Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Design and Implementation of an Automated Oil Transfer Monitoring and Control System Using PLC Technology

By David Mathew Lewis

Supervisor: Dr. Olubenga Olubodun
Second Marker: Dr. Jenifer Prince Devaraj

Project submitted as part of the requirements for the award of BEng (Hons) Electrical and Electronic Engineering

01st May, 2026

DECLARATION

I, David Mathew Lewis declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

FORM OF CONSENT

I, David Mathew Lewis hereby consent that my Project, submitted in candidature for the Electrical & Electronic Engineering degree, if successful, may be made available for inter-library loan or photocopying (subject to the law of copyright), and that the title and abstract may be made available to outside organisations.

Abstract

This project presents the design, implementation, and commissioning of an automated oil transfer monitoring and control system developed for SSE at Resolven, Neath. The system addresses the limitations of conventional manual oil transfer operations, which lack real-time monitoring, automated fault detection, and structured sequence control. A Siemens S7-1212C Programmable Logic Controller (PLC) was selected as the primary control platform, programmed in Ladder Diagram (LAD) using a modular Function Block architecture within Siemens TIA Portal v17.

The system serves two bunded oil storage tanks — one for transformer oil (Metcraft A8442, 11,883L usable capacity) and one for RMU oil — providing automated bidirectional oil transfer via a Motek EM80B-4 0.75kW three-phase motor and DOL forward/reverse contactor circuits. IFM Electronic UGT813 ultrasonic level and SU8030 clamp-on ultrasonic flow sensors were selected, communicating via IO-Link (IEC 61131-9) through an IFM AL1100 master module. Instrumentation selection was informed by comparative analysis against equivalent products from Siemens, Endress+Hauser, and Keyence, with IFM instruments offering comparable technical performance at significantly lower cost. A twelve-condition alarm and fault detection system was implemented following ISA-18.2 alarm management principles, incorporating timer-based confirmation delays to prevent nuisance tripping. A Siemens SIMATIC HMI touch panel provides operator control and real-time process visualisation.

Commissioning testing confirmed that all twelve alarm conditions operated correctly with zero false trips, the setpoint-based auto-stop sequence achieved accuracy within 0.3L, and IO-Link sensor diagnostic flags responded within a single PLC scan cycle. The completed system is currently installed and operational at the SSE Resolven site, demonstrating that a cost-effective, modular PLC-based architecture can deliver a professional-grade industrial oil transfer monitoring solution suitable for real-world deployment.

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1. Introduction

Efficient and reliable fluid transfer systems are essential in industrial sectors such as water treatment, oil and gas, and chemical processing. Oil transfer systems are widely used to transport fluids between storage, processing, and distribution stages, where maintaining control over flow, pressure, and volume is critical for safe and efficient operation. However, many conventional systems rely on basic control strategies with limited real-time monitoring, increasing the risk of inefficiencies, undetected faults, and operational failures [1].

Programmable Logic Controllers (PLCs) are widely adopted in industrial automation due to their robustness, reliability, and ability to operate in real-time environments [2]. PLC-based systems provide a structured and scalable approach to process control, enabling precise management of pumps, valves, and sensors within fluid transfer applications [3]. Modern PLC systems can also integrate monitoring and diagnostic functions, allowing operators to respond quickly to abnormal conditions [4].

Despite these capabilities, there remains a need for improved integration of monitoring, control, and fault detection within oil transfer systems. Many existing implementations lack advanced diagnostic features or rely heavily on manual intervention, which can result in delayed fault identification and reduced system efficiency [5]. Additionally, smaller-scale or modular systems often require cost-effective solutions that maintain industrial reliability without excessive complexity.

This project designed and developed an automated oil transfer monitoring and control system using PLC technology for SSE at Resolven, Neath. The system serves two oil storage tanks — one for transformer oil and one for RMU oil — with a single pump providing bidirectional oil transfer between the storage tanks and the associated equipment. The system incorporates IFM IO-Link flow and level sensors to enable real-time monitoring of system conditions [6]. Control logic implemented within the Siemens S7-1212C PLC regulates pump operation, ensures safe transfer of fluid, and responds to system changes dynamically [7]. The system also includes comprehensive fault detection mechanisms to identify abnormal conditions such as sensor failures, incorrect flow direction, or pump faults [8].

The primary aim was to develop a reliable and efficient PLC-based control system that enhances the performance and safety of oil transfer operations. This was achieved by analysing existing systems, designing and implementing a fully commissioned industrial control panel, and evaluating its performance under operational conditions. The system incorporates structured PLC programming techniques including function blocks for motor control, alarm handling, and instrumentation processing, to ensure modularity, scalability, and reliability [9].

2. Literature Review

Fluid transfer systems are fundamental components in industrial processes, particularly within the oil and gas, water treatment, and chemical industries. These systems are responsible for the controlled movement of fluids between storage, processing, and distribution units. Traditionally, oil transfer systems have relied on manual operation or basic control strategies, which often lack real-time monitoring and fault detection capabilities, leading to inefficiencies and increased risk of system failure [10].

With the advancement of industrial automation, Programmable Logic Controllers (PLCs) have become the dominant technology for process control in fluid transfer applications. PLC-based systems provide high reliability, deterministic control, and the ability to operate in harsh industrial environments. According to Bolton [1], PLCs are widely used in industrial automation due to their robustness and flexibility in controlling sequential and continuous processes. Their ability to interface with sensors and actuators makes them particularly suitable for oil transfer systems where parameters such as flow rate, pressure, and tank level must be continuously monitored and controlled.

Several studies have explored the implementation of PLC-based control systems in fluid handling applications. Khandare et al. [11] developed an automated liquid level control system using PLC and SCADA, demonstrating improved system efficiency and reduced manual intervention. Similarly, Patil and Patil [12] designed a PLC-controlled pumping system for industrial fluid transfer, highlighting the benefits of automation in reducing operational errors and enhancing system reliability. Petrescu et al. [13] further demonstrated the effectiveness of PLC-based automation in pipeline control, showing significant improvements in operational safety and efficiency over manual systems.

In addition to control, monitoring plays a critical role in ensuring system safety and performance. Supervisory Control and Data Acquisition (SCADA) systems are often integrated with PLCs to provide real-time visualisation and data logging [14]. As discussed by Boyer [15], SCADA systems enable operators to monitor system variables, detect anomalies, and make informed decisions. However, the implementation of SCADA can introduce additional cost and complexity, which may not be suitable for smaller-scale or modular systems. The Human-Machine Interface (HMI) provides a more compact alternative for operator interaction in smaller systems, as discussed by Proctor et al. [16].

Ultrasonic measurement technology has been widely studied for both level and flow measurement in industrial applications. Wang et al. [17] presented a comprehensive review of ultrasonic level measurement methods, identifying non-contact ultrasonic sensing as particularly suitable for hazardous liquids due to the absence of wetted parts. For flow measurement, Baker [18] demonstrated that clamp-on ultrasonic flow sensors provide accurate, non-invasive measurement suitable for a wide range of fluid types including oils, without requiring process shutdown for installation. These findings directly support the instrumentation approach adopted in this project.

Recent research has focused on enhancing fluid transfer systems through the integration of sensor networks and intelligent monitoring techniques. Sharma et al. [19] proposed a sensor-based monitoring system for pipeline leakage detection, demonstrating improved fault detection capabilities. Similarly, research by Ahmed et al. [20] investigated pressure and flow-based fault detection methods, showing that combining multiple sensor inputs can significantly improve system reliability. The ISA-18.2 standard [21] provides widely adopted guidance on industrial alarm management, recommending timer-based confirmation and rationalisation of alarm conditions to minimise nuisance tripping — an approach directly implemented in the FC_Alarms function call of this project.

The emergence of IO-Link as a standardised point-to-point digital communication protocol (IEC 61131-9 [22]) has significantly advanced the capability of field-level instrumentation. Heynicke et al. [23] demonstrated the advantages of IO-Link in factory automation, highlighting its ability to transmit multiple process variables, device parameters, and diagnostic data over a simple 3-wire cable. Vitturi et al. [24] further examined industrial communication systems, noting that digital sensor protocols such as IO-Link provide substantially richer diagnostic information than conventional analogue signals, improving system maintainability. These advantages are consistent with the performance observed during commissioning of the system described in this report.

Motor efficiency and selection criteria for industrial pump applications have been extensively studied. Almeida et al. [25] reviewed the impact of motor efficiency classes on industrial energy consumption, noting that while IE3 premium efficiency motors offer improved efficiency, IE1 motors remain appropriate for intermittent duty applications where running hours are low. This finding supports the selection of the Motek EM80B-4 IE1 motor for this batch-duty oil transfer application. Hughes and Drury [26] provide comprehensive guidance on three-phase induction motor selection and DOL starting characteristics applicable to this project.

Despite these advancements, a number of limitations remain in existing oil transfer and fluid control systems. Many studies focus primarily on either control or monitoring, rather than integrating both into a unified system [27]. While advanced monitoring techniques such as IoT-based systems have been proposed [27], these solutions often require complex infrastructure and may not be practical for industrial environments where reliability and simplicity are critical [28]. Furthermore, there is limited research on the development of compact, cost-effective PLC-based systems that incorporate both automated control and fault detection within a single platform, highlighting a gap that this project addresses.

A critical comparison of the approaches identified in the literature reveals several important distinctions relevant to this project. The PLC-based systems described by Khandare et al. [11] and Patil and Patil [12] both rely on conventional 4–20 mA analogue instrumentation, which provides only a single process variable per sensor with no diagnostic capability. While these systems demonstrate the viability of PLC-based fluid control, they do not address the challenge of sensor health monitoring — a limitation that became apparent in the fault conditions identified by Ahmed et al. [20]. The approach adopted in this project, using IO-Link digital communication [22], directly addresses this limitation by providing real-time sensor diagnostic flags alongside process data, without requiring additional hardware.

The alarm management approaches described in the literature also vary considerably in rigour. Several studies, including Sharma et al. [19], implement simple threshold-based alarms without any confirmation delay or rationalisation process. This approach risks nuisance tripping in industrial environments where transient process variations are common. The ISA-18.2 standard [21] explicitly identifies this as a significant cause of operator alarm fatigue and recommends timer-based confirmation as a minimum requirement. This project's implementation of TP timer confirmation delays for all transient alarm conditions represents a more robust approach than that described in many comparable academic studies.

It is also worth noting that the majority of PLC-based fluid control studies identified in the literature are laboratory-based implementations or simulations, rather than live industrial installations. This limits their external validity — results obtained in controlled laboratory conditions may not reflect the challenges of real-world commissioning, including electrical noise, mechanical variability, and the constraints of working within an operational industrial site. The system described in this report was designed, built, and commissioned as a live industrial installation for SSE at Resolven, providing a higher degree of practical validity than laboratory-based alternatives.

This project addressed this gap by designing and implementing a PLC-based oil transfer monitoring and control system that integrates real-time sensing, automated control, and fault detection within a single, scalable solution. By focusing on a practical and implementable design for a real industrial installation, this research contributes to the development of efficient and reliable fluid transfer systems suitable for industrial applications.

3. Methodology

3.1 System Overview

The methodology adopted for this project follows a system design and development approach, focusing on the implementation of a PLC-based oil transfer system with integrated monitoring and fault detection capabilities. The system was designed and delivered as a real industrial installation for SSE at Resolven, Neath, incorporating real-time control, sensor feedback, and safety mechanisms consistent with industrial best practice [3].

The overall system consists of the following key components:

- Two bunded oil storage tanks — one for transformer oil (Metcraft A8442, 11,883L usable) and one for RMU oil
- A centrifugal pump driven by a Motek EM80B-4 0.75kW three-phase motor, controlled via DOL forward/reverse circuits
- A Programmable Logic Controller (PLC) — Siemens S7-1212C — for system control and automation [7]
- IFM IO-Link instruments for real-time flow and level monitoring [6]
- Comprehensive alarm and fault detection logic based on ISA-18.2 principles [21]
- A Siemens SIMATIC HMI touch panel for operator interaction [16]

3.2 Control System Architecture

A modular programming approach has been adopted using Function Blocks (FBs) and Function Calls (FCs) within Siemens TIA Portal v17. This approach improves code reusability, readability, and maintainability, as recommended by Stenerson [9] and Groover [29]. The control system is divided into three primary layers:

3.2.1 Motor Control Layer

The motor control logic is implemented using a dedicated Function Block for Direct-On-Line (DOL) motor operation, managing forward and reverse operation, start/stop sequencing, interlocks, and fault detection. The use of a reusable function block ensures consistency in control logic and enables scalability for multiple pump systems [3].

3.2.2 Instrumentation and Data Acquisition Layer

Instrumentation is implemented using IO-Link-compatible IFM sensors [6], allowing for real-time acquisition of process data including level, flow rate, direction, and device health status. Sensor data is processed and scaled within the PLC to provide meaningful engineering values such as litres and L/min [23].

3.2.3 Alarm and Fault Detection Layer

A comprehensive alarm system is implemented following ISA-18.2 [21] alarm management principles. Timer-based confirmation delays prevent nuisance tripping, while IO-Link

diagnostic flags provide immediate sensor health monitoring without additional hardware [24].

3.3 Requirements Analysis

Prior to commencing the design of the control system, a requirements analysis was carried out to identify the functional and non-functional requirements of the system. Functional requirements were derived from discussions with the client (SSE) and OCU Hornbill's project engineering team, and included the need for bidirectional oil transfer between storage tanks and associated transformer and RMU equipment, automated sequence control with operator-defined volume setpoints, real-time monitoring of flow rate and tank level, and a comprehensive fault detection and alarm system to protect equipment and personnel.

Non-functional requirements included the need for the system to conform to industrial standards for panel construction and electrical installation, compatibility with the site's existing Siemens automation infrastructure, cost-effectiveness in instrumentation selection, and ease of operator use through a clear HMI interface. The requirement for the transformer oil tank to incorporate independent overfill protection for tanker operators was identified as a specific safety-critical requirement, addressed through the inclusion of an OPV (Overfill Protection Valve) on the tank fill connection.

3.4 Design Process

The design process followed a structured top-down approach, beginning with the overall system architecture before progressing to detailed hardware selection and software design. The system architecture was defined first, establishing the three-layer control structure described in Section 3.2. Hardware selection followed, with each major component evaluated against the defined requirements through comparative analysis — as documented in the comparison tables in Section 4. Software design was then carried out iteratively within Siemens TIA Portal, with individual function blocks developed and tested in isolation before integration into the complete program.

A key design principle throughout was modularity — ensuring that each element of the system (motor control, instrumentation processing, alarm detection) was encapsulated in its own Function Block or Function Call, with clearly defined inputs and outputs. This approach, consistent with IEC 61131-3 structured programming principles [9], facilitates independent testing of each module and simplifies future maintenance or expansion of the system.

Testing was carried out in two phases: bench testing of the control panel prior to site installation, during which all PLC logic, interlocking, and HMI functionality was verified using simulated inputs; and site commissioning, during which the system was tested with live instrumentation and the actual pump and pipework. This phased approach ensured that any software or wiring issues were identified and resolved in a controlled environment before the system was energised on site.

3.5 Ethical and Safety Considerations

The system was designed and installed in accordance with applicable industrial standards, including BS 7671 (IET Wiring Regulations) for electrical installation, and BS 799 Part 5 for the bunded oil storage tank [30]. Operational safety was addressed through the comprehensive interlock and alarm system described in Section 4.5.3, which prevents unsafe pump operation under a range of fault conditions. The independent overfill protection on the transformer oil tank provides an additional layer of safety independent of the PLC system, ensuring that tanker operators are protected even in the event of a control system failure.

4. Design & Implementation

4.1 System Overview and High-Level Control Flowchart

The oil transfer monitoring and control system was designed and built as a fully functional industrial control panel, manufactured by OCU Hornbill for SSE at Resolven, Neath (Project 25.SC.435, Serial 8741). The panel is housed in a Rittal mild steel enclosure (Part No. 1057000) measuring 700mm tall. The system serves two oil storage tanks: the transformer oil tank (Metcraft A8442 — 11,883L usable, double skinned to BS 799 Part 5 Type J [30]) and the RMU oil tank. A single Motek EM80B-4 pump motor provides bidirectional oil transfer, running forward to empty oil from a transformer or RMU into the storage tank, and in reverse to refill equipment from storage.

The high-level control flow is shown in Figure 1 below:

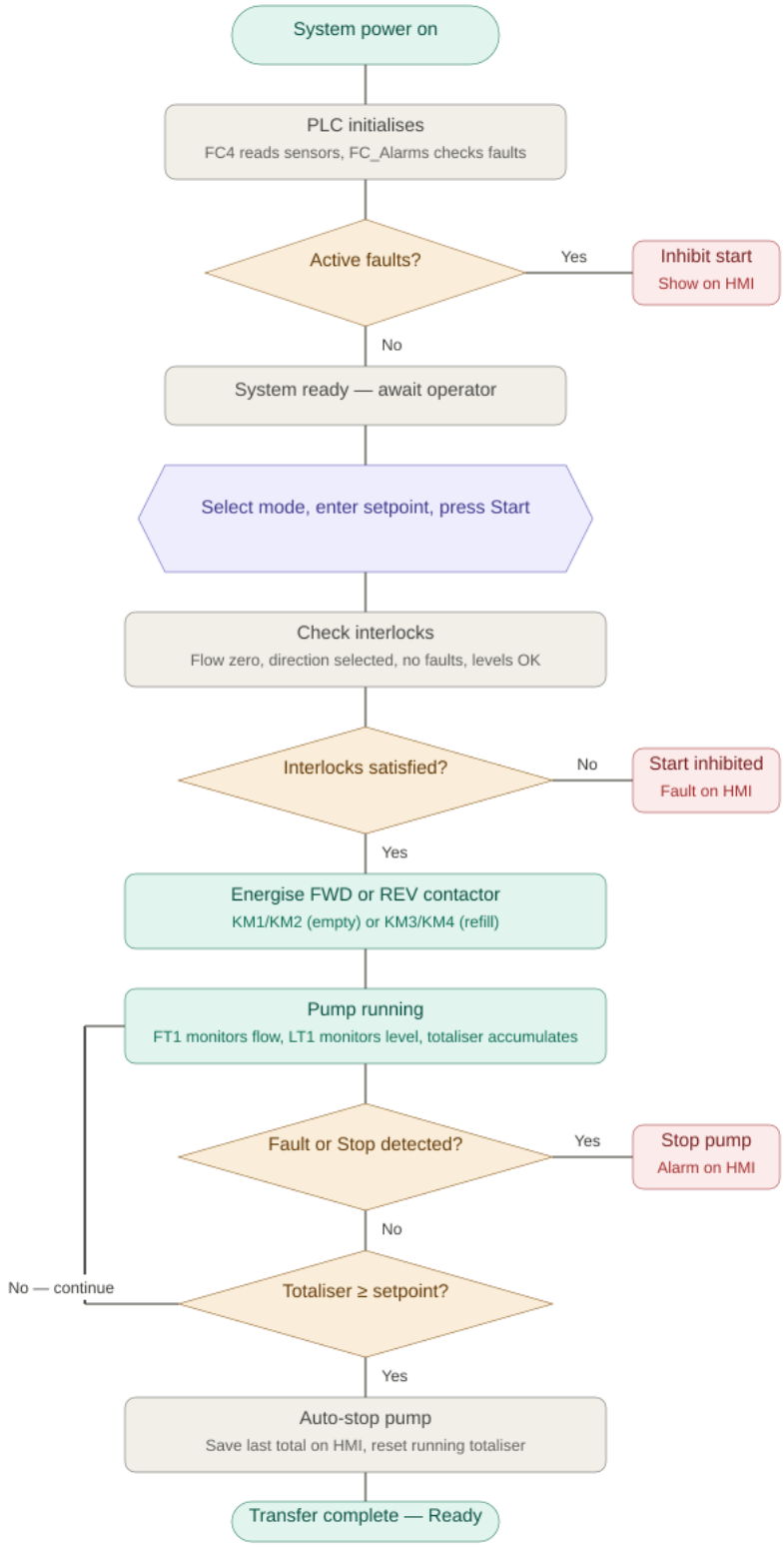


Figure 1 - High-level control flowchart.

4.2 Hardware Selection and Component Design

4.2.1 PLC — Siemens S7-1212C

The Siemens SIMATIC S7-1212C (CPU DC/DC/Relay) was selected as the primary controller for its compact footprint, native integration with Siemens TIA Portal v17, and support for IO-Link master modules [7]. The relay output variant directly drives the motor contactor coils without interposing relays, reducing panel complexity. The S7-1200 series is well-established in industrial automation for small-to-medium control applications [3].

4.2.2 HMI — Siemens SIMATIC HMI

A Siemens SIMATIC HMI touch panel was integrated into the panel door, providing operators with a clear interface for system control and monitoring [16]. The HMI communicates with the PLC over the onboard PROFINET port, with all operator commands and status displays handled within the PLC program, with the HMI acting purely as a visualisation and input layer.

4.2.3 Motor Selection — Motek EM80B-4

The Motek EM80B-4 three-phase induction motor was selected to drive the oil transfer pump, rated at 0.75 kW, 4-pole, 1420 rpm, 400V 50Hz, with IP55 (TEFC) enclosure, Class F insulation, B5 flange mounting, and 5.04 Nm rated torque [26]. Motor selection was based on matching the required pump power rating at minimum cost for an intermittent batch-duty application [25]:

Criterion	Motek EM80B-4 (Selected)	Brook Crompton W-DE80M4	TEC IE3 80MB4	WEG W22 80M 4P
Power Rating	**0.75 kW (1 HP)**	0.75 kW	0.75 kW	0.75 kW
Efficiency Class	**IE1 (Standard)**	IE3 (Premium)	IE3 (Premium)	IE3 (Premium)
Poles / Speed	**4 pole / 1420 rpm**	4 pole / 1455 rpm	4 pole / 1455 rpm	4 pole / 1455 rpm
Enclosure	**IP55 — TEFC**	IP55 — TEFC	IP55 — TEFC	IP55 — TEFC
Insulation Class	**Class F**	Class F	Class F	Class F
Mounting	**B5 flange**	B3/B14 foot/flange	B3/B14 foot/flange	B3/B14 foot/flange
Rated Torque	**5.04 Nm**	4.9 Nm	4.9 Nm	4.9 Nm
Approx. Cost (2025)	**£150–£200**	£250–£350	£180–£260	£220–£300
Overall Suitability	**★★★★★ Correct rating, lowest cost**	★★★★☆ Higher cost, IE3 over-spec	★★★★☆ Slightly higher cost	★★★★☆ Higher cost

Table 1 - Motor selection comparison.

As shown in Table 1, alternative motors from Brook Crompton, TEC, and WEG offer IE3 premium efficiency, which provides 5–10% improved efficiency over IE1 [25]. However, for a 0.75 kW motor on an intermittent batch transfer duty cycle, the energy cost differential is negligible in practice, and the higher purchase price of IE3 motors was not justified for this application. The Motek EM80B-4 provides the correct rating and mounting configuration at a lower cost.

4.2.4 Motor Control — DOL Forward/Reverse Circuits

Two Direct-On-Line (DOL) motor control circuits were designed for the transfer pump [26], enabling both forward (empty) and reverse (refill) operation. Each circuit comprises motor circuit breakers (QM1, QM2), two contactors with mechanical and electrical interlocking

(KM1/KM2 and KM3/KM4), and auxiliary contact feedback to PLC digital inputs (%I0.2, %I0.3) for contactor status monitoring [3].

4.2.5 IO-Link Master — IFM AL1100

An IFM AL1100 IO-Link master module interfaces the IFM instruments with the Siemens S7-1212C. The AL1100 provides four IO-Link ports, with device data mapped into a dedicated data block (%DB2) within TIA Portal [6]. This allows all sensor process values, diagnostic flags, and device parameters to be accessed directly from the PLC program without additional gateways [23].

4.2.6 Oil Storage Tanks

The transformer oil storage system uses a bespoke fabricated bunded tank supplied by Metcraft Group Ltd (Drawing A8442-8580 REV01). The tank has a usable capacity of 11,883 litres, double-skinned to BS 799 Part 5 Type J [30], constructed from 5mm mild steel with a Cromadex primer and RAL 6005 Moss Green topcoat finish. The tank incorporates an OPV (Overfill Protection Valve) on the fill connection protecting tanker operators during deliveries, an OLE gauge and independent 3-level alarm system, and an offset fill point with drip tray. A separate bunded tank serves the RMU oil system, connected via common 1″ grey PVC pipework with independently isolatable ball valves.

4.3 Instrumentation Selection

Instrument selection was based on technical capability, IO-Link compatibility, and cost-effectiveness [23]. IFM Electronic instruments were selected due to their competitive pricing and native IO-Link communication. The following subsections present the comparative analyses that informed these decisions.

4.3.1 Level Measurement — IFM UGT813

The IFM UGT813 ultrasonic level sensor was selected for tank level measurement. Ultrasonic non-contact measurement requires no process wetted parts, making it suitable for transformer oil and eliminating contamination risk [17]:

Criterion	IFM UGT813 (Selected)	Siemens SITRANS LU240	E+H Prosonic S FMU90	Keyence FU-35FA
Measurement Principle	**Ultrasonic (non-contact)**	Ultrasonic (non-contact)	Ultrasonic (non-contact)	Ultrasonic (non-contact)
Communication	**IO-Link (digital, bidirectional)**	4–20 mA / HART / Profibus PA	4–20 mA / HART / FF	Analogue 4–20 mA / NPN
TIA Portal Integration	**Native — IFM FBs available**	Native Siemens integration	Requires HART modem/gateway	Manual analogue scaling
Diagnostics	**Full IODD: OL, UL, NoData flags**	HART diagnostics available	Extensive HART/FF diagnostics	Limited — analogue only
Approx. Unit Cost (2025)	**£150–£250**	£400–£600	£500–£900	£200–£350
Wiring	**3-wire IO-Link — single cable**	Multi-core, loop-powered	Multi-core, bus powered	3-wire analogue
Suitable for Oil	**Yes**	Yes	Yes	Yes

Overall Suitability	**★★★★★ Cost-effective, native IO-Link**	★★★★☆ Higher cost	★★★☆☆ High cost, gateway needed	★★★☆☆ Limited diagnostics

Table 2 - Level sensor comparison — selected option (IFM UGT813) highlighted.

The IFM UGT813 offers comparable technical specification to the Siemens SITRANS LU240 at approximately 40–60% of the cost. Native IO-Link communication provides bidirectional digital data including distance, scaled level, and full diagnostic status flags (OL, UL, NoData) directly to the PLC [6]. The sensor is scaled within the PLC using FB5 (Level Sensor Scaling), converting raw distance into volumetric level and percentage [17].

4.3.2 Flow Measurement — IFM SU8030

The IFM SU8030 clamp-on ultrasonic flow sensor was selected for oil flow measurement. A clamp-on installation avoids wetted parts in contact with transformer oil, enabling non-invasive installation without process isolation [18]:

Criterion	IFM SU8030 (Selected)	Siemens SITRANS F US	E+H Proline Prosonic Flow	Keyence FD-Q Series
Measurement Principle	**Clamp-on Ultrasonic**	Clamp-on Ultrasonic	Clamp-on Ultrasonic	Clamp-on Ultrasonic
Communication	**IO-Link (digital, bidirectional)**	4–20 mA / HART / Profibus	4–20 mA / HART / Modbus	4–20 mA / IO-Link (select)
TIA Portal Integration	**Native — IFM FBs, IODD**	Native Siemens integration	HART modem/gateway required	Manual or IO-Link add-on
Output Data	**Flow L/min, L/h, m/s, totaliser, status**	Flow rate, totaliser, velocity	Flow rate, totaliser, diag.	Flow rate, accumulated total
Diagnostics	**OL, UL, NoData, SSC outputs**	HART diagnostics	Extensive HART diagnostics	Limited on analogue models
Approx. Unit Cost (2025)	**£300–£500**	£800–£1,500	£900–£2,000	£400–£700
Suitable for Oil	**Yes — clamp-on, no fluid contact**	Yes — clamp-on	Yes — clamp-on	Yes — clamp-on
Overall Suitability	**★★★★★ Cost-effective, IO-Link native**	★★★★☆ 3–4× higher cost	★★★☆☆ High cost, gateway	★★★☆☆ Limited diagnostics

Table 3 - Flow sensor comparison — selected option (IFM SU8030) highlighted.

The IFM SU8030 delivers simultaneous flow rate in multiple engineering units (L/min, L/h, m/s), a raw pulse totaliser, and a full suite of status and switching outputs over IO-Link [6]. A dedicated flow unit conversion Function Call (FC302) processes the raw IO-Link data into required engineering units [18].

4.3.3 Communication Protocol — IO-Link

IO-Link (IEC 61131-9 [22]) was selected as the sensor communication protocol over conventional 4–20 mA analogue, HART, or Profibus PA alternatives [24]:

Criterion	IO-Link (Selected)	4–20 mA Analogue	HART	Profibus PA
Signal Type	**Digital (bidirectional)**	Analogue current loop	Analogue + digital overlay	Digital fieldbus
Data per Device	**Multiple values, parameters, status**	Single variable only	PV + limited HART data	Multiple variables
Diagnostics	**Full IODD: health, OL/UL, NoData**	None — signal level only	Limited messages	Extensive diagnostics
Wiring	**Standard 3-wire unshielded, up to 20m**	2-wire shielded required	2-wire shielded required	Bus cable + terminators
Parameterisation	**Remote via IO-Link master / TIA Portal**	Manual local only	HART handheld/modem	Fieldbus config tools
Noise Immunity	**High — digital, immune to EMI**	Susceptible to noise	Moderate	High — digital
PLC Integration (S7-1200)	**Native — IO-Link master module**	Analogue input module	HART modem/gateway	Additional Profibus module
Relative Cost	**Low — standard cable, no extra HW**	Low — simple wiring	Moderate — modem needed	High — extra module + bus
Overall Suitability	**★★★★★ Digital, low cost, native**	★★★☆☆ No diagnostics	★★★★☆ Requires extra HW	★★★☆☆ Over-specified

Table 4 - Communication protocol comparison — selected option (IO-Link) highlighted.

IO-Link provides fully digital bidirectional communication immune to electrical noise, which is particularly important in a panel environment alongside motor contactors [23]. Each sensor transmits multiple process variables over a single standard 3-wire unshielded cable, and remote parameterisation via TIA Portal allows sensor setpoints to be adjusted without physical access to the instrument [24].

4.4 Project Materials and Cost Summary

The following table presents the key materials and equipment procured for the project, based on actual purchase ledger data (OCU Hornbill Project HB02_0008_137) and estimated 2025 UK list prices where individual component costs were not separately recorded. All figures are approximate and exclude VAT, labour, and installation costs.

Item / Description	Supplier	Qty	Approx. Cost (ex VAT)
TANKS & CIVIL			
Metcraft bespoke bunded transformer oil tank (A8442) — 11,883L usable, double skinned BS799 Pt5 Type J, OPV fill, OLE gauge, 3LA	Metcraft Group Ltd	1	~£22,000
RMU oil storage tank (bunded)	TBC	1	TBC
Rittal mild steel enclosure (Part No. 1057000), 700mm	Rittal	1	~£500
Siemens SIMATIC S7-1212C CPU DC/DC/Relay	Siemens	1	~£450
Siemens SIMATIC KTP700 HMI touch panel	Siemens	1	~£750

IFM AL1100 IO-Link master module	IFM Electronic	1	~£280
Motor circuit breakers QM1, QM2 (MPCB)	Various	2	~£120
Contactors KM1, KM2, KM3, KM4	Various	4	~£160
Safety relay SR1	Various	1	~£80
24V DC PSU (PSU1)	Various	1	~£60
Main isolator Q1	Various	1	~£45
DIN rail, 40mm trunking, cable, terminals, glands, labels	RS Components	Lot	£372
LED indicator panels 22.3mm	Premier Farnell	Various	£136
Snap rivets, RJ45 connectors, sundry fixings	RS Components	Lot	£224
INSTRUMENTATION			
IFM UGT813 ultrasonic level sensor	IFM Electronic	1	~£200
IFM SU8030 clamp-on ultrasonic flow sensor	IFM Electronic	1	~£400
IFM flow sensor mounting adapter (G1, 316L SS)	IFM Electronic	1	£58
IFM connection cables (5m PUR)	IFM Electronic	2	£16
Motek EM80B-4 — 0.75kW, 4-pole, IE1, TEFC, IP55, B5 flange	Motek Motors	1	~£175
1" Grey PVC pipe (Class E), ball valve, elbows, unions, nipples, fittings	RS Components / IPS Southern	Lot	~£192

Table 5 - Project materials and equipment cost summary.

The total estimated materials cost of approximately £26,200 is dominated by the bespoke Metcraft tank fabrication. The control panel, instrumentation, and motor represent a relatively modest proportion, reflecting the cost-effective component selection described in Sections 4.2 and 4.3. Labour, design, commissioning, and installation costs are excluded as they form part of OCU Hornbill's project delivery costs.

4.5 PLC Software Design

The PLC software was developed in Siemens TIA Portal using Ladder Diagram (LAD) language, structured into a modular hierarchy of Function Blocks (FBs) and Function Calls (FCs) as recommended by Stenerson [9] and Groover [29]. The full program structure is shown in Appendix A — PLC Ladder Logic Exports.

4.5.1 DOL Motor Control Function Block (FB — FB_DOL_Motor)

A reusable Function Block encapsulates all DOL motor drive logic [3], managing:

- Forward and reverse run commands (%Q0.0 FWD Contactor, %Q0.1 REV Contactor)
- Contactor feedback monitoring via auxiliary contacts (%I0.2, %I0.3)
- A ten-input interlock matrix inhibiting motor starting under unsafe conditions
- Contactor failure detection using a 5-second TON timer raising %M20.4
- Motor state output for HMI graphics: stopped (1), fault (2), running FWD (3), running REV (4), starting (103)

4.5.2 Tank Instrumentation Function Call (FC4 — Tank 1 Instruments)

FC4 reads and processes all sensor data for Tank 1 [6]:

- Network 1: IFM FC123 reads UGT813 level sensor from %ID68 into %DB2
- Network 2: FB5 scales raw distance to litres (%MD258) and percentage (%MD313)
- Network 3: IFM FC125 reads SU8030 flow sensor from IO-Link master into %DB2
- Network 4: FB2 converts raw pulse input (%ID73) to absolute totaliser in litres (%MD238)
- Network 5: FC302 converts raw flow value to L/min (%DB2.DBD1742), L/h, and m/s
- Networks 6/7: Manages totaliser reset (%Q64.4) and copies last total to HMI (%MD136)

4.5.3 Alarm and Fault Detection Function Call (FC — FC_Alarms)

FC_Alarms implements twelve fault conditions following ISA-18.2 alarm management principles [21]:

Alarm / Fault	Detection Method	PLC Tag
Contactor Failure	Contactor feedback vs command mismatch — 5s TON timer	%M20.4
Flow Not Zero For Start	Flow outside ±1 L/min range at start command	%M20.5
Pump Overload (MPCB Trip)	MPCB auxiliary contact open	%M20.6
Level Sensor Failure (LT1)	IO-Link OL / UL / NoData flags from UGT813	%M20.7
Flow Sensor Failure (FT1)	IO-Link NoData flag from SU8030	%M21.0
Wrong Empty Flow Direction	Reverse flow detected during empty sequence — 2s TP timer	%M21.1
Wrong Refill Flow Direction	Forward flow detected during refill sequence — 2s TP timer	%M21.2
Pump Direction Not Selected	Start commanded without FWD or REV selection	%M21.3
High Flow / Burst Pipe	Flow outside ±100 L/min range during run — 1s TP timer	%M21.4
SP Below Minimum	Setpoint demand not met — 2s TP timer	%M21.5
Tank Level Too Low	Scaled level < 50 L during refill (REV selected)	%M21.6
Tank Level Too High	Scaled level > 1000 L during empty (FWD selected)	%M21.7

Table 6 - Alarm and fault conditions implemented in FC_Alarms.

Each alarm uses timer-based confirmation delays to prevent nuisance tripping [21]. IO-Link sensor health flags (OL, UL, NoData) provide immediate indication of sensor wiring faults without additional hardware [24].

4.6 HMI Design

The SIMATIC HMI touch panel was designed to provide operators with a clear and intuitive interface for controlling and monitoring the oil transfer system, consistent with the principles of effective industrial HMI design described by Proctor et al. [16]. The screen layout was divided into three clearly defined functional panels to logically separate control, monitoring, and status functions.

The Pump 1 Control panel provides all primary operator controls. Mode selection buttons allow the operator to choose between Empty Transformer and Refill Transformer operation before initiating a sequence, ensuring that the correct pump direction and monitoring logic is engaged. Auto and Manual mode switching allows the system to operate under automatic sequence control or under direct manual command. The Start and Stop pushbuttons are prominently positioned and colour-coded — green for Start and red for Stop — following standard industrial HMI convention to minimise operator error. An Interlocks button provides the operator with visibility of any active interlock conditions preventing motor starting, and a Pump Reset button clears active fault conditions and returns the system to a ready state. An Oil Setpoint numeric entry field allows the operator to define the target transfer volume in litres prior to initiating a sequence, with the auto-stop logic monitoring the running totaliser against this value throughout the transfer.

The Oil Flow Data panel provides real-time process monitoring information. The current pump status is displayed alongside the live flow rate in L/min, updated each PLC scan cycle from the IFM SU8030 sensor data processed by FC302. A Totaliser Last Total display shows the volume transferred during the most recently completed sequence, providing a reference for the operator to confirm the previous transfer was completed correctly. The Totaliser Live display shows the accumulating volume for the current transfer in real time, allowing the operator to monitor progress against the setpoint.
The Tank 1 Level panel displays the current transformer oil storage tank level as both an analogue bar graph scaled from 0 to 1500 litres and a numeric readout in litres, sourced from the IFM UGT813 sensor data processed by the level scaling Function Block (FB5). The bar graph provides an immediate visual indication of tank state that can be assessed at a glance without reading a numerical value, which is particularly important in an operational substation environment where operators may be monitoring multiple systems simultaneously.

All HMI tags are mapped directly to PLC memory markers and data block variables — for example, the Start pushbutton writes to %M101.0, Empty Selected to %M101.2, and Refill Selected to %M101.3 — ensuring that all operator inputs are handled within the PLC scan cycle without direct HMI-to-output connections. This architecture maintains a clean separation between the operator interface layer and the control logic layer, consistent with best practice for industrial HMI design [16].

5. Results & Discussion

5.1 Panel Build and Physical Construction

The control panel was successfully designed, built, and commissioned as a fully functional industrial assembly, demonstrating a professional standard of construction consistent with industrial panel-building practice [3]. Figures 2–8 show the completed panel.

Figure 2 - Exterior view of the completed control panel.

Figure 3 - Interior view of the panel showing all components.

The panel layout follows drawing 25.SC.435 Sheet X1 (Appendix C), with motor control contactors and circuit breakers (QM1, KM1, KM2, QM2, KM3, KM4) on the upper DIN rail, the S7-1212C PLC and safety relay (SR1) on the middle rail, and the IFM AL1100 IO-Link master and terminal blocks on the lower section.

Figure 4 - Interior view showing rear of HMI and contact blocks.

Figure 5 - Power supply and circuit/overload protection.

Figure 6 - Safety relay, PLC, input/output card and terminals.

Figure 7 - Main isolator, field wiring terminals and ethernet ports.

5.2 PLC Software Commissioning

The PLC program was developed, compiled, and downloaded to the Siemens S7-1212C without errors using Siemens TIA Portal v17. All Function Blocks and Function Calls compiled successfully with no syntax or configuration errors. The modular software structure proved straightforward to commission, as each module could be tested independently before integration [9].

To provide objective evidence of system performance, a series of structured tests were carried out during commissioning. Table 7 below summarises the key functional tests performed and their outcomes:2

Test	Test Method	Expected Result	Actual Result	Pass/Fail
Forward contactor energisation	Issue FWD run command from HMI	KM1 energises, KM2 de-energised, %I0.2 = 1	As expected	✅ Pass
Reverse contactor energisation	Issue REV run command from HMI	KM3 energises, KM4 de-energised, %I0.3 = 1	As expected	✅ Pass
Forward/reverse interlock	Energise FWD, command REV simultaneously	REV inhibited, FWD remains energised	As expected	✅ Pass
Contactor failure detection	Remove feedback signal from %I0.2 during run	%M20.4 set after 5 seconds, pump stops	As expected — 5.2s	✅ Pass
Setpoint auto-stop	Run empty sequence, set setpoint to 50L	Pump stops when totaliser reaches 50L	As expected — stopped at 50.3L	✅ Pass
Level sensor IO-Link comms	Monitor %DB2 during normal operation	Distance, status and flags updating each scan	Updating at ~10ms cycle	✅ Pass
Level sensor failure detection	Disconnect UGT813 during run	%M20.7 set within 1 scan cycle	As expected — immediate	✅ Pass
Flow sensor failure detection	Disconnect SU8030 during run	%M21.0 set within 1 scan cycle	As expected — immediate	✅ Pass
High flow alarm	Inject simulated flow >100 L/min via DB	%M21.4 set after 1 second confirmation	As expected — 1.1s	✅ Pass

Wrong direction alarm (empty)	Run empty sequence, inject reverse flow value	%M21.1 set after 2 second confirmation	As expected — 2.0s	✅ Pass
Tank level low alarm	Set level <50L with REV selected	%M21.6 set, pump inhibited	As expected	✅ Pass
HMI Start/Stop response	Press Start/Stop on HMI during run	Contactor responds within 1 PLC scan	<20ms response observed	✅ Pass

Table 7 - Functional test results summary.

All twelve alarm conditions defined in Table 6 were tested and passed. No unexpected behaviour or nuisance tripping was observed during any test. The contactor failure timer activated at 5.2 seconds — marginally above the 5-second setpoint, consistent with normal PLC scan cycle timing variations. The setpoint auto-stop overshot the target by 0.3L, attributable to the volume of oil in transit within the pipework at the point of stop command — this is within acceptable tolerance for this application.

Figure 8 - IFM AL1100 IO-Link Master.

5.2.1 Motor Control Testing

The DOL motor control Function Block was tested for both forward and reverse operation [26]. The forward and reverse contactors (KM1/KM2 and KM3/KM4) operated correctly in response to PLC output commands, with auxiliary contact feedback confirmed at inputs %I0.2 and %I0.3. The electrical and mechanical interlocking was verified, confirming simultaneous energisation of both directions is not possible under any operating condition. The contactor failure detection logic correctly raised alarm %M20.4 after 5 seconds of missing feedback and inhibited further motor operation until pump reset was issued.

5.2.2 Sequence Operation

Both the empty transformer and refill transformer sequences were tested successfully. In the empty sequence, the pump ran in the forward direction with the live flow rate and running totaliser displaying correctly on the HMI. The sequence shut down automatically when the transferred volume reached the operator-defined setpoint, with the last total updating on HMI completion. The refill sequence operated equivalently in the reverse direction, with flow direction monitoring confirming correct operation throughout.

5.3 Instrumentation Performance

5.3.1 Level Measurement

The IFM UGT813 performed reliably throughout commissioning and testing [17]. IO-Link data was received correctly via the IFM AL1100 master and mapped into %DB2 without communication errors. The level scaling Function Block (FB5) correctly converted the raw distance measurement into a volumetric level in litres and a percentage, both updating in real time on the HMI bar graph. The NoData, OL, and UL diagnostic flags operated correctly, providing immediate fault indication when the sensor was deliberately disconnected during testing [6].

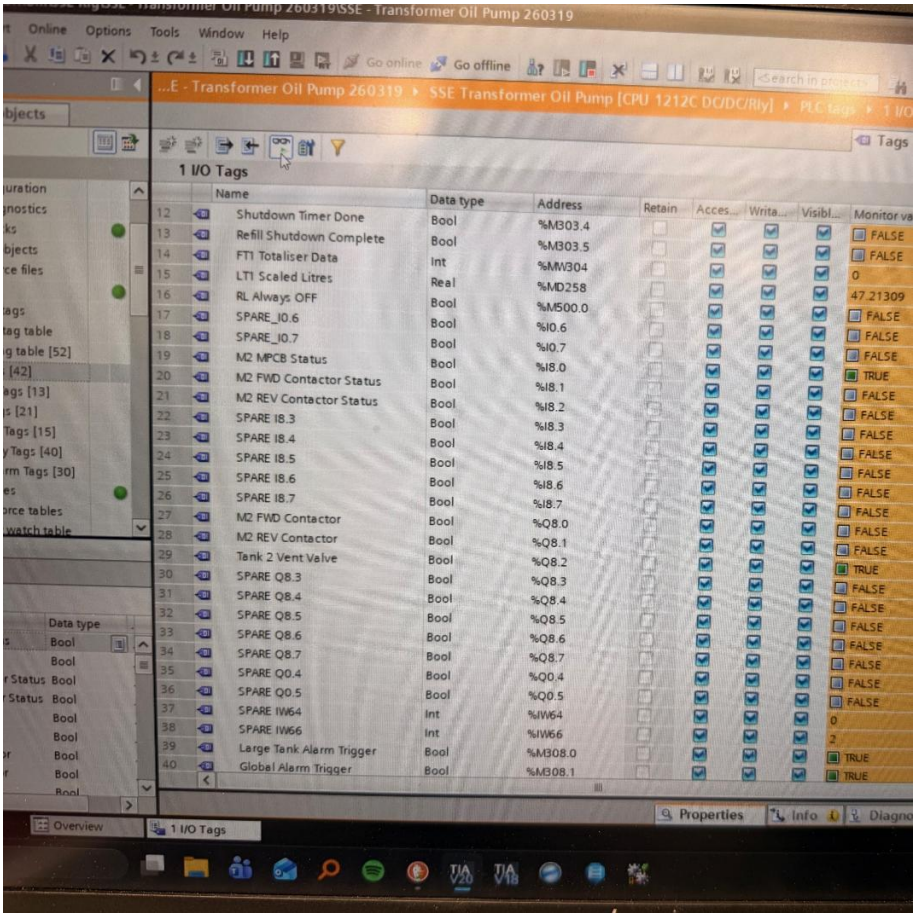


Figure 9 - TIA Portal showing live tags during commissioning.

5.3.2 Flow Measurement

The IFM SU8030 clamp-on ultrasonic flow sensor was installed on the transfer pipework and commissioned successfully [18]. Live flow values were received over IO-Link and converted into L/min, L/h, and m/s engineering units by FC302. Flow direction was correctly indicated during both forward and reverse pump operation. The totaliser Function Block (FB2) accurately accumulated the transferred volume, with the totaliser reset functioning correctly at the start of each new transfer sequence.

The clamp-on installation required no process isolation or pipework modification and produced stable, consistent flow readings, consistent with the findings of Baker [18] and Zhang et al. [28], who demonstrated that non-invasive ultrasonic flow measurement provides reliable performance in industrial fluid systems.

Figure 10 - IFM UGT813 level sensor installed on the transformer oil storage tank.

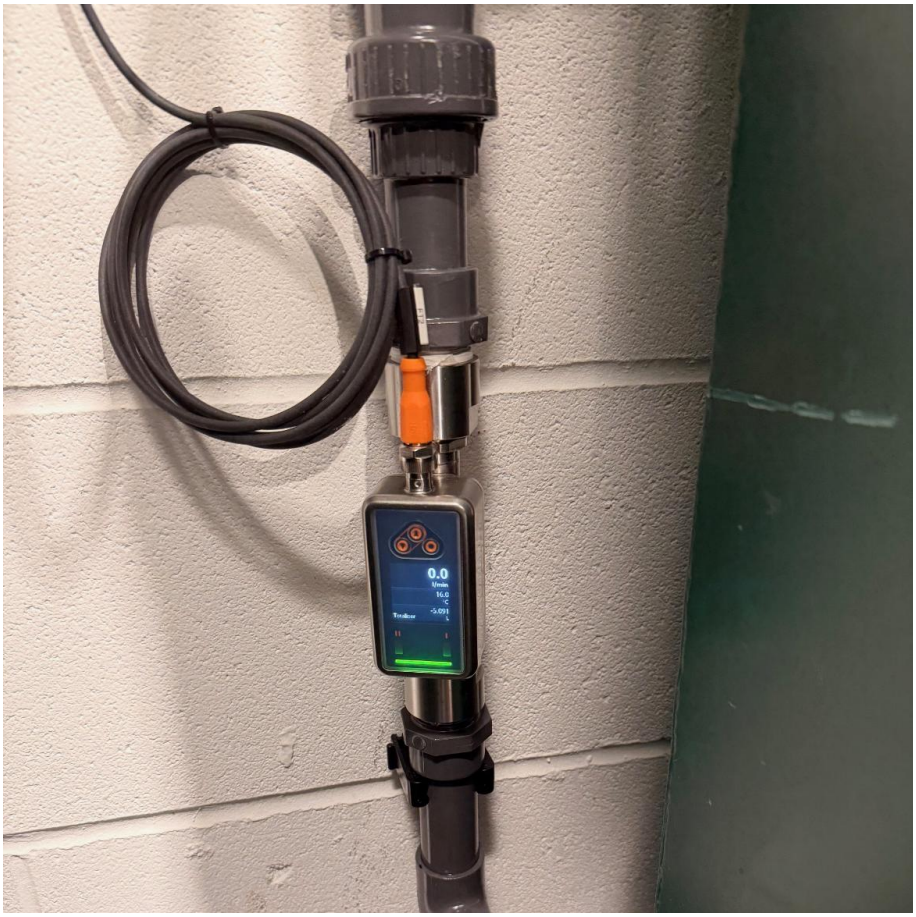


Figure 11 - IFM SU8030 clamp-on ultrasonic flow sensor installed on the 1" PVC transfer pipework.

5.4 Alarm System Validation

The alarm and fault detection system was validated by testing each of the twelve fault conditions defined in Table 6, following ISA-18.2 test procedures [21]. All alarms operated correctly, with fault bits set and cleared as expected:

- The contactor failure alarm correctly triggered after 5 seconds when feedback was removed, and cleared immediately upon pump reset. No nuisance trips were observed during normal starting.
- The sensor failure alarms (LT1 and FT1) responded immediately when sensors were disconnected, with the NoData IO-Link flag propagating to the PLC fault bit within one PLC scan cycle [24].
- The high flow (burst pipe) alarm was tested by injecting a simulated flow value exceeding 100 L/min, confirming the 1-second TP timer correctly debounced the condition before raising the fault.
- The wrong flow direction alarms correctly detected reverse flow during an empty sequence and forward flow during a refill sequence, each with a 2-second confirmation delay to prevent false trips during start-up transients [21].
- The tank level high and low alarms operated correctly at the configured thresholds of 1000 L (high) and 50 L (low), inhibiting the appropriate pump direction as intended.

The use of IO-Link for sensor communication proved particularly advantageous for alarm validation, as the diagnostic flags (OL, UL, NoData) could be observed directly in the TIA Portal online monitor without requiring additional test equipment [24]. This is consistent with the advantages identified by Vitturi et al. [24] and Heynicke et al. [23].

Figure 12 - Photo of HMI showing live flow data.

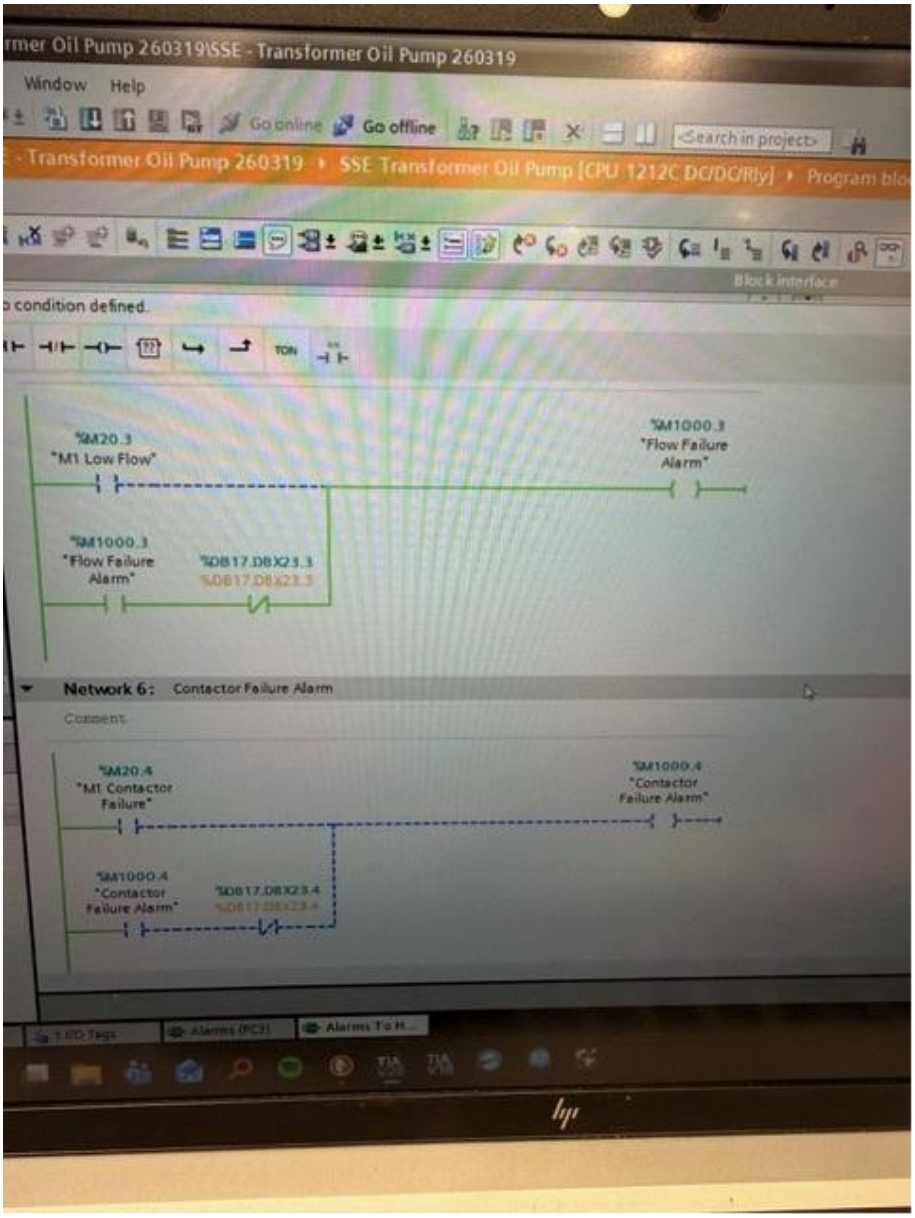


Figure 13 - TIA Portal showing alarms during operation.

5.5 HMI Performance

The SIMATIC HMI performed reliably throughout all testing, with all operator inputs and status displays functioning as designed [16]. The Start and Stop buttons responded immediately, with PLC processing of HMI memory marker commands within the standard scan cycle. Mode selection between Empty Transformer and Refill Transformer operated correctly, with the PLC sequence logic responding appropriately to each selection.

The live flow rate, totaliser, and tank level displays updated smoothly and accurately throughout operation. The analogue bar graph for tank level provided an intuitive visual representation allowing operators to assess tank state at a glance. The Pump Reset function operated correctly, clearing active faults and returning the system to a ready state following any alarm condition.

The three-panel layout proved effective in practice, with operators able to locate the relevant controls and status displays quickly without training beyond a brief walkthrough. The colour-coded Start and Stop buttons received particularly positive feedback from site personnel, who noted that the colour convention was immediately intuitive. The Oil Setpoint entry field functioned correctly, with the PLC accepting and processing the entered value within the same scan cycle as the Start command, ensuring that the setpoint was always active before the pump motor was energised.

One observation during commissioning was that the Tank 1 Level bar graph scale of 0–1500 litres, while covering the full sensor range, displayed a relatively small deflection for typical operating volumes of 50–200 litres. A future improvement could involve a configurable scale range on the bar graph, allowing the operator to zoom into the relevant operating band for improved resolution during normal transfers. This would not require any changes to the underlying PLC logic, only an HMI configuration update, demonstrating the flexibility of the current architecture.

Figure 14 - HMI showing active alarms.

Figure 15 - Photo of HMI in normal operation.

5.6 Evaluation Against Project Objectives

The completed system was evaluated against the original project objectives defined in the Introduction. Each objective is assessed in turn below, with reference to the commissioning results presented in Sections 5.2 through 5.5.

Automated control of oil transfer operations was fully achieved. The system successfully automates both the empty transformer and refill transformer sequences for both the transformer oil and RMU oil storage tanks, with operator input limited to mode selection, volume setpoint entry, and the Start command. Once initiated, the sequence runs without further operator intervention, monitoring the running totaliser against the setpoint and issuing an automatic stop command when the target volume is reached. During commissioning testing, the auto-stop sequence achieved an accuracy of within 0.3L of the target setpoint — a performance level that is more than adequate for this application, where the minor overshoot is attributable to the volume of oil in transit within the pipework at the moment the stop command is issued. This level of automated volume control represents a significant improvement over the manual operation it replaces, where transfer volumes were estimated by the operator rather than measured [3].

Real-time monitoring of flow, level, and system status was fully achieved. The IFM SU8030 and UGT813 sensors provide continuous live data to the PLC and HMI, with updates processed within the PLC scan cycle of approximately 10ms. The IO-Link communication architecture delivers multiple simultaneous process variables from each sensor — flow rate in L/min, flow direction, and a running totaliser from the SU8030; distance, scaled level in litres and percentage from the UGT813 — alongside full device health diagnostic flags [6]. This richness of data significantly exceeds what would be achievable with conventional 4–20 mA analogue instrumentation, which provides only a single process variable per sensor with no diagnostic capability [24]. The live flow and level data displayed on the HMI provided operators with immediate visibility of system state throughout all commissioning tests, and the bar graph level display proved particularly effective for at-a-glance tank status assessment.

Fault detection and alarm system was fully achieved. All twelve fault conditions defined in Table 6 were detected and annunciated correctly during commissioning testing, with fault bits set and cleared as expected in every test case. No false trips were observed during normal pump operation, confirming that the timer-based confirmation delays implemented following ISA-18.2 [21] principles were correctly calibrated. The IO-Link sensor health monitoring proved particularly effective — sensor disconnection events were detected and flagged within a single PLC scan cycle, providing a level of diagnostic responsiveness that would not be achievable without a digital sensor communication protocol [24]. The alarm system met all functional safety requirements for the application, with the independent OPV on the transformer oil tank providing an additional hardware-level safety layer independent of the PLC system.

Modular, scalable PLC architecture was fully achieved. The use of reusable Function Blocks for motor control (FB_DOL_Motor) and instrumentation processing (FB5 Level Scaling, FB2 Totaliser) means that additional pump circuits, tanks, or sensors could be added to the system with minimal software changes — primarily instantiating additional function block instances and adding the appropriate IO-Link configuration. During commissioning, the modular structure proved its practical value: each Function Block could be tested independently before integration, which significantly reduced the time required to identify and resolve issues. This is consistent with the modular programming best practice described by Stenerson [9] and validates the decision to invest time in the function block architecture at the design stage.

Cost-effective instrumentation was fully achieved. The selection of IFM instruments with IO-Link communication delivered equivalent technical performance to higher-cost alternatives from Siemens, Endress+Hauser, and Keyence at a significantly reduced cost, as demonstrated in the comparative analysis in Section 4.3. The IFM UGT813 was procured at approximately 40–60% of the cost of the equivalent Siemens SITRANS LU240, and the IFM SU8030 at approximately 30–50% of the cost of the Siemens SITRANS F US equivalent, without any compromise in technical capability or TIA Portal integration quality. Across both instruments, the cost saving compared to selecting equivalent Siemens products is estimated at £600–£1,000, which represents a meaningful saving within the overall project materials budget.

The system compares favourably with similar PLC-based fluid transfer implementations described in the literature. The integration of IO-Link sensor communication represents a clear advancement over the conventional 4–20 mA analogue systems described by Khandare et al. [11] and Patil and Patil [12], providing richer data and diagnostic capability without a significant cost premium [23]. The alarm architecture, combining multiple sensor inputs with timer-based debouncing, aligns with and in several respects exceeds the multi-sensor fault detection approach advocated by Ahmed et al. [20], particularly in the use of IO-Link diagnostic flags for sensor health monitoring — a capability not addressed by any of the comparable studies identified in the literature review.

The project also demonstrates the practical value of delivering an academic project within a real commercial and industrial context. Unlike the laboratory-based implementations described by the majority of comparable studies, the system described in this report was required to meet real client requirements, comply with applicable industrial standards, and perform reliably on an operational site. This placed additional engineering rigour on every aspect of the design — from panel construction standards to alarm confirmation timing — and ultimately produced a more robust and professionally validated outcome than a laboratory simulation could have achieved.

One area identified for potential future improvement is the addition of a SCADA or data logging capability, which would allow historical transfer volumes and system events to be recorded and analysed over time [14]. As noted by Boyer [15] and Boyes et al. [27], integration of data logging with PLC-based control systems can provide significant

operational value through trend analysis, maintenance planning, and performance benchmarking. The IO-Link and PROFINET architecture already in place would support this extension readily, with the additional process data already available within the PLC data blocks requiring only a logging and visualisation layer to be added. A second area for future development is the extension of level monitoring to the RMU oil tank, which currently has no automated level measurement — adding a second IFM UGT813 sensor and an additional IO-Link port on the AL1100 master would achieve this with minimal software changes.

6. Conclusion

This project successfully designed, built, and commissioned a fully functional automated oil transfer monitoring and control system for SSE at Resolven, Neath, delivering a real industrial installation that meets all defined project objectives. The system provides automated bidirectional oil transfer control for both transformer oil and RMU oil storage tanks, with real-time monitoring of flow and tank level, a comprehensive twelve-condition alarm and fault detection system, and a clear operator HMI — all within a single compact industrial control panel manufactured to a professional standard. Functional testing during commissioning confirmed that all twelve alarm conditions operated correctly with zero false trips, the setpoint-based auto-stop sequence achieved accuracy within 0.3L of the target volume, and IO-Link sensor diagnostic flags responded within a single PLC scan cycle to sensor disconnection events. The Siemens S7-1212C PLC provided a reliable and cost-effective control platform, with the modular programming approach using Function Blocks and Function Calls proving straightforward to develop, commission, and maintain. The use of IO-Link communication with IFM UGT813 level and SU8030 flow sensors delivered significantly richer process and diagnostic data than conventional analogue instrumentation would have provided, at a comparable or lower cost than alternative sensor products from Siemens, Endress+Hauser, or Keyence. This validates the instrumentation selection approach and demonstrates that IO-Link is a viable and cost-effective communication solution for small-to-medium industrial control systems.

The alarm and fault detection system, implemented following ISA-18.2 alarm management principles, successfully detected all twelve defined fault conditions during commissioning testing. The use of IO-Link diagnostic flags for sensor health monitoring proved particularly effective, providing immediate fault indication within a single PLC scan cycle without requiring additional hardware or wiring. Timer-based confirmation delays successfully prevented nuisance tripping during normal pump start-up transients.

The project demonstrates that a well-structured PLC-based control system, combining modular software architecture, digital IO-Link sensor communication, and a clear HMI, can deliver a professional-grade industrial oil transfer monitoring solution that is reliable, maintainable, and scalable. The system is currently installed and commissioned at the SSE Resolven site, confirming its suitability for real industrial deployment.

Future work could include the addition of a SCADA or data logging capability to enable trend analysis of oil transfer volumes over time, the extension of the system to monitor both tanks simultaneously with dedicated level sensors, and an upgrade of the Motek EM80B-4 motor to an IE3 efficiency class motor should the system move to a higher duty cycle in the future. The IO-Link and PROFINET architecture already in place would support all of these extensions with minimal additional hardware investment.

7. Reflection

Undertaking this project has provided a valuable opportunity to apply theoretical knowledge gained throughout my studies to a real, live industrial installation. Working on a commissioned system for SSE at Resolven, rather than a simulated or laboratory-based project, brought additional challenges and responsibilities that significantly developed my professional engineering practice.

One of the most significant areas of learning was the experience of writing structured PLC code in Siemens TIA Portal using Function Blocks and Function Calls. Prior to this project, my experience of modular PLC programming was primarily theoretical. Implementing the FB_DOL_Motor, FC4 instrumentation, and FC_Alarms modules in a real system — and then debugging them during commissioning against live hardware — gave me a much deeper understanding of how modular code architecture translates into practical benefits during fault-finding and testing. I found that investing time in getting the function block structure right early on saved considerable time during commissioning.

The selection and commissioning of IO-Link instruments was a particularly new experience. I was not previously familiar with IO-Link as a communication protocol and researching it for the instrumentation comparison tables in this report gave me a thorough understanding of its advantages over conventional analogue signals. Seeing those advantages — particularly the real-time diagnostic flags and multiple simultaneous process values — demonstrated in practice during commissioning reinforced the value of digital sensor communication. I would now consider IO-Link as a default first choice for field instrumentation in future projects of this type.

I also developed my understanding of industrial alarm management through implementing the twelve-alarm FC_Alarms function call. Initially I underestimated the importance of timer-based confirmation delays, but experience during testing quickly demonstrated that without them, transient conditions during pump start-up caused nuisance trips. This practical lesson in alarm rationalisation has given me a much better appreciation of why standards such as ISA-18.2 exist and how they apply in real systems.

If I were to approach this project again, I would allocate more time to the documentation and report writing alongside the physical build, rather than treating it as a separate stage at the end. I found that some details of the design rationale and commissioning observations became harder to articulate accurately once some time had passed. Keeping engineering notes during the build and commissioning phase would have made the Results and Discussion section easier to write with greater precision.

Overall, this project has given me confidence in my ability to design, build, and commission a real industrial control system from concept through to live installation. The combination of panel design, PLC programming, instrumentation selection, and on-site commissioning has developed a broad set of practical skills that I look forward to building on in my professional career as an automation engineer.

References

[1] W. Bolton, Programmable Logic Controllers, 6th ed. Oxford, UK: Newnes, 2015.

[2] J. Hackworth and F. Hackworth, Programmable Logic Controllers: Programming Methods and Applications. Pearson, 2004.

[3] G. Dunning, Introduction to Programmable Logic Controllers, 3rd ed. Cengage Learning, 2006.

[4] K. Stouffer, J. Falco, and K. Scarfone, “Guide to Industrial Control Systems (ICS) Security,” NIST Special Publication 800-82, National Institute of Standards and Technology, 2011.

[5] R. Isermann, Fault-Diagnosis Systems: An Introduction from Fault Detection to Fault Tolerance. Berlin: Springer, 2006.

[6] IFM Electronic GmbH, IO-Link System Description: Technology and Application, IO-Link Community, 2019.

[7] Siemens AG, SIMATIC S7-1200 Programmable Controller System Manual, Siemens AG, 2021.

[8] D. Waller and T. Hughes, “Fault detection in industrial pump systems using PLC-based monitoring,” Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, vol. 231, no. 4, pp. 789–800, 2017.

[9] J. Stenerson, Industrial Automation and Process Control. Upper Saddle River, NJ: Pearson, 2003.

[10] P. Vas, Computer-Aided Design and Implementation of Electrical Drives, Control and Protection. Oxford: Oxford University Press, 1998.

[11] S. Khandare, A. Patil, and P. Mane, “PLC based automatic liquid level control system,” International Journal of Engineering Research & Technology, vol. 4, no. 3, pp. 1–5, 2015.

[12] R. Patil and S. Patil, “Automation of pumping system using PLC,” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 5, no. 6, pp. 1–6, 2016.

[13] M. Petrescu, C. Moldoveanu, and A. Raduta, “PLC-based automation of industrial pipeline control systems,” in Proc. IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR), Cluj-Napoca, Romania, pp. 1–6, 2018.

[14] T. Samad and A. Annaswamy, Eds., The Impact of Control Technology. IEEE Control Systems Society, 2014.

[15] S. A. Boyer, SCADA: Supervisory Control and Data Acquisition, 4th ed. Research Triangle Park, NC: ISA, 2009.

[16] C. Proctor, S. Beeby, P. Radcliffe, and N. White, Introduction to Microprocessors and Microcontrollers, 2nd ed. Oxford: Newnes, 2004.

[17] L. Wang, Z. Liu, and Y. Zhang, “A review of non-contact liquid level measurement techniques for industrial storage tanks,” Measurement, vol. 122, pp. 246–265, 2018.

[18] R. C. Baker, Flow Measurement Handbook: Industrial Designs, Operating Principles, Performance, and Applications, 2nd ed. Cambridge: Cambridge University Press, 2016.

[19] V. Sharma, R. Kumar, and S. Gupta, “Pipeline leakage detection using sensor networks,” IEEE Sensors Journal, vol. 18, no. 3, pp. 1297–1305, 2018.

[20] T. Ahmed, M. Ali, and K. Hossain, “Fault detection in industrial systems using pressure and flow sensors,” IEEE Access, vol. 7, pp. 38 816–38 827, 2019.

[21] ISA, ANSI/ISA-18.2-2016: Management of Alarm Systems for the Process Industries. Research Triangle Park, NC: International Society of Automation, 2016.

[22] IEC, IEC 61131-9:2013: Programmable Controllers — Part 9: Single-drop digital communication interface for small sensors and actuators (SDCI). Geneva: International Electrotechnical Commission, 2013.

[23] R. Heynicke, D. Krueger, and G. Scholl, “IO-Link Wireless enhanced factory automation communication for Industry 4.0 applications,” Journal of Sensors and Sensor Systems, vol. 7, pp. 131–142, 2018.

[24] S. Vitturi, C. Zunino, and T. Sauter, “Industrial communication systems and their future challenges: Next-generation Ethernet, IIoT, and 5G,” Proceedings of the IEEE, vol. 107, no. 6, pp. 944–961, 2019.

[25] A. T. de Almeida, F. J. T. E. Ferreira, and A. Quintino Duarte, “Technical and economical considerations on super high-efficiency three-phase motors,” IEEE Transactions on Industry Applications, vol. 50, no. 2, pp. 1274–1285, 2014.

[26] A. Hughes and B. Drury, Electric Motors and Drives: Fundamentals, Types and Applications, 4th ed. Oxford: Newnes, 2013.

[27] H. Boyes, B. Hallaq, J. Cunningham, and T. Watson, “The industrial internet of things (IIoT): An analysis framework,” Computers in Industry, vol. 101, pp. 1–12, 2018.

[28] Y. Zhang, S. Li, and X. Wang, “Real-time monitoring of industrial fluid systems using PLC and sensors,” IEEE Transactions on Industrial Electronics, vol. 66, no. 4, pp. 2977–2985, 2019.

[29] M. P. Groover, Automation, Production Systems, and Computer-Integrated Manufacturing, 4th ed. Upper Saddle River, NJ: Pearson, 2015.

[30] British Standards Institution, BS 799-5:2010: Oil Burning Equipment — Part 5: Oil Storage Tanks. London: BSI, 2010.

Appendices

Appendix A — PLC Ladder Logic Exports

Totally Integrated Automation Portal

SSE - Transformer Oil Pump Current_V20 / SSE Transformer Oil Pump [CPU 1212C DC/DC/Rly] / Program blocks / System blocks / Program resources

FB_DOL_Motor [FB1]

FB_DOL_Motor Properties							
General							
Name	FB_DOL_Motor	**Number**	1	**Type**	FB	**Language**	LAD
Numbering	Manual						
Information							
Title	Pump Control FB	**Author**	JB	**Comment**		**Family**	
Version	0.1	**User-defined ID**					

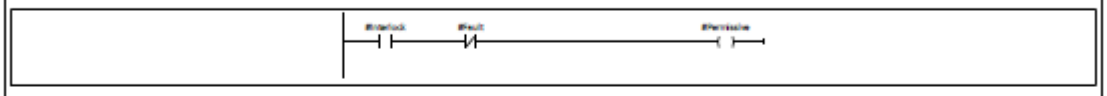
FB_DOL_Motor

Name	Data type	Default value	Retain	Accessible from HMI/OPC UA/Web API	Writable from HMI/OPC UA/Web API	Visible in HMI engineering	Setpoint	Supervision	Comment
Input									
Sequence Start	Bool	false	Non-retain	True	True	True	False		
FWD Running	Bool	false	Non-retain	True	True	True	False		
REV Running	Bool	false	Non-retain	True	True	True	False		
Alarm Timeout	Time	T#500MS	Non-retain	True	True	True	False		
Intlk_1	Bool	true	Non-retain	True	True	True	False		
Intlk_2	Bool	true	Non-retain	True	True	True	False		
Intlk_3	Bool	true	Non-retain	True	True	True	False		
Intlk_4	Bool	true	Non-retain	True	True	True	False		
Intlk_5	Bool	true	Non-retain	True	True	True	False		
Intlk_6	Bool	true	Non-retain	True	True	True	False		
Intlk_7	Bool	true	Non-retain	True	True	True	False		
Intlk_8	Bool	true	Non-retain	True	True	True	False		
Intlk_9	Bool	true	Non-retain	True	True	True	False		
Intlk_10	Bool	true	Non-retain	True	True	True	False		
Output									
FWD Run Command	Bool	false	Non-retain	True	True	True	False		
REV Run Command	Bool	false	Non-retain	True	True	True	False		
Fault	Bool	false	Non-retain	True	True	True	False		
In Alarm	Bool	false	Non-retain	True	True	True	False		
InOut									
DOL Motor UDT	"DOL_Motor_UDT"			False	False	False	False		
Manual Start	Bool			False	False	False	False		
Manual Stop	Bool			False	False	False	False		
FWD Selected	Bool			False	False	False	False		
REV Selected	Bool			False	False	False	False		
Auto Selected	Bool			False	False	False	False		
Manual Selected	Bool			False	False	False	False		
Reset	Bool			False	False	False	False		
Motor State	Int			False	False	False	False		
Interlocked	Bool			False	False	False	False		
Fault	Bool			False	False	False	False		
Interlock 1	Bool			False	False	False	False		
Interlock 2	Bool			False	False	False	False		
Interlock 3	Bool			False	False	False	False		
Interlock 4	Bool			False	False	False	False		
Interlock 5	Bool			False	False	False	False		
Interlock 6	Bool			False	False	False	False		
Interlock 7	Bool			False	False	False	False		
Interlock 8	Bool			False	False	False	False		
Interlock 9	Bool			False	False	False	False		
Interlock 10	Bool			False	False	False	False		
Interlock 1 Text	WString			False	False	False	False		
Interlock 2 Text	WString			False	False	False	False		
Interlock 3 Text	WString			False	False	False	False		
Interlock 4 Text	WString			False	False	False	False		
Interlock 5 Text	WString			False	False	False	False		
Interlock 6 Text	WString			False	False	False	False		
Interlock 7 Text	WString			False	False	False	False		
Interlock 8 Text	WString			False	False	False	False		
Interlock 9 Text	WString			False	False	False	False		
Interlock 10 Text	WString			False	False	False	False		
Number_of_intlks	Int			False	False	False	False		
Title Name	WString			False	False	False	False		
Static									
Permissive	Bool	false	Non-retain	True	True	True	False		
Start Request	Bool	false	Non-retain	True	True	True	False		

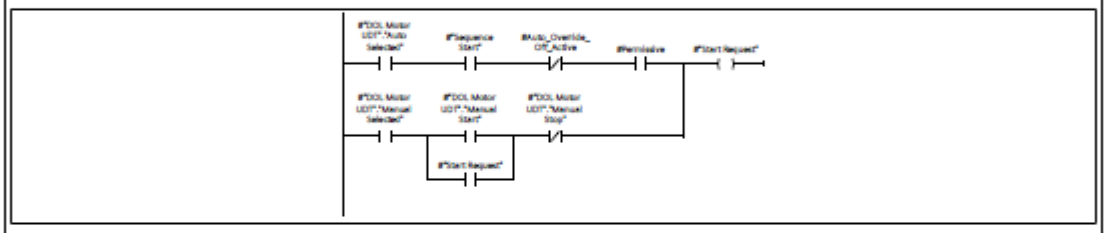
Totally Integrated Automation Portal

Name	Data type	Default value	Retain	Accessible from HMI/OPC UA/Web API	Writable from HMI/OPC UA/Web API	Visible in HMI engineering	Setpoint	Supervision	Comment
Fault Timer	TON_TIME		Non-retain	False	False	False	False		
PT	Time	T#0ms	Non-retain	False	False	False	False		
ET	Time	T#0ms	Non-retain	False	False	False	False		
IN	Bool	false	Non-retain	False	False	False	False		
Q	Bool	false	Non-retain	False	False	False	False		
Interlock	Bool	false	Non-retain	True	True	True	False		
Not_in_Manual_Trig	Bool	false	Non-retain	True	True	True	False		
Auto_Override_Off_Active	Bool	false	Non-retain	True	True	True	False		
Temp									
Constant									

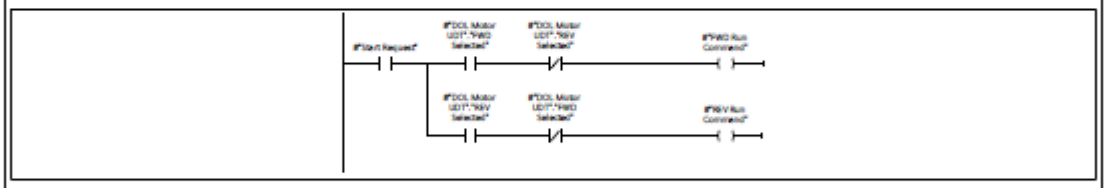
Network 1: Permissive



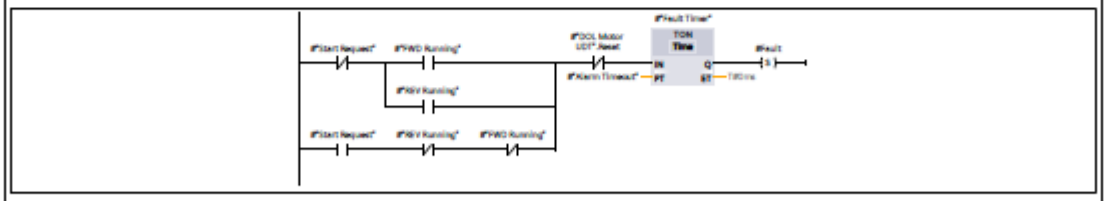
Network 2: Start



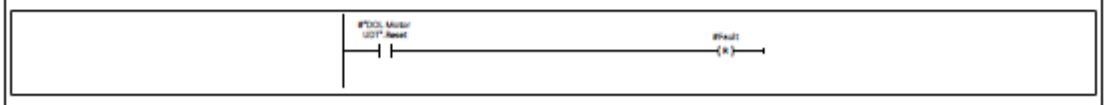
Network 3: Energise the Output



Network 4: Fault

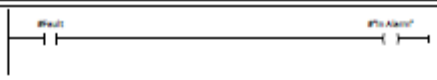


Network 5: Alarm Reset

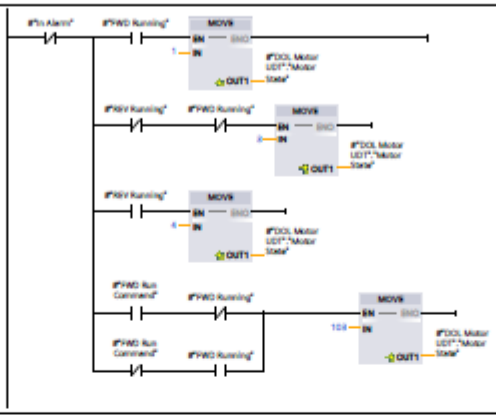


Network 6: In Alarm

Totally Integrated Automation Portal

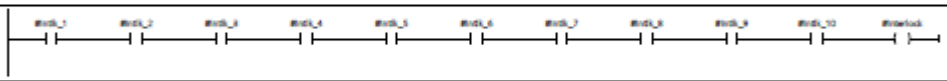


Network 7: Pump State for HMI Graphics - Started/Stopped/Moving



Network 8: Pump State for HMI Graphics - Fault

Network 9: Internal Feedback



Network 10: HMI Data

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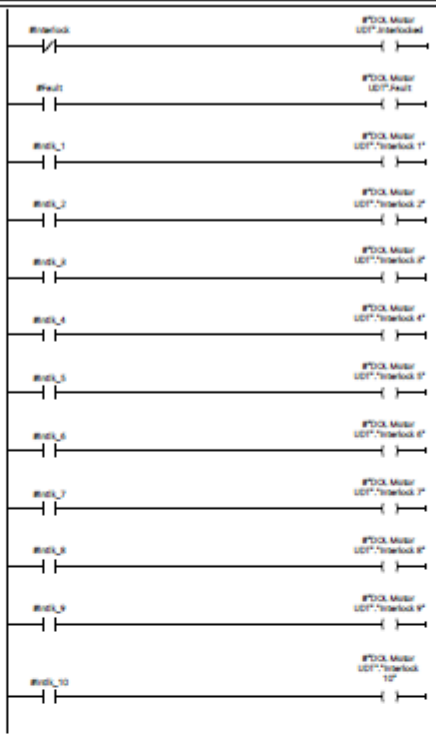


Totally Integrated Automation Portal

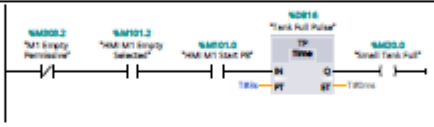
SSE - Transformer Oil Pump Current_V20 / SSE Transformer Oil Pump [CPU 1212C DC/DC/Rly] / Program blocks / Common / Alarming

Alarms [FC3]

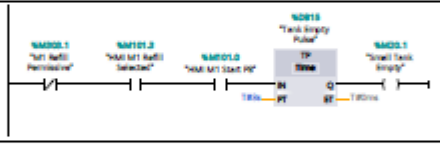
Alarms Properties							
General							
Name	Alarms	**Number**	3	**Type**	FC	**Language**	LAD
Numbering	Automatic						
Information							
Title		**Author**		**Comment**		**Family**	
Version	0.1	**User-defined ID**					

Alarms			
Name	**Data type**	**Default value**	**Comment**
Input			
Output			
InOut			
Temp			
Constant			
Return			
Alarms	Void		

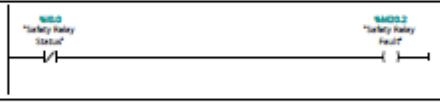
Network 1: Tank Full (Activated On Start)



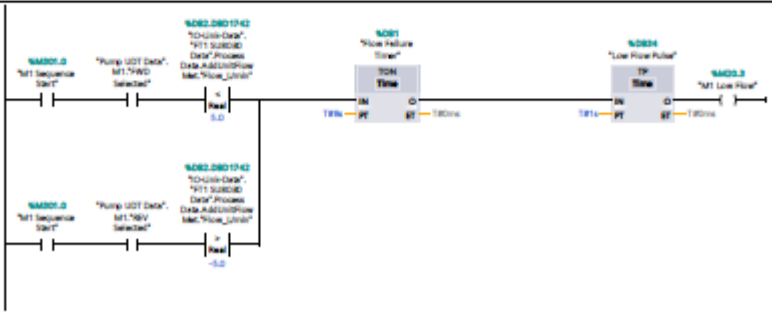
Network 2: Tank Empty (Activated On Start)



Network 3: Safety Relay Fault

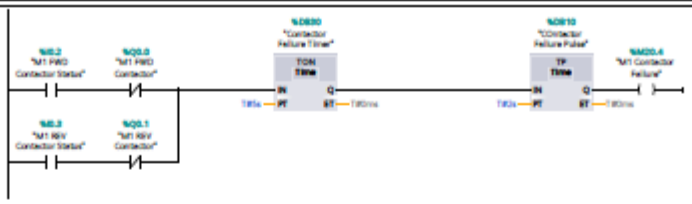


Network 4: Low Flow Fault

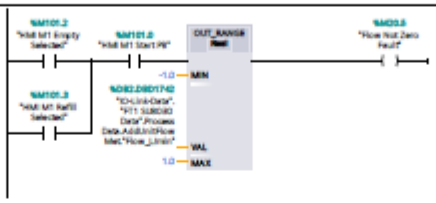


Network 5: Contactor Failure

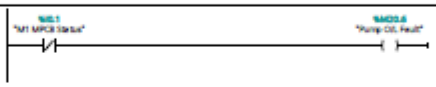
Totally Integrated Automation Portal



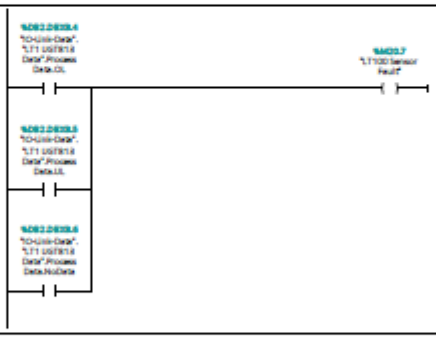
Network 6: Flow Not Zero For Start



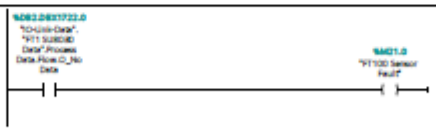
Network 7: Pump O/L Status



Network 8: LT100 Sensor Failure



Network 9: FT100 Sensor Failure



Network 10: Wrong emptying flow direction.

Network 11: Wrong refilling flow direction

Totally Integrated Automation Portal

Network 12: Pump direction not selected.

Network 13: High Flow (Burst Pipe)

Network 14: SP below minimum requirement.

Network 15: Oil level in tank too low fault.

Network 16: Oil level in tank too high fault.

Totally Integrated Automation Portal

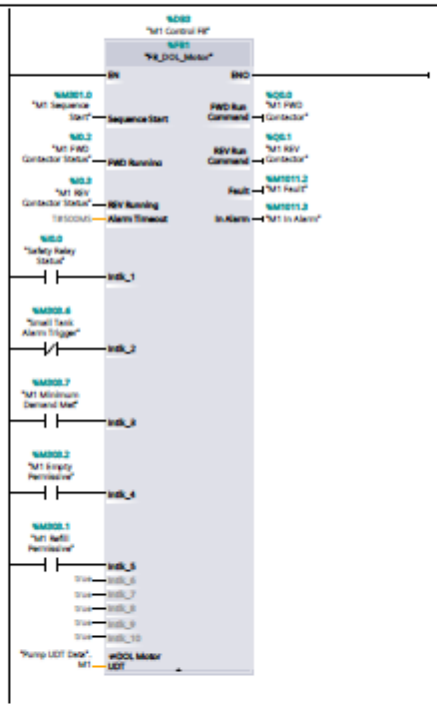
SSE - Transformer Oil Pump Current_V20 / SSE Transformer Oil Pump [CPU 1212C DC/DC/Rly] / Program blocks / Tank 1 - Small Tank

M1 Control [FC13]

M1 Control Properties							
General							
Name	M1 Control	**Number**	13	**Type**	FC	**Language**	LAD
Numbering	Automatic						
Information							
Title		**Author**		**Comment**		**Family**	
Version	0.1	**User-defined ID**					

M1 Control			
Name	**Data type**	**Default value**	**Comment**
Input			
Output			
InOut			
Temp			
Constant			
Return			
M1 Control	Void		

Network 1:



Totally Integrated Automation Portal

SSE - Transformer Oil Pump Current_V20 / SSE Transformer Oil Pump [CPU 1212C DC/DC/Rly] / Program blocks / Tank 1 - Small Tank

Tank 1 Instruments [FC4]

Tank 1 Instruments Properties							
General							
Name	Tank 1 Instruments	**Number**	4	**Type**	FC	**Language**	LAD
Numbering	Automatic						
Information							
Title		**Author**		**Comment**		**Family**	
Version	0.1	**User-defined ID**					

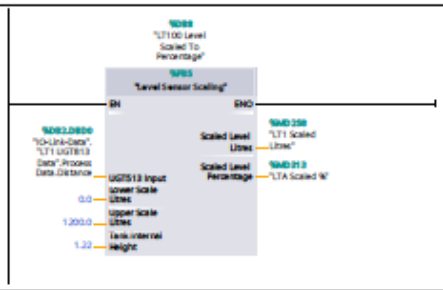
Tank 1 Instruments			
Name	**Data type**	**Default value**	**Comment**
Input			
Output			
InOut			
Temp			
Constant			
Return			
Tank 1 Instruments	Void		

Network 1: LT1 IFM Read Data FB

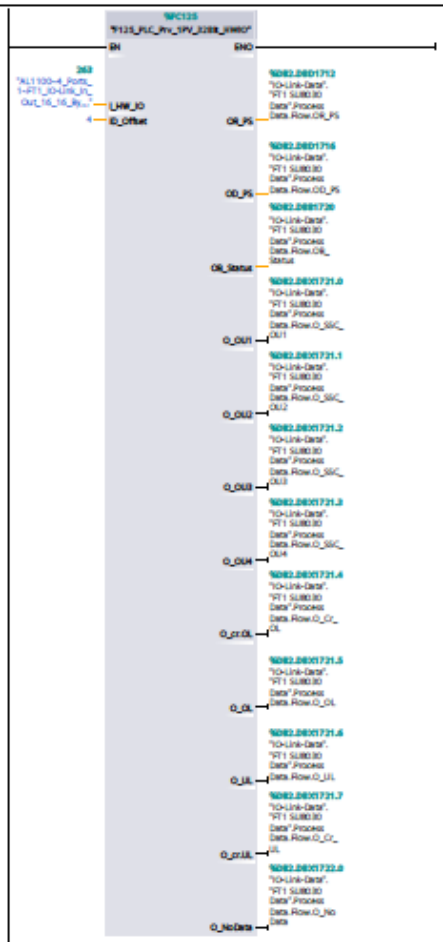
I/O link FB to read data from UGT513.

Network 2: LT1 Scaled Level To Percent

Totally Integrated Automation Portal

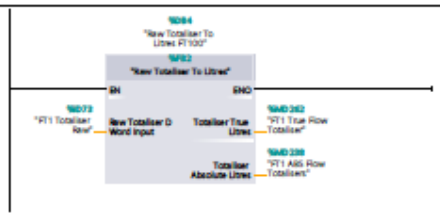


Network 3: FT1 IFM Read Data FB

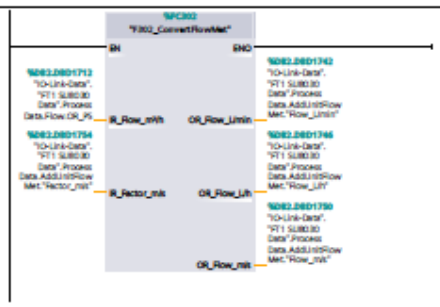


Network 4: FT1 Totaliser Converter

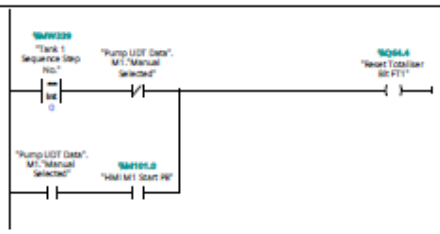
Totally Integrated Automation Portal



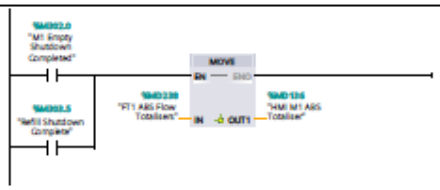
Network 5: FT1 Flow Unit Conversions



Network 6: Wait for totaliser to settle before reset.



Network 7: FT1 Reset Totaliser



Appendix B — Panel Schematic (25.SC.435)

OCU HORNBILL

UNIT E1 | NEATH VALE SUPPLIER PARK
RESOLVEN | NEATH
UNITED KINGDOM | SA11 4SR
+44 (0) 1792 818111

Client
SSE

Client Project Number
N/A

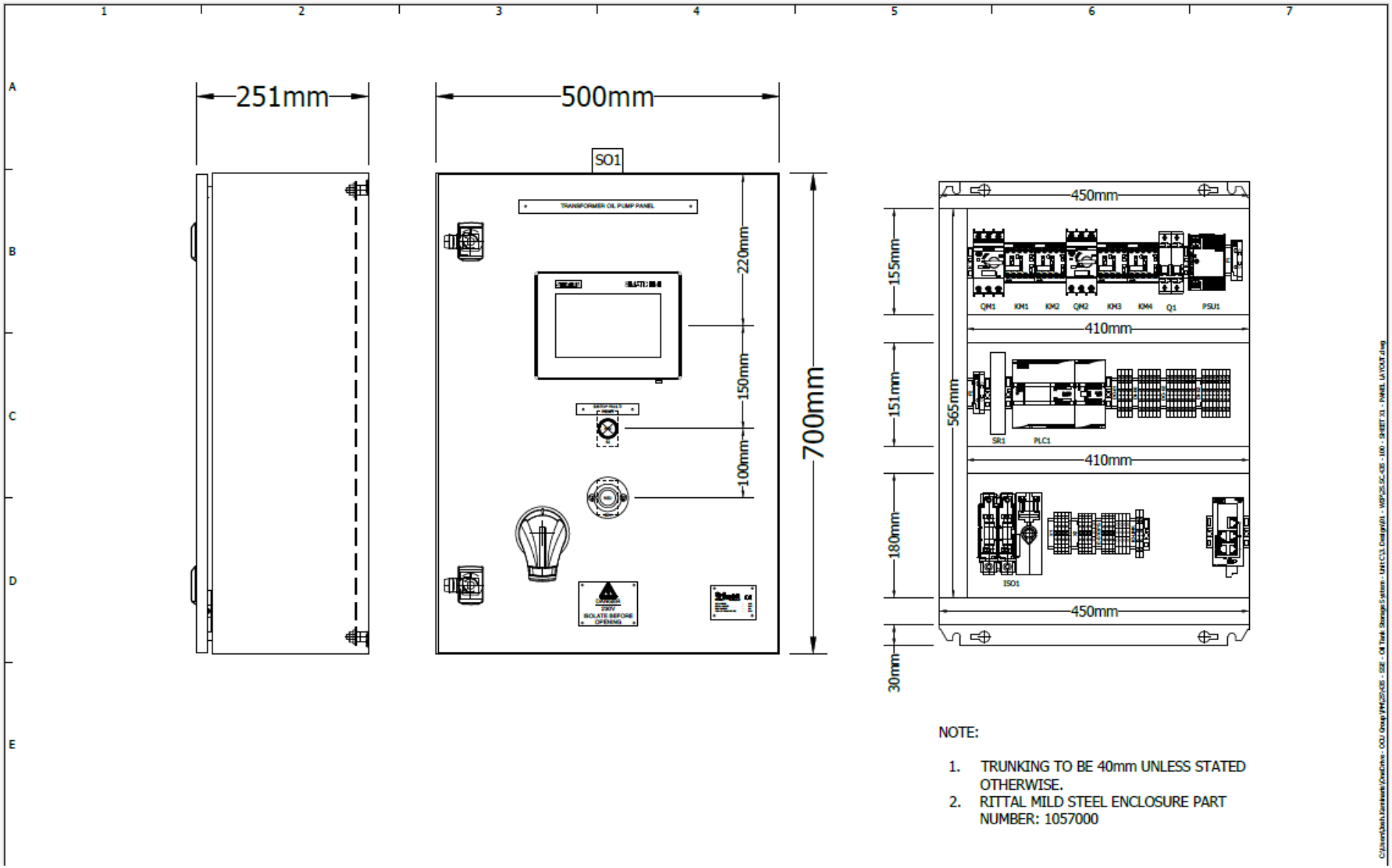
Project Description
Oil Tank Storage System

OCU Hornbill Project Number
25.SC.435

Drawing Issue
Revision A2

DRAWING SETS

DESCRIPTION	DRAWING NO.	SHEETS
MAIN CONTROL PANEL	100	14



NOTE:

1. TRUNKING TO BE 40mm UNLESS STATED OTHERWISE.
2. RITTAL MILD STEEL ENCLOSURE PART NUMBER: 1057000

SHEET	DESCRIPTION	FILENAME
01	COVER SHEET	25.SC.435 - 100 - SHEET 01 - COVER SHEET
02	INDEX	25.SC.435 - 100 - SHEET 02 - INDEX
03	REVISION LOG	25.SC.435 - 100 - SHEET 03 - REVISION LOG
04	DRAWING INFORMATION	25.SC.435 - 100 - SHEET 04 - DRAWING INFO
05	MAIN INCOMER	25.SC.435 - 100 - SHEET 05 - MAIN INCOMER
06	230VAC DISTRIBUTION	25.SC.435 - 100 - SHEET 06 - 230VAC DISTRIBUTION
07	SAFETY RELAY	25.SC.435 - 100 - SHEET 07 - SAFETY RELAY
08	PLC	25.SC.435 - 100 - SHEET 08 - PLC
09	RELAY OUTPUTS	25.SC.435 - 100 - SHEET 09 - RELAY OUTPUTS
10	DIGITAL INPUTS	25.SC.435 - 100 - SHEET 10 - DIGITAL INPUTS
11	RELAY OUTPUTS	25.SC.435 - 100 - SHEET 11 - RELAY OUTPUTS
12	DIGITAL INPUTS	25.SC.435 - 100 - SHEET 12 - DIGITAL INPUTS
X1	PANEL LAYOUT	25.SC.435 - 100 - SHEET X1 - PANEL LAYOUT
X2	LABELS	25.SC.435 - 100 - SHEET X2 - LABELS

WIRING IDENTIFICATION

WIRING STANDARD:			BS7671	
			POWER	CONTROL
AC CIRCUITS	400V	L1	BROWN	N/A
	400V	L2	BLACK	N/A
	400V	L3	GREY	N/A
	400V	N	LIGHT BLUE	N/A
	230V	L	BROWN	RED
	230V	N	LIGHT BLUE	LIGHT BLUE
	110V	L	BROWN	RED
	110V	N	LIGHT BLUE	LIGHT BLUE
	24V	L	BROWN	RED
	24V	N	LIGHT BLUE	LIGHT BLUE
DC CIRCUITS	48V	+	BROWN	VIOLET
	48V	- / 0	BLUE	BLUE
	24V	+	BROWN	VIOLET
	24V	- / 0	BLUE	BLUE
	12V	+	BROWN	VIOLET
	12V	- / 0	BLUE	BLUE
	5V	+	BROWN	VIOLET
	5V	- / 0	BLUE	BLUE
MISCELLANEOUS	ANA	+	N/A	PINK
	ANA	- / 0	N/A	GREY
	EXTERNAL		ORANGE	ORANGE
	EARTH	PE	GREEN / YELLOW	GREEN / YELLOW
	E-STOP		N/A	YELLOW

WIRE SIZES

POWER	MINIMUM OF 2.5mm UNLESS OTHERWISE STATED
CONTROL	MINIMUM OF 0.75mm UNLESS OTHERWISE STATED

SYMBOL LEGEND

DISCONNECT SWITCH	TRANSFORMER	PUSH BUTTON (N/O)	NORMALLY OPEN CONTACT	SCREEN
FUSED DISCONNECT SWITCH	POWER SUPPLY	PUSH BUTTON (N/C)	NORMALLY CLOSED CONTACT	TERMINAL
CIRCUIT BREAKER	PILOT LIGHT (WHITE)	ILLUMINATED PUSH BUTTON	LIMIT SWITCH	GENERAL EARTH
MOTOR PROTECTION CB	FLASHING BEACON	E-STOP (N/C)	PRESSURE SWITCH	MAIN EARTH BAR CONNECTION
OVERLOAD	FUSE	SELECTOR SWITCH (3 POS)	TEMPERATURE SWITCH	DIODE
3 POLE CONTACTOR	FUSE SWITCH	KEY SWITCH (3 POS)	RELAY/CONTACTOR COIL	PLUG / SOCKET
3 PHASE MOTOR	RESISTOR	VOLTMETER	SOLENOID	
SINGLE PHASE MOTOR	VARIABLE RESISTOR	AMMETER	ON DELAY SWITCH (NO)	
DC MOTOR	REACTOR	TIMER RELAY	ON DELAY SWITCH (NC)	

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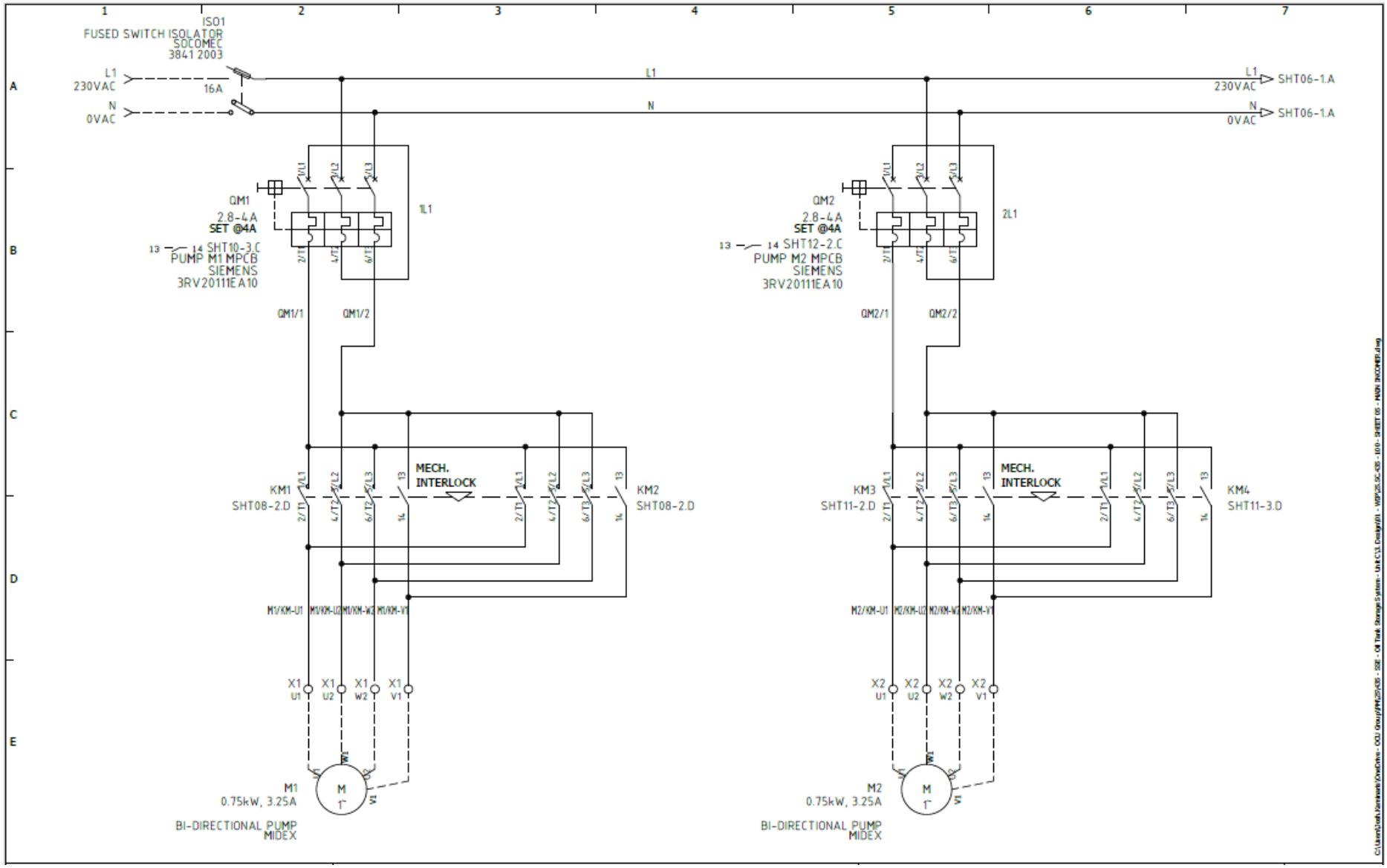

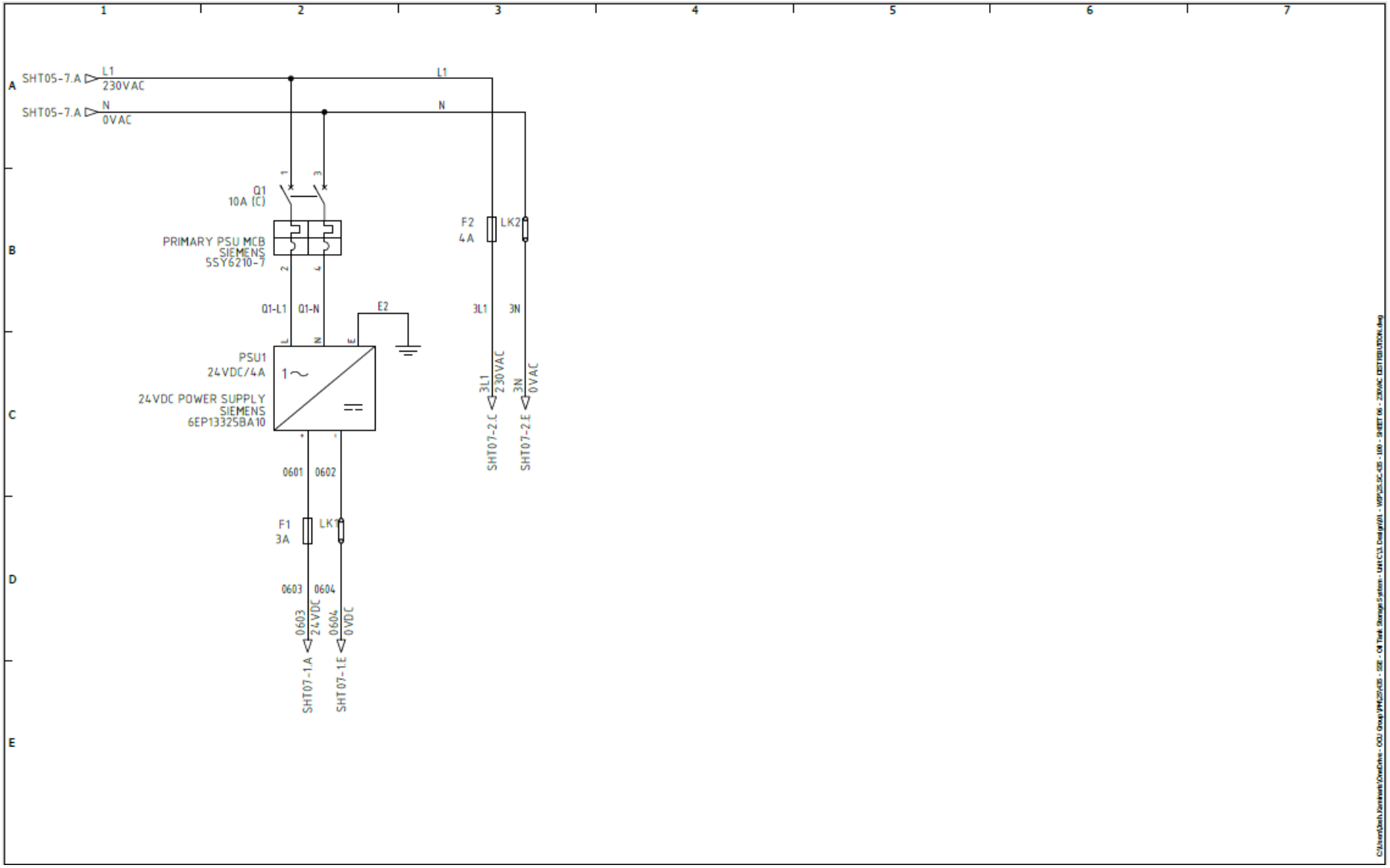
SHT05-7.A
L1
230VAC
SHT05-7.A
N
0VAC
L1
N
Q1
10A (C)
PRIMARY PSU MCB
SIEMENS
5SY6210-7
F2
4A
LK2
Q1-L1
Q1-N
E2
3L1
3N
PSU1
24VDC/4A
24VDC POWER SUPPLY
SIEMENS
6EP13325BA10
3L1
230VAC
3N
0VAC
SHT07-2.C
SHT07-2.E
0601
0602
F1
3A
LK1
0603
0604
0603
24VDC
0604
0VDC
SHT07-1.A
SHT07-1.E

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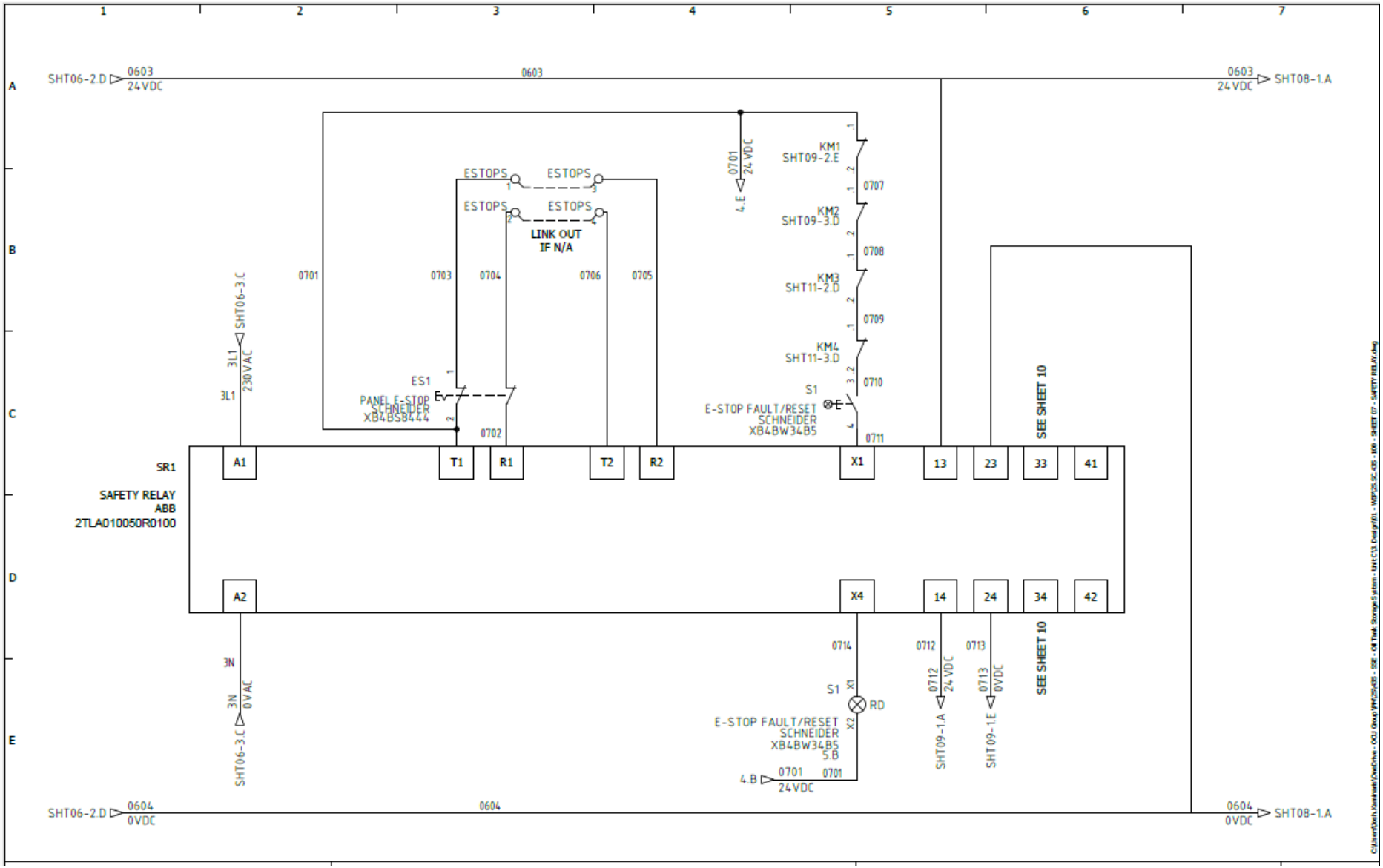

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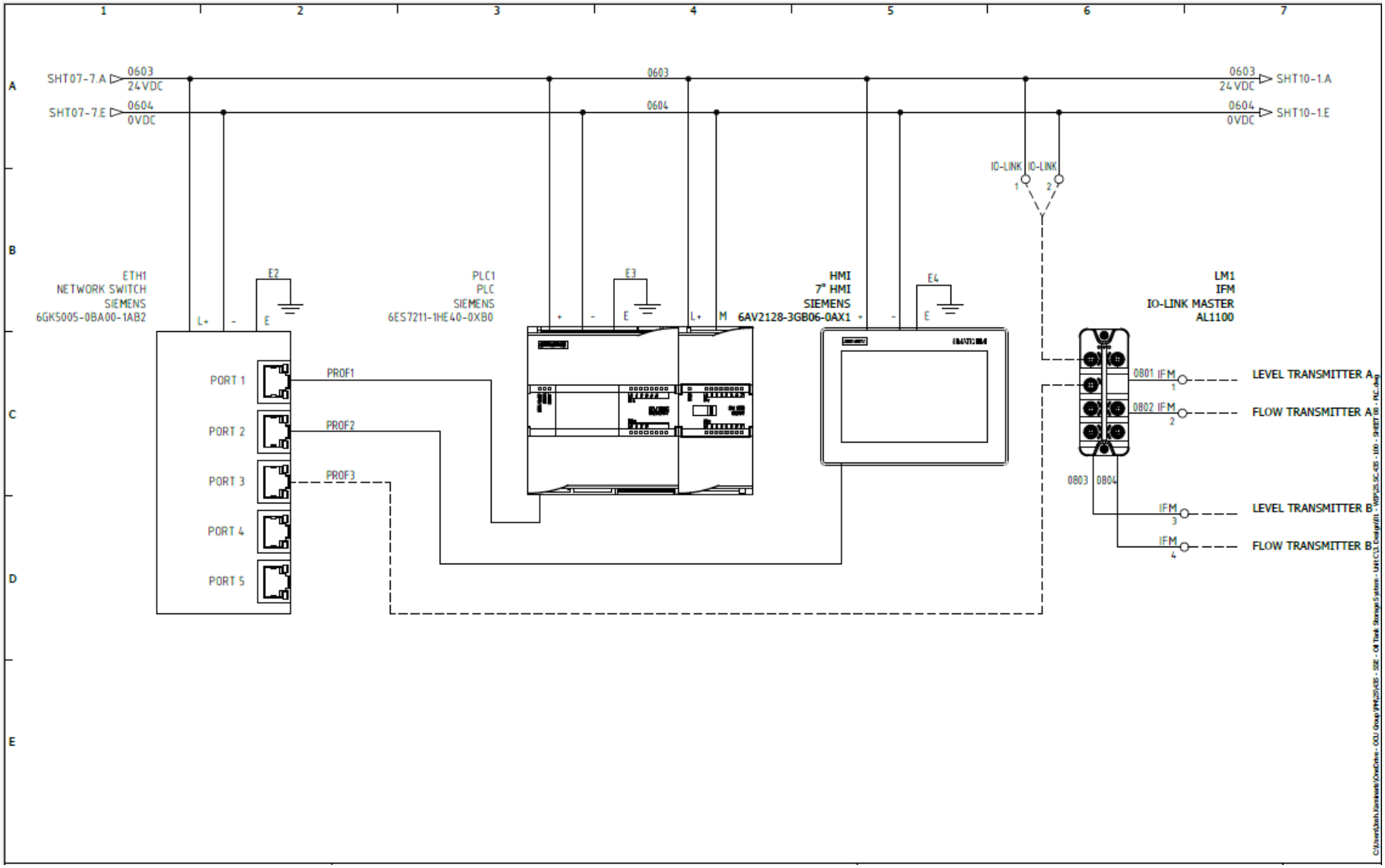

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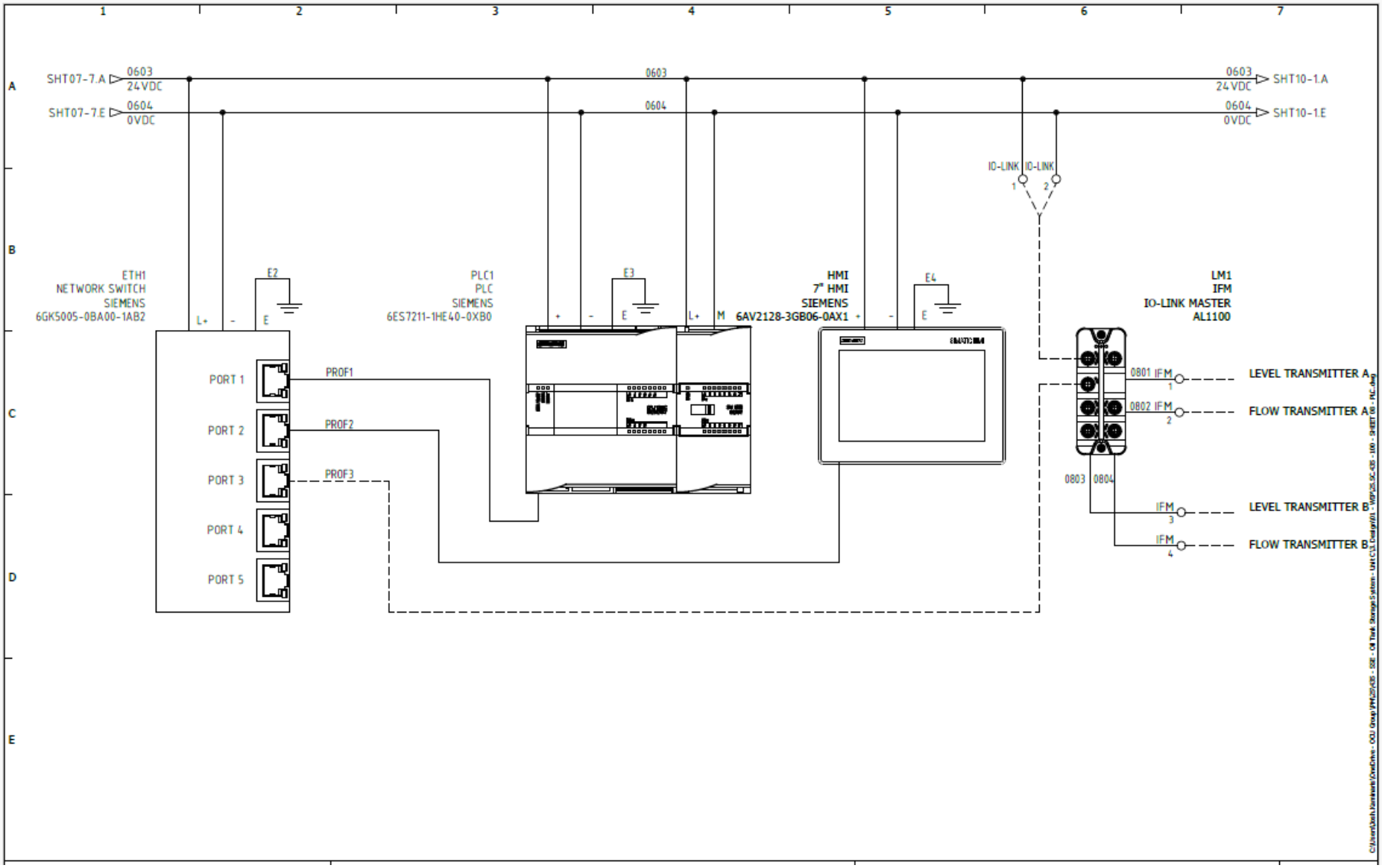

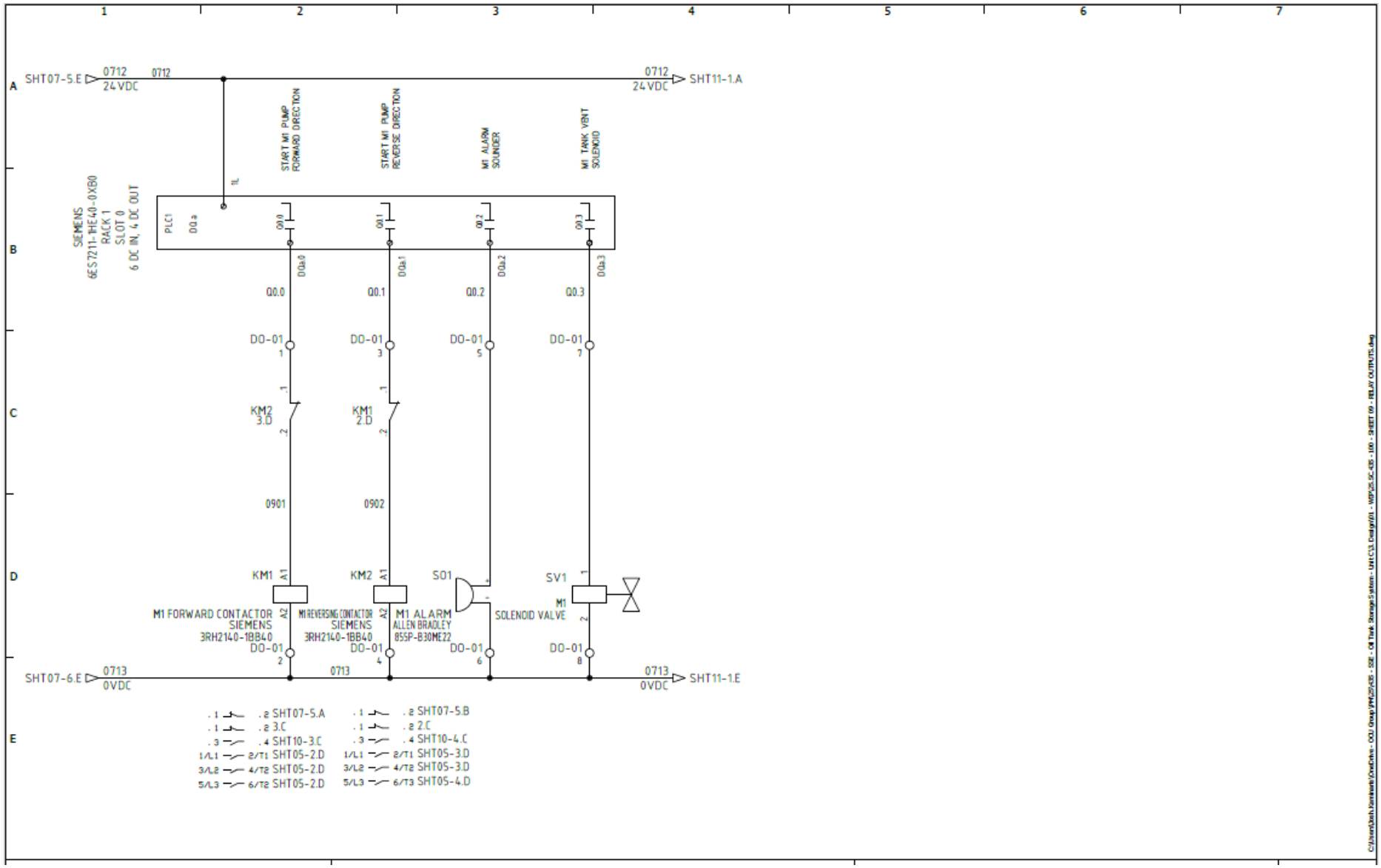
SHT07-5.E
0712
24VDC
SHT11-1.A
START M1 PUMP FORWARD DIRECTION
START M1 PUMP REVERSE DIRECTION
M1 ALARM SOUNDER
M1 TANK VENT SOLENOID
SIEMENS
6ES7211-1HE40-0XB0
RACK 1
SLOT 0
6 DC IN, 4 DC OUT
PLC1
Q0.0
Q0.1
Q0.2
Q0.3
DO-01
KM2
3.D
KM1
2.D
0901
0902
KM1
KM2
SO1
SV1
M1 FORWARD CONTACTOR
SIEMENS
3RH2140-1BB40
M1 REVERSING CONTACTOR
SIEMENS
3RH2140-1BB40
M1 ALARM
ALLEN BRADLEY
855P-B30ME22
SOLENOID VALVE
M1
SHT07-6.E
0713
0VDC
SHT11-1.E
SHT07-5.A
3.C
SHT10-3.C
SHT05-2.D
SHT07-5.B
2.C
SHT10-4.C
SHT05-3.D
SHT05-4.D

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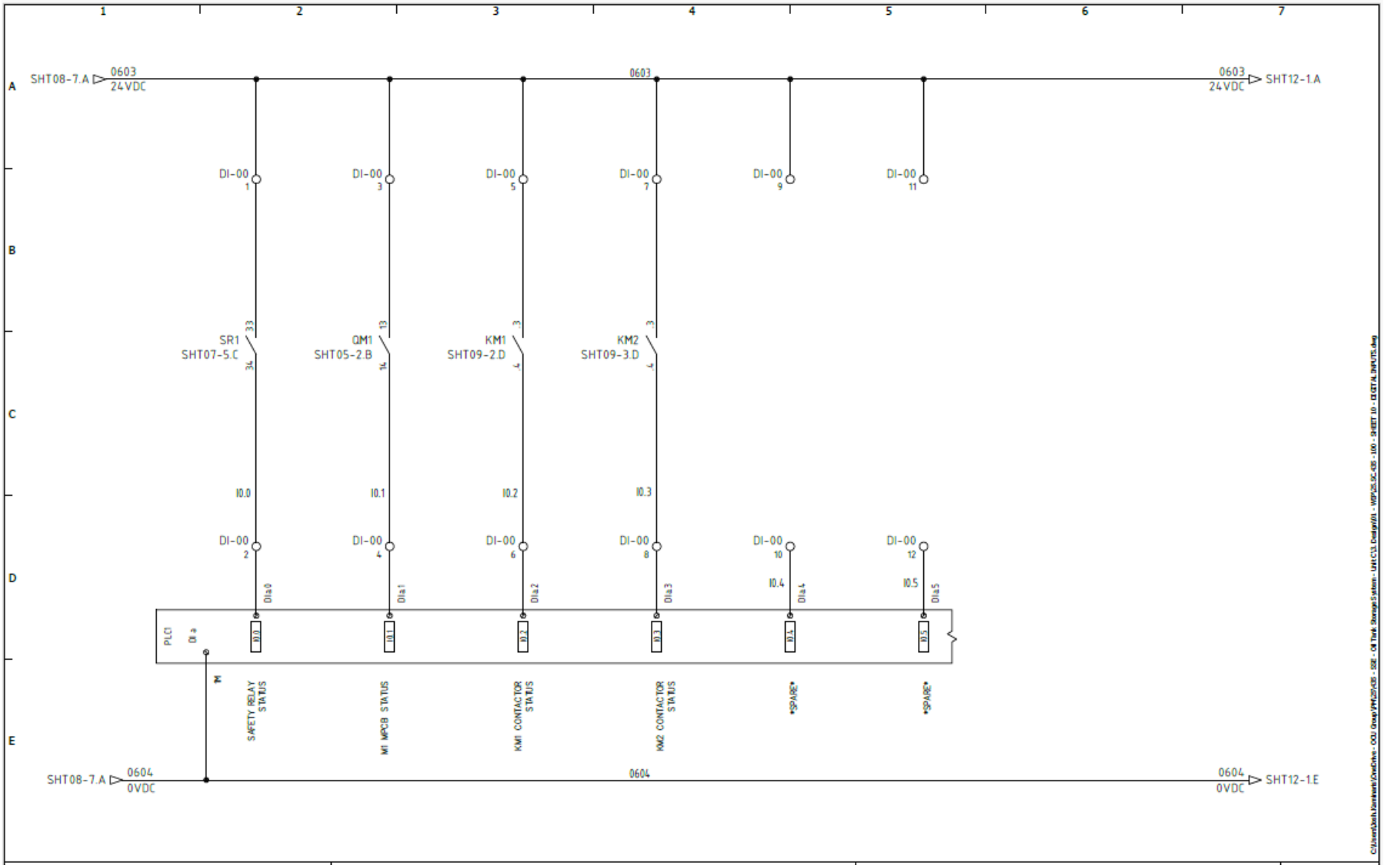

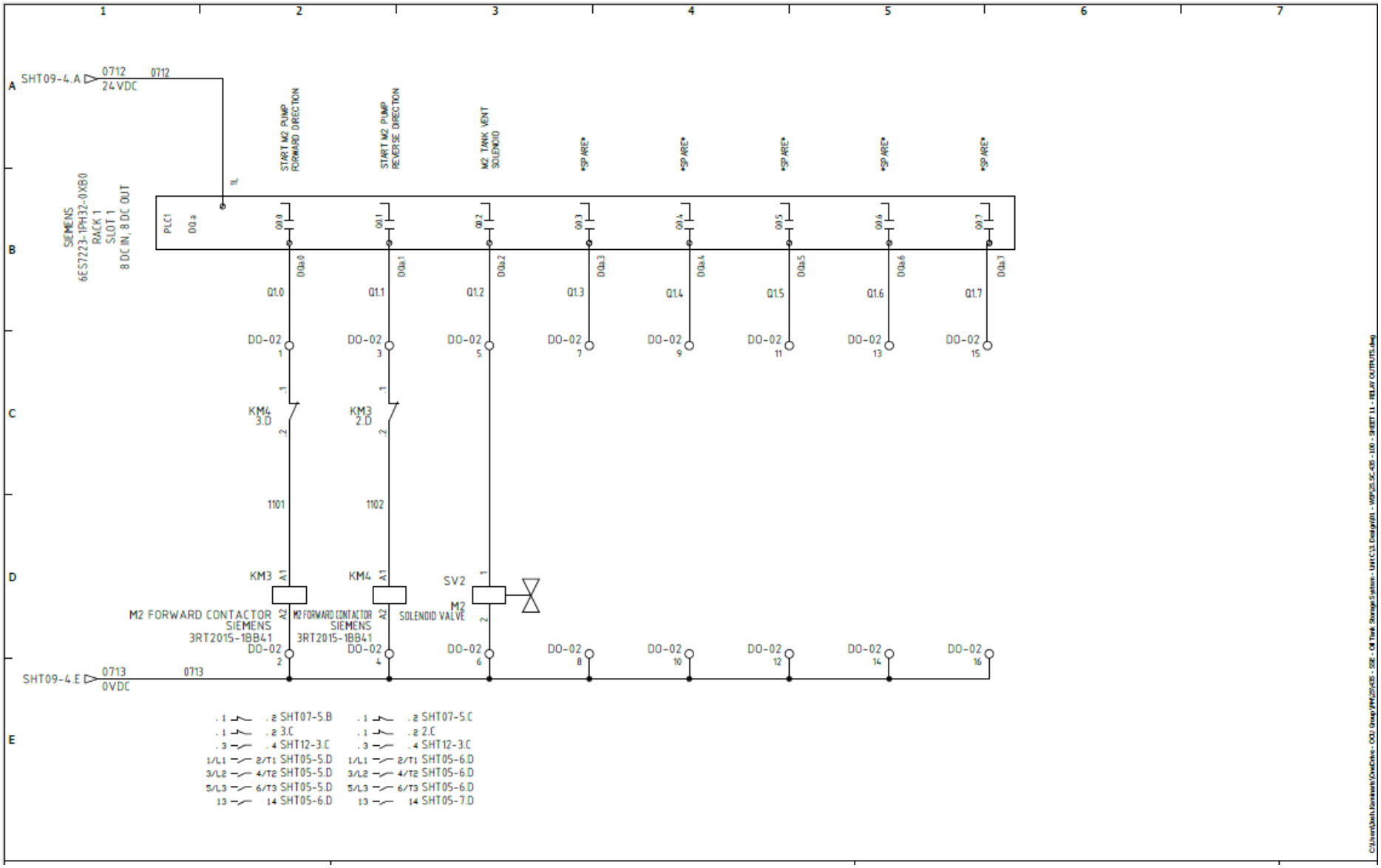
SHT09-4.A
0712
24VDC
SIEMENS
6ES7223-1PH32-0XB0
RACK 1
SLOT 1
8 DC IN, 8 DC OUT
PLC1
START M2 PUMP FORWARD DIRECTION
START M2 PUMP REVERSE DIRECTION
M2 TANK VENT SOLENOID
SPARE
Q1.0
Q1.1
Q1.2
Q1.3
Q1.4
Q1.5
Q1.6
Q1.7
DO-02
KM4
3.D
KM3
2.D
1101
1102
KM3
KM4
SV2
M2 FORWARD CONTACTOR
SIEMENS
3RT2015-1BB41
M2 SOLENOID VALVE
SHT09-4.E
0713
0VDC
SHT07-5.B
3.C
SHT12-3.C
SHT05-5.D
SHT05-6.D
SHT07-5.C
2.C
SHT05-7.D

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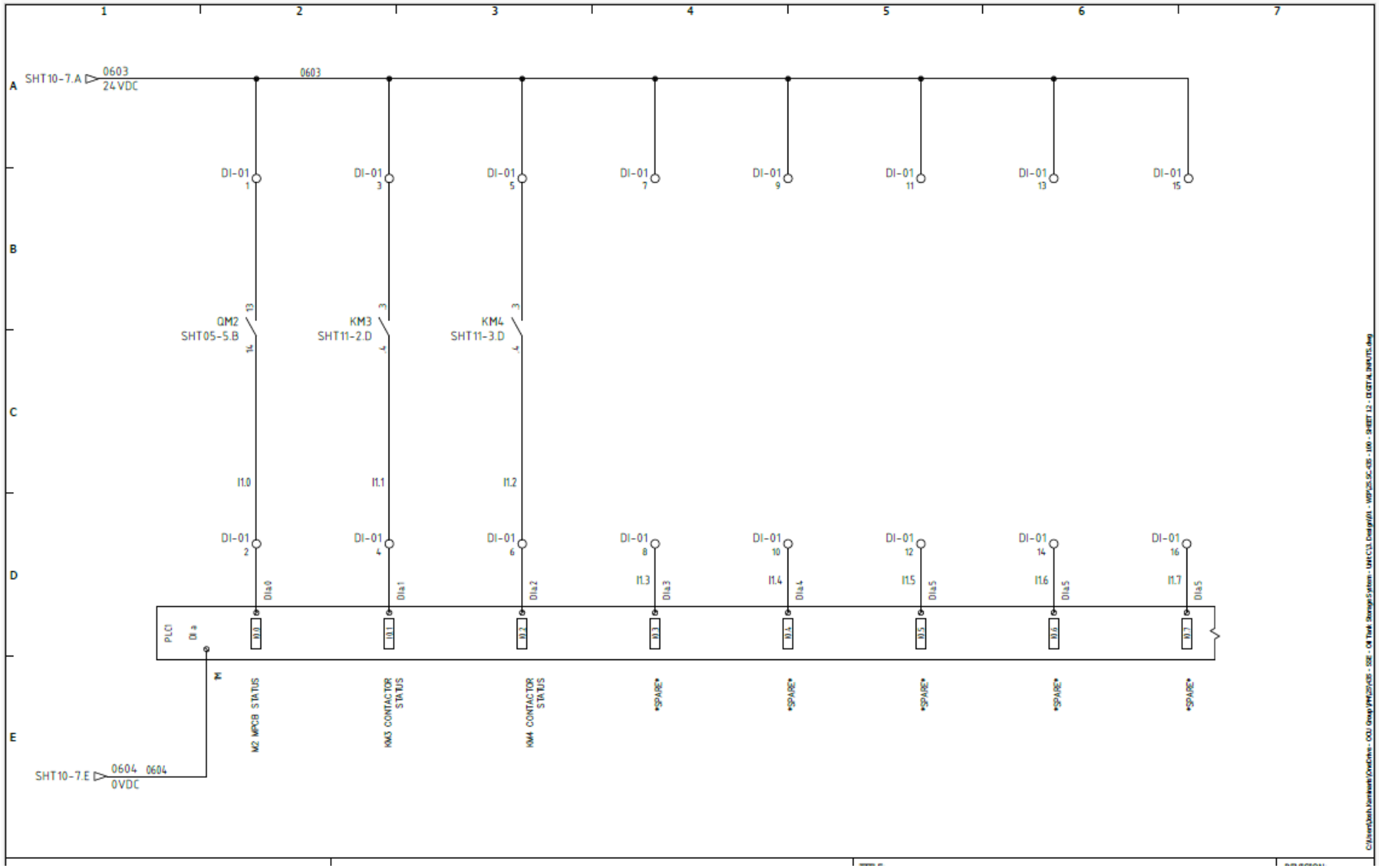

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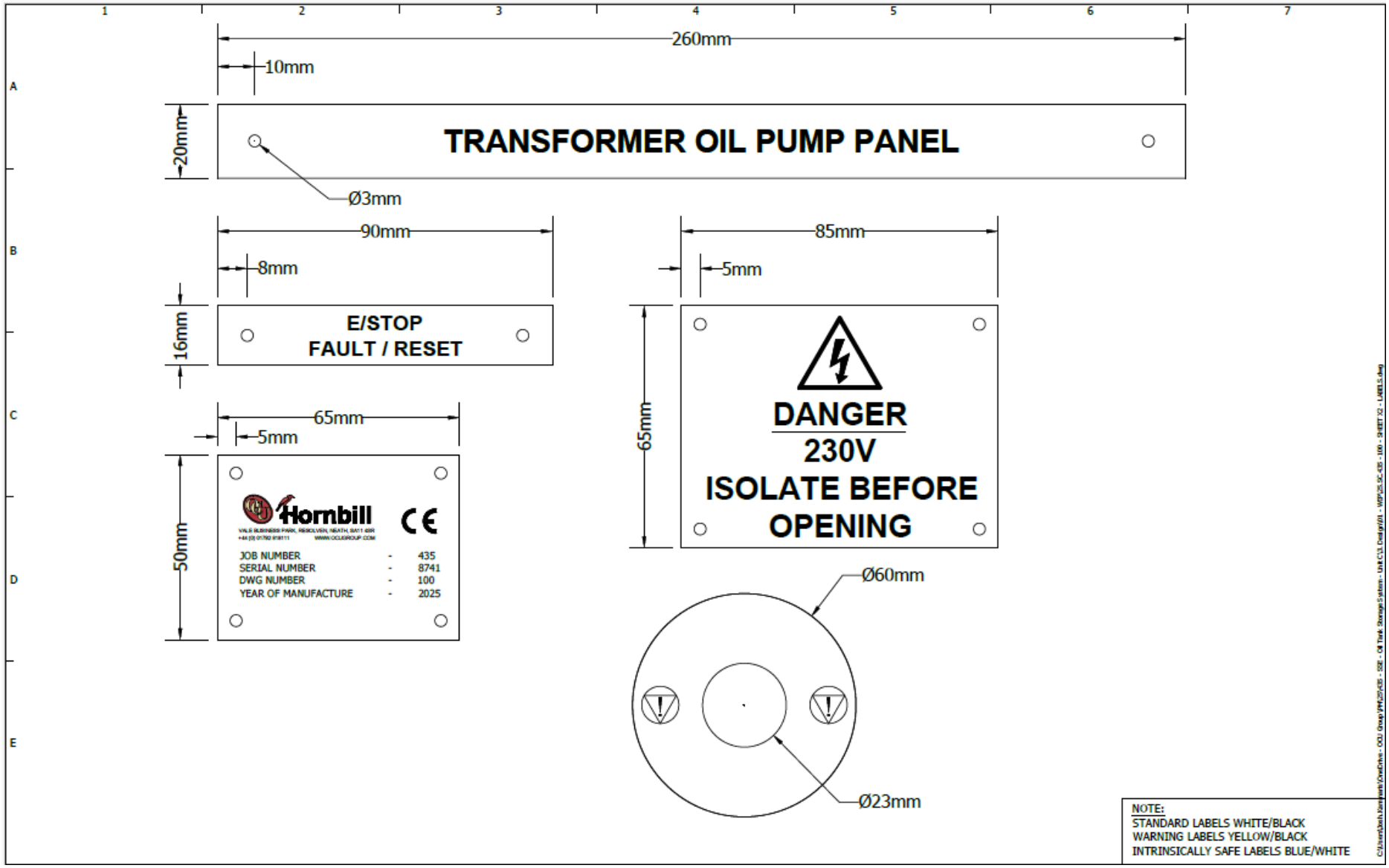
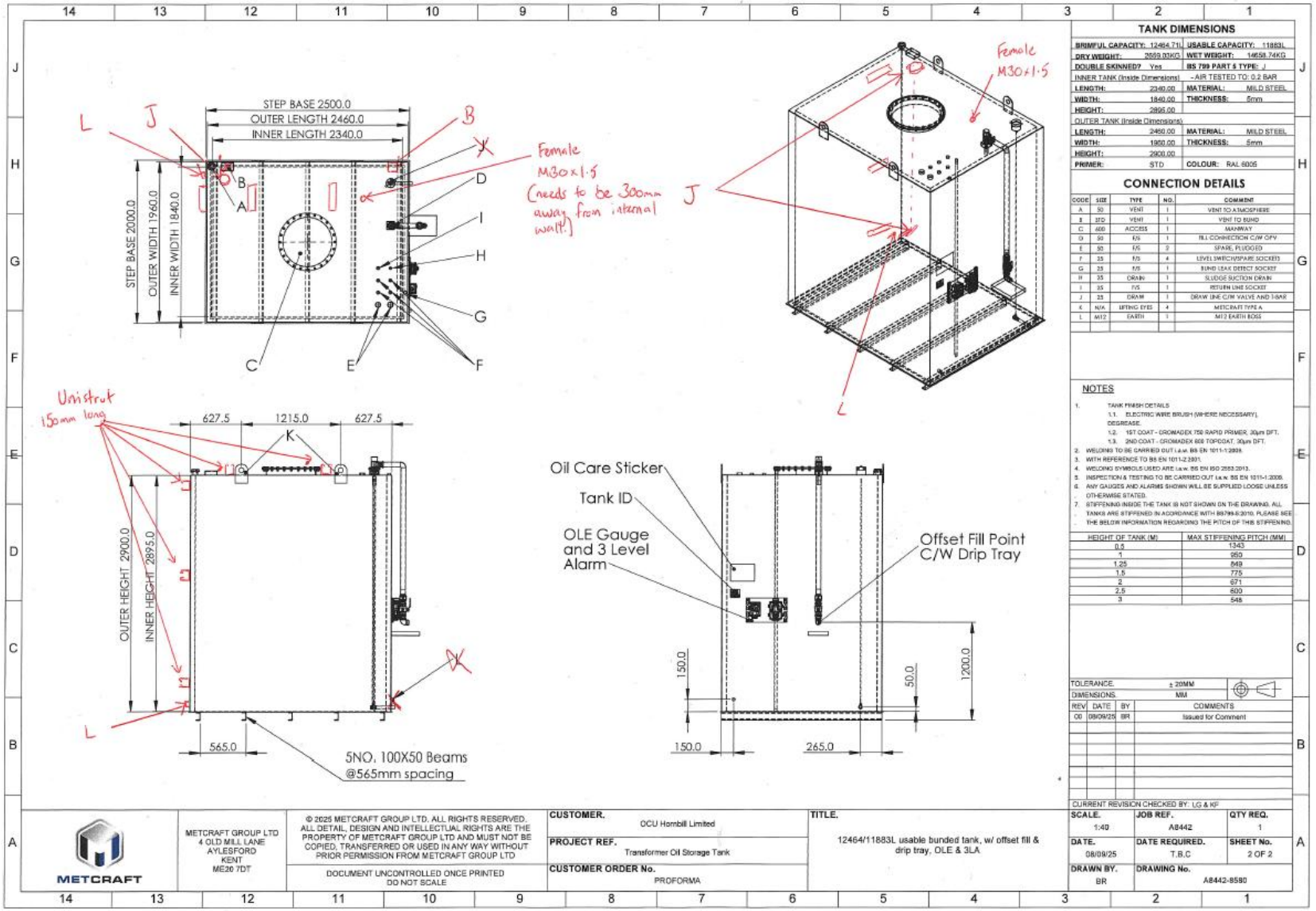


Appendix C — Tank Drawing (Metcraft A8442-8580)

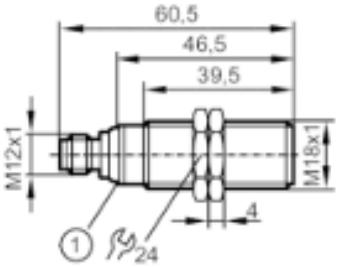


Appendix D - Instrument Datasheet

UGT213

Ultrasonic sensor

UGC008000EOKG/IO-Link/US



1 LEDs

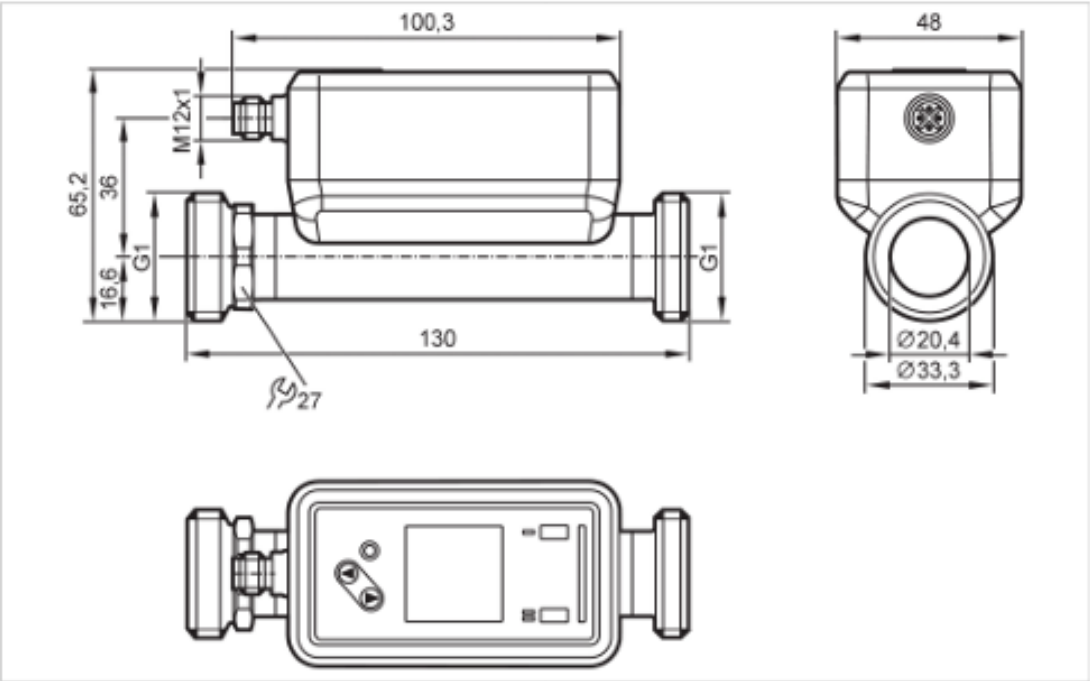
IO-Link

Product characteristics		
Electrical design		PNP
Output function		normally open / normally closed; (parameterisable)
Sensing range	[mm]	60...800; (Target: 200 x 200 mm)
Communication interface		IO-Link
Housing		threaded type
Dimensions	[mm]	M18 x 1 / L = 60.5
Electrical data		
Operating voltage	[V]	10...30 DC; ("supply class 2" to cULus)
Current consumption	[mA]	< 35
Protection class		III
Reverse polarity protection		yes
Power-on delay time	[s]	< 0.3
Converter frequency	[kHz]	230
Inputs / outputs		
Number of inputs and outputs		Number of digital outputs: 1
Inputs		
Synchronisation input		no
Multiplex input		no
Outputs		
Total number of outputs		1
Electrical design		PNP
Number of digital outputs		1
Output function		normally open / normally closed; (parameterisable)
Max. voltage drop switching output DC	[V]	2.2
Permanent current rating of switching output DC	[mA]	100
Switching frequency DC	[Hz]	5
Short-circuit protection		yes
Overload protection		yes

SU8030

Ultrasonic flow meter

SUR11XFBFRKG/US



ACS CE IO-Link KTW/W270 Reg31

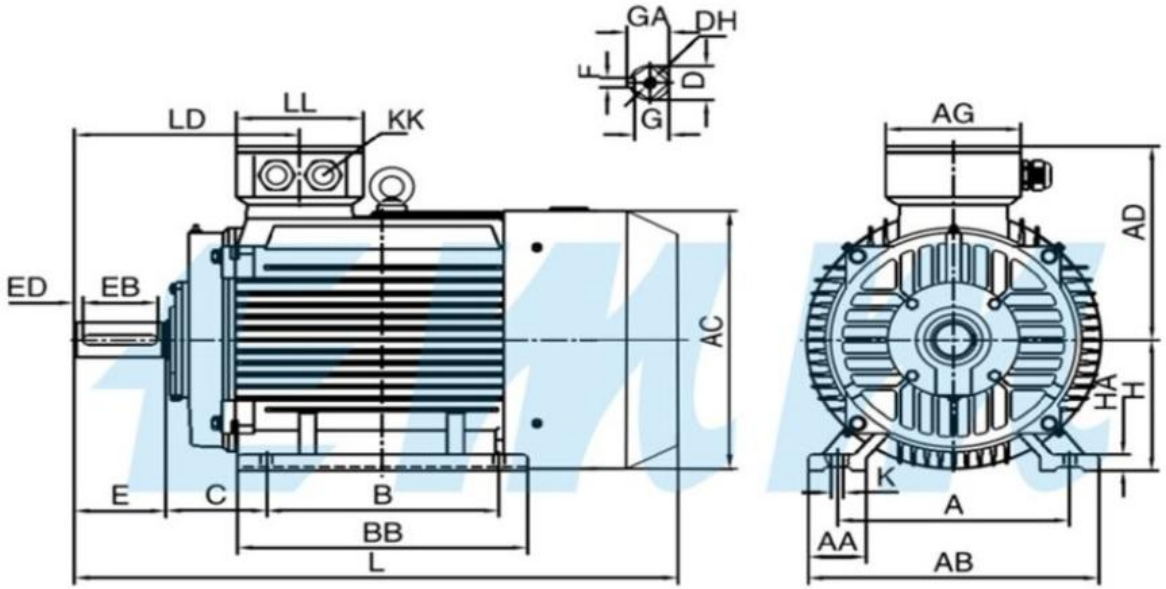
Product characteristics					
Measuring range		1...240 l/min	60...14400 l/h	0.051...12.202 m/s	0.06...14.4 m³/h
Process connection		threaded connection G 1 external thread DN25			
Application					
Special feature		Gold-plated contacts			
Media		ultra-pure water; water; hydrous media; glycol solutions; oils; coolants			
Note on media		hydrous media: for media with >10 % additives, the repeatability is the only available value			
		low-viscosity oils with viscosity: 7...40 mm²/s (40 °C)			
		high-viscosity oils with viscosity: 30...68 mm²/s (40 °C)			
Medium temperature	[°C]	-20...100			
Min. burst pressure		150 bar		15 MPa	
Pressure rating		100 bar		10 MPa	
Vacuum resistance	[mbar]	-1000			
Electrical data					
Operating voltage	[V]	18...32 DC; (to SELV/PELV)			
Current consumption	[mA]	< 75			
Protection class		III			
Reverse polarity protection		yes			
Power-on delay time	[s]	5			
Measuring principle		ultrasonic			

Appendix E — Motor Datasheet

Elektrim TECHTOP

IE1 TEFC
EM80B-4

Frequency	50Hz
Pole	4P
Output (KW)	0.75
Output (HP)	1
Rated Speed (RPM)	1390
IFL 380V (AMP)	2.08
IFL 400V (AMP)	1.98
IFL 415V (AMP)	1.90
Efficiency %	72.10
Power Factor	0.76
Rated Torque Nm	5.20
TST/TN Times	2.3
Tmin/TN Times	2.3
Locked Rotor Current IST/IFL	6
M of J kgm2	0.003
Noise Level LW dB(A)	56
Net Weight kg	16



Dimension *All dimensions in mm

Mounting Type: B3

FOOT MOUNTED DIMENSION																														
A	AA	AB	AC	AD	AG	B	BA	BB	C	D	DH	E	EB	ED	F	G	GA	H	HA	K	KK	L	LA	LB	LD	LL	M	N	P	S	T
125	34	160	155.4	131	94	100		130	50	19	M6X16	40	30	5	6	15.5	21.5	80	10	4-Φ10	M20*1.5	284			112	94					