OPERATING MANUAL

SECURE WATER TREATMENT SYSTEM (SWaT) FOR SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN (SUTD)

12 Feb 2014
Revision 0.0

This document supersedes the following document(s):

NA				

Revision	Date	Prepared by	Approved by	Comments
0				
1				
2				
3				
4				

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PURPOSE

The Singapore University of Technology and Design (SUTD) awarded the Tender for the Supply, Delivery, Installation, Testing and Commissioning of one (1) set of US five (5) gallons per minute (GPM) Secure Water Treatment System (the "System") consisting of both the physical and the cyber components to Flotech Controls Pte Ltd.

The purpose of this document is to provide a detailed description and understanding of the physical water process and control system.

PROCESS & SYSTEM OVERVIEW

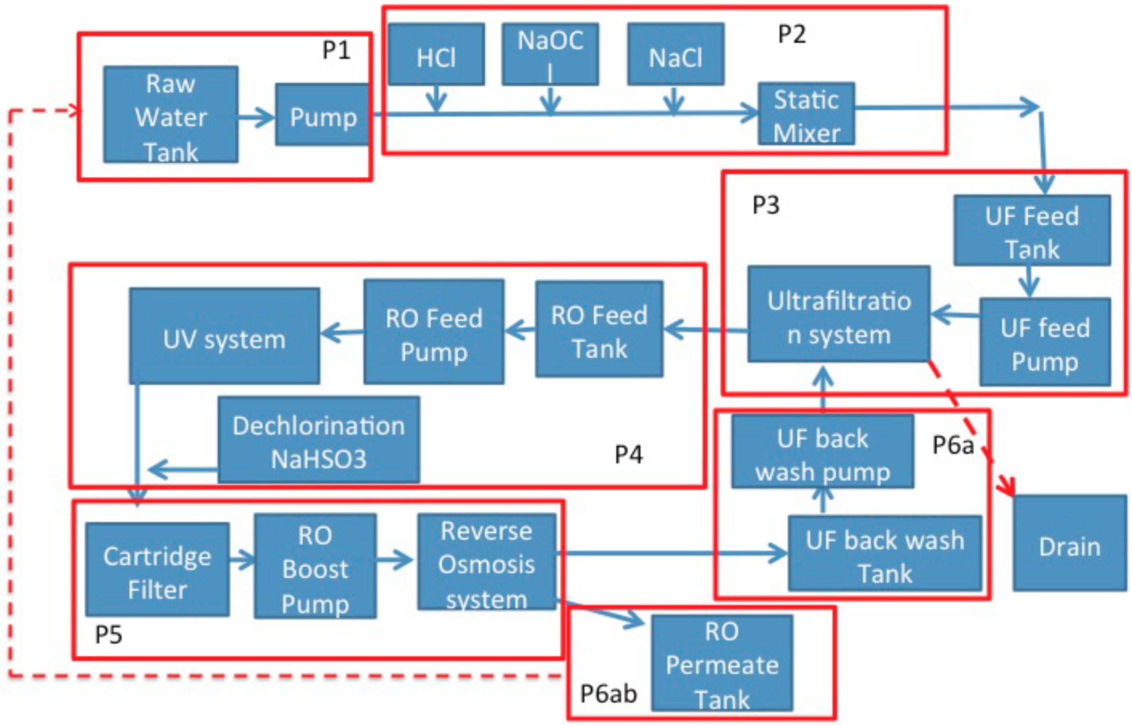

Figure 1: Physical Process Overview

We classified the water purification process into the following sub-processes, P1 through P6 (see Figure 1). For experimentation purposes, SUTD requires the Vendor to design a DCS with one PLC dedicated for each of the six processes.

Each of these PLCs is to be provided with a redundant hot-standby PLC. Operation status of the PLCs shall be monitored by the SCADA system.

The six processes are the following:

P1: Supply and storage
P2: Pre-treatment
P3: Ultrafiltration and backwash
P4: De-Chlorination System
P5: Reverse Osmosis (RO)
P6: RO Permeate Transfer, UF Backwash and Cleaning

P1: Supply and Storage

Water Source

City Water is supplied from the external supply pipe-line and is stored in the ground floor site raw water storage tank. This acts as the main buffer supplying water to the water treatment system. City water supply comes from a surface water source.
The two options for the water source shall be either NEWater or PUB Potable water for which the system can treat

Source Raw Water Flow Transmitter / Totaliser

An electromagnetic flowmeter is installed in this project to provide flow rate indication of the raw water from the source (PUB/NEWater), as well as the totalized flow volume from the raw water source (PUB/NEWater). Typical flowrate is 2.5~ 2,6m^3/h

Raw Water Tank

A polyethylene (PE) panel tank is provided to store the Raw Water. The tank supplied is sized at 1.8m^3 to provide a storage time of 1 hour under normal operation, based on the operating transfer pumps and recycling of RO permeate (70% recovery)
A set of non-contact type ultrasonic level sensors and transmitters is installed in the tank to provide four Level set-points. The Level set-points are interlocked with the raw water inlet valve upstream / protects the raw water pumps downstream as well as control of RO permeate transfer pimp
The continuous level indication and High-Low alarm status are monitored on the Human Machine Interface (HMI) of the SCADA system.

Raw Water Pump

The raw water pumps are designed to transfer the NEWater/ Potable from the raw water tank at to the System Ultrafiltration (UF) Feed tank
The raw water pump operation shall be interlocked to the Level Transmitter at the UF tank. At the low level, the feed water inlet valve is activated. At the high level the pump is stopped.

Raw Water Flow Transmitter / Totaliser

An electromagnetic flow transmitter provides flow indication of the raw water as well as the totalized flow to the UF feed tank. Typical flowrate is 2.4~ 2,5m^3/h

P2: Pre- Treatment

Raw Water Conducitiviy Analyser

The conductivity analyser provides conductivty indication of the inlet water as well as controlling of the NaC*l* dosing pump operation. Typical conductivity varies between 50 to 150 µS/cm.

Raw Water Inlet pH Analyser

The pH analyser provides pH indication of the inlet water as well as controlling of the HC*l* dosing pump operation. Typical pH varies between 6 and 9.
The set-point is linked to the pH range based on the target range for effective chlorination, typically between 6.0 and 7.0.

Raw Water Inlet Oxidation Reduction Potential (ORP) Analyser

The ORP analyser provides an indication of the chlorine level of inlet water as well as controlling of the NaOC*l* dosing pump operation. Target ORP setpoint is 500mV

Chemical Dosing Systems

A level float switch is mounted on the top of each chemical dosing tank. When the chemical dosing tank level decreases to an unacceptably low level, an alarm shall trigger. The operator shall be required to refill the dosing tank. If the chemical dosing tank level drops to the low-low level, the chemical dosing pump stops and an alarm shall activate. The dosing of chemicals is controlled by the water flow and the relevant contaminant in the feed water.

Hydrochloric Acid (HC*l*) Dosing

The HC*l* Dosing system is to provide a stock solution of concentrated Hydrochloric HC*l* acid at 9% to be added to the raw water at the intake pipe to maintain the raw water pH value of 6.5 to 7.5 in the UF Feed Tank.
The trigger for dosing is determined based on the raw water pH analyser.
The HC*l* dosing system consists of a dosing tank, two sets of metering pumps and a set of pH Transmitters.
The storage tank is sized based on a minimum of one week top up operation. The operator should top up the chemical (Hydrochloric Acid Solution) when the level switch indicates Low Level.
The two metering pumps are configured for one in normal operation and one on standby. The operation of the operating pump is interlocked to the raw water inlet valves operation and controlled by the pH transmitter pre-set high pH set-point.

Pre-Chlorination

The chlorine dosing system is to provide a stock solution of sodium hypochlorite (NaOC*l*) at 10 - 12% to be added to the raw water at the intake pipe to maintain a free chlorine residue of 0.5 mg/l in the UF Feed Tank.
The dosing rate is pre- determined based on the water filling rate and monitored by a set of Oxidation Reduction Potential (ORP) analysers.
The sodium hypochlorite dosing system consists of a dosing tank, two sets of dosing pump and an ORP analyser.
The dosing tank is sized based on approximately one week top up operation.
The two metering pumps are configured for one in normal operation and the other one on standby. The operation of the operating pump is interlocked to the raw water inlet valve operation and is controlled by the ORP analyser pre-set Low Level set-point.

Salt (NaC*l*) Dosing

The NaC*l* Dosing system is to provide a stock solution of concentrated Sodium Chloride to be added to the raw water at the intake pipe to maintain the raw water conductivity at around 250 µS/cm in the UF Feed Tank. The dosing rate is determined based on the conductivity analyser.

Static Mixer

The inline static mixer is to provide a turbulent flow along the intake pipe after the chemical dosing to disperse and mix the chemical solutions added to the raw water before the pH monitor and ORP transmitter.

P3: Ultrafiltration and Backwash

Ultrafiltration (UF) Feed Tank

This is a 1.8m^3 tank which is used to store the Pre-treatment Raw Water and also serve as chlorine Contact Tank. The tank is sized to provide a contact time of >30 minutes retention time under normal operation to effectively destroy bacteria and oxidise the organic containments from the raw water source. In the event of interruption with no raw water top-up, the UF feed tank provides retention of 40 minutes, based on the operating UF feed pumps to the level downstream UF membrane filtration system.
A set of non-contact type ultrasonic level sensors and transmitters is installed in the tank to provide four Level set-points. The Level set-points are interlocked with the raw water inlet valve upstream / protects the UF feed water pumps downstream

Ultrafiltration (UF) Feed Water Transfer Pumps

The UF feed water transfer pumps are designed to boost the raw water pressure to that necessary to feed the UF Membrane Filter Unit.
Two (2) sets of UF feed water pumps are supplied and they are arranged in a parallel configuration. Normally, one pump shall be in service and the second pump shall serve as a standby pump.
The service pump is interlocked to the operation of the UF membrane filters downstream. A pressure relief valve on the pump common discharge header prevents the pump from operation on dead head during the low water demand.
The service UF feed water pump is used to supply the chlorinated raw water flow through the set of ultrafiltration membrane filters. The filtered water shall fill up the downstream RO feed tank.
The operation of the UF feed water pump is interlocked to the Level Transmitter at the UF feed tank. At below the High Level set-point, the UF feed pumps operate. At a level above the High High Level set point, the UF feed water pumps stop.

UF Feed Water Pump Output Flow Transmitter

The flow sensor and transmitter provides continuous flow rate indication of the UF feed water pump discharge as well as the totalized flow in volume.
An electromagnetic flow meter is installed before the Ultrafiltration membrane filter to measure the incoming flow rate. The flow set-point is based on a specified minimum and maximum flow rate.

Pressure Switch for Ultrafiltration Membrane Filter (UF)

The high pressure switch generates a high pressure alarm and shuts down the UF feed pump when the inlet pressure exceeds the programmable set-point. This is to protect the UF.
The set-point is based on a High Level Set-point. It shall generate an alarm and trip the UF feed pump.

Differential Pressure Switch for Ultrafiltration Membrane Filter (UF)

The differential pressure switch generates a high pressure alarm and shuts down the UF feed pump when the difference in inlet pressure and outlet pressure exceeds the programmable set-point. This is to protect the UF.
The set-point is based on a High Level Set-point. It shall generate an alarm and trip the UF feed pump.

Differential Pressure Transmitter for Ultrafiltration Membrane Filter (UF)

The differential pressure transmitter continiuously monitors the difference in inlet pressure and outlet pressure and will trigger an alarm and backwash sequence should the UF membrane fouled upabnormally. This is to protect the UF.
The set-point is based on a High Level Set-point. It shall generate an alarm and trip the UF feed pump.

Ultrafiltration Membrane Systems

The Ultrafiltration membranes shall remove the bulk of the feed water solids and colloidal material upstream of the filter.
The Ultrafiltration membrane filtration system is a membrane modulated and pressure-activated ultra-filtration process. In Ultra Filtration (UF), the feed water flows into the membrane modules that are enclosed in the housing. The water molecules and particles whose molecular size and weight that are below the membrane molecular weight cut-off limit shall permeate through the membrane and emerge as filtrate.
The ultrafiltration (UF) system is set to operate on direct flow mode in an outside in flow path.
During the filtration process, the rejected contaminants are retained, accumulated in the modules and progressively concentrated in the process stream. The build-up of the concentrated contaminants on the membrane surfaces is periodically back-flushed away by a back pulsing process after either reaching a set period or based on reaching the threshold of Trans-Membrane Pressure (TMP) difference. Both the set period at Trans-Membrane pressure different shall be programmable via HMIs.
The accumulation of the concentrated contaminants creates a pressure differences across the membrane modules are monitored by differential pressure switch mounted across the inlet and outlet header of the system. When the pre-set pressure difference threshold is achieved or exceeded, an alarm is activated to alert the operator to carry out Chemical-In-Process (CIP) cleaning for the Ultra Filtration (UF) membrane.

Differential Pressure Switch for Ultrafiltration Membrane Filter (UF)

The differential pressure switch is designed to generate alarm to alert the operator to carry out chemical cleaning for UF.
The set-point includes a High Level Set-point that reflects the manufacturers guide psig. A differential set-point above the High level shall generate an alarm.

Ultrafiltration Membrane Filter Control Valves

The valve opening sequence for the UF Membrane Filters shall be programmed to take into account the Filtration mode and backwash mode of operations.

Hardness Analyser

The hardness analyser monitors and indicates the level of hardness to avoid scaling within the RO system.
When the hardness exceeds the pre-set level, it generates an alarm to the PLC.
The set-point shall reflect the maximum hardness allowed for the reverse osmosis system design based on the Langelier Saturation Index (LSI).

P4: De-Chlorination System

RO Feed Tank

This is a Polyethylene (PE) tank that is used to store the pre-treated water from the UF membrane filters. The tank also provides a buffering capacity when the Ultra filtration (UF) units are in backwash mode. The retention time is at least 30 minutes of the RO feed flow rate.
The UF treated water is fed to the RO system downstream.
A set of level sensor and transmitters in the RO Feed tank provides high and low level set-points. The High Level set-point operates the UF Feed pumps while the Low Level set point protects the RO Feed pump downstream.

RO Feed Water Pump

The RO feed water pumps are to booster up the UF treated water pressure to 2 bar for the downstream RO operation.
The RO feed water pump operation is interlock to the Level Transmitter at the RO feed water tank and the RO sequencer. At above the low level, the RO feed water pump is activated.

Ultraviolet (UV) Chlorine Destruction Unit

The UV Chlorine Destruction Unit is to eliminate residual chlorine and chloramines present in the feed water to the RO system. The Free chlorine residual and chloramines residual shall be successfully destroyed by the application of UV radiation.
The UV unit that is ahead of the RO system is set to operate in conjunction with the RO system that is downstream of the UV unit.

RO Feed Water Inlet ORP Analyser

The ORP analyser provides an indication of any residual chlorine level of inlet water as well as triggering the Sodium Bisulphite dosing pump operation.

Sodium Bisulphite ($NaHSO_3$) Dosing

The RO system feed water is protected by a set of sodium bisulphite ($NaHSO_3$) dosing system with ORP monitor on the feed line to prevent residual chlorine break through from the UV chlorine destruction unit.
The $NaHSO_3$ Dosing system is to provide a stock solution of Sodium Bisulphite to be added to the UF filtered water at the intake pipe to remove the total chlorine in event where the ultraviolet dechlorination fails. The dosing rate is determined based on the ORP meter reading linked to the maximum residual chlorine level.
The $NaHSO_3$ dosing system consists of a dosing tank and two sets of metering pumps. The storage tank is sized based on a minimum of one week top up operation.
The two metering pumps are configured for one in normal operation and one on standby. The operation of the operating pump is interlocked to the raw water inlet valves operation and controlled by the conductivity pre-set high set-point.

P5: Reverse Osmosis

Pre-RO Cartridge Filters

The treated water shall flow through the 1.0 micron RO Pre filters to protect the RO membrane downstream.

RO Feed/Permeate Conductivity Analyser

The RO feed water and permeate conductivity is monitored at the RO control panel. The RO product water conductivity value is transferred to the conductivity monitor and is continuous displayed on the RO control panel.
When the throughput of the RO permeate flow rate decreases from the target level by 20% of the normal capacity with no change in feed pressure, the PLC shall be set to alert the operator.
The CIP system shall be designed to ensure that the RO system is appropriately cleaned.
The data can be used to provide trending results on Human Machine Interface (HMI).
The set-point is based on the expected and maximum allowable conductivity.

RO Inlet ORP Analyser

The ORP analyser controls the sodium bisulphate dosing pump operation. Sodium bisulphite dosing is designed to remove the chlorine and thus protect the downstream RO from oxidation. The ORP indication is provided on the HMI.
The set point is based on a mV level that reflects the presence of chlorine (Set point to be adjusted based on testing and commissioning results).

RO Feed Pressure Transmitter

The pressure transmitter is provided to monitor the RO feed pressure as well as protect the RO from high pressure.
The set-point is based on the RO projection values for both high and low pressure.

Low & High Pressure Switches

A low-pressure switch is provided on the high pressure pump suction header and a high-pressure switch is provided at the pump discharge to protect the pump. When the incoming flow rate is very low, the low-pressure switch shall turn off the RO feed pump to protect it from running dry. Similarly, when the discharge pressure is higher than the pre-set value, the high-pressure switch shall shut down the high pressure RO feed pump to protect the RO vessels from overloaded.
The set-point is based on the minimum feed pressure required by the pump manufacturer.

RO Feed Flow Transmitter

The flow transmitter provides continuous flow rate indication of the RO feed as well as the totalized flow.

RO Process

The RO system is designed to provide for the bulk reduction of in-organic impurities reduction. One unit of RO system is provided.
UF-filtered water from the RO feed tank is fed into the RO system by the RO feed water pumps through the UV & chlorine destruction units and the cartridge filter with the Sodium Bisulphite serve as the backup option.
The RO feed water is further boosted in pressure by a high pressure pump RO Boost pump to force the water through the reverse osmosis membranes to remove almost all the impurities in the water.
The proposed RO system is designed for a minimum of 70% recovery.
The RO permeate water shall flow to the RO permeate tank.
The RO system operates continuously. The operation of the RO system is automatically controlled by the PLC after automatic initiation of the high pressure Boost pump supported by a Variable Frequency Drive (VFD) or Variable Speed Drive (VSD).
The respective instruments on the RO system feed supply line monitor the feed water's parameter such as conductivity, flow and pressure and all parameters are to be monitored by the HMI.
The RO module boost pump raises the feed water pressure for the membrane module to operate.
Pressure gauges are installed at the feed line, after the first array reject and second array reject. The information is fed back to the HMI.
The permeate stream from the 1st array and 2nd array are collected in a set of common manifold whereas the concentrate reject stream from the 2nd array is split into 2 streams as RO reject and Reject Recycle streams. If necessary, the reject recycle stream is fed back to the RO modules boost pump suction to make up the total RO feed.
The RO reject stream is piped to the UF backwash. The RO reject water is collected for the backwash of the membrane filters and the excess is sent to the drain.
Whenever the RO supply or reject stream stops and starts again, there is a product flushing to the reject stream for a pre-set time, typically two minutes

RO Permeate Flow Transmitter

The flow transmitter provides flow indication of the RO permeate as well as the totalized flow. Together with the feed
flow transmitter can be used to trend the RO recovery and to display the permeate flow-rate trending results on HMI.
The set-point is based on the minimum and maximum flow-rate.

RO Permeate Pressure Transmitter

The pressure transmitter is provided to monitor the RO permeate pressure and together with the RO feed pressure transmitter and RO reject pressure transmitter, generates a differential pressure (DP) reading that can be used to alert the operators when the DP is above the guideline so they can react accordingly. The data can be used to provide trending results on HMI.
The set-point is based on the RO projection values for both high and low pressure.

RO Reject Flow Transmitter

The flow transmitter provides flow indication of the RO reject as well as the totalized flow. Together with the feed flow transmitter, the differential data can be used to trend the RO recovery and to display the reject flow-rate trending results on HMI.
The set-point is based on the minimum and maximum flow rate.

RO Reject Pressure Transmitter

The pressure transmitter is provided to monitor the RO reject pressure and together with the RO feed pressure transmitter and RO permeate pressure transmitter, generates a differential pressure (DP) reading that can be used to alert the operators when the DP is above the guideline so they can react accordingly. The data can be used to provide trending results on HMI.
The set-point is based on the RO projection values for both high and low pressure.

P6: Permeate Transfer, Cleaning and Back-wash

RO Permeate Tank

This is a Polyethylene (PE) tank that is used to store the RO filtered water from the RO membrane filters. The retention time is at least 30 minutes of the RO product flow rate. A set of level switches in the tank provides high and low level set-points. The High Level set-point operates the RO transfer pump while the Low Level set point stops the RO transfer pump.

RO Permeate Transfer Pump

The operation of the RO PermeateTransfer Pump is controlled by the water level in the RO Permeate Tank through the PLC. When the water level in the tank falls to a pre-set low level, the PLC shall stop the transfer pump. When the water level in the tank reaches a pre-set high level, the PLC shall recirculate the water back to the front end Filtered Water Tank.

Backwash Pump

The operation of the Ultrafiltration membrane system is continuous and is controlled automatically by the PLC. In full automatic mode when the system reaches a pre-set run time, the PLC shall put the UF membrane system into backwash mode.
The Trans-Membrane Pressure (TMP) is also measured by the differential pressure transmitter. During the backwashing process, the HMI shall indicate the backwashing process. All backwash sequential steps shall be clearly displayed on HMI. Backwash step duration shall be programmable via HMI.
Under semi-automatic mode of operation, the operator manually initiates the backwashing process and the PLC would automatically complete the backwash process and place the ultrafiltration membrane system back into filtration service. The operator shall have the flexibility to manually control the operation of the filters.
The backwash pump is used to backwash the ultrafiltration membrane system.
The back flushing is carried out with the RO reject water collected in the UF backwash tank by the UF backwash pump to flush away the accumulated particles to drain.
Chlorine in the form of sodium hypochlorite is added into the backwash water to enhance the backwash efficiency if necessary.
The backwash water from the Ultrafiltration Membrane shall be sent to drain.

UF Backwash Pump Discharge Flow Transmitter

The flow sensor and transmitter provides flow indication of the UF Backwash pump discharge as well as the totalized flow in volume.

RO Cleaning System

An RO Cleaning system shall be provided as an option to maintain the RO membrane performance. RO cleaning shall be operated when the surface of RO membrane is fouled by foreign materials which may be present in the feed water such as hydrates of metal oxides, calcium precipitates, organics and biological matters.
The RO system shall have access points built in to clean the arrays separately.

KEY DESIGN CONSIDERATIONS & SIZING

Selection of RO Membranes

1. Permeate output to be at least US 5 GPM Ξ 1.135 m^3/hr
2. Raw water conductivity to be maintained at 250 µS/cm ; pH 6 ~ 7
3. Permeate conductivity to be at least 10 µS/cm
4. Concentrate recirculation rate is less than 50%
5. Recovery to be at least 70%

a) **Design permeate output is based on 1.2 m^3/hr**

b) **PUB water quality**

Characteristics	**Unit**	**Average (Design Parameter)**	**Range**
Microbiological Parameter			
Escherichia coli (E. coli)	cfu/100ml	<1	<1
Physical Parameters			
Colour	Hazen	<5	<5
Conductivity	uS/cm	193	84-426
pH Value	Units	8.1	7.5-8.3
Total Dissolved Solid	mg/l	133	68-270
Turbidity	NTU	0.19	<0.1 - 0.50
Total Organic Carbon (TOC)	mg/l	1.3	0.2 - 2.6
Total Alkalinity (as CaCO3)	mg/l	17	<5 - 44
Total Hardness (as CaCO3)	mg/l	59	25 - 145
Chlorine (waterworks)	mg/l	**2.26**	**1.2 - 3.0**

Source:
http://www.pub.gov.sg/general/watersupply/Pages/DrinkingWQReport.aspx

c) Water quality of Feedwater at SUTD

The lab test result was used for simulation parameters.

Amtek
Re-engineering Success

TEST REPORT

Report No : AL14082423
Company Name : Flotech Controls Pte Ltd
Address : 438 Tagore Industrial Avenue
Singapore 787814

Page 1 of 1

Our Reference : --
Your reference : --
Date Received : 05-Aug-14
Date Report : 08-Aug-14
Date Tested : 05-Aug-14 to '08-Aug-14
Sample Description : One (1 x 1L plastic bottle) water sample was received with the following marking:
SUTD-EXPO, 1/8/14

RESULTS

Based on analysis, the following results were obtained:

Test Item	Result	Unit	Test Method
pH value @ 23.5°C	8.1	pH units	APHA 4500 H+ B
Total Hardness (as $CaCO_3$)	34.2	mg/l	APHA 2340 B
Total Alkalinity (as $CaCO_3$)	25	mg/l	APHA 2320 B
Total Dissolved Solids (TDS)	50.0	mg/l	APHA 2540 C

Li Jing
Laboratory Manager

William Pang
Deputy General Manager

This report is governed by the "Terms and Conditions" overleaf.

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FIGURE 2: WATER PARAMETERS FROM SITE

Simulation Summary

Simulation Software: *TorayDS2.exe*
Membrane Element Selected:

Manufacturer	Model	Active Area	Diameter	Length
TORAY	TMH10A	8.00 m^2	4''	1016 mm

Configuration:
a. Stage 1-1 Array: 2 vessel x 3 elements
b. Stage 1-2 Array: 1 vessel x 4 elements
c. Pentair Codeline 40S30-4 (Non-Coded) - 3 x RO vessels

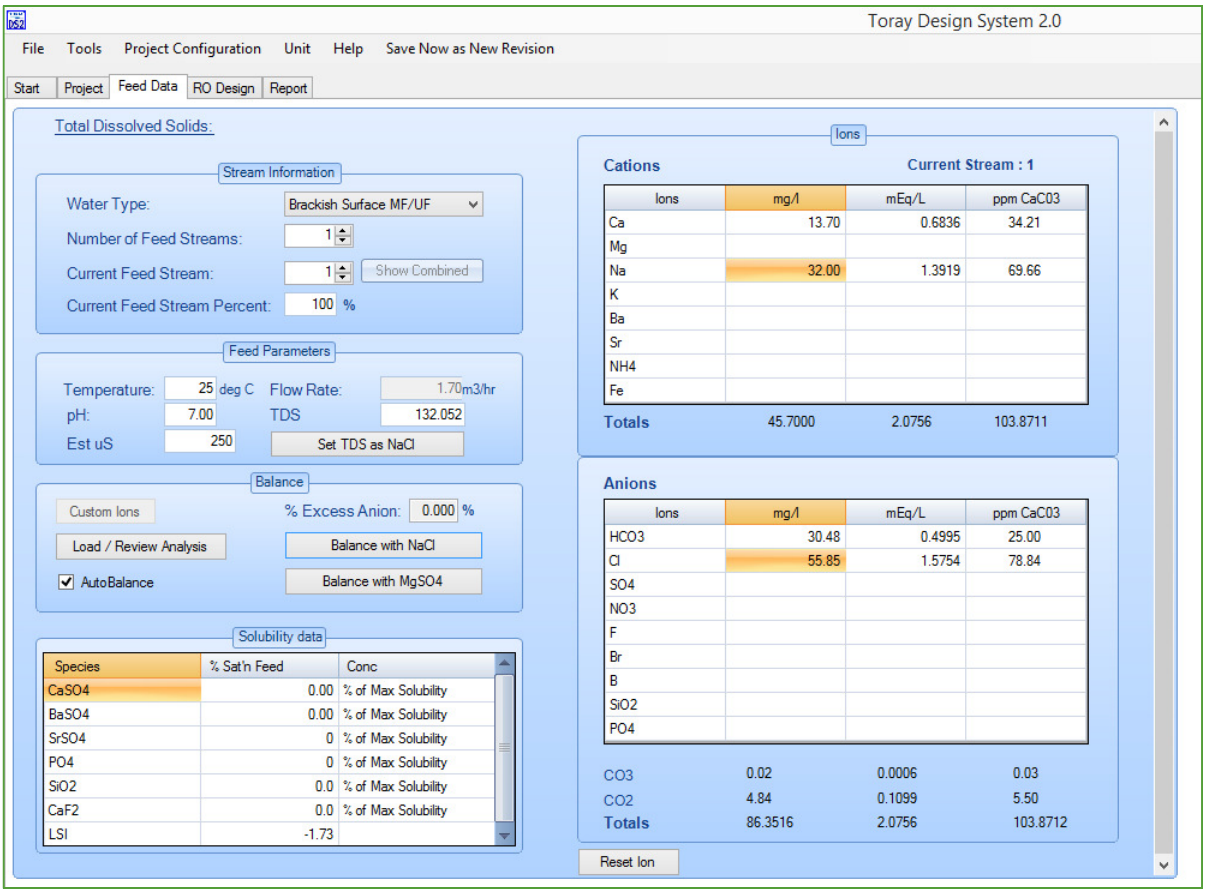


FIGURE 3: RO FEED DATA

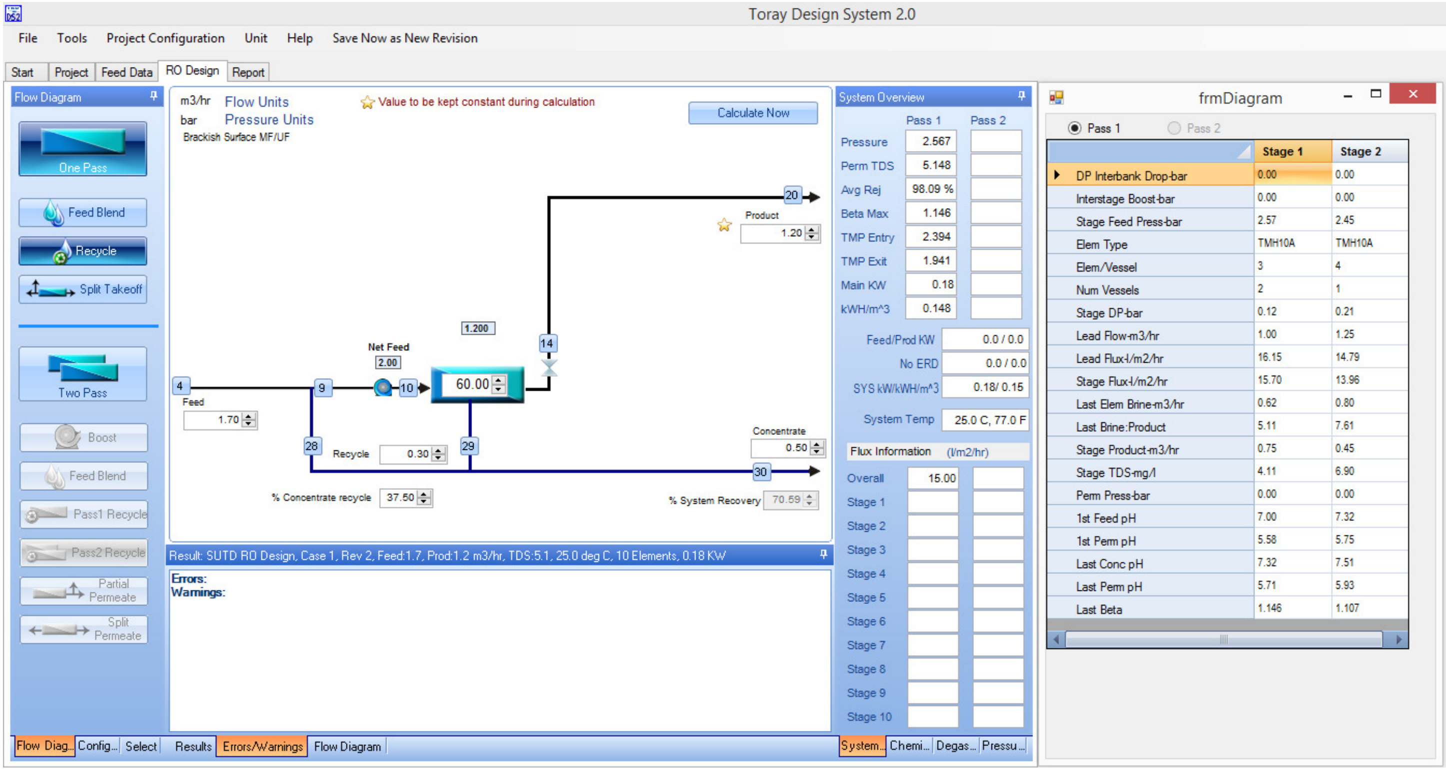


FIGURE 4: RO SIMULATION OVERVIEW

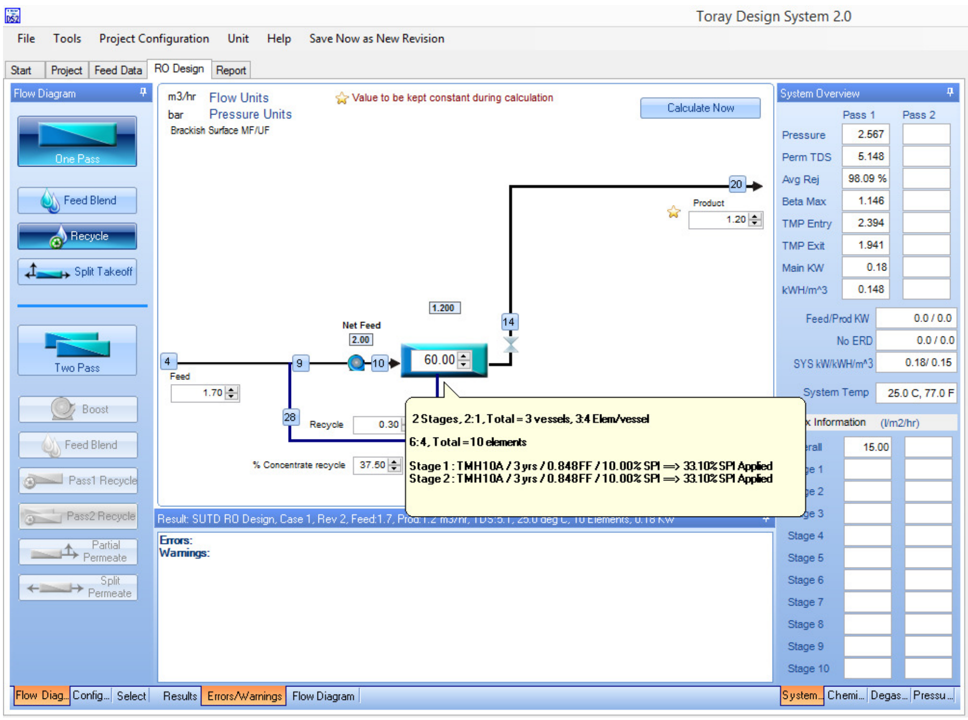


FIGURE 5: STAGES CONFIGURATION

OVERALL WATER TREATMENT SYSTEM LAYOUT

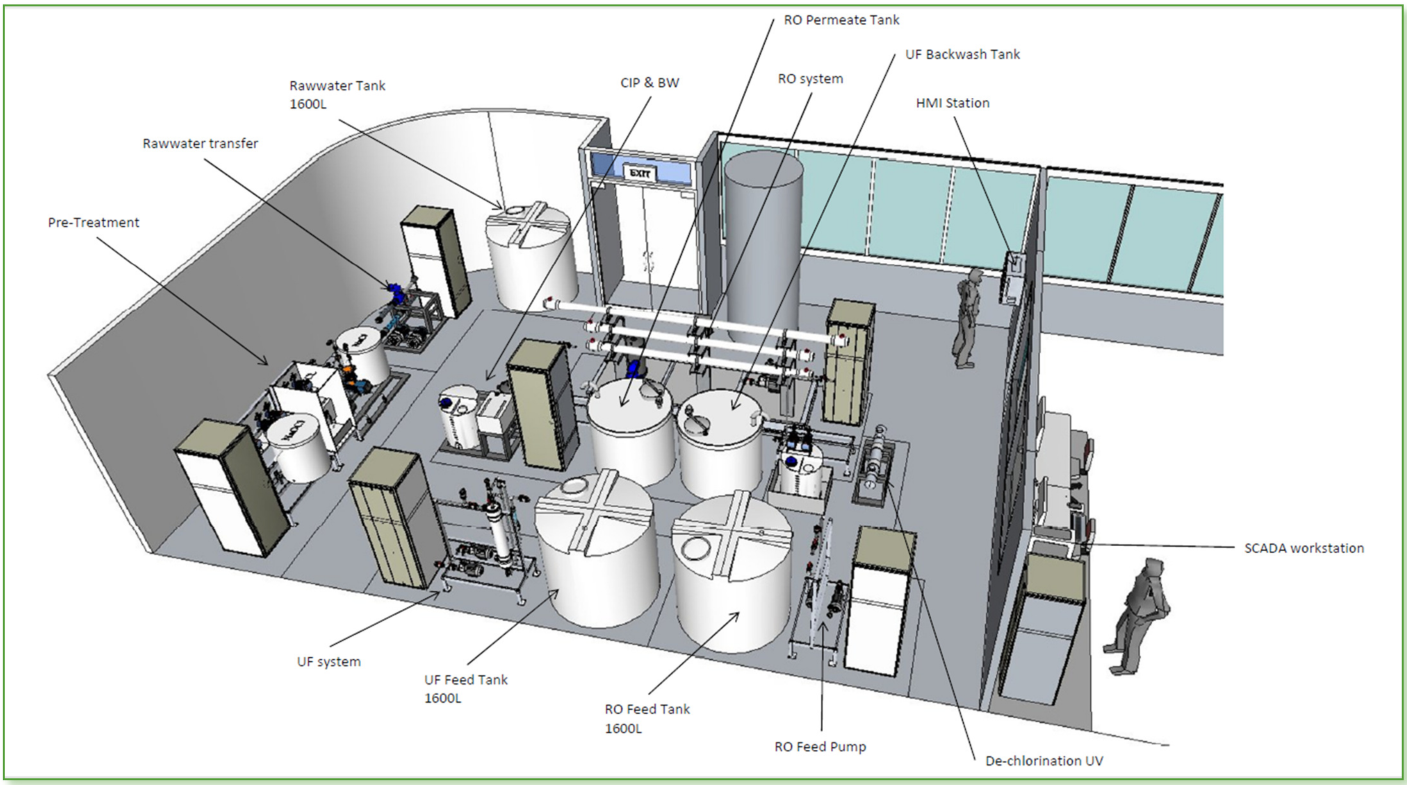


FIGURE 6: SYSTEM OVERVIEW

Completed System View

Figure 7: Completed Views

DETAILED PROCESS CONTROL

Raw Water System (P1)

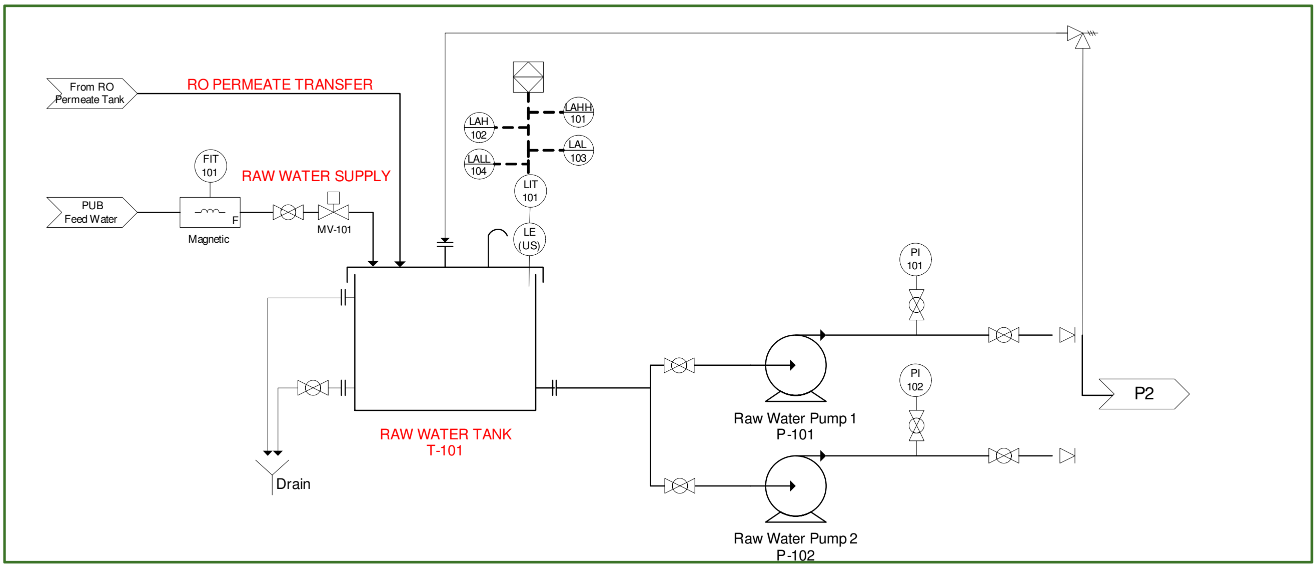


Figure 8 : PID Raw Water Supply & Storage System

Control Strategy For P1

1) Raw water inlet valve (MV-101) shall be activated by raw water tank level (LIT-101)
   a. Low Setpoint: 500mm → Valve MV-101 OPEN
   b. High Setpoint: 800mm → Valve MV-101 CLOSE
   c. Low Low Setpoint: 250mm → Alarm & Pump P-101/ P-102 STOP
   d. High High Setpoint: 1200mm → Alarm

2) Raw water pump (P-101 & P-102) shall be interlocked with
   a. One duty, one standby
   b. To interlocked with UF feedwater tank level (LIT-201)
      i. Low Setpoint: 800mm → Pump P-101/ P-102 START
      ii. High Setpoint: 1000mm → Pump P-101/ P-102 STOP
   c. To interlocked with Feedwater flowmeter (FIT-201)
      i. Low Setpoint: 0.5m³/h → Pump P-101/ P-102 STOP

Major Equipment Details For P1

Description	Design Specification	Material	Qty	Brand & Model	Remarks
Pumps & Tanks					
Raw Water Tank	Capacity: 1.8m³ Dia x H= 1.38 x 1.36	PE	1	Rotamas CPE 1800	
Raw Water Transfer Pump	Duty: 2.5 m³/h @ 20m	Casing: Chrome Nickel SS Impeller: Noryl Shaft: SS	2	CALPEDA MXH 203	
Instrumentation					
Raw Water Tank LIT	Ultrasonic, Range 0.2 to 6m	Non Contact	1	iSOLV LevelWizard II	
Raw Water to UF Feed Tank FIT	Electromagnetic DN25	PTFE	1	iSOLV EFS803/CFT183	
Piping & Accessories					
Piping	SCH80	PVC	Lot	Glywed	
Raw Water Inlet On/Off Valve	DN 25, Electric Actuated	PVC	1	Burkert EV2650	
PRV	DN 25	PVC	1	Prominent DHV-DM PVC	

Pre-Treatment system (P2)

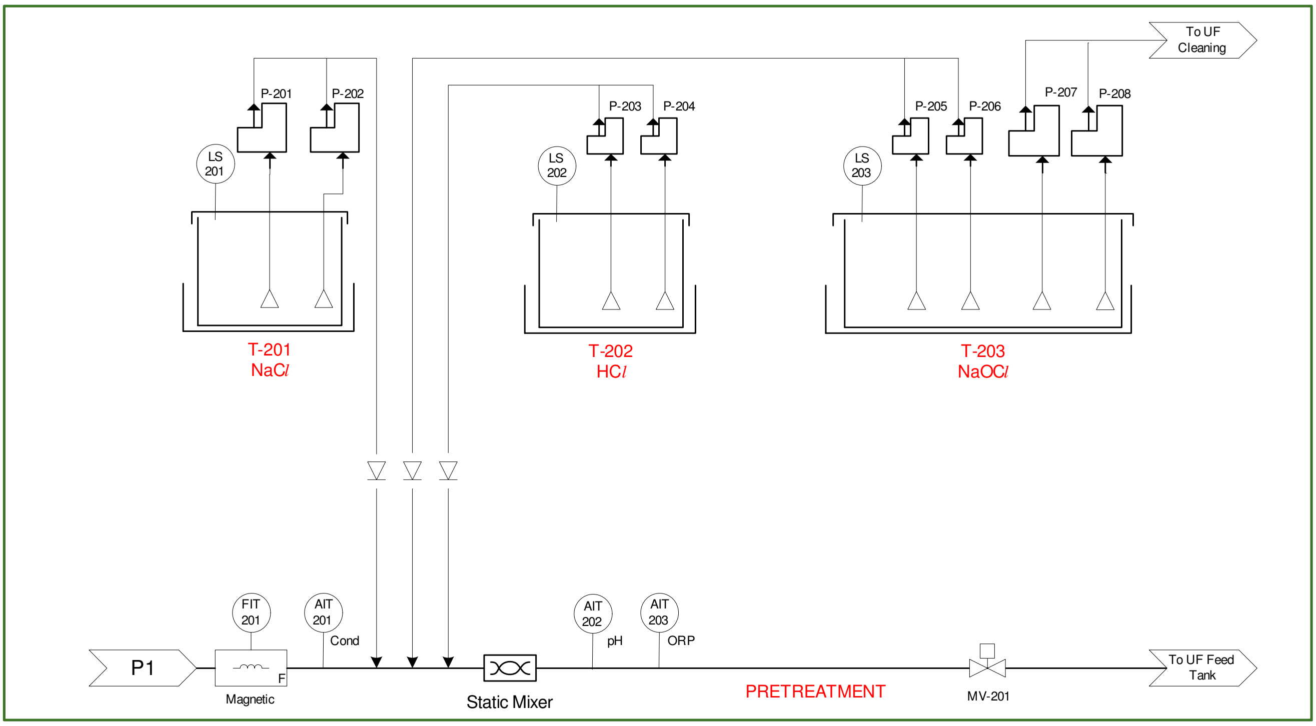


Figure 9: PID Pre-Treatment

Control Strategy For P2

1) NaC*l* Dosing System
    a. 250 litres Chemical tank (T-201) level control by level switch (LS-201)
        i. Low: 50 Litres ➔ Low Alarm & P-201/ P-202 STOP
    b. Dosing pump (P-201/ P-202) operation
        i. One duty, One standby.
        ii. Raw water tank outlet valve (MV-201) OPEN AND below Cond (AIT 201) setpoint of 250 µS/cm: ON pump
        iii. Above Cond (AIT 501) setpoint of 250 µS/cm OR raw water tank outlet valve(MV-201) CLOSE: OFF pump

2) pH Dosing System
    a. 9% HC*l* is used in order to comply to local regulations
    b. 25 Litres Chemical tank (T-202) level control by level switch (LS-202)
        i. Low: 4 Litres ➔ Low Alarm & P-203/ P-204 STOP
    c. Dosing pump (P-203/ P-204) operation
        i. One duty, One standby.
        ii. Raw water tank outlet valve (MV-201) OPEN AND Above pH (AIT-202) setpoint of 7.05: ON pump
        iii. Below pH (AIT-202) setpoint of 6.95 OR raw water tank outlet valve (MV-201) CLOSE: OFF pump

3) NaOC*l* Dosing System
    a. 10% NaOC*l* solution prepared
    b. 200 litres Chemical tank (T-203) level control by level switch (LS-203)
        i. Low: 30 Litres ➔ Low Alarm
        ii. Low Low: 15 Litres ➔ Low Alarm & Pump P-205/ P-206 STOP
    c. Dosing pump (P-205/ P-206) operation
        i. One duty, One standby.
        ii. Raw water tank outlet valve (MV-201) OPEN AND below ORP (AIT-203) setpoint of 420mV: ON pump
        iii. Above ORP(AIT-203) setpoint of 500mV OR raw water tank outlet valve (MV-201) CLOSE: OFF pump

Major Equipment Details For P2

Description	Design Specification	Material	Qty	Brand & Model	Remarks
Pumps & Tanks					
NaC*l* Tank	Capacity: 250*l*	PE	1	Rotamas CGD 250	
NaC*l* Dosing Pump	Capacity : 50 *l*/h @ 10 bar	Liquid end : PVDF Diaphragm : PTFE faced	2	Prominent Sigma S1Ba	
HC*l* Tank	Capacity: 250*l* Capacity: 25*l* (9% HC*l*)	PE	1	Rotamas CGD 250 25L Carboy	Double Containment
HC*l* Dosing Pump	Capacity : 0.78 *l*/h @ 08 bar	Liquid end : Plexiglas Diaphragm : PTFE faced	2	Prominent GALa1601	
NaOC*l* Tank	Capacity: 250*l*	PE	1	CGD 250	
NaOC*l* Dosing Pump (FAC)	Capacity : 0.78 *l*/h @ 8 bar	Liquid end : Plexiglas Diaphragm : PTFE faced	2	Prominent GALa1601	
NaOC*l* Dosing Pump (UF Cleaning)	Capacity : 65 *l*/h @ 7 bar	Liquid end : PVDF Diaphragm : PTFE faced	2	Prominent Sigma S1Ba	
Instrumentation					
Static Mixer	2" NPT M/ 12 elements	PVC	1	Omega	
Raw Water FIT	Electromagnetic DN25	PTFE	1	iSOLV EFS803/CFT183	
AIT - Conductivity	Up to 1000µS/cm	-	1	Mettler Toledo M200 Single/ easySense Cond 71	
AIT – pH & ORP	pH: 0-14 ORP: -800mV to 800mV	-	1	Mettler Toledo M200 Dual/ easySense pH 32 & ORP 41	
NaC*l* Level Switch	Low Alarm	PVC	1	iSOLV LS880	
HC*l* Level Switch	Low Alarm	PVC	1	iSOLV LS880	
NaOC*l* Level Switch	Low Alarm	PVC	1	iSOLV LS880	
Piping & Accessories					
Piping	SCH80	PVC	Lot	Glywed	
Raw Water Tank Outlet On/Off Valve	DN 25, Electric Actuated	PVC	1	Burkert EV2650	

UF System (P3)

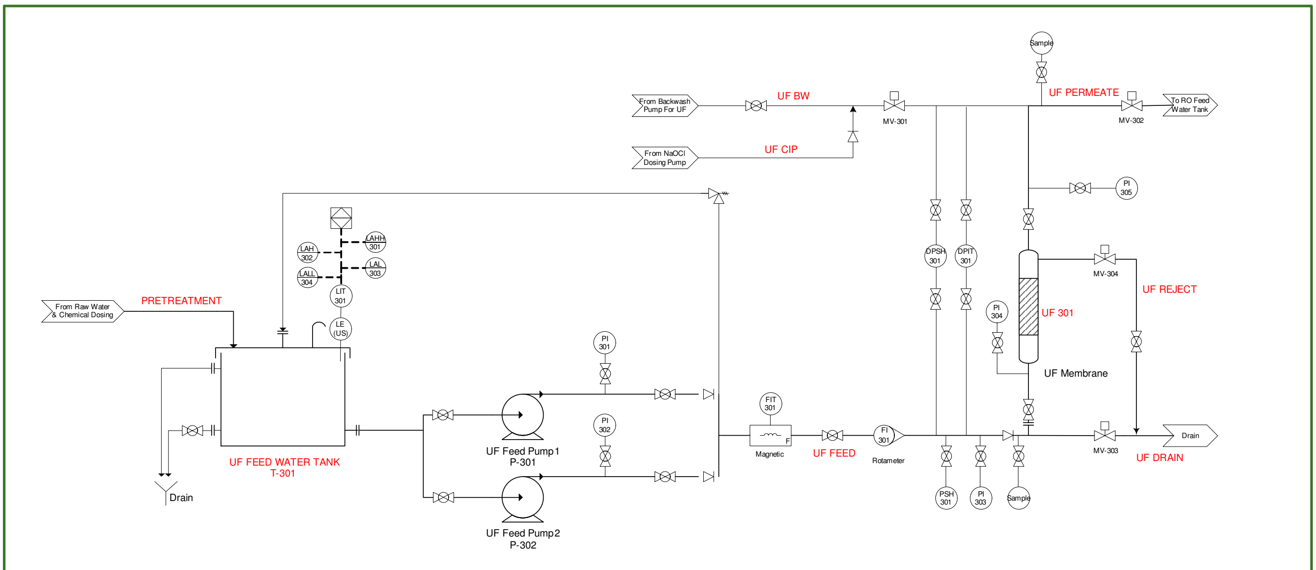


Figure 10: PID UF System

Control Strategy For P3

1) UF Feedwater Tank Level (LIT-301)
    a. Low Setpoint: 800mm → Valve MV-201 OPEN & Pump P-101/ P-102 START
    b. High Setpoint: 1000mm → Valve MV-201 CLOSE & Pump P-101/ P-102 STOP
    c. Low Low Setpoint: 250mm → Alarm & Pump P-301/ P-302 STOP
    d. High High Setpoint: 1200mm → Alarm

2) UF Transfer Pump (P-301/ P-302) Operation
    a. One duty, one standby
    b. To interlock with RO Feed Tank level (LIT-401)
        i. Low Setpoint: 800mm → UF Pump (P-301/ P-302) ON
        ii. High Setpoint: 1000mm → UF Pump (P-301/ P-302) OFF
    c. To interlock with UF Feed Tank Level (LIT-301)
        i. Low Low Setpoint: 250mm → Alarm & UF Pump (P-301/ P-302) OFF
    d. To interlock with UF Feed Flowmeter (FIT-301)
        i. Low Setpoint: 0.5m^3/h → Pump P-301/ P-302 STOP

3) Pressure Switch (PSH-301) For UF
    a. High Setpoint: 2.5 Bar → UF Pump (P-301/ P-302) OFF

4) Differential Pressure Switch (DPSH-301) For UF:
    a. High Setpoint: 0.5 Bar → UF Pump (P-301/ P-302) OFF

5) Differential Pressure Indicating Transmitter (DPIT-301)
    a. For TMP feedback on triggering backwash operation.
    b. High Setpoint: 0.4 Bar → UF Backwash operation under Automatic mode will initiate

6) UF Start Up Sequence
    a. MV-304 OPEN
    b. UF Pump (P-301/ P-302) START for 30 Seconds
    c. MV-302 OPEN
    d. MV-304 CLOSE
    e. UF Filtration In Place

7) UF Backwash Sequence
    a. Frequency: Every 30 Minutes Interval
    b. UF Pump (P-301/ P-302) STOP
    c. MV-302 CLOSE
    d. MV-301 OPEN
    e. MV-303 OPEN
    f. BW Pump (P-602) START for 30 Seconds
    g. BW Pump (P-602) STOP
    h. MV-301 CLOSE
    i. Drain for 45 Seconds
    j. MV-303 CLOSE
    k. Activate UF Start Up Sequence

Major Equipment Details For P3

Description	Design Specification	Material	Qty	Brand & Model	Remarks
UF Membranes					
UF Membranes	2.5 m^3/h	PVDF	1	TORAY HFU-2020	
Pumps & Tanks					
UF Feedwater Tank	Capacity: 1.8m^3 Dia x H= 1.38 x 1.36	PE	1	Rotamas CPE 1800	
UF Feedwater Pump	Duty: 2.5 m^3/h @ 20m	Casing: Chrome Nickel SS Impeller: Noryl Shaft: SS	2	CALPEDA MXH 203	
Instrumentation					
UF Feed Water Tank LIT	Ultrasonic, Range 0.2 to 6m	Non Contact	1	iSOLV LevelWizard II	
UF Feed Water FIT	Electromagnetic DN25	PTFE	1	iSOLV EFS803/CFT183	
UF Feed Water FI	Rotameter, 1"	PVC	1	FSIV Flowmeter	
Pressure Switch	Switch High/ 0-7 Bar Adjustable	SS316 Port	1	CCS 604GZ	
Differential Pressure Switch	Switch High/ 0-1 Bar	SS316 Port	1	CCS 604DZ	
Differential Pressure Indicating Transmitter	Range: 0-2 Bar	SS316 Port	1	SPT 100 DP	
Piping & Accessories					
Piping & Manual Valves	SCH80	PVC	Lot	Glywed	
PRV	DN 25	PVC	1	Prominent DHV-DM PVC	
Backwash On/Off Valve	DN 25, Electric Actuated	PVC	4	Burkert EV2650	

De-Chlorination (P4)

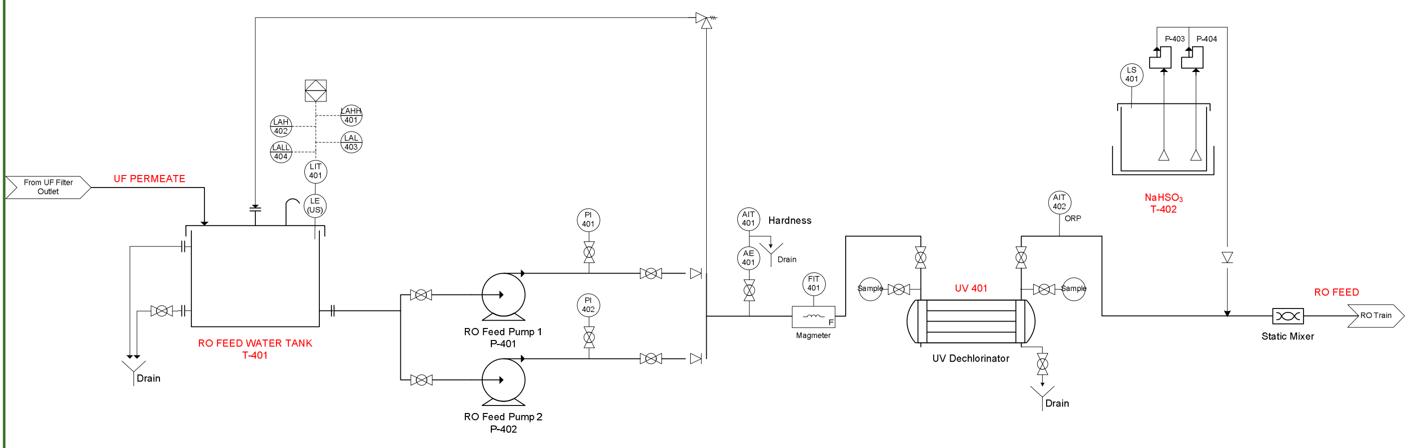


Figure 11: PID De-Chlorination

Control Strategy For P4

1) RO Feedwater Tank Level (LIT-401)
    a. Low Setpoint: 800mm → Pump P-301/ P-302 START
    b. High Setpoint: 1000mm → Pump P-301/ P-302 START
    c. Low Low Setpoint: 250mm → Alarm & Pump P-401/ P-402 STOP
    d. High High Setpoint: 1200mm → Alarm

2) RO Feedwater Transfer Pump (P-401/ P-402) Operation
    a. One duty, one standby
    b. To interlock with RO High Pressure Pump (P-501/ P-502). RO Feedwater Transfer Pump ON before RO High Pressure Pump is ON
    c. To interlock with RO Feedwater Tank Level (LIT-401).
        i. Low Low Setpoint: 250mm →Alarm & Pump (P-401/ P-402) OFF
    d. To interlock with RO Fit-401
        i. Low Setpoint: 0.5m³/h → Pump P-401/ P-402 STOP

3) Hardness Analyser (AIT-401)
    a. High Setpoint: 80 ppm → Alarm
    b. High High Setpoint: 100 ppm → Alarm & RO Filtration SHUT DOWN After Delay of 10 Minutes

4) UV Chlorine Destruction Unit
    a. To ON before RO Feed Transfer Pump (P-401/P-402) START

5) $NaHSO_3$ Dosing System
    a. 10% $NaHSO_3$ solution prepared
    b. 25 Litres Chemical tank (T-402) level control by level switch (LS-401)
    c. Dosing pump (P-403/ P-404) operation
        i. One duty, One standby.
        ii. RO Transfer pump (P-401/ P-402)ON AND Above ORP (AIT-402) Setpoint of 250mV
            → ON dosing pump (P-403/ P-404)
            → OFF dosing pump (P-205/P-206)
        iii. Below ORP (AIT-402) Setpoint of 240mV OR RO transfer pump OFF
            →OFF dosing pump (P-403/ P0404)

Major Equipment Details For P4

Description	Design Specification	Material	Qty	Brand & Model	Remarks
Pumps & Tanks					
RO Feedwater Tank	Capacity: 1.8m³ Dia x H= 1.38 x 1.36	PE	1	Rotamas CPE 1800	
RO Feedwater Pump	Duty: 2.5 m³/h @ 20m	Casing: Chrome Nickel SS Impeller: Noryl Shaft: SS	2	CALPEDA MXH 203	
$NaHSO_3$ Tank	Capacity: 250*l* Capacity: 25*l* (10% $NaHSO_3$)	PE	1	Rotamas CGD 250 25L Carboy	Double Containment
$NaHSO_3$ Dosing Pump	Capacity : 0.78 *l*/h @ 8 bar	Liquid end : Plexiglas Diaphragm : PTFE faced	2	Prominent GALa1601	
UV Chlorine Destruction Unit					
UV Unit	Removal up to 0.5ppm 2.3m³/h	SS316	1	Aquafine Optima 200	
Instrumentation					
RO Feed Water Tank LIT	Ultrasonic, Range 0.2 to 6m	Non Contact	1	iSOLV LevelWizard II	
Hardness Monitor	Range: 0-10ppm	-	1	HACH APA 6000	
AIT –ORP	ORP: -800mV to 800mV	-	1	Mettler Toledo M200 Singlel/ easySense ORP 41	
RO Feed FIT	Electromagnetic DN25	PTFE	1	iSOLV EFS803/CFT183	

RO System (P5)

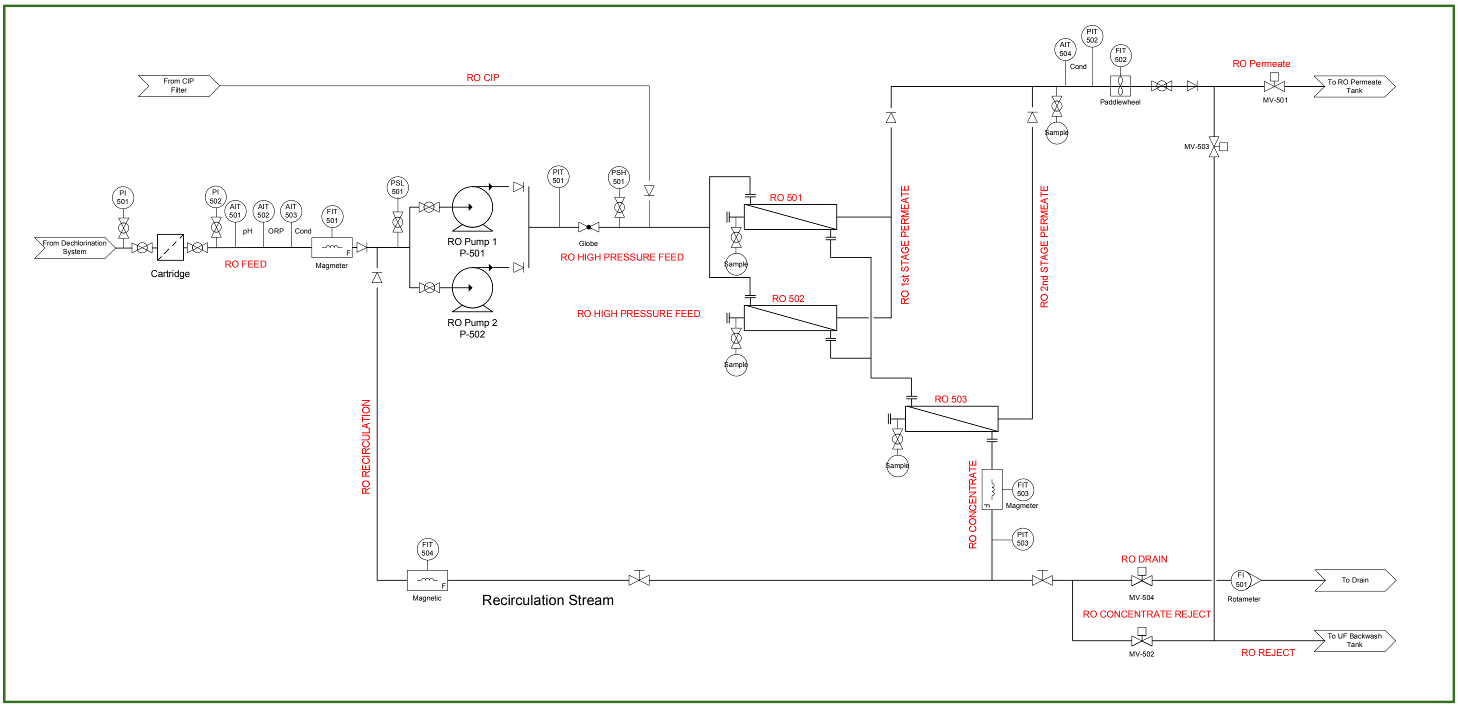


Figure 12: PID RO System

Control Strategy For P5

1) RO High Pressure Booster Pumps (P-501/ P-502)
    a. One duty, one standby
    b. VSD Operated; Setpoint: 25Hz
    c. Interlock with Pressure Switches
        i. Pressure switch (PSL-501) Setpoint: 0.6 Bar
            ➔ LOW at pump suction: OFF Pump (P-501/P-502)
        ii. Pressure switch (PSH-502) Setpoint: 4.6 Bar
            ➔ HIGH at pump discharge: OFF Pump (P-501/P-502)
    d. Interlock with RO Feed PIT-501 (After pump discharge)
        i. HIGH pressure Setpoint 5.0 Bar: OFF Pump

2) RO Feed ORP (AIT-502)
    a. High Setpoint: 250mV
        ➔ Alarm
        ➔ Activate RO Shutdown Sequence After 30 mins

3) RO Feed Flow (FIT-501)
    a. To provide continuous flow rate and totalised flow
    b. Normal Flow: 1.7m³/h
    c. Low Setpoint: 0.5m³/h ➔ Pump P-501/ P-502 STOP

4) RO Feed Cond (AIT-503) & Permeate Cond (AIT-504)
    a. For monitoring control on permeate quality.
    b. AIT-504 High Setpoint: 10 µS/cm ➔ Alarm
    c. AIT-504 High High Setpoint: 15 µS/cm ➔ RO Shutdown Sequence After 30 mins

5) RO Permeate FIT (FIT-502)
    a. To provide continuous flow rate and totalised flow
    b. Normal Flow: 1.2 m³/h
    c. To be used with RO Feedrate (PIT-501) for RO recovery trending
    d. To provide ALARM when RO permeate flow is 20% lower with no change in RO feed pressure

6) RO Reject FIT (FIT-503)
    a. To provide continuous flow rate and totalised flow
    b. To be used with RO Feedrate (PIT-501)for RO recovery trending

7) RO Recirculation Flow (FIT-503)
    a. To provide continuous flow rate and totalised flow
    b. Normal Flowrate: 0.3 m³/h

8) RO Permeate Pressure (PIT-502)
    a. To monitor RO reject pressure

9) RO Reject Pressure (PIT-503)
    a. To monitor RO reject pressure
    b. To be used with RO Feed Pressure (PIT-501) and RO Permeate Pressure (PIT-502) for TMP trending
        i. TMP HIGH: Alarm for CIP Cleaning

10) RO Startup Sequence
    a. Permeate Reject Valve MV-503 OPEN
    b. RO Drain Valve MV-504 OPEN
    c. RO Feed Pump (P-401/ P-402) ON & Flush for 20 Mins
    d. RO High Pressure Pump (P-501/ P-502) ON
    e. VSD Speed Ramp Up to 30 Hz
    f. AIT-504 < High Setpoint: 10 µS/cm
    g. RO Permeate Valve MV-501 OPEN
    h. Permeate Reject Valve MV-504 CLOSE
    i. RO Concentrate Reject Valve MV-502 OPEN
    j. RO Drain Valve MV-504 CLOSE
    k. RO Filtration Mode

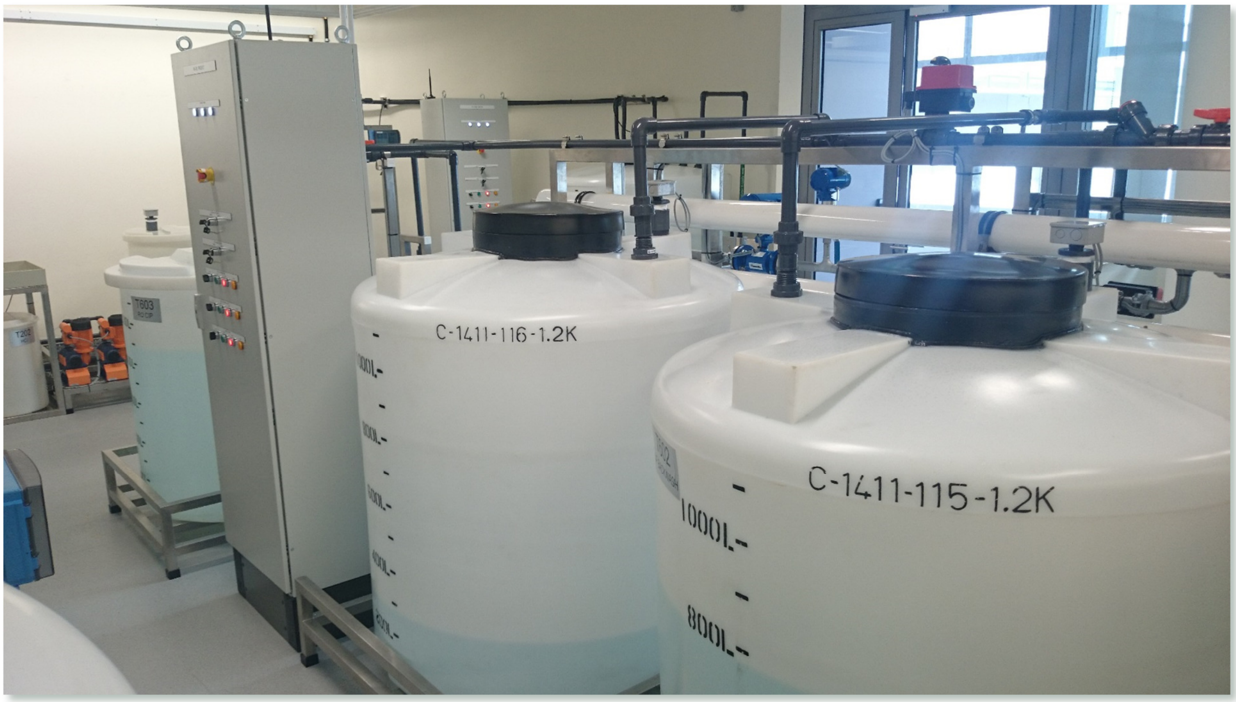
11) RO Shutdown Sequence
    a. VSD Speed Ramp Down
    b. RO High Pressure Pump (P-501/ P-502) OFF
    c. RO Drain Valve MV-504 OPEN
    d. RO Concentrate Reject Valve MV-502 CLOSE
    e. Permeate Reject Valve MV-503 OPEN
    f. RO Permeate Valve MV-501 CLOSE
    g. RO Feed Pump (P-401/ P-402) Flush for 20 Mins
    h. RO Feed Pump (P-401/ P-402) STOP
    i. Permeate Reject Valve MV-503 CLOSE
    j. RO Drain Valve MV-504 CLOSE

Major Equipment Details For P5

Description	Design Specification	Material	Qty	Brand & Model	Remarks
RO Membranes					
Pre RO Cartridge Filter	Heavy Duty Multi-Cartridge Housing Max Pressure: 125PSI Number of Cartridges & Size: (4) 10" Flowrate: 28 GPM Element: 1 Micron	SS304 Housing	1	Graver 4MC1-VB-316L-1.5N-B	
RO Membrane	As Per Design Considerations	-	3+3 4	Toray TMH10A	
RO Vessel	-	Shell: Epoxy/Glass Composites	3	Pentair Codeline 40S30	
Pumps					
High Pressure RO Pump With VSD	Duty: 2m³/h @ 5bar	Casing: Chrome Nickel SS Impeller: Noryl Shaft: SS	2	CALPEDA MXH206	
Instrumentation					
AIT – Conductivity (RO Feed)	Up to 1000µS/cm	-	1	Mettler Toledo M200 Dual/ easySense Cond 71	
AIT – Conductivity (RO Permeate)	Range: 0.02 to 20 µS/cm	-	1	easySense Cond 71	
AIT – pH & ORP (RO Feed)	pH: 0-14 ORP: -800mV to 800mV	-	1	Mettler Toledo M200 Dual/ easySense pH 32 & ORP 41	
Pressure Switch (Before High Pressure RO Pump)	Low Alarm, 0-10 Bar (Adjustable)	SS316 Port	1	CCS 604GZ	
Pressure Switch (After High Pressure RO Pump)	High Alarm, 0-10 Bar (Adjustable)	SS316 Port	1	CCS 604GZ	
PIT (After High Pressure RO Pump)	0-10 Bar	SS316 Port	1	iSOLV SPT 100	
PIT (RO Concentrate)	0-10 Bar	SS316 Port	1	iSOLV SPT 100	
PIT (RO Permeate)	0-10 Bar	SS316 Port	1	iSOLV SPT 100	
FIT (RO Concentrate)	Electromagnetic DN25	PTFE	1	iSOLV EFS803/CFT183	
FIT (RO Recirculation)	Electromagnetic DN25	PTFE	1	iSOLV EFS803/CFT183	

Description	Design Specification	Material	Qty	Brand & Model	Remarks
FIT (RO Feed)	Electromagnetic DN25	PTFE	1	iSOLV EFS803/CFT183	
FIT (RO Permeate)	Paddlewheel 1"	CPVC	1	FIP Flow X3	
Piping & Valves					
Piping & Valves	SS316L		Lot		
On/Off Valves	1" Electric Act	SS316L	4	Burkert EV2650	

CIP (P6)



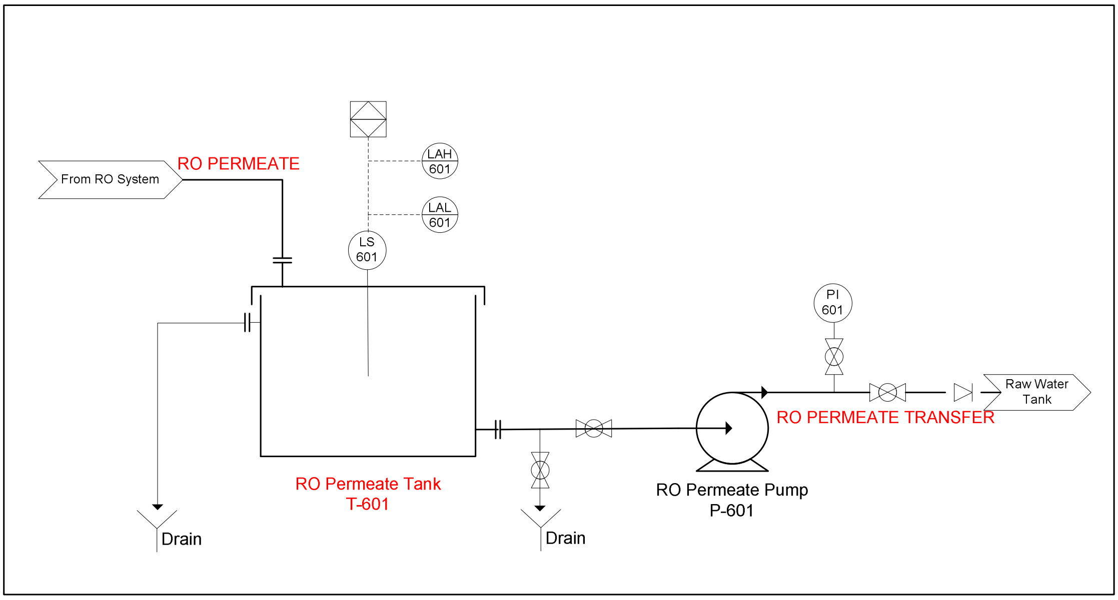


FIGURE 13: PID RO PERMEATE TRANSFER SYSTEM

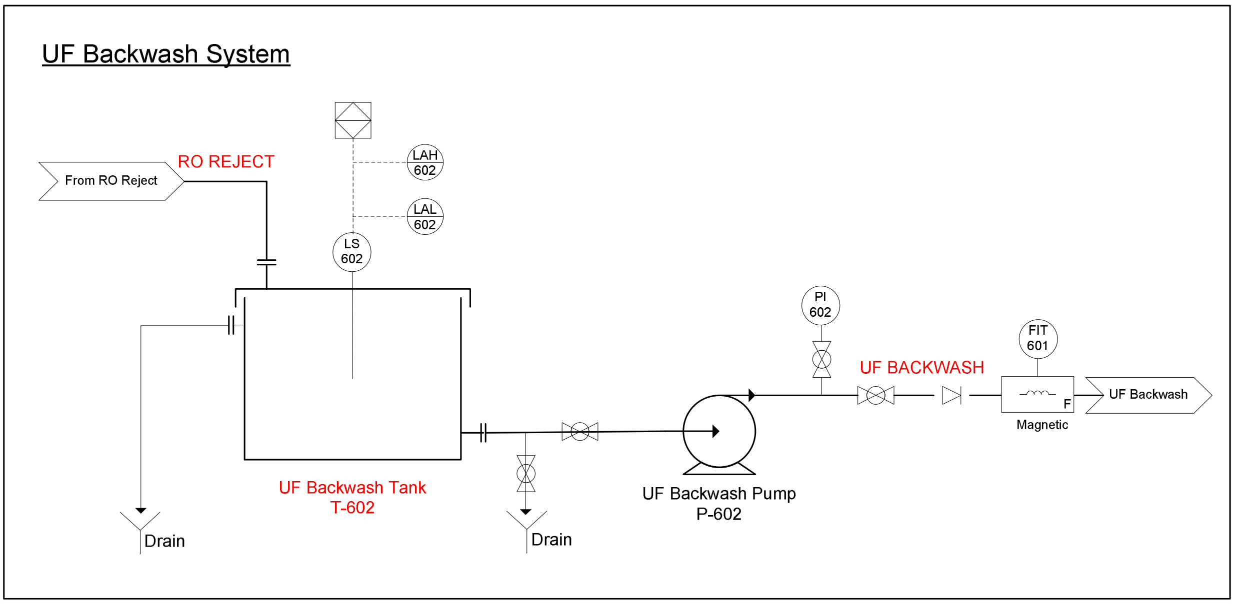


FIGURE 14: PID UF BACKWASH SYSTEM

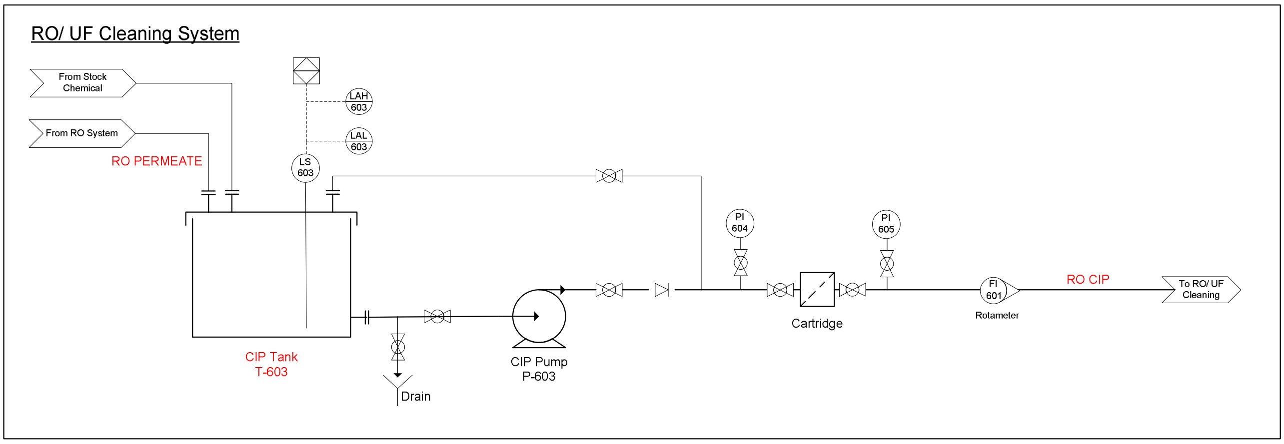


FIGURE 15: PID RO CIP SYSTEM

Control Strategy For P6

RO Permeate Transfer Operation

1) RO Permeate Tank Level Switch (LS-601)
   a. High Level Setpoint: 700L ➔ Permeate Transfer Pump (P-601) ON (To Raw water tank) IF AIT-202 (pH) NOT < 7.0
   b. Low Level Setpoint: 200L ➔ Permeate Transfer Pump (P-601) OFF

UF Backwash Operation

1) UF Backwash Tank Level Switch (LS-602)
   a. High Level Setpoint: 700L ➔ Alarm High (Will Overflow to drain)
   b. Low Level Setpoint: 200L ➔ UF Backwash Pump (P-602) OFF
   c. Backwash Pump
      i. Initiated by PLC- UF Backwash Sequence
      ii. Interlock with NaOCl transfer pump for adding chlorine once every X cycles
      iii. Interlock with LS-602 to STOP at LOW level

CIP Cleaning System (Manual Control By Maintenance Staff)

1. CIP Tank Level Switch (LS-603)
   a. High Level Setpoint: 500L ➔ Ready for CIP
   b. Low Level Setpoint: 100L ➔ CIP Pump (P-603) OFF

CIP Flowrate and Pressure: 1.5-2.2 m^3/hr per 4" Vessel at between 15-30 PSI (1-2 Bar)

Please refer to RO Manual for details

Major Equipment Details For P6

Description	Design Specification	Material	Qty	Brand & Model	Remarks
Pumps & Tanks					
RO Permeate Tank	Capacity: 1.2m³ DiaxH = 1.16 x 1.24	PE	1	Rotamas CPE 1200	
RO Permeate Transfer Pump	Duty: 2.5 m³/h @ 20m	Casing: Chrome Nickel SS Impeller: Noryl Shaft: SS	1	CALPEDA MXP 203	
UF Backwash Tank	Capacity: 1.2m³ DiaxH = 1.16 x 1.24	PE	1	Rotamas CPE 1200	
UF Backwash Tank Pump	Duty: 2.5 m³/h @ 20m	Casing: Chrome Nickel SS Impeller: Noryl Shaft: SS	1	CALPEDA MXP 203	
CIP Tank (UF/RO)	Capacity: 550*l*	PE	1	CGD 550	
CIP Pump	Duty: 2.5 m³/h @ 20m	Casing: Chrome Nickel SS Impeller: Noryl Shaft: SS	1	CALPEDA MXP 203	
Cartridge Filter					
Pre RO Cartridge Filter	Heavy Duty Multi-Cartridge Housing Max Pressure: 125PSI Number of Cartridges & Sze: (4) 10" Flowrate: 28 GPM Element: 1 Micron	SS304 Housing	1	Graver 4MC1-VB-316L-1.5N-B	
Instrumentation					
RO Permeate Tank Level Switch	Low & High Alarm	PVC	1	iSOLV LS880	
UF Backwash Tank Level Switch	Low & High Alarm	PVC	1	iSOLV LS880	
CIP Tank Level Switch	Low & High Alarm	PVC	1	iSOLV LS880	
FIT (UF Backwash)	Electromagnetic DN25	PTFE	1	iSOLV EFS800/CFT180	
FI (RO/UF Cleaning)	Rotameter, 1"	PVC	1	FSIV Flowmeter	

PROCESS PARAMETERS SUMMARY

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
1	SWaT-PID-1	Raw Water Inlet	FIT-101	Flow Transmitter (EMF)	0-10m^3/h	2.5-2.6m^3/h		>2.6m^3/hr OR <2.5m^3/hr		Adjust Manual Valve to Operating Range
2	SWaT-PID-1	Raw Water Tank	T-101	Raw Water Tank	1.8m^3	500 - 1100mm				
3	SWaT-PID-1	Raw Water Inlet	MV-101	Motorised Valve						
4	SWaT-PID-1	Raw Water	LIT-101	Level Transmitter (Ultrasonic)	0-1.2m	500 - 1100mm		>HH OR <LL	HH=1100mm H=800mm L=500mm LL=250mm	>HH: P601(Permeate Transfer Pump) Cannot Run >H: Close MV-101 <L: Open MV-101 <LL: Stop P-101 & P-102
5	SWaT-PID-1	Raw Water	P-101	Pump						
6	SWaT-PID-1	Raw Water	P-102	Pump						
7	SWaT-PID-1	Raw Water	PI-101	Pressure Gauge	0-10 Bar	2-3 Bar		> 3 Bar		
8	SWaT-PID-1	Raw Water	PI-102	Pressure Gauge	0-10 Bar	2-3 Bar		> 3 Bar		

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
9	SWaT-PID-1	Raw Water Outlet	FIT-201	Flow Transmitter (EMF)	0-4m^3/h	2.4 - 2.5m^3/h		>2.5m^3/hr OR <2.4m^3/hr	L = 0.5m^3/hr	Adjust Manual Valve to Operating Range
10	SWaT-PID-1	Chemical Dosing	AIT-201	Analyser (Conductivity)	0-1000µS/cm	30 - 260µS/cm		>H=260 µS/cm	H=260 µS/cm L=250 µS/cm	>H=Stop P-201 & P-202 <L= Start P-201 & P-202 IF AIT-503 NOT High
11	SWaT-PID-1	Chemical Dosing	AIT-202	Analyser (pH)	2-14	6-9		<6 Or >9	H=7.05 L=6.95	>H=Start P-203 & P-204 <L= Stop P-203 & P-204
12	SWaT-PID-1	Chemical Dosing	AIT-203	Analyser (ORP)	0 - 800mV	200 - 500mV		> 800mV	H=500mV L=420 mV	>H=Start P-205 & P-206 <L= Stop P-205 & P-206
13	SWaT-PID-1	Chemical Dosing (NaCl)	LS-201	Level Switch					L=50L	<L= Alarm Warning / Stop P-201 & P-202
14	SWaT-PID-1	Chemical Dosing (HCl)	LS-202	Level Switch					L=4L	<L= Alarm Warning/ Stop P-203 & P-204
15	SWaT-PID-1	Chemical Dosing (NaOCl)	LS-203	Level Switch					L=30L LL=15L	<L= Alarm Warning <LL= Alarm Warning/ Stop P-205 to P-208
16	SWaT-PID-1	Chemical Tank (NaCl)	T-201	Chemical Tank	250L	50L to 200L		<50L		Top Up Chemical
17	SWaT-PID-1	Chemical Tank (HCl)	T-202	Chemical Tank	25L	4L to 20L		<4L		Top Up Chemical
18	SWaT-PID-1	Chemical Tank (NaOCl)	T-203	Chemical Tank	150L	15L to 100L	30L	<15L		Top Up Chemical

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
19	SWaT-PID-1	Chemical Dosing (NaCl)	P-201	Dosing Pump	0-65l/h	12%			12%	
20	SWaT-PID-1	Chemical Dosing (NaCl)	P-202	Dosing Pump	0-65l/h	12%			12%	
21	SWaT-PID-1	Chemical Dosing (HCl)	P-203	Dosing Pump	0-0.74l/h	6%			6%	9% HCl
22	SWaT-PID-1	Chemical Dosing (HCl)	P-204	Dosing Pump	0-0.74l/h	6%			6%	9% HCl
23	SWaT-PID-1	Chemical Dosing (NaOCl)	P-205	Dosing Pump	0-0.74l/h	4%			4%	10% NaOCl
24	SWaT-PID-1	Chemical Dosing (NaOCl)	P-206	Dosing Pump	0-0.74l/h	4%			4%	10% NaOCl
25	SWaT-PID-1	Chemical Dosing (NaOCl)	P-207	Dosing Pump	0-65l/hr	2%			2%	10% NaOCl
26	SWaT-PID-1	Chemical Dosing (NaOCl)	P-208	Dosing Pump	0-65l/hr	2%			2%	10% NaOCl
27	SWaT-PID-1	Chemical Dosing (Outlet)	MV-201	Motorised Valve						
28	SWaT-PID-2	UF Feed Water Tank	T-301	UF Feed Water Tank	1.8m^3	800 - 1000mm				

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
29	SWaT-PID-2	UF Feed Water Tank	LIT-301	Level Transmitter (Ultrasonic)	0-1.2m	800 - 1000mm		>HH OR <LL	HH=1200mm H=1000mm L=800mm LL=250mm	>HH: Alarm Warning >H: Stop P-101/P-102 <L: Start P-101/P-102 <LL: Stop P-301 & P-302
30	SWaT-PID-2	UF Feed	P-301	Pump						
31	SWaT-PID-2	UF Feed	P-302	Pump						
32	SWaT-PID-2	UF Feed	PI-301	Pressure Gauge	0-7 Bar	2-3 Bar		>3 Bar		
33	SWaT-PID-2	UF Feed	PI-302	Pressure Gauge	0-7 Bar	2-3 Bar		>3 Bar		
34	SWaT-PID-2	UF Feed	FIT-301	Flow Transmitter (EMF)	0-4m^3/h	2.2 - 2.4m^3/h		>2.4m^3/hr OR <2.2m^3/hr	L = 0.5m^3/hr	Adjust Manual Valve to Operating Range
35	SWaT-PID-2	UF Feed	FI-301	Flow Indicator	10-70 LPM	30 - 45 LPM				
36	SWaT-PID-2	UF Feed	PSH-301	Pressure Switch					2.5 Bar	>2.5 Bar: Stop P-301 & P-302
37	SWaT-PID-2	UF Filter	DPSH -301	DP Switch					0.5 Bar	>0.5 Bar: Stop P-301 & P-302
38	SWaT-PID-2	UF Filter	DPIT-301	DP Transmitter	0-1 Bar	0.1 - 0.3 Bar			0.4 Bar	>0.4 Bar: Activate UF Backwash Cycle
39	SWaT-PID-2	UF Filter	PI-303	Pressure Gauge	0-7 Bar	1.5- 2.2 Bar		>2.5 Bar		

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
40	SWaT-PID-2	UF Filter	PI-304	Pressure Gauge	0-7 Bar	1.5- 2.2 Bar		>2.5 Bar		
41	SWaT-PID-2	UF Filter	UF-301	UF Filter						
42	SWaT-PID-2	UF Backwash	MV-301	Motorised Valve						
43	SWaT-PID-2	UF Backwash	MV-302	Motorised Valve						
44	SWaT-PID-2	UF Backwash	MV-303	Motorised Valve						
45	SWaT-PID-3	UF Backwash	MV-304	Motorised Valve						
46	SWaT-PID-3	RO Feed Water Tank	T-401	RO Feed Water Tank	$1.8m^3$	800 - 1000mm				
47	SWaT-PID-3	RO Feed Water Tank	LIT-401	Level Transmitter (Ultrasonic)	0-1.2m	800 - 1000mm		>HH OR <LL	HH=1200mm H=1000mm L=800mm LL=250mm	>HH: Alarm Warning >H: Stop P-301 & P-302 <L: Start P-301 & P-302 <LL: Stop P-401 & P-402
48	SWaT-PID-3	RO Feed (Dechlorination)	P-401	RO Transfer Pump						
49	SWaT-PID-3	RO Feed (Dechlorination)	P-402	RO Transfer Pump						

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
50	SWaT-PID-3	RO Feed (Dechlorination)	PI-401	Pressure Gauge	0-7 Bar	1.5 - 2.5 Bar		>2.5 Bar		
51	SWaT-PID-3	RO Feed (Dechlorination)	PI-402	Pressure Gauge	0-7 Bar	1.5 - 2.5 Bar		>2.5 Bar		
52	SWaT-PID-3	RO Feed (Dechlorination)	FIT-401	Flow Transmitter (EMF)	0-4m^3/h	1.5 - 2m^3/h		>2.0m^3/hr OR <1.5m^3/hr	L = 0.5m^3/hr	Adjust Manual Valve to Operating Range
53	SWaT-PID-3	RO Feed (Dechlorination)	AIT-401	Analyser (Hardness)	0-150 ppm	5-30ppm	>80ppm	>100ppm	HH=100 H-80	>HH: Alarm Warning & RO Shutdown Sequence >H: Alarm Warning
54	SWaT-PID-3	RO Feed (Dechlorination)	UV-401	Dechlorination						ON When P-401/P-402 ON
55	SWaT-PID-3	RO Feed (Dechlorination)	AIT-402	Analyser	0-800mV	150 - 300mV		>250mV (Check UV Unit)	H=250mV L=240mV	>H: Alarm Warning ==> P-403 & P-404 ON/ STOP P-205 & P-206 <L: STOP P-403 &P-404/ START P-205 & P-206
56	SWaT-PID-3	RO Feed (Dechlorination)	T-402	$NaHSO_3$	250L	4-20L		<4L		Top Up Chemical
57	SWaT-PID-3	RO Feed (Dechlorination)	P-403	$NaHSO_3$ Dosing	0.74l/h	10%			10%	10% $NaHSO_3$

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
58	SWaT-PID-3	RO Feed (Dechlorination)	P-404	$NaHSO_3$ Dosing	0.74l/h	10%			10%	10% $NaHSO_3$
59	SWaT-PID-4	RO Feed	PI-501	Pressure Gauge	0-7 Bar	1-2 Bar				
60	SWaT-PID-4	RO Feed	PI-502	Pressure Gauge	0-7 Bar	1-2 Bar				
61	SWaT-PID-4	RO Feed	Cartridge-501	Filter	1 Micron					
62	SWaT-PID-4	RO Feed	AIT-501	Analyser (pH)	2-14	6-8			H=8 L=6	>H: Alarm Warning <L: Alarm Warning
63	SWaT-PID-4	RO Feed	AIT-502	Analyser (ORP)	0-800mV	100-250mV		>250mV	H=250mV	>H: Alarm Warning/ START P-403 & P-404 Shutdown Sequence After 30 mins
64	SWaT-PID-4	RO Feed	AIT-503	Analyser (Cond)	0-1000µS/cm	200- 300µS/cm		>300µS/cm	H = 260µS/cm	>H: Stop P-201 & P202, Overriding AIT 201
65	SWaT-PID-4	RO Feed	P-501	RO Pressure Pump		VSD: 25 Hz				
66	SWaT-PID-4	RO Feed	P-502	RO Pressure Pump		VSD: 25 Hz				
67	SWaT-PID-4	RO Feed	PSL-501	Pressure Switch	0.55-5.2 Bar	0.6 Bar			0.6 Bar	<0.6 Bar: Stop P-501 & P-502
68	SWaT-PID-4	RO Feed	PSH-501	Pressure Switch	0.55-5.2 Bar	4.6 Bar			4.6 Bar	>4.6 Bar: Stop P-501 & P-502

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
69	SWaT-PID-4	RO Membrane Inlet	FIT-501	Flow Transmitter	0-4m^3/h	1-2m^3/h		<1 or >2m^3/h		Design Flow: 1.7m^3/h
70	SWaT-PID-4	RO Membrane Inlet	PIT-501	Pressure Transmitter	0-5 Bar	2-3 Bar	>2.6 Bar	>3 Bar		
71	SWaT-PID-4	RO Permeate	AIT-504	Analyser (Cond)	0-20 µS/cm	5-10 µS/cm	>10 µS/cm	>15µS/cm	HH: 15 µS/cm H: 10 µS/cm	>HH: Alarm Warning, ==>Shutdown Sequence After 30 mins >H: Alarm Warning
72	SWaT-PID-4	RO Permeate	FIT-502	Flow Transmitter (Paddlewheel)	0-4m^3/h	1.1 - 1.3m^3/h		<1.1 m^3/h or >1.3m^3/h		Design Flow: 1.2m^3/h
73	SWaT-PID-4	RO Permeate	PIT-502	Pressure Transmitter	0-5 Bar	0-0.2 Bar		>0.2 Bar		
74	SWaT-PID-4	RO Permeate	MV-501	Motorised Valve						OPEN only when Permeate Conductivity < 10µS/cm
75	SWaT-PID-4	RO Reject	FIT-503	Flow Transmitter (EMF)	0-4m^3/hr	0.7 - 0.9m^3/h		<0.7 m^3/h or >0.9m^3/h		Design Flow: 0.8m^3/h
76	SWaT-PID-4	RO Reject	PIT-503	Pressure Transmitter	0-5 bar	1-2 Bar		>2 Bar or < 1 Bar		
77	SWaT-PID-4	RO Recirculation	FIT-504	Flow Transmitter (EMF)	0-2m^3/hr	0.25 - 0.35m^3/h		<0.25 m^3/h or >0.35m^3/h		Design Flow: 0.3m^3/h

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
78	SWaT-PID-4	RO Reject	FI-501	Flow Indicator	0-70 LPM					
79	SWaT-PID-4	RO Reject To UF BW Tank	MV-502	Motorised Valve						
80	SWaT-PID-4	RO Permeate Drain	MV-503	Motorised Valve						CLOSE only when Permeate Conductivity < 10µS/cm After MV-501 OPEN
81	SWaT-PID-4	RO Reject To Drain	MV-504	Motorised Valve						
82	SWaT-PID-4	RO Vessel	RO-501	RO Vessel (4 Elements)						
83	SWaT-PID-4	RO Vessel	RO-502	RO Vessel (4 Elements)						
84	SWaT-PID-4	RO Vessel	RO-503	RO Vessel (6 Elements)						
85	SWaT-PID-5	RO Permeate	T-601	Tank	1.2m^3	200 - 700L				
86	SWaT-PID-5	RO Permeate	LS-601	Level Switch (2pts)		200 - 700L			H=700L L=200L	>H: Alarm Level High/ START P-601 IF T-101 NOT HH & AIT-202 > 7 pH <L: Alarm Level Low/ STOP P-601
87	SWaT-PID-5	RO Permeate	P-601	Permeate Pump						

S/No	PID No	Location	ID	Instrument	Range (4-20mA)	Operating Range	Alert Points	Actions Required	Control Setpoints	Remarks
88	SWaT-PID-5	UF Backwash	T-602	Tank	$1.2m^3$	200 - 700L				
89	SWaT-PID-5	UF Backwash	LS-602	Level Switch (2pts)		200 - 700L			H=700L L=200L	>H: Alarm Level High <L: Alarm Level Low/ STOP P-602
90	SWaT-PID-5	UF Backwash	P-602	UF BW Pump						
91	SWaT-PID-5	UF Backwash	FIT-601	Flow Transmitter	$0\text{-}4m^3/h$	$2\text{-}3m^3/h$		$>3m^3/h$ or $<2m^3/h$		
92	SWaT-PID-5	RO/UF CIP	T-603	Tank	$0.6m^3$	100 - 500L				
93	SWaT-PID-5	RO/UF CIP	LS-603	Level Switch (2pts)		101 - 500L			H=500L L=100L	>H: Alarm Level High <L: Alarm Level Low/ STOP P-603
94	SWaT-PID-5	RO/UF CIP	P-603	CIP Pump		$1.5\text{-}2.2m^3/hr$				Adjust Manual Valve
95	SWaT-PID-5	RO/UF CIP	PI-601	Pressure Gauge	0-7 Bar	1-2 Bar				Max 2 Bar
96	SWaT-PID-5	RO/UF CIP	PI-602	Pressure Gauge	0-7 Bar	1-2 Bar				Max 2 Bar
97	SWaT-PID-5	RO/UF CIP	Cartridge-502	Filter	1 Micron					
98	SWaT-PID-5	RO/UF CIP	FI-601	Flow Indicator	0-70 LPM					

EQUIPMENT LOAD LIST

S/N	Description	Qty.	Working	Standby	KW per unit	Total Load (Kw)	Working Load (Kw)	Standby Load (Kw)	BKW (P2)	Total Power	Rated Current (Amp)	Startup Current (Amp)
1	Raw water Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
2	Raw Water Magnetic Flow Meter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
3	Raw Water Tank Level Transmitter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
4	Raw Water Control Valve	1	1	0	0.015	0.015	0.015	0	0.01	0.01	0.08	0.08
5	PLC P1	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02
6	NaCL Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
7	HCL Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
8	NaOCL Pump	4	2	2	0.75	3	1.5	1.5	0.50	1.00	2.46	2.46
9	Pre- Treatment Magnetic Flow Meter	1	2	0	0.1	0.1	0.2	0	0.07	0.13	1.02	1.02
10	Pre-Treatment Conductivity Meter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
11	Pre-Treatment pH/ORP Meter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
12	Pre-Treatment Control Valve	1	1	0	0.015	0.015	0.015	0	0.01	0.01	0.08	0.08
13	PLC P2	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02
14	Ultra-Filtration Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
15	Ultra-Filtration Magnetic Flow Meter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
16	Ultra-Filtration Tank Level Transmitter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
17	Ultra-Filtration Control Valve	3	3	0	0.015	0.045	0.045	0	0.02	0.05	0.23	0.23
18	PLC P3	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02

S/N	Description	Qty.	Working	Standby	KW per unit	Total Load (Kw)	Working Load (Kw)	Standby Load (Kw)	BKW (P2)	Total Power	Rated Current (Amp)	Startup Current (Amp)
19	RO Feed Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
20	NaHSO3 Pump	1	1	0	0.75	0.75	0.75	0	0.25	0.25	3.84	3.84
21	RO Water Tank Level Transmitter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
22	RO Feed ORP Meter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
23	UV	1	1	0	0.3	0.3	0.3	0	0.10	0.10	1.53	1.53
24	PLC P4	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02
25	RO Pump	2	1	1	2.2	4.4	2.2	2.2	0.73	0.73	3.60	3.60
26	RO Magnetic Flow Meter	4	7	0	0.1	0.4	0.7	0	0.23	1.63	3.58	3.58
27	RO Conductivity Meter	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02
28	RO pH/ORP Meter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
29	RO Pressure Transmitter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
30	RO Control Valve	4	4	0	0.015	0.06	0.06	0	0.02	0.08	0.31	0.31
31	PLC P5	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02
32	UF Backwash Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
33	RO Permeate Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
34	Chemical Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
35	CIP Pump	2	1	1	0.75	1.5	0.75	0.75	0.25	0.25	1.23	1.23
36	CIP Tank Level Transmitter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
37	RO Permeate Tank Level Transmitter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
38	UF Backwash Tank Level Transmitter	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51

S/N	Description	Qty.	Working	Standby	KW per unit	Total Load (Kw)	Working Load (Kw)	Standby Load (Kw)	BKW (P2)	Total Power	Rated Current (Amp)	Startup Current (Amp)
39	UF Backwash Magnetic Flow Meter	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02
40	PLC P6	2	2	0	0.1	0.2	0.2	0	0.07	0.13	1.02	1.02
41	PLC P7	1	1	0	0.1	0.1	0.1	0	0.03	0.03	0.51	0.51
42	12" Touch Panel	1	1	0	0.07	0.07	0.07	0	0.02	0.02	2.92	2.92
43	Ethernet Switch	10	10	0	0.003	0.03	0.03	0	0.01	0.10	1.25	1.25
44	Wireless Access Point	2	2	0	0.003	0.006	0.006	0	0.00	0.00	0.25	0.25
45	Wireless Client	8	8	0	0.003	0.024	0.024	0	0.01	0.06	1.00	1.00
46	SCADA Workstation	1	1	0	1.1	1.1	1.1	0	0.37	0.37	5.63	5.63
47	SCADA Server	1	1	0	0.825	0.825	0.825	0	0.28	0.28	4.22	4.22

Total Load: 58A

Power Factor: 0.85

DOSING PUMPS CALCULATIONS

Chemical Dosage & Consumption (Based on Continuous Operations)

pH Adjustment			
Flow Name	Flow Rate (mL/h)	pH Value	Remarks
Raw Water	2400000	8.5	
9% Hydrochloric Acid	**26.966**	**-0.4**	Need to factor in pH increase due to NaOCl
UF Feed Flow	2400000	6.5	
		Dosing Pump (Max Capacity: 0.74l/hr)	4%
		Weekly Consumption of Acid (L/wk)	4.53

FAC Dosing (1 ppm)			
Flow Name	Flow Rate (mL/h)	FAC (ppm)	Remarks
Raw Water	2400000	0	
10% NaClO Solution	**24.000**	**100000**	
UF Feed Flow	2400000	1	Dosage
		Dosing Pump (Max Capacity: 0.74l/hr)	3.2%
		Weekly Consumption of Solution (L/wk)	4.03

Conductivity (TDS) Adjustment			
Flow Name	Flow Rate (mL/h)	TDS(ppm)	Remarks
Raw Water	2400000	50	
Saturated Brine	**8040.201**	**30000**	
UF Feed (250 microSiemens/cm)	2408040.201	150	250ppm Cond Approx 150ppm TDS
		Dosing Pump (Max Capacity: 65l/hr)	12%
		Weekly Consumption of Brine (L/wk)	1350.75
		Weekly Consumption of Salt (kg/wk)	40.52

UF Chemical Wash			
Flow Name	Flow Rate (mL/h)	FAC (ppm)	Remarks
Raw Water	2400000	0	
10% NaClO Solution	**1200.600**	**100000**	1 min/wash
Wash Flow @ 50ppm	2400000	50	3 wash/wk
		Dosing Pump (Max Capacity: 65l/hr)	2%

Weekly Consumption of Solution (L/wk)	0.06

NaHSO₃ Neutralization			
Flow Name	Flow Rate (mL/h)	Conc.(ppm)	Remarks
Pre-RO Flow	2000000	1	
10% NaHSO3	**60.000**	**100000**	1mg FAC consume 1.46 mg Na HSO_3, Dosing at double of requirement
Dosing Pump (Max Capacity: 0.74l/hr)			8.11%
Weekly Consumption of Solution (L/wk)			10.08

MAINTENANCE

Preventive Maintenance

To ensure proper functioning of system and unnecessary repair costs, proper preventive maintenance has to be carried out by competent personnel.

Component	Frequency (Recommended)	Actions
pH Sensor	Quarterly	- Clean probe and visually examine for hairline cracks - Calibrate with pH 4, pH 7 and pH 10 standard buffers
pH Sensor	Yearly	- Replace pH Sensor
ORP Sensor	Quarterly	- Clean probe and visually examine for hairline cracks - Calibrate with standard solution eg. 475mV
ORP Sensor	Yearly	- Replace ORP Sensor
Conductivity Sensor	Quarterly	- Clean probe - Calibrate with standard solution eg. 470 µS/cm
Conductivity Sensor	3 Years	- Replace Sensor (Only when value drift by more than 10%)
Centrifugal Pumps	Monthly	- Visual inspection for leaks - Check for pump vibration and temperature. - Check for cavitation sound including airlock. - Greasing of pump, if required.
Chemical Metering Pumps	Quarterly	- Check the metering diaphragm for damage - Check that the hydraulic lines are fixed firmly to the liquid end. - Check that the suction valve and discharge valve are correctly seated. - Check the tightness of the entire liquid end - particularly around the leakage hole - Check that the flow is correct: Allow the pump to prime briefly - turn the multifunctional switch briefly to "Test" - Check that the electrical connections are intact - Check the integrity of the housing. - Check that the dosing head screws are tight - Check that the bypass line is fixed firmly to the liquid end

Component	Frequency (Recommended)	Actions
		- Check that the bleed valve is tight. - Check the discharge and bypass line for kinks - Check that the bleed valve is operating correctly.
Hardness Analyser	Monthly	- Replace the reagents and standards - Examine the pump, valve and mixer modules - Examine the sample conditioning block filter - Examine the backpressure at the drain block
Hardness Analyser	Quarterly	- Replace the pump piston seals - Lubricate the pump module - Replace the valve rotor
Hardness Analyser	Half Yearly	- Examine the tubing and fittings, replace if necessary
UV Dechlorinator	After 8000 hrs/ 24 Months	- Replace UV Lamps
UV Dechlorinator	6 Months	- Inspect quartz sleeve - Clean if necessary
Cartridge Filter	Monthly	- Review difference pressure between inlet and outlet - Change filter elements when DP > 0.5 bar
UF System	Monthly	- Check for abnormality of permeate flow - Check for abnormality of permeate quality - Perform CIP if necessary - Check for leaks
RO System	Monthly	- Review operation data from Historian - Review performance data and commence CIP procedure if 1. Normalized differential pressure increases more than 20% OR 2. Normalized permeate flow rate decreases by more than 10 % OR 3. Normalized salt passage increases by more than 20 %. - Check for leaks
Tanks	Monthly	- Review performance of 1. Valves 2. Level Controls - Check for leaks

TROUBLESHOOTING GUIDE

Troubleshooting: Process & Operations

Process	Symptom/ Issue	Possible Causes/ Actions
P1: Raw Water	Pump P101/ P102 Cannot Start/ Stopped Suddenly	1. FIT-201 Reading Low/ Faulty 2. MV 201 Faulty 3. LIT-301 Faulty
P1: Raw Water	Raw Water Tank T-101 Low/ Empty	1. Drain Valve Open 2. MV 101 Faulty 3. Incoming Water Manual Valve Closed 4. LIT-101 Faulty
P2: Pre Treatment	NaC*l*/ HC*l* Or NaOC*l* Pumps Cannot Start	1. Respective Level Switch Low ➔ Top Up Chemical
P2: Pre Treatment	NaC*l*/ HC*l* Or NaOC*l* Pumps "Fault" Light on Panel	1. Manual Switchover Respective Dosing Pump
P3: UF System	UF Feedwater Tank T-301 Low/ Empty	1. Drain Valve Open 2. Pump P101/P102 Faulty 3. FIT-201 Reading Low/ Faulty 4. MV 201 Faulty 5. LIT-301 Faulty – Reading High
P3: UF System	Pump P301/ P302 Cannot Start/ Stopped Suddenly	1. FIT-301 Reading Low/ Faulty 2. LIT-301 Low Low Setpoint Triggered 3. PSH-301 Triggered 4. DSPH-301 Triggered 5. LIT-401 Faulty – Reading High
P3: UF System	FIT-301 Reading Low/Zero When Pump P301/P302 is On	1. MV-302 is Faulty
P4: Dechlorination System	RO Feedwater Tank T-401 Low/ Empty	1. Drain Valve Open 2. Pump P301/P302 Faulty 3. FIT-301 Reading Low/ Faulty 4. LIT-401 Faulty – Reading High
P4: Dechlorination System	Pump P401/ P402 Cannot Start/ Stopped Suddenly	1. FIT-401 Reading Low/ Faulty 2. LIT-401 Low Low Setpoint Triggered

Process	Symptom/ Issue	Possible Causes/ Actions
P4: Dechlorination System	AIT-402: ORP remain high & P-403/P-404 Pump Continuously	1. Check UV Lamp Indicator and replace UV Lamps After 8000 Hr
P4: Dechlorination System	$NaHSO_3$ Pumps Cannot Start When AIT-402 > High Setpoint	1. Level Switch Low ➔ Top Up Chemical
P4: Dechlorination System	$NaHSO_3$ Pumps "Fault" Light on Panel	1. Manual Switchover Respective Dosing Pump
P5: RO System	Pump P501/ P502 Cannot Start/ Stopped Suddenly	1. FIT-501 Reading Low/ Faulty 2. LIT-401 Low Low Setpoint Triggered 3. PSL-501 Triggered ➔ Check P-401/P-402 4. PSH-501 Triggered ➔ Check Motorised Valves Positions
P5: RO System	FIT-501 Reading Low/ Zero When P401/P402 is On	1. Check Motorised Valves 2. Check Cartridge Filter
P5: RO System	RO Permeate Flow (FIT-502)Decreasing	1. Check Design Flowrate (i) FIT-501 = 1.7 m^3/hr (ii) FIT-503 = 0.8 m^3/hr (iii) FIT-504 = 0.3 m^3/hr 2. To Perform CIP According to Manufacturer's Guidelines
P5: RO System	RO Permeate Conductivity (AIT-504) > High High Setpoint	1. Check AIT-503, design to be less than 300 µS/cm 2. If AIT-503< 300 µS/cm ; RO Vessel O-Ring Damage
P6: RO Permeate	RO Permeate Tank T-601 Low/ Empty	3. Drain Valve Open 4. MV-501 Faulty
P6: RO Permeate	RO Permeate Tank T-601 High/ Overflow	1. LS601 (High) Faulty 2. P-601 Faulty 3. LIT-101 Faulty (At High High)
P6: RO Permeate	RO Permeate Pump P-601 Cannot Start/ Stopped Suddenly	1. LS601 Low Alarm 2. LIT-101 At High High/ Faulty

Process	Symptom/ Issue	Possible Causes/ Actions
P6: UF Backwash	UF Backwash Tank T-602 Low/ Empty	1. Drain Valve Open 2. MV-502 Faulty
P6: UF Backwash	UF Backwash Pump P-602 Cannot Start/ Stopped Suddenly	1. LS-602 At Low Alarm 2. FIT-601 Reading Zero/ Low ➔MV 301 Faulty
P6: RO CIP	RO CIP Pump P-603 Cannot Start	1. LS-603 At Low Alarm

Troubleshooting – Instruments

1. Level Transmitter – iSOLV Level Wizard

Symptom	What to Do
Display blank, transducer not firing.	Check power supply, voltage selector switch and fuse.
Displays "No Xducer"	Check wiring to transducer.
Displays "Xducer Flt"	There is a fault with the transducer wiring, so check wiring to transducer.
Incorrect reading being displayed for current level.	Measure actual distance from transducer head to surface of material. Enter Program Mode and directly access P21 (Set Distance) type in the measured distance, ENTER, ENTER again when prompted, wait until SET displayed and return to Run Mode, display should now update to correct reading.
Material level is consistently incorrect by the same amount.	Check empty level, (P105) display offset, (P802) and measurement offset (P851).
Relay indicators change at relevant relay switch points but relays do not change state.	Check supply to unit and ensure voltage selector set to correct position.

2. Flow Transmitter

a. iSOLV EFS 803

Symptom	What to Do
Converter is showing no flowrate even with steady flow.	Check if the sensor and liquid are correctly grounded. Check that the sensor is full with liquid. Electrical conductivity of the liquid is too low or is not compatible with the material used for the sensor electrodes.
Flow reading is highly unstable	Check if the sensor and liquid are correctly grounded. There is air in the pipe, try to avoid the creation of bubbles selecting a more suitable position for the sensor (see installation paragraph).
External pulse totalizer shows results different from what is expected.	Test the output with the internal flow simulator and the converter-pulse counter system simulating a flowrate with System > Simulation
Incorrect reading being displayed for current level.	Measure actual distance from transducer head to surface of material. Enter Program Mode and directly access P21 (Set Distance) type in the measured distance, ENTER, ENTER again when prompted, wait until SET displayed and return to Run Mode, display should now update to correct reading.
The display is off and does not turn on.	There is no voltage supply, or the voltage supply is mistaken. Check the power supply voltage on the name plate of the converter.
Liquid flowing an pipe full - but NO reading	Reduce the flow cut off filter (factory settings is 2% of the full scale)

b. FIP FlowX3

Symptom	What to Do
Leaking	Improper installation Worn or damaged O-rings.
Flow reading is highly inaccurate	Improper installation Improper velocity profile Improper alignment / installation Worn paddle and/or axle Accumulated reading error
No display	Electronics damaged Dead batteries.
Display shows zero flow	Electronics damaged Flow rate is out of range

3. Pressure Transmitter – iSOLV SPT 100

Symptom	What to Do
Transmitter milliamp reading is zero	Verify power is applied to signal terminals Check power wires for reversed polarity Verify terminal voltage is 10.5 to 42.4 Vdc Check for open diode across test terminal
Transmitter Not Communicating with Field Communicator	Verify the output is between 4 and 20 mA or saturation levels Verify terminal voltage is 10.5 to 42.4 Vdc IVerify clean DC Power to transmitter (Max AC noise 0.2 volts peak to peak) Check loop resistance, 250 Ω minimum (PS voltage - transmitter voltage/loop current)
Transmitter milliamp reading is low or high	Verify applied pressure Verify 4 and 20 mA range points Verify output is not in alarm condition Verify if 4 – 20 mA output trim is required
Transmitter will not respond to changes in applied pressure	Check test equipment Check impulse piping or manifold for blockage Verify the transmitter is not in multidrop mode Verify applied pressure is between the 4 and 20 mA set points Verify output is not in alarm condition Verify transmitter is not in Loop Test mode
Milliamp reading is erratic	Verify power source to transmitter has adequate voltage and current Check for external electrical interference Verify transmitter is properly grounded Verify shield for twisted pair is only grounded at one end

4. Pumps – CALPEDA MX Series

Symptom	What to Do
Little or No Discharge	Casing not initially filled with water. (Fill pump casing---prime pump) Total head too high. (Shorten suction and/or head) Suction lift too high , or too long (Lower suction lift, install foot valve and prime, or shorten length of suction line) Impeller plugged (Clean impeller) Hole or air leak in suction line (Repair or replace; do not use Teflon tape;use pipe sealing compound) Foot valve too small (Match foot valve to piping or install one size larger foot valve) Foot valve or suction line not submerged deep enough in water (Submerge lower in water--at least 3 feet) Impeller damaged (Replace impeller) Insufficient inlet pressure or suction head (Increase inlet pressure by adding more water to tank or increasing back pressure) Suction piping too small (Increase to pump inlet size or one size larger) Motor wired incorrectly (Check wiring diagram) Casing gasket or "O" ring leaking (Replace) Suction or discharge valve closed (Open) Pump flow is greater than well flow capacity (Match pump flow to well capacity)
Loss of Suction	Air leak in suction line (Repair & replace) Suction lift too high (Lower suction lift, install foot valve and prime) Insufficient inlet pressure or suction head (Increase inlet pressure by adding more water to tank or increasing back pressure) Clogged foot valve check valve or strainer (Unclog) Defective foot valve or check valve (Replace) Defective priming hose bibb on suction pipe (Replace) Defective well (Repair or replace)
Motor Overheats and Shutdown (Overload)	Motor voltage does not match power supply voltage (Check motor connection against wiring diagram on the motor nameplate and against the power supply voltage) Improper wire size (Consult with a licensed electrician or refer to the National Electrical Code for definite guide to wire sizeand circuit protection devices)

Symptom	What to Do
	Impeller is rubbing against pump case or not turning freely (Dismantle pump, unclog or replace the impeller) Low voltage at the motor (Make sure electrical connections are tight)
Pump Leaks At Shaft	Worn mechanical shafts (Replace mechanical shafts)
Pump Vibrates & Make Excessive Noise	Mounting plate or foundation not rigid enough (Reinforce) Foreign material in pump (Dismantle pump and clean) Impeller damaged (Replace impeller) Worn motor bearings (Replace bearings) Suction lift too high (Lower suction lift, install foot valve and prime)
Pump Will Not Start Or Run	Improperly wired (Check wiring against diagram on motor) Blown fuse or open circuit breaker (Replace fuse, reset circuit breaker) Loose or broken wiring (Tighten connections, replace broken wiring Stone or foreign object lodged in impeller (Dismantle pump and remove foreign object) Motor shorted out (Replace motor) Thermal overload has opened circuit (Allow unit to cool, restrart after reason for overload has been determined

5. Dosing Pumps - PROMINENT

Symptom	What to Do
Pump does not prime in spite of full stroke motion and bleeding	Minor crystalline deposits on the ball seat due to the valves drying out ➔ Take suction hose out of the storage tank and thoroughly flush out the liquid end Major crystalline deposits on the ball seat due to the valves drying out ➔ Dismantle the valves and clean them
Fluid is escaping from the backplate	The screws in the dosing head are too loose ➔ Tighten the screws in the dosing head crosswise - refer to "Repair" for tightening torque. The metering diaphragm is not tight. ➔ Replace the metering diaphragm - refer to "Repair"
Green LED display (operating display) does not light up	The wrong mains voltage or no mains voltage is connected. ➔ The specified mains voltage can be found on the nameplate.

6. Hardness Analyser – HACH APA 6000

Symptom/ Message	What to Do
POWER FAILURE	The power source was temporarily disconnected or set to off. Check and reconnect
CAL STD1 (or 2) REPEATABILITY	The readings of the calibration standard vary ➔ This warning is typically caused by a mechanical failure. Refer to General troubleshooting procedure on page 19 of manual.
STD1 (or 2) FAIL ACC/REP	The readings of the standard are not within acceptable calibration limits and are not repeatable. ➔ This warning is typically caused by a mechanical failure. Refer to General troubleshooting procedure on page 19 of manual.
STD1 (or 2) LOW or REAGENT1 (or 2) LOW or CLEANER LOW	The standard, reagent or cleaning solution level is less than 5%. ➔ Identify the fluid level in each analyzer bottle. If the fluid level is almost empty, replace the bottle. Refer to Replace the reagents and standards on page 5 of manual. If the fluid level is not almost empty, set the fluid level to the correct level.
STD1 (or 2) FAIL ACCURACY	The reading of the standard is not within acceptable limits. ➔ Replace the reagents and/or standard solutions.
DETECTOR LIGHT LEAKAGE	Light is getting into the colorimeter. ➔ Replace the colorimeter module.
LED OUTPUT LOW/ HIGH	The colorimeter LED light output is too low/ too high ➔ Replace the colorimeter module if the problem continues.
A/D FAILURE	The main analog to digital converter of the colorimeter module has failed. ➔ Start the analyzer. Refer to Put the analyzer back into operation on page 5 of manual. Replace the colorimeter module if the problem continues.
RAM TEST FAILED	The RAM on the APA main circuit board has malfunctioned ➔ Start the analyzer. Refer to Put the analyzer back into operation on page 5. Contact technical support if the problem continues
VALVE COMM FAIL	The valve module is not communicating with the controller. ➔ Make sure that all the cables are securely connected. If corrosion is present on the harness that connects to the

Symptom/ Message	What to Do
	backplane, clean the contacts. Replace the harness or backplane if corrosion is visible. Replace the valve module if the problem continues
BURETTE1 COMM FAIL	The autoburette (pump) module is not communicating with the controller ➔ Replace the autoburette module.
MIXER COMM FAIL	The mixing module is not communicating with the controller. ➔ Replace the mixing module.
DETECTOR COMM FAIL	The colorimeter module is not communicating with the controller. ➔ Replace the colorimeter module.
INTERNAL COMM FAIL	There is an internal communication problem. ➔ Contact technical support.
VALVE NO HOME	The valve was not able to find its home signal ➔ Replace the valve module if the problem continues.
VLV HOME SIG ON	The home signal of the valve is always on. ➔ Replace the valve module.
VLV MOVE ERR	The valve was not able to move to the necessary port. ➔ Replace the valve module if the problem continues.
BURETTE1 HOME ERR **BURETTE1 HOME DRIFT** **BURETTE1 NO HOME** **BURETTE1 HOME ON**	Identify if the tubing has a blockage or if there is plumbing that is not correct. Replace the pump (autoburette) module if the problem continues.
SAMPLE1 (or SAMPLE2) OUT	There is no sample flow to the analyzer. ➔Identify if the sample conditioning unit has a blockage. Make sure that there is sample flow to the analyzer.
LOW ALARM value units	The sample measurement is less than the set point value selected by the user.
HIGH ALARM value units	The sample measurement is more than the set point value selected by the user.
RATE ALARM value units	The sample measurement rate change is more than the set point value selected by the user.
General Troubleshooting Procedures	1. Make sure that none of the analyzer bottles are empty. If an reagent or standard solution bottle is empty, replace all the reagent and standard solution bottles. Make sure that the cleaning solution bottle is full. Refer to Replace the reagents and standards on page 5. 2. Make sure that 12.7 mm (0.5-in.) of the tubing comes out of the bottom of each straw that goes in the analyzer bottles.

Symptom/ Message	What to Do
	3. Make sure that the tubing going into the analyzer bottles is the correct tubing. Each tube has a label that identifies the corresponding bottle. 4. Make sure that the tubes connected to the rotary valve are filled with fluid and not air. If there is air in the tubes: a. Examine the tubing for kinks and/or crushed areas that prevent flow through the tubing. Replace tubing with damage. Refer to Replace a tube on page 14. b. Make sure that flow is not prevented by fittings that are overtightened. Cut off the pinched end of the tube and use a new ferrule. Refer to Figure 7 on page 15 and Figure 8 on page 15. c. Examine the tubing connections and the seal on the bottle caps for leaks. Fix any leaks. 5. If the tubing to the rotary valve has been recently been disconnected, make sure that the tubing is correctly connected to the rotary valve. • Premature wear may occur in the valve. Replace the valve rotor and examine the stator for scratches. Refer to Replace the valve rotor on page 10. • Clean or replace a tube fitting if it has a leak. Refer to Figure 7 on page 15 and Figure 8 on page 15. • If the valve module body has a leak, replace the valve module. Refer to Replace a module on page 16. • If reagents or sample are not flowing, the fittings may have been over-tightened. Cut off the pinched end of the tube and use a new ferrule. Refer to Figure 7 on page 15 and Figure 8 on page 15. 6. If air moves through the pump piston seals during operation, examine the sample conditioning block filter. If the filter has a blockage, replace the filter. Refer to Replace the sample conditioning block filter on page 13. If filter does not have a blockage, replace the pump piston seals. Refer to Replace the pump piston seals on page 7. 7. If there is fluid leakage around the pump body, replace the pump piston seals. Refer to Replace the pump piston seals on page 7. 8. Examine the pressure at the drain block. Refer to Examine the backpressure at the drain block on page 7.

7. Analyers pH, ORP, Conductivity – Mettler Toledo

Symptom	What to Do
Display is blank	– No power to M200 easy. – Blown fuse. – LCD display contrast set incorrectly. – Hardware failure.
Incorrect measurement readings.	– Sensor improperly installed. – Incorrect units multiplier entered. – Temperature compensation incorrectly set or disabled. – Sensor needs calibration. – Sensor or patch cord defective or exceeds recommended maximum length. – Hardware failure
Measurement readings not stable	– Sensors or cables installed too close to equipment that generates high level of electrical noise. – Recommended cable length exceeded. – Averaging set too low. – Sensor or patch cord defective.
Displayed ⓘ is flashing.	– Setpoint is in alarm condition (setpoint exceeded). – Alarm has been selected (see chapter 8.5 Alarm/Clean) and occurred

Troubleshooting – UF System

Symptom	What to Do
Low System (Feed) Pressure	Low system pressure occurs when sufficient feed water pressure and flow are not obtained. This may cause any of the pumps installed on the UF system to cavitate. Failure to provide the proper feed flow and pressure will result in lower system pressure that may result in low production and poor rejection. Check the following components: LEAKS: Check the system for leaks, as this can result in low pressure. MOTOR: The motor may not be drawing the correct current or may be wired improperly. Use a clamp-on ammeter to check the current draw. If the three-phase legs are reversed, the motor rotation will be reversed and the pumps will not generate the specified discharge flow or pressure. FLOW CONTROL VALVES: The flow control or concentrate control valves may be defective, thereby prohibiting the system from achieving any backpressure. Remove the valve, inspect the internals, and replace if necessary. SUCTION VALVES: Check the isolation valve between the tanks and the Raw Water and UF Filtrate Pump suction. These valves must be open for the pumps to operate. PUMP: Isolate the pump and determine how much pressure can be achieved. This can be determined by checking the pump discharge pressure gauge at this point. The pressure of the pump should reach at least 2 bar (20 psi) when the flow is restricted.
Abnormal Filtrate Flow – Low Filtrate Flow	COLD FEED WATER: Ultrafiltration membranes achieve optimal performance at a feed water temperature of 77F (25C). The exact change in membrane performance, as a function of temperature is specific to each membrane type and manufacturer. In general, the production of the membrane increases by 2% for each degree C above 25C and declines by about 2% for each degree C below 25C. For example, at 10C feed water temperature, the

	typical UF membrane will operate at about 50% of its specified flow rate at 25C. Increasing the concentrate pressure (to the extent permitted by the capacity of the Raw water pump and maximum recommended pressure ratings of the membrane module will increase the filtrate flow when feed water is cold. LOW OPERATING PRESSURE: The filtrate flow and the concentrate (operating) pressure are directly related. Increase the operating pressure by closing the concentrate valve slightly. If the pressure does not increase, check the mechanical devices as indicated previously. FOULED OR SCALED MEMBRANE: Accumulation of foulants or mineral scale on the membrane surface will reduce the filtrate or permeate flow. In most cases, membrane cleaning will be required. Refer to cleaning instructions in this manual and the Appendix for more information on determining the type of membrane cleaning required. A short-term alternative should membrane cleaning not be feasible is to perform and automatic flush or to feed filtrate water through the system and soak the membranes in filtrate or permeate by leaving the filtrate or permeate water in the system overnight.
Abnormal Filtrate Flow – High Filtrate Flow	DEFECTIVE PRODUCT O-RING: If the filtrate o-ring(s) or seals are damaged, out-ofposition, or missing, concentrate water may be able to enter the filtrate or permeate piping and cause a dramatic increase in filtrate flow and decline in filtrate quality. Remove the fitting connections from the modules and examine the product-tube o-rings to ensure they are in position and free of nicks, cuts, debris and separations. (Note that the physical configuration of UF membranes vary, and some membrane modules may not use seals or o-rings) DEFECTIVE OR OXIDIZED MEMBRANE: If the membrane has been exposed to certain solvents or oxidants the membrane may suffer irreversible damage, evidenced by high filtrate flow and low solids rejection. UF membranes are made of an inert material (PVDF) that is highly chemical-resistant. In most cases, membrane replacement will be required to restore filtrate flow. Before replacing membranes, determine the source of the

	oxidation or other contaminant and install the proper pre-treatment. In addition, the UF membrane fibers can break, thereby allowing the feed water to enter the filtrate water. If the cause of the failure is unknown, obtain a return authorization from the membrane supplier and return the defective membrane for a destructive test and failure analysis.
Abnormal Filtrate Flow – Poor Filtrate Quality	LOW OPERATING PRESSURE: The filtrate quality and the concentrate (operating) pressure are directly related. Higher operating pressures typically result in greater solids removal. Increase the operating pressure by closing the concentrate valve slightly. If the pressure does not increase, check the mechanical devices as indicated previously. DEFECTIVE OR OXIDIZED MEMBRANE: If the membrane has been exposed to certain solvents or oxidants the membrane may suffer irreversible damage, evidenced by high filtrate flow and low solids rejection. In most cases, membrane replacement will be required to restore filtrate flow. Before replacing membranes, determine the source of the oxidation or other contaminant and install the proper pre-treatment. In addition, the membrane fibers can break, thereby allowing the feed water to enter the filtrate water. If the cause of the failure is unknown, obtain a return authorization from the membrane supplier and return the defective membrane for a destructive test and failure analysis.

Troubleshooting – UV Dechlorination System

Symptom	What to Do
UV SYSTEM NONPERFORMANCE - Chlorine Breakthrough	UV Lamp Maintenance ➔ Lamps may require maintenance Water Flow Too High ➔ If the capacity of the equipment exceeds the design capacity, then performance will be compromised. Water Quality ➔ If the water has debris, chemicals or materials that absorb the UV energy, the performance will be compromised. Quartz Sleeve Maintenance-Dirty ➔ The quartz sleeves may need maintenance. Sampling Procedures ➔ Sampling procedures can contribute to measuring errors. Concentration Spikes ➔ Contamination or concentration spikescan result in temporary negative performance. Piping Contamination ➔ System sanitation is critical. If the pipe system is contaminated, then performance may be flawed. Leaking ➔ Leaking can result in system contamination.
SYSTEM NOT OPERATING	Blown Fuse ➔ Check main fuse. A complete inspection to determine the cause of failure should be completed. Power to the Unit ➔ Main power to the unit should be checked.
LAMP IS NOT OPERATING ON LED DISPLAY(IS NOT YELLOW)	Lamp Failure ➔ The UV lamp should be inspected for damage. Replace UV Lamp.

Symptom	What to Do
	Lamp Connection ➔ The socket should be inspected to insure that the lamp connection is tight and no damage is present. Replace if defective. Ballast Overheating ➔ Each of the ballasts have an overheat circuit. When the ballast temperature reaches the preset temperature, the ballast automatically shuts “OFF”. When the ballast cools down, the ballast will reenergize. Excessive continuous heat will destroy the ballast. LED Board ➔ The LED board may be defective, indicating false lamp-out.
PREMATURE (LESS THAN 8,000 HOURS) LAMP FAILURE	Leaking/Water in Quartz Sleeve ➔ If water is present in the quartz sleeve, the leak should be repaired immediately. Water can cause the lamp socket to arc, corrosion on the lamp pins, burning of the lamp sockets and damage to the ballast and LED components. Ballast Power ➔ The ballast controls the current to the lamps. The lamps current should be measured to determine if the current is within specification. The ballast should produce 0.8 Amps to each lamp. Lamp Cycling ➔ Systems in which the UV is turned “ON“ and “OFF” frequently (more than 3X) will cause lamp filament damages. Electrical Power ➔Low equipment power will cause damage to the electrical equipment. The electrical power should be within 5% of the nameplate voltage. Small transformers may be required to boost low voltages. Electrical Connection ➔ Vibration can cause the electrical connections to become loose. The connections should be inspected and repaired if damaged.

Symptom	What to Do
	Heat ➔ Excessive heat from "no flow conditions" can damage the lamps. Mechanical Vibration ➔ Vibration from "water hammer", pumps and unsupported piping can cause excess stress to the lamp filament and equipment. Compression Nut ➔ Inspect the compression nut and O-ring to ensure that they are installed properly. Over Pressure ➔ System pressure greater than the design pressure will cause the sealing material to fail.
LEAKING	Gasket Failure ➔ The gasket and O-rings should be inspected for deterioration. These materials can be subjected to UV, ozone and heat, which is damaging to the material. O-Rings ➔ O-rings, which are not compressed properly, will cause the quartz sleeves to leak. Reinstall and replace the O-ring. Sealing Material ➔ O-ring and gasket material that are damaged due to UV, ozone and physical damage, will result in leaking. The material should be changed. "Water Hammer" ➔ "Water hammer" pressure can be 5 -10X higher than the static pressure of a water system. "Water hammer" can cause leaking and breakage to the quartz sleeves. Broken Quartz Sleeves ➔ The ends of the sleeves should be inspected for cracks and chips. Any broken sleeves should be replaced. Heat Damaged Part ➔ If the unit is operating with compression nuts manufactured with CPVC (gray plastic) and has been

Symptom	What to Do
	exposed to elevated temperatures, the compression nut may be damaged. Excessive heat can distort the plastic material, resulting in a loss in compression of the O-ring seal. Change compression nuts to stainless steel.

Troubleshooting – RO System

Trouble with the performance of an RO system normally means at least one of the following:

1. Loss of normalized permeate flow rate; in practice this is normally seen as a feed pressure increase in order to maintain the permeate output.
2. Increase in normalized solute passage; in RO this is typically associated with an increase in permeate conductivity.
3. Increase in pressure drop: the difference between feed pressure and concentrate pressure at constant flow rate becomes larger.

Changes of the permeate flow, the salt passage and the differential pressure are symptoms which can be attached to specific causes in many cases.
Although, the symptoms of different causes may over-lap in reality, and the symptoms are more or less pronounced in specific cases.
An overview of symptoms, their possible causes and corrective measures are given in the troubleshooting grid below

Permeate flow	Salt passage	Differential pressure	Direct cause	Indirect cause	Corrective measure
⇧	⬆	⇔	Oxidation damage	Free chlorine, ozone, $KMnO_4$	Replace element
⇧	⬆	⇔	Membrane leak	Permeate backpressure; abrasion	Replace element, improve cartridge filtration
⇧	⬆	⇔	O-ring leak	Improper installation	Replace O-ring
⇧	⬆	⇔	Leaking product tube	Damaged during element loading	Replace element
⬇	⇧	⇧	Scaling	Insufficient scale control	Cleaning, scale control
⬇	⇧	⇧	Colloidal fouling	Insufficient pretreatment	Cleaning, improve pretreatment
⇩	⇔	⬆	Biofouling	Contaminated raw water, insufficient pretreatment	Cleaning, disinfection, improve pretreatment

Permeate flow	Salt passage	Differential pressure	Direct cause	Indirect cause	Corrective measure
⇩	⇔	⇔	Organic fouling	Oil; cationic polyelectrolyte water hammer	Cleaning, improve pretreatment
⇩	⇩	⇔	Compaction	Water hammer	Replace element or add elements

Legend:
⇧: Increasing ⇩: Decreasing ⇔: Unchanged ⇩: Main Symptom

Low Flow

If the system suffers from loss of normalized permeate flow performance and the problem can be localized, the general rule is:

- First stage problem: deposition of particulate matter; initial biofouling
- Last stage problem: scaling
- Problem in all stages: advanced fouling

A low flow performance may be combined with a normal, a high or a low solute passage. Depending on this combination, conclusions as to the causes may be drawn.

Low permeate flow associated with normal solute passage

A. BIOFOULING AND NATURAL ORGANIC MATTER (NOM):

Biofouling of the membranes is indicated by the following changes in the operating parameters, predominantly at the front end of the system:

- Permeate flow decreases when operated at constant feed pressure and recovery.
- Recovery decreases when operated at constant feed pressure, in cases where biofouling is advanced to large biomasses.
- Feed pressure has to be increased if the permeate flow is to be maintained at constant recovery. Increasing the feed pressure is however self-defeating when done for a long time, since it increases the fouling, making it more difficult to clean later.

- Differential pressure increases sharply when the bacterial fouling is massive or when it is combined with silt fouling. Since pressure drop across the pressure vessels can be such a sensitive indicator of fouling, it is strongly recommended that provisions for installing differential pressure monitoring devices be included for each stage in a system.
- Solute passage remains normal or even low at the beginning, increasing when fouling becomes massive.
- High counts of microorganisms in water samples taken from the feed, concentrate, or permeate stream indicate the beginning or the presence of biofouling.
- Biofilms feel slippery to the touch, often have a bad smell
- A quick test for biofouling is the burn test: a sample of biofilm is collected with a spatulum or the point of a knife and incinerated over the flame of a lighter. The smell of a burnt biofilm is like the smell of burnt hair. *(This is really just a quick test for an indication but not for a proof.)*

Causes for biofouling are mostly the combination of a biologically active feedwater and improper pretreatment.
The corrective measures are:

- Clean and sanitize the entire system, including the pretreatment section and the elements. See *Section 6* for details. An incomplete cleaning and disinfection will result in rapid re-contamination.
- High pH soak and rinse – see cleaning instructions, *Section 6*
- The installation or optimization of the pretreatment system to cope with the fouling potential of the raw water
- Installation of Fouling Resistant (FR) elements.

B. AGED PRESERVATION SOLUTION

Elements or RO systems preserved in a bisulfite solution can also become biologically fouled, if the preservation solution is too old, too warm, or oxidized by oxygen. An alkaline cleaning usually helps to restore the permeate flow. Renew preservative solution if storing elements. Store in cool, dry, dark environment.

C. INCOMPLETE WETTING

RO elements that have been allowed to dry out, may have a reduced permeate flow, because the fine pores of the polysulfone layer are not wetted.

Low Flow and High Solute Passage

Low flow associated with high solute passage is the most commonly occurring condition for plant failure. Possible causes are:

A. COLLOIDAL FOULING

To identify colloidal fouling:

- Review recorded feedwater SDI's. The problem is sometimes due to infrequent excursions or pretreatment upsets.
- Analyze residue from SDI filter pads.
- Analyze accumulations on prefilter cartridges.
- Inspect and analyze deposits on feed scroll end of 1st stage lead elements.

The corrective measures are:

- Clean the elements depending on foulant.
- Adjust, correct and/or modify the pretreatment.

B. METAL OXIDE FOULING

Metal oxide fouling occurs predominantly in the first stage. The problem can more easily be localized when permeate flow meters have been installed in each array separately. Common sources are:

- Iron or aluminium in feedwater
- Hydrogen sulfide with air in feedwater results in metal sulfides and/or elemental sulfur.
- Corrosion of piping, vessels or components upstream of membrane elements.

To identify metal oxide fouling:

- Analyze feedwater for iron and aluminium.
- Check system components for evidence of corrosion.

Iron fouling can easily be identified from the look of the element (Brown substances)

The corrective measures are

- Clean the membrane elements as appropriate
- Adjust, correct and/or modify the pretreatment
- Retrofit piping or system components with appropriate materials.

C. SCALING

Scaling is a water chemistry problem originating from the precipitation and deposition of sparingly soluble salts. The typical scenario is a brackish water system operated at high recovery without proper pretreatment. Scaling usually starts in the last stage and then moves gradually to the upstream stages. Waters containing high concentrations of calcium, bicarbonate and/or sulfate can scale a membrane system within hours. Scaling with barium or with fluoride is typically very slow because of the low concentrations involved.

To identify scaling:

- Check feedwater analysis for the scaling potential at prevailing system recovery.
- Analyze the concentrate for levels of calcium, barium, strontium, sulfate, fluoride, silicate, pH and Langelier Saturation Index (Stiff & Davis Saturation Index for seawater). Try to calculate the mass balance for those salts, analyzing also feed water and permeate.
- Inspect concentrate side of system for scaling.
- Weigh a tail element: scaled elements are heavy.
- Autopsy tail element and analyze the membrane for scaling: the crystalline structure of the deposits can be observed under the microscope. A foaming reaction with acid indicates carbonate scaling. The type of scaling is identified by a chemical analysis, EDXRF or ICP analysis.
- Scaling is hard and rough to the touch – like sand paper. Cannot be wiped off.

The corrective measures are:

- Cleaning with acid and/or an alkaline EDTA solution An analysis of the spent solution may help to verify the cleaning effect.
- Optimize cleaning depending on scaling salts present.
- Carbonate scaling: lower pH, adjust antiscalant dosage.
- Sulfate scaling: lower recovery, adjust antiscalant dosage and type.
- Fluoride scaling: lower recovery, adjust antiscalant dosage or type.

Low Flow and Low Solute Passage

A. COMPACTION AND INTRUSION

Membrane compaction and intrusion is typically associated with low permeate flow and improved salt rejection. Compaction is the result of applied pressure and temperature compressing the membrane which may result in a decline in flux and salt passage. Intrusion is the plastic deformation of the membrane when pressed against the permeate channel spacer under excessive forces and/or temperatures. The pattern of the permeate spacer is visibly imprinted on the membrane. Intrusion is typically associated with low flow. In practice, compaction and intrusion may occur simultaneously and are difficult to distinguish from each other. Although the FILMTEC™ membrane shows little compaction and intrusion when operated properly, significant compaction and intrusion might occur under the following conditions:

- high feed pressure
- high temperature
- water hammer

Water hammer can occur when the high pressure pump is started with air in the system.
Damaged elements must be replaced, or new elements must be added to the system to compensate for the flux loss. If new elements are installed together with used elements, the new elements should be loaded into the tail positions of a system to protect them from too high flux operation. New elements should be distributed evenly into parallel positions. It should be avoided to have vessels loaded exclusively with new elements installed in parallel with other vessels containing exclusively used elements. This would cause an uneven flow distribution and recovery of the individual vessels.
For example, if six elements of a 4(6):2(6) system are to be replaced, the new elements should go into position 4,5 and 6 of each of the two vessels of the 2nd stage. Likewise, if six elements are to be added, they should go into positions 5 and 6 of the 3 vessels of the 2nd stage of an enlarged 4(6):3(6) system. If for some reason this is not possible, at least positions 1 and 2 of the first stage should not be loaded with brand new elements.

B. ORGANIC FOULING

The adsorption of organic matter present in the feed water on the membrane surface causes flux loss, especially in the first stage. In many cases, the adsorption layer acts as an additional barrier for dissolved salts, or plugs pinholes of the membrane, resulting in a lower salt passage. Organics with a high molecular mass and with hydrophobic or cationic groups can produce such an effect. Examples are oil traces or cationic polyelectrolytes, which are sometimes used in the pretreatment. Organics are very difficult to remove from the membrane surface.
To identify organic fouling:

- Analyze deposits from filter cartridges and SDI filter pads.
- Analyse the incoming water for oil and grease, as well as for organic contaminants in general.
- Check pretreatment coagulants and filter aids, especially cationic polyelectrolytes.
- Check cleaning detergents and surfactants.

The corrective measures are:

- Clean for organics. Some organics can be cleaned successfully, some cannot (e.g. heating oil).
- Correct pretreatment: use minimal coagulant dosages; monitor feedwater changes to avoid overdosing.
- Modify pretreatment, i.e. oil/water separators.

High Solute Passage

High Solute Passage and Normal Permeate Flow

High solute passage at normal permeate flow may have different causes.

A. LEAKING O-RING

Leaking O-rings can be detected by the probing technique. Inspect O-rings of couplers, adapters and end plugs for correct installation and as-new condition. Replace old and damaged O-rings.

O-rings may leak after exposure to certain chemicals, or to mechanical stress, e.g. element movement caused by water hammer. Proper shimming of the elements in a pressure vessel is essential to minimize the wear to the seals

Sometimes, O-rings have simply not been installed, or they have been improperly installed or moved out of their proper location during element loading.

B. TELESCOPING

RO elements can be mechanically damaged by an effect called telescoping, where the outer membrane layers of the element unravel and extend downstream past the remaining layers. A modest telescoping does not necessarily damage the membrane, but in more severe cases the glue line and/or the membrane can be ruptured. Telescoping is caused by excessive pressure drop from feed to concentrate. Make sure that a thrust ring is used with eight inch elements to support the elements' outer diameters.
Telescoping damage can be identified by probing and by a leak test Replace the damaged element(s) and correct the causes.

C. MEMBRANE SURFACE ABRASION

Crystalline or sharp-edged metallic particles in the feed water may enter into the feed channels and scratch the membrane surface. This would cause salt passage increase from the lead elements. Check the incoming water for such particles. Microscopic inspection of the membrane surface will also reveal the damage. Damaged membranes must be replaced. The prefiltration must be verified to cope with this problem. Ensure that no particles are released from the pump and the high pressure piping, and the piping has been rinsed out before the start-up.

D. PERMEATE BACKPRESSURE

When the permeate pressure exceeds the concentrate pressure by more than 5 psi (0.3 bar) at any time, the membrane may tear. The damage can be identified by probing and by the leak test and confirmed by a visual inspection during autopsy. When a leaf of a backpressure damaged element is unrolled, the outer membrane typically shows creases parallel to the permeate tube, usually close to the outer glue line. The membrane delaminates and forms blisters against the feed spacer (see Figure 8.8). The rupture of the membrane occurs mostly in the edges between the feed-side glue line, the outer glue line, and the concentrate-side glue line

High Solute Passage and High Permeate Flow

A. MEMBRANE OXIDATION

A high salt passage in combination with a higher than normal permeate flow is mostly due to oxidation damage. When free chlorine, bromine, ozone or other oxidizing chemicals are present in the incoming water, the front end elements are typically more affected than the others. A neutral to alkaline pH favors the attack to the membrane.
Oxidation damage may also occur by disinfecting with oxidizing agents, when pH and temperature limits are not observed, or when the oxidation is catalyzed by the presence of iron or other metals. In this case, a uniform damage is likely.
A RO element with just oxidation damaged membrane is still mechanically intact when tested with the *vacuum decay test*. The chemical membrane damage can be made visible by a dye test on the element or on membrane coupons. Autopsy of one element and analysis of the membrane can be used to confirm oxidation damage. No corrective action is possible. All damaged elements must be replaced.

B. LEAK

Severe mechanical damage of the element or of the permeate tubing can allow feed or concentrate to penetrate into the permeate, especially when working at high pressures. The vacuum test will show a distinct positive response. Possible causes are discussed in the next section.

High Pressure Drop

High differential pressure, also called pressure drop or Δp from feed to concentrate, is a problem in system operation because the flux profile of the system is disturbed in such a way that the lead elements have to operate at excessively high flux while the tail elements operate at a very low flux. The feed pressure goes up which means increased energy consumption. A high differential pressure causes a high force in flow direction on the feed side of the element. This force has to be taken by the permeate tubes and, in the case of 8" elements, by the membrane scrolls and the fiberglass shells of adjacent elements in the same vessel. The stress on the last element in the vessel is the highest: it has to bear the sum of the forces created by the pressure drops of upstream elements.
The upper limit of the differential pressure per multi-element vessel is 50 psi (3.5 bar), per single fiberglassed element 15 psi (1 bar). When these limits are exceeded, even for a very short time, the RO elements might become telescoped and mechanically damaged.
Eight-inch elements will break circumferentially at any location of the fiberglass shell, or the endcap will be pushed out, or the spokes of the endcap will break, or the feedspacer will be pushed out from the concentrate channels. Although such damage is easily visible, it does not normally affect the membrane performance directly. However, they indicate that the differential pressure has been too high. Cracks around the endcap cause bypass of feedwater and may lead to fouling and scaling.

An increase in differential pressure at constant flow rates is usually due to the presence of debris, foulants or scale within the element flow channels (feed spacer). It usually occurs together with a decreasing permeate flow, and the causes for that have been discussed above
An excessive pressure drop occurs when the recommended maximum feed flow rates are exceeded. It can also occur when the feed pressure builds up too fast during start-up (water hammer). The effect is dramatically increased with a foulant being present, especially biofilm causes a high pressure drop.
Water hammer, a hydraulic shock to the membrane element, can also happen when the system is started up before all air has been flushed out. This could be the case at initial start-up or at operational start-ups, when the system has been allowed to drain. Ensure that the pressure vessels are not under vacuum when the plant is shut down (e.g. by installation of a vacuum breaker); otherwise air might enter into the system. In starting up a partially drained RO system, the pump may behave as if it had little or no backpressure. It will suck water at great velocities, thus hammering the elements. Also the high pressure pump can be damaged by cavitation.
The feed-to-concentrate differential pressure is a measure of the resistance to the hydraulic flow of water through the system. It is very dependent on the flow rates through the element flow channels and on the water temperature. It is therefore suggested that the permeate and concentrate flow rates be maintained as constant

as possible in order to notice and monitor any element plugging that is causing an increase in differential pressure.
The knowledge of the extent and the location of the differential pressure increase provide a valuable tool to identify the cause(s) of a problem. Therefore it is useful to monitor the differential pressure across each array as well as the overall feed-to-concentrate differential pressure.

Some of the common causes and prevention of high differential pressure are discussed below.

A. BYPASS IN CARTRIDGE FILTERS

Cartridge filters have to protect the RO system from large debris that can physically block the flow channels in the lead-end elements. Such blocking can happen when cartridge filters are loosely installed in their housing, connected without using interconnectors, or completely forgotten.
Sometimes cartridge filters will deteriorate while in operation due to hydraulic shock or the presence of incompatible materials. Cellulose- based filters should be avoided because they may deteriorate and plug the RO elements.

B. PRETREATMENT MEDIA FILTER BREAKTHROUGH

Occasionally, some of the finer media from sand, multimedia, carbon, weak acid cation exchange resin, or diatomaceous earth pretreatment filters may break through into the RO feedwater.

C. PUMP IMPELLER DETERIORATION

Most of the multistage centrifugal pumps employ at least one plastic impeller. When a pump problem such as misalignment of the pump shaft develops, the impellers have been known to deteriorate and throw off small plastic shavings. The shavings can enter and physically plug the lead-end RO elements. It is suggested that the discharge pressure of RO pumps be monitored before any control valves as part of a routine maintenance schedule to see if the pump is maintaining its output pressure. If not, it may be deteriorating.

D. SCALING

Scaling can cause the tail-end differential pressure to increase. Make sure that scale control is properly taken into account, and clean the membranes with the appropriate chemicalsEnsure that the designed system recovery will not be exceeded.

E. BRINE SEAL ISSUES

Brine seal damage can cause a random increase in differential pressure. Brine seals can be damaged or ―turned over‖ during installation or due to hydraulic surges. This results in a certain amount of feedwater bypass around the element and less flow and velocity through the element, thus exceeding the limit for maximum element recovery. When this occurs, the element is more prone to fouling and scaling. As a fouled element in one of several multi-element pressure vessels becomes more plugged, there is a greater tendency for the downstream elements to become fouled due to insufficient concentrate flow rates within that vessel.
In case of fullfit or heat sanitizable elements there are no brine seals installed. This is to deliberately encourage a flow around the sides of the elements to keep them free from bacterial growth. Brine seals should not be installed in plants that use fulfil elements as there is no groove in the element to keep the brine seal in place, it would eventually become dislodged and cause unpredictable problems in the system.

F. BIOLOGICAL FOULING

Biological fouling is typically associated with a marked increase of the differential pressure at the lead end of the RO system. Biofilms are gelatinous and quite thick, thus creating a high flow resistance.

G. PRECIPITATED ANTISCALANTS

When polymeric organic anti-scalants come into contact with multivalent cations like aluminium, or with residual cationic polymeric flocculants, they will form gumlike precipitants which can heavily foul the lead elements. Cleaning will be difficult; repeated application of an alkaline EDTA solution may help.

GENERAL PRECAUTIONS FOR CHEMICAL HANDLING

1. For each chemical in use, all faculty, staff, and students shall make themselves aware of:

- Chemical hazards and appropriate safety procedures as described in the Material Safety Data Sheet (MSDS), as may be specified by the supervisor, and through other appropriate references, as may be necessary;
- The appropriate safety eyewear and other personal protective equipment to be used;
- Symptoms of exposure for the chemicals with which they work and with the precautions necessary to prevent exposure;
- Location and proper use of emergency equipment, including fire extinguishers, safety showers, and eyewash stations;
- Proper storage for the chemical when it is no longer in use;
- Appropriate personal work practices;
- Proper waste disposal procedures; and
- Emergency procedures, including spill clean-up methods and evacuation routes.

2. Do not block access to emergency showers, eyewashes, or exits.

3. Skin contact with chemicals is to be avoided, and all personnel are to wash hands before leaving the laboratory.

4. When working with flammable liquids, be certain that there are no sources of ignition nearby that might cause a fire or explosion.

5. Storage, handling, and consumption of food or beverages, or the application of cosmetics, is not allowed in laboratories or chemical storage areas, nor in refrigerators, glassware, or utensils used for laboratory operations.

CONTROL AND COMMUNICATION NETWORK

ISA -99(Industrial Automation and Control Systems Security)

The Network Architecture for SWaT system is constructed to comply ISA-99, a security standard designed for industrial Automation and Control Systems (IACS). This standard suggests a core concept which is "Zone and Conduits" and "Layer". It offers a level of segmentation and traffic control inside the Control and Communication Network.

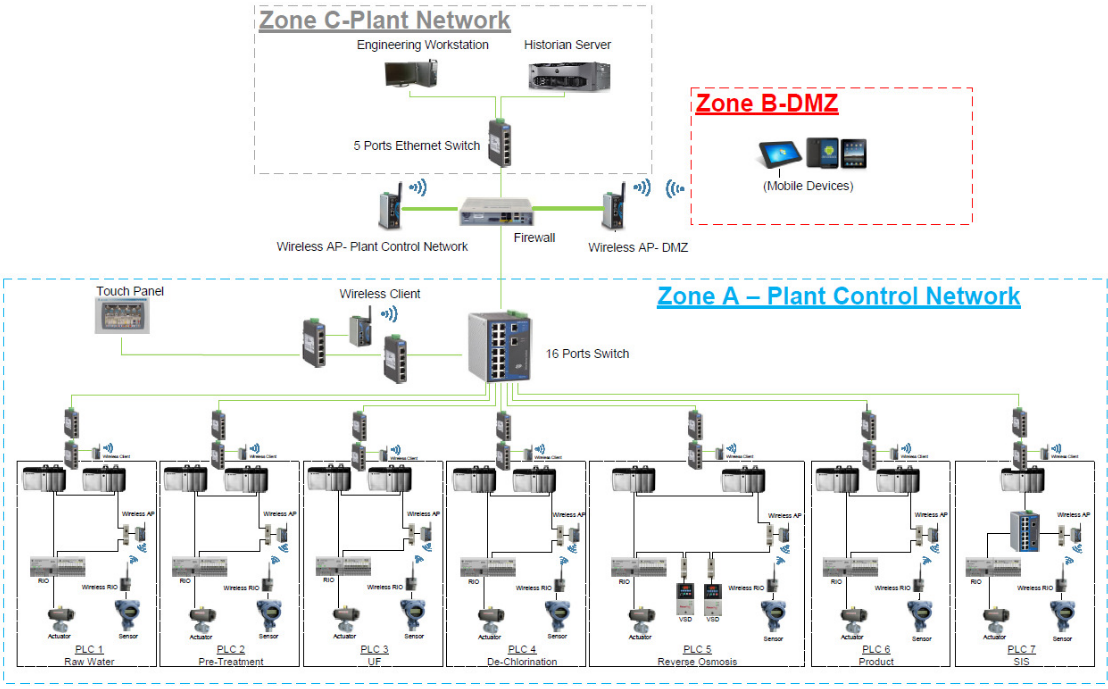


FIGURE 16: NETWORK ARCHITECTURE

Zones and Conduits

Zone is defined as a grouping of logical or physical assets that share common security requirements, which each zone has a clearly defined border. In SWaT, zones are defined as follow:

a. Zone A- Plant Control Network
b. Zone B- Demilitarized Zone (DMZ)
c. Zone C- Plant Network

FIGURE 17: ZONES

Conduit is a path for the flow of data between zones which provides the security functions that allow different zones to communicate securely. In base Wired- Network design, conduits are referring to the LAN network constructed by CAT 5 Ethernet cables. Meanwhile, conduits are also referring to the IEEE 802.11 wireless network.

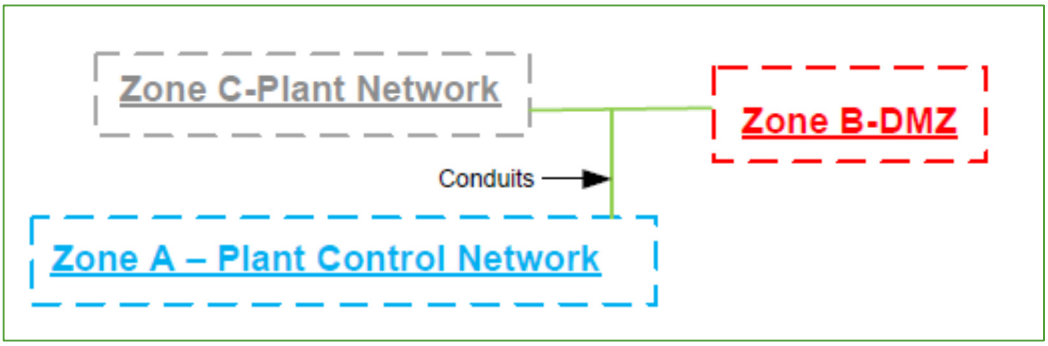


FIGURE 18: ZONES & CONDUITS

To secure the conduits and zones, industrial security is installed in each conduit using an Industrial Firewall Service Router which allows filtering of all traffic passing through that conduit. This firewall simplifies building intrinsically secured networks because it automatically blocks and reports any traffic for which there is no "allow" rule.

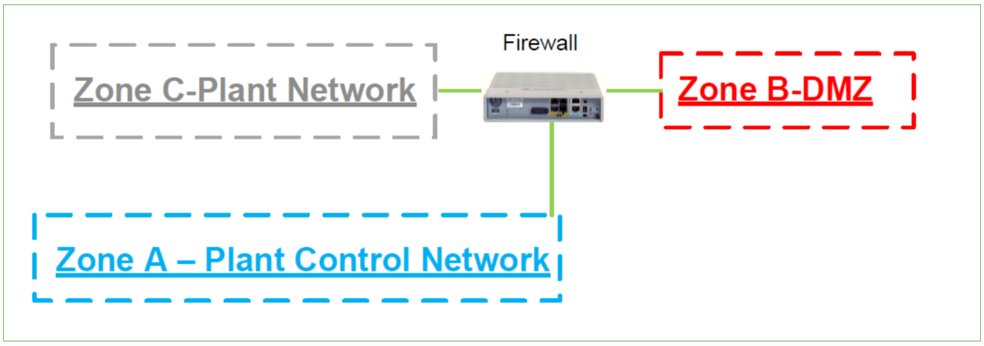


FIGURE 19: ZONE CONDUITS WITH FIREWALL

Layers

This Control and Communication Network is divided into layers based on control function as follow:

a. Layer 3.5- De-Militarized Zone (DMZ)
b. Layer 3- Operation Management (Historian)
c. Layer 2- Supervisory Control (Touch Panel, Engineering Workstation, HMI Control Clients)
d. Layer 1- Plant Control Network (PLCs)
e. Layer 0- Process (Actuator / Sensors and Input /output modules)

Layer 3.5 -Militarized Zone (DMZ)

Another benefit of implementing firewalls is its ability to establish DMZ between Plant Network and Control Network. In SWaT, DMZ holds the wireless access point or remote access . As shown in Figure 18 , the firewall blocking or limiting packets from Plant Network to Plant Control Network . By judicious use of access control, clear separation can be maintained between Plant Control Network with no traffic directly between ach zones.

Through the implementation of DMZ, remote access allows remote relevant personnel to access a particular portion of the Plant Control Network and Plant Network in the system. However, a secured Remote Access system must be in place to prevent any security attack. To offer a secured Remote Access system, the following common practices are recommended:

- Firewall/ DMZ allows tight control of the access into the network , including limiting the type of applications that can be used to access the plant applications , proxy to hide details about the network and devices and enabling IPS to monitor the traffic for known security attacks.
- Terminal services such as Remote Desktop Services (Microsoft based) or Virtual Network Computing (VNC). DMZ will enable the service to be hosted in a network zone where both internal and external personnel can access, but direct communication may be limited.

Layer 3 –Operation Management

Layer 3 is referring to the communication in between Engineering Workstation, Historian Server and Plant Control Network. It is implemented by using Star Topology and it consists of the following network components:

- Process PLCs
- Engineering Workstation
- Historian Server
- 5 Port Ethernet Switch

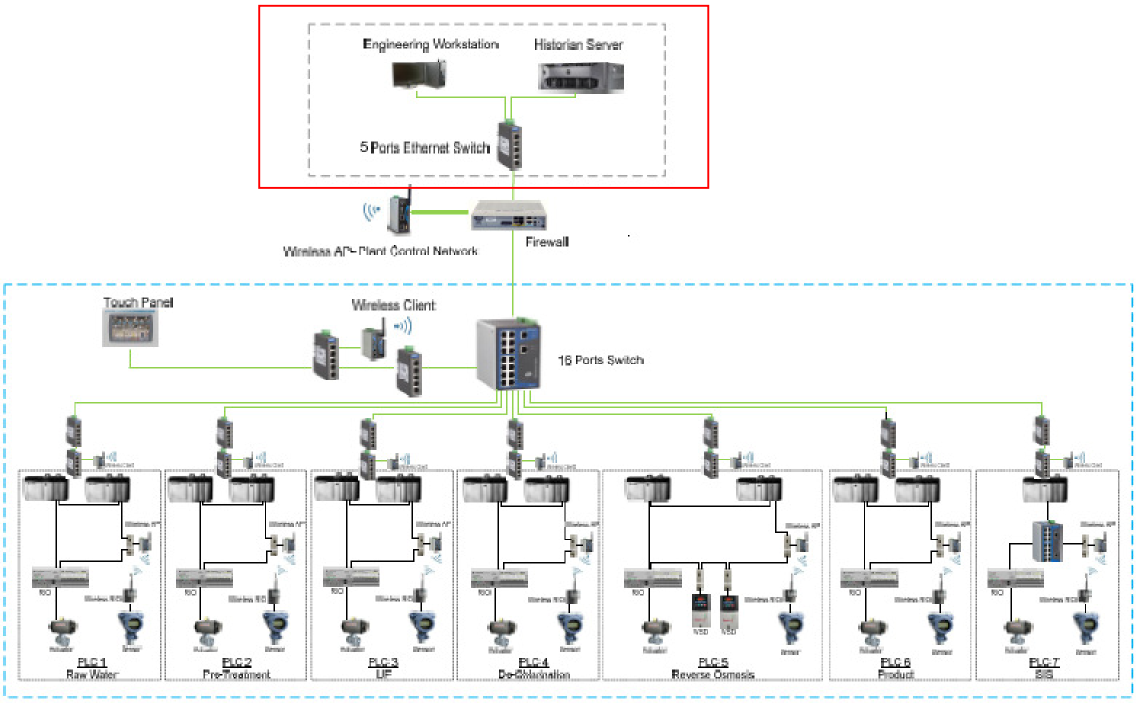


FIGURE 20: LAYER 3 –OPERATION MANAGEMENT

Layer 2 –Supervisory Control

Layer 2 is referring to the communication in between Touch Panel HMI and Plant Control Network. It is implemented by using Star Topology and it consists of the following network components:

- Process PLCs
- 5 Ports Ethernet Switches
- 16 Ports Ethernet Switches
- 802.11 Wifi Clients
- 15" Touch Panel HMI

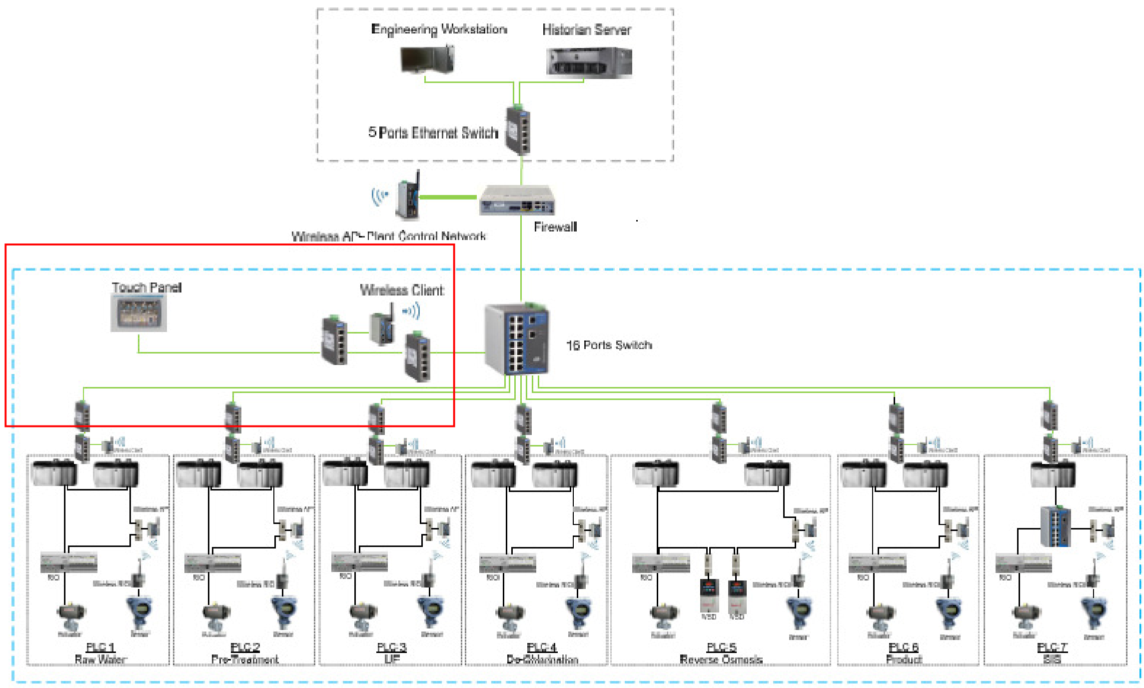


FIGURE 21: LAYER 2 –SUPERVISORY CONTROL

Layer 1 – Plant Control Network

Layer 1 is referring to the communication among Process PLCs. It is implemented by using Star Topology and it consists of the following network components:

- Process PLCs
- 5 Ports Ethernet Switches
- 16 Ports Ethernet Switches
- 802.11 Wifi Access Point
- 802.11 Wifi Clients

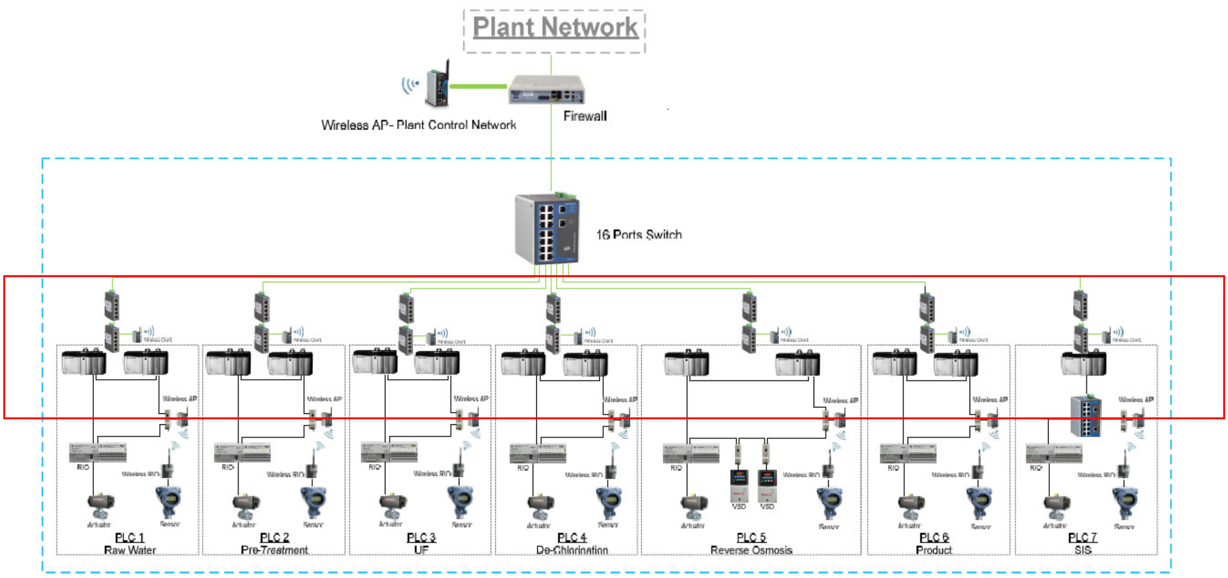


FIGURE 22: LAYER 1 –PLANT CONTROL NETWORK

Layer 0 – Process

Layer 0 is referring to the communication between sensors, actuator and among PLCs. It is implemented by "Device Level Ring". The Ring topology is able to tolerate Single Node Failure and Duty PLC controller is serving as the "Ring Supervisor"

Layer 0 consists of the following network components:

- Process PLCs
- Remote IO Adaptor
- Ring Network Adaptor
- Wireless Remote IO Adaptor

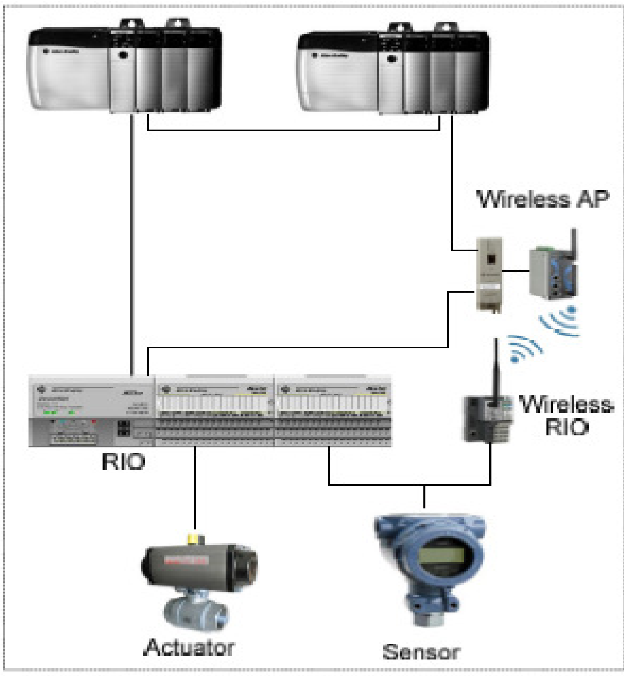


FIGURE 23: LAYER 0 –PROCESS

WIRELESS COMMUNICATION

Wireless Communication is also been constructed and configured as an alternative solution for Control and Communication Network based on the IEEE 802.11 Standard. The wireless communication is able to enable/disable by using key lockable selector switch located on enclosure front door. The wireless security implemented on the system is based on Temporal Key Integrity Protocol (TKIP) and Wifi Protected Access II-Advanced Encryption Standard (WPA2-AES).

It is implemented on the following layers:

- Layer 2- Communication among Touch Screen HMI and Process PLCs
- Layer 1-Communication among Process PLCs
- Layer 0- Communication between Remote IO and PLC

Wireless Communication –Layer 0

Wireless Communication is only implemented on monitoring devices such as Sensors, Analyzers. Electrical signal from monitoring devices (4-20mA) are duplicated by using current splitter and being send to both Flex IO Analog Input Module (with Ethernet Ports) and Point IO Analog Input module (with Wireless Adaptor). Control Devices such as pumps, actuator are still implemented using hardwired connection.

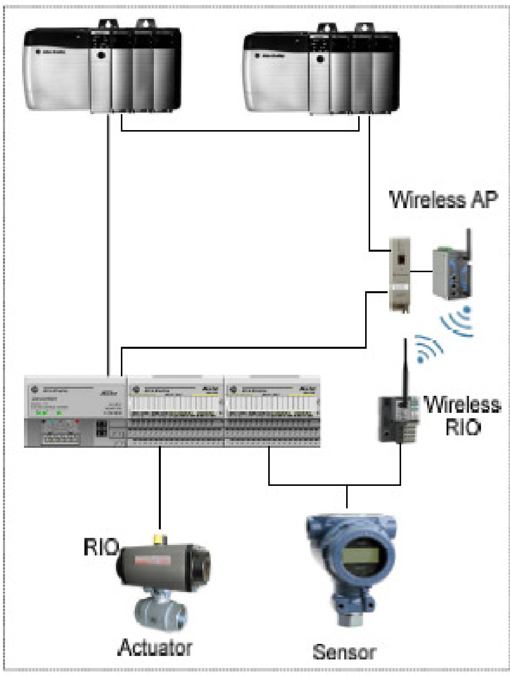


FIGURE 24: WIRELESS COMMUNICATION-LAYER 0

There is Wifi Access Point installed in layer 0, in order to establish the connection to Wireless IO adaptor in the event of wireless communication has been selected. The Wifi Access Points are being configured as follow:

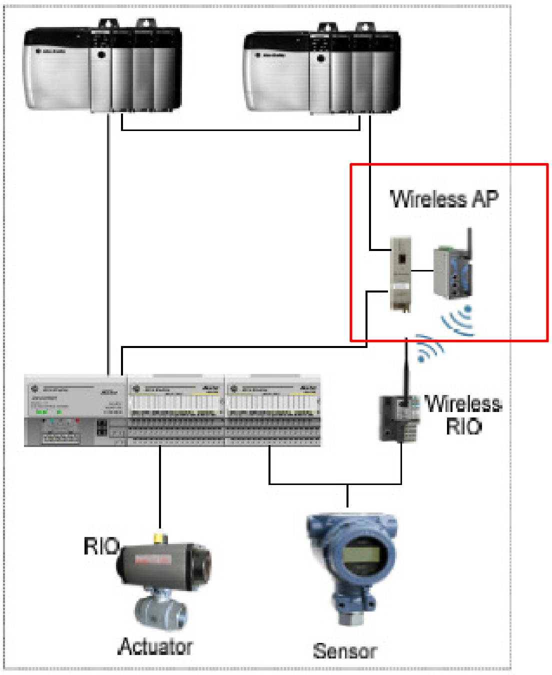


FIGURE 25: ACCESS POINT -LAYER 0

Country Code	EU
Operation Mode	AP
Channel	11
RF Type	B/G Mixed
Security Mode	WPA2
WPA Type	Personal
Encryption	AES

FIGURE 26: WIFI ACCESS POINT CONFIGURATION -LAYER 0

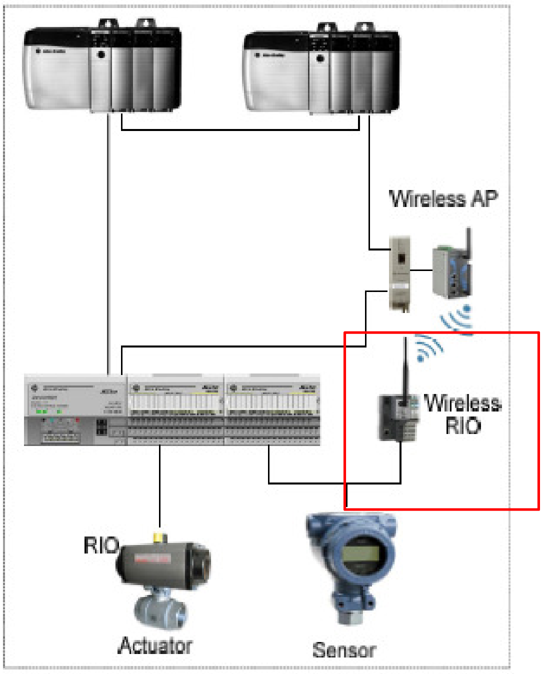


FIGURE 27: CLIENT -LAYER 0

Country Code	EU
Operation Mode	Client
Channel	11
RF Type	B/G Mixed
Security Mode	WPA2
WPA Type	Personal
Encryption	AES

FIGURE 28: WIFI CLIENT CONFIGURATION -LAYER 0

PLC	SSID	AES KEY
1	PLC_1_AP	PLC1APSWATSUTD
2	PLC_2_AP	PLC2APSWATSUTD
3	PLC_3_AP	PLC3APSWATSUTD
4	PLC_4_AP	PLC4APSWATSUTD
5	PLC_5_AP	PLC5APSWATSUTD
6	PLC_6_AP	PLC6APSWATSUTD
7	PLC_7_AP	PLC7APSWATSUTD

FIGURE 29: DEFAULT SSID AND AES KEY -LAYER 0

Enable Wireless Communication –Layer 0

To enable the wireless communication for layer 0 , user is required to make the selection by switching the selector switch to " Enable" position . By doing so, Flex IO Analog Input module will be turn off, and Wireless Access Point will be turn on. Wireless Remote IO Adaptor will establish the connection with Wireless Access Point and hence transfer the data between PLCs.

FIGURE 30: ENABLE WIRELESS SELECTOR SWITCH-LAYER 0

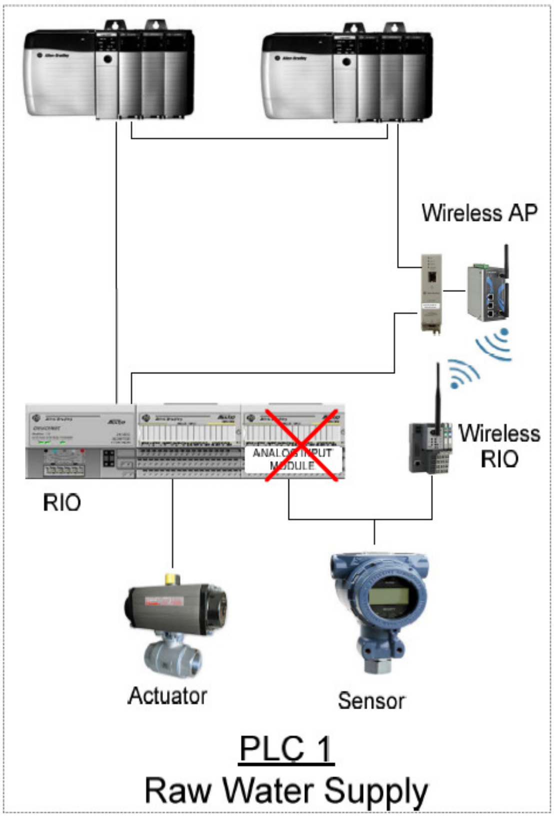


FIGURE 31: ENABLE WIRELESS COMMUNICATION- LAYER 0

Disable Wireless Communication –Layer 0

To disable the wireless communication for layer 0 , user is required to make the selection by switching the selector switch to " Disable " position . By doing so, Flex IO Analog Input module will be turn on, and Wireless Access Point will be turn Off. Data from Analog Input will now communicates with PLCs through Ethernet Ports on Flex IO Ethernet Adaptor

FIGURE 32: DISABLE WIRELESS SELECTOR SWITCH-LAYER 0

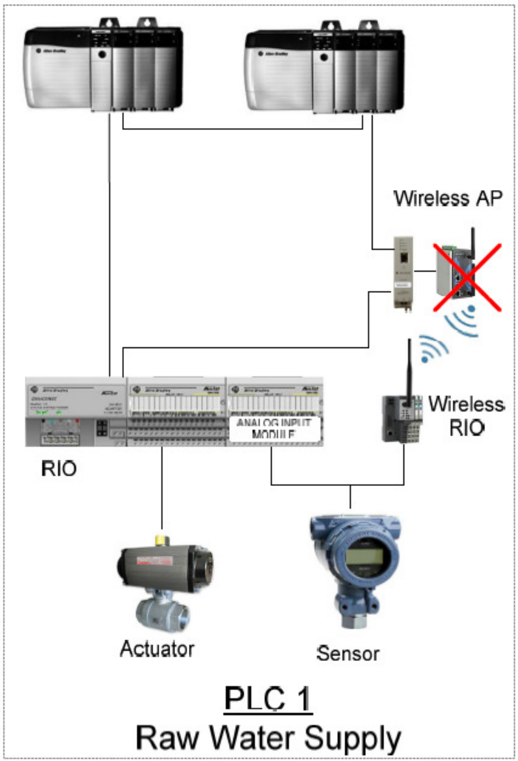


FIGURE 33: DISABLE WIRELESS COMMUNICATION – LAYER 0

Wireless Communication –Layer 1

There is a Wireless Access Point installed for the entire Plant Control Network. However there are individual Wireless Client installed in each PLC Enclosure so user is able to make individual Wireless Selection at respective PLC Enclosure. Similarly, user is requiring making the selection by using the selector switch on the front door of PLC Enclosure.

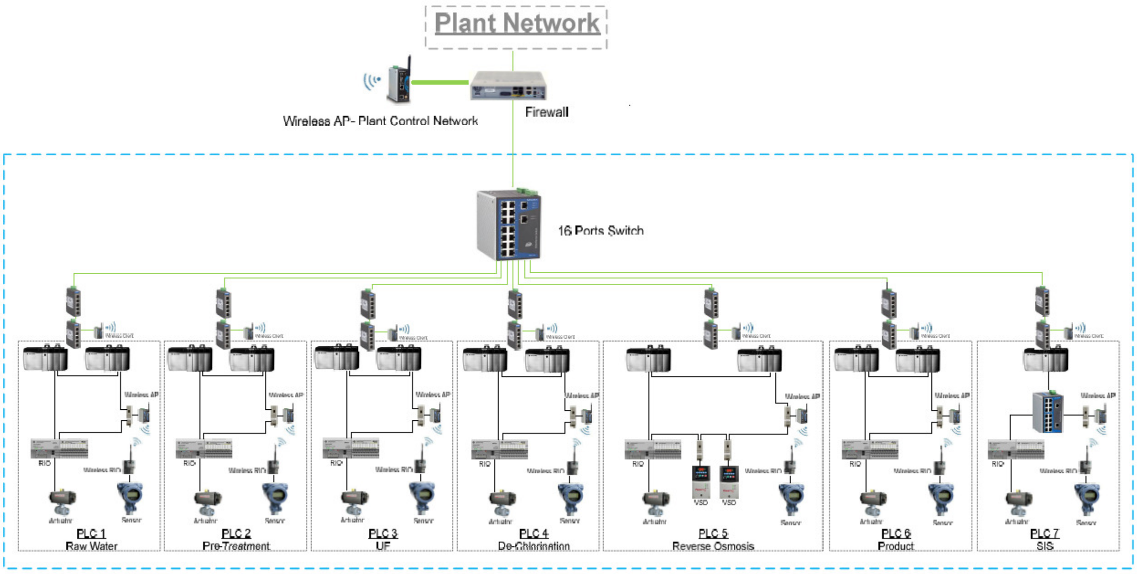


FIGURE 34: WIRELESS COMMUNICATION-LAYER 1

The Plant Control Network Wifi Access Point is being configured as follow:

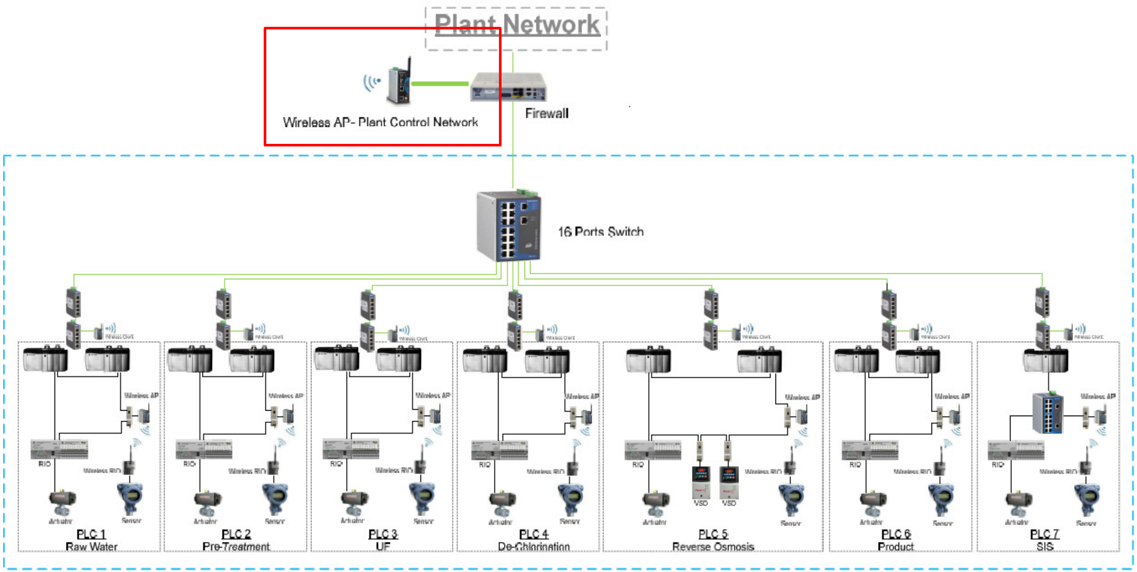


FIGURE 35: WIRELESS ACCESS POINT-LAYER 1

Country Code	EU
Operation Mode	AP
Channel	11
RF Type	B/G Mixed
SSID	PCN_AP
Security Mode	WPA2
WPA Type	Personal
Encryption	TKIP
AES KEY	PCNAPSWATSUTD

FIGURE 36: WIFI ACCESS POINT CONFIGURATION -LAYER 1

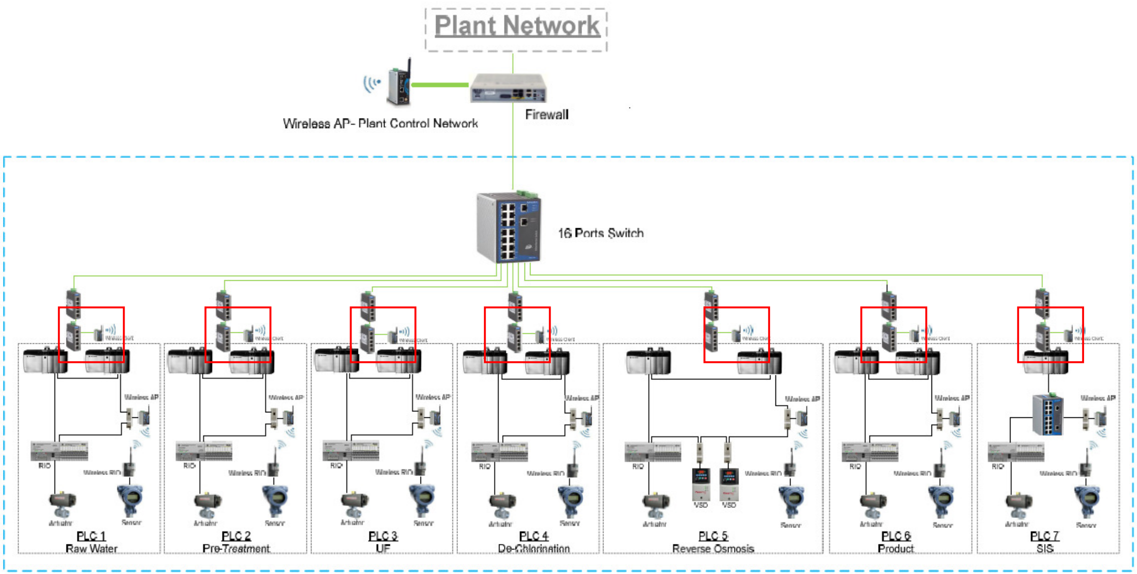


FIGURE 37: WIRELESS CLIENT-LAYER 1

Country Code	EU
Operation Mode	Client
Channel	11
RF Type	B/G Mixed
Security Mode	WPA2
WPA Type	Personal
Encryption	TKIP

FIGURE 38: WIFI CLIENT CONFIGURATION -LAYER 1

Enable Wireless Communication –Layer 1

To enable the wireless communication for layer 1 , user is required to make the selection by switching the selector switch to " Enable" position . By doing so, the respective Wireless Client will be turn On meanwhile the 5 port switch will be turn off.

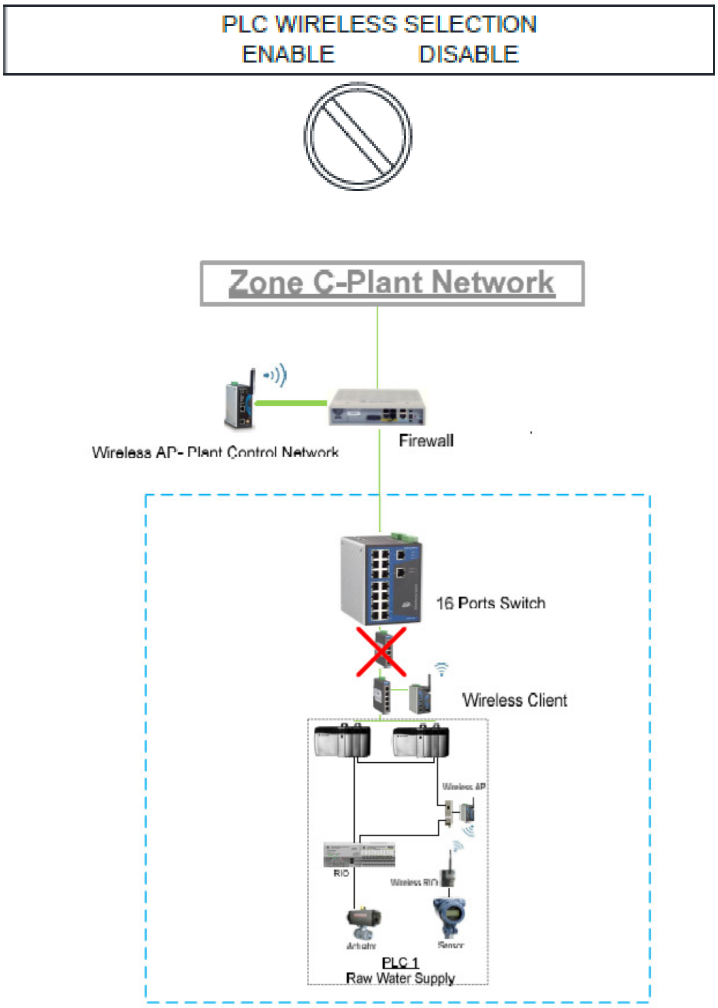


FIGURE 39: ENABLE WIRELESS COMMUNICATION – LAYER 1

Disable Wireless Communication –Layer 1

To disable the wireless communication for layer 1, user is required to make the selection by switching the selector switch to " Disable " position . By doing so the respective Wireless Client will be turn off meanwhile the 5 port switch will be turn on.

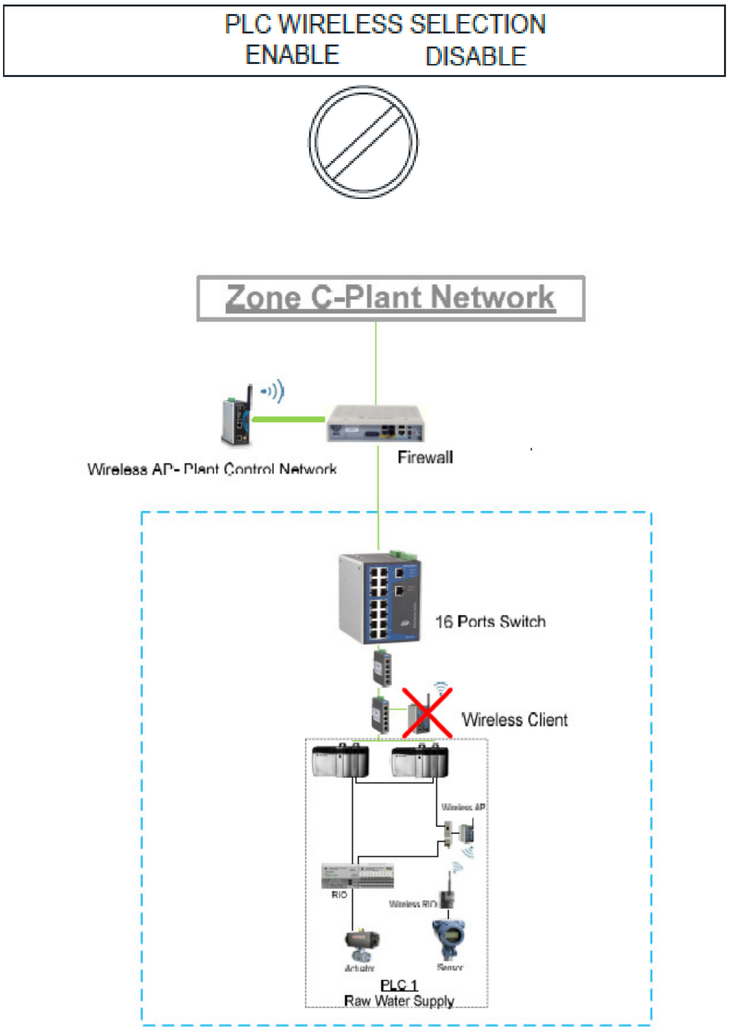


FIGURE 40: DISABLE WIRELESS COMMUNICATION – LAYER 1

Wireless Communication –Layer 2

In layer 2, Wireless Client installed for Touch Screen HMI I is able to communicate via Plant Control Network Access point. Similarly user is required to make the selection on Aux Panel

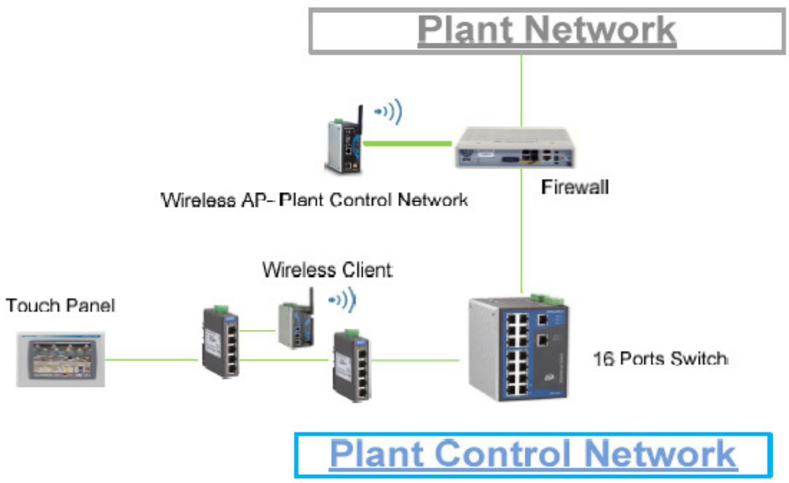


FIGURE 41: WIRELESS COMMUNICATION –LAYER 2

Enable Wireless Communication –Layer 2

To enable the wireless communication for layer 2 , user is required to make the selection by switching the selector switch to " Enable" position . By doing so, the Wireless Client installed in Aux Panel will be turn On meanwhile the 5 port switch will be turn off.

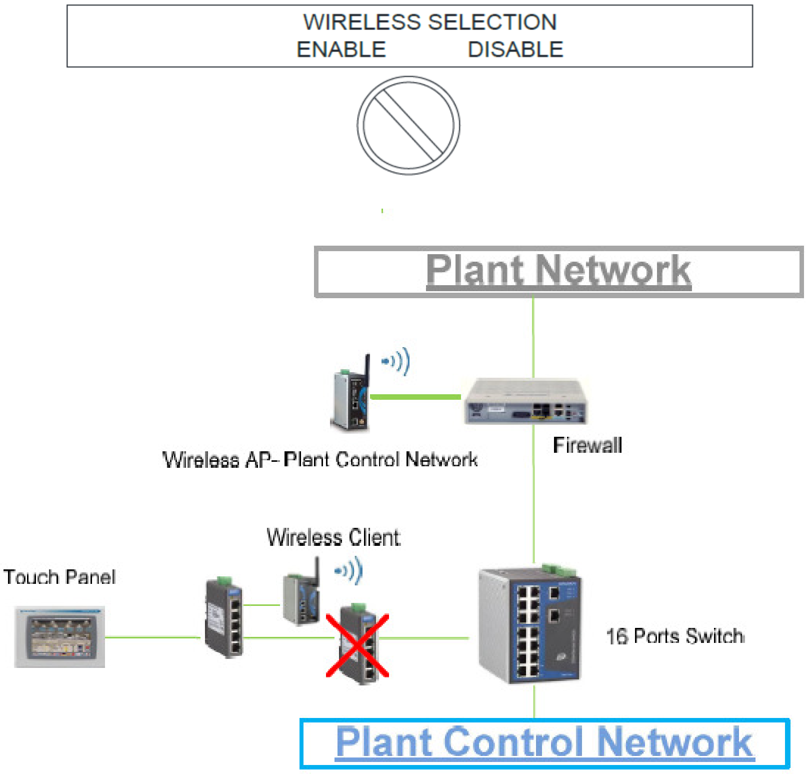


FIGURE 42: ENABLE WIRELESS COMMUNICATION – LAYER 2

Disable Wireless Communication –Layer 2

To disable the wireless communication for layer 2, user is required to make the selection by switching the selector switch to "Disable " position . By doing so the respective Wireless Client will be turn off meanwhile the 5 port switch will be turn on.

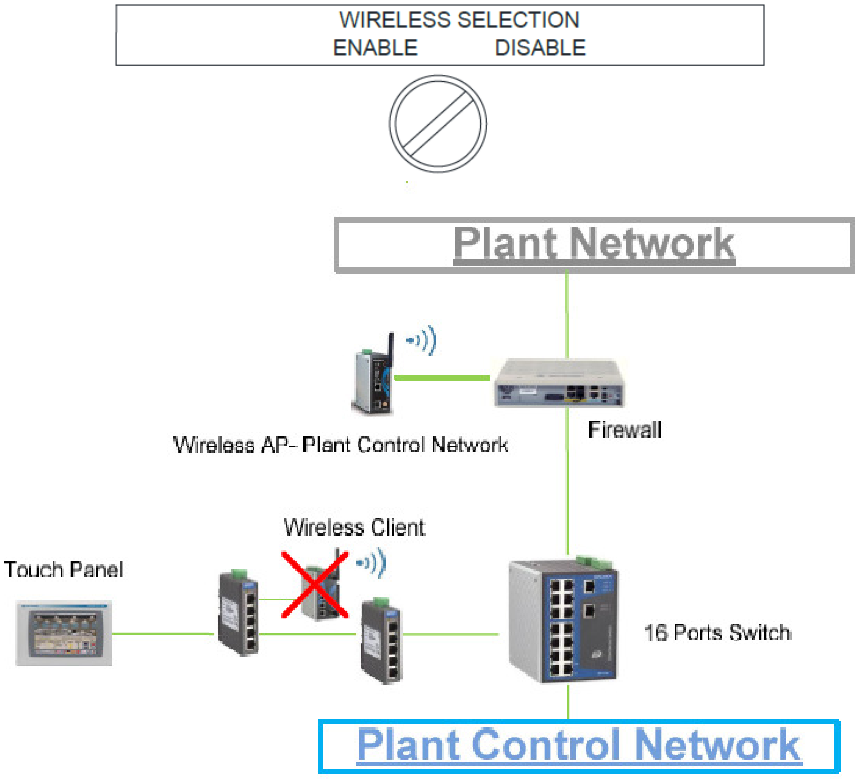


FIGURE 43: DISABLE WIRELESS COMMUNICATION - LAYER 2

Wireless Communication –Layer 3.5

There is a dedicated Wireless Access Point for DMZ , to allow the Remote Access through Tablets , laptop or mobile phones etc.

The DMZ Wifi Access Point is being configured as follow:

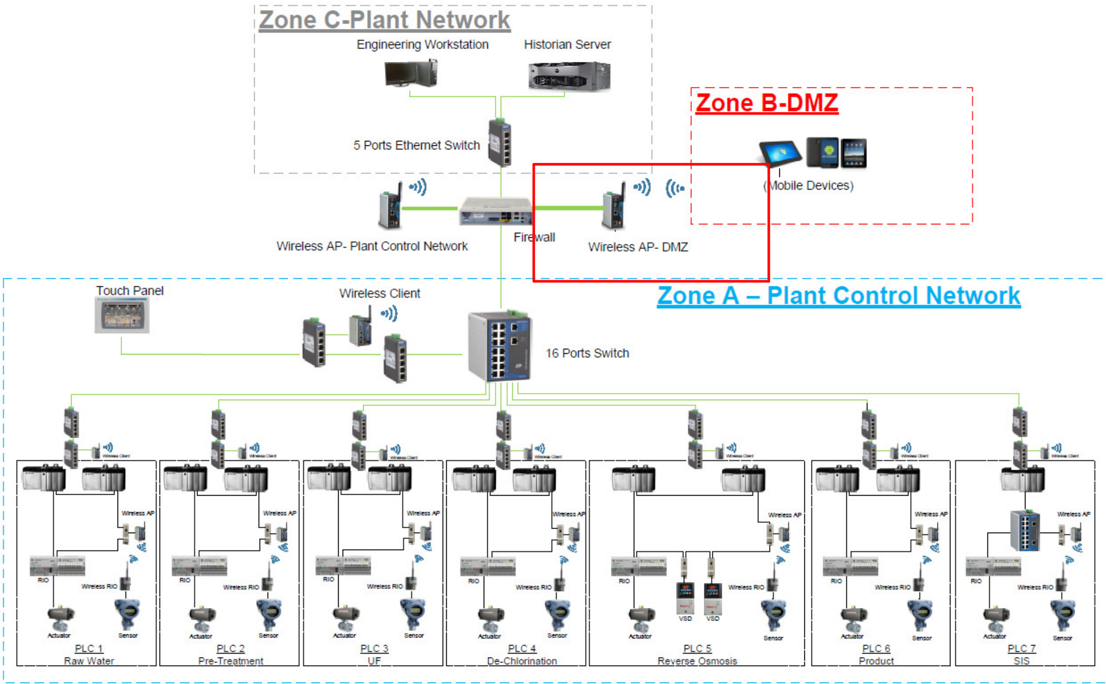


FIGURE 44: WIRELESS ACCESS POINT-LAYER 3.5

Country Code	EU
Operation Mode	AP
Channel	11
RF Type	B/G Mixed
SSID	DMZ_AP
Security Mode	WPA2
WPA Type	Personal
Encryption	TKIP
AES KEY	DMZAPSWATSUTD

FIGURE 45: WIFI ACCESS POINT CONFIGURATION -LAYER 3.5

PROGRAMMABLE LOGIC CONTROLLER (PLC)

Redundancy PLC (P1-P6)

Each of the six process PLCs will be provided with a set of redundant hot-standby PLC chassis and being connected to the same common Remote IO modules in order to control / monitor the plant equipments and instruments.

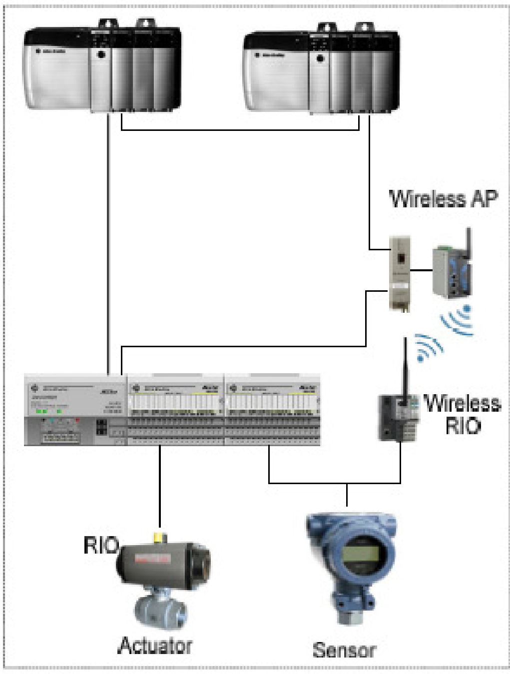


FIGURE 46: REDUNDANCY HOT STANDBY PLC

The redundant chassis pair will require matching components to enable the redundancy. Each Chassis in redundant chassis pair contains the following Control Logix Components

1756-PA2	Control Logix AC Power Supply Unit
1756-L71	Control Logix 2MB Controller
1756-EN2T	Ethernet I/P Module (For Layer 1)
1756-EN2TR	Dual Port Ethernet I/P Module (For Layer 0)
1756-RM2	Control Logix Redundancy Module
1756-RMC1	Control Logix Redundancy Fibre Optic Cable

Once the redundancy modules in the redundant chassis pair are connected (by Fibre Optic Cable) and powered up, the system determine which chassis is the Primary chassis and which is the secondary chassis.

The redundancy module sin both primary and secondary chassis monitor events that occurs in each of the chassis. If certain faults occur in the primary chassis, the redundancy modules execute a switch over to the un-faulted secondary chassis.

When the redundant system is first started, the redundancy modules checks on the redundant chassis to determine of the chassis contain the appropriate module to establish the redundant system. This is refer to as "Qualification"

After the redundancy modules complete qualification, synchronization took place. Synchronization is the state which the redundancy modules executes the following tasks

- Verify that the connection between redundancy modules is ready to switchover
- Verify that the redundant chassis continue to meet qualification requirements
- Synchronize the data between the redundant controllers also referring to "cross loading". The data being cross loaded :
    - Updated tag values
    - Force values
    - Online edits
    - Project information

Synchronization will always take places immediately following qualification.

During the operation of redundant system, any of the following condition will trigger a switchover from Primary chassis to secondary chassis:

- Loss of power
- Major Fault on controller
- Removal or insertion of any module
- Failure of any module

After the switch over, the new primary controller continues to execute programs that had been executing on the previous primary controller.

Experimental Security and Safety PLC (P7)

One multi-purpose PLC will be provided for experimental purpose. This PLC is intended to be used for security and safety research and shall be programmed and configured by SUTD. This PLC is able to interface all of the sensors and actuators in the system. Unlike six process PLCs, this seventh PLC will be provided in Single PLC chassis configuration.

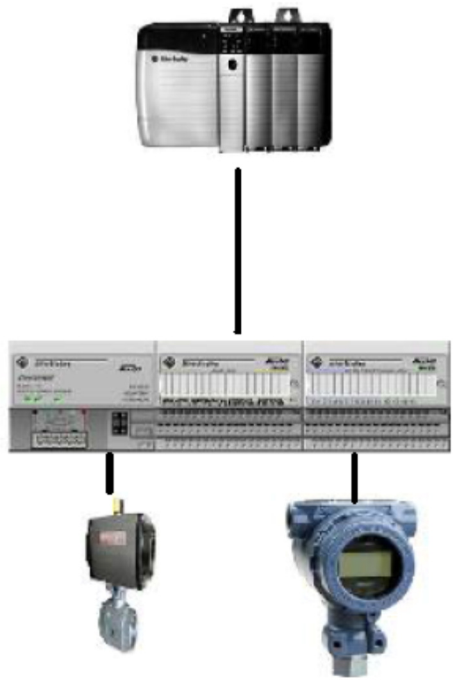


FIGURE 47: STANDALONE PLC

Remote Input and Output Modules

Remote Input and Output (RIO) modules are installed on act as the interfacing in between Process PLC and Process equipment and instruments.
Each RIO system in under each Process PLC consists of:

1794-AENTR	Flex Dual Port Ethernet I/P Adaptor
1794-IB32	Flex 32 Points Digital Input Module
1794-OB16	Flex 16 Points Digital Outputs Module
1794-IE12	Flex 12 Points Analog Input Module

The Remote IO system is being connected to each Process PLC controller (excludes PLC 7-SIS) by “Device Level Ring” topology which has been mentioned in “Layer 0 Communication”.

PLC PROGRAMMING METHODOLOGY

IEC-61131-3 is the third part of the open International standard IEC 61131 for PLC which deals with programming languages as follow:

- Ladder Diagram (LD) - Graphical
- Functional Block Diagram (FBD) , Graphical
- Structure Text (ST) , Textual
- Instruction List (IL), Textual

For SWAT, all PLC logic is developed mainly by using two types of programming languages, which provides a great expandability and flexibility:

- Functional Block Diagram (FBD) for all equipment i.e. pumps, valves, flow transmitter, level transmitter etc
- Structure Text (ST) for main sequence logic

Functional Block Diagram (FBD)

Functional Block Diagram (FBD) is a graphical language to describe the function between inputs variables (Status from Inputs Module, Command or Set point from SCADA) and outputs variables (Command to Outputs Module, Status to SCADA)
Functional Block Diagram will be used to develop for all following major equipment:

- Actuated Valves
- Pump (DOL/VSD)
- Transmitter with 4 to 20mA Analog Signal (Flow Transmitter, Level Transmitter, Analyzer)

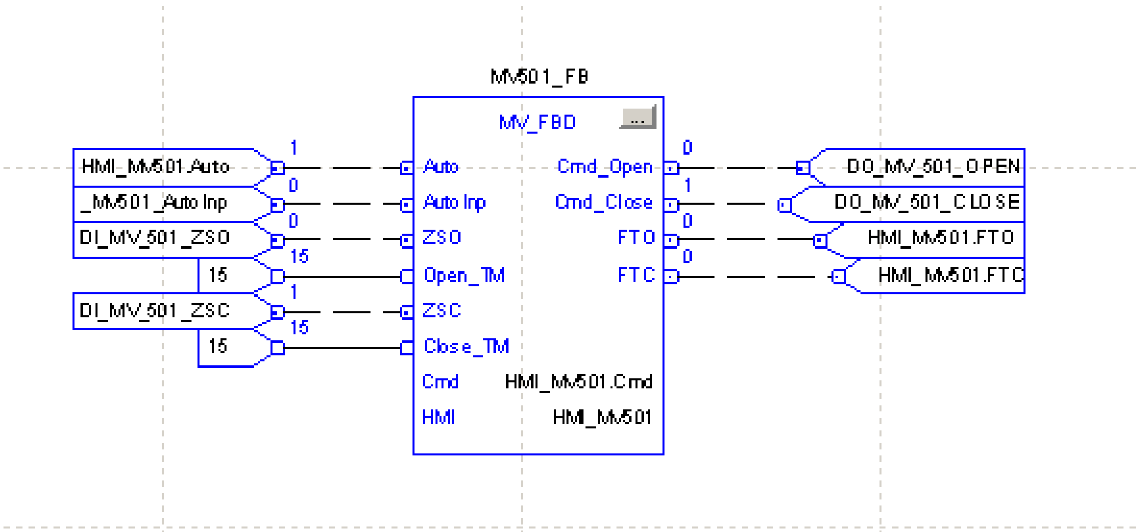


FIGURE 48 : ACTUATED VALVE FBD

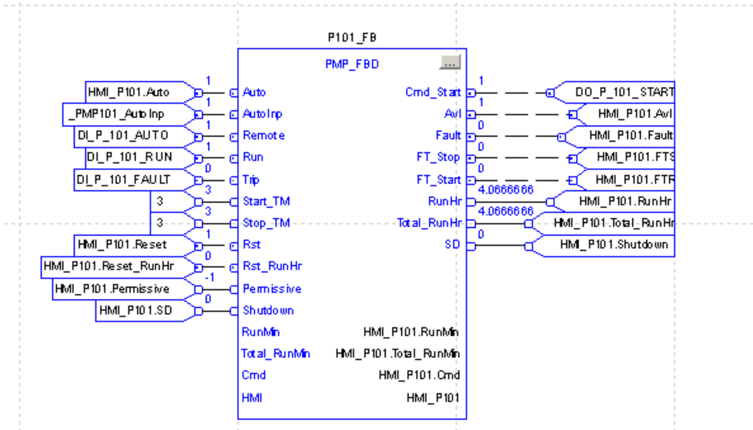


FIGURE 49 : PUMP FBD

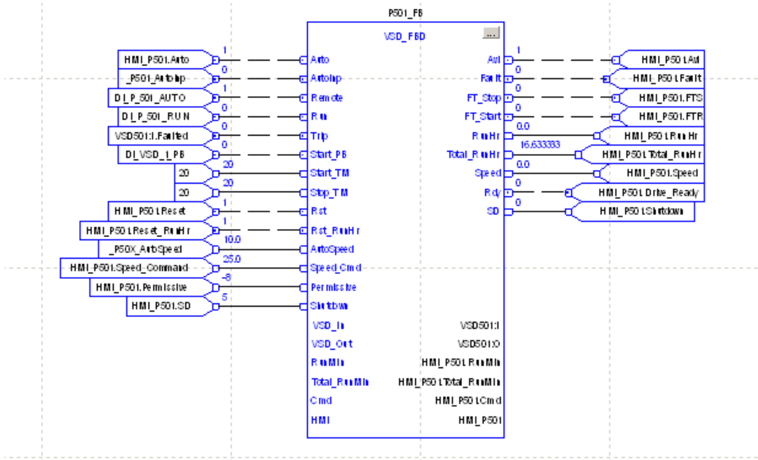


FIGURE 50 : PUMP(WITH VSD) FBD

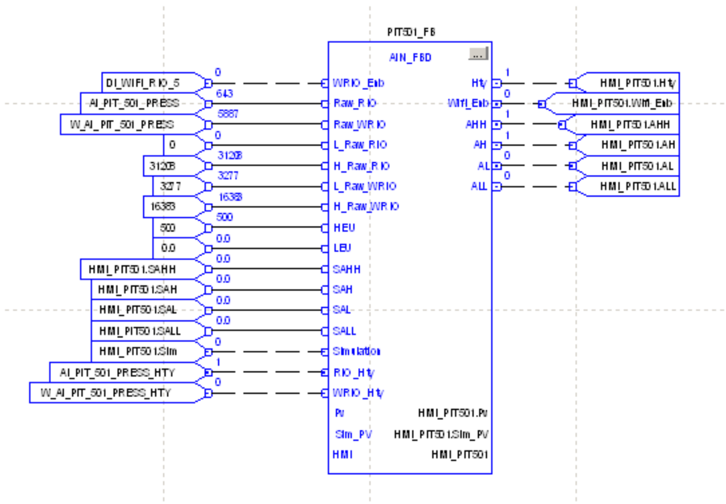


FIGURE 51 : ANALOG INPUT FBD

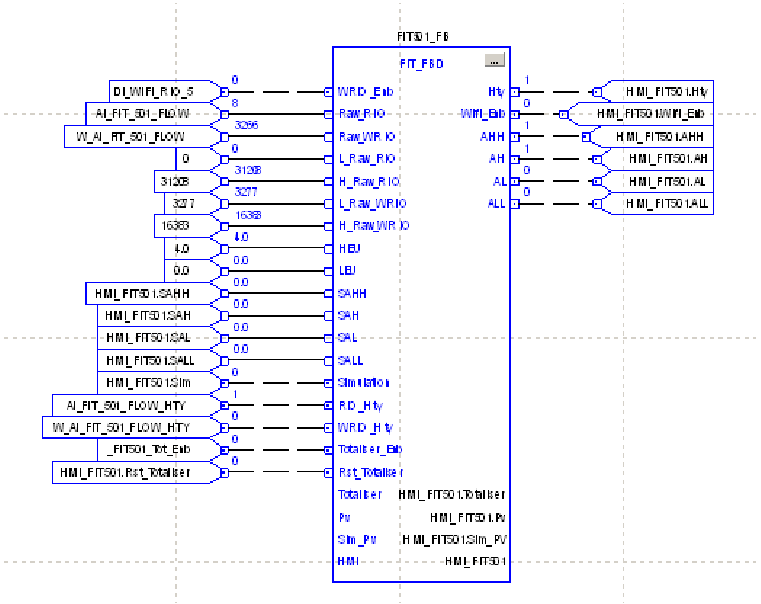
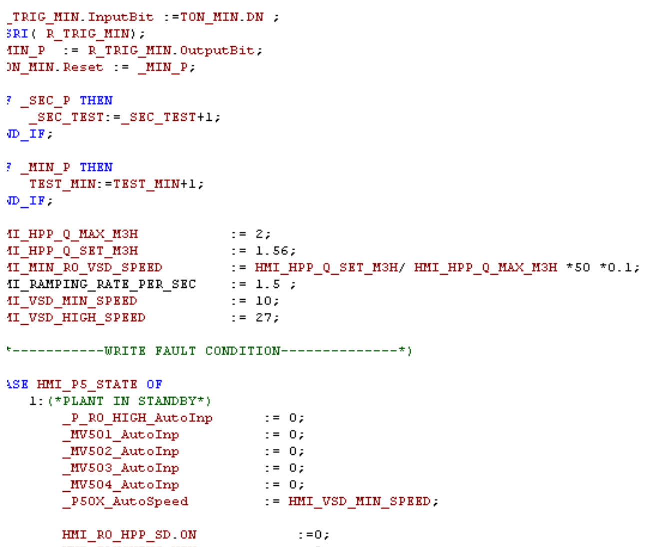


FIGURE 52 : FLOW METER FBD

Structure Text (ST)

Structure Text (ST) is a high level language that is block structured and syntactically resembles Pascal Complex statement and nested instructions are supported:

- Iteration loops (REPEAT-UNTIL; WHILE-DO)
- Conditional execution (IF-THEN-ELSE; CASE)



```
_TRIG_MIN.InputBit :=TON_MIN.DN ;
SRI( R_TRIG_MIN);
MIN_P   := R_TRIG_MIN.OutputBit;
ON_MIN.Reset := _MIN_P;

F _SEC_P THEN
   _SEC_TEST:=_SEC_TEST+1;
ND_IF;

F _MIN_P THEN
   TEST_MIN:=TEST_MIN+1;
ND_IF;

MI_HPP_Q_MAX_M3H           := 2;
MI_HPP_Q_SET_M3H           := 1.56;
MI_MIN_RO_VSD_SPEED        := HMI_HPP_Q_SET_M3H/ HMI_HPP_Q_MAX_M3H *50 *0.1;
MI_RAMPING_RATE_PER_SEC    := 1.5 ;
MI_VSD_MIN_SPEED           := 10;
MI_VSD_HIGH_SPEED          := 27;

*-----------WRITE FAULT CONDITION--------------*)

ASE HMI_P5_STATE OF
   1:(*PLANT IN STANDBY*)
      _P_RO_HIGH_AutoInp        := 0;
      _MV501_AutoInp            := 0;
      _MV502_AutoInp            := 0;
      _MV503_AutoInp            := 0;
      _MV504_AutoInp            := 0;
      _P50X_AutoSpeed           := HMI_VSD_MIN_SPEED;

      HMI_RO_HPP_SD.ON              :=0;
```

FIGURE 53 : STRUCTURE TEXT (ST)