MATRIX | INDUSTRIAL MAINTENANCE

Maintenance of Closed Loop Systems: Flow User Manual

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INTRODUCTION

This manual supports tutors, technicians and students in the safe use of the Closed-Loop Flow Training Rig. The rig demonstrates feedback-controlled pumping using a Siemens S7-1200 PLC and Unified HMI. Users can observe PID control, induce software or wiring faults, and practise industrial maintenance techniques aligned with EAL Level 3 Maintenance and T-Level Engineering & Manufacturing (8712 / 8713) outcomes.

Intended Audience;

- College / university students aged 16 +, studying industrial maintenance, mechatronics or process control.
- Instructors / technicians responsible for classroom delivery and equipment upkeep.

SAFETY INFORMATION

Read this section before operating the system. Failure to follow safety guidance may result in injury or equipment damage.

Hot Surface Warning	
Pump & Valve surfaces may exceed 45 °C during operation. Allow to cool before touching. **Symbol:** ISO 7010 W017 – Hot surface warning	
Electrical Equipment Caution	
24 V DC – disconnect power before opening or servicing. **Symbol:** ISO 7010 W012 – Risk of electric shock	
Moving Parts Warning	
Turbine inside flow sensor rotates at high speed. Do not insert objects. **Symbol:** ISO 7010 W001 – General warning	
Water Hazard Warning	

Safety Information

Risk of water spill. Do not operate with tank lid removed. **Symbol:** ISO 7010 W011 – Slippery surface	
Emergency Stop Instruction	
Push to stop. Twist to release. Simulated function only – not safety-rated. **Symbol:** ISO 7010 E007 - Emergency Stop	
Disconnect Before Maintenance	
Disconnect power before accessing wiring or components. **Symbol**: ISO 7010 M002	

Residual risk statement

This product has been designed to minimise hazards as far as reasonably practicable (ALARP). The following residual risks remain:

- Hot surfaces – pump and valve assemblies may exceed 40 °C during prolonged use.
- Water spills – leakage or overflow may occur during misuse or fault conditions.
- Rotating turbine – the flow sensor contains a moving part.
- Electrical exposure – although operating at 24 V DC, improper use may still pose risk.

Always keep the enclosure closed during operation and ensure users are supervised when in a learning environment.

Electrical safety

- Only use the supplied Class II (double insulated) 24 V DC power supply.
- Disconnect the PSU before performing any maintenance or inspection.
- Do not bypass the PLC by wiring the pump or valve directly to 24 V. This may result in uncontrolled operation and thermal damage.
- Inspect power cables periodically for signs of damage or wear.

Mechanical and thermal safety

- The pump and solenoid valve may reach surface temperatures of 45 °C. Allow components to cool before touching.
- Always open the hand valve before starting the system to prevent hydraulic shock.
- Do not restrict or bypass system piping while the pump is active.
- Never wire the solenoid directly to 24 V – this may cause overheating and permanent damage.

Personal protective equipment (PPE)

- No PPE is required under normal use.
- In a fault scenario involving water leaks or heat, basic hand protection may be advisable.
- In educational environments, ensure water is cleared promptly to prevent slip hazards.

EMERGENCY PROCEDURES

This system is intended for educational use and does not include a hardware-certified emergency stop circuit. The E-Stop is implemented in software only, without a safety relay, and is not compliant with BS EN 60204-1. However, it still performs a simulated safety function for training purposes.

In the event of unsafe or unexpected system behaviour, follow the procedure below:

- Press the Emergency Stop button. This simulates a dual-channel fault in the PLC and immediately disables pump and valve outputs.
- If the system does not respond, or remains active despite the E-Stop, immediately disconnect the 24 V DC power supply from the rear of the unit.
- Do not restart the system until the cause has been identified and addressed.
- Release the E-Stop by twisting clockwise, then press the Reset button before restarting.
- For issues that persist, check the Faults or IO screen for more information, or consult your instructor or technician.

Emergency Conditions Reference

Situation	Immediate action	Reset sequence
Emergency stop pressed	PLC disables pump and valve; status LED red	Twist E-Stop, press Reset, then press Start
Tank temperature > 40 °C	Software trip; pump and valve shut off	Allow cooling to below 38 °C, then press Reset
Low water level	Pump is turned off to prevent dry running	Top up tank, press Reset

Emergency Procedures

Situation	Immediate action	Reset sequence
Leak detected	Disconnect power, contain and clean spill	Inspect hoses, dry unit, reconnect and retest

This table provides a quick summary of typical emergency events and how to respond safely. Always refer to the full procedures and safety notes before resuming operation.

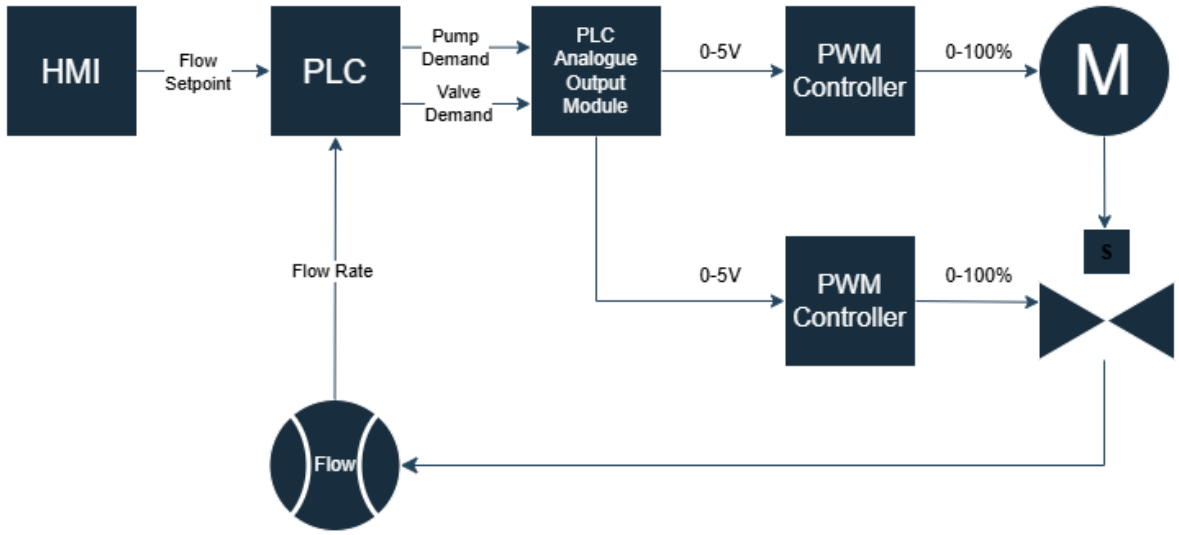
SYSTEM DESCRIPTION

Functional overview

The rig forms a recirculating water loop controlled to a user-defined flowrate. Sensor feedback is processed in the PLC's PID algorithm; speed-controlled pump and proportional valve form the final control elements. Simulated faults allow realistic diagnosis.

Block diagram

The diagram illustrates the control flow within the Closed-Loop Flow Training Rig, showing how user input, real-time sensor feedback, and actuator control work together to maintain a target flow rate. The system is fully automated and uses a Siemens S7-1200 PLC and Unified HMI.



PROCESS OVERVIEW

1. HMI
    - The user enters a desired flow setpoint via the HMI touchscreen.
    - This value is transmitted to the PLC for processing.
2. PLC
    - The PLC continuously compares the flow setpoint with the actual flow rate, measured by a turbine-type flow sensor.
    - It calculates how much the pump and valve need to open/close to meet the target.
    - The PLC generates two control values:
        - Pump Demand
        - Valve Demand
3. PLC Analogue Output Module
    - These demand values are output as 0–5 V analogue signals.
    - This signal range is appropriate for controlling external PWM controllers.
4. PWM Controllers (Pump & Valve)
    - Each controller converts the 0–5 V analogue signal into a PWM signal (0–100%).
    - PWM (Pulse Width Modulation) allows for precise speed and position control of:
        - The DC pump motor (flow generation)
        - The proportional valve (flow restriction)
5. Process Loop
    - The pump circulates water through the system.
    - The proportional valve fine-tunes flow rate.
    - Flow passes through the flow sensor, which sends live feedback to the PLC.
6. Feedback & Correction
    - If a disturbance (e.g. partially closed hand valve) reduces flow, the PLC detects this drop and increases pump or valve output as required.
    - This is a continuous closed-loop feedback control system, governed by PID logic in the PLC.

Process Overview

Key components

This training rig is built using real industrial-grade components to provide students and engineers with hands-on experience in closed-loop control, sensor interfacing, and fault diagnosis.

Each component has been carefully selected to align with UK industry standards, allowing learners to build confidence with hardware they're likely to encounter in real-world maintenance, process, and automation environments.

The following section outlines the purpose and capabilities of the core components used in the rig.

PLC – Siemens S7-1200 (CPU 1214C)
• **Purpose:** Central controller for logic, PID control, safety interlocks, and I/O processing
• **Key Features:**
  ○ 14x Digital Inputs, 10x Digital Outputs (24VDC)
  ○ 2x Analog Inputs (0–10V)
  ○ Handles PID algorithm for flow regulation.
  ○ Interfaces with HMI for setpoint, alarms, and diagnostics
	

AQ Module (Analog Output Module)
• **Purpose:** Provides analogue output signals (0–10V or PWM control) to actuators
• **Key Features:**
  ○ Controls proportional valve and pump via voltage or PWM
  ○ Enables smooth adjustment of flow rates.
  ○ Interfaces directly with field devices for closed-loop control
	

Process Overview

Unified HMI – Siemens Unified Basic Panel (MTP700)
• **Purpose:** Operator interface for real-time monitoring, fault display, and parameter input
• **Key Features:**
  ○ 7" touch screen for flow setpoint input and system feedback
  ○ Displays alarms, I/O status, PID values, and temperature cutoffs.
  ○ Setup page allows editing of temperature cutout limits and viewing system state
	

Pump – COMET 24V Immersion Pump
• **Purpose:** Drives water through the flow circuit
• **Key Features:**
  ○ Controlled by analogue signal (via PWM)
  ○ Variable speed to match flow setpoint.
  ○ Monitored for conditions like dry running and flow blockage
	

Valve – Burkert Proportional Solenoid Valve
• **Purpose:** Fine-tunes water flow based on PID control
• **Key Features:**
  ○ Receives analogue or PWM signal from AQ module.
  ○ Works with pump to maintain target flow.
  ○ Includes "deadband" behaviour (opens above 10% demand)
	

Process Overview

Tank – Water Reservoir with Integrated Safety Sensors
• **Purpose:** Holds system fluid and houses level and temperature sensors
• **Key Features:**
  ○ High and low float switches for overfill/dry run protection.
  ○ IFM PT100 RTD sensor for fluid temperature monitoring
  ○ Proximity switch on lid to detect open/closed state
	

TECHNICAL SPECIFICATIONS

The system is designed for safe, low-voltage use in training environments. Key electrical, mechanical, and environmental parameters are summarised below:

Parameter	Value
Supply voltage	24 V DC (via external double-insulated PSU)
Input current	1.5 A nominal, 2A peak
Power consumption	< 60 W
Fuse / MCB	3A type B MCB (Siemens 5SY4103-7)
Ingress protection	IP20 (training lab use)
Ambient temperature	5 °C … 35 °C
Tank capacity	3L nominal
Max flow	384 L/h (software limited to 300 L/h)
Max water temp	40 °C (software limit)
Noise emission	< 60 dB A at 1m
Overall dims (W×H×D)	520 × 435 × 461 mm
Mass	6 kg

Note: The rig operates at SELV levels only; no mains voltages are present inside the enclosure.

STANDARDS & COMPLIANCE

This product has been designed and assembled in accordance with the following UK and EU standards and directives to ensure electrical safety, electromagnetic compatibility, and suitability for use in educational and training environments:

BS EN 60204-1:2018 – Safety of machinery – Electrical equipment of machines

The system uses 24 V DC SELV switchgear, with compliant control wiring, labelled terminals, and a dual-channel emergency stop circuit in line with Clause 9.2.2.

> Note: While the E-Stop is dual-channel, it is not monitored by a safety-rated relay and does not remove power directly from actuators. The E-Stop functionality is processed in software via standard PLC inputs. This means the system does not meet full functional safety requirements (e.g. Performance Level d or Category 3). As such, it is not compliant for industrial machinery under the Machinery Directive but is considered acceptable for controlled educational use. A risk assessment and signage are provided to communicate this limitation.

BS 7671 (IET Wiring Regulations) – Requirements for Electrical Installations
All circuits operate below 50 V AC / 120 V DC, classifying the system under Safety Extra-Low Voltage (SELV). This eliminates the need for protective earthing and reduces electrical risk in an open-access training setting.

Low Voltage Directive (2014/35/EU)
Applies only to the external 24 V DC power supply unit, which is CE-marked and tested under EN 62368-1 for IT and AV equipment.

EMC Directive (2014/30/EU)
The system has been evaluated for electromagnetic compatibility and complies with:

EN 61000-6-1 / EN 61000-6-2 – Immunity for industrial environments

EN 61000-6-3 – Emissions for light industrial environments

Standards & Compliance

Machinery Directive (2006/42/EC)

This product is classified as partly completed machinery. It includes built-in safeguards, clear instructions, and a supporting risk assessment. The system is not suitable for unsupervised or production use and must be operated in a supervised training environment.

A formal UKCA / CE Declaration of Conformity is provided in Appendix D, along with supporting documentation covering electrical design, safety considerations, and component certifications.

DESCRIPTION OF COMPONENTS

This section describes all major components used in the training rig, organised into functional categories. Each item plays a distinct role in delivering safe, accurate, and realistic closed-loop control behaviour. Where relevant, drawing references are provided to aid in system understanding, maintenance, and fault-finding.

The categories are as follows:

- **Control Hardware**: The programmable logic controller (PLC) and HMI used for automation and user interface.
- **Safety Devices**: Components designed to detect unsafe conditions and shut down the system accordingly.
- **Operator Controls**: Push buttons and user input devices used to reset or manage system operation.
- **Indicators**: Visual indicators that show system state (e.g. running, faulted, or in E-Stop).
- **Actuators**: Final control elements that physically move water or restrict flow to meet process setpoints.
- **Sensors**: Devices that measure process variables such as flow, temperature, tank level, and lid status.
- **Power & Protection**: Electrical supply and protective devices ensuring the system operates within safe parameters.

Each item listed in this section includes a short description of its function within the system, the signal type it uses (if applicable), and how it interacts with the PLC and HMI. These components form the foundation for both the control logic and the training experience.

Description of Components

Control Hardware

1. Siemens S7-1200 PLC

Part Number: S7-1214C
Manufacturer: Siemens
Drawing Reference: PLC1

The S7-1200 is an industrial-grade Programmable Logic Controller (PLC) that forms the core of the system's control architecture. It executes real-time logic and manages all system input/output signals. In this training rig, it is responsible for:

- Executing the PID control loop for flow regulation
- Monitoring digital and analogue inputs (e.g. float switches, flow sensor, temperature)
- Driving outputs to the pump, valve, and indicators
- Handling fault detection, including software-simulated and physical wiring faults
- Managing system interlocks, emergency stop logic, and safety flags
- Communicating with the HMI via internal Ethernet

This PLC supports expansion if additional IO or communication modules are required.

2. Siemens Unified HMI – 7" Touch Panel

Part Number: MTP700 Unified Basic
Manufacturer: Siemens
Drawing Reference: HMI1

The HMI (Human-Machine Interface) provides a user-friendly touchscreen interface for operators and students to interact with the system. Key features include:

- Live visualisation of the process (flowrate, valve position, temperature) via mimic diagram
- Alarm and fault pages showing real-time errors with timestamps
- Setup menus for adjusting PID parameters, flow setpoints, and temperature cutouts
- Reset and control buttons, allowing the user to safely start or stop the system

- Navigation structure aligned with high-performance HMI principles for clarity and ease of use

The HMI is connected directly to the PLC over Ethernet and uses the Siemens Unified Runtime environment.

Safety Devices

3. Emergency Stop

Drawing Reference: S5

The emergency stop is a dual-channel, latching pushbutton assembly designed to safely shut down the system in the event of an emergency. It consists of:

- A large 40 mm red mushroom-head actuator, which is twist-release to reset.
- A yellow backing plate, providing visual compliance with machinery safety standards.
- Two normally closed (NC) contact modules, wired separately into the PLC for dual-channel monitoring, allowing detection of mechanical or wiring faults.

When activated, the E-Stop immediately stops system operation and triggers a safety fault condition shown on the HMI and stack light. The system remains locked out until the E-Stop is released and the reset button is pressed.

> Note: While this system simulates dual-channel E-Stop behaviour in software, it does not include a safety relay and does not fully meet the requirements of BS EN 60204-1 for industrial deployment. See the Safety section for details.

Operator Controls

4. Reset Button

Drawing Reference: S3

- Blue illuminated plastic push button (momentary)
- **Function:** Used to reset system faults and re-enable operation after an E-Stop or error

Description of Components

Indicators

5. Indicator – Multi-Colour LED Beacon

Model: Banner K50LGRYPQ
Type: Sealed RGB LED indicator beacon (not stack light)
Voltage: 18–30 V DC
Protection Rating: IP67 / IP69
Mounting: Base mount, M30 thread

This compact, high-visibility LED beacon provides clear indication of system status via full-surface colour changes:

- **Green** – System operating normally
- **Yellow** – Fault detected (e.g. flow error, temperature offset)
- **Red** – Safety stop or E-Stop triggered

Unlike traditional stack lights, this unit shows status via a single lens that changes colour. It is IP-rated for harsh environments, making it ideal for workshop and classroom conditions where visibility and robustness are critical.

Actuators

These components directly regulate the movement of water within the system, responding to control signals from the PLC as part of the closed-loop flow regulation process.

6. Proportional Solenoid Valve

Drawing Reference: SV1
This electrically actuated valve adjusts its opening based on a 0–10 V analogue signal from the PLC's analogue output module. It provides fine, continuous control over flow restriction, working in tandem with the pump to stabilise flow rate.

- Valve position is directly proportional to control voltage
- Fully open at 10 V, fully shut near 0 V
- Responds quickly to PID output for tight flow control

Description of Components

7. DC Immersion Pump

Drawing Reference: P1

A 24 V DC submersible pump used to drive water through the system loop. Pump speed is controlled using PWM (Pulse Width Modulation), enabling variable-speed operation:

- PWM duty cycle from 0% to 100% controls flow output
- The pump provides the primary pressure head in the loop
- Works in coordination with the valve to achieve setpoint

Together, these two actuators form the final control elements in the PID loop, reacting continuously to flow sensor feedback under PLC command.

Sensors

These components provide live system data to the PLC, enabling accurate closed-loop control, interlocks, and fault handling.

8. PT100 RTD Temperature Sensor with Transmitter

Drawing Reference: TH1

A precision temperature probe used to monitor the tank water temperature. It is paired with a 4–20 mA transmitter for robust signal delivery to the PLC.

- Accurate thermal feedback for process protection
- Used in over-temperature and under-temperature shutdown logic
- Configurable cut-out thresholds via HMI

9. Turbine Flow Sensor

Drawing Reference: FL1

A mechanical flowmeter that outputs **pulse frequency (PWM)** proportional to flow rate. The faster the internal rotor spins, the higher the pulse rate sent to the PLC.

- Main feedback input for the PID flow control loop
- Real-time display on HMI mimic and IO page
- Also used to simulate faults by applying offsets

Description of Components

10. Float Switch – Low Level (Normally Closed)

Drawing Reference: FS1

A safety-critical switch that opens when tank water drops below minimum level.

- Immediately stops the pump to prevent dry running
- Status displayed on HMI IO and fault page
- Triggers warning and blocks system start

11. Float Switch – High Level (Normally Open)

Drawing Reference: FS2

Mounted near the tank top to prevent overfilling.

- Closes contact when water reaches critical height
- Triggers fault condition and halts pump operation
- Supports overflow detection in fault scenarios

12. Inductive Proximity Sensor (Tank Lid Detection)

Drawing Reference: PX1

Detects whether the tank lid is open or closed using non-contact metal sensing.

- Interlock to prevent operation with open lid
- Flicker mode used to simulate intermittent sensor faults
- Status shown on IO page and used in safety logic

Power & Protection

13. 24 V DC Power Supply (Class II Isolated)

Drawing Reference: PSU1

Converts mains input to a **safe SELV 24 V DC output** for all system components.

- CE/UKCA marked
- Double-insulated (no protective earth required)
- Plug-in barrel connector simplifies setup

14. 3 A Miniature Circuit Breaker (Type B, 1P)

Drawing Reference: MCB1

Protects the low-voltage circuit from overcurrent and short circuits.

- Fast tripping on fault detection
- Mounted in rear panel and labelled for isolation
- Compliant with BS EN 60898 and BS EN 60204-1

UNPACKING & INSTALLATION

1. Inspect packaging for transit damage.
2. Verify contents against packing list (Appendix B-1).
3. Place rig on a level bench; leave 100 mm clearance each side.
4. Connect **24 V DC > 2.5 A** supply to barrel jack (centre +).
5. Fill tank with **clean water** up to MAX mark.

COMMISSIONING / START-UP

Step	Action	Expected result
1	Release E-Stop & press **Reset**	Status light green
2	On HMI, press **Start**	Pump & valve ramp up/open
3	Setpoint defaults to 150 L h-1	Flow settles within ±5 L h-1
4	Close hand valve 50 %	Valve demand increases, pump speed rises
5	Close the hand valve fully	Amber fault, pump stops
6	Press **Reset**	System ready to restart

Commissioning Advice

- Check tank level before starting float switches must be free and not submerged above limit.
- Ensure hand valve is initially fully open to allow proper flow ramp-up.
- Observe valve % demand and pump speed on the HMI as you restrict flow this demonstrates the system’s closed-loop response.
- When the hand valve is fully closed, the system will fail to reach setpoint, triggering a PID unreachable fault this is expected and useful for training.
- Use this process to familiarise students with how a real PID system behaves under load conditions and restrictions.

Commissioning / Start-up

Resetting the system after a fault ensures all logic paths are cleared before re-enabling outputs. Always observe the status light and fault page for confirmation.

Air Lock Advisory

In some cases, especially after draining and refilling the tank, air may become trapped in the system. This can prevent the pump from building sufficient pressure to establish flow, even when running at full speed.

To resolve this, you may need to manually assist the system in purging the air. Please see the troubleshooting section of this document for more details.

NORMAL OPERATION

Once the system has been successfully commissioned, it can be operated via the HMI interface. The flow control loop will continuously adjust pump speed and valve position to match the user-defined setpoint based on feedback from the flow sensor.

Setpoint Adjustment

The flow rate setpoint is adjusted using the + / – buttons on the HMI.

- Adjustment step: 20 L/h increments
- Operating range: 0–300 L/h
- Changes to the setpoint will be processed by the PLC and reflected immediately in the control output signals sent to the pump and valve.

System Feedback

The Main Mimic screen provides real-time visualisation of the system's process status:

- Flow Rate – shows measured flow from flow sensor
- Pump demand (%) – indicates PWM output to the pump
- Valve position (%) – shows how far the valve is open
  This screen enables clear monitoring of control behaviour and response to any disturbances or manual interventions.

Fault Indication

If the system enters a fault condition, the indicator beacon will display amber.

- Navigate to the Faults page on the HMI to identify the active condition
- Review sensor readings on the IO screen for further diagnostic information
- Once the issue is resolved, press the Reset button to clear the fault and restore normal operation

Normal Operation

Fault Insertion Mode

The system includes a fault simulation feature accessible via the HMI menu.

- Selecting Random Fault will disable standard Faults and Alarms pages
- One of eight predefined faults will be injected into the system (see §13.3)
- The user must identify the source of the fault using live IO data and wiring diagrams

This mode is intended to support functional testing and system validation in controlled environments.

HMI MANUAL

The Human-Machine Interface (HMI) provides a structured and user-friendly way to operate, monitor, and diagnose the system. It is divided into clearly labelled screens, accessible via the Main Menu, each serving a specific function.

This section of the manual explains the purpose and layout of each screen, including how to interact with system controls, view real-time data, respond to faults, and configure operating parameters.

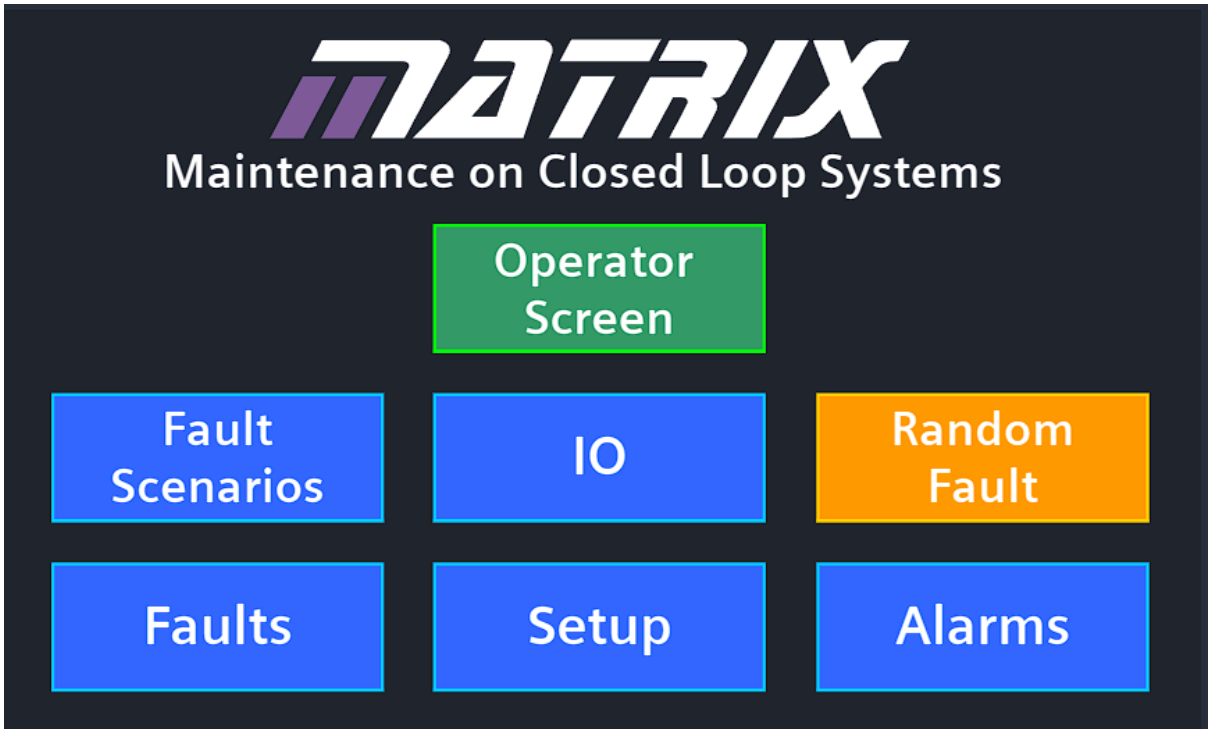
The HMI consists of the following main screens:

- **Main Menu** – Central navigation point to access all other screens
- **Main Mimic (Start Program)** – Live visualisation of the system with flow controls and status indicators
- **Scenarios** – Predefined troubleshooting or diagnostic scenarios (if applicable)
- **IO** – Displays raw input and output signals for monitoring and diagnostics
- **Faults** – Shows active software or hardware faults with logic status
- **Alarms** – Time-stamped alerts for flow, temperature, level, or safety issues
- **Setup** – Configuration screen for PID tuning, setpoint limits, and cut-out thresholds

Each screen is designed for clarity and ease of use, supporting both normal operation and fault investigation workflows.

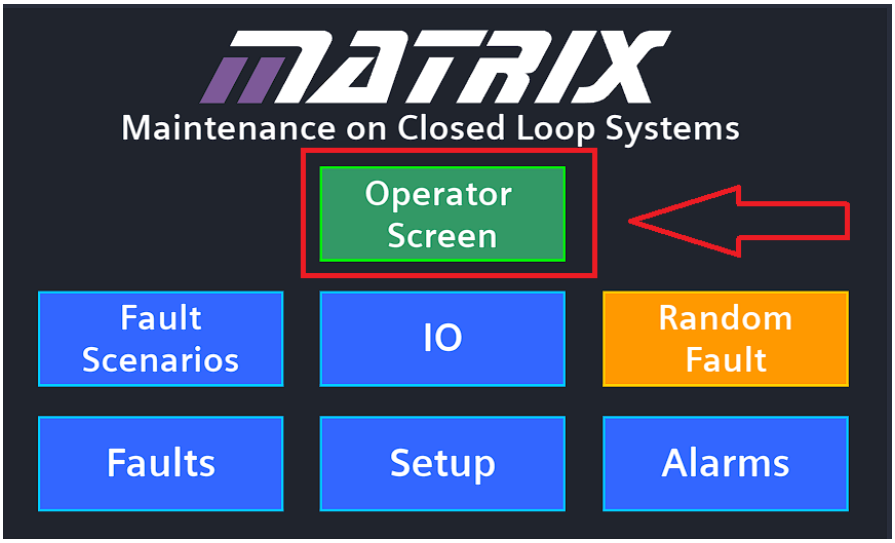
Main Menu Screen

This is the screen that loads when the software starts. It serves as the main navigation panel and all other screens have a “Menu” button in the top left corner that leads back to this screen.



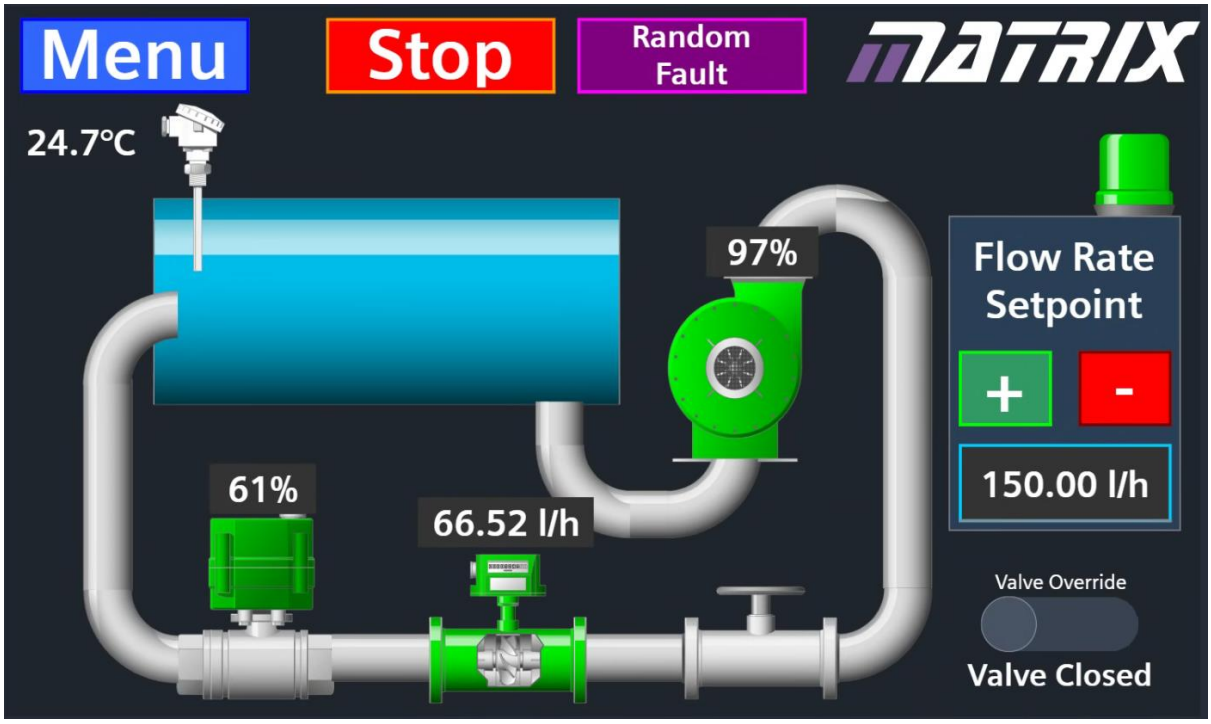
Starting The Program

You start the program by pressing the “Start Program” button on the main menu. This takes you to the Main Mimic screen and starts the flow system.



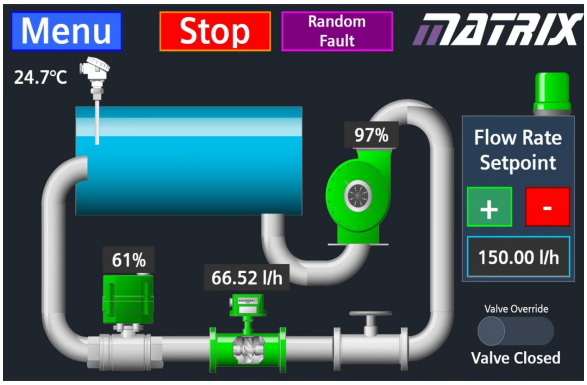
Main Mimic Screen

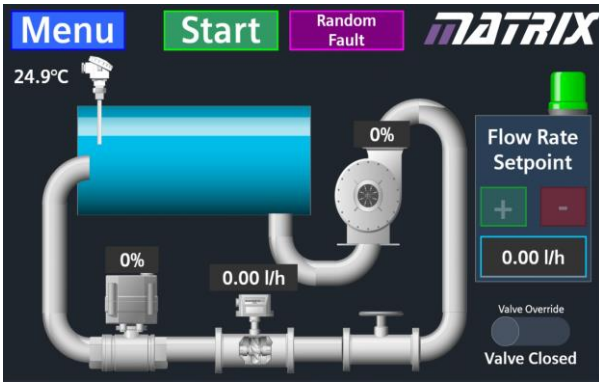
Once you've selected "Start Program", you will be taken to the "Main Mimic" and the system will begin running. This is the main screen for controlling the training rig and completing the curriculums.



Differences Between Running & Stopped

When the system is not running, it will look slightly different to the above picture. In its stopped state, the "Start" button is visible and the flow rate adjustment buttons are greyed out.

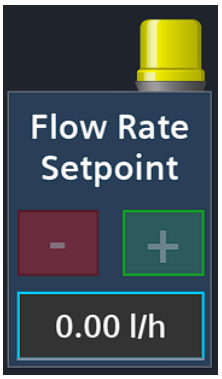




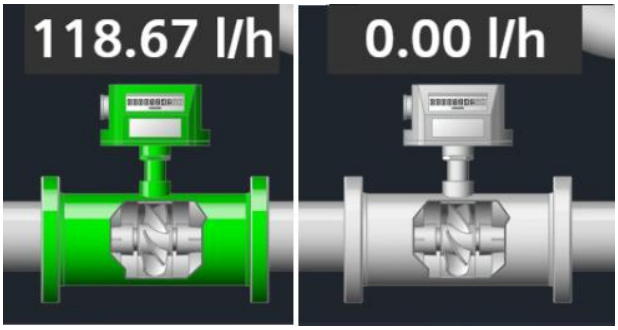
Flow Rate Setpoint Panel

Located on the right-hand side of the screen, this panel allows adjustment of the system's flow setpoint.

The green "+" and red "–" buttons increment or decrement the target in 20 L/h steps, with an operating range of 0 to 300 L/h. The current setpoint is shown clearly beneath the controls.



Live Flow Reading

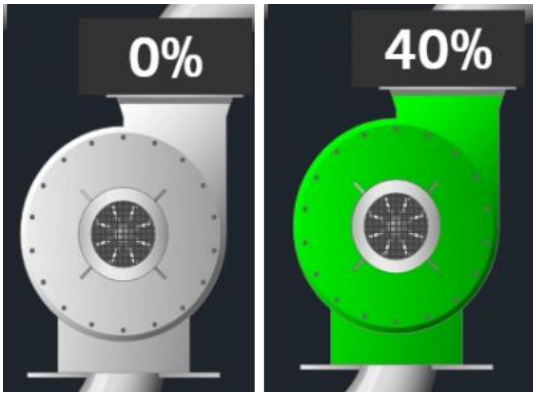


Displayed centrally above the flow sensor icon, this numeric value (e.g. 118.67 L/h) represents the actual flow rate measured by the turbine flow sensor. It reflects the real-time process variable used by the PLC for PID control.

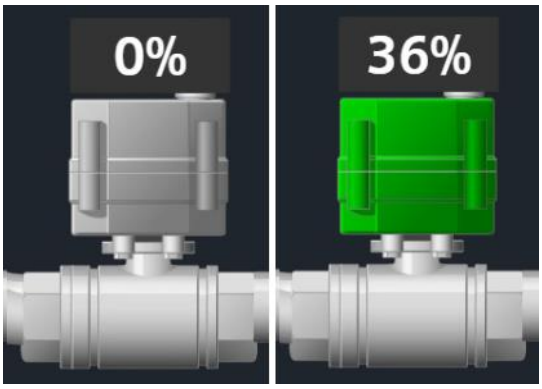
Pump Output (%)

Shown above the green circular fan graphic, this figure represents the PWM control signal being sent to the DC immersion pump.

A value of 97%, for example, means the pump is running near full capacity to achieve the setpoint.



Valve Output (%)



Positioned above the green valve graphic on the left side of the screen, this percentage shows the current valve opening based on the 0–10 V analogue control signal. The valve operates proportionally to fine-tune flow rate.

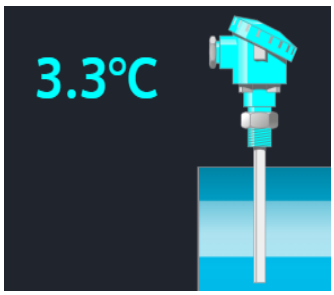
Valve Override Toggle

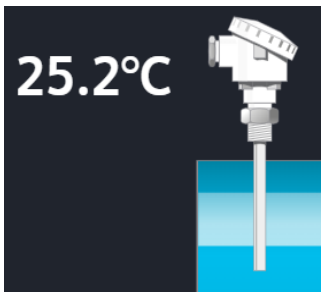
Located below the Flow Setpoint, this toggle switch allows manual override of the valve position. When enabled, PID control to the valve is disabled and the valve is opened fully.

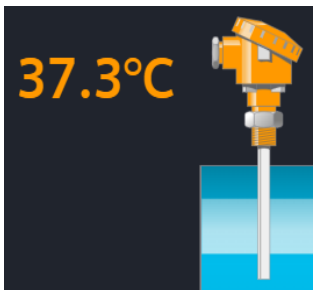
Temperature Reading

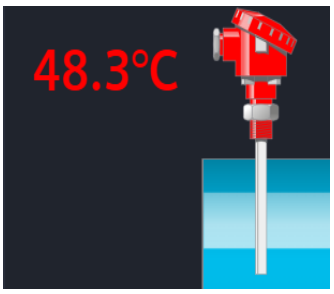
Displayed in the top-left corner, this value indicates the current water temperature as measured by the RTD sensor. It is monitored for safety purposes, and over-temperature conditions will trigger protective shutdowns.

When the system temperature is inside the typical operating range of 16-35 degrees Celsius, the sensor will display as white. As it approaches high temperatures (36-39 degrees) the temperature sensor will display as orange. Anything above 40 degrees, the sensor will be red and anything below 15 degrees, the sensor will be blue.



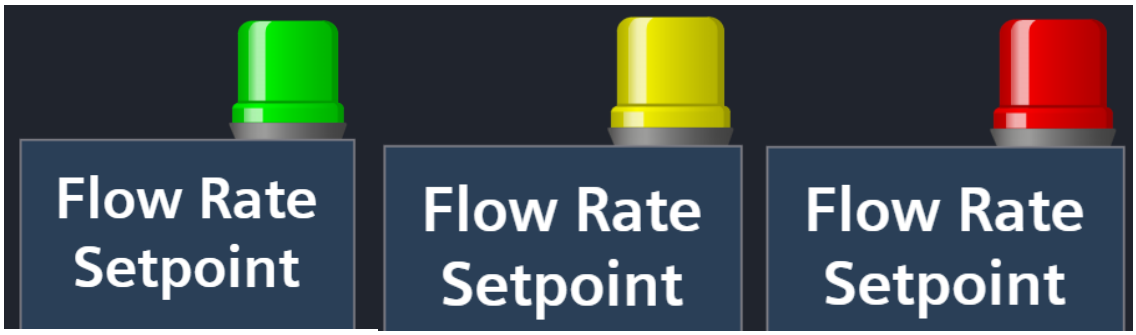






In the top-right of the screen, the beacon changes colour to reflect system status:

- Green – Normal operation
- Flashing Amber & Red – Fault detected



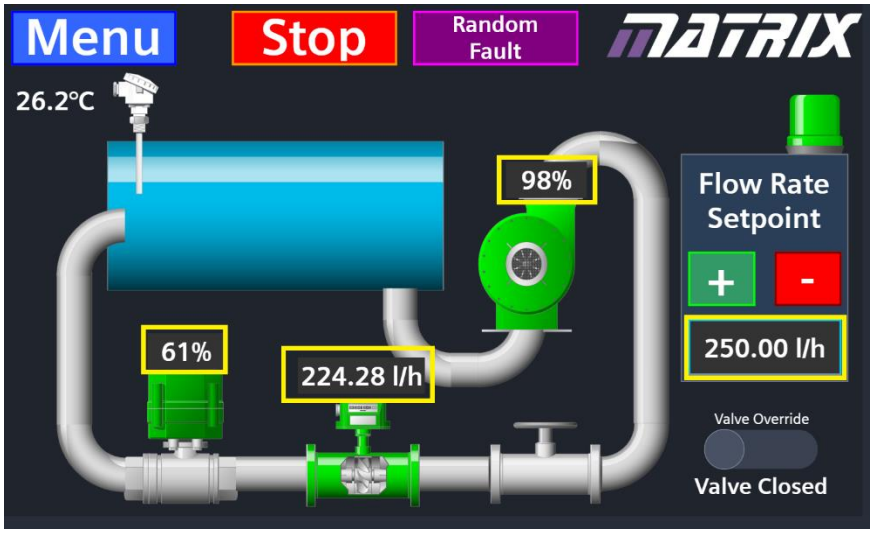
Navigation Buttons

The top navigation bar includes:

- Menu – Return to the HMI main menu
- Start/Stop – Start or Stop all system operations
- Random Fault – Inject a random software fault

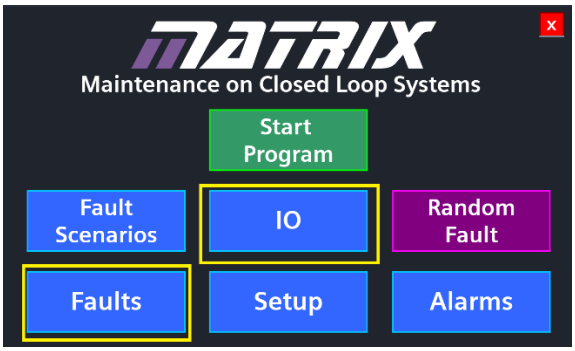
Real Time Updates

The setpoint flow value, actual flow rate, and control outputs (pump and valve) update in real time to reflect PID performance.



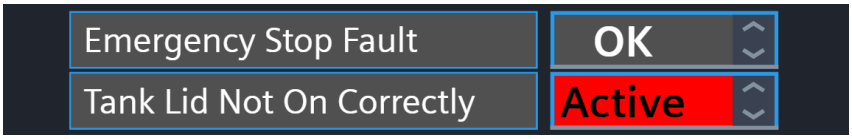
Faults

If the system fails to reach the setpoint, or if abnormal behaviour is detected, consult the Faults page or IO screen for further diagnostics.



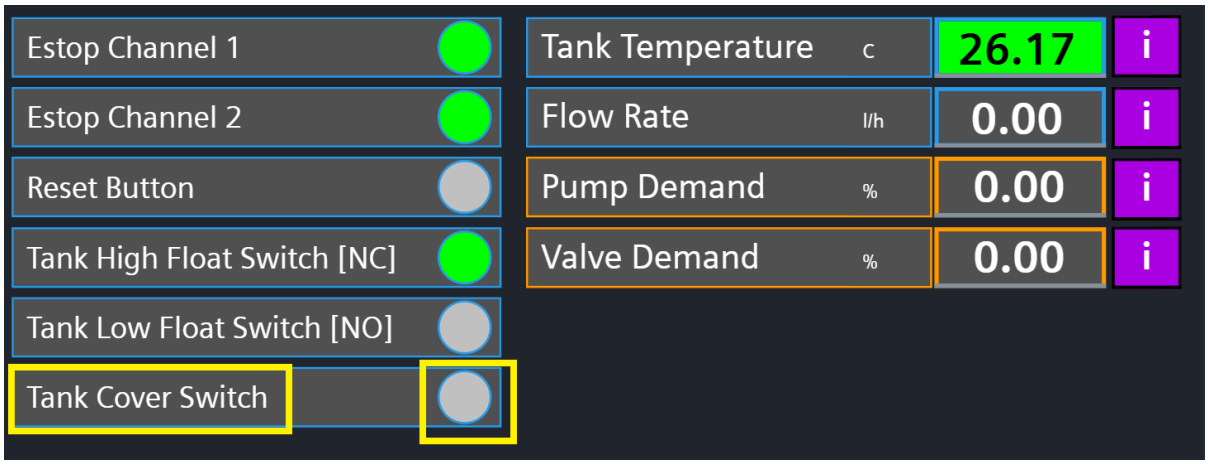
Example Fault – Tank Lid

Should a fault occur, navigate to the Main Menu and then to the Faults page. This will show you active faults. If a fault is active it will show as “Active” and be highlighted red. All inactive faults will state either “OK” or “-“.



You can also use the IO screen to help assist in fault diagnosis. Navigate to the Main Menu, then IO screen. This shows the status of each input on the system.

For the tank cover switch, the LED should be green, showing it is reading the signal. In this case we can see it is grey, meaning no signal and then we can diagnose from there.



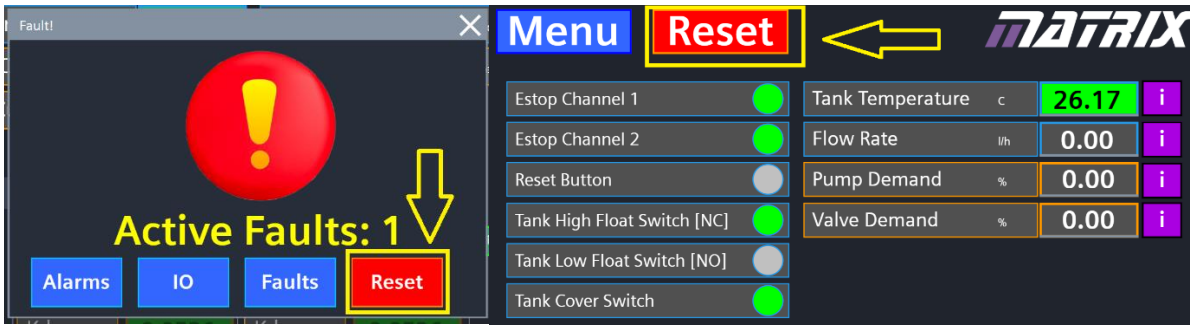
Safety Fault

If a safety fault occurs relating to the emergency stop, the system will shut down, and the beacon will turn red.

Fault Reset

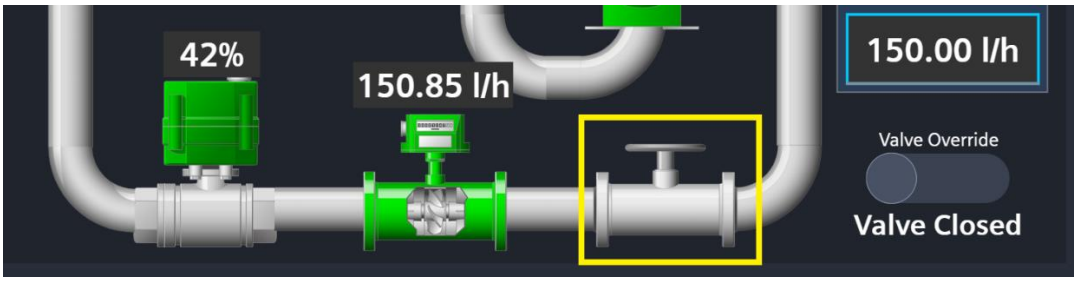
Always press Reset after resolving any fault to re-enable control logic.

The reset button is mounted on the top left of the physical system and also shown on the top of a few of the HMI pages. You can find the reset button on the fault popup window,



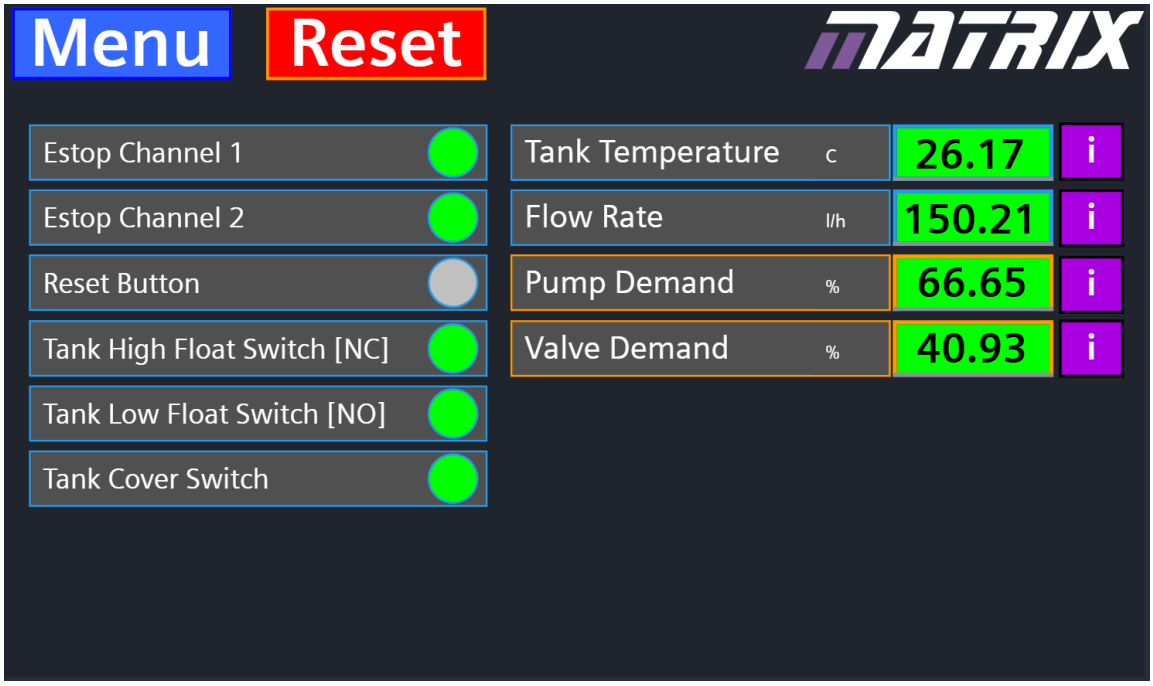
Hand / Gate Valve

Please note the screen shows a depiction of the hand or gate valve on the system but as this has no switch, it is not possible for the PLC to determine which position this valve is in.



IO Screen

The IO screen is a diagnostic page that shows the real-time status of key system inputs and outputs. It is a vital tool for fault diagnosis, signal tracing, and verifying system behaviour during operation.



Screen Content

- **Digital Inputs (Left Side)**: Displays live status for emergency stops, reset button, float switches, and lid proximity sensor.
- **Analogue Values (Right Side)**: Displays live values for:
    - Tank Temperature (°C)
    - Flow Rate (litres/hour)
    - Pump Demand (%)
    - Valve Demand (%)

Interpreting the Colours

Each digital indicator lights green when its signal is ON and turns grey when OFF. However, green does not always mean “good” — it simply reflects the sensor’s electrical status. You must interpret this in context:

Input	Status = Green	Status = Grey	Interpretation
Reset Button	Being pressed	Not pressed	Grey is normal here
EStop Channels	Circuit complete	Open (EStop pressed or wiring fault)	Grey = Fault
Tank High Float Switch [NC]	Tank NOT full	Tank is full	Grey = High level reached
Tank Low Float Switch [NO]	Tank has liquid	Tank is empty	Grey = Low level condition
Tank Cover Switch	Lid closed	Lid open	Grey = System will not run

So, while green often indicates a “good” state, this is not always true. For example:

- If the Tank High Float Switch [NC] turns grey, it means the circuit has opened, the float has risen, indicating the tank is overfilled.
- If the Reset Button were green, it would mean it is being physically held down, this is not normal during system operation.

Using This Screen in Practice

- During troubleshooting, check the state of each input here first. Compare the HMI status with actual sensor conditions.
- Use the “i” buttons next to each analogue signal to view or apply an offset (advanced users only).
- Remember that certain faults like intermittent proximity switch behaviour or temperature sensor offsets may only be visible here.

Summary

- Green = ON, Grey = OFF. Importantly, not good vs bad.
- Understand the logic type of each input (e.g. NC or NO) to interpret correctly.
- Use this screen as your first check when the system won’t start or behaves unpredictably.

Fault Scenarios Screen

The Scenarios screen allows you to activate one of eight pre-programmed fault simulations. Each scenario introduces a realistic system fault that must be identified and resolved using observation and reasoning.

How it works

- Select any of the scenario buttons (1 to 8) to trigger a fault.
- Only one scenario can be active at a time.
- Once a scenario is active, the Fault and Alarm screens are disabled to encourage fault-finding using the Main Mimic and IO screens.
- Use the Menu button to return to the main navigation screen.

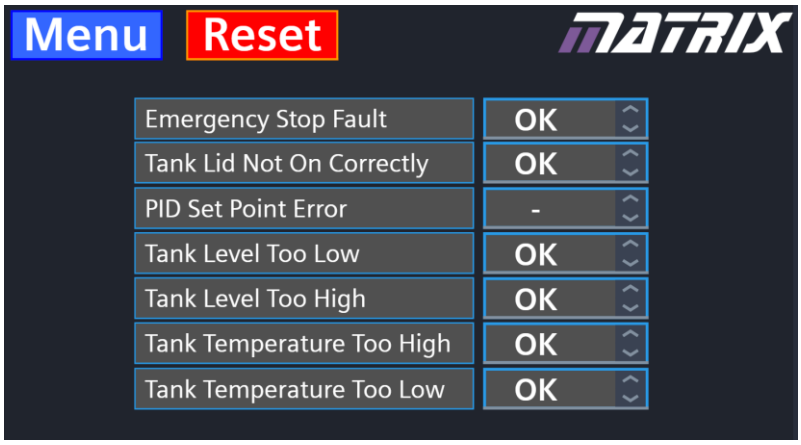
What you should do

- Use the IO screen and Main Mimic screen to observe system behaviour and identify abnormal values or sensor states.
- Look for signs such as unexpected flow rates, missing signals, or incorrect temperatures.
- You are encouraged to take notes before attempting any reset or configuration changes.
- To clear a scenario, return to the main menu and select a new scenario or restart the system if needed.

After completing the relevant sections of the curriculum CP6773, you may refer to the accompanying scenarios answers document titled *CP6773 – Troubleshooting & Fault-Finding Closed Loop Systems – Answers* for guidance, expected outcomes, and further explanations.

Faults Screen

The Faults screen displays the live status of critical system conditions. It helps you quickly identify whether any active fault is preventing the system from running safely or correctly.



How it works

Each row represents a predefined fault condition monitored by the PLC. The status shown on the right indicates whether that fault is currently active or not.

- A status of OK or "-" means the condition is normal and not currently triggering a fault.
- If a fault occurs, the status will change to "ACTIVE".

The Reset button in the top-right corner allows you to clear latched faults once the issue has been resolved.

Fault conditions monitored

- Emergency Stop Fault – checks for breaks in either of the dual-channel E-Stop circuits.

- Tank Lid Not On Correctly – monitors the tank's proximity switch for an open lid.
- PID Set Point Error – detects if the system is unable to reach the target flow setpoint.
- Tank Level Too Low – triggered by the low float switch when the water level drops too far.
- Tank Level Too High – triggered by the high float switch when the tank nears overflow.
- Tank Temperature Too High – triggered when the tank temperature exceeds the configured upper limit.
- Tank Temperature Too Low – triggered when the tank temperature drops below the configured lower limit.

What you should do

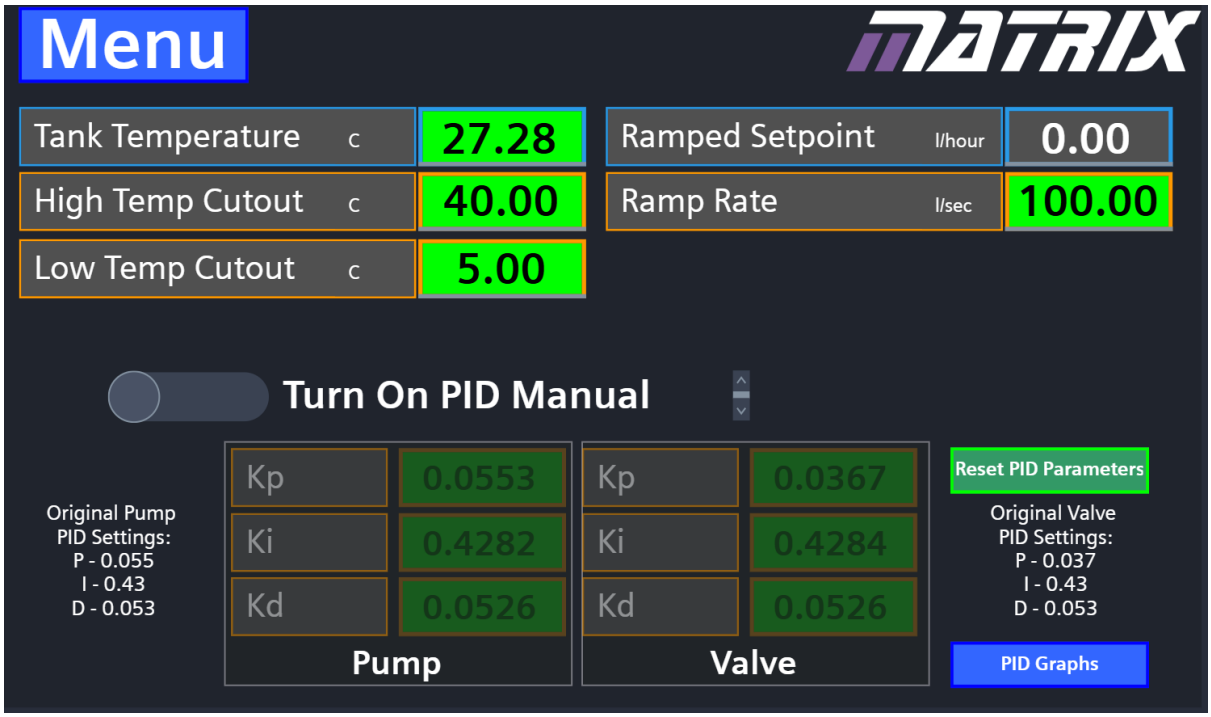
- Check this screen if the system fails to start or stops unexpectedly.
- Confirm all fault statuses are showing OK before attempting to run the system.
- If a fault is active, investigate the root cause (e.g. lid open, low water, high temperature).
- Once resolved, press Reset to clear the fault and attempt a system restart.

This screen is used during normal operation but is intentionally disabled during scenario-based training, where you are expected to diagnose faults using observation and the IO screen.

Setup Screen

Setup Screen Page 1

This screen allows you to adjust temperature safety limits, flow ramp settings, and PID control parameters for both the pump and valve. It also provides access to manual PID mode and graphing tools for tuning.



Temperature settings

- Tank Temperature shows the live reading from the temperature sensor.
- High Temp Cutout defines the maximum allowable tank temperature. If exceeded, the system will shut down.
- Low Temp Cutout defines the minimum allowable temperature. If the tank drops below this value, the system will stop.

These limits are safety features to protect components and maintain process conditions.

- Ramped Setpoint is the target flow the system will gradually approach using a defined ramp rate.
- Ramp Rate sets how fast the system increases or decreases flow (in litres per second). A higher value gives faster response, while a lower value creates a gentler change.

PID manual mode

You can toggle between automatic and manual PID mode using the switch labelled Turn On PID Manual.

- In automatic mode, the system uses preset PID values stored in the PLC.
- In manual mode, the PID values displayed on screen can be edited directly by the user.

The current PID values for both the pump and valve are displayed. These control how the system responds to flow changes:

- Kp (Proportional gain)
- Ki (Integral gain)
- Kd (Derivative gain)

Changing these values will affect how aggressively or smoothly the system responds to errors in flow rate.

PID parameter tools

- Reset PID Parameters returns all PID values to their original factory-set values.
- The PID Graphs button opens the second page of the setup screen, explained in the next section of this manual.

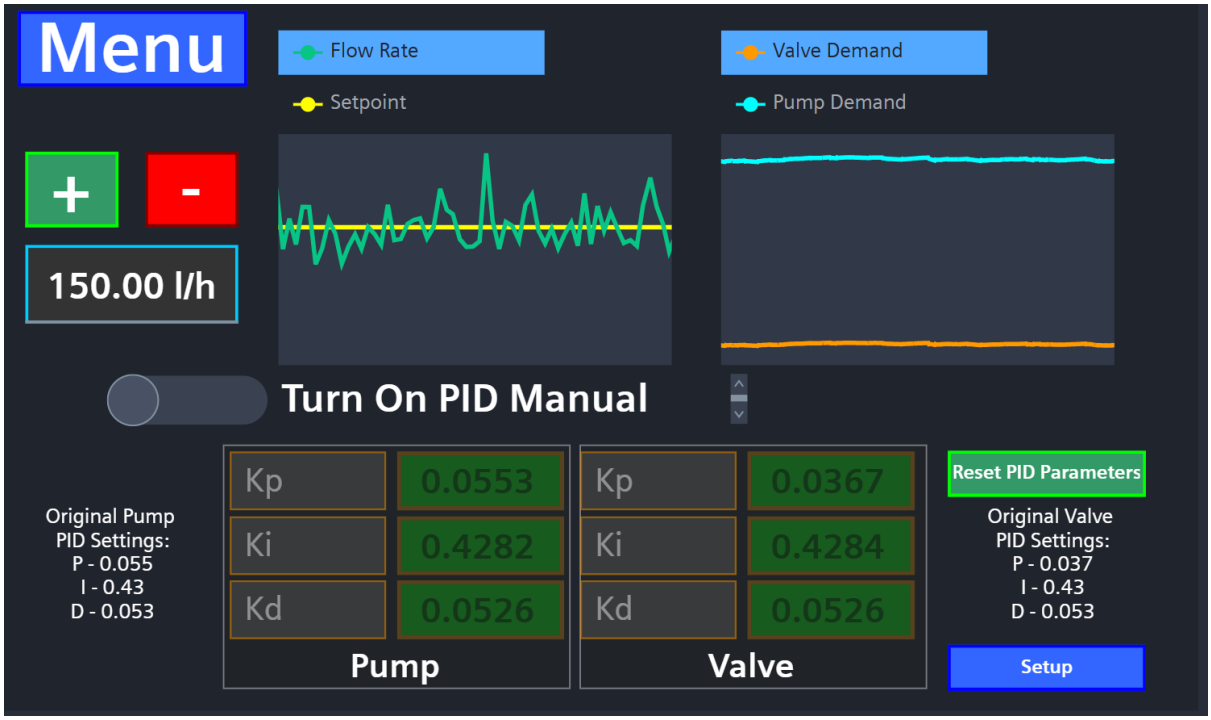
The original PID settings for both pump and valve are shown as reference values beside their respective tuning boxes.

This page is intended for advanced users or those performing diagnostic exercises as part of the curriculum.

Note: Please note as this is an Industrial Maintenance product, PID tuning is outside the scope of this product. We only allow parameter changing here to simulate real world conditions.

Setup Screen Page 2

This screen displays live graphs for flow rate, setpoint, pump demand and valve demand. It is used for visual analysis of system performance and PID tuning.



Flow graph

The graph on the left compares:

- Flow Rate (actual measured value)
- Setpoint (target flow)

This helps you observe how closely the system is tracking the target value. A large gap may indicate poor PID tuning or a system fault.

Output graph

The graph on the right shows:

- Pump Demand
- Valve Demand

These outputs show how the PLC is controlling each actuator in response to flow errors. High or erratic output levels may suggest the PID parameters are too aggressive or that mechanical limits are being reached.

Controls

- The plus and minus buttons increase or decrease the flow setpoint in 20 l/h increments.
- The numeric display below shows the current setpoint.
- The PID manual toggle allows switching between automatic and manual PID control. In manual mode, the Kp, Ki and Kd values can be edited live.
- The reset button restores original PID parameters.
- Use the Setup button in the bottom right to return to Setup Screen – Page 1.

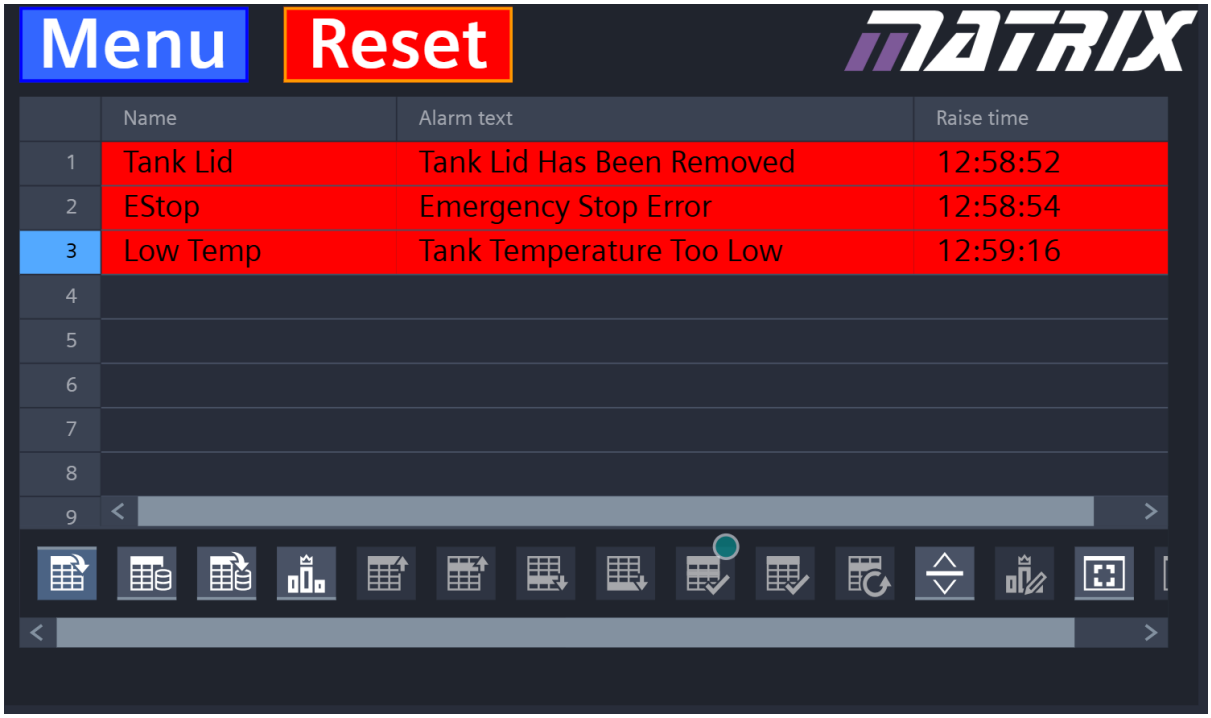
What you should do

- Use this screen to evaluate how the system responds to changes in setpoint.
- Look for signs of overshoot, delay, or instability.
- Adjust PID values if necessary and observe the effect on the graph.
- Use the original PID values shown to return to known working settings if needed.

This screen is intended to be used as a show piece, to show Maintenance Engineers what a typical system looks like. It is not recommended to adjust any of these settings.

Alarms Screen

The Alarms screen displays a live list of all currently active alarms. These are triggered when the system detects conditions that may prevent safe or reliable operation.



Alarm table

Each row shows:

- the name of the alarm source
- a brief description of the problem
- the exact time the alarm was triggered

Alarms are colour-coded. Red indicates a critical condition that must be resolved before the system can restart.

Examples of alarm conditions include:

- tank lid removed
- emergency stop pressed or wiring fault detected
- temperature outside of safe limits

Resetting alarms

Use the Reset button at the top of the screen to clear all resolved alarms. The system will not reset automatically. You must first correct the fault (e.g. close the lid, release the E-Stop) before pressing Reset.

Navigation

Use the Menu button in the top left to return to the main menu. If many alarms are present, scroll or navigate using the arrow and page controls at the bottom of the screen.

What you should do

- check this screen any time the system stops running unexpectedly
- read the alarm text carefully to understand what has triggered the fault
- resolve the issue and press Reset to clear the fault state

The alarms screen is a key diagnostic tool and is available during normal operation. It is disabled during scenario-based exercises to encourage manual diagnosis using the IO screen and mimic display.

Accessing Siemens Internal HMI Settings

Tap on the Matrix logo anywhere within the app and this will bring up the About page.

Pressing the red “X” button on the top right of the About page will shut down the runtime and take you to the Siemens settings. There should be no need for you to ever do this and it is not advised to edit any settings here unless you are experienced.

MAINTENANCE & CALIBRATION

This system does not require much regular maintenance but nonetheless there should be some care taken to ensure reliable performance, accurate readings, and safe operation.

The tasks below should be performed according to the schedule shown. Maintenance should only be carried out by trained staff.

12.1 Maintenance schedule

Task	Interval	Method
Visual inspection (hoses, wiring)	Before each class	Perform a brief check for leaks, cracks, or loose wires.
Drain & refill tank	Monthly	Remove the lid from the tank. Carry the tank to a sink and drain the water into a sink.
Verify float switch function	Termly	Manually lift both floats. Observe input status change on IO screen.

TROUBLESHOOTING

System Won’t Start

There are only a few reasons why the system won’t start. The PLC is checking the faults table shown on the Faults Screen. If any of them are active, the system won’t run. The Status LED must be green for the system to run.

Check the table on the fault screen.

No Flow

If there is no flow, check the following;

1. Ensure the pump is running, check the Main Mimic screen to ensure you seem pump demand.
2. Ensure the hand/gate valve on top of the tank is open.
3. Ensure the solenoid valve has demand on the Main Mimic screen. You can use the valve override switch on the bottom right of the Main Mimic screen to force this open.

Faults Screen & Alarms Screen Greyed Out

If these screens are greyed out and unclickable, likely a random fault is active. Press the Random Fault button on the Main Menu or on the Main Mimic screen to reset the Random Fault.

Air Lock Advisory

In some cases, especially after draining and refilling the tank, air may become trapped in the system. This can prevent the pump from building sufficient pressure to establish flow, even when running at full speed. Symptoms include:

- No flow despite pump running at 100%
- Flow sensor showing 0 L/h
- System unable to reach setpoint and triggering PID faults

To resolve this, you may need to manually assist the system in purging the air:

Troubleshooting

- With the system running, unclip the tank from its seated position.
- Gently tilt the tank approximately 45° toward the right-hand side (towards the pump and valve).
- Maintain this position for 5–10 seconds to allow trapped air to move toward the pump inlet.
- Observe the flow sensor on the HMI, flow should resume once the air clears.

Only perform this procedure under supervision, and do not tilt the tank beyond what is necessary. Ensure tubing remains securely connected during this operation.

This method helps prime the pump and is particularly useful after maintenance or extended periods without use.

CRITICAL SPARES

This system uses standard, commercially available components that can be replaced as needed. Most parts are not considered critical, and replacements can typically be sourced through major suppliers. However, downtime should be accounted for when planning lessons.

Two components are considered critical due to their essential role in powering and protecting the system. These are recommended for on-site storage to minimise disruption:

Item	Part number / Order Code	Qty	Notes
Power Supply (24 V DC, 60 W)	Mean Well GEM60I24 P1J	1	IEC C8 inlet, main system PSU
Mini Blade Fuse (3 A, violet)	RS PRO 563-712	1	32 V DC mini blade fuse for WAGO fuse terminal, essential circuit protection

Important note:

The PLC and HMI are pre-programmed with custom Matrix software. If either unit is damaged or requires replacement, the new device will not function correctly without reloading the project files. This process requires specific technical knowledge and is not intended to be carried out by the end user. If you need to replace the PLC or HMI, please contact Matrix Technology Solutions for technical support or reprogramming services.

TEACHING & ASSESSMENT AIDS

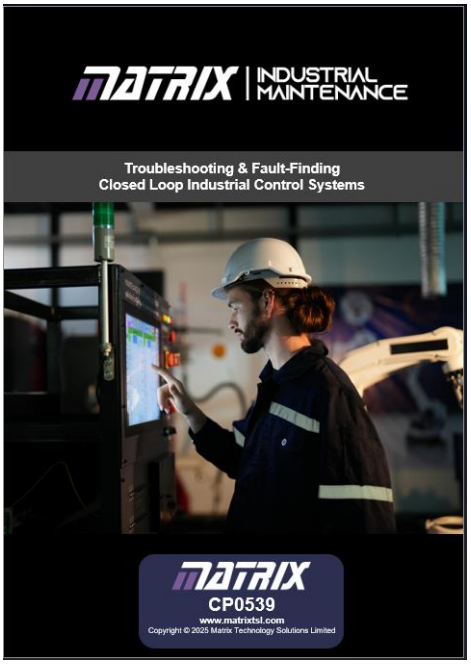
For training environments using this equipment, structured worksheets and troubleshooting scenarios are available separately:

- CP0539 – Maintenance of Closed Loop Systems
- CP6773 – Troubleshooting & Fault-Finding Closed Loop Systems

Refer to these documents for further information on structured procedures, fault analysis, and control system behaviour.

CP0539 – Industrial Maintenance of Closed Loop Systems

CP6773 - Troubleshooting & Fault-Finding Closed Loop Systems



WARRANTY & SUPPORT

12 months parts & labour from invoice date.

Warranty void if operated outside specs, modified, or unclean water is used.

For support:

Email: support@matrixtsl.com

Phone: +44 (0)1422 252 380

Quote serial number: IM0004

APPENDIX A – ELECTRICAL DRAWINGS

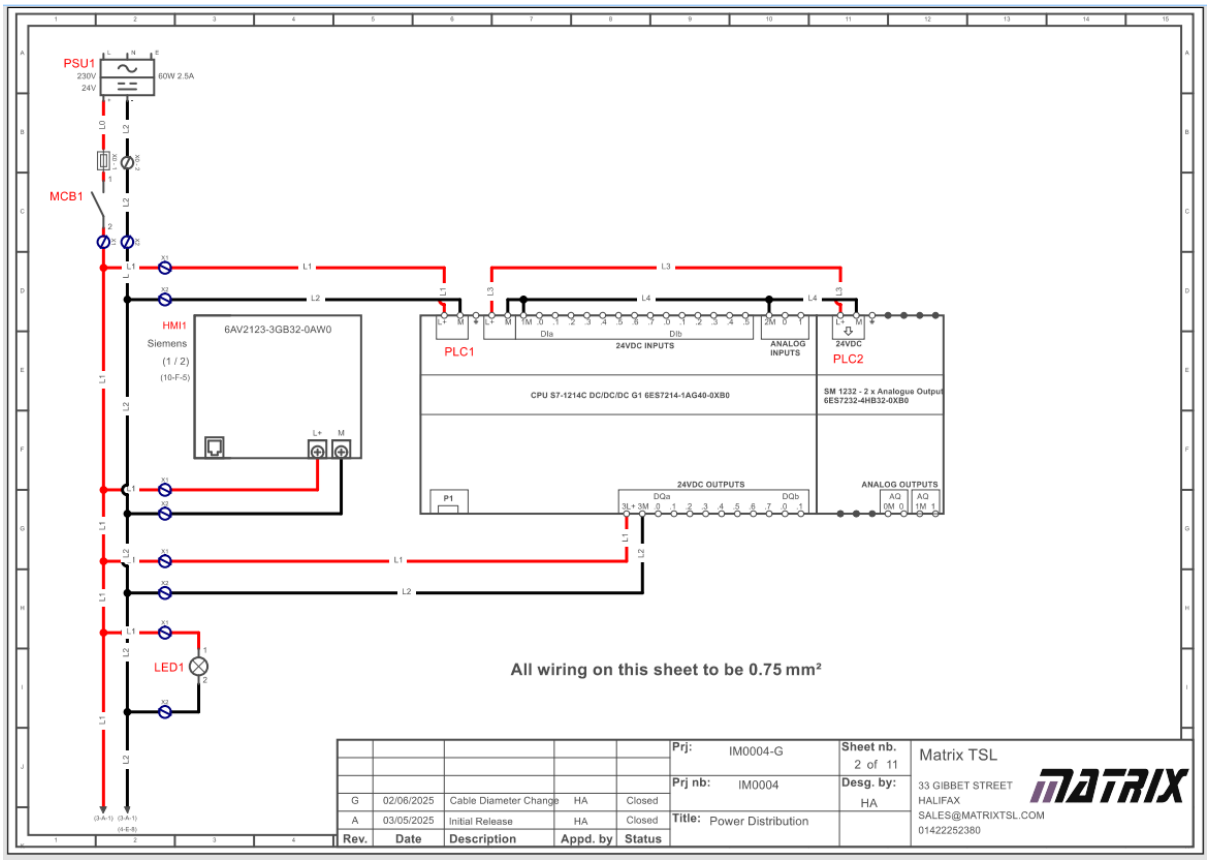
IM0004-G (Table of contents)

Number	Title
1	Table of Contents
2	Power Distribution
3	PLC Inputs
4	PLC Analogues
5	PLC Outputs
6	PLC Actuators
7	Terminal Layout Rear
8	Terminal Layout Front
9	Connector Layout
10	Network
11	Parts List

Rev.	Date	Description	Appd. by	Status
G	02/06/2025	Cable Diameter Change	HA	Closed
A	03/05/2025	Initial Release	HA	Closed

Prj: IM0004-G | Sheet nb. 1 of 11
Prj nb: IM0004 | Desg. by: HA
Title: Table of Contents

Matrix TSL
33 GIBBET STREET
HALIFAX
SALES@MATRIXTSL.COM
01422252380



Rev.	Date	Description	Appd. by	Status
G	02/06/2025	Cable Diameter Change	HA	Closed
A	03/05/2025	Initial Release	HA	Closed

Prj: IM0004-G | Sheet nb. 2 of 11
Prj nb: IM0004 | Desg. by: HA
Title: Power Distribution

Matrix TSL
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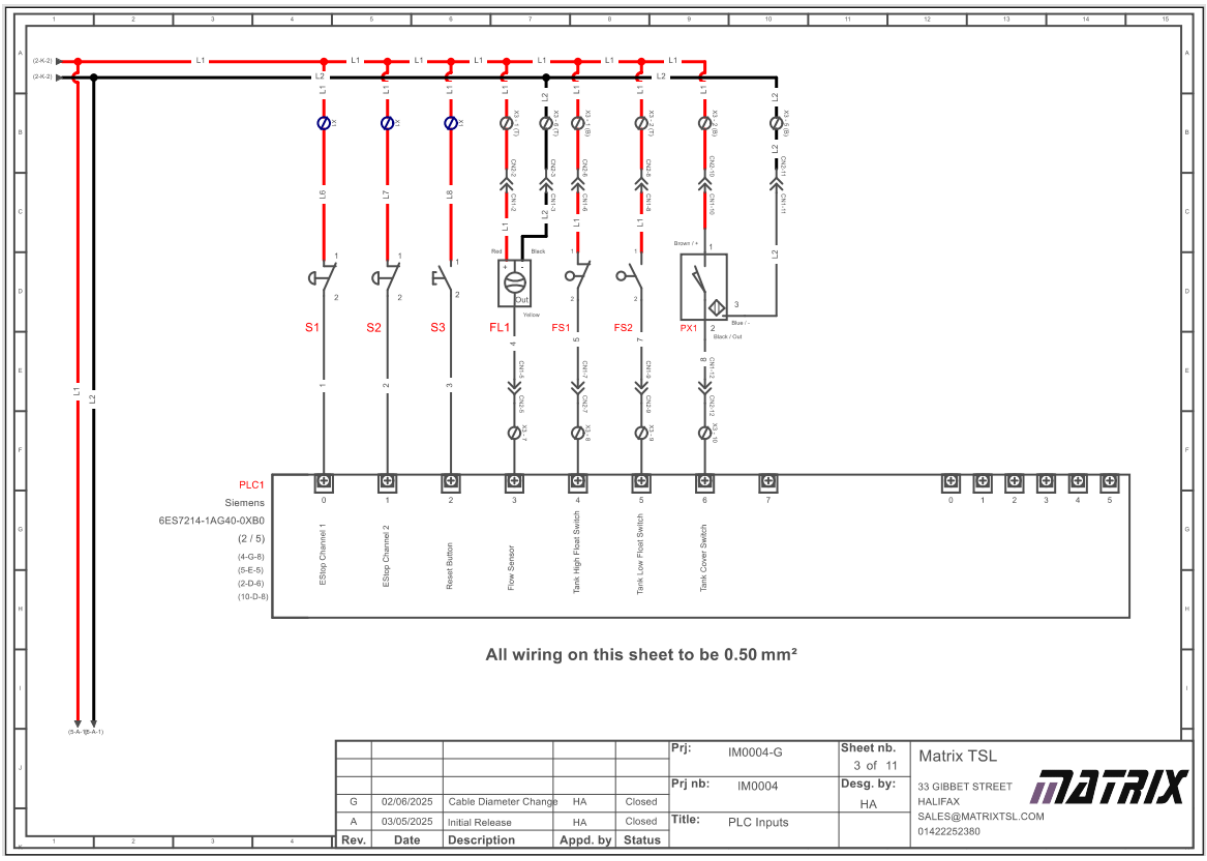
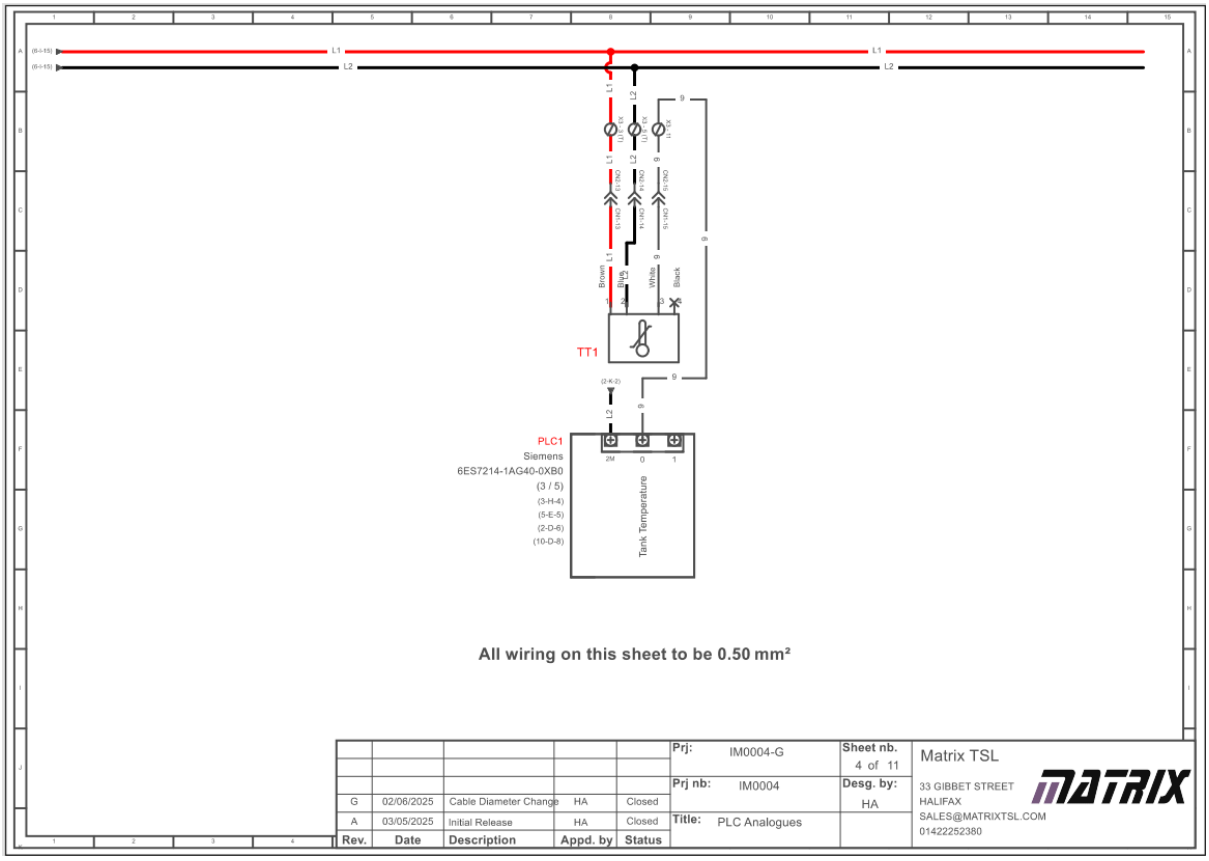
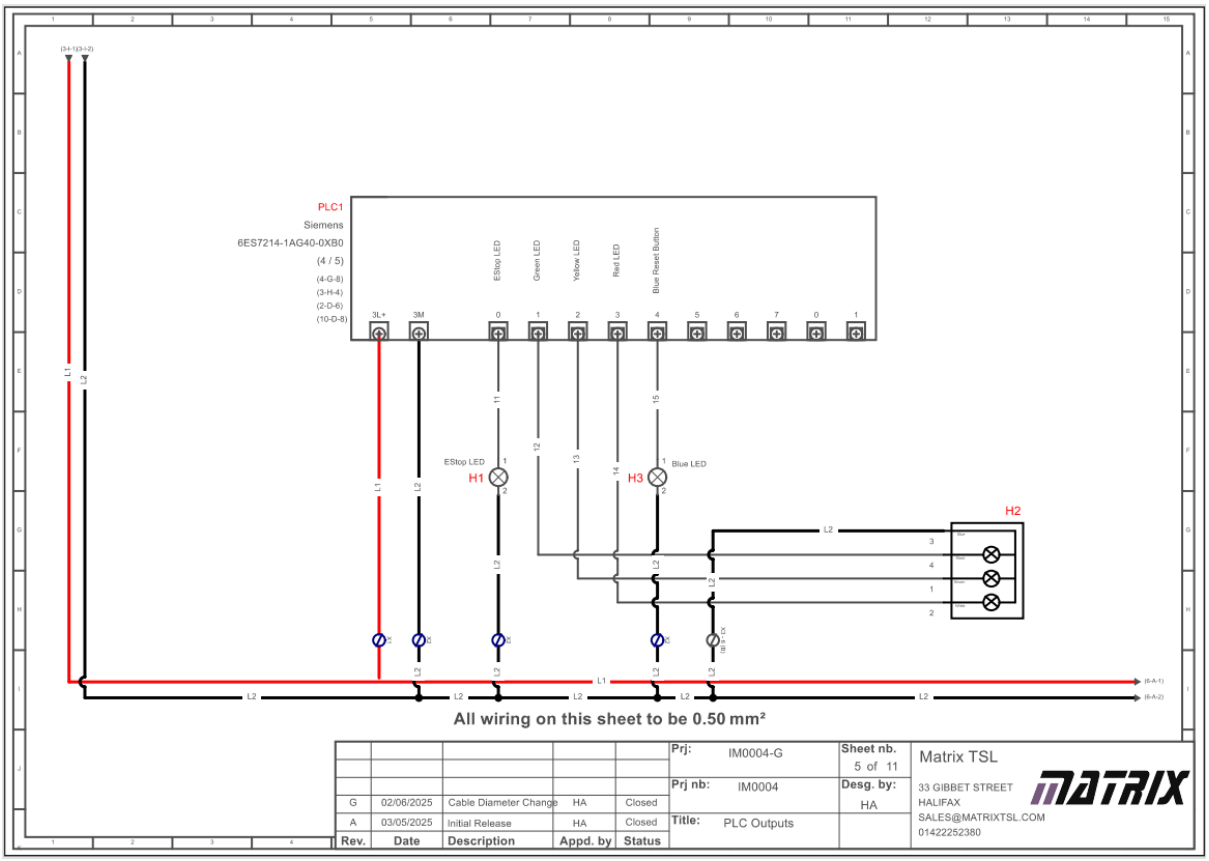
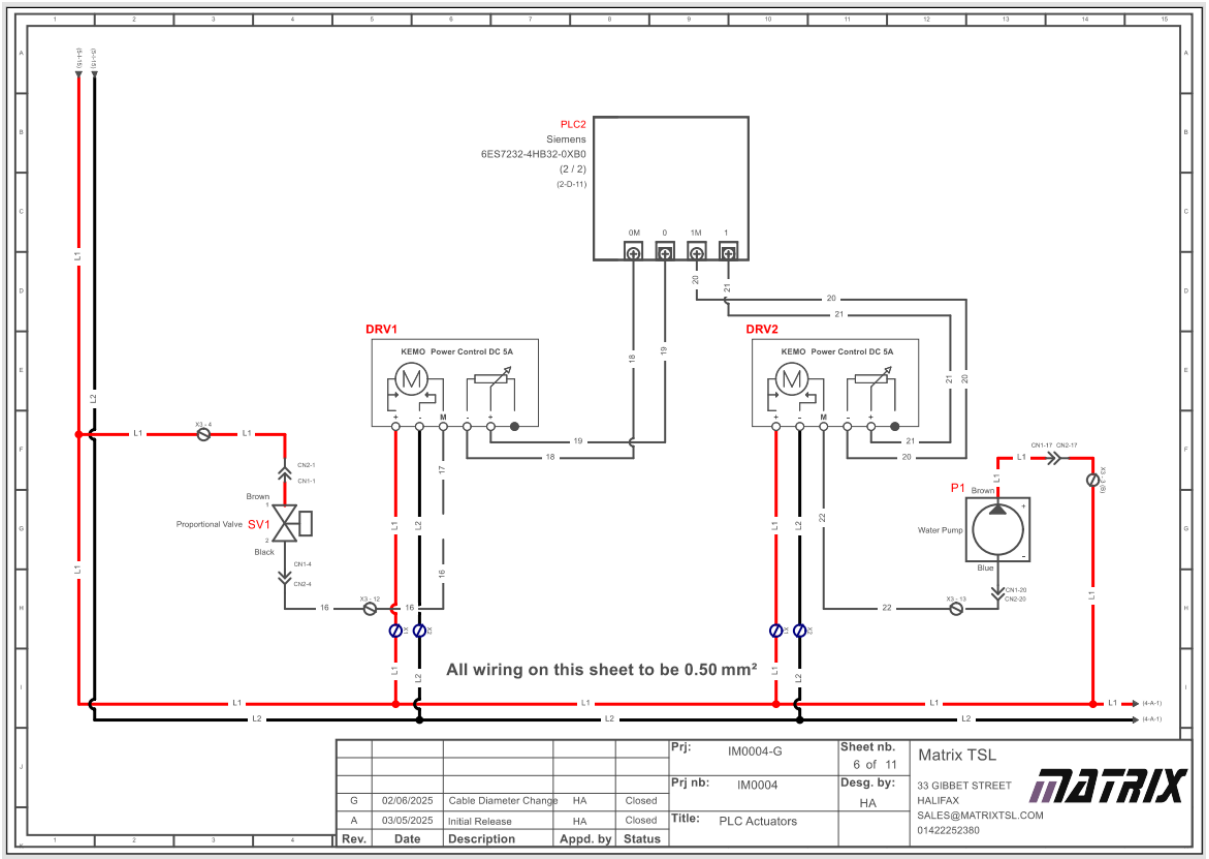
Appendix A – Electrical Drawings



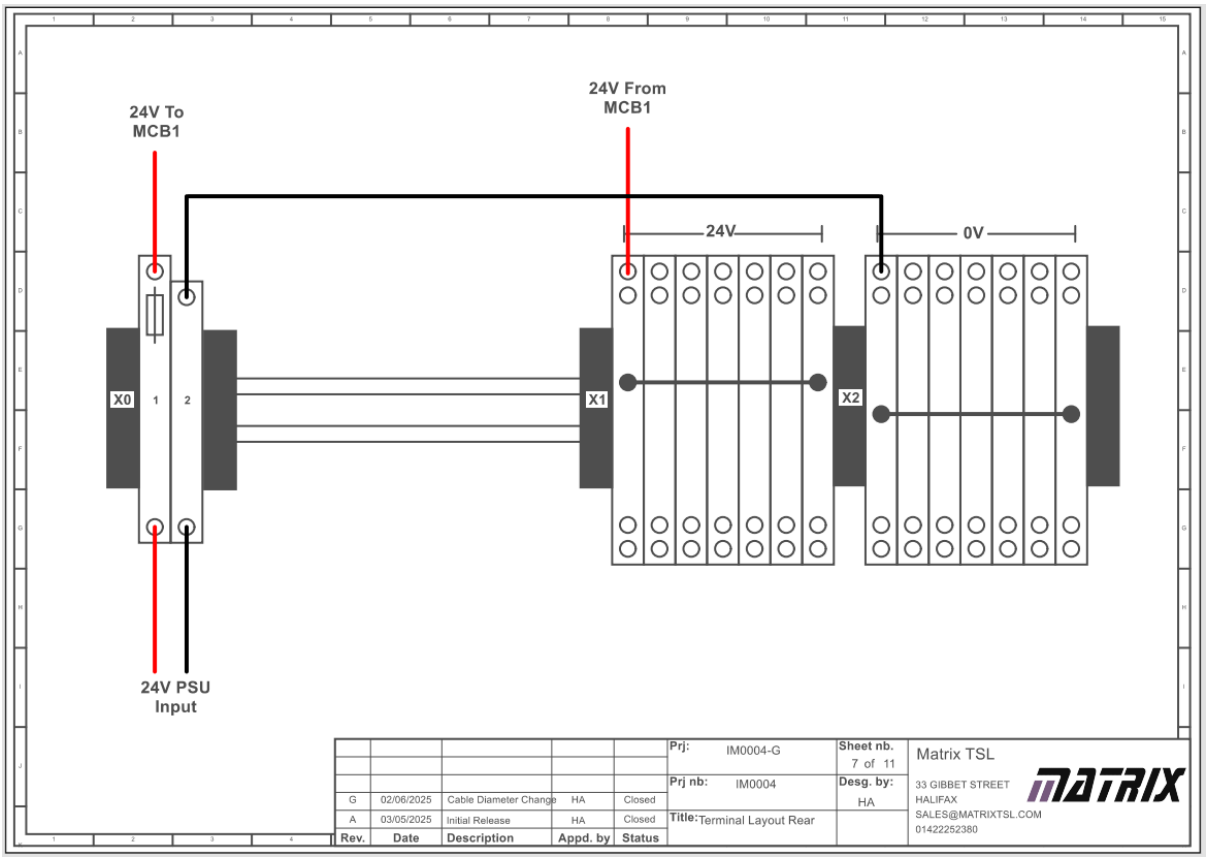


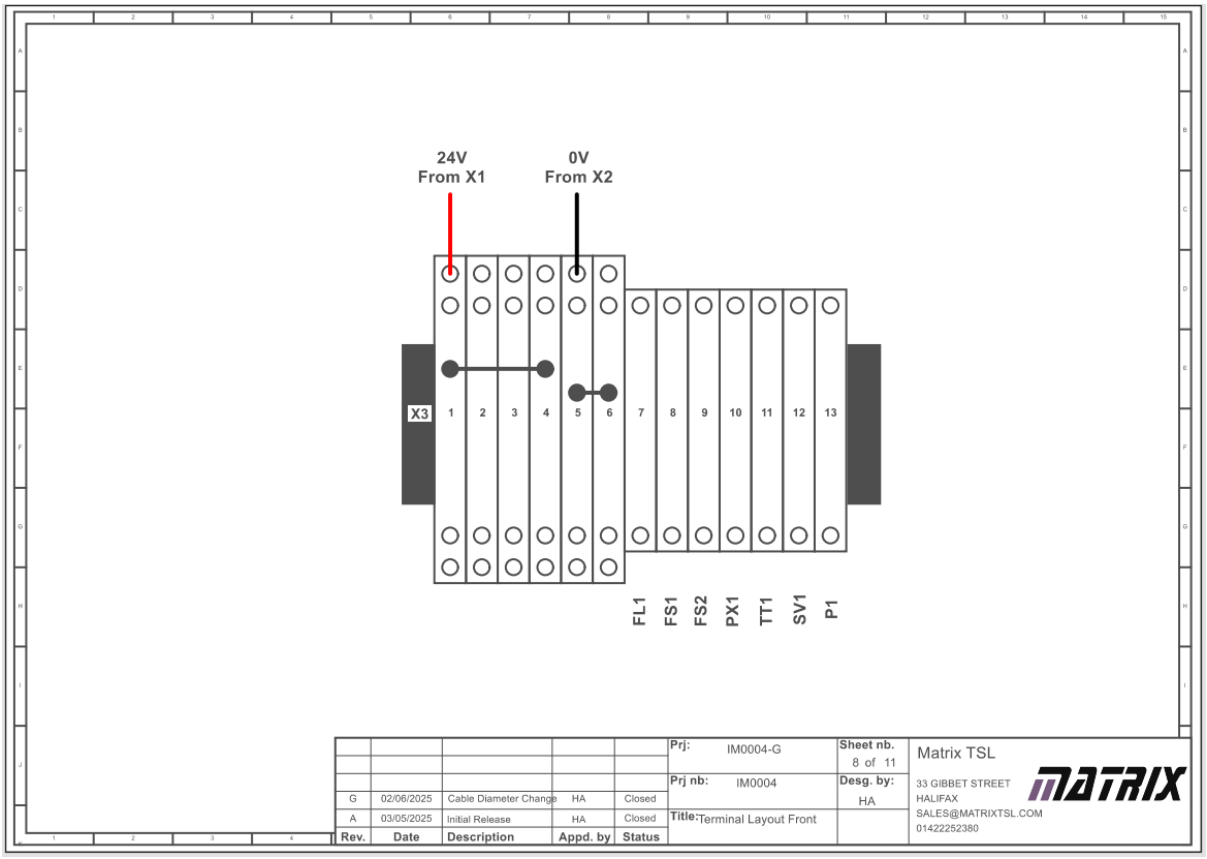
Appendix A – Electrical Drawings



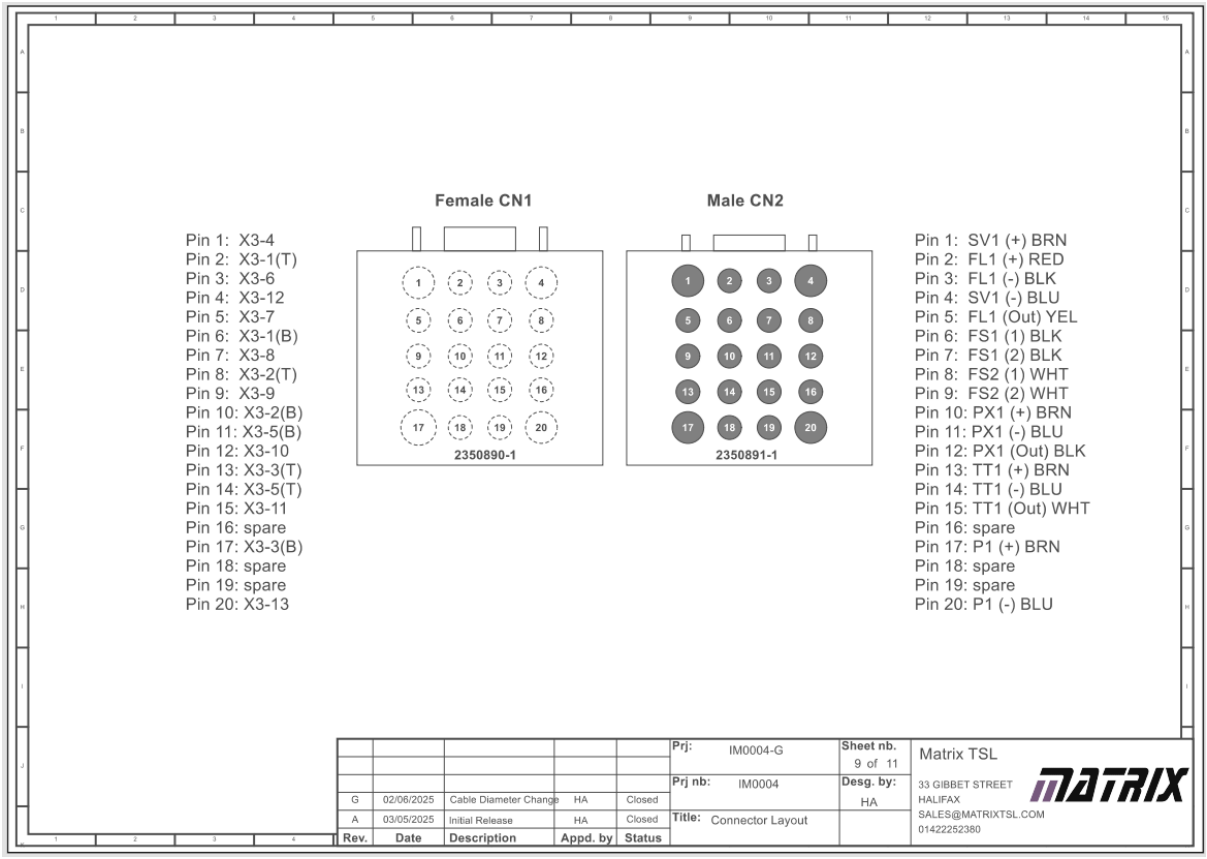


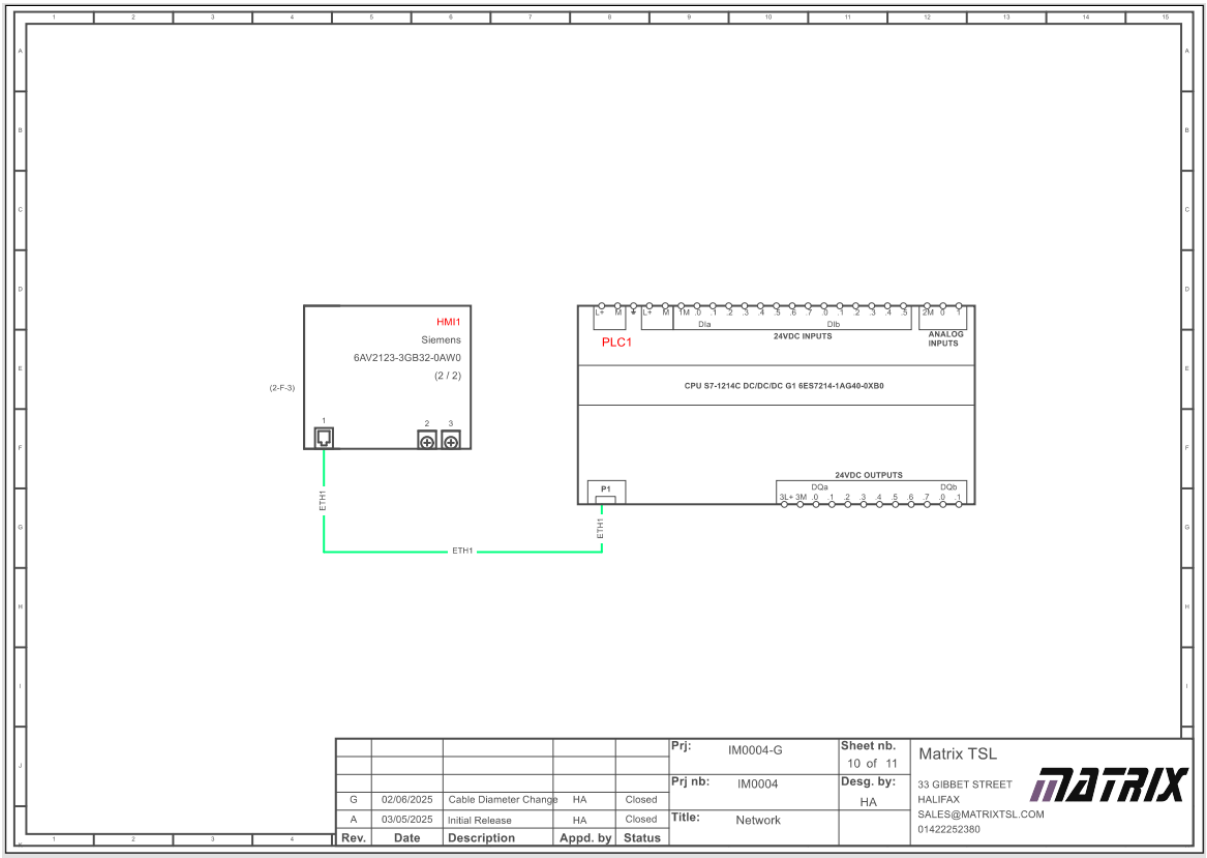
Appendix A – Electrical Drawings





Appendix A – Electrical Drawings





APPENDIX B – BILL OF MATERIALS

#NAME?	Class name	Description	Manufacturer	Part number	Quantity
CN1	Connector	Male NTSEAL Automotive Connector Socket Cable Mount 20 Way, Solder Termination	TE Connectivity	2350891-1	1
CN1	Wire management accessory	Size 16 Deutsch Male Pin	TE Connectivity	1060-16-0122	1
CN1	Wire management accessory	Size 20 Deutsch Male Pin	TE Connectivity	1060-20-0122	1
CN2	Connector	Female NTSEAL Automotive Connector Socket Cable Mount 20 Way, Solder Termination	TE Connectivity	2350890-1	1
1	Harness accessory	Expandable Braided PET Black Cable Sleeve, 15mm Diameter, 5m Length	RS PRO	408-205	1
CN2	Wire management accessory	Size 16 Deutsch Female Pin	TE Connectivity	1062-16-0122	1
CN2	Wire management accessory	Size 20 Deutsch Female Pin	TE Connectivity	1062-20-0122	1
CRIMP1	Connector	RS PRO Red Insulated Female Spade Connector, Receptacle, 4.8 x 0.5mm Tab Size, 0.5mm² to 1.5mm²	RS PRO	534-418	10

Appendix B – Bill of Materials

DRV1	Drive	PWM Power Control Module 9-28 V/DC, max. 10A	KEMO ELECTRONIC	M171	1
DRV2	Drive	PWM Power Control Module 9-28 V/DC, max. 10A	KEMO ELECTRONIC	M171	1
F1	Fuse holder	WAGO TOPJOB S Series Grey, 2.5mm², 1-Level, Push In Termination, Fused, CSA	Wago	2002-1681	1
F1	Fuse	3A Violet Mini Blade Car Fuse, 32V dc	RS Pro	563-712	1
FL1	Encoder	Seeed Studio Accessories G1&2" Water Flow Sensor	Seeed	314150005	1
FS1	Float Switch	NC Float Switch, 59630 Series, Vertical, SPST-NC, 200 Vdc, 10 W	HAMLIN	59630-4-T-02-A	1
FS2	Float Switch	NO Float Switch, Float, 300mm Cable, Direct Load, 140V ac Max, 200V dc Max	RS Pro	519-242	1
H1	Indicator	LED module with integrated LED, 24 V AC/DC, red	Siemens	3SU1401-1BB20-1AA0	1

Appendix B – Bill of Materials

H2	Indicator	Banner K50L Series Green, Red, Yellow Beacon, 18 → 30 V dc, Base Mount, LED Bulb, IP67, IP69	Banner	K50LGRYPQ	1
H2	Wire management accessory	Straight Female 4 way M12 to Actuator/Sensor Cable, 1m	RS PRO	283-4880	1
H3	Indicator	LED module with integrated LED, 24 V AC/DC, blue	Siemens	3SU1401-1BB50-1AA0	1
HMI1	HMI	SIMATIC HMI MTP700, Unified Basic Panel, touch operation, 7" widescreen TFT display	Siemens	6AV2123-3GB32-0AW0	1
LED1	Indicator	LED Lighting Modules DC LINEAR 11.50"x0.7" 3000K CRI 80 W/ 4 CONNECTORS (32 LEDS	American Bright LED	AB-L29D06W304N2	1
MCB1	Circuit Breaker	Siemens SENTRON 5SY MCB, 1P, 3A Curve B	Siemens	5SY4103-7	1
NS1	Networking	Flat Cat5e LSOH Ethernet Patch Lead, 0.5m Black -	PRO SIGNAL	PSG90664	1
P1	Motor	COMET – Immersion Pump 24 V	Comet	1305.79.00	1

Appendix B – Bill of Materials

PLC1	PLC	CPU 1214C - 24 VDC PSU, 14 DI (24 VDC), 10 DQ (24 VDC), 2 AI (0-10V), 150kB	Siemens	6ES7214-1AG40-0XB0	1
PLC2	PLC	SM 1232 - 2 x Analogue Output 13 Bit	Siemens	6ES7232-4HB32-0XB0	1
PSU1	Power supply	AC-DC 24V PSU	MEAN WELL	GEM60I24-P1J	1
PX1	Proxy Switch	Inductive Threaded Barrel Proximity Sensor, M12, 16 mm Detection, PNP NO, 10 → 30 V dc	Omron	E2E-X16MB1T12 2M	1
S1	EStop	Contact module with 1 contact element, 1 NC	Siemens	3SU1400-1AA10-1CA0	1
S2	EStop	Contact module with 1 contact element, 1 NC	Siemens	3SU1400-1AA10-1CA0	1
S3	Button	Contact module with 1 contact element, 1 NO	Siemens	3SU1400-1AA10-1BA0	1
S3	Pilot device accessory	Blue - Plastic illuminated push button with flat button, momentary Contact	Siemens	3SU1001-0AB50-0AA0	1
S3	Wire management accessory	Siemens Label Holder for Use with Labeling Plate 12.5 mm x 27 mm	Siemens	3SU1900-0AG10-0AA0	1

Appendix B – Bill of Materials

S4	EStop	Backing plate round, for emergency stop mushroom pushbutton, yellow: Emergency Stop	Siemens	3SU1900-0BC31-0DA0	1
S5	EStop	Emergency stop mushroom pushbutton, illuminated, 22 mm, round, plastic, red, 40 mm	Siemens	3SU10011HB200AA0	1
S6	Button	Button/LED Holder for 3 modules, plastic	Siemens	3SU1500-0AA10-0AA0	2
SV1	Solenoid valve	Proportional Solenoid Valve 239092, 2 port(s) , NC, 24 V dc, 1/2in	Burkert	239092	1
TH1	Thermocouple & RTD	Electronic PT100 RTD Sensor, 6mm Dia, 86mm Long, 4 Wire, G1/2, +150°C Max	IFM	TM4431	1
TT1	Temp. Transmitter	Evaluation unit for PT100/PT1000 temperature sensors	IFM	TP9237	1
TT1	Wire management accessory	Right Angle Female 4 way M12 to Unterminated Sensor Actuator Cable, 2m	RS PRO	212-1703	1

Appendix B – Bill of Materials

X1	Power Distribution Block	4-conductor through terminal block; 2.5 mm²; side and center marking; for DIN-rail 35 x 15 and 35 x 7.5; Push-in CAGE CLAMP®; 2,50 mm²; gray	Wago	2002-1401	7
X1	DIN rail accessory	7-Way 22 (TOPJOB S) Jumper for use with for use with Terminal Blocks	Wago	2002-407	3
X1	Terminal block accessory	249 Group Marker Carrier	Wago	249-119	4
X1	Terminal block accessory	Screwless end stop; 6 mm wide; for DIN-rail 35 x 15 and 35 x 7.5; grey	Wago	249-116	7
X2	Power Distribution Block	4-conductor through terminal block; 2.5 mm²; for DIN-rail 35 x 15 and 35 x 7.5; Push-in CAGE CLAMP®; 2,50 mm²; gray	Wago	2002-1401	7
X3-1-6	Power Distribution Block	4-conductor through terminal block; 2.5 mm²; for DIN-rail 35 x 15 and 35 x 7.5; Push-in CAGE CLAMP®; 2,50 mm²; gray	Wago	2002-1401	6
X3-1-6	Terminal block accessory	Marker Card, Horizontal, 1-10, White, Identification	Wago	248-502	1

Appendix B – Bill of Materials

X3-7-17	Power Distribution Block	2-conductor through terminal block; 2.5 mm²; for DIN-rail 35 x 15 and 35 x 7.5; Push-in CAGE CLAMP®; 2,50 mm²; gray	Wago	2002-1201	11
X3-7-17	Terminal block accessory	Marker Card, Horizontal, 11-20, White, Identification, Pack of 5, Each 10 Strips	Wago	248-503	1

APPENDIX C – RISK ASSESSMENT SUMMARY

RISK	LIKELIHOOD	IMPACT	RISK RATING	RESPONSE (ACTION)
Solenoid valve generates excessive heat when operated continuously at full 24V, potentially causing surface temperatures high enough to pose a minor burn risk or, in extreme cases, a localized fire hazard.	2	3	6	The system normally limits the valve voltage to between 12V and 20V to reduce heat generation. In the event of a software or control failure applying full 24V continuously, the valve may become hot enough to cause discomfort or minor burns upon contact. To mitigate this, users will be warned in training and documentation not to touch energised valves during operation. Thermal insulation or physical card will also be added for additional protection.
Incorrect Power Supply Used or Incorrect Voltage applied. This could damage the components and be a hazard should they use mains voltage.	2	4	8	We have used a DC barrel jack for our power input, which mitigates against someone trying to input 240V IEC connector. We will label the power input as 24V only. We will also attach a 4A fuse internally in the product to additionally mitigate against incorrect power input.
Continuous system operation may cause a gradual rise in tank water temperature due to pump circulation and component heat. If left unchecked, water temperature may exceed safe limits for touch in an educational environment, presenting a potential scald	3	2	6	A software-configurable high-temperature cutout is being added, set to trigger system shutdown at 40°C. This provides a 5–10°C safety buffer before approaching regulated temperature limits for touch safety in educational settings. Visual warning will be shown on the HMI when the high-temperature threshold is reached. This configurable setting will be permitted to be lowered but not increased above 40 degrees.

Appendix C – Risk Assessment Summary

or discomfort risk.				
Emergency stop does not physically cut power and the system relies on non-safety-rated PLC logic for stop function (pseudo E-Stop). In a real emergency, someone may press it expecting full shutdown, but it may fail.	2	2	4	Although the E-Stop is software-based, the system operates at 24V with built-in short circuit and overload protection, plus a circuit breaker. The pump and valve are not capable of producing work to any dangerous/harmful levels. The E-Stop will be clearly labelled as non-safety-rated. Documentation and training will reflect this limitation. Dual-channel monitoring of the E-stop circuit will be implemented in the PLC logic to detect wiring faults such as open circuit conditions on either channel. Each channel will be read independently, and the system will trigger a fault if either channel opens. This approach simulates dual-channel safety logic for non-safety applications and educational purposes only, and does not provide certified safety integrity.
Pump runs dry due to float switch failure or wiring issue	2	2	4	The pump was selected to tolerate dry running without immediate damage. If run dry, they may overheat but not dangerously. The system includes a circuit breaker and protected PSU. Redundant float switch monitoring and fault detection will be implemented where possible.
Software updates overwrite PID parameters or offsets, causing instability	1	1	1	While theoretically possible, the likelihood is low. Most users will not modify PID parameters. Even if incorrectly configured, the system may exhibit instability but not dangerous behaviour. Defaults will be backed up and documentation will guide proper restoration.
Incorrect wiring during setup causes short circuit or component failure	3	1	3	The system runs on a 24V supply with built-in protection, so risk is limited. However, clear wiring diagrams and setup guides will be provided. All staff will be trained to safely wire the system and test it before operation.
Valve sticks or fails to respond to control signal, leading	2	1	2	Valve sticking is possible but impact is minimal. If it occurs, the pump may overcompensate against a closed valve, which the system is designed to tolerate.

Appendix C – Risk Assessment Summary

to overshoot or flow error				Manual and software diagnostics will help identify such behaviour quickly.
Exposed terminals or connectors pose shock hazard	2	1	2	All terminals operate at 24V DC. While electrical contact may cause small, harmless sparks, there is no shock hazard. Clear labelling and optional covers will be included to guide safe interaction.

	SEVERITY				
	1	2	3	4	5
1	LOW 1	LOW 2	LOW 3	MEDIUM 4	MEDIUM 5
2	LOW 2	MEDIUM 4	MEDIUM 6	HIGH 8	HIGH 10
3	LOW 3	MEDIUM 6	HIGH 9	HIGH 12	EXTREME 15
4	MEDIUM 4	HIGH 8	HIGH 12	HIGH 16	EXTREME 20
5	MEDIUM 5	HIGH 10	EXTREME 15	EXTREME 20	EXTREME 25

Severity Ratings (Aligned to EN ISO 12100 / 13849 Concepts)

Severity	Description	Example from EN ISO/IEC Frameworks
1 – Negligible	No injury or only superficial injury, no equipment damage	Minor spark, no hazard; operator startled but unharmed
2 – Minor	Slight injury requiring first aid; minor equipment damage	Small burn, mild shock, or overshoot of flow without consequence
3 – Moderate	Injury requiring medical treatment; moderate equipment downtime	Overheated valve or minor electrical fire (contained)
4 – Serious	Serious injury (e.g., fracture), possible hospital stay; equipment disabled	Unexpected motion or system failure causing entrapment risk
5 – Critical	Fatal or life-altering injury; catastrophic system damage	Contact with mains voltage, high-pressure rupture, etc.

This risk assessment uses a Likelihood × Severity matrix to evaluate hazards associated with the product. Likelihood (1–5) reflects the probability of occurrence, while Severity (1–5) reflects the potential impact. Their product gives a Risk Rating (1–25). Risk levels are categorised as Low (1–3), Medium (4–6), High (8–12), or Extreme (15–25), helping to determine the appropriate level of response. Control measures detailed in the Response column include design features, documentation, labelling, and training, ensuring proportionate risk management while acknowledging the non-safety-rated nature of the PLC system.

Appendix D – CE Declaration

APPENDIX D – CE DECLARATION

EU Declaration of Conformity

Manufacturer: **Matrix Technology Solutions Ltd**
The Factory, 33 Gibbet Street, Halifax, West Yorkshire, HX1 5BA
United Kingdom

Product Description: **Industrial Maintenance Closed Loop PID Control System**
Model: **IM0004**
Comprising: Siemens S7-1200 PLC, Siemens Unified Basic HMI, water pump, proportional control valve, turbine-type flow sensor, analogue flow gauge, IFM temperature sensor, dual float switches (high/low cut-off), tank lid proximity sensor. The system is integrated into a modular training rig designed specifically for educational environments to teach fault detection, troubleshooting, and maintenance in industrial closed-loop systems.

Serial Numbers / Batch Numbers: **IM0004**

We hereby declare under our sole responsibility that the above-mentioned product conforms to the following applicable Directives:

- Low Voltage Directive (2014/35/EU)
- Electromagnetic Compatibility (EMC) Directive (2014/30/EU)
- RoHS Directive (2011/65/EU as amended by 2015/863)

Applied Harmonised Standards:

- EN 61010-1:2010 – Safety requirements for electrical equipment for measurement, control, and laboratory use
- EN 61000-6-2:2019 – EMC Immunity for industrial environments
- EN 61000-6-4:2019 – EMC Emission for industrial environments

Technical Documentation Includes:

- Product description and intended educational use
- Circuit diagrams and wiring schematics
- Bill of Materials (BOM)
- Electrical and functional test reports
- Risk identification summary (non-machinery scope)
- Manufacturer's component declarations and CE certificates
- User manual and safety instructions

This declaration is made in accordance with the above Directives and is valid only when the product is installed, maintained, and used according to the accompanying documentation.

Technical File Contact: Liam Walton liam.walton@matrixtsl.com

Authorised Signatory:
Name: Hamed Adefuwa
Position: Electrical Engineering Product Manager
Place of Issue: Halifax, UK
Date of Issue: 03/05/2025
Signature: H.Adefuwa

VERSION CONTROL

20 05 25	First Revision Created

