Chapter 10 I&C (SCADA)

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Chapter 10 I&C (SCADA)

This chapter of the Design Standards and Guidelines (DSG) contains standards and design guidelines for instrumentation and control (I&C), also commonly referred to as Supervisory Control and Data Acquisition (SCADA), in the Seattle Public Utilities (SPU) drinking water, drainage, and wastewater systems. The primary audience for this chapter is SPU design engineers who design new or upgraded water, storm drainage, and wastewater infrastructure and require specific knowledge of I&C (SCADA) design. DSG standards are shown as underlined text.

The SCADA system consists of control panels with programmable logic controllers (PLC) for water or programmable automation controllers (PAC) for drainage and wastewater. These systems are used for the control of motors and valves and monitoring and alarming. These data are sent back to the Operations Control Center (OCC) as status and or alarms. This chapter consists of the following standards and guidelines:

- I&C Design Resources, Specifications, Drawings and Checklists.
- SCADA Electrical Standards – An expansion of the general electrical standards and guidelines identified in Chapter 10 that is specific to SCADA electrical designs.
- SCADA Control Panel Fabrication Standards – Identifies the hardware standards and guidelines required when designing SCADA control panels for fabrication by the City of Seattle (the City) or an outside contractor.
- SCADA Installation Standards – Identifies the standards and guidelines for installing and testing SCADA system hardware and software.
- SCADA Instrumentation Standards – This section categorizes recommended SCADA instrumentation by facility type. This section also includes standards and guidelines for specific instrumentation categorized by use in drinking water facilities or drainage and wastewater facilities.

Note: *This chapter provides guidelines for developing contract requirements where interfacing or expanding the SPU SCADA system is part of a project. Comments and ideas presented in this standard are not designed to be directly included in a contract document but to inform the project design team about what should be required.*

The SCADA electrical standards are a subset of the DSG Chapter 9, Electrical Design. I&C electrical design typically comprises low-voltage environments of 24 volts (V) DC and below and requires additional design standards and guides. For detailed discussion of basic electrical design topics, see DSG Chapter 9, Electrical Design. SPU recommends that the user review DSG Chapter 9 before referring to this chapter.

Unless specific reference is made to a particular piece of equipment, the term SCADA system will be used hereafter to mean all elements of the I&C (SCADA) system.

10.1 KEY TERMS

Abbreviations and definitions given here follow either common American usage or regulatory guidance.

10.1.1 Abbreviations

Abbreviation	Term
A	ampere
AC	alternating current
AMR	automatic meter reading
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWG	American wire gauge
CMRR	common mode rejection ratio
CSI	Construction Specifications Institute
CSO	combined sewer overflow
Cv	valve flow coefficient
dB	decibels
DC	direct current
DSG	Design Standards and Guidelines
EMI	electromagnetic interference
FAT	factory acceptance test
gpm	gallons per minute
GFI	ground fault interrupter
HMI	human machine interface
H-O-A	hand-off-auto
I&C	instrumentation and control
ICEA	Insulated Cable Engineers Association
IEEE	Institute of Electrical and Electronics Engineers
I/O	input/output
ISA	International Society of Automation
kW	kilowatt
kWh	kilowatt hour
LED	light emitting diodes
L-O-R	local-off-remote
mA	milliampere

Abbreviation	Term
MCC	motor control center
mm	millimeter
mΩ	milliohms
ms	millisecond
mV	millivolt
MTW	machine tool wire
NEC	National Electric Code
NECA	National Electrical Contractors Association
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NMRR	normal mode rejection ratios
O&M	operations and maintenance
OCC	Operations Control Center
OIU	operator interface unit
OSHA	Occupational Safety and Health Administration
ohm	unit of electrical resistance
PAC	programmable automation controller
pF	picofarad
PLC	programmable logic controller
psid	pounds per square inch differential
PRV	pressure regulating valve
PVC	polyvinyl chloride
RCM	reliability centered maintenance
RMS	root mean square
RTU	remote telemetry unit
SAT	site acceptance test
SCADA	Supervisory Control and Data Acquisition
SPG	single point ground
TCP/IP	Transmission Control Protocol/Internet Protocol
TSP	twisted shielded pair
UL	Underwriters Laboratories, Inc.
UOCC	Utility Operations Control Center
UPS	uninterruptible power supply
UVT	ultraviolet transmittance

Abbreviation	Term
V	volt
VAC	volts alternating current
VDC	voltage direct current
VFD	variable frequency drive

10.1.2 Definitions

Term	Definition
4-20mA	An analog current loop used by instrumentation for transmitting engineering values to control equipment. 4mA value would typically represent the lowest engineering unit and 20mA would represent the highest engineering unit.
calibrate	To standardize a device so that it provides a specified response to known inputs.
codes	Refers to the legal documents whose use is determined by the jurisdictions governing a project or electrical manufacturing industry codes. Codes are typically geographically dependent.
DIN Rail	35 mm metal rail used for mounting control equipment.
guidelines	Advice for preparing an engineering design. Guidelines document suggested minimum requirements and analysis of design elements to produce a coordinated set of design drawings, specifications, or lifecycle cost estimates. Design guidelines answer *what*, *why*, *when,* and *how* to apply design standards and the level of quality assurance required. See also *standards*.
hazardous areas	Class I, II or III areas as defined in NFPA 70.
highly corrosive and corrosive areas	Rooms or areas identified on the drawings where there is a varying degree of spillage or splashing of corrosive materials such as water, wastewater, or chemical solutions; or chronic exposure to corrosive, caustic, or acidic agents; chemicals, chemical fumes, or chemical mixtures.
human machine interface	Computer systems used as an interface between utility operations staff and SCADA system.
I/O	The collection of input and output (I&O) signals connected to a site's PLC or remote telemetry unit (RTU). The signals are provided by instruments and control components at the site.
intrinsically safe circuit	A circuit in which any spark or thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air under test conditions as prescribed in UL 698A.
I&C	The terms I&C (instrumentation and control) and SCADA are interchangeable in the context of this design guide.
OIU	Field-panel-mounted graphical operator interface unit.
outdoor area	Exterior locations where the equipment is normally exposed to the weather and including below grade structures, such as vaults, manholes, handholes and in-ground pump stations.
operations optimization applications	Software applications developed by SPU for identifying the most cost-effective methods of delivering water to customers.
PAC	Programmable automation controller (PAC) is a programmable microprocessor-based device that is used for discrete manufacturing, process control, and remote monitoring applications. Designed for use in rugged, industrial environments, PACs combine the functions of a

Term	Definition
	programmable logic controller (PLC) with the greater flexibility of a personal computer. They are also more easily set up for data collection and integration with the company's business applications than are PLCs. One major difference between a PLC and a PAC is the programming interface. Most PLCs are programmed in a graphical representation of coils and contacts called Ladder Logic. Most PACs are programmed in a modern programming language such as C or C++.
PLC	A PLC is an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices.
references	Sources of content and include sufficient detail (e.g., document, section, and table number and/or title) that the user can easily refer to the source. The National Electrical Code (NEC) and National Electrical Manufacturers Association (NEMA) documents are frequent references in this chapter.
regulations	Legal design standards that must be incorporated into the design. Examples include Occupational Safety and Health Administration (OSHA) requirements and the Americans with Disabilities Act (ADA).
RCM	Reliability centered maintenance (RCM) is a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context.
SCADA	Supervisory Control and Data Acquisition (SCADA) is a term that refers to an entire industrial control system that consists of instrumentation, communications, PLC automation equipment, and human machine interface (HMI) computer systems. The term I&C (instrumentation and control) and SCADA are interchangeable in the context of this design guide.
SCADA communications	SCADA communications refers to the methods of transmission of data between facilities that are part of the SCADA system. SCADA communications can travel over telecommunication landlines and wireless radio networks.
SCADA database	A collection of tags that are entered into the SCADA system's real-time database.
standards	For the DSG, the word *standard*, refers to the following: drawings, technical or material specifications, and minimum requirements needed to design a particular improvement. A design standard is adopted by the department and generally meets the functional and operational requirements at the lowest lifecycle cost. It serves as a reference for evaluating proposals from developers and contractors. For a standard, the word must refer to a mandatory requirement. The is used to denote a flexible requirement that is mandatory only under certain conditions.
tag	A name within a SCADA database that uniquely defines data used by the SCADA system. A tag has a number of attributes that, together, completely define the tag.
UOCC	Utility Operations Control Center. SPU facility used for supervisory monitoring and control of SPU utility operations via the SCADA HMI Systems.

10.2 GENERAL INFORMATION

SPU I&C (also known as SCADA) design is project specific and applied to a variety of facility types. The role of the I&C design engineer varies accordingly. This section provides general background information on design elements and design resources.

10.2.1 SPU Facility Types

SPU builds, operates, and maintains all water, drainage, wastewater, and solid waste facilities for the City. These include two large water treatment plants at the Tolt and Cedar watersheds, which are operated by private companies under long-term contracts. SPU's support facilities include North and South operations centers, server rooms, storage structures, pump stations, and other maintenance facilities and labs. For more information, see the relevant chapters in this DSG for each type of facility.

10.2.2 DGS Design Resources

DSG design resources include standard specifications, drawings, typical instrument installation details, and other technical guidelines found only in the DSG. In general, specifications spell out the level of quality expected, while the drawings and schedules indicate quantities, dimensions, and sizes. The following design resources are available from this chapter.

10.2.2.1 Technical Specifications

DSG standard technical specifications for I&C design describe SPU requirements for products and installation and quality control measures for checking the products and for construction. They are presented in Construction Specifications Institute (CSI) Master Format 2004. I&C specifications make up only a portion of the complete specifications for a project.

I&C technical specifications are:

Division 40 - Process Integration

- 40 90 00 Instrumentation for Process Control: Basic Requirements
- 40 90 00a Loop Check-Out Sheet
- 40 90 00b Instrument Certification Sheet
- 40 90 00c Final Control Element Certification Sheet
- 40 90 05 Control Loop Descriptions
- 40 91 10 Primary Elements and Transmitters
- 40 94 43 PAC Control System
- 40 97 00 Control Auxiliaries
- 40 98 00 Control Panels and Enclosures
- 40 99 00 Surge Protection Devices (SPD) for Instrumentation and Control

The DSG Standard Specifications examples for I&C Design are available in **Appendix 10A - I&C Design Specifications Examples**.

10.2.2.2 Drawings

I&C drawings must be consistent with and reference other related discipline drawings: mechanical, electrical, structural, and civil drawings.

For an example of Standard SPU I&C drawings and details, see **Appendix 10B - Example Set of Standard SPU I&C Drawings and Details**.

10.2.2.3 Design Checklists

Design checklists provide guidelines and requirements for the design process. Design checklists should be made part of the quality assurance (QA) and quality control (QC) process for all SPU projects that include I&C components and should be filed with other project documents.

For an example set of Standard SPU I&C design checklists, see **Appendix 10C - Example Set of Standard SPU I&C Design Checklists**.

10.3 GENERAL REQUIREMENTS

Design engineer should consider industry standards and code requirements. If industry standards and City requirements conflict, the design engineer must discuss any discrepancy with the line-of-business owner, Facilities and Operations and Maintenance (O&M) manager, and owner of this DSG chapter.

10.3.1 Standards and Industry Codes

This DSG chapter contains procedures and standards for designing facilities and components in SPU's system, including relevant installation details and specifications. They also incorporate or reference other standards that must be followed, such as City policies, local building codes, state regulations, and industry standards developed by organizations such as the American National Standards Institute (ANSI), the International Society of Automation (ISA), and the National Fire Protection Association (NFPA) (see Table 10-1).

It is the responsibility of designers to ensure that they are following all applicable codes and standards. Appropriate codes must be verified with the project manager, architect, and local building official.

Table 10-1
Industry Standards and International and National Codes used in I&C design

Organization	Standard	Description
Industry Standards		
ANSI		American National Standards Association
IEEE		Institute of Electrical and Electronics Engineers
IEEE	Standard 446	Emergency and Standby Power
ISA		International Society of Automation
ISA	S5.1	Instrumentation Symbols and Identification
ISA	S5.3	Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems
ISA	S5.4	Standard Instrument Loop Diagrams
ISA	S20	Standard Specification Forms for Process Measurement and Control Instruments, Primary Elements and Control Valves
OSHA		Occupational Safety and Health Administration

Organization	Standard	Description
UL		Underwriters Laboratories, Inc.
UL	913	Standard for Safety, Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1, Hazardous (Classified) Locations
UL	698A	Standards for Intrinsic Safety
UL	508A	Industrial Control Panels
International and National Codes		
CSA		Canadian Standards Association
NEMA		National Electrical Manufacturers Association
NEMA	250	Enclosures for Electrical Equipment (1,000V Maximum)
NFPA	70	National Electric Code (NEC)
NEC	Section 500	Hazardous (Classified) Locations, Classes I, II, and III, Divisions 1 and 2
NFPA	820	Standard for Fire Protection in Wastewater Treatment and Collection Facilities
NIST		National Institute of Standards and Technology
IBC		International Building Code
SBC		Seattle Building Code
UBC		Uniform Building Code
UL		Underwriters Laboratories, Inc.

10.4 DESIGN PROCESS

For a general discussion of the SPU design process, see *DSG Chapter 1, Design Process*. This section describes additional information for I&C design.

Typical design process involves an I&C engineer in the following phases:

- Planning and Initiation
- 30% Design
- 60% Design
- 90% Design

10.4.1 Planning and Initiation

An I&C engineer is usually involved in SPU's Capital Improvement Project (CIP) planning and initiation stage, during which the following activities are performed:

1. Identify design criteria, including a list of applicable codes and the authorities having jurisdiction; project-specific design criteria are documented.

2. Strategy development:
    a. Develop overall control strategy, including level of instrumentation, automation, and system architecture.
    b. Develop overall strategy for data management and reporting:
        i. Data output for regulatory reporting
        ii. Archiving for historical purposes
        iii. Process management reporting
        iv. Computerized maintenance system
        v. Alarm management
        vi. Online O&M manual
    c. Develop overall strategy for integration with SPU SCADA system.
    d. Develop typical drawings:
        i. Equipment plant control
        ii. Loop designations
    e. Develop P&ID legend sheet.
3. Prepare planning-level cost estimate.
4. Scope project:
    a. Develop/update list of I&C drawings.
    b. Define requirements for accommodating future expansions.
    c. Identify responsibility for remediation of existing code non-conformance conditions.
    d. Conservatively determine dimensional requirements for layout of control rooms and coordinate with design team.
5. Identify, tag, and number equipment:
    a. Collect/prepare preliminary copies of equipment data sheets & equipment list:
        i. Design requirements (e.g., pump system curves)
        ii. Equipment size
        iii. Weight
        iv. Alternative manufacturers
        v. Electrical requirements
        vi. Control description
        vii. Catalog cuts and information
        viii. Other utility requirements (e.g., air, water, other)
6. Preliminary Design Report:
    a. Prepare design basis memorandum that describes the design concepts, design criteria, and facilities.

10.4.2 30% Design

The following activities are performed by I&C engineers during 30% design stage:

1. Equipment Definition and Tag Numbering:
    b. In conjunction with process mechanical, develop a list of primary elements and prepare equipment data sheets and catalogue cuts.
    c. Develop equipment/instrument tag numbering, naming, and abbreviation conventions.
2. Process Flow Diagrams:
    a. In conjunction with mechanical processes, prepare a process flow diagram for each system.
3. Control System Configuration:
    a. Select control system concept for implementation.
    b. Select control system configuration (local control panels, PLC-based controls, or DCS-based controls).
    c. Develop control system block diagram:
        i. Evaluate compatibility of existing controls/instrumentation with new design.
        ii. Draft SCADA network schematic.
4. Control System Development:
    a. In conjunction with process mechanical/heating, ventilation, and air conditioning (HVAC) and electrical, prepare a written operational, monitoring, and control description for each unit process.
    b. Develop typical control descriptions for valves, pumps, and adjustable speed drives.
    c. Prepare preliminary input/output (I/O) list.
    d. Size and locate I/O locations for control system.
    e. Draft I/O point (P&ID) details.
    f. Draft PLC control panel control wiring.
5. P&ID and Control Drawings:
    a. Prepare preliminary P&ID drawings, including loop numbers, instrumentation, and I/O.
    b. Prepare preliminary typical control diagrams/loop diagram for each type of control scheme to be used.
    c. Draft P&ID (with spec section called out).
    d. Draft PLC power distribution schematic.
6. Design Coordination:
    a. Finalize control strategy.
    b. Review P&IDs and block diagrams.
    c. Coordinate with design team to finalize selection of instruments and size requirements.
    d. Coordinate with design team to identify I/O requirements for vendor-furnished and other local control panels.

   e. Coordinate with electrical to define power and wiring needs for I&C system equipment.
   f. Coordinate with HVAC regarding control system requirements.
   g. Provide control system component heat loads to HVAC.
   h. Identify special requirements for interface with existing facilities (connections to existing equipment/facilities, provisions for construction/installation sequencing).
   i. Identify specific requirements for coordination with special systems, including security/fire alarm & CCTV systems.
   j. Transmit preliminary I/O list to process and electrical engineers.
   k. Provide sizing of control panels, control system enclosures, and uninterruptible power supplies as required.
   l. Locate control panels/instruments on mechanical and electrical drawings.
   m. Coordinate control and electrical room needs with electrical and architectural disciplines. Verify final room sizes.
   n. Review material selection and enclosure design with corrosion engineer.
   o. Identify software procurement and development requirements.
   p. Identify who will be responsible for programming and the contracting mechanism to be used for the programming work.
7. Specifications:
   a. Prepare specification list.
8. Drawings:
   a. Confirm final drawing list.
9. Implementation Plan:
   a. Identify and document key issues, constraints or sequencing requirements that could impact the construction sequence and schedule.
   b. Develop pseudocode that will be used to convert to program in PLC/PAC
10. 30% Design Submittal:
    a. Assemble documents for inclusion in 30% design submittal (per contract requirements).
11. Coordinate with ITD for the need to access SCADA system for commissioning/testing to prevent cyber security hacking.
12. Confirm the communication bandwidth needs for current and future design/installation.

10.4.2.1 Process Hazard Analysis

Process Hazard Analysis (PHA) ensures that process equipment is not under-protected, and that process hazards are fully identified, and that an appropriate interlock is applied. Interlocking devices are factory fitted with screw terminals or wire landing contacts that are integrated into the relay logic of the local electrical control system. Devices are fitted with dry or auxiliary parallel contacts to support remote status monitoring.

Examples of Acceptable Process Interlocks:

- Safety interlocks:
  - Combination of logical and electromechanical interlock to protect a worker from the machine.
  - Combination of logical and electromechanical interlocks that protect equipment from contamination and damage.
- Non-Safe interlocks:
  - Protecting equipment from unintended operation:
  - Electrical--Current limiting devices such as thermomagnetic overload
  - Logical--Software dependent instruction in the PAC/PLC code
  - Mechanical--Reversing motor starters mechanically linked

Examples of unacceptable interlocks:

- Logical interlocks residing as software code in the PAC/PLC applied as a single interlocking element of a system.
- Mechanical and electromechanical interlocks that don't support monitoring.
- Typical applied safety interlocking elements:
  - Thermal overloads
  - Temperature switches
  - Pressure switches
  - Flow switches
  - Limit switches
  - Float switches
  - E-STOPS
  - Safety pull strings

Exceptions:

- Integrated device interlocks such as those configured on Variable Frequency Drives, Actuators and general devices that support built-in user configurable locking settings.
- Standards applicable to all hazardous process: ISA-TR84.00.03-2019, ANSI/ISA-61511-1-2018, IEC 61511-1:2016, OSHA PSM {29 CFR 1910.119}, EPA RMP 40 CFR Part 68 covered chemicals

10.4.3 60% Design

At 60% design stage I&C design should be mostly completed. Below are the tasks to be performed at this stage:

1. Equipment Definition and Tag Numbering:
   a. Verify/update equipment data sheets.
   b. Verify instrument size requirements.
   c. Add and coordinate any remaining tag numbers.
2. Control System Configuration:
   a. Finalize control system block diagram.
   b. Draft SCADA network schematic.

    c. Draft communication diagram.
3. Control System Development:
    a. Update and finalize control descriptions.
    b. Finalize control interface provisions with existing systems.
    c. Draft SCADA block diagram.
    d. Final PLC control panel control wiring.
4. P&ID and Control Drawings:
    a. Finalize P&IDs.
    b. Check P&IDs and other I&C sheets for uniformity of presentation and conformance to standards, including both graphical and technical detail.
    c. Finalize control/loop diagrams.
    d. Prepare instrumentation installation drawings.
    e. Prepare all miscellaneous I&C drawings.
    f. Draft I/O point (P&ID) details.
    g. Final P&ID (spec section called out).
    h. Final PLC power distribution schematic.
5. Space Requirements:
    a. Finalize layouts of control rooms.
    b. Finalize locations and sizes of all control panels.
6. Design Coordination:
    a. Review P&IDs with process mechanical, HVAC and electrical engineers.
    b. Coordinate final I/O list with process mechanical, HVAC and electrical engineers.
    c. Coordinate power supply and field wiring requirements with electrical engineer.
    d. Check field panel locations and sizes to ensure convenient operator access.
    e. Check for physical conflicts.
    f. Review actuator and package control system specifications.
    g. Review equipment specifications with control sections.
7. Incorporation of PDR and 30% Review Comments:
    a. Resolve all QC comments on the preliminary design report.
    b. Respond in writing to all major review comments.
    c. Incorporate accepted comments and coordinate with other affected disciplines.
8. Specifications:
    a. Edit technical specifications to produce initial draft.
    b. Prepare instrument lists, panel schedules, and loop specifications.
    c. Submit draft specifications to prospective manufacturers & suppliers for review and comment.
9. Drawings:
    a. Review final drawing list and identify variances from original scope assumptions.
10. Implementation Plan:

   a. Provide input to the overall construction sequencing plan and schedule for the project.
   b. Provide input to the sequence of work specification.
11. 60% Design Submittal:
   a. Assemble documents for inclusion in 60% design submittal (per contract requirements).
12. Finalize Pseudocode that is used to convert to program in PLC/PAC

10.4.3.1 Control Loop Descriptions

The design engineer shall format the process control strategy by distributing each instrument cluster or clusters within structures with unique control loop identifiers typical of the physical and procedural models were equipment control and steps in operations are defined and given unique loop identifiers. In some instances, where a single instrument occupies a structure then a single loop number is allocated to the descriptive functioning of that instrument. The design engineer shall coordinate with the owner to align project control loop descriptions with established standard formatting. In general, the objective of this scope is to stablish consistency on bridging document content, document flow in supporting programming development and system integration.

Examples of acceptable control loop descriptions:

- Control loop descriptions are in numerical order.
- Control loop descriptions shall contain detailed language of the process to support the programming functions, Alarm thresholds and setpoints.
- Each loop description contains details on the combined instrument cluster required for normal operation and monitoring of the process.
- Each loop has definitions of instruments with locking and permissive functionality.
- Each loop has setpoint tables such as pump call etc. as required by the process.
- Each instrument supporting range and span configuration as a specified range, span, and as required compensatory offset.
- Each control loop description can be easily bridged/crossed referenced back to the project specification, P&ID and Loop drawing package.
- Contents of each control loop when applicable shall include references to P&ID tags or instrument addresses as it pertains to the project I/O schedule.
- A project I/O schedule limited to field instrumentation.
- Control loop defines normal and not normal operating conditions.
- Control loops defines monitoring and control requirements.
- Control loops are in alignment with front end system where all three alarming fields H, HH, and HHH thresholds are defined in advanced by the design engineer per instrument.

Examples of unacceptable control loop descriptions:

- Control loops are not cross referencing to P&ID and Loop drawings.
- Control loops are not organized by number.
- A single control loop description for multiple instrument clusters within multiple structures.

- Undefined field instrumentation I/O.
- Undefined interlock definitions.
- High level descriptions of the process.
- Undefined alarm thresholds.
  - Undefined process permissive
- Typical control loop description:
- SPU Drainage and wastewater systems.

Exceptions:

- None

Standards:

- IEC 61131, IEC 62443, IEC 61499, IEC 61850 SCADA, IEC 62264, IEC 61512-1, ISA 88

10.4.3.2 Instrument Location and Layout Plans

An Instrument Location Plan provides a visual representation of the physical layout of the instrumentation and control devices distributed throughout a facility or structures within a campus. It leverages civil, mechanical, and electrical drawings to superimpose and document the instrument mounting location with respect to the facility, structure, or campus as well as facilitating maintenance planning activities.

The visual arrangement of an instrument in a process area is included in the Instrument Location Layout that shows instrument locations in regard to the equipment, structure, machine, or wider campus.

Example of an acceptable instrument plan:

- Instrument location plan displays each instrument's precise location with respect to the equipment.
- Instrument location plan has instrumentation requiring interphase to the local controller.
- Instrument location plan incorporates auxiliary equipment to accommodate mechanical gauges.
- Symbols for Analog, Discrete and Analyzer type devices are segregated with unique tag and number.
- Instrument location plan has mounting elevations and tag number.
- It provides a map of the control system, allowing engineers and technicians to quickly locate and identify individual instruments and control devices.
- It helps to ensure that the control system is properly designed and installed, by providing a clear and accurate representation of the locations and functions of the various instrument signal distances to the controller.
- It aids in the maintenance and troubleshooting of the control system, by providing a clear overview of the various components and their interconnections.
- It serves as a reference for ongoing operations and maintenance of the control system, providing a clear and detailed record of the instrumentation and control devices in the system.

Examples of unacceptable instrument plan:

- Instrumentation design package does not include an instrumentation location plan.
- Instrumentation location plan is missing mounting elevations and tags.

Typical instrument plan:

Instrument locations are marked with a unique symbol identifying the various types of instrument and signals.

Instrument location plan tagging conventions where the same instrument element is consistently identified throughout the design documents.

Exceptions:

- None

Standards:

- ISO 10628:1997, ISA 5.1, ISA 5.7 ISA 5.4

Figure 10-1
Typical Pressure Regulation Station Vault Plan

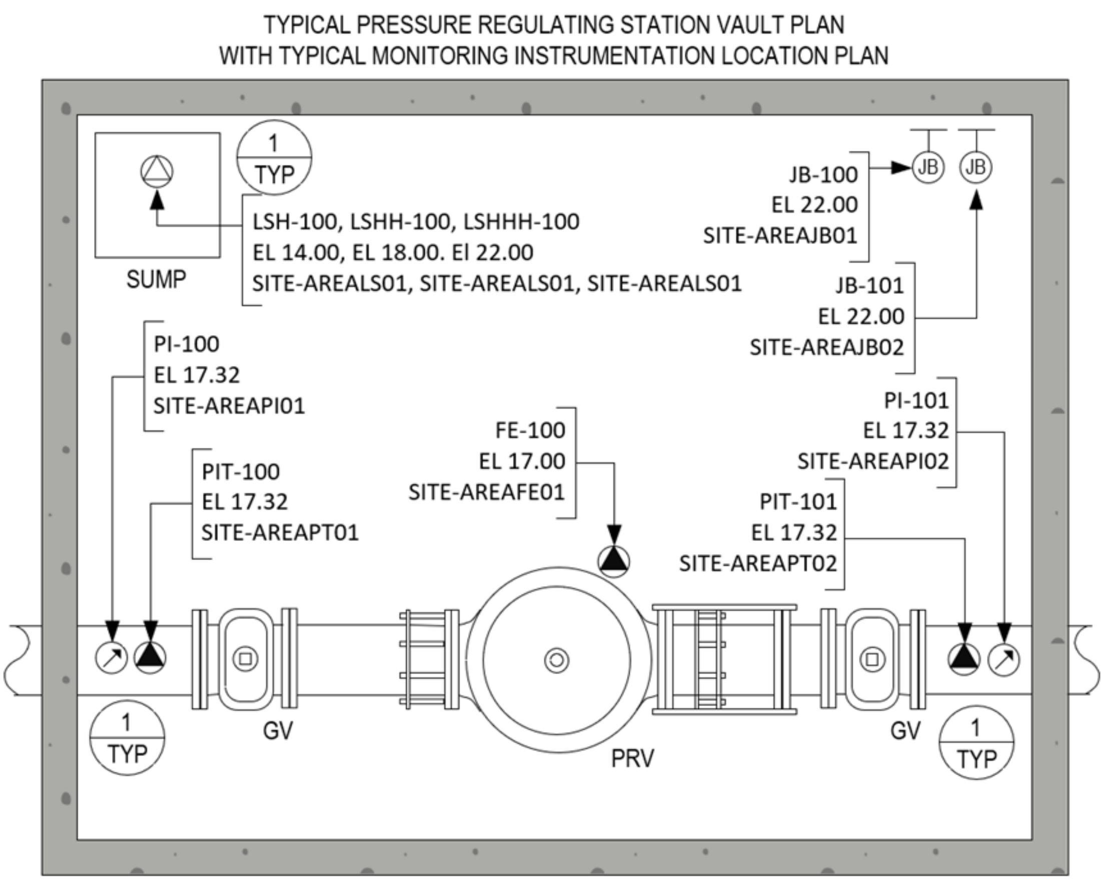
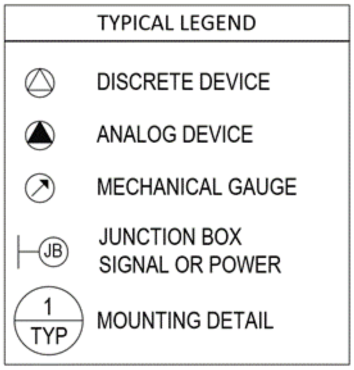


Figure 10-2
Typical Instrument Location Plan Legend



10.4.3.3 Process Flow Diagrams

Process Flow Diagrams (PFDs) are used in instrumentation and process control design. They illustrate a practical process that to show the total interconnections of process equipment, but omit details such as instrument signal lines and auxiliary instrument connections.

Example of acceptable process flow diagrams:

- Symbols for Analog, Discrete and Analyzer type devices are segregated with unique identifiers.

Examples of unacceptable process flow diagrams:

- Multipurpose P&ID drawing intended to capture all instrumentation and monitoring requirements of a process.
- A civil or mechanical rendering intended to be the process flow diagram.
- Typical process flow diagrams:
- The PFD is a schematic representation of the total production process. P&IDs provide a detailed schematic representation of the connectivity/network between all equipment, fittings, pipes, valves, and instruments.

Exceptions:

- None

Standards:

- ISO 10628:1997, ISA 5.1, ISA 5.4, ISA 5.7

Figure 10-3
Typical P&ID Vs. PFD Comparison

P & ID Shows	PFD Shows
• More information regarding piping and safety relief valves than process flow diagrams. • Minor piping systems or other minor components • Controllers, valve types and the materials of construction • Stream flows and compositions • No Operating Conditions	• Does not include minor piping systems or other minor components • Exactly what a process does during an operation • Connectivity and relationships between the major equipment and materials in a process. • Operating Conditions

10.4.4 90% Design

The following activities are typical for 90% I&C design stage:

1. P&ID and Control Drawings:
    a. Complete details.
    b. Review and update all P&ID and control drawings to reflect any project changes.
    c. Final I/O point (P&ID) details.
    d. Final P&ID (spec section called out).
    e. Final PLC control panel control wiring.
2. Design Coordination:
    a. Cross check all I&C drawings for consistency.
    b. Check I&C drawings against equipment specifications and electrical plans to verify I/O requirements & provisions.
    c. Check panel locations for physical conflicts and access.
3. Incorporation of 60% Review Comments:
    a. Resolve all QC and stakeholder comments on the 60% submittal.
    b. Respond in writing to all major review comments.
    c. Incorporate accepted comments and coordinate with other affected disciplines.
4. Specifications:
    a. Finalize I&C specifications.
5. Implementation Plan:
    a. Finalize construction sequencing specification with respect to electrical facilities.
6. 90% Design Submittal:
    a. Assemble documents for inclusion in 90% design submittal (per contract requirements).

10.4.4.1 Process Flow Diagrams

Process Flow Diagrams (PFDs) are used in instrumentation and process control design. They illustrate a practical process that to show the total interconnections of process equipment, but omit details such as instrument signal lines and auxiliary instrument connections.

Example of acceptable process flow diagrams:

- Symbols for Analog, Discrete and Analyzer type devices are segregated with unique identifiers.

Examples of unacceptable process flow diagrams:

- Multipurpose P&ID drawing intended to capture all instrumentation and monitoring requirements of a process.
- A civil or mechanical rendering intended to be the process flow diagram.

Typical process flow diagrams:

- The PFD is a schematic representation of the total production process. P&IDs provide a detailed schematic representation of the connectivity/network between all equipment, fittings, pipes, valves, and instruments.

Exceptions:

- None

Standards:

- ISO 10628:1997, ISA 5.1, ISA 5.4, ISA 5.7

Figure 10-4
Typical P&ID vs PFD Comparison

P & ID Shows	PFD Shows
• More information regarding piping and safety relief valves than process flow diagrams. • Minor piping systems or other minor components • Controllers, valve types and the materials of construction • Stream flows and compositions • No Operating Conditions	• Does not include minor piping systems or other minor components • Exactly what a process does during an operation • Connectivity and relationships between the major equipment and materials in a process. • Operating Conditions

10.4.4.2 Piping and Instrumentation Diagrams

Piping and Instrument Diagrams (P&IDs) are based on design best practices and standards as defined in ANSI/ISA-5.1, ISO14617-6, ISO10628, PIP PIC001, and owner approved instrument symbols. P&IDs minimize documentation one-offs, and establish a uniform means of depicting and identifying instruments with their inherent functions across water and wastewater facilities.

Examples of acceptable P&ID drawing package content:

- Instrument layout plan
- Process flow diagram with structure elevations. Describes what the process in conjunction with this facility does.
- Project specific symbols legend

- Left to right reading of pictorial elements.
- P&ID contains a maximum of 32 tags/graphical symbols of mixed analog or discrete elements per sheet.
- P&ID element/symbol signal connecting upward vertically to the PAC/PLC controller. The connecting signal path mush be shown as it passes through the applicable junctions, interlocks and enclosures up to the final destination at the PAC/PLC, and sub junctions.
- P&ID contains a listing and definitions of process interlocks.
- P&ID contains a listing and definition of process permissive where the combined safe operation of a process is supported by a cluster or a single physical sensor. A combined permissive will need to be defined to support its integration in to the controller logic.
- P&ID contains a Local Area Network diagram of devices supporting serial or ethernet communication.
- Best effort to draw up P&IDs with the project civil, electrical and mechanical process.
- Technical sheet text minimal front size 8 excluding sheet frames.

Examples of unacceptable P&ID drawings:

- Combinations of asset IDs with PI&D tags
- One-off custom tag designations
- Overcrowded signal loops and hard to follow P&ID
- High-level modularized rendering not in alignment with project civil, electrical, and mechanical drawings.
- Font too small to read.

Typical P&ID’s:

- SPU Drainage and Wastewater systems.

Exceptions:

- None

Standards:

- ISA 5.1, ISA 5.4, ISA 5.7

10.4.4.3 Loop Drawings

Instrumentation Loops define all necessary hardware and software necessary to describe measurements, communications, and control of a process variable. Loop drawings are extensions of P&ID’s.

Loop drawings follow best practices as defined by ISA 5.4. The standard provides a uniform method for diagramming the physical interconnections of looped instruments as well as other information about instrument installation.

Examples of acceptable loop drawings:

- Loop drawing design sheet set contains Panel component layout, Panel bill of materials, Panel network diagram, Instrument loop terminations, Ancillary device terminations, I/O schedule, Panel wire termination schedule, Instrument elevation, instrument offset and instrument mounting details.

- Loop drawing design sheet set contains Panel component layout, Panel bill of materials, Panel network diagram, Instrument loop terminations, Ancillary device terminations, I/O schedule, Panel wire termination schedule, Instrument elevation, instrument offset and instrument mounting details.
- Each sheet shall not contain more than 8 loops (I/O points terminations) interfaced to the PAC/PLC controller I/O module.
- Loops traversing through junction boxes, structures, marshaling units, and control cabinets where a signal shall be identified and shown in the drawing as loop junctions.
- Each analog device shall be represented with a suitable process P&ID symbol, tag and instrument measuring range.
- Each analog loop shall contain terminal number, conduit ID, wire tag, instrument tag, instrument range, instrument polarity, instrument threshold alarms, and functioning P&ID symbol.

Examples of unacceptable loop drawings:

- Loop drawings are not electrical diagrams.
- Loop drawings are missing junction hops.
- Loop drawings are missing terminal number, conduit ID, wire tag, instrument tag, instrument range, instrument polarity, instrument threshold alarms, and functioning P&ID symbol.
- Loop drawings are not printout of the controller I/O rack.

Typical loop drawings:

- SPU Drainage and Wastewater systems.

Exceptions:

- None

Standards:

- ISA 5.1, ISA 5.4, ANSI/ISA-62382-2012, IEC 62382.

10.4.5 Design Checklist

Checklists are used to verify that required information is included in each design phase. For the detailed checklists for I&C design at SPU, see **Appendix 10C - Example Set of Standard SPU I&C Design Checklists**.

10.5 SCADA ELECTRICAL STANDARDS

This section identifies electrical standards that are specific to SPU SCADA systems design and implementation. The electrical standards identified in this section are an expansion of the SPU electrical standards presented in *DSG Chapter 9, Electrical Design* that are specific to SCADA equipment design.

10.5.1 Power Requirements

Providing power that is free from voltage fluctuations and power outages for the SCADA system is critical. Voltage fluctuations and outages can cause output errors, data loss, equipment damage, and other problems. High-speed transients can damage memories, power supplies, and semiconductor components. Transients can also cause data errors in instrumentation, communication, and computing devices.

Typical electrical utility problems include load switching, load shedding, accidents, and brownouts. Normal power network switching by a local electrical utility can cause several hundred outages per year, each lasting a fraction of a second or more. The inability of utilities to meet power demands in peak periods forces them to schedule "brownouts" (i.e. a planned 3%, 5%, or 8% voltage reduction at the generating point). Such a major reduction could take the computer's voltage below its lower operating limit. On-site power generation has many of the problems mentioned above, plus capacity limitations and frequency stability difficulties.

Typical electrical power requirements for most control system servers, workstations, and PLCs are 120 volts alternating current (VAC), ± 10%, measured at the equipment connections. This is important because voltage drops along the line from the service entrance to the equipment can cause up to a 9% loss. Also, large loads coming on line can drive voltage down 20% or more for periods up to 30 minutes.

Various types of devices may be installed to clean up line power, eliminate noise, and provide backup power in emergencies. These include isolation transformers, voltage regulators, line conditioners, uninterruptible power supplies, and motor generator sets.

Use the following guidelines when setting up a power source for an SPU SCADA system:

- Primary power should come from the most reliable source available.
- The second power feed, if available, should come from a completely separate source.
- PLCs should have battery backup or standby power. It is important to consider the size and power requirements of PLCs when using batteries as backup.
- The SCADA system, including instrumentation power supplies, should be the only equipment fed from the particular branch feeder service.
- Each instrument or power feed from the PLC power supply should have its own circuit protection utilizing a fused terminal connection with a blown fuse indicator.
- Do not route the branch circuit close to other lines that supply noise-generating equipment. If circuits must run close together, keep parallel paths as short as possible (and where possible, route at a 90˚angle).
- The power source should be selected to:
  - Reduce the effect of devices turning on and off
  - Supply lighting loads rather than equipment loads
- The feeder where the branch circuits originate should have enough capacity to accommodate future load increases.

- All of the workstations, communications equipment and servers should be on the same power system.
- Avoid using the power conditioned and distributed to SCADA equipment for supplying other non-SCADA related equipment.

10.5.1.1 Isolation Transformers

To protect the SCADA system head end (workstations and servers) from high-speed transients, and high-frequency noise, an isolation transformer may be used. An isolation transformer has physically separated primary and secondary windings, and an electrostatic (Faraday) shield between the windings. The shield attenuates capacitive coupling between the windings and reduces common mode effects in the secondary winding.

Most modern shielding methods can achieve a common mode rejection ratio (CMRR) of 10,000,000:1 or 140 decibels (dB). Utilize the following specifications when selecting an isolation transformer:

- Input-to-output capacitance of 0.005 picofarad (pF) or less.
- Leakage resistance of 1,000 milliohms (mΩ) or greater between the primary and secondary windings, or between either winding and ground.

Some isolation transformers are available with normal mode rejection ratios (NMRR) of 100 dB or better. These transformers often use three shields: a primary shield, a secondary shield, and a Faraday shield between the primary and secondary shields. This configuration provides maximum noise attenuation. Some common sources of isolation transformers include:

- Sola
- Tierney
- MagnaTec
- Best Power

10.5.1.2 Voltage Regulators and Conditioners

Power line regulators try to maintain a constant voltage output despite deviations on the AC input. Regulators are available with various levels of line filtering to help reduce transients and voltage distortions.

Although several types of voltage regulators are commercially available, the ferroresonant transformer is the most effective for computer use.

The ferroresonant unit not only provides voltage regulation and line filtering, it also attenuates normal-mode noise. The device also contains fewer components than other regulator types; therefore, less maintenance is needed.

For maximum protection, an isolation transformer and a voltage regulator may be installed in tandem. Another possibility is to install a line conditioner, a device that combines the characteristics of an isolation transformer and a regulator. Such protection should be installed if line voltage fluctuations or site conditions that might cause a great deal of common-mode and normal-mode noise on the power lines are either suspected or detected. Site areas with large variable-speed motor drives are prime examples where noise on the power lines should be expected. Common manufacturers are:

- PULS
- SOLA
- Best Power

10.5.1.3 Uninterruptible Power Supplies

If low line voltage or outages regularly occur—or could have serious consequence—the installation of an uninterruptible power supply (UPS) should be considered.

The UPS to be supplied must meet the following specifications:

- Harmonic distortion of 5% or less
- Frequency regulation of 60 Hz ± 1%
- Output voltage regulation of 120V AC ± 2%

Because the AC power line may be used during inverter failure and when the UPS is being serviced, proper surge suppression equipment must be utilized on the AC line prior to the UPS. There are times when the UPS may be down for servicing or has failed and the power is being bypassed. It is important to have conditioned power or, at a minimum, proper surge suppression at all times.

10.5.1.4 Motor Generator Sets

It is also possible to combine a UPS with a diesel engine or gas turbine generator set, which allows operation even if power is off for long periods. The UPS provides enough time for the generator to start and reach optimum speed. For example, a diesel generator typically takes about 10 to 20 seconds to respond to a power failure. In such a system, the generator should have about 2.5 times the power rating of the UPS to sustain the computer and its environmental support system. In most cases, a motor generator set is only warranted if other critical loads at the site must be supported.

10.5.2 Grounding and Shielding

This section presents standards and guidelines for grounding and shielding for SCADA in the SPU system.

10.5.2.1 General

Electromagnetic Interference (EMI) is unwanted time varying transient energy consisting of electric and magnetic field disturbances. *Radiated interference* is unwanted electromagnetic energy that emanates from a source into the surrounding area. *Conducted interference* utilizes power and communication lines/channels for propagation paths.

Conducted EMI is always a potential problem within control rooms. Modern computer and data processing systems use low level signaling internally and between units. In control rooms with both heavy power circuits and low-level signal wiring, attention to electrical isolation is necessary regarding electrical grounding and shielding. Lack of attention to this area can result in serious degradation of control system operation that is often very difficult to isolate and correct once installed.

National Electric Code (NEC) Article 250 covers general requirements for grounding and bonding of electrical installations. The NEC emphasizes safety for power circuits. Additionally, the problems of crosstalk and injection of unwanted signals into low-level data circuits and equipment must be considered.

To minimize interference between various equipment groups, SPU recommends the single point ground (SPG) concept. The following definitions apply to SPG:

- Earth Ground: A high-quality earth ground of as low an impedance as practical.
- Site Reference Ground: A central ground tie point consisting of a large copper plate heavily secured to earth ground. It serves as a single reference ground point for all parts of the system and the building.
- Grounding Circuits: With SPG, several independent insulated ground circuits are established by functional usage and all are terminated at the Site Reference Ground point. Except for structural rebar ground, the individual ground system circuits must be insulated from each other except at the Site Reference termination point. Computer panel and signal grounds must never share electric power ground circuits. Typically ground system circuits are established for:
  - Electric AC neutrals
  - Electrical equipment panel/conduit grounds
  - Computer/peripheral panel grounds
  - Signal ground
  - Facility/structure ground

Site-specific ground circuits can be established in different parts of a building. For example, all computer equipment in the control room may be connected by insulated cable to an isolated ground bar located in the communications room. This bar, in turn, is then terminated to the Site Reference Ground. Similar arrangements can be made in other areas.

10.5.2.2 Grounding Guidelines

In most cases, an isolated SPG system is used with electronic instrumentation and process control computers. This means that the system's ground connects to earth at only one point. This point may be a facility ground or a dedicated ground rod. If a dedicated ground rod is used, it must connect to the equipment or facility ground to be compliant with the NEC. This connection should be at only one point.

A SPG system has grounding branches that serve various parts of the computer and instrumentation system. Major branches connect to the system ground plate, while minor branches connect to analog, digital, or rack ground buses. Each ground branch must be connected at one end only; the far ends of each ground branch must be disconnected from ground.

The system ground plate must be an isolated ¼-inch thick copper plate that is centrally located to all system components. Dimensions should be such that the plate will have enough tapped holes to accommodate all the ground buses that need to be connected.

Conduit, cable raceways, or building steel must not be used to distribute the SPG from point to point. Distribution should be through a well-insulated, dedicated wire of appropriate size.

The earth ground for a SPG system should conform to the NEC, Section 250-81 and 250-83. The buried ground should:

- Be made of good electrical conductors
- Withstand mechanical abrasion
- Provide sufficient contact area with the soil to minimize grounding resistance

Ground resistance is measured using methods outlined in Standard Handbook for Electrical Engineers, or by following procedures recommended by vendors of ground-measuring equipment.

The conductor connecting the earth ground to the system ground should be insulated and stranded copper wire, #2/0 American wire gauge (AWG). This conductor should follow the most direct path between the ground points. Sharp turns decrease the conductor's ability to carry high currents, such as those encountered when lightning strikes nearby, and should be avoided.

10.5.2.3 Grounding Programmable Logic Controller Input/Output Racks

Guidelines for setting up grounds for PLC I/O racks containing analog and digital signals are:

- Each I/O rack should have an isolated signal ground bus, 1-inch wide by ¼-inch thick, running from top to bottom next to the rack. The bus should have tapped holes to accommodate ground connections from various devices in the rack. The signal ground bus should connect to the system ground plate at only one point, via a stranded, insulated copper wire of #8 AWG or larger. If the rack contains analog and digital signals, a separate bus should be provided for each.
- The rack frame must be connected to the system ground, via a connection that is kept isolated from the signal ground bus.
- Each chassis or panel in a rack should have internal grounding lines that connect to the signal ground bus. Connections should be via ring tongue connectors that bolt to the bus. If the chassis has several types of signals that need to be grounded, such as low-level sensor signals, high-level output modules, or noisy switching circuits-each should have a separate line to the signal ground bus. Only circuits of the same voltage level should share the same ground return line.
- Rack power should be supplied through an isolation transformer or UPS. This prevents ground loops between the instrument and electrical power grounds.

10.5.2.4 Grounding Computer Components

Grounding requirements for the SCADA system computer are similar to those for the PLC I/O racks. Grounding workstations and servers require the computer ground be an integral part of the UPS or isolation transformer ground.

The following are grounding requirements for computer components:

1. The panels of the communications equipment must be connected to the system ground via a separate conductor.
2. Shell grounds for all computer peripherals or communication equipment must be connected to the system ground and not the building ground. Special orange receptacles can be used to signify an isolated ground connection for computers and the peripherals.

3. The computer ground bus (usually located with the UPS) must be connected to the system ground plate using an insulated #4 AWG (or larger) wire. The ground conductor should run in conduit, using the shortest possible path to the ground plate. This line must be separate from the panel frame ground. Follow the guidelines noted in DSG section 10.5.2.3 for the I/O signal bus ground.
4. In all cases, the computer ground bus must connect to the building ground. Electrical codes and safety require all grounds be bonded together. The computer ground should be connected to the building ground at only one place. The location of the connection should be as close to the computer system ground rod as possible.
5. A full-sized neutral should be included on each power circuit serving computer components.

10.5.3 Electrical Installation

This section reviews general provisions for installation of electrical work that must be covered in a specification. This section includes information that must be reviewed before requirements are developed and incorporated into a contract document.

10.5.3.1 Codes and Standards

The contract documents should require that all work by the Contractor conform to the applicable requirements of the current NEC NFPA 70 codes, together with the code and regulations of public utilities and all other authorities having jurisdiction where the PLC equipment is installed. Contract documents should require that all equipment be designed, constructed, installed, and tested and be in conformity with all requirements and applicable standards. For general electrical codes required for SPU electrical design and installation, see section 9.3.1 of *DSG Chapter 9, Electrical Design*. In addition to these electrical codes, Underwriters Laboratories, Inc. (UL) code compliance will be required for control system hardware and installation to pass inspection.

All materials and equipment must be listed by Underwriters' Laboratories, Inc., except for classes of materials and equipment not available with such listing. In the case of conflicting standards or codes, mediation of the most applicable code rests with the owner (SPU) and the local jurisdiction if the work is not in the City. National codes and standards take precedence when no other codes cover the work.

Note: *SPU projects, including the SCADA system, may physically reside in a jurisdiction outside the City. The local codes where the equipment is going to be located must be reviewed to ensure the installation is compliant. Codes for other jurisdictions and cities may incorporate the following standards:*

- *Institute of Electrical and Electronics Engineers (IEEE)*
- *UL*
- *National Electrical Manufacturers Association (NEMA)*
- *National Electrical Code (NEC)*
- *NFPA*
- *National Electrical Contractors Association "Standard of Installation" (NECA)*
- *Instrument Society of America (ISA)*
- *Occupational Safety and Health Administration (OSHA)*

10.5.3.2 Clearances

Clearances must be maintained in front of electrical panels and other electrical installations as required by the NEC. It is also important to maintain working clearances around electrical equipment required for proper maintenance, operation, and accessibility.

10.5.3.3 Separation of Signal and Power Circuits

This section describes measures that help prevent noise from entering the SCADA control system wires carrying low-level signals. *Signal conduits* are conduits containing 4-20 milliamperes (mA) analog signal circuits, thermocouple leads, or discrete input circuits to PLCs. Signal conduits also include conduits containing communication link cables between PLCs and remotely located I/O modules. *Power conduits* are conduits containing power, light, or control circuits operating on AC, or on direct current (DC) operating at more than 48 voltage direct current (VDC) or 20mA DC.

The following are SPU standards for signal and power conduits:

1. Signal and power conduits must be separated in accordance with Table 10-2.
2. Signal and power conduits must be separated by 3 inches minimum where runs cross. The runs must cross at right angles.

Table 10-2
SPU Standards for Signal and Power Conduit Separation

Maximum Operating Voltage VAC (RMS) or VDC	Maximum Current Amperes (RMS)	Minimum Clearance between Signal and Power Conduits (inches)
0–125	Less than 30	2
0–125	30 to 100	4
0–125	100 or more	6
125–240	Less than 100	6
125–240	100 or more	6
More than 240	Less than 100	12
More than 240	100 or more	12

Acronyms and Abbreviations
RMS: root mean square
VAC: volts alternating current
VDC: volts direct current

The following are guidelines for signal and power conduits:

- Signal conduits should be separated from equipment generating high levels of electrical noise—such as motors, solid state motor starters, transformers, and inverters—by 5 feet (ft) minimum.
- Signal circuits should not be contained in the same raceway or boxes with power, light, or control circuits.

- Signal circuits within equipment panels should be separated from power, light, or control circuits by:
  - Metal partitions
  - Containing the power, light, or control circuits in metal raceways
  - Containing the signal circuits in metal raceways

10.5.4 Contractor's Submittals

This section covers what should be included in an electrical submittal to maintain control over the final product. All submittals must be made to the project manager.

10.5.4.1 Shop Drawings

The following electrical shop drawings must be provided and defined in the contract documents as a minimum submittal list for all SPU SCADA projects:

- Overall site plans. Show exterior conduits and wiring to radio antennas, telephone poles, yard valves and meters, and all other related components.
- Interior power plans. Show interior conduits, wiring, junction boxes, all control system equipment, control panels, instruments, and all other related components.
- Interior and exterior wall elevations. Show mounting of PLCs, disconnect switches, power distribution panels, conduit connections to existing power distribution panels, light switches, emergency pull-switches in control centers, antenna feedline routing, and locations of all other electrical devices and conduit systems.
- Detail drawings for backup panel, interposing relay panel, relay control panel, and PLC assembly and installation. Include conduit entry, exterior panel elevations, interior panel elevations, device and nameplate schedules, wireway and terminal block placement, electronic module and power supply placement, fans, heaters, thermostats, filters, and all other devices.
- Elementary control and wiring diagrams for all backup panels, interposing relay panels, relay control panels, PLC panels, PLC I/O panels, and remote I/O panels.
- Elementary control diagrams for all switchgear, motor starters, and process equipment control circuits having interfaces with the project.
- Instrument loop diagrams per ISA S5.4 for all instruments, pump controls, valve and gate controls, solenoid valve controls, status contacts, and all other devices connected to PLC I/O systems. Include terminal designations for all wiring, including shields of instrumentation cables. Include wire and cable numbers.

The Contractor must provide elementary control diagrams and must use the ladder diagram format incorporating line number, operation function statement, contact location line and a description of operation of each device. Each contact must be labeled with its function, as well as its number (e.g., LSH-1, SUMP HI LEVEL). Format and symbols require SPU approval. The Contractor or integrator must show terminals for field wiring and field wiring as dashed lines.

10.5.4.2 Cable and Conduit Schedules

The Contractor must provide an instrumentation cable and conduit schedule in format acceptable to SPU, detailing each cable and conduit routing. Point-to-point conduit, wire, and cable lists in an industry standard database format for all conduit, wiring, and cabling from field devices to and from I/O panels. Include conduit, wiring, and cabling for all intermediate conduit runs to junction boxes, manholes, pull-boxes, termination panels, interposing relay panels, backup panels, and all other points of access or termination for wiring and cabling. The schedule must include database fields shown in Table 10-3 for each cable or conduit.

Table 10-3
Cable and Conduit Schedules

Cable	Conduit
Cable number	Conduit tag number
Cable type and conductor size	Conduit/raceway source
Conductor insulation color each cable conductor	Conduit/raceway destination
Instrument loop number served by each conductor group	Conduit/raceway length
Terminating instrument numbers (source and destination)	Conduit/raceway intersections name (name derived from conduits or raceways intersecting at that point)
Conductor numbers	Conduit/raceway size
Conduit number through which cable is routed	Wire sizes and types for all wires in that run
Power distribution panel schedules	Cable type and conductor sizes for all wires in that run
	Wire tag numbers for all wires in that run
	Cable tag numbers for all cables in that run
	Instrument loop numbers for all wires and cables in that run

10.5.4.3 Manuals

The specifications must require that all instruction booklets, operating manuals, and manufacturer's recommended list of spare parts and parts list be provided. The specifications should further require all information necessary to install and maintain equipment and to order replacement parts. Manufacturers' data sheets are useful for the following items:

- Cable
- Circuit breakers
- Conduit
- Control panels
- Disconnect switches
- Enclosures
- Fuse blocks
- Heat tracing system
- Indicator lights
- Lighting equipment
- Power line conditioners
- Relays
- Selector switches
- Small UPS systems
- Sockets
- Terminal blocks
- Termination panels
- Wire
- Power supplies
- Pull-boxes
- Pushbuttons

Where catalog data sheets describe more than one model or option, the Contractor should circle the item that applies, or stamp the item with a bold arrow pointing to it. In addition, the Contractor should draw a bold line through all text and pictorial information that does not apply to the item.

10.5.4.4 Submittal Approval

The specifications must require that detailed drawings, descriptive data, and other data sheets showing design information that verifies that the equipment meets the technical requirements be provided.

Information submitted for approval must include:

- Specification section and paragraph number
- Manufacturer's name and product designation or catalog number
- Electrical ratings
- Standards or specifications of ANSI, American Society for Testing Materials (ASTM), Insulated Cable Engineers Association (ICEA), IEEE, ISA, NEMA, NFPA, OSHA, UL, or other organizations, including the type, size, or other designation
- Assembly drawings in sufficient detail to identify every part of the specified equipment
- Dimensioned plan, sections, and elevations showing means for mounting, conduit connections, grounding, and showing layout of components
- Materials and finish specifications, including paints
- List of components including manufacturers' names and catalog numbers

10.6 SCADA PANEL FABRICATION STANDARDS

This section describes SPU standards for panels used by control systems and general requirements for materials, type of construction, and construction guidelines. This standard must be used for all new control panels installed in SPU facilities. This standard does not apply to and is not intended for retrofit of existing panels and/or custom panels.

10.6.1 Approved Panel Types

SCADA panel types must be compatible with and suitable for the environment of their installed location. NEMA area classification should be designated according to the environment by SPU according to NFPA/NEC regulations. Only the following NEMA types are approved for installation in SPU water and wastewater facilities:

1. **NEMA Type 4. Water Tight and Dust Tight –** Indoor and outdoor panels are intended for use indoors or outdoors to protect the enclosed equipment against splashing water, seepage of water, falling of hose-directed water, and severe external condensation.
2. **NEMA Type 4X. Water Tight**, **Dust Tight and Corrosion Resistant –** Indoor or outdoor panels have the same provisions as Type 4 panels and, in addition, are corrosion-resistant. Type 316 stainless steel boxes that utilize non-corrosive hinge and locking components must be used for outdoor locations. Use fiberglass panels for underground

chambers. Use fiberglass panels for areas with chemical exposure, such as hypochlorite facilities.

3. **NEMA Type 12. Industrial Use - Dust Tight and Drip Tight –** Indoor panels are intended for use indoors to protect the enclosed equipment against fibers, insects, lint, dust and dirt, and light splashing, seepage, dripping, and external condensation of non-corrosive liquids.

The SPU SCADA engineer must approve the use of other NEMA types on a case-by-case basis.

PLC panels, local panels, and termination panels must never be located in hazardous locations. These areas sometimes occur in water distribution systems near backup generators that utilize fuel and require fuel storage. These areas are defined by the NFPA and local codes, which may at times be more restrictive. Local panels consisting of a remote/local switch or limited start/stop control may be located in a hazardous area only if all devices and the panel are rated for the hazardous area.

10.6.1.1 Underwriters Laboratories, Inc.

Electrical equipment and material must be listed and labeled for the purpose for which it is used by UL. The equipment and control panel must be certified and labeled as compliant with UL508, Industrial Control Equipment.

10.6.2 Panel Construction

The following are SPU standards for panel construction:

1. Panels must be designed to accommodate all necessary accessories. These accessories include instrument air, power supplies, mounting hardware, terminal blocks, and any signal conditioning or conversion equipment that may be necessary to make operational all monitored and controlled equipment to be mounted in the panel.
2. Panel layout and equipment spacing must be designed to allow for device removal, calibration, and maintenance without disassembly of adjacent devices.
3. On larger panels, removable eye bolts must be provided to facilitate sling handling of each panel. Eyebolt mounting must be a part of the structural support bracing to distribute stresses and panel weight while sling handling panels during installation.
4. Standardizing on well-known suppliers such as Hoffman, B-Line, Rittal, or equal will ensure that all panels have sufficient structural reinforcements to ensure a plane surface, limit vibration and to provide rigidity during shipment, installation and operation without distortion or damage to the panel, or injury to any mounted instruments.
5. All panels must be provided with continuous flush hinges:
    a. Exterior panel doors less than 36 inches high must be equipped with a hasp and staple suitable for accepting a ⅜-inch padlock.
    b. All panel doors 36 inches high and larger must require 3-point latch assemblies with key-locking handle. The key lock assembly must be equipped with a Best Access Systems key core. Panels should be constructed of a minimum of 12-gauge steel, except for single door wall-mounted panels, which may be constructed of 14-gauge steel.

c. Interior panel doors less than 36 inches must have a single-point latch with key-locking handle.

10.6.3 Panel Mounting

There are three basic panel mounting configurations that may be specified for SPU facilities: pedestal, wall-mounted, or free-standing:

1. All pedestal-mounted panels must be specified to be constructed of a minimum of 12-gauge stainless steel. Mounting must utilize either an existing pedestal or the pedestal supplied with the panel must utilize the existing base mounting hardware.
2. Single door, wall-mounted panels must be specified up to a maximum of 48 inches high by 12 inches deep.
3. All free-standing panels must be specified to be constructed of a minimum of 12-gauge steel.

10.6.4 Panel Interior and Appurtenances

All interior panels must be specified to be primed and finished with two coats of a factory finished ANSI #61 light gray lacquer finish on all exterior surfaces. The panel interior must be white. All exterior pedestals and panels are Type 316 stainless steel.

Suitable heaters must be specified with thermostat control for condensation and freezing protection in all outdoor panels. SPU-recommended assemblies are:

- Hoffman D-AH1001A, 100-watt heater for panels under 36 inches high, or approved equal
- Appropriately sized Hoffman type D-AH heaters for larger panels, or approved equal

Exposed strip heaters are not acceptable due to UL rules regarding enclosures of heating elements.

An interior light emitting diode (LED) light fixture and a duplex ground fault interrupter (GFI) convenience outlet with on/off GFI circuit breaker for maintenance purposes must be specified for all medium and large panels, including communications and termination panels. Small handhold and junction boxes may be excluded from the requirement.

10.6.5 Panel Cooling

10.6.5.1 Maximum Temperature

All panels must have ample cooling or be sized to prevent high temperatures from shortening the life of the equipment mounted inside. The specification must prohibit any location within the panel or interior of the equipment mounted inside reaching temperatures more than 15 ˚F above the ambient temperature outside of the panel. In some cases, outdoor panels will require sun shields. The requirement for sun shields should be included in the site description details.

10.6.5.2 Intake Air Filters

If panels require air exchange for cooling, fans drawing air into the panel must be filtered. The filter surface area must be sized three times larger than the fan intake area for each fan. This sizing requirement lowers the velocity of the air moving through the filters and extends the period between filter changes.

10.6.5.3 Cooling without Air Exchange

Panels with excessive heat loads located in areas of heavy particulate contamination must be cooled without air exchange between the interior and the exterior of the panel. Either solid-state cooling equipment or refrigeration must be used to cool the panel. The heat dissipation portion of the cooling unit must be designed for use in areas with heavy particulate contamination and be capable of running extended periods without cleaning. Areas within water treatment facilities with high levels of particulate contamination may need carbon filtering or lime addition.

10.6.6 Panel Power Supply

Panel power supply refers to a number of components that provide a study supply of DC voltage to control system equipment during normal and abnormal power conditions. Power supplies are designed for industrial applications and require equipment rated for this type of application.

10.6.6.1 Surge Protection

Surge protection equipment is used to isolate AC voltage surges from reaching control system components. These devices use clamping, diversion, and restriction circuitry to isolate power surges. All devices must be DIN rail mountable. Approved manufacturers (or approved equal) include:

- Phoenix Contact PT 2-PE/S-120AC/FM
- Ditek 120/240CM+
- Cutler Hammer AGSHW CH-120N-15-XS
- EDCO HSP121BT-1RU
- MTL MA15/D/1/SI

10.6.6.2 DC Power Supply with Battery Chargers

The AC-DC power supply is used to convert AC voltage to DC voltage using a switching power supply design with a battery backup system. The battery backup system can charge backup batteries and automatically use them for backup power when AC power is lost. All devices must be DIN rail mountable. Approved manufacturers include the following:

- Puls Power
- Traco Power
- Sola Hevi-Duty
- Phoenix Contact

10.6.6.3 DC-to-DC Power Supplies

DC-DC power supplies are typically used for converting 24 VDC from the main panel power supply to lower voltages such as 12 VDC and 5 VDC. These lower voltages are sometimes required for control panel devices that are not designed for the standard 24 VDC used by most PLCs and their control loops. Some DC power supplies from manufacturers such as PULS allow for multiple voltages out of one power supply unit thereby eliminating the need for a DC-DC power supply. Approved DC-DC power supply manufacturers (or approved equal) include:

- Puls Power
- Traco
- Mean Well

10.6.6.4 Backup Batteries

Backup DC batteries are used as backup power when AC power has been lost. The ampere-hour size of the DC battery is dependent on the control panel power requirements and the amount of backup time required. SPU standard is minimum of eight hours. An acceptable battery for most applications is the CSB GPL-12520, which is a 52 ampere-hour 10-year battery that is leak and maintenance free. Multiple batteries can be used in series or parallel depending on the application and the DC power supply. Similar batteries from other manufacturers such as Power Sonic, and Optima are acceptable as well as long as they meet the following criteria:

1. Sealed Lead-Acid
2. Leak proof
3. Rechargeable
4. Maintenance free
5. 10-year design life

10.6.7 Panel Wiring and Terminations

All internal panel wiring and terminations must be designed in accordance with the latest applicable standards of the NEC and applicable state and local electrical codes.

10.6.7.1 General Requirements

The following are SPU standards for panel wiring and terminations:

1. Wire bundles must be secured using plastic wiring wraps, except within wiring ducts. The bundles must be securely fastened to the steel structure at suitable intervals, not exceeding 12 inches in diameter. All wire retention devices, including wire ducts, must be mounted to the back plate with appropriately sized machine screws. The back plate must be drilled and tapped to accept machine screws. No double-faced tape must be permitted.
2. Where shielding is required, only shields with continuous foil or metalized plastic providing 100% coverage must be permitted. The drain wire must not be used as a control signal conductor.
3. No wiring within a panel may be spliced. Wire must be run in continuous lengths from terminal block to terminal block. Wire service loops must be provided to permit device removal. Terminal blocks should be the compression type with captive screws. The use

of three tier terminal blocks, or locating the terminal blocks where line-of-site is impaired, making insertion or removal of wires difficult is not acceptable. Fork-type lugs are not permitted. Internal raceways must be sized per NEC standards and have removable covers.

4. Power wiring insulation must be rated at 600V at 90 ˚C and be copper type machine tool wire (MTW). No wire smaller than 14 AWG must be used for power wiring. All other wiring insulation must be rated at not less than 300V at 90 ˚C.

All individual wires that are a source of power to the instruments or contacts (wetting voltage) should be fused with indicating style fuse holders. Larger current conductors (>10 amperes [A] and 120 VAC) supplying individual instruments or equipment should have circuit breaker protection devices.

10.6.7.2 Signal Separation

Signal wiring must be segregated from control power wiring and arranged neatly to facilitate circuit tracing.

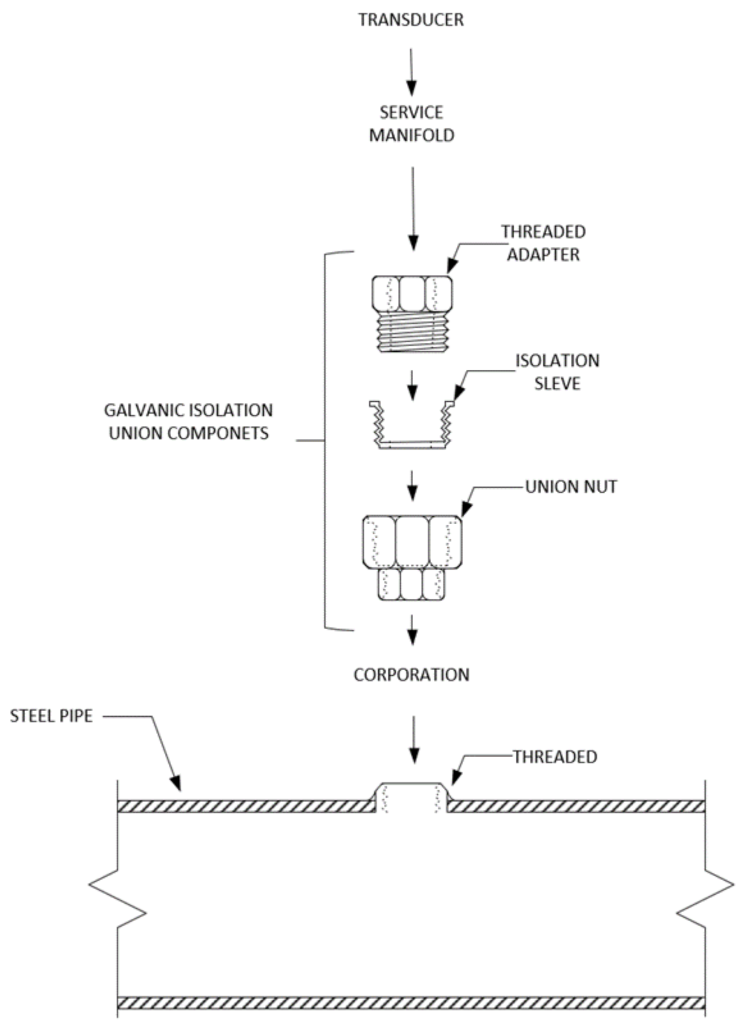
Low-level analog signals of 100 millivolts (mV) or less must not be run in the same bundle, duct, or wire duct as digital input or control output wiring.

All DC signal wiring must be segregated from wire conducting AC signals.

10.6.7.3 Galvanic Isolation

Galvanic isolation is installed on pipe mounted instruments to reduce electrolysis between power supplies and instrumentation. Loop isolators are used to provide galvanic isolation between instrument 4-20mA current loops. Approved manufacturers include M-Systems, Moore Industries or Phoenix Contact. See Figure 10-4.

Figure 10-5
Galvanic Isolation Implementation



10.6.7.4 Terminal Blocks

Cables from field instruments and from outside the panel must be landed on termination blocks prior to being routed within the panel.

Design of the terminal block layout must include a grounded barrier to segregate those terminals devoted to current type signals from others. The terminal blocks must be mounted on a channel and the channel bolted to the inside of the panel. Terminals must accept wire size 12 AWG and smaller.

Terminal blocks must be rated at least 300V for general industrial control devices and 600V for limited power circuits. Miniature terminal blocks for low-voltage signals are permitted if they are mounted with ample access for servicing. All terminals must have a continuous marking strip and each terminal block assembly must be labeled.

Acceptable manufactures include Phoenix Contact, Allen-Bradley, or Weidmuller.

10.6.7.5 Wire Colors

Control panel wiring must be color-coded to help identify their purpose. Refer to DSG section 10.8.3.5 for acceptable SPU wire colors.

10.6.7.6 Wire Identification

All wires and cable terminated within control panels, instrumentation panels and termination panels should be provided with identification tags to identify cables, terminations, and conductors. Wires must be identified in accordance with SPU's PLC Installation Standard in DSG section 10.8.3.6. A specific format has been developed that is supported by the SCADA database, instrumentation names and existing wiring. Allowing the Contractor to randomly identify wires is not acceptable as it complicates hardware and software maintenance.

10.6.7.7 Wiring for Intrinsically Save Environments

Any wiring that is installed into a Class 1, Division 1, Group D environment will require an intrinsically safe circuit according to the NEC Article 500 for methods and practice. The theory behind intrinsic safety is to ensure that the combined electrical and thermal energy in the system is always low enough that ignition of the hazardous atmosphere cannot occur. This is achieved by ensuring that only low voltages and currents enter the hazardous area and that all electric supply and signal wires are protected by intrinsically safety barriers. Intrinsic safety also refers to installing physical barriers that isolate hazardous gases from non-intrinsically safe equipment and other sources of ignition.

10.6.7.8 Intrinsically Safe Guidelines for Enclosures

Field wiring of intrinsically safe circuits should be segregated from non-intrinsically safe wiring by use of suitable barriers, separate wireways or trays.

Intrinsically safe and non-intrinsically safe connection points should be located sufficiently apart to prevent any possibility of bypassing or mis-wiring during installation or servicing of equipment.

The following are SPU standards for intrinsically safe panels:

1. The panel must contain a cautionary statement, such as: CAUTION: ANY SUBSTITUTION OF COMPONENTS MAY IMPAIR INTRINSIC SAFETY.
2. The mounting plate must be grounded to ensure intrinsic safety. Resistance between the plate and earth ground should be less than 1 ohm.
3. UL 913 is the Underwriter Laboratories standard for Safety Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III Division 1, Hazardous (Classified) Locations. This standard must be followed for all intrinsically safe installations.

10.6.8 Panel Display Devices

Display devices consist of rectangular panel meters, edgewise panel indicators, analog controllers, recorders, annunciators, and graphic displays.

Instruments or devices furnished for front of panel mounting must be suitable for panel mounting and selected to match each other and present a coordinated, aesthetically pleasing, and functional arrangement. The arrangement of devices on the panel must be as symmetrical as possible. Devices must be grouped functionally to enable operators to easily locate groups of devices or individual devices to control the process. Panel indication or display devices must be mounted between 48 and 60 inches above the floor to be easily operable and readable by the operator.

All display devices must have scales that indicate the actual process value with the measured variable reading in engineering units (e.g., 0–300 gallons per minute [gpm]). The full-scale range of the process being monitored must also be displayed. It is unacceptable for display devices to indicate the measured value as a percent of maximum (e.g., 0–100% full scale) except for those devices displaying position (e.g., % valve open and % valve closed). Programming parameters for all display devices (such as Red Lion LED displays and programmable chart recorders) must be included in the as-built documentation.

10.6.8.1 Analog Controllers

If required, analog controllers should be completely self-contained, stand-alone, microprocessor-based, and configurable by user through the internal software, such as a controller manufactured by Red Lion, ABB, Moore or Foxboro. The controller must be configurable for all analog control applications. The internal programming should have a minimum of 70 function blocks stored in non-volatile memory. The controller must be designed for interfacing to a PLC. Controllers must also be capable of being tied together through the use of a local instrument link allowing communication between multiple controllers.

Controllers must be programmable by selection and interconnection of function blocks to establish the station type and control strategy. All configuration data must be stored in the non-volatile memory to prevent loss of data during an electrical power interruption. The controller must be programmable by using a personal computer (PC) to download the software configuration. The software in the PC must also be capable of uploading programs from the controllers to archive, modify, and verify these programs. Programming parameters for all controllers must be included in the as-built documentation.

10.6.8.2 Display Devices

Video display devices from manufacturers such as Red Lion may be used in stations where local monitoring and control of the station is deemed appropriate. Before fabricating panels, vendors must submit for SPU approval a colored copy of any video displays with a description of the how the display functions.

10.6.9 Switches, Pushbuttons and Lights

All selector switches, pushbuttons, and indicating lights must match the NEMA rating of the panel in which they are installed and be of the same series or model. Recommended manufacturers are Square D, Allen Bradley, or approved equal.

10.6.9.1 Switches and Pushbuttons

Selector switches and pushbuttons must be the type that are supplied with the add-on operator mechanisms so that the appropriate number of contact blocks and block type can be attached to the switch. Contact block terminals must be labeled for identification purposes and contain not less than one single pole, double throw contact.

Contacts must be specified as heavy-duty type, rated 10A at 120 VAC breaking current.

In the case where the contact blocks are handling low-level signal currents, the contacts must be rated for electronic duty and provide mechanical self-cleaning action for reliable operation on electronic loads where thermal cleaning action is not present. The contacts should be rated at 1A at 28 VDC and be constructed of gold or gold flashing over silver.

Pushbuttons must match the existing function color. It is unacceptable to utilize color or styles that could create confusion.

10.6.9.2 Indicating Lights

SPU requires use of LED as indicating lights because they are less expensive than traditional lamps over the life of the equipment. Removal and replacement of indicating lights must be accessible through the panel front. A push-to-test-feature must be used on indicating lights to provide a positive test of light condition. Indicating lights operating on 24 VDC must have lights rated for 28 VDC for longer life. Lights should meet the NEMA classification for the area and the panel that they are used on. Failure to use the right types of components within the rating of the panel will violate the UL listing.

A. Nomenclature

The following is the nomenclature SPU prefers on indicating lights:

- **Trouble/Malfunction:** equipment has malfunctioned, is operating in a non-normal mode caused by the malfunction of other components, or is not operating within its normal operating limits
- **Status:** status of components or mode of operation of equipment is within normal operating limits
- **Running:** equipment is operating
- **Open:** circuit breaker, valve, gate, or switch is open
- **Closed:** circuit breaker, valve, gate, or switch is closed
- **Standby/Energized:** power is applied to control equipment and is available to operate the motor

B. Color Coding

Indicating lights must be color-coded as shown in Table 10-4.

Table 10-4
SPU Color Coding for Indicating Lights

Legend Nomenclature	Lens Color
General	
Trouble/malfunction	Amber
Status	White
Running	Red
Condition of danger, active state	Red
Condition of safety, inactive state	Green
Computer acknowledge	Blue

Legend Nomenclature	Lens Color
Motors	
Stand-by/energized	Green
On/run	Red
Valves	
Open	Red
Closed	Green
Neither open nor closed (traveling)	Red and Green lamps lit

The table above reflects SPU SCADA standard for Water LOB. Drainage and Wastewater LOB standards are different. This needs to be addressed on LOB level, but engineers and designers need to be aware of these anomalies in the utility.

10.6.10 Relays and Timers

This section presents SPU standards for relays and timers.

10.6.10.1 General

The following are SPU general standards for relays and timers:

1. Relays controlled by PLC outputs must provide an adequate burden. Adequate burden refers to a condition when the output is turned off the relay coil, the relay will de-energize even though a low-level leakage current may still flow from the PLC output through the relay coil. All relays must be UL recognized and have a minimum mechanical life of ten million operations. For applications requiring switching of very low current signals, such as 4-20mA control loops, relays must be hermetically sealed and use mercury wetted contacts.
2. All relays with similar functions must be supplied by the same manufacturer to ensure similar appearance and uniform operating characteristics. The operating temperature range must be compatible with the environment in which the relay will be installed.

10.6.10.2 Relay Control Logic and Interposing Relays

All control logic and interposing relays must be heavy-duty, machine tool industrial type with contacts rated not less than 10A at 240 VAC. Relay coils must be molded construction and operate on 24 VDC or 120 VAC 60 Hz +10% as required. All relays must have a clear polycarbonate dust cover and internal indication to show if the relay is energized.

10.6.10.3 Timing Relays

The following are SPU standards for timing relays:

1. All timing relays must be of the solid-state pulse-count type using a high frequency RC oscillator and integrated circuit counter for timing. Electrolytic capacitors must not be used in the timing circuits. Solid state timing relays must be Agastat, STA series, or approved equal.
2. Time delays from 0.1 second to 48 hours must be available with each timer model, adjustable over a 20:1 range. The timer must reset in 0.03 second or less. Timer

accuracy must be ± 2% under normal conditions. On-delay and/or off-delay must be supplied as required. Repeat accuracy must be ± 5% or better. Reset and recycle time must be 200 milliseconds (ms) maximum. All time delays must be adjustable via a digital selector switch on the timer body.

3. The timing relay must have two NEMA Form-C timed contacts and one Form-C instantaneous contact. Two additional NEMA Form-C timed contacts must be provided where required.

10.6.10.4 Intrinsically Safe Relays

Intrinsically safe relays are required for direct connection of float switch instrumentation installed in a Class 1, Division 1, Group D, hazardous wastewater environments.

10.6.11 Intrinsic Barriers

Intrinsic safety barriers are devices that limit the current, voltage, and total energy delivered to a sensor in a hazardous area or flammable environment to prevent an explosion. Zener barriers are passive devices that contain Zener diodes, resistors, and fuses to limit excess voltage and current. They divert potentially dangerous energy to ground and are the basic building blocks for all other types of intrinsically safe barriers.

Intrinsic barriers must be used for direct connection of discrete or analog instrumentation installed in a Class 1, Division 1, Group D hazardous wastewater environments. SPU standard barriers are Pepperl+Fuchs KFD2=STC4-Ex2 for analog signals and KDF2-SR2-Ex2W for discrete signals.

10.6.12 Nameplates and Identification Tags

Panels and all equipment within them must be identified as to their name and function.

10.6.12.1 Nameplates

The following are SPU standards for nameplates:

1. Nameplates must be secured to equipment fronts using screws. Rivets or adhesive may be used for securing nameplates to the inside face of recessed panel doors in finished locations or other types equipment that are enclosed in panels.
7. Nameplates must be made of laminated plastic approximately 3/32 of an inch thick, beveled edge, white with black engraved lettering, attached with corrosion-resistant machine screws with self-locking nuts. Nameplates must be a minimum size of 1¼ inches high by 3½ inches wide.
8. Nameplates must identify the function, position, and/or condition indicated for each pushbutton, switch, indicating light, or other control device. Nameplates for pushbuttons, switches, indicating lights, and similar control devices must be the standard type furnished with the device.
9. Nameplates must be provided for the following equipment and match existing size, color, and lettering height for similar applications:
    a. Each panel
    b. All individual equipment pieces within a panel

c. All PLC panels
d. All power supplies, UPS systems, and transfer switches
e. All electrical distribution and control equipment, and loads served
f. Individual circuit breakers, and switches, with identification of circuit and load served, including location
g. Receptacles with identification of panel board and circuit number
h. All junction boxes terminal boxes

10. Nameplates made of embossed tape must not be permitted for any application, even temporary.

10.6.13 Design Submittals

The following are SPU standards for design submittals:

1. Before manufacture, shop drawings must be provided for review. AutoCAD format drawings must be provided on computer CDROM or DVD and three sets of 11-by-17-inch hardcopies. Under no circumstances should panel fabrication occur without prior approval by a SCADA team representative.
11. Drawings provided must include the following minimum information:
    a. Scaled panel face and subpanel faces with associated sizes.
    b. Panel interior layout with all components located.
    c. Wiring schematics with each wire identified.
    d. Power connection wiring details.
    e. Device identifications.
    f. Nameplate layout and engraving details.
    g. Bill of material.

10.7 PROGRAMMABLE CONTROLLER EQUIPMENT GUIDELINES

This section defines PLC and PAC equipment and configurations to be used at the SPU facilities. To provide the maximum standardization between facility configurations, use of these guidelines is recommended for new design.

These guidelines also define communication requirements to the SPU SCADA system, and to any required local operator interface devices.

Note that SPU Programming Software Standards for PLCs are available upon request from SCADA Manager.

10.7.1 General Recommendations

SPU supports two separate SCADA systems: one to support the Water System and another for the Drainage and Wastewater System. Depending on the SCADA system, SPU currently standardized on two different programmable controllers.

The Water SCADA system must use the Allen Bradley ControlLogix controllers. The Drainage and Wastewater SCADA system must use the Opto 22 SNAP-PAC controllers. The exact model types and configuration are dependent on the application of the controller. Modern PLC controllers are considered modular in that their components can be configured in many different ways. Typical PLC options include the following items:

- **Central processing unit (CPU) –** The CPU typically defines the speed, expandability, program size, software features, and other capabilities of the entire PLC system.
- **Communications –** Communications capabilities are usually related to the CPU type but can also be added to the system as standalone communications devices. The communications capabilities are critical for integrating a PLC system into the existing SPU SCADA networks.
- **Input/Output –** This feature relates to the types of instrumentation that will be monitored and controlled by the PLC system. This would typically include discrete, analog, and digital input and output instrumentation. The types and number of I/O devices that a PLC can support depends on the PLC platform, the type of CPU, and the amount of expandability in the PLC platform.

Follow the recommendations below in configuring a PLC system:

- Redundant PLC CPUs are not required.
- Redundant power supplies are not required.
- Each facility should be equipped with an operator interface unit (OIU).
- All I/O points are to be wired to terminals.

Drawings of typical PLC configurations are provided in the **Appendix 10D - Drawings of Typical PLC Configurations and I/O Modules Wiring Diagrams**.

10.7.2 Programmable Logic Controllers for Water SCADA System

All facilities at Water SCADA System utilize an Allen-Bradley ControlLogix PLC.

10.7.2.1 CPU Module

All facilities should be configured with an Allen-Bradley ControlLogix PLC model 1756-L71, unless otherwise specified.

This PLC CPU is a single slot module, with 2 MB of non-volatile user memory, and built-in USB 2.0 Programming/Download Port. The high-speed communications ports are described below.

10.7.2.2 Power Supplies

PLC configurations should use 10A power supplies, A-B model 1756-PB72. Power supplies are capable of being used standalone or in a summing configuration. Power is configured for 24 VDC and is fed from the internal battery backed up 120 VAC to 24 VDC power supply.

10.7.2.3 Input/Output Racks

PLC configurations should use a 4, 7 or 10-slot I/O rack assembly, A-B model 1756-A7/B, A10/B, or A4/B, as space permits. PLC configurations requiring more than 10, 13, or 17 slots, including spares, should use multiple I/O rack assemblies.

10.7.2.4 Module Arrangement

The first I/O rack, called Rack 1, should be configured as follows:

- CPU module should be installed in slot 00 (the first slot).
- Ethernet/IP interface module should be installed in slot 01.
- Analog Input (AI) Modules should be installed in slot 02, 06, and higher, as required.
- Digital Input (DI) Modules should be installed in slot 03, 05, and higher, as required.
- Digital Output module (DO) should be installed in slot 04.
- SCADA Communications Interface (Modbus) module should be installed in slot 07.

10.7.2.5 Input/Output Modules

A. Analog Input Modules

Analog Input modules should be A-B model 1756-IF6I. This module has six single-ended inputs, each capable of being configured as either 4-20mA or 1-5 VDC. Normally, analog inputs will be configured to operate at 4-20mA.

B. Analog Output Modules

Analog Output modules should be A-B model 1756-OF4 or 1756-OF8. Modules have non-isolated outputs, each capable of driving 4-20mA into a 750-ohm load. Analog Input Module Adapter FLKM 14-PA-AB/1756 and Interface Module part number UM 45-2FLK14/AB-1756 by Phoenix should be used to streamline wiring process and accommodate troubleshooting.

> ***Note:*** *If an Analog Output module is used to drive a load located remotely from the PLC enclosure, use a separate isolation module such as Pepperl+Fuchs KFD0-SCS-1.55 to prevent damage to the PLC.*

C. Discrete Input Modules

Discrete DC Input modules should be A-B model 1756-IB32. This module has 32 inputs arranged in four groups of eight inputs each sharing a common supply/return. Digital Input Module Adapter part number FLKM 50-PA-AB/1756IN and Digital Input Interface Module part number FLKM 50/PLC (both by Phoenix) should be used to streamline wiring process. Multiple groups of inputs are required, since the discrete signals may originate from systems with different common return potentials.

D. Discrete Output Modules

High Density Discrete DC output modules should be A-B model 1756-OB32 (10-28 VDC, sourcing). This module should have 32 outputs arranged in two groups of 16, each with common power supply connections. The module outputs source current when turned ON, and each output is rated 350mA at 28 VDC. Total module output current should be limited to 10 A. Digital Output Module Adapter part number FLKM 50-PA-AB/1756IN alone with an interface module part number PLC-V8/FLK 14/OUT (both by Phoenix) should be used to streamline wiring process.

E. Communication Modules

The following communication modules are approved for use in SPU systems:

- Modbus RS485/422
- Ethernet/IP Communication Interface Module should be Allen-Bradley model 1756-ENBT, with no exceptions
- Allen-Bradley ControlLogix PLC system utilizes a Modbus communications interface adapter, ProSoft model MV156-MCM, with no exceptions

F. Deviations and Waivers

Written permission from SPU SCADA engineer should be required to use other than the above specified I/O modules.

10.7.3 Programmable Automation Controllers for Drainage and Wastewater SCADA System

All facilities at DWW SCADA System must use an Opto22 Controller, which is comprised of a CPU module, power supply, and I/O rack.

10.7.3.1 CPU Module

All facilities with less than 100 I/O points are configured with an Opto22 model SNAP-PAC-R2 controller, with 2MB battery-backed RAM flash memory and 2GB of removal storage (micro-SD cards). No exceptions are allowed. Facilities with more than 100 I/O points should be configured with an Opto22 SNAP-PAC-EB1 Ethernet Brain and Opto22 model SNAP-PAC-S1 standalone controller with 8MB battery-backed RAM flash memory and 32GB removal storage (micro-SD cards). No exceptions are allowed.

The controller has two independent, 10/100 Mbps Ethernet network interfaces with separate IP addresses and can be used to segment the control network from local network or to provide Ethernet link redundancy in case of link failure or maintenance. In addition, the controller has an RS-232 serial port with hardware handshaking, which can be used for PPP (Point-to-Point Protocol) communication over a modem or for direct connection to serial devices.

In addition to control, the SNAP-PAC-R2 provides communication. Because it is based on the Internet Protocol (IP), the SNAP-PAC-R2 can communicate simultaneously using several different protocols, including TCP/IP, Ethernet/IP, PPP, Modbus/TCP and others.

10.7.3.2 Power Supplies

PAC configurations should use Dimension C-series 24 VDC, 10 A power supply by Puls, model CS10.243.

Opto22 PAC should use 24 VDC to 5 VDC power supply model SNAP-PS5-24DC. The power supplies should be configured for 24 VDC and should be fed from the Puls 10A DC-UPS, model UB10.242 that is backed up by batteries in 17-130 Ah range depending on application.

10.7.3.3 Input/Output Racks

The controller should be mounted on a SNAP PAC mounting rack with 8, 12, or 16 digital, analog, serial, and special-purpose I/O modules. Most commonly used 12-slot rack model SNAP-PAC-RCK12.

10.7.3.4 Module Arrangement

I/O rack, called Rack 0, should be configured as follows:

- Digital Input (DI) Modules should be installed in slot 00, 07, and higher as required.
- Analog Input (AI) Isolated Voltage Module should be installed in slot 01.
- Analog Input (AI) Isolated Current Module should be installed in slot 02.
- Digital Output module (DO), non-isolated, should be installed in slot 03.
- Digital Output module (DO), isolated, should be installed in slot 04.
- SCADA Communications Interface RS-485 (Modbus) module should be installed in slot 05.
- Analog Input (AI) –non-Isolated Current Module should be installed in slot 06.

10.7.3.5 Input/Output Modules

A. Analog Input Modules

Analog Input modules should be the following Opto22 models:

- SNAP-AIV2-i - This module has two (2) analog isolated voltage inputs ranging 0 – 100 VDC.
- SNAP-AIMA-i - Two channel analog isolated current module, 4-20mA.
- SNAP-AIMA4 - Four channel current input module, 4-20mA.
- SNAP-AIMA8 - Eight channel current input module, 4-20mA.

B. Analog Output Modules

Analog Output modules should be Opto22 model SNAP-AOA-23. Modules have non-isolated outputs, each capable of driving 4-20mA into a 750-ohm load.

C. Discrete Input Modules

Discrete DC input modules should be:

- Opto22 module SNAP-IDC-32 is a 32-channel digital input module. Breakout rack Opto22 part number SNAP-IDC-HDB should be used with each of 32-channel DI module to simplify wiring process and provide light indication for each channel. Prefabricated 6-ft header cable for SNAP 32-channel DI should be used in conjunction with breakout board, Opto22 part number SNAP-HD-BF6.
- Opto22 module SNAP-IDC5 is a 4-channel digital 10-32 VDC input module.

D. Discrete Output Modules

Discrete DC Output modules should be the following Opto22 models depending on application and IO number needed:

- SNAP-ODC5SRC is a 4-channel digital non-isolated outputs.
- SNAP-ODC5-I is an isolated 4-channel digital output module.

E. Serial Communication Modules

- SNAP-SCM-232 is a 2-channel serial communication module.
- SNAP-SCM-485-422 is a 2-channel serial communication module.

F. Deviations and Waivers

Written permission from an SPU SCADA engineer should be required to use other than the above specified I/O modules.

10.8 PROGRAMMABLE CONTROLLER INSTALLATION GUIDELINES

This section defines the requirements for installing PLCs and PACs in SPU facilities. The term PLC is used for drinking water sites, and PAC is used for drainage and wastewater sites. The guideline is intended to provide a common installation appearance, thereby increasing the effectiveness of the maintenance department in maintaining the equipment and improving operational uniformity.

This section describes the minimum requirements for installation of a PLC at SPU facilities. Project documents will provide additional requirements specific to each project.

10.8.1 General Requirements

This section describes minimum requirements for installation of control equipment at SPU facilities. These facilities include drinking water, drainage, and wastewater facilities.

10.8.1.1 Enclosure requirements

The PLC or PAC and its I/O racks (if required), which are described in the PLC Equipment Guideline, are to be installed within either an existing or new panel, as specified in the contract documents. Mount the PLC equipment on a rigid back panel(s) that may be mounted in the cabinet after any existing PLC and its I/O modules are removed. The dimensions of the back panel should be subject to the approval of an SPU project representative.

The completed PLC enclosure assembly must be certified and labeled as compliant with UL-508A.

The back panel should meet the following minimum requirements:

- Fabricated from minimum 12-gauge steel, braced as required to prevent buckling.
- Mounting hardware should be 316 stainless steel.
- Surface should be prepared, primed, and finish coated in accordance with the coating manufacturer’s recommendations.
- Finish coat should be air-dry polyurethane or epoxy enamel.
- Color should be Federal Standard 595, Color 27722 (white).

The PLC must be mounted to the back panel(s) in accordance with the PLC manufacturer's recommendations. The placing of the PLC on the back panel(s) must allow adequate space for installation of plastic raceways to route the I/O module cables to the existing terminal blocks, plastic raceways, and other PLC racks. The spacing must ensure that the minimum bending radius of all cables is not violated. All projects should attempt to standardize on panel sizes and mounting orientation in an attempt to keep the control systems similar between like facilities. This improves assembly and maintenance efficiencies.

10.8.1.2 Environmental Requirements

If the PLC and its I/O (if required) are to be installed in an existing or new panel that may be outdoors, the panel must be provided with heating and ventilation equipment to ensure the following environment within the panel:

- Temperature: 35 °F to 122 °F
- Humidity: 10% to 95% non-condensing

In all cases where panels are used outdoors the rating of the panels must be rated for the conditions and include a low-watt density heater and ventilation fans controlled by a thermostat.

Climate control calculations for each panel should be provided to demonstrate that sufficient ventilation, dissipation, and/or generation of heat is provided to maintain interior panel temperatures within the rated operating temperatures of panel components.

10.8.1.3 Electrical Requirements

A. Power Supply

The PLC power supply should be operated from an uninterruptable power supply with the following characteristics:

Output voltage:

- Alan Bradley: 24 VDC ± 5%
- Opto22: 5 VDC ± 5%

B. Grounding

The following are SPU standards for setting up grounds for I/O racks containing analog and digital signals:

- Each PLC must have an isolated signal ground bus, ½ -inch wide ½ -inch thick, mounted in close proximity to the analog wiring terminals. The ground bus must be insulated from the panel and be sized to allow proper termination of shield drain wires. The bus must have tapped holes to accommodate ground connections from various instruments and low-level signal devices in the rack. The signal ground bus must connect to the system ground plate at only one point, via a stranded, insulated copper wire of #8 AWG or larger. Use Electro Motion Company part number EM 4251-12SSO or equal.
  - Using the existing ground bus is acceptable if the instrument shields are already connected to the bus.

  - If a new panel is used and the wires are extended from the existing panel to the new panel, the ground should be extended to the isolated ground bus in the new panel.
- The PLCs rack and I/O frame must be connected to the facility electrical system ground, via a connection that is kept isolated from the signal ground bus. The isolated ground must eventually connect to the building ground to be compliant with the NEC Article 250.
- Applications using small PLCs may use a grounding system composed of a terminal strip with a common connection bar substituting for the copper ground bus bar. The common connection bar must be tinned and provide ample material for the compression style terminal strip make the proper low-resistance connections.

C. Isolating and Protecting Input/Output Modules

Analog optical isolation must be provided between PLC analog input module loops and field analog loops to prevent ground loops. All analog inputs must have isolated analog inputs, either per input or per group of four inputs. Separate I/O isolators may be used to prevent ground loops in applications utilizing small PLCs with less than four analog inputs.

All digital inputs must have optically isolated inputs, either per input or per group depending on I/O module.

Surge suppression must be provided for the AC power in the panel. Surge protection must be provided for analog loops between the PLC and field (remote) devices for use in Water SCADA sites. This is not used with wastewater.

10.8.2 Input/Output Modules Wiring

This section presents SPU standards for wiring I/O modules.

The drawings in **Appendix 10D - Drawings of Typical PLC Configurations and I/O Modules Wiring Diagrams** show typical wiring diagrams for I/O modules.

10.8.2.1 General

Each PLC I/O module must be wired to a terminal block using color-coded wire. The minimum acceptable wire gauge for cable conductors is 16 AWG. For 4-20mA signals and other analog signals provide 18 AWG stranded copper, twisted pair, shielded cable, 80 ˚C rated, UL listed, 0.25 inches maximum outside diameter, with 100% coverage aluminum foil Mylar-lines shield and 22 AWG (minimum) stranded tinned copper ground drain.

Where additional power wiring is required, extending signal cables, or adding terminal blocks, the following sections must apply.

10.8.2.2 Input Module Wiring

Provide each I/O module with 16 inputs or more with a removable edge connector and wiring. Terminate all I/O points, whether used or not, on new or existing terminal strips, as specified by project drawings. Use IEC 4.0 millimeter $(mm)^2$ series 600V, 30A-rated terminals. Locate new terminal strips within the MCP cabinet or on the PLC back panel, as specified by the project drawings.

10.8.2.3 Output Module Wiring

For output modules, provide terminal strips with integral indicating fuse holders. Use IEC 4.0 mm^2 600V series fuse blocks with socket for 5 x 20 mm fuse, and blown fuse indicators, as required. Provide 2PDT, 3PDT, or 4PDT interface relays with 10A contact rating, when switching AC voltage or if single output is used in multiple control functions.

10.8.3 Wiring

10.8.3.1 General

Each piece of equipment requiring AC power that is to be plugged into an AC receptacle must be provided with an NFPA No. 70 Type SJ cord with molded-on grounding type plug for AC power connection.

10.8.3.2 Panel Connection Wire

Connection wiring refers to all wires that have both ends terminated within the same panel. Panel wiring must be MTW. This wire provides high flexibility and easy routing within panels. Thermoplastic covered fixture wire flexible stranding may be used to wire panels but it is a second choice since it is not as flexible as MTW.

Power and control wiring must be sized to meet all codes. The minimum acceptable wire gauge for stranded copper wire is 16 AWG. For 4-20mA signals and other analog signals provide 18 AWG stranded copper, twisted pair, shielded cable, 80 ˚C rated, UL listed, 0.25 inches maximum outside diameter, with 100% coverage aluminum foil Mylar-lines shield and 22 AWG (minimum) stranded tinned copper drain.

10.8.3.3 Signal Connection Wire

Signal wiring refers to all wires that are used to connect instrumentation to the control panel terminal blocks. Wiring must be sized to meet all codes. For discrete signals, provide stranded MTW copper wire. For 4-20mA signals and other analog signals provide stranded copper, twisted pair, shielded cable, 80 ˚C rated, UL listed, with 100% coverage aluminum foil Mylar-lines shield and 22 AWG (minimum) stranded tinned copper drain. For Modbus communication use Industrial Twinax (Blue Hose) Data Highway Cable, 1-pare, 20 AWG stranded tinned copper, Beldfoil +55% tinned copper braid and drain wire with blue sunlight-resistant polyvinyl chloride (PVC) jacket. Nominal diameter: 0.238 inches. Use Belden 9463 or Allen-Bradley 1770-CD or approved equal.

10.8.3.4 Wire Tagging

The Contractor must tag all panel connection wiring at terminations with machine printed shrink fitted plastic sleeves.

The Contractor must tag 120 VAC power circuit wires as with the letters L, N, or PG as appropriate.

Tag numbers for control circuit wires consist of the equipment number followed by a dash, followed by the wire number. Match wire numbers with interconnection wire numbers when they are electrically identical.

10.8.3.5 Wire Colors

Power conductors in panels for 120 VAC must be provided with the insulation colors shown in Table 10-5.

Table 10-5
Insulation Wire Colors for 120 VAC

Code	120 VAC Wire	Color
L	Power	Black
N	Neutral	White
PG	Ground	Green
C	Control Circuits	Red
C COM	Control Interconnections	Yellow

Acronyms and Abbreviations
VAC: volts alternating current

Codes and associated wire colors for AC/DC voltages of 24V and less are shown in Table 10-7.

Table 10-6
Insulation Wire Colors for Low Voltage (Typically 24 VAC/DC or less)

Code	Low Voltage Wire	Color
VDC	VDC Power Supply	Blue
VAC	VAC Power Supply	Black
DC COM	DC Ground	Blue/White
AC COM	AC Ground	White/Gray
S	Signal, Analog	White or Clear
PG	Equipment Ground	Green or Green/Yellow
C	Discrete Events and Low-Voltage Control	Blue

Acronyms and Abbreviations
AC: alternating current
DC: direct current
VAC: volts alternating current
VDC: volts direct current

Codes and associated wire colors for other connections are shown in Table 10-8.

Table 10-7
Insulation Wire Colors for Other Connections

Code	Wire	Color
ISC	Intrinsically Safe Circuits	Orange
FVC	Foreign Voltage Circuits	Pink

10.8.3.6 Wire Numbers

Power distribution wire numbers consist of three parts separated by a dash. The first part of the wire number is the instrument loop number. If an instrument loop number is not available, the design engineer should use the lowest mechanical equipment number of all final drives associated with the circuit. The second part of the number is a code to indicate wire type. The third part of the wire number identifies wires in a circuit that are electrically identical.

Example

Tag Number = PS24-VDC-2

Where:

PS24 = mechanical equipment number

VDC = VDC power supply with blue wire

2 = electrical identity wire number (sequential numbers)

Wire numbers for PLC and PAC input and output signals consist of three parts separated by colons. The first part of the wire number is the signal code described in Table 10-9. The second part of the number is the PLC chassis slot number in 2-digit format. The third part of the wire number identifies the IO point number on the card in 2-digit format.

Table 10-8
PLC I/O Signal Type

Code	Description
AI	Analog Input
AO	Analog Output
DI	Digital Input
DO	Digital Output

Example

Tag Number = DI:01:03

Where:

DI = I/O is type of digital input

01 = Digital input card slot number is 01 in PLC chassis.

03 = Digital input wire is landed on input point number 03 in input card.

10.8.3.7 Terminal Blocks

Additional terminal blocks required to complete the installation must be the captive screws with pressure plate type, DIN EN 50035 rail 300V rating. Terminal blocks must be mounted vertically in the panels. Provide 20% spare unused terminals. There must be ample clearance to provide visual guidance for installing wires. Three-tier terminal strips are not acceptable. Provide terminal blocks as specified in Table 10-10.

Table 10-9
Terminal Blocks

Description	Type	Application
120 VAC power and control		
Fuse terminal block with blown fuse LED indicator	Phoenix or equal	Power supply for field panels
Terminal block	Phoenix or equal	Neutral and control wiring
Grounding terminal block	Phoenix or equal	Equipment grounding conductor
Disconnect terminal block	Phoenix or equal	Foreign circuit disconnect
24 VDC (and other voltage) signals		
Fuse terminal block with blown fuse LED indicator	Phoenix or equal	4-20 mA current loop (supply side)
Terminal block with test sockets	Phoenix test plug socket, or equal	1-5 VDC analog signals
Terminal block	Phoenix or equal	4-20 mA current loop (return side) shield drains
Terminal block	Phoenix or equal	Splicing cables where space is limited
Terminal markers		
Terminal marking card	Phoenix or equal	All terminal blocks

Acronyms and Abbreviations
LED: light emitting diode
VAC: volts alternating current
VDC: volts direct current

10.8.3.8 Terminal Tags, Covers and Markers

Each terminal strip must be marked as follows:

Unique (for the panel) identifying alphanumeric code at one end.

- Plastic marking strip running the entire length with a unique (for the terminal strip) number for each terminal.
- Machine printed with ⅛-inch high numbers.
- Terminal blocks carrying power circuits must include a transparent, hinged cover for personnel protection and accessibility.

10.8.3.9 Fuses and Fuse Holders

On 120 VAC circuits, ceramic tube type fuses must be used that have 25,000A interrupting capacity at 125V and neon blown fuse indicator lamps. Draw out fuse holders must be provided.

For 24V DC circuits fast acting glass tube type fuses rated ¼A for 4-20mA loops and for the power supply to individual instruments sized to protect load. Draw out fuse holders with LED blown fuse indicator.

10.8.3.10 Wiring Duct

Slotted plastic wiring duct with dust cover, Panduit Type E or NE, must be used between the PLC I/O racks, and wherever new wiring duct is required to complete the installation. Wiring duct must be mounted by drilling back panel for appropriate plastic rivets. No double face tape may be used on equipment mounts or wiring supports.

10.8.3.11 Wiring Methods

Wiring must be routed in a manner that is mechanically safe with the wires supported by means other than the connections. Wires must not be supported by connections. Wires must be contiguous from connector to connector. Wire splices are not allowed. All connection must be within panels and must be completed using terminal strips. If field wires are too short to reach their final termination point, then terminate on a terminal strip and extend wire of same color to final point. Wire colors must be the same from initiating point to final termination point.

Shield drain wires must not be used as a signal conductor. All shields must be terminated at an isolated ground terminal strip nearest to a SCADA input as possible or must be wrapped around the shielded cable and heat shrunk. *Do not* trim back to the jacket of the shielded cable. Shields that are connected to ground must either be tinned by solder or must have a piece of heat shrink insulation placed over the wires to prevent stray strands from either reaching ground or shorting to other terminals. Crimps on connectors, such as spade lugs, are unacceptable.

10.8.4 Communications Interfaces

SCADA communications design currently consists of communications within a remote facility and long-distance communications between remote facilities and SPU control locations. Some SPU SCADA communications standards are undisclosed for security reasons. This secrecy, along with the complexity and changing communications standards in the industry, require that the SCADA engineer be involved during communications design.

10.8.4.1 Communications to the SCADA System

SPU utilizes a contract with CenturyLink for using MPLS circuits to communicate between remote sites and the central SCADA system. Communications between the PLC/PAC and the SCADA system should be over IP based telephone circuit using a NETVANTA3200 router by Adtran.

The following components for PAC system (drainage and wastewater sites) should be supplied:

- Unmanaged five Port Ethernet Switch, WIEDMULLER part IE-SW-BL05-5TX or equal.
- CAT5e cable with appropriate connectors, to connect from the RJ-45 Ethernet port on SNAP Controller to Ethernet switch.
- CAT5e cable with appropriate connectors, to connect from the E-port on Ethernet switch to the Adtran router.
- CAT5e cable with appropriate connectors, to connect from the Adtran router to telco supplied interface.
- Factory-made CAT5e cables of proper length.

The following components for PLC system (water sites) should be supplied:

- Unmanaged five Port Ethernet Switch, WIEDMULLER part IE-SW-BL05-5TX or equal.
- 1756-ENBT EtherNet/IP Communication Interface Module by Allen-Bradley, no exceptions.
- CAT5e cable with appropriate connectors, to connect from the Ethernet Interface Module to Ethernet switch.
- CAT5e cable with appropriate connectors, to connect from the E-port on Ethernet switch to the Cisco router.
- CAT5e cable with appropriate connectors, to connect from the Adtran router to telco supplied interface.
- Factory-made CAT5e cables of proper length.

Where fiber connection is available, it is preferable to utilize this mode of communication due to its increased data transfer speed and bandwidth. In this case, the component arrangement is similar to that above, except instead of telco-supplied interface, the cable from the router is connected to the Cisco 5505 Network Appliance (provided by SPU).

10.8.4.2 Communications to Local Devices

Communication between PLCs and peripheral equipment is dependent on the existing systems and the application of any system updates. PLC and peripheral equipment communications currently consists of the following standards:

- Discrete switch connections for instruments such as float switches, flow meter pulse outputs, limit switches, pressure switches, and intrusion switches. Communications wiring for these types of connections typically use shielded or unshielded wire pairs.
- 4-20mA based analog communications for input and output connections to instruments such as level sensors, pressure sensors, flow meters, chemical analyzers and dosing pumps, and variable frequency drive (VFD) motor monitoring and control. Twisted shielded pair (TSP) wiring is typically used for analog instrumentation connections.

- Serial Modbus network communication using RS-232 or RS-485 wiring standards between equipment. This type of communications typically uses TSP wiring and is heavily used in the industry but is slowly being replaced by high-speed digital communications.
- High-speed TCP/IP based communications between facility equipment, such as PLC-to-PLC or PLC-to-Operator interface. This method of communications allows the designer to create a high-speed local area network (LAN) among the facility equipment.

The selection of the type of communications protocol and physical wiring to implement should be left to the SCADA section to identify based on security concerns, existing facility equipment, existing SCADA communications infrastructure, and industry standards.

A. Transmission Control Protocol/Internet Protocol Communications Uses the Following Standard

A 5-port Ethernet switch should be used as specified in DSG section 10.8.4.1 for the connection of TCP/IP based local devices to the Ethernet/IP port on the PLC/PAC system. These devices are:

- Network router
- Operator interface
- Ethernet based radio transceiver
- Programming laptop computer
- Flow meters
- Intelligent motor control system
- Environmental monitoring equipment

All permanent local devices on the high-speed network should be designed to have designated ports to be permanently connected to the PLC/PAC.

The programming laptop connection should be designed to be temporary, with easy removal and replacement of the cable. The cable extension to the programming laptop must not more than 50 ft in length. It should not be necessary to disconnect the network router to connect or use the programming laptop.

B. Serial Modbus Network Communication

SPU utilizes serial Modbus network communication modules to communicate with the variety of devices that utilize serial Modbus protocol, for example:

- Power monitors
- Flow meters
- Motorized operating valve actuators

With SNAP controller system, the following Modbus modules are used:

- SNAP-SCM-232
- SNAP-SCM-485-422

Allen-Bradley ControlLogix PLC system utilizes a Modbus communications interface adapter, ProSoft model MV156-MCM (no exceptions).

10.8.4.3 Operator Interface

The local operator interface should be a color graphic terminal—Red Lion, 7 inches or 10 inches as required, high-speed Ethernet/IP serial port for communication to the PLC, touchscreen only, and 24 VDC. Models should be as listed in Table 10-11 below. The local operator interface should be used to access control loop, timer, and counter parameters, and to display critical variables, alarms, and trending.

The local operator interface will be permanently connected to the PLC. The panel should be flush mounted on the door of the PLC enclosure.

Table 10-10
Approved Interface Models

Screen Size	Hi-Speed Interface	Model Number
10 inches	Ethernet IP	G10R 0000 (800 x 600 Display)

10.8.5 Testing Requirements

Testing requirements must be part of every PLC installation contract developed by SPU. Testing specifications require the Contractor to demonstrate that the system was fully tested during assembly and installation and is a functioning, integrated, and reliable control system. If equipment or software does not have specific tests defined in the contract, then the Contractor must develop testing procedures. All software and all equipment related to the PLC system must be tested.

Through the standard contract process, the Contractor must prepare and submit for review and approval:

- Factory acceptance test (FAT) plan and procedures
- Site acceptance test (SAT) plan and procedures
- Test schedules
- Test reports
- PLC program documentation
- Instrument and (applicable) component calibration sheets

10.8.5.1 Test Plans

The Contractor must prepare and document a separate test plan for each FAT and SAT. The actual test procedures must be formally submitted to SPU for review and approval before the start of the tests.

The test procedures must be structured in a step-by-step, efficient manner with checkpoints at critical functions. The procedures must facilitate the reporting of test results and the re-creation of error conditions.

Test data sheets must be used to record applicable drawing numbers, test equipment, discrepancies, corrective action(s) required, and test data. Data entries must be referenced to the applicable procedures and allowable limits for each entry must be indicated on the data sheets.

10.8.5.2 Test Reports

The Contractor must develop, maintain, and update test reports of all test results and conditions that were recorded during testing. Test results must include:

- Identification of test being conducted
- Date and time of test
- Prerequisite tests and demonstrations
- Brief statement of test objective(s) and scope
- Brief test description
- List of calibrated (within the past calendar year) test and monitoring equipment required to perform test
- Test results
- List of test deficiencies and their resolutions
- Retesting requirements (if required)
- Failure events
- Contractor's certification (as applicable)

10.8.5.3 Factory Acceptance Test

A FAT and verification for all deliverable equipment, programs, and associated documentation must be performed before the system is shipped. Tests must verify that the equipment is manufactured and assembled correctly, is operating as designed, and complies with contractual requirements. The tests must verify that the software and hardware meet the functional and performance requirements of the project. The FAT should be performed at the Contractor's factory and should be witnessed by owner personnel.

The FAT must include the following major test and verification activities:

A. System Configuration Verification

Before FAT, the system must be subjected to system deliverable configuration verification. A copy of the configuration and record of quantities of part numbers must be included with the FAT report. SPU does not permit equipment replacement or substitutions without rigorous quality control accounting and re-testing of affected equipment.

B. Owner Provided Software

Since the owner is providing the application software, coordination between the Contractor and owner is required. The Contractor is responsible for proper functioning of the hardware, while the owner is responsible for proper functioning of the software. The FAT should primarily test the control cabinet hardware and the Contractor is responsible for developing and administering the testing procedure that was approved in the submittal process. In addition to the hardware test, the Contractor should allow the owner up to five days of access (either before or after the hardware test) to the control cabinet at the Contractor's fabrication facility in which the owner will load the software onto the PLC and confirm proper configuration and hardware-software interface. During this time, the owner may perform functional testing of the software to verify proper operation; provide up to 16 hours of support during this 5-day period.

C. Equipment Test and Verification

FAT for equipment consists of visual inspection and verification that the equipment is assembled in accordance with the approved drawings:

- All hardware panels must be verified to determine the structural integrity. The following must be inspected and verified, as a minimum:
  - Back panel structure
  - Paint work and finish
  - Dimensions
- The following verification of wiring and connections must be performed, as a minimum:
  - Wire in terminal block, including correct connection, wiring installation, and wire stripping
  - Cable runs, including correct connection, supports, routing, shielding, wireway design, and terminal security
  - Fuse and breakers for correct rating and placement
  - Grounding strips, including layout, cables, connection security, and correct size
- The following must be visually inspected:
  - Card wiring support
  - I/O rack clearances
  - I/O and equipment labeling
  - I/O card type verification
  - I/O card layout
  - Power supply mounting
  - Power cable routing
  - Data cable routing

D. Functional Test

The FAT should include a functional test of the system after a burn-in test has been performed. The panel should be fully energized for a minimum period of 48 hours prior to the functional test. The test should then exercise every specified system function, including:

- Rigorous exercising of all inputs and outputs both individually and collectively, by measuring or connecting circuits at the field terminal blocks.
- Demonstrate analog input and analog output accuracy.
- Test all indicators.
- Test all operator interface functions.

- Verify all control operations to ensure they result in the correct sequence of operation at the PLC.
- Simulation of PLC communication error conditions and demonstration of error detection and handling.
- Demonstrate PLC power supply failure and recovery.
- Demonstrate the ability to remove and insert each I/O module.
- Demonstrate the correct operation of all digital communication devices.
- Allow time required by owner to test operation of all owner-provided application programs and control strategies using whatever simulations are necessary. Provide the owner with all materials and components required for the duration of their testing (at no additional cost to the owner).
- Provide certified test results for the deliverable equipment.
- Demonstrate correct calculation of totalized quantities.
- Make the following documentation available to the Engineer at test site during the tests:
  - Contract documents
  - Factory demonstration testing procedures
  - List of equipment to be testing including make, model, and serial number
  - Shop drawing submittal data for equipment being tested
- Deficiencies should be corrected prior to shipment from the Contractor's factory. The system should be packaged and shipped to the Contractor at the site for installation.

E. Test location

Test location should be within 50 miles of downtown Seattle.

10.8.5.4 Installation

Install control panels only in non-hazardous areas. Install free-standing panels on 4-IN high concrete housekeeping pads. Install anchor panels in a manner to prevent the enclosure from racking, which may cause the access doors to become misaligned. Obtain approved panel layouts prior to installation of conduits. Install products in accordance with manufacturer's instructions. Provide sunshields where required per the contract documents.

10.8.5.5 Site Acceptance Test

After the FATs are complete, the system must be packaged and shipped to the project site for installation. The following tests must be performed once the system is installed:

- System installation test
- System operational test
- Final documentation acceptance
- SAT should be witnessed by owner personnel

A. Installing New Programmable Logic Controller Control Panels

The system installation test should include the requirements as follows whether installing a PLC at an existing or new location. Since the owner is providing the PLC application programs, coordinate and schedule directly with owner personnel a minimum of two months prior to the start of any testing. Provide all labor as required to support the owner's testing, at no additional cost to owner:

- After the installation of the panel and all associated wiring, but prior to making final terminations to the field components, send dummy discrete and analog signals that duplicate the signals at the site to the OCC and verify the communication path and the software are working.
- Verify all indication devices.
- Verify communications to the SCADA system is operational. Verify analog and discrete points are functional and transmission control from the OCC is operating where applicable.
- The installation test should verify that the equipment and all cables have been properly installed, have not been damaged, and have not failed in shipment or storage.
- The installation test should demonstrate stable operation of all PLC I/O modules, wiring, and data transmission to the OCC under actual operating conditions. The test should also demonstrate proper operation of all digital or sequential control. All start/stop, open/close, raise/lower, and similar commands and all discrete status inputs should be tested for proper operation. In addition, all alarms, both analog and discrete, should be tested.
- After one week of operation without notable events or failures, finalize the wiring between the new PLC and the I/O, and organize unused wiring to provide a neat and clean appearance.

B. System Operational Test

A system operational test of the system functions, software, and performance must be performed after completion or site, including additional tests required to verify field-installed equipment, which was not available at the factory. The Contractor should be required to perform the following:

- Verify the facility installation.
- Verify the system installation test.
- Verify proper operation of the PLC program under field operational conditions by repeating the tests performed during the FAT.
- Verify proper data exchange and operation between the PLC and the local operator interface device during the SAT.
- Verify proper data exchange and operation between the PLC and the SCADA system at the Utility Operations Control Center (UOCC) during Control Center Acceptance Test (CCAT).

C. Final Documentation Acceptance

Final documentation acceptance should follow the completion of all system testing previously described. Final acceptance of any work should be linked to the proper operation and documentation of the controls installed by the Contractor. The following actions must be defined in the contract documents and be a prerequisite for final acceptance of the control system:

- Successful completion of the SAT.
- Delivery of all record (as-built) documentation and drawings.
- Resolution of all outstanding system deficiencies.
- Delivery of the record (as-built) PLC program and configuration documentation in print and on electronic copy.

10.9 SCADA DATA REQUIREMENTS BY FACILITY TYPE

This section describes the typical monitored and controlled signals from SPU remote sites field equipment and instrumentation required in SCADA database by SPU facility type.

A list of standard IO data signals from remote site to SPU SCADA system arranged by facility type can be found in **Appendix 10F - Typical SCADA signals by facility type**.

10.9.1 All SPU Facility Control Panels

This section presents instrumentation signals that are universal standards for all SPU facilities and SCADA control panels, including facility intrusion alarms.

10.9.1.1 SCADA Control Panel Signals

The standard control panel data signals include:

- Control panel AC power failure alarm
- Control panel PLC battery low voltage alarm
- Control panel PLC battery charging status
- Control panel PLC replace battery alarm
- Control panel door open alarm
- PLC state (program-remote-run)
- PLC communication fail alarm
- PLC error alarm
- Battery voltage
- Cabinet temperature

10.9.1.2 Intrusion Detection

Intrusion devices for monitoring site entry is added as required based on SPU site security standards. Specific intrusion and security systems are undisclosed in this section for security reasons. For additional security information, refer to the SPU SCADA group and the Security Group.

Intrusion detection also extends intrusion monitoring between Operations and Security groups. See Table 10-12.

Table 10-11
Intrusion Detection Applications and Considerations

Instrument Solution	Field Application	Design Considerations
Lever-type limit switch	Common building entrances such as doors, windows, hatches, rolling sheet door, access gates and control cabinets general.	Attempts to defeat.
Plunger-type limit switch	Control cabinets general.	Sensing plates gap, attempt to defeat.
Proximity switch	Common building entrances such as doors, windows, hatches, rolling sheet door, access gates and control cabinets general.	Attempt to defeat. Class I Division I certification.
Through-beam photoelectric switch	Asymmetrical structures such as manholes, limited access vaults, manhole covers and odd egress structures where a holding bracket may obstruct safe access.	Attempts to defeat. Reflective element state. Class I Division I certification.
Occupancy sensor	Common building spaces, Asymmetrical structures such as manholes, limited access vaults, manhole covers and odd egress structures where a holding bracket may obstruct safe access.	Sensitivity. Class I Division I certification.
Magnetic switch	Common building entrances such as doors, windows, hatches, rolling sheet door, access gates, machinery safety, and control cabinets general.	Sensing plates gap, attempt to defeat. Class I Division I certification.

10.9.2 Drinking Water Storage Facilities

This section identifies recommended storage facility SCADA data/instrumentation signal standards for all existing reservoir sites, tank sites, standpipes, and reservoirs located at SPU pump station sites. The instrumentation signals described monitor all storage level information, flows, system pressures, valves status, water quality, and SCADA communication status data. Typical standard signals are described below.

10.9.2.1 Level Signals

Reservoir, tank, or standpipe level signals must be provided on all of the existing SCADA system at storage facilities.

Reservoir level signal fail alarm signal is provided at all storage facilities. High-level and overflow float switches are required at storage facilities for alarming. SCADA operators are notified by the SCADA system of the level signal failure. See Table 10-13 for a list of continuous transducers.

Table 10-12
Continuous Level Transducers.

Instrument Solution	Field Application	Design Considerations
Hydrostatic pressure transducer	Combination influent and effluent piping supporting water storage facilities such as Standpipes, Above ground tanks and reservoirs.	Compensatory offsets.
Differential pressure transducer	Storage tanks.	Compensatory offsets, Liquid specific gravity
Submergible tethered pressure transducer with atmospheric compensation	Above ground water storage facilities, Embankments, holding ponds and large water storage vessels without below grade piping infrastructure to support a pipe mounted instrument.	Attempt to defeat. Class I Division I certification.
Radar level transducer	Symmetrical tanks and structures where the liquid surface is not in motion and agitated.	Compensatory offsets, Radar beam angle, Asymmetrical structures, Deflection edges, Moving fluids, Choppy/agitated surface water, uneven structure floor. Empty tank or structure. Class I Division I certification.
Ultrasonic level transducer	Symmetrical tanks and structures where the liquid surface is not in motion and agitated.	Compensatory offsets, Echoing, Asymmetrical structures, Deflection edges, Moving fluids, Choppy/agitated surface water, uneven structure floor. Empty tank or structure. Class I Division I certification.
Optical-level (Laser) transducer	Tanks, Symmetrical and Asymmetrical structures in water and wastewater applications.	Fluid turbidity, Lense fogging, Class I Division I certification.

10.9.2.2 Distribution System Pressure

Distribution system pressure is measured on the distribution system side of any storage facility isolation valves. SCADA operators use pressure data to verify customer supply pressure. This verification is important during periods when the storage facility is isolated from the distribution system due to altitude valve closure or when manual valves are closed for storage facility maintenance.

10.9.2.3 Inflow/Outflow

Storage facility inflow and outflow instruments must be provided on storage facilities. Flow meters provide flow data that can be used to calculate water losses, zone transfer flows, and pump efficiencies.

Storage facility inflow meters and outflow meters must be installed at storage facilities where piping space is available. Piping space must allow for a spool piece magnetic flow meter to be installed so that meter section is full at all times with no air gap and with manufacturer's recommended upstream and downstream distances to provide a ± 0.5% to 1.0% accuracy reading over expected flow range. The flow meter must be capable of reading forward and reverse flows.

10.9.2.4 Reservoir Bypass Flow

Reservoir bypass flow meters must be provided so flow data can be used to calculate water losses, zone transfer flows, and pump efficiencies.

Where the reservoir configuration allows water to bypass the reservoir inlet piping, and where the piping allows, a spool piece magnetic flow meter should be installed so that meter section is full at all times with no air gap and with manufacturer's recommended upstream and downstream distances to provide a ± 0.5% to 1.0% accuracy reading over expected flow range.

10.9.2.5 Overflow Alarm

SPU provides overflow detection and alarms on some of its storage facility overflow lines. The overflow alarm is used by the PLC to calculate the overflow rate and total based on inflow rate, outflow rate, and bypass flow rate.

Overflow alarm instruments must be float switches.

10.9.2.6 Overflow Flow Rate Measurement

Storage facility piping should be evaluated to determine the most economical way to measure the water that is overflowing from a storage facility.

- **Alternative 1:** The overflow alarm could be used by PLC logic to trigger the calculation of the overflow rate based on inflow rate, outflow rate, and bypass flow rate.
- **Alternative 2:** The overflow flow rate could be measured with a spool piece magnetic flow meter installed downstream of the valves. The flow meter must be installed in a piping configuration that maintains a full pipe under conditions of flow and no flow. If an overflow meter is installed, the PLC can calculate the overflow alarm based on the overflow flow rate.

10.9.2.7 Reservoir Under Floor Drain Flow Rate Measurement

Reservoir under floor drains direct water that leaks through the reservoir liner or from the external water table to a drain. The storage facility piping should be evaluated to determine the most economical way to measure the water that is pumped or drained from the reservoir under floor drain system. Current configuration includes float switches and flow monitors.

10.9.2.8 Water Quality Monitoring

Depending on the facility, the SPU Water Quality Lab has specified various real-time water quality monitoring equipment throughout the City's storage facilities. Water quality sensors usually consist but are not limited to the following types of instruments:

- Chlorine Residual Sensors – SPU provides chlorine residual monitoring instruments for internal water on its large, covered storage facilities. These instruments use recirculation of water with sodium hypochlorite injection. Chlorine residual measurement is a very important water quality parameter required for compliance with regulations.
- pH Sensors – Used to measure the acidity or basicity of drinking water. pH levels can affect water quality compliance and can degrade SPU infrastructure if not kept within a specific range.
- Turbidity Sensors – These types of sensors are used to identify the amount of particulate matter in water. Turbidity is a key measurement of water quality compliance.
- Fluorine, Temperature, Ozone, ultraviolet transmittance (UVT), and others – Miscellaneous sensors used to monitor various water quality parameters.

Typical data from these types of instruments include the following:

- Water Quality Analog Data – This information would consist of data such as free chlorine quantity, turbidity in NTU's or pH level.
- High/Low Discrete Alarms – These alarms would be based on preset high and low values in the instrumentation or the local PLC controller.
- Equipment Warning and Failure Discrete Alarms – These alarms could consist of calibration alarms or equipment failures that would compromise the accuracy of the water quality data.

Communications with these instruments may consist of discrete inputs, 4-20mA analog inputs and digital communications. Digital communications may consist of Modbus over RS-485 or Ethernet TCP/IP communications.

Bypass Valve Open/Close Command
Storage facility bypass valves must be monitored and controlled as a basic data requirement.

10.9.2.9 Altitude Valve Control and Monitoring

SPU provides altitude valve status monitoring at many of its storage facilities. PLC control of the altitude valve is provided at some SPU storage facilities.

10.9.2.10 Inlet/Outlet Valves

Some SPU storage facility sites are configured with inlet and/or outlet valves. All inlet and outlet valves should include the standard PLC interface signals noted in the storage facility standard equipment list:

- Valve open limit switch
- Valve closed limit switch
- Valve open command
- Valve close command
- Local-off-remote (L-O-R) in remote switch status
- L-O-R in local switch status
- Valve motor run
- Valve high torque alarm on close

- Valve high torque alarm on open
- Valve position 0 to 100% status analog input
- Valve position 0 to 100% analog output command (optional)

10.9.3 Drinking Water Remote-Controlled Valve Stations

This section describes SPU signal standards for remote-controlled valve stations. The goal at remote controlled valve sites is to monitor all valve pressure information, valve flow, site security, and SCADA communication status data. Typical standard signals are described below.

10.9.3.1 Upstream Pressure

Upstream pressure monitoring at a remote-controlled valve station measures the pressure at the upstream or lower pressure zone side of the valve. Upstream pressure monitoring provides an indication of local zone pressure when the valve is closed and provides a dynamic pressure indication while the valve is open and water is flowing from high elevation zone to lower elevation zone. Pressure comparisons at more locations in the distribution and transmission systems will provide valuable information about the system hydraulic conditions to SCADA operators and optimization applications.

Low upstream pressure alarms can be set to advise the operator that customer low-pressure complaints could occur.

10.9.3.2 Downstream Pressure

Downstream pressure monitoring at a valve station measures the pressure at the downstream or low-pressure zone side of the valve. Downstream pressure monitoring provides the following:

- An indication of local downstream zone pressure when the valve is closed
- A dynamic pressure indication while the valve is open and water is flowing from high elevation zone to lower elevation zone

Pressure comparisons at more locations in the distribution and transmission system will provide valuable information about the dynamic distribution system hydraulic conditions to the SCADA operators and optimization applications.

High downstream pressure alarms can be set to advise the operator that customer high-pressure complaints could occur.

10.9.3.3 Downstream Pressure High Alarm

A pressure switch connected to the downstream side of the valve will provide a downstream pressure high alarm. This alarm is used as a backup alarm when a failure or calibration error occurs with the downstream pressure transmitter. This is a basic data requirement that is used to provide additional high-pressure protection at valve stations.

10.9.3.4 Valve Station Flow to Zone

Flow monitoring of the water flow to the low-pressure zone is measured at some SPU remote-controlled valve stations. SPU monitors valve station flow at remote controlled valve stations with larger sized valves, or where remote-controlled valves are used on transmission lines. Valve station flow should be provided at all remote-controlled valve stations and added as basic data at stations that do not currently have flow monitoring.

Flow monitoring at all valve stations will provide the benefit of tracking water flows and aid in detection of water leaks and losses. Flow monitoring will also allow operator and operations optimization applications to reduce the cost of water delivery by finding the lowest cost delivery strategy.

10.9.3.5 Remotely Controlled Valves

SPU installs three types of motor operated remote-controlled valves: ball, butterfly, and gate valves. Remote-controlled valves include different control and monitoring signals at different sites. The SPU-preferred configuration for remote-controlled valves used for flow or no-flow control is the following discrete open/close control interface:

- Valve open and close commands generated by PLC logic and sent from discrete outputs to the valve actuator. Open and close commands are sent from the operator SCADA workstation if the operator control is in SCADA manual mode or by the local PLC logic if the operator control is in SCADA auto mode.
- Valve open and closed status signals are sent from limit switches on the valve to discrete inputs to be used by PLC logic and sent to the SCADA operator workstation for display.
- The preferred configuration for remote-controlled valves used to provide modulating or variable flow rates is controlled by an analog position signal from the PLC. These valves should also monitor the analog valve position signal and send the position signal to the operator SCADA workstation. Currently valves are controlled by varying pulse width durations to the open or close command relays.
- Preferred communication mode with the valve actuator is Modbus RS-485.
- One option to control valve position is by 0% to 100% analog output commands generated by PLC logic. The position commands can be sent from the operator SCADA workstation if the operator control is in SCADA manual mode or by the local PLC logic if the operator control is in auto mode. *Note: SPU has not implemented this option.*
  - The valve position signal of 0% to 100% is monitored by an analog input channel to be used by PLC logic and sent to the SCADA operator workstation for display.
  - Remote controlled valves with discrete open/close control interface can be used in modulating control applications, but the position feedback should always be monitored by the PLC and sent to the operator's SCADA workstation.
- Valve L-O-R switch in remote or local.
  - The remote status of the valve local control switch is an input to the PLC, used by the PLC logic, then sent to the SCADA operator to confirm the valve is ready to accept commands from a remote location.
  - The local status of the valve control switch is also an input to the PLC and is provided to the SCADA operator.
  - Valves may have two L-O-R switches. One is located inside of the valve vault and the other is located outside of the vault. This allows for local valve control without City staff having to be inside of the valve vault. The valve L-O-R switch outside of the vault is a slave to the L-O-R switch inside of the vault.

  - With two L-O-R switches, the valve L-O-R switch inside of the vault must be in remote mode for the outside valve L-O-R switch to have control. The outside valve L-O-R switch must also be in remote mode for the local PLC or SCADA operator to have control of the valve.
  - With two L-O-R switches, if the valve L-O-R switch inside of the vault is in Local mode, then valve control is isolated to the vault control panel. If it is set to Remote mode and the outside valve L-O-R switch is set to Local mode, then the valve control is isolated to the outside control panel.
- Valve fails to open/close alarm.
- The PLC should generate a valve fail to open or close alarm that is based on the comparison of the open or close command with the open or closed position status. If the command does not match the status after an adjustable time delay, the valve fail alarm is generated.

10.9.4 Drinking Water Delivery to Wholesale Customers

SPU monitors water delivery to wholesale customers with flow meters that are interfaced to an automatic meter reading (AMR) system. These flow meters are remotely read by meter reading staff in vehicles that must visit each meter at the meter reading interval of once per month.

The current wholesale customer flow meter AMR system is based on the Itron and Metron platforms and is currently not integrated into the SCADA system.

10.9.5 Pressure Regulating Valve Stations

Pressure regulating valve (PRV) station data/instrumentation standards include only PRV sites for the distribution system. SPU currently has 65 PRV stations that are operational in the distribution system. The SCADA system monitors and controls only three of these PRV stations. The existing PRV stations typically include two valves: one smaller PRV that has a higher pressure setpoint and one larger PRV that is has a lower pressure setpoint. Two different sized PRVs provide better pressure regulation over a wider range of flows than one PRV. This configuration also provides a PRV as a backup in the event that one PRV fails to operate.

The SPU-recommended PRV station signal standard includes upstream pressure monitoring, downstream pressure monitoring and flow to each zone with monitoring by the SCADA system. Operations optimization applications will require flow measurement to account for most of the water flow from zone to zone to effectively detect leaks and determine the most efficient method to move water to each distribution area.

Typical recommended standard signals are described below.

10.9.5.1 Upstream Pressure

Upstream pressure monitoring at a PRV station measures the pressure at the upstream or high-pressure zone side of the valve. Upstream pressure monitoring provides an indication of local zone pressure when the valve is closed and provides a dynamic pressure indication while the valve is open and regulating pressure from high elevation zone to lower elevation zone. Pressure comparisons at more locations in the distribution system will provide valuable information about the system hydraulic conditions to the SCADA operators and operations optimization applications.

Low upstream pressure alarms can be set to advise the operator that customer low-pressure complaints could occur.

10.9.5.2 Downstream Pressure

Downstream pressure monitoring at a PRV station measures the pressure at the downstream or low-pressure zone side of the valve. Downstream pressure monitoring provides an indication of local zone pressure when the valve is closed and provides a dynamic pressure indication while the valve is regulating water pressure from high elevation zone to lower elevation zone.

High downstream pressure alarms can be set to advise the operator that customer high-pressure complaints could occur.

10.9.5.3 Downstream Pressure High Alarm

A downstream pressure high alarm is provided with a pressure switch connected to the downstream side of the valve. A downstream pressure high alarm, using a pressure switch, is provided as a backup pressure alarm that alarms if the pressure is high when a failure or calibration error occurs with the downstream pressure transmitter. This is a basic data requirement that can provide additional high-pressure protection at valve stations.

10.9.5.4 Pressure Regulating Valve Station Flow to Zone

Monitoring of the water flow to the low-pressure zone is an option for critical PRV stations. Valve station flow should be provided at all large and medium sized PRV stations and added as basic data at stations that do not currently have flow monitoring.

Flow monitoring at all large and medium size PRV stations will provide the benefit of tracking water flows and aid in detection of water leaks and losses. The flow monitoring will also allow operator and operations optimization applications to reduce the cost of water delivery by finding the lowest cost delivery strategy.

Flow measurement equipment for PRVs can be based any one of two types of flow meters: Cla-Val PRV Integrated Flow Measurement and Spool Piece Magnetic Flow meter.

A. Alternative 1 – Cla-Val Pressure Regulating Valve Integrated Flow Measurement

The PRV manufacturer Cla-Val can provide flow measurement equipment that is integrated with the PRV and does not require cutting a pipeline to add a spool piece flow meter. This type of flow measurement is made by adding a differential pressure transmitter that is piped to a manufacturer supplied monitoring taps upstream of the valve and downstream of the valve. A valve position transmitter is installed on the valve stem. The differential pressure and the valve position signals are connected to a flow conversion instrument that computes the flow based on the valve flow coefficient (Cv), then sends the flow rate signal to the PLC. The PLC can also be programmed to convert the valve position signal and differential pressure signal into the flow rate using the valve Cv table stored in PLC logic. This measurement system provides typical accuracy of 2% to 3% of actual flow that is suitable for PRV flow measurement. This alternative provides the lowest installed cost for flow measurement equipment at PRV stations because it minimizes the need for site modifications.

The Cla-Val PRV differential flow measurement system for 3-inch to 24-inch Cla-Val PRVs is a cost-effective method of identifying PRV flow. This method does not require the upstream and downstream straight pipe lengths that are required for other types of flow meter systems. This type of instrument can usually fit into an existing PRV vault instead of having to increase the vault size or install flow measurement vault next to the PRV vault.

B. Alternative 2- Spool Piece Magnetic Flow Meter

Spool piece magnetic flow meters can provide better than ± 0.5% accuracy and can be installed within pipes with 5 diameters of undisturbed flow upstream and 5 diameters of undisturbed flow downstream of the flow element. Magnetic flow meters will provide the most accurate flow measurements at PRV stations. The meter cost is high for large pipe metering, and the piping and the vaults may require modification to install the large diameter equipment. Spool piece magnetic flow meters should be used where the pipeline is less than 24 inches in diameter and Alternative 1 (Cla-Val) cannot be used because the valve diameter is less than 3 inches.

10.9.5.5 Vault Flood Alarm

A float switch should be installed and connected to the PLC to provide a vault flood alarm at 1 inch Above Finished Floor (AFF).

10.9.5.6 Sump Pump

A sump pump should be installed to pump water from the vault to a drain line.

10.9.6 Pressure or Flow Monitoring Station

Remote monitoring stations are installed at strategic locations in the distribution system to provide real-time pressure and flow data to the SCADA system operator. These monitoring stations provide pressure and flow data the operator can use to view the dynamic conditions within a zone to detect high or low-pressure conditions to make operational decisions to correct the condition. The stations also provide data used for operations optimization applications.

Additional pressure and flow monitoring stations may be required to provide sufficient data to develop the system simulator and optimizer application. The pressure or flow monitoring station signal standards should be used to design and install new monitoring stations.

10.9.6.1 Pressure Equipment

Pressure monitoring at a remote monitoring station measures the pressure at the pipeline tap where the monitoring site is located.

10.9.6.2 Flow Equipment

Flow monitoring at a remote monitoring station measures the transmission line flow or zone to zone flow at that location.

10.9.7 Drinking Water Pump Stations

This section describes the SPU drinking water pump station signal standards for all SPU water pump stations in the distribution system. SPU currently has 31 pump stations that are operational in the distribution system. The design goal for each water pump station is to monitor pump run status for each pump, pump station suction pressure, discharge pressure, discharge flow, bypass valve flow, pump station power consumption, site security, and SCADA communication status data. Typical pump station standard signals are described below.

10.9.7.1 Suction Pressure

Suction pressure monitoring at a drinking water pump station measures the pressure at the upstream side of the pump suction connections and downstream of the station inlet or storage facility connection.

Low-suction pressure alarms should be programmed in PLC logic based on value of the suction pressure input signal to alert the SCADA operator and shutdown the facility pumps.

10.9.7.2 Discharge Flow

Drinking water pump station discharge flow rate is measured by a flow meter between the pump discharge header and the discharge zone. The pump station discharge flow rate provides flow data that is used to track water transfer from zone to zone, calculate and monitor pump efficiency, and detect water leakage on a system wide basis.

Discharge flow meters should be added as basic data to all pump stations that do not currently have the discharge flow rate measured.

10.9.7.3 Discharge Pressure

A drinking water pump station discharge pressure transmitter measures the pump station discharge pressure and sends the signal to the PLC then to the SCADA operator. Discharge pressure provides data that can be used to calculate pump efficiency, provide high pressure alarm for the discharge zone before damage occurs, and provide data for operations optimization applications.

Discharge pressure transmitters should be installed as basic data at all pump stations that currently do not have the pressure monitored.

10.9.7.4 Electrical Power Consumption

Electrical power total consumption in kilowatts (kW) and energy consumption rate in kilowatt hours (kWh) should be measured at the drinking water station, input to the PLC and sent to the SCADA system and operator at less than 15-minute intervals. Electrical power consumption data can be used to check the power company billing information on a monthly interval and is required at one to five-minute intervals to calculate the pump efficiency.

The standard for monitoring facility power at pumping plants will include one facility power monitor unit and individual power monitoring units in the motor control center (MCC) for each pump motor.

This type of power monitoring provides the following advantages:

- Much more accurate power consumption total and rate information.
- Electrical variables (e.g., kW, kWh, and voltage and power factor) and alarms (e.g., high voltage, power failure, and low voltage) can be monitored to help resolve pump station electrical problems.
- Ability to diagnose individual motor/pump failures.

10.9.7.5 Discharge Pressure High Alarm

For a drinking water pump stations, the discharge pressure high alarm signal is provided by a pressure switch connected to the pump station discharge line or by PLC logic, which monitors the analog signal from the discharge pressure transmitter. The alarm can be used to provide only an alarm to the SCADA operator or stop the pumps with either PLC logic or a hardwired interlock. An alarm is sent to the SCADA operator.

Discharge pressure high switches should be added at all stations as basic data at all pumps stations that currently do not have the pressure alarms monitored.

10.9.7.6 Flood Alarm

The drinking water pump station flood alarm detects a high-water level or flood condition in the pump station building.

10.9.7.7 Fire Alarm

The domestic water pump station fire alarm detects a possible fire in the pump station building.

10.9.7.8 Electrical Power Fail Alarm

The pump station power fail condition is detected with a power fail relay or a more sensitive phase failure relay that monitors the incoming power at drinking water pump station. The power failure can be detected with the new power monitor equipment that was recommended in the power consumption monitoring section.

10.9.7.9 Pump Running

The pump running status is monitored by a run contact in each pump motor starter. The run status signal is sent to the PLC, then to the SCADA operator workstation.

10.9.7.10 Local-Off-Remote Switch Status

The PLC monitors the pump L-O-R switch position status for each drinking water pump. When this L-O-R switch is in the remote position, the signal is a permissive to permit a pump start command to the respective pump.

10.9.7.11 Start Signal

The PLC sends a pump start signal to each drinking water pump MCC when the pump is required to run. The PLC outputs the pump start command when the pump L-O-R switch is in the remote position and a command is received from the master station.

10.9.7.12 Pump Available Status

For drinking water pump stations, the pump available status is calculated by the PLC and is true when the L-O-R switch is in remote position and there are no pump alarms.

10.9.7.13 Motor and Pump Alarms

For drinking water pump stations, the following motor and pump alarms are recommended:

- **Pump and Motor Bearing High-Temperature Alarm.** Bearing high-temperature switches will be interfaced to the PLC. An additional relay may be required to add a dry contact for PLC input.
- **Motor Overload Alarm.** Motor overload relays will be interfaced to the PLC. An additional relay may be required to add a dry contact for PLC input.

10.9.7.14 Pump Discharge Valve Status

For drinking water pump stations where pump discharge valves are installed, the open and closed status can be monitored by the SCADA system PLC to provide an alarm if the valve is not open when the pump is running.

10.9.7.15 Pump Station Bypass Valve or Other Valves

Pump station bypass valves or other remote-controlled valves at pump stations should include the same valve monitoring and control equipment recommended in DSG section 10.9.3.

10.9.8 Wells

As of this DSG publication, SPU has not developed a well data/instrumentation standard for its drinking water distribution system wells. SPU currently has several wells that are operational in the distribution system but used only for an emergency backup water supply. Existing SPU well pump stations are monitored but not controlled by the SCADA system.

10.9.9 Wastewater Pump Stations

The following section outlines SPU signal standards for wastewater pump stations. Please refer to *Chapter 11, Pump Stations* for Pump Station design guidelines. The design goal for wastewater pump stations is to monitor pump status for each pump, wet well level, effluent flow, site alarms, and SCADA communication status data. Removed for Security There are currently four types of wastewater pump stations:

- Wet well/dry well
- Submersible
- Single pot air lift
- Double pot air lift

10.9.9.1 General

A. Wet Well/Dry Well and Submersible Pump Stations

Wet well/dry well pump stations consist of a storage well for wastewater and a dry vault adjacent to the storage well for pumps, motors, valves, and sometimes electrical equipment. Submersible pump stations have the motors, pumps, and sometimes valves submerged in the wastewater storage vault with the electrical equipment located in a dry vault or above ground.

Setpoints are used to control the pumps based on wet well levels. The setpoints include lead level for a first pump run, lag level for a second pump run, and an off level to shut off both pumps. After each pump run, the pumps will alternate lead and lag selection. If one pump becomes locked out due to a pump failure or has been turned off, then the other pump will always become the lead pump. When the remote facility pumps are in AUTO mode, they can be controlled from the central SCADA system via setpoints. Most new or upgraded wastewater pump stations have been of the submersible type.

B. Single and Double Pot Airlift (Compressed Air) Pump Stations

Air-lift facilities use compressed air in one or more air chambers to push wastewater to a higher elevation. The facility pumps are used to compress air rather than pump wastewater.

Air-lift facilities are controlled by conductivity sensors in the wastewater container. When the level in the air-lift container reaches the start level, a lead pump will run on a timer based on the container size and the effluent flow rate. After each pump run, the pumps will alternate the lead selection. If one pump becomes locked out due to a pump failure or has been turned off, then the other pump will always become the lead pump. A single pot air-lift station uses a single wet well and air compression tank where a double pot air-lift stations uses two of each.

These facilities do not use lead/lag/off setpoints. They are triggered to run based on a conductivity probe that senses when the containment tank is full. It is unlikely that any new air-lift stations will be built. Any air-lift pump stations that require upgrades will most likely be replaced with a submersible facility. Typical wastewater pump station standard equipment and signals are described below.

10.9.9.2 Station Discharge Flow

Wastewater pump station discharge flow rate is measured by a flow meter between the pump discharge header and the discharge zone.

10.9.9.3 Wet Well Level

Level signals should be provided for non-air-lift wastewater wet well storage tanks. Level signals should not be provided for air-lift wastewater inflow chamber storage tanks. Wet well level is primarily used for automatic wastewater pump control and primary high/low and overflow level alarming. Existing wastewater pump stations use wet well level sensors to identify flow rate but future new and upgraded facilities will standardize on magnetic flow meters.

Level signal fail alarm signal should also be provided at all SPU wastewater pump station facilities. The alarm signal is calculated by the PLC and is used in the data quality monitor and for disabling the automatic level control strategy so that the wet well floats will be used for pump control. SCADA operators will be notified by alarm system of the level signal failure.

10.9.9.4 High Level Float

Wastewater pump station facilities have high level floats located above the level sensor high level setpoint. These floats identify when the wet well level has reached a high point that could possibly cause an overflow condition. In airlift facilities, the high float is only used to help operators identify if facility pumps are not capable of keeping up with influent flow.

10.9.9.5 Station Flood Alarm

The wastewater pump station flood alarm detects a high-water level or flood condition in the pump station building.

10.9.9.6 Electrical Power Fail Alarm

The wastewater pump station power fail condition is detected with a power fail relay or a more sensitive phase failure relay that monitors incoming power at the pump station.

10.9.9.7 Pump Running

The wastewater pump running status is monitored by a run contact in each pump motor starter. The run status signal is sent to the PLC, then to the SCADA operator workstation. The location of this run contact is dependent on the Motor Control panel design.

10.9.9.8 Pump Hand-Off-Auto Switch

Each pump in the wastewater pump station must be equipped with a hand-off-auto (H-O-A) switch. The status of each pump must be monitored by the SCADA PLC 24/7.

When this switch is in the auto position, the signal is a permissive for a pump auto start command to the respective pump. All SPU pump stations currently include this status signal.

10.9.9.9 Pump Available Status

The wastewater pump available status is calculated by the PLC and is true when the H-O-A switch is in auto position and there are no pump alarms.

10.9.9.10 Motor Overload Alarm

Motor overload relays must be interfaced to the PLC. An additional relay may be required to add a dry contact for PLC input.

10.9.9.11 Pump Discharge Valve Status

See DSG section 10.9.7.14.

10.9.9.12 Electrical Power Consumption

Electrical power consumption monitoring standards are the same for water and wastewater pump stations. For more detail on water pump station electrical power consumption, see 10.9.7.4.

10.9.9.13 Start Signals

Wastewater station pump call start signals are used to control the level of the facility wet well. For wet well/drywell and submersible facilities, the pumps are called to lower the wet well level by pumping the wastewater into the next wastewater basin or interceptor. Air-lift facilities use the pump calls to compress air in a tank. When the level of wastewater in the wet well reaches a high setpoint, the compressed air is released, and the wastewater is pushed into the next wastewater basin or interceptor. The PLC sends a pump start signal when the pump or airlift is required to run. The PLC outputs the start command when the pump H-O-A switch is in the auto position.

10.9.10 Combined Sewer Overflow

The following section outlines the data/instrumentation standards for combined sewer overflow (CSO) stations. The design goal at the CSO stations depends on the type of CSO facility. Most CSO sites consist of weir diversions for overflowing wastewater/stormwater into local waterways when stormwater flows become too high. At these sites, the primary design goal is to identify when an overflow occurs and the total quantity of flow that has gone into local waterways.

Newer CSO facilities have on-site storage to hold overflowed wastewater/stormwater and prevent point source water pollution. These CSO sites monitor storage levels and diversion overflows. Most of these facilities use special types of valves to slowly release their stored wastewater/stormwater into the wastewater transmission system. These valves require no control and are not monitored. Some of the latest CSO sites have added control of pumps and valves for automatic flow from the CSO storage facilities into the wastewater transmission system.

Most these facilities currently transmit data to a third-party service instead of a SPU SCADA system. SPU is currently planning to integrate the CSO facilities into the drainage wastewater SCADA system. Newer CSO Storage facilities are monitored and controlled via SPU SCADA, but these facilities are not included in current DS&G update.

10.9.10.1 Overflow Level

All CSO facilities have a weir diversion from the main wastewater transmission system. When the transmission flow reaches levels that are too high for the transmission systems, flow travels over the weir and into a local waterway. A level sensor is located on the transmission side of the weir to collect level data. This data is used for identifying when overflows are imminent due to high flow rates or clogged transmission pipes. This data is also used to confirm actual overflow conditions when CSO effluent flow is identified.

10.9.10.2 Storage Level

At CSO facilities that have storage containment, level sensors are installed to monitor the wastewater/drainage level. At facilities that have control over the containment effluent, this level is used to control flow rates. RADAR and pressure level sensors are currently used for containment level measurements.

10.9.10.3 Effluent Flow

Effluent flow is measured from a number of different locations at CSO facilities depending on their capabilities. For CSO facilities without containment storage, the effluent overflow that occurs into local waterways is monitored. For facilities with containment storage, effluent flows from the containment vessel are also monitored. Bubbler depth sensors are used for monitoring small effluent pipe flows. Doppler ultrasonic velocity sensors are used for larger effluent pipe flows.

10.9.10.4 Valve Control

At some SPU facilities with storage containment, electrically controlled gate valves have been added to manually and automatically control effluent flow based on the containment level.

10.10 INSTRUMENTATION FOR PROCESS AND CONTROL SYSTEMS

This section identifies the types of equipment required at remote facilities to interface between field processes and the SPU SCADA system. The data are used by the UOCC operators, LOB engineers, and hydraulic system modelers.

10.10.1 Instrument Degree of Protection

Instrument degree of protection, is defined by IEC 60529. An instrument protection rating is a four-digit code that gives an indication to the degree of protection of an instrument that provides a means of mitigating an ingress of foreign bodies. This includes intrusion from solid particles such as dust, condensation gases and liquids such as water.

For instruments mounted on structures where the risk of flooding is high, minimal instrument protection is a factory-set IP68 degree of protection. In applications where the device manufacturer only offers a lower degree of protection, i.e. IP64.

Legacy devices are grandfathered in under the condition that the device is protected by a third-party solution, such as field potting or equivalent combinations, to upgrade the device degree of protection to IP68.

Examples of good instrument protection:

- Factory potted circuitry.
- Factory IP68 protected circuitry.
- Signal cables with fastened to the device body with mechanical cable glands.
- Device applications where a combination of mechanical glands, conformal coatings and conduit drip loops are applied to mitigate dust and water egress.

Examples of unacceptable instrument protection:

- Devices with no protection to mitigate ingress of dust and water.
- Devices with degree of protection of less than IP64

Typical instrument protection:

- Pipe mounted pressure transducers
- Flow meters and indicators
- Exposed device terminals
- Untreated circuit boards.

Exceptions:

- None

Standards:

- IEC 60529, NEMA 4X,

Appendix 10E - Typical Installation Details for Instrumentation includes typical installation details for many of the instruments identified in this section.

10.10.2 General

This section presents data/instrumentation standards and catalog of recommended manufacturer and part number for each type of instrument. The manufacturer names and part numbers recommended in this section are a guideline for the instrument accuracy, quality, and features that SPU specifiers require. To minimize spare parts inventory and technician training, it is recommended by SPU Operations that standardized equipment not be substituted if possible.

10.10.3 Level Measurement Instrumentation

10.10.3.1 Pressure Transmitters

A. Drinking Water Facilities

SPU currently specifies Rosemount 2088 series pressure transmitters with a ± 0.1% accuracy specification for both pressure measurement and elevated tank level measurement. SPU specifies pressure transmitters with the Hart option for calibration use. The standard 4-20mA signal is used to interface the pressure transmitter to the PLC and SCADA system. SPU uses a Rosemount Hart handheld interface for calibration only.

SPU has standardized on the following Rosemount pressure transmitter models for these applications and substitutes are not accepted (see Table 10-14).

Table 10-13
Rosemount Pressure Transmitter Models

Application	Model Number	Calibration Range
All Pressure Measurements	2088G3S22A1B4M7	0 to 800 psig
Elevated Tank Level Measurements	2088G2S22A1B4M7	0 to 150 psig

Acronyms and Abbreviations
psig: pounds per square inch gauge

The Rosemount 2088 series pressure transmitter's ± 0.1% accuracy specification is adequate for most pressure measurement and elevated tank level applications.

10.10.3.2 Differential Pressure Transmitters

A. Drinking Water Facilities

SPU standards recommend the Rosemount model 3051S series with ± 0.025% accuracy for differential pressure transmitters. The improved accuracy will provide more accurate flow readings when used as the differential pressure transmitter for the Cla-Val flow meter conversion applications.

10.10.3.3 Submersible Pressure Transmitters

A. Drinking Water Facilities

SPU has standardized on the GE Druck PTX-1830 series submersible pressure transmitters for all reservoir level transmitters. Currently only the top 20 ft of all reservoirs are measured, although the reservoirs typically are 30 ft of actual depth.

The GE Druck submersible transmitter is installed in a perforated PVC pipe that is run from outside the reservoir. This is done so the transmitter can be removed and re-installed into the reservoir without having to enter its interior. The perforated PVC pipe is mounted to the inside of the reservoir with the top of the pipe open for the level transmitter and bottom sealed with a removable cap. During reservoir maintenance when the tank is empty, this cap can be removed so the perforated PVC pipe can be cleaned.

The level transmitters are calibrated to a full-scale span to reading of 2 ft above overflow so operators can see how high the water rises above the overflow structure when the reservoir is overflowing at a high flow rate.

B. Drainage and Wastewater Facilities

SPU has standards on the following types of submersible pressure sensor for wet well and CSO storage level measurement:

- Measurement Specialties Pressure Systems, Inc. - KPSI 750
- G. E. Druck PTX 1830 with STE-110

The KPSI 750 transmitters are designed for sitting on the bottom of a facility wet well with a weighted protected cage around the pressure sensor bottom.

GE Druck type should be used when low flow (level) measurement is required.

Refer to **Appendix 10E - Typical Installation Details for Instrumentation**.

10.10.3.4 RADAR Level Sensor

A. Drainage and Wastewater Facilities

RADAR level sensors are typically used to identify open channel flow by measuring the water level through Parshall flumes and over weirs, as well as CSO storage tanks level. These are non-contact level measurement instruments that measure the RADAR waves off a water/wastewater surface. SPU standards recommend the VEGA RADAR DISPLAY with HART communication for this type of application.

10.10.4 Flow Meters

10.10.4.1 Spool Piece Magnetic Flow Meter

A. Drinking Water, Drainage, and Wastewater Facilities

Spool piece magnetic flow meters are currently used in new SPU billing flow meter applications and for well flow meter applications. The spool piece magnetic flow meters are available in sizes from 2 to 120 inches in diameter. Table 10-15 lists the advantages and disadvantages of spool piece magnetic flow meters.

Table 10-14
Advantages and Disadvantages of Spool Piece Magnetic Flow Meters

Advantages	Disadvantages
• Accuracy is ± 0.5% of full scale when installed per the manufacturer's recommendations. • Meters can be installed as close as 5 pipe diameters upstream and downstream of flow disturbances such as tees, elbows, and valves and still provide the specified accuracy. The meter body averages the flow velocity in the cross section of the pipe diameter to provide flow measurement that is not noticeably affected by changes in the flow velocity profile. • Very low maintenance. There are no moving parts or bearings to wear out in the flow sensor. The measurement technology is long proven and optimized with internal diagnostic features. The cost has been reduced. • Flow meter transmitter can be calibrated easily and quickly without the access to the magnetic flow element. • Spool piece magnetic flow meters are extremely reliable and the flow measurement readings can be used with confidence if the transmitter is regularly checked for calibration. • Can measure and indicate bi-directional flow spool piece magnetic flow meter.	• Spool piece magnetic flow meter installed cost is higher than most other types of flow meters.

SPU recommends spool piece magnetic flow meters for all wholesale customer billing, water, and wastewater pump stations, remote controlled valves, and storage facility flow meter applications with pipe diameters up to 60 inches.

Note: *SPU currently has Krohne magnetic flow meters installed at some sites. Maintenance personnel prefer this meter for its accuracy, reliability, and diagnostics. Water intrusion into the flow meter sensor terminal box from the conduit leakage has been a problem with Krohne magnetic flow meter on a previous SPU installation. Future SPU magnetic flow meter installation designs should be revised to stop rainwater from entering the conduit to the meter sensor terminal box.*

SPU recommends for drinking water sites the Krohne Enviromag 4000 spool piece sensor with polyurethane liner and the IFC-300, IFC-020, or IFC-100 series of remote transmitter that includes local indication, 4-20mA output signal, pulse output, and complete meter diagnostic features.

SPU recommends for wastewater sites the Toshiba LF654/LF622 mount-anywhere series magnetic flowmeter with remote transmitter that includes local indication, 4-20mA output signal, pulse output, and complete meter diagnostic features.

Ground Rings must be placed on flange of spool and grounded to ground grid.

10.10.4.2 Insertion Averaging Magnetic Flow Meters

A. Drinking Water Facilities

Insertion averaging magnetic flow meters use the same principle as a spool piece magnetic flow meter, except the magnetic coil and electrodes are embedded in a probe that is inserted directly into the pipe through a tap in the pipe wall. The insertion averaging magnetic flow meter can be installed in pipes from 4 inch to 120-inch diameter. Table 10-15 lists the advantages and disadvantages of insertion averaging magnetic flow meters.

Table 10-15
Advantages and Disadvantages of Insertion Averaging Magnetic Flow Meters

Advantages	Disadvantages
• Accuracy is ± 1.0% of full scale when installed per the manufacturer's recommendations. • Installation cost is low because the meter sensor probe can be installed in the pipeline through a tap in the pipe wall. The pipeline does not require shutdown and draining to install the tap and probe. • Meter probe can be removed for maintenance or repair without dewatering the pipeline.	• Meter equipment cost is higher than most flow meters except spool piece magnetic flow meters. • Sensitive to upstream and downstream pipe flow disturbances. Based on the manufacturer's application notes, the flow meter may not operate within the accuracy specifications in a location where the flow profile is skewed. The manufacturer recommends the meter be installed at least 25 pipe diameters downstream from an open or closed butterfly valve. A modulating butterfly valve located 25 pipe diameters upstream of the flow meter can cause up to 100% error. The meter requires more than 10 pipe diameters upstream from an open butterfly valve. • The meter requires a large vault with careful design to permit the full pipe diameter probe to be removed from the side of the pipeline without obstruction.

Refer to **Appendix 10E - Typical Installation Details for Instrumentation** for a detailed magnetic flow meter installation drawing.

10.10.4.3 Propeller Flow Meters

A. Drinking Water Facilities

Propeller flow meters use one of the older flow metering technologies and still provide moderate flow accuracy for many water utility applications. Propeller flow meters cannot be used for wastewater facilities. Sparling propeller flow meters with an electronic SCADA interface module are still used at some SPU sites for SCADA data. Table 10-17 lists the advantages and disadvantages of propeller flow meters.

Table 10-16
Advantages and Disadvantages of Propeller Flow Meters

Advantages	Disadvantages
• Moderate accuracy of ± 2.0% of rate. • About 10:1 flow range for a given meter diameter. • Specified accuracy can be provided with short distance requirements of 5 diameters upstream of the flow meter and 1 pipe diameter downstream of the flow meter from flow disturbances such as elbows, tees, and valves. • Low cost for most pipeline sizes.	• Mechanical propeller bearings and gears in the display register require frequent maintenance. • Pipeline must be shut down and dewatered to perform mechanical maintenance of the propeller bearings.

Some SPU propeller meters have been replaced with Seametrics insertion paddle wheel meters with analog signal interface to the SCADA system. The propeller flow meters can provide the specified accuracy with only 5 diameters of straight upstream pipeline while an insertion paddlewheel flow meter could require 50 diameters of straight upstream pipeline from a butterfly valve to provide the specified accuracy. Due to this design constraint, SPU recommends that future field equipment improvement designs use spool piece magnetic flow meters to replace old propeller flow meters for the following reasons:

- Spool piece magnetic flow meters can directly replace propeller meters because they provide the specified accuracy with only 5 diameters upstream and downstream from flow disturbances.
- Vault and piping modification cost will be less than for the insertion paddlewheel meters if flow disturbances such as elbows and butterfly valves are in the upstream pipeline.
- Replacing a propeller flow meter with a spool piece magnetic flow meter will require less maintenance and have higher reliability.

SPU recommends replacing the existing propeller flow meters that are interfaced to the SCADA system in storage facilities, pump stations, and distribution lines with spool piece magnetic flow meters to improve flow meter accuracy and reliability while reducing flow meter mechanical and electronic maintenance.

Refer to **Appendix 10E - Typical Installation Details for Instrumentation**, for a detailed installation drawing.

10.10.4.4 Insertion Paddlewheel and Insertion Turbine Flow Meters

A. Drinking Water Facilities

Insertion paddlewheel meters use a small paddlewheel flow sensor and insertion turbine meters use a small turbine flow sensor mounted on the end of a probe that is inserted through a tap in the pipe wall. The rotation of the flow sensor is monitored with a magnetic Hall Effect sensor to provide an electronic signal to the flow indicator and flow transmitter, which provides analog and pulse signals to the SCADA PLC. Table 10-18 lists the advantages and disadvantages of insertion paddlewheel meters.

Table 10-17
Advantages and Disadvantages of Insertion Paddlewheel Meters

Advantages	Disadvantages
• Low initial equipment cost. • Moderate accuracy of ± 1.0 percent if installed according to the manufacturer's recommendations. • Low installation cost because the small diameter probe can be installed through a clamp-on tap without dewatering the pipeline. • Simplified maintenance because the sensor probe can be removed for maintenance without dewatering the pipeline.	• Very sensitive to upstream and downstream flow disturbances such as elbows, tees, and butterfly valves. • Manufacturer recommends 50 pipe diameters of straight pipe between an upstream butterfly valve and the flow meter. • Requires careful consideration of any type of upstream or downstream flow disturbance.

Insertion paddlewheel and turbine flow meters are not recommended for permanent installation due to accuracy and maintenance issues.

Refer to **Appendix 10E - Typical Installation Details for Instrumentation**, Figures 10-3 and 10-4, for a detailed installation drawing.

10.10.4.5 Pressure Regulating Valve Flow Meter

A. Drinking Water Facilities

The PRV flow measuring system is a specialized flow measurement system for use with certain PRV valves. Cla-Val and Singer have valve flow meter systems based on this technology. This system consists of a valve position transmitter connected to the valve position stem and a differential pressure transmitter connected between the valve inlet and outlet ports. The SCADA PLC receives the valve position signal and the differential pressure signal with analog inputs and calculates the flow based on a comparison to the Cv table stored in the PLC. Alternatively, a hardware flow computing module can be used to calculate the flow based on the valve position, valve differential pressure, and the Cv curve in tabular format from the CLA-VAL factory. The flow system is available for globe valve sizes from 3 inches to 24 inches in diameter. Table 10-19 lists the advantages and disadvantages of PRV flow meters.

Table 10-18
Advantages and Disadvantages of PRV Flow Meters

Advantages	Disadvantages
• No external flow meter needs to be installed. • Moderate accuracy of ± 3.0 % of actual flow. • Minimum installation cost in a PRV flow measurement retrofit application because the pipeline does not require dewatering if the existing PRV is used. • PRV vault does not require modification.	• Minimum flow rate accuracy may be 100 to 200 gpm. • Not available for 2-inch PRVs that are installed at many SPU sites with dual range PRVs. • Not accurate when differential pressure is less than 0.5 psid, which could occur if valve is 100% open. • Not accurate if valve position is less than 5%.

Acronyms and Abbreviations
gpm: gallons per minute
PRV: pressure regulating valve
psid: pounds per square inch differential
SPU: Seattle Public Utilities

SPU recommends installing the CLA-VAL flow measuring system on the large PRV in a dual PRV station if the valve meets the manufacturer's flow metering criteria of operating between 5% open and 100% with greater than 0.5 pounds per square inch differential (psid). The small PRV in the dual valve station should have a spool piece magnetic flow meter installed because the upstream and downstream distances from the meter can be obtained without vault modifications or an additional vault.

10.10.4.6 Ultrasonic Flow Meters

A. Drinking Water, Drainage and Wastewater Facilities

Transmissive ultrasonic flow meters use an ultrasonic transducer on each side of the pipe to calculate the flow velocity based on the time difference between reception of an ultrasonic signal sent upstream and that of an ultrasonic signal sent downstream. Ultrasonic flow meters can be used on water and wastewater applications. Single path ultrasonic flow meters provide one pair of transducers and multi-path ultrasonic flow meters use as many as four pairs of transducers to provide more accuracy for large diameter pipelines with full or partially full lines. Table 10-19 lists the advantages and disadvantages of transmission ultrasonic flow meters.

Table 10-19
Advantages and Disadvantages of Transmissive Ultrasonic Flow Meters

Advantages	Disadvantages
• Single path ultrasonic flow meters are moderate cost for pipelines of less than 36-inch diameter. • Multi-path ultrasonic flow meters can provide better than ± 1.0% accuracy for pipelines larger than 36 inches in diameter with full or partially full conditions.	• Single path meters are very sensitive to upstream flow disturbances such as elbows, tees, and open valves. • Single path meters should be installed with caution when required to be downstream of the pump discharge headers or flow control valves because of flow disturbances. • Multi-path ultrasonic flow meters are expensive and require special training for maintenance.

Single path ultrasonic flow meters were used for SPU billing meters but have been removed because the Mesa Labs model 8000 is now obsolete. SPU standards now recommend replacing ultrasonic flow meters for all applications with spool piece magnetic flow meters for sizes of 60 inches or less in diameter. Spool piece magnetic flow meter prices are now similar to single path ultrasonic flow meters in pipe sizes of 36 inches or less in diameter. For meter installations larger than 60 inches, consider the Accusonic multi-path ultrasonic flow meter.

10.10.5 Level/Float Switches

A. Drinking Water Facilities

Water level float switches should be specified as one of the following Gems Models listed in Table 10-20.

Table 10-20
Gems Models

Application	Model	Model Description
All tank level measurements	LS-52100	Float on an arm, all stainless steel
Where conduit is installed for float mounting	LS-1950	Ball float, all stainless steel
All sub-drains and reservoir level measurements	LS-270	Bracket mounted with “slosh guard”

B. Drainage and Wastewater Facilities

Wastewater level float switches should be specified as one of the following models:

- Non-mercury weighted float switch - for wet well or inflow chambers.
- For dry well use standard Gems switch LS-270 or Evoqua Water Technologies W2T294055 (101GX).

  Refer to **Appendix 10E - Typical Installation Details for Instrumentation**, Figures 10-07 and 10-06 for detailed installation drawings.

10.10.6 Valve Position Transmitters

10.10.6.1 Drinking Water Facilities

Valve position transmitters convert the mechanical valve position into a 4-20mA signal that is transmitted to the SCADA PLC. SPU has standardized on the Honeywell model PK88136 valve position transmitter to retrofit the valve position function on existing valves that do not include the position transmitter in the existing valve electric actuator. This position transmitter can be installed on PRVs instead of the CLA-VAL position transmitter that is supplied with the CLA-VAL flow measuring system.

For ball valves, a set of micro limit switches are typically used to identify the full open or full close status of the valves.

Refer to **Appendix 10E - Typical Installation Details for Instrumentation**, Drawing 10-14 for a detailed installation drawing.

10.10.7 Electric Valve Actuators

Control valve applications in designated water pumping stations are fitted with electrical dual action hydraulic pistons to actuate plug or ball valves. These valves are actuated through an integrated five-port, three-position solenoid valve with a manual override option. These are commonly referred as a 5/3 solenoid valve control for the following applications:

- Cylinder port (open)
- Pressurized center (trap)
- Cylinder port (close)

Supply pressure for a 5/3 solenoid valve passes through the pump discharge header. The hydraulic circuit can increase of decrease velocity using needle speed controls. The circuit can also manually isolate open, close, and trap valve applications. See Figure 10-5 and Figure 10-6

Figure 10-6
Five-Port, Three-Position Solenoid Actuated Spring Return Valve

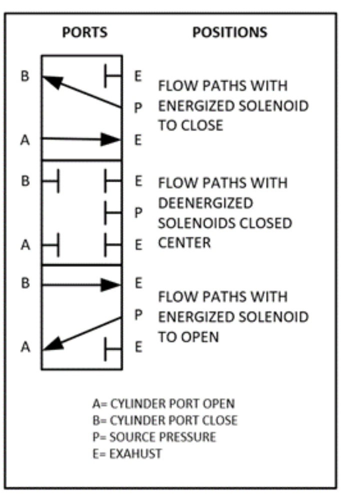
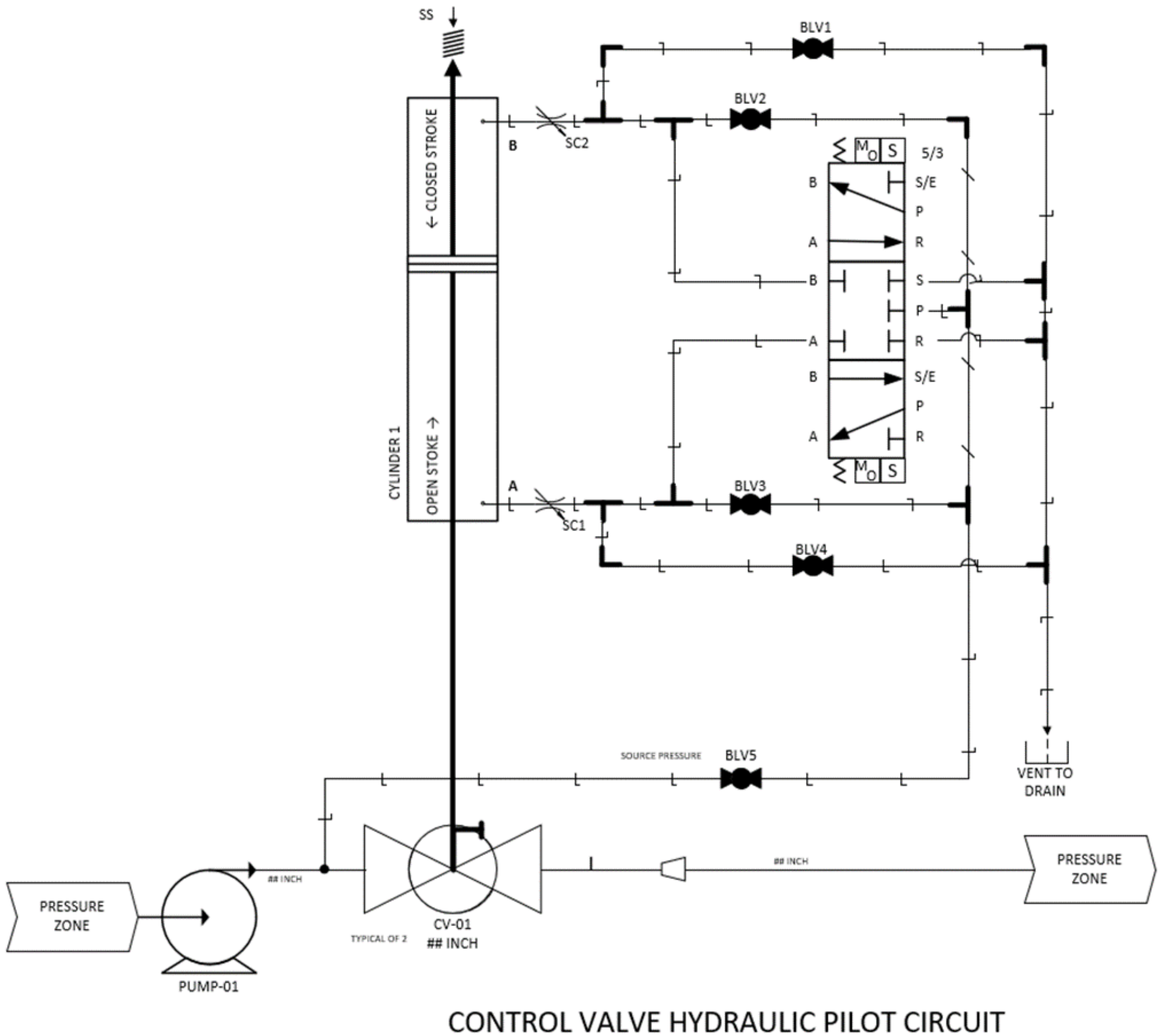


Figure 10-7
Hydraulic Control Valve Circuit



10.10.7.1 Drinking Water Facilities

Valve Electric actuators should include open/close service models and modulating service models. Rotork electric valve actuators have been installed at sites and have operated with minimal failures. SPU prefers Rotork series actuators for all butterfly, globe, ball, and gate valve applications.

Valve electric actuators must provide the following functions as a minimum standard requirement:

- Modbus communication capability that provides the following status signals:
  - L-O-R selector switch with "remote" and "local" status'
  - L-O-R selector switch with "remote" and "local" status of remote-control module if supplied
  - Opened and closed status signals
  - Valve motor running status signal
  - Valve position to the PLC
  - Remote open and close commands
  - High torque on open
  - High torque on close
- Discrete input status readings from the following:
  - "remote" status
  - "local" status
  - Opened and closed status signals
  - Valve motor running status signal
- Analog 4-20mA input reading from the following:
  - Valve position to the PLC
- Remote valve position command via operator initiated digital output jog signal from the PLC.
- Integral digital display on the valve actuator to allow non-intrusive display of all valve calibration functions without removing the valve covers.
- Remote digital display to be placed inside the roadside cabinet or within the facility to operate or troubleshoot the valve manually without accessing the valve underground.
- Bluetooth operation if available must be disabled.
- Configuration changes should be made using Rotork Remote Control Display or the Rotork Local Control Display on the Actuator Body such as the following.
  - Electronic torque limit alarm
  - Position limits
  - Torque history for troubleshooting assistance

10.10.7.2 Drainage and Wastewater Facilities

Valve Electric actuators should include open/close service models and modulating service models. Rotork electric valve actuators have been installed at sites and have operated with minimal failures. SPU prefers Rotork series actuators for all butterfly, globe, ball, and gate valve applications.

Valve electric actuators must provide the following functions as a minimum standard requirement:

- Modbus communication capability that provides, as a minimum, the following status signals:

  - L-O-R selector switch with "remote" and "local" status'
  - L-O-R selector switch with "remote" and "local" status of remote-control module if supplied
  - Opened and closed status signals
  - Valve motor running status signal
  - Valve position to the PLC
  - Remote open and close commands
  - High torque on open
  - High torque on close
- Remote valve position command with 4-20mA signal from the PLC.
- Integral digital display on the valve actuator to allow non-intrusive display of all valve calibration functions without removing the valve covers.
- Remote digital display to be placed inside the roadside cabinet or within the facility to operate or troubleshoot the valve manually without accessing the valve underground.
- Bluetooth operation if available must be disabled.
- Configuration changes should be made using Rotork Remote Display or the Rotork Local Display such as the following.
  - Electronic torque limit alarm
  - Position limits
  - Torque history for troubleshooting assistance

10.10.8 Water Quality Analyzers

10.10.8.1 Drinking Water Facilities

Water quality analyzers are used to monitor water chemistry such as the following parameters:

- Free and Residual Chlorine – Wallace & Tiernan Micro 2000
- Turbidity – Hach 1720e
- pH, temperature, fluorine, ozone, UVT, and others – typically use Hach products

Because water quality analyzer standards change quickly, any design that requires water quality monitoring equipment should check with SPU Water Quality Lab to identify the current standards.

Refer to **Appendix 10E - Typical Installation Details for Instrumentation**, Drawings 10-10, 10-11, 10-12, and 10-13 for a detailed installation drawings for temperature and pH sensors.

10.10.9 Power Quality Monitoring

Each motor circuit in the MCC design, including the incoming main must be equipped with power monitoring devices, which also includes pertinent voltage transformers (VT) and current transformers (CT). An end-user interface is used for monitoring power quality and motor efficiency.

Each power monitor must be configured to fit the project's electrical configuration, and will communicate with the local Programmable Logic Controller or Programmable Automation Controller (PLC/PAC) serial network via an RS 485 connection. PQM devices are configured to communicate with the PLC/PAC through a RS485 connection using the Modbus protocol.

No other interface will be configured with the PQM. PQM specifications are written in a clear and concise manner so that a contractor can successfully configure and commission a PQM. Class A or class B devices must include minimal capabilities for device monitoring, power demand, and power quality.

PQM devices and their data variables serve selected operational purposes and engineering processing analysis for power quality measurements. A clear and concise power quality monitoring program and PQM device standardization adds value in regard to failure resolution, proactive planning, and understanding power quality patterns.

Exceptions:

- Smart drives such as VFD and Soft staters with integrated features supporting power quality monitoring.

Standards:

- IEC 62586
- IEC 4-7
- IEC 6100-4-15
- IEC 4-30
- IEEE 1159
- IEEE 519 and IEC-62053-21
- Meter Accuracy Class 0.2S and 0.5S for electronic type meters dynamic loads and with presence of harmonics. Current Transformers (CT's) accuracy as defined on IEC-60044-1 Class 0.1, 0.2, 0.5, 1 and 3.

10.10.9.1 Drinking Water and Wastewater Pump Stations

Pump station power usage data, such as kW and kWh, are monitored by the SCADA system to permit pump efficiency testing remotely. Power billing records can also be checked by comparing the power company kW readings from the billing meter to the kW readings from the station power monitor.

Pump station power monitors with network communication to the PLC should be installed. The following power monitors should be specified for monitoring power usage data and to provide additional data to improve the electrical maintenance data at pump stations:

- **Facility Power.** Allen-Bradley Power Monitor 3000 with Powermonitor II display module and Ethernet communications interface to the water system PLCs. The Ethernet signal should connect to an existing port on the Ethernet switch in the PLC panel. The Ethernet interface will permit basic electrical power data to be monitored by the PLC and additional data from the power monitor to be sent directly from the power monitor to a PC on the SCADA network at UOCC.

- **Individual Motor Power Monitoring.** The Square D PM820 series (or equal) is a device used to monitor individual motors. These devices can monitor over 60 different electrical parameters. They use Modbus RS-485 to communicate with the facility PLC. With an optional Ethernet communication card, the power meter should provide 10/100base TX Ethernet communication utilizing TCP/IP.

The kW, kWh, and power factor data should be transferred from the power monitors to the PLC. The PLC will send the power data to the SCADA master station when polled for the data.

10.11 RESOURCES

Removed for Security