

# **Isochronous Load Sharing Setup at STH - HUB**

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## BACHELOR'S THESIS

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### Abstract

At STH in Vasklot, eight test cells have been built for testing customer engines and for research and development purposes. To have solutions ready for special tests in the future, Wärtsilä wanted to have a system installed, where it is possible to perform isochronous load sharing tests. At STH, most of the hardware needed to run these tests was already installed, but no definitive plan on what needs to be addressed in order to get a working system, where it is possible to run in isochronous load sharing mode.

The task of this thesis was to get setup installed at STH-HUB, where it would be easy in the future to carry out isochronous load sharing tests. In order to accomplish this task, a comprehensive understanding of how isochronous load sharing works, how the electrical system was built for engine tests at STH -HUB and the working principles of different electrical apparatuses was necessary.

The methodology consisted of reviewing various documents, such as electrical drawings, user manuals, and functional documentation manuals in addition with an analysis of the current system and practical implementation to establish a functional isochronous load sharing system. The results show a thorough analysis of the electrical system at STH. Requirements identified for isochronous load sharing operation at STH-HUB and solutions needed to get a complete isochronous load sharing system working. Finally, it also shows solutions on how to segment multiple engines into different load sharing groups.

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Language: english

Key Words: Isochronous, UNIC, CAN-bus, AVR, UNITROL 1020

## EXAMENSARBETE

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### Abstrakt

Vid STH i Vasklot har åtta testceller byggts för testning av kundmotorer och för forsknings- och utvecklingsändamål. För att ha lösningar redo för specialtester i framtiden ville Wärtsilä ha ett system installerat, där det är möjligt att utföra isokrona lastfördelningstester. På STH hade man redan installerat det mesta av den hårdvara som behövs för att köra dessa tester, men det fanns ingen definitiv plan på vad som behöver åtgärdas för att få ett system som kan köras i isokron lastfördelningsläge.

Uppgiften i detta examensarbete var att få en lösning installerad vid STH-HUB, så att det i framtiden skulle vara lätt att utföra isokrona lastfördelningstester. För att kunna utföra denna uppgift var det nödvändigt att ha en omfattande förståelse för hur isokron lastfördelning fungerar, hur det elektriska systemet är uppbyggt för motortester vid STH -HUB och hur olika elektriska apparater fungerar.

Metoden bestod av en granskning av olika dokument, såsom elritningar, användarmanualer och manualer för funktionsdokumentation, tillsammans med en analys av det nuvarande systemet och ett praktiskt genomförande för att skapa ett fungerande isokron lastfördelningssystem. Resultaten visar en grundlig analys av STH:s elsystem. Även krav som identifierats för isokron lastfördelning vid STH-HUB och lösningar som behövs för att få ett komplett isokron lastfördelningssystem att fungera studerades. Resultatet visar också förslag på lösningar hur man kan dela in flera motorer i olika lastdelningsgrupper.

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Språk: engelska

Nyckelord: Isokron, UNIC, CAN-bus, AVR, UNITROL 1020

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### Tiivistelmä

STH:n Vaskiluodossa on rakennettu kahdeksan testisolua asiakkaiden moottoreiden testausta sekä tutkimus- ja kehitystoimintaa varten. Jotta Wärtsilä saisi tulevaisuudessa valmiit ratkaisut erikoistestejä varten, yhtiö halusi asentaa järjestelmän, jossa on mahdollista tehdä isokronisia kuormitusjakaumatestejä. STH:ssa suurin osa näiden testien suorittamiseen tarvittavasta laitteistosta oli jo asennettu, mutta ei ollut olemassa lopullista suunnitelmaa siitä, mitä on tehtävä, jotta järjestelmä voisi toimia isokronisessa kuormanjakotilassa.

Tämän opinnäytetyön tehtävänä oli saada STH-HUBiin asennettua järjestelmä, jonka avulla isokronisen kuormanjakotestien suorittaminen olisi tulevaisuudessa helppoa. Tehtävän suorittamiseksi tarvittiin kattava käsitys siitä, miten isokroninen kuormanjako toimii, miten STH-HUB:n moottoritestejä varten rakennettu sähköjärjestelmä toimii ja miten eri sähkölaitteiden toimintaperiaatteet toimivat.

Menetelmään kuului erilaisten dokumenttien tarkastelu, kuten sähköpiirustuksia, käyttöoppaita ja toimintakäsikirjoja, sekä nykyisen järjestelmän analyysi että sen käytännön toteutus toimivan isokronisen kuormanjakojärjestelmän luomiseksi. Tulokset näyttävät perusteellisen analyysin STH:n järjestelmästä. Myös STH-HUBin isokronista kuormanjakoa varten tunnistettuja vaatimuksia ja ratkaisuja, joita tarvitaan täydellisen isokronisen kuormanjakojärjestelmän toimintaan, tutkittiin. Lopuksi esitetään myös ratkaisuja siihen, miten useat moottorit voidaan jakaa eri kuormituksenjakoryhmiin.

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Kieli: englanti

Avainsanat: Isokroninen, UNIC, CAN-bus, UNITROL 1020

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## **ABBREVIATIONS**

Genset – Generating Set

Isoch - Isochronous

CB – Circuit Breaker

STH – Sustainable Technology Hub

LS – Load Sharing

PPTT – Parts Per Ten Thousand

FPC – Full Power Converter

SLD - Single Line Diagram

MCB – Miniature Circuit Braker

VAC – Volts Alternating Current

EMI – Electromagnetic Interference

HF – Halogen Free

R&D – Research and Development

T&V – Testing and Validation

PF – Power Factor

IGBT – Insulated Gate Bipolar Transistor

CT – Current Transformer

VT – Voltage Transformer

MV – Medium Voltage

SWG – Switchgear

FAT – Factory Acceptance Test

VDC – Voltage Droop Compensation

# 1 Introduction

This section describes the company Wärtsilä, which the thesis is made for. In addition, it describes the background and context of the thesis, in order to provide information about why this topic has been chosen. Lastly, it covers goal and purpose, which is intended to provide a clear view on the goal of the thesis and what research is necessary to accomplish this goal.

## 1.1 Company

Wärtsilä was established in 1834 in the county of Karelia, the company started as a sawmill. In the beginning of 1954, Wärtsilä made the decision to commence the design of its own diesel engines in Vaasa. [1]

Wärtsilä is a global leader in innovative technologies and lifecycle solutions for the marine and energy markets. Wärtsilä emphasises in the innovation of sustainable technology and services to help Wärtsilä's customers continuously improve their environmental and economic performance. Wärtsilä employs approximately 17,000 people in more than 200 locations in 68 countries. [2]

Wärtsilä's marine market share in 2021 was 62% with medium-speed main engines and 5% with auxiliary engines. On the energy side, Wärtsilä had an 8% market share in gas and liquid fuelled power plants in 2021. [3]

## 1.2 Background

At the new STH that Wärtsilä has built in Vasklot they have several facilities for testing engines, so called test cells, these cells are used for FAT tests on production engines and for R&D, T&V purposes.

In the marine sector of Wärtsilä, multiple gensets are regularly installed onboard vessels, these gensets are frequently operated in parallel to share a common load, in this case the propulsion for the vessel. The gensets are often operated in isochronous load sharing mode. Therefore, Wärtsilä wanted to have the possibilities to use STH's new test cells to run multiple engines in isochronous load sharing mode for testing purposes. At STH in Vasklot most of the hardware to run this is already installed, but no plan on how to do this in practise.

### **1.3 Purpose**

The purpose of this thesis is to investigate the requirements of installing a fully functional isochronous load sharing system at STH-HUB. The study will analyse the current system installed and review the necessary elements needed in order to acquire a functional system, where it is possible to run several cells in isochronous load sharing mode.

In order to obtain a fully functional system, a deeper knowledge of how isochronous load sharing works and an understand how things are interconnected electrically at STH are needed, as well as knowing which systems and equipment need to be configured and connected to be able to run on isochronous load sharing mode.

### **1.4 Goal**

The goal of this project is to get a system installed at STH, where it is easy in the future to test multiple engines together in isochronous LS mode. Having this system installed and ready in the future makes it easy for the R&D department to further develop isochronous load sharing systems. For customer engines, it could be possible to run FAT test on engines before delivery to the customer, this adds value to Wärtsilä by having the ability to do special FAT test for customer needs.

In addition to the previously stated goal, a second objective of this thesis would be to test the installed system with two engines running in parallel in isochronous load sharing mode at STH-HUB. After achieving this objective, the system would be scaled to all cells at STH-HUB, where every cell would have the opportunity to run in parallel with compatible cells. This would only be done if there is enough time, and no other conflicting priorities interfere.

## **2 Theory**

This section covers the theory of all necessary elements that are important to understand in order to know how a complete system works when paralleling several engines in isochronous load sharing mode. The theory should give the reader a comprehensive understanding of important elements involved when operating in isochronous load sharing mode.

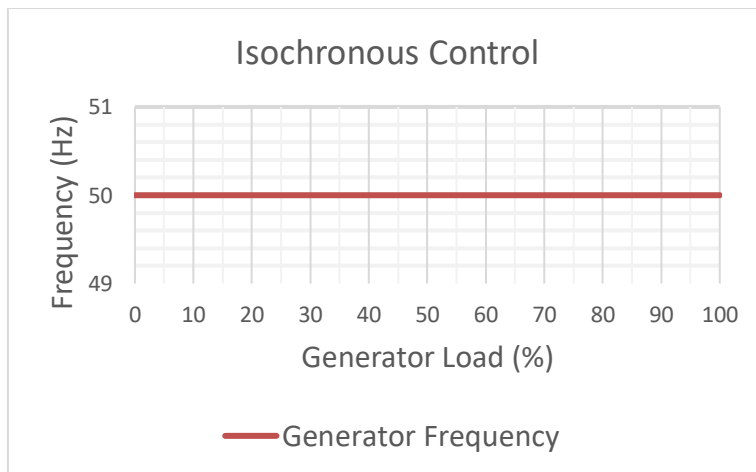
### **2.1 Engine Control modes**

There are multiple engine control modes available, but when operating multiple engines in an islanded system, there are two main methods used for controlling the engines, these are called isochronous control and droop speed control. Both modes are used in Wärtsilä installations but depending on the system criteria and installation type, the most adequate operational mode is selected.

#### **2.1.1 Isochronous Control**

The concept of isochronous load sharing entails controlling the output of two or more generators which is controlled via the prime mover speed governors to maintain the desired frequency during load imbalances. In simpler terms this means that the speed of the engine crankshaft will rotate at a fixed speed from 0-100% load.

When operating in isochronous mode, all the governors need to be able to communicate with each other to be able to share the load equally. In this case the governors are Wärtsilä's UNIC engine control system, which communicates with each other on a common CAN bus network. If this connection is lost, the system will automatically switch to droop mode. Figure 1 gives a visual representation of how the system behaves when operated in isochronous load sharing mode. [4]



**Figure 1 Isochronous control**

### **2.1.2 Droop Speed Control**

In droop speed control mode, the frequency output of the generator will decrease by a predetermined value in % relative to the generator load. Droop speed control mode has been a very popular engine control mode with engines that have mechanical governors. Figure 2 gives a visual representation of how the system behaves when operated in droop speed control mode.

Because droop speed control does not require any communication between governors, it's a more fail-safe method of controlling the engines compared to isochronous control, which requires constant communications between engines to work.

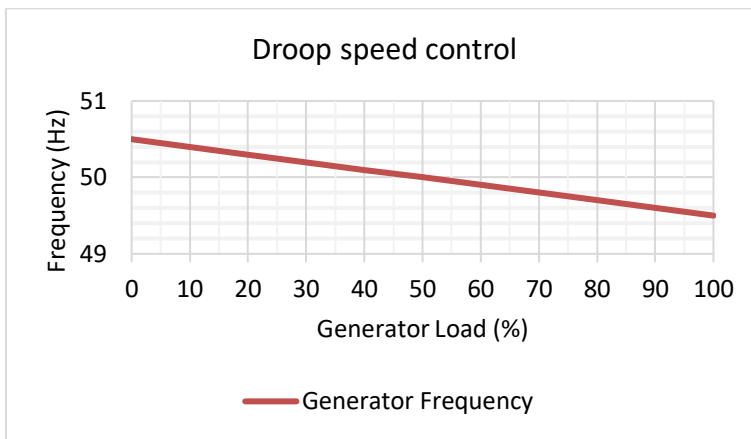


Figure 2 Droop control

## 2.2 Generator Control Modes

The synchronous generator's control of voltage and reactive power is handled by the AVR. As with engine control, AVR: s includes different generator control modes, but the two main operational modes are PF control and automatic voltage control. Different modes are typically used when operating in different network configurations, such as when running an islanded system or in parallel with grid.

### 2.2.1 P.F Control

P.F control mode regulates the power factor or reactive power of the generator. Power factor is the ratio between real power (kW) and apparent power (kVA), this ratio equals  $\cos \Phi$  as shown in Figure 3. P.F control mode is a popular control mode at a power plant when connected to the grid. [10]

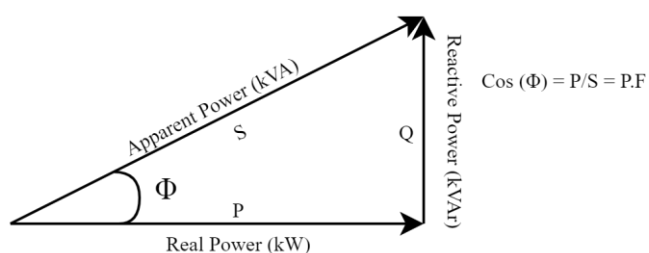


Figure 3 Power factor triangle

### 2.2.2 Voltage Control

Regulates the terminal voltage of the generator to a specific set point. Voltage control is rarely used when connected to the grid, only when operating in standalone or island mode. UNITROL 1020 AVR: s run on PID based voltage control mode, which means it works on a closed loop control mode in which the output voltage is regulated using a feedback system and algorithms as shown in Figure 4.

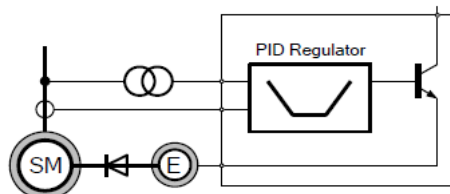


Figure 4 PID control mode [10]

### 2.3 Automatic Voltage Regulator

An automatic voltage regulator (AVR) is a device that automatically adjusts and stabilizes the terminal voltage of a synchronous generator to a fixed level. The AVR continuously reads the terminal voltage of the generator and compares the value to a set point. If needed, the AVR raises or lowers the voltage of the generator by increasing or decreasing the generator's excitation, which strengthens or weakens the generator magnetic field thus leading to increased or decreased levels in voltage. [7]

By inducing an DC current to the generator's field winding it is possible to change the generators excitation, leading to a change in the generators magnetic field. The main purpose of a AVR is to ensure safety in an electrical system by keeping the terminal voltage within acceptable limits. Wärtsilä uses mainly UNITROL 1020 and DECS-250 AVR: s made by ABB and Basler Electric.

### 2.3.1 UNITROL 1020

At STH, ABB UNITROL AVR: s are mostly used. UNITROL 1020 is an automatic voltage regulator of the latest design for synchronous generators. The unit contains the most advanced microprocessor technology together with IGBT semiconductor technology.[10]

Figure 5 shows a connection diagram for 1020 AVR: s. Measurement of the machine voltage ( $U_M$ ), network voltage ( $U_{NET}$ ) and machine current ( $I_{M2}$ ) is measured through VT: s and a CT respectively.

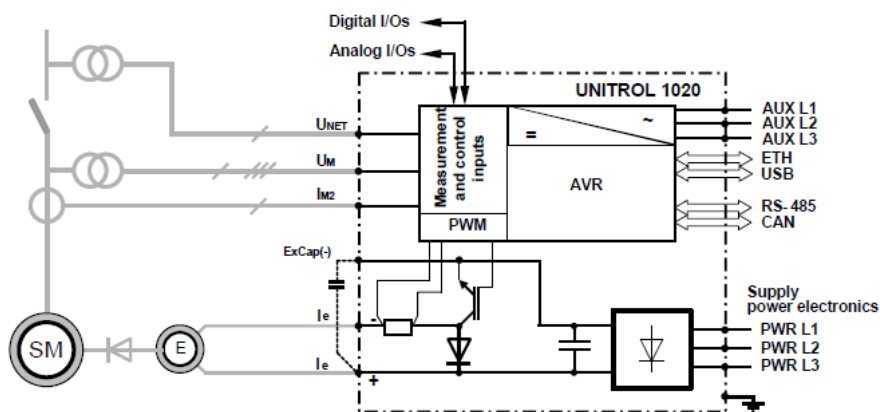


Figure 5 UN1020 connection diagram [10]

### 2.4 Voltage Droop Compensation

ABB UNITROL AVR: s includes an operation mode called voltage droop compensation, VDC mode is only used in island operation. When voltage droop compensation (VDC) is used, all AVR: s operates in voltage control mode and share the reactive power equally. During VDC mode, terminal voltage is set at 100% between VAr min and max setpoint, outside the VAr setpoints, a compensation droop is set at -5% as illustrated in Figure 6. [10]

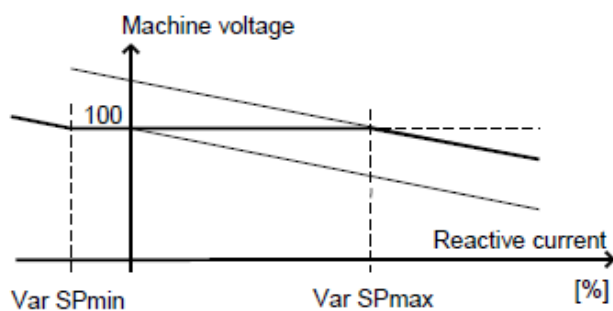


Figure 6 VDC mode terminal voltage [10]

### 2.4.1 The Purpose of Reactive Load Sharing

When two machines are operating in voltage control in parallel, tolerances in voltage measurement can lead to an unbalanced situation (Figure 7). Even small voltage differences can provide substantial reactive current flow from one machine to another, therefore reactive load sharing is used to eliminate unwanted imbalances in an islanded system. [20]

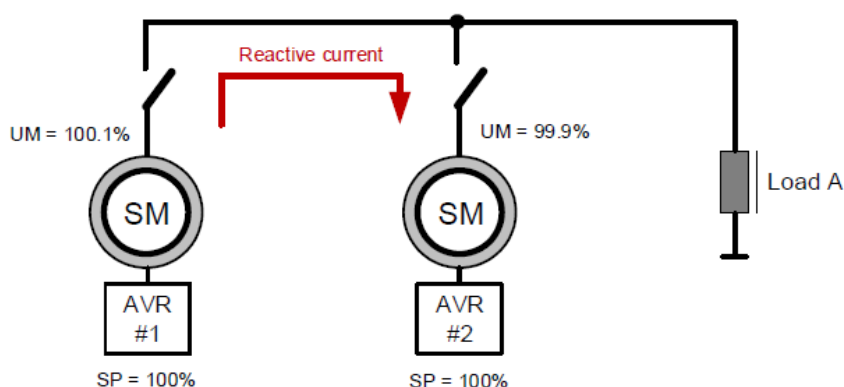


Figure 7 Unbalanced system [20]

### 2.4.2 Requirements

When operating multiple ABB UNITROL AVR: s in VDC mode, all the units need to communicate with each other. Communication is established over a common RS-485 bus, with a maximum of 31 units that can be connected to the same bus. The RS-485 bus needs to be terminated at both ends by connecting jumpers to a dedicated terminal X1300 on the AVR: s as shown in Figure 8.

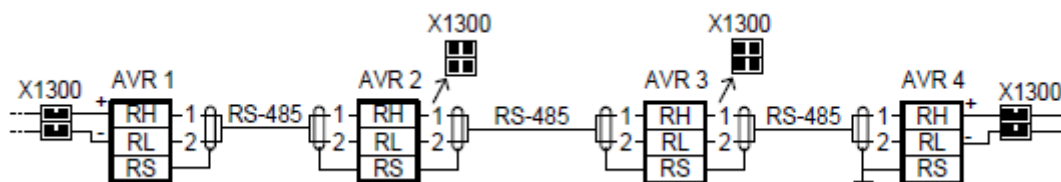


Figure 8 RS-485 wiring [20]

To establish communication between multiple AVR: s on the common RS-485 bus, a unique AVR ID must be configured for each unit. The AVR ID defines timing on the RS-485 bus, therefore two units cannot have the same AVR ID configured. [20]

### 2.4.3 Secondary Nets

To separate multiple AVR: s connected on the common RS-485 bus into different load sharing groups, UNITROL AVR: s makes use of two digital inputs called Secondary Net1 and Secondary Net2, with these digital inputs it's possible to change the NET ID of the AVR. Active units with the same NET ID will share load together. With two secondary net digital inputs, it's possible to establish several NET ID groups, with a maximum of 31 units connected to the same bus.

Figure 9 shows an example where AVR: s 1-4 use a Secondary Net1 digital input signal from a bus tie breaker between units 4 and 5. This signal allows units 1-4 and units 5-8 to work separately when the bus tie breaker is open, when the breaker is closed all AVR: s have the same NET ID and share load together.

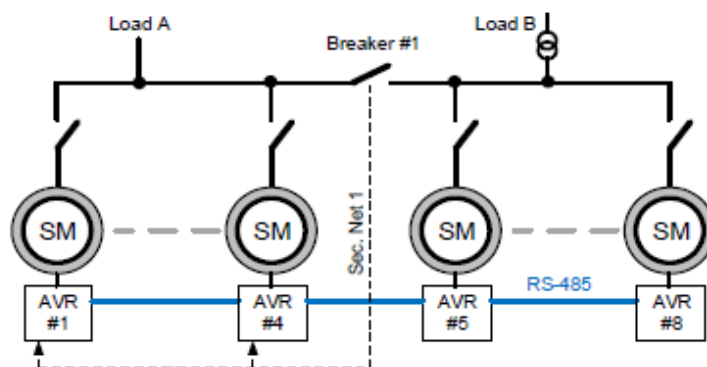


Figure 9 Secondary net signal

## 2.5 Generating Set

Onboard vessels multiple Wärtsilä gensets are often installed, genset is an abbreviation from the word generating set. A generating set consist of a prime mover, in this case a Wärtsilä engine and a generator. Both the engine and the generator are connected to a common base frame. Wärtsilä offers a wide range of gensets, from smaller models like the Wärtsilä 20 engine family to larger models, such as the Wärtsilä 50 engine family. The numbers 20 and 50 indicate the cylinder bore in centimetres. These genset models come in a variety of cylinder configurations such as inline and V-type.

### 2.5.1 Generator

A generator is an electrical machine that converts mechanical energy into electrical energy. An electric generator uses the principle of electromagnetism and Faraday's law, which is the ability to create an electrical current in a conductor by moving a magnetic field past a conductor.

In most AC generators, the magnetic field is produced with exciting a DC current through a conductor that is wound around a piece of metal like iron, also called an electromagnet. The electromagnets are mounted on a shaft that rotates. This magnetic field rotates around a conductor formed into a coil. The rotating electromagnet in a generator is called rotor and the conductor formed into a coil called a stator. As the rotor turns, it induces a current to the stator coil. (Figure 10)

A generator can also use permanent magnets instead of electromagnets mounted on the shaft. Permanent magnets have a constant magnetic field around it and does not need an external current like electromagnets.[16][17]

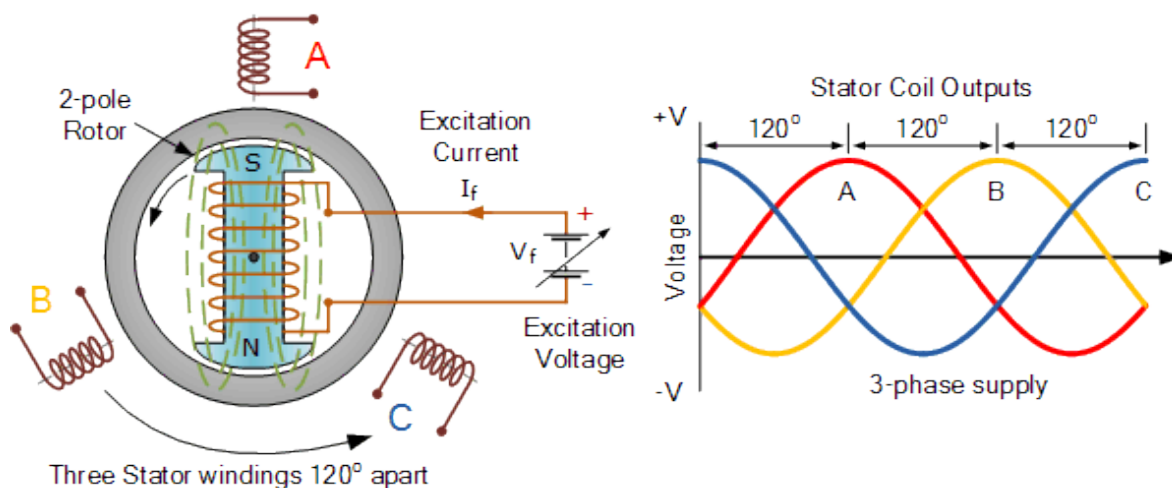


Figure 10 AC generator working principle [21]

## 2.6 UNIC

Wärtsilä Unified Controls (UNIC) is the engine control system for Wärtsilä 4-stroke engines. Made by Wärtsilä, the UNIC engine control system is designed for reliability and modularity. UNIC is made up of different modules that are resistant to high temperatures and vibration in high demanding engine environments. The modular design allows for directly mounting on the engine which reduces space and the necessity for external cabinets.[8]

The different modules that the UNIC system consists of are:

LOP-Local Operator Panel:

The local operator panel is located on the engine and can be used for visualising the engine information through a HMI, local start & stop and operating the engine locally.

COM – Communication Module

Used for system communication, the COM module is an essential part of the UNIC system. The module supports multiple communication interfaces such as Modbus, OPC, CAN etc.

## CCM – Cylinder Control Module

This module controls combustion of the cylinders, it does this by monitoring and controlling injection, combustion and inlet valve timing.

## IOM – Input/Output Module

Handling digital and analogue input/output signals, the IOM module for example handles measurements from sensors around the engine.

## ESM – Engine Safety Module

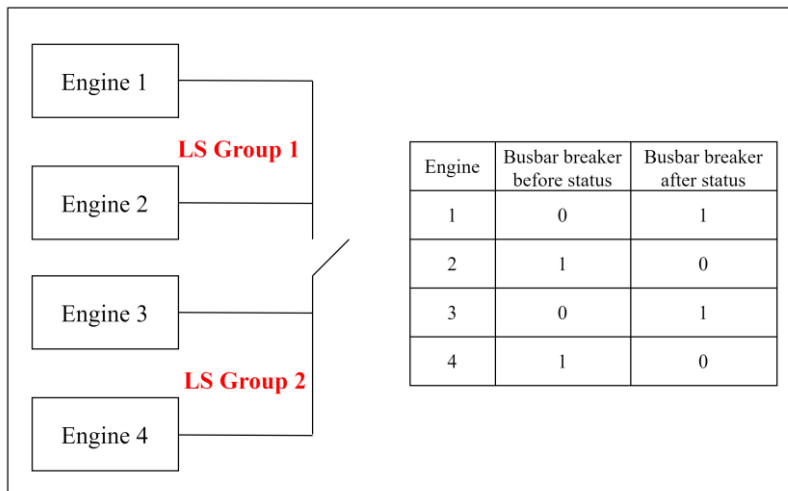
The engine safety module handles the safety aspects of the engine, for example shutting down the engine if it detects a failure in the system.[13]

### **2.6.1 Isochronous LS Scheduler**

The isochronous load sharing scheduler is a software application in UNIC that processes all Isoch load sharing data communicated over the load sharing CAN to achieve load sharing between engines. The scheduler is made up of many different sub applications that handle various tasks used for load sharing such as:

### **2.6.2 Isochronous Load Sharing Active Group Calculation**

In isochronous load sharing mode when multiple engines are connected to different loads, it is necessary to be able to differentiate and specify which groups are sharing a load. UNIC does this by using busbar breaker before and after digital signals, the status of the signals determines which of the engines share a common load. The busbar breaker status can be configured in multiple ways according to the real layout of the busbar, for example a non-existing busbar breaker between engines can be configured to always closed. Figure 11 illustrates 4 engines in two different load sharing groups, separated by busbar breaker signals.[13]



**Figure 11 Busbar breaker status**

## 2.7 Serial Communication

### 2.7.1 RS-485

RS-485 stands for recommended standard 485 and is a serial communication standard that has been used extensively by the industry for multipoint, differential data transmission. RS-485 is known for allowing multiple nodes to communicate with a duplex system over a single twisted pair, additionally the RS-485 standard also allows communication in long distances and is not very susceptible to external electrical noise. [5]

### 2.7.2 CAN-BUS

CAN stands for Controller Area Network and is a two wire, multidrop, serial communication protocol. CAN-BUS was developed by Bosh and was later organised into the ISO11898-1 standard. CAN-BUS is known for its high resistance to electrical interference alongside its ability to self-diagnose and repair data errors, these aspects has made it very popular with industries such as building automation and manufacturing. [6]

The CAN bus line consists of two signals, CANH and CANL, which stand for CAN high and CAN Low. At both ends of the CAN bus line a 120-ohm resistor needs to be terminated between CANH and CANL, indicated as  $R_L$  in Figure 12.

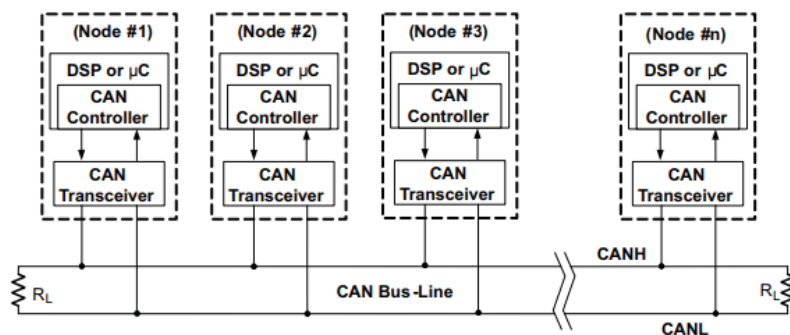


Figure 12 CAN bus line [6]

### 2.7.3 Optical Fiber

Optical fiber is a form of communication which uses light as a signal compared to the electrical signals used other conventional communication forms. Especially in internet communication, optical fiber has replaced the copper wire due to its advantages in long distance communication, small losses, large transmission capacity, low cost and total immunity to EMI. [12] Advantages of optical fiber communication are:

#### Wider bandwidth

High transmission frequency in the range of  $10^{13}$  to  $10^{15}$  Hz allows optical fiber to transmit data much faster in bits per second compared to other conventional communication methods.

#### Low transmission loss

Using high quality and low loss fibers in modern optical fiber communication systems achieves almost lossless transmission. Typical attenuation in high quality optical fibers is about 0.002 dB/km, which can allow for up to 100km distance between repeaters.

#### Dielectric waveguide

Optical fibers are made of glass, this attribute makes optical fiber less susceptible to electromagnetic interference than other types of cables. Furthermore, optical fiber produces almost zero EMI, which allows for multiple optical fibers assembled together in one cable, without any cross interference between fibers.

### **Small size and weight**

Compared to copper cables, optical fiber cables are much lighter and compact. This makes for easier handling and installation than traditional copper wires. [14]

## **2.8 Load sharing Communication**

When sharing a load between multiple Wärtsilä engines in isochronous load sharing mode, all the engines need to communicate with each other to be able to share the load equally. This also is true for the UNITROL AVR: s when operating in VDC mode and sharing the reactive load equally.

### **2.8.1 UNIC**

Load sharing communication between UNIC units happens through a dedicated load sharing CAN-bus. The data that is communicated between the engines is:

#### **Relative Engine Load**

Engine load in kW is shared as a percentage on the LS CAN-bus to other engines.

#### **Relative Speed Reference**

A relative speed reference in PPTT is shared on the CAN-bus to allow engines with different speeds to be connected to the same load sharing group.

#### **Isoch LS active**

Isoch LS active is a binary data and states that isochronous load sharing mode has been activated, this mode can be activated through a digital input to or with UNIC software.

#### **Generator CB status**

This status states if the generators CB is open or closed.[13]

### 2.8.2 UNITROL 1020

In order to be able to operate ABB:S UNITROL 1020 AVR: s in VDC mode, all AVR: s need to be connected to a common RS-485 bus, this is because communication is required to successfully share the reactive load. When operating in VDC mode, each of the AVR: s sends out data about their own amount of reactive power to the common bus, then all AVR: s calculates a common average MVAR setpoint and compensate the effect of the voltage droop. Requirements for the RS-485 cables used for VDC communication, which is specified in the UNITROL 1020 manual, is shown in Table 1. [10]

Min cable cross-section:	2 x 0.25 mm <sup>2</sup>
Characteristic impedance:	100-120 $\Omega$
Type of cable:	Shielded twisted pair
Max. cable length:	500 m

**Table 1 RS-485 requirements**

## 2.9 AutoCAD Electrical

AutoCAD Electrical is an electrical design software made to help electrical design engineers create and modify electrical schematic drawings. The software is built on AutoCAD with additional electrical functionalities added, that helps the designer create:

- Component List
  - Creating a component list from an entire electrical drawing. With AutoCAD you can quickly generate a component list with all the components used in a design project. It does this by collecting the metadata stored in all components and then generates a list that displays the data.

- Schematic Drawing
  - AutoCAD Electrical helps the designer to create schematical drawings, with a symbol library for many different electrical standards, the designer can choose their desired standard and insert electrical symbols from the chosen library into the schematical drawing. In this thesis electrical symbols from the standard IEC 60617 were used.
- Panel Layout
  - When creating a panel in AutoCAD Electrical, the designer can insert component footprints from an AutoCAD component library, if the footprint is not found, the designer can make his own footprints and add them to the component library.
- Terminal List
  - Similar to creating a component list, the designer can create a visual terminal list of all the terminal used in a design project. This helps to display how many terminals are used when manufacturing the electrical cabinet and to display on which side of the terminal the wire should be connected.

## 2.10 Synchroniser

Used when synchronising the generator to the busbar, the synchroniser checks the voltage difference, phase angle and slip frequency between the busbar and generator, when the difference with these three values are within limits, the synchroniser provides a signal to the generator CB to close. This thesis encounters DEIF FAS-115DG synchronisers, which includes CB time compensation, where you can set CB closure time, the synchroniser will include this time in its CB closure signal. [9]

To get the generator voltage and frequency to match the busbar, the FAS-115DG sends out a voltage and speed increase/decrease signal. At STH this signal goes to a common PLC, which then tells the AVR to inc/dec voltage and tells UNIC to inc/dec speed on the engine.

## 2.11 Full Power Converter

FPC is an AC-AC frequency and voltage converter used for instance when connecting the output of a variable speed generator to the grid. Especially used in wind power, FPC: s are used to adjust the generator frequency and voltage to match the grid.

The full power converter performs the reactive power compensation and a smooth grid connection for the entire speed range of the engine. The generator can be a permanent magnet generator, electrically excited synchronous generator or an asynchronous generator [18]. Figure 13 shows a variable speed generator connected to the grid via a full power converter,

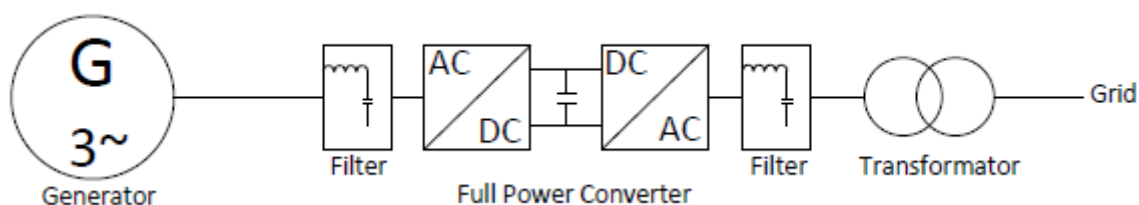


Figure 13 Connection scheme, generator-FPC-grid

## 2.12 Cables

Choosing the right type of cable for different electrical applications is a crucial part when planning and designing an electrical system. At STH all cables needed to be halogen free, HF cables do not release any toxic gases when in contact with fire.

### 2.12.1 CAN / RS-485 cable

CAN and RS-485 use the same type of cables, both protocols use two wires for communication, important characteristics for CAN and RS-485 cables are twisted pair with 120-ohm characteristic impedance. Two different types of cables used are shielded and non-shielded, its recommended to use a shielded cable when running long routes and when there is a possibility for EMI. [6]



Figure 14 CAN cable, twisted pair with braided shield

### 2.12.2 Optical Fiber Cable

Optical fiber uses a glass core to transmit a light signal. There are two different types of optical fiber cables, single mode and multimode cables. Single mode has a much smaller glass core than multimodal fiber, smaller core in an optical fiber cable allows for longer distances. Standard core diameters for multimode cables are  $50\ \mu m$  and for single mode cables are  $8 - 9\ \mu m$  as shown in Figure 15.

The glass core is surrounded by a cladding made of glass that has a slightly lower refractive index than the glass core, meaning it is made from a material that slows down the light more than the glass core with higher refractive index. The cladding is necessary, because it provides proper light guidance as well as provide high mechanical strength and safety to the core from scratches.[14]

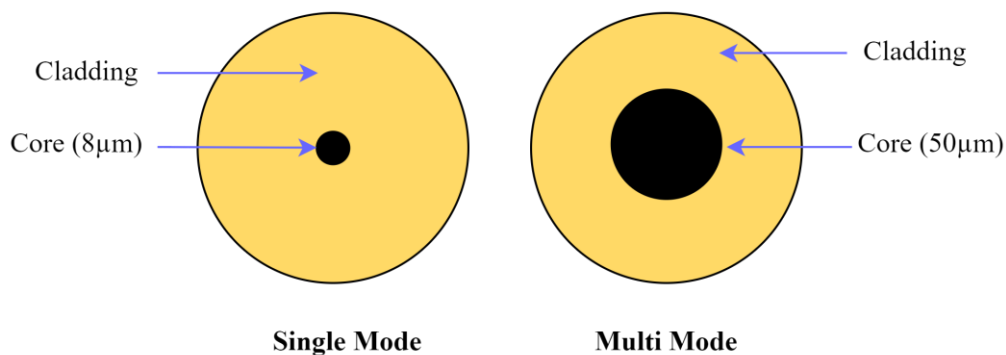


Figure 15 Single & multi-mode optical fiber cable structure

### 2.12.3 Cable Shielding

Cable shielding and proper termination to ground is very important, especially in signal cables when there is a possibility for EMI from other electronic cables or appliances.

There are many types of shields used in different cables, but for signal cables typical configurations are:

- Metal braid shields
- Foil shields
- Spiral shields
- Combination shields e.g., braided and foil shield

The performance of a cable shield is known as transfer impedance ( $Z_t$ ), The transfer impedance relates a current on the surface of the shield to the voltage drop generated by this current on the opposite surface of the shield as shown in the formula below:

$$Z_t = \frac{U_2}{I_1 * L} , \text{ where } L \text{ is the length of the cable (Figure 16) [19].}$$

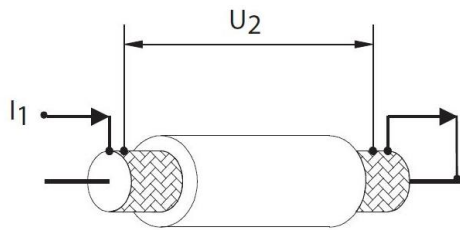
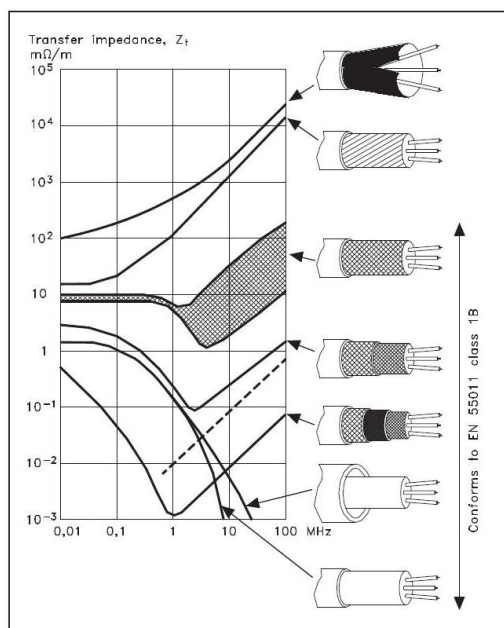


Figure 16 Shield termination [19]

Figure 17 illustrates transfer impedances for different shield configurations at different frequencies, lower transfer impedances are desired.



- Aluminium foil with copper drain wire
- Twisted copper wires or steel wire armoured cable
- Single layer braided copper wire – with various percentages of screen coverage
- Dual layer braided copper wire
- Dual layer braided copper wire with high permeable middle layer
- Cable runs in rigid copper or steel conduit
- Lead cable with 1.1 mm wall thickness – full coverage

Figure 17 Transfer impedances, different types of shields [19]

### 2.12.4 Shield Termination

Transfer impedances can drastically increase by incorrect shield termination, the shield needs to be terminated with and 360-degree connection to work correctly (Figure 18). [19]

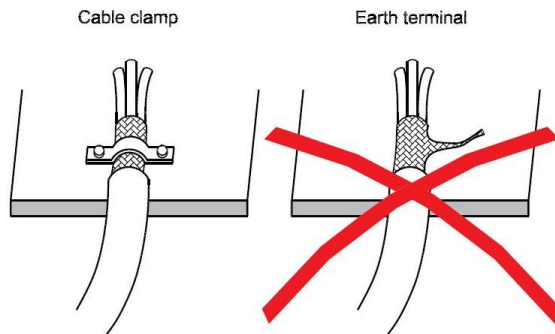


Figure 18 Shield termination [19]

### 2.13 ADFWEB

ADFWeb is a company based in Italy that develops and produces electronic equipment such as:

- Gateways for the connection between field bus and/or different protocols (CANopen, Modbus, Zigbee etc.).
- I/O Electronic boards.
- Electronic apparatus for measuring and acquiring data.
- Customized electronic apparatus, including driver and software. [15]

### 2.13.1 HD67702-C-0-H5S-H5S

HD67702-C-0-H5S-H5S is a product developed by ADFweb that converts CAN communication into single modal optical fiber. With 4 optical fiber ports, this unit allows for multidrop topology, which makes it easy to connect multiple devices in a row, as can be seen in Figure 19. The HD67702-C-0-H5S-H5S can be configured for multiple CAN baud rates ranging from 10 kB/s to 1000 kB/s, multiple units connected on the same network can be segmented into 4 different working groups by configuring them with different channel IDs.

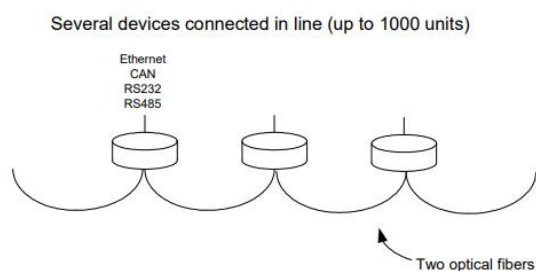


Figure 19 Multidrop topology

## 3 Methods

This section expands on practical implementations and challenges that needed to be solved in order to establish a functional isochronous load sharing system at STH-HUB. In addition, the section also covers solutions for future challenges that may occur when operating in different isochronous load sharing configurations at STH-HUB.

### 3.1 Possibilities

At STH there are 8 test cells, it is not possible to run every cell in parallel on the same load, due to every cell is not connected to the same switchgear. This is an important factor, because paralleling one cell to another cell that is connected to a different switchgear would lead to synchronising problems. This is because the busbar would be deenergized and the synchronoscope would not have a reference to measure and synchronise to. Cells at STH are numbered from 10-17, cells that are connected to the same switchgear and allow for load sharing are 10-13, 14-15 and 16-17. Figure 20 Shows a simplified version on how the cells are connected at STH.

When running on isochronous LS mode at STH, it is possible to simulate an island load with no connection to grid with load banks or FPC: s as a load. When operating against the load banks, a maximum load of 30 MVA is possible, the FPC: s allows for a maximum load of 32 MVA. It is not possible operate against both loads simultaneously.

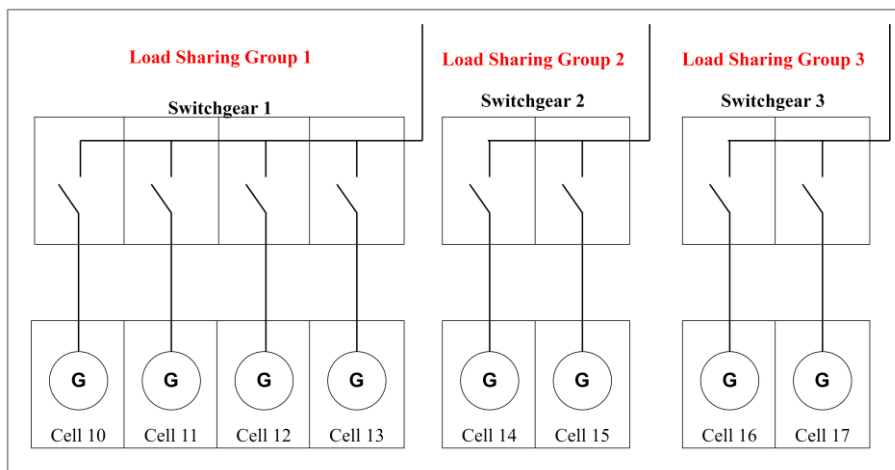


Figure 20 Simplified SLD, Cells 10-17

### 3.2 Limitations

At STH, it was discovered that the AVR: s was not connected together on a RS-485 bus, which is required for VDC communication. As well as there was no LS CAN bus established between each cell for UNIC to communicate.

According to ISO-11898 standard, the maximum bus length of a CAN network at 500 kbit/sec is 100 meters. At STH, these CAN cable lengths would be exceeded, therefore a solution for CAN communication between engines had to be implemented.

### 3.3 CAN to Optical Fiber Converter

To overcome the CAN distance problems, a CAN to optical fiber solution was found. From the company ADFWeb, a CAN to fiber converter model name HD67702-C-0-H5S-H5S (Figure 21) was acquired that offered multiple devices to be connected with a multidrop topology. Optical fiber allows cells to be connected over long distances on cable trays with minimal signal attenuation, thanks to its property of total immunity to electromagnetic interference (EMI).

An important factor in choosing a suitable CAN-Fiber converter was device latency. Wärtsilä engines operating in isoch mode will transition to droop mode if communication on the CAN-bus is lost, therefore it was essential to choose a device that had low latency with minimal delay. The HD67702-C-0-H5S-H5S uses high speed communication with a latency below 1 ms.



**Figure 21** ADFWeb HD67702-C-0-H5S-H5S

This converter will be mounted in a cabinet specially made for isochronous load sharing between engines. The cabinets will be mounted in every cell and a optical fiber connected between the cabinets.

### 3.3.1 Configuration

Configuration of the CAN to fiber converter was made in a software named SW67701 made by ADFWeb. Because the ADFWeb unit can handle a variety of communication protocols, it is necessary to configure the correct protocol used, Figure 22 shows which protocols are available. The most crucial things to configure for the CAN communication is shown in figure 23, these are baud rate of the CAN communication, ID board and channel. To establish communication with other devices on the same network, every unit needs to have an individual ID board number and they all need to be configured to the same channel.



### 3.4 CAN to Fiber Cabinet

#### Cabinet

A cabinet was designed for the CAN to fiber converter in AutoCAD Electrical. A Rittal AX 1380.000 metal cabinet was chosen (Figure 24), that can withstand harsher environments that occurs during daily operations at a test cell. Appendix 1 shows drawings on cabinet layout, schematical drawings and bill of material.



Figure 24 CAN-fiber cabinet

## Components

The cabinet needed to include 3 main things CAN: to fiber converter, 24V DC power supply and a MCB for the 230 VAC incoming supply. A 230 VAC to 24 VDC power supply was chosen to power the CAN to fiber converter. Due to low power consumptions, an ABB S201 C2 MCB was chosen as an over current protection. Finally, a main switch was installed as a breaker of incoming supply in accordance with SFS 600-1-1:2018 § 462.1.[11]

## CAN – Quick connection

For the CAN cable, a quick connection solution was made. Internally, a CAN cable was connected between the CAN-Fiber unit and a 5-pin socket located on the cabinet door (E1 in Appendix 1), this will allow for quick connection with an extension cord. A 15 m extension cord will be made that can be connected between the CAN-Fiber cabinet and the UNIC cabinet when operating in isoch mode and removed when not operating in isoch mode.

## Shield termination

To properly connect the CAN cable shield to earth, a Phoenix Contact AKGNYE 16 earthing clamp was mounted close the CAN to Fiber converter, this clamp gives a proper 360° connection to the shield (Figure 25)



Figure 25 Shield termination

### 3.5 Stage 1

The first stage of this thesis is to get 4 cells operational and able to run in parallel, in this case cells 10-13 are intended to get operational first. In order to get this done, all the cells AVR: s and CAN-Fiber cabinets needs to be connected together, respectively as shown in Figure 26.

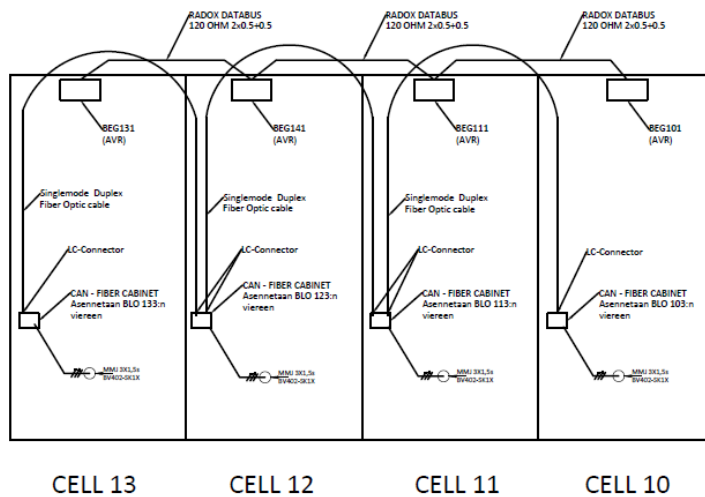


Figure 26

### 3.6 Stage 2

The second stage includes connecting all the cells AVR: s and CAN-Fiber cabinets together like shown in Figure 27.

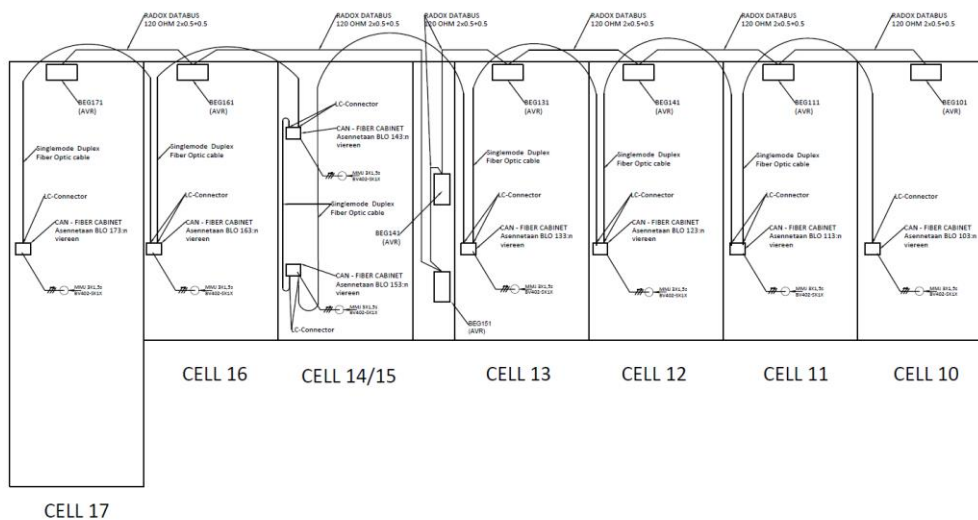


Figure 27

### 3.7 Cables Installed

#### Fiber optic Cable

Between all CAN-Fiber cabinets, a Draka Afumex - FTMSU 4xSM BB D-s2d2a1 optical fiber cable will be installed (Figure 28). The Draka cable is a halogen free optical fiber cable with 4 single mode optical fibers inside. The cable is made for higher stress installation environments, which allows installation on cable trays.



Figure 28 Draka Afumex - FTMSU 4xSM BB D-s2d2a1

#### CAN – Cable

A Radox DATABUS 120 Ohm 2x0.5+0.5 was chosen to be used between the AVR: s for VDC communication. The Radox cable was chosen because it included critical features like twisted pairs, braided outer screen, 120-ohm characteristic impedance and it is halogen free.



Figure 29 Radox DATABUS 120 Ohm 2x0.5+0.5

#### Installation cable

To each CAN-Fiber cabinet a 230 VAC supply needs to be supplied from a low voltage switchgear in the cell. This connection is made by a MMJ 3x1,5s halogen free installation cable.

### 3.8 Future Solutions

In the future, when all cells at STH have a CAN-Fiber cabinet installed and all necessary cables are connected, different solution must be implemented to be able to run different configurations of cells together, especially when they are not connected to the same MV SWG on the generator side, in this case the main obstacle would be:

- Synchronising
  - Synchronising two engines that are connected to different switchgears with no voltage and frequency reference available to the synchronisers.

#### 3.8.1 Load sharing group segmentation

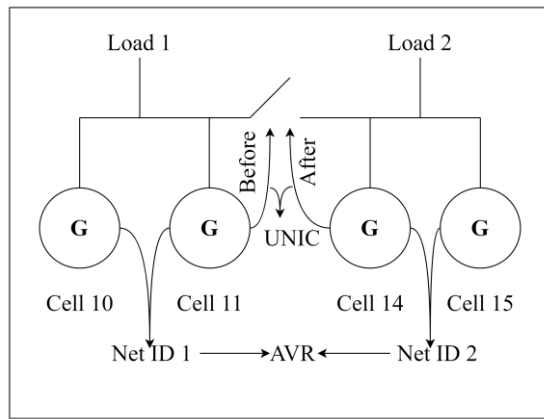
When several cells are connected to different switchgears, it would be difficult to divide AVR: s into different groups with digital secondary net signals from bus tie breakers when running many different cells at the same time. For example, running cells 10-11 and 14-15 simultaneously in isochronous load sharing mode to different loads would mean that the AVR: s would require different secondary net ID: s.

#### AVR group segmentation

A solution for getting the AVR: s in different load sharing groups would be to configure different default net id settings for both groups of AVR: s. This configuration allows multiple UNITROL AVR: s to be separated into different communication groups, while connected to the same RS-485 bus.

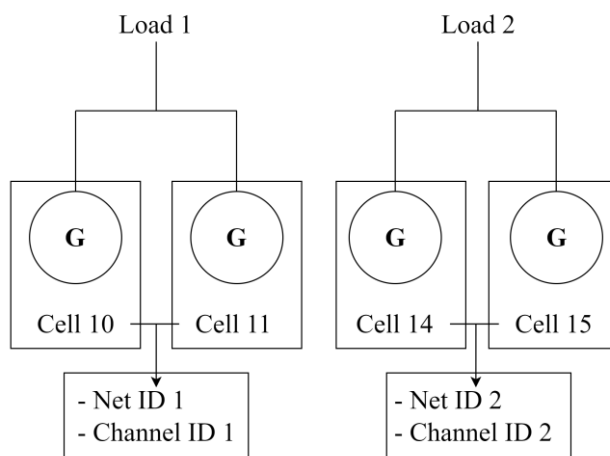
#### UNIC group segmentation

Because all UNIC units are going to be connected on a common CAN bus, it's necessary to divide the four cells into two groups. This can be done by simulating a busbar breaker open status between cells 11 and 14 like shown in Figure 30.



**Figure 30**

Another solution would be to configure different channel ID:s for the CAN to fiber units in cells 10&11 than in cells 14&15. Configuring different channel ID:s for these converters would mean that they would not communicate with each other, even though they are connected on the same bus. Figure 31 illustrates necessary settings needed for this kind of solution.

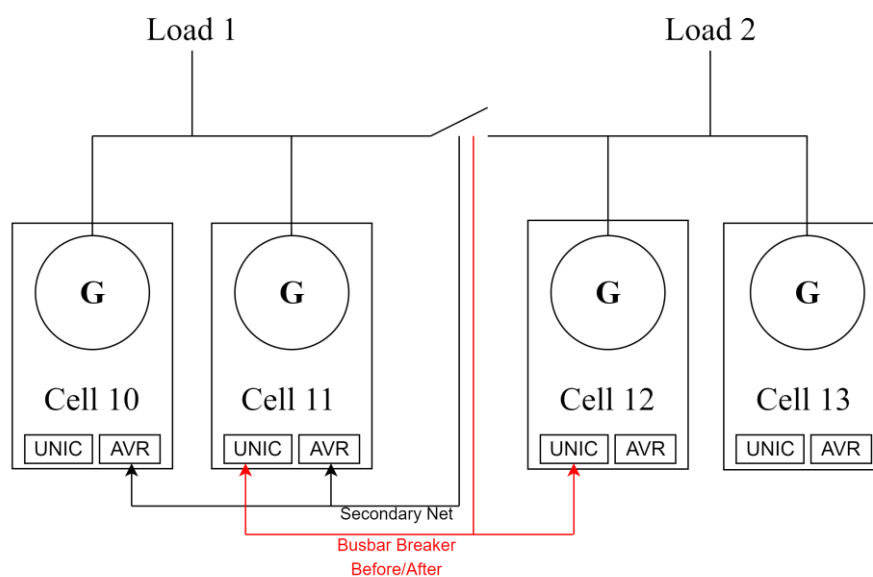


**Figure 31**

### 3.8.1.1 Cells 10-13

At cells 10 to 13 it could be possible to run cells 10-11 and cells 12-13 to different loads. To be able to run in this configuration cell 10 and 11 AVR: s needs a secondary net signal from the bus-tie breaker between cell 11 and 12. Additionally, cell 11 and 12 UNIC units also need a busbar breaker before and after signal, from the same bus-tie breaker. For cell 12 the busbar breaker signal would be configured to before and for cell 11 it would be configured to after.

These signals would make it possible for cells 10-13 to run on different loads and not interfere with each other. Closing the breaker would send a secondary net signal to cells 10 & 11 AVR: s and a busbar breaker before/after status to cells 11&12 UNIC units, which would make it possible to share loads between all the cells. Figure 32 illustrates how the digital signals would be connected.



**Figure 32 Bus tie breaker signals**

## 4 Results

After analysing the electrical system at STH on the possibilities and limitations of running several engines together in isochronous load sharing mode, solutions were found for the limiting factors that prevented isochronous load sharing operation. The solutions found in this thesis were the following:

- UNIC LS communication
  - After examining the UNIC functionality documents, it was evident that CAN communication between engines had to be established for isochronous load sharing to be possible on the engine side.
- UNITROL 1020 VDC communication
  - Reading the UNITROL 1020 manual it was found that all AVR: s operating in VDC mode needed to be connected with a RS-485 cable for communication.
- CAN distance problem
  - After a meeting with colleagues, it emerged that the CAN cable distance between cells. This was solved with finding a CAN to fiber converter that allowed for further distances.
- CAN to Fiber cabinet
  - Because the CAN to fiber converter needed to be placed somewhere inside the cells, a custom cabinet had to be made. This was solved with designing the cabinet in AutoCAD and then assembling it.
- Possible load sharing groups
  - After observing the single line diagram at STH, it was apparent that all cells were not compatible for isochronous load sharing, this is due to not all cells are connected to the same switchgear.
- Load sharing group segmentation
  - To be able to divide several cells into different load sharing groups, a plan was created on how to achieve this.

## 5 Discussion

I am satisfied with the results of this thesis, however, it was not possible to install the cabinets and connect the necessary cables needed for load sharing communication during the time period of this thesis, this is due to the cells being in normal operation and no available time was found to install everything. One thing that especially makes me thrilled about this project is that some customers have already reached out and are interested in this kind of test for their upcoming projects.

The most challenging part of the thesis was to analyse the current project at STH-HUB and find all the requirements in order to be able to operate in isochronous load sharing mode at STH-HUB, the solutions were found by reading instructional manuals of different electrical equipment and with asking questions from experts at Wärtsilä. Looking back at how I tried to find different solutions for this project, I would put more time in reading the manuals more thoroughly so that I would not have missed so many small details.

While working on this thesis I have learned a lot of new things, especially about UNIC, AVR and the how the electrical system works at STH-HUB. I believe that with this new knowledge I have gained a great advantage for my future working life. This is because I have learned a lot about many different essential electrical equipment that are especially used in power generation and power plants. With this knowledge I believe that it gets easier to obtain a workplace in the future.

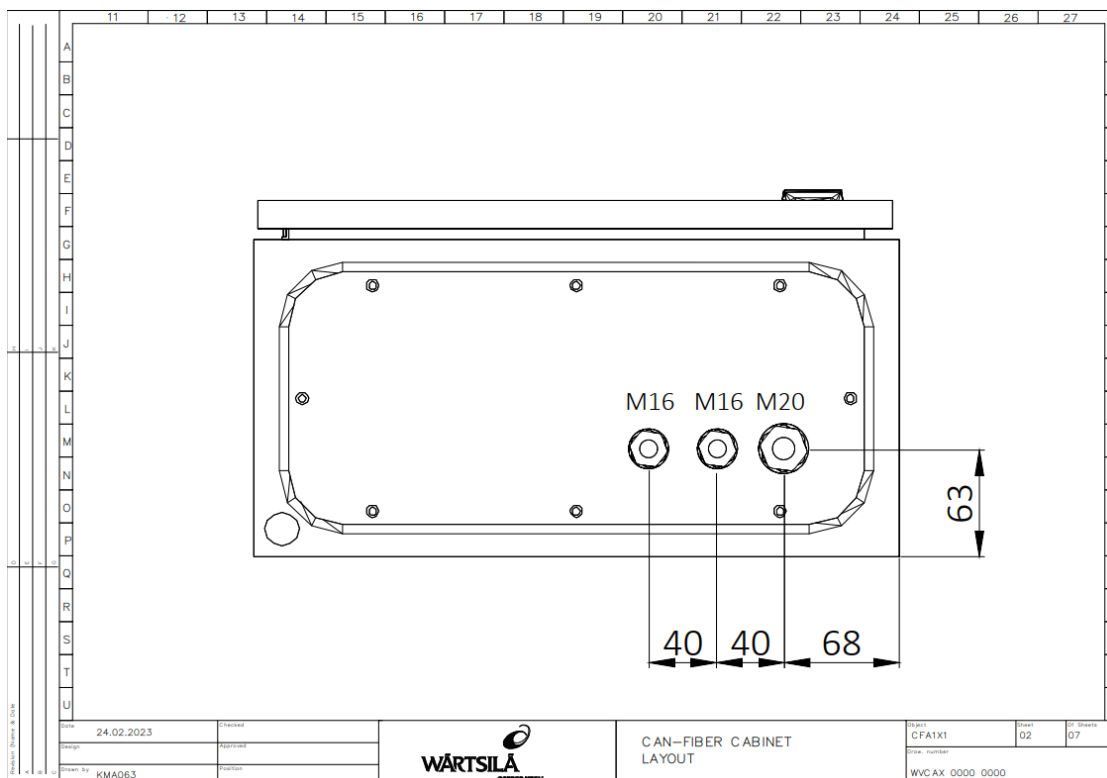
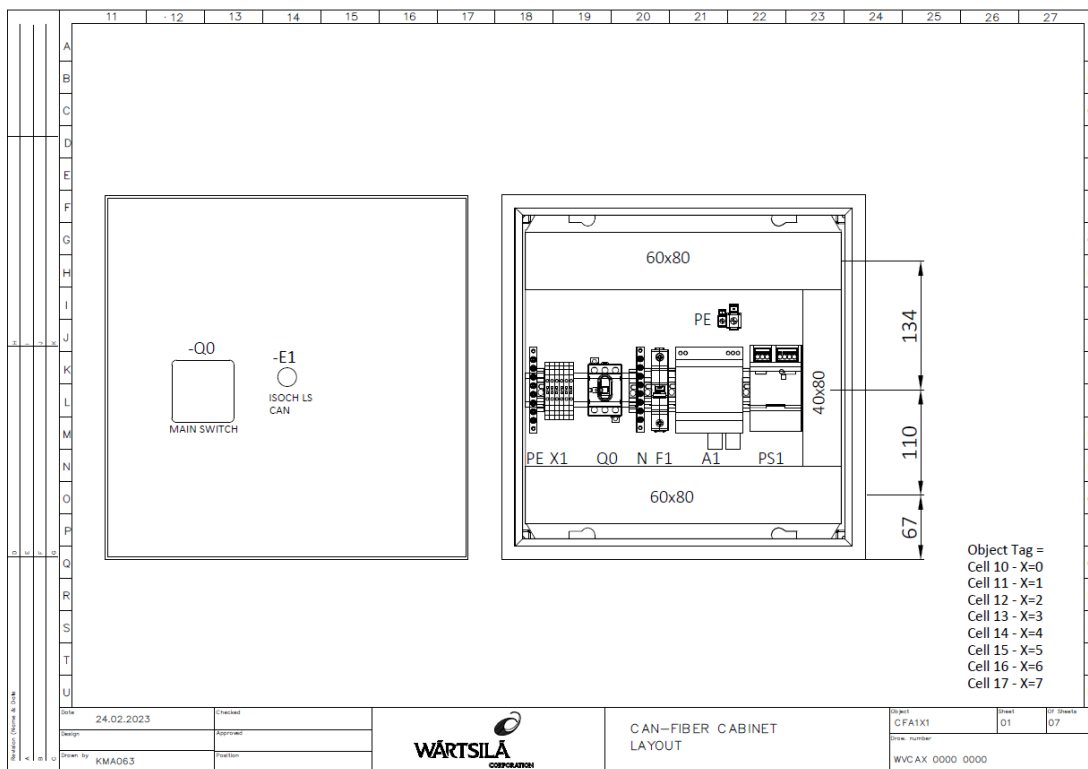
I believe that this thesis has given more value to Wärtsilä. By adding this kind of special test to Wärtsilä's portfolio they are ready to offer isochronous load sharing test solutions if the customer demands it in the future. By installing this system in every cell at STH-HUB, Wärtsilä has made it easy to perform isochronous load sharing test in the future in addition with removing potential problems in the future.

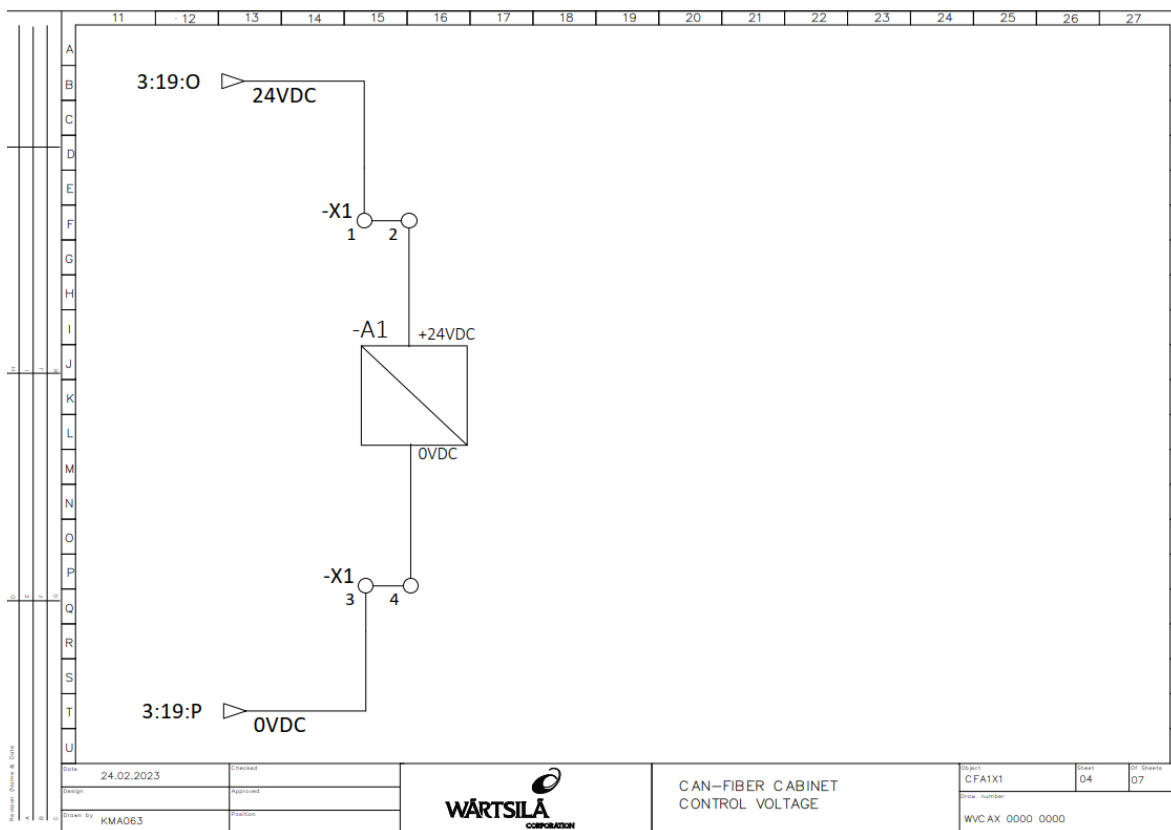
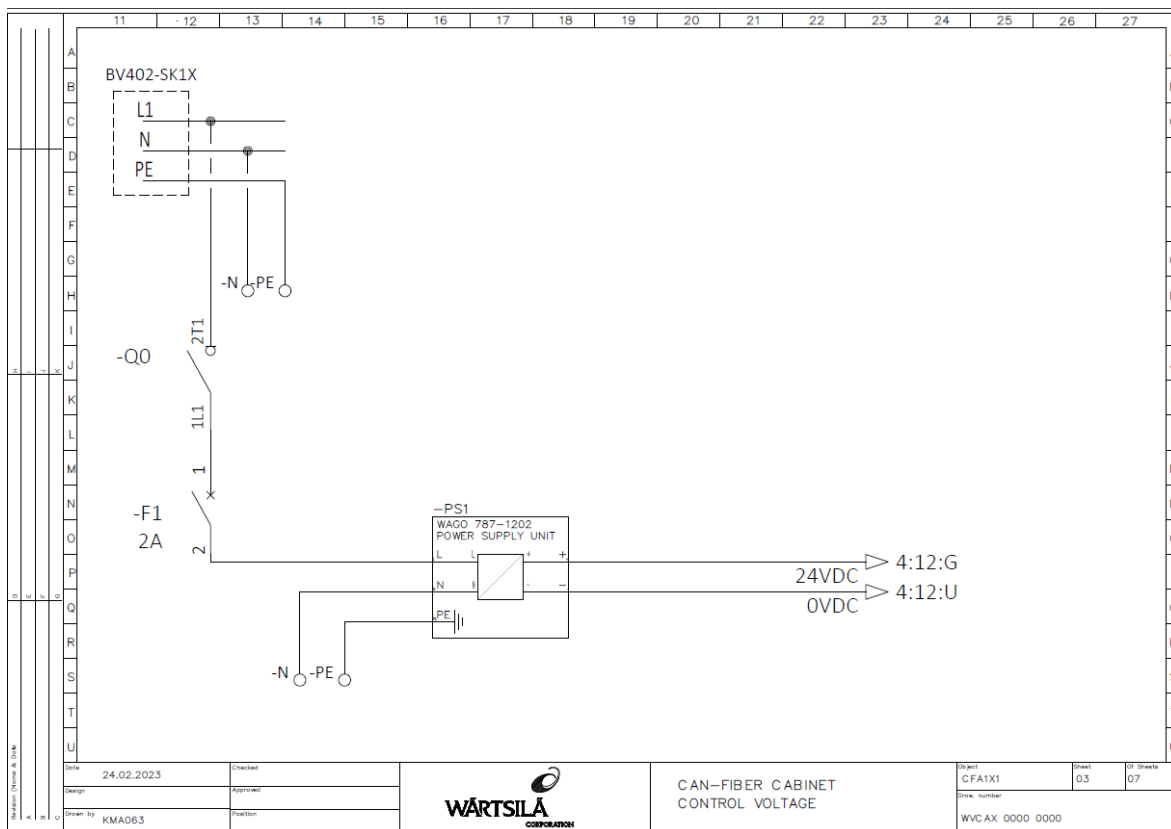
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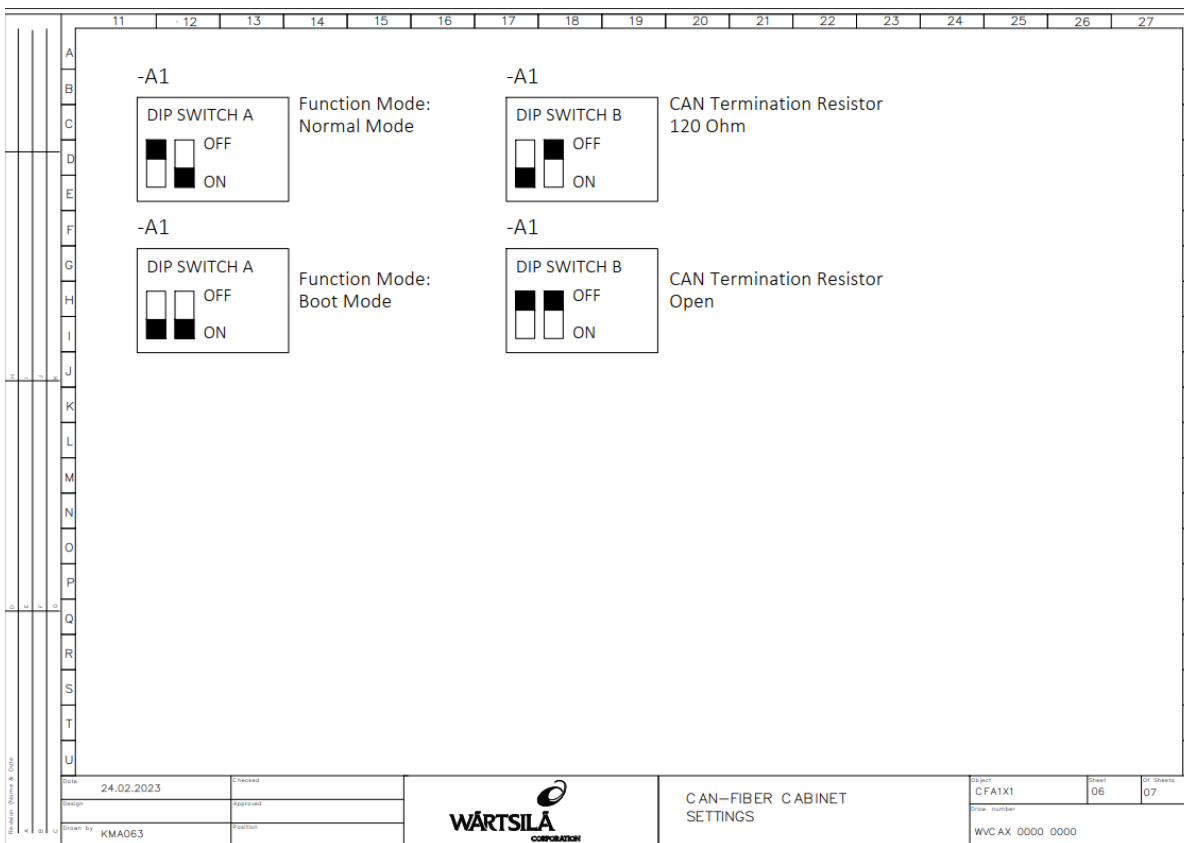
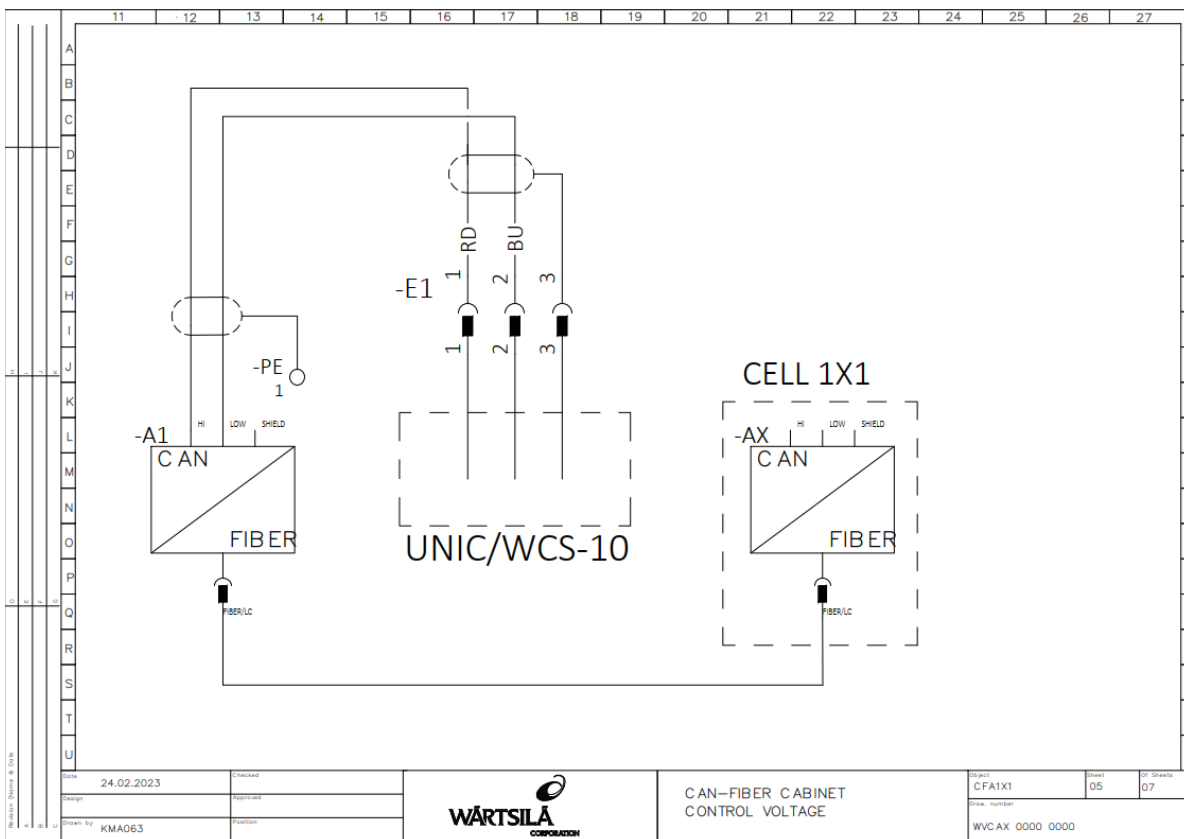
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Appendix 1: CAN to fiber cabinet drawings








TA G	QTY	CATALOG	MFG	DESCRIPTION
-Q0	1	OHBS2AJ	ABB	OHBS2AJ SELECTOR HANDLE
	1	OT16F3	ABB	OT16F3 SWITCH-DISCONNECTOR 16 A
-F1	1	S 201-C 2	ABB	S200 MINIATURE CIRCUIT BREAKER, PRO M COMPACT 1-POLE CIRCUIT BREAKER 2AMPS C-TRIP CHARACTERISTICS - CABLE AND EQUIPMENT PROTECTION 480Y/277VAC, INTERRUPTING CAPACITY: 6ka, DIN RAIL MOUNTING 2CDS251001R0024
-A1	1	HD67702-C-0-H5S-H5S	ADFWEB	CAN / Single-Mode Optic Fiber - Converter (Daisy chain fiber connections allowed: Multi-drop, redundand Double loop, Point to Point)
-PE	1	KM10G	HAGER	BUSBAR TERMINAL BLOCK WITH 10 MOUNTING POINTS FOR EARTHING CONNECTIONS 750 V
	1	0423027	PHOENIX CONTACT	POWER TERMINAL BLOCK - AKG 16 GNYE POWER DISTRIBUTION 76AMPS GREEN-YELLOW, 1.5-16MM^2, 16-6 AWG CLIPLINE - MODULAR SCREW TERMINAL BLOCK
-N	1	KM11N	HAGER	BUSBAR TERMINAL BLOCK WITH 11 MOUNTING POINTS FOR NEUTRAL CONNECTIONS 750 V
-PS1	1	787-1202	WAGO	SWITCH MODE POWER SUPPLY 24 VDC OUTPUT, 2.5 A SINGLE-PHASE
-X1	4	1011200000	WEIDMULLER	DISCONNECT TEST TERMINAL - WTR 2.5 DISCONNECT 10AMPS DARK BEIGE WEMID, 22-12AWG, 2 StB 2.3 SERIE W - SCREW CLAMP, MOUNTS ON DIN RAIL
-E1	1	SP2112-5S	WEIPU	Waterproof panel connector IP68 5-pin female

Date	24.02.2023	Checked			CAN-FIBER CABINET BOM	Project	CFA1X1	Sheet	07	Of Sheets	07
Design		Approved				Draw. number					
Drawn by	KMA063	Position									