POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Design of Electrical Power distribution system for oil & gas storage depot

TESI DI LAUREA MAGISTRALE IN
AUTOMATION AND CONTROL ENGINEERING
INGEGNERIA INDUDTRIALE E DELL'INFORMAZIONE

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Academic Year: 2021-22

Abstract

The Electrical system is efficiently designed to provide continuous and reliable services. The main goal of the system design is the simplicity of maintenance and operation, personnel and equipment safety and minimizing power losses, mechanical protection of equipment, interchanging equipment, and additional loads. It requires a scientific study based on various theories and some practical experience to achieve the desired goals and results.

In this study, we are investigating newly installed/constructed appliances/material and plant engineering works related to the electrical system of one unit of an oil and gas storage plant in Italy, serving the plant referred to the goals as briefly indicated below.

The design study briefly concerns the supply and implementation of the Interchange of the existing compartments with the new drawers in the motor control center, Primary and secondary earth network, Light system and power sockets, Sizing of the LV power supply cables for new equipment, Protection calibration tables of the latest equipment.

This study provides solutions in different ways; stable power supplies energize the electrical loads. In addition, the critical role of short circuit resistance of transformers in controlling short circuit current has been provided. Also, the selection procedures for electrical equipment and supplied by components, including cables, transformers, circuit breakers, etc. The load flow study checks the equipment sizing and specification, losses, and voltage drop. Meanwhile, a detailed analysis of the short circuit current calculation Earthing and lightning calculation, and Illumination calculations are implemented, and check the system performance by the results of this study.

Because there is a wide variety of equipment on one side and the research on economic matters on the other is time-consuming, this report mainly focuses on technical aspects and results. It does not cover economic factors. Anyhow, Oil and gas industry requires high-standard engineering to design electrical systems.

Keywords: Power supply, Oil and gas, Electrical system, Component selection and specification, Load flow, Circuit Braker, Short circuit current.

Abstract in Italiano

L'impianto elettrico è progettato in modo efficiente per fornire servizi continui e affidabili. L'obiettivo principale della progettazione del sistema è la semplicità di manutenzione e funzionamento, la sicurezza del personale e delle apparecchiature, la riduzione al minimo delle perdite di potenza, la protezione meccanica delle apparecchiature, l'interscambio di apparecchiature e carichi aggiuntivi. Richiede uno studio scientifico basato su varie teorie e una certa esperienza pratica per raggiungere gli obiettivi e i risultati desiderati.

In questo studio, si stanno esaminando apparecchiature di nuova installazione/costruzione/opere materiali e impiantistiche relative all'impianto elettrico di un'unità di un impianto di stoccaggio di petrolio e gas in Italia, a servizio dell'impianto per le finalità di seguito sinteticamente indicate.

Lo studio progettuale riguarda in sintesi la fornitura e realizzazione di Interscambio dei vani esistenti con i nuovi cassetti in centrale di controllo motori, Rete di terra primaria e secondaria, Impianto luce e prese di alimentazione, Dimensionamento dei cavi di alimentazione BT per le nuove apparecchiature, Tabelle di taratura delle protezioni nuova attrezzatura.

Lo scopo di questo studio è quello di fornire le soluzioni in diversi modi, i carichi elettrici sono alimentati da alimentatori stabili. Inoltre è stato evidenziato il ruolo importante della resistenza di cortocircuito dei trasformatori nel controllo della corrente di cortocircuito. Anche le procedure di selezione delle apparecchiature elettriche e dei componenti forniti, inclusi cavi, trasformatori, interruttori di circuito, ecc. Il dimensionamento e le specifiche delle apparecchiature, le perdite e la caduta di tensione sono verificati mediante uno studio del flusso di carico. Nel frattempo vengono implementati uno studio dettagliato del calcolo della corrente di cortocircuito, il calcolo della messa a terra e dell'illuminazione, i calcoli dell'illuminazione e verificate le prestazioni del sistema dai risultati di questo studio.

Poiché vi è un'ampia varietà di apparecchiature da un lato e la ricerca su questioni economiche dall'altro richiede molto tempo, lo scopo di questa relazione è concentrarsi principalmente sugli aspetti tecnici e sui risultati, non copre i fattori economici. Ad ogni modo, l'industria petrolifera e del gas richiede un'ingegneria di alto livello per progettare sistemi elettrici

Parole chiave: Alimentazione, Petrolio e gas, Impianto elettrico, Selezione e specifica dei componenti, Flusso di carico, Circuit Braker, Corrente di cortocircuito.

Acknowledgments

At this moment, I would like to thank my examiner, Prof. Castelli Dezza Francesco, for his professional advice after reviewing my reports.

I would also like to thank all of my Professors at Politecnico di Milano University for the dexterous knowledge that I received from them.

Many thanks to my supervisor Mr. Andrea Niccoli and teammates, Mr. Renato Scotti and Mr. Federico Gorra, for their invaluable technical support at Soplant Srl Consultant Engineering Company.

I dedicate this report to my parents, relatives, and friends, who always inspired me to study academically and supported me unconditionally.

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1 Introduction

This chapter is dedicated to presenting the thesis overview by defining the main background, objectives, and scope of the coursework.

1.1. Background

The project is about the power supply system for the Italian oil and gas storage plant. The work consists of two levels of implementation: Basic design and detailed design. Site inspection, environmental conditions, process flow, rough load type and demand estimation are obtained at the basic design stage. Then study the different networks and supplies (Based on technical and economic factors) are surveyed and choose the best one and the basic calculations, drawings, and specifications are provided consequently. All these documents will lead to the primary goal of our project. However they will not be sufficient to implement the project.

In the Detail design, we expect to submit the accurate drawings that are considered our choices for material purchasing (procurement) and implementation of the project (installation and commissioning). For this purpose, all the engineering details and documents should be done entirely. All the documents must coincide with project requirements and define the basic design.

Here, it has been tried to have an extensive view of the basic and detailed design. To achieve this, the main parameters and design of the electrical system were discussed and presented.

1.2. Motivation

Today, the use of energy resources is considered one of the most challenging tasks around the world. Compared with all energy resources, oil and gas play an important role in the supply of human needs. Therefore, finding the most optimal and efficient ways to use these resources is important. Indeed electrical engineering has a significant influence on this industry and needs to measure many parameters to achieve stable power. Thus, achieving a positive result in the above subject by working academically could be considered a success in the energy industry and human lives.

Additionally, the study from this thesis helps engineers to gain a better understanding of the electrical system of the oil and gas industry, which can be considered an excellent way to design electrical systems for similar industries.

1.3. Objectives

- To gain a deeper understanding of the electrical system in the oil and gas industries.
- To Learn the designing of stable power supply systems for different projects with the help of relevant software and applications.
- To be able to troubleshoot potential problems and able to solve them.

1.4. Scope of the Thesis

In this industry, having a stable network is very important and will require spending a lot of money and time. An electrical expenditure is considered less or no value compared with this huge cost; therefore, spending time and energy during stable electrical network design can avoid potential cost failure in the future.

The primary purpose of this work is to design a power supply with a good choice of components.

1.5. Organization of the Thesis

This report contains seven chapters as follows:

Chapter - 1: Thesis overview has been presented.

Chapter – 2: Discussed the technical requirements.

Chapter – 3: Defined the basic design criteria under the two considerations: Electrical and Instrumentation.

Chapter – 4: It contains the system's static and dynamic study including load flow and short circuit study.

Chapter – 5: Deals with the protection of the system.

Chapter – 6: Concludes the report and discusses the system's stable and reliable design.

Description of the company

This study has been done at Soplant s.r.l. The main activities of Soplant are the basic study, detail design, cost estimation, construction management and supervision of EPC projects in the Oil and Gas industry in the different engineering departments including Civil, Electrical, Mechanical, Instrumentation, Process Control and Piping & Instrumentation.

2 Technical requirements

This section describes the software skill set requirements for this work. The reader can find the similarities and differences in conditions. Knowledge of electrical equipment and sensors is considered essential. Here we will look at the software requirements for system design and some simulation tools to verify the results.

ABB e-design software is used to find basic design parameters. And implemented the detailed design and simulations are performed by using Ampere software. AutoCAD software was also used to design the Junction box and loop wiring and for Piping and instrumentation scheme design. Dialux software is mainly used to calculate the required lighting for the closing zone of the factory. We also make the 3D model of the system by using this Dialux software.

To get started with this software one should have good knowledge of Electrical & Instrumentation Engineering. A better understanding of mechanical engineering drawing and the ability to study P&I drawing. For the signaling and configuration knowledge about the sensor's input and output is much important. A basic understanding of DCS and Industrial Safety standards is a mandatory concern.

Knowledge about process control has been considered primary knowledge to develop the instrumentation system. To design the instrumentation system should join with chemical process engineering team. This report does not deal with instrumentation design, specification, sizing and all.

3 Method of Design

This Chapter deals with the method of design of the system. Initially, the ABB user manual for plant designing was presented and additionally defined the limitations of the engineering work by introducing the design criteria. From the electrical point of view, the load list has been prepared, and cable sizing has been discussed. From the Instrumentation point of view, Prepare the instrument list and cable list and the specifications concerned. Then designed the junction box & Loop wiring for these instruments and prepared the input-output signal list for DCS.

3.1. Methodology

Here we used the ABB Power distribution manual for reference. Also considered some standards as design criteria. To better understand the power supply distribution system, The ABB's procedure is shown in figure [3.1].

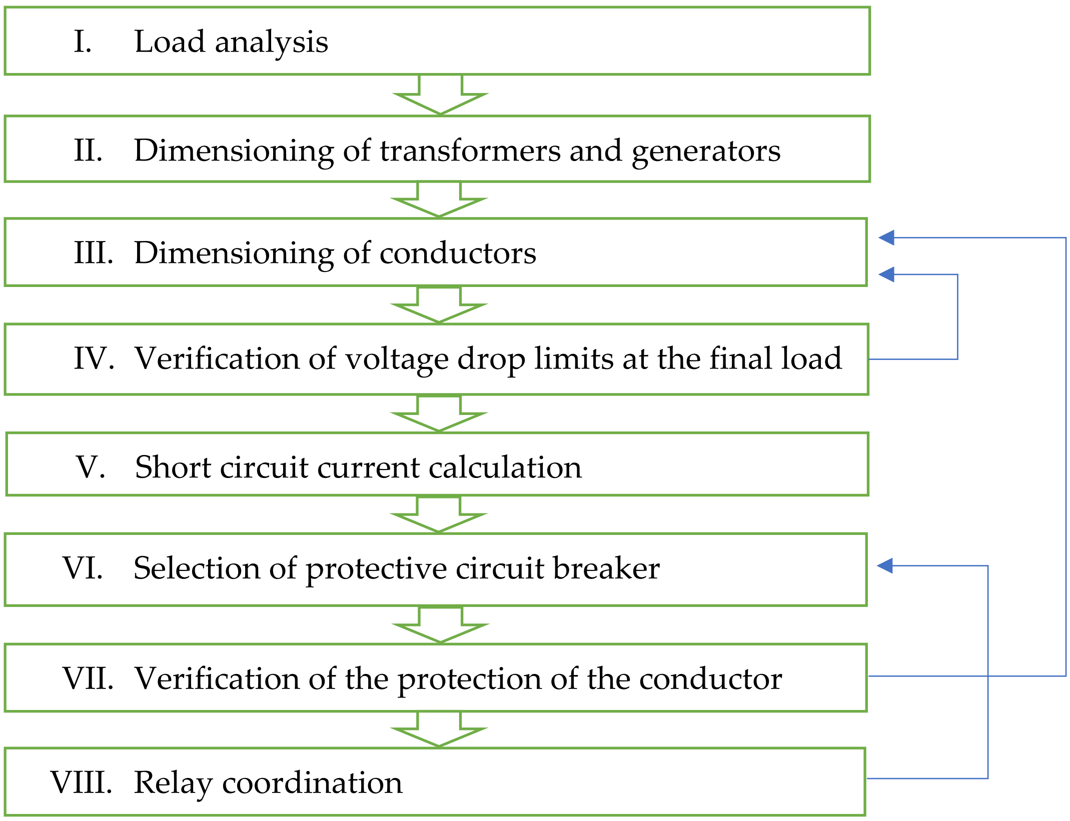

Figure 3.1: Design of plant's power supply

i. Load analysis:

- Define the power consumption by the total load ;
- Definition of the position of power centers;
- Definition of cable layout and the length of connection elements;
- Define the total absorbed power, with consideration of utilization factors and demand factors.

ii. Dimensioning of transformers and generators:

- Considered the 15 to 30% margin for the future;

iii. Dimensioning of conductors:

- Analyzing the current carrying by the conductors;
- Specify the conductor type and insulator;
- Specify the cross-section and current conducting capacity
- Find the voltage drop in the load during the motor's starting and normal running conditions.

iv. Verification of the voltage drop limits at the final load:

- If the voltage drop is out of the limit, should modify the conductor dimensions in stage (iii);

v. Short Circuit Current Calculation:

- Maximum value at the bus bar and minimum value at the end of the line;

vi. Selection of protective circuit breaker:

- High breaking capacity than maximum short circuit current value;
- High-rated current than load current;
- Compatible characteristics with protected loads such as motors, capacitors, etc.

vii. Verification of the protection of the conductor:

- Verification against overload: The circuit breaker's rated current should be higher than the load current but lower than the current carrying capacity of the conductor;

- Verification against short circuit: In short circuit conditions, the specific load of the circuit breaker should be lower than the specific energy withstand by the cable ($I^2t \leq k^2S^2$);
- If any of these points are not satisfied, repeat all steps from the stage (iii);

viii. Relay coordination:

- If it obtains a negative result, repeat all steps from the stage (vi);

Definition of other components

Generally, the detailed engineering design documents are delivered after the front-end engineering design which will be delivered next to the basic design. In this project, we directly delivered detailed engineering design documents for commissioning next to the basic design which contains basic design criteria and specifications.

Required power can be calculated using a load list, the first document to be prepared. The single line diagram can be developed concerning voltage level and load list. Although the load balance document could help us to do some preliminary calculations, to get accurate calculations to need to study load flow after sizing the conductors and short circuit study as well. The results of this study are verified. In case of disagreeable results, either adjust the transformer's impedance or change the transformer's size to get desirable results. In real plants, tap changers could compensate for the voltage drop while starting up and operating. But it's not the right choice to consider it during design. Even though sometimes it's inevitable to adjust the tap changer instead of increasing the size of the transformer. It strongly recommended choosing a circuit breaker after load flow and short circuit studies. In the final stage, if necessary, the start of the motor is studied, and the final modification is done.

Here we discussed the Load list preparation and cable sizing. Verification of transformer or generator sizing and load balance/load flow studies were not discussed briefly.

3.2. Design criteria

To design a technically qualified system, it should follow some standards and technical specifications. Some criteria are discussed below.

3.2.1 Voltage level

The following voltage levels are selected for the electrical system at the rated frequency of 50Hz. The equipment would be suitable for continuous operation with voltage variation within 5% of nominal values.

SERVICE	VOLTAGE LEVEL	PHASE
Generation	11 kV	3
Main distribution	132 kV	3
Emergency power	6 kV	3
Motors > 2500 kW	11 kV	3
Motors > 160kW to Motors < 2500 kW	6 kV	3
Motors > 0.4 kW to Motors < 160 kW	4 kV	3
Motors < 0.4 kW	230V or 400V	1 or 3
Lighting circuit	230V	1
Power Socket	400V	3
Instrument power supply system	230V	1
Contactor control voltage	230V	1
Switchgear control	110 VDC	-

Table 3.1: Voltage Levels.

3.2.2 Voltage drop limit

Voltage drop limit considered according to the standard
CEI EN 60909-0, at the load's terminals: 5%.
The transient voltage drop during motor starting is 15%.

3.2.3 Short Circuit current limits

According to the IEC 60056 [5] , the RMS value of the a.c. components of the short-circuit breaking current of the circuit breaker should not exceed 25 kA for the power systems over 1000 V.

For the power systems (< 1000 V) the RMS value of the a.c. component of the short circuit breaking current of the circuit breaker designed should not exceed 50 kA according to IEC 60947-2 [1].

3.2.4 Power factor

The Power factor for the overall system should not be less than 0.85 considering the distribution system equipment's and transformer's reactive power losses. It has been determined from generator terminals.

3.2.5 Transformer

According to the IPS-E-EL-100 [8], In normal operating conditions each transformer should have a minimum of 20% spare. If in case of the trip in one transformer, another transformer should be able to withstand the entire downstream load.
According to IEC 60076-5, the short circuit voltage percentages of the transformers 2.5MVA and 12.5MVA are 6% and 8% respectively [4].

3.3. Load list preparation

This document determines each load of the plant. Generally, the process department specifies the required loads and further supplementary information is completed by the mechanical and electrical departments. Preliminary data are estimated and the vendor will provide accurate data during the project. Objectives of issuance of this document as mentioned below,

- Recognized industrial and non-industrial loads of the plant to prepare the single line diagrams, cable sizing and routing, etc.
- Control the load variation during the design and construction of the project and update the relevant data.
- Specifying a total load of switchgear and MCCs and their normal current.
- Sizing the transformers and generators.
- Emergency load calculation and finding the suitable method to provide it. (Emergency generator rating calculations)
- Determine the maximum load of the project to specify the power demand.

This is the reference document for the design and other related documents and also following data are included in the load list.

Duty types:

This factor shows load operation status and is very important in load summary calculations in terms of what extent the load contributes to power consumption. The following duty types may be considered for a load.

- Continuous operation: When the consumer works and consumes electrical power continuously.
- Stand-by operation: The load which will not work in a normal situation is also known as a backup. It will activate when their considered normal load fails.
- Intermittent operation: If some loads in the group for special process purposes run into the circuit alternatively are known as intermittent loads.

Feeding types:

Different loads are fed by different methods as considered as follows.

- Normal feeding (N): Loads are fed by normal buses, If there is a fault, loads will stop receiving electricity.
- Normal feeding with reacceleration (NR): These loads are also fed by normal buses but in cases of a short interruption of power (under voltage) they will restart as so fast.
- Essential feeding: It should be assured that, feed by an emergency generator.
- Vital feeding: It implies that no interruption in the power supply is allowed.

Load types and required power:

- Motor loads.
- Lighting & Socket loads.
- UPS & DC loads.

An electrical engineer is responsible for calculating electrical consumed power and rated power. For this, data for motor efficiency must be available that can be extracted from standards for various power types of motors. In this report, Italian standards have been used.

The calculation base is mechanical power (electrical output power) divided by efficiency resulting in electrical absorbed power (electrical input). Knowing mechanical power, a rated motor can be selected considering environmental conditions and temperature. To see the Load list concerning this project, please refer the Appendix A.1.

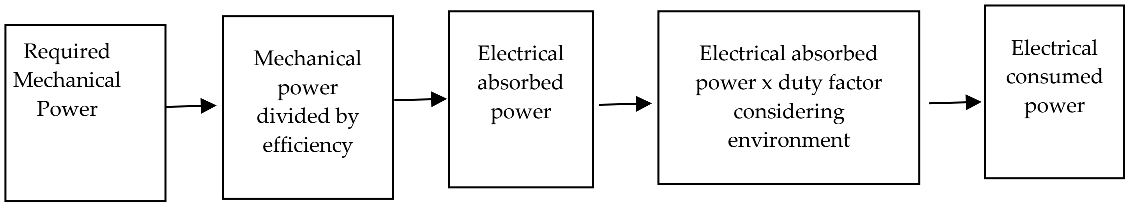

Figure 3.2: Consumed power calculation

Absorbed power versus rated power

Since motor ratings are considered per the output power, the absorbed power (input power) can be lower or higher than the rated power due to its operating efficiency.

Example

If mechanical power and efficiency are 17 kW and 0.9, then rated power and absorbed power are equal to 18.5 kW and 18.8 kW respectively. But if we use a motor with better efficiency such as 0.95 then rated and absorbed powers are 18.5kW and 17.89 kW.

Factors:

During the total load calculation, the factors are considered as follows,

- Load factor (LF) = mechanical power divided by rated power.
- Efficiency of motor considering load factor (efficiency varies in different load factors).
- Power factor considering load factor (Power factor varies in different load factors).
- Starting power factor for motors
- Duty factor = Utilization factor

3.4. Cable Sizing

This document determines each load of the plant. Generally, the process department specifies the required loads and further supplementary information is completed by the mechanical and electrical departments. Preliminary data are estimated data the vendor will provide accurately during the project. Objectives of issuance of this document as mentioned below,

Software calculation method

The Sizing and verification of cable were carried out using the Ampere Professional software from Electro Graphics Srl, version 11.0.6. of 2021. The criterion followed for the sizing of the cables is to be able to guarantee the protection of the conductors against overload currents.

In fact, according to CEI 64-8 / 4 (par. 433.2), the protection device must be coordinated with the pipeline to verify the conditions.

$$a)\ I_b \leq I_n \leq I_z$$

$$b)\ I_f \leq 1.45 * I_z$$

For condition a) it is necessary to size the cable according to the rated current. The rated current of protection is therefore determined from the current I_b (following the normalized values) and with this one proceeds to the determination of the section. The sizing of the cable also respects the following cases:

- Unprotected conduits derived from the main conduit protected against I overloads with a suitable device capable of guaranteeing the protection of the branch pipes;
- Conduit that feeds various branches individually protected against overloads, when the sum of the rated currents of the protection devices of the branches does not exceed the flow rate I_z of the main pipe.

The identification of the section is carried out using the laying tables assigned to the cables.

We listed some tables suitable for the Italian market:

- IEC 60364-5-52 (PVC / EPR);
- IEC 60364-5-52 (Mineral);
- CEI-UNEL 35024/1;

- CEI-UNEL 35024/2;
- CEI-UNEL 35026;
- CEI 20-91 (HEPR).

In medium voltage, the management of calculation is divided according to the tables chosen:

- CEI 11-17;
- CEI-UNEL 35027 (1-30kV)
- EC 60502-2 (6-30kV);
- IEC 61892-4 off-shore (up to 30kV);

In addition to reporting the allowable current I_z as a function of the type of cable insulation, kind of insulation and the number of active conductors, also report the methodology of evaluation of derating coefficients. The minimum carrying capacity of the cable is calculated as follows:

$$I_{z\,min} = \frac{I_m}{k}$$

Where the coefficient k has the purpose of derating the cable and takes into account the following factors:

- Type of conductor material:
- Type of cable insulation;
- Number of conductors in the vicinity, including any parallels;
- Any downgrading decided by the user.

The section is chosen so that its flow rate (multiplied by the coefficient k) is higher than the $I_{z\,min}$. Any parallels are calculated on the assumption that they all have the same section, length, and type of installation (see standards 64.8 par.433.3), considering he minimum flow rate as a result of the sum of the single flows (downgraded by the number of parallels from the proximity derating coefficient).

Condition b) does not require verification as the switches that respond to CEI 23.3 have a ratio between conventional operating current I_f and rated current I_n less than 1.45 and is constant for all settings less than 125 A. Per industrial equipment, on the other hand, the CEI 17.5 and IEC 947 standards establish that such ratio may vary according to the rated current, but must remain smaller or equal to 1.45.

It, therefore, appears that based on this regulation, condition b) will always be verified. Pipes sized with this criterion are consequently protected against overcurrents.

Integral of Joule:

From the section of the cable, conductors derive the calculation of the Joule integral, that is the maximum specific energy admitted by the same through:

$$I^2 * t = K^2 * S^2$$

The constant K is given by the CEI 64-8 / 4 standard (par. 434.3), for phase conductors & neutral and from the paragraph 64-8 / 5 (par. 543.1), for the protective conductors in operation at conductor material and insulating material. For mineral insulated cables, the standards are currently being studied; however the above paragraph report in the comment section prudential values.

The value of K reported by the standard is for phase conductors (par. 434.3) tab.54A:

Name of the cable	K value
Copper and PVC insulated	115
Copper and rubber insulated G	135
Copper and ethylene propylene rubber insulated G5-G7	143
L series copper covered by thermoplastic material	115
Bare L series copper cable	200
H series copper covered by thermoplastic material	115
H series bare copper	200
Aluminum and PVC insulated	74
Aluminum insulated by G, G5 – G7	92

The values of K for single-pole protective conductors

Name of the cable	K value
Copper and PVC insulated	143
Copper and rubber insulated G	166

Copper and rubber insulated G5-G7	176
L series copper covered by thermoplastic material	143
Bare L series copper cable	228
H series copper covered by thermoplastic material	143
H series bare copper	228
Aluminum and PVC insulated	95
Aluminum and rubber insulated G	110
Aluminum and rubber insulated G5 – G7	116

The values of K for multi pole protective conductors

Name of the cable	K value
Copper and PVC insulated	115
Copper and rubber insulated G	135
Copper and rubber insulated G5-G7	143
L series copper covered by thermoplastic material	115
Bare L series copper cable	228
H series copper covered by thermoplastic material	115
H series bare copper	228
Aluminum and PVC insulated	76
Aluminum and rubber insulated G	89
Aluminum and rubber insulated G5 – G7	94

Table 3.2 : K values.

Sizing of the neutral conductors

The standard CEI 64-8 par. 524.2 and par. 524.3 provides that the conductor section of neutral, in the case of polyphase circuits, may have a section smaller than that of the conductor's phase if the following conditions are met:

- Phase of the conductor has a section greater than 16 mm^2
- The maximum current that the neutral conductor can travel does not exceed its capacity.
- The section of neutral conductor is at least equal to 16 mm^2if the conductor is in copper and 25 mm^2 if the conductor is made of aluminum.

If there are single-phase or polyphase circuits and the latter with a phase conductor section of less than 16 mm^2 if a copper conductor and 25 mm^2 if an aluminum conductor, the neutral conductor must have the same section as the phase conductor.

Based on the design requirements, up to three sizing methods of the neutral conductor are managed using the following:

- Determination about the phase section;
- Determination through the relationship between the capacities of the conductors;
- Determination about the range of the neutral.

The first criterion consists in determining the section of the conductor in question according to the following constraints given by the standard:

$$S_f < 16\ mm^2 : \qquad S_n = S_f$$
$$16 \leq S_f \leq 35\ mm^2 : \quad S_n = 16\ mm^2$$
$$S_f > 35\ mm^2 : \qquad S_n = \frac{S_f}{2}$$

The second criterion sets the ratio between the capacities of the phase conductor and the neutral conductor, and the program will determine the section based on the capacity.
The third criterion consists in dimensioning the conductor, considering the operating current circulating in the neutral as for a phase conductor.
The section of the neutral can however assume different values concerning the methods just mentioned, however always calculated in a workmanlike manner.

Sizing of the protective conductors

The standard CEI 64-8 par. 543.1 provides two methods of dimensioning the conductors of protection:

- Determination about the phase section;
- Determination by calculation.

The first criterion consists in determining the section of the protective conductor following constraints similar to those introduced for the neutral conductor:

$$S_f < 16\, mm^2 : \qquad S_{PE} = S_f$$
$$16 \leq S_f \leq 35\, mm^2 : \quad S_{PE} = 16\, mm^2$$
$$S_f > 35\, mm^2 : \qquad S_{PE} = \frac{S_f}{2}$$

The second criterion determines this value with Joule integral, i.e., the section of the protective conductor must not be less than the value determined with the following formula:

$$S_p = \frac{\sqrt{I^2 * t}}{K}$$

Where,

- S_p is the section of the protective conductor (mm^2)
- I is the effective value of the fault current that the conductor of protection for a fault of negligible impedance (A)
- t is the tripping time of the protection device (S)
- K is a factor whose value depends on the material of the protective conductor, insulation and other parts.

If the result of the formula is not a unified section, a unified next higher is taken. In both cases, paragraph 543.1.3 must be considered as regards the minimum section. It states that the cross-section of each protective conductor that is not part of the power supply line must not, in any case, be less than:

- 2.5 mm^2 copper or 16 mm^2 aluminum if mechanical protection is provided;
- mm^2 copper or 16 mm^2 aluminum if mechanical protection is not provided;

It is also possible to determine the section using the ratio between the capacities of the phase conductor and the protective conductor. In TT systems, the section of the protective conductors can be limited to:

- 25 mm^2 if in copper or 35 mm^2 if in aluminum

Voltage loss

Voltage drops are calculated vectorially. For each user, the vector voltage drop is calculated along each phase and the neutral conductor (if distributed). The most significant voltage drop is considered between the phases, which is reported as a percentage of the rated voltage:

$$c.d.t.(ib) = \left(\left|\sum_{i=1}^{k} \dot{Z}f_i * \dot{I}f_i - \dot{Z}n_i * \dot{I}n_i\right|\right)_{f=R,S,T}$$

Where,
with f representing the three phases R,S,T;
with n representing the neutral conductor;
with I representing the k users involved in the calculation;
The calculation therefore provides the exact value of the approximate formula:

$$cdt(I_b) = k_{cdt} * I_b * \frac{L_C}{1000} * (R_{cavo} * \cos\varphi + X_{cavo} * \sin\varphi) * \frac{100}{V_n}$$

With:
k_{cdt} = 2 for single–phase systems;
k_{cdt} = 1.73 for three–phase systems;
The R_{cavo} and X_{cavo} parameters are obtained from the UNEL table according to the type of cable (unipolar/multipolar) and to the section of the conductors; From these, the first parameter refers to $70^{\circ}C$ for cables with PVC insulation, to $90^{\circ}C$ for cables with EPR insulation; while the second refers to 50 Hz, without prejudice to the units of measurement in W/km.
If the operating frequency is different from 50 Hz, is set that,

$$X'_{cavo} = \frac{f}{50} * X_{cavo}$$

The voltage drop from upstream to downstream (total) of a user is determined as the sum of the vector voltage drops, referred to as a single conductor, of the branches upstream to the user in question, from which the voltage drop is subsequently determined as percentage referring it to the system (three-phase or single-phase) and to the rated voltage of the user in question. The total voltage drops are adequately calculated if there are transformers along the line (for example MV / LV or LV / LV

transformers). In this circumstance, the calculation of the total voltage drop takes into account both the internal drop in the transformers and the presence of plugs for adjusting the turn ratio of the transformers themselves.
If at the end of the voltage drop calculation, some users have values higher than those defined, an optimization procedure is used to bring the voltage drop back within predetermined limits (limits given by CEI 64-8 par.525). The cable sections are forced to higher values trying to follow a uniform growth until all voltage drops are below the limits.

Calculation of the cable temperature

The evaluation of the cable temperature is carried out based on the operational current and the rated current using the following expressions:

$$T_{cavo}(I_b) = T_{ambient} + \left(\alpha_{cavo} * \frac{I_b^2}{I_z^2}\right)$$

$$T_{cavo}(I_n) = T_{ambient} + \left(\alpha_{cavo} * \frac{I_n^2}{I_z^2}\right)$$

Factors:

During the total load calculation the factors are considered as follows,

- Load factor (LF) = mechanical power divided by rated power.
- Efficiency of motor considering load factor (efficiency varies in different load factors).
- Power factor considering load factor (Power factor varies in different load factors).
- Starting power factor for motors
- Duty factor = Utilization factor

Note : Please see Appendix A.2 for information on cable sizing of the VRU of this Project.

4 Static and dynamic design of the system

Using the requirements outlined in Chapter 3 as a guide, the appropriate single-line diagram is created for feeding the loads in this chapter. To do this, manual calculations of the necessary power should be done first to help us choose the right equipment and bus bars.

4.1. Preliminary single line diagram

After creating the necessary load list(s) and determining the level of demand, we must create a reliable network to deliver the necessary power. To get a rough notion of how to feed the loads, the design process should consider the feeding type and voltage level specified in the load list into consideration. Normal loads and necessary loads like emergency lighting are fed from the normal bus bar.

Emergency shutdown (ESD) systems and other vital loads are fed by UPS.

The final single line diagram would differ from the primary one as illustrated in figure 4.1 following our thorough calculations. As a result, the change process may be seen when the final single line is displayed.

The accompanying diagram illustrates how this plant is supplied by 15kV incoming, and the 3.9kV output voltage is provided by 200 kVA transformers. They must complement one another so that, in the event of a potential breakdown in another, one transformer can generate adequate capacity to supply all the loads. It follows from the discussion above that each transformer is loaded with half of the total load during normal operation.

On the other hand, an "automatic change over system" has been developed to feed emergency loads if the regular bus is missed.

The source of the important loads fed by UPS is the batteries that are charged during regular operation. Additionally, emergency operations are also used when neither normal nor emergency supplies are available.

Note: Please see the Single line diagram for the project in Appendix A.3.

4.2. Short circuit calculation

The calculation of the short-circuit currents was performed using the Ampere Professional software of the Electro Graphics Srl company version 11.0.6.0 of 2021.

4.2.1. Software Calculation Method

The knowledge of the supply of the network is necessary for the initialization of the same to perform the calculation of the faults.

The types of supply can be:

- In low voltage
- In medium voltage
- In high voltage
- With known impedance
- In direct current

The parameters found in this phase are used to initialize the calculation of the faults, I.e., they will be added to the corresponding fault parameters of the downstream user. Having known the parameters of the sequences at the supply point, it is possible to initialize the network and calculate the short-circuit currents according to the CEI EN 60909-0 standards.

These currents will be used when choosing the protections for checking the breaking capacities of the equipment.

4.2.2. Low voltage

This can be used when the circuit is powered by the low voltage distribution network, or when the circuit to be dimensioned is a sub-panel connected to a pre-existing network of which the short-circuit current at the delivery point is known.

The required data are as follows:

- Concatenated power supply voltage expressed in V;
- Three-phase short-circuit current of the supply network expressed in kA.
- single-phase short-circuit current of the supply network expressed in kA.

The direct impedance corresponding to the short-circuit current I_{cctrif}, in mΩ, is determined from the first two values:

$$Z_{cctrif} = \frac{V_2}{\sqrt{3} \cdot I_{cctrif}}$$

Based on the table provided by the CEI 17-5 standard which provides the short-circuit cosø cc about the short-circuit current in kA, we have:

$$\begin{array}{ll}
50 < I_{cctrif} & \cos\phi_{cc} = 0.2 \\
20 < I_{cctrif} \le 50 & \cos\phi_{cc} = 0.25 \\
10 < I_{cctrif} \le 20 & \cos\phi_{cc} = 0.3 \\
6 < I_{cctrif} \le 10 & \cos\phi_{cc} = 0.5 \\
4.5 < I_{cctrif} \le 6 & \cos\phi_{cc} = 0.7 \\
3 < I_{cctrif} \le 4.5 & \cos\phi_{cc} = 0.8 \\
1.5 < I_{cctrif} \le 3 & \cos\phi_{cc} = 0.9 \\
I_{cctrif} \le 1.5 & \cos\phi_{cc} = 0.95
\end{array}$$

From these data the resistance to the direct sequence is obtained, in mΩ:

$$R_d = Z_{cctrif} \cdot \cos\phi_{cc}$$

and finally the relative reactance to the direct sequence, in mΩ:

$$X_d = \sqrt{Z_{cctrif}^2 - R_d^2}$$

From the knowledge of the single-phase fault current Ik1, it is possible to obtain the homopolar impedance values.
Inverting the formula:

$$I_{k1} = \frac{\sqrt{3} \cdot V_2}{\sqrt{(2 \cdot R_d + R_0)^2 + (2 \cdot X_d + X_0)^2}}$$

with the hypotheses $\frac{R_0}{X_0} = \frac{Z_0}{X_0} \times cos\varphi_{cc}$, i.e. the angle of the homopolar components equal to that of the direct components, we obtain:

$$R_0 = \frac{\sqrt{3} \cdot V}{I_{k1}} \cdot \cos\varphi_{cc} - 2 \cdot R_d$$

$$X_0 = R_0 \cdot \sqrt{\frac{1}{(\cos\varphi_{cc})^2} - 1}$$

Medium and High voltage

If the supply is a medium or high voltage, the following starting data are considered:

- Supply voltage V mt (in kV);
- Maximum three-phase short-circuit current, Ikmax (in kA);
- Maximum single-phase short-circuit current to earth, Ik1ftmax (in kA);
- If you know you can also add the currents;
- Minimum three-phase short-circuit current, Ikmin (in kA);
- Minimum single-phase short-circuit current to earth, Ik1ftmin (in kA);

The equivalent impedances of the supply network are obtained from the data to determine the equivalent voltage generator.

$$Z_{ccmt} = \frac{1{,}1 \cdot V_{mt}}{\sqrt{3} \cdot I_{k\,\max}} \cdot 1000$$

From which the direct components are derived:

$$\cos\varphi_{ccmt} = \sqrt{1-(0{,}995)^2}$$

$$X_{dl} = 0{,}995 \cdot Z_{ccmt}$$

$$R_{dl} = \cos\varphi_{ccmt} \cdot Z_{ccmt}$$

and homopolar components:

$$R_0 = \frac{\sqrt{3} \cdot 1{,}1 \cdot V_{mt}}{I_{k1\,ft\max}} \cdot 1000 \cdot \cos\varphi_{ccmt} - (2 \cdot R_{dl})$$

$$X_0 = R_0 \cdot \sqrt{\frac{1}{(\cos\varphi_{ccmt})^2} - 1}$$

Correction factors for generators and transformers

The EN 60909-0 standard provides a series of corrective factors for calculating the impedances of some machines present in the network. Those used for the calculation of faults concern generators and transformers.

Correction factor for transformers

For transformers with two windings, with or without winding regulation, when calculating the maximum short-circuit currents, an impedance correction factor KT must be introduced such that:

$$Z_{cctK} = K_T \cdot Z_{cct}$$

$$K_T = 0.95 \cdot \frac{c_{max}}{1 + 0.6 \cdot x_T}$$

Where,

$$x_T = \frac{X_{cct}}{V_{02}^2 / P_n}$$

is the relative reactance of the transformer and Cmax is taken from table 1 and is relative to the low side voltage of the transformer.
This factor must be applied to the direct, inverse and homopolar impedance.

Correction factor for synchronous generators

In calculating the maximum initial short-circuit currents in systems powered directly by generators without intermediate transformers, a correction factor KG must be introduced such that:

$$Z_{GK} = K_G \cdot Z_G$$

With,

$$K_G = \frac{V_{02}}{U_{rG}} \cdot \frac{c_{max}}{1 + x'' \cdot \sqrt{1 - \cos \varphi_{rG}}}$$

Where,

$$x'' = \frac{X''}{V_{02}^2 / P_n}$$

is the sub-transient relative saturated reactance of the generator.
This factor must be applied to the direct, inverse and homopolar impedance.
In the formula, the rated system voltage and the rated voltage of the generator (UrG) appear in the numerator and denominator. In Ampere UrG is not managed, therefore V02 / UrG = 1 is considered.

Correction factor for production groups with automatic regulation of the transformer voltage

In calculating the maximum initial short-circuit currents in the production groups, an impedance correction factor K_s must be introduced to be applied to the overall impedance on the high side of the transformer:

$$Z_{SK} = K_S \cdot (t_r^2 \cdot Z_G + Z_{THV})$$

With

$$K_S = \frac{c_{max}}{1 + |x'' - x_T| \cdot \sqrt{1 - \cos \varphi_{rG}}}$$

This factor must be applied to the direct, inverse and homopolar impedance. The formula for K_s does not consider any differences between the rated values of the machines and the rated voltage of the electrical system.

Correction factor for production groups without automatic regulation of the transformer voltage

In calculating the maximum initial short-circuit currents in the production groups, an impedance correction factor K_{so} must be introduced to be applied to the overall impedance on the high side of the transformer:

$$Z_{SOK} = K_{SO} \cdot (t_r^2 \cdot Z_G + Z_{THV})$$

With

$$K_{SO} = (1 \pm p_T) \cdot \frac{c_{max}}{1 + x'' \cdot \sqrt{1 - \cos \varphi_{rG}}}$$

Where P_T is the voltage variation of the transformer through the selected plug socket. The factor (1-P_T) is set in the program, with P_T = (| P_{sec}-V_{02}) / V_{02}.
This factor must be applied to the direct, inverse and homopolar impedance. The formula for K_{so} does not consider any differences between the rated values of the machines and the rated voltage of the electrical system.

4.2.3. Calculation of faults

The calculation of the faults determines the minimum and maximum short-circuit currents immediately downstream of the user protection (start of line) and downstream of the user (end of the line).
The conditions under which they are determined are:

- Three-phase (symmetrical) fault;
- Two-phase (dissymmetric) fault;
- Two-phase-neutral fault (dissymmetric);
- Two-phase-earth fault (unbalanced);
- Earth phase fault (unbalanced);
- Neutral phase fault (unbalanced).

The parameters to the sequences of each user are initialized by the upstream user's corresponding ones, which, in turn, initialize the parameters of the downstream line.

Calculation of the maximum short-circuit currents

The calculation of the maximum short-circuit currents is carried out as described in the CEI EN 60909-0 standard. The following general conditions are envisaged:

- Failures with the contribution of the supply and the generators in a sub-transitory failure regime. Possible management of the attenuation of the current for the three-phase fault 'close' to the source.
- Rated supply voltage evaluated with voltage factor Cmax;
- Minimum fault impedance of the network, calculated at a temperature of 20 ° C.

The direct resistance, of the phase conductor and the protection one, is brought back to 20°C, starting from the resistance given by the UNEL 35023-2012 tables which can be referred to as 70°C or 90°C depending on the insulation, so expressing it in its results:

$$R_{dc} = \frac{R_c}{1000} \cdot \frac{L_c}{1000} \cdot \left(\frac{1}{1 + (\alpha \cdot \Delta T)}\right)$$

where ΔT is 50°C or 70°C and $\alpha = 0.004$ at 20°C.

Then note from the same tables the reactance at 50Hz, if f is the operating frequency, it results:

$$X_{dc} = \frac{X_c}{1000} \cdot \frac{L_c}{1000} \cdot \frac{f}{50}$$

we can add these to the direct parameters of the upstream user thus obtaining the minimum fault impedance at the end of the user.
For users in busbars, the components of the direct sequence are:

$$R_{db} = \frac{R_b}{1000} \cdot \frac{L_b}{1000}$$

The reactance is instead:

$$X_{db} = \frac{X_b}{1000} \cdot \frac{L_b}{1000} \cdot \frac{f}{50}$$

For loads with known impedance, the components of the direct sequence are the same values of resistance and reactance of the impedance.
As regards the homopolar sequence parameters, a distinction must be made between the neutral conductor and the protective conductor.
For the neutral conductor, direct ones are obtained using the following:

$$R_{0cN} = R_{dc} + 3 \cdot R_{dcN}$$
$$X_{0cN} = 3 \cdot X_{dc}$$

For the protective conductor, on the other hand, we obtain:

$$R_{0cPE} = R_{dc} + 3 \cdot R_{dcPE}$$
$$X_{0cPE} = 3 \cdot X_{dc}$$

where the resistances P_{dcN} and R_{dcPE} is calculated as the R_{dc}.

For users in busbars, the components of the homopolar sequence are distinguished between the neutral conductors and protective conductors.
For the neutral conductor we have:

$$R_{0bN} = R_{db} + 3 \cdot R_{dbN}$$
$$X_{0bN} = 3 \cdot X_{db}$$

The fault loop reactance parameter provided by the manufacturers is used for the protective conductor:

$$R_{0bPE} = R_{db} + 3 \cdot R_{dbPE}$$
$$X_{0bPE} = X_{db} + 3 \cdot (X_{b-ring} - X_{db})$$

The parameters of each user are added with the parameters, in the same sequence, of the upstream user, expressed in mΩ:

$$R_d = R_{dc} + R_{d-up}$$
$$X_d = X_{dc} + X_{d-up}$$
$$R_{0N} = R_{0cN} + R_{0N-up}$$
$$X_{0N} = X_{0cN} + X_{0N-up}$$
$$R_{0PE} = R_{0cPE} + R_{0PE-up}$$
$$X_{0PE} = X_{0cPE} + X_{0PE-up}$$

For users in busbars it is sufficient to replace the cable busbar.
The impedances of the supply are also added to the total values.

Known these parameters, the three-phase fault impedances (in mΩ) are calculated:

$$Z_{k\,\min} = \sqrt{R_d^2 + X_d^2}$$

Phase neutral (if neutral is distributed):

$$Z_{k1N\,min} = \frac{1}{3} \cdot \sqrt{(2 \cdot R_d + R_{0N})^2 + (2 \cdot X_d + X_{0N})^2}$$

Earth phase:

$$Z_{k1PE\,\min} = \frac{1}{3} \cdot \sqrt{\left(2 \cdot R_d + R_{0PE}\right)^2 + \left(2 \cdot X_d + X_{0PE}\right)^2}$$

From these we obtain the three-phase short-circuit currents Ikmax, neutral phase Ik1Nmax, phase earth Ik1PEmax and two-phase Ik2max expressed in kA:

$$I_{k\,max} = \frac{V_n}{\sqrt{3} \cdot Z_{k\,min}}$$

$$I_{k1N\,max} = \frac{V_n}{\sqrt{3} \cdot Z_{k1N\,min}}$$

$$I_{k1PE\,max} = \frac{V_n}{\sqrt{3} \cdot Z_{k1PE\,min}}$$

$$I_{k2\,max} = \frac{V_n}{2 \cdot Z_{k\,min}}$$

Finally, the peak values of the currents are obtained from the values of the maximum fault currents:

$$I_p = \kappa \cdot \sqrt{2} \cdot I_{k\,\max}$$

$$I_{p1N} = k \cdot \sqrt{2} \cdot I_{k1N\,max}$$

$$I_{p1PE} = \kappa \cdot \sqrt{2} \cdot I_{k1PE\,\max}$$

$$I_{p2} = \kappa \cdot \sqrt{2} \cdot I_{k2\,\max}$$

Where,

$$\kappa \approx 1.02 + 0.98 \cdot e^{-3 \frac{R_d}{X_d}}$$

It is calculating the peak current for a three-phase fault according to IEC 61363-1: Electrical installations of ships. If required, Ip can be calculated by applying the simplified method of the standard reported in paragraph 6.2.5 Neglecting short-circuits current decay. It provides for the use of a coefficient k = 1.8 which takes into account the maximum current asymmetry after the first half-period of failure.

Calculation of the minimum short-circuit currents

The calculation of the minimum short-circuit currents is carried out as described in the standard CEI EN 60909-0 par 7.1.2 as regards:

- Failures with contribution from the supply and generators. The contribution of the generators is in the permanent regime for 'near' three-phase faults, while for 'far' or asymmetrical faults the sub transitory contribution is considered;
- The rated voltage is multiplied by the voltage factor Cmin, which can be 0.95 if Cmax = 1.05, or 0.90 if Cmax = 1.10 (Tab. 1 of the CEI EN 60909-0 standard); in medium and high voltage the factor Cmin is equal to 1;

For the conductor temperature you can choose between:

- The Cenelec R064-003 ratio, for which the resistances at the limit temperature of the insulation in ordinary service of the cable are determined;
- The CEI EN 60909-0 standard indicates the temperatures at the end of the fault.
- The temperatures are about the type of insulation of the cable, namely:

Insulating	Cenelec R064-003 [° C]	CEI EN 60909-0 [° C]
PVC	70	160
G.	85	200
G5 / G7 / G10 / EPR	90	250
HEPR	120	250
L series coated	70	160
nude L series	105	160
coated H series	70	160
naked H series	105	160

Table 4.1: Temperature values for Insulation of cables.

From these it is possible to calculate the direct and homopolar sequence resistances at the temperature relative to the cable insulation:

$$R_{d\,max} = R_d \cdot (1 + \alpha \cdot \Delta T)$$

$$R_{0N\,max} = R_{0N} \cdot (1 + \alpha \cdot \Delta T)$$

$$R_{0PE\,max} = R_{0PE} \cdot (1 + \alpha \cdot \Delta T)$$

These, added to the upstream resistances, give the maximum resistances. After evaluating the impedances using the same expressions as the maximum fault impedances, the three-phase short-circuit currents Ik1min and phase earth can be calculated, expressed in kA:

$$I_{k\,min} = \frac{0.95 \cdot V_n}{\sqrt{3} \cdot Z_{k\,max}}$$

$$I_{k1N\,min} = \frac{0.95 \cdot V_n}{\sqrt{3} \cdot Z_{k1N\,max}}$$

$$I_{k1PE\,min} = \frac{0.95 \cdot V_n}{\sqrt{3} \cdot Z_{k1PE\,max}}$$

$$I_{k2\,min} = \frac{0.95 \cdot V_n}{2 \cdot Z_{k\,max}}$$

Calculation of two-phase-neutral and two-phase-earth faults

Here are the formulas used for the calculation of faults. We call with Z_d the direct impedance of the network, with Z_i the inverse impedance, and with Z_0 the homopolar impedance.

In the following formulas, Z_0 corresponds to the phase-to-neutral or phase-to-earth homopolar impedance.

$$I_{k2} = \left| -j \cdot V_n \cdot \frac{\dot{Z}_0 - \alpha \cdot \dot{Z}_i}{\dot{Z}_d \cdot \dot{Z}_i + \dot{Z}_d \cdot \dot{Z}_0 + \dot{Z}_i \cdot \dot{Z}_0} \right|$$

and the peak current:

$$I_{p2} = k \cdot \sqrt{2} \cdot I_{k2\max}$$

Single-phase earth faults of MV lines

Calculation of homopolar currents following a phase-earth fault in medium-high voltage circuits.

The calculation of earth faults in medium and high voltage networks involves

the study of the capacitive effect of the network during the fault regime.
Furthermore, the techniques for determining faulty lines using relays require knowledge of the homopolar current values as a function of the fault points.
The new CEI 0-16 (and previously the Enel DK5600), with the introduction of the ground connection of the star point on average, requires a tool for sizing the Petersen coil and coordinating user protections.
To answer all these problems, Ampère Professional calculates the homopolar current regime following a phase-to-earth fault.
The calculation model of homopolar currents, following the theory of direct, inverse and homopolar sequences, for a phase-to-earth fault is the following:

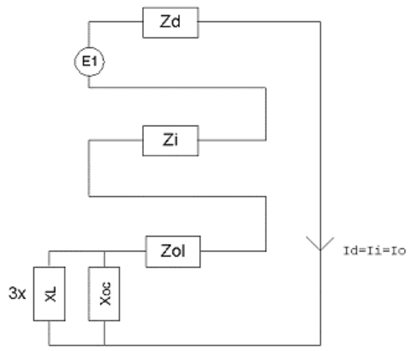

Figure 4.1: Inverse sequence for a phase-to-earth fault

With Z_d and Z_i we mean the impedances to the direct and inverse sequences.
For the calculation of the homopolar impedance it is necessary to consider several elements (see figure below, example with two transformers in parallel):

- Zol: homopolar impedance of the line section from the fault point to the upstream transformer;
- Ztr: homopolar impedance of the transformer (secondary view);
- Zbpet: (Rbp + jXbp) Petersen coil impedance, consisting of a resistor and an inductance in parallel;
- Rt: earth resistance point of connection to earth of the star point of the transformer;
- Rimp: resistance for earth fault not free;
- Xoc: capacitive reactance of the whole network belonging to the same zone as the faulty user and downstream of the same transformer.

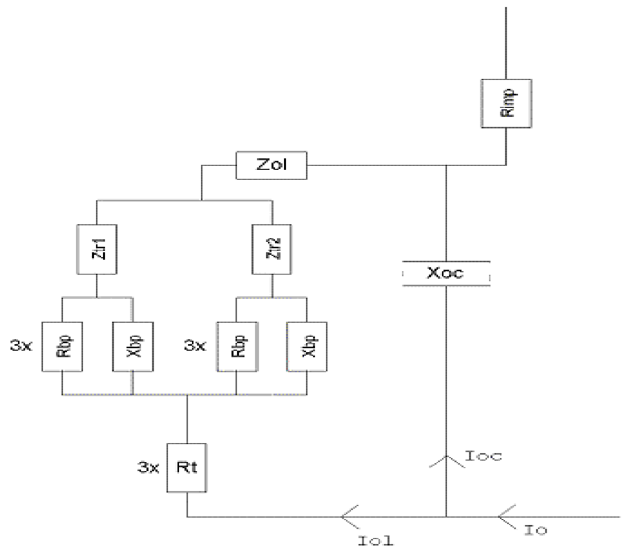

Figure 4.2: Homopolar sequences for a phase-to-earth fault

Note: The value of Xoc is practically the same for any point of failure. References: Lectures on electrical systems by Antonio Paolucci (Dipartimento Energia Elettrica Università di Padova) and CEI 11-37.

To calculate the Xoc with a good approximation, the two formulas are used:

$$I_g = \frac{3 \cdot E}{X_{oc}}$$

$$I_g = (0.003 \cdot L1 + 0.2 \cdot L2) \cdot V_{kV}$$

where Ig is the earth fault current calculated considering only the capacitive reactance in the first formula, while in the second its value is reported if one is aware of the lengths (in km) of overhead network L1 and in cable L2 of the network on average. Vkv is the rated phase-to-phase voltage value expressed in kV.

By equating the two formulas, and making them explicit for Xoc we obtain:

$$X_{oc} = \frac{\sqrt{3} \cdot 10^9}{(0.003 \cdot l1 + 0.2 \cdot l2)} \cdot \frac{f_0}{f}$$

with l1 and l2 expressed in meters, Xoc expressed in mohm, fo = 50 Hz and f the working frequency.

Having calculated the homopolar fault current Io, according to the diagram shown in the previous figure, concerning all the fault points (downstream of the users), it is necessary to calculate how it is distributed in the network and how much is seen by each homopolar protection 67N distributed in the

network .
First of all, the Io must be divided into two currents: Ioc for the Xoc, and the other (Iol) for the star center of the transformer through the Petersen coil.
Then, the Iol is divided among the eventual transformers in parallel, in proportion to the power.
The Ioc, being the capacitive current that closes through the capacities of the network, must be divided between the cable or aerial users on average in proportion to the capacity of each (capacitors in parallel).
For the time being, the reduction factors relating to the guard ropes of overhead power lines and the metal shields of underground cables are not considered.
These factors would determine a reduction of the Ioc and Iol current as a third component in the Ego closes through these elements.

4.3. Asynchronous motors

The characteristic variables of the motors are:

- Urm-rated motor voltage [V] (concatenated for three-phase motors, phase for single-phase motors connected phase-neutral or phase-phase);
- Irm-rated motor current [A];
- Srm nominal apparent electrical power [kVA];
- P number of pole pairs;
- Ilr / Irm ratio between the locked motor current (DC) and the rated motor current;
- Starting power factor.
- Possibility of star/delta starting for three-phase motors, for which Ilr / Irm is reduced by 3.

The impedance of the motor is calculated:

$$Z_M = \frac{1}{I_{lr}/I_{rm}} \cdot \frac{U_{rm}^2}{S_{rm}}$$

Fault current attenuation for symmetrical and close faults

If the motor (or generator) is close to the fault point, it is necessary to calculate the coefficients μ and q to obtain the breaking current *ib* taking into account the delay time (by default equal to 0.02s).
The coefficient μ is calculated according to the following table:

$$\mu = 0.84 + 0.26 \cdot e^{-0.26 \cdot (I_{lr}/I_{rm})} \quad t_{\min} = 0.02\,s$$
$$\mu = 0.71 + 0.51 \cdot e^{-0.30 \cdot (I_{lr}/I_{rm})} \quad t_{\min} = 0.05\,s$$
$$\mu = 0.62 + 0.72 \cdot e^{-0.32 \cdot (I_{lr}/I_{rm})} \quad t_{\min} = 0.10\,s$$
$$\mu = 0.56 + 0.94 \cdot e^{-0.38 \cdot (I_{lr}/I_{rm})} \quad t_{\min} \geq 0.25\,s$$

If $I_{lr}/I_{rm} \leq 2$ then $\mu = 1$.

For the coefficient q we must take the mechanical active power expressed in MW and divide it by the number of polar pairs P to obtain the variable m:

$$m = \frac{S_{rm} \cdot \cos\varphi \cdot \eta}{1000 \cdot P}$$

With power factor cosφ and motor efficiency η.
Therefore:

$$q = 1.03 + 0.12 \cdot \ln m \quad t_{\min} = 0.02\,s$$
$$q = 0.79 + 0.12 \cdot \ln m \quad t_{\min} = 0.05\,s$$
$$q = 0.57 + 0.12 \cdot \ln m \quad t_{\min} = 0.10\,s$$
$$q = 0.26 + 0.10 \cdot \ln m \quad t_{\min} \geq 0.25\,s$$

If $q > 1$ we set $q = 1$.
Divide Z_M by the coefficients μ and q to obtain the equivalent impedance seen at the time of the fault:

$$Z_{Mib} = \frac{Z_M}{\mu \cdot q}.$$

Which, depending on the voltage and power of the motor, we can have:

$X_M = 0.995 \cdot Z_{Mib}$ $R_M = 0.10 \cdot X_M$	for medium voltage motors with power Prm for pole pairs> = 1 MW
$X_M = 0.989 \cdot Z_{Mib}$ $R_M = 0.15 \cdot X_M$	for medium voltage motors with power Prm per pair of poles <1 MW
$X_M = 0.922 \cdot Z_{Mib}$ $R_M = 0.42 \cdot X_M$	for low voltage motors

Table 4.2: Xm and Rm values of different motors.

For the components to the sequences, only the direct components are considered while the homopolar ones are not considered, as the contribution to the faults is given only by the three-phase motors. They contribute to three-phase and two-phase faults in three-phase and two-phase loads.

$$R_d = R_M$$
$$X_d = X_M$$

Note: Fault Conditions for Three Phase systems and Single phase systems are attached in Appendix A.4.

4.4. Relation for the Earth-Plant (Verification and sizing)

4.4.1. Electrical systems

The electrical systems present at the plant are the following:

15kV MT Network (Distribution):

- Rated voltage: 15 kV
- Maximum system voltage: 17.5 kV
- Ground voltage: 8.66 kV
- Rated frequency: 50 Hz
- State of the neutral of the electrical system: Compensated
- Single-phase earth fault current: 50 A

Note: In the areas covered by the following report there are no Medium Voltage users for which the verification of a medium voltage fault will not be taken into consideration.

0.4 kV BT NETWORK (POWER):

Double radial low voltage electrical distribution system.

- Rated voltage: 380-220V
- Maximum system voltage: 660V
- Ground voltage: 220V
- Rated frequency: 50Hz
- State of the neutral of the electrical system: Free to ground (TN-S).

4.4.2. Ground resistivity

The ground can be represented with a model that takes into account both its electrical resistance and a capacitive effect. When the impressed current does not have a high frequency or does not have a particularly steep wave front, the ground can be represented with a simple resistance.

The conduction of the current in the soil takes place essentially electrolytically, for this reason, the resistivity of the soil is greatly affected by the humidity present in the soil itself and increases rapidly when the moisture content falls below 15% by weight.

In order not to greatly alter the behavior of the ground, some attention must also be given to the maximum temperature that the conductor reaches during the phenomenon of current dispersion.

In the case of the plant there is no definitive value relating to the ground resistivity as the Customer has communicated the absence of a report of measurements carried out on-site. In the absence of precise data, reference is made to the Geological Report relating to Project 800 loading shelters always c / o the plant depot, as shown in the figure.

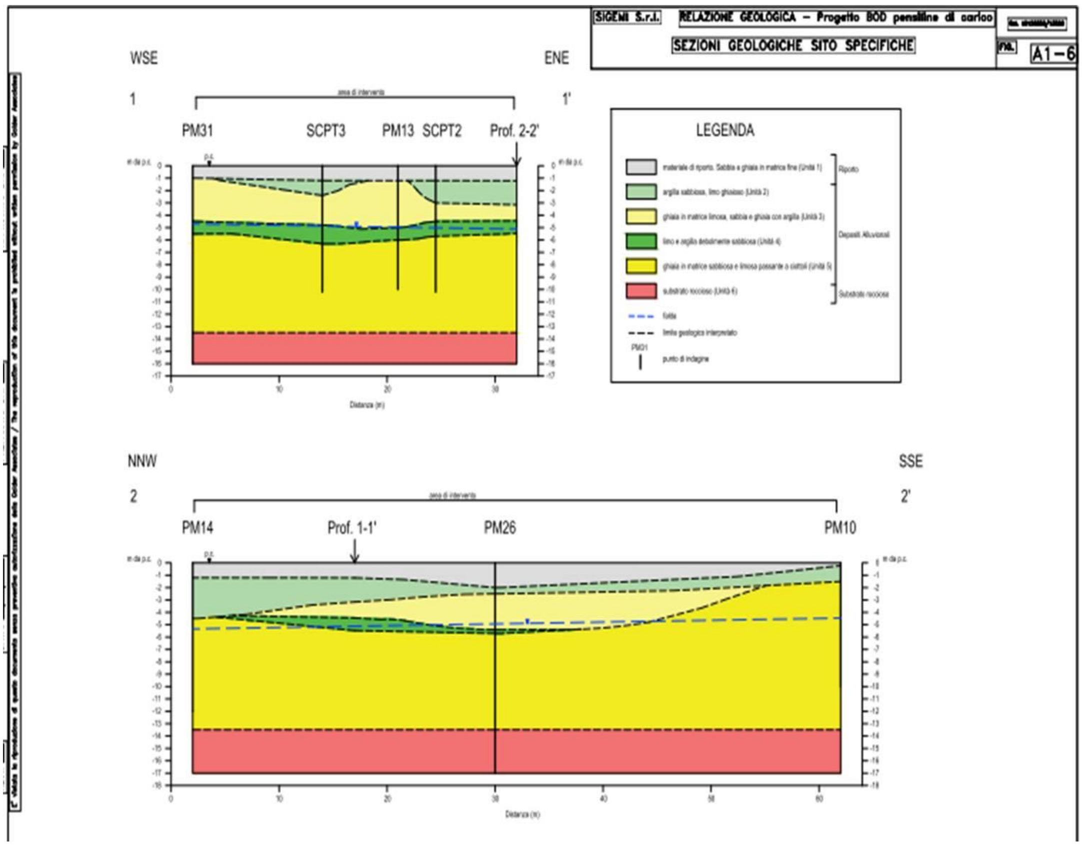

Figure 4.3: Geological Report

From the Report it is clear that the soil has a first layer of about 1m of backfill composed of sand and gravel then a variable layer up to a depth of 3m of clay and gravel, therefore a value of:

$\rho_E = 250\ \Omega m$

4.4.3. Affected area

The earth leakage system that is now being tested will only affect the surface where electrical equipment is located within the surface of the installation.

The plant areas where the new equipment is located have a total area of approximately interconnected with the earth conductors and connected at least one point with the factory earth network to consider them as a single earth.

4.4.4. Premise

This report aims to check the grounding network relating to low voltage (380 / 220V) as these are the plant's voltages.

4.4.5. Calculation of the minimum sections

Low Voltage

The calculation of the minimum section of the protective conductor will be by Standard CEI 64-8 par.543.1.1:

$$S_p = \frac{\sqrt{I^2 \times t}}{K} = \frac{\sqrt{40.000^2 \times 0{,}15}}{228} = 67{,}95 mm^2$$

where :

- $S_P =$ section of the protective conductor in mm2
- $I =$ RMS value of the fault current that can flow through the protective conductor for a fault of negligible impedance, in amperes.
- Note: Despite the variable distance (100-250m) of the plant subject to this calculation, the fault current value present on the busbars of the MCC-3 panel is assumed to be 40kA as a precaution.
- t = tripping time of the protection device in seconds
- $K =$ factor whose value depends on the material of the protective conductor, insulation and other parts and the initial

and final temperatures. Values of K for protective conductors in different applications are given in Tabb . 54B, 54C, 54D and 54E of Standard CEI 64-8 par. 543.1.1, where - 0 indicates the initial temperature and - f is the final temperature.

4.4.6. Calculation of the earth's resistance

The earth resistance calculation is carried out with the aid of the following relation valid for regular square mesh rods without stakes obtained from the CEI EN 50522 Annex J2 standard:

$$R_E = \frac{\rho_E}{2D} = \frac{250}{2 \times 35{,}692} = 3{,}5\Omega$$

where :

$\rho_E =$ resistivity of the land

$D =$ diameter of a circle with an area equal to that of the mesh rod

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 1000}{3{,}14}} = 35{,}692m$$

Furthermore, to lower the earth resistance value, 6 cross pegs of 50x3mm with a length of 3m are used.

The earth resistance value of the single rod is carried out with the aid of the following relationship valid for vertically fixed earth rods obtained from the CEI EN 50522 Annex J2 standard:

$$R_P = \frac{\rho_E}{2\pi L} \times ln\frac{4L}{d} = \frac{50}{2 \times 3{,}14 \times 3} \times ln\frac{4 \times 3}{0{,}05} = 14{,}55\Omega$$

Where,

$L =$ length of the stake (m)

$d =$ rod diameter (m)

$N =$ number of stakes

For the total resistance value given by the stakes it turns out to be:

$$R_{pt} = \frac{R_P}{N} = \frac{14{,}55}{6} = 2{,}425\Omega$$

At this point the total value of the earth's resistance is :

$$R_t = \frac{R_E \times R_{pt}}{R_E + R_{pt}} = \frac{3{,}5 \times 2{,}425}{3{,}5 + 2{,}425} = 1{,}43\Omega$$

4.4.7. Conclusions

The calculation of the grounding network was carried out in the absence of precise information from the Client, assuming input values based on the literature or on assumptions that must be verified such as:

- Ground resistivity equal to 250Ωm

As far as the low voltage is concerned, the earth value is very low, and considering that all motors are protected by differential relays with a minimum set of 300mA, the regulatory condition is respected $Z_s \times I_a \leq U_0$.

Furthermore, based on the calculated minimum section, it is recommended to use a conductor with a section of at least 70mm ^{2} as an underground earth rod.

In any case, after the installation of the earth network, it is advisable to carry out measurements to verify the real earth resistance, the contact, and step voltage, comparing them with the data required on the CEI EN 50522 standard.

If the measured values do not fall within limits required by the Standard, reference must be made to Annex "E" of the CEI EN 50522 Standard, description of the measures M.

4.5. Verification and sizing of the light system

The lighting calculation was performed using the Dialux EVO version 8.1 software.

4.5.1. Levels of illuminance

The lighting system is designed to ensure the following illumination levels referred to the worktop placed at 850mm above the finished floor level.
The lighting system covers the external areas of the plant and includes the following types of lighting systems:

- Normal lighting
- Emergency lighting

The listed values are intended as an "average" value taking into account the following depreciation factors:

Maintenance factor: 0.8

External reflection coefficient: 0.01 (toward the cardinal points and work plane at 850mm.)

Floor reflection coefficient: 0.3

The lighting levels have been calculated by the Regulations indicated in paragraph 2.2, in any case, the minimum lighting levels will be as follows:
Process areas (operational areas): 100 Lux
Process areas (non-operational areas): 50 Lux

After installation, a check of the whole lighting levels must be provided, as deviations from the values listed above could be detected due to tolerances in positioning, type of lamps, photometric curves of the purchased luminaires, possible interference of pipes and process equipment, etc.
Should the measured values deviate negatively, a necessary number of lighting bodies must be added to achieve the above values.

Note: Dialux Illumination calculation report for the Vapors Recovery unit has been attached in Appendix A.5.

5 Protections of the system

This Chapter deals with the method of design of the system. Initially, the ABB user manual for plant designing was presented and additionally defined the limitations of the engineering work by introducing the design criteria. From the electrical point of view, the load list has been prepared, and cable sizing has been discussed. From the Instrumentation point of view, Prepare the instrument list and cable list, and specifications are concerned. Then designed the junction box & Loop wiring for these instruments, and finally prepared the input-output signal list for DCS.

5.1. Selection of protection devices

The checks below were carried out using the Ampere Professional software from Electro Graphics Srl, version 11.0.6.0 of 2021.

5.1.1. Choice Of Protections

The verification was made taking into consideration the following users:

QL-DA-01 Emergency Section

- ABB XT2H160 4x160A panel line arrival switch
- Siemens Model 5SX4-C 4x32A Power Switch (Larger Size)
- Siemens Model 5SY4-C 2x4A Power Switch (Smaller Size)

QL-DA-01 Normal Section

- ABB XT2H160 4x160A panel line arrival switch
- Siemens Model 5SY7-C 4x16A Power Switch (Larger Size)
- ABB S 803N-C 3x10A Power Switch (Smallest Size)

Note: Verification of protection devices reports are attached in Appendix A.6.

5.2. Calculation Reports for the verification of coordinates and Protections

5.2.1. Choice Of Protections

The choice of protection is made by checking the nominal electrical characteristics of the pipes and the fault values; in particular the quantities that are verified are:

- Current, according to which the pipeline was sized;
- Number of poles;
- Type of protection;
- Operating voltage, equal to the rated voltage of the user;
- Capacity, the value of which must be higher than the maximum fault current upstream of the user l km max;
- Calibration of the magnetic tripping current, whose maximum value to guarantee protection against indirect contacts (in the absence of differential) must be less than the minimum fault current at the end of the line (image max).

The above checks were carried out using the Ampere Professional software of Electro Graphics Srl version 11.0.6.0 of 2021.

Note: Normal Network Power Supply Protection Calibration results are enclosed in Appendix A.7.

5.3. Equipmentent’s protection in Hazardous areas

When it comes to combustible gases or liquids, oil and gas refineries are typically not safe locations. Consequently, special measures should be taken into account while choosing electrical equipment. Here are a few brief explanations of several equipment selection techniques and their key definitions:

5.3.1. Hazardous area zones

Three zones are used to categorize hazardous areas, as shown in [6]:

Zone 0 :

A site is considered in Zone 0 if ignitable concentrations of flammable gases or vapors are constantly present or for an extended time.

Zone 1 :

Zone 1 refers to an area where ignitable concentrations of flammable gases or vapors are either regularly present due to pump or compressor station maintenance or are anticipated to occur under normal operating conditions.

Zone 2 :

In Zone 2, ignitable quantities of flammable gases or vapors are unlikely to exist during routine activities save for a brief window.

The distance in either direction (vertical and horizontal, for example) from the source of release to the point where the flammable mixture has been sufficiently diluted by air to a level below the mixture's lower explosive level (LEL) is known as the extent of a zone. If a location is not designated as a Zone 0, Zone 1, or Zone 2 area, it is regarded as unclassified or non-hazardous. See the table below for a cross-reference between Zones and other Classification techniques.

<table>
<tr><th>Standards</th><th colspan="3">Classified Area</th></tr>
<tr><td>IEC 60079-10
CENELEC</td><td>Zone 0</td><td>Zone 1</td><td>Zone 2</td></tr>
<tr><td>API RP 500A
or NFPA 70
or NEC 500.5
to NEC 500.7</td><td colspan="2">Class 1 Division 1</td><td>Class1 Division 2</td></tr>
</table>

Table 5.1: Hazardous classification Cross Reference Table

5.3.2. Gas Groups

Flammable liquid, gas, and vapor could be divided into the basic gas group as follows:
IIA – Propane
IIB – Ethylene
IIC – Hydrogen
IID – Acetylene

Definitions

According to IEC [7], hazardous locations are places where the materials above may be present along with explosive or ignitable gas (or vapor) atmosphere.

IEC 60079-12	**EN 50.014**	**NEC/UL 1604**		
Gas Group	**Gas Group**	**Class**	**Division**	**Group**
I	I	I	I or 2	**D**
IIA	IIA			
IIB	IIB	I	I or 2	C or B
IIC	IIC	I	1 or 2	A or B

Table 5.2: IEC Gas Groups versus EN and NEC/UL codes

5.3.3. Temperature Class

Under typical circumstances, flammable gas, vapor, or mist mixed with air have a minimum ignition temperature. When usually used or during an anticipated overload, electrical equipment in a hazardous area must have a minimum surface temperature of the gas mixture's minimum ignition temperature.
For use in hazardous environments, the surface temperatures of various electrical devices were established. The following temperature classes are

used to describe the maximum surface temperatures at that they are intended to operate at:

- T1- Maximum surface temperature of 450°C
- T2- Maximum surface temperature of 300°C
- T3- Maximum surface temperature of 200°C
- T4- Maximum surface temperature of 135°C
- T5- Maximum surface temperature of 100°C
- T6- Maximum surface temperature of 85°C

5.3.4. Protection Methods

Table 5.5 illustrates equipment protection techniques appropriate for usage in the relevant zones.

Zone	**Letter Designation of Protection**	**Type of Protection**
Zone 0	Ia	Intrinsically Safe – The apparatus is incapable of releasing enough energy to cause an explosion
Zone 1	M	Encapsulation – Arcing device is enclosed in resin.
	D	Flameproof - Enclosure can contain an internal explosion.
	E	Increased Safety – Enclosure does not allow the ingress of hazardous gases.
	Ib	Intrinsically Safe – The apparatus is incapable of releasing enough energy to cause an explosion
	O	Oil Immersion – Arcing device is enclosed in oil.
	Q	Powder Filling – Arcing device is enclosed in finely ground power
	P	Purged/pressurized enclosure – Pressure is higher than the area surrounding the enclosure.
Zone 2	NC	Non-incendive – Hermetically sealed
	NA	Non-Sparking Device
	NR	Restricted Breathing – Enclosure restricts the ingress of hazardous gases.

Table 5.3: Protective equipment type in hazardous area

6 Conclusion and future development

This study aims to develop a stable electrical system for the oil and gas industry, as indicated in the previous chapters. Important critical metrics that confirm a secure, reliable, and continuous power supply include taking into account the following factors:

1. a detailed load list that considers the necessary power, load factors, load type, and suitable feeding type ensures the system's dependability. Since energizing electrical loads is the primary function of electrical networks, better load comprehension will result in better network design.

2. It is critical to consider regular feeding, emergency feeding, and vital feeding (for applicable loads).

3. Reliable safeguards, such as relays and circuit breakers, must be considered to protect employees and equipment in case of failure.

Additionally, are safe refinery will be ensured by adequately connecting electrical protection and relays with other instrumentation systems like fire and gas protection systems, distribution control systems, and emergency shutdown systems.

4. Important studies, such as those on load flow, short circuits, and transients, help us to verify the system's stability. Additionally, it should be recognized that any changes to one study will affect the outcomes of other studies. In the end, the outcomes of all studies should be evaluated to ensure that the anticipated outcomes were achieved.

5. The cable size is crucial in terms of cost, voltage drop, and reactive power losses. The wrong cable sizing can negatively impact the system by causing malfunctions and incurring high expenditures for diagnosing the problem and repairing the cable, which can be expensive and time-consuming.

6. Even though the power factor in this project met design requirements, capacitor banks are advised to boost the power factor to have fewer reactive losses, better control over voltage drops, and smaller cable sizes. A smaller cable cross-section may be more cost-effective.

7. The transformer's short circuit impedance can be changed to manage the short circuit current. However, losses increase as short circuit impedance does. For this reason, using transformers of larger sizes is occasionally advised. The needed voltage level at the site can be ensured by considering the transformer tap changer.

8. The proper equipment selection for refineries' hazardous regions can prevent explosions and other potential catastrophes.

9. The necessary torque must be supplied to test the motors' capacity to start up, and the start-up time is a crucial element that should be as brief as feasible.

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A Appendix A

A.1. Load List

A.2. Cable Sizing

A.3. Single Line Diagram

A.4. Short Circuit Calculation Result

A.5. Illumination Calculation Report

A.6. Verification of Protection Devices

A.7. Protection Calibration Result

A.1.
Load List

ELENCO UTENZE ELETTRICHE - Electrical load list

POS.	SIGLA	SERVIZIO	COEFF. OPER.	TENSIONE	AVVIAMENTO	SERVIZIO	POTENZA / CORRENTE Inst. kW	Inst. A	Load/Start A	Load/Start A	GRADO DI PROTEZ.	PARTENZA ALIMENTAZIONE	CABINA	NOTE
1	P-101	I	0.5	380	DOL	POMPA CARICO GASOLIO B0	75	127			IP 65	MCC-3 / A / 5	MT-2	
2	P-102	I	0.5	380	DOL	POMPA CARICO GASOLIO B7	75	127			IP 65	MCC-3 / A / 8	MT-2	
3	P-103	I	0.5	380	DOL	POMPA CARICO GASOLIO B7	75	127			IP 65	MCC-3 / C / 1	MT-2	
4	P-104	I	0.5	380	DOL	POMPA CARICO BENZINA	55	93			IP 65	MCC-3 / G / 1	MT-2	
5	P-105	I	0.5	380	DOL	POMPA CARICO BENZINA	55	93			IP 65	MCC-3 / G / 3	MT-2	
6	P-106	I	0.5	380	DOL	POMPA CARICO BENZINA 100 RON	55	93			IP 65	MCC-3 / G / 6	MT-2	
7	P-107	I	0.5	380	DOL	POMPA CARICO GASOLIO IGLOO	75	127			IP 65	MCC-3 / C / 4	MT-2	
8	P-110	I	0.5	380	S/S	POMPA SCARICO BIODIESEL	18.5	41			IP 65	MCC-3 / B / 10	MT-2	
9	P-112	I	0.5	380	DOL	POMPA SVUOTAMENTO V-106	5.5	12			IP 65	MCC-3 / G / 8	MT-2	
10	P-113	I	0.5	380	S/S	SCARICO SOVRACCARICHI ATB	11.0	24			IP 65	MCC-3 / C / 10	MT-2	
11	FM-01	I	0.3	380	I	PRESE PER ALIM. MISURA CAMPIONE - CORSIA 2	---	32			IP 65	QL-DA-01	MT-2	
12	FM-02		0			PRESE PER ALIM. MISURA CAMPIONE - CORSIA 4	---	32			IP 65			
13	MOV-101	I	0.5	380	I	VALVOLA MOTORIZZATA	4	6				QL-DA-01	MT-2	POTENZA STIMATA
14	PK-101	C	1	220	I	QUADRO DISTR. ALIM. - CARICO CORSIA 1	0.90					JB-UPS-01 / INT. I-1	MT-2	
15	PK-201	C	1	220	I	QUADRO DISTR. ALIM. - CARICO CORSIA 2	0.90					JB-UPS-01 / INT. I-2	MT-2	
16	PK-301	C	1	220	I	QUADRO DISTR. ALIM. - CARICO CORSIA 3	0.75					JB-UPS-01 / INT. I-3	MT-2	
17	PK-401	C	1	220	I	QUADRO DISTR. ALIM. - CARICO CORSIA 4	0.75					JB-UPS-01 / INT. I-4	MT-2	
18	PK-501/502 <1>	C	1	380/230	I	PKG ADDIT. (DENAT. GASOLIO AGRICOLO/RISCALD.)	3.2					QL-DA-01	MT-2	
19	PK-503	C	1	220	I	PKG ADDIT. (GASOLIO B7 Q8)	0.20					QL-DA-01	MT-2	
20	PK-505	C	1	220	I	PKG ADDIT. (GASOLIO B7 / GASOLIO IGLOO)	0.20					QL-DA-01	MT-2	
21	PK-507	C	1	220	I	PKG ADDIT. (BENZINA IP)	0.20					QL-DA-01	MT-2	
22	PK-508	C	1	220	I	PKG ADDIT. (BENZINA 100 RON Q8)	0.20					QL-DA-01	MT-2	
23														

ELENCO UTENZE ELETTRICHE - Electrical load list

POS.	SIGLA	SERVIZIO	COEFF. OPER.	TENSIONE	AVVIAMENTO	SERVIZIO	POTENZA / CORRENTE				GRADO DI PROTEZ.	PARTENZA ALIMENTAZIONE	CABINA	NOTE
							Inst.		Load/Start					
							kW	A	A	A				
24	NUOVA COL. F&G	C	1	220	I	ALIMENTAZIONE NUOVO QUADRO F&G	0.50					JB-UPS-01 / INT. I-8	MT-2	POTENZA STIMATA
25	NUOVO NODO DCS	C	1	220	I	ALIMENTAZIONE NUOVO NODO DCS	0.50					JB-UPS-01 / INT. I-9	MT-2	POTENZA STIMATA
26	QL-ARIA (QL-PK-601)	I	0.5	380	I	PACKAGE PRODUZIONE ARIA	15.0	24				MCC-101-S / 2 / 2	MT-2	
27	CIRCUITO LUCE	I	0.5	380/230	I	LUCE PENS. CARICO ATB / AREA ADDITTIVI		16				QL-DA-01	MT-2	
28	M-CANC	I	0.5	220	I	MOTORE CANCELLO	1.10	5.00			IP 65	QL-DA-01	MT-2	POTENZA STIMATA
29	QL-JZ (QL-VRU-01)	I	0.5	380/220	I	MCC VRU (CABINATO)	90	…			IP 30	MCC-101-S / 2 / 1	MT-2	
30	CM-1	I	0.5	380	VFD	POMPA VUOTO	55	93			IP 65	MCC-VRU / X22	CABINATO VRU	DA J..Z.
31	P-111	I	0.5	380	DOL	POMPA ALIMENTAZIONE ASSORBITORE	5.5	9			IP 65	MCC-VRU / X23	CABINATO VRU	FINALE
32	P-2	I	0.5	380	VFD	POMPA RITORNO AD ASSORBITORTE	4	7			IP 65	MCC-VRU / X21	CABINATO VRU	DA J.Z.
33	A-11	I	0.5	220	DOL	VENTILATORE DI RAFFREDDAMENTO	0.75	3			IP 65	MCC-VRU / X25	CABINATO VRU	DA J.Z.
34	PLC-JZ	I	1	220	I	ALIMENTAZIONE PLC	2.50	11.4			IP 65	MCC-VRU / X..	CABINATO VRU	DA J.Z.
35	PLC-JZ	C	1	220	I	ALIMENTAZIONE PLC VRU - JOHN ZINK	3	13				JB-UPS-01 / INT. I-5	MT-2	POTENZA DA J.Z.
36	MOV-101	I	0.5	220	I	VALVOLA MOTORIZZATA	0.15	0.68		4.0	IP 65	MCC-VRU / X3.1	CABINATO VRU	DA J.Z.
37	MOV-102	I	0.5	220	I	VALVOLA MOTORIZZATA	0.15	0.68		4.0	IP 65	MCC-VRU / X3.1	CABINATO VRU	DA J.Z.
38	MOV-103	I	0.5	220	I	VALVOLA MOTORIZZATA	0.15	0.68		4.0	IP 65	MCC-VRU / X3.1	CABINATO VRU	DA J.Z.
39	MOV-801	I	0.5	220	I	VALVOLA MOTORIZZATA	0.03	0.14		1.1	IP 65	MCC-VRU / X3.1	CABINATO VRU	DA J.Z.
40	MOV-201	I	0.5	220	I	VALVOLA MOTORIZZATA	0.15	0.68		4.0	IP 65	MCC-VRU / X4.1	CABINATO VRU	DA J.Z.
41	MOV-202	I	0.5	220	I	VALVOLA MOTORIZZATA	0.15	0.68		4.0	IP 65	MCC-VRU / X4.1	CABINATO VRU	DA J.Z.
42	MOV-203	I	0.5	220	I	VALVOLA MOTORIZZATA	0.15	0.68		4.0	IP 65	MCC-VRU / X4.1	CABINATO VRU	DA J.Z.
43	MOV-601	I	0.5	220	I	VALVOLA MOTORIZZATA	0.03	0.14		1.1	IP 65	MCC-VRU / X8.1	CABINATO VRU	DA J.Z.
44	FV-701	I	0.5	220	I	VALVOLA MOTORIZZATA	0.03	0.14		1.1	IP 65	MCC-VRU / X8.1	CABINATO VRU	DA J.Z.
45	MOV-702	I	0.5	220	I	VALVOLA MOTORIZZATA	0.03	0.14		1.1	IP 65	MCC-VRU / X8.1	CABINATO VRU	DA J.Z.
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A.2. Cable Sizing

Identificazione

Sigla utenza:	**+Cab. MT-2 (1° Piano.MCC-101S-QL-VRU-01**
Denominazione 1:	
Denominazione 2:	
Informazioni aggiuntive/Note 1:	
Informazioni aggiuntive/Note 2:	

Utenza

Tipologia utenza:	**Distribuzione generica**		
Potenza nominale:	**90 kW**	Sistema distribuzione:	**TN-S**
Coefficiente:	**1**	Collegamento fasi:	**3F+N**
Potenza dimensionamento:	**90 kW**	Frequenza ingresso:	**50 Hz**
Potenza reattiva:	**35,4 kVAR**	Pot. trasferita a monte:	**96,7 kVA**
Corrente di impiego Ib:	**150,2 A**	Potenza totale:	**164,5 kVA**
Fattore di potenza:	**0,931**	Potenza disponibile:	**67,8 kVA**
Tensione nominale:	**380 V**		

Cavi

Formazione:	**2x[3x120+1x70]**		
Tipo posa:	34(E) - Multi-core cables on ladder		
Disposizione posa:	1 cable ladder, cleat, wire mesh tray, etc., touching cables		
Designazione cavo	FG16OR16 0.6/1 kV Cca-s3,d1,a3		
Isolante (fase+neutro+PE):	**EPR**	K^2S^2 conduttore fase:	**1,178E+09 A^2s**
Tabella posa:	**IEC 60364-5-52 Ed.3**	K^2S^2 neutro:	**4,008E+08 A^2s**
Materiale conduttore:	**RAME**	Caduta di tensione parziale a Ib:	**0,761 %**
Lunghezza linea:	**110 m**	Caduta di tensione totale a Ib:	**0,984 %**
Corrente ammissibile Iz:	**497,5 A**	Temperatura ambiente:	**40 °C**
Corrente ammissibile neutro:	**353,7 A**	Temperatura cavo a Ib:	**44,6 °C**
Coefficiente di prossimità:	**0,79 (Numero circuiti: 6)**	Temperatura cavo a In:	**52,6 °C**
Coefficiente di temperatura:	**0,91**	Coordinamento Ib<=In<=Iz:	**150,2<=250<=497,5 A**
Coefficiente di declassamento	**0,719**		

Condizioni di guasto (CEI EN 60909-0)

Ikm max a monte:	**33 kA**	Ik1ftmax:	**13,8 kA**
Ikv max a valle:	**14,8 kA**	Ip1ft:	**18,7 kA (Lim.)**
Imagmax (magnetica massima):	**3969 A**	Ik1ftmin:	**9,03 kA**
Ik max:	**13,6 kA**	Ik1fnmax:	**7,18 kA**
Ip:	**18,8 kA (Lim.)**	Ip1fn:	**17,7 kA (Lim.)**
Ik min:	**8,95 kA**	Ik1fnmin:	**3,97 kA**
Ik2ftmax:	**13,8 kA**	Zk min:	**16,1 mohm**
Ip2ft:	**18,6 kA (Lim.)**	Zk max:	**23,3 mohm**
Ik2ftmin:	**9,06 kA**	Zk1ftmin:	**15,9 mohm**
Ik2max:	**11,8 kA**	Zk1ftmax:	**23,1 mohm**
Ip2:	**17,5 kA (Lim.)**	Zk1fnmin:	**30,5 mohm**
Ik2min:	**7,75 kA**	Zk1fnmx:	**52,5 mohm**

Protezione

Costruttore protezione:	**ABB**		
Sigla protezione:	**XT4N 250 + XT4 Ekip LSIG**		
Tipo protezione:	**MTD**		
Corrente nominale protez.:	**250 A**	Taratura magnetica neutro:	**2500 A**
Numero poli:	**4**	Taratura differenziale:	**50 A**
Taratura termica:	**250 A**	Potere di interruzione PdI:	**36 kA**
Taratura magnetica:	**2500 A**	PdI >= I max in ctocto a monte:	**36 >= 33 kA**
Sg. magnetico < I mag. massima:	**2500 < 3969 A**	Norma:	**Icu-EN60947**
Taratura termica neutro:	**250 A**		

Stato utenze

Utenza
+Cab. MT-2 (1° Piano.MCC-101S-QL-VRU-01

Coord. Ib < Ins < Iz [A]

	Ib	<=	Ins	<=	Iz
Fase	150,183		250		497,479
Neutro	5,002		250		353,699

1) Utenza +Cab. MT-2 (1° Piano.MCC-101S-QL-VRU-01: Ins = 250 [A] (sgancio protezione termica)

Verifica contatti indiretti

	Verificato
Ia c.i. [A]	n.a.
Tempo di interruzione [s]	5
VT a Ia c.i. [V]	50
VT a Iccft [V]	0

Sistema distribuzione: TN-S
(Nota: l'analisi termina alla prima protezione utile trovata)
La protezione dell'utenza +Cab. MT-2 (1° Piano.MCC-101S-QL-VRU-01
interviene tramite sgancio differenziale; I prot. = 50 <= Ia c.i. = 1E22

Potere di interruzione [kA]

A transitorio inizio linea — Verificato

PdI	>=	Ikm max	/_Ikm max [°]
36		33,044	71,92
		DeltaIkm max	/_DeltaIkm max [°]
		6,494	57,856

Sg. mag.<Imagmax [A]

Sg. mag.	<	Imagmax
		Verificato
2500		3968,54

Cavo

Designazione FG16OR16 0.6/1 kV Cca-s3,d1,a3
Formazione 2x[3x120+1x70]
Temperatura cavo a Ib [°C] 40 <= 45 <= 85
Temperatura cavo a In [°C] 40 <= 53 <= 85

K²S²>I²t [A²s]

	Verificato
K²S² conduttore fase	$1,178 \cdot 10^{9}$
K²S² neutro	$4,008 \cdot 10^{8}$

Caduta di tensione [%]

Tensione nominale [V] 380

Cdt (Ib)	CdtT (Ib)	Cdt max
0,761	0,984	4
Cdt (In)	CdtT (In)	
1,281	1,577	

Correnti di guasto [kA]

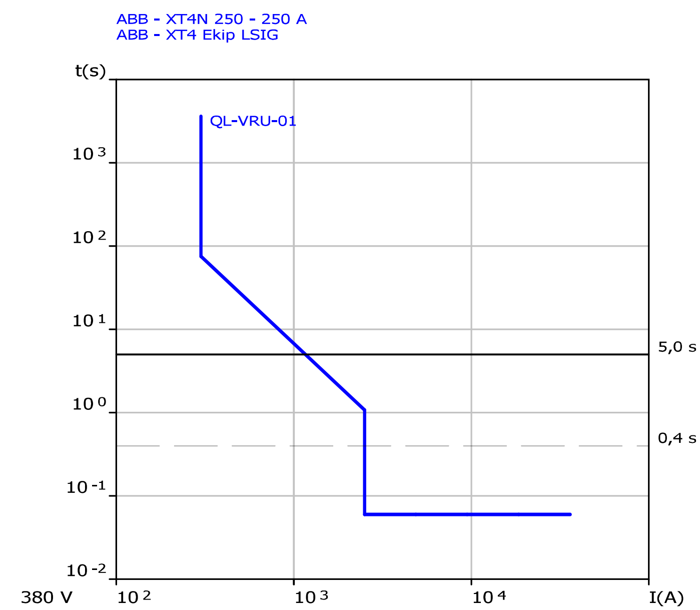
A regime fondo linea, Picco a inizio linea

	Max	Min	Picco
Trifase	13,593	8,95	18,786
Bifase	11,772	7,751	17,5
Bifase-N	12,946	8,232	18,752
Bifase-PE	13,819	9,062	18,604
Fase-N	7,184	3,969	17,74
Fase-PE	13,799	9,026	18,701

A transitorio fondo linea

Ikv max	/_Ikv max [°]
14,841	41,867

Protezione



A.3. Single-line diagram

NUOVO QUADRO AUX QL-DA-01
PIANTA CHIAVE DEPOSITI DI GENOVA SAN QUIRICO
CABINA BT1
CABINA MT1 ENEL
CABINA DEPOSITO LIBERO
PENSILINE
SERBATOI
CABINA MT-2 PT +PP
SALA CONTROLLO
DEPOSITO LIBERO
QUADRO "MCC-4" COLONNA A
QUADRO "MCC-4" COLONNA C
QUADRO "MCC-4" COLONNA B
(CABINA LIBERO)
CANTIERE 3C
DISPOSIZIONE QUADRI CABINA DEPOSITO LIBERO
QUADRO "QSA-BT-101-S" (CABINA BT1)
DISPOSIZIONE QUADRI CABINA BT1 (FRONTE SALA POMPE P1/P2/P3)
QUADRO "QSA-BT-104-S" (CABINA BT1)
DEPOSITO DOGANALE - DISP. QUADRI CAB. MT-2 / PIAMO PRIMO
DEPOSITO DOGANALE DISPOSIZIONE QUADRI CABINA MT-2 PIANO TERRA
QUADRO-MCC3 COLONNA D (CABINA MT-2/P.PIANO)
QUADRO-MCC3
QM-101S (CABINA MT-2)
QR-101S (CABINA MT-2)
QUADRO BT 2 CABINA-MT2 COLONNA 2 SEZ. B
QUADRO BT 2 CABINA-MT2 COLONNA 2 SEZ. C
Q.GE (LOC. ANT.)
QUADRO "QD3" (CABINA MT-2)
QUADRO "PCMCC-102S" (CAB. BT1)
QUADRO "AP-1"
JB-UPS-01
QUADRO MCC-101S (CABINA MT-2/I PIANO) COLONNA 1
QUADRO MCC-101S (CABINA MT-2/I PIANO) COLONNA 2
QUADRO MCC 3/A (CABINA MT-2/I PIANO)
QUADRO "FILTRAZIONE"
BATTERIA AD-PE/2
QUADRO "QD4" (LOCALE ANTINCENDIO)
QUADRO POZZO
LOCALE CENTRALE TERMICA
MAGAZZINO EX-CENTRALE TERMICA
QUADRO "QL0-2" (LOC. ANTINC.)
(CABINA BT-1)
TR-A
TR-B
COLONNA A
COLONNA B
COLONNA C

A.4. Short-circuit calculation result

Condizioni di guasto sistemi trifase

Utenza	Ikm max [kA]	/_Ikm max	Ikm max by	DeltaIkm max [kA]	Ikv max [kA]	Ik1ftmax [kA]	Ip1ft [kA]	Ik1ftmin [kA]	Ik2ftmax [kA]	Ip2ft [kA]	Ik2ftmin [kA]
	Imagmax [A]	/_Imagmax	Ik max [kA]	Ip [kA]	Ik min [kA]	Ik1fnmax [kA]	Ip1fn [kA]	Ik1fnmin [kA]	Ik2max [kA]	Ip2 [kA]	Ik2min [kA]
Cab. MT-2 (1° Piano QL-DA-01 NORMALE											
Arrivo da MCC-101S	11,8	0,85	n.c.	1	11,8	10,6	7,83	6,52	10,3	7,68	6,26
	2454	0,986	11,3	8,06	6,68	4,73	6,16	2,45	9,77	7,6	5,78
MOV-101	11,8	0,85	n.c.	1	0,361	0,36	3,17	0,179	0,354	3,12	0,177
	154,8	0,877	0,361	3,25	0,179				0,312	3,08	0,155
Circuito Luce	11,8	0,85	n.c.	1	0,091	0,091	3,6	0,045	0,091	3,5	0,045
	22,6	1	0,091	3,74	0,045	0,046	3,06	0,023	0,079	3,45	0,039
CABINATO QL-VRU-01											
Arrivo da MCC-101S	14,6	0,734	n.c.	1,15	14,8	13,8	11,5	9,03	13,8	11,5	9,06
	3969	0,961	13,6	11,6	8,95	7,18	8,26	3,97	11,8	10,4	7,75
C-1	14,7	0,739	n.c.	1,5	0,606	0,198	11,5	0,185	0,198	11,5	0,184
	160,9	0,868	0,199	11,6	0,186				0,172	10,4	0,161
P-2	14,8	0,744	n.c.	1,69	0,051	0,017	11,5	0,016	0,017	11,5	0,016
	13,7	0,866	0,017	11,6	0,016				0,015	10,4	0,014
P-111	14,8	0,746	n.c.	1,67	0,467	0,434	11,5	0,215	0,428	11,5	0,214
	186,5	0,878	0,434	11,6	0,215				0,376	10,4	0,186
A-11	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-101	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-102	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			

Condizioni di guasto sistemi trifase

Utenza	Ikm max [kA] / Imagmax [A]	/_Ikm max / /_Imagmax	Ikm max by / Ik max [kA]	DeltaIkm max [kA] / Ip [kA]	Ikv max [kA] / Ik min [kA]	Ik1ftmax [kA] / Ik1fnmax [kA]	Ip1ft [kA] / Ip1fn [kA]	Ik1ftmin [kA] / Ik1fnmin [kA]	Ik2ftmax [kA] / Ik2max [kA]	Ip2ft [kA] / Ip2 [kA]	Ik2ftmin [kA] / Ik2min [kA]
CP-MOV-103	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-801	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-201	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-202	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-203	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-601	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-FV-701	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
CP-MOV-802	14,7	0,738	n.c.	1,31	0,361	0,361	11,5	0,179			
	89,3	1				0,181	8,25	0,089			
PLC-JZ	14,8	0,745	n.c.	1,7	4,24	4,2	3,81	2,15	4,2	3,8	2,15
	1024	0,997	4,2	3,82	2,15	2,04	3,4	1,02	3,64	3,59	1,86

Condizioni di guasto sistemi monofase

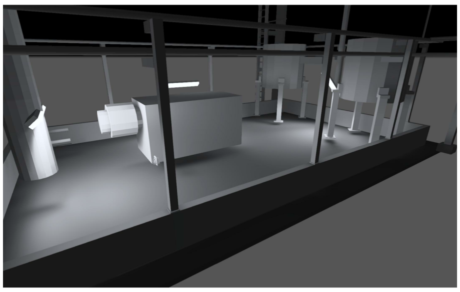
Utenza	Imagmax [A]	Ikm max [kA]	Ikv max [kA]	Ik1fnmax [kA]	Ip1fn [kA]	Ik1fnmin [kA]	Ik1ftmax [kA]	Ip1ft [kA]	Ik1ftmin [kA]	IkITmax [kA]	IkITmin [kA]
Cab. MT-2 (1° Piano QL-DA-01 NORMALE											
Arrivo da MCC-101S	2454	11,8	11,8	4,73	6,16	2,45	10,6	7,83	6,52		
MOV-101	154,8	11,8	0,361				0,36	3,17	0,179		
Circuito Luce	22,6	11,8	0,091	0,046	3,06	0,023	0,091	3,6	0,045		
CABINATO QL-VRU-01											
Arrivo da MCC-101S	3969	14,6	14,8	7,18	8,26	3,97	13,8	11,5	9,03		
C-1	160,9	14,7	0,606				0,198	11,5	0,185		
P-2	13,7	14,8	0,051				0,017	11,5	0,016		
P-111	186,5	14,8	0,467				0,434	11,5	0,215		
A-11	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-101	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-102	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-103	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-801	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-201	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-202	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-203	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-601	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-FV-701	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
CP-MOV-802	89,3	14,7	0,361	0,181	8,25	0,089	0,361	11,5	0,179		
PLC-JZ	1024	14,8	4,24	2,04	3,4	1,02	4,2	3,81	2,15		

A.5. Illumination Calculation Report

Luminaire list

Φtotal	Ptotal	Luminous efficacy
12990 lm	162.0 W	80.2 lm/W

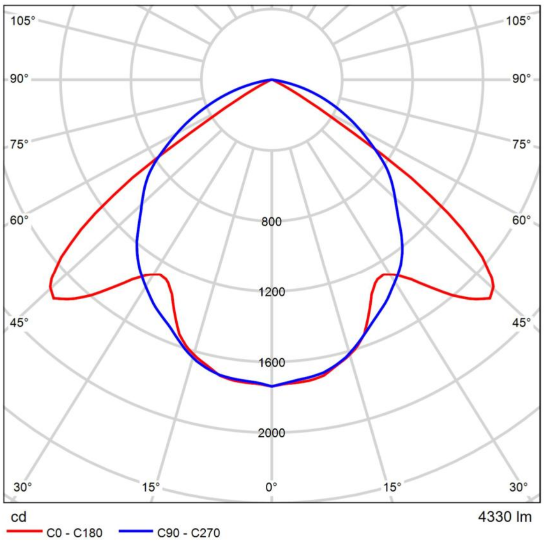
pcs.	Manufacturer	Article No.	Article name	P	Φ	Luminous efficacy
3	EATONS CROUSE-HINDS BUSINESS	eLLK-LED	eLLK_92_LED_800_5600K	54.0 W	4330 lm	80.2 lm/W



Product data sheet

EATONS CROUSE-HINDS BUSINESS eLLK_92_LED_800_5600K

Article No.	eLLK-LED
P	54.0 W
$\Phi_{Luminaire}$	4330 lm
Luminous efficacy	80.2 lm/W
CCT	5181 K
CRI	86

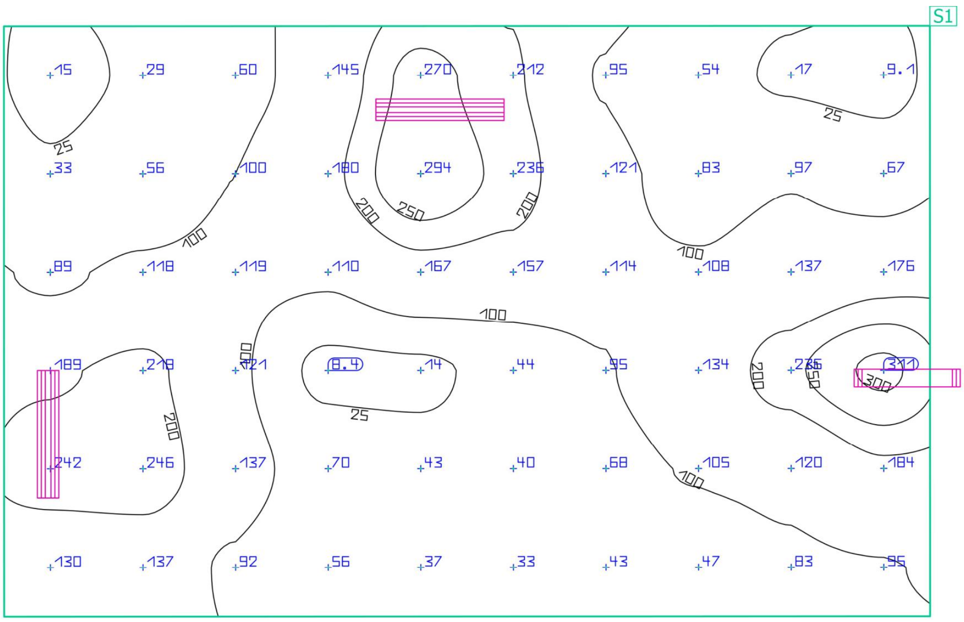


Polar LDC

eLLK800 LED
Zone 1, 2, 21, 22 Rated
5600K Colour

Site

Calculation surface



Properties	Ē	Emin	Emax	g1	g2	Index
Calculation surface Perpendicular illuminance Height: 0.150 m	114 lx	8.41 lx	311 lx	0.074	0.027	S1

Utilisation profile: DIALux presetting, Standard (outdoor transportation area)

A.6. Verification of Protection Devices

Verifica di selettività

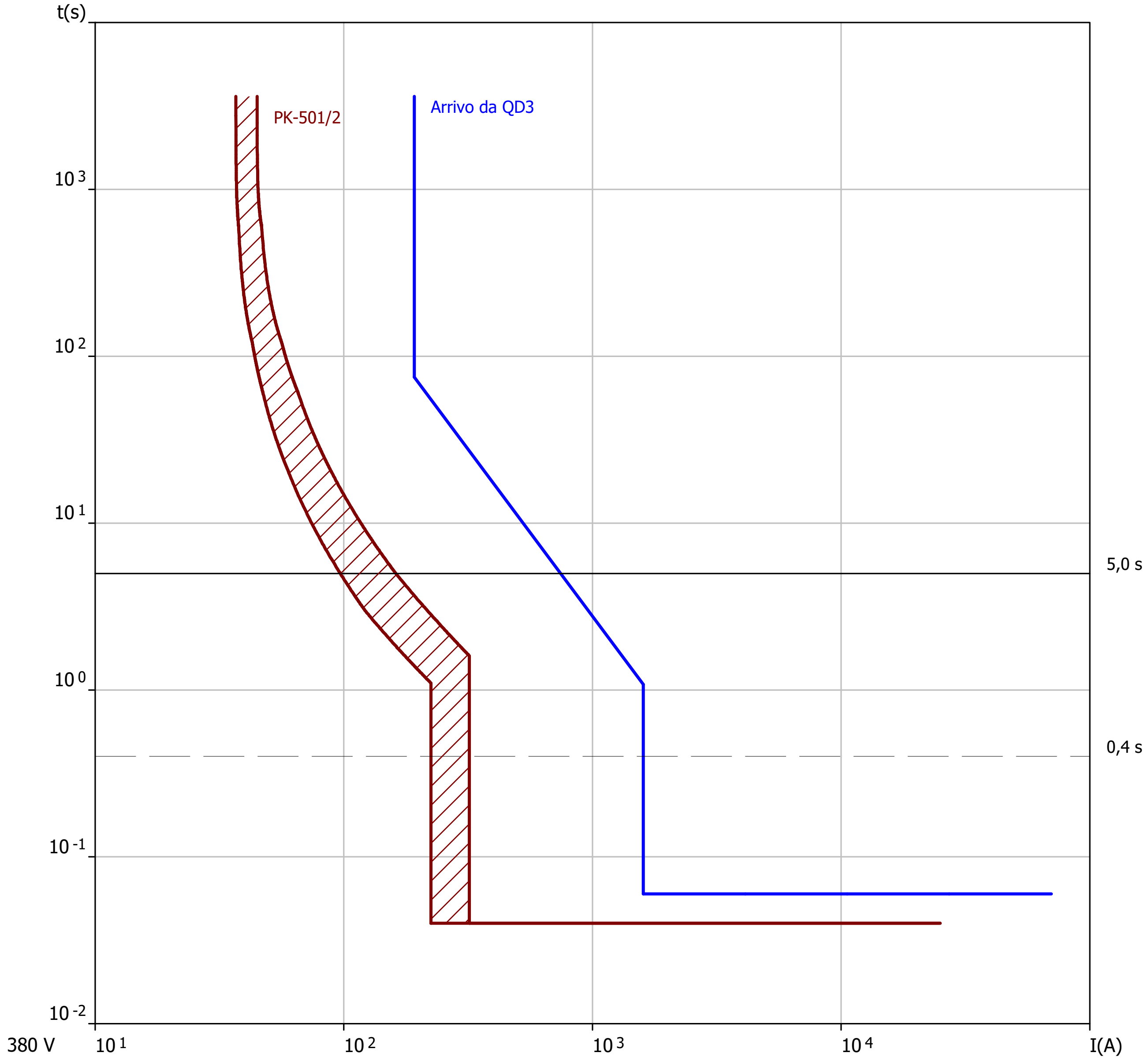
QL-DA-01
SEZIONE EMERGENZA

Verifica di selettività

	Monte:	**Valle:**
Utenza:	Arrivo da QD3	PK-501/2
Zona:	Cab. MT-2 (1° Piano	Cab. MT-2 (1° Piano
Quadro:	QL-DA-01 Emergenza	QL-DA-01 Emergenza
Tensione nominale utenza:	380 V	380 V
Sigla protezione:	XT2 Ekip LSI	5SX4-C
Tipo protezione:	MT	MT Curva C
Corrente nominale:	160 A	32 A
Sgancio magnetico:	1600 A	320 A
Sgancio a: 5 s / 0,4 s:	743,6 A / 1600 A	161,7 A / 320 A
Icc minima:		
Tempo di intervento:		

Rapporto tra magnetiche:	5
Selettività:	Totale
Selettività amperometrica:	n.d.
Selettività cronometrica:	n.d.

Arrivo da QD3
PK-501/2

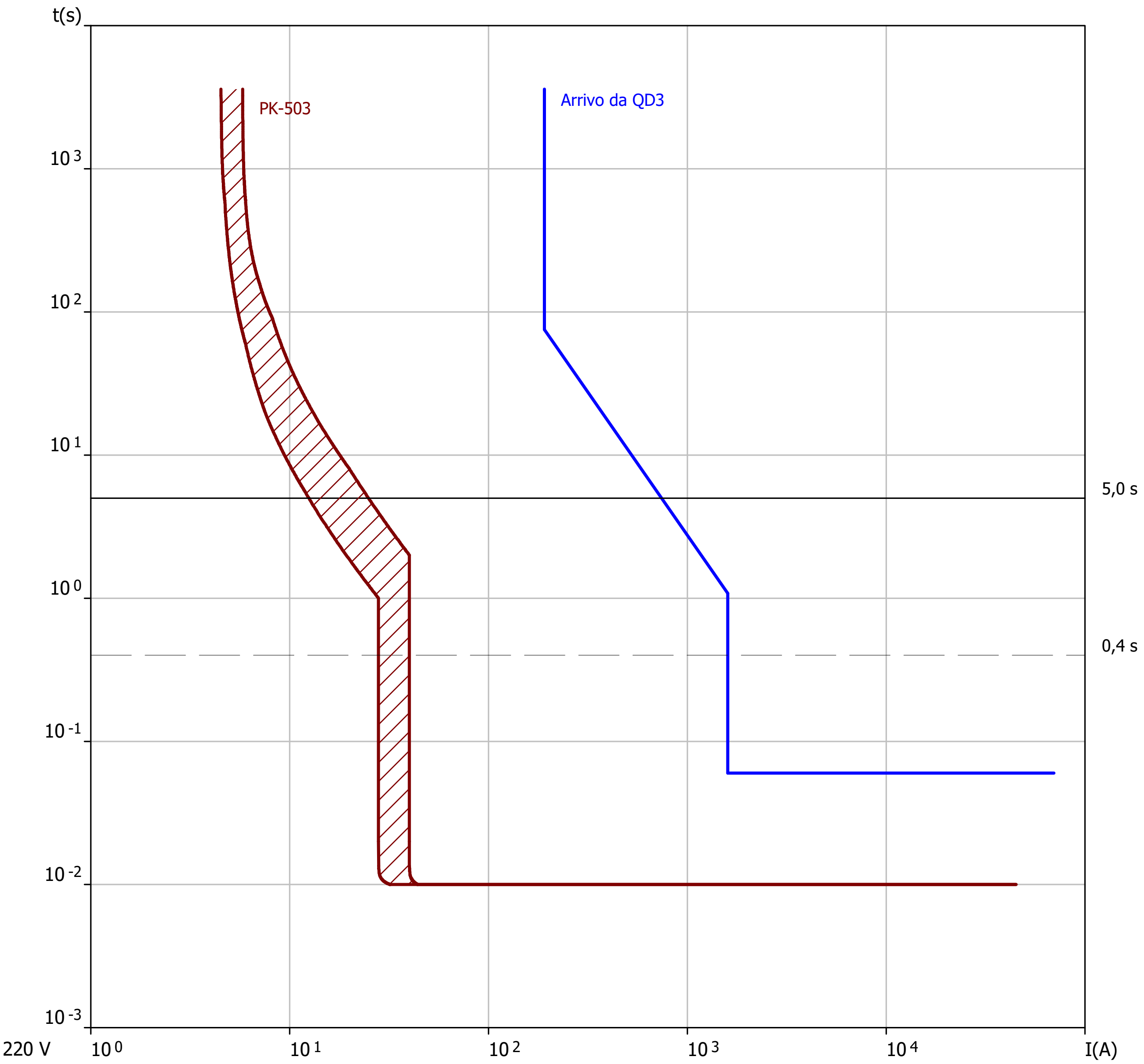


Verifica di selettività

	Monte:	**Valle:**
Utenza:	Arrivo da QD3	PK-503
Zona:	Cab. MT-2 (1° Piano	Cab. MT-2 (1° Piano
Quadro:	QL-DA-01 Emergenza	QL-DA-01 Emergenza
Tensione nominale utenza:	380 V	220 V
Sigla protezione:	XT2 Ekip LSI	5SY4-C
Tipo protezione:	MT	MT+D Curva C
Corrente nominale:	160 A	4 A
Sgancio magnetico:	1600 A	40 A
Sgancio a: 5 s / 0,4 s:	743,6 A / 1600 A	24,9 A / 40 A
Icc minima:		
Tempo di intervento:		

Rapporto tra magnetiche:	39,9
Selettività:	Totale
Selettività amperometrica:	n.d.
Selettività cronometrica:	n.d.

Arrivo da QD3
PK-503



Verifica di selettività

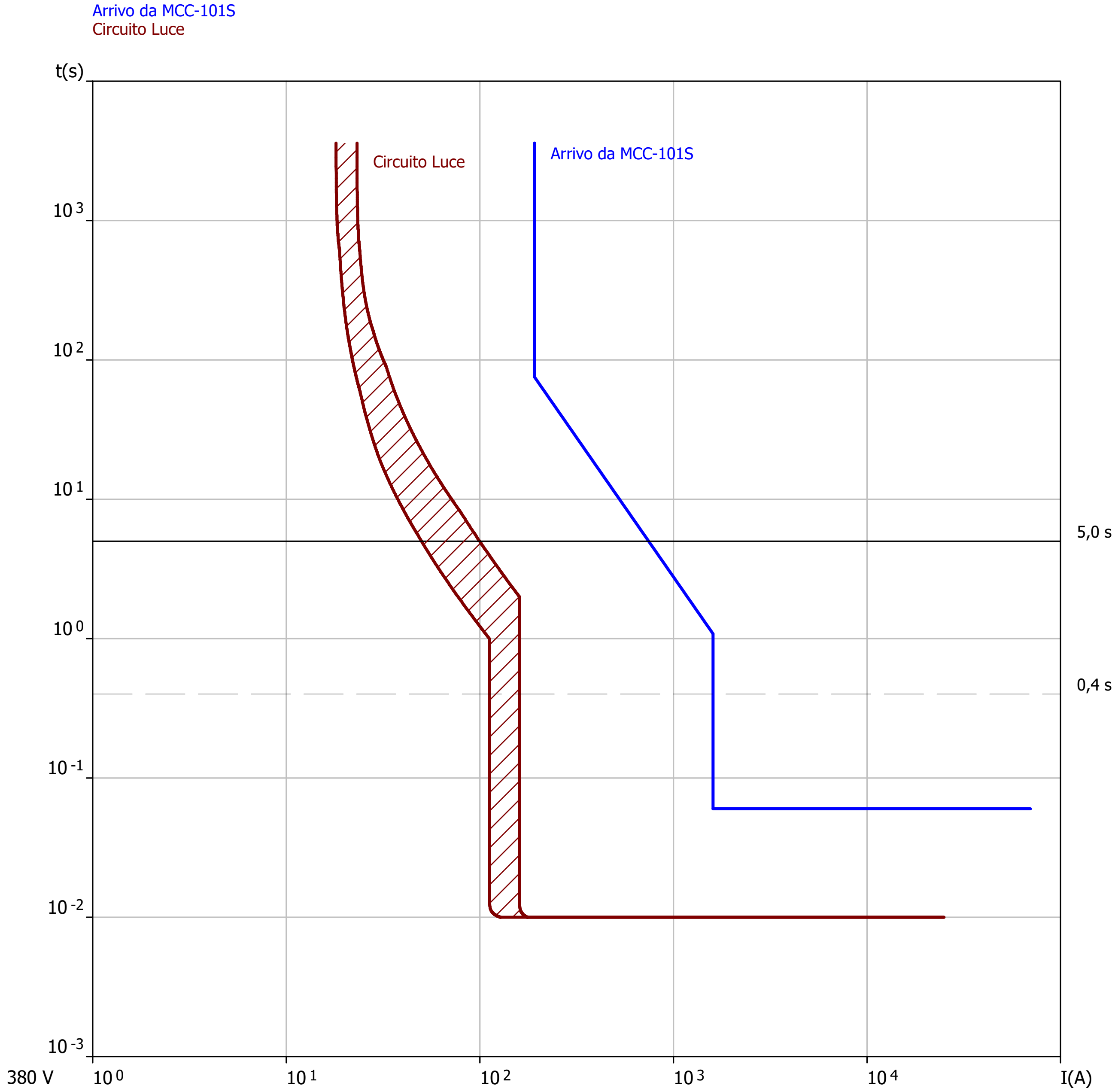
QL-DA-01

SEZIONE NORMALE

Verifica di selettività

	Monte:	**Valle:**
Utenza:	Arrivo da MCC-101S	Circuito Luce
Zona:	Cab. MT-2 (1° Piano	Cab. MT-2 (1° Piano
Quadro:	QL-DA-01 NORMALE	QL-DA-01 NORMALE
Tensione nominale utenza:	380 V	380 V
Sigla protezione:	XT2 Ekip LSI	5SY7-C
Tipo protezione:	MT	MT+D Curva C
Corrente nominale:	160 A	16 A
Sgancio magnetico:	1600 A	160 A
Sgancio a: 5 s / 0,4 s:	743,6 A / 1600 A	99,7 A / 160 A
Icc minima:	2454 A	22,6 A
Tempo di intervento:	0,06 s	0,01 s

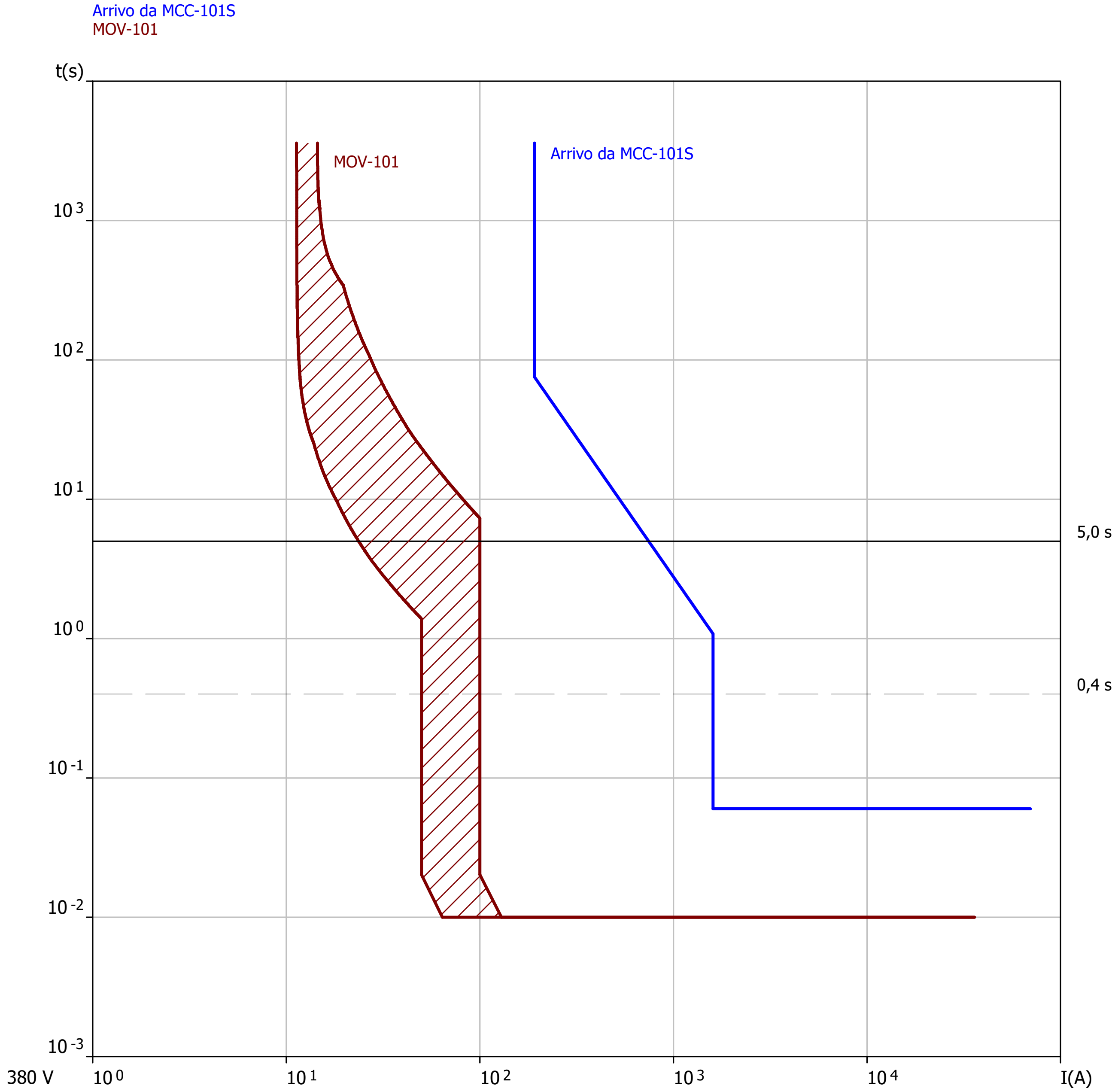
Rapporto tra magnetiche:	10
Selettività:	Totale
Selettività amperometrica:	n.d.
Selettività cronometrica:	0,05 s



Verifica di selettività

Data: 23/09/2021
Responsabile:
Cliente:

	Monte:	**Valle:**
Utenza:	Arrivo da MCC-101S	MOV-101
Zona:	Cab. MT-2 (1° Piano	Cab. MT-2 (1° Piano
Quadro:	QL-DA-01 NORMALE	QL-DA-01 NORMALE
Tensione nominale utenza:	380 V	380 V
Sigla protezione:	XT2 Ekip LSI	S 803 N-C
Tipo protezione:	MT	MT Curva C
Corrente nominale:	160 A	10 A
Sgancio magnetico:	1600 A	100 A
Sgancio a: 5 s / 0,4 s:	743,6 A / 1600 A	100 A / 100 A
Icc minima:	2454 A	154,8 A
Tempo di intervento:	0,06 s	0,01 s
Rapporto tra magnetiche:	16	
Selettività:	Totale	
Selettività amperometrica:	n.d.	
Selettività cronometrica:	0,05 s	



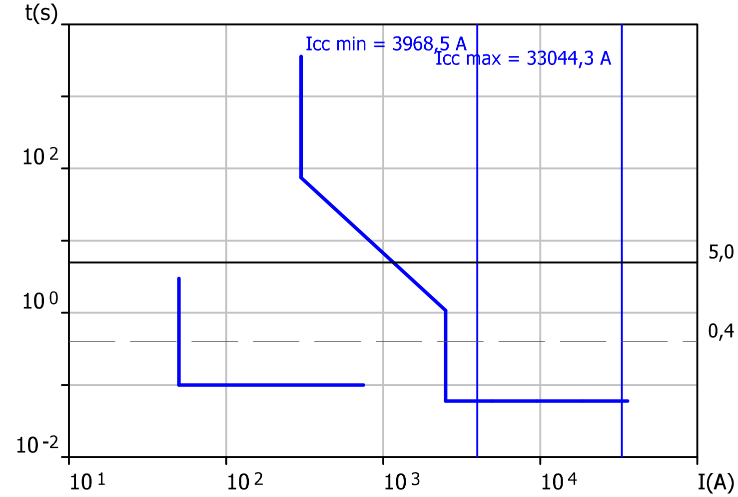
A.7. Protection Calibration Result

Data: 25/07/2021

Responsabile:

Tarature protezioni

Utenza:	**QL-VRU-01**	
Zona - Quadro:	Cab. MT-2 (1° Piano	MCC-101S
Denominazione 1:	-	
Denominazione 2:	-	
Costruttore - Sigla:	ABB	XT4N 250
Poli - Corrente nominale IN:	4	250
Costruttore - Sigla sganciatore:	ABB	XT4 Ekip LSIG
Ith [A]:	250	
Im [A]:	2500	
Ist [A]:	2500	



Regolazione correnti		Minima	Massima	**Regolazione tempi**		Minima	Massima
Corrente Is [A]:	**250**						
LR (Ir = x Is):	**1**	0,4	1	LR (tr) [s]:	**12**	3	60
CR (Im = x Is): [I2T = ON]	**10**	1	10	CR [s]:	**0,1**	0,05	0,4
IST (Ist = x Is):	**10**	1	10	IST [s]:	**0,06**		
T (T = x Is):	**0,2**	0,2	1	T [s]:	**0,1**	0,1	0,8
Sgancio neutro - Rapporto neutro/fase:	**1**	0,5	1				