of individual panel-mounted buttons, switches, and indicators (no touchscreens or multi-function displays).
- The vendor-supplied PLC provides process data and alarms to the PCS via Modbus TCP and/or hardwired I/O.

Deviations from these preferences must be approved in writing by BES on an individual basis. The most important criterion for vendor-supplied PLCs is that BES must be able to repair or replace a failed PLC without having to reverse-engineer the program if the vendor is not available for support. If the vendor is unwilling to share proprietary PLC program information, BES requires a spare processor with the program pre-loaded.

9.2.7. HVAC Systems

HVAC equipment used for ordinary space conditioning is not monitored by the PCS. The PCS only monitors HVAC equipment when it is used for:

- Reduction of hazardous area classification per NFPA 820
- Operator safety
- Equipment protection

9.2.8. Security and Camera Systems

The doors of some non-process buildings are equipped with card readers for access control. Motion detectors and/or door contactors may also be used. Cameras are installed at some key locations but are not typically used in process areas unless required for operational purposes. Access control and closed-circuit television (CCTV) devices are connected to the fiber IT network. BTS manages the network switches and Genetec access control software. BES manages the access card panels, cameras, and fiber.

9.2.9. Fire Alarm Systems

BES's fire mitigation strategy is based on the use of non-combustible building materials in all new construction. Because of the risk of water damage to critical electrical equipment, the use of fire sprinkler systems is discouraged. When a fire sprinkler system and associated fire alarm panel would be required by the Oregon Structural Specialty Code, the requirement must be appealed based on use of non-combustible building materials per BDS appeals procedures.

9.3. Signals and Wiring

9.3.1. General

- Instruments and actuators communicate via individual hard-wired I/O connections.
- PLCs and other smart devices use the Modbus TCP communications protocol.
- VFDs communicate via individual hard-wired I/O connections and are also provided with Modbus TCP cards for future networking options.
- Network cables are Cat 6.
- Fiber patch cables are 2 mm.
- Communication cables are color-coded per Table 9-3.

9.3.2. Discrete I/O

- Discrete I/O signals are 120 Vac.
    - Exception: HYDRA discrete I/O signals are 12 Vdc.
- Discrete field wiring is 14 AWG.
    - Exception: HYDRA discrete field wiring is 16 AWG twisted shielded pair (TSP).
- All PLC discrete outputs use interposing relays for isolation.

9.3.3. Analog I/O

- Analog I/O signals are 4-20 mA at 24 Vdc.
- Analog field wiring for 2-wire and 4-wire devices is 18 AWG TSP.
- Analog field wiring for 3-wire devices (when separate 24 Vdc power and signal circuits share a common GND) is 16 AWG twisted shielded triad (TST).
- TSP and TST shielding must maintain continuity for the entire wiring run between the PLC card and the field device.
- Each TSP or TST shield is grounded at exactly one location: the GND terminal block in the PLC panel.
- 4-20 mA analog input signals are converted to 1-5 V at PLC input cards with 250 Ω resistors in parallel with the inputs.
- Analog output signals are powered from PLC output cards.
- Analog devices must support the HART communication protocol.
- Analog field wiring must not share raceways or conduits with AC power or controls wiring.

Table 9-3: Communication Cable Colors

Cable Type	Cable Usage	Cable Color	Hood Color
Serial	Modbus	Gray	N/A
Serial	Modbus Plus	Gray	N/A
Cat 3	Telephone	Gray	N/A
Cat 6	Ethernet / PLC LAN	Yellow	Black
Cat 6	Ethernet / PC LAN	Yellow	Yellow
Cat 6	Crossover Cable	Pink	Black
Cat 6	Serial Data	Red	Black
Cat 6	Telephone / Business	Blue	Blue
Cat 6	Premises Wiring (Patch Panel)	Blue or Gray	N/A
Cat 6	T1	Black or Orange	Black or Orange
Fiber	Trunk Cable MM	Black or Orange	N/A
Fiber	Jumper Cable MM	Orange	N/A
Fiber	Trunk Cable SM	Black or Yellow	N/A
Fiber	Jumper Cable SM	Yellow	N/A

9.4. Instrumentation

9.4.1. General Instrument Preferences

- Instruments must have certification marks from an OSHA Nationally Recognized Testing Laboratory (NRTL).
- Instruments in hazardous (classified) locations, intrinsically safe circuits, or other specialized applications must be FM Approved for that application.
- Provide all instruments with local displays.
- Provide south-facing sunshades for outdoor instruments and standalone displays that are exposed to the sun for most of the day.
- Provide local lockable electrical disconnects for 120 Vac instruments.
- Use analog instruments for all measurements used for process control. Discrete sensors are not usually allowed.
    - Exception: Air flow switches are allowed for proof of flow.
- For critical process measurements, consider redundant instruments.

9.4.2. Preferred Technologies and Manufacturers

Table 9-4 lists the preferred technology and manufacturer for each type of measurement. For specific product family and part number preferences, refer to the BES Instrument Preferences document.

Table 9-4: Preferred Instrument Technologies and Manufacturers

Function	Technology	Manufacturer
Analysis – Chlorine	Colorimetric	Hach
Analysis – DO	Luminescent	Hach
Analysis – H_2S	Infrared	MSA
Analysis – LEL	Infrared	MSA
Analysis – pH	Potentiometric	ABB
Analysis – Sulfite		Ati
Analysis – TSS		YSI
Electric Current	True RMS split-core Current Transducer (CT)	NK Technologies
Electric Power		Electro Industries
Flow – Gas	Thermal Mass	FCI
Flow – Liquid	Magnetic	Emerson | Rosemount
		Schneider | Foxboro
		Endress+Hauser
	Area Velocity	Hach
Level – Liquid	Radar (preferred)	VEGA
		Endress+Hauser
	Ultrasonic	Siemens | Milltronics
	Pressure	Emerson | Rosemount
Pressure	All transmitter types	Emerson | Rosemount
Temperature	RTD	Emerson | Rosemount
		Ultra Energy | Weed
		Moore Industries

9.4.3. Hardware and Installation

- Refer to BES Instrument Standard Details for specific mounting preferences.
- Mount instruments on piping or instrument racks/stands where practical.
- Mounting hardware must not interfere with any other equipment.
- Insertion instruments must be installed with sufficient slack in flex conduit and wiring to allow removal of the instrument without disconnecting wiring.
- Use diaphragm seals with flushing connections for slurries, chemicals, and corrosive fluids.
- Provide all connections to process liquids with unions, couplings, adaptors, shut-off valves, and test fittings.
- Process tubing must be sloped:
  - Down from the instrument toward the process for gas measurement
  - Down from the process toward the instrument for liquid measurement
- Provide drain/vent valves or fittings at any point in the process tubing where the proper slope cannot be maintained.

9.4.4. Analysis

- Use reagent-less analyzers whenever possible.

9.4.5. Current

- Motor current monitoring is only required for critical motorized equipment or when the data is useful for troubleshooting and alarms, subject to owner's requirements. Some examples when current is monitored include:
  - Pump motor current at pump stations
  - Belt-driven equipment where low current could indicate a broken belt
  - Jam detection applications where high current indicates a locked rotor
- Motor current is not usually monitored for:
  - HVAC equipment, small sump pumps, seal water pumps, conveyors, actuators, dampers, chillers, and most other skid-mounted equipment
- VFDs and soft starters typically have analog outputs that can be configured for current feedback. If unavailable, use a current transducer (CT).
- When current monitoring is required and there is no VFD or soft starter display on the MCC bucket, use a loop-powered current display.
- When current monitoring is required, consider using motor current in addition to the motor run relay status to determine running/fail status in the PLC.

9.4.6. Flow

- Use magnetic flow meters for full pipe flows with good access to the pipe.
  - Install per manufacturer's recommendations for orientation and straight, unimpeded pipe runs on either side of the device.
- Install elevated magnetic flow meters so they can be serviced safely:
  - Reserve unobstructed floor space below the instrument for scaffolding.
  - For large flow tubes, provide rigging provisions above the instrument.
  - Mount the transmitter separately from the flow tube so it can be viewed and accessed from ground level or a platform.
- Provide below-grade flow meters with provisions for access and removal.
- Use magnetic or Coriolis flow meters for chemical lines.
- Use radar level instruments with weir flow calculations for open channel flows with no foam.

9.4.7. Level

- Radar level instruments are preferred for wet wells, chemical tanks, and flow-through structures.
- Ultrasound and bubbler instruments are acceptable in certain applications.
- Designs must provide justification for instrument type selection. Consider:
  - Instrument/sensor location and accessibility for maintenance
  - Contact vs non-contact sensors
  - Liquid surface and substrate conditions (foam, standing waves, etc.)

9.4.8. Power

- Provide electrical power meters at the main breaker / main lug compartments of all switchgear, switchboards, and MCCs.
- Power meters communicate with the SCADA system via Modbus TCP.

9.4.9. Pressure

- For solids and chemical lines, use diaphragm seals with flushing connections.
- Do not use annular seals.

9.4.10. Speed

- Speed feedback from VFDs is not required. If equipment speed must be monitored, use a speed sensor on the final control element itself.

9.4.11. Temperature

- Use RTDs except when thermocouples are required for high temperatures.
- RTD/thermocouple input cards for PLCs are not allowed. Use standalone temperature transmitters. DIN-rail-mounted temperature transmitters inside panels are acceptable.

9.5. Valve Actuators

BES prefers AUMA, Beck, and EIM actuators.

- Provide actuators with vendor-standard pushbutton controls.
- Provide remote actuator controls for actuators that are not easily accessible.
- Use non-contact proximity limit switches instead of mechanical "snap" type.
- Provide electric actuators with local lockable electrical disconnects.
- Provide electric actuators with double-sealed termination chambers to reduce water intrusion.
- Refer to Chapter 8 for guidance on 120 V vs 480 V actuator motor selection.

9.6. Access Warning Lights

Access warning lights are used in combination with monitoring equipment at some BES locations to alert staff that the atmosphere in the monitored space could be compromised. They are never to be used in place of personal protective equipment, including calibrated muti-gas detectors. The purpose for and initiating conditions of access warning lights must always be clearly identified with standardized signage so staff are aware of the process condition(s) that may have initiated the warning. Installation and warning light colors must comply with NFPA 820.

9.6.1. Triggering Conditions

- Combustible gas at or above 10 % of the lower explosive limit: 10 % LEL (the most common triggering condition)
- H_2S gas level at or above alarm setpoint
- Air changes less than design setpoint / proof of air flow lost
- Smoke detected
- Any other condition selected by the design team

9.6.2. Mounting Locations

- At the entrance to a space, two lights are used to positively show that the notification system is working. One light should be on at all times. If no lights are on, the system is not working. Lights are colored per NFPA 820:
  - GREEN: Atmosphere is not compromised – light is continuous
  - RED: Atmosphere is compromised – WARNING – light flashes
- Mount access warning lights at all entrances to the monitored space.
  - Single doors: Mount on the same side of the door as the door handle.
  - Double doors: Mount to the left of the doorway as viewed from outside the space.
- Mount above eye level, but clearly visible from the doorway.
  - Nominally 5 to 6 feet above grade and within 2 feet of the doorway
- Outside pump stations and other locations visible to the public:
  - Use the smallest indicator lights that meet staff notification needs. 30 mm push-to-test LED pilot lights are preferred.
  - Do not use strobes or large beacons.
- Access warning lights must be clearly visible from any vehicles that might otherwise enter a compromised area.
  - At locations where vehicles can park over a monitored wet well, use large format loading dock style "traffic lights" with sunshades ahead of the parking area, so staff can see the warning lights from a distance as they approach.
- Inside a monitored space, a flashing red light and audible alarm are used together to alert workers that the atmosphere is compromised. The green light is not used. The light and audible alarm must be rated for the area.
- Inside pump stations:
  - Use a strobing alarm beacon and audible alarm rated for the space:
    - Wet Well – Class 1 Div. 1
    - Dry Well – Class 1 Div. 2 (unventilated)
    - Dry Well – Unclassified (with ventilation per code)
  - A test button for the beacon and audible alarm are located inside the entrance to the pump station.
  - A green light is not required unless there is an entrance to a classified space from inside the pump station.

9.6.3. Signage

Every access warning light or light and audible alarm combination must be identified with an explanatory sign in the following format:

- Text sized to be legible from 6 feet away
- White background with black lettering
- Large CAUTION symbol
- Description of light colors and alarm function
- List of all monitored conditions that trigger the alarm and their loop numbers
- The loop number of the warning light itself

9.6.4. Loops and Signals

- All access warning lights for a single monitored area use the same base loop number with a unique suffix (-1, -2, -3) for each warning light location.
- Sensors that are part of the monitoring system have separate loop numbers.
- Warning light wiring must fail to the alarm state if communication with the PLC is lost:
    - Relay coil energized = green light = alarm state FALSE
    - Relay coil deenergized = red light = alarm state TRUE
- When % LEL is monitored, provide the 4-20 mA % LEL signal to the PLC for historical trending and display in iFIX.
    - % LEL analog loop range is 0 to 100 % LEL.
    - 7 % LEL triggers iFIX medium priority % LEL HI – CAUTION alarm.
    - 10 % LEL triggers iFIX high priority % LEL HIHI – WARNING alarm and access warning light.
    - At pump stations, gas detector discrete outputs are configured to send 7 % LEL CAUTION and 10 % LEL WARNING signals directly to HYDRA.

9.7. Operator Controls

BES processes are normally designed to operate automatically under remote PLC control, with remote monitoring and control options available to operators via the iFIX SCADA system. In some cases, operators may need to provide manual control inputs to adjust the process. Operator controls are available at MCCs, local control panels (LCPs), iFIX, and/or vendor-supplied control panels when present.

9.7.1. Control Modes

Operators use mode selector switches to choose between process control modes. Usually there is a physical LOCAL-OFF-REMOTE (L-O-R) switch on the equipment, an LCP, and/or the MCC, as well as AUTO/MANUAL buttons in iFIX.

Local Manual Control

- The L-O-R switch at the LCP is in LOCAL

Most equipment control panels have a LOCAL-OFF-REMOTE switch that allows operators to control the equipment locally for troubleshooting purposes or during abnormal operating conditions. All local manual control functions are implemented directly in hardware, and do not pass through the PLC. Remote operation from the PLC is inhibited in local manual mode. The equipment icon in iFIX is displayed with a white outline to indicate that it is not under remote control.

Local Automatic Control

- The L-O-R switch at the LCP is in LOCAL
- The mode selector on the equipment is in AUTO

Some vendor-furnished equipment packages have automatic functions that are performed locally by a standalone controller. Other processes are so simple that they can be automated entirely in hardware with just a few relays, like on-off level controls for a sump pump. Additional control modes may be available for these systems, or local automatic control may be the only mode option. In either case, equipment status information should be monitored by the PCS whenever possible.

Remote Manual Control

- The L-O-R switch at the LCP is in REMOTE
- The mode selector button in iFIX is in MANUAL

This mode allows operators to control individual portions of the process remotely from iFIX workstations. Local panel controls are inhibited in this mode. Remote manual control may override some automatic software control functions and interlocks, but hardware interlocks for life safety or equipment protection must remain active. The equipment icon in iFIX is displayed with an orange outline to indicate that it is under operator control.

Remote Automatic Control

- The L-O-R switch at the LCP is in REMOTE
- The mode selector button in iFIX is in AUTO

Equipment and processes are usually designed to run in this mode during normal operation. The PLC manages the process independently, based on pre-programmed logic and real-time data from field instruments. Local panel controls are inhibited in this mode. Loss of communications with the iFIX system will not interrupt automatic operation. Certain control parameters like PID controller setpoints can be adjusted by operators in iFIX while the equipment is running in auto. The equipment icon in iFIX is displayed with a black outline to indicate that it is under PLC control.

9.7.2. Control Devices

- Implement local controls with individual 30 mm pushbuttons, selector switches, and potentiometers. Do not use touchscreens.
- Implement equipment run circuits with a LOCAL mode switch position and momentary START and STOP buttons that latch via a seal-in relay contact. Do not use HAND switch positions that run equipment immediately.
- Mode selector switches must send an IN REMOTE status to the PLC.
- When possible, locate controls within sight of the controlled equipment.
- When equipment can be controlled from multiple control stations, only one set of controls may be enabled at a time.
- Fault conditions that require operator inspection before resetting the fault must have a corresponding local fault reset button accessible from a location where the equipment can be observed.

9.7.3. Indicators and Displays

- Provide individual 30 mm push-to-test indicator lights for equipment status.
- When a local panel or MCC bucket is powered, at least one indicator light must be lit. Provide an OFF or STOPPED light if necessary.
- Provide individual ALARM, FAIL, or FAULT indicator lights for specific faults that require defined operator action to clear, like JAM or MOTOR OL FAULT.
- Indicator lights are not necessary for conditions that are already indicated by switch positions on the panel, e.g. LOCAL-OFF-REMOTE status.
- Provide individual loop-powered local displays for any analog process values required to run the equipment manually. BES prefers the Red Lion CUB 4.
- Provide hardwired non-resettable runtime meters for all motors, powered directly by the motor run circuit (not the PLC.)

Table 9-5: Indicating Light Colors

Condition	Lens Color
Generic status	White
RUNNING / ON	Red
OPENED (valve, gate, etc.)	Red
FORWARD	Red
Personnel hazard	Red
STOPPED / OFF	Green
CLOSED (valve, gate, etc.)	Green
Normal condition / No warning	Green
Abnormal condition / Warning	Amber
LOW / HIGH	Amber
REVERSE (if abnormal)	Amber
ALARM	Blue
FAIL / FAULT	Blue
FIRE	Clear

9.7.4. VFD Controls

- VFD keypads must be readily accessible, not mounted inside enclosures.
- Provide standalone panel-mounted controls for any VFD functions that will be used by operators, such as START/STOP buttons and SPEED potentiometers.

9.7.5. Interlocks

- Life safety and equipment protection interlocks must be implemented with hardware devices and active in all control modes, independent of the PLC.
  - For hardware interlocks based on an analog process value, use a programmable alarm module. BES prefers the Moore SPA[2].
  - A relay contact from the alarm module must be wired directly to an interlock relay in the MCC/VFD/starter to lock out the equipment.
  - An auxiliary contact from the interlock relay in the MCC/VFD/starter must be wired to a PLC input for monitoring, alarming, and trending.
- The status of any hardware interlock or fault condition that stops the equipment must be monitored, alarmed, and trended by the PLC and iFIX.
- Interlocks that are not critical for life safety or equipment protection may be implemented in the PLC program.

9.7.6. Emergency Stop Devices

- Provide emergency stop (E-stop) devices where required by the equipment manufacturer, or wherever a risk assessment shows that operators may encounter hazards such as unguarded pinch points.
- E-stops must be installed in compliance with NFPA 79 Articles 10.7 and 10.8.
- Control circuits with E-stops must use momentary START and STOP pushbuttons with a latching seal-in contact from the motor run relay, rather than a HAND switch position that runs the equipment continuously. This is so that resetting the E-stop button does not immediately start the equipment.
- The status of all E-stops must be monitored by the PLC.

9.7.7. Control Panel Marking

Control panels must have UL 508A certification marks and all marks required by NEC 409.110, including short-circuit current rating (SCCR). Control panel SCCR must be considered in the preliminary and final short circuit, coordination, and arc flash studies.

9.8. PLC Cabinet Design

9.8.1. General Considerations

- Locate PLC cabinets near the process to optimize field wiring when possible.
- Locate PLC cabinets indoors or under shelter for workers performing service.
- PLC cabinet maximum height is 72”, measured from the housekeeping pad.
- PLC design must include heat generation calculations to justify panel cooling requirements. Use fans unless air conditioning is absolutely necessary.
- Do not mount anything on PLC cabinet side panels. If there is insufficient space on the back panel, use a wider cabinet.
- PLC wiring must be color-coded per Design Guidelines Chapter 8 Table 8-2.

9.8.2. DIN Rails

- Use 2” high elevated DIN rail, except for very tall devices like power supplies.
- Orient DIN rails vertically wherever possible. Note that some devices must be mounted on horizontal DIN rails for adequate cooling.

9.8.3. Wiring Duct Layout

- Provide at least 3” of space between plastic wiring ducts and the top, bottom, and side walls of the cabinet. Where conduits enter the cabinet, provide 6”.
- Wiring ducts must be 4” high and 3” wide, except around the outside edges of the back panel where they can be 2” wide.
- Allow 2” between component terminal screws and wiring ducts to allow space for wire labels, and/or 6” from the centerline of the wire duct to the centerline of the DIN rail.
- If devices must be mounted on side panels, use corner-style wiring ducts.

9.8.4. Terminals and Terminations

- Use single-level terminal blocks only. Multi-level terminals are only allowed on relay bases and specialized devices.
- Use screw terminals only. Do not use push-in or spring terminals.
- Use ferrules on all factory-supplied wiring terminations.
- Do not terminate more than one wire under a single screw terminal.

9.8.5. Uninterruptable Power Supply

- Most PLC cabinets should be equipped with a UPS, unless very low criticality.
- The UPS must use true online double conversion topology.
- Size the UPS for minimum 5 minutes of battery backup power.
- Mount the UPS to a DIN rail or secure it to a shelf attached to the back panel.
- Include a UPS-OFF-BYPASS maintenance bypass switch inside the cabinet. The bypass circuit must include a fully-rated overcurrent protective device.
- Monitor UPS FAULT and UPS IN BATTERY MODE statuses with the PLC.

9.8.6. Surge Suppressor

- Monitor surge suppressor status with the PLC.

9.8.7. 24 Vdc power supplies

- Use two 24 Vdc power supplies paralleled through a passive diode module.
- Monitor 24 Vdc power supply statuses with the PLC.

9.8.8. PLC Backplane

- Mount the PLC backplane at the top of the cabinet near eye level.
- Use the largest-capacity backplane that will fit comfortably in the cabinet.
- Use an ethernet-capable backplane for the first rack in a drop.
- Consider backplanes with dual power supplies for high-criticality applications.

9.8.9. PLC I/O Cards

- Arrange I/O cards on the backplane in the following order: DI, DO, AI, AO.
- Consider process resiliency when choosing I/O point assignments. Try to arrange I/O to minimize process impact from a single failed I/O card.
- Do not split the I/O for a single device between cards.
- 25 % of the channels on each I/O card must be reserved for spares.
- Distribute spares evenly between all the equipment on a card. For example, if a DI card serves two pumps, group half the spares with each pump's DIs.

9.8.10. I/O Terminal Blocks

- Install I/O terminal blocks on vertical DIN rails below the PLC backplane.
- Orient I/O terminal blocks such that all field wiring lands on the left side of the TBs and all internal panel wiring lands on the right side of the TBs.
- Arrange each loop's DI terminal blocks and DO relays together in one group.
- Arrange each loop's AI and AO terminal blocks together in a separate group.
- Arrange and label the terminal block groups in the following order:
  - Discrete I/O by loop number TB-AC-[loop1, loop2, loop3…]
  - Discrete input spares TB-AC-SPDI[1, 2, 3…]
  - Discrete output spares TB-AC-SPDO[1, 2, 3…]
  - Analog I/O by loop number TB-DC-[loop1, loop2, loop3…]
  - Analog input spares TB-DC-SPAI[1, 2, 3…]
  - Analog output spares TB-DC-SPAO[1, 2, 3…]
- Reserve 20 % spare space on each I/O DIN rail for future I/O TB expansion.
- Group all devices associated with a specific loop (signal conditioners, RTD temperature transmitters, etc.) together with that loop's I/O terminal blocks.
  - Exception: Conductors of intrinsically safe circuits must be separated from conductors of other circuits per NFPA 70 Article 504.30.
- For very large cabinets that are transported in separate sections, all I/O TBs for a given PLC backplane must be in the same section as that backplane.
- See BES I/O Terminal Block Standard Details for preferred I/O TB layouts.

9.9. Naming and Numbering Conventions

9.9.1. Loop Numbering Convention

The complete system of all instruments, controllers, control elements, and/or indicators associated with a specific process variable (flow, level, temperature, etc.) is called a control loop, or loop. Each loop is assigned a unique loop number of up to five digits. Leading zeroes are not used.

Secondary functions not related to the loop's primary variable are assigned different loop numbers. Motor current and seal water flow are common examples.

All devices are assigned identification letters according to ANSI/ISA-5.1 Table 4.1. ISA identification letters combine with the loop number to form a unique identifier or "tag name" for each device. When this system would assign the same tag name to multiple devices, suffixes are used:

- When a loop includes multiple parallel devices that measure or manipulate the same variable, the devices and signals use the same loop number with unique letter suffixes, e.g. LIT-100A, LIT-100B, LIT-100C. This is common with wet well LITs and other applications where redundancy is required.
- When a loop includes multiple series devices that manipulate or display the same variable in different locations, the devices and signals use the same loop number with unique number suffixes separated by a dash, e.g. PI-200-1, PI-200-2, PI-200-2. This is not common, mainly seen with analog displays.

Assigning ISA identification letters is usually a straightforward process, but some devices do not have obvious letter combinations. Table 9-6 lists BES preferences for less intuitive ISA letter applications, such as PLC I/O points.

When new loop numbers are required for new equipment, the designer estimates the number of loops required (including spares) and requests a block of numbers from the BES Maintenance Planning group. Planners identify an available block of loop numbers and reserve them for the project. As part of the project as-built documentation, the designer or integrator delivers a complete list of assigned loops with descriptions to the planners so that the Master Loop List can be updated.

9.9.2. Rack/Slot/Point Numbering Convention

- Individual PLC I/O channels are referred to by their unique rack/slot/point designations. The R/S/P numbers must match the manufacturer's documentation and be consistent across all BES documents and drawings.
  - The first rack in a Modicon X80 drop is Rack 0.
  - Slot numbering begins at 0, but the CPU occupies the first slot(s). An M340 CPU occupies Slot 0, and an M580 CPU occupies Slots 0 and 1. So the first I/O card in a Modicon X80 rack will use Slot 1 or 2.
  - The first channel on a Modicon X80 I/O card is Point 0.

Table 9-6: ISA Identification Letter Preferences

\\\\\\\\\\\\\\\\\\	Description	ISA Letters	ISA Letters Description
PLC Discrete Inputs	General discrete status (e.g. RUNNING, IN REMOTE)	YY	State Convert
	Discrete position status (e.g. OPENED)	e.g. ZYO	e.g. Position Convert Open
	General alarm status (e.g. MOTOR OL, FAULT)	YA	State Alarm
	Alarm status for a specific variable (use that variable's ISA letters)	e.g. PAH	e.g. Pressure Alarm High
PLC Discrete Outputs	General discrete command (e.g. motor RUN command)	YC	State Control
	Discrete position command (e.g. valve OPEN command)	e.g. ZCO	e.g. Position Control Open
	General alarm output (not associated with a variable)	YA	State Alarm
	Alarm output for a specific variable (use that variable's ISA letters)	e.g. PAH	e.g. Pressure Alarm High
PLC Analog Inputs	Analog process variable input (use that variable's ISA letter)	e.g. LY	e.g. Level Convert
PLC Analog Outputs	Analog command for a control loop (use the loop variable's ISA letter)	e.g. FC	e.g. Flow Control
	Analog command not part of a control loop (use ISA letter, e.g. S)	e.g. SC	e.g. Speed Control
Operator Control Hardware	Buttons and switches (e.g. START and STOP buttons, L-O-R switches)	HS	Hand Switch
	Potentiometers (e.g. analog speed controls)	HC	Hand Control
Indicator Lights	General status light (e.g. RUNNING, OFF)	YL	State Light
	Position status light (e.g. OPENED)	e.g. ZLO	e.g. Position Light Open
	General alarm light (e.g. MOTOR OL, FAULT)	YA	State Alarm
	Alarm light for a specific variable (use that variable's ISA letters)	e.g. PAH	e.g. Pressure Alarm High
Analog Display Hardware	Analog display (use the variable's ISA letter)	e.g. LI	e.g. Level Indicate
	Elapsed time meter (e.g. motor run time)	KQI	Time Totalize Indicate

9.9.3. Discrete Control Wire Naming Convention

120 Vac discrete control wires are named [LN][A], where:

- [LN] is the number of the first line on the drawing where the wire appears.
- [A] is a letter that starts at A with the first unique circuit node on a line and increments after each device on the line from left to right.
    - [A] does not change at terminal blocks.
    - G, I, N, O and Q are not used for [A]. G and N are reserved for ground and neutral. I, O, and Q can be confused with the numbers 1 and 0.
- Wires that are electrically identical (i.e. part of the same circuit node) must have the same wire name.
- Neutral wires have a unique and distinctive name, usually N.
- Ground wires have a unique and distinctive name, usually G or GND.
- Terminal blocks have the same name as the wires that connect to them.

Manufacturers of some high-volume equipment like MCCs may be unable to accommodate BES wire naming preferences on their schematics and wire labels. In these cases, the manufacturer’s standard naming is acceptable with BES approval.

9.9.4. Analog Control Wire Naming Convention

24 Vdc analog current loop wires are named [W]-[XXXXX]-[YY]-[ZZ], where:

- [W] is a special letter prefix for secondary feedback signals, separate from the loop’s primary controlled variable. For example, consider a loop that measures flow in a pipe and modulates that flow with a valve.
    - Flow is the primary controlled variable. The wire names for the flow input from the flow meter and the position command to the valve (effectively a flow command) start with [XXXXX]. [W] is not used.
    - The position feedback from the valve is a secondary variable and begins with a Z- in the [W] prefix location (Z for position, using standard ISA letters).
- [XXXXX] is the loop number assigned by the designer, up to five digits.
- [YY] is a sequential number that begins at the highest-voltage point in the current loop (excluding power supply wiring) and increments each time the voltage drops, e.g. across an instrument or resistor. In other words, each node in the circuit gets a unique number. This number does not change at terminal blocks where there is no voltage drop.
    - For analog inputs, [YY] begins at 1 (after power wiring if present).
    - For analog outputs, [YY] begins at 21.
    - When there is an isolator in the loop, skip two numbers before continuing the numbering on the output of the isolator.
    - For power and common wires between the power distribution blocks / power TBs and individual loop TBs, [YY] is either VDC+ or VDCCOM.
- [ZZ] is the terminal block that the wire lands on. This number is different at each end of a wire segment, because they land on different terminals.

9.10. Control System Design Drawings and Documents

Whenever a project constructs new facilities or modifies existing ones, the PCS is expanded and modified to control the new process equipment and integrate it with the existing process. New PCS equipment requires new I&C drawings and documentation, of which there are many specialized types. BES maintains example drawing and document templates, available for reference on request:

- P&ID Templates (future)
- Control Schematic Templates (future)
- Loop Diagram Templates
- PLC Network Architecture Diagram Template (future)
- Instrument Standard Details
- I/O Terminal Block Standard Details (future)
- I/O Table Template
- Control Narrative Package Template
- Control Narrative Package Template Instructions

This is not a comprehensive list of all drawing types required for every project. Some projects require drawing types not mentioned, and not every project will require drawings of every type. On small projects, some of the less complex I&C drawing types can be combined on one sheet.

When a project includes multiple pieces of equipment with identical configurations, the design drawing set may use "typical" control schematic drawings and/or loop diagrams instead of individual drawings for each piece of equipment in the set. A "typical" is an otherwise normal drawing showing the first piece of equipment in the set with all associated loop numbers, I/O points, circuit numbers, etc. as well as a table that lists all of this unique information for the other equipment in the set. For each piece of equipment in the set, it must be possible to derive all the information necessary to wire and program that equipment from the typical drawing.

Typicals must be replaced in the as-built drawing set by individual schematics and/or loop diagrams for each piece of equipment. Individual device schematics and loop diagrams are as-built on a loop-by-loop basis, and their drawing numbers correspond to the loop numbers of the devices e.g. E1234 or I1234 for loop 1234.

9.10.1. Piping and Instrumentation Diagrams

BES P&IDs are divided into two major regions. The main “field” region of the drawing shows all piping, equipment, control elements, instruments, LCPs, and MCCs in the process area. Equipment control panels are depicted as rectangles and labeled with their BES equipment name. All hand switches, indicators, hardware interlocks, and signals entering and leaving each panel are shown.

A smaller region at the top of the drawing shows PLC and SCADA functions. Every PLC I/O point and corresponding hardwired I/O signal is shown in this region. Major alarms, software interlocks, and controllers are shown, but it is not necessary to show every PLC function in detail.

- Use BES 10 pt. font for all text in the body of the drawing.
- Use BES 12 pt. font for general sheet notes and sheet key notes.
- Use ISA S5.1, S5.3, S5.4, and S5.5 standard symbology.
- Show equipment and panel names per BES Equipment Naming Guidelines.
- Label I&C devices with ISA identification letters and BES loop numbers.
- Depict I&C devices using ISA symbology to show function and location.
- Show all hardwired I&C signals using ISA standard line types.
- Use arrowheads to show the direction of signal flow on signal lines.
- Show all PLC I/O points individually.
- Symbols may be drawn with any orientation, but tag names and other labels must always be drawn horizontally.
- Show instrument locations accurately relative to valves and equipment.
- Show multi-function instruments with individual symbols for each function.
- Do not show sensing elements separately from transmitters unless they are installed in different locations.
- Show electrical supply voltages and pneumatic supply pressures.
- Do not show complete electrical, pneumatic, or other power supply lines to a device unless it is essential to an understanding of the device’s operation.
- Include brief notes adjacent to symbols to clarify complex functions.

9.10.2. PLC Network Architecture Diagrams

Most PLC cabinets at BES treatment plants contain a network switch to connect the PLC to the plant fiber network and integrate local process equipment with the PCS. Any project that adds a new network switch to the fiber network must include a PLC network architecture diagram. This drawing includes the new switch and PLC racks, as well as all connections and modifications to upstream and downstream switches and fiber patch panels on the local fiber ring. Different cable types (Cat 6, SM fiber, etc.) are shown with distinct line types, and a legend is included.

9.10.3. Discrete Control Schematics

PLC cabinets, LCPs, and MCCs are common examples of equipment that use 120 Vac discrete control. Discrete control schematics are drawn using the industry standard “ladder diagram” format.

- The “rail” on the left side of the drawing is the “hot” (ungrounded) rail.
- The “rail” on the right side of the drawing is the “neutral” (grounded) rail.
- Each line or “rung” of the drawing is labeled on the left side with a unique number that starts at 1 and increments by 1 with each rung. Leading zeros are not used.
- When a drawing set contains multiple separate control schematics for distinct devices, rung numbering restarts at 1 for each MCC bucket, LCP, etc.
- Control schematics for enclosures associated with a single loop number, like MCC buckets and some LCPs, are assigned drawing numbers that correspond to the loop numbers of the devices, e.g. E1234 for loop 1234.
- Loads like relay coils and indicator lamps are located on the right side of the rung, closest to the neutral rail.
- The only device that may be located between a motor run relay and the neutral rail is an OL contact from the motor’s overload relay.
- Control relays are named CR[x], where x is the number of the rung on which the relay coil is located. Special relay types and other devices may have special letter designations, like TDR[x] for a time delay relay.
- Include an English language description of each relay’s function to the right of the rung where that relay’s coil is located.
- Under each relay’s description, include a complete list of the rung numbers where that relay’s contacts are located. Indicate normally closed contacts with underlined rung numbers.
- Label each relay contact with the name of the relay to which it belongs, and the rung number where that relay’s coil is located.
- Do not use latching relays. Implement latching behavior with ladder logic.
- Wire labels must follow the BES discrete control wire naming convention.
- Show field wiring with dashed lines. Do not label field wiring on schematics.

9.10.4. Loop Diagrams

Loop diagrams show how field devices are connected to the PCS. Every loop with field devices must have a loop diagram, and all field devices and wiring for the loop appear together on the same drawing. The information on a loop diagram includes:

- The locations of all field devices
- Power wiring for all field devices
- Complete signal wiring for the entire control loop
- All terminal blocks
- PLC input terminals and rack/slot/point numbers
- Calibration and scaling data
- Model numbers
- Setpoints and Alarms

9.10.5. I/O Table

The designer or integrator prepares an expanded I/O table during construction as a supplement to the basic I/O list included with the PLC design drawings. The I/O table is an aid to PLC programming and consolidates the following information in one searchable spreadsheet that receives continual as-built updates as required:

- P&ID sheet references
- Equipment names
- ISA tag names
- Loop numbers
- I/O descriptions
- Rack/Slot/Point numbers
- Ranges and units for analog loops
- Setpoints
- Alarm descriptions, setpoints, and priority levels

9.10.6. Control Narrative Package

The control narrative package is a design document that guides and informs PLC programming. It contains all the information necessary to build a complete PLC program that automates and monitors the process in accordance with the design intent and interfaces effectively with the rest of the PCS. The control narrative is divided into two main sections:

Process Control Strategy

This is the high-level control strategy for the entire process area. Each subprocess has a subsection listing all major components and controlled equipment, their purpose, details of operation (including control modes, interlocks, and interaction with other parts of the PCS), major alarms, failure modes, historical trends, and SCADA screens.

Loop Narratives

Every control loop in the process has a detailed loop section that contains the complete set of information required to program that control loop in the PLC. This includes all instruments, control elements, and I/O points associated with the loop, as well as software functions such as PID controllers, setpoints, calculations, totalizers, interlocks, alarms, and SCADA displays and historical trends. Similar or related loops can be combined in one loop section, but the section heading must list all loop numbers and the tables must list all unique rack/slot/point info, alarms, etc. for each loop individually.

9.10.7. iFIX Screen Markups

When new equipment is added to the PCS, AST Programmers create new iFIX screens and make modifications to existing screens so that operators can monitor the new equipment and control it remotely. iFIX screen markups are provided to AST during construction as a guide to creating the new or modified screens.

iFIX screens are normally laid out similarly to the respective P&IDs, with all major equipment and process streams shown. Devices with status feedback are animated according to iFIX standard color codes. Analog process measurements are color-coded and displayed at the location in the process where they are measured.

- Provide a list of new screens and historical trends.
- Indicate where in the existing iFIX menu structure the new screens should be located, and how they should link to each other and existing screens.
- Mark up existing screens to show and link to the new equipment.
- Indicate which equipment graphics should open sub-screens or pop-ups for those devices when clicked.
- Design animations to show important process states such as liquid level in a tank, whether a trough is filling or dumping, or whether a flame is lit.
- Design status tables for complex permissive and interlock sequences.
- Show buttons for operator-entered commands.
- Show normally hidden alarm status boxes for important alarms that require operator action.

When designing new historical trends, provide a list of all variables that appear on each historical screen and suggestions for grouping and color-coding related variables. Historians should normally appear on their own dedicated screens. Do not embed trends in regular iFIX process screens unless they are very simple.

Note that the range of each variable displayed on a historian does not have to be the same as the actual range of that control loop. In cases when many trends must be displayed on one screen, consider adjusting the displayed range of some trends up or down so that they do not overlap during normal operation and the graph is easier and more intuitive to read. This is especially useful for discrete statuses.

Designing iFIX modifications is a collaborative process between the integrator, the Operations group, and AST. Confer with operators to ensure their needs for the new process area are met and to receive feedback and suggestions on the new screens.