Manufacturing Guidelines for a Solar Ice Maker in Indonesia

Beyond Rural Electrification:

Advancing Solar PV for Ice Production.
Delivering renewable-powered cooling solutions for coastal communities and the fisheries sector in Indonesia.

GIZ Indonesia, 2025

kerja sama jerman
DEUTSCHE ZUSAMMENARBEIT

MINISTRY OF ENERGY AND MINERAL RESOURCES
REPUBLIC OF INDONESIA

Federal Ministry
for the Environment, Climate Action,
Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

IKI INTERNATIONAL CLIMATE INITIATIVE

Implemented by:
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Imprint

Manufacturing Guidelines for a Solar Ice Maker in Indonesia

Published by:

GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, on behalf of the Federal Ministry of Economic Cooperation and Development (BMZ), Federal Republic of Germany

Registered offices:

Bonn and Eschborn, Germany, and GIZ Indonesia/ASEAN, Energy Program Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH De RITZ Building, Jl. HOS. Cokroaminoto No. 91 Menteng, Jakarta Pusat 10310 Indonesia

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Printed and distributed by GIZ

Jakarta, 2025

Introduction

The Solar Ice Maker is an innovative technology that uses solar energy to produce ice, addressing a critical challenge for small-scale fishers in Indonesia's coastal communities. In many parts of Eastern Indonesia – despite being vital fisheries hubs – unreliable electricity restricts access to ice, forcing fishers to sell lower-quality catch and suffer avoidable income losses and economic hardship.

To address this challenge, GIZ Indonesia launched an international technology cooperation in 2017 to develop, demonstrate, and localize a solar-powered cooling solution for Indonesia: the Solar Ice Maker. The initiative was implemented under the Indonesian–German Energy Programme, in partnership with the Ministry of Energy and Mineral Resources of the Republic of Indonesia, and funded by the Federal Ministry for Economic Cooperation and Development (BMZ) and the International Climate Initiative (IKI) of the Federal Government of Germany.

The technology was developed by the Institute of Air Handling and Refrigeration (ILK Dresden), in collaboration with PT. Selaras Mandiri Tehnik (AIREF) as the Indonesian manufacturer and other private sector partners. Key contributors to the system components included PT. ATW Solar Indonesia, REC Solar Pte. Ltd., BAE Batterien GmbH, BITZER Kühlmaschinenbau GmbH, Ziehl-Abegg SE, Studer Innotec SA, OMRON Corporation, and PT Pertamina.

The Solar Ice Maker integrates solar photovoltaics with advanced cooling technology to produce up to 1.2 tonnes of block ice per day. Designed for full off-grid operation, the system requires neither a grid connection nor large battery storage, thanks to smart energy management. Equipped with sensor-based controls, it operates climate-neutrally, using propane (R290) as a natural refrigerant and salt water as thermal energy storage.

This innovation delivers reliable ice production in remote coastal areas, helping small-scale fishers preserve the quality of their catch and secure higher market prices. For example, sustainably caught tuna can achieve up to 100% higher value when properly chilled. Each Solar Ice Maker reduces annual CO_2 emissions by around 80 tonnes, prevents post-harvest losses, and generates an estimated USD 120,000 in additional local value per installation.

As a game-changing solution, the Solar Ice Maker combines renewable energy with cutting-edge refrigeration to ensure fresh, high-quality fish, boost fisher incomes, strengthen rural economies, and accelerate Indonesia's clean energy transition. It has been listed as a Finalist under the Smarter E Award's Outstanding Project Category in 2025.

To drive commercialization and local manufacturing in Indonesia, GIZ will publish the Solar Ice Maker Manufacturing Guidelines in 2025. This open resource – complete with detailed manufacturing guidelines, component specifications, and wiring diagrams – invites private companies and manufacturers to join the innovation journey and adopt knowledge for their own approach. By enabling co-learning and scale-up, the guidelines help to expand cold-chain access and unlock new market opportunities across Indonesia's fisheries sector.

Overview of the Solar Ice Maker Manufacturing Guideline

The Manufacturing Guideline of the Solar Ice Maker provides a step-by-step reference for developers, manufacturers, and private sector partners interested in replicating or scaling the technology. It presents the essential components, system integration methods, and operational principles necessary to design, construct, and run a dynamic Solar Ice Maker system effectively.

Introduction

The introduction presents the background and objectives of the guideline, emphasizing the role of the Solar Ice Maker (SIM) as an innovative decentralised technology that uses solar energy to produce ice, addressing a critical challenge for small-scale fishers in Indonesia's coastal communities in Indonesia.

Chapter 1 – Technology Overview of Solar Ice Maker

This chapter explains the basic working principle of the SIM, describes the main subsystems (PV, refrigeration, brine, ice bins, control), and introduces the available solar ice maker technology design (building-integrated and containerized designs).

Chapter 2 – Electrical System and Components

This chapter explains the design and implementation of the electrical subsystem, covering the concept of the PV-powered electrical system, selection criteria for key components such as PV modules, inverters, charge controllers, and batteries, as well as the configuration of both the main supply circuit for powering the cooling units and the auxiliary supply circuit. It also includes hardware specifications for the control system and cabling, manufacturing instructions to ensure proper wiring, safety, and assembly, and appendices with a complete parts list and technical data specification.

Chapter 3 – Cooling System and Components

This chapter focuses on the refrigeration and brine systems, which are central to the ice-production process. It outlines the general operation of a PV-powered dynamic ice machine, provides step-by-step manufacturing instructions for the cooling unit, brine tank, ice bins, and pumps, and includes appendices with diagrams and technical data to support replication and implementation.

Chapter 4 – Dynamic Control and Automation System

This chapter explains how the Solar Ice Maker operates under fluctuating solar conditions by leveraging automation and intelligent controls. It introduces the concept of the dynamic control system, highlights key operational principles such as automated daily ice cycles, and details the integration of the Variable Frequency Drive (VFD) with the compressor. Furthermore, it provides an in-depth explanation of control principles and software functions, complemented by the Omron VFD parameter list, wiring diagrams, references, and appendices to support accurate replication.

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Foreword

Frank Stegmueller

Lead Industry Decarbonisation & Energy Island Solutions, Energy Programme, GIZ Indonesia & ASEAN

The publication of these Manufacturing Guidelines marks an important milestone in the long-standing cooperation between Germany and Indonesia in advancing sustainable and locally adapted energy solutions.

Through the joint efforts of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Ministry of Energy and Mineral Resources of Indonesia, the Solar Ice Maker technology has been developed to address the specific needs of Indonesia's coastal and island communities. From the outset, the aim was to go beyond an innovative concept and develop a solution that is technically robust, economically viable, and commercially scalable, with relevance at national level.

This initiative was implemented by GIZ on behalf of the German Federal Government, under funding by the International Climate Initiative and the Federal Ministry for Economic Cooperation and Development.

Over several years, this initiative has evolved through close collaboration with a wide range of partners, including Indonesian, German and international private sector companies, research institutions, and implementation partners. This collaboration has been key to refining the technology, testing it under real conditions, and building the technical and entrepreneurial capacities needed for adoption. Important contributions were made by the Dresden Applied Research Institute for Air Handling and Refrigeration and its researchers.

A key achievement of this cooperation is the transfer of knowledge and manufacturing know-how. From the first prototype onwards, the technology has been co-developed and manufactured in Indonesia together with local companies, building capabilities step by step. This has laid the foundation for local value creation and for scaling the technology. The ambition is clear: to move from pilot projects to broader commercial deployment, supporting livelihoods, reducing dependency on fossil fuels, and contributing to Indonesia's energy transition.
These Manufacturing Guidelines are meant to support this next phase by enabling this technology to transition into a commercial product. They bring together the lessons learned, technical standards, and practical experience from this cooperation, and outline the core principles of the technology in a way that can be adapted and further developed – both in Indonesia and beyond.

We hope they will support other manufacturers, investors, and practitioners in taking the next steps towards scale.

Last but not least, this publication stands as a testament to what can be achieved through strong international cooperation, shared commitment, and a clear focus on impact.

Preface

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Director General of New, Renewable Energy and Energy Conservation Ministry of Energy and Mineral Resources, Republic of Indonesia

As Indonesia continues to advance its national commitment to an inclusive and sustainable energy transition, solar power emerges as a promising support to ensure access to clean and reliable energy. This is particularly important for communities in remote, coastal, and island regions to support local livelihoods, economic development, and climate resilience. Within the fisheries sector, limited access to reliable electricity and affordable cooling technologies has long contributed to significant post-harvest losses and reduced incomes for small-scale fishers. Therefore, enhancing solar cold-chain capacity is critical to improving productivity, strengthening value chains, and supporting broader national development priorities.

Within this framework, the Directorate of New, Renewable Energy and Energy Conservation is honored to present the Manufacturing Guidelines for the Solar Ice Maker in Indonesia. This publication is the result of a long-standing cooperation between Indonesia and Germany through the GIZ Energy Programme. Since 2017, this collaboration has supported the development of the Solar Ice Maker, an innovative off-grid cooling system powered by solar photovoltaic energy and natural refrigerants (R290).

To illustrate the success of Solar Ice Maker, field implementations in Kupang, East Nusa Tenggara and West Seram, Maluku have shown that the Solar Ice Maker can reliably produce ice in off-grid systems and inadequate grid infrastructure. The success of the project is also demonstrated through the reduction of fuel dependence, maintaining higher product quality, and improving the income of small-scale fishers. For example, there's a 34% increase of export quality grade fish with 0% reject after the use of Solar Ice Maker in Maluku.

Based on the accomplishment of the project, a manufacturing guidelines is thus formulated. This book, the Manufacturing Guidelines for the Solar Ice Maker in Indonesia, provides practical, detailed guidance covering component specifications, production processes, wiring diagrams, and quality assurance measures. This is important to support Indonesian manufacturers in adopting, replicating, and further improving this technology. By making this resource publicly accessible, the publication aims to encourage wider industry participation, strengthen domestic manufacturing capabilities, and promote the broader deployment of renewable-energy-based cold-chain solutions across Indonesia.

The Directorate General of New, Renewable Energy and Energy Conservation extends its appreciation to all partners who have contributed to the development of this project. We hope that this publication serves as a useful and impactful reference for manufacturers, developers, and all stakeholders working to advance clean energy technologies. We also look forward for this publication to help empower Indonesia's coastal communities and support the country's energy transition.

1

Technology Overview of Solar Ice Maker

1. Technology Overview of Solar Ice Maker

1.1. Description

The solar ice maker integrates solar PV generation, advanced cooling, and automated control into one system. Its main subsystems and components are:

- **Solar PV Power Supply System**
  » Solar photovoltaic (PV) generator (main power source, fully off-grid).
  » Battery storage to support auxiliary devices (stirrer, valves, PLC).
  » Charge controller and inverter for power management.
  » Variable Frequency Drive (VFD) to dynamically optimize compressor operation based on solar irradiance and energy storage status.

- **Cooling Unit**
  » Compressor and condenser, operating with natural refrigerant propane (R290).
  » Condenser fan with temperature-based speed control, synchronized with compressor performance.

- **Brine & Ice Production System**
  » Brine storage tank with evaporator and stirrer for efficient heat exchange.
  » Six bin tanks, each equipped with brine circulation pumps and 20 ice bins.
  » Brine storage as thermal energy storage

- **Automation & Control System**
  » Programmable Logic Controller (PLC) for system automation.
  » Remote monitoring and maintenance capability.

The PV generator directly powers the cooling unit, with a Variable Frequency Drive (VFD) adjusting the compressor speed in real time according to available solar power. This ensures efficient utilization of fluctuating PV output. At the same time, the battery provides stable power for auxiliary devices, guaranteeing reliable operation of essential components such as the stirrer, valves, and control system.

The ice-making cycle begins automatically each day at a fixed start time. At this point, the refrigeration unit and agitator are activated, and water filling commences. The refrigeration unit operates until approximately 95% of the ice production process is completed. The remaining freezing is achieved using the residual cooling capacity of the brine system. By the following morning, the ice is fully solidified and ready for harvesting.

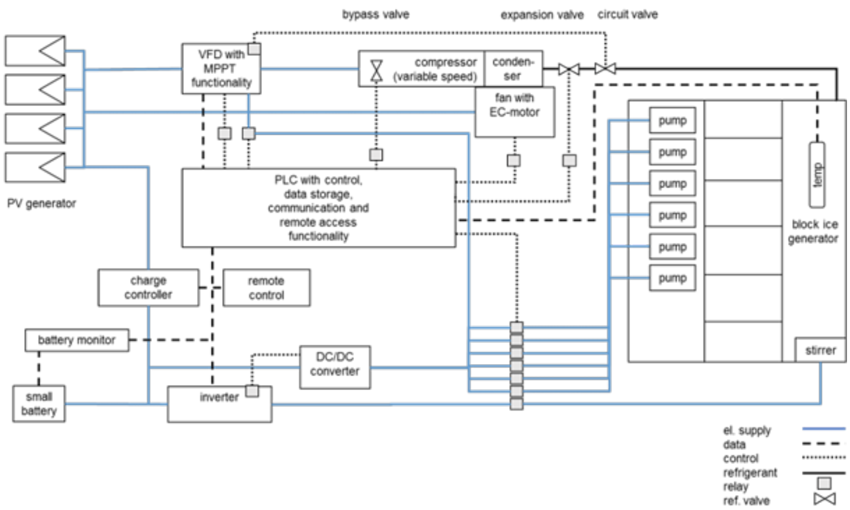


FIGURE 1 | illustrates a simplified schematic of the solar ice maker, highlighting the system layout and main energy flows.

1.2. Type of Solar Ice Maker

The development of the solar ice maker has been a multi-year journey, beginning with concept design, followed by prototype development, extensive testing, and commissioning. Today, GIZ Indonesia, in collaboration with multiple partners, has successfully established two operational units of solar ice makers in Indonesia.

- **Solar Ice Maker 1.0 (SIM 1.0)**
  - » Deployed in 2022 in Sulamu, Kupang, East Nusa Tenggara Timur.
  - » Installed inside a building with a rooftop solar PV system.

- **Solar Ice Maker 2.0 (SIM 2.0)**
  - » Commissioned in 2024 in Kawa, West Seram, Maluku.
  - » Built in a containerized design for easier installation and transport, particularly suited for remote islands with ship and ferry infrastructure access.

The ice-making cycle begins automatically each day at a fixed start time. At this point, the refrigeration unit and agitator are activated, and water filling commences. The refrigeration unit operates until approximately 95% of the ice production process is completed. The remaining freezing is achieved using the residual cooling capacity of the brine system. By the following morning, the ice is fully solidified and ready for harvesting.

FIGURE 2 | Solar Ice Maker in operation, Sulamu (2022).

FIGURE 3 | Integrated cooling system of the Solar Ice Maker, Sulamu, installed within the facility.

FIGURE 4 | Solar Ice Maker in Kawa, powered by a 27 kWp solar PV installation.

FIGURE 5 | Modular container-based design of the Solar Ice Maker in Kawa, comprising three interconnected units.

2

Electrical System and Component

2. Electrical System and Component

2.1. Concept of the electrical system

The selected system concept corresponds to the described Case 2 in report ILK-B-4-17-3496 using a photovoltaic (PV) generator directly coupled to the variable frequency drive (VFD) with a speed variable compressor. Figure 1 shows the concept.

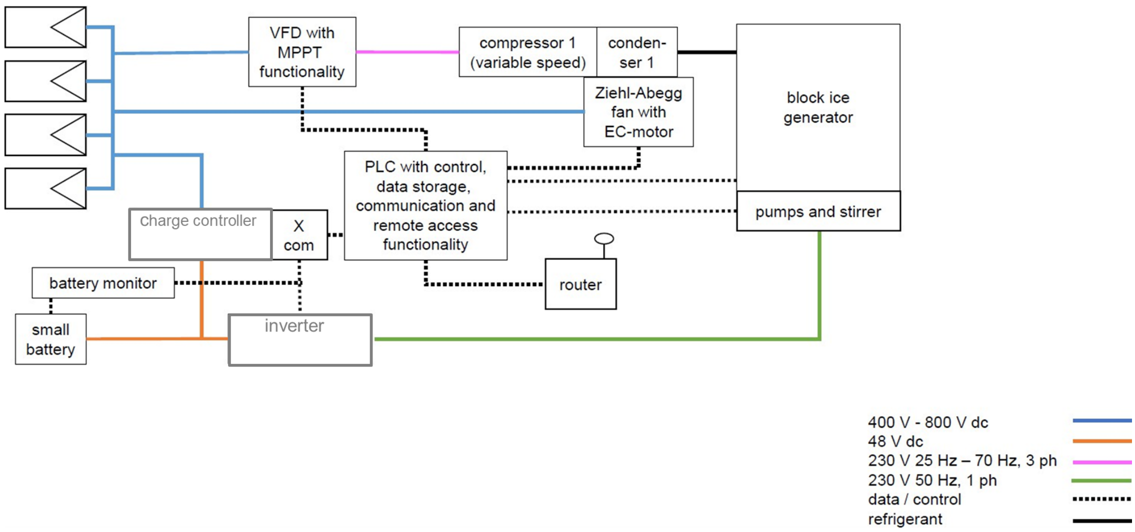


FIGURE 1 | Concept of electrical system

One central PV generator supplies the compressor (main circuit), the condenser fans and the auxiliary parts (auxiliary circuit). The VFD, which is driving the compressor, is connected to the dc output of the PV generator directly. The VFD works as a Maximum Power Point – Tracker (MPPT) and is adjusting the compressor speed to match the optimum operating point of the PV generator according to a control concept developed by ILK. Fans of the air cooled condenser of the refrigeration system are also connected to the PV generator directly. Brushless dc (BLDC) motors are used for the fans. The speed of the fans is adjusted according to the condensing pressure considering the ambient temperature. The power supply of the auxiliary components (pumps, stirrer) is intended to be realized by installation of a parallel operating 230 VAC inverter with battery buffer. Battery buffering is required for night operation of the components. The battery is charged with energy, which is not used by the compressor with a charge controller connected to the PV generator. Charging is done primarily in the morning, in the evening when the compressor is not running (due to too low PV power) and during times when excess energy is available

A programmable logic controller (PLC) controls the operation of the components with a superordinated energy management. Communication busses are required for the VFD (via RS485 and Modbus protocol) and the charge controller (via RS232 with a proprietary protocol).

The condenser fans are controlled by the PLC with digital and analog outputs. An optional Modbus connection is possible. A touch panel (HMI) is used for data visualization, storage and user inputs. For remote access to the PLC and connected devices, a router with internet access is required. Additional sensors could be connected to the PLC for monitoring purposes.

2.2. Selection of main components

This chapter describes the selection of main parts and lists the selected components of the electrical system. A summarized list of the main parts is given in Appendix A.

2.3. Main supply circuit

- **Variable frequency drive (VFD)**

The sizing of the VFD is mainly determined by the power demand of the compressor and by the motor current. The selected 4-cylinder reciprocating compressor can be operated in the frequency range from 25 Hz to 70 Hz. The achievable refrigerating capacity rises nearly linear with the frequency. The motor power and current are also depending on the operating point of the refrigerating cycle. With rising frequency up to the nominal motor frequency, the motor voltage rises but the current keeps stable. Above the nominal motor frequency, the current is rising whereas the voltage stays at the maximum level. Therefore, the motor needs a power and current reserve at nominal conditions. [BIT06]

Data of selected compressor and motor:
Type : Bitzer 4TESP-12P-40S
Nominal voltage : 400 V (3 phase)
Nominal frequency : 50 Hz
Maximum input current : 25.1 A
Maximum input power : 14 kW

Assumed operating conditions of compressor for VFD selection process: Maximum ambient temperature: +35 °C
Maximum condensing temperature: +50 °C Maximum evaporating temperature: +10 °C Minimum evaporating temperature: - 25 °C

t_o/t_c [°C]	P_{el} [kW]	I [A]	$\dot{Q}_0$ [kW]
- 25 / + 50	5.45	11.01	7.92
- 10 / + 50	7.74	13.98	16.83
+ 10 / + 50	9.53	16.55	36.7

TABLE 1 | Power data for nominal operation at 400 V / 50 Hz from Bitzer software [BIT15]

t_o/t_c [°C]	P_{el} [kW]	I [A]	$\dot{Q}_0$ [kW]
- 25 / + 50	7.63	15.41	11.09
- 10 / + 50	10.84	19.57	23.56
+ 10 / + 50	13.34	23.17	51.38

TABLE 2 | Extrapolated data for maximum operation at 400 V / 70 Hz

At worst case operating conditions (marked bold in Table 2) the current consumption is 23.17 A and the input power is 13.34 kW. These data are lower than the maximum allowed data of the motor and operation in this range will be possible. The VFD was selected to fulfill these conditions including a buffer.
Selected VFD:
Type : Omron MX2-A4150-E
Maximum motor current : 31 A
Maximum motor power : 15 kW
According to the given requirements from BITZER [BIT06], the following inverter settings have to be made:
Switching frequency : 3 kHz
Rise time to 25 Hz : 3 s

A motor inductor is recommended to reduce electrical stress of the motor windings. Alternatively, a sinusoidal filter could be necessary depending on the maximum voltage for motor windings and cable length. But both components, an inductor as well as a sinusoidal filter would cause conversion losses and increased costs. Therefore, it is the intention of the electrical design to avoid such voltage smoothing components. However, the output of the VFD is pulsed with 3 kHz which may cause (depending on e.g. cable properties) significant voltage spikes if no inductor or filter is used. Therefore, the speed of voltage increase and the maximum level have to be measured at the installed system and have to be compared to the maximum ratings according to the motor manufacturer [BIT06] (Figure 2). If necessary, a sinusoidal filter has to be installed.

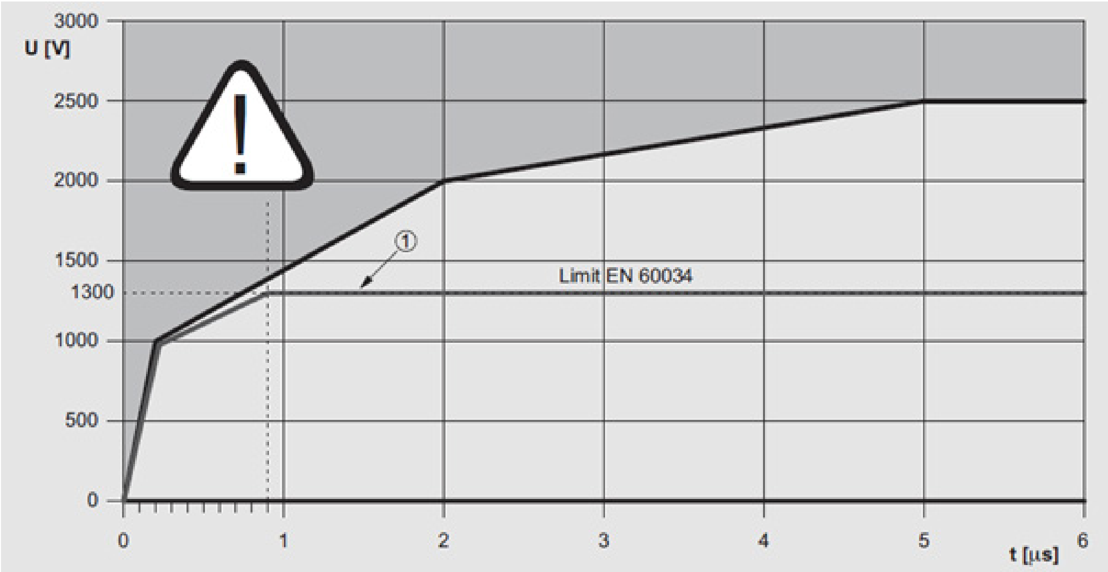


FIGURE 2 | Concept of electrical system

<u>Selected motor inductor:</u>
Type: Omron AX-RAO02000320-DE

<u>Selected sinusoidal filter (is necessary alternative to motor inductor):</u>
Type: Max Fuss 3AFS400-035(IG)

A RFI-Filter in the PV supply line could be necessary according to local and international standards. If this is the case:
<u>Selected RFI-Filter:</u>
Type: Max Fuss 2F1000-050.200 (1200 VDC, 50 A) (acc. to EN 61000)

Remark: The VFD has to be equipped with a special software for MPP tracking.

Resulting PV-supply data of VFD:
Nominal PV voltage : 540 VDC
Maximum used PV power : 16 kW
Nominal PV current : 29 A

- **PV generator**
  In addition to the energetic sizing, the PV generator has to be configured to fulfill the voltage requirements of the direct-coupled VFD and the condenser fan. The following restrictions result from the inverter data:
  Nominal AC input voltage : 380…480 V (+10 % / -15 %), 50 Hz
  Under voltage lockout dc voltage : 345 V_{DC}
  Overvoltage lockout dc voltage : 800 V_{DC}
  Minimum dc voltage : 436 V_{DC} (corresponds to lowest tolerance of ac input voltage)
  Maximum DC voltage* : 713 V_{DC} (corresponds to highest tolerance of ac input voltage)
  *Operation is allowed up to the over voltage lockout DC voltage of 800 V.

  The condenser fan operates at DC input voltages up to 748 V.

Considering these boundary conditions the MPP voltage range should be within the minimum and maximum DC voltage: 436…713 V. The open circuit voltage of the PV generator must not be higher than the overvoltage lockout value of the VFD (800 V_{DC}) and the maximum input voltage of the condenser fan (748 V)[1] at any operating condition.

As the voltage of the PV generator mainly depends on the temperature, the maximum and minimum temperature of the modules has to be considered.

Data of the given module type REC265TP at standard test conditions (STC) [REC265]:

Data of the given module type REC265TP at standard test conditions (STC) [REC265]:

$V_{MPP (STC)}$	31.10 VDC
$I_{MPP (STC)}$	8.53 A
$P_{MPP (STC)}$	265 W
$V_{OC (STC)}$	38.80 VDC
$I_{SC (STC)}$	9.21 A
V_{MAX}	1000 VDC

Temperature coefficients [REC265]:

TC_{P_MPP}	-0.39 %/K
TC_{V_OC}	-0.31 %/K
TC_{I_SC}	0.045 %/K

Stating from the ambient temperature range of 20…35 °C, the temperature range of the modules was assumed to be +15…+80 °C (For module temperatures, the Meteonorm database gives a range from 20 °C to 77 °C for the reference year.). The given coefficients for V_{OC} and I_{SC} were also used to estimate voltage and current in the MPP:

Assumed operating conditions of compressor for VFD selection process: Maximum ambient temperature: +35 °C
Maximum condensing temperature: +50 °C Maximum evaporating temperature: +10 °C Minimum evaporating temperature: - 25 °C

T_{Module}	80 °C	15 °C
V_{OC}	31.8 V_{DC}	39.5 V_{DC}
I_{SC}	9.4 A	9.2 A
V_{MPP}	24.6 V_{DC}	32.3 V_{DC}
I_{MPP}	8.8 A	8.5 A
P_{MPP}	208 W	275 W

TABLE 3 | Temperature corrected data for one module REC265TP

The series connection of 19 modules in one string is a suitable configuration to fulfill the voltage requirements (ref. to Table 4).

T_{Module}	80 °C	15 °C	25 °C (STC)
V_{OC}	604 V_{DC}	750 V_{DC}	728 V_{DC}
I_{SC}	9.4 A	9.2 A	9.2 A
V_{MPP}	467 V_{DC}	613 V_{DC}	591 V_{DC}
I_{MPP}	8.8 A	8.5 A	8.5 A
P_{MPP}	3955 W	5231 W	5035 W

TABLE 4 | Temperature corrected and STC data for 19 modules REC265TP in series connection

[1] Important update 09/22/2017: Voltage must not be higher than 748 V, please refer to Appendix B

Remark:
At the lowest design temperature of 15 °C, the PV open circuit voltage is reaching 750 VDC. This level is slightly higher than the maximum input voltage of the condenser fan, but not in the critical range[2]. The condenser fan would stop temporally but this fan overvoltage error would rarely happen because this temperature (15 °C) is lower than the common temperatures and the compressor is already running when the fan starts (and thus no open circuit voltage will apply to the fan).

With five parallel-connected strings, the installed power is about 25 kWp (95 modules in total). Connection of the strings should be done in a PV junction box.

String diodes or fuses:
In case of faulty PV modules in one string, reverse current from other strings could arise. At the recommended configuration with five strings, the maximum reverse current from four strings into one string could be 4 times 9.4 A = 37.6 A (ref. to Isc in Table 4). The maximum allowed reverse current of the planed PV modules is given by the manufacturer with 25 A [REC265]. There are two common ways to protect the modules against higher reverse currents:
- Use of string diodes which are capable to carry the reverse current or
- Use of string fuses to disconnect the strings in case of high flowing currents.

As the power losses in fuses will be lower than in diodes, the use of string fuses is recommended. The maximum series fuse rating for the REC265TP modules is 25 A [REC265]. With the MPP current value up to 9 A, a fuse with a nominal value of about 15 A is sufficient. The voltage rating of the fuses has to be 900 VDC or higher (special PV fuses).

Part	Type (example)	I [A]
Fuse holder	Eaton Bussmann CHPV1IU (with indication), 1000 V_{DC} / 30 A, 1 pole	5 pieces are required, optional indication for easy fault detection
Fuse	Eaton Bussmann PV-15A10F, 1000 V_{DC} / 15 A	5 pieces are required

TABLE 5 | Example fuse configuration

2.4. Auxiliary supply circuit

For the supply of the auxiliary parts, a dc and ac power supply is needed. According to the suggested concept, a charge regulator is connected to the main PV generator in parallel to the VFD and the condenser fans. The operation of this charger is controlled by the VFD and the central PLC. For powering the auxiliary AC loads, an off-grid inverter is connected to the battery and provides 230 V / 50 Hz. The DC loads are connected to the battery directly or via a DC/DC- converter (48 V -> 24 V).

- **Charge regulator**
  The charge regulator has to handle the high DC voltage of the PV generator. Therefore, the following device was selected [STU1]:

Type	: Studer Innotec VarioString VS-120
Configuration	: MPPT 1 + 2 (two string inputs) connected in series
Maximum PV voltage	: 900 V_{DC}
Minimum PV voltage	: 400 V_{DC}
MPP voltage range	: 500…750 V_{DC}
Maximum PV current	: 13 A
Nominal battery voltage	: 48 V_{DC}
Maximum charging current	: 120 A

For an efficient operation, the application of the following additional components is recommended.

[2] Important update 09/22/2017: Voltage must not be higher than 748 V, please refer to Appendix B

Part type	Function
BSP-500	Battery monitor with shunt to calculate the SOC, temperature measurement
Xcom-232i	Communication interface to PLC including SD card
RCC-02/-03	Remote control and display, data storage
CAB-RJ45-8-2	Cable for communication connections

TABLE 6 | Additional required components

- **Inverter**

The size of the inverter depends on the power demand of the auxiliary devices (Table 7).

Load	Effective / apparent power	Operating time per day* day (10h)	night (14h)	Voltage	Remark
Stirrer/pump	500 W / 625 VA	10 h	0 h	230 V / 50 Hz	
Pumps for bin tanks (6 pcs.)	360 W / 600 VA	10 h	2 h	230 V / 50 Hz	
Compressor crankcase heater	Avg. 70 W / 70 VA	0 h	14 h	230 V / 50 Hz	During compres-sor off times, overnight,
					PTC with automatic power reduction
PLC, HMI, Router	40 W / 40 VA	10 h	14 h	24 V_{DC}	Converter from 48 V_{DC} battery needed (efficiency 80 %)

* day = app. ten hours with sunshine (operation of loads direct out of PV)

TABLE 7 | Auxiliary loads

The total required ac power is about 1000 W and the dc power is 40 W. The continuous output power of the inverter has to be larger than 1300 VA at higher ambient temperatures (40 °C).

Selected inverter type: XTM 2600-48 [STU3, STU4] Continuous output power 2000 VA @ 40 °C

This inverter could be connected to the same communication bus as the charge regulator.

- **Battery**

The battery has to buffer the auxiliary supply overnight and during times when all available PV power is used to supply the compressor.

Sizing of battery:

Sizing of the battery is an iterative process, due to the planed use of excess energy for charging the battery and the unknown performance of that process. With the data given in Table 7, the daily energy demand will be about 13 kWh. Assuming that only the night demand has to be buffered, the storage demand will be about 4.5 kWh; with an overall efficiency of about 85 % (battery, inverter) it will be 5.2

kWh/d. At a maximum depth of discharge of 50 %, the required battery capacity is about 215 Ah (C_{10}) at 48 $V_{DC.}$
Type (examples): a) AGM, Q-Batteries 4 x 12LC-225 ($C_{10(1.8V)}$ = 225 Ah)
b) VRLA, Exide 4 x S12-230, ($C_{10(1.7V)}$ = 190 Ah)

Battery cable and fuses:
Keep battery cables as short as possible! The size of the battery fuses depends on the cable cross section and the device specification (refer to chapter 3).

2.5. Hardware of control system

Figure 3 shows the schematic of the system with sensors and actors. All sensors and actors are connected to inputs and outputs of the PLC with the exception of the sensors of the EXV (electronic expansion valve). The high- and low-pressure switches are primarily planned to be used for safety purposes and have to stop the refrigerating unit directly.

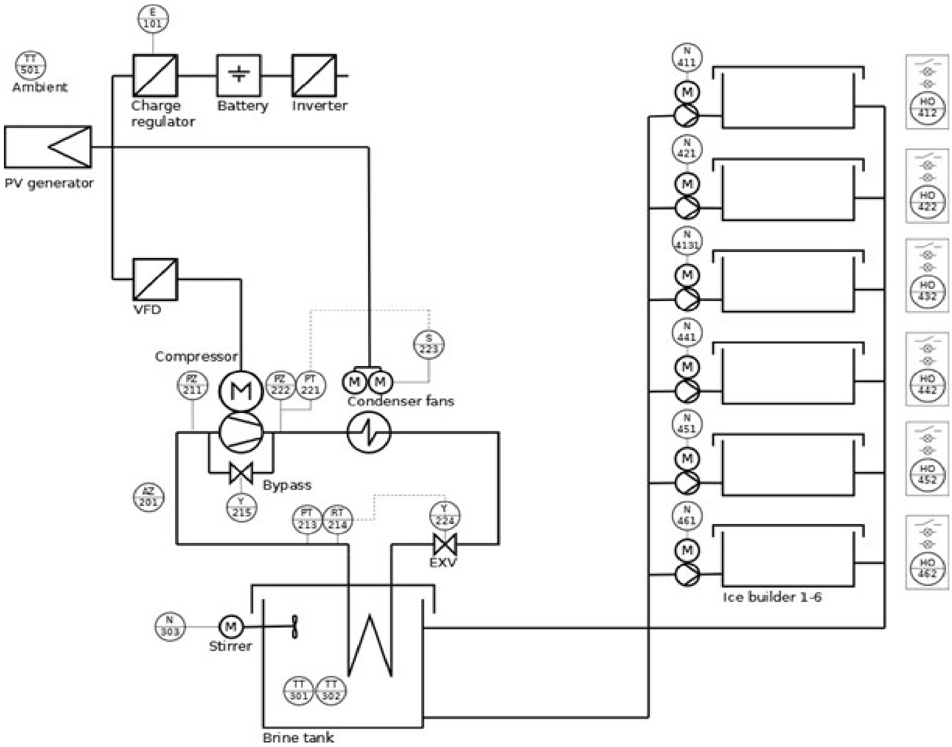


FIGURE 3 | Schematic of control instrumentation

Remark: Further sensors for monitoring purposes could be required.

Number	Device	Place	Function
E 101	Charge regulator	Electrical system	Controlled by PLC via RS232
AZ 201	Propane detector	Refrigerating unit	Safety (stop of compressor), additional contact for PLC alarm
PZ 211	Pressure switch	Refrigerating unit, low pressure side	Safety (stop of compressor), additional contact for PLC alarm
PT 213	Pressure transmitter	Refrigerating unit, low pressure side	Autonomous control of EXV
Y 215	Bypass solenoid valve	Refrigerating unit, compressor bypass	Controlled by PLC

RT 214	Temperature transmitter	Refrigerating unit, low pressure side	Autonomous control of EXV
PT 221	Pressure transmitter	Refrigerating unit, low pressure side	Control of condenser fan
PZ 222	Pressure switch	Refrigerating unit, low pressure side	Safety (stop of compressor), additional contact for PLC alarm
Y224	Electronic expan-sion valve (EXV)	Refrigerating unit, low pressure side	Control, enable by PLC
TT 301	Temperature transmitter	Brine tank	Control
TT 302	Redundant tempe-rature transmitter	Brine tank	Control, redundant sensor for TT 301
N 303	Stirrer/pump	Brine tank	Controlled by PLC
N 411	Pump	Ice builder 1	Controlled by PLC
HO 412	Switch, lamp	Ice builder 1	Manual control, indication
N 421	Pump	Ice builder 2	Controlled by PLC
HO 422	Switch, lamp	Ice builder 2	Manual control, indication
N 431	Pump	Ice builder 3	Controlled by PLC
HO 432	Switch, lamp	Ice builder 3	Manual control, indication
N 441	Pump	Ice builder 4	Controlled by PLC
HO 442	Switch, lamp	Ice builder 4	Manual control, indication
N 451	Pump	Ice builder 5	Controlled by PLC
HO 452	Switch, lamp	Ice builder 5	Manual control, indication
N 461	Pump	Ice builder 6	Controlled by PLC
HO 462	Switch, lamp	Ice builder 6	Manual control, indication

TABLE 8 | Sensor and actor parts in Figure 3

In addition to the parts listed in Table 8 the main power electronic devices (VFD, charge regulator, inverter) are connected via communication bus to the control system. The expansion

valve (EXV) is usually controlled by a separate controller. Both condenser fans are operating synchronously.

Pressure switches at low- and high-pressure side of the refrigerating unit are safety device and have to stop the compressor in case of a low- or high-pressure event. A propane gas detector could be required according to local and international rules.

The planed main control system consists of a central control unit (PLC), including several IO- expansion modules, a touch panel (HMI, human machine interface) and an operation software designed with the application development system of the manufacturer Omron. For installation instructions, refer to manuals of the manufacturer e.g. [OMR17]. For remote access, a router with internet connection is required. The following parts were selected for the control system:

Part	Description
NX1P2-9024DT1	Main controller (PLC)
NX1W-CIF12	Communication module RS485 for Modbus
NX1W-CIF101	Communication module RS232 for charger
NX-PF0630	Power supply unit for IO-expansion modules
NX-AD3204	Analog input expansion module 0…20 mA, 4 channels
NX-TS3201	Analog input expansion module PT100, 4 channels
NX-OD5256	Digital output expansion module, 16 channels

NX-DA2603	Analog output expansion module 0…10 V, 2 channels
NB7W-TW01B	Touch panel (HMI), 7" TFT
SYSMAC-LE201L	Sysmac Studio Lite Edition (application development system)
eWON COSY 131 LAN / 3G + antenna + SIM card	VPN Router for mobile Internet access (Wachendorf Prozesstechnik GmbH & Co. KG)
Coupling relays	For digital outputs, 14 pieces (various manufacturers)

TABLE 9 | Main parts of control system (Omron unless no other manufacturer is listed)

Control IO – configuration:

Channel	Function	Sensor
1	Switch start	Contact
2	Switch stop	Contact
3	Error high pressure	Pressure switch high pressure side, alarm contact normally closed
4	Error low pressure	Pressure switch low pressure side, alarm contact normally closed
5	Alarm propane detector	Propane detector alarm contact, normally closed
6	Error fan 1	Output of condenser fan 1
7	Error fan 2	Output of condenser fan 2
8	Switch ice builder 1	Manual switch ice builder 1
9	Switch ice builder 2	Manual switch ice builder 2
10	Switch ice builder 3	Manual switch ice builder 3
11	Switch ice builder 4	Manual switch ice builder 4
12	Switch ice builder 5	Manual switch ice builder 5
13	Switch ice builder 6	Manual switch ice builder 6
14	Reserve	

TABLE 10 | Digital inputs (14, integrated NX1P2-9024DT1)

Channel	Actor	Remark
1	Enable Expansion valve	Power supply of EXV
2	Enable condenser fans	Enable input of fans
3	Enable solenoid valve by-pass	Valve normally closed
4	Enable stirrer/pump	
5	Enable pump 1	
6	Enable pump 2	
7	Enable pump 3	
8	Enable pump 4	
9	Enable pump 5	
10	Enable pump 6	

TABLE 11 | Digital outputs (10, integrated NX1P2-9024DT1, with additional coupling relays)

Channel	Actor	Remark
1	Signal LED 1 ice builder 1	LED green 24 V
2	Signal LED 1 ice builder 2	LED green 24 V
3	Signal LED 1 ice builder 3	LED green 24 V
4	Signal LED 1 ice builder 4	LED green 24 V
5	Signal LED 1 ice builder 5	LED green 24 V
6	Signal LED 1 ice builder 6	LED green 24 V
7	Signal LED 2 ice builder 1	LED red 24 V
8	Signal LED 2 ice builder 2	LED red 24 V
9	Signal LED 2 ice builder 3	LED red 24 V
10	Signal LED 2 ice builder 4	LED red 24 V
11	Signal LED 2 ice builder 5	LED red 24 V
12	Signal LED 2 ice builder 6	LED red 24 V
13	Enable PTC crankcase heater	Self-limiting PTC heater
14	Reserve	
15	Reserve	
16	Failure output	Option

TABLE 12 | Digital outputs (16, expansion NX-OD5256, with additional coupling relays)

Channel	Process signal	Sensor signal	Range	Remark
1	Pressure high pressure side	Current 4…20 mA	0…25 bar	Control
2	Reserve	Current 4…20 mA		
3	Reserve	Current 4…20 mA		
4	Reserve	Current 4…20 mA		
5	Temperature brine tank 1	Pt100	-20…+50 °C	Control
6	Temperature brine tank 2	Pt100	-20…+50 °C	Redundant control
7	Temperature ambient	Pt100	0…50 °C	Control
8	Reserve	Pt100		

TABLE 13 | Analog inputs (8, expansion NX-AD3204, NX-TS3201)

Channel	Process signal	Sensor signal
1	Set value fan 1	Voltage 0…10 V
2	Set value fan 2	Voltage 0…10 V

TABLE 14 | Analog outputs (2, expansion NX-DA2603)

2.6. Cables

Sizing of cables depends on current and length and has to be approved according to local and international regulations and the final electrical design. The following table summarizes cable design examples which would result into a voltage drop less than 1 %. The sizing of circuit breakers/fuses is subject of the electrical design and has to be approved according to local and international regulations and the safety concept.

Connection	Current	Estimated cable length	Minimum cross section	Circuit breaker (sizing example)	Remark
PV junction box – VFD	32 A	10 m	10 mm²	32 A	Solar cable (max. 13 mm² possible)
PV junction box – charge regulator	11 A	10 m	4 mm²	15 A	Solar cable
PV junction box – condenser fan	1.3 A	15 m	1.5 mm²	2 A	Solar cable
VFD – compressor motor	25 A	<10 m	6 mm²	-	Shielded, as short as possible
Battery – charge regulator	120 A	<5 m	70 mm²	125 A	Battery cable, as short as possible, fuse near battery
Battery – inverter	31 A	<5 m	35 mm²	35 A	Battery cable, as short as possible, fuse near battery
Grounding system			16 mm²		All metal parts grounded

TABLE 15 | Main cable sizes (example with max. 1 % voltage drop)

Schematic of power connections with circuit breakers:

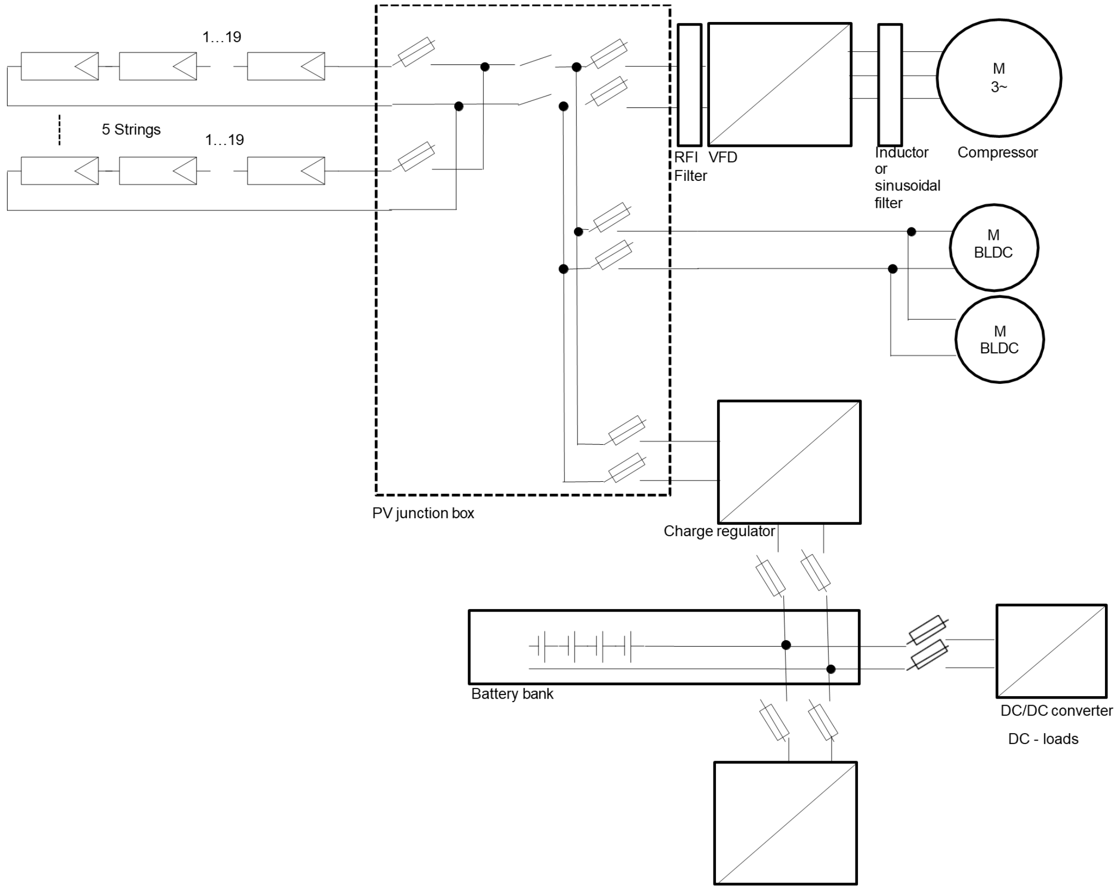


FIGURE 4 | Schematic of power wiring

AC loads are connected to the inverter via separate fuses. The installation of a RCD between inverter and AC loads is recommended. DC loads are connected to the DC/DC-converter via separate fuses. Charge regulator and inverter need separate fuses in the battery connection. A PV load break switch and main switches for emergency disconnection of all loads, at least for fans and stirrer, are recommended.

2.7. Manufacturing instructions

The following hints contain only points, which seem to be of special importance to the authors regarding the expected functionality. These instructions cannot replace the basic knowledge of an engineer that is therefore presumed. A qualified electrical design has to be prepared. Components which are available locally and which fulfill the specifications should be preferred

Safety:
DANGER! RISK OF LIFE! HIGH VOLTAGE! HIGH CURRENT!

- PV modules are connected in series, resulting in very high dc-voltage (>700 VDC).
- Batteries can supply very high short circuit current.
- Design and installation have to be made according to local and international regulations, technical rules and manufacturer instructions. Electrical grounding requirements have to be considered.
- Electrical installation and service must be done by electrically qualified staff only.
- PV installation has to fulfill class II equipment rules.
- Metal parts have to be grounded

DANGER! RISK OF LIFE! EXPLOSIVE ATMOSPHERE!

- A propane filled refrigeration system is planned. Explosive atmosphere and ignition sources have to be avoided under every condition. In case of a propane leakage the power supply has to be disconnected automatically and sufficient ventilation is required.
- Installation of the propane refrigerating system and safety devices have to be made according to local and international regulations and technical rules.
- Installation of the battery bank has to be made according to local and international regulations and technical rules. Proper ventilation is required according to manufacturer instructions.

A safety concept has to be made and safety measures have to be taken by the system manufacturer/ operator. All risks during all lifetime phases have to be evaluated within this concept and technical and/or further measures have to be taken to minimize the risks.

Low- and high-pressure switches of the refrigerating unit have to stop the compressor immediately in case of a low- or high-pressure event (levels according to refrigerating unit limits).

Emergency stop switches and contactors are recommended for all moving parts and could be required according to the safety concept.

User manuals:

Installation and wiring of all components have to be performed according to the manufacturer instructions and local and international regulations. Please refer to the installation and user manuals of the manufacturers.

Placement and housing of electrical components:

All components have to be placed in an environment according to their protection degree specification. Most of the selected parts are suitable for indoor mounting in non-corrosive atmosphere only (IP 20). Placement should be done in a protected electrical operating room. Outdoor installation would require water and dust proof electrical cabinets. All equipment should be protected against sunshine to prevent high temperatures (install cooling equipment if required).

Battery cabinet

The battery bank has to be placed in a sealed but ventilated battery cabinet separated from other electrical equipment. Ventilation requirements have to be considered according to local and international regulations and manufacturer instructions.

The recommended battery bank consists of four 12 V battery blocks, which have to be connected in series as schematically shown in Figure 5.

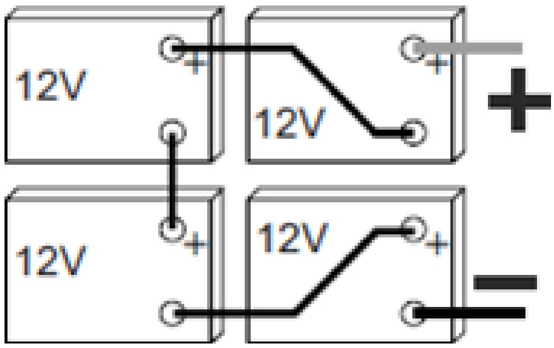


FIGURE 5 | Wiring of four 12 V blocks to a 48 V battery bank [STU4]

Overvoltage protection:

The installation of lightning and overvoltage protection equipment is recommended to avoid damages by external lightning events.

Cabling:

Suitable cables according to voltage, current, environmental conditions have to be used. Cables have to be protected against mechanical and environmental stress. Special care has to be taken for cabling the PV and battery system. Special solar and battery cables have to be used. A shielded motor cable is required for the connection of the VFD, the motor inductor and the compressor. Sensor and communication cables should be installed separated from power cables to avoid electromagnetic influences and shielded cables with twisted pairs should be used.

Grounding:

All metal installation parts have to be grounded properly and have to be connected to earth electrodes according to local and international regulations.

Literature

[BIT06] Bitzer Kuehlmaschinen GmbH, Technical Information KT-420-1, Application of Frequency Inverters with Reciprocating Compressors, Revision 01.06, www.bitzer.de

[BIT15] Bitzer Kuehlmaschinen GmbH, Bitzer Software Version 6.5.0.1607

[REC265] REC, Datasheet REC Twinpeak Series REC65TP, www.recgroup.com

[STU1] Studer Innotec, Datasheet VarioString VS-120, www.studer-innotec.com, downloaded 07/31/17

[STU2] Studer Innotec User Manual VarioString VS-120, www.studer-innotec.com, downloaded 07/31/17

[STU3] Studer Innotec Dataseet Extender XTM 2600-48, www.studer-innotec.com, downloaded 07/31/17

[STU4] Studer Innotec User Manual Extender XTM 2600-48, www.studer-innotec.com, downloaded 07/31/17

[OMR17] Omron, Hardware User Manual NX1P, https://industrial.omron.de, downloaded 08/10/2017

Appendix A

Main parts for electrical system (further aux. parts are required)

Part	Selected type	Manufacturer	Remark
Main power supply			
PV modules	REC265TP	REC	Provided by GIZ
DC RFI Filter	2F1000-050.200	Max Fuss	If required
Variable frequency drive VFD	MX2-A4150E-DE	Omron	Special MPPT software required
IO option board for inverter	MX2-EIO15-E	Omron	
Motor inductor	AX-RAO02000320-DE	Pt100	-20…+50 °C
Sinusoidal filter	3AFS400-035(IG)	Max Fuss	Optional instead of motor inductor if required
Main power supply			
Charge regulator	VarioString VS-120	Studer Innotec	2 MPPT in series for HV
Inverter	Extender XTM 2600-48	Studer Innotec	
Battery monitor	BSP-500	Studer Innotec	SOC calculation
Communication module	Xcom-232-i	Studer Innotec	Control of charge regulator by PLC
Display and remote control	RCC-02 4x 12LC-225	Studer Innotec	
Battery (example)	4x 12LC-225	Q-Batteries	48 V battery bank C_{10} = 225 Ah
Control system			
Main controller (PLC)	NX1P2-9024DT1	Omron	
Communication module RS485	NX1W-CIF12	Omron	Modbus
Communication module RS232	NX1-CIF101	Omron	
Power supply unit for IO-expansion modules	NX-PF0630	Omron	
Analog input expansion module 0…20 mA, 4 channels	NX-AD3204	Omron	
Analog input expansion mod-ule PT100, 4 channels	NX-TS3201	Omron	
Digital output expansion module, 16 channels	NX-OD5256	Omron	
Analog output expansion module 0…10 V, 2 channels	NX-DA2603	Omron	
Touch panel (HMI), 7” TFT	NB7W-TW01B	Omron	
Sysmac Studio Lite Edition	SYSMAC-LE201L	Omron	Programming software
VPN Router for mobile Internet access	eWON COSY 131 LAN / 3G	Wachendorf	Antenna and SIM card required

Appendix B

Update 22nd September 2017 regarding chapter “PV generator” (pages 8-9) considering new information given by Ziehl-Abegg at 20th September 2017

PV generator configuration - condenser fan input voltage limit

PV module type	: REC265TP
Datasheet	: ds_rec_twinpeak_sereis_rev_g_eng.pdf (Ref: NE-05-07-02-01 Rev- G 08.16)
Open circuit voltage VOC at STC (T Module = 25 °C)	: 38.3 V
Temperature coefficient of VOC	: -0.31 % / °C (-0.11873 V / °C)
Condenser fan type	: ZIEHL-ABEGG ZN063-ZIL.DG.V7P2

<u>Calculation:</u>

Lowest module temperature resulting by PVSYST calculation (Ambon with module type REC260)	: 20 °C
Open circuit voltage at T Module = 20 °C	: 38.9 V
Open circuit voltage at T Module = 16 °C	: 39.37 V
Max. allowed open circuit voltage limited by fan input range	: 748 V
Max. number of series connected modules at 20 °C	: 19 (739 V)
Max. number of series connected modules at 16 °C	: 19 (748 V)

<u>Recommendation:</u>

As the lowest calculated PV-module temperature is 20 °C, the series connection of 19 modules results in a maximum voltage of 739 V. Nevertheless, at a module temperature of 16 °C or less, the open circuit voltage will be higher than 748 V. There is only a safety margin of 4 K (or 9 V) down to a module temperature of 16 °C.

As it seems that temperatures below 16 °C are unlikely and as it is important to achieve a high PV generator power, it is recommended to connect 19 modules of the REC265TP in series per string (5 strings à 19 modules: 25.2 kWp).

For protection of the fans, they have to be electrically disconnected from the PV generator, if the voltage rises above 748 V (module temperature below 16 °C)! Therefore, a DC-contactor with flyback diode in the PV connection line has to be installed and voltage supervising has to be implemented into the control algorithm. This is a protection measure for the first pilot project. As a result of the monitoring, this additional measure can be omitted in further installations if not required.

3

Cooling System and Component

3. Cooling System and Component

3.1. General Operation of the PV Supplied Dynamic Ice Machine

The design of the dynamic ice machine was developed to adapt the daily production of ice blocks to the daily amount of solar irradiation without utilization of a large electrochemical storage.

The cooling unit is running as long as there is enough energy produced by the PV generator. It is frequency controlled to follow the current amount of irradiation. The cold is stored in a so called storage tank which contains a significant amount of brine. Six bin tanks are separated from the storage tank. The bin tanks are cooled by pumping cold brine from the storage tank to each individual bin tank. A control unit decides which bin tank is supplied at what time with brine. It is the aim of the control algorithm to finalize every day as many ice blocks as possible independently from the irradiation. The basis for the supply decision of the control unit is the temperature in the storage tank and the current part of the day (morning, afternoon, night). Freezing will take place over the day and in the evening. Ice harvest and refilling of the ice bins should be done in the morning.

The following chapter describe technical details as manufacturing instructions for the pilot project. They contain only points which seem to be of special importance to the authors for the expected functionality. This instruction cannot replace the basic knowledge of an engineer that is therefore presumed. Details which are not mentioned should be manufactured according to established processes of the manufacturer. Components which are available locally and which fulfill the specifications should be preferred.

3.2. Manufacturing Instructions

The design of the dynamic ice machine was developed to adapt the daily production of ice blocks to the daily amount of solar irradiation without utilization of a large electrochemical storage.

Brine

- The brine should have a freezing point at or lower than -20 °C.
- We used a solution of NaCl in water as brine. In principle, the utilization of other brines is possible. In case of the intention to use other fluids than NaCl solution please contact the authors beforehand. The following statements are given for the application of NaCl solution.
- Use a concentration of 0.23 kg NaCl per 1 kg water.
- For information purposes: 3000 l brine weigh 3560 kg.

General arrangement

- The general arrangement is designed to keep the fluid connections between storage tank and bin tanks as short as possible to reduce the thermal losses (see Figure 1).
- All pumps should be accessible for service reasons.

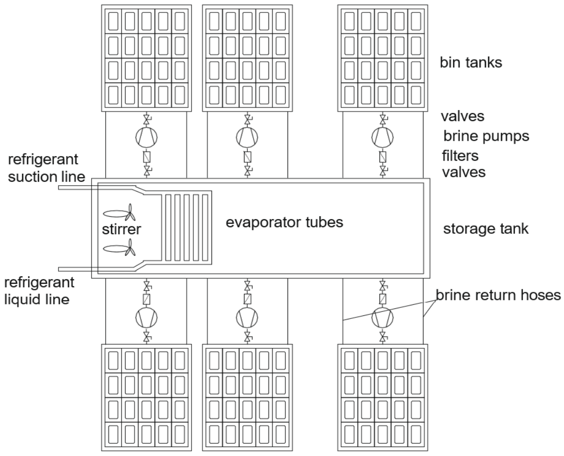


FIGURE 1 | Suggestion for the general arrangement, topview

Bins

- Dimensions of the individual bins are the basis for the dimensions of the bin tank.
- Means to support the lifting of the filled ice bins should be considered in the bin design.
- The free cross section of the bins must be not larger than 100 mm x 200 mm. The bins should be 650

mm tall. A slightly conical design can support the ice harvest. In this case the free cross section of 100 mm x 200 mm must be the maximum dimension (at the opening of the bin).

- A marking at the height of 10 liters filling will support daily work.
- The material to fabricate the bins from should be corrosion resistant with respect to highly concentrated NaCl brine. Please carry out corrosion tests beforehand. According to literature, stainless steel with a pitting resistance equivalent (PRE) > 30, better PRE > 35 is suggested. Surfaces of welding seams should be pickled.
- We made good experiences with a steel sheet thickness of 1.5 mm.

Bin tank

- One bin tank should cover 20 bins.
- It is the aim of the bin tank design that all bins of a bin tank should finalize the freezing process at nearly the same time. To achieve this, similar brine flow conditions should be around all bins. This can only be realized by a vertical flow direction.
- At the bottom the tank comprises a plenum chamber with the connection to the brine pump (brine feed). This chamber has a little over pressure and ensures an equal distribution of the cold brine. It is connected to the main tank by a distribution floor.
- The brine flows from the plenum chamber to the main tank through 30 bore holes with a diameter of 4 mm. The position of the bore holes is marked in Figure 2.

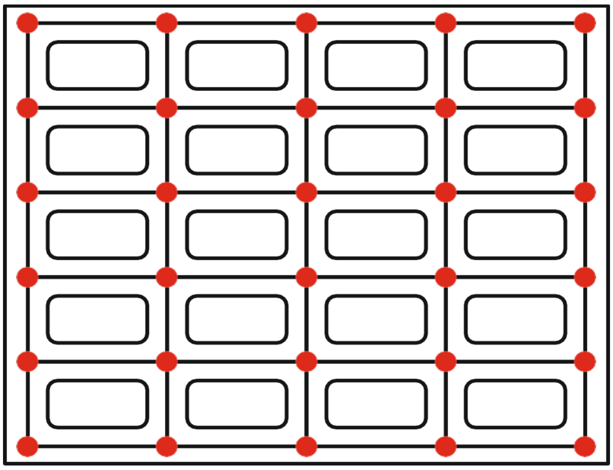


FIGURE 2 | Holes (red dots) in relation to the ice bins; topview

- The headroom of the plenum chamber must be 80 mm. The distribution floor is fixed by support pads. The fixing must be able to withstand an overpressure in the plenum chamber of 1200 Pa (converted with the area of the distribution floor equivalent to a load of about 100 kg)
- The distribution floor must be sealed against leakages at the connection with tank walls.
- We made the tank and the distribution floor from 10 mm thick sheets of polyethylene PE
- 100. In principle every non-corrosive plastic or fiber reinforced plastic material with specified continuous operation temperatures of -20 °C or lower should be suitable.
- To increase mechanical stability of the tank circumferential strengthening elements should be used. We applied four elements per tank made of galvanized steel with a rectangular cross section 40 mm x 40 mm and a thickness of 3 mm. The mechanical stability of the brine filled tank must be proved experimentally or by FEM calculations.
- The bins are hold in position by means of a rack. For the rack hold the same material selection criteria as for the ice bins.
- It has to be ensured that the feet of the pillars of the rack do not cover the bore holes of the distribution floor. If this is the case drill a new distribution hole close by the covered one. But be careful:
- The plenum chamber must be free of any pollutions. Otherwise the holes in the distribution floor may get clogged under operation conditions.
- Further details of the tank and the rack are given in the drawings of Appendix A.

Storage tank

- The storage tank must contain at least 3000 liters of brine even in case that all six pumps are running simultaneously. Footprint dimensions could be for example 3000 mm x 1000 mm with a wall height of 1300 mm and a brine level of 1100 mm.
- The additional brine volume of 300 l, which can be calculated from these geometrical relations arises from the volume of evaporator tubes, the volume of the stirrer(s) and a reserve to compensate the rise of the brine level in the bin tanks during pump operation.
- For the storage tank the same material and strengthening recommendations are valid as for the bin tank.

Insulation, basis, lid

- Due to the comparatively large surface of the ice machine (in comparison to the conventional one-tank ice machine) thermal insulation is an important issue.
- The heat transfer coefficient for the side walls of the tanks should be equal or smaller $\alpha \leq$
- 0.425 W/m²K. To achieve this we used the following material: Styrodur sheets, thickness 80 mm, thermal conductivity level 034 (equal to a thermal conductivity of λ = 0.034 W/mK, product: double sheet of 40 mm Bachl Styrodur 2800 C).
- All tanks should be placed on compression proof foam sheets with similar thermal properties as the wall insulations. We used 100 mm thick extruded polystyrene sheet with a thermalconductivity level of 038 (thermal conductivity: 0.038 W/mK ÷ 0.1 m = 0.38 W/m²K) and a compressive strength of 300 kPa (product: 100 mm URSA XPS D N-III-L).
- For the lid 40 mm thick foam sheets of the same material as for the tank walls are sufficient.
- The surfaces of the insulation must be covered with a vapor barrier (vapor tight metal sheets or vapor tight metalized foil) to avoid wetting by vapor condensation and with that loss of functioning of the insulation.

Pumps, filters

- Every bin tank is supplied with cold brine from the storage tank by a dedicated pump. The pumps are individually switched by the control unit.
- The pump must be suitable to operate continuously with NaCl brine at temperatures down to -20 °C. Components with fluid contact must be corrosion resistant.
- The pump must provide a volume flow of at least 25 l/min in installed position with 0 °C NaCl brine of the specified concentration. The pump we used fulfilled this requirement. It was a centrifugal pump specified in the data sheet with 37 l/min volume flow at free flow (no pressure drop) for 20 °C water.
- The pump should operate either with 48 V dc directly from the battery or with 230 V ac from the inverter. The power consumption at operation conditions should not be significantly larger than 60 W.
- We used a pump with the identification “Mag-Rex VTM37-13-24”.
- Filters should be integrated in the feed line of the pump to prevent damages by flowing particles. We used a stainless steel mesh filter with mesh openings of 0.4 mm.
- To make service of the pumps or filters possible without dumping the brine it is suggested to enclose them by temperature and corrosion stable hand operated valves (see Figure 1).

Hydraulic connection between storage tank and bin tanks; brine return pipes and hoses

- The connections between the tanks should be preferably made from hoses instead from tubes. This can avoid leakages of the connections due to small movements of the tanks during filling (see Figure 3).
- Brine return pipes (inside the tank) and hoses should have a sufficiently large diameter to avoid unnecessary pressure drops at the nominal brine flow of 25 l/min and thermal insulation to avoid thermal losses. We used hoses with an inner diameter of 20 mm for the brine supply of the bin tank (to connect pump, filter and valves) and hoses with 30 mm inner diameter for the two brine return hoses. Use narrow hose connectors to avoid constrictions of the free diameter.
  • The two brine return pipes inside each bin tank have a free inner diameter of 30 mm. They run between bins and bin tank walls underneath the horizontal rack rods. Each pipe is closed at its end opposite to the pump side. For the brine inlet we drilled two holes with adiameter of 26 mm perpendicular to the pipe extension at a distance of about 5 cm to each tube end. This arrangement was chosen to generate an even drain from the four corners of the bin tank.

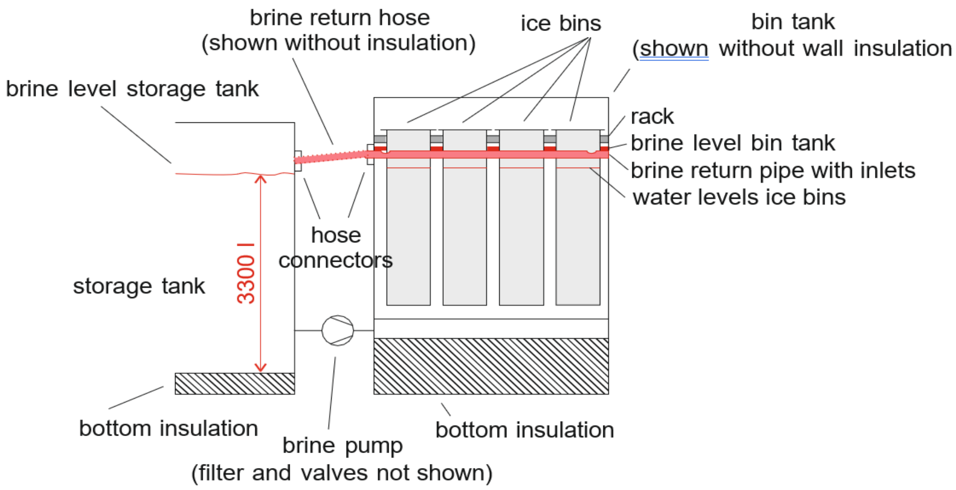


FIGURE 3 | Brine level relations between storage tank and bin tank, sideview

- The vertical position of the return pipes defines the brine levels in both tanks under stable conditions when the pump is running.
  » The brine level in the bin tank should take shape somewhat below the horizontal rack rods. In our experimental setup the vertical space between rack rods and return pipes was about 30 mm.
  » The brine level of the bin tank should be about 5 cm above the ice level of the bins (108 % of the water level) when the bins are filled to generate 10 kg of ice and arranged in freezing position.
  » The return hoses are arranged with slight inclination.
  » The outfall of the return hose should be somewhat above the brine level of the storage tank. By this means a revers brine flow can be avoided in case there is no pump running at all (high brine level in the storage tank).

Stirrer

- The stirrer is necessary to achieve a high heat transfer coefficient between brine and evaporator (important for the efficiency of the cooling unit) and to homogenize the temperature distribution in the storage tank.
- The brine flow velocity perpendicular to the evaporator tubes should be not lower than 0.5 m/s.
- The submersed parts of the stirrer must be corrosion resistant.
- The electrical power consumption of the stirrer must not be above 500 W. It should be either supplied by 48 V dc or 230 V ac. Use two stirrers side by side if necessary.
- We used an electrical outboard motor in our experimental set-up (which worked fine) but we have doubts regarding its long term corrosion stability.
- Figure 4 shows the expected flow pattern and the relative position of tank, stirrer and evaporator.

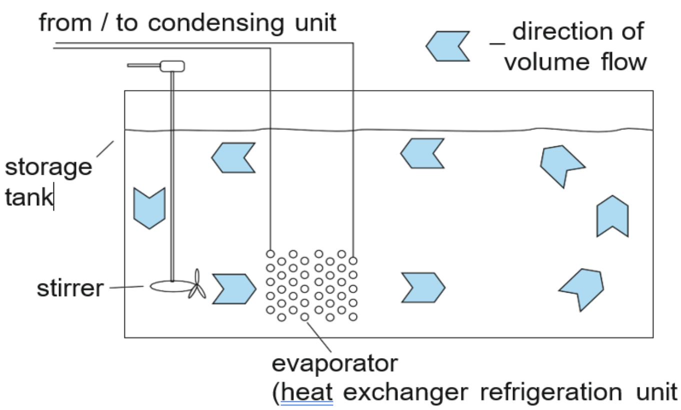
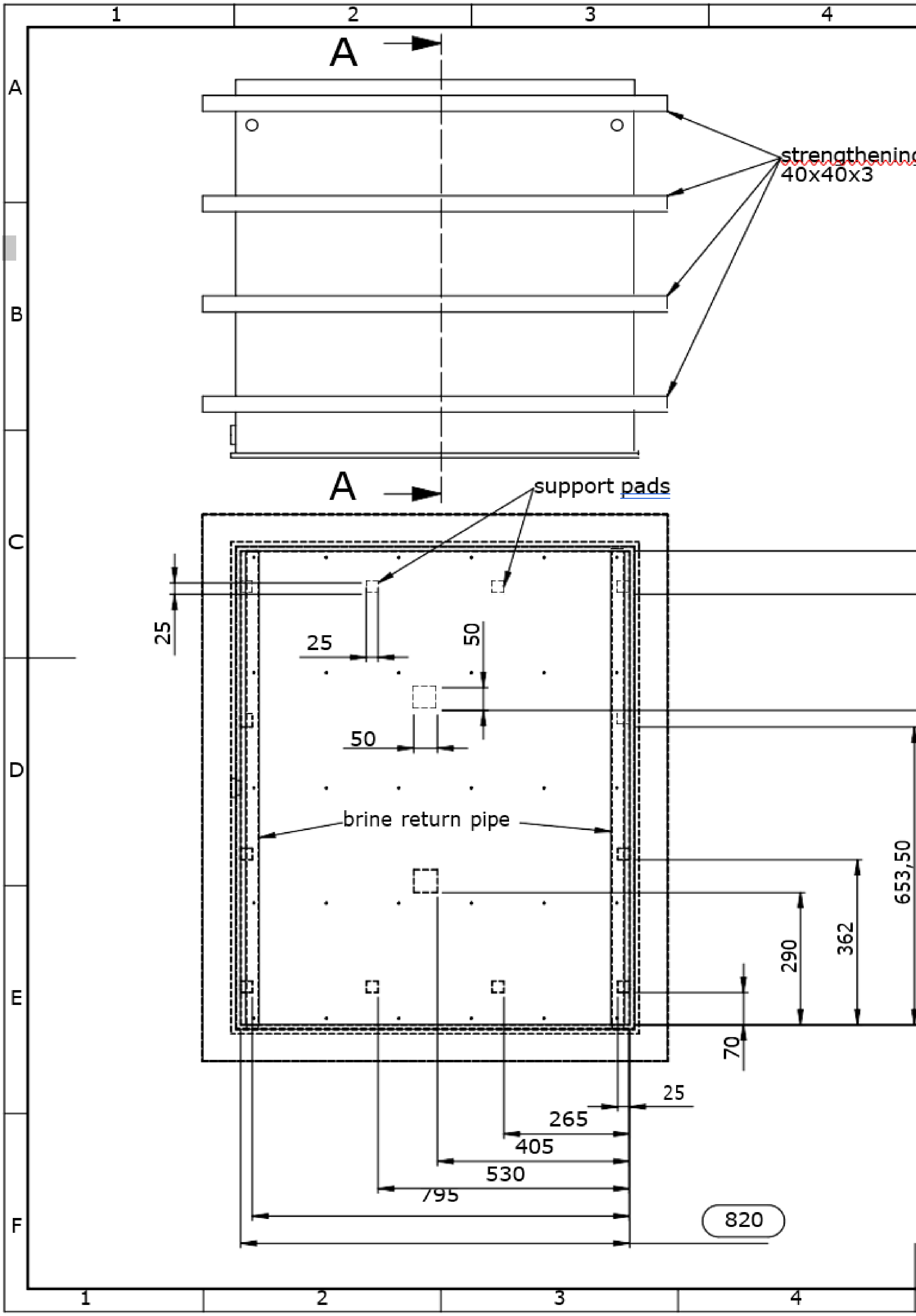
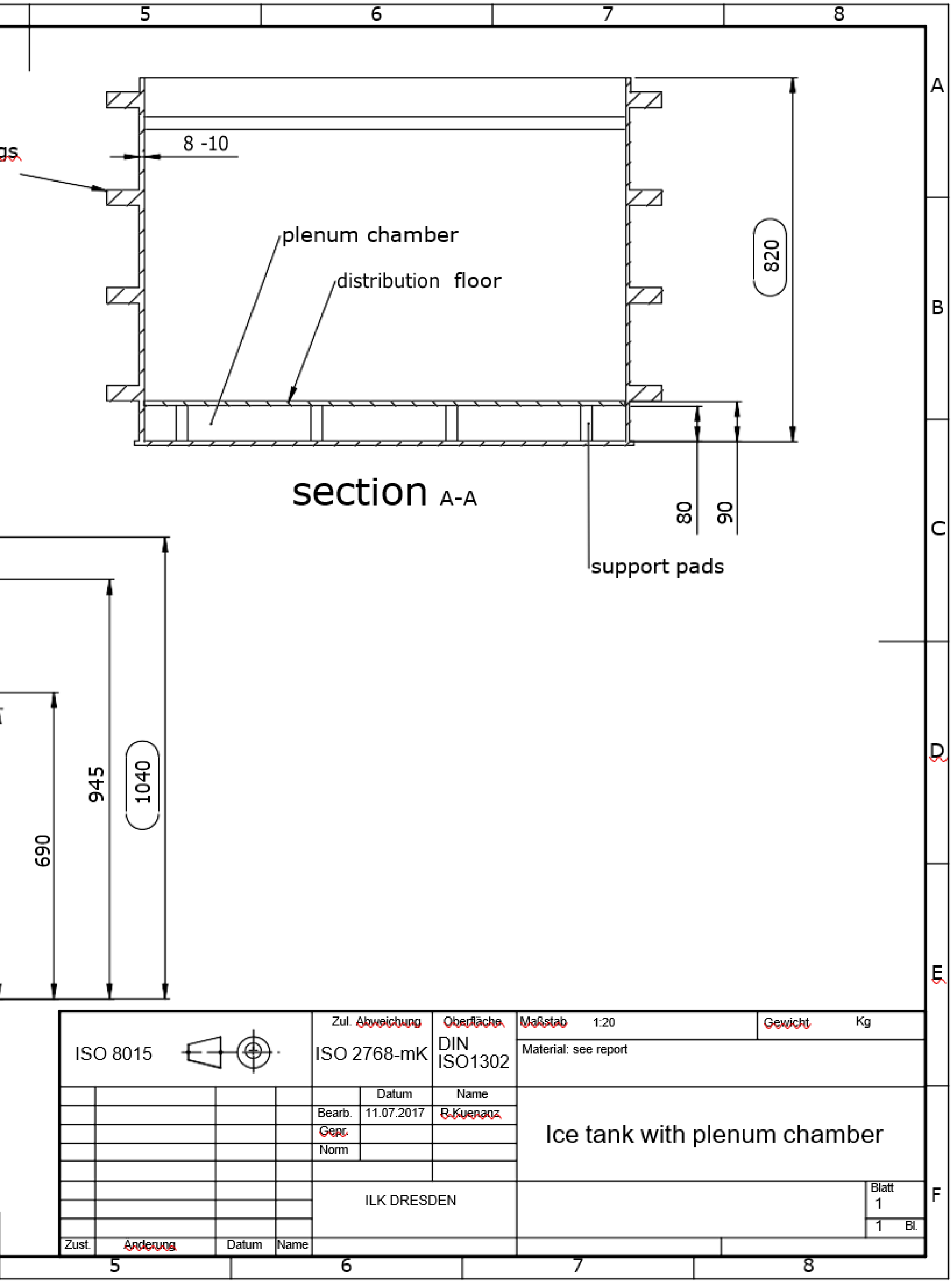
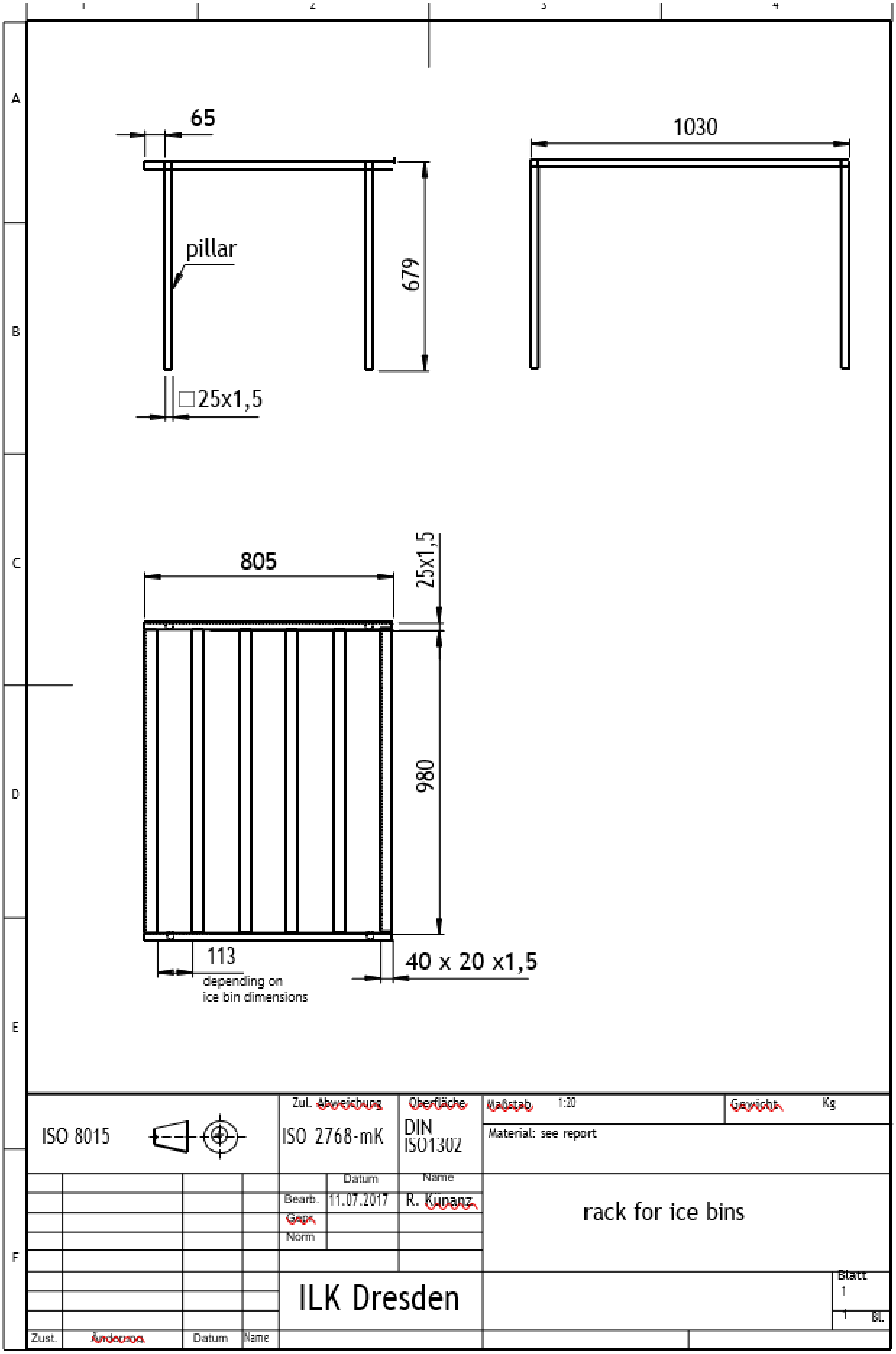


FIGURE 4 | Flow pattern inside the storage tank



1
2
3
4
A
B
C
D
E
F
A
A
strengthening
40x40x3
support pads
25
25
50
50
brine return pipe
653,50
362
290
70
25
265
405
530
795
820


8 -10
plenum chamber
distribution floor
820
80
90
support pads
section A-A
945
1040
690
ISO 8015
Zul. Abweichung
ISO 2768-mK
Oberfläche
DIN ISO1302
Maßstab 1:20
Gewicht Kg
Material: see report
Datum
Name
Bearb. 11.07.2017 R.Kuenanz
Gepr.
Norm
Ice tank with plenum chamber
ILK DRESDEN
Blatt 1
1 Bl.
Zust. Änderung Datum Name


65
1030
pillar
679
□25x1,5
805
25x1,5
980
113
depending on
ice bin dimensions
40 x 20 x1,5
ISO 8015
Zul. Abweichung
ISO 2768-mK
Oberfläche
DIN
ISO1302
Maßstab 1:20
Gewicht Kg
Material: see report
Datum
Name
Bearb. 11.07.2017 R. Kunanz
Gepr.
Norm
rack for ice bins
ILK Dresden
Blatt
1
1 Bl.
Zust.
Änderung
Datum
Name

4

Dynamic Control and Automation System

4. Dynamic Control and Automation System

4.1. Concept of dynamic control system

A general description of the dynamic ice machine was given in ILK-B-4-17-3549. Furthermore, the report ILK-B-4-17-3564 contains the hardware components for the machine control system. The content of this report will be a process description of the basic control system which has to be implemented into a software for the PLC. The knowledge of the above mentioned reports is prerequisite for the understanding of the following explanations.

Boundary conditions for the development of the control regime were:

- the unknown amount of the daily available irradiation,
- the intention to maximize the amount of finished ice blocks per day. This includes effort to operate the ice machine as energy efficient as possible.

To achieve this goal the PLC controls the brine supply of each of the six bin tanks. On the basis of the temperature and the duration of the brine supply the PLC calculates a freezing state value (FSV) for the bins of each individual bin tank. For practical reasons the FSV is the numerical value of the cooling and freezing enthalpy (enthalpy difference between the initial state ‘filled with warm water’ and the final state ‘blocks completely frozen’) for all bins of one bin tank. As soon as the calculations indicate that the ice block production in a certain bin tank is finished the brine supply will be stopped.

In the following chapter the control operations for a typical ice generation day are described in a time flow. The handling of errors and exceptional cases are not described. Numeric values like temperature thresholds are given exemplarily and have to be verified at the pilot system. The described control algorithm was tested by time step simulations to some extent.

The described control regime may be subject to changes during the further development process.

4.2. Operation and Control

To reduce the size of storage devices to a necessary minimum the ice machine has to operate at times when the sun provides sufficient energy. From that boundary condition follows:

- ice production takes place during daytime,
- recommendation: harvest of the ice blocks produced at the previous day should be done in the morning,
- refilling of the ice bins with new fresh water should be done in the morning before the compressor starts operation.

To every bin tank a switch and a two colored indicator light is allocated (see report ILK-B-4- 17-3564). When all bins of a certain bin tank are refilled the operator should press the corresponding switch. The PLC receives this signal and recognizes that this bin tank is ready for the ice production process. The indicator light shines in a certain color (e.g. green).

When the voltage of the PV generator rises to a certain level (this indicates to the control algorithm that it is daytime) the VFD starts periodically a check-up of the power which is momentarily available from the PV generator. When there is sufficient power available the VFD starts the compressor and communicates this event to the PLC. At this point in time the PLC executes the following actions:

- stop the operation of the charge controller,
- start peripheral components of the refrigeration circuit (open bypass valve temporarily, start condenser fans, start electronic expansion valve, start brine circulation of the storage tank),
- check which bin tank is freshly refilled and which bin tank contains not yet finished ice blocks from the cooling process yesterday (see below),
- for all freshly refilled bin tanks: reset of the FSV and start of supply with cold brine (switch on the corresponding pumps),
- change the color of the indicator lights (e.g. from green to read) indicating that the ice production of the corresponding tank is in operation.

The VFD is now driving the compressor at a frequency at which its energy demand is equivalent to the energy which can be supplied by the PV generator when it is working at the maximum power point for the current irradiation conditions.

The PLC measures continuously the temperature of the brine in the storage tank and recalculates the FSV. At a FSV which is equivalent to a water in the bin temperature of about

3 °C the PLC stops the brine supply of all bin tanks. This procedure of simultaneous cool down of all freshly filled tanks at comparatively high brine temperatures (about 0 °C) is introduced to operate the cooling unit as long as possible at high evaporation temperatures which is prerequisite for a high cold generation efficiency.

After switch off of all brine supply pumps the brine temperature in the storage tank decreases fast. When the brine temperature falls below -3 °C the bin tank which has not been finished the day before starts freezing (brine supply). The FSV calculation continues at a value close to the end value from the day before. If the control algorithm works properly there should be only one remaining bin tank from the day before.

At further decreasing brine temperatures the brine supply starts again for additional brine tanks (e.g. one tank at -5 °C brine temperature, the next tank at -6 °C and the next tank at -7 °C).

During the freezing time of the bins an increasing ice layer arises inside the bins. This ice layer has thermally insulating effects so that the ice growing process is nonlinear. Therefore, the PLC calculates a time step ice generation model for the bins of every bin tank. The result are different FSV values for each bin tank.

The automatic switch-on of bin tanks with decreasing brine tank temperatures is only active until noon. Because the target of the algorithm is to generate as many completely frozen blocks as possible and the remaining solar irradiation until sunset is unknown the bin operation strategy has to be changed at noon.

On the basis of the brine temperature and the (known) amount of brine in the storage tank it is possible to calculate an enthalpy value (difference between the brine temperature at 0 °C and at the current temperature below zero). This value gives an indication, how much ice can be generated when the brine from the storage tank cools the bins. On the other hand the PLC recognizes the FSV of each bin tank. This FSV is the “amount of cold” which is necessary to complete the freezing process. In the afternoon the PLC compares periodically, how much “cold” is required to complete the freezing process of the active bin tanks (this is the sum of the FSV) and how much “cold” is available in the storage tank (its enthalpy value).

In the afternoon the PLC starts freezing of a new (in the morning precooled) bin tank when the enthalpy of the storage tank is larger than the sum of all FSV of already active bin tanks.

Around noon it is furthermore likely that the compressor is running at full speed and that the PV generator would be able to provide even more energy (excess energy). If this state is

indicated by the VFD this information is handed over to the PLC and it will activate the charge regulator to recharge the battery. The charge regulator will operate as long as there is excess energy available. The operation of the charge regulator must be supervised by the PLC to ensure that the energy supply for the compressor has priority in comparison to the battery charging. In exceptional cases (battery down) battery charging must be prioritized.

At dawn there will be no longer enough solar irradiation to operate the refrigeration system. When the VFD stops the compressor due to a lack of energy and indicates that moment to the PLC the controller it will perform the following actions:

- start the operation of the charge controller (to use residual solar irradiation to charge the battery),
- stop peripheral components of the refrigeration circuit (stop condenser fans, stop electronic expansion valve, stop brine circulation in the storage tank).

Additionally, the PLC has to compare the actual storage tank enthalpy and the sum of FSV of the active bin tanks. If the amount of the cold, which is stored in the storage tank, is too small to finish the ice making process of all active bin tanks, the cold supply of that tank which was activated at last has to be stopped. This will be the only bin tank which contains uncompleted ice blocks at the harvest time. It will be finished the next day (see above). Figure 1 shows a graphical representation of the afternoon operation principle.

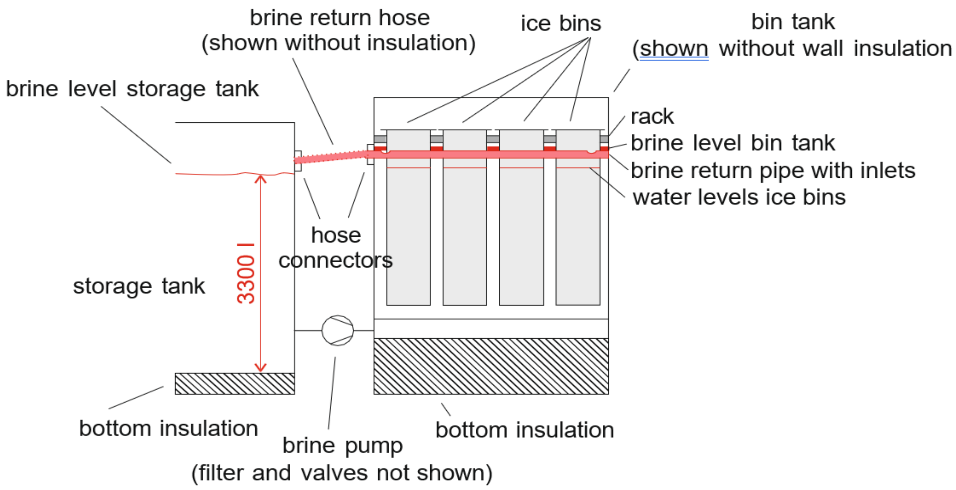


FIGURE 3 | Operation principle of the ice machine in the afternoon;
1 – The refrigeration system is running: brine cools down (enthalpy is rising) and ice in the bins is growing (FSV is decreasing); 2 – The absolute values of enthalpy and FSV are equal. A new bin tank is put into operation. FSV is rising. 3 – Cold production is stopped. Enthalpy and FSV are compared. FSV is larger than enthalpy. Brine supply to the tank which was put into operation at last is stopped. 4 – Enthalpy is larger than FSV. Ice production of all operating bin tanks can be finished.

For all other bin tanks the brine supply continues until the FSV indicates that the freezing process has been finished for the individual tank. In that case the brine supply of the respective tank is interrupted and the indicator light indicates (e.g. by flashing) that the ice blocks of the corresponding tank can be harvested.

When the ice production of all tanks is stopped (which can be the case in the late evening or early morning) the brine in the storage tank has a temperature slightly below 0 °C. To keep the quality of the produced ice blocks the pumps of the bin tanks should run periodically to exchange the brine in the bin tanks by cold brine from the storage tank.

In the morning all finished ice blocks will be harvested and the ice production starts again by refilling the bins.

SAFETY
FIRST
Apa saja alat pelindung diri yang harus dikenakan?
Bahaya percikan api

4.3. Variable Frequency Drive (VFD) Integration

A variable frequency drive (VFD) is used to supply a refrigerating compressor out of a Photovoltaic (PV) generator. For this purpose, the PV generator is directly connected to the internal dc bus of the VFD. The characteristic of the PV generator is nonlinear and has an optimum operating point - the maximum power point (MPP) (Figure 1).

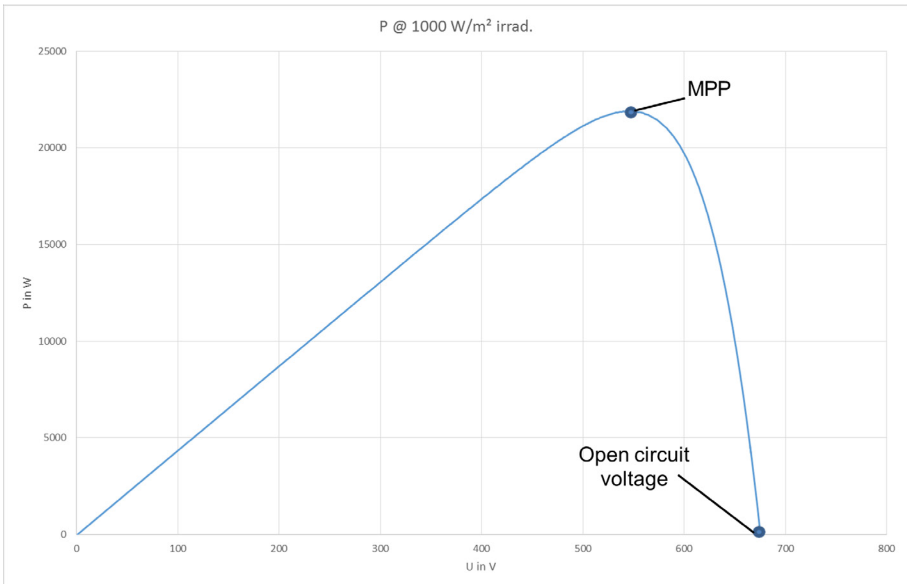


FIGURE 1 | Principle characteristic of PV generator P = f(U)

This point is not constant but depends mainly on the temperature and the solar irradiation. A MPP control algorithm is required to achieve the maximum power at different ambient conditions. The operating point of the system can be shifted towards the MPP by adjusting the input resistance of the load by varying the motor speed via the output frequency of the VFD. ILK has developed a tracking algorithm in a previous project, which has been adapted according to the system configuration in this project. This tracking algorithm is documented within this report and the implementation for the Omron VFD is described. The software description by flow charts is product independent. For the Omron VFD type MX2 the relevant parameters are listed, the CX-Programmer drive file is appended to this report and the inverter for the demonstration project is equipped with this software.

4.4. Principle of control

A variable frequency drive (VFD) is used to supply a refrigerating compressor out of a Photovoltaic (PV) generator. For this purpose, the PV generator is directly connected to the internal dc bus of the VFD. The characteristic of the PV generator is nonlinear and has an optimum operating point - the maximum power point (MPP) (Figure 1).

Energy management interface to external PLC:

- A general enable flag has to be set by the PLC via Modbus to enable the operation of the motor and the MPP tracking.
- If the current speed of the motor equals the maximum allowed speed, no MPP tracking will be performed. This state indicates excess energy i.e. not all of the available energy could be used by the VFD. A flag is set and can be read by the PLC via Modbus.
- If the energy management requires the reduction of the energy use by the VFD (e.g. to use energy for battery charging), the PLC could temporarily limit the maximum speed setting of the VFD (writing parameter A061 via Modbus) or disable the motor by resetting the enable flag.

If the enable flag is set, the implemented software checks periodically the PV voltage and the available power of the PV generator to minimize start attempts of the motor. If voltage and power are higher than the minimum required values, the motor and the MPP tracking will be started. If the voltage drops below a defined minimum value, the motor will be stopped by the program.

Detection of minimum PV power:
Detection of minimum PV power is done by using the motor as resistive load. For this purpose, the VFD is parametrized to inject a dc current into the motor windings for some seconds before start rotating the motor. During this phase, the PV generator is loaded by the motor winding and the PV voltage decreases. The value of this voltage drop-down corresponds to the available PV power. The maximum voltage drop, which still enables a compressor start, has to be determined empirically. It depends on the motor data and the configuration of the PV generator (installed power, nominal voltage). If the voltage drop is less than parametrized, the PV power is sufficient to start the motor with lowest speed.

After the start of the motor, the MPP tracking algorithm will be performed periodically. Operating in the maximum power point means, the motor runs with the maximum possible speed depending on the current ambient conditions.

Motor speed adjustment:
The MPP tracker runs a seeking procedure to locate the maximum power point by stepwise variation of the PV voltage set value. The PID controller of the VFD is used to adjust the PV voltage according to the calculated set point of the MPP tracking by controlling the motor speed (see Figure 1).

Adjustment of the motor speed by the PID control changes the input resistance of the VFD and shifts the operating point.

The MPP tracking algorithm starts with the open circuit voltage of the PV generator and decreases the voltage set value as long as the speed rises. If the speed drops down after decreasing the PV voltage, the tracking algorithm will reverse its search direction, which means that the voltage will be increased until the speed is lowered again and vis-a-versa.

To follow changes of the MPP due to temperature and irradiation variations, the tracking will be continuously performed.

To fasten up the seeking algorithm, the voltage steps are increased dynamically, if the search direction is not changed.

The set value of the PV voltage is only adjusted if the motor speed is stable. The MPP operation range is limited to an adjustable window.

The control schematic with MPP tracker and PID controller is shown in Figure 2.

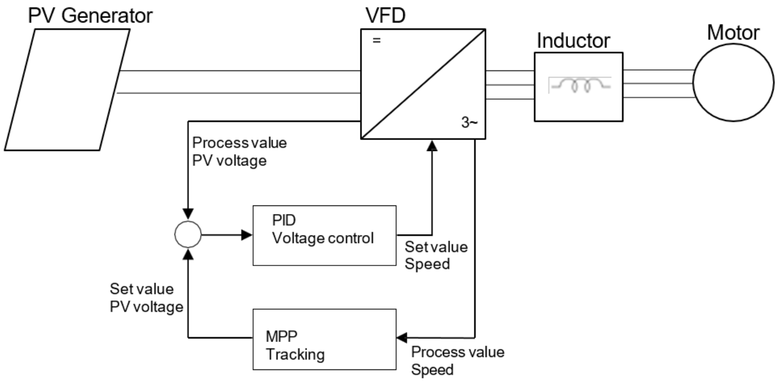


FIGURE 2 | Control scheme

Most of the parameters for the algorithm are user adjustable. As the process value for the PID control has to be given as analog input of the VFD, it is written to the analog output terminal of the VFD, which is wired to the analog input terminal.

4.5. Software description

The VFD software is organized as a multitasking solution. The processing time of each task correlates to its length. Task 5 is a fast task with only few instructions. This is important, as the process value for the PID control is set there.

Tasks:

- Task 1: "Output1" - Output of PV voltage set value
- Task 2: "Main" - Main task with start / stop of the motor, detection of minimum required PV power
- Task 3: "MPPT" - MPP tracking for determining the new voltage set value
- Task 4: "Trip" - Stop motor at alarms and observe minimum off time
- Task 5: "Output2" - Output of voltage process value for PID to analog terminal

For the used type of Omron VFD, the software is implemented using the programming feature of the Omron software CX-Drive [1]. Nevertheless, the following documentation is product independent and could be transferred to other inverter types.

Variable name	Parameter (Omron VFD)	Comment
Enable	U(00)	Enable by PLC
U01	U(01)	Unused
UPV_SV	U(02)	PV voltage set value
UPVstart	U(03)	Start voltage
dUcheck	U(04)	Voltage difference for start check
UPVmin_on	U(05)	Min. voltage during start check
UPVmin_off	U(06)	Cut off voltage
Excess	U(07)	Flag excess energy available
UMPP_SV	U(08)	MPP voltage set value
UMPPmin	U(09)	Max. or min. value of MPP set voltage (used for both val-ues temporary)
MPPStep	U(10)	Current step of MPP tracking
f1	U(11)	Motor speed for stability check
f2	U(12)	Motor speed for stability check
U13	U(13)	Unused
SpeedOld	U(14)	Motor speed before tracking
SpeedNew	U(15)	Motor speed after tracking
dUMPP	U(16)	Voltage step for MPP tracking
dfmax	U(17)	Max. speed fluctuation for stability check
tempUMPP	U(18)	Temporary value of UMPP_SV
SeekDir	U(19)	Seek direction for MPP tracking
U20	U(20)	Unused
temSpeed	U(21)	Temporary value of motor speed
DelayMPP	U(22)	Delay before tracking
DelayLOL	U(23)	Delay for LOL detection
I_LOL	U(24)	Calculated current for loss of load detection (LOL)
FlagLOL	U(25)	Loss of load detected
PminOK	U(26)	PV power lager than minimum value for start of compres-sor
U27	U(27)	Debug
U28	U(28)	Debug
U29	U(29)	State monitor at error

U30	U(30)	State monitor at error
U31	U(31)	State monitor at error
DF	UL(00)	Speed difference
absDF	UL(01)	Absolute value of speed difference
UL02	UL(02)	Unused
dfMPP	UL(03)	Speed difference caused by MPP tracking
UL04	UL(04)	Unused
UL05	UL(05)	Unused
UL06	UL(06)	Unused
UL07	UL(07)	Version date
MPP	UB(0)	Flag MPP enabled
UB1	UB(1)	Unused
ReqChangeDir	UB(2)	Flag request change of seek direction of MPP tracking (pow-er decreased)
FlagSameDir	UB(3)	Flag MPP tracking tow times in same direction
TripOccured	UB(4)	Flag trip has occurred
ReqChangeDirLimit	UB(5)	Flag request change of seek direction of MPP tracking (MPP volt-age limit reached)
ChangeDir	UB(6)	Flag = ReqChangeDir AND ReqChangeDirLimit in task 4
UB7	UB(7)	Unused
Analog output	YA(1)	UPV output for PID PV
Analog input	XA(1)	UPV input for PID PV
Digital output 1	Y(00)	Unused
Digital output 2	Y(01)	Unused
Digital output 3	Y(02)	Relay (unused)

TABLE 1 | Global variables and IOs

For the Omron VFD the internal global variables U(00) to U(31) are stored in parameters P100 to P131 of the VFD. The following flowcharts showing the functions of the software tasks (The full listin for Omron VFD is printed in Appendix I). Within the comments below each flowchart, the variable names used in the software are written in *italic* script.

Task 1:

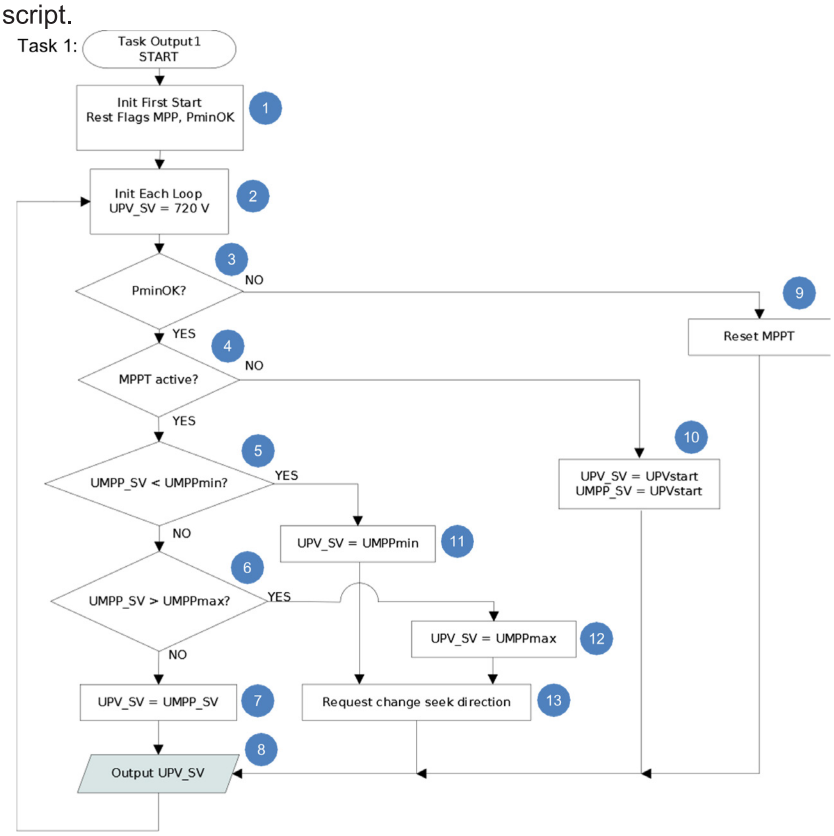


FIGURE 3 | Scheme of task 1 ("Output1")

No.	Comment
1	Reset flags MPP tracking (*MPP*) and minimum power detection (*PminOK*)
2	Set PV voltage set value (*UPV_SV*) to a maximum value of 720 V Read PV voltage start value parameter *(UPVstart)* Read PV voltage cut-off value parameter *(UPVmin_off)*
3	Check, if minimum power detection is true *(PminOK)*
4	Check if MPP tracking is enabled *(MPP)*
5	Check if MPP voltage set value *(UMPP_SV)* is not lower than the minimum allowed value for MPP voltage set value
6	Check if MPP voltage set value *(UMPP_SV)* is not higher than the maximum allowed value
7	Write MPP voltage set value *(UMPP_SV)* to PV voltage set value *(UPV_SV)*
8	Write set value *(UMPP_SV)* to PID controller *(Set-Freq)* (Remark: If PID is used, *Set-Freq* is the set value of the PID controller)
9	Clear flag for MPP tracking *(MPP)*
10	Use PV voltage start value *(UPVstart)* as PV and MPP voltage set value *(UPV_SV, UMPP_SV)*
11	Limit PV voltage set value *(UPV_SV)* to minimum allowed value for MPP voltage set value
12	Limit PV voltage set value *(UPV_SV)* to maximum allowed value
13	Set flag for request of changing seek direction (performed in task 4)

TABLE 2 | Comments task 1

Task 2:

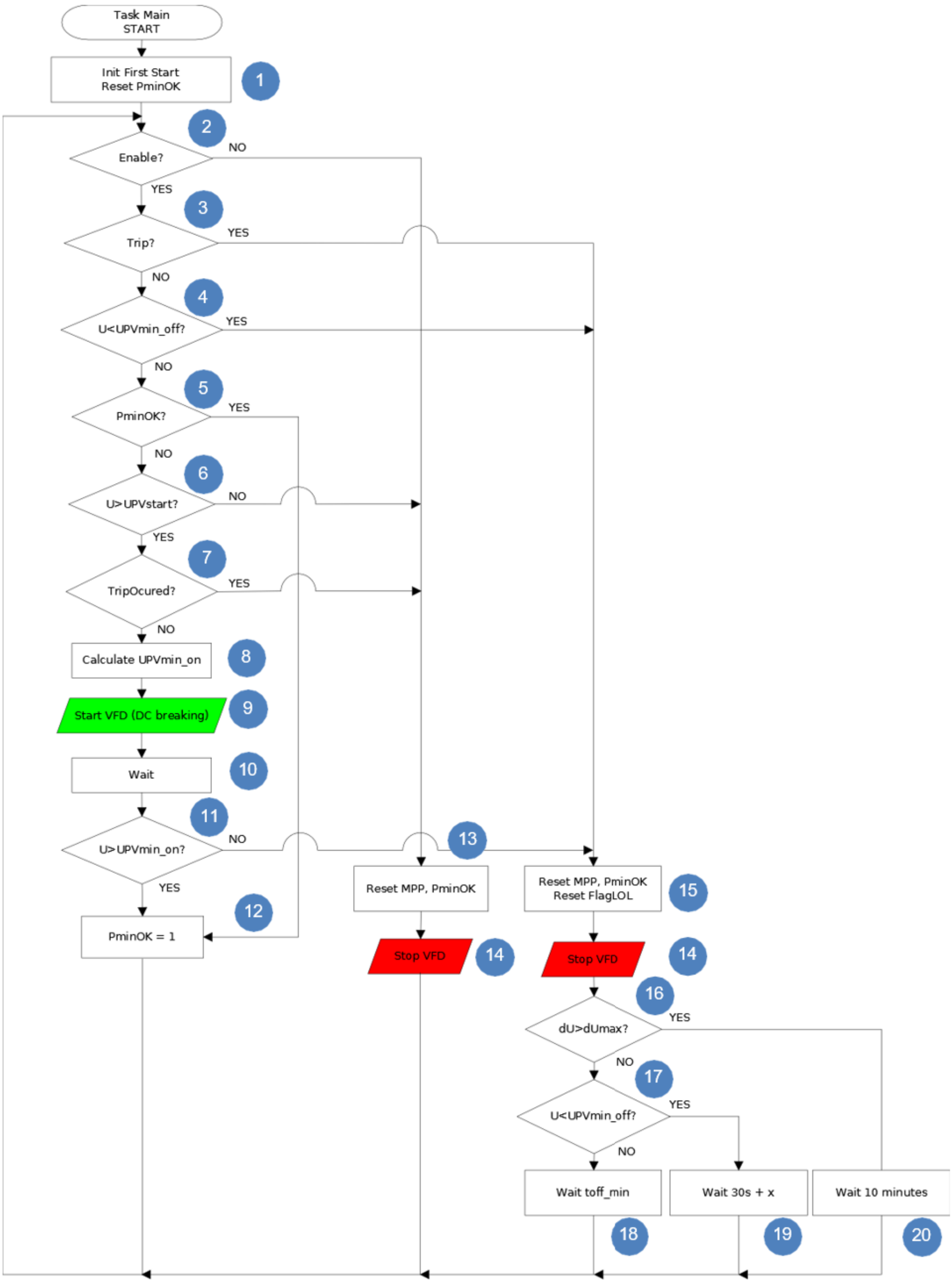


FIGURE 3 | Scheme of task 1 (“Output1”)

No.	Comment
1	Reset Flag *PminOK*
2	Continue, if *Enable* is active (set by PLC via Modbus) (Else stop motor)
3	*Continue, if no trip has occurred (Alarm of VFD)* *(Else stop motor)*
4	Continue, if PV voltage higher than defined voltage level for cut-off *(UPVmin_off)* (Else stop motor)
5	Check if minimum power detection is already true *(PminOK)*
6	Check if PV voltage higher than start voltage *(UPVstart)*
7	Check if trip has occurred *(TripOccured)* (set in task 4)
8	Calculate minimum voltage *(UPVmin_on)* during start of motor with DC break current from parameter *(dUcheck)* (for detection of minimum power)
9	Start the motor with dc breaking
10	Wait during dc breaking (time required for voltage drop down depends on system configuration)
11	Check if voltage is not below minimum value (Else stop motor and wait long)
12	Set flag for detection of minimum power to true *(PminOK)*
13	Reset flags *MPP* and *PminOK*
14	Stop compressor
15	Reset flags *MPP, PminOK* and *FlagLOL*
16	Check if voltage drop larger than defined maximum value ()
17	Check if PV voltage below cut off value
18	PV voltage too low, Pause toff_min
19	Dynamic pause calculated with voltage drop at Pmin test
20	Voltage drop was too large, wait long

TABLE 3 | Comments task 2

Task 3:

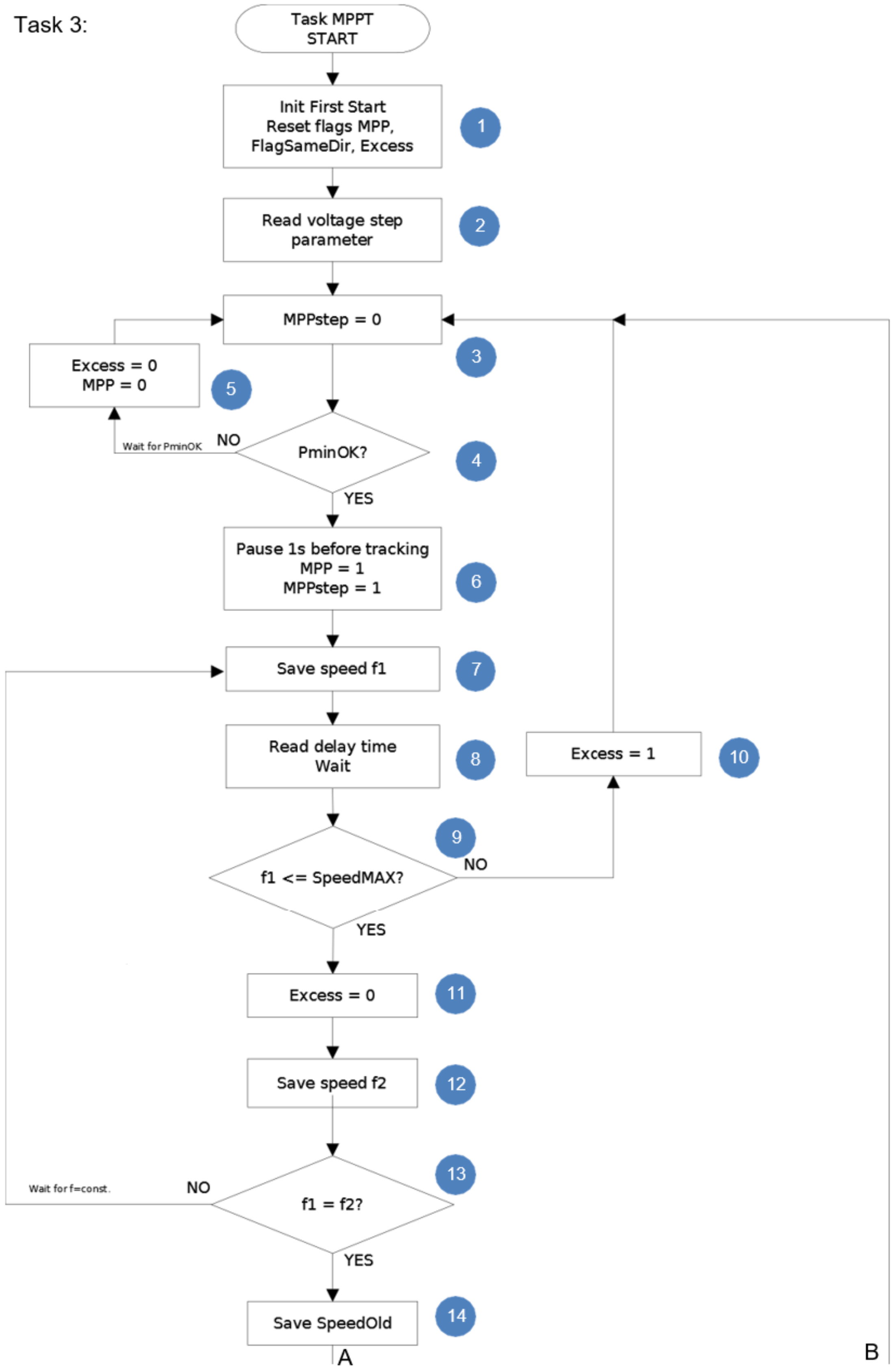


FIGURE 5 |Scheme of task 3 part 1 ("MPTT")

Task 3:

FIGURE 6 | Scheme of task 3 part 2 ("MPTT")

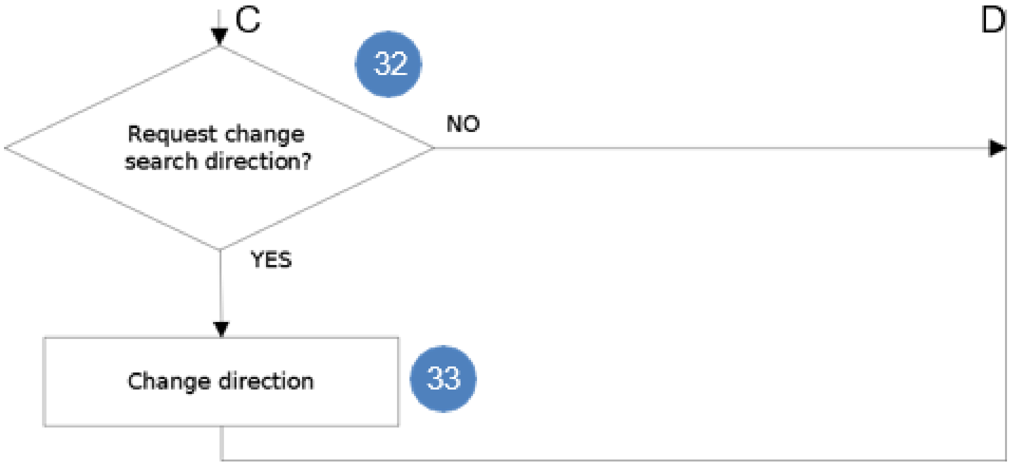


FIGURE 7 |Scheme of task 3 part 3 ("MPTT")

No.	Comment
1	Reset flags *MPP* (indicates MPP tracking is active), *FlagSameDir* (indicates same seek direction as last tracking), *Excess* (indicates excess energy)
2	Read voltage step from parameter *(dUMPP)*
3	Set MPP step 0
4	Continue if P>Pmin *(PminOK=1)*
5	Rest flags MPP , Excess
6	Wait 1 second before tracking, set flag MPP, set MPP step 1
7	Save first speed *(f1)* for stability check
8	Read delay time from parameter an wait for stability check
9	Check if speed is not higher than maximum speed
10	If maximum speed is reached, excess energy is available (set flag *Excess*), (no tracking)
11	Reset flag *Excess* (max. speed not reached, no excess energy available)
12	Save second speed *(f2)* for stability check
13	Continue if speed is stable (f1 ~ f2), deviation less than *dfmax* from parameter
14	Save speed before tracking *(SpeedOld)*
15	Check for search direction (up or down) *(SeekDir)*
16	Increase MPP voltage set value by *dUMPP*
17	Decrease MPP voltage set value by *dUMPP*
18	Read delay time after tracking from parameter and wait (settling time of new operation point)
19	Save first speed *(f1)* for stability check
20	Read delay time from parameter an wait for stability check
21	Save second speed *(f2)* for stability check
22	Continue if speed is stable (f1 ~ f2), deviation less than *dfmax* from parameter
23	Save speed after tracking *(SpeedOld)*
24	If speed is risen after tracking *(SpeedNew > SpeedOld)* keep search direction
25	Check if it is the second tracking with the same direction *(FlagSameDir)*
26	Double voltage step *(dUMPP)* for faster tracking
27	Overwrite *dUMPP* with value original from parameter (not further doubled)
28	Set flag for same direction *(FlagSameDir)*
29	Set flag for request of changing search direction *(ReqChangeDir)*
30	Reset flag same direction *(FlagSameDir)*

31	Overwrite MPP set voltage with current PV voltage to avoid drift
32	Check if request for changing search direction is set
33	Change search direction and reset flags for request

TABLE 4 | Comments task 3

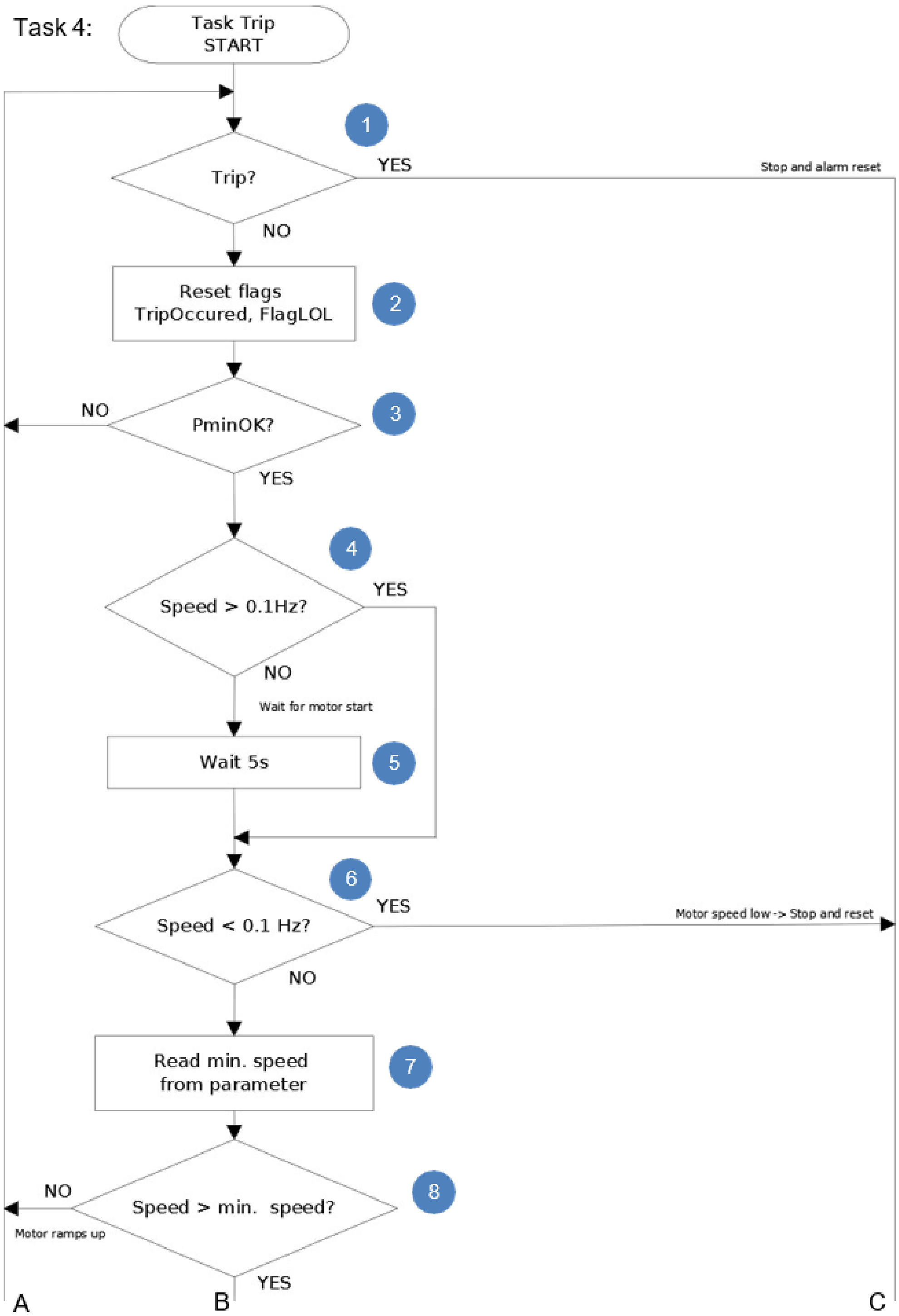


FIGURE 8 | Scheme of task 4, part 1 (“Trip”)

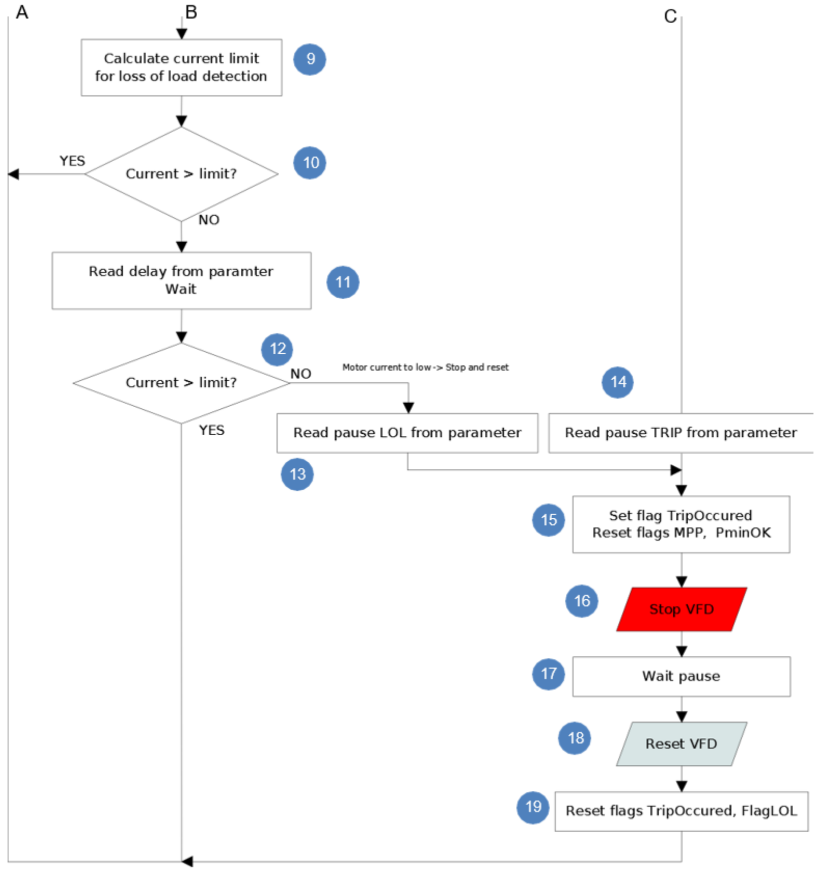


FIGURE 9 | Scheme of task 4, part 2 ("Trip")

No.	Comment
1	Check if trip of VFD has occurred
2	Reset flags for indication of trip and loss of load *(TripOccured and FlagLOL)*
3	Continue if P > Pmin *(PminOK=1)*
4	Check if motor is running (speed > 0.1 Hz)
5	Wait 5s if speed is too low (wait for start of motor)
6	Check if speed is still too low (speed > 0.1 Hz)
7	Read min. speed from parameter
8	Continue if speed is higher than min. speed (else: motor ramps up)
9	Calculate current limit for loss of load detection (LOL) (value from parameter plus offset depending on speed)
10	Check if current > limit
11	Read delay time from parameter and wait, if current too low
12	Check again if current > limit
13	Read off time after LOL from parameter, Set flag FlagLOL
14	Read off time after trip from parameter
15	Set flags for trip *(TripOccured)* and reset flags *MPP, PminOK*
16	Stop VFD
17	Wait off time
18	Reset VFD (alarms)
19	Reset flags *TripOccured, FlagLOL*

TABLE 5 | Comments task 4

Task 5:

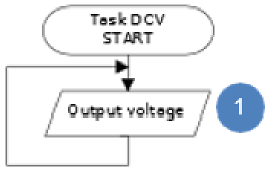


FIGURE 10 | Scheme of task 5 (“Output2”)

No.	Comment
1	Write PV voltage to analog output terminal as process value of PID control

TABLE 6 | Comments task 5

4.6. Parameter list of Omron VFD

For different system configurations, it is necessary to adjust the settings of the MPP tracking. Beside the parameters U(00) to U(31) there are no further user definable parameters for the drive program. Therefore, the settings for the MPP software are stored in unused standard parameters of the VFD (Unused only for this application!). The following parameters are used for the VFD control algorithm or are important for proper functionality of them (Table 7, Table 8).

Important:
The values are preliminary and have to be adjusted during putting into operation phase.

Para meter	Description	Real value [unit]	Numbers internal	Comment
A243	Voltage step size for MPP tracking	2.0 [V]	20	
A247	Allowed voltage drop for detection of minimum PV power	3 [V]	30	
A292	Wait time after voltage adjustment	5.00 [s]	500	
A293	Divisor LOL detection	20	20	
F202	Wait time before tracking for check for stability	2.00 [s]	200	
F203	Wait time after tracking for check for stability	1.00 [s]	100	
P142	Wait time after loss of load detection	180 [s])	0x4650 (=18000)	Max. 0xFFFF (=32767)
P143	Start value of UPVset	650 [V]	0x1964 (=6500)	
P145	Value of UPVstart	650 [V]	0x1964 (=6500)	
P146	Value of UPVmin (cut off)	436 [V]	0x1108 (=4360)	
P148	Value of motor current for loss of load detection	4.50 [A]	0x1C2 (=450)	
P149	Max. value of MPP voltage	613 [V]	0x17F2 (=6130)	
P151	Min. value of MPP voltage	467 [V]	0x123E (=4670)	
P152	Wait time after trip	300 [s]	0x7530 (=30000)	

P161	Delay time loss of load detection	15 [s]	0x5DC (=1500)	
P162	Max. voltage drop for min power de-tection long pause	24.0 [V]	0xF0 (=240)	Max. 0xF0 (=240)
P163	Min. wait time after power too low	300 [s]	0x7530 (=30000)	Max. 0xFFFF (=32767)
P164	Max. allowed fluctuation of speed	0.10 [Hz]	0xA (=10)	

TABLE 7 | VFD parameters required for MPP algorithm

Para meter	Description	Value [unit]	Adjustable	Comment
A001	Frequency source setting	7	N	Set value from drive programming
A003	Base frequency setting	50 [Hz]	N	Nominal frequency of motor
A004	Maximum frequency setting	100 [Hz]	N	Maximum set value of PID
A016	Analog input filter	1	Y	Filter: n x 2 ms
A017	Drive Programming Selection	1	N	PRG terminal
A051	DC braking enable	1	N	Enabled for min. power detection
A053	DC braking wait time	0.0 [s]	N	
A057	DC braking force at start	50 [%]	Y	Adjustment required
A058	DC braking time at start	8.0 [s]	N	Time important for drive program
A059	Carrier frequency during DC braking	3.0 [kHz]	Y	Bitzer: 2 – 6 kHz [2]
A061	Frequency upper limit setting	70.0 [Hz]	N	Bitzer: max. allowed motor speed [2]
A062	Frequency lower limit setting	25.0 [Hz]	N	Bitzer: min. allowed motor speed [2]
A071	PID enable	1	N	Required for PV voltage setting
A072	PID proportional gain	1.50	Y	Adjustment required
A073	PID integral time constant	0.2 [s]	Y	Adjustment required
A074	PID derivative time constant	0.0 [s]	Y	Adjustment required
A076	PV source setting	1	N	Input via terminal O
A077	Reverse PID action	1	N	Enabled
A078	PID output limit	100.0 [%]	N	According to A004
A079	PID feed forward selection	0	N	Disabled
A081	AVR function select	2	Y	Off during deceleration
A082	AVR voltage select	6: 400 [V]	N	Nominal motor voltage
A083	AVR filter time constant	0.050 [s]	Y	
A092	Acceleration (2) time setting	15.60 [s]	Y	According to Bitzer document “kt-420-1” [2]
A093	Deceleration (2) time setting	1.00 [s]	Y	Fast to avoid large PV voltage drop on missing power state
A094	Select method to switch to Acc2/ Dec2 profile	1	N	Transition frequency (A095, A096) [2]
A095	Acc1 to Acc2 frequency transition point	25.00	N	According to Bitzer document “kt-420-1” [2]

A096	Dec1 to Dec2 frequency transition point	25.00	N	According to Bitzer document “kt-420-1” [2]
A097	Acceleration curve selection	0	Y	Linear
A098	Deceleration curve selection	0	Y	Linear
B002	Allowable under-voltage power fail-ure time	1.0 [s]	Y	Adjustment required
B005	Number of restarts on power failure / under-voltage trip events	1	N	Unlimited
B012	Level of electronic thermal setting	38.00 [A]	Y	According to motor
B022	Overload restriction level setting	37.65 [A]	Y	According to motor
B027	OC suppression selection	1	Y	Enabled
B033	Motor cable length parameter	20 [m]	Y	According to installation
B035	Rotation direction restriction	1	N	Enable for forward only
B046	Reverse run protection	1	N	Enabled
B049	Dual Rating Selection	1	N	ND (Normal Duty)
B050	Controlled deceleration on power loss	1	Y	Decelerates to stop, no trip
B051	DC bus voltage trigger level of con-trol deceleration	430.0 [V]	Y	Adjustment required
B052	Over-voltage threshold of control deceleration	800.0 [V]	Y	Should never occur
B053	Deceleration time of control deceleration	0.01 [s]	Y	Fast deceleration
B054	Initial frequency drop of control deceleration	10.00	Y	
B083	Carrier frequency setting	3.0 [kHz]	Y	Bitzer: 2 – 6 kHz [2]
B089	Automatic carrier frequency reduction	2	Y	Enabling (fin temperature controlled)
B091	Stop mode selection	1	N	Free-run stop
B092	Cooling fan control	2	Y	Depend on the fan temperature
B120	Brake control enable	0	N	Disabled
B130	Deceleration overvoltage suppression enable	0	N	Disabled
B145	GS input performance selection	1	Y	Trip, adjustment according to safety concept required
B146	Automatic return to the initial display	1	Y	Enabled
C001	Terminal [1] function	255	Y	No function
C002	Terminal [2] function	255	Y	No function
C003	Terminal [3] function	77	Y	GS1 (GS1 input), adjustment according to safety concept required
C004	Terminal [4] function	78	Y	GS2 (GS2 input), adjustment according to safety concept required
C005	Terminal [5] function	19	N	PTC (PTC thermistor Thermal Protection (C005 only))
C006	Terminal [6] function	82	N	PRG (Executing Drive Program)
C007	Terminal [7] function	18	Y	RS (Reset Inverter)
C013	Terminal [3] active state	1	N	NC
C014	Terminal [4] active state	1	N	NC

C016	Terminal [6] active state	0	N	NO
C021	Terminal [11] function	43	Y	Y(00) Drive Programming (MO1)
C022	Terminal [12] function	255	Y	Y(01) Drive Programming (MO2)
C026	Alarm relay terminal function	46	Y	Y(02) Drive Programming (MO3)
C027	EO signal selection (Pulse/PWM output)	12	Y	YA(0) Drive Programming (General-purpose output 0)
C028	[AM] signal selection	13	N	YA(1) Drive Programming (General-purpose output 1)
C030	Terminal [11] active state	0	Y	NO
C031	Terminal [12] active state	0	Y	NO
C036	Alarm relay active state	0	Y	NO
C041	Overload level setting	43.7 [A]	Y	According to VFD
C064	Heat sink overheat warning	90 [°C]	Y	
C071	Communication Speed Selection	7	Y	38400 bps, according to setting in PLC
C072	Modbus address	1	Y	According to setting in PLC
C074	Communication Parity Selection	0	N	No parity, according to setting in PLC
C077	Communication error time-out	2.00 [s]	Y	
C078	Communication wait time	10 [ms]	Y	
C081	O input span calibration	100	Y	Calibration, if required
C106	AM gain adjustment	99 [%]	Y	Calibration, if required
C109	AM bias adjustment	0 [%]	Y	Calibration, if required
F002	Acceleration (1) time setting	12.00 [s]	Y	According to Bitzer document “kt-420-1” [2]
F003	Deceleration (1) time setting	1.00 [s]	Y	According to Bitzer document “kt-420-1” [2]
H003	Motor capacity	13	Y	11.00 kW (-10/+50@70Hz)
H004	Motor poles setting	1	N	4 poles

TABLE 8 | General VFD parameters according to system concept and motor type

4.7. Wiring of the Omron VFD

The wiring of the VFD has to be done according to the terminals used in the control software of the VFD. The following schematic shows the required connections of the control circuit.

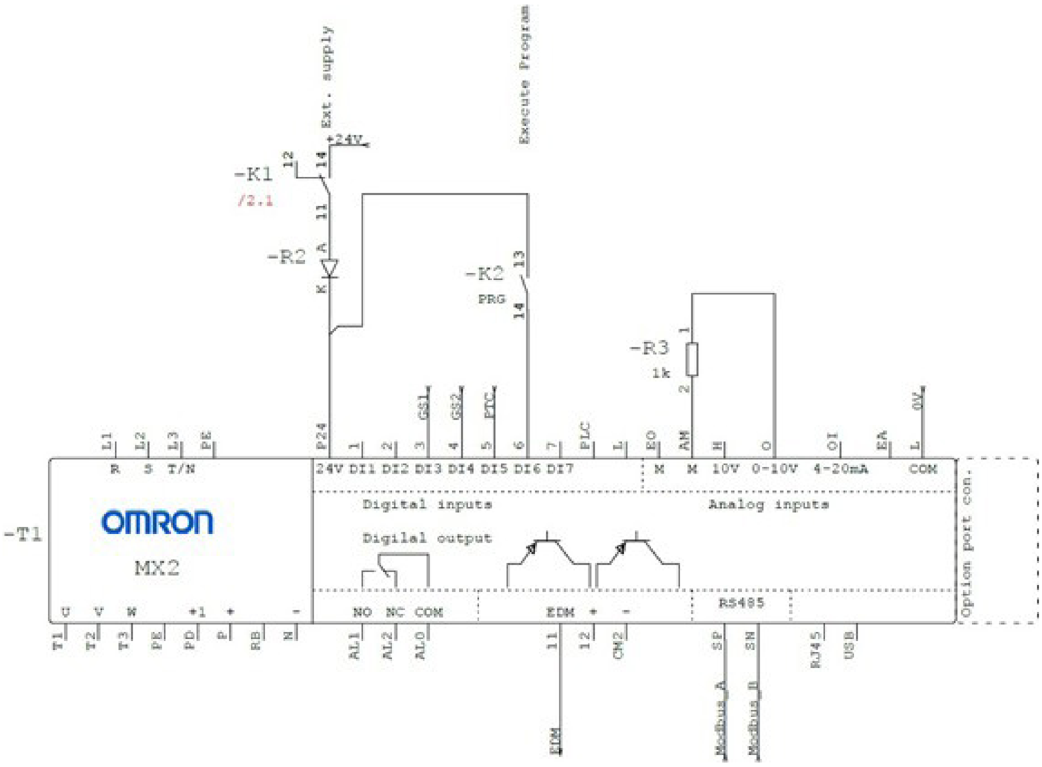


FIGURE 11 | Control wiring of VFD

An external 24 VDC power supply is connected via a diode to ensure the internal control supply of the VFD during morning and evening hours. The relay K1 is controlled by the PLC and it can disconnect the power supply during night and day times. The digital input DI6 of the VFD is used for start/stop of the drive program and is set by the PLC (digital output via coupling relay K2). The analog input of the process value of the PID control is generated by the drive program via the analog output of the VFD. A resistor is connected in series to limit the current flow. Digital inputs DI3, DI4 and EDM could be used for safe stop functionality (Safe Torque Off - STO) considering the safety concept (e.g. for stop after pressure failure). The input DI6 is defined as input of the motor thermistor. Regarding the safe stop functionality of the Omron VFD, it is important to observe the manufacturer instructions listed in the user manual appendix E Safety [3]. Further measures could be necessary according to the safety concept.

Literature

[1] CX-Drive: VFD programing software, Omron, Version 2.9.5.25

[2] Technical Information KT-420-1, Application of Frequency Inverters with Reciprocating Compressors, Revision 01.06, Bitzer Kuehlmaschinen GmbH,

https://www.bitzer.de/shared_media/documentation/kt-420-1.pdf

[3] MX2 User’s Manual, 2013, Omron Europe B.V.,

https://assets.omron.eu/downloads/manual/en/v1/i570_mx2_users_manual_en.pdf

Appendix

[I] Listing of MX2 program for MPP tracking

[2] Omron MX2 drive file with program

Appendix I - Listing of the MX2 program for MPP tracking

Task 1:

'Global variables for all tasks

#alias global Enable as U(00) 'enable by PLC
#alias global Enable_LOL as U(01) 'enable LOL by PLC
#alias global Enable as U(00) 'enable by PLC #alias global Enable_LOL as U(01) 'enable LOL by PLC #alias global UPV_SV as U(02) 'PV voltage set value #alias global UPVstart as U(03) 'Start voltage
#alias global dUcheck as U(04) 'Voltage difference for start check
#alias global UPVmin_on as U(05) '
#alias global UPVmin_off as U(06) 'Cut off voltage
#alias global Excess as U(07) 'Flag excess energy available
#alias global UMPP_SV as U(08) 'MPP voltage set value
#alias global UMPPmin as U(09) 'or UMPPmax (used for both values temporary)
#alias global MPPStep as U(10) 'Current step of MPP tracking #alias global f1 as U(11) ' M o t o r speed for stability check #alias global f2 as U(12) 'Motor speed for stability check '#alias global U13 as U(13) 'unused
#alias global SpeedOld as U(14) 'Motor speed before tracking #alias global SpeedNew as U(15) 'Motor speed after tracking #alias global dUMPP as U(16) 'Voltage step for MPP tracking
#alias global dfmax as U(17) 'Max. speed fluctuation for stability check
#alias global tempUMPP as U(18) 'Temporary value of UMPP_SV #alias global SeekDir as U(19) 'Seek direction for MPP tracking '#alias global U20 as U(20) 'unused
#alias global temSpeed as U(21) 'Temporary value of motor speed
#alias global DelayMPP as U(22) 'Delay before tracking
#alias global DelayLOL as U(23) 'Delay for LOL detection
#alias global I_LOL as U(24) 'Calculated current for loss of load detection (LOL)
#alias global FlagLOL as U(25) 'Loss of load detected
#alias global PminOK as U(26) 'P>Pmin
#alias global U27 as U(27) 'Debug
#alias global U28 as U(28) 'Debug
'#alias global U29 as U(29) 'State monitor at error #alias global U30 as U(30) 'State monitor at error #alias global U31 as U(31) 'State monitor at error

#alias global DF as UL(00) 'Speed difference
#alias global absDF as UL(01) 'Absolute value of speed difference

#alias global UL02 as UL(02) 'limit wait time to 32767
#alias global dfMPP as UL(03) 'Speed difference caused by MPP tracking '#alias global UL04 as UL(04) 'unused
'#alias global UL05 as UL(05) 'unused '#alias global UL06 as UL(06) 'unused #alias global UL07 as UL(07) 'Version date

#alias global MPP as UB(0) 'Flag MPP enabled '#alias global UB1 as UB(1) 'unused
#alias global ReqChangeDir as UB(2) 'Flag request change of seek direction of MPP tracking (power decreased)
#alias global FlagSameDir as UB(3) 'Flag MPP tracking tow times in same direction
#alias global TripOccured as UB(4) 'Flag trip has occurred
#alias global ReqChangeDirLimit as UB(5)'Flag request change of seek direction of MPP tracking (MPP

```
voltage limit reached)
#alias global ChangeDir as UB(6)  '= ReqChangeDir AND ReqChangeDirLimit in task 4 '#alias global UB7 as UB(7)      'unused

'IOs
'YA(1) = UPV output for PID PV 'XA(1) = UPV input for PID PV 'Y(00) = unused
'Y(01) = unused
'Y(02) = Relay (unused)

'other
'DCV = PV voltage [0.1V]
'SET-Freq = set value for PID control (0...10000 = 0...1000V)

:S1         'Task1: write PID set value
entry
UL07 := 20180104          'Version date
MPP := 0 'First start initialization
PminOK := 0       'Reset for start

:Loop_T1
UPV_SV := 7200 'Initialize PV voltage set value to highest value (720V) (no operation)
UPVmin_off := P146        'Read minimum PV voltage for cut-off in Task 2
if PminOK = 0 then        'CheckPmin failed -> no operation(UPV_SV = 720 V)

MPP := 0 'To avoid restart
goto Set_SP      'Output max. set value
endif
if MPP = 1 then   'If MPPT enabled
goto MPP_Set     'Take UMPP_SV
else        'Else use start values for start procedure UPV_SV := P143        'Read UPV_SV start value
UMPP_SV := P143          'Read UMPP_SV start value
goto Set_SP      'Output start set value
endif
:MPP_Set            'if MPPT enabled UMPPmin := P151     'Read Umpp_parameter
if UMPP_SV < UMPPmin goto Lim_Umpp 'Limit UMPP_SV to min. value U(09) := P149      'Read Umpp_max parameter
if UMPP_SV > U(09) goto Lim_Umpp      'Limit UMPP_SV to max. value UPV_SV := UMPP_SV 'New Umpp set value
goto Set_SP
:Lim_Umpp        'Limit Umpp
UPV_SV := U(09)'Limit UPV_SV (min or max!) UMPP_SV := UPV_SV        'Refresh UMPP_SV with limited value
ReqChangeDirLimit := 1  'Request change of seek direction for MPPT at limits of UMPP_SV (Reset in Task 4)
:Set_SP
SET-Freq := UPV_SV      'Output UPV_SV to PID control
goto Loop_T1
end

Task 2:

:S2         'Task 2: check enable terminal / check P>Pmin
entry
PminOK := 0
U27 := 0  'Reset counter for debug
U28 := 0  'Reset counter for debug

:Loop_T2'Main loop
while Enable = 1  'Read enable input (from PLC)
on trip goto Pause          'Pause if VFD trip UPVstart := P145       'Read start voltage UPVmin_off := P146       'Read stop voltage
```

```
if DCV < UPVmin_off goto Pause  'Voltage too low -> stop with pause
if PminOK = 1 goto EN_RUN       'Already checked -> skip check of P>Pmin
if DCV <= UPVstart goto DIS_RUN 'Voltage below start level -> stop
if TripOccured = 1 goto DIS_RUN 'Trip -> stop
:Get_dU
dUcheck := A247  'Read value for allowed voltage drop during dc brake UPVmin_on := DCV - dUcheck
'Calculate min. voltage during dc brake
FW := 1   'Start VFD with dc brake
wait 300  'Wait 3s for voltage drop
if DCV < UPVmin_on goto Pause 'If voltage too low -> stop with Pause
:EN_RUN
PminOK := 1       'Set Flag, keep running
wend      'End of main loop for operation

:DIS_RUN          'Stop no pause
MPP := 0 'Disable MPPT
PminOK := 0       'Reset flag P>Pmin
inc U28   'Counter for debug
stop      'Stop VFD
goto Loop_T2

:Pause    'Stop with pause
U(04) := UPVmin_on - DCV 'Get voltage drop (min. allowed Upv - DCV) MPP := 0  'Disable MPPT
PminOK := 0       'Reset flag P>Pmin
FlagLOL := 0      'Reset flag LOL
inc U27   'Counter for debug
stop      'Stop VFD
U(05) := P162     '24 V (Parameter)
if U(04) > U(05) goto Pause_long 'Wait long, voltage drop too large
if DCV < UPVmin_off then                  'Voltage too low (P146) U(05) := P163   'Read      toff_min
(max. 32767)
else
UL02 := U(04) * 120        'Calculate dynamic pause from voltage drop 1V=12s (10V: 100*120=12000 -
> 120s + 30s)
UL02 := UL02 + 3000        'Min. 30s (7V: 70*120=8400 -> 84s, +30s = 114s; 20V: 270s; 24V: 318s)
endif
U(04) := 32767
if UL02 > U(04) then       'Limit to 32767 for wait

U(05) := 32767
else
U(05) := UL02
endif
wait U(05)        'Pause 30s or longer (dUmax=6V->Pause>60*120+3000=102s)
goto Loop_T2
:Pause_long       'Wait 10 minutes
wait 30000        'Wait 5 minutes (max. 32767)
wait 30000        'Wait 5 minutes (max. 32767)
goto Loop_T2
end
```

Task 3:

```
:S3       'Task 3: MPP tracking
entry
MPP := 0 'Reset
FlagSameDir := 0 'Reset
Excess := 0       'Reset
if PminOK = 0 goto S3      'Wait for P > Pmin dUMPP := A243       'Read voltage step
:InitMPP  'Loop entry
```

```
MPPStep := 0      ‘Init Step-monitor
if PminOK = 0 then
Excess := 0
MPP := 0
goto InitMPP      ‘Wait for P > Pmin (again to ensure)
endif
:StartT3  ‘Start task 3
wait 100  ‘Pause 1s before tracking
MPP := 1 ‘Enable MPPT
MPPStep := 1      ‘MPP-Step = 1
:MEM_f1_1
f1 := FM  ‘Save speed f1 DelayMPP := F202        ‘Read pause
wait DelayMPP     ‘Pause for check stability before tracking U(22) := A061  ‘Read fmax
if f1>=U(22) then  ‘Speed >= fmax -> no tracking, keep running Excess := 1          ‘Indicates  unused
energy is available
goto InitMPP

else
Excess := 0       ‘No unused energy available
endif
:MEM_f2_1
f2 := FM  ‘Save speed f2
:df_1      ‘Check for stability
DF := f1 - f2       ‘Speed fluctuation absDF := abs DF      ‘Abs speed fluctuation
:df_max_1
dfmax := P164     ‘Allowed speed fluctuation
:Instabil_1
if absDF > dfmax goto MEM_f1_1 ‘Speed fluctuation too large -> wait
:MEM_SpeedOld
SpeedOld := FM  ‘Save speed before tracking
if SeekDir = 1 then          ‘positive SeekDir = up tempUMPP := UMPP_SV + dUMPP        ‘New   set
value +
else       ‘negative SeekDir
tempUMPP := UMPP_SV - dUMPP         ‘New set value -
endif
UMPP_SV := tempUMPP ‘Take new set value (output in task 1)
U(22) := A292     ‘Read pause
wait U(22)        ‘Pause for voltage setting
:Step2
MPPStep := 2      ‘MPP-Step = 2
:MEM_f1
f1 := FM  ‘Save speed f1
U(22) := F203     ‘Read pause
wait U(22)        ‘Pause for check stability after tracking
:MEM_f2
f2 := FM  ‘Save speed f2
:df        ‘Check for stability
DF := f1 - f2       ‘Speed fluctuation
absDF := abs DF  ‘Abs speed fluctuation
:Instabil_2
if absDF > dfmax goto MEM_f1     ‘Speed fluctuation too large -> wait
:MEM_SpeedNew
SpeedNew := FM ‘Save speed after tracking
dfMPP := SpeedNew - SpeedOld  ‘Calculate speed change
:Step3

MPPStep := 3      ‘MPP-Step = 3
ReqChangeDir := 0          ‘Keep direction dUMPP := A243 ‘Read voltage step
if dfMPP > 0 goto StepW1 ‘Speed higher -> keep direction ReqChangeDir := 1       ‘Speed  not  higher
-> change direction (task 4)
FlagSameDir := 0 ‘Reset flag
```

```
goto LimDCV      'Voltage step unchanged
:StepW1
if FlagSameDir = 1 goto StepW2  '2. times same direction -> large voltage step FlagSameDir := 1  '1. time same direction -> set flag
goto LimDCV      'Voltage step unchanged
:StepW2
dUMPP := dUMPP * 2      'Voltage step doubled
:LimDCV
UMPP_SV := DCV          'Actual voltage as new set value (synchronize)
:Dir
ChangeDir := ReqChangeDir and ReqChangeDirLimit 'ReqChangeDirLimit = request from task 1
if ChangeDir = 0 goto ET3 'Keep direction ReqChangeDir := 0
ReqChangeDirLimit := 0
if SeekDir = 1 then     'Change direction SeekDir := 0   '0 - down
else
SeekDir := 1     '1 - up
endif
:ET3
goto InitMPP     'End
end
```

Task 4:

```
:S4     'Task 4: VFD trip / monitoring / change SeekDir MPPT / LOL
entry

:Loop_T4
on trip goto Stop_Trip      'VFD trip UMon(0) := PminOK     'Debug
UMon(1) := MPP  'Debug
UMon(2) := Iout  'Debug
U31 := MPP       'Monitoring
TripOccured := 0  'Reset flag

FlagLOL := 0     'Reset flag
if PminOK = 1 goto Check'
goto Loop_T4     'Wait for PminOK
:Check   'Check running
temSpeed := FM  'Read speed
if temSpeed>10 goto Check2 'Runs -> no pause
wait 500  'Wait 5s (possible start ramp)
temSpeed := FM  'Read speed again
:Check2
if temSpeed < 10 goto Stop_Trip 'Low speed -> stop U(24) := A062        'Read fmin
if temSpeed <= U(24) goto Loop_T4       'Ramp up is in progress
:CheckLOL
U(21) := FM - U(24)     'Calculate speed difference U(24) := A293       'Read divisor
U(21) := U(21) / U(24)     'Calculate offset for LOL I_LOL := P148  'Read LOL current I_LOL := I_LOL + U(21)      'Increase by offset
U30 := I_LOL     'Debug

if Enable_LOL=0 goto Loop_T4    'no LOL check

if Iout < I_LOL then        'Current too low -> start delay DelayLOL := P161'Read delay
wait DelayLOL    'Wait
else
goto Loop_T4     'End
endif
if Iout < I_LOL then        'Current still too low -> stop FlagLOL := 1
goto Stop_LOL
else
goto Loop_T4     'End
```

```
endif
:ET4_2    'End task 4
goto Loop_T4

:Stop_Trip          'On trip
U(23) := P152       'Read pause toff_min Trip

goto StopReset

:Stop_LOL           'On LOL
U(23) := P142       'Read pause toff_min LOL

:StopReset TripOccured := 1
MPP := 0 'Disable MPPT
PminOK := 0         'Reset P<Pmin
stop        'Stop VFD
U31 := MPP          'Monitoring
wait U(23)          'Wait
TripOccured := 0  'Reset flag
FlagLOL := 0        'Reset flag
goto Loop_T4
end

Task 5:

:S5         'Task 5: output process value to PID controller
entry       '!!! FAST TASK, NO FURTHER STEPS !!!
:Loop_T5
YA(1) := DCV        'output process value to PID
goto Loop_T5
end
```

AIREF

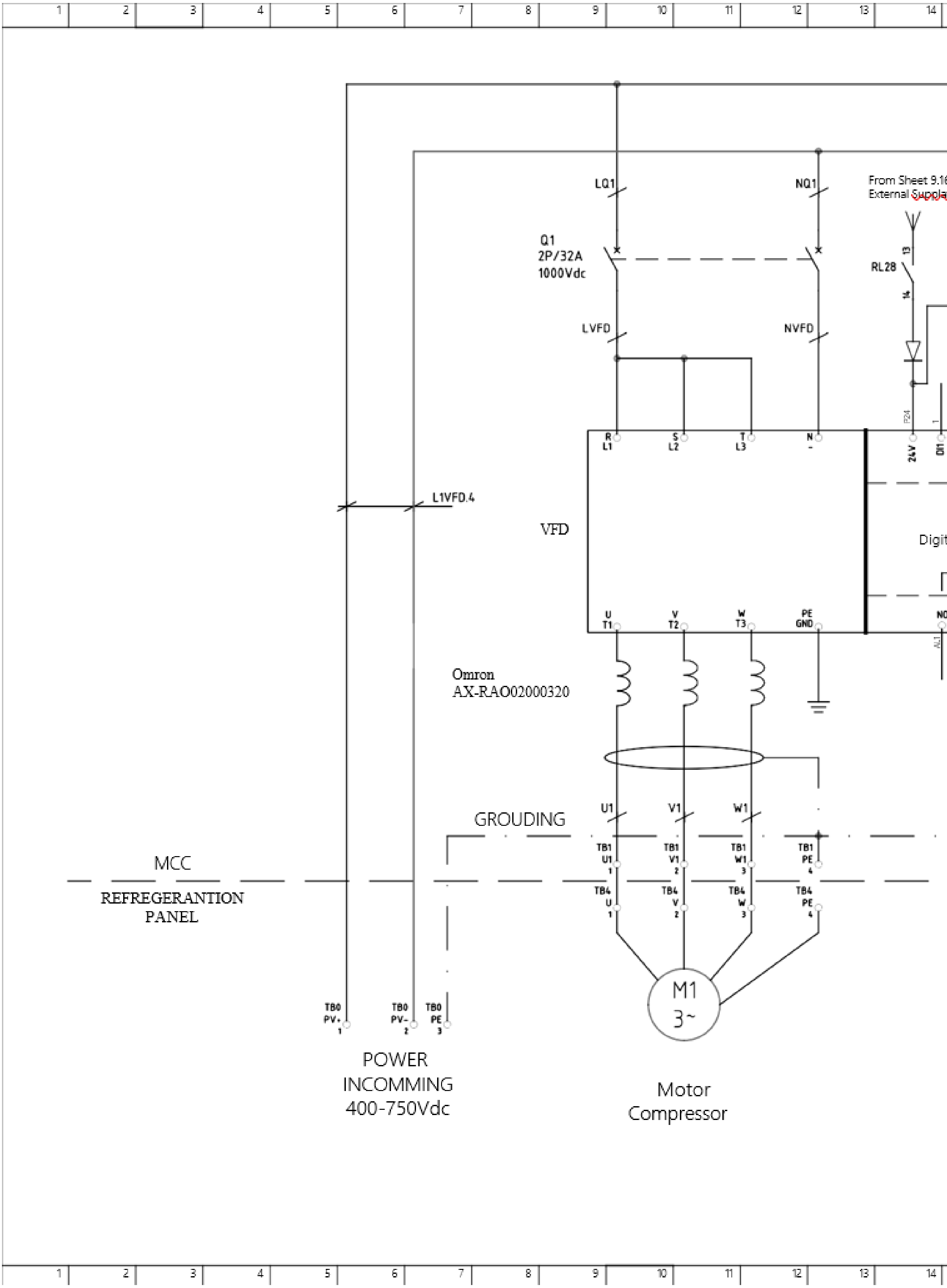
PT.SELARAS MAN

DRAWING NAME : WIRING DIAGRAM PANE

DRAWING NO : IB-R290-WD

NDIRI TEHNIK

EL CONDENSING UNIT ICE BANK-R290



1
2
3
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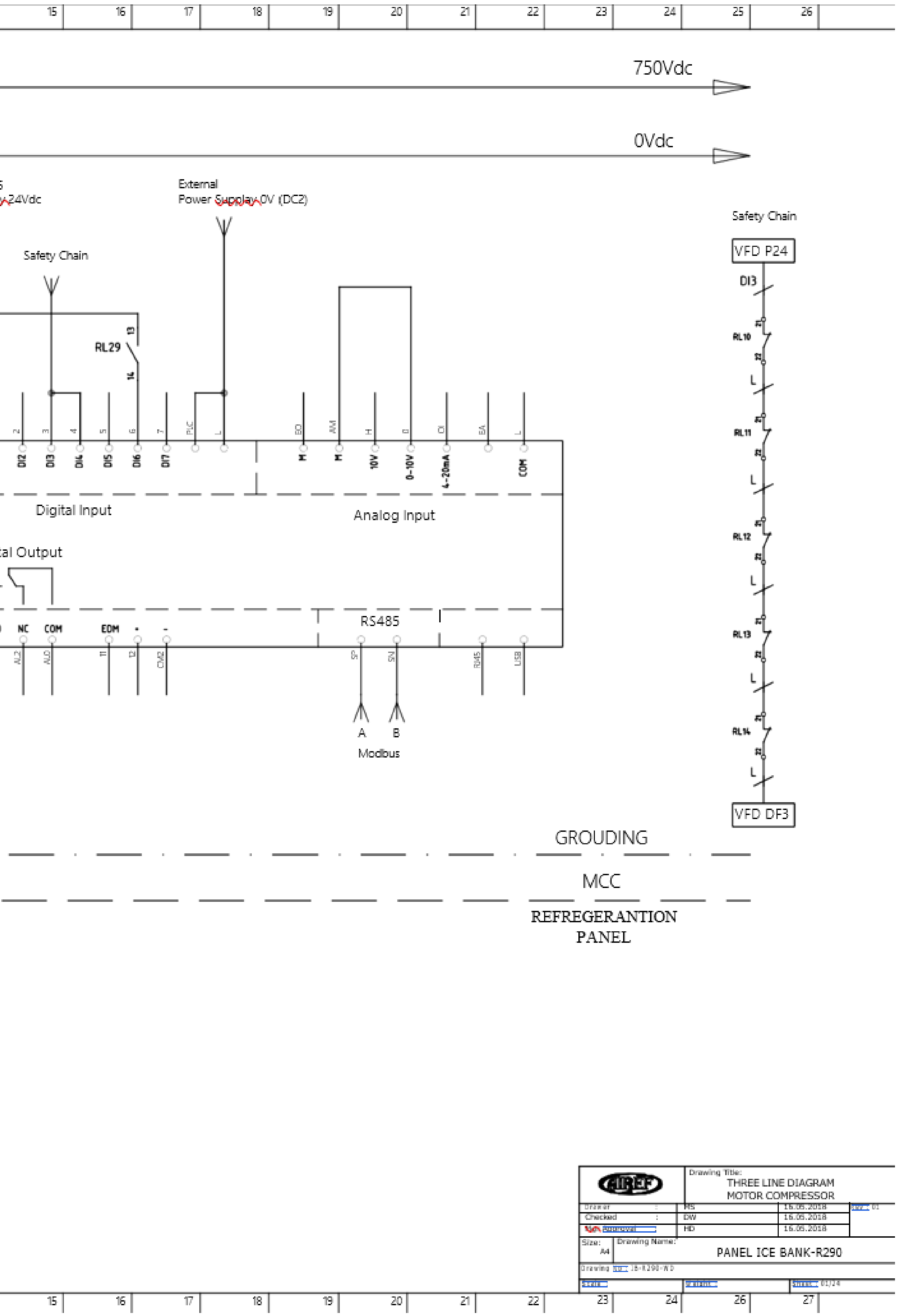
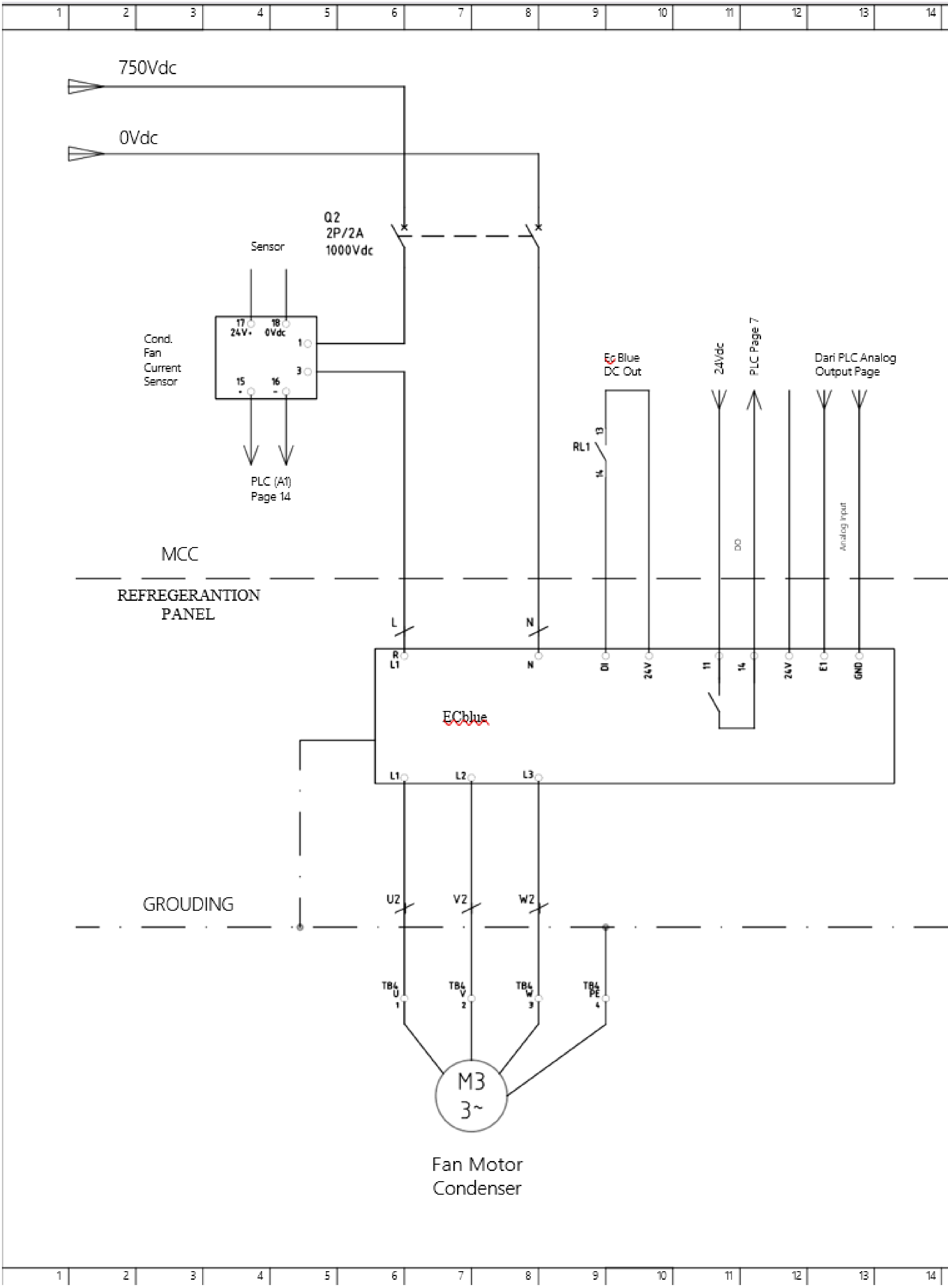
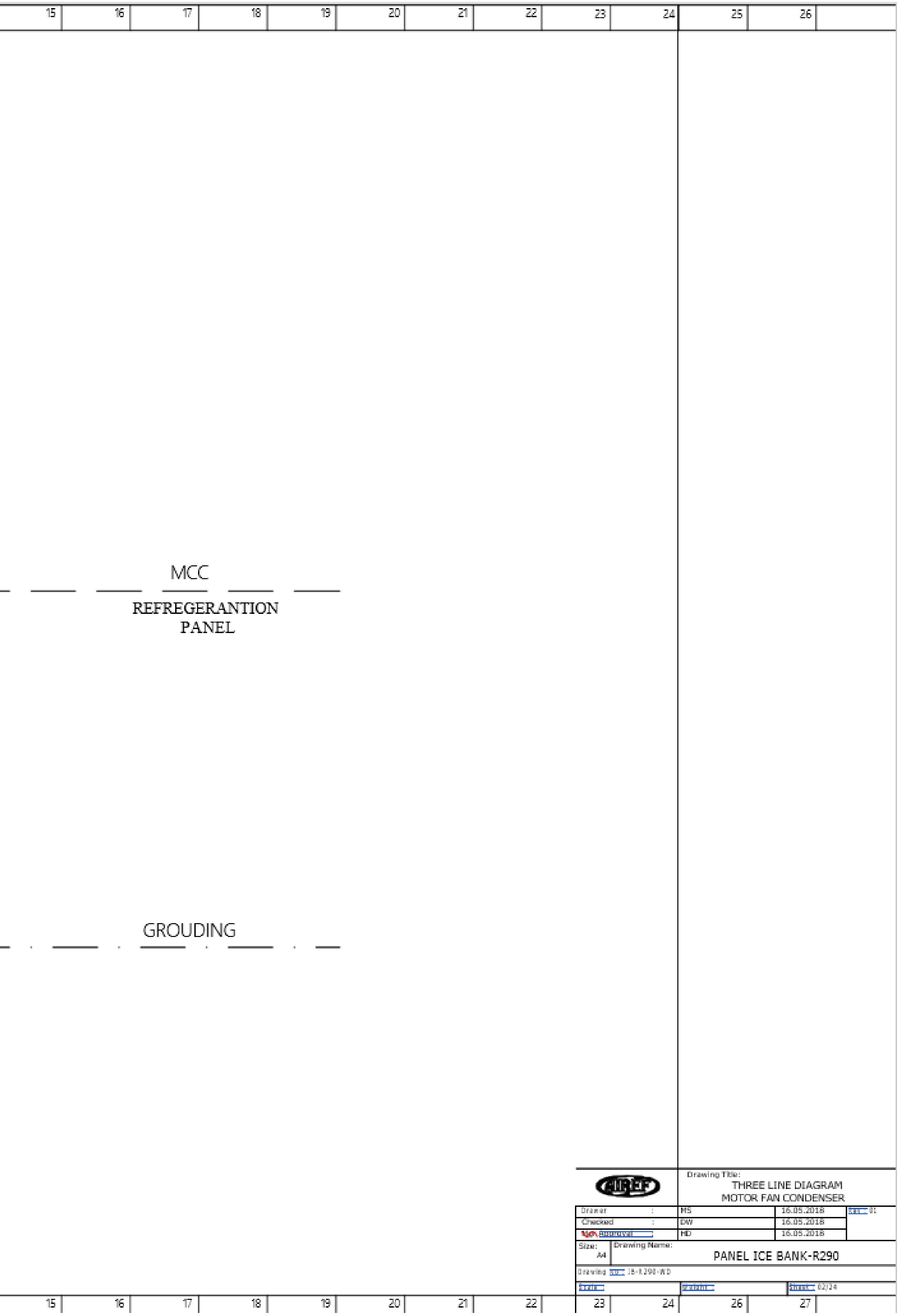
5
6
7
8
9
10
11
12
13
14
LQ1
NQ1
From Sheet 9.16
External Supply
Q1
2P/32A
1000Vdc
RL28
LVFD
NVFD
R L1
S L2
T L3
N -
24V
DI1
L1VFD.4
VFD
Digit
U T1
V T2
W T3
PE GND
Omron
AX-RAO02000320
U1
V1
W1
GROUDING
MCC
REFREGERANTION
PANEL
TB1 U1 1
TB1 V1 2
TB1 W1 3
TB1 PE 4
TB4 U 1
TB4 V 2
TB4 W 3
TB4 PE 4
TB0 PV+ 1
TB0 PV- 2
TB0 PE 3
M1
3~
POWER
INCOMMING
400-750Vdc
Motor
Compressor

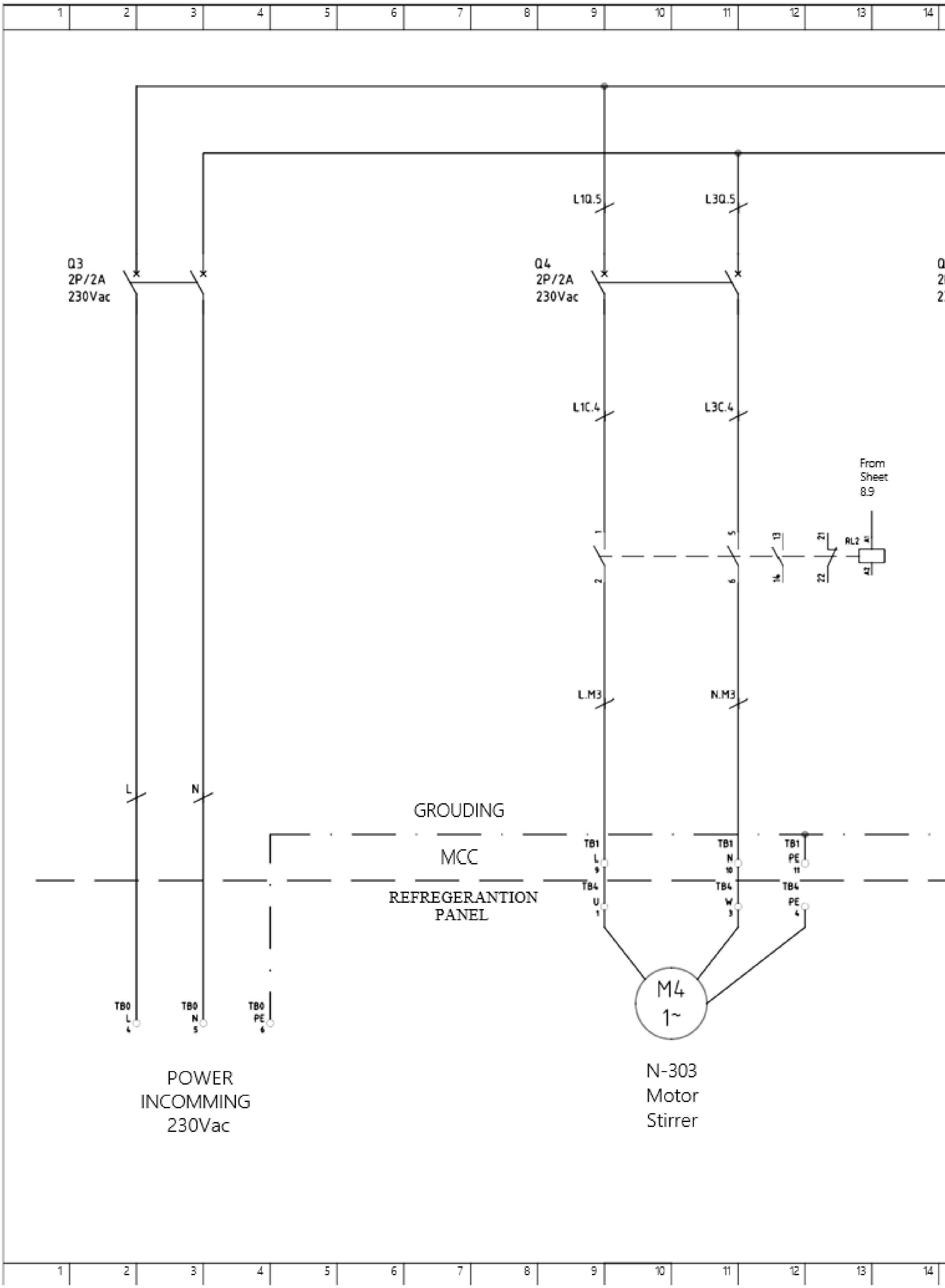


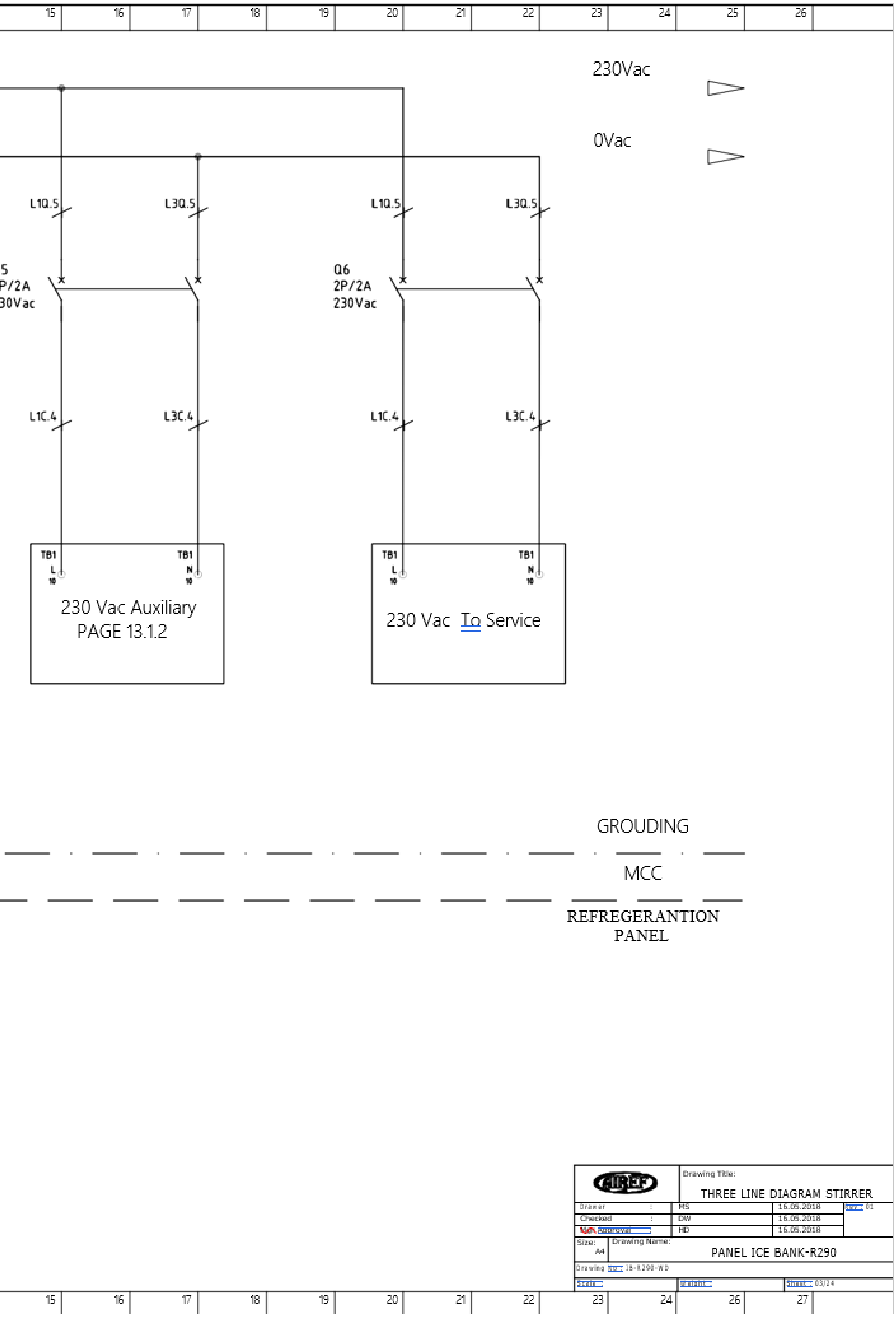
750Vdc
0Vdc
External
Power Supply 0V (DC2)
Safety Chain
RL29
Digital Input
Analog Input
RS485
A
B
Modbus
Safety Chain
VFD P24
DI3
RL10
RL11
RL12
RL13
RL14
VFD DF3
GROUDING
MCC
REFREGERANTION
PANEL
Drawing Title:
THREE LINE DIAGRAM
MOTOR COMPRESSOR
Checked
DW
HD
16.05.2018
Drawing Name:
PANEL ICE BANK-R290


750Vdc
0Vdc
Q2
2P/2A
1000Vdc
Sensor
Cond.
Fan
Current
Sensor
17
24V+
18
0Vdc
1
3
15
16
PLC (A1)
Page 14
Ec Blue
DC Out
24Vdc
PLC Page 7
Dari PLC Analog
Output Page
RL1
13
14
DO
Analog input
MCC
REFREGERANTION
PANEL
L
N
R
L1
N
DI
24V
11
14
24V
E1
GND
ECblue
L1
L2
L3
GROUDING
U2
V2
W2
TB4
U
1
TB4
V
2
TB4
W
3
TB4
PE
4
M3
3~
Fan Motor
Condenser

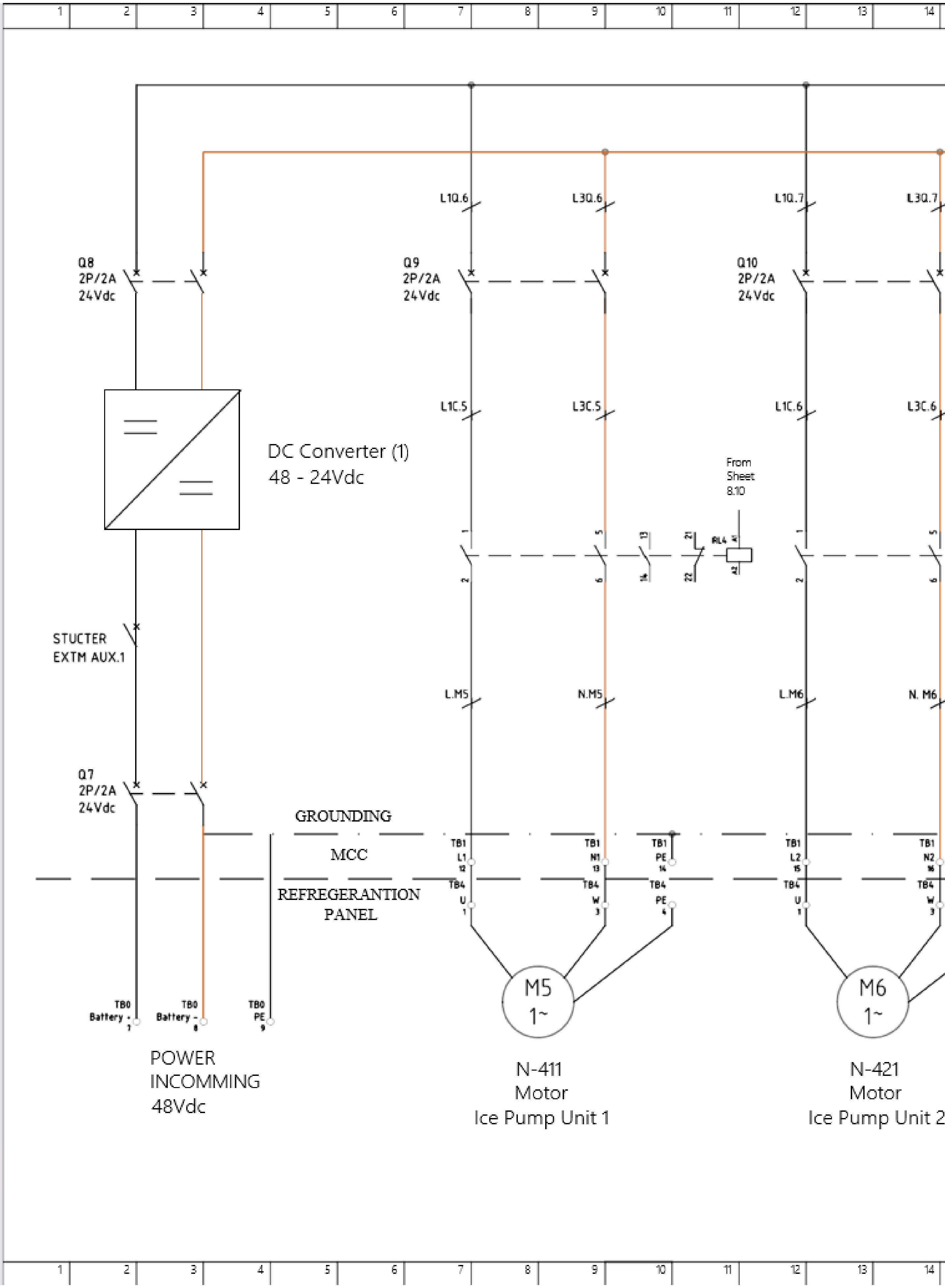


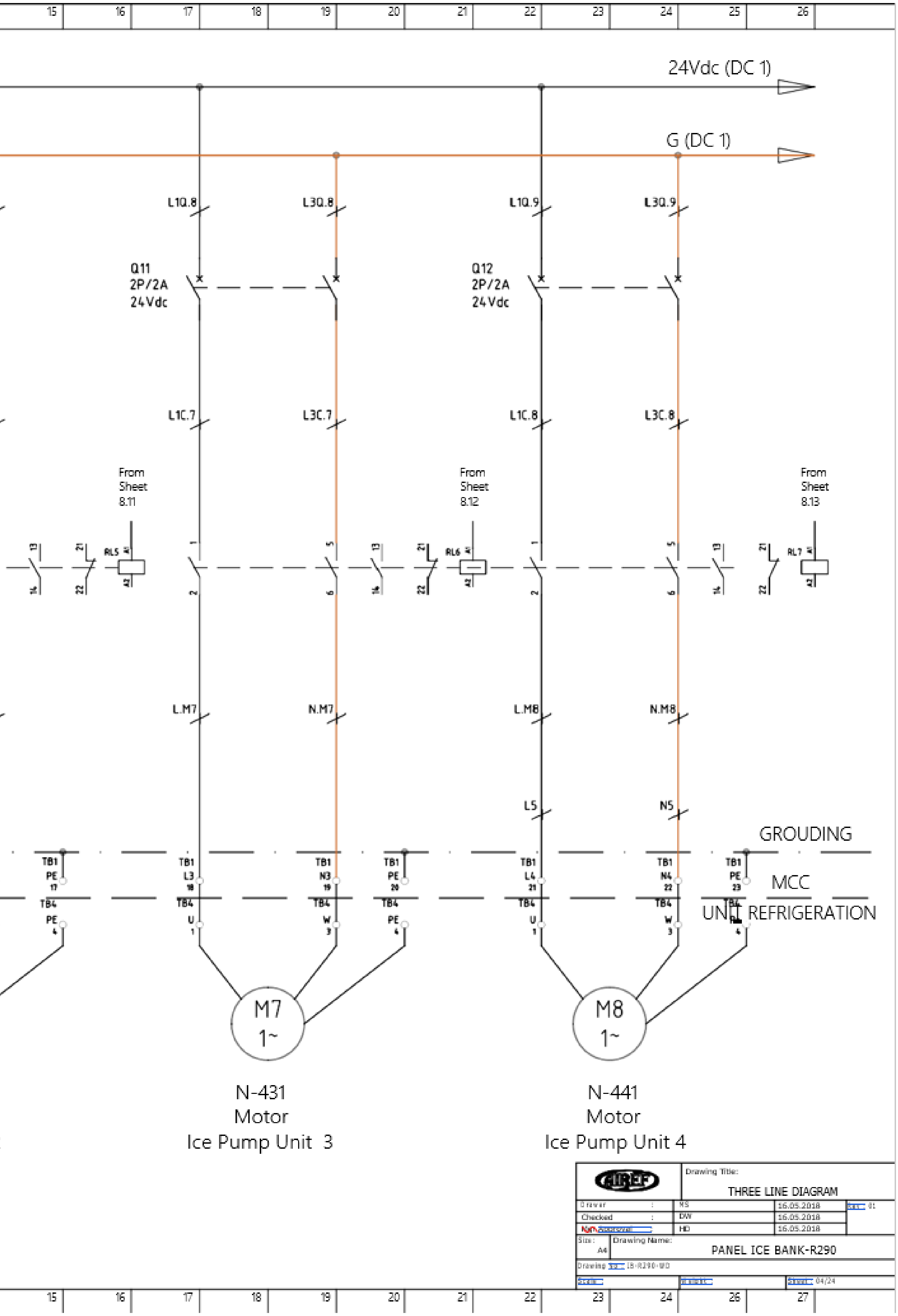
15
16
17
18
19
20
21
22
23
24
25
26
MCC
REFREGERANTION
PANEL
GROUDING
Drawing Title:
THREE LINE DIAGRAM
MOTOR FAN CONDENSER
Drawer :
MS
16.05.2018
Checked :
DW
16.05.2018
HD
16.05.2018
Size:
A4
Drawing Name:
PANEL ICE BANK-R290
Sheet : 02/24
27

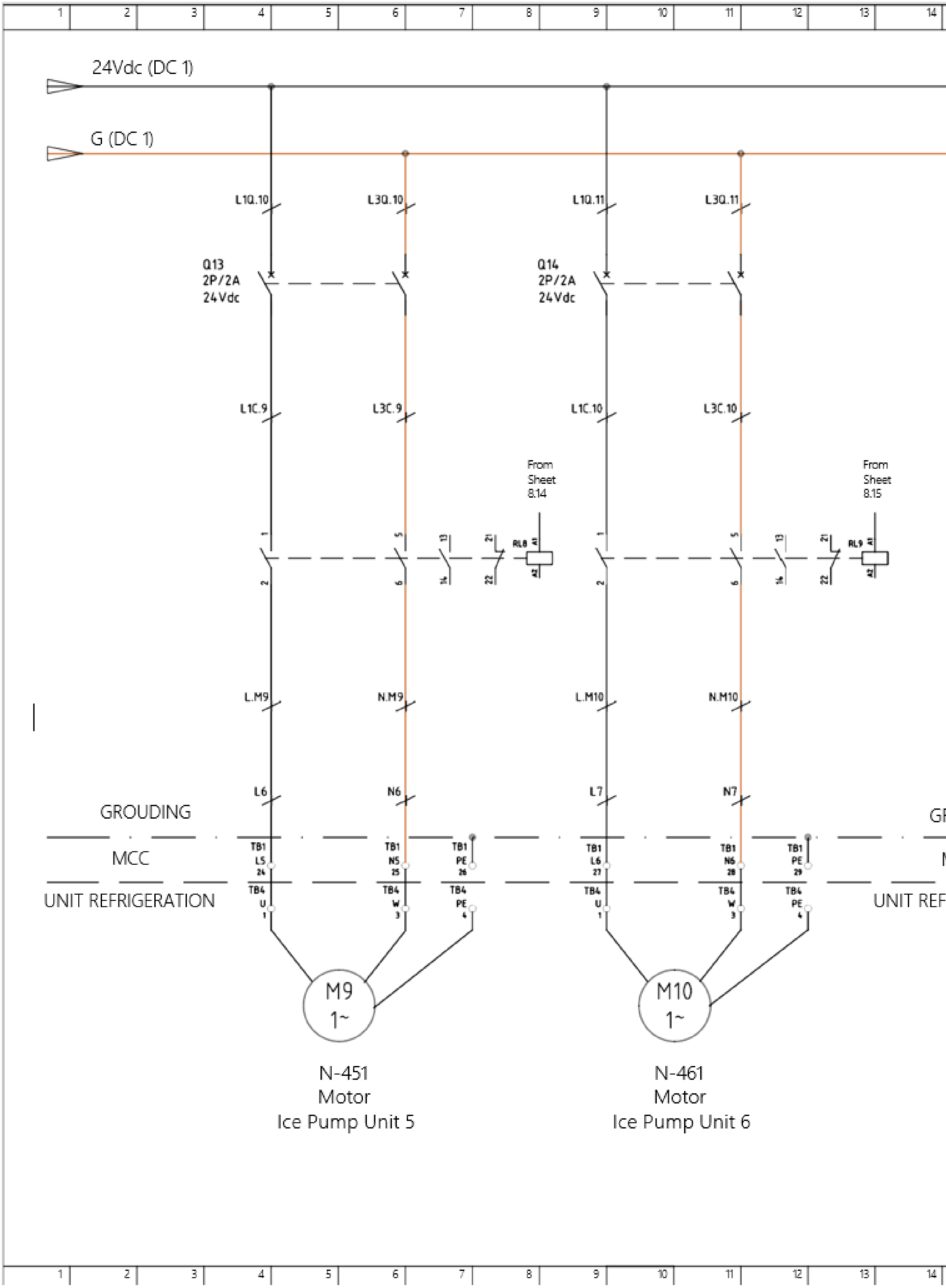

Q3
2P/2A
230Vac
Q4
2P/2A
230Vac
L1Q.5
L3Q.5
L1C.4
L3C.4
From
Sheet
8.9
RL2
L.M3
N.M3
L
N
GROUDING
MCC
REFREGERANTION
PANEL
TB1
TB4
TB0
M4
1~
POWER
INCOMMING
230Vac
N-303
Motor
Stirrer



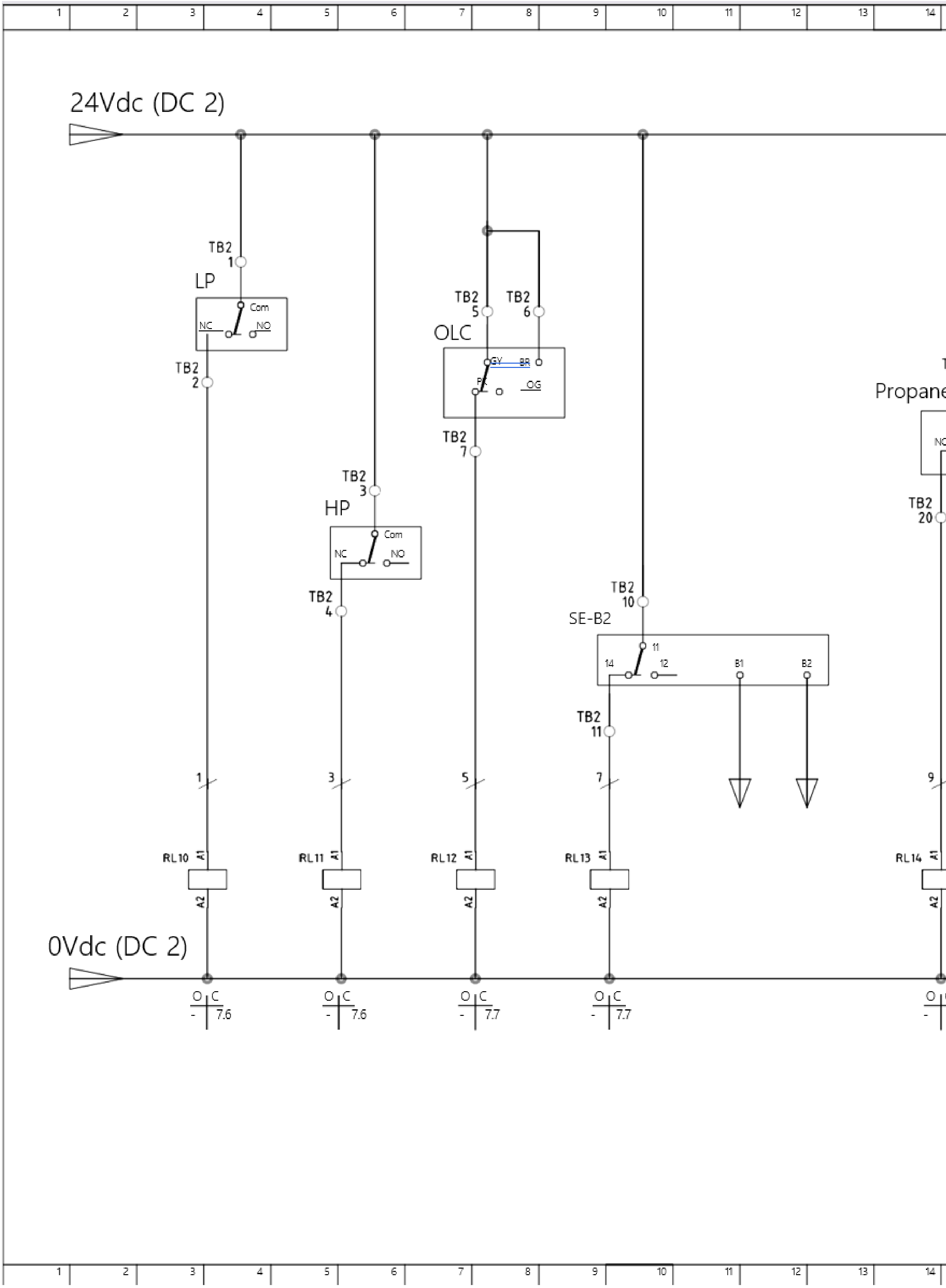
15 16 17 18 19 20 21 22 23 24 25 26
230Vac
0Vac
L1Q.5
L3Q.5
L1Q.5
L3Q.5
Q6
2P/2A
230Vac
L1C.4
L3C.4
L1C.4
L3C.4
TB1 L 10
TB1 N 10
230 Vac Auxiliary
PAGE 13.1.2
TB1 L 10
TB1 N 10
230 Vac To Service
GROUDING
MCC
REFREGERANTION
PANEL
Drawing Title:
THREE LINE DIAGRAM STIRRER
Checked : DW 16.05.2018
HD 16.05.2018
Size: A4
Drawing Name:
PANEL ICE BANK-R290
Sheet : 03/24
15 16 17 18 19 20 21 22 23 24 26 27


1 2 3 4 5 6 7 8 9 10 11 12 13 14
L1Q.6
L3Q.6
L1Q.7
L3Q.7
Q8
2P/2A
24Vdc
Q9
2P/2A
24Vdc
Q10
2P/2A
24Vdc
L1C.5
L3C.5
L1C.6
L3C.6
DC Converter (1)
48 - 24Vdc
From
Sheet
8.10
RL4
STUCTER
EXTM AUX.1
L.M5
N.M5
L.M6
N. M6
Q7
2P/2A
24Vdc
GROUNDING
MCC
REFREGERANTION
PANEL
TB0
Battery +
TB0
Battery -
TB0
PE
POWER
INCOMMING
48Vdc
M5
1~
M6
1~
N-411
Motor
Ice Pump Unit 1
N-421
Motor
Ice Pump Unit 2

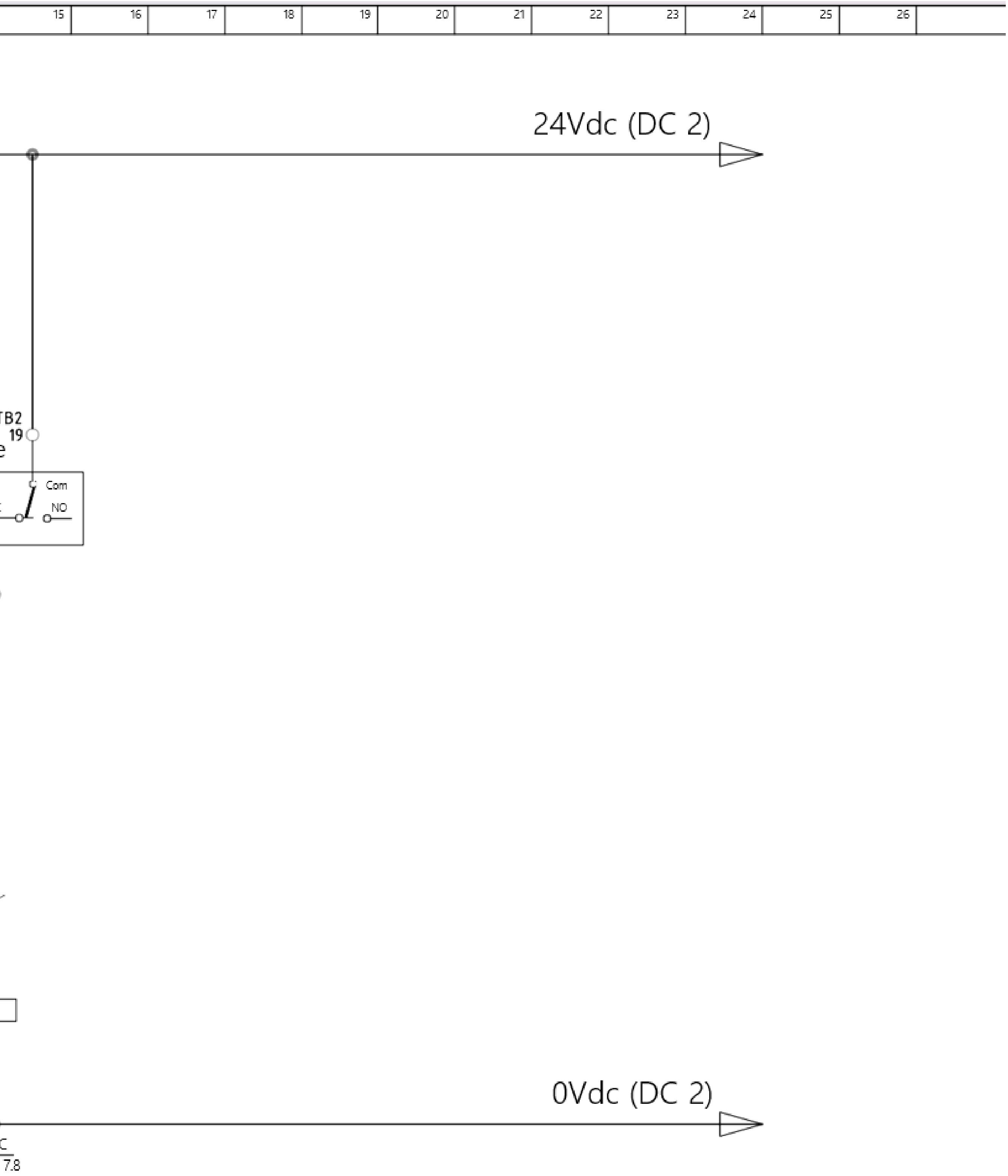

15 16 17 18 19 20 21 22 23 24 25 26
24Vdc (DC 1)
G (DC 1)
L1Q.8
L3Q.8
L1Q.9
L3Q.9
Q11
2P/2A
24Vdc
Q12
2P/2A
24Vdc
L1C.7
L3C.7
L1C.8
L3C.8
From
Sheet
8.11
From
Sheet
8.12
From
Sheet
8.13
RL5
RL6
RL7
L.M7
N.M7
L.M8
N.M8
L5
N5
GROUDING
MCC
UNIT REFRIGERATION
M7
1~
M8
1~
N-431
Motor
Ice Pump Unit 3
N-441
Motor
Ice Pump Unit 4
AIREF
Drawing Title:
THREE LINE DIAGRAM
Checked
DW
HD
16.05.2018
16.05.2018
16.05.2018
Drawing Name:
PANEL ICE BANK-R290
Size:
A4
15 16 17 18 19 20 21 22 23 24 26 27


24Vdc (DC 1)
G (DC 1)
L1Q.10
L3Q.10
L1Q.11
L3Q.11
Q13
2P/2A
24Vdc
Q14
2P/2A
24Vdc
L1C.9
L3C.9
L1C.10
L3C.10
From
Sheet
8.14
From
Sheet
8.15
RL8
RL9
L.M9
N.M9
L.M10
N.M10
L6
N6
L7
N7
GROUDING
MCC
UNIT REFRIGERATION
M9
1~
M10
1~
N-451
Motor
Ice Pump Unit 5
N-461
Motor
Ice Pump Unit 6

15
16
17
18
19
20
21
22
23
24
25
26
24Vdc (DC 1)
G (DC 1)
ROUDING
MCC
RIGERATION
Drawing Title:
THREE LINE DIAGRAM
Checked
16.05.2018
Drawing Name:
PANEL ICE BANK-R290

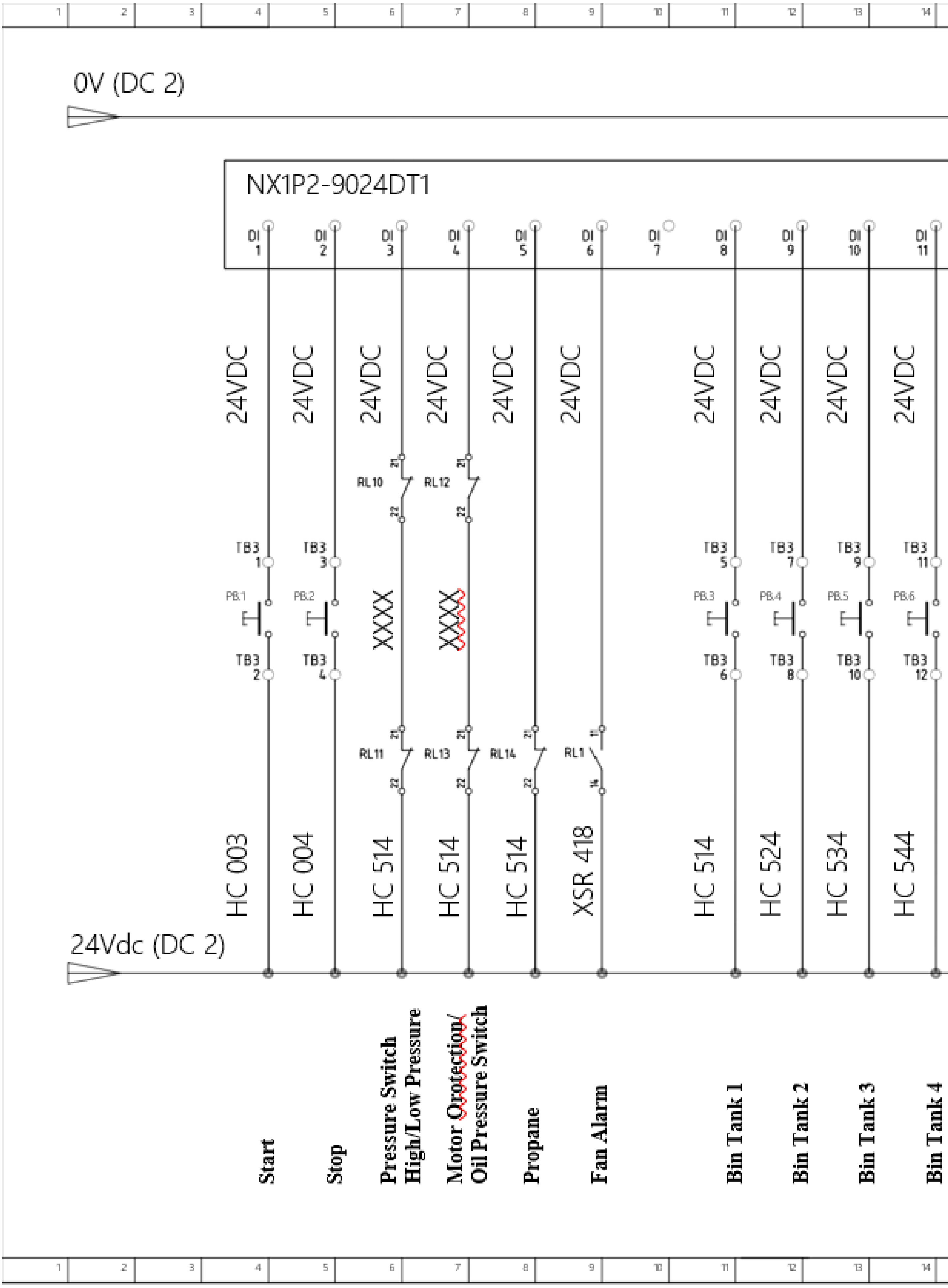


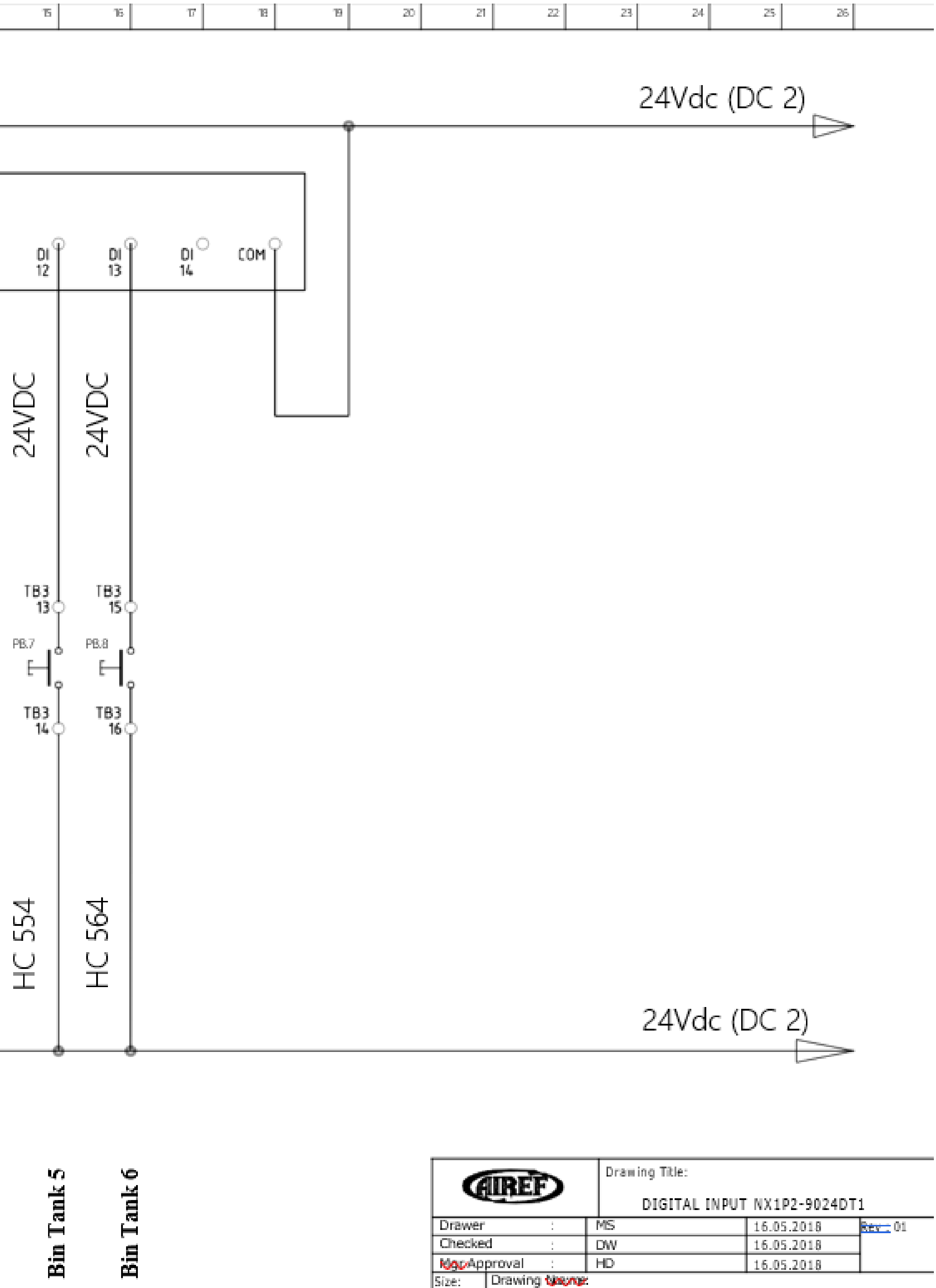
1 2 3 4 5 6 7 8 9 10 11 12 13 14
24Vdc (DC 2)
TB2 1
LP
Com
NC
NO
TB2 2
TB2 3
HP
Com
NC
NO
TB2 4
TB2 5
TB2 6
OLC
GY
BR
PK
OG
TB2 7
TB2 10
SE-B2
11
14
12
B1
B2
TB2 11
Propane
TB2 20
1
3
5
7
9
RL10
RL11
RL12
RL13
RL14
A1
A2
0Vdc (DC 2)
O C
7.6
7.6
7.7
7.7



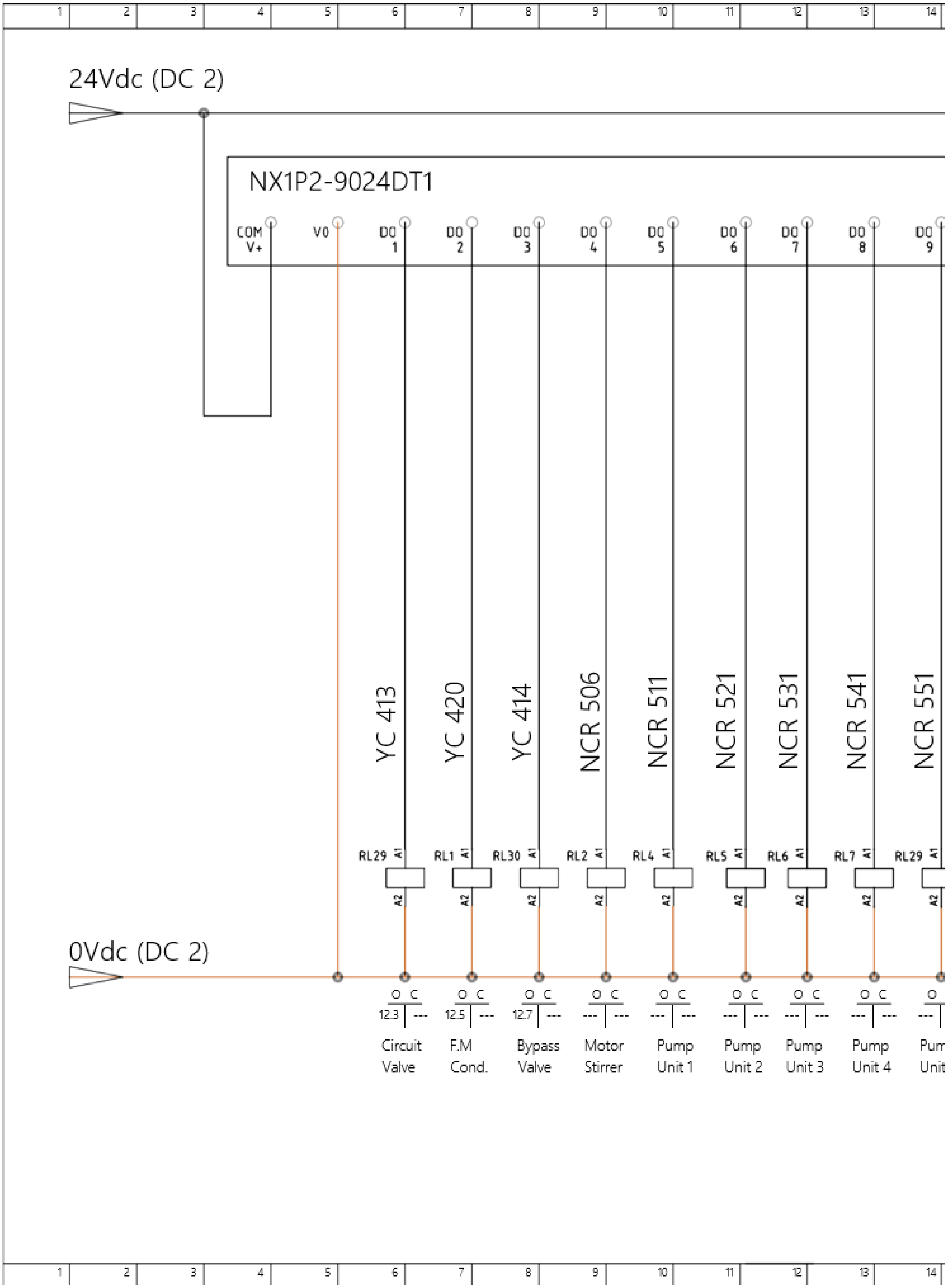
AIREF	Drawing Title: SCHMATIC DIAGRAM			
Drawer	:	MS	16.05.2018	Rev : 01
Checked	:	DW	16.05.2018	
Mgr Approval	:	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290			
Drawing No : IB-R290-WD				
Scale :	Weight :	Sheet : 06/24		

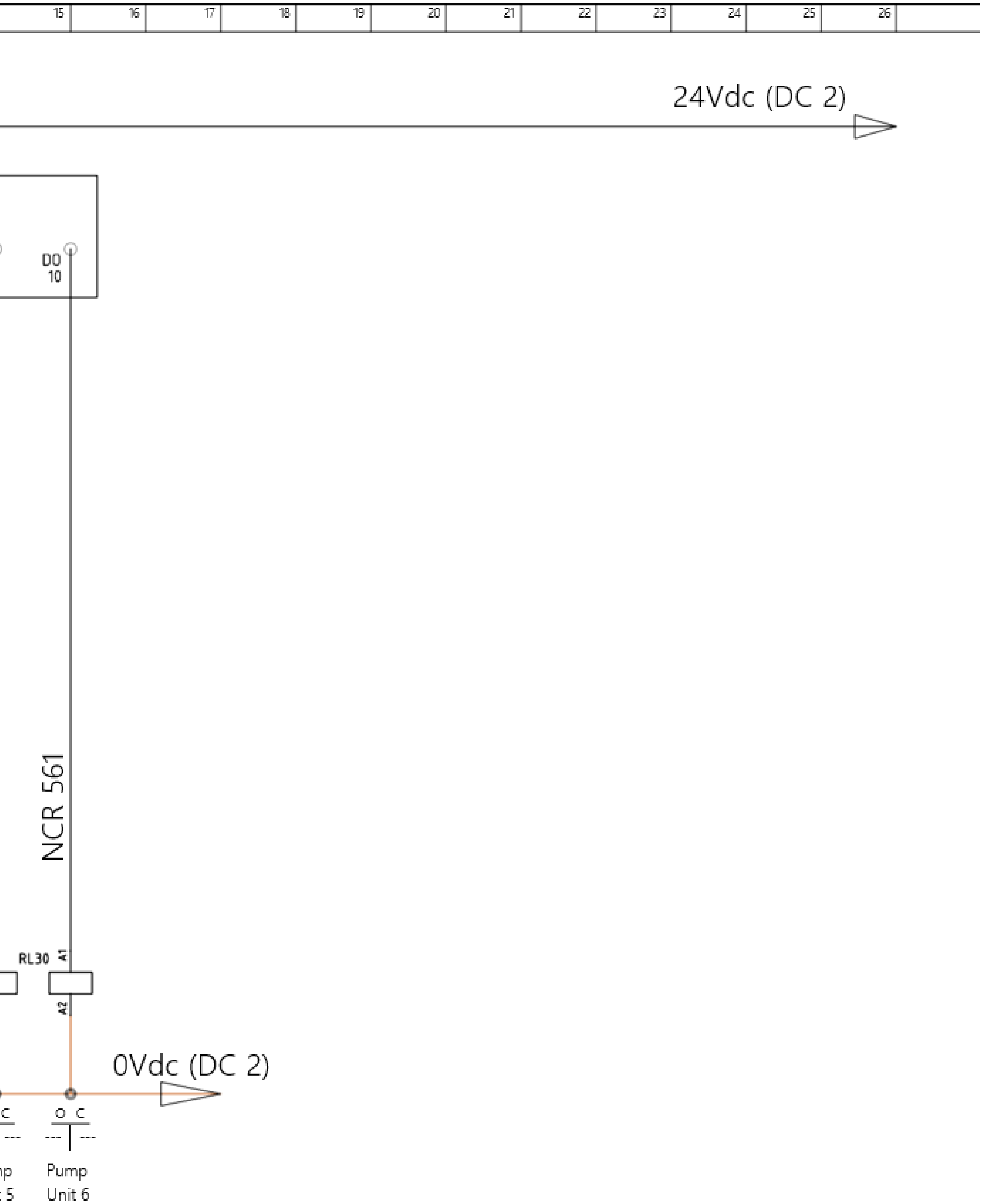
15 16 17 18 19 20 21 22 23 24 26 27


0V (DC 2)
NX1P2-9024DT1
DI 1
DI 2
DI 3
DI 4
DI 5
DI 6
DI 7
DI 8
DI 9
DI 10
DI 11
24VDC
RL10
RL12
TB3
PB.1
PB.2
PB.3
PB.4
PB.5
PB.6
XXXX
RL11
RL13
RL14
RL1
HC 003
HC 004
HC 514
XSR 418
HC 524
HC 534
HC 544
24Vdc (DC 2)
Start
Stop
Pressure Switch High/Low Pressure
Motor Orotection/ Oil Pressure Switch
Propane
Fan Alarm
Bin Tank 1
Bin Tank 2
Bin Tank 3
Bin Tank 4

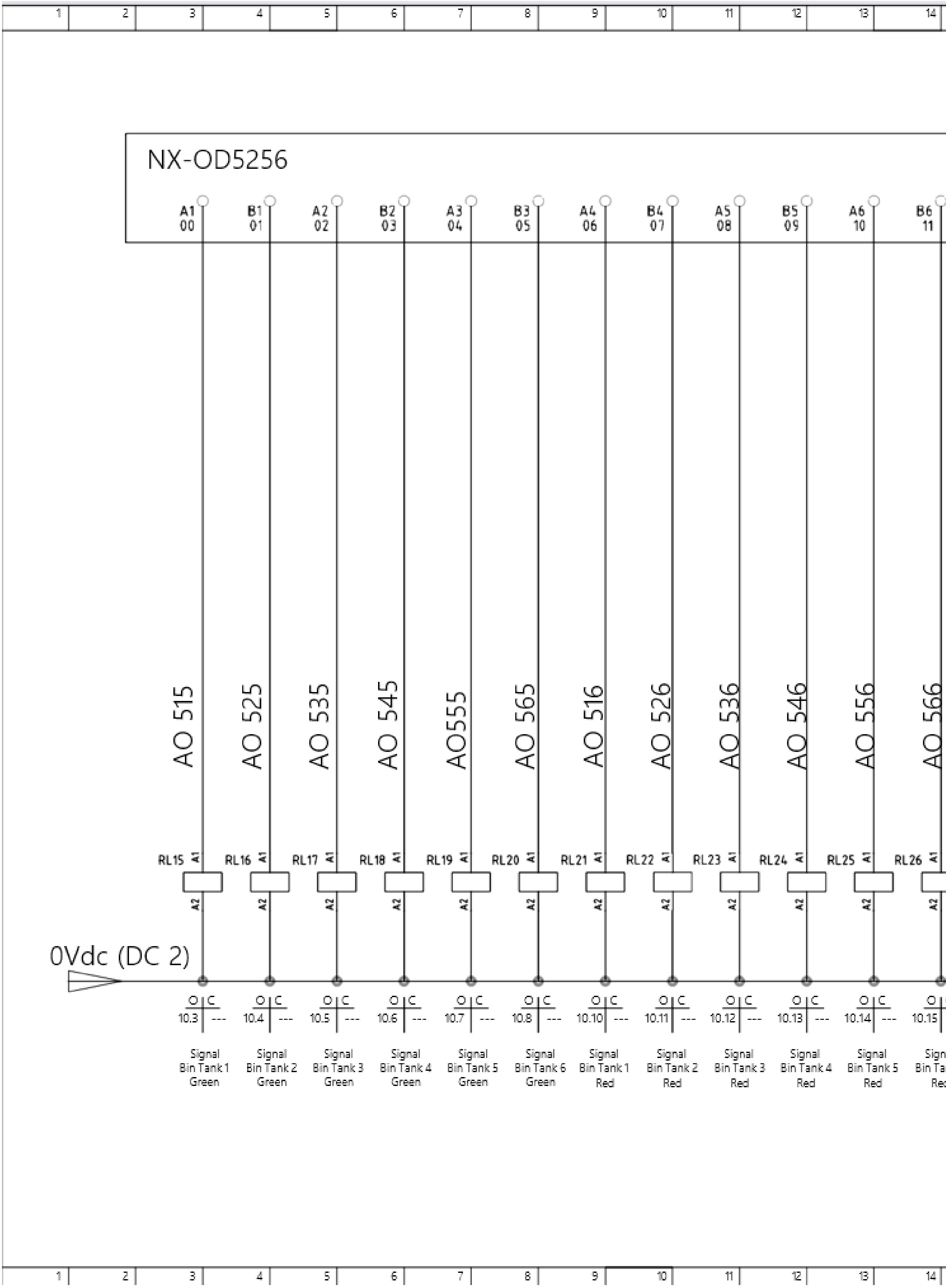


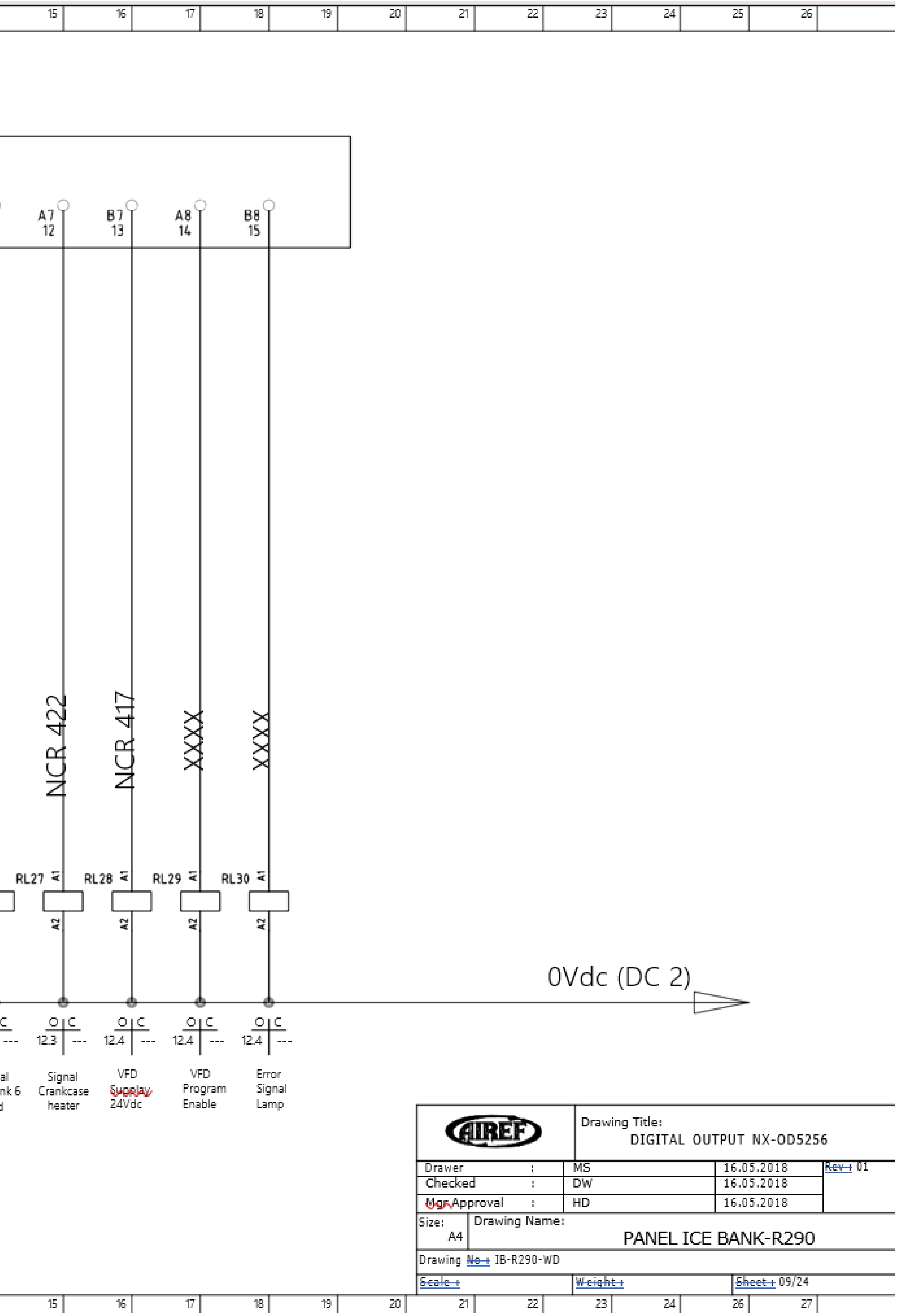
AIREF	Drawing Title: DIGITAL INPUT NX1P2-9024DT1			
Drawer :	MS	16.05.2018	Rev : 01	
Checked :	DW	16.05.2018		
Mgr.Approval :	HD	16.05.2018		
Size: A4	Drawing Name: PANEL ICE BANK-R290			
Drawing No : IB-R290-WD				
Scale :	Weight :	Sheet : 07/24		


24Vdc (DC 2)
NX1P2-9024DT1
COM V+
V0
DO 1
DO 2
DO 3
DO 4
DO 5
DO 6
DO 7
DO 8
DO 9
YC 413
YC 420
YC 414
NCR 506
NCR 511
NCR 521
NCR 531
NCR 541
NCR 551
RL29
RL1
RL30
RL2
RL4
RL5
RL6
RL7
RL29
0Vdc (DC 2)
12.3
12.5
12.7
Circuit Valve
F.M Cond.
Bypass Valve
Motor Stirrer
Pump Unit 1
Pump Unit 2
Pump Unit 3
Pump Unit 4

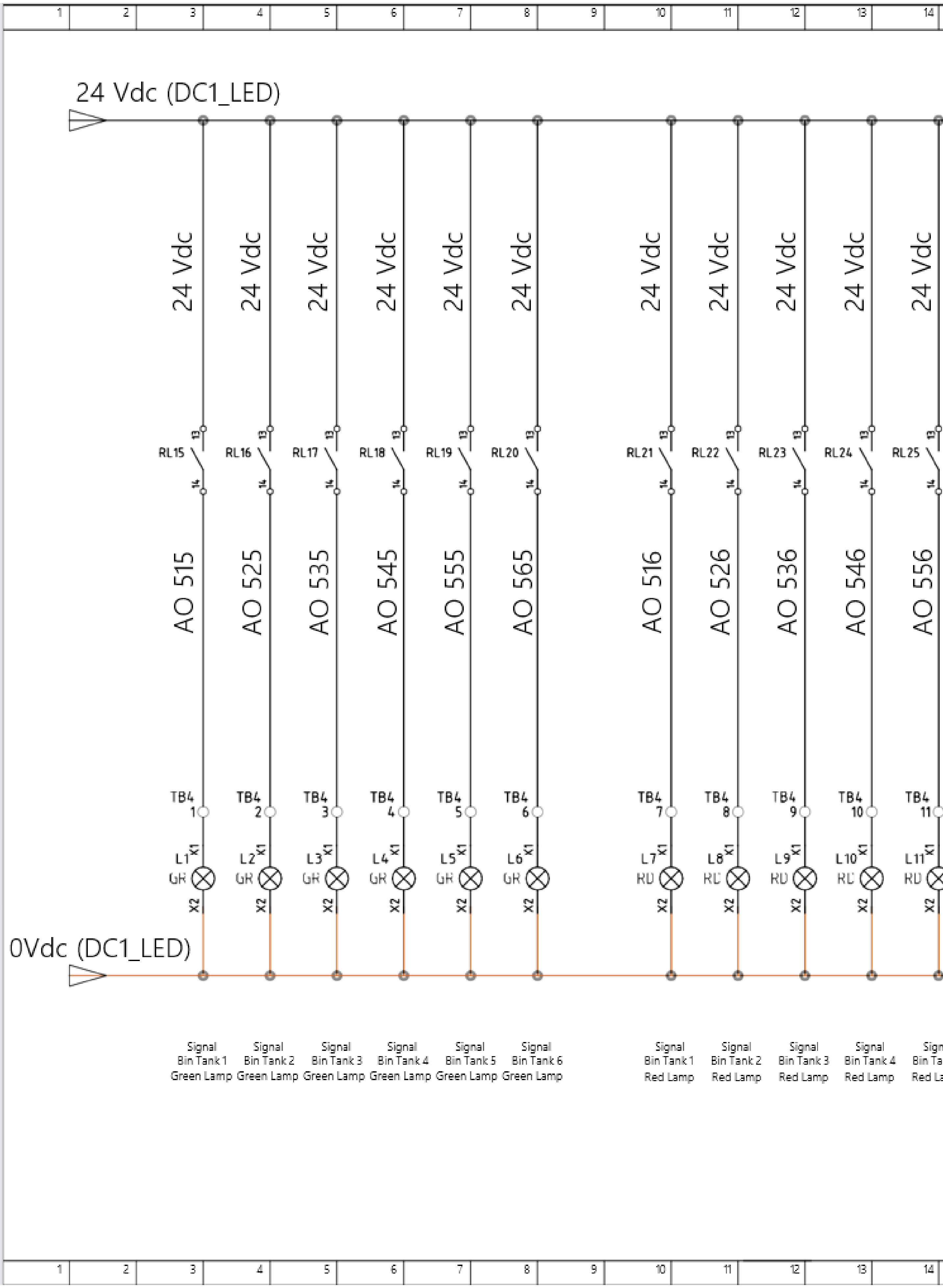


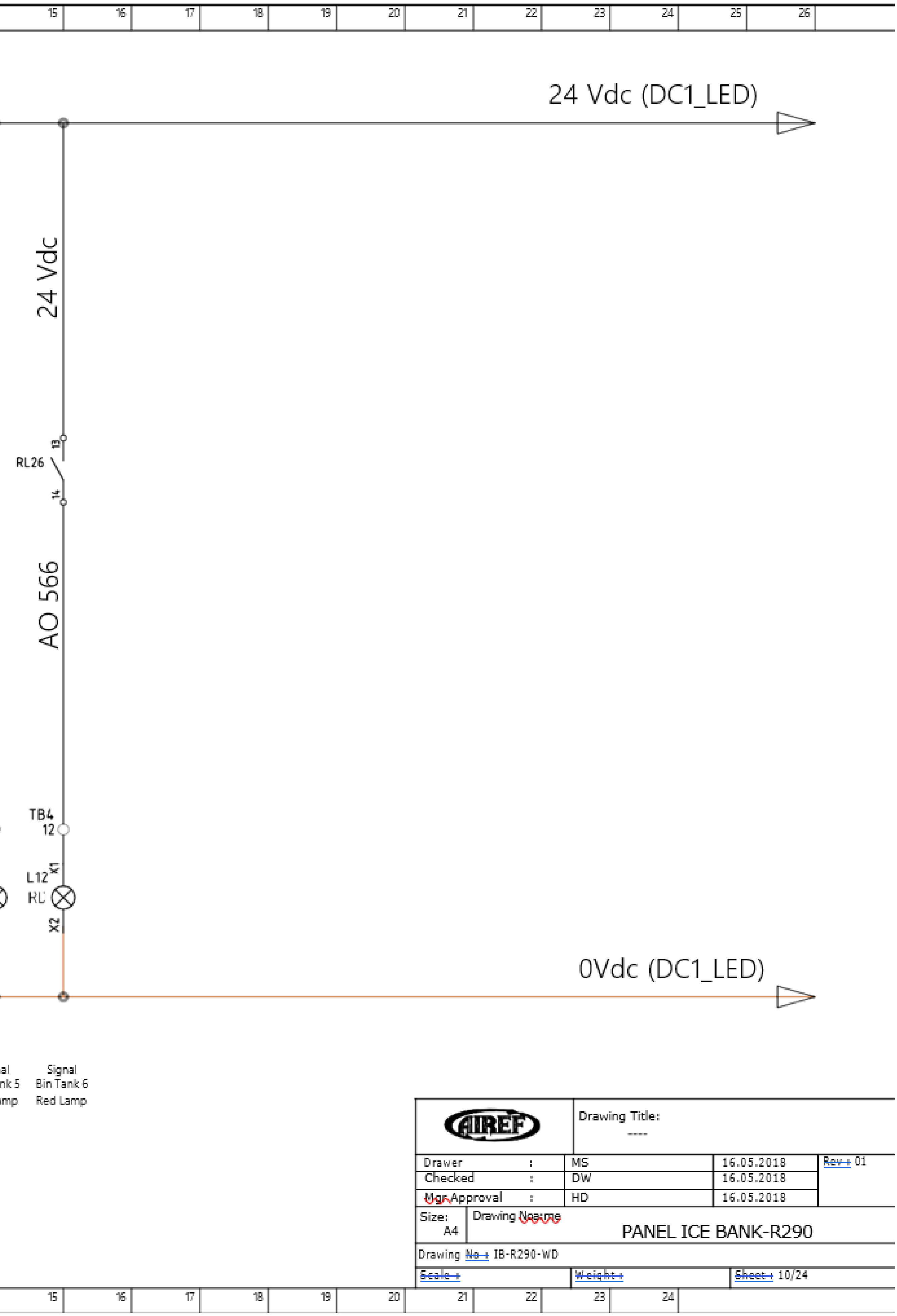
AIREF	Drawing Title: DIGITAL OUTPUT NX1P2-9024DT1			
Drawer :	MS	16.05.2018	Rev : 01	
Checked :	DW	16.05.2018		
Mgr Approval :	HD	16.05.2018		
Size: A4	Drawing Name: PANEL ICE BANK-R290			
Drawing No : IB-R290-WD				
Scale :	Weight :	Sheet : 08/24		


NX-OD5256
A1 00
B1 01
A2 02
B2 03
A3 04
B3 05
A4 06
B4 07
A5 08
B5 09
A6 10
B6 11
AO 515
AO 525
AO 535
AO 545
AO555
AO 565
AO 516
AO 526
AO 536
AO 546
AO 556
AO 566
RL15
RL16
RL17
RL18
RL19
RL20
RL21
RL22
RL23
RL24
RL25
RL26
0Vdc (DC 2)
10.3
10.4
10.5
10.6
10.7
10.8
10.10
10.11
10.12
10.13
10.14
10.15
Signal Bin Tank 1 Green
Signal Bin Tank 2 Green
Signal Bin Tank 3 Green
Signal Bin Tank 4 Green
Signal Bin Tank 5 Green
Signal Bin Tank 6 Green
Signal Bin Tank 1 Red
Signal Bin Tank 2 Red
Signal Bin Tank 3 Red
Signal Bin Tank 4 Red
Signal Bin Tank 5 Red



A7 12
B7 13
A8 14
B8 15
NCR 422
NCR 417
XXXX
XXXX
RL27
RL28
RL29
RL30
A1
A2
0Vdc (DC 2)
12.3
12.4
12.4
12.4
Signal Crankcase heater
VFD Supplay 24Vdc
VFD Program Enable
Error Signal Lamp
AIREF
Drawing Title:
DIGITAL OUTPUT NX-OD5256
Drawer : MS 16.05.2018
Checked : DW 16.05.2018
Mgr Approval : HD 16.05.2018
Rev : 01
Size: A4
Drawing Name:
PANEL ICE BANK-R290
Drawing No : IB-R290-WD
Scale :
Weight :
Sheet : 09/24


24 Vdc (DC1_LED)
0Vdc (DC1_LED)
24 Vdc
RL15
RL16
RL17
RL18
RL19
RL20
RL21
RL22
RL23
RL24
RL25
AO 515
AO 525
AO 535
AO 545
AO 555
AO 565
AO 516
AO 526
AO 536
AO 546
AO 556
TB4
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
GR
RD
Signal Bin Tank 1 Green Lamp
Signal Bin Tank 2 Green Lamp
Signal Bin Tank 3 Green Lamp
Signal Bin Tank 4 Green Lamp
Signal Bin Tank 5 Green Lamp
Signal Bin Tank 6 Green Lamp
Signal Bin Tank 1 Red Lamp
Signal Bin Tank 2 Red Lamp
Signal Bin Tank 3 Red Lamp
Signal Bin Tank 4 Red Lamp



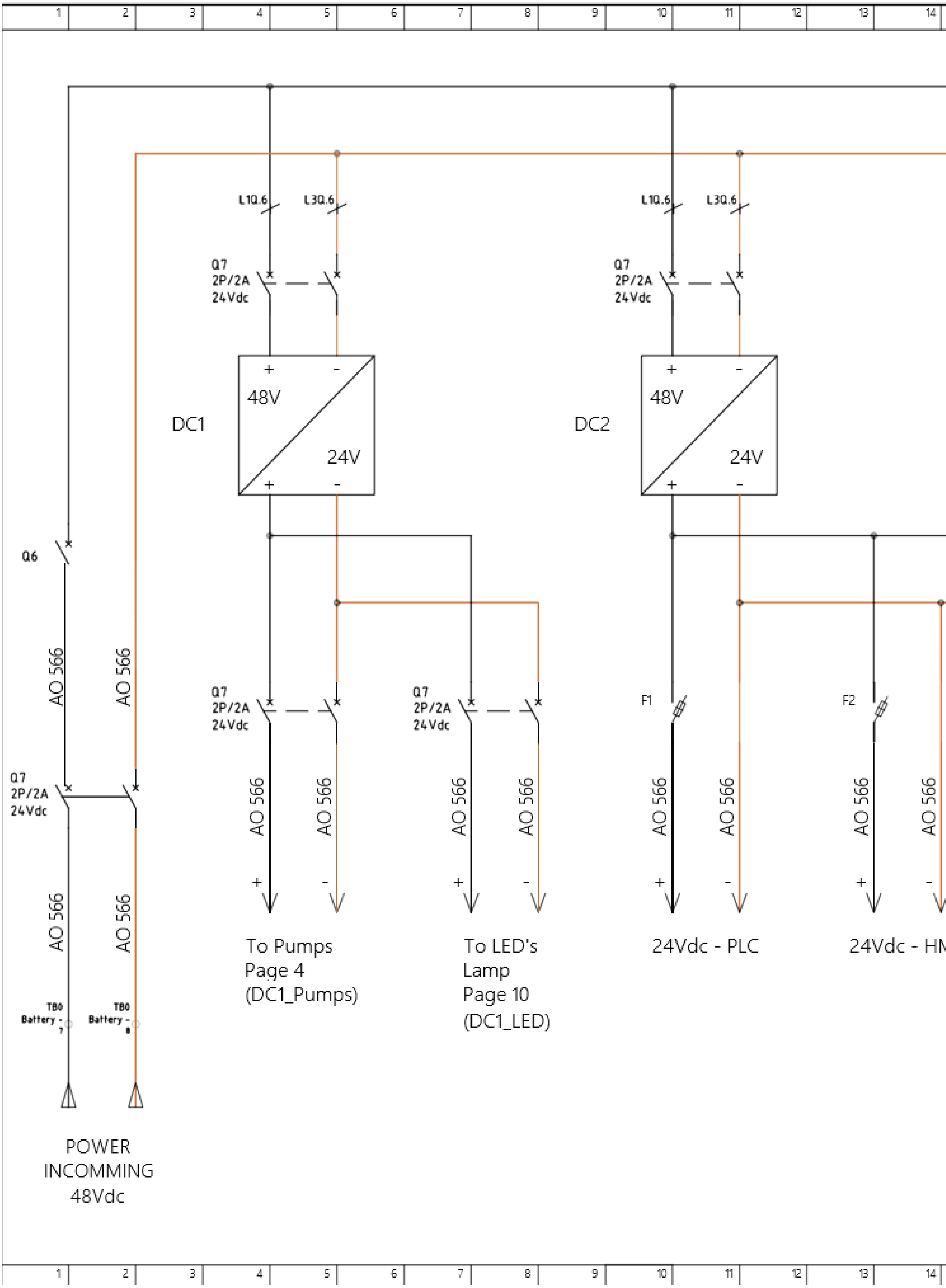
AIREF	Drawing Title: ----

Drawer	:	MS	16.05.2018	Rev : 01
Checked	:	DW	16.05.2018	
Mgr.Approval	:	HD	16.05.2018	

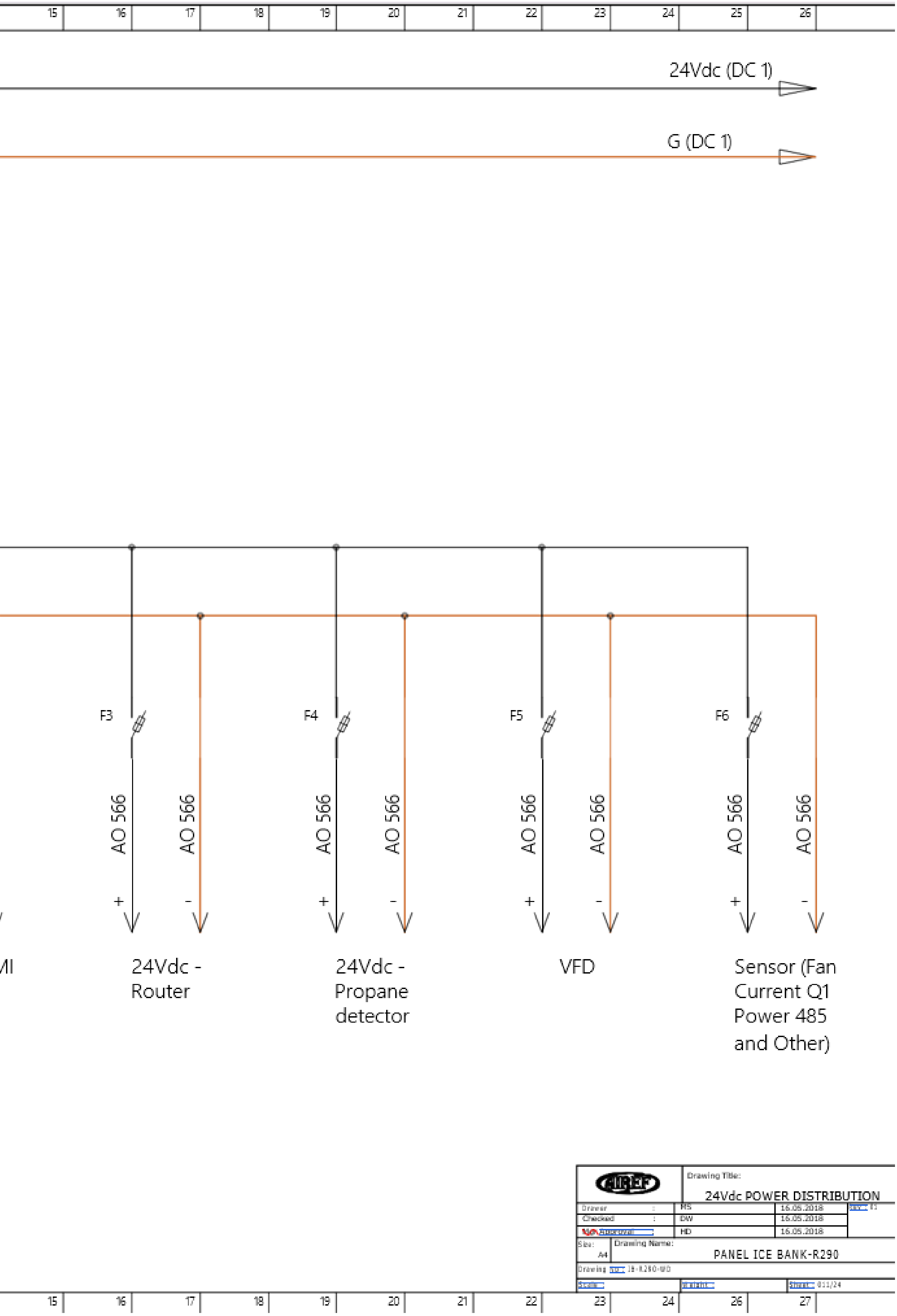
Size: A4 | Drawing Name: PANEL ICE BANK-R290

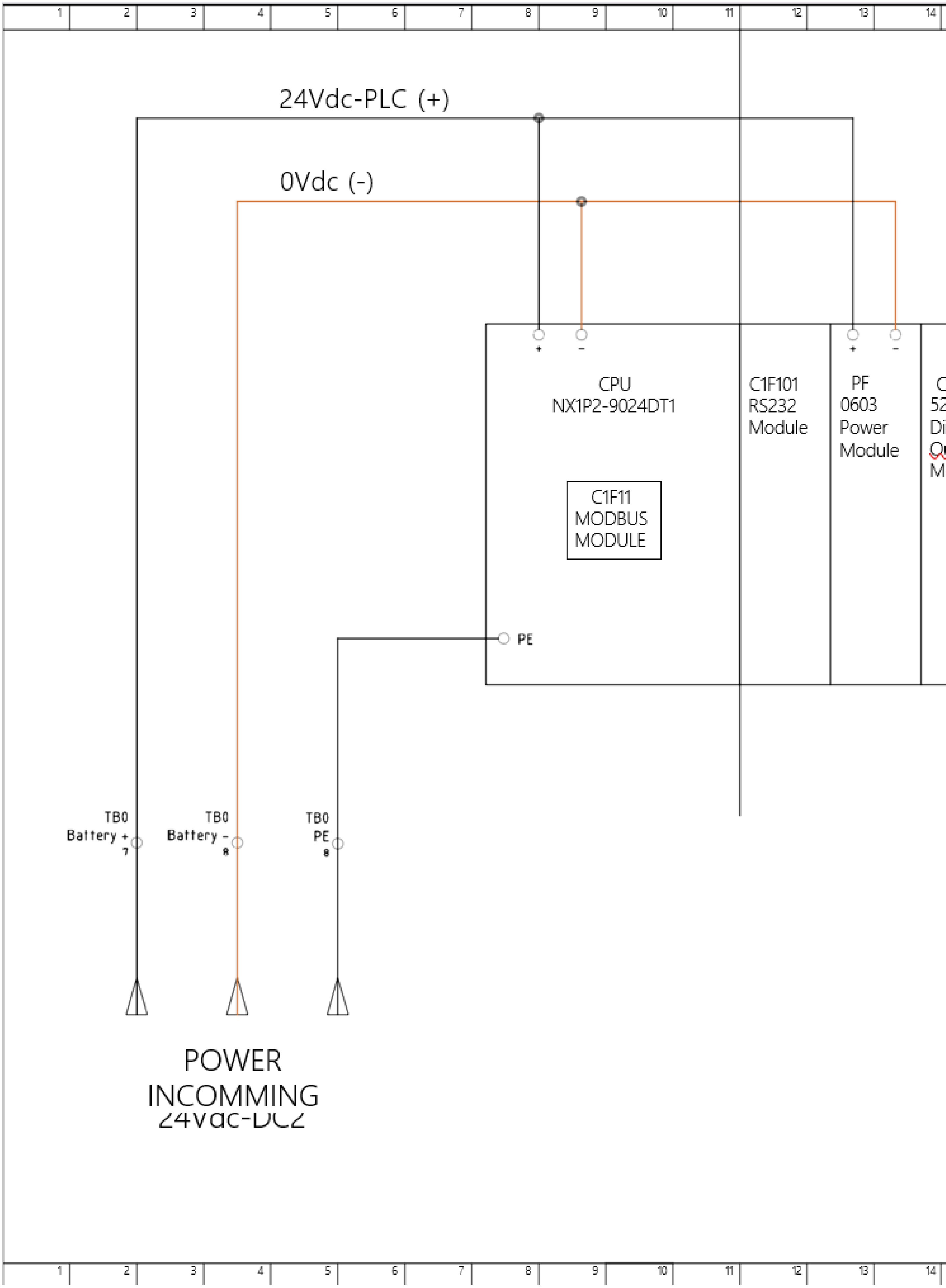
Drawing No : IB-R290-WD

Scale : | Weight : | Sheet : 10/24



DC1
DC2
48V
24V
Q6
Q7
2P/2A
24Vdc
L1Q.6
L3Q.6
F1
F2
AO 566
TB0
Battery
To Pumps
Page 4
(DC1_Pumps)
To LED's
Lamp
Page 10
(DC1_LED)
24Vdc - PLC
POWER
INCOMMING
48Vdc


15 16 17 18 19 20 21 22 23 24 25 26
24Vdc (DC 1)
G (DC 1)
F3
F4
F5
F6
AO 566
+
-
24Vdc - Router
24Vdc - Propane detector
VFD
Sensor (Fan Current Q1 Power 485 and Other)
Drawing Title:
24Vdc POWER DISTRIBUTION
MS 16.05.2018
Checked DW 16.05.2018
HD 16.05.2018
Drawing Name:
PANEL ICE BANK-R290
A4
15 16 17 18 19 20 21 22 23 24 26 27

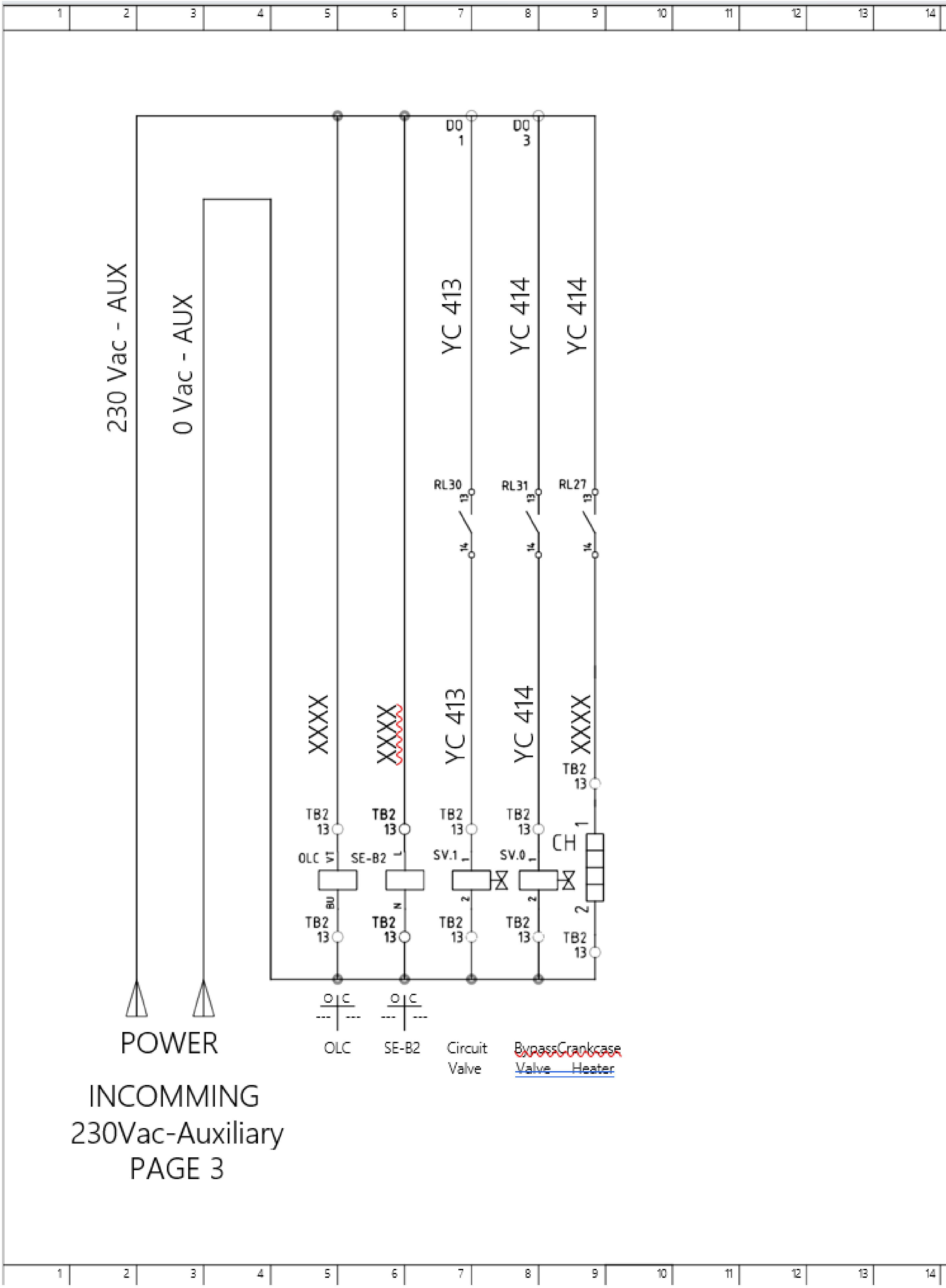

24Vdc-PLC (+)
0Vdc (-)
CPU
NX1P2-9024DT1
C1F11
MODBUS
MODULE
PE
C1F101
RS232
Module
PF
0603
Power
Module
TB0
Battery +
7
TB0
Battery -
8
TB0
PE
8
POWER
INCOMMING
24Vdc-DC2

15 16 17 18 19 20 21 22 23 24 25 26

D 256 gital utput odule	TS 3201 Temp. Sensor Module	AD 3604 Analog Input 0-10V Module	AD 3204 Analog Input 4-20V Module	DA 2603 Analog Output Module

AIREF	Drawing Title: 24Vdc POWER DISTRIBUTION		
Drawer :	MS	16.05.2018	Rev : 01
Checked :	DW	16.05.2018	
Mgr Approval :	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290		
Drawing No : IB-R290-WD			
Scale :	Weight :	Sheet : 12/24	

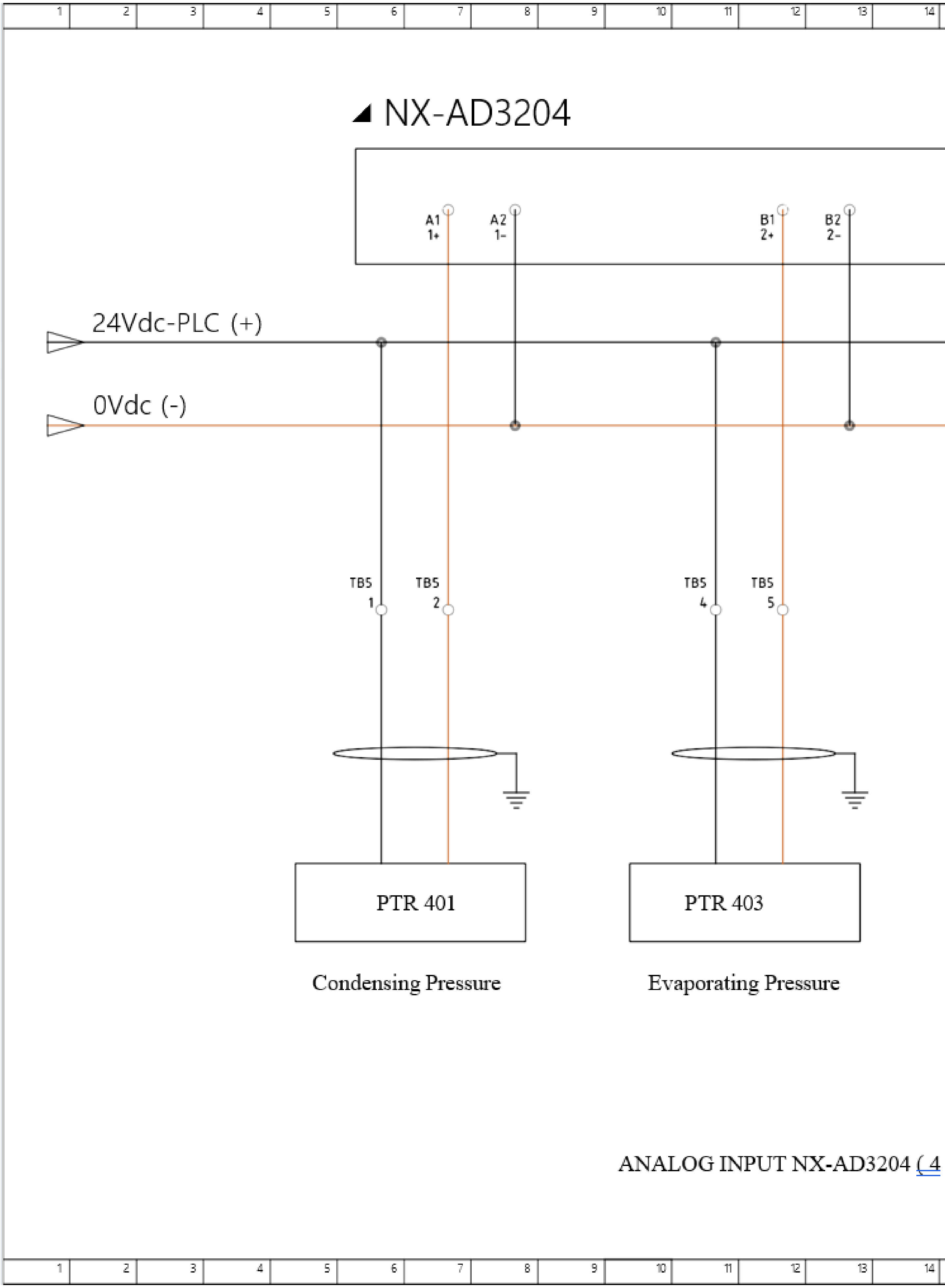
15 16 17 18 19 20 21 22 23 24 26 27

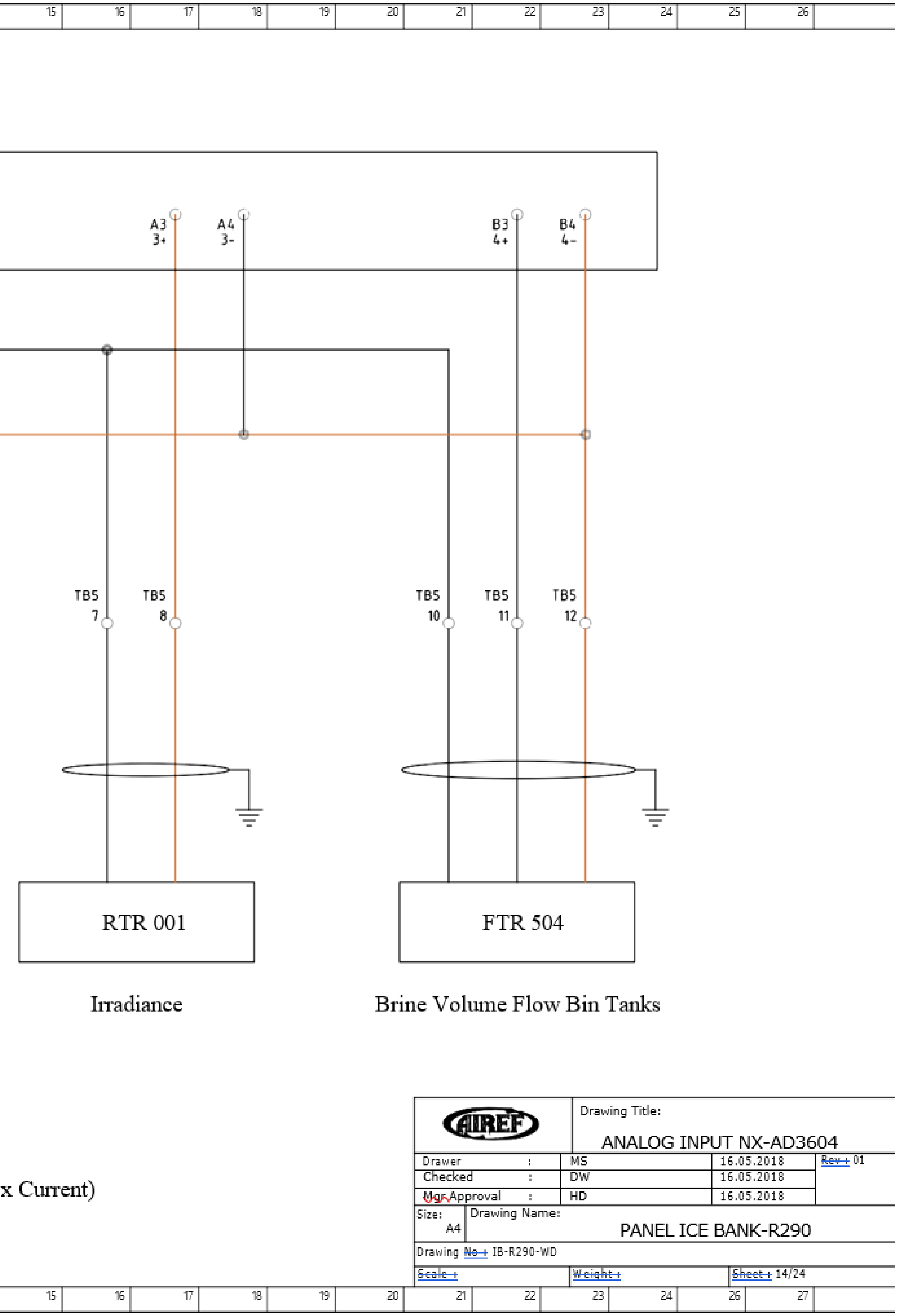

1 2 3 4 5 6 7 8 9 10 11 12 13 14
230 Vac - AUX
0 Vac - AUX
DO 1
DO 3
YC 413
YC 414
YC 414
RL30
RL31
RL27
13
14
XXXX
XXXX
YC 413
YC 414
XXXX
TB2 13
OLC
SE-B2
SV.1
SV.0
CH
BU
N
1
2
O C
POWER
OLC
SE-B2
Circuit Valve
Bypass Valve
Crankcase Heater
INCOMMING
230Vac-Auxiliary
PAGE 3

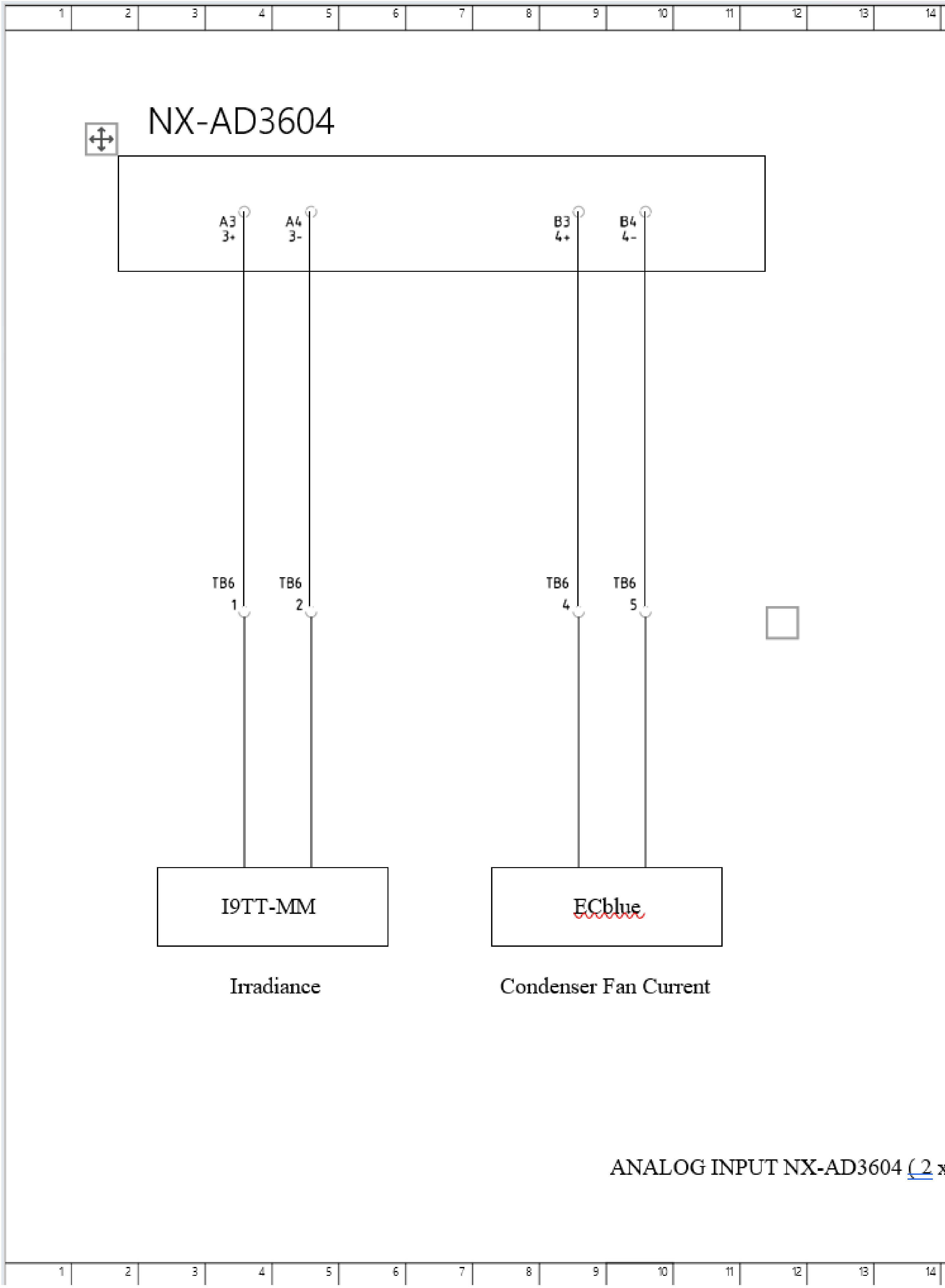
15	16	17	18	19	20	21	22	23	24	25	26

AIREF	Drawing Title: ----		
Drawer :	MS	16.05.2018	Rev : 01
Checked :	DW	16.05.2018	
Mgr Approval :	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290		
Drawing No : IB-R290-WD			
Scale :	Weight :	Sheet :13/24	

15	16	17	18	19	20	21	22	23	24	26	27


NX-AD3204
A1 1+
A2 1-
B1 2+
B2 2-
24Vdc-PLC (+)
0Vdc (-)
TB5 1
TB5 2
TB5 4
TB5 5
PTR 401
PTR 403
Condensing Pressure
Evaporating Pressure
ANALOG INPUT NX-AD3204 (4


15 16 17 18 19 20 21 22 23 24 25 26
A3 3+
A4 3-
B3 4+
B4 4-
TB5 7
TB5 8
TB5 10
TB5 11
TB5 12
RTR 001
FTR 504
Irradiance
Brine Volume Flow Bin Tanks
x Current)
Drawing Title:
ANALOG INPUT NX-AD3604
Drawer : MS 16.05.2018
Checked : DW 16.05.2018
Mgr.Approval : HD 16.05.2018
Rev : 01
Size: A4
Drawing Name:
PANEL ICE BANK-R290
Drawing No : IB-R290-WD
Scale :
Weight :
Sheet : 14/24
15 16 17 18 19 20 21 22 23 24 26 27

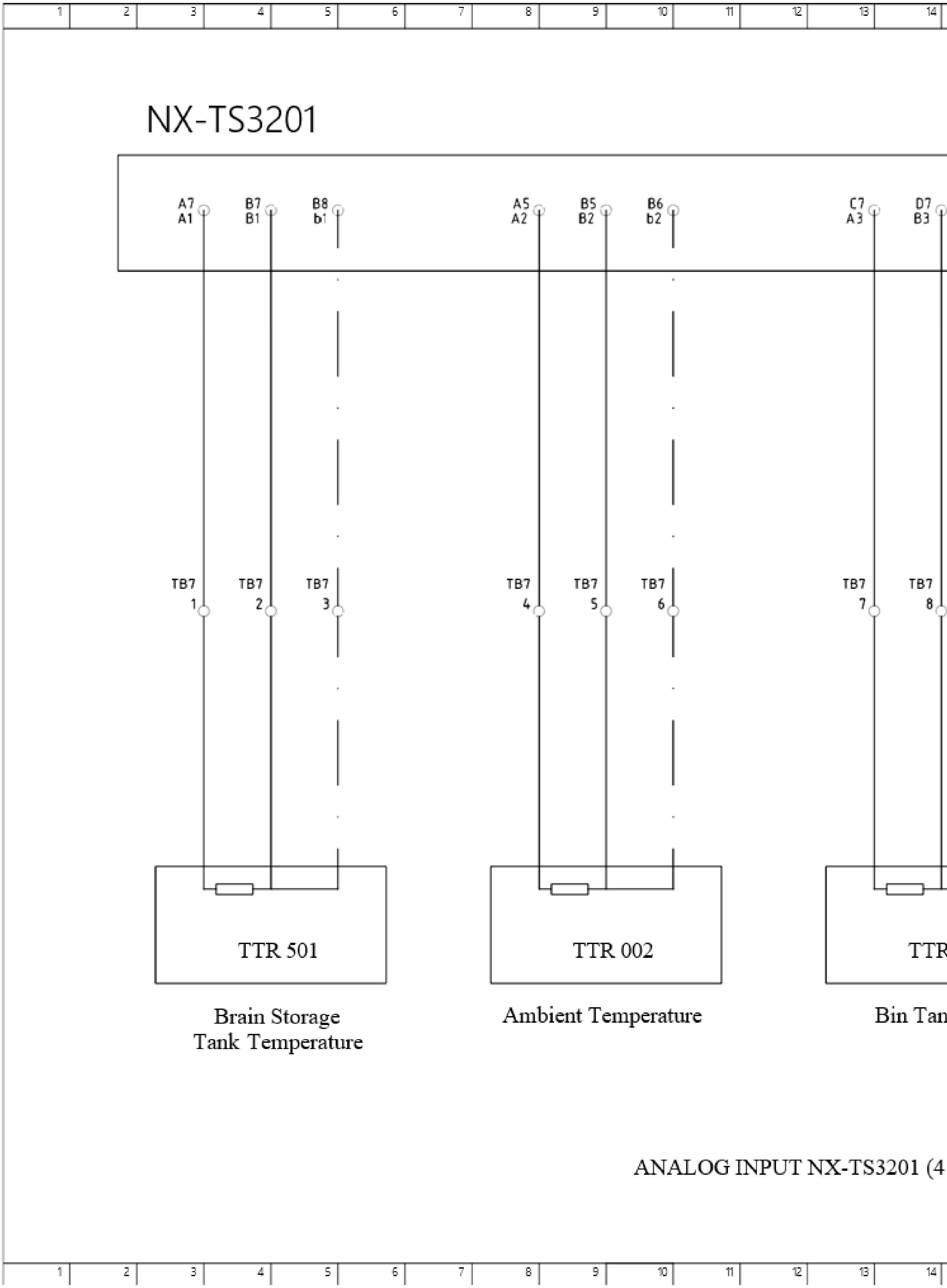

1
2
3
4
5
6
7
8
9
10
11
12
13
14
NX-AD3604
A3
3+
A4
3-
B3
4+
B4
4-
TB6
1
TB6
2
TB6
4
TB6
5
I9TT-MM
ECblue
Irradiance
Condenser Fan Current
ANALOG INPUT NX-AD3604 (2 x

15 16 17 18 19 20 21 22 23 24 25 26

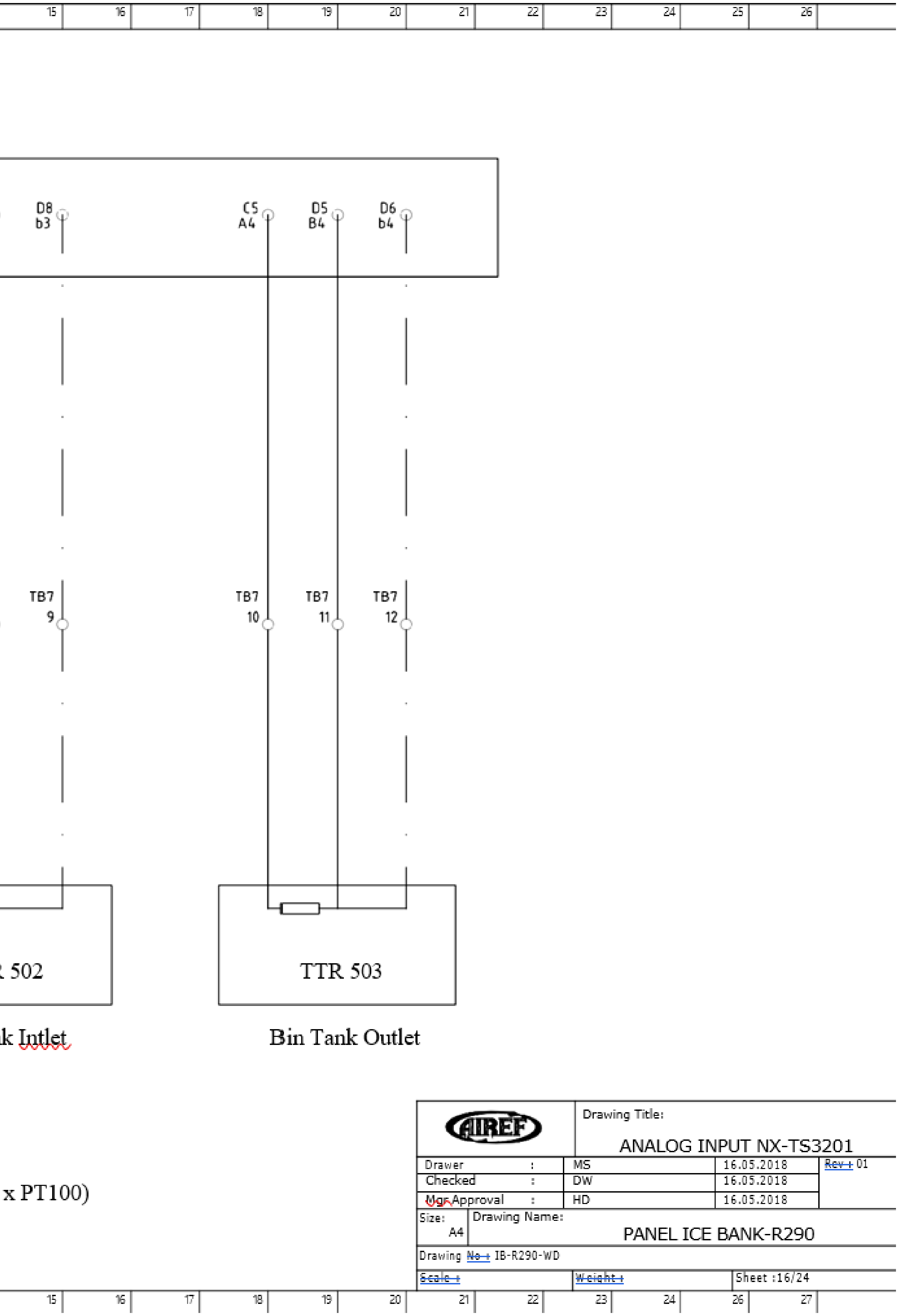
k Voltage)

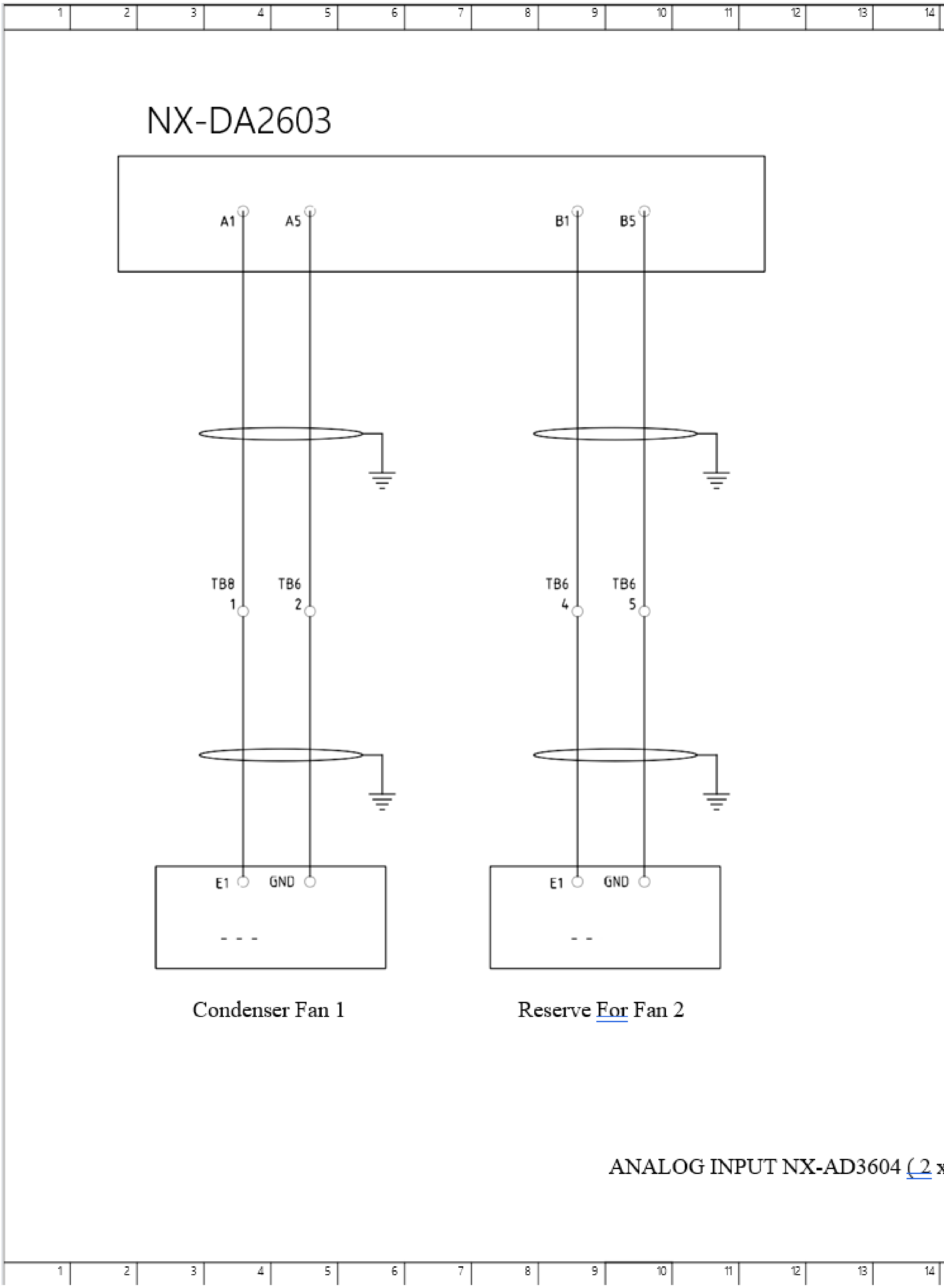
Drawing Title:			
ANALOG INPUT NX-AD3604			
Drawer :	MS	16.05.2018	~~Rev :~~ 01
Checked :	DW	16.05.2018	
Mgr Approval :	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290		
Drawing ~~No :~~ IB-R290-WD			
~~Scale :~~	~~Weight :~~	~~Sheet :~~ 15/24	

15 16 17 18 19 20 21 22 23 24 26 27



ANALOG INPUT NX-TS3201 (4


15 16 17 18 19 20 21 22 23 24 25 26
D8 b3
C5 A4
D5 B4
D6 b4
TB7 9
TB7 10
TB7 11
TB7 12
R 502
TTR 503
k Intlet
Bin Tank Outlet
x PT100)
Drawing Title:
ANALOG INPUT NX-TS3201
Drawer : MS 16.05.2018
Checked : DW 16.05.2018
Mgr Approval : HD 16.05.2018
Rev : 01
Size: A4
Drawing Name:
PANEL ICE BANK-R290
Drawing No : IB-R290-WD
Scale :
Weight :
Sheet :16/24
15 16 17 18 19 20 21 22 23 24 26 27

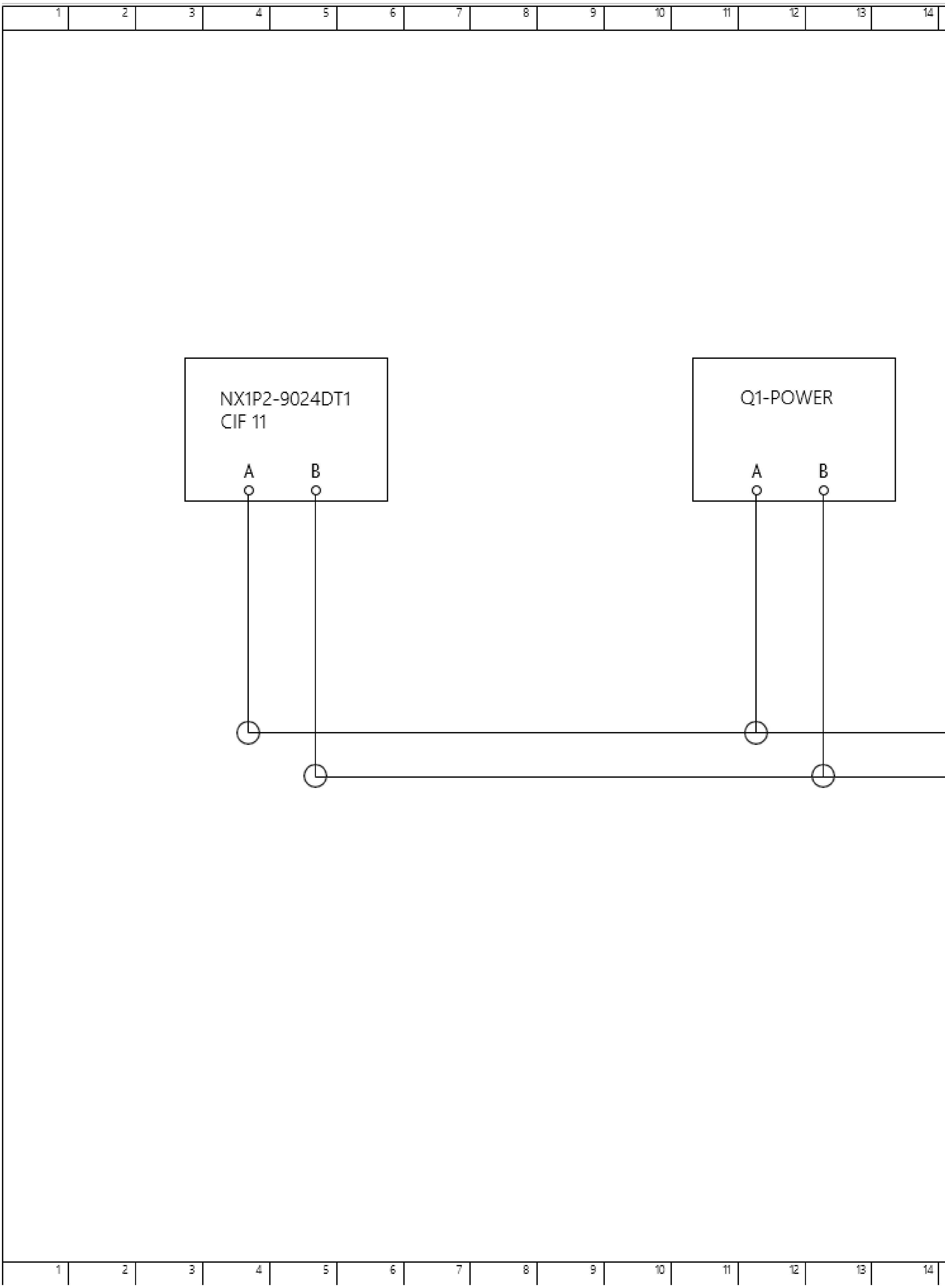

1 2 3 4 5 6 7 8 9 10 11 12 13 14
NX-DA2603
A1
A5
B1
B5
TB8 1
TB6 2
TB6 4
TB6 5
E1
GND
- - -
E1
GND
- -
Condenser Fan 1
Reserve For Fan 2
ANALOG INPUT NX-AD3604 (2 x

15 16 17 18 19 20 21 22 23 24 25 26

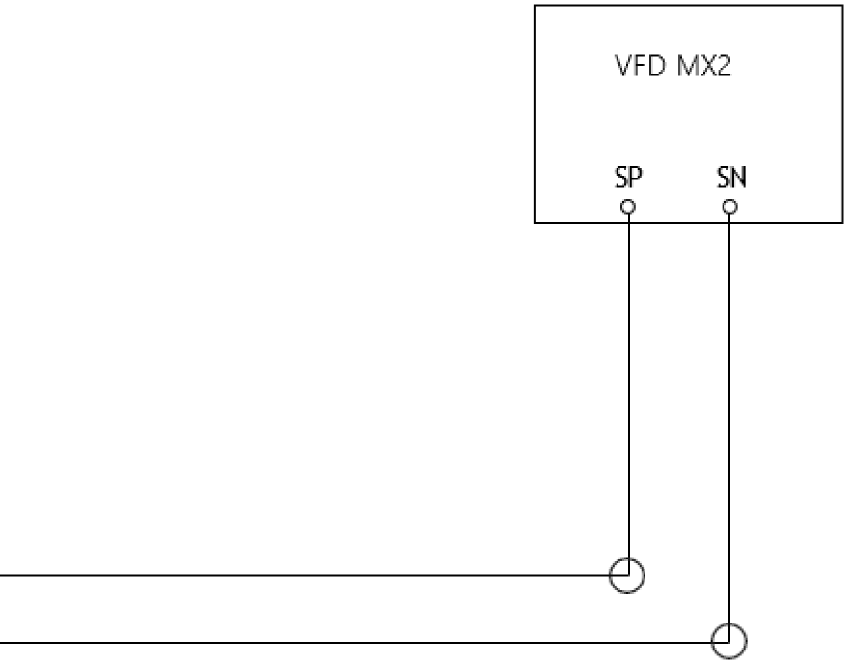
Voltage)

AIREF	Drawing Title: ANALOG OUTPUT NX-DA2603		
Drawer :	MS	16.05.2018	Rev : 01
Checked :	DW	16.05.2018	
Mgr Approval :	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290		
Drawing No : IB-R290-WD			
Scale :	Weight :	Sheet : 17/24	

15 16 17 18 19 20 21 22 23 24 26 27

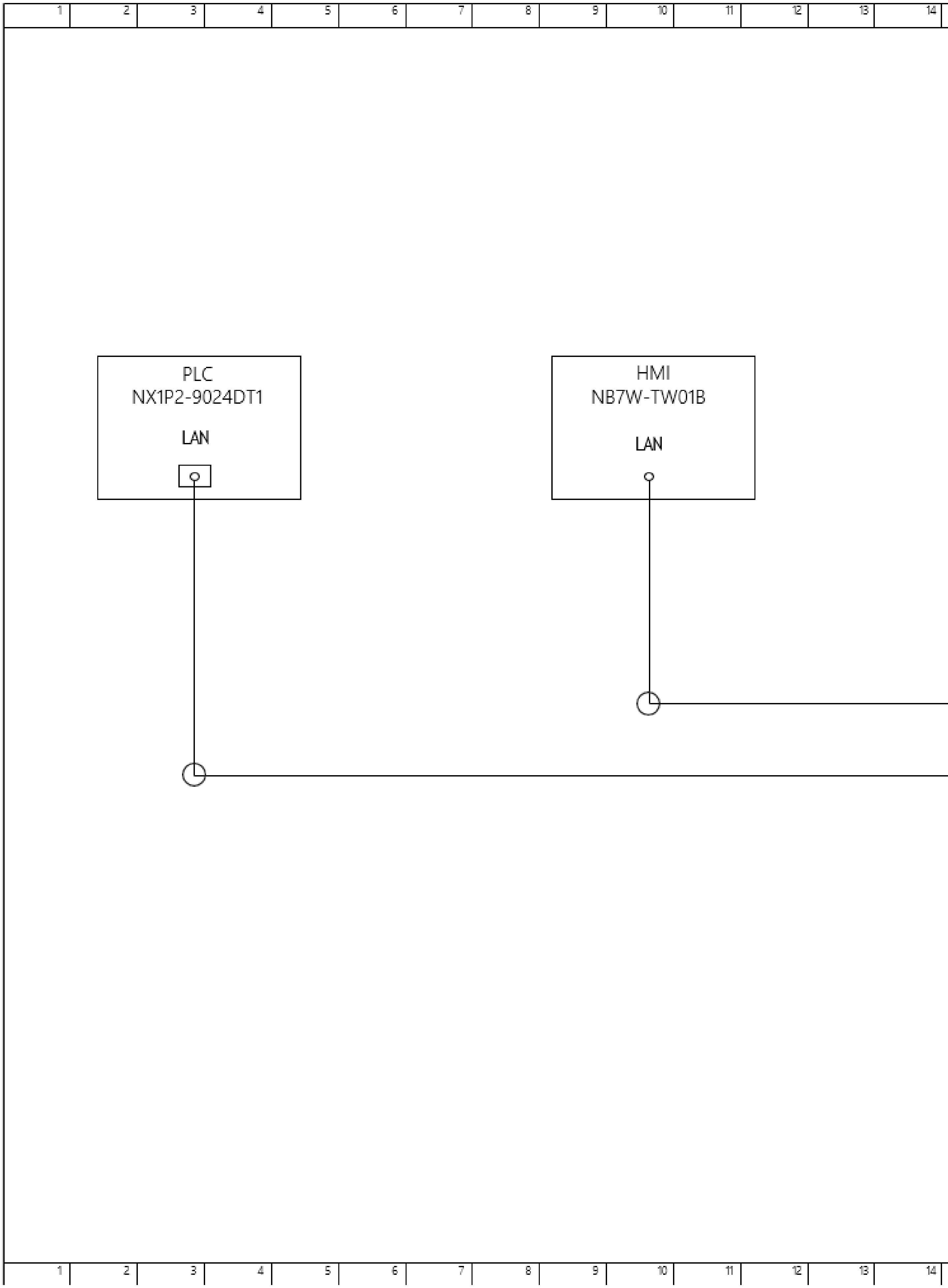

1 2 3 4 5 6 7 8 9 10 11 12 13 14
NX1P2-9024DT1
CIF 11
A
B
Q1-POWER
A
B
1 2 3 4 5 6 7 8 9 10 11 12 13 14

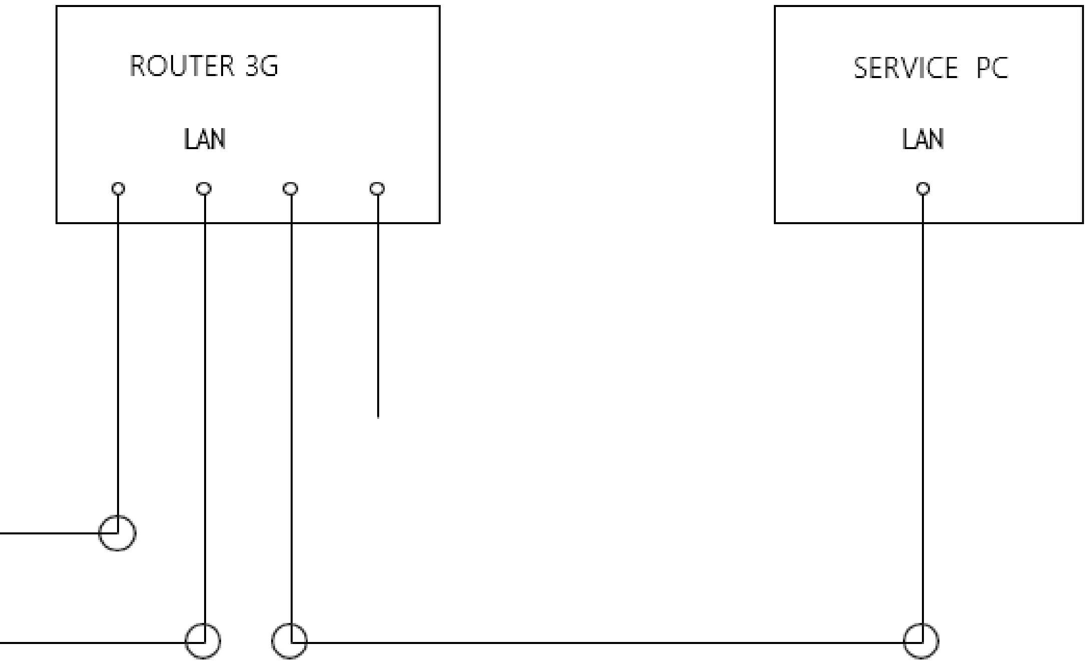
15 16 17 18 19 20 21 22 23 24 25 26



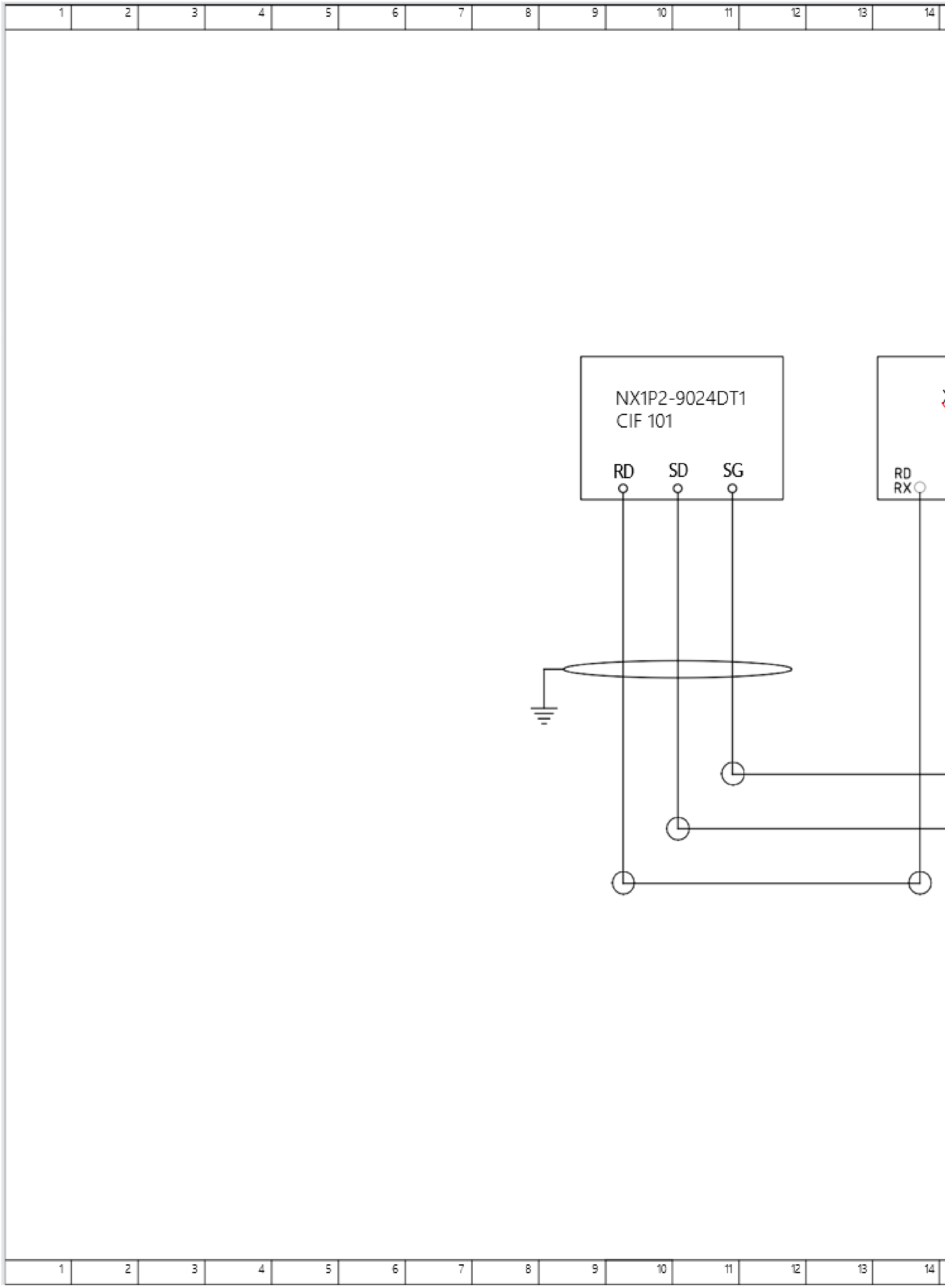
AIREF	Drawing Title: COMMUNICATION RS485		
Drawer :	MS	16.05.2018	Rev : 01
Checked :	DW	16.05.2018	
Mgr Approval :	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290		
Drawing No : IB-R290-WD			
Scale :	Weight :	Sheet : 18/24	

15 16 17 18 19 20 21 22 23 24 26 27

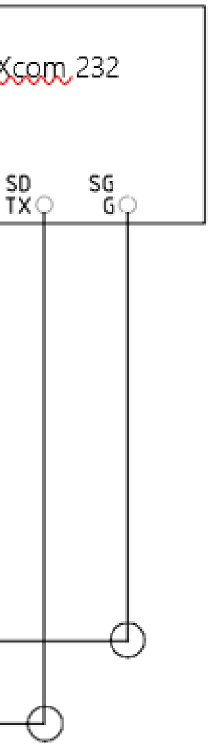

1 2 3 4 5 6 7 8 9 10 11 12 13 14
PLC
NX1P2-9024DT1
LAN
HMI
NB7W-TW01B
LAN



AIREF	Drawing Title: COMMUNICATION LAN			
Drawer :	MS	16.05.2018	Rev : 01	
Checked :	DW	16.05.2018		
Mgr Approval :	HD	16.05.2018		
Size: A4	Drawing Name: PANEL ICE BANK-R290			
Drawing No : IB-R290-WD				
Scale :	Weight :	Sheet : 19/24		

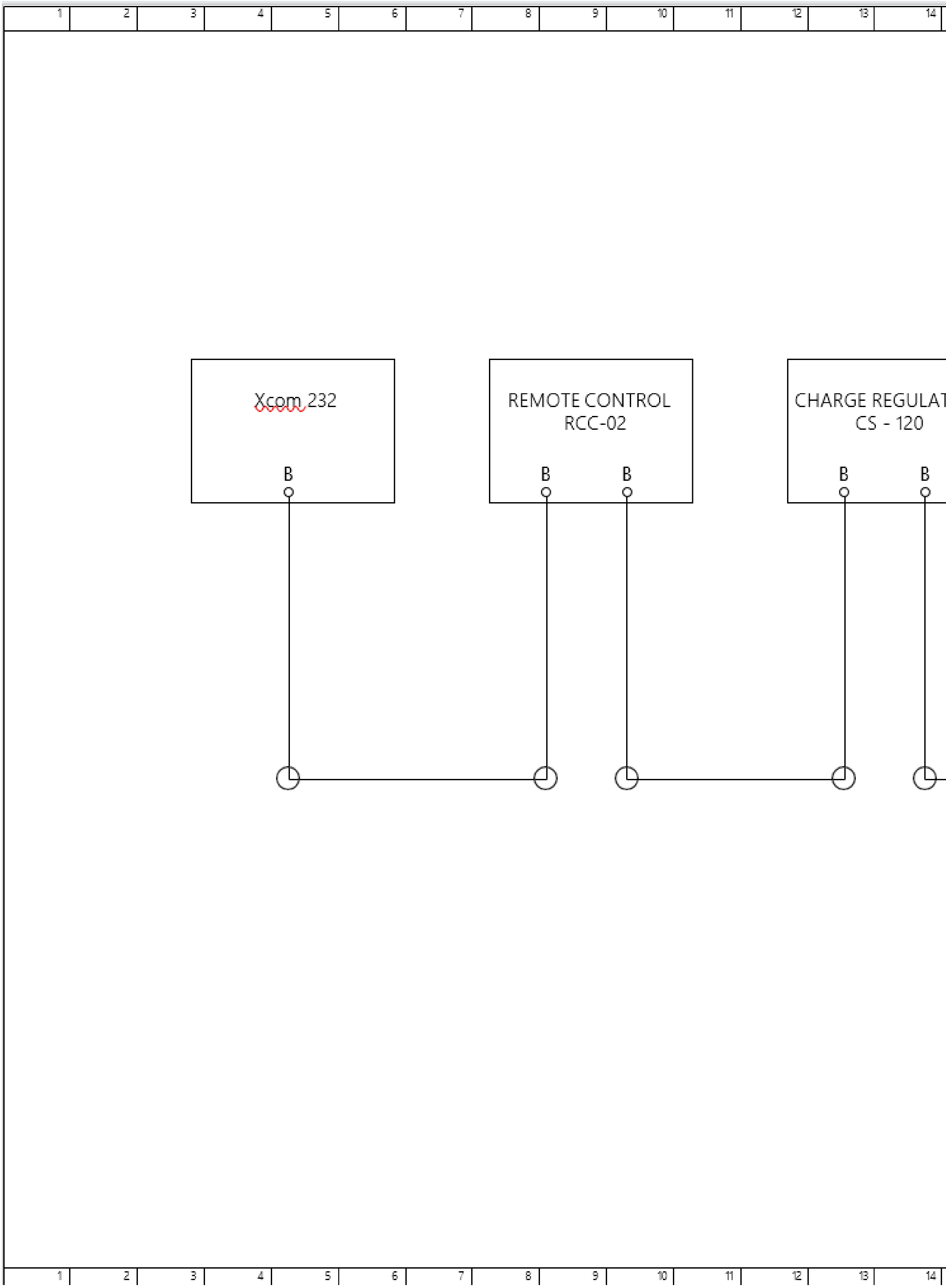

1
2
3
4
5
6
7
8
9
10
11
12
13
14
NX1P2-9024DT1
CIF 101
RD
SD
SG
RD
RX

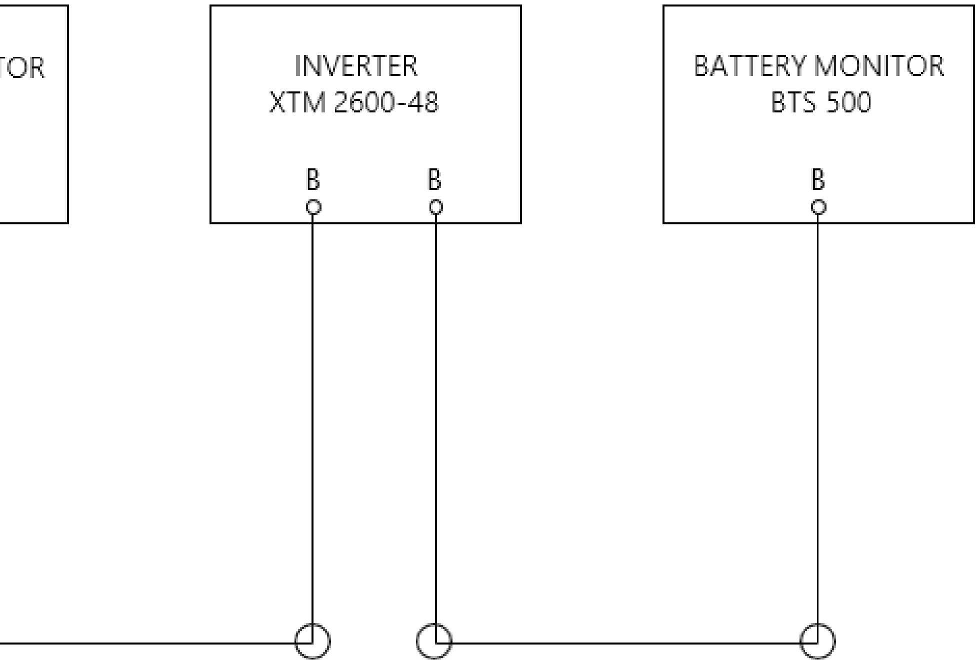
15 16 17 18 19 20 21 22 23 24 25 26



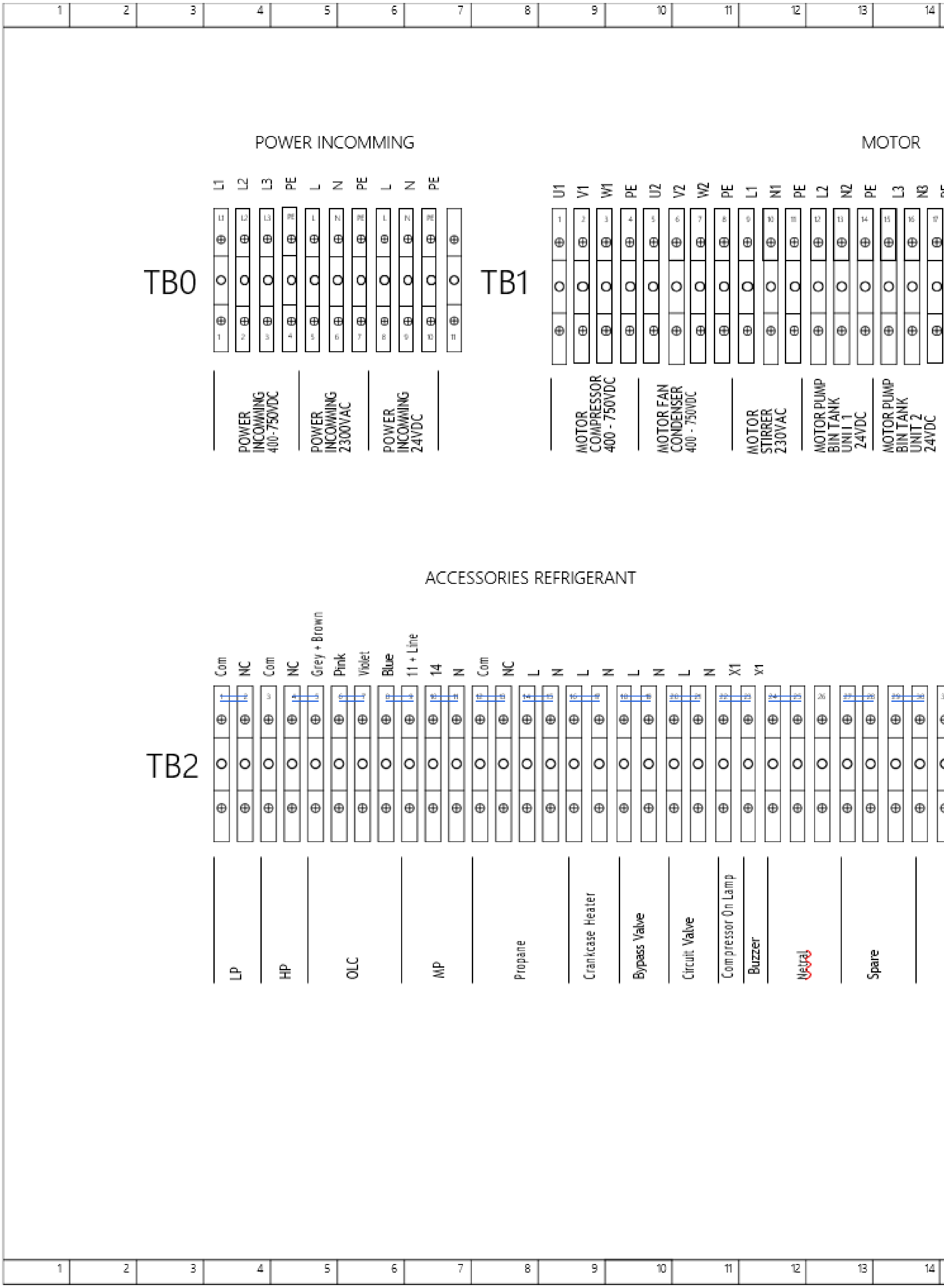
AIREF	Drawing Title: COMMUNICATION RS232			
Drawer	:	MS	16.05.2018	Rev : 01
Checked	:	DW	16.05.2018	
Mgr Approval	:	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290			
Drawing No : IB-R290-WD				
Scale :	Weight :	Sheet : 20/24		

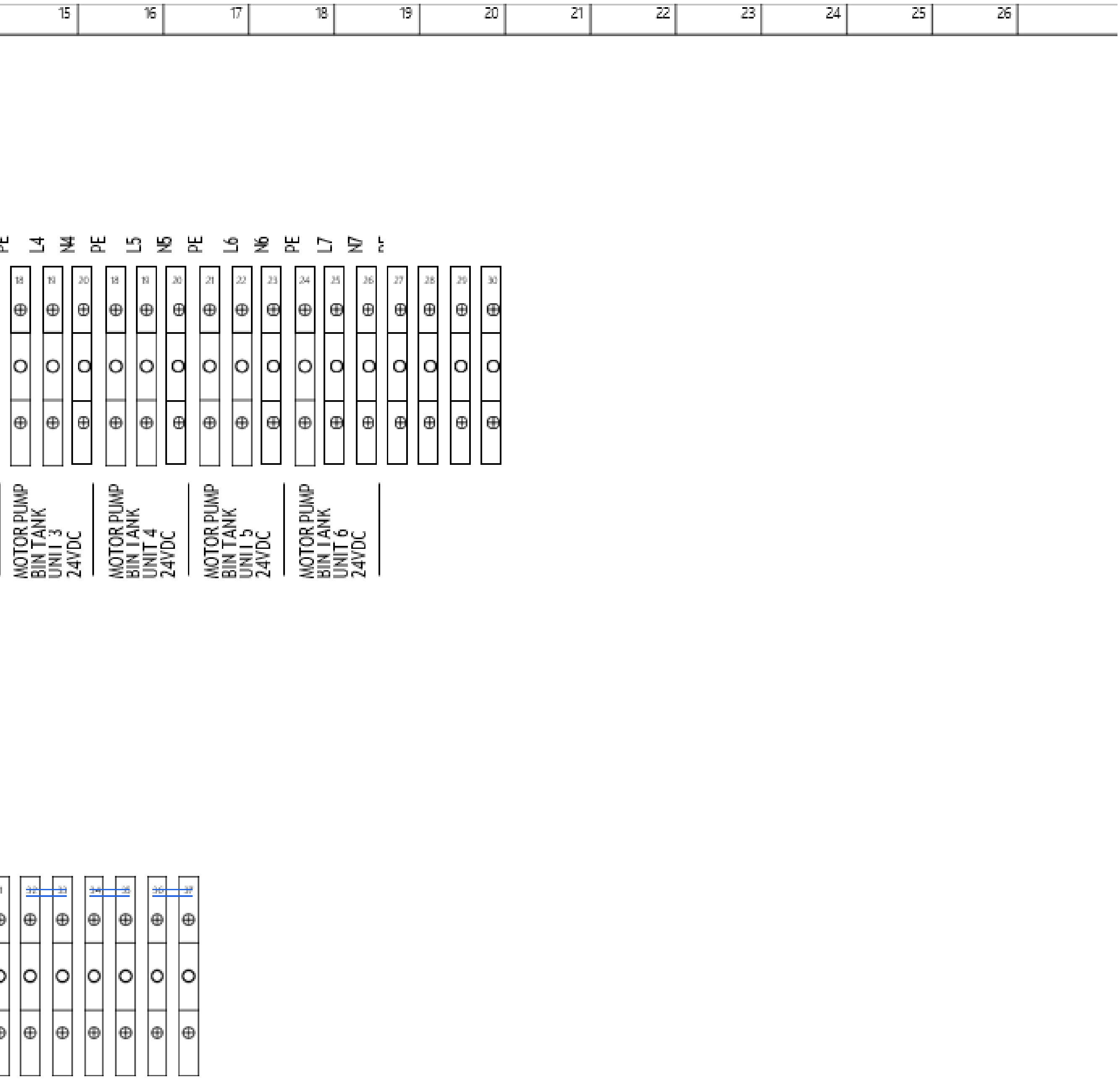
15 16 17 18 19 20 21 22 23 24 26 27


1
2
3
4
5
6
7
8
9
10
11
12
13
14
Xcom 232
B
REMOTE CONTROL
RCC-02
B
B
CHARGE REGULAT
CS - 120
B
B



AIREF	Drawing Title: COMMUNICATION MODBUS		
Drawer :	MS	16.05.2018	~~Rev :~~ 01
Checked :	DW	16.05.2018	
Mgr Approval :	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290		
Drawing ~~No :~~ IB-R290-WD			
~~Scale :~~	~~Weight :~~	~~Sheet :~~ 21/24	


POWER INCOMMING
MOTOR
TB0
L1 L2 L3 PE L N PE L N PE
POWER INCOMMING 400-750VDC
POWER INCOMMING 2300VAC
POWER INCOMMING 24VDC
TB1
U1 V1 W1 PE U2 V2 W2 PE L1 N1 PE L2 N2 PE L3 N3
MOTOR COMPRESSOR 400 - 750VDC
MOTOR FAN CONDENSER 400 - 750VDC
MOTOR STIRRER 230VAC
MOTOR PUMP BIN TANK UNI I 1 24VDC
MOTOR PUMP BIN TANK UNIT 2 24VDC
ACCESSORIES REFRIGERANT
TB2
Com NC Com NC Grey + Brown Pink Violet Blue 11 + Line 14 N Com NC L N L N L N L N X1 X1
LP
HP
OLC
MP
Propane
Crankcase Heater
Bypass Valve
Circuit Valve
Compressor On Lamp
Buzzer
Netral
Spare



AIREF

Drawing Title: ARRAGEMENT TERMINAL

Drawer	:	MS	16.05.2018	Rev : 01
Checked	:	DW	16.05.2018	
Mgr Approval	:	HD	16.05.2018	

Size: A4 — Drawing Name: PANEL ICE BANK-R290

Drawing No : IB-R290-WD

Scale : | Weight : | Sheet : 22/24

15 16 17 18 19 20 21 22 23 24 26 27

1 2 3 4 5 6 7 8 9 10 11 12 13 14

DRAWING INFOR

M1	Motor Compressor
M2	Fan Motor Condenser
M3	Motor Stirrer
M4	Motor Pump Ice Bin Tank Unit 1
M5	Motor Pump Ice Bin Tank Unit 2
M6	Motor Pump Ice Bin Tank Unit 3
M7	Motor Pump Ice Bin Tank Unit 4
M8	Motor Pump Ice Bin Tank Unit 5
M9	Motor Pump Ice Bin Tank Unit 6
Q0	Moulded Case Circuit Breaker Power 400 – 750VDC
Q1	Moulded Case Circuit Breaker Compressor
Q2	Mini Circuit Breaker Fan Motor Condenser
Q3	Mini Circuit Breaker Power 230VAC
Q4	Mini Circuit Breaker Motor Stirrer
Q5	Mini Circuit Breaker Power 24VDC
Q6	Mini Circuit Breaker Pump Ice BinTank Unit 1
Q7	Mini Circuit Breaker Pump Ice BinTank Unit 2
Q8	Mini Circuit Breaker Pump Ice BinTank Unit 3
Q9	Mini Circuit Breaker Pump Ice BinTank Unit 4
Q10	Mini Circuit Breaker Pump Ice BinTank Unit 5
Q11	Mini Circuit Breaker Pump Ice BinTank Unit 6
RL1	Fan Motor Condenser Relay
RL2	Motor Stirrer Relay
RL3	Power PV Relay
RL4	Motor Pump Ice Bin Tank Unit 1 Relay
RL5	Motor Pump Ice Bin Tank Unit 2 Relay
RL6	Motor Pump Ice Bin Tank Unit 3 Relay
RL7	Motor Pump Ice Bin Tank Unit 4 Relay
RL8	Motor Pump Ice Bin Tank Unit 5 Relay
RL9	Motor Pump Ice Bin Tank Unit 6 Relay
RL10	Auxiliary Low Pressure Relay
RL11	Auxiliary High Pressure Relay
RL12	Auxiliary Oil Level Control Relay
RL13	Auxiliary SE–B2 Relay
RL14	Auxiliary Propane Relay

RL15	Auxiliary Signal Bin Tank 1
RL16	Auxiliary Signal Bin Tank 2
RL17	Auxiliary Signal Bin Tank 3
RL18	Auxiliary Signal Bin Tank 4
RL19	Auxiliary Signal Bin Tank 5
RL20	Auxiliary Signal Bin Tank 6
RL21	Auxiliary Signal Bin Tank 1
RL22	Auxiliary Signal Bin Tank 2
RL23	Auxiliary Signal Bin Tank 3
RL24	Auxiliary Signal Bin Tank 4
RL25	Auxiliary Signal Bin Tank 5
RL26	Auxiliary Signal Bin Tank 6
RL27	Auxiliary Crankcase Heater
RL28	Auxiliary Power External VF
RL29	Auxiliary Circuit Valve Relay
RL30	Auxiliary Bypass Valve Rela
PB.1	Push Buttom Unit Off
PB.2	Push Buttom Unit On
PB.3	Push Buttom On Ice Bin Ta
PB.4	Push Buttom On Ice Bin Ta
PB.5	Push Buttom On Ice Bin Ta
PB.6	Push Buttom On Ice Bin Ta
PB.7	Push Buttom On Ice Bin Ta
PB.8	Push Buttom On Ice Bin Ta
LP	Low Pressure
HP	High Pressure
OLC	Low Oil Level Control
SE–B2	Motor Protector
DPWLP	Leakge Gas Detector
SV.0	Circuit Valve
SV.1	Bypass Valve
CH	Crankcase Heater Compress
VFD	Inverter Motor Compressor
ECblue	Inverter Fan Motor Condens

1 2 3 4 5 6 7 8 9 10 11 12 13 14

15	16	17	18	19	20	21	22	23	24	25	26

MATION

Ready Relay
Ready Relay
Ready Relay
Ready Relay
Ready Relay
Ready Relay
Operational Relay
Operational Relay
Operational Relay
Operational Relay
Operational Relay
Operational Relay
Relay
D Relay
/
y
nk Unit 1
nk Unit 2
nk Unit 3
nk Unit 4
nk Unit 5
nk Unit 6
sor
er

L1	Signal Bin Tank 1 Ready Lamp
L2	Signal Bin Tank 2 Ready Lamp
L3	Signal Bin Tank 3 Ready Lamp
L4	Signal Bin Tank 4 Ready Lamp
L5	Signal Bin Tank 5 Ready Lamp
L6	Signal Bin Tank 6 Ready Lamp
L7	Signal Bin Tank 1 Operational Lamp
L8	Signal Bin Tank 2 Operational Lamp
L9	Signal Bin Tank 3 Operational Lamp
L10	Signal Bin Tank 4 Operational Lamp
L11	Signal Bin Tank 5 Operational Lamp
L12	Signal Bin Tank 6 Operational Lamp

AIREF	Drawing Title: LEGEND DRAWING		
Drawer :	MS	16.05.2018	Rev : 01
Checked :	DW	16.05.2018	
Mgr Approval :	HD	16.05.2018	
Size: A4	Drawing Name: PANEL ICE BANK-R290		
Drawing No : IB-R290-WD			
Scale :	Weight :	Sheet : 24/24	

15	16	17	18	19	20	21	22	23	24	26	27

THE smarter AWARD

OUTSTANDING PROJECTS

2025 FINALIST

GIZ Indonesia, 2025