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PLANNING OF AN EMERGENCY STOP SYSTEM FOR A TESTING FACILITY

Wärtsilä Vaskiluoto Engine Laboratory

School of Technology
2017

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TIIVISTELMÄ

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Tämän opinnäytetyön tarkoituksena on tutkia ja kehittää hätäpysäytysjärjestelmä Wärtsilän Marine Solutions - moottorilaboratorioon. Moottorilaboratorio sijaitsee Vaasassa, Vaskiluodossa. Nykyinen hätäpysäytysjärjestelmä on rakennettu muokkaamalla alkuperäistä järjestelmää. Rakennus on alunperin toiminut voimalaitoksena, josta se on muutettu moottorilaboratorioksi vuonna 2004. Moottorilaboratoriota on laajennettu useampaan otteeseen vuosien saatossa.

Monien muutosten vuoksi nykyisen järjestelmän muokkaaminen tarpeita vastaavaksi on hidasta ja monimutkaista. Järjestelmän toiminta pohjautuu useampaan erilaiseen ratkaisuun, suurilta osin vanhaan relelogiikkaan, joka ei täytä nykyisiä tarpeita. Tässä työssä suunniteltu järjestelmä on sopiva moottorilaboratorioon. Suunnittelu ja yksityiskohtaiset piirustukset kahdesta hätäpysäytysjärjestelmän paneelista on tehty AutoCAD 2016 ohjelmalla, sisältäen tarpeelliset sähkö- ja mekaaniset piirustukset.

Käyttämällä safety PLC:tä ja hardwire – kommunikaatiota, saadaan rakennettua hätäpysäytysjärjestelmä, joka on ominaisuuksiltaan sopiva jakuvasti muuttuvaan ympäristöön. Järjestelmä on suunniteltu mahdollisimman itsenäiseksi, mikä mahdollistaa järjestelmän toimivuuden ympäristöstä riippumatta. Tämä vähentää muutoksista johtuvien pysähdyksien määrää, parantaen testilaboratorion toimintaa vähentämällä turhia pysäytyksiä. Suunniteltu systeemi täyttää sille asetetut toimintavaatimukset. Suunniteltu systeemi otetaan käyttöön moottorilaboratoriossa alue kerrallaan, mahdollisuuksien mukaan. Tavoitteena on laajentaa suunniteltu systeemi kattamaan koko moottorilaboratorio.

Avainsanat järjestelmä, logiikka, safety PLC ja testilaboratorio

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ABSTRACT

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The purpose of this thesis is to study different possibilities of emergency stop systems to Wärtsilä Marine Solutions engine laboratory. The engine laboratory is located in Vaasa, Vaskiluoto. The current system has been expanded several times on top of original system. The facilities was originally a power plant and had been rebuilt as an engine laboratory in 2004, the engine laboratory has been rebuilt and enlarged on multiple times during the years.

Due to multiple expansions, flexibility in updating the emergency stop system needs improvement. The current system is based on multiple different technical solutions, partially on old relay logic, which does not meet the requirements on flexibility. The new system is designed to fit in the test facility environment. The designed system is planned and detailed drawings for the two panels were made with the AutoCAD 2016, including detailed electrical drawings with the mechanical drawings.

With the safety PLC system and hardwire communication, the emergency stop system is made suitable for constantly changing environment. The system is designed to be as independent as possible to ensure the functionality of the system, as well minimizing the downtime caused by the modifications and chances around the system. Designing of the system fulfils the requirements given to it and the designed system is taken in use at the test laboratory, one area at a time wherever possible.

Keywords system, logic controller, safety PLC and test laboratory

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The appendices were removed due to customer's request.

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APPENDIX 3. Electrical cabin CJU541 mechanical drawings.

APPENDIX 4. Electrical cabin CJU941 electrical drawings.

APPENDIX 5. Component listing.

LIST OF ABBREVIATON

CUS	Customer order specific
FBD	Function Block Diagram
HFO	Heavy fuel oil
kW_e	Electrical power
kW_m	Mechanical power
NC	Normally closed contact
NO	Normally open contact
PDT	Pole Double Throw, NO/NC contact
VDC	Direct Current Voltage
WPPP	Wärtsilä Pilot Power Plant

1 INTRODUCTION

1.1 History of Wärtsilä Oyj

Wärtsilä was established in 1834 at Saario rapids as a sawmill. The sawmill was bought by N.L. Arppe, who build an iron mill on the place of the sawmill. In the following years Wärtsilä grew rapidly expanding various manufacturing plants and companies. The company´s headquarters moved to Helsinki in 1935 and Wärtsilä invested heavily in ship manufacturing business. In 1942 the first diesel engine was manufactured in Turku factory as a licence engine. Today Wärtsilä is the global leader in advanced marine technology and energy markets. /1/

1.2 Organisation

Wärtsilä Oy consists of three divided areas, Energy Solutions, Marine Solutions and Service. /2/ Energy Solution focuses on delivering flexible, efficient multi fuel power plants for customers and fuel handling solutions. /3/ Marine Solutions is focused on marine industry, mainly on marine engines, ship designing, propulsion systems and auxiliary systems at marine industry. /4/ Service is focused on supporting Energy Solutions and Marine Solutions. Service offers spare parts, maintenance and operation solutions for Energy Solutions and Marine Solutions customers. /5/

1.3 Vaskiluoto Engine Laboratory

The Vaskiluoto Engine Laboratory is located in Vaskiluoto, Vaasa. Wärtsilä Pilot Power Plant, WPPP Diesel Combined Cycle Plant was taken in use an 1997. The Power plant consisted of two engines and a steam turbine.

The two Wärtsilä engines were Wärtsilä 12V64 (23,280 kW_m) and Wärtsilä 20V46F (23000 kW_m). The engines used a heavy fuel oil (HFO) as a fuel. The exhaust heat of the engine was recovered in boilers and used to power the steam turbine. The steam turbine was manufactured by ABB Turbinen Nürnberg GmbH. The electrical efficiency of the turbine was 5 MW.

The power plant was producing electricity for the Vaasa area until 2004 Wärtsilä converted the power plant into a testing facility for validating engines and engine parts. The testing facility environment required changes and the steam turbine with steam boilers have been removed. The facility has been expanded many times as the original power plant building consisted of two engine cells, an auxiliary area, two boilers and the steam turbine. Today the building consist of three engine test cells, two single cylinder test cells and multiple test rig areas with auxiliary areas.

1.4 Objectives and Requirements

The objectives of this work are to create a standard expandable emergency stop system solution which is suitable for the test cell environment at engine test laboratory. The work consists of a study of a current system, a comparison of different technical solutions and selecting the most suitable one. The suitable solution should have the following characteristic:

- The emergency stop system should be modular for adding or removing emergency system areas without having an effect on the rest of the facility.
- Adding or removing functions to the emergency stop system without disturbing the operation of the rest of the facility.
- Universally expandable for new test cells and areas in the testing facility.

The chosen solution is planned in details, then one module should be constructed, implemented and tested.

2 ORIGINAL SYSTEM

2.1 The Building

The engine laboratory has been expanded for a few times and testing facilities has been rebuild multiple times. The testing facilities are under constant changes for meeting requirements for testing and validation purposes. The engine laboratory consists of three engine test cells, two single cylinder test cells and multiple test rig areas with auxiliary areas. The emergency stop system has been expanded along with the old system as the facilities has been rebuild and expanded. The expansions have been built with own emergency stop systems connected to the original system. At the expansions some new solutions have been tested for the emergency stop system, varying from simple relay based solutions to the safety PLC solution.

The most complex system is the original emergency stop cabin, named as BAP903, located in the auxiliary area. It was built in 1997 to be used as an engine power plant emergency stop system and modified to suit test facility environment. The cabin works as an emergency stop cabin for engine test cells 1 & 2 as the auxiliary area, controlling the equipment in the auxiliary area according to the test cells emergency stop requirements. The BAP903 acts as a junction point for the fire alarm signal. If a fire alarm occurs, the BAP903 creates a fire alarm signal for all emergency stop areas, generating emergency stop to the testing facility.

2.2 Impracticality of BAP903

The electrical cabin BAP903 consists of 48 pieces of 110 VDC relays, creating relay logic for emergency stop function. The cabin is powered with one 110 VDC UPS feeder (UPS = Uninterruptible Power Supply) through circuit breaker. A circuit breaker protects the cabin electrical equipment in case of short circuit or other fault in the electrical cabin. This non-redundant power supply system creates a situation; when a circuit breaker trips or feeder shuts down, it creates a situation equal to fire alarm, generating an emergency stop to testing facility.

Some of the cabin functions have been bypassed with jumping cables for modifying the functionality of the relay logic more suitable for current setup, as part of the systems has been removed or modified heavily. As seen in Figure 1, the cabin cabling has been modified many times creating a messy wiring. One of the greatest problems with the cabin is that the documentation for modifications is unclear, the cabin is not in the same state as shown in the electrical drawings. The modifications have not been marked with full details or marked at all. The cabin has limited space for expansions or modifications.

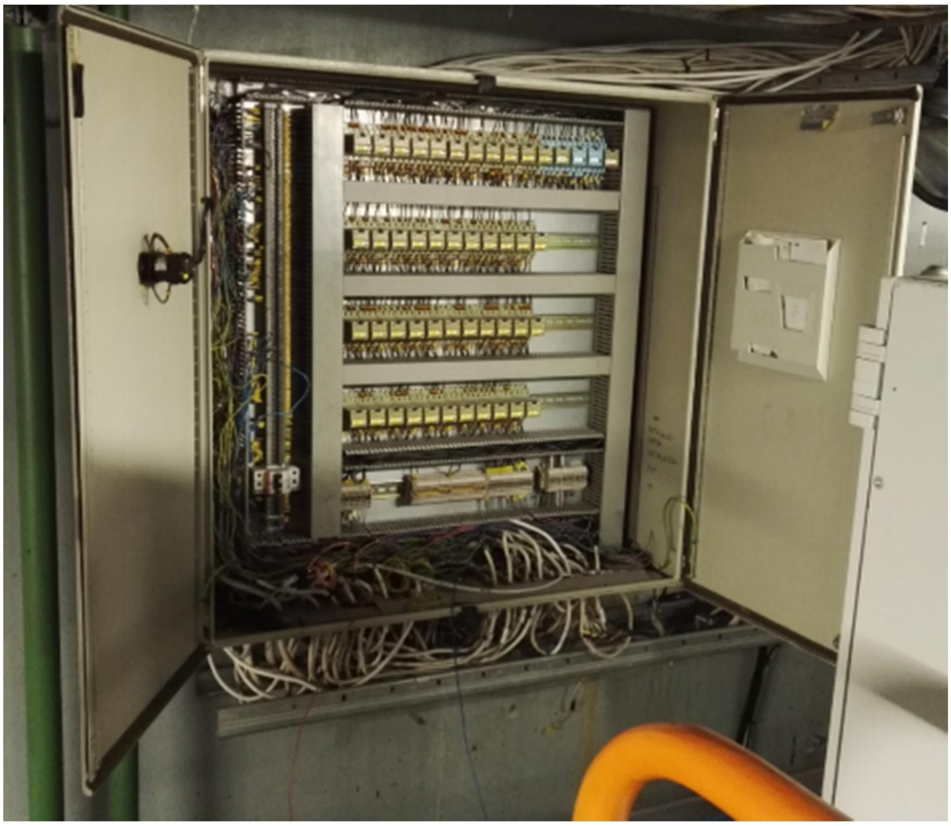


Figure **1.** Common panel BAP903 messy and unclear wiring created by many modifications and add-ons.

As the cabin has been built using a relay logic the single fault at wiring or faulty contact in the logic tree can create a danger situation as functionality of the relay logic is crippled. A crippled system may have part of functions intact and the system may seem to work as it should be. A danger situation is created when an emergency stop is demanded but the partially crippled system cannot perform a full emergency stop as required, for example some machines do not get a stop signal and stay on.

2.3 Current System

As in test cells, the emergency stop system varies and every test cell has its own solution. Without common guidelines or instructions the emergency stops in the test cells have been built with a solution found to be most suitable to use at the moment. Solutions vary from simple relay logics to safety PLC solutions. Different areas have different solutions, without common guidelines every design is different. The simplest solution is the relay based solution, a simple relay logic with the relay contact connected on the machine control circuit for emergency stop purposes. The safety relay is slightly advanced version compared to the relay solution, slightly reducing the relay logic as the safety relay itself has an integrated locking for blocking an unintended start after an emergency stop button has been restored. The safety PLC solution is programmable logic controller based solution, consisting of safety-classified, freely programmable PLC-hardware.

The main difficulties with the current system have occurred with the common panel BAP903. BAP903 has been originally used as an emergency stop cabin for the power plant and modified for the use of testing laboratory. The main modification for BAP903 is to share the fire alarm signal for all parts of the building to stop the machines for safety reasons and shut down the building equipment to prevent the fire spreading as a fire alarm occurs.

2.4 System Usability and Flexibility

At the moment (2017) BAP903 is serving as an emergency stop cabin for test cells 1 & 2 and the auxiliary area as sharing the fire alarm signal. As the cabin serves many areas, it creates an inflexible junction for adding or removing areas. Many expansions and modifications have created messy wiring and cabling inside BAP903, increasingly slowing down the modifications. In case of modification of the relay logic the whole building is affected for one point modification, slowing down the testing inside the building unnecessarily. For adding new equipment for the emergency stop system the cabin has a few potential free contacts left. Other areas consist of emergency stop system comprising a relay or safety relay based solution integrated into the control cabin. The newest test cell, number 7 has safety PLC – based solution. Test cell 7 uses Phoenix Contact freely configurable safety module PSR-TRISAFE-M, with one safety relay expansion to archive the needed functionality for the single cylinder engine.

3 STANDARD SYSTEM PLANNING

3.1 Emergency Stop Effected Areas

The EU Machinery Directive 2006/42/EC determines the emergency stop installation requirements for machines as following: “*Machinery must be fitted with one or more emergency stop devices to enable actual or impending danger to be averted.”*. /6/

And adding following expectations:

- “*machinery in which an emergency stop device would not lessen the risk, either because it would not reduce the stopping time or because it would not enable the special measures required to deal with the risk to be taken,*
- *portable hand-held and/or hand-guided machinery.”* /6/

The EU Machine Directive 2006/42/EC requires an emergency stop device to be fitted on machine or equipment to stop the dangerous situation if the emergency stop reduces the stopping time of the machine. In the test laboratory the emergency stop reduces stop time as the control system has a possibility for the fault and the control system may not have total control of all the machines in the area. For this reason the emergency stop system is required on the testing facility. The test laboratory consists of many machines creating a complex systems that can cause an actual or impending danger for the operator. A danger situation can be ended or averted quickly with an emergency stop. When the operator notices a danger or a potentially dangerous situation in the area, the closest emergency stop pushbutton located in the area has to be effective to stop the machines and stop the danger or the potential danger situation. If an emergency situation occurs, the operator should to be able to stop the potential danger situation or danger at the closest emergency stop pushbutton in the area and in the control room.

3.2 Emergency Stop Areas

The emergency stop system controls a certain limited area. Mostly the building itself creates the limits on what is practical and safe to connect to the emergency stop system in the area. As the emergency stop has been modified from the original emergency stop system, it has created overlapping in the area at test cell 1 and 2 in the auxiliary area seen in Figure 2.

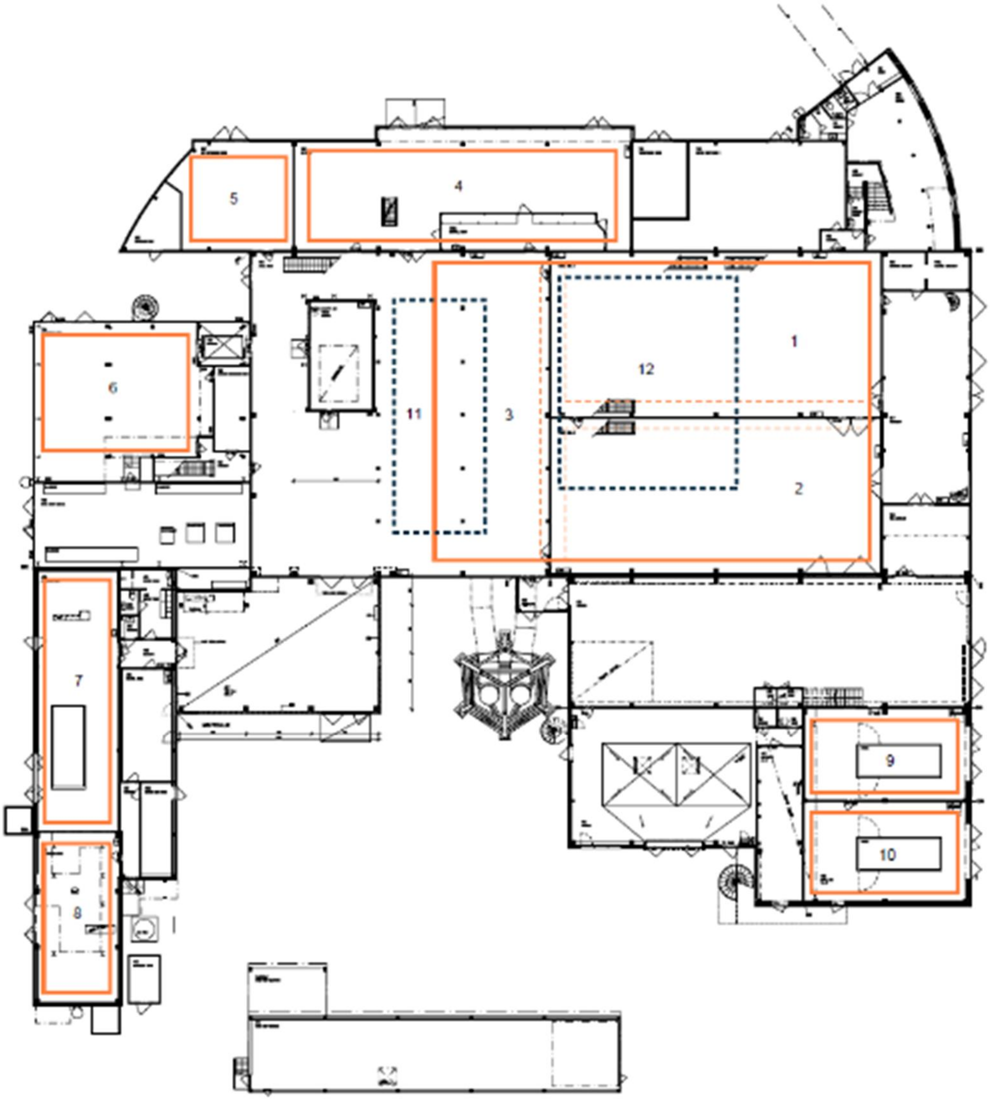


Figure **2.** Existing emergency stop areas in the building. Orange lines shows the 1st. floor emergency stop areas and blue dotted line the 2nd. floor emergency stop areas.

By separating the over-lapping areas and creating a fully independent emergency stop area, it is possible to ensure the correct functionality for the emergency stop at all the areas without a effecting other areas. For ensuring the functionality the auxiliary area emergency stop system has a hard wire communication for test cells 1 and 2. The control of the auxiliary area equipment emergency stop is in auxiliary area emergency stop system. If an emergency stop occurs on test cells 1 or 2, the auxiliary area emergency stop system controls the auxiliary area equipment according to needs of the test cells 1 and 2. In the other areas the emergency stop system has only effect on the machines in the area of the emergency stop pushbutton. This area is limited physically to a room or a certain area. The main point with the emergency stop areas is that if the operator sees a danger or potential danger situation, the operator can stop or avert the danger on closest emergency stop pushbutton in the area.

The only change in the existing areas of the emergency stop systems are in the auxiliary area, separating the auxiliary are to its own emergency stop system for test cells 1 and 2. The building consists of three engine test cells, five test rig areas, two single cylinder test engines and two multi-purpose areas as seen in Figure 3. All the areas have to have their own emergency stop system only serving an exact area. This ensures the independency of emergency stop areas and meets the requirement as independent emergency stop areas can be modified and added/removed without disturbing of the functionality of other areas, eliminating downtime of the test cells and test rigs in case of modification of the system.

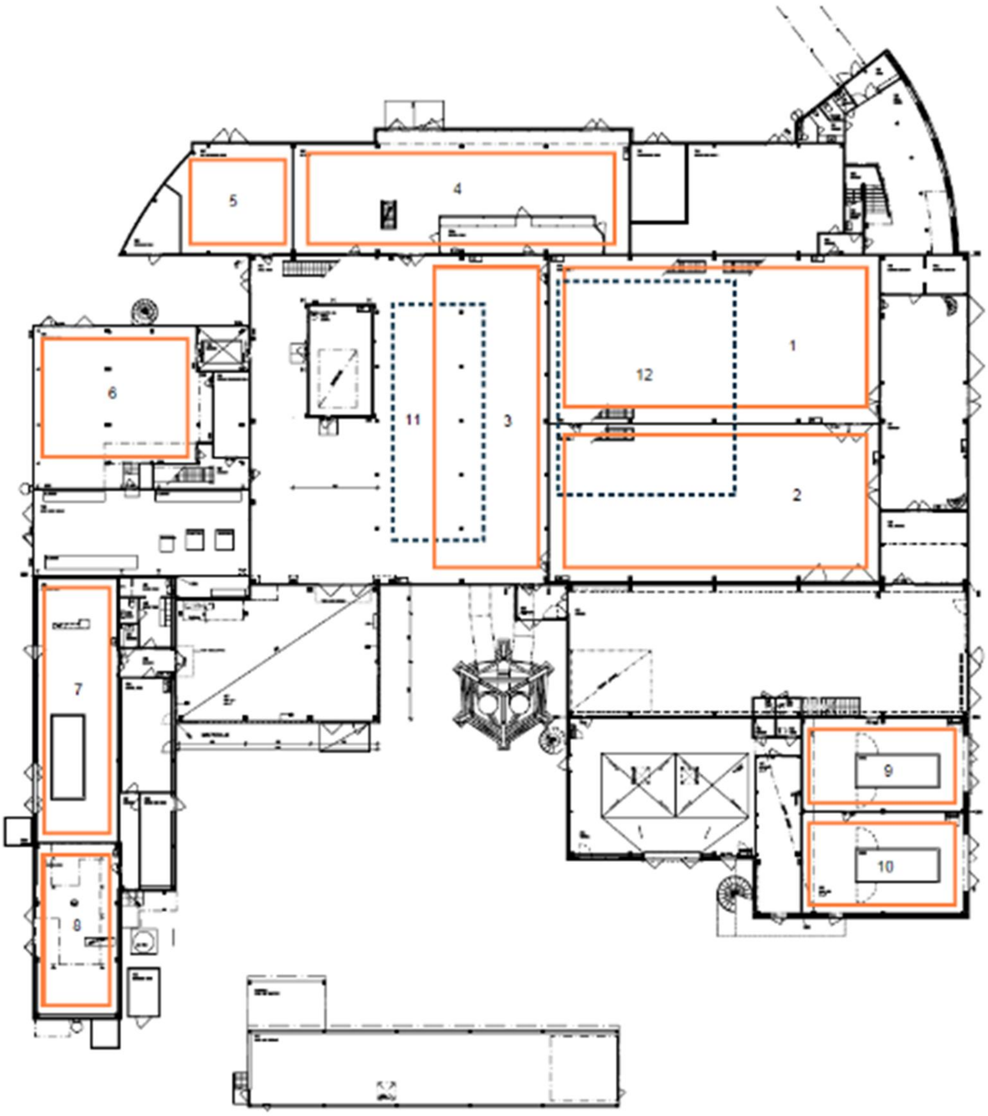


Figure **3.** Planned building emergency stop areas. Orange lines shows the 1st. floor emergency stop areas and blue dotted line the 2nd. floor emergency stop areas. Building consist 12 areas and 12 emergency stop areas.

3.3 Different Technical Solutions

The most common technical solutions can be divided into three different technologies already used at the building: 1. Relay 2. Safety relay 3. Safety PLC. Each of these three different technical solutions has its advantages. A short review shows differences between the solutions.

3.3.1 Relay solution

The emergency stop solution with relays requires a hardwired relay logic. Adding and removing equipment for the emergency stop system is simply to add a new relay on the emergency stop cabin in the control circle with others to archive the required potential free contact for the equipment. Adding more functions or modifying the functionality requires carefully planned wire and relay modifications. The relay based solution has a few advantages:

- Low cost solution
- Simple design
- Easy repairs and maintains by simplicity

While relay based solutions have a few notable advantages, there are also disadvantages:

- Inflexibility for the changes
- Functionality modifications requires hardware modifications
- Relay logic failure can paralyze the system in emergency situation

3.3.2 Safety Relay Solution

The emergency stop solution with safety relays integrates interlocking with the emergency stop system. The safety relay reduces the number of relays as the safety relays add interlocking. Safety relays require relays as an expansion to share the alarm on with the equipment and to a create sub-logic for necessary logic functions and functionality as the system serves a lot of equipment in the electrical cabin. The advantages of the safety relay solutions includes:

- Low cost solution
- Interlocking function integrated in safety relay
- Safe functionality through the safety relay

As the safety relay is a more advanced solution compared to the relay solution, it comes with a few disadvantages:

- Inflexibility for changes
- Logical functionality for the equipment control with relay extensions
- Relay logic failure can paralyze the system in an emergency situation
- Different alarms their own safety relay

3.3.3 Safety PLC solution

The emergency stop solution with a safety PLC solution eliminates all needs for a hardwired logic, as the safety PLC programming functionality allows all the logic functions inside the safety PLC. Every equipment is connected to the safety PLC and the safety PLC logic controls the equipment according to the logic programming. For changing the safety functions no hard wire modifications are needed as the safety functions can be changed through the safety PLC programming. Every times the safety PLC programs are modified, the program functionality needs to be tested with suitable methods to ensure the safety of the system. The advantages of the safety PLC solution includes:

- Flexibility for modifications
- Functionality modifications do not require the wire modifications
- Programming allows many individual safety functions
- Hard-wired communication

The safety PLC solution has only a few disadvantages compared with other solutions, including the high cost of parts and relatively high space requirements for the cabin installation.

3.4 Suitable Solution

The customer recommended creating the emergency stop system using the safety PLC solution as the building is in constant changing for the test purposes. With the flexibility of the safety PLC the emergency stop system is a flexible. Independent safety areas give a significant advantage for the current system, adding or removing area does not have an effect on the functionality of the other areas, reducing valuable test time loss for modifications of the safety system.

When comparing the technical solutions the safety PLC system has many advantages over the relay and safety relay solution. The main advantages of the safety PLC solution over the other solutions include programming, wiring simplicity, expandability and hardwired cross - area communication possibilities. The cross area communication enables the possibility to control safely the devices safely, which affects the safety of the area but are located on the other areas.

3.5 Hierarchy of Planned System

The hierarchy of the emergency stop system is divided into two levels. The first level, the common panel controls all the test emergency stop areas and building equipment and the second level at the independent emergency stop areas with each one with the own emergency stop equipment. Common panel alarms override the functionalities of the emergency stop areas. For example, when a fire alarm occurs, the common panel stops the common equipment in the building and every test cells emergency stop system gets a signal for fire alarm. The own systems in the emergency stop area performs an emergency stop according to the programming, stopping all the equipment in the area for the fire alarm. The common panel has no direct effect on the emergency stop areas, only through the area emergency stop system.

If the operator pushes the emergency stop pushbutton, the emergency stop system in the area is activated and performs an emergency stop in the area, stopping a potential danger or danger situation. The area emergency stop system is only effective inside the emergency stop area, unless necessary for safety of the area. The basic principle of the hierarchy can be seen in Figure 4.

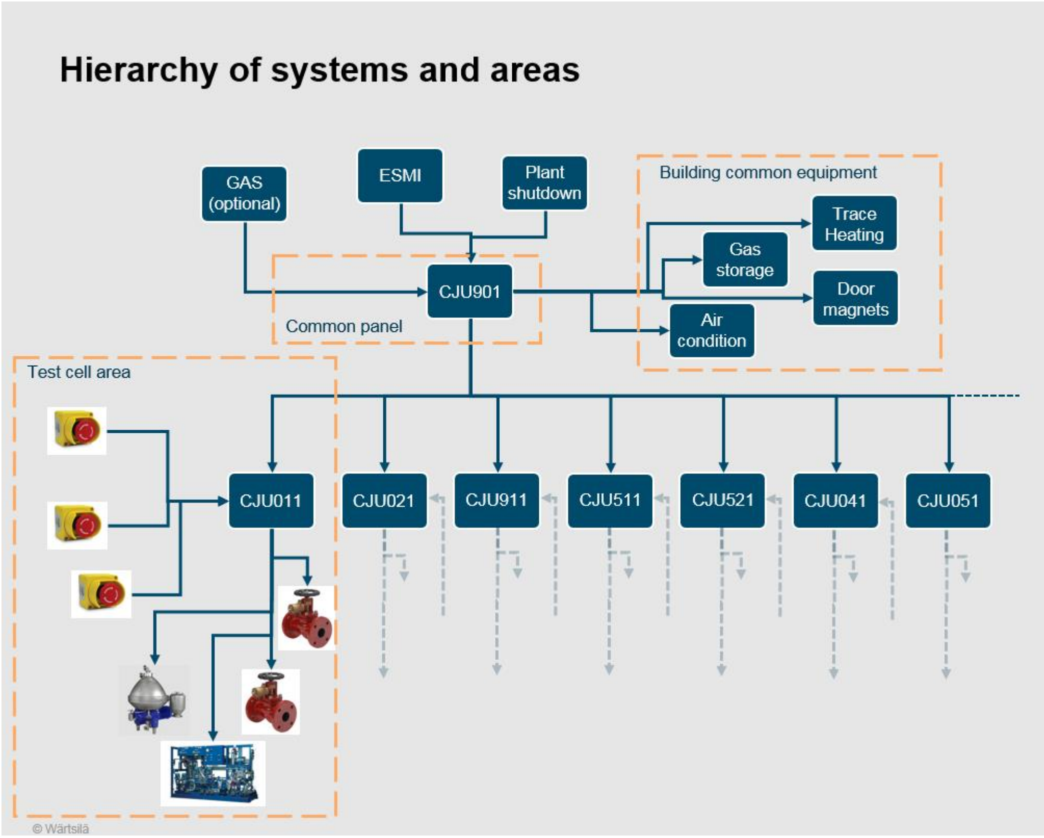


Figure **4.** Principle of hierarchy in the emergency stop system.

3.6 Technical Solution of Emergency Stop

The emergency stop has an effect on the equipment in the emergency stop area creating a stop-signal for the machines located in the area. Every machine has its own control system, mainly operated on/off by the operator or the test cell PLC. When the operator requests an emergency stop, the operator pushes the closest emergency stop pushbutton opening the emergency stop circuit. The opening of emergency stop circuit is noted by the safety PLC and the safety PLC controls electrical components according to the program.

In the emergency stop cabin every machine has one potential free N/O contact in use for the emergency stop control. With a potential free contact the machine connected to the emergency stop system has no voltage limitations and requires less modifications for connecting equipment into the emergency stop system. The N/O contact is connected to the equipment control circuit as the contact is closed, equipment can run. If the contact opens, the machine stops by de-energising the power circuit, done directly by N/O contact cutting the power for the machine main contactor or machine control circuit. The machines might need minor modifications to suit on system. A usual modification of the machine to fit the system is to connect an emergency stop relay K700 on control circuit. Relay K700 controls the main contactor of the machine, blocking the activation of main contactor in case of an active emergency stop. A fire alarm comes to the common panel as a hard-wired signal. The technical principle is shown in Figure 5.

Usually emergency stops have been connected to one “ring”. For adding flexibility all emergency stops have individual input on the safety PLC. Emergency stop pushbuttons is connected to the safety PLC with programming. Adding an emergency stop pushbutton as individuals reduces the time used for modifications, as every emergency stop has individual cabling and adding a new pushbutton does not require modifications in the existing installations.

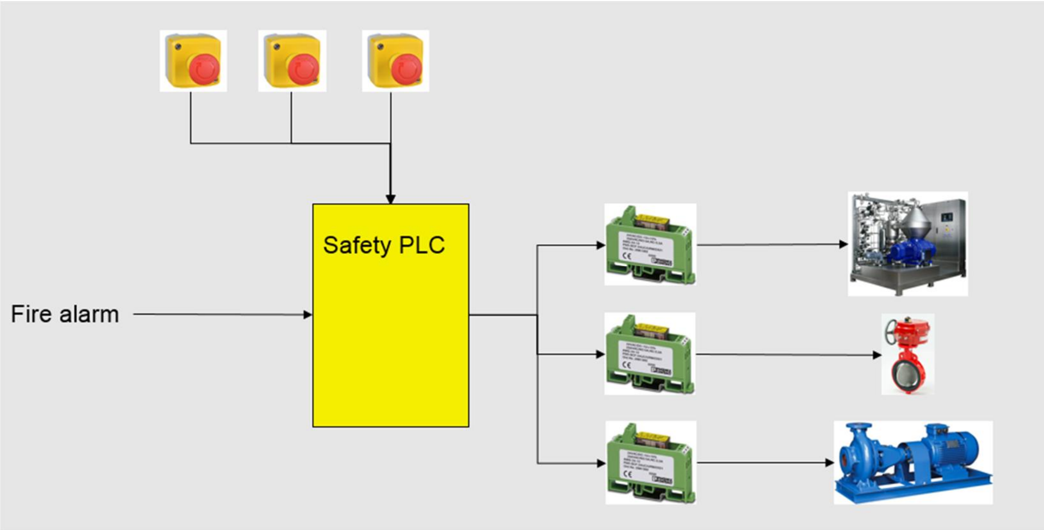


Figure **5.** Technical principle of the emergency stop area.

If cross-area communication is needed between different emergency stop areas, for example test cell 1 and auxiliary area, the common cabin has six pre-wired connection to all emergency stop cabins. One pair is used for fire alarm information, leaving two pairs for each test cell free to use. If the safety of the system requires the control of the equipment in another area, these existing connections can be used to hard-wire communication the between areas. Common panels act as a junction box for hardwire communication as minor wiring modification allows hard-wired communication between the test cells, saving installation time as no cable installations needed.

For increasing the independency of each emergency stop system, the emergency stop system is installed in its own electrical cabin inside the emergency stop area.

3.7 Technical Solution of Common Panel

The common panel replaces original BAP903 in the building. The main function of the common panel is to share fire alarms in the emergency stop areas and control the building equipment. BAP903 emergency stop functions for the auxiliary area, test cell 1 and 2 will have their own emergency stop cabins as divided into their own emergency stop areas. The common panel shares the fire alarm signal a hard-wired signal for the emergency stop areas, maximizing the independency of the emergency stop system areas. Hardwired communication is technically done with the relay contact of the safety PLC extension cards, each extension card has four independent relay contacts. Hard-wired communication allows modifications and adding a new emergency stop area without affecting other emergency stop areas. Hard-wired communication keeps the system reliable and simple, allowing flexible modifications unlike any other technical solutions. The basic principle can be seen in Figure 6.

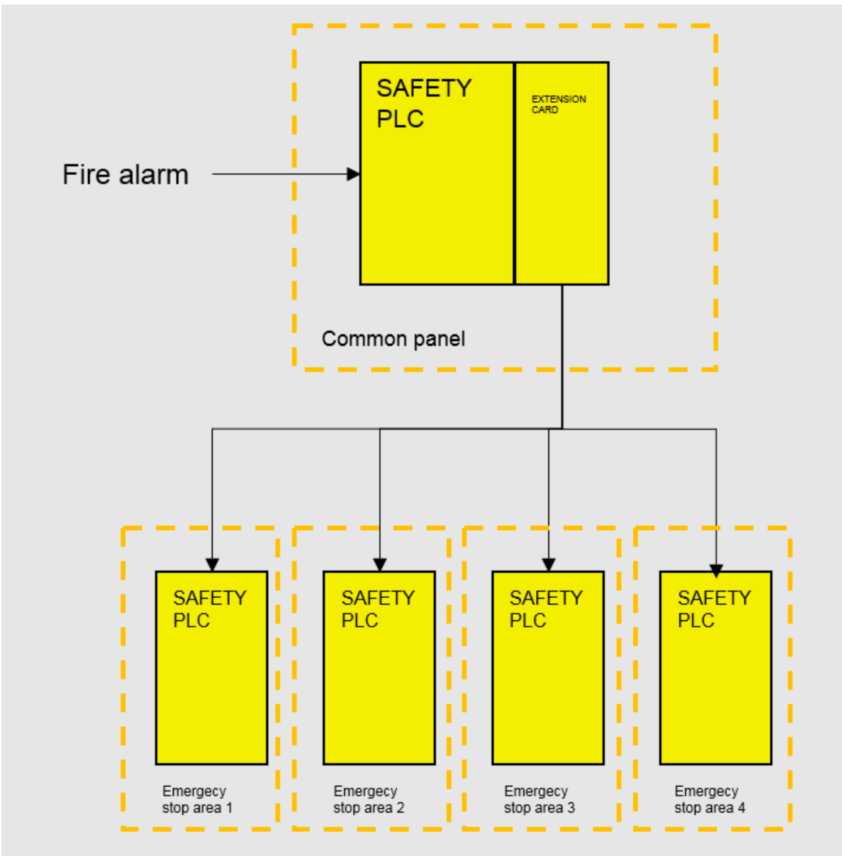


Figure **6.** Technical principle of the common panel.

3.8 Naming of the System

The naming of the emergency stop cabins has a certain kind of logic. The name of the common panel name CJU901 consists of the following logic:

- CJU = According to Wärtsilä Power Plants grouping & coding of process & signals the code of emergency stop system
- 901 = 9 as the first number indicates the common system and 01 indicates the first in the series

An emergency stop cabin CJU021 at the test cell areas:

- CJU = According to Wärtsilä Power Plants grouping & coding of process & signals the code of emergency stop system
- 021 = 02 as the first two number indicate the second test cell. 1 as the third number indicates the first system in the area

An emergency stop cabin CJU511 at the test rig areas:

- CJU = According to Wärtsilä Power Plants grouping & coding of process & signals the code of emergency stop system
- 511 = 5 as the first number indicates the system to be part of the test rig system. The second number 1 indicates the first area and last 1 indicates the first system in the area.

All the building emergency stop areas will follow this naming logic, keeping naming compatible with Wärtsilä Power Plants grouping & coding of process & signals.

4 DESIGN OF SAFETY PLC SOLUTION

4.1 Functionality Requirements

The requirements of the emergency stop system created a common guideline for functionality and the functionality itself created hardware requirements. The designing of the system has been planned to meet the requirements and to be user friendly at the same time without compromising the functionality and safety.

- The system requires easy modification, an independent emergency system should to be modular for adding or removing emergency system areas without affecting the rest of the facility.
- Adding or removing functions to the emergency stop system without disturbing the operation of the rest of the facility.

The design of the emergency stop system was mostly done with AutoCAD 2016 as the drawings were done to construct and implement the design of the system. In the meetings the customer instructed that they do not prefer using semiconductor outputs at all if other options are available. Designs for two electrical cabins, common panel CJU901 and test rig area emergency stop cabin CJU541, consist mainly of the same parts. The full electrical drawings for both cabins can be seen in Appendices 2 and 4

4.2 Hardware

The hardware design was mainly driven by system requirements and earlier experience with products. The Vaskiluoto engine laboratory has experience of using Phoenix Contact products. Some level of standardising has been done with the most common parts in use, for example a certain model of relay has been chosen to be commonly in use as the replacement part. Standardising the common parts in the use of one type reduces the need of different spare parts, saving the storage room for other uses and eases the maintaining of the electrical systems as a variety of the parts is reduced. All the electrical components inside the electrical cabin will be mounted on 35mm DIN-rail. The complete list of used parts is available in Appendices 5 with detailed information and trade numbers.

4.2.1 Power Source

The power supply for the emergency stop system was chosen to be two 110 VDC UPS feeders located at the building, ensuring the functionality of the emergency stop system even in case of a partial power loss, maximizing the system uptime and reducing the unnecessary stops of the test equipment. With two power supplies the power feed for the emergency stop system is redundant, the loss of one power supply does not result in the loss of power. As the safety PLC requires the 24V DC voltage level, the 110V DC power feeds connect to the power supply transforming 110V DC to 24 V DC. A redundant system requires the diode or redundancy module to block the possibility for back feed. Without the diode or redundancy module if either of the power sources fails, the intact power supply may start to feed power to the failed power supply creating a back feed situation.

The power source model was chosen to be a common model in use around the building, regulating the need of different power sources as spare parts. The suitable power source was chosen to be Phoenix Contact QUINT-PS/1AC/24DC/10. (Figure 7)

The technical data for Phoenix Contact QUINT-PS/1AC/24DC/10 power source

- Nominal input voltage: 100 V AC … 240 V AC / 110 V DC … 250 V DC
- AC frequency range: 45 Hz … 65 Hz
- Nominal power consumption: 257 W
- Nominal output voltage: 24 V DC ± 1 %
- Nominal output current (I_N): 10 A
- Connection method: Pluggable screw connection

The technical data for Phoenix Contact QUINT-ORING/24DC/2X10/1X20 redundancy module

- Nominal input voltage: 24 V DC
- Nominal input current: 2x 10 A, 1x 20 A
- Nominal output voltage: 0.1 V < DC input
- Nominal output current (I_N): 20 A (increased power) 10 A (redundancy)
- Power loss nominal load max.: 2 W (I_{OUT} = 20 A)

Figure **7.** Phoenix Contact QUINT-PS/1AC/24DC/10 power source (left and in the middle) QUINT-ORING/24DC/2X10/1X20 redundancy module. (on the right) /7/

The power supplies are connected parallel to the redundancy module. The redundancy module monitors both inputs and balances the use of two power supplies evenly maximizing the lifetime of the power supplies. If one power supply fails, the redundancy module has normally closed contact to inform for the loss of redundancy. The second contact in the redundancy module informs if the voltage of one of the power supplies is lower than required. The redundancy module model has been chosen to be compatible with the power modules. The redundancy module has an advantage over diode module with power loss. According to the manufacturer the power loss of equal performing diode redundancy module (Phoenix Contact TRIO-DIODE/12-24DC/2X10/1X20) has a power loss approx. 10 W at nominal 10 A load /8/. The redundancy module power loss on maximum nominal load 20 A is 2 W (Phoenix Contact QUINT-ORING/24DC/2X10/1X20) /9/.

4.2.2 Safety PLC

The safety PLC for the project was chosen to be the same model as in use in the building in one of the test cells. The safety PLC model is the same as used in the emergency stop system in the test cell 7. The safety PLC master module is Phoenix Contact PSR-SCP-24DC/TS/M freely configurable safety module (Figure 8). The safety PLC is part of the Phoenix Contact PSR-TRISAFE configurable Safety PLC-series. The PSR-TRISAFE product series consists of different Safety PLC master and extension modules. The PSR-TRISAFE-M master device is expandable with 10 extension modules. Extension modules connects to the master module with the PSR-TBUS – connectors underneath the extension module to the master module. The principle of PSR-TBUS connectors can be seen in Figure 9.

The technical data of Phoenix Contact PSR-SCP-24DC/TS/M

- Nominal input voltage: 24 V DC
- Typical input current U_N: 110 mA
- Number of safety inputs: 20
- Number of safe semiconductor outputs: 4
- Limiting continuous current for safe semiconductor: 2 A
- Number of alarm outputs: 4
- Limiting continuous current for alarm outputs: 100 mA

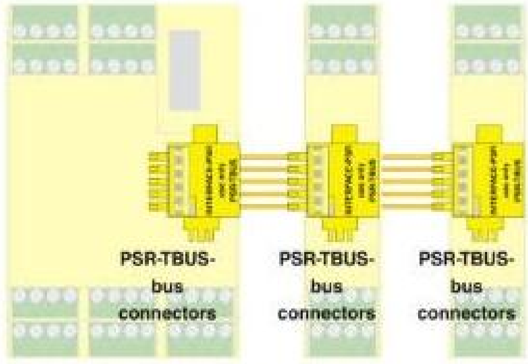


Figure **8** (left). Phoenix Contact PSR-SCP-24DC/TS/M. Figure **9** (right). Principle of PSR-TBUS bus connector for connecting extension modules for PSR-TRISAFE modules. /10 – 11/

The PSR-SCP-24DC/TS/M programming is made with the SAFECONF-programming tool, free to download program is found on the Phoenix Contact web page. The tool is easy to use and the programming style is function block diagram. The SAFECONF program does not need to have any outside connection for creating a program and SAFECONF has a simulation abilities for testing the program without hardware, allowing to make a changes in the program beforehand, thus minimizing the downtime of the emergency stop system for the maintenance.

4.2.3 Safety PLC Extension Module

The extension modules have two different options, relay output extension module PSR-SCP- 24DC/TS/SDOR4/4X1 (Figure 10) and input/output extension module PSR-SCP- 24DC/TS/SDI8/SDIO4 (Figure 11). Both the extension modules connect to the PSR-TRISAFE-M master module with a PSR-TBUS connector and both extension modules have identical outside dimensions. For the design of the emergency stop system only PSR-SCP-24DC/TS/SDOR4/4X1 was used as an extension module as the customer preferred not to have semiconductor outputs in use.

The technical data of Phoenix Contact PSR-SCP-24DC/TS/SDOR4/4X1

- Nominal input voltage: 24 V DC (via PSR-TBUS)
- Typical input current at U_N: 120 mA
- Number of safe relay output contacts: 4
- Maximum switching voltage: 250 V AC / 24 V DC
- Limiting continuous current: 4 A
- Number of alarm outputs: 4

The technical data of Phoenix Contact PSR-SCP-4DC/TS/SDI8/SDIO4

- Nominal input voltage: 24 V DC (via PSR-TBUS)
- Typical input current at U_N: 100 mA
- Number of safety inputs: 12
- Typical current consumptions: 4 mA
- Number of safe semiconductor outputs: 4
- Limiting continuous current: 4x 0.5 A

Figure **10** (left). Phoenix Contact PSR-SCP-24DC/TS/SDOR4/4X1. Figure **11** (right). Phoenix Contact PSR-SCP-4DC/TS/SDI8/SDIO4. /12 – 13/

If the system expansion requires more inputs, the only option is to add one PSR-SCP-4DC/TS/SDI8/SDIO4 extension card to the safety PLC system. One card adds 12 safety inputs to the system at the time.

4.2.4 Control Relays

As the manufacturer of PSR-SCP-24DC/TS/SDOR4/4X1 allows the maximum switching voltage to be 250 V AC / 24 V DC in case of potential free contact for the machines and equipment control, the 24 V DC limit is not enough for every machine, part of the test machines use higher control voltage. To bypass the voltage limitation as well as current limits the expansion card controls the universal safety relay with forcibly guided contacts. Phoenix Contact PSR-SCF-24UC/URM/2X21 relay is in use in many machines and equipment control circuits as well accepted in multi-purpose relay in engine laboratory for reducing the number of different spare parts (Figure 12). The relay contact type is 2 PDT as seen in Figure 13.

The technical data of Phoenix Contact PSR-SCF-24UC/URM/2X21

- Nominal input voltage: 24 V AC/DC
- Typical input current at U_N: 30 mA
- Contact type: 2 PDT
- Maximum switching voltage: 250 V AC/DC
- Limiting continuous current: 5 A (N/O contact) 3.5 A (N/C contact)

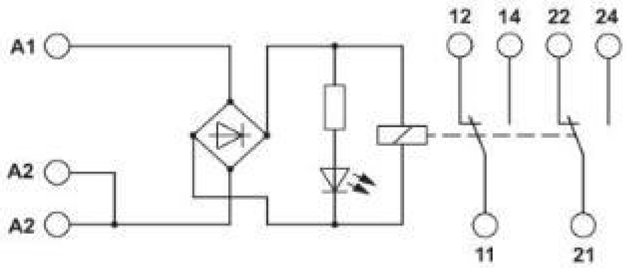


Figure 12 (left). Phoenix Contact PSR-SCF-24UC/URM/2X21. Figure 13 (right). The circuit diagram of PSR-SCF-24UC/URM/2X21. /14 – 15/

Phoenix Contact PSR-SCF-24UC/URM/2X21 is a common and reliable relay for the emergency stop system to use and by using it for multiple purposes in future reduces the need of different spare parts. An integrated diode bridge allows to use AC voltage for relay control.

4.2.5 Terminal Blocks

Terminal blocks for the cables take a major part of the electrical cabin as all the cables coming into and leaving the cabin are installed to the system through the terminals. For saving space for future expansions a part of the terminal bocks are double-level terminals. Double level terminals save the space used by terminals by 50% and offer the same usability as single level terminals. Part of the terminals are regular feed-through terminal blocks for practicality reasons. For 24 V DC voltage power distribution the terminal blocks used are 2- connection feed-through terminal blocks as they offer four connection points per terminal block. The connection method for all terminal blocks used is the push-in connection. The terminal blocks can be connected vertically with potential bridges and double level terminal block levels can be connected internally with a potential bridge.

All terminal blocks used in the emergency stop system are manufactured by Phoenix Contact. Three types of terminal blocks are used in the project. Phoenix Contact Feed-through terminal block ST 1,5 (Figure 14), Phoenix Contact feed-through terminal block ST 1,5-QUATTRO (Figure 15) and Phoenix Contact double-level terminal block PTTB 1,5/S (Figure 16).

The technical data of Phoenix Contact feed-through terminal block ST 1,5, Phoenix Contact feed-through terminal block ST 1,5-QUATTRO, Phoenix Contact double-level terminal block PTTB 1,5/S

- Number of levels: 1
- Number of connections: 2
- Nominal cross section: 1.5 mm^2
- Nominal current I_N: 17.5 A
- Nominal voltage U_N: 500 V
- Connection method: Spring-cage connection

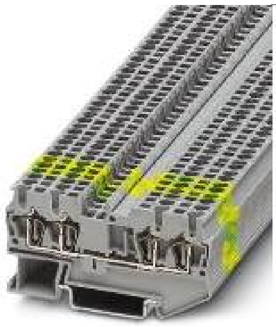
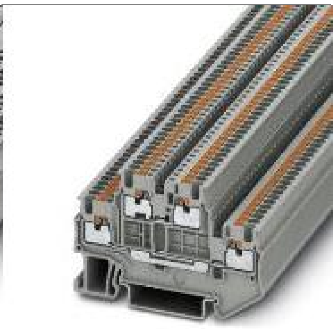




Figure **14** (left). Phoenix Contact ST 1.5 with two ST 1.5-PE. Figure **15** (middle). Phoenix Contact 1.5-QUATTRO with two 1.5-QUATTRO-PE. Figure **16** (right) Phoenix Contact PTTB 1.5/S. /16 – 18/

The double level terminals area used for emergency stop pushbutton cable connections and equipment cable connections. Using the double level terminal blocks for connecting the emergency stop pushbuttons, the emergency stop pushbutton can be simulated for the safety PLC by shortcutting the double level terminal with the potential bridge. To install an emergency stop pushbutton the wires can be connected to the short cut double level terminal block, while the system is running normally. After connecting the wires, the removal of the potential bridge connects the installed emergency stop to the system. This allows the installation and removal of emergency stop pushbuttons without programming modifications, when emergency stop pushbuttons have been pre-programmed on the safety PLC.

4.2.6 Terminal Block Accessories

Terminal block accessories include terminal block end covers, end clamps, terminal marker carrier, plug-in bridge and terminal block numbering. The end covers close the open side of the terminal block. For saving space the Phoenix Contact terminal blocks have the right side open. As terminal blocks are installed in a row the next terminal block on the right side closes the previous terminal block open side. The last terminal block of the row needs to be closed with an end cover to ensure the electrical safety of the terminal block. Three types of terminal blocks are in use in the project and all of the three types need a correct end cover. The end covers are used to separate the certain groups of the terminal blocks in the terminal block rows as extra guidance for installation. The three models of the end covers used in the project are Phoenix Contact end cover D-ST 2.5, Phoenix Contact end cover D-ST 2.5-QUATTRO and Phoenix Contact end cover D-PTTB 1.5/S.

The end clamp keeps a row of terminal block tightly together on the DIN-rail as possible mechanical vibration can divide and move terminal blocks on the DIN-rail. A terminal marker carrier is used for marking the identification code for the row of terminal blocks or other electrical cabin equipment. The terminal marker carrier is installed on top of the end clamp. The identification code of the terminal block row is located on right side of the terminal block row or equipment. The end clamp model used is Phoenix Contact E/UK-NS 35 and the marker model is Phoenix Contact KLM-A.

With a plug-in bridge the terminal block can be connected in groups without any wiring, for example the power distribution with ST 1.5-QUATTRO. The terminal block numbering allows to name and identify a terminal block. Identifying the terminal block is vital for installing and wiring the electrical equipment to the electrical cabin. Phoenix Contact offers terminal block number printing service. Correctly printed terminal numbers save installation time as terminal block numbers can be installed as snap-on parts. The suitable terminal number model for Phoenix Contact feed-through terminal block ST 1.5 and Phoenix Contact feed-through terminal block PTTB 1.5/S is ZB 4 CUS (CUS = customer order specific). For Phoenix Contact feed-through terminal block PTTB 1.5/S model is ZBF 3.5 CUS.

5 CABIN ASSEMBLY

5.1 Planning

The cabin assembly has to be clear and easy to understand. By designing the position of the electrical components properly it is possible to use the minimum amount of wiring and installation time for cabin assembly. For the positioning of electrical components there is a common practice. These kind of practises include the use of terminal blocks to connect the outside cables to the cabin assembly, the position of terminals in the cabin assembly and the common positioning of electrical components.

At the Vaskiluoto engine laboratory the Rittal enclosures have been preferred to use because of good experiences of the Rittal products and to keep the enclosures as homogenous as possible as good practice.

5.1.1 Cabin

The cabins preferred in the emergency stop system is Rittal Compact enclosure AE. Rittal Compact enclosure AE is a sheet metal compact enclosure electrical cabin, powder-coated outside with texture painting and a detachable mounting plate. As for the size the recommended cabin depth is the minimum of 300mm to ensure enough space for electrical components. For leaving room for future expansions at the Vaskiluoto engine laboratory the common practise for estimating expansion room is the following equation:

Used space x π = recommended total space

The cabin door has two lights, one pushbutton and inside the cabin the drawing pocket for keeping electrical drawings in the cabin for later use. As for cabin installation, the following accessories are recommended:

- Wall mounting bracket for AE, Rittal Model No. SZ 2508.100

- Mounting bars for AE, door mounting, Rittal. Model No. varies with length, check for suitable one.
- Outlet filter standard Rittal Model No. SK 3238.200
- Wiring plan pocket, plastic, Rittal Model No. SZ 2514.000

Rittal offers 11 sizes of compact enclosure AE cabins with the depth of 300mm as seen in Figure 17. For aesthetic reasons enclosure that are higher than wider are preferred.

Model No. ⬍	Width ⬍	Height ⬍	Depth ⬍	Doors ⬍
▸ AE 1037.500	400 mm	800 mm	300 mm	1
▸ AE 1055.500	800 mm	600 mm	300 mm	1
▸ AE 1073.500	760 mm	760 mm	300 mm	1
▸ AE 1110.500	1000 mm	1000 mm	300 mm	2
▸ AE 1114.500	1000 mm	1400 mm	300 mm	2
▸ AE 1130.500	1000 mm	760 mm	300 mm	2
▸ AE 1180.500	800 mm	1000 mm	300 mm	1
▸ AE 1213.500	1000 mm	1200 mm	300 mm	2
▸ AE 1260.500	600 mm	1200 mm	300 mm	1
▸ AE 1280.500	800 mm	1200 mm	300 mm	1
▸ AE 1350.500	500 mm	500 mm	300 mm	1

Figure 17. Product range of Rittal compact enclosure AE-cabins. /19/

As for CJU901 and CJU541 the suitable cabin size leaving enough room for future expansions is model AE 1180.500 with the physical size of 800 mm x 1000 mm x 300 mm as seen in Figure **18**.

Figure **18.** Rittal AE 1180.500 compact enclosure. /20/

5.2 Cabin Layout

The cabin layout outside the cabin includes emergency stop reset pushbutton, two warning lights and outlet filter for enabling air circulation for ensuring the cooling of electrical components. The cabin outlet filter is located on the door approx. halfway between the safety PLC and power sources for ensuring the cooling as seen in Figure **19**.

The recommended installation height of the electrical cabin from the ground to electrical cabin bottom is 100 cm, leaving pushbuttons and two warning lights at the height of 163 cm for ground. The height of pushbuttons and lights are on the eye-level, making the lights easy to notice and the level of pushbutton at a practical height.

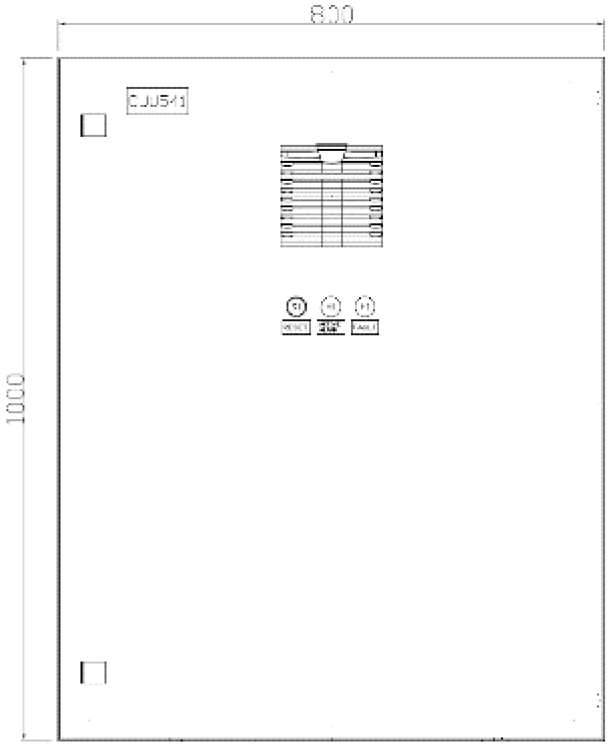


Figure **19.** Face layout for emergency stop cabin CJU541. The electrical cabin doors of the emergency stop system are mostly identical.

The full layout drawings of electrical cabins CJU901 and CJU541 with drill plans are found in Appendices 1 and 3. The layout can be modified depending on the cabin size and number of doors. The main guideline is to keep the components in symmetrical positions on the vertical centre line of the cabin. The bottom of the cabin has a gland plate. Cable glands are mounted on the cable gland plate for cable entry inside the cabin. Enough cable gland places are reserved for needed cables for the system. If the gland plate has not enough space needed for cable glands the bottom of cabin can be used for installing more cable glands. The cable gland drawings can be seen in Appendices 1 and 3.

5.2.1 Mounting Plate Layout

The mounting plate of Rittal AE 1180.500 cabin is slightly smaller compared to the dimensions of the electrical cabin. The cabin dimensions are W 800 mm x H 1000 mm and the size of the mounting plate is W 739 mm x H 955 mm. 35 mm DIN rails are used to mount electrical components on the mounting plate and two different sizes of cable ducts act as a cable way for internal cabling. The position of cable ducts and DIN rails is planned to leave enough room for all the electrical components, making wiring easy to install and ensuring easy component change. Short, self-drilling screws are used to attach DIN rails and cable ducts on the mounting plate. Components do not require special versions for DIN rails, the DIN rail size is 35 mm x 7.5 mm. Two sizes of cable ducts used are Phoenix Contact CD-HF 100x80 and Phoenix Contact CD-HF 60x80. Layout for DIN rails and cable ducts can be seen in Figure 20. The detailed plan for CJU901 and CJU541 in Appendices 2 and 4.

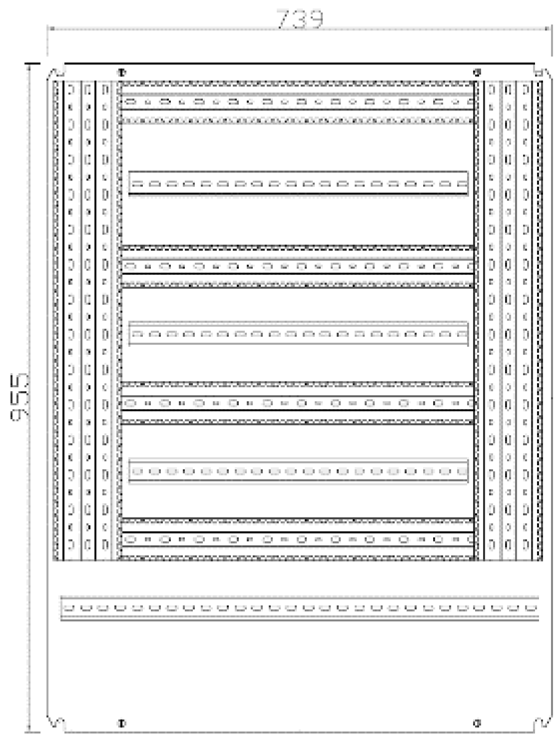


Figure **20.** Layout of the DIN-rails and cable ducts on Rittal AE 1180.500 cabin mounting plate.

For designing the position of the DIN rails and cable ducts the physical size of the hardwire determines the location of cable duct for the DIN rails. For wiring smoothness and proper fit for components, the minimum distance between the components and cable duct is recommended to be at least 20 mm. Active components might have requirements for the minimum distance between next components, the minimum distance requirements should always be checked from the manual.

5.2.2 Layout of Mounting Plate Components

When attaching components on the mounting plate the location of electrical components have a huge effect on the amount of wiring used as well as the installation time of wiring. A good component layout uses the minimum amount of wiring, has clear sections and enough space for future expansions. All the cables to the electrical cabin connects through the terminal block. The terminal blocks should be located near the cable entry for minimizing amount of cable running inside electrical cabin as well leaving enough space for incoming cables. Seen an example of CJU901 component layout in Figure 21. The detailed layout drawing for CJU901 and CJU541 can be found in Appendices 1 and 3.

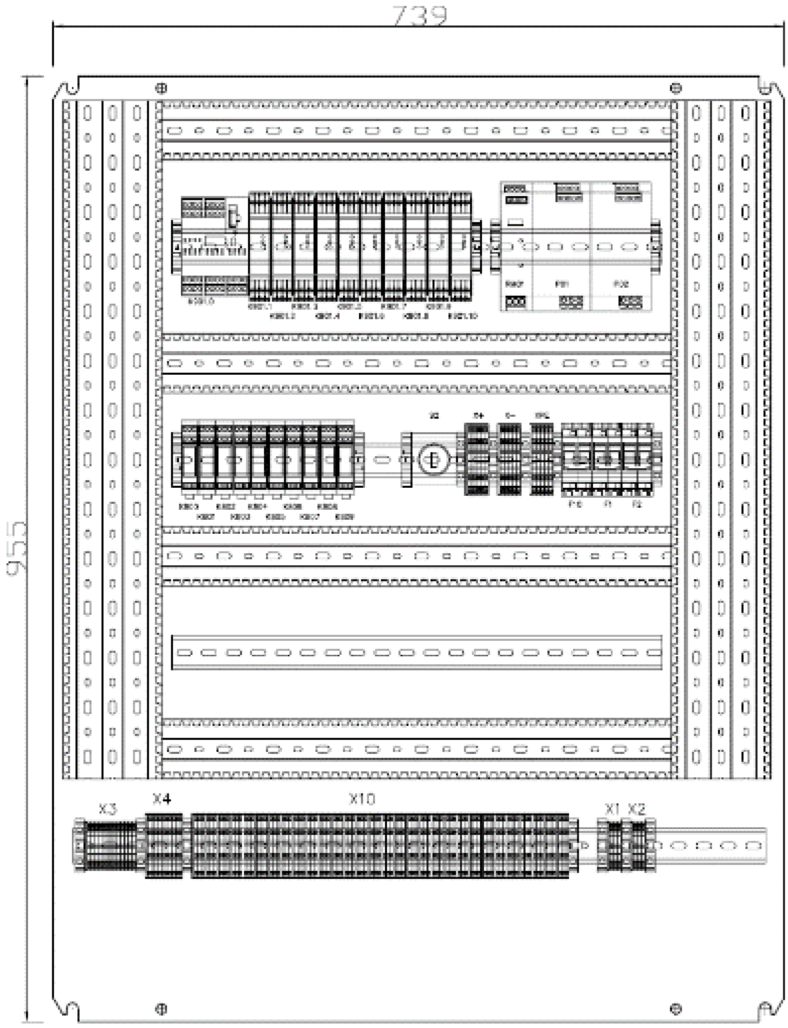


Figure **21.** CJU901 layout.

This layout is on common panel CJU901. The common panel has a key operated contact for momentary bypass for the fire alarm. The bypass is used in the monthly functionality test of the fire alarm, allowing the test without disturbing the rest of the facility. The layout for CJU541 is slightly different as more relays have been used for potential free contacts. (Figure 22)

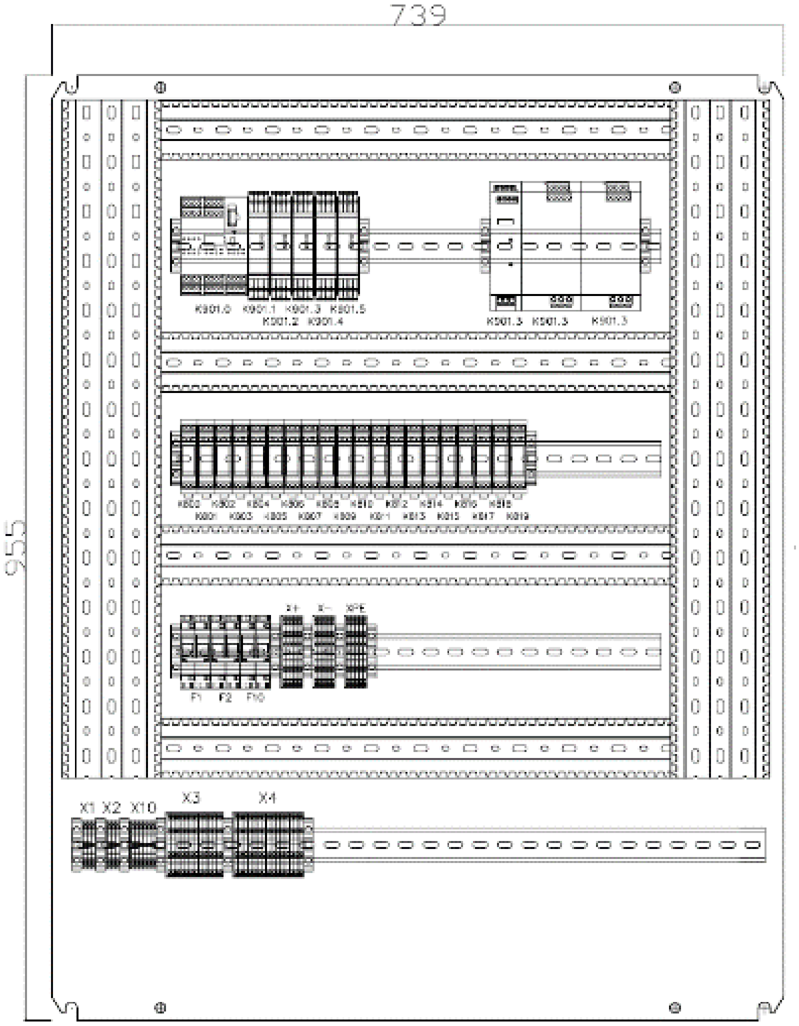


Figure **22.** CJU541 layout, slightly different compared to CJU901.

A notable difference to the common panel CJU901 is the number of relays used. Because every machine and equipment connected to the system has a relay with a potential free contact, the relay is used for bypassing the safety PLC extension card voltage and current limits.

6 PROGRAMMING WITH SAFECONF

6.1 SAFECONF Programming Tool

The SAFECONF – program is free of charge configuration program for configuring Phoenix Contact TRISAFE and SafetyBridge products. The program has simulation abilities for simulating and testing a safety program without hardwire or connection for hardwire. The safety features of programming include password for hardwire, password for program and time stamped network locking with a certificate of the editor´s information.

The programming of safety PLC is made with SAFECONF program. The program has a wide variety of features for documenting program revisions, hardwire, documenting, testing of program and hardwire. These documentation abilities increase the safety of the program as every step and modification is documented for future use. The programming language used on SAFCONF is FBD (FBD = Function Block Diagram) as FDB is a commonly used programming language. The easiness of FBD comes for graphically visualised functions and connections. Visualised functions allow the monitoring of program performance graphically. The view of the program main window is shown in Figure 23.

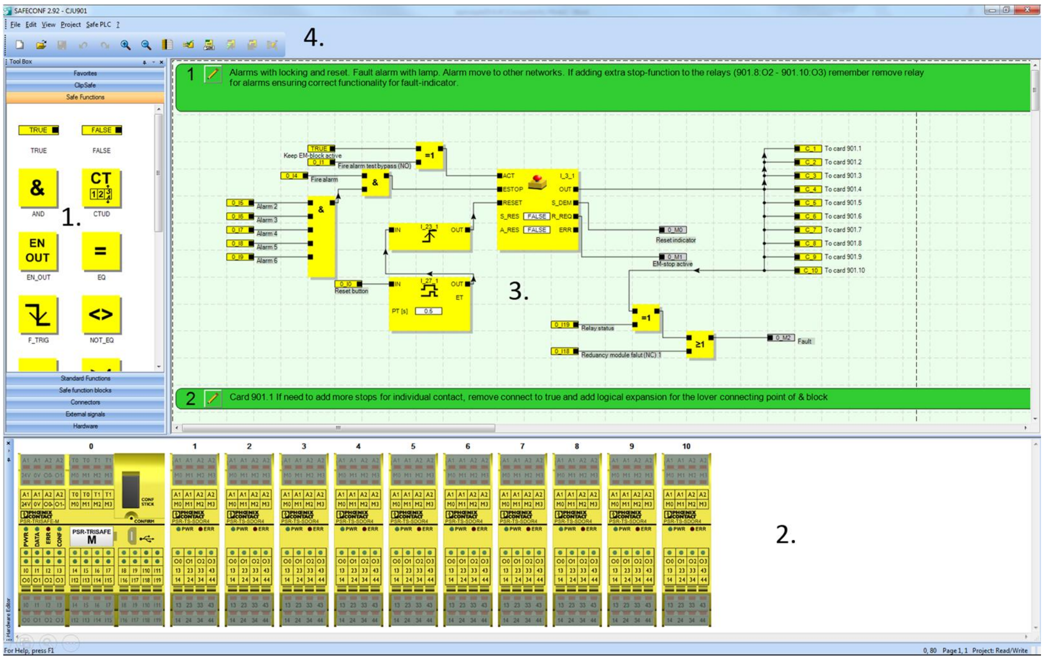


Figure **23.** The SAFECONF – main window. 1. Tool Box, drag & drop logical functions for toolbox. 2. Hardwire Editor, modify hardwire suitable on project and program. Add hardware for toolbox menu with drag & drop. 3. Program Network, add and connect logical functions, inputs and outputs for program network. 4. Menu for properties and tools.

6.2 Connecting SAFECONF to Safety PLC

For programming the safety PLC the computer connects the TRISAFE safety PLC with a USB cable. A mini USB port is located on top of the safety PLC for connecting by means of programming or monitoring. The connection for the safety PLC is opened on top menu, Safety PLC > Log On. Connecting does not have an effect on the performance of function and connecting can be made while the system is active and running. When logging on, the program asks for the password of the safety PLC hardware. If the password is not entered, the connection allows only uploading the existing program for the safety PLC to monitor online values.

6.3 Programming

The programming of the safety PLC with the SAFECONF program is made simple with the FBD programming. The chosen function is added on the safety network to the tool box menu by dragging on the safety network area. The safety network area has a grid and every function block lines with the grid. The program can consist of multiple networks. Connecting a signal between networks is made with a connector. The connector moves signal line between two networks. The connector can leave a signal on multiple networks but can have only one input on one network.

Two types of functions are available, safety functions and standard functions. The safety functions can be used to control safety inputs and the outputs and standard functions can be used to control standard input and outputs. A safety output cannot be controlled with standard functions but a standard output can be controlled with safety functions.

Available functions for programming includes most commonly used Boolean logic blocks as well common FBD – blocks seen in Figure 24.

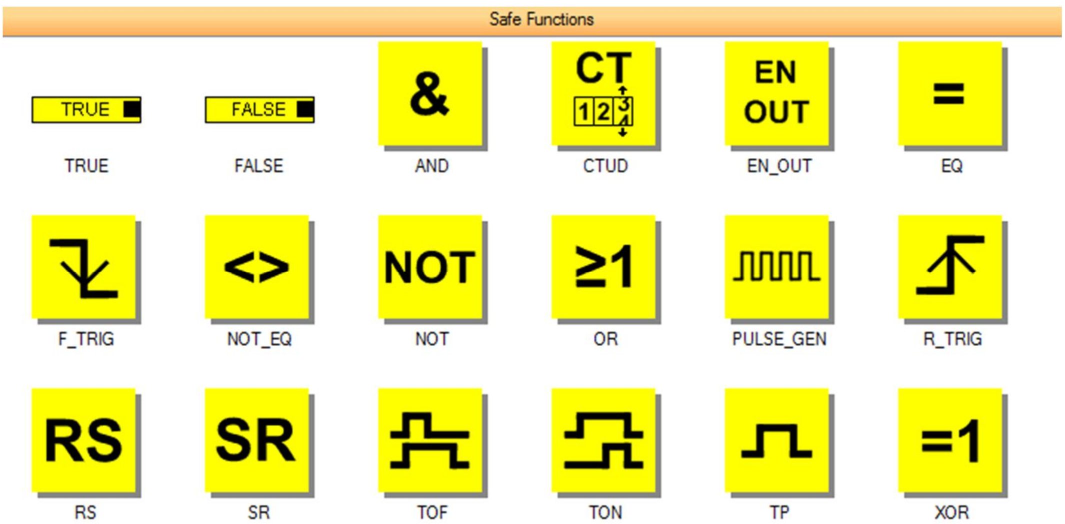


Figure **24.** Safety functions available for FBD programming of safety PLC.

The program has a variety of safe function blocks ready to use, the EmergencyStop block is used to monitor and control emergency stop pushbuttons and emergency stop functions correctly. Other safe function blocks include valve monitoring, two hand controls, external device monitoring and more. Safe function blocks have a feature for defining start-up behaviour as the system starts. All available safety function blocks can be seen in Figure 25.

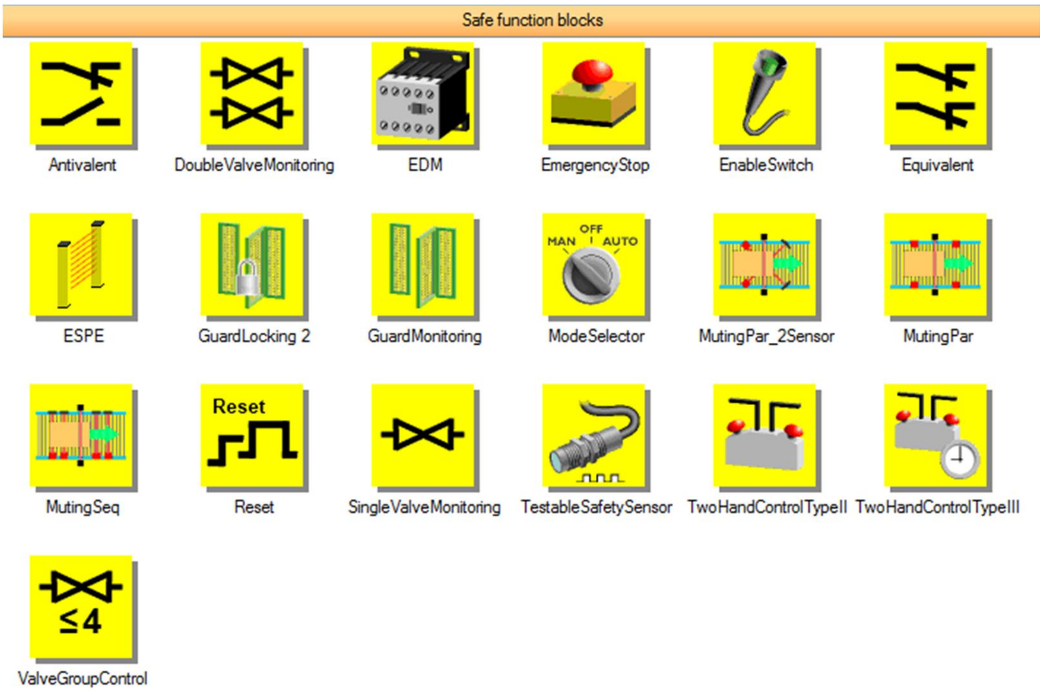
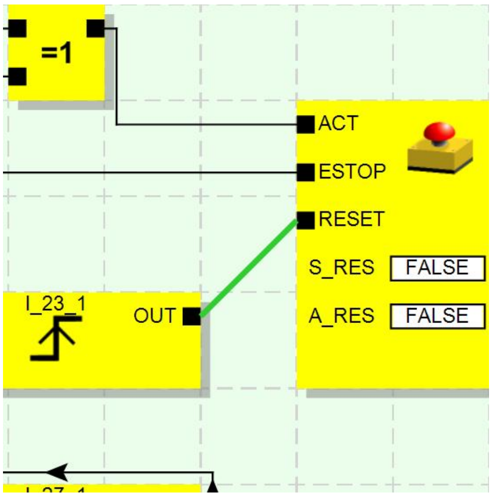


Figure **25.** Available safety function blocks for programming.

When starting a new project, a password is required to set on the project and opening an existing project requires a password. With the password the project is unlocked for modifications and without the password the program is only available for viewing. Protecting the project with a password disables the possibility for unauthorized modifications of the program and safety PLC hardwire setup, increasing the safety of system design. Downloading the project to the safety PLC without the project password is possible.

When a function has been added on networks, the signal connections need to be made for forming a logic. The signal connection starts with the function connection box, a small black square on the left and right side of the function block. The connection box on the left side of the function block is the input connection, the connection boxes on the right side are function output. For basic functions the numbers of inputs can be increased or decreased depending on the need. The connection example is shown in Figure 26 and Figure 27.



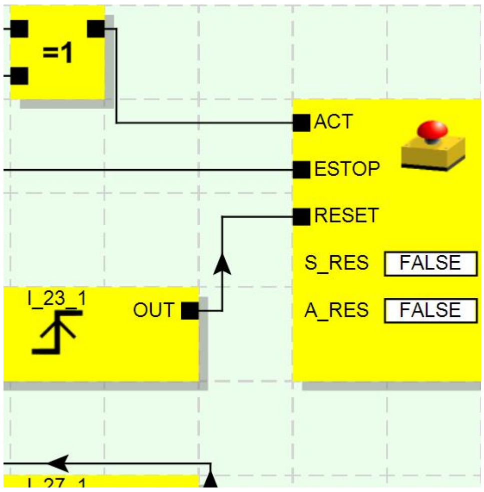


Figure **26** (left). If connection is allowed the straight line apperas in green colour. If connection is not allowed line is red and connection is not made. Figure **27** (right). Succsesfull connection.

Downloading the program to the safety PLC stops all functions of the safety PLC, changing all outputs to zero. When the program is loaded onto the safety PLC, it has to be confirmed with the CONFIRM button located on top of the master module. (Figure 28.)

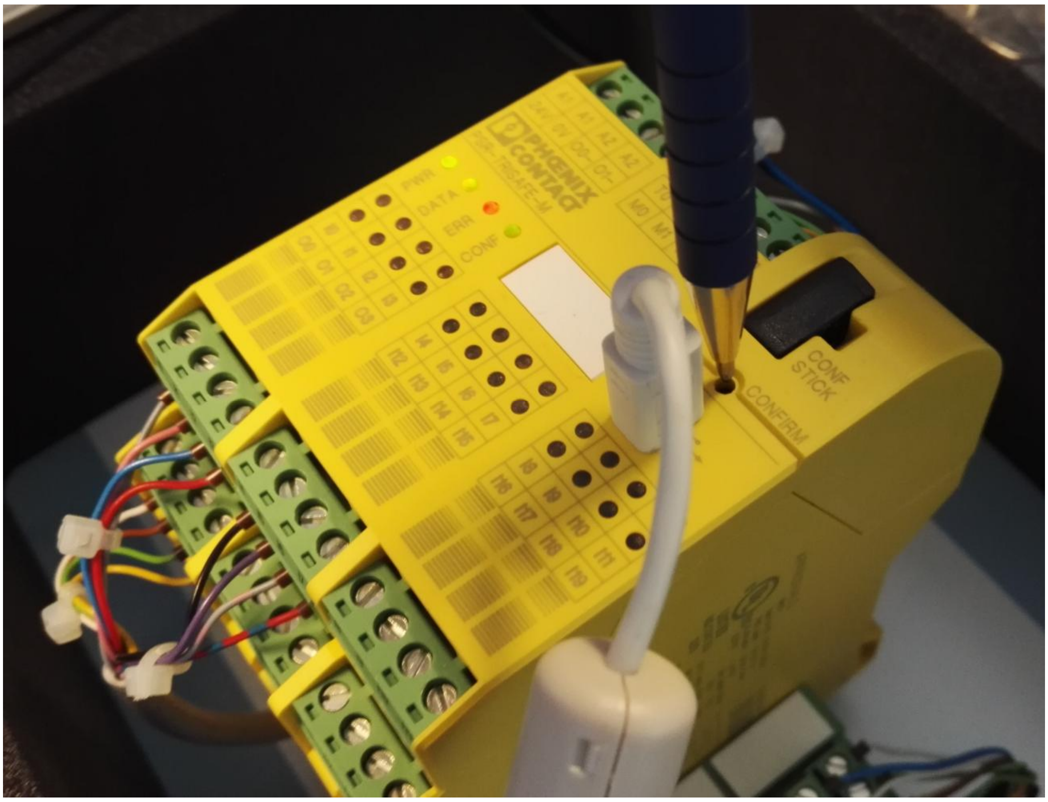


Figure **28.** CONFIRM – button is located in a hole right above Mini USB port. The button can be used with a pen or a match. A small click is enough for confirming the new program downloaded on the safety PLC.

After confirming the downloaded project, the safety PLC performs a restart in order to take the downloaded program in use. Downloading a new program is only the interruption in the emergency stop system as the new program is taken in use.

6.4 CJU901 and CJU541 Program

Programs for two systems, common panel CJU901 and test rig area CJU541 are nearly identical. The main feature of the program are emergency stop function, indications and extension possibilities for programming. The emergency stop function block is used for emergency stop control.

The program of CJU901 consists of the main safety network and ten extension card networks. The main network consists of the emergency stop program with reset abilities. All the logical functions are built in the main network. The main network can be seen in Figure 29.

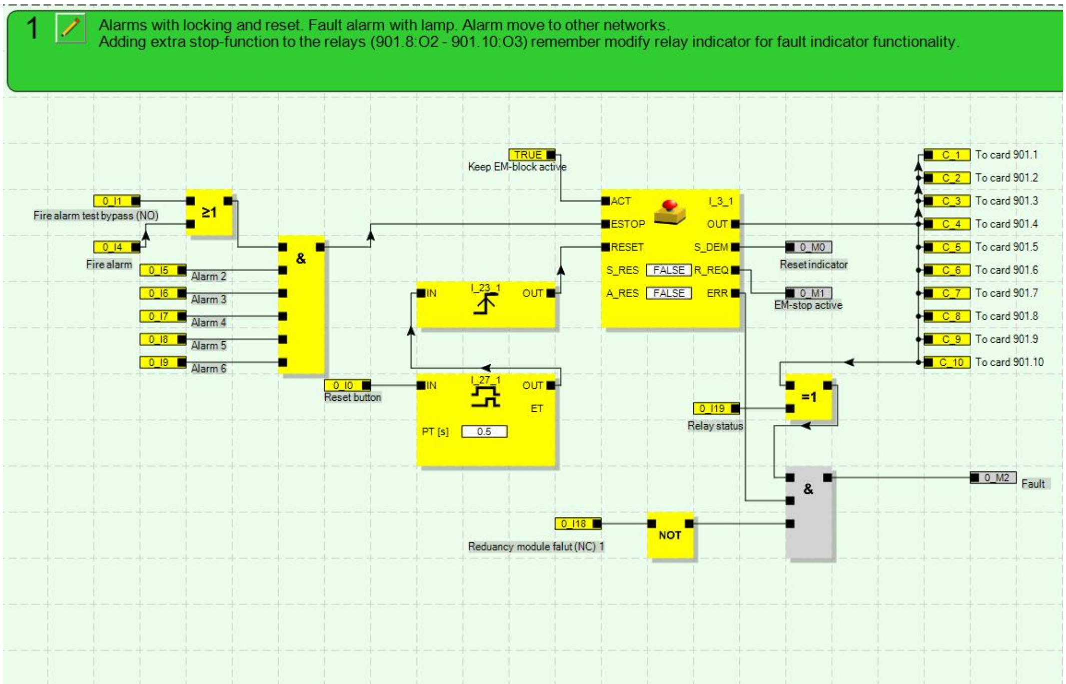


Figure **29.** Main network on Common panel CJU901 program. The main network has all properties on build.

The main network has all common panel alarms in one single place. The emergency stop function block is used to control all the alarms. Fire alarm bypassing de-activates the fire alarm input effect. All the alarm input reserved for common panel alarms are pre-programmed in the main network, small modifications might be needed when connecting more alarms to the system. Reset has a half second turn on delay, limiting the possibility of unintended reset, as the reset button has to be pressed more than half a second.

Non-safety outputs are used in indication lamps, seen as grey outputs. Transferring the emergency stop signal to the extension card is made with connectors, seen in Figure 30 on the right side. Connectors can have a single input but can be placed as output signal in many networks.

The extension card safety network is simply just reserving space for future programming expansions. If an individual logic for single contacts is needed, the extension card network has reserved space for extensions. Safety functions can be added by simply replacing TRUE block for extension card network. Extension networks are identical for all cards. See Figure 30.

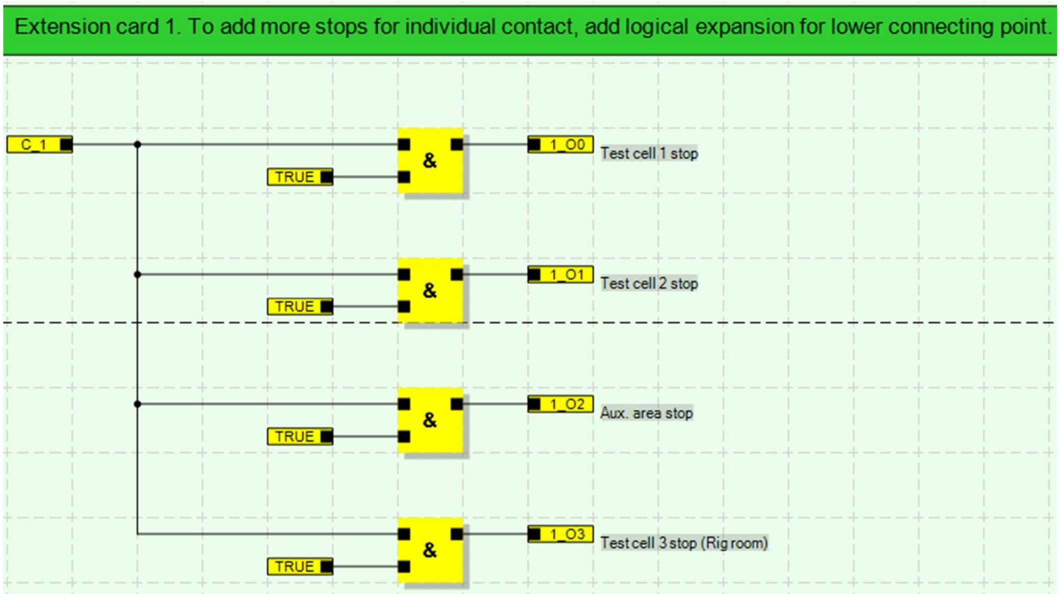


Figure **30.** Common panel CJU901 extension card program, each extension card program has its own program network.

Keeping an extension card program on its own, an individual network facilitates the main network programming and leaving more space for future program expansions, as part of the programming can be made on extension card network.

The emergency stop CJU541 program has a lot of similarities with CJU901 program, as two cabins have the similar hardware. Differences between programming are see in Figure 31.

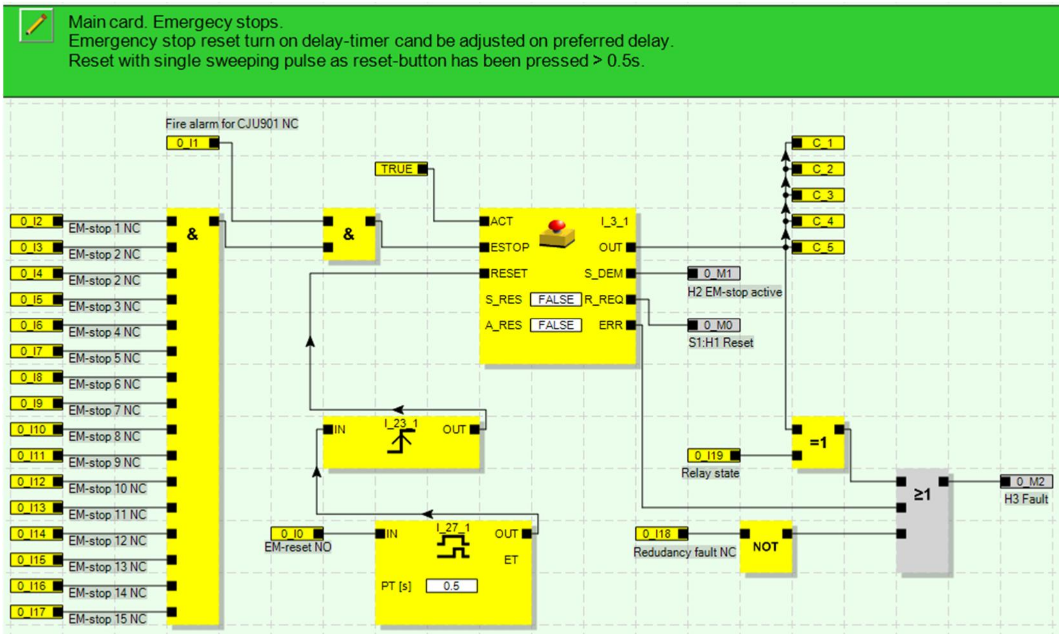


Figure **31.** CJU541 area main network. Similarities between common panel and test rig area emergency stop is notable.

CJU541 programming has the same basic principle, the emergency stop function block controls the alarms. The fire alarm is seen as its own input on the same level as a regular emergency stop. Each individual emergency stop available is pre-programmed in the program as the short-circuited terminal block simulates the emergency stop pushbutton in the program. This allows the installation of emergency stop pushbutton without modifications in the program, as installation can be made and taken into use by removing the short circuiting for the terminal block. Resetting has the same half second delay.

The emergency stop cabin CJU541 program has individual networks for extension cards, as does the common panel program. An example of extension card program can be seen in Figure 32.

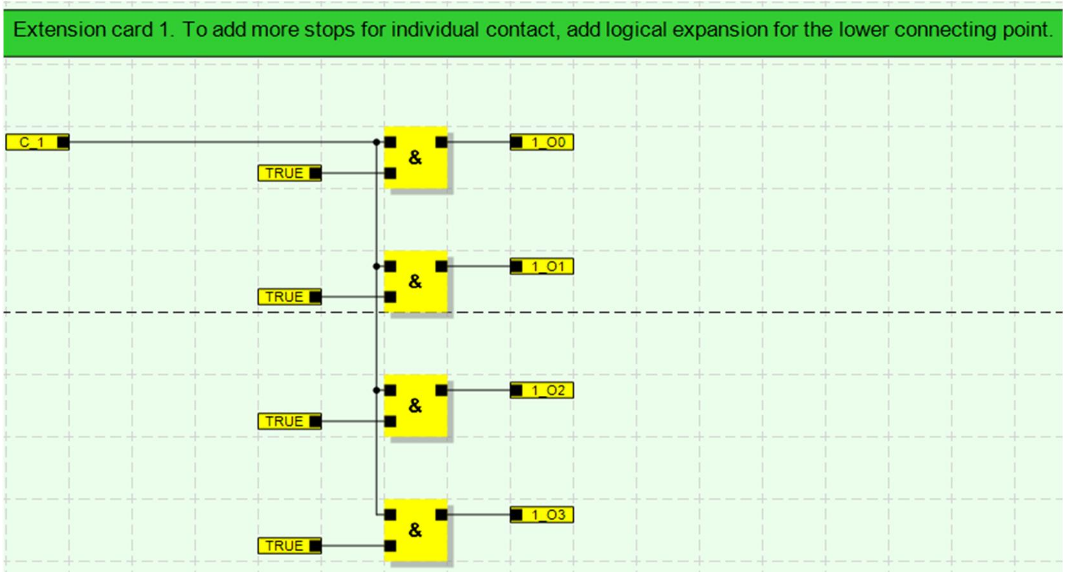


Figure **32.** CJU541 extension card program. Every extension card has own network giving more space for future program modifications.

7 CONCLUSIONS

In this thesis the main goal was to create a standard solution for the engine laboratory for future use and understanding the old complex system with it disadvantages and advantages. The old system had been expanded to many directions, connected to new areas creating a complicated mess. Understanding the old system took quite a while, as documentation was imperfect. Drawing the new electrical pictures based on the old modified pictures did help quite a lot. Still lot of research was made to find all connections around the building.

As for planning the new system, recommendation to use the safety PLC solution gave a direction to go with the designing. The simplicity of system keeps everything under control as complicated sections can easily confuse and cause unnoticed mistakes, creating potentially a danger. The safety PLC solution is a good choice for the future, it can be used in a much complicated way and leaving a lot of extra space for cabin helps a lot for a future modifications.

A lot of thinking has been done to ponder what can and cannot be done with the system up and running, as one requirement was to keep everything independent and not affecting each other. This also added simplicity, usually complicated systems will have a huge effect on the entire system if one part is down for maintenance or broken.

As for timing, it followed quite well the ideal timing. Now at end of the project the installation and cabin assembly is made a couple of weeks later than though. A lot of time was given to do the work and the work place is real professional. A complicated building creates complicated problems, still time to time it can be solved with a simple solutions.

The design is making its way in use, the first panels, the common panel CJU901 and the emergency stop cabin CJU541 are begin built and will be taken in use at incoming weeks.

8 SOURCES

/1/ Wärtsilä Oyj. Home page. History. Accessed 3.3.2017.
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