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ENHANCING LOW VOLTAGE SYSTEM THROUGH OPTIMIZED AND FUTURE-PROOF LV -SWITCHGEAR SETUP

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Työn toimeksiantajana toimi Wärtsilä Energy Business. Työn tehtävänä oli tukea meneillä olevaa kehitysprojektia ja dokumentoida siinä kehitettävää pienjännitekojeistoa. Pieni kehitystiimi koottiin tämän työn tueksi. Työn keskipisteenä on pienjännitespesifikaation päivittäminen ja pienjännitekatkaisijoiden ominaisuuksiin tutustuminen.

Tutkimusaineistona työssä toimi pienjännitekatkaisijoiden ominaisuuksiin ABB:n datalehdet, tekniset spesifikaatiot käytiin läpi yrityksen sisäisissä kokouksissa ja selektiivisyyslaskelmat tehtiin yhteistyössä suunnitteluyrityksen kanssa.

Työssä saatiin mahdollisia syitä standardien vaikuttamista eroista ja saatiin tärkeitä uudistuksia pienjännitespesifikaatioihin. Tämän lisäksi saatiin tietoa Febdok-ohjelman hyvistä ja huonoista puolista selektiivisyyslaskennoissa.

Avainsanat	Wärtsilä, pienjännite, kojeisto, standardit, selektiivisyys

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ABSTRACT

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The thesis was commissioned by Wärtsilä Energy Business. The task involved supporting an ongoing development project and documenting the low voltage switchgear being developed. A small development team was assembled to support this work. The focal point of the task was updating the low voltage specifications and getting familiar with the characteristics of low voltage circuit breakers.

The research material for the task consisted of ABB's data sheets on the characteristics of low voltage circuit breakers. The technical specifications were reviewed in internal company meetings, and selectivity calculations were carried out in collaboration with the design company.

The thesis identified possible reasons for differences influenced by standards and important updates were made to the low voltage specifications. In addition, information was obtained on the strengths and weaknesses of the Febdok program in selectivity calculations.

Keywords Wärtsilä, low voltage, switchgear, standards, and selectivity.

SISÄLLYS

FIGURE AND TABLE LIST

1 INTRODUCTION

1.1 Aims of the Thesis

This thesis aims to address Wärtsilä's need of enhancing the low voltage switchgear used multi-engine power plants with the ongoing development project. This thesis aims to support the project and document the changes to the low voltage system that will be made.

The thesis looks to improve the Low Voltage Technical specifications for smoother project procurement and execution in different projects. It focuses on aligning LV consumer lists with specific circuit breaker trip unit models for better LV system coordination studies. At the same time, it ties in with an ongoing development project, aiming for configured-to-order models, modular power plant setups, and more automation for lean and possibly unmanned operations.

1.2 About Wärtsilä

Wärtsilä is an internationally leading company that focuses on marine and energy markets. Wärtsilä focuses on helping its customers in improving their environmental and economic performance through sustainable technology and services. The company consists of 17 500 professionals that reside in over 240 locations in 79 different countries. Wärtsilä's net sales were 5,8 billion euros in 2022. [1]

Wärtsilä has four different businesses: Wärtsilä Energy, Wärtsilä Marine Power, Wärtsilä Marine Systems and Wärtsilä Portfolio Business. This thesis is made for and with Wärtsilä Energy, which is developing decarbonization services, future-fuel enabled balancing power plants, hybrid solutions, energy storage and optimization. Wärtsilä Energy's track record consists of 76 GW of capacity in power plants and 110 operational energy storage systems all in 180 countries over the world. [1.]

2 ENGINE POWER PLANT

2.1 Modern Combustion Engines

With the excellent flexibility the modern combustion engines are well suited for wide range power generation applications with their high simple cycle efficiency. In simple cycle the temperature and pressure of each cylinder are set high to achieve higher efficiency; the peak pressure can be as high as 200 bars. Engine power plants can be built according to power need, starting from only one generating set ranging up to tens of generation sets. [3] The generating set, genset in short is comprised of an engine that is connected to an electric generator with a shaft, engine and generator are running at same speed so there is no need for gearbox. Gensets are in standardized sizes that range from 4 to 20 MW. [2]

Medium-speed engine technology is most used in combustion engines for power plants and the simple cycle outputs normally range from 1 to 23 MW per unit and run between 300 to 1000 rpm and in ideal setting combustion engines could achieve the efficiency rating of over 60 %. With achieved enhancements to efficiency, modern combustion engines reach an efficiency rating a little more than 50 % with a simple cycle. The engines can be run with gaseous or liquid fuels since the engines are engineered with two different operating process principles. [3;4]

The most efficient gas engine Wärtsilä 20V31SG is given here as an example. The cylinder specifications of the engine are written in the name: “20V” means it has 20 cylinders in v-form configuration and “31” refers to the cylinder bore, 310 mm. Wärtsilä’s 31 genset ranges from 8 to 20 cylinders from which smaller cylinder setups are often used for marine solutions and 20-cylinder setup is built for engine power plants. 20V31SG runs at a speed of 750 rpm in 50 Hz and outputs 10 798 kW with an efficiency of 52,2 %, meaning that when a 12 -engine power plant is built with these engines it outputs 129 MW. [4;5]

2.2 Engine power plant applications

Engine power plants can be used for maintaining grid stability, maintaining base load operation, or assisting during peak loads. Engine power plant suffers minimal losses of ambient conditions performance and functionality wise, which means that the plants can be easily located close to consumption centers enabling minimal losses in transmission. [3]

Since power grids suffer from constant load variations from day to day and between seasons especially with increase in wind power generation. For this reason, the power grid has power plants dedicated for base, intermediate and peak loads. Thanks to combustion engines, the high efficiency in different loads of the power plants and for their fast starts and stops, they can be used for multiple functions in power systems, the functions that have been managed with separate different types of power plants. [3]

2.3 Low voltage system

Low voltage system includes not only the power generation equipment such as transformers and black start units but also power distribution equipment such as main switchgears and/or motor control centers (MCC). This system is engineered in such way that it provides reliable and high-quality power to all power production related auxiliary consumers within the power plant. [6.]

2.3.1 Purpose of low voltage system

The purpose of the low-voltage switchgear is to distribute low-voltage power for the electrical consumers included in Wärtsilä’s scope of supply, such as sub panels or switchgears, pumps, fans, heaters, and auxiliary units. There should not normally be any external power users connected to LV power distribution. [6.]

The main functions of the LV -Switchgear:

- Central distribution point of auxiliary power

- Feed in point for auxiliary transformer
- Feed in point for emergency diesel generator (BSU)
- Connecting point for all auxiliary consumer
- Separation of distribution networks via bus tie breaker (for example, per Genset group and common group or for BSU)
- Control circuits for remote start functions (e.g., Ventilation, fuel pumps) [7.]

2.3.2 System description

The power consumption of the equipment connected are decisive in choosing station service transformers capacity. This should be determined with help of the LV consumer list that should be created separately for each project. The main power consumers for genset in a low voltage system are engine auxiliaries, engine preheating, cooling radiators, and ventilation. For common related consumers there are compressed air, fuel oil, ventilation, air conditioning equipment and plant lighting. This means that the level of station consumption is mostly influenced by plants cooling method and the fuel oils heating method. [6.]

Low-voltage switchgear consists of both incoming breakers as well as distribution feeders and breakers. It can be built up of one or many busbar sections. Typically, there are tie breakers between separate busbar sections. [7.]

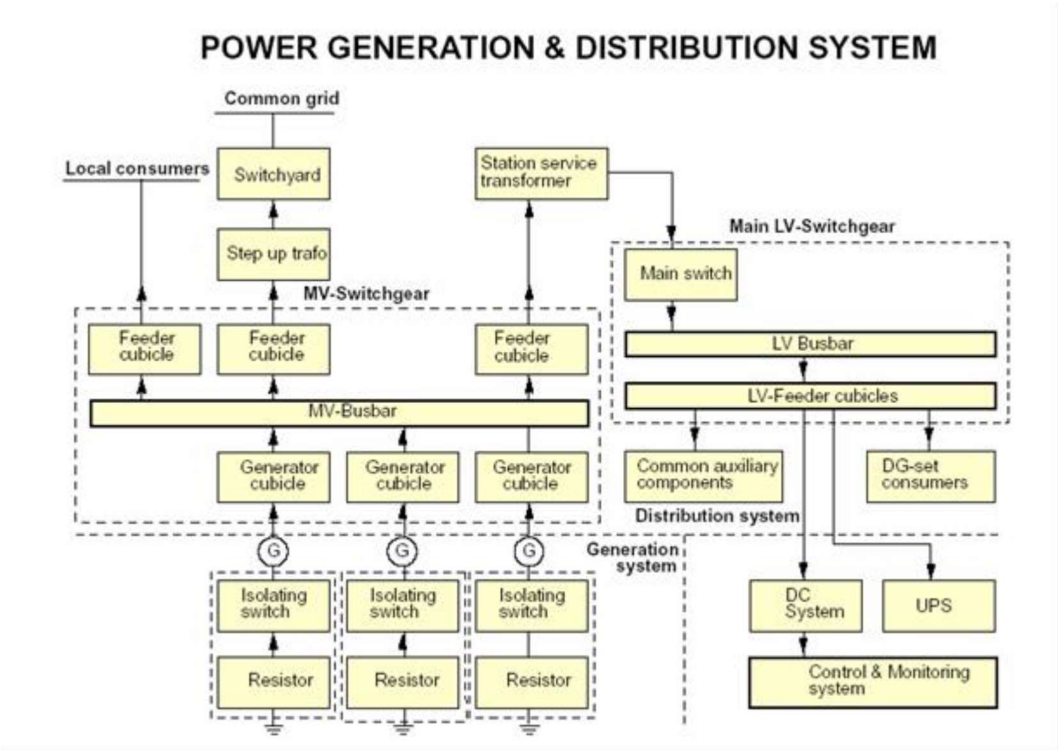

Figure 1. Power generation & distribution system [8.]

2.3.3 Design conditions

There are a number of things that influence the design of power plants low voltage system, including power need, plant layout and external influence. [6.]

The total power need is a deciding factor when choosing the size and the number of transformers. If only a single large transformer was use, the short circuit capacity of the LV switchgears could become far too large. This means that there is always some balancing between the size and number of transformers, but another measure is genset grouping meaning how many gensets there are per MV busbar. [6.]

It is always the easiest when the plant layout enables the power consumers to be well grouped together, this affects how many switchgears are needed for the plant. If there is wider spread out of the consumers, some consumers may need their own LV system, for example steam turbines may sometimes need their own LV system because of its location in power plant. [6.]

Finally external influences, meaning local rules and regulations may dictate restrictions to the design. On top of this, customer preferred requirements can have a great impact on the design, which need to be met to satisfy project specific requirements. [6.]

2.3.4 Low Voltage Network

The voltage levels are chosen according to international or national standards. In the countries using 50 Hz, the most used voltage level is 380 – 415 V and in 60 Hz countries, it is 440 – 480 V, but there could be site or customer specific voltage levels. If there is an extension of existing installations, the already existing voltage level should be used. [6.]

In case of transformers, the connections need to be matched which in new installations is automatically done in ordering identical transformers, but with extending existing systems, there is a need for more attention to detail. [6.]

Due to short-circuit limitations, the station system layout is done in such a way that the auxiliary transformers capacity is generally limited to 3500 kVA per transformer; usually the layout includes one transformer per medium voltage bus bar. [6.]

2.3.5 Low voltage earthing network

An LV system is defined as a power distribution system or equivalent due to its restricted nature, as a result, the standards do not require as mandatory that a TN-S system is used throughout the installation. [6.]

IEC 60364-1 standard defines the types of system earthing accordingly:

Table 1. System earthing definitions.

First letter	Second letter	Subsequent letter(s)	Explanation
T			one point is directly connected to earth
I			the system is floating, or one point is connected to the earth through a high impedance connection
	T		all conductive parts are directly connected to earth, independent of the earthing of any point of the power system
	N		all conductive parts are directly connected to earth, independent of the earthing of any point of the power system (i.e., to PE or PEN conductor)
		-S	separate neutral and protective earthing conductors
		-C	neutral conductor and protective conductor are combined

Based on the definitions in Table 1, the following earthing arrangements are for Wärtsilä power plant low voltage systems as identified in the IEC 60364-1:

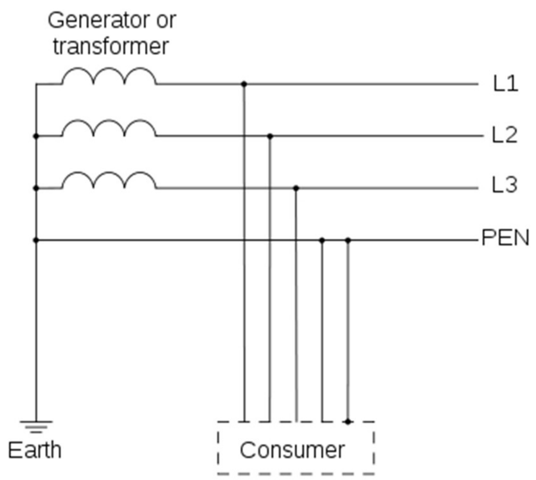

Figure 2. TN-C system, neutral and protective conductors are combined (PEN). [9.]

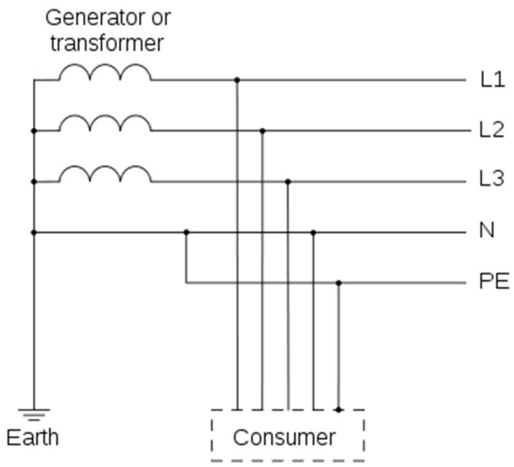

Figure 3. TN-C-S system is a combination of arrangements in TN-S and TN-C. Once PE and N are separated, separation must be maintained downstream in the system. [9.]

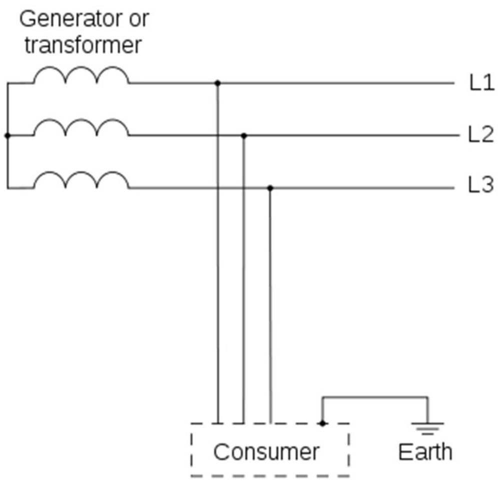

Figure 4. IT system is a floating system or earthed through high impedance. [9.]

TN-C-S is the minimum requirement that would be used in the installation of LV system at Wartsila power plants and is also the recommended system, however the point where PE and N is separated needs to be determined on a case-by-case basis. The earliest separation of the two can be done at the switchgear after the transformer but depending on, for example, the cable size it can also be done later down in the power system if required. [6.]

3 STANDARDS FOR SWITCHGEARS, SWITCHBOARDS AND MOTOR CONTROL CENTERS

As Wärtsilä delivers power plants globally complying with main standards, it is crucial to ensure the safety, reliability, and interoperability across diverse projects. The two major standards are International Electrotechnical Commission (IEC) and American National Standards Institute (ANSI). The purpose of this chapter is to see how the two standards differ and how it affects building low voltage switchgears.

3.1 ANSI/UL and IEC standards

Installation of distribution or motor control equipment is usually covered by a recognized standard that has been officially verified or approved by one or more nationally recognized testing laboratories. For the United States, standard evaluation must be performed by Occupational Safety and Health Administration (OSHA) approved NRTL, as for example UL short for Underwriters Laboratories, meaning that even if the equipment has been designed, tested, and rated in a way that is covered by an appropriate US standard it is still not be usable in the US without further evaluation with approved NRTL. [10.]

IEC, short for International Electrotechnical Commission, has about 10 000 IEC international standards which provide a good basis for risk and quality management, and give governments a chance to build national quality infrastructure, for which is safe for everyone to buy and sell reliable products in most countries of the world. [11.]

3.2 Comparing of IEC and ANSI/UL standards

Switchgears, switchboards, and motor control centers are all part of IEC 61439-2 - Low-voltage switchgear and controlgear assemblies – Part 2: Power switchgear and controlgear assemblies and the equipment designed to meet the IEC 61439-2 requirements must also cover the requirements of IEC 61439-1 - Low-voltage switchgear and controlgear assemblies – Part 1: General rules. [12.]

The ANSI standards are done with the help of building and safety codes since the standard is used in North America, making the ANSI standard more of a design-based standard. Because IEC is designed for worldwide use, it is used for large variety of local practices, codes, and legal environments, this means that the standard needs to be performance-based. [13.]

For the United States, the equipment under IEC 61439 is divided into three different UL standards, which are UL 845 for low-voltage motor control centers, UL 891 for low-voltage switchboards and UL 1558 for low-voltage switchgears. [13.]

For IEC standardized equipment to be used in the US, it would need to be tested by recognized NRTL and vice versa, for UL standardized equipment for IEC countries, but mismatching these may prove difficult with significant differences between these standards. One of the biggest differences is in comparing the IEC 61439-1 – General rules to UL 845 standard. IEC 61439-1 allows greatly smaller minimum creepage distances and minimum clearances in air between live parts and for live parts and equipment enclosure than the UL 845 standard. [14.]

3.2.1 Air clearance and creepage distance

The air clearances and creepage distances in the IEC 61439-1 are calculated of rated impulse withstand voltages, which is declared by manufacturer. IEC 61439-1 Annex G, Table G. 1 shows that rated impulse withstand voltage is 8 kV in origin of installation (service entrance) level for 600 V. Checking from the Table 1 – minimum clearances in air we can see that for 8 kV minimum clearance is 8,0 mm, and from Table 2 the minimum creepage distance for 8 kV now depending on the material group can also be 8 mm. [15.]

Now according to UL 845 standards Table 19, the minimum spacing through air for 301 – 600 V is 25,4 mm and for minimum creepage distance of 50,8 mm is required, showing that equipment which was designed to meet IEC 61439-1 standards is not acceptable for UL 845. [14;16;17.]

3.2.2 Interlocking

IEC 61439-1 discloses that if there is not an intermediate barrier giving the degree of protection of at least IPXXB to live parts, there must be interlocking mechanism that can only be overridden with a use of a tool or key, and interlocking mechanism should be automatically restored on reclosing the door(s). [16.]

According to UL 891, an uninsulated live part with a peak potential of 42,4 V should be protected with either a fiber barrier of at least 0,71 mm thick or with an interlock acting when door opened. UL 891 also states that in the case of multiple source switchboards if not specifically intended for parallel use a tiebreaker should be equipped with mechanical, key, or electrical interlocking with the service disconnects so that both sources cannot be paralleled accidently. Finally, the standard states that switches that are connected to a power bus and that have a nominal voltage of 250 V or more should be interlocked preventing operation under load. [17.]

4 IMPROVEMENT INPUTS FROM PROJECTS

4.1 Project engineering

LV Technical specifications need to be updated to better support project procurement and execution processes. This includes more accurate pricing for sales tools and implementing standardized configurations.

The LV consumer list update would need to maintain specific circuit breaker trip unit models for each application providing good starting point for LV system coordination study used in cable sizing and CB protection settings. [18.]

4.2 Development project

One of the goals of this thesis was to support the targets of on-going development project. Which include using configured to order model, modular power plant setup, high rate of pre-fabrication productized system solutions, meaning that the system is tested and configured at factory, automation update for lean manned remote operation with direction to unmanned operation and data collection & condition-based monitor. [18.]

5 CIRCUIT BREAKERS AND THEIR FUNCTIONS AND FEATURES

The IEC standard defines a circuit breaker as a “mechanical switching device that is capable of not only making connection but also carrying and breaking currents under normal circuit conditions furthermore making, carrying for a predetermined time, and breaking currents under abnormal circuit conditions such as in the event of short-circuit.” [19.]

Most used circuit breakers for low voltage distribution are Air Circuit Breakers (ACB), Molded Case Circuit Breakers (MCCB), and Miniature Circuit Breakers (MCB) [20.] By far most common one is MCCB, used in residential, commercial, and industrial facilities [21.]

5.1 ACB (Air Circuit Breaker)

An air circuit breaker (ACB) is usually a metal-hulled spring-loaded breaker that can be tuned manually or automatically and as the name suggests it functions in atmospheric pressure [20.] The air circuit breaker usually consists of two different contacts which are the main contacts and arc contacts, which reduces the constraint of main contacts in the time of breaker switching [22.]

The rated current and breaking capabilities of an ACB vary on different brands and models but for example ABB’s air circuit breaker called SACE Emax 2 has rated current of 100 – 6300 A and its breaking capabilities are between 42 – 200 kA [23.]

The use case of air circuit breakers would be more limited without addition of air-break interrupting devices, such as deion chambers, which greatly increase its breaking capabilities [24.] With this addition, the time of breaking the arc can be directed to deion chambers with the correctly shaped contacts, where the arc can be cooled and put off [22.]

5.2 Molded Case Circuit Breaker

Molded case circuit breakers (MCCB) have contracts exposed to ambient air, and they are controlled electromechanically or with microprocessor. Molded case circuit breakers are mostly used for the main power distribution in small to medium-sized facilities and industrial plants, [21] but they can also be used for residential and distribution panels and for controlling low-voltage motor starters [25.]

The rated current and breaking capabilities of a MCCB vary on different brands and models but for example ABB's MCCB called SACE Tmax XT has rated current of 16 – 1600 A and breaking capabilities of 65 – 200 kA [23.]

5.3 MCB (Miniature Circuit Breaker)

As an MCCB, a miniature circuit breaker has contacts exposed to ambient air and it provides overload protection properties of the fuse, without needing to be replaced after breaking a short circuit inside its rated current [26.]

They have either only thermal, or both thermal and magnetic elements. MCBs are largely used in Europe for residential panelboards and commercial distribution boards. [21.]

5.4 Comparison of thermomagnetic trip unit and electronic trip unit

A trip unit is often referred as a "brain" of the circuit breaker. The trip unit can measure the electrical parameters to determine when the circuit breaker should trip [27.]

A thermomagnetic trip unit has two parts to it, which are the thermal trip unit and the magnetic trip unit. The thermal trip unit is composed of a bimetal thermal device that has a trip delay depending on the overcurrent value. This tripping unit is suited for the protection against overloads. The other part is the magnetic trip unit, which consists of an electromagnetic device, which can have two different tripping thresholds, a fixed instantaneous trip and an adjustable instantaneous trip. These instantaneous trips actuate the opening of a circuit breaker on an overcurrent value with a constant trip time that are determined in the manufacturing of this device. The magnetic trip unit is suited for the protection against short circuit. [28.]

As electronics have been refined over the past years and as there has been a need for both more accurate measurements and for more coordinated circuit protection, the first-generation trip units were invented. These electronic trip units were straightforward analog circuits that were made up by resistors, capacitors, inductors, and transistor, but even in their early phase they gave a better accuracy over the old thermal-magnetic design. The electronic trip units continued evolving with small improvements until the first modern microprocessor trip units were made. They offered even better protection accuracy and adjustability and allowed coordinating breakers closer together which allowed installing breakers in series. Until recently electronic trip unit sensors have been too inaccurate, but now with traditional sensors being replaced by Rogowski Coils, it is feasible to use them for also the measuring. [29.]

As a more practical example with the traditional thermal magnetic breakers, it is only possible to have coordination up to three levels, meaning that for example apart from having a switchboard main to a switchboard feeder to a power panel branch. It is not possible to coordinate an additional feed to lighting panels from the power panel as it requires the fourth level of coordination. LSI breakers, however, are not limited to only three levels but can have up to five levels of coordination. Coordination means that the breaker closest to a fault acts, so protection is done selectively by zone. [29.]

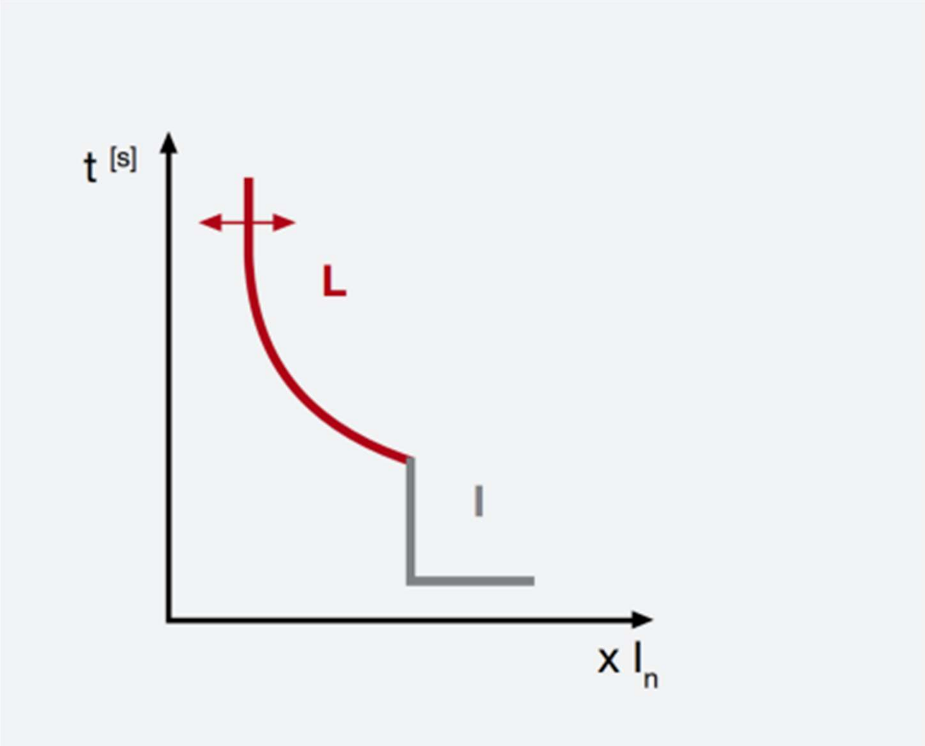

Figure 5 Typical Thermal Magnetic Time Current Curve. [29.]

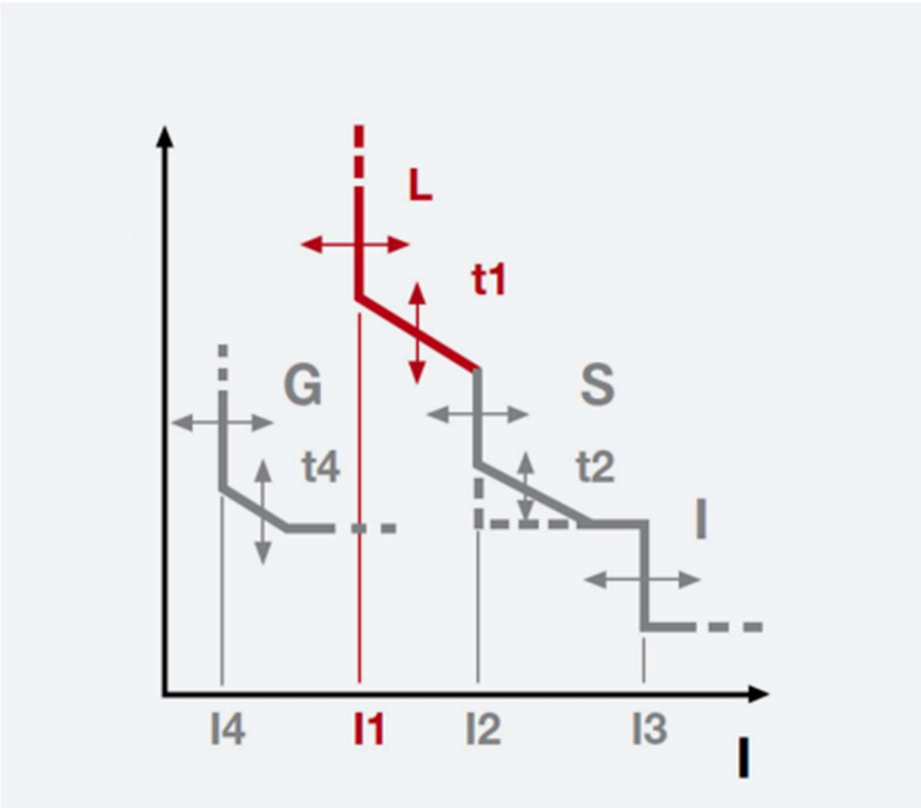

Figure 6 Typical LSIG Time Current Curve. [29.]

Electronic trip unit breakers are usually preferred for their tripping features, for example ‘LSI’ or ‘LSIG’, ‘L’ meaning the long-time trip (60-600 seconds), ‘S’ meaning the short time trip (0,1 to 60 seconds), ‘I’ meaning instantaneous trip and ‘G’ meaning ground fault trip. The protection functions ‘L’ and ‘S’ are replacing the traditional thermal element and function ‘I’ replaces the magnetic element. [29.]

5.5 Electronic trip unit functions and options

This chapter explains electronic trip units’ functions, capabilities, and options of an electronic trip unit for the commonly used ACB and MCCB at Wärtsilä, which are ABB’s SACE Emax 2 and SACE Tmax XT.

Both breakers can be configured operating with Ekip Dip, which has an interface via DIP switches or with Ekip Touch with a touchscreen, additionally there are four Ekip Touch models which are Ekip Touch, Ekip Hi-Touch, Ekip G Touch and Ekip G-Hi Touch. These models vary on their default functions, but each can be optionally configured added functions. The broad main functions are measurement, protection, and signalling. [30.]

All the protections have the same operating principle but with different signals for example, currents, voltages, frequencies, or powers. The operation principle is the following: if a measured signal exceeds the set threshold, that specific protection tied to that signal activates the pre-alarm and/or alarm. However, if the signal exceeding the threshold drops below it before the trip time has elapsed, it stops the alarm and returns to normal operating conditions. [30.]

5.5.1 Synchrocheck module

The Synchrocheck accessory module is used to detect synchronism conditions on both sides of the circuit breaker, as well as dead bus conditions. Typically, the synchro contact is used as the final lock in the control circuit to enable manual operator action for closing. Optionally, Synchrocheck can be used for the direct closing of the circuit breaker when the conditions defined above are met, and automated control is required. [30.]

The Ekip synchrocheck module can operate in two different modes, which can be configured by the user or by the unit with automatic-mode configuration. These modes are busbar active and dead busbar and configuration. The busbar active synchronism process begins when the external voltage reaches at minimum 50 % of the nominal voltage for at least 1 second. Synchronism is reached when the differences between RMS values, frequencies and the voltage phases are less than 12 % of nominal voltage, 0,1 Hz and 50 °. For the dead busbar and configuration mode the roles of the internal and external voltages are reversed, meaning synchrocheck process begins when the internal voltage reaches at minimum 50 % of the nominal voltage for at least 1 second. Here synchronism is reached when the external voltage is 20 % of nominal voltage or less for at least 1 second. All the values listed are only default ones and can be altered manually. [30.]

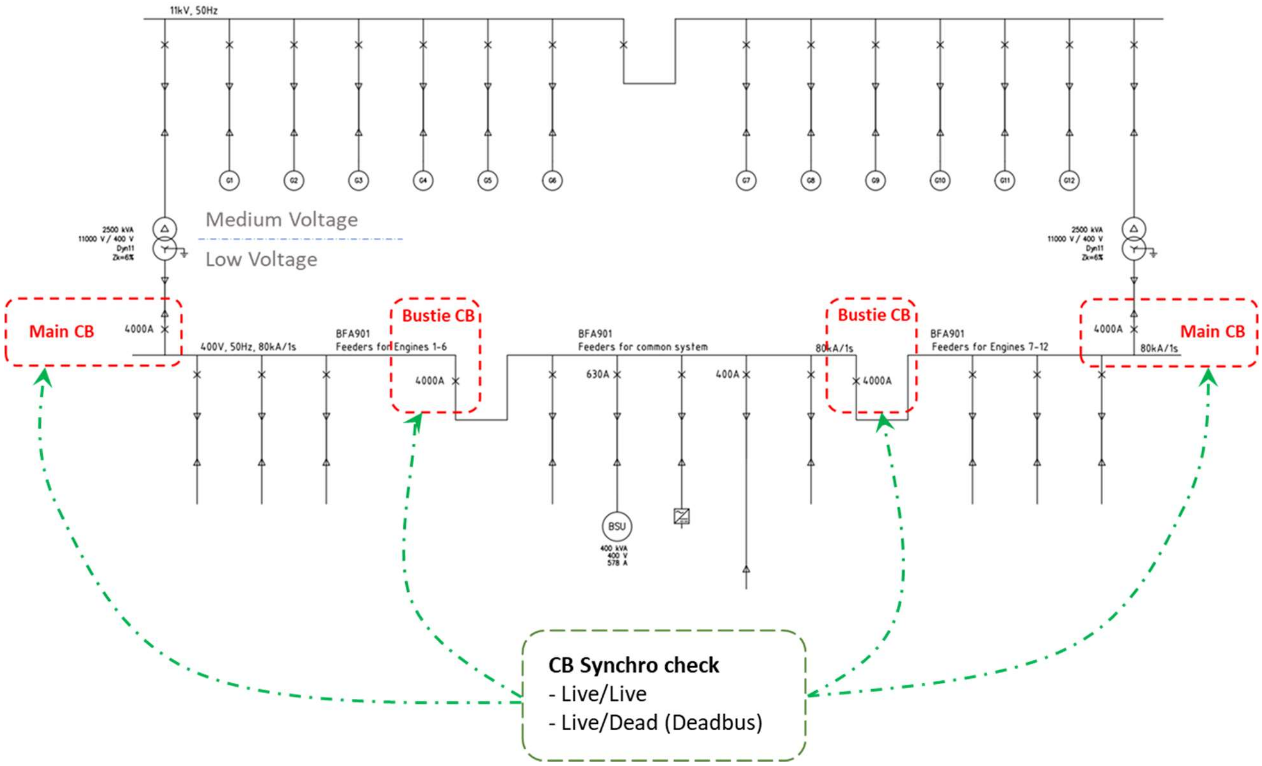

Figure 7. Synchrocheck in single line diagram. [18.]

5.5.2 Synchronizer

An external synchronizer is used for LV supply changeover between the main and tie breakers from different power sources. The source, target voltages and controlled breaker are selected via the synchronizer. The select button is for choosing the dedicated circuit breaker. In the case of an island-operated or factory feed setup, MV side power sources can be controlled when there is no grid connection. For alternative grid feed power plants, such as baseload or balancer types, only an emergency supply source, the Black Start Unit (BSU), can be controlled. [18.]

Synchronization can be controlled manually from the synchronizer control station or automatically via an external auto-synchronizer in the same circuit. It is selected via the auto/manual selection button that is on duty. In the manual mode, the voltage and frequency of the source bus are adjusted by the increase and decrease buttons to correspond to the target bus voltage and frequency, and the sync pulse close order is triggered by the operator at the right time according to the synchroscope 12 o'clock indicator. The auto-synchronizer manages the same with automated manner without operator action. [18.]

The external synchronizer function provides flexibility for the LV system together with the Black Start Unit (BSU) source bus voltage and frequency control in back synchronization situations when the power plant starts up after a grid failure or other blackout circumstances via the BSU on duty. The Wärtsilä generating set starts, and the generator circuit breaker (GCB) closes to the MV dead bus. The auxiliary transformer energizes, and the main incoming breaker for LV is ready for synchronization by the above operation. The LV voltage source (BSU) plays a vital role in smooth changeovers and back synchronization situations. [18.]

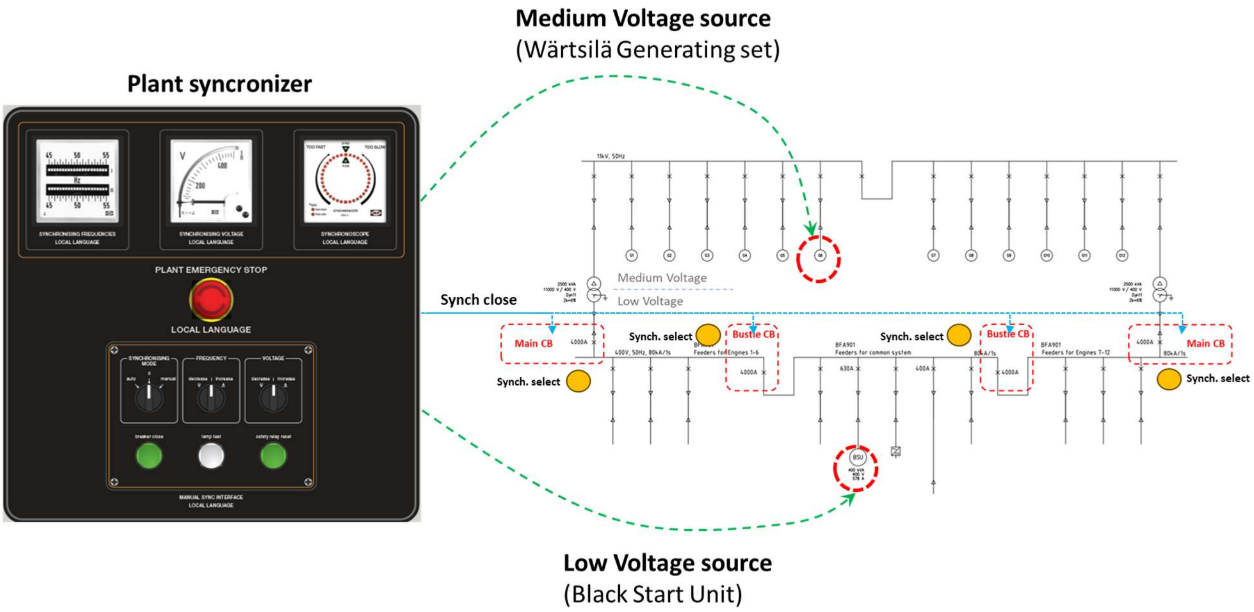

Figure 8. Plant synchronizer. [18.]

5.5.3 Communication module

With the help of a communication accessory Ekip Com, Ekip Touch can be connected to an ethernet network. With Wärtsilä, the Modbus TCP communication protocol is currently in use, which is planned to be replaced by the IEC61850 vertical protocol to obtain timestamps from the source. This will require a change of the communication card to the 61850 model and synchronization with the existing

SCADA setup. This enables remote monitoring and control functions. Specifically, the module can allow reading of measurements and information, control of specific functions for example, opening and closing of a circuit breaker, accessing to information and parameters not available on the display and for withdrawable version of circuit breaker this allows the checking if the circuit breaker is racked-in or racked-out. [30.]

To open and close the circuit-breaker remotely using Ekip Com an MOE-E motor operator for MCCB models needs to be added. Without it the state of the circuit-breaker only can be acquired. [31.]

Ekip Com is always supplied with Ekip AUP and Ekip RTC. The communication module uses dedicated Ekip AUP auxiliary position contacts, which is intended for a withdrawable circuit-breaker, to give the position of rack mentioned before. The Ekip RTC auxiliary contacts provides the ready to receive a close command signal for the trip unit. [30.]

Safety and cyber security are always important factor in these situations where communication modules allow the circuit-breaker to be connected to Ekip Touch through connected networks [30.]

5.5.4 Datalogger and network analyzer

The datalogger function records analog measurements from line-to-line voltages and phase currents. It also records protection events, alarms, circuit-breaker status signals and protection trips. This function enables reviewing of data in the event of triggers. The datalogger can stop reading data after trigger event or after a user set time, data is stored and can be downloaded to a PC. The datalogger is used for troubleshooting in the event of CB trip or fault in the network and helping to analyze the possible causes of the initial problems occurred in the LV network. [18.]

The network analyzer function enables the system analysis with a long period voltage and current controls. It also indicates the quality and the state of electrical network. Monitored values include voltage sequences for over, under, positive and negative, unbalances between voltages, short voltage drops and increases and voltage and current harmonic distortions. [18.]

5.5.5 Additional internal accessories

Additional internal accessories include:

- Additional open/closed auxiliary contacts
    - Additional “switching” contacts can be installed, the number of these varies between different circuit-breaker models. Contacts are used in signalling then open/closed state of circuit-breaker. These contacts can be standard or digital contacts.
- Ekip protection trip unit tripping signalling contact – S51
    - When The Ekip protection trip unit is tripping S51, the contacts signal the opening of the circuit-breaker. Either Standard or digital contacts can be chosen.
- First and second opening coil – YO
    - The circuit-breaker can be opened remotely, opening of the circuit breaker can always be done when the circuit-breaker is closed.
- First and second closing coil – YC
    - The circuit-breaker can be closed remotely, closing of the circuit-breaker can be done when open and the closing springs are charged.
- Remote resetting – YR
    - When opening of the circuit-breaker is done by tripping of the Ekip protection trip unit, this remote resetting coil can deactivate the lock at the closing of the circuit-breaker.
- Undervoltage coil – YU

- The undervoltage coil is controlling the connected circuits voltage level. YU opens the circuit-breaker when its energizing voltage is below a set value between 35 – 70 % of nominal voltage. The circuit-breaker cannot be reclosed if the energizing voltage is not back between 85 – 110 % of nominal voltage. [29.]

5.5.6 Motor operator

The front of the MOE Motor operator has a selector switch for choosing between auto, manual and locked modes. When the auto mode is selected, the push button for closing is locked and is only accessible through a remote command by an electric impulse. Opening, however, is accessible by a push button and remotely. When in the manual mode, only the push buttons in front of the motor operator can be used for opening and closing. The locked mode can be selected when the circuit-breaker is open and the safety padlock device can be withdrawn, allowing the motor to be locked to open position. Spring charging is automatically initiated when the CB is ordered to open in normal operator open/close command sequences. In the event of a protection trip, the CB needs to be reset to clear the protection trip. This enables the execution of spring charging by giving the open order to the CB, and the trip signal is then reset to normal after the next closing sequence when the breaker is confirmed to be closed. [29.]

The status auto/manual of the motor operators can be monitored by digital input to know the set function in the circuit breaker [29.]

When Ekip Com is used MOE-E must be used instead of MOE, which allows Ekip Coms received digital signals from the supervision and monitoring system to be converted into power signals to control the motor operator. [29.]

5.6 Protection package solutions

On top of usually used protections in Wärtsilä power plants which are LS/I, LSI and TM there are other protections to choose if needed. These protections are categorized into different packages. The standard protections are available for all the Ekip Touch models and 'LSI' protections are part of it. Additional protections to choose from the standard package are:

- S2 protection differs from S protection by not having a thermal memory and having a fixed time trip curve.
- G protection uses the vector sum of the phase currents to acquire the internal earth fault current Ig. When Ig goes over the set limit, the protection trips.
- MCR protection measures the current of phase or phases for a period after an open or closed command. In case the current exceeds the set limit, the protection sends the trip command. When MCR is used, I protection must be disabled.
- 2I protection differs from I protection by needing both an exceeding current and a trip event present to trip.
- IU protection checks for the balance of different current readings. When unbalanced with respect to max or average currents the protection sends a trip command. The unbalance ratio can be set between 2 to 90 %.
- Neutral protection is used in controlling the setting from protections 'LSI' on the neutral pole using a control factor different from the other phases.
- Harmonic Distortion protection alarm is activated when distorted waveforms occur. The alarm is activated for waveforms higher than 2,1.
- T protection is protecting the circuit-breaker from irregular temperatures. A warning is given for temperatures between -40 °C and -25 °C or between 70 °C and 85 °C and an alarm is for under -40 °C or over 85 °C.
- Hardware Trip protection trips if during the circuit-breaker being closed any current sensors, the rating plug or trip coil disconnects or there is event for faults inside the unit. [31.]

Additionally, ABB offers separately purchased software packages, such as voltage, voltage advanced, frequency, power and ROCOF. [31]

Voltage protections include protection against minimum voltage, maximum voltage, phase sequence error and voltage unbalance. Voltage advanced protections include short-circuit protection with voltametric control and insulation loss protection with residual voltage. Frequency protections include minimum and maximum frequency protections. Power protections are for reverse active and reactive power, active over and underpower, maximum reactive power, minimum cos phi and directional short circuit. ROCOF protects against rapid frequency variations. [29.]

5.6.1 Incoming feeder for low voltage system

Typically, withdrawable ACB with LSI protection is used for the main feeder of the low voltage system and a withdrawable MCCB with LSI protection is used for subsystems. For the incoming feeder, synchrocheck is used in case of multiple sources available in the LV busbar. The synchrocheck is used for both between the live connections and for a dead busbar between live and dead connections. [18.]

5.6.2 Distribution feeder

For the distribution feeder, a fixed MCCB is typically used with Ekip Touch measuring package. Monitoring is done with Modbus TCP as default, controlling is optional and if chosen motor operator needs to be added. [18.]

5.7 Remote operation & monitoring

Circuit breakers can be controlled remotely via communication over Ethernet or hardwired signals, depending on the accessories chosen for the CB. Operators can switch between local and remote operation from the control room, and this can also be done locally from the LV switchgear. [18.]

Remote operation includes operator station manual controls and power plant manual synchronizer commands, or CB auto-synchronizing via power plant auto-synchronizer [18.]

Local operation is typically used for LV switchgear testing purposes, but it also provides more options for the operator to control when needed [18.]

Monitoring can be done in an extensive or simple way through SCADA, depending on the needs and accessories included in the CB and the application used. The simple way involves using hardware signals from breaker auxiliary contacts (Open, Close, trip, and withdrawable positions, etc.) wired to the control system. [18.]

The extensive way involves utilizing selected Ethernet communication from the CB, which allows full access for monitoring CB properties, including power measurements, electrical network quality (network analyzer), all the states of the CB, dedicated trips and alarms, and CB diagnostics and statistics [18.]

Typical monitoring interface with WOIS/ATVISE can look as seen in Figure 9. and 10. The figures show the structure of the system and with clicking on to different circuit breakers, it is possible to control them and check their status. [18.]

5.7.1 CBM (Condition-Based Monitoring)

The CBM system is developed to detect potential failures ahead of time, to compare expected lifetime to actual lifetime and to find out the root cause of the problems. In short, the system is comparing actual values to the reference values given to the system, of which we can determine the actual status of devices. [18.]

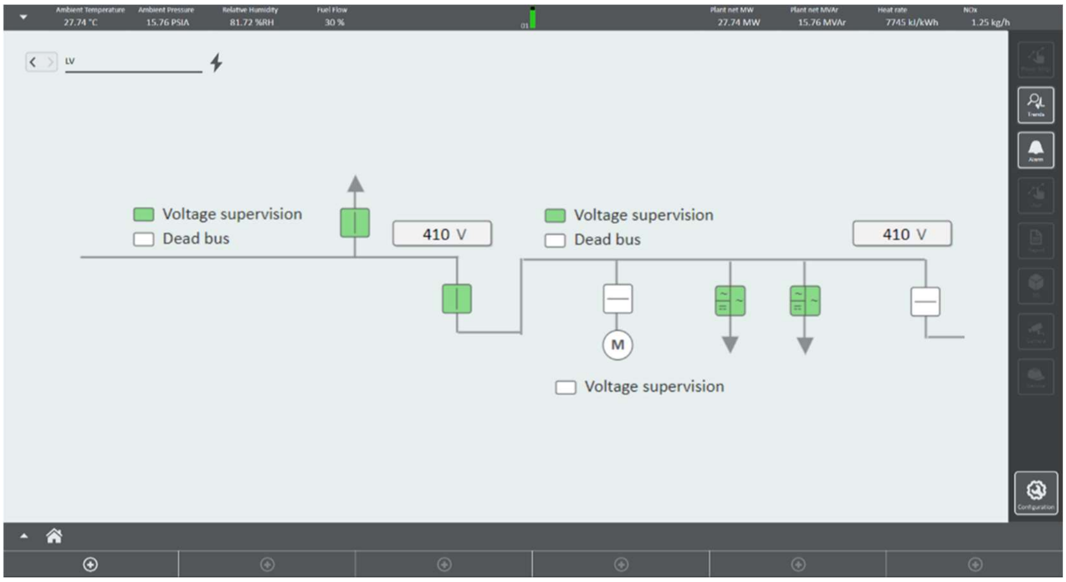

Figure 9. Overview of the system. [18.]

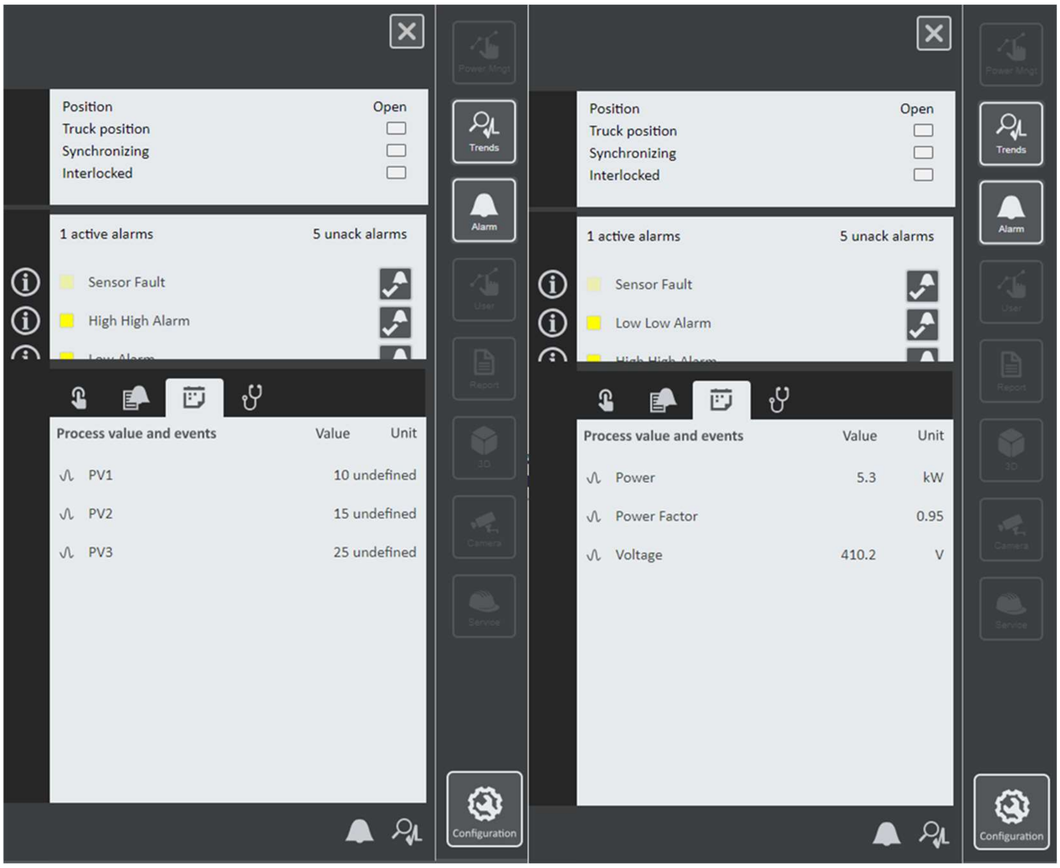

Figure 10. Status and controls of the selected circuit breaker. [18.]

The benefits of the CBM system are reduced process downtime, decrease of down unexpected faults, timing and optimization of maintenance and reduction of the inventory of spare part stock. With this monitoring the maintenance needs to be improved with it, an essential part is to know what and when to maintain. The company maintenance strategy needs to be aligned when CBM is taken into use with the fullest potential. [18.]

LV breakers data that can be monitored are following:

- Consumption measurement (for analysis)
- Network analyzing (Quality of electrical network)
- CB statistics & state (Counters and states)
- Contact wear monitoring (Wear & tear tracking)
- Timing analysis (Opening and closing times of CB)
- Travel analysis (Binding or misalignments)
- Faults and alarms (help for root cause analysis)
- CT / VT supervisions & internal components

For example, when monitoring consumption over a long period, a clear increase in consumption indicates that something in the subsystem is not working as efficiently as it was when installed. Example causes for increased consumption can be a dirty fan filter causing increased speed of fan due to decreased air intake of speed drive control or a clogged pump filter causing the pump running with a higher speed trying to keep the set pressure to the variable-frequency driver. [18.]

Additionally, monitoring of consumption will give the base for further optimization of own consumption via new service business models to optimize system efficiency. The first level for this step is to know better the system energy consumption as a base point. [18.]

Addition to the consumption related matters, the CBM can also be used in determining the equipment wear. The degree of wear in the circuit breaker can be supervised by monitoring the operation times of the circuit breakers operation times with measuring nominal and peak currents during the breaking. Usually there is an algorithm that calculates the wear of the circuit-breaker by calculating the nominal and peak currents during opening and closing the breaker. For example, the algorithm can combine the duration of arcing with the interrupted root-mean-square (RMS) current. Meaning that it considers both the duration of arcing and the severity of the arcing with the measured RMS current in the moment of interruption. With this information, it is possible to determine the percentage of wear with each opening and closing of the circuit breaker. Combining the information, makes it possible to identify that normal opening of the circuit breaker with a small load only causes a small decrease in the lifetime of the breakers while a short-circuit trip can cause significantly higher stress and wear, leading to a larger reduction to the breaker lifespan. [18.]

This type of circuit-breaker wear is monitored to assess the breaker's status and to indicate the need of maintenance or replacement before a fault in the breaker occurs. This proactive approach helps ensure the reliability and safety of the electrical system by addressing potential issues before they lead to failures or faults. [18.]

The CBM data can be analyzed and sent to Supervisory Control and Data Acquisition (SCADA) system and cloud or in standalone setup the raw data is sent to the edge of a network for further analysis in the local manner allowing to include an edge process without cloud services [18.]

5.8 ARC flash protection

For Wärtsilä’s low voltage system, arc light detection sensors are used for detecting an arc flash. All feeder breakers open when an arc flash is detected in the busbar space and the MV breaker in the feeding transformer opens the main switchgear feed after the arc light sensor inside the incoming cable space sends trip information to the MV breaker, the trip is latching until a reset. Arc light sensors are used to trigger the fault with the location of one of the sensors in the closed busbar section. Due to current measurement requiring external current transformers with arc option modules, it is rarely used together with light sensors. Commonly ARC protection is equipped for below 40 kA switchgear rate applications but could be optionally used for lower rate if needed. [18.]

ARC protections for LV switchgear can be used with either PLC communication over Modbus or via hardwired digital inputs with remote monitoring possibilities. An ARC protection internal fault is always hardwired digital input, preventing possible reliability issues with communication losses causing unknown relay states in Modbus and longer response times. [18.]

6 LOW VOLTAGE DOCUMENTATION IMPROVEMENTS

6.1 Technical specifications

Technical specifications is a detailed document of technical requirements, features, and functionalities of a product, often according to specific acceptance criteria such as international standards forming basis to the design development and production processes [18.]

This chapter aims to improve the base of technical specification to cover more widely the requirements of setting up the projects [18.]

6.1.1 Different feeders for applications

LSI is used for circuit-breakers that are feeding switchboards. This is also great for nonlinear loads since it allows an instantaneous trip to be defined for faster breaking. Nonlinear loads are generated by for example variable frequency drives, where current is not proportional to the voltage. [18.]

For an ethernet communication unit, a TCP bus electronical trip unit is used while a thermomagnetic trip unit can be used for standalone situations [18.]

For MCBs, b and c types are commonly used. [18.]

6.1.2 Power connections

Power connections to the circuit-breakers have been a problem with larger cables not being able to be fitted for the regular connectors of the breaker. To ease the site installation all MCCB and ACB circuit-breakers need to be defined for sites cables to check if there is a need for front extended terminals that are intended for connections with cable lugs. [18.]

6.1.3 Fixed or withdrawable

Every circuit-breaker connected to an incoming power or busbar is to be a withdrawable version for easy replacement, safe isolation, lock-out and earthing switches interlocks. For these applications both ACB and MCCB can be used. Fixed circuit-breakers are to be used for distribution since they are not needed for interlocks and there is no danger of reverse feeding. MCCBs and MCB groups are used for distribution, their small size makes them easily replaceable, while not being vital for whole system. [18.]

6.1.4 Operation mechanics

Remote use requires a motor operating circuit-breaker to be used. Door mounted switch handles are equipped for local and manual operation. [18.]

6.1.5 Switchgear interlocks

An earthing switch interlock, circuit breakers isolated, or test position allows earthing switch to be closed. The earthing switch closed state disables feeding circuit-breakers undervoltage coils unless circuit breaker is in a test position. [18.]

Main circuit breaker undervoltage coil interlocks consists of LV circuit breaker test position, earthing switch state and optionally emergency stop circuit via safety relay and contactors. The emergency stop is there to stop equipment in the event of emergency, breakers test position enables the testing of the circuit breaker when the earthing switches are closed. The MV circuit breaker closed position is used for close coil circuit for close release of LV CB. An Intertrip from the MV circuit breaker open state signal controls the LV CB open coil securing trip functions for the MV and the LV CBs and preventing back feeding to auxiliary transformer from LV. [18.]

There are also interlocks between feeding circuit-breakers which takes care of maintaining only one feed per busbar to prevent parallel feeds and to limit short-circuit currents for acceptable levels. Most typically used in Wärtsilä power plants is the 3/4 interlock between the main and the bus tie circuit breakers. [18.]

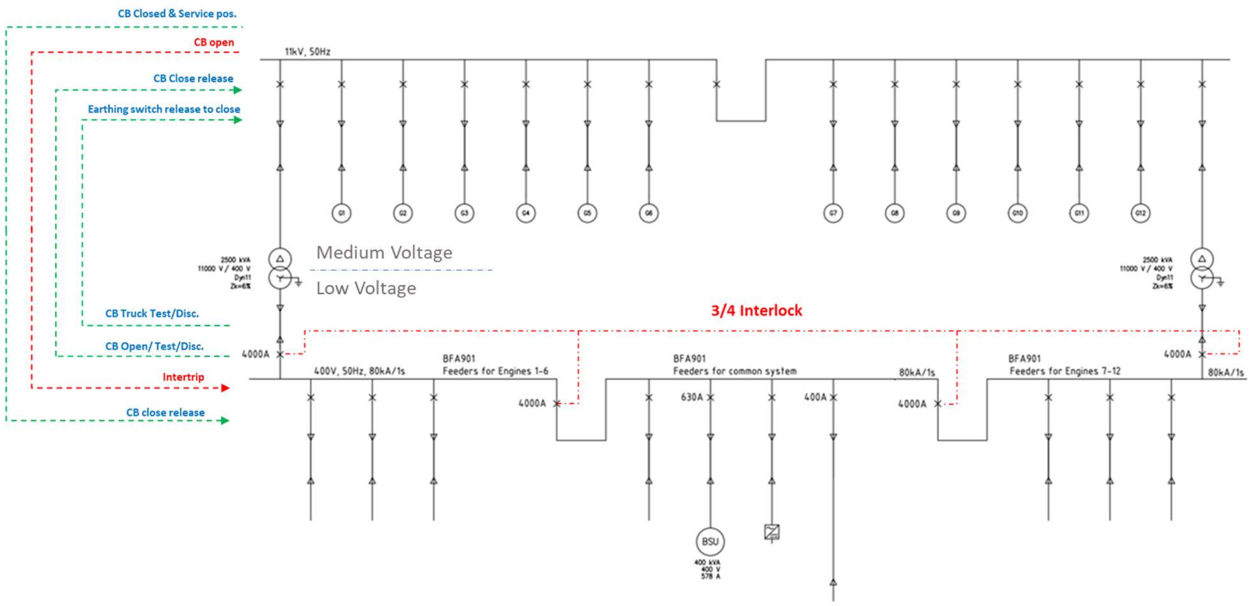

Figure 11. Switchgear interlocks [18.]

LV main feeding circuit-breakers from the auxiliary transformer isolated or test position is used for the medium voltage side of the auxiliary transformer, earthing the switch interlock for users' safe operation. Breaker open or isolated position is used for MV breaker close enable to secure the transformer energizing without load. [18.]

6.1.6 ARC Protection

ARC protection could be provided in the specification with more detail. Information about the ARC light sensor location and validated vendors for the equipment can be included in the technical specifications. The DIP switch settings should be fully included into the documentation and if the signals are taken via HW or through communication network protocol, it should include HW trips to MV and LV circuit breakers open coils. Finally, the dedicated ARC protection drawings should be delivered together with the LV switchgear drawings bid. [18.]

6.2 LV Consumer list base

The base LV consumer list is initial configuration of LV system, where installed base power and current characteristics are given for LV systems. Feeders are pre-configured with certain type (ACB MCCB, MCB, RCB etc.). Phase and neutral needs are indicated as well as direct online starter, non-linear load, Y/D (Star/Delta starter) etc. [18.]

The LV consumer list is giving feeder-based plant codes for all sub systems and electrical cabinets with identification letters and numbers. [18.]

The consumer list defines consumptions in different operating states of power plant or applications such as standby / hot standby, engine run, Black start condition or emergency condition. With this, the total consumption of LV busbars is defined with different engine or power plant operating states. Auxiliary transformers are selected based on the LV consumer list together with the project specific single line diagram (SLD) and project specific requirements. [18.]

The LV Consumer list is also used for cable sizing and coordination study, where selected breaker model and protection characteristics have a big impact on the end results. [18.]

It is used for project specific LV configuration and gives a good start for projects with default configurations for all Wärtsilä used engine type of Power Plants. Engine segment consumers are more standardized than common consumers which are adjusted during the project according needs. [18.]

Determining more specifically feeder types and trip units used with protection ranges will eventually benefit in the coordination of circuit breakers downstream and cable size optimizing for feeders. Electronic trip units with LS/I, LSI or LSIG gives more properties and possibility to standardize the circuit breaker size with a wider range of adjustments per needs. [18.]

Building the LV consumer list in a modular manner defined by the scope of supply of Wärtsilä delivered power plant is seen beneficial when sorting out the best possible starting point and more accurate LV consumer list for wide scope of projects [18.]

The LV Consumer tool would be a good approach to develop this further which means building up the Project specific LV consumer list from system based standard configurations according to sales phase configured and confirmed scope of supply [18.]

7 LV PROTECTION IMPROVEMENTS

This chapter contains the problems and solutions for adjusting breakers for being selective in relative to each other. At the same time, we can show that it is cost efficient to do so; on the other hand, aiming for complete selectivity can make the system more expensive to implement.

7.1 Breaker settings and selectivity study

Selectivity studies are currently done depending on the scope, but choosing to do this as a standard for every project could have benefits, including but not limited to better protection coordination, optimized cable sizing, cost savings, standard compliance, and reliability. [18.]

Selectivity is a term used in situations where trip devices can distinguish a circuit from its normal and abnormal state beginning its action during the abnormal conditions in the specific part of the system to isolate the affected part out of the healthy system [32.]

Selectivity can be achieved for example in selecting of trip devices, cables, and ratings of equipment [25.]

7.1.1 Cost efficiency

Using LSI circuit breakers, whether it is done electronically or with dip switches will eventually give an offer benefit in terms of optimizing site cable sizing, due to the larger scale of selected circuit breakers base current adjustments compared to thermal magnetic breakers. It is vital that LV circuit breaker protection relay settings and coordination study is done together when determining the site cables used in between the systems. This way the cost optimization can be achieved and helps to avoid the use of excessively large cables that often lead to issues in the interconnections of subsystems. [18.]

This gives a better foundation for more accurate standardization of certain type applications, where consumer rates vary from project to project. Circuit breaker protection relays need to be set correctly according to the factory acceptance tests and given project specific settings. [18.]

7.2 Febdok software

FEBDOK is software designed for the dimensioning and documentation of low-voltage electrical installations. For example, it is possible to make selectivity studies for power distribution and verify the compliance of electrical installations with the SFS 6000 standard in Finland. Additionally, separate modules are available for design based on the standards in Norway, Sweden, and the United Kingdom. The software includes extensive component libraries from major manufacturers and can be used for both inspecting existing installations and designing new ones. [33.]

7.2.1 Febdok selectivity studies

The documentation for installation Febdok report is given as an example of the software. Showcasing K-1.4.4 which is under the CLV901 AUX branch circuit as seen in Figure 12. below [34.]

From Figure 13. below we can see the maximum short-circuit current for the K-1.4.4 which is 29,164 kA. The maximum breaking capacity is shown on the right as 40 Icu. I_{cu} is the breaking capacity when K-1 is considered as a feeder CB. This value is automatically found by Febdok when using the same manufacturers circuit breakers, but mismatching the manufacturers, would usually require manually finding this value. [34.]

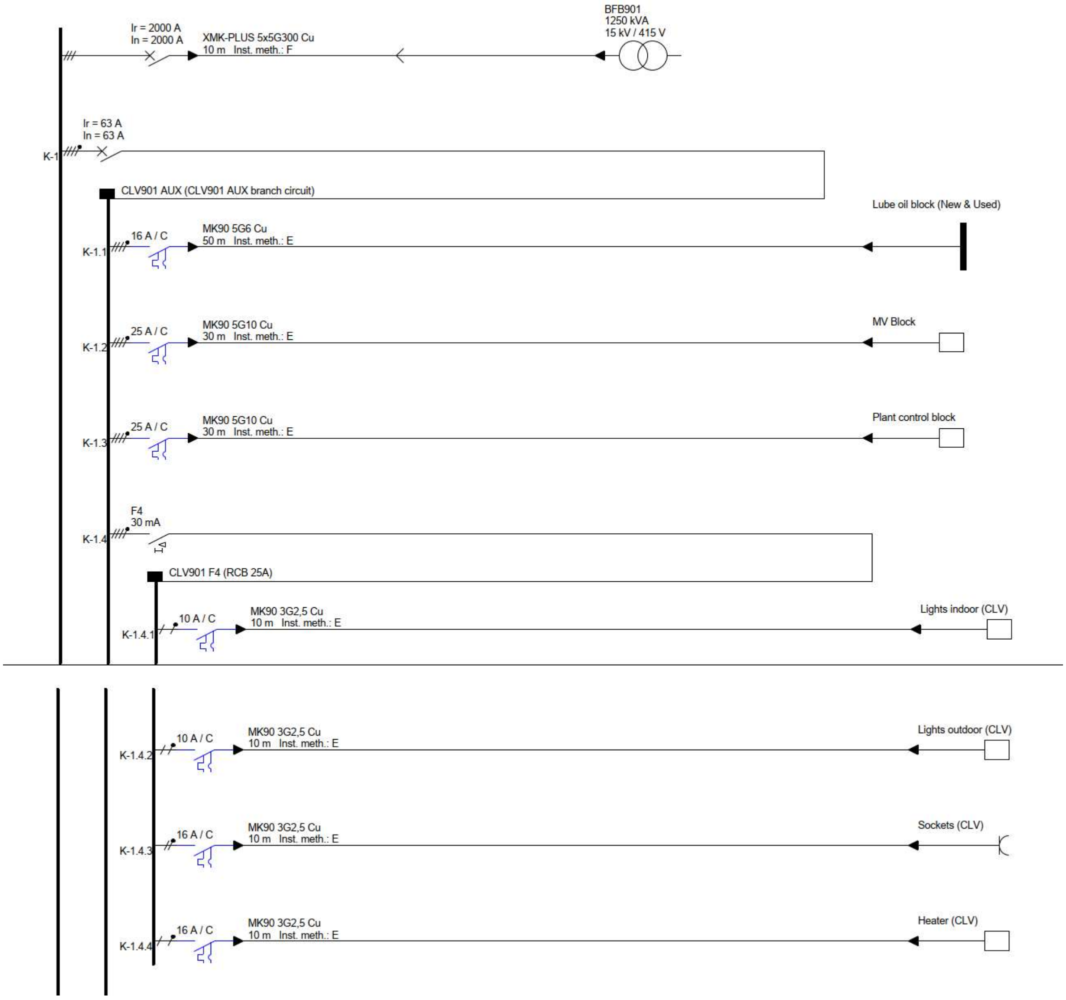

Figure 12. Circuit breaker structure in Febdok

Circ. Id.	Identification Load description Earthing/Equipot.	Load type Live cond. arr. Dist.Type	Cable ref.des. Cabletype/-conf. Installation method	Length [m]	k_t k_p k_f	I_z [A] I_b [A] ΔU [%]	Equipment	I_{scmax} [kA] I_{scmin} [kA] I_{efmin} [kA]	PD Identification Manufacturer Type	I_N [A] I_c [kA] I_{lm} [m]
K-1.4.2	CLV901 F22	Fixed load			1.03	21.60		29.164		10
**	Lights outdoor (CLV)	L2-N	MK90 3G2,5 Cu		1.00	1.00		1.088	ABB	40 Icu
			E	10	0.70	-2.54		1.088	S200P C 10 A	109.8
K-1.4.3	CLV901 F23	Variable load			1.03	21.60		29.164		16
**	Sockets (CLV)	L3-N	MK90 3G2,5 Cu		1.00	10.00		1.088	ABB	40 Icu
			E	10	0.70	-1.80		1.088	S200P C 16 A	68.6
K-1.4.4	CVL901 F24	Fixed load			1.03	21.60		29.164		16
**	Heater (CLV)	L1-N	MK90 3G2,5 Cu		1.00	5.00		1.088	ABB	40 Icu
			E	10	0.70	-2.22		1.088	S200P C 16 A	68.6

Figure 13. Circuit breaker details

Febdok does notify that in the case of k-1.4.4 “The service breaking capacity in accordance with IEC 60947 - Ics - of the protective device is less than the maximum prospective fault current. The ultimate breaking capacity in accordance with IEC 60947 - Icu - of the protective device is greater than the maximum prospective fault current." But as there is the proper backup protection in the form of K-1 it is in accordance with IEC 60947-2. [34.]

The breaker settings are listed as seen below in Figure 14; inspecting K-1 which is ABB XT2 circuit breaker equipped with electronic trip unit Ekip touch LSI. There we can see long time trips settings. Current is set to $1*I_n$ with a 3,0 s time constant. Short time trip is set to $3,5*I_n$ with 0,1 s trip time. [34.]

Circ. Id.	Manufacturer Breaker Unit Tripping Unit In [A]	Overload	Short circuit protection-Short time	Short circuit protection - instantaneous	Earth fault
K-0	ABB E2.2 EKIP TOUCH LSI 2000.00	Current: I1 1.000 / 2000.0 A Time: t1 3.000 s	Current: I2 3.500 / 7000.0 A Time: t2 0.100 s	Current: I3 15.000 / 30000.0 A	
K-1	ABB XT2 EKIP TOUCH LSI XT2 63.00	Current: I1 1.000 / 63.0 A Time: t1 36.000 s	Current: I2 5.500 / 346.5 A Time: t2 0.100 s		

Figure 14. Circuit breaker settings

For the discrimination analysis Febdok uses two fault locations, which form maximum, and minimum short-circuit currents I_{kmax} and I_{kmin} as seen in Figure 15. Returning to Figure 12, the fault that forms I_{kmin} is located at the end of the cable of K-1.4.4, meaning at the heater and the I_{kmax} is formed by a fault at the circuit breaker. [34.]

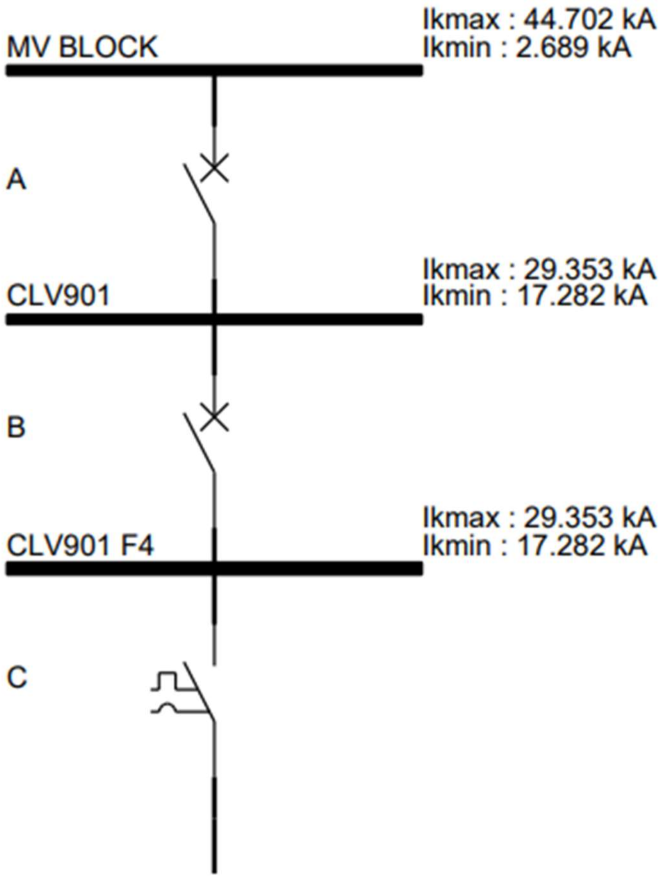

Figure 15. Selectivity structure

Figure 16 shows an overlapping of breakers B and C at over 2000 A, but in this case, it hardly going to be a problem since the tripping times are just 0,01 s. So most often when the current rises the circuit breaker C is tripping before circuit breaker B. [34.]

Discrimination analysis
Circ. No.: K-1.4.4

PD		Manufacturer	Type	I_n [A]
A		ABB	E2.2 2500 A EKIP TOUCH LSI 2000 A	2000
B		ABB	XT2 160 A EKIP TOUCH LSI XT2 63 A	63
C		ABB	S200P C 16 A	16

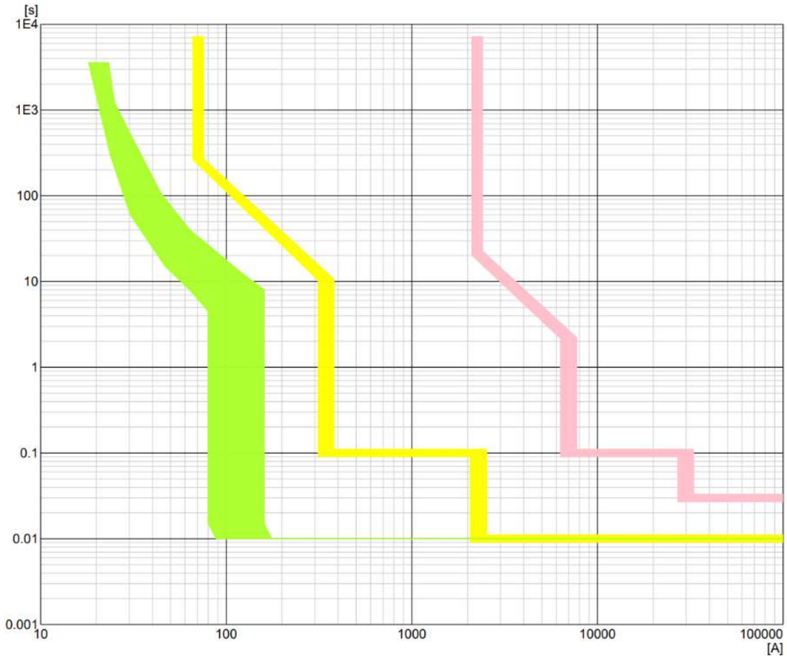

Figure 16. Time-current graph

When selectivity studies are done for the project this documentation for installation is given and explained to the projects chief project engineer who then delivers PD settings to the switchgear manufacturers and/or to the site team who will set or check that the settings are correct for each circuit breaker. [34.]

7.2.2 Usual problems and solutions

Example 1:

165 A circuit-breaker with a thermomagnetic trip unit is chosen for the circuit when the load is under 110 A, which is often done when the supply current is not precisely known in advance. With circuit-breakers equipped with thermomagnetic trip units the possible current range can be set between 0,7 – 1x of its nominal current so in this scenario it should be set for 0,7x which comes to 115,5 A.

Therefore, the cable should be rated for over 115,5 A to be protected by the circuit-breaker. This means that adding a larger rated circuit-breaker can also bring up the cable cost. [34.]

Solution: In this case it is possible to choose a circuit-breaker with an electronic trip unit which allows the nominal current of the circuit breaker to be set between 0,1 – 1x, making the cable costs lower but increasing the cost of the trip unit. Another solution is to use a smaller rated circuit-breaker. [34.]

Example 2:

C type MCB with 10 A current rating is chosen for feeding a lighting group since 10 A is advised for led lighting for their high starting current. However, the current of the lighting groups is only about 1 A, and the feed is far away from the lighting. Due to this, the short-circuit current is too low for the MCB to trip fast enough. [34.]

Low short-circuit currents are also a problem with using UPS, DC converters and intermediary transformers which are usual in the US since 480 V needs to be transformed fitting for lighting and other building electricity users. [34.]

Solution: Using B type or lower rated MCB. This can cause problems by a starting current causing trips in the normal state. Other solution is to use a larger cable, which brings up the overall cost of the feed. [34.]

8 CONCLUSIONS

In conclusion, this thesis highlights the importance of refining the Low Voltage (LV) Technical specifications for efficient project execution within the context of a project at Wärtsilä Energy. Aligning LV consumer lists with specific circuit breaker trip unit models enhanced coordination studies, supporting the objectives of the ongoing development project which are configured-to-order models, modular setups, and increased automation. These efforts aimed to improve efficiency and align with industry standards, contributing to the pursuit of operational effectiveness and compliance in the energy sector. Familiarising with Febdok helps in the future when making the decision of what software needs to have for efficient selectivity studies.

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