UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA

TRABAJO FIN DE MASTER EN INGENIERÍA INDUSTRIAL

DISEÑO Y SIMULACIÓN DE UNA SUBESTACIÓN TRANSFORMADORA GIS ENTERRADA 200/20kV 50MVA

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Resumen

Este proyecto fin de master tiene como objeto el diseño y simulación de una subestación de transformación eléctrica, situada en un entorno urbano. En la subestación se transforma el voltaje con el objeto de adecuarlo y distribuirlo por zona urbana.

Tiene la singularidad de encontrarse soterrado, para ello se ha utilizado un diseño por unidades blindadas y aisladas con SF6, ya que las ventajas en cuanto a volumen y dinero son primordiales en este tipo de instalación, pero también teniendo en cuenta el bajo mantenimiento necesario y el mínimo impacto ambiental que este tipo de diseño permite. Para su diseño se incluyen los cálculos eléctricos necesarios, los cálculos de la red de tierras, las características técnicas del equipo escogido, los planos correspondientes, y la simulación de la instalación y contraste de los resultados.

Abstract

The aim of this project is to design and simulate an underground electrical substation, which will be located in an urban surround. At the substation the voltage will be transformed in order to adapt and distribute it for the urban area.

It has the singularity of being underground, for this purpose it has been set an armored and isolated design using SF6. In this type of installation, the advantages in terms of volume and money are essential, but also it will be accounted the low required maintenance and the minimum environmental impact that this type of design permit. The design it will integrate the electrical calculations, the design of the earthing network, the technical characteristics of the equipment, the corresponding plans, the simulation of the installation, and the contrast of the results.

MAIN INDEX

1.INTRODUCTION

INTRODUCCION INDEX

1. INTRODUCTION

The purpose of this project consists on the renewal of the old electric substation at the district of Patraix (Valencia, Spain), as a part of the remodeling of Valencia's electrification. The project will consist on the constructive, technical, design and simulation of an underground substation.

In order to better understand the different parts of the substation and its role in the electric grid:

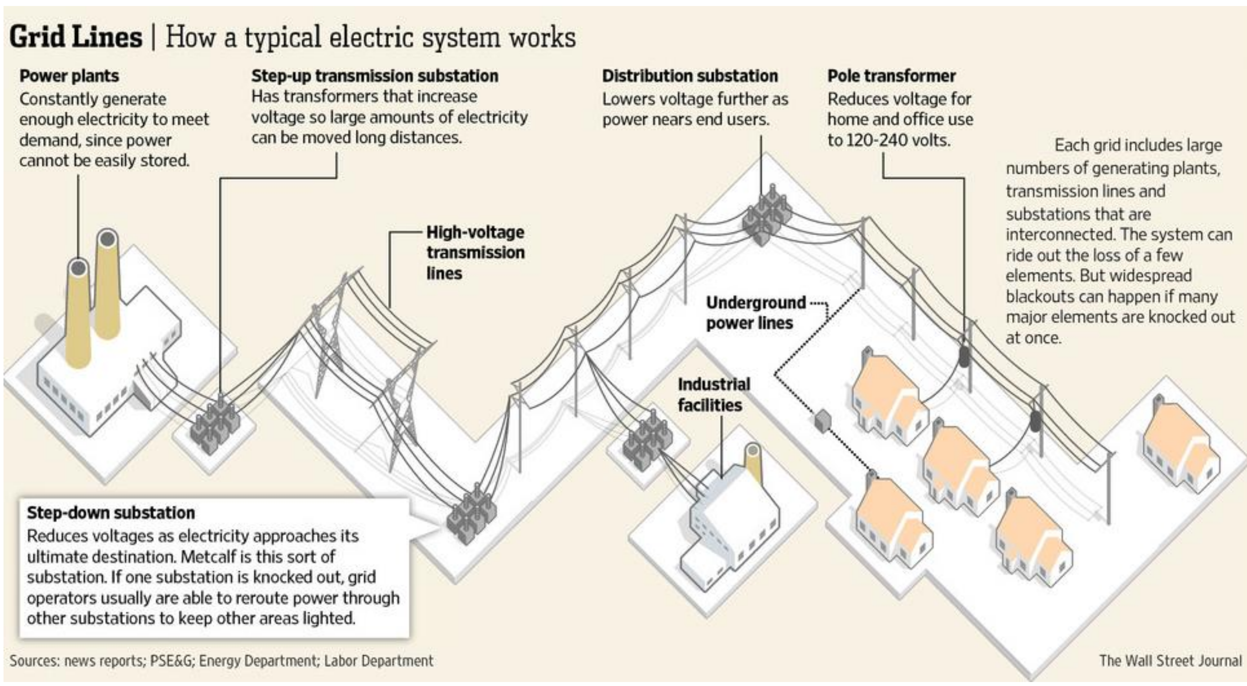


Figure 1.Grid line, source: https://breakingenergy.com

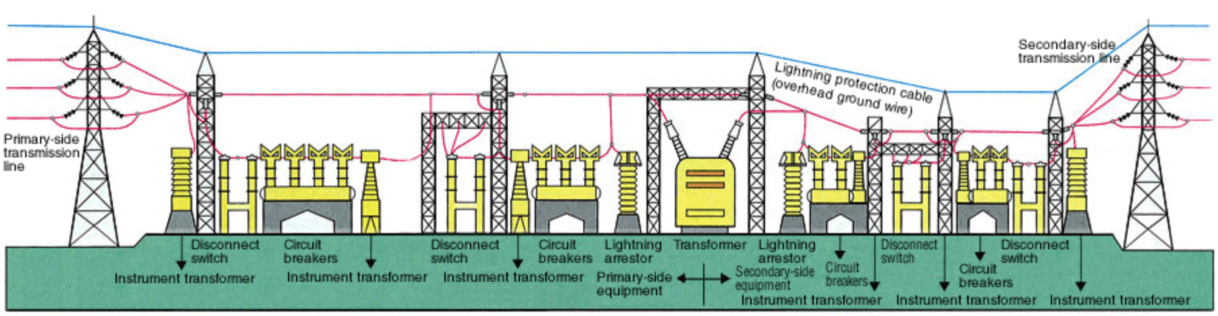


Figure 2.Power station scheme AIS model, source: www.tepco.co.jp

1.1.Main objectives of the project

The main objectives of this project are the following:

- To know all the elements of a GIS technology substation.
- To dimension each of the elements that make up the substation, justifying if appropriate with the relevant calculations.
- To carry out and calculate the earthing.
- To size the protections of the substation and transformers.
- To size the auxiliary services of the substation.
- To model the substation and simulate the model.
- To make the plans corresponding to:
    - Single-line diagrams (General, Auxiliary Systems, Protections).
    - Underground substation (Plant, Sections, Situation).
    - Earthing network.
- To calculate the total cost of what it would be to carry out the substation, through a detailed economic study including all the components of the substation, its unit and global costs.

1.2.Scope of the project

The goal of the substation is the electric supply of the Patraix district and the reinforce of the Valencia electric network. It will be, accomplished the objective by dint of the building of an underground substation.

It will be based on a station of 220/20 kV ratio transformer, with two power transformers of 25 MVA each one. For the bay set up a double bar arrangement it would be chosen, on both sides, high and medium voltage.

The substation will be placed under the circular roundabout of the Cabecera park, between the confluence of Pío Baroja, General Avilés and Bulevar North avenues, and will the subterranean building

Figure 3. Location in maps.

For this purpose, the technology used will be GIS, (Gas Insulated Substations), since the advantages compared to conventional technology are remarkable for the reduction of the necessary space. This space reduction is due to the decrease on the minimum distances between the equipment at the substation. The sulfur hexafluoride gas (SF6), is used in this type of substation as, is an insulator, it allows to shorten the distances between equipment without endangering the physical integrity of these.

The construction will consist on a square building, with a basement for the cables. The edifice will shelter the most powerful systems all over with the necessary equipment, control communication, protection, as well as the cooling system, vigilance equipment or the fire-fighting equipment. The power transformers will be collected together with the refrigeration, of the same ones, that will be forced by means of fan equipment.

The access to the substation will be protected by a security system installed in the main access doors, and since the authorized personnel has different ranges of responsibility, a second security measure will be installed in the access to the control room, leaving the building fully protected against possible intrusions.

2. DESCRIPTIVE MEMORY

DESCRIPTIVE MEMORY INDEX

2. DESCRIPTIVE MEMORY

2.1. Background of the project

As it was previously commented, the target of the current project is to strengthen the city's electrical supply. The construction of the substation is necessary to respond the energy demand of the market, since the current electrical network lies frequently on saturation, specially that sector of the city.

According to the news the investment, to the substation building amounts to 15 million euros, of which 9.41 million correspond to Iberdrola and 5.6 to REE, as reported by the council in a statement.

This new electrical infrastructure will improve the quality of the supply, as well as, will reduce the losses of load of the underground networks of the electrical service of Valencia.

2.2. Justification

The interest of this project lies in the growing need to transport the electric power, with high tensions, to areas with a high population density and industrial centers. This transport poses great difficulties because of the dimensions of the facilities involved. Even if such terrain is found, the official requirements and urban requirements, make it difficult to build.

In relation to the problem of the contamination of the insulators, these conditions lead us more and more to the construction of interior facilities. But the increase in construction costs reinforces the tendency to reduce the dimensions of the installation. Therefore, to solve this problem it should dispose smaller facilities, less sensitive to the atmospheric conditions, which can be installed in a building, exterior or underground, and requiring little maintenance. They must also be silent, not cause radio disturbances and not pose any danger at the surrounding inhabited areas. To provide a solution to these problems, systems are used armored modules with SF_6 insulation.

2.3. Energetic approach

First of all, we should discuss how Spain gets the energy and how to distribute it. If we simplified the energy balance, we can say that the resume of the energy balance is:

- Source: Nuclear 40%, renewable 6% and import 50% energy.
- Destination: 1/3 industry, 1/3 housing 1/3 services.

The keys of the electric network in Valencia are:

- Single generation, wind power plant in Eliana.
- Eliana receives electricity and distributes all the city.
- Torrente, Beniferri, Patraix and Fuente de san Luis are the main substations.
- Fuente San Luis and Patraix are within the city and the radiation is very harmful because they work at 220kV.
- The rest of the substations work at 100 kV, distributed around the city and go to small transformers or other substations.

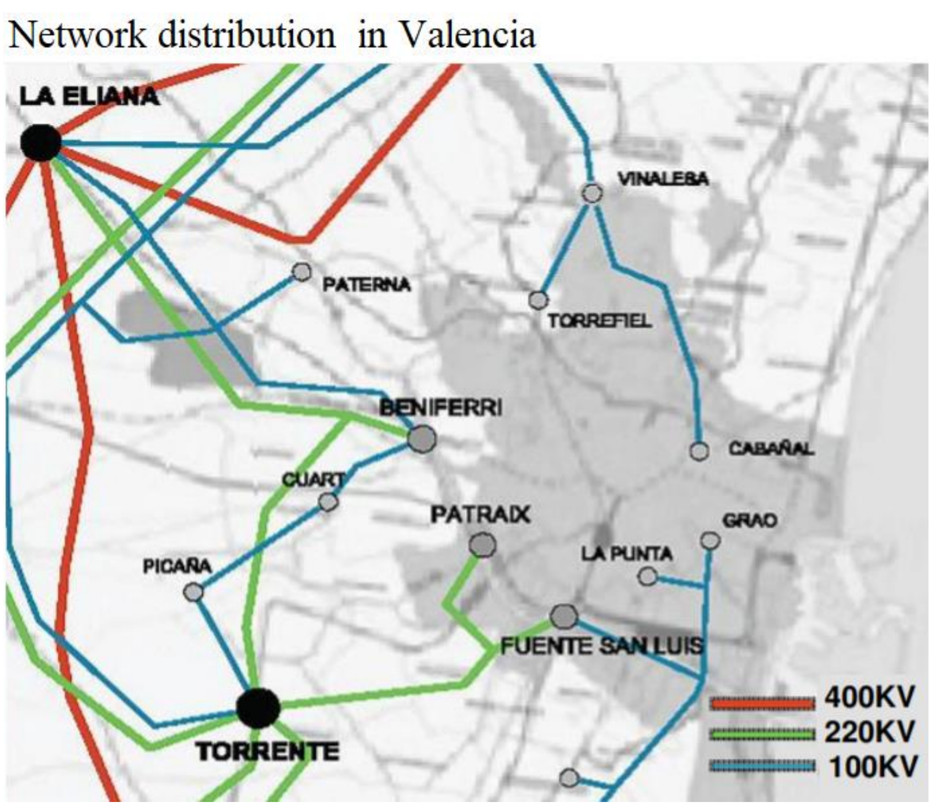


Figure 4. Electric network of Valencia, source: REE Red Eléctrica Española

The urban substations in inner-city areas pose a risk to the population. The electromagnetic radiation can result in risk of diseases such as leukemia, cancer, alzheimer, stress, etc. Scientific studies recommend a safety distance of 1 meter per kilo-volt processed.

The problem in Patraix can be understood from two factors. The first one was the overexploitation of the plant and the vicinity (the electromagnetic radiation depends on the distance) with the population. And the second one was the incident of the plant in May of 2007, when the plant suffered a fire after the explosion of one of the transformers (as the consequence of an over-heat at the insulators).

Figure 5.Vicinity of the substation.

Both factors provoked the rejection of the neighborhood, there was some popular protest against the reopening of the substation, which is why now is currently being translocating towards at the extra-radio.

To sum up, we should impinge on how and why this situation has been reached, and how we should raise the issue. The energy is controlled by Iberdrola, a private company. There is little organization because the state does not regulate it, and so on it is not reflected in the urban plans. Furthermore, there is the problem with the radiation, which exceeds the recommended limits, as in Patraix and the new line under the Turia garden.

Figure 1. A photo of the substation during the explosion.

Logically one of the goals of the state should be the energy equilibrium with the use of renewable energies (biomass, wind, solar energy ...), a new electromagnetic regulation, achieve energy self-sufficiency and turn the Community (Comunidad de Valencia) into an exporter, guarantee the quality of the electricity supply, promote the supply of natural gas, intensify the uses of renewable energies. The government should invest in better solutions for the sustainable development.

Figure 6. Sustainable energies.

2.4. Location

As It has been commented previously it will be located totally underground under the roundabout located at the confluence of the Paseo and Menorca street.

Figure 7. Location of the new network program, and our substation, situated in maps.

The environmental conditions of the site are the following:

• Average height above sea level:	+ 15 m above sea level
• Type of Zone: located less than 500 meters above the sea level	A (According to RLAT) Zone A: The one
• Extreme temperatures:	+ 40º C / + 5º C
• Environmental pollution:	57(ICA = AQI) Medium
• Fog level:	Medium
• Seismic acceleration:	0.06-0.07g (k = 1)

2.5.Holder

The owner of the present installation is Iberdrola.

Figure 8. Iberdrola plate in the Patraix substation.

2.6.Execution deadline

The term for the execution of the work will be three years, from the day when the legal availability is obtained, to proceed with the material occupation of all the necessary land for the execution of the facilities. However, prior to the end of that period, Iberdrola could request a specific extension, by means of a reasoned request, along with the documentation justifying the delay and the new deadline that it would request.

2.7.Standards and regulations

For the preparation of the project have been taken into account compliance with the specifications of the regulations described below and the following rules and decrees, where it will be applicable:

1. Regulation on Power Plants, Substations and Transformation Centers, (CER).
2. High Voltage Electrotechnical Regulation (RLAT).
3. Low Voltage Electrotechnical Regulation, (REBT).
4. Standards approved by the International Electrotechnical Commission (IEC).
5. UNE standards and UNESA recommendations that are applicable.
6. Conditions imposed by the affected public entities.
7. IEEE 80 standards for grounding.
8. Regulation on technical conditions and guarantees of electrical plant safety, substations, transformation centers, and complementary technical instructions.
9. Royal Decree 1316/1989. Protection of workers against noise.
10. Royal Decree 485/1997. Signaling in workplaces.
11. Royal Decree 487/1997. Minimum provision in the handling of loads.
12. Royal Decree 1215/1997. Use of work equipment.
13. Royal Decree 1495/1986. Machine Safety Regulation.
14. Royal Decree 1627/1997. Minimum conditions of safety and health in works of building.
15. Law 31/1995. Occupational Risks Prevention.
16. Royal Decree 97/1997. Regulation of prevention services.
17. General Ordinance on Safety and Hygiene at Work, March 9, 1971, chapter 6 Electricity).
18. Highway code.
19. Safety regulations for work and maneuvers in electrical installations (AMYS).
20. Safety prescriptions for mechanical and diverse works, (AMYS).
21. Basic Plan for Risk Prevention for Contractors Companies, (MODIDYC).

2.8.Conventional electric substation

The conventional substations or also called AIS substations, are those that have their own park, formed by its equipmen, isolated with air.

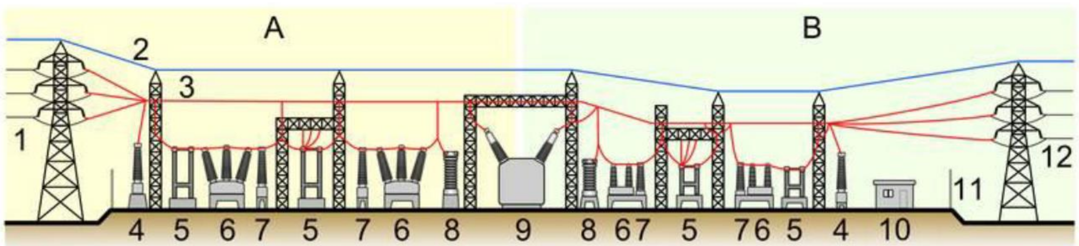


Figure 9. Conventional electric scheme of a substation.

1. Main overhead lines
2. Earthing wind
3. Lying overhead line
4. Tension transformers
5. Isolator
6. Switches
7. Current transformers
8. Self-valves.
9. Power transformers
10. Control building
11. Perimeter fence (for safety).
12. Main overhead lines

Figure 10. Conventional electric substation and underground substation (model by abb).

2.9.GIS and AIS substations

According with the type of its isolated switchgear there is two principal kind of substations: the traditional technology, AIS (air insulated switchgear) which uses air, and GIS (gas insulated switchgear), which uses gas SF_6. There is also a hybrid technology with common characteristics.

The AIS technology is the oldest and traditionally more common. All the switchgear busbars and the lines are isolated by air. Depending on the rated voltage, the switchgear must to respect some safety distances. Moreover, the fact that each part is individual, and it is separated of the remaining material, force to use big extensions of field to its deployment.

In order to save room at the construction, of the substations, appears the GIS technology, where lines and busbars are encapsulated and isolated with $SF_{6.}$ This way the distances can we shorter saving space. Although this technology has other requirements such as the pressure of the gas, the sealing of the room.

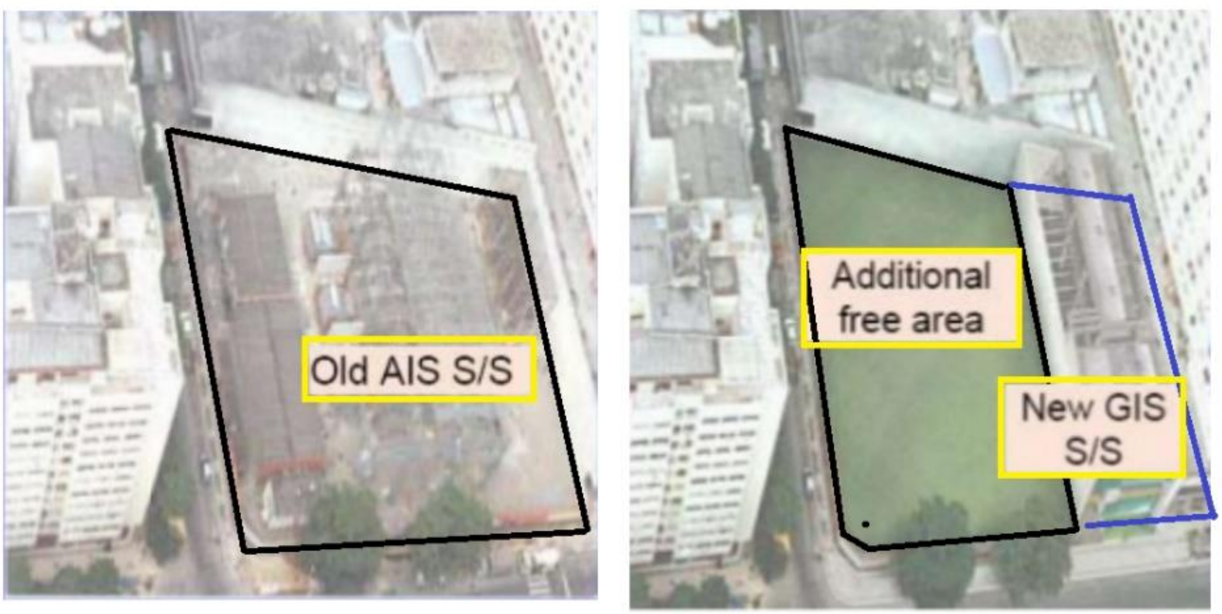


Figure 11. Real example of space use with both models, own montage with a photo of SIEMENS.

2.10. GIS: armoured substations

The armored substations use the same switchgear as the conventional ones, but with a somewhat different design and characteristics. The substation assembly is integrated inside an aluminum envelope filled with SF6, which ensures the isolation. It is the base of the insulation of the armored substations.

The SF6 provides the characteristics that differentiate them from conventional substations, the dielectric resistance in a homogeneous field is about 2.5 times bigger that the air, at the same temperature and pressure. The design of the components under tension is such that produces a distribution of a homogeneous electric field, which leads to a more efficient use of the intrinsic resistance of the insulating gas. The charging pressure is approximately 15% higher than the rated insulation pressure, this guarantees a sufficient gas density over a long period of operation.

To ensure minimum gas loss during operation, all closures, connections and valves are anchors, at the factory, to rigorous gas tightness tests. According to the design, each pole constitutes an individual gas compartment, or all three are under a common armored enclosure. Since the dielectric strength of the switching devices, and the switch breaker power with SF6 depend on the density of the SF6 gas, a relay is installed in each chamber to control the gas density and to detect losses.

For protection against excessive overpressure due to unforeseen faults by internal arc, it has a metallic diaphragm installed (rupture disc). When it reaches a predetermined overpressure, the rupture disk will break, open and release the pressure that would cause the casing to break. Deflectors placed in front of the diaphragm guarantee the safety of the personnel.

Figure 12. GIS model by ABB.

2.11. Underground substations

The urban centers need efficient and reliable electricity, but sometimes there is no room for large electrical installations. Placing the substation underground reduces space and the free surface area can be used for other purposes, such as roundabouts or parks. The purpose of is to provide all the functionality of a conventional substation while minimizing the occupied area. Underground substation enables up to hide around the 95 percent of the volume. However, the cooling conducts and the access routes need to be above ground. The stations are considered environmentally friendly.

Building new transformers or expanding existing facilities is a challenging owing to the lack of acceptance by the resident community, the expense the absence of space. Nevertheless, the finest way of bringing high-voltage electricity straight into the city to guarantee highly reliable power supplies at a reasonable cost.

The substation essential equipment comprises, inter alia of: transformers, gas-insulated, high-voltage switchgear, medium-voltage switchgear, automation, protection and control systems, auxiliary equipment for station services, AC and DC distribution boards, batteries, ventilation and air-conditioning systems, as well as fire protection systems.

Although the stations are ordinarily unmanned, redundant escape routes must be provided on all levels. Switching and transformer noise emissions must be kept inside specified limits. The concept safeguards that urban substations are almost invisible to the public.

Figure 13.Substation underneath of a roundabout, by ABB.

2.12. Modular substations

There are other solutions that in many cases are chosen for their economic qualities of maintenance, space or its rapid assembly and commissioning. These are the following:

Prefabricated substations: Prefabricated substations arise as a simple solution and short implementation time for configurations standards that do not require any characteristics. The most important prefabricated substations are the compact and modular. They use prefabricated modules of integrated connection in each part of the substation, getting a simple and reliable design in the transportation and distribution systems. There are different configurations depending on the voltage level and the required utility. Moreover, it is possible to add other devices for measurement, sectioning or protection of surges. The base is an SF6 switch and the sectioning functions allow voltages from 52 to 245 kV, through removable performance and permit voltages from 300 to 800 kV through a disconnector pantograph. The first ones perform a sectioning displacing the block of the busbar switch, the second has incorporated a classic disconnector.

Another possibility is the integrated modular compact substations, where a specifically designed device performs simultaneously the functions of switch, current transformer and sectioning.

Figure 14. Modular substations, model by ABB.

2.13. Hybrid substations

This type of modular substation has characteristics of both AIS and GIS technologies. The busbars are still isolated in air, but the switchgear is integrated in a single compartment isolated in GIS, this way, a phase of an isolated substation can be compacted in air, in a simple element and much smaller.

A HIS substation requires less than half the space comparable to an AIS, so that the construction is very simple, easy and economical. In the case of new projects, the high land prices and the high complexity of the approval processes, make of space one of the most decisive and costly factors in the planning of a substation.

With the HIS solution, the switches, disconnectors, start-up earthing blades and transformers are housed in compressed gas casings, which makes the substation extremely compact. It can be used for a range of voltages between 72.5 kV and 550 kV, for external service. Each module is consisting of a switch, disconnectors, voltage measuring elements, current and passages. For the design of the switches, the disconnectors and the grounding disconnectors, it is used the armored substation technology. The conventional measurement and protection transformers are replaced by toroidal transformers for the current measurement and the capacitive transformers for the voltage measurement.

Figure 15.HIS model by SIEMENS.

2.14. Mobile substations

It is an easily transportable equipment that includes high voltage mobile park, low voltage mobile park and mobile transformer, normally from 15 to 25 MVA, forming a single functional equipment electrically interconnected to each other. The protection cabinet is usually included for each position, high and low voltage, as well as its own alternating and continuous current supply and at the communication level of, which gives it a characteristic of autonomy that enables its implementation outside the substation.

The applications of mobile substations allow the rapid establishment of service during emergency situations, guaranteeing the continuity of the supply during scheduled maintenance or repairs, and the extensions of conventional substations. Also, they act as support during peaks, allowing to manage the investments depending on the growth rate demand and giving immediate attention during urgent supply request.

Figure 16. Mobile substation by Bluebonnet.

2.15. Parts of the electric substation, its elements

2.15.1. Protection system: relays

Protection relays have the function of disconnect any equipment or part of the system, when this part start to operate in an abnormal way, limiting the damage in other parts of the equipment, by this anomaly, and at the same time, keeping the integrity and stability of the power system. In the electrical equipment we can use different types of relays, such us:

- **Overcurrent relay**, acting when the current is bigger than a rated value, simple and cheap.
- **Differential relay.** They compare the current in two defined points of the equipment, performing when a differential of the current is detected.
- **Distance relay.** It is the most generalized protection. They are fast and permit a bigger operation zone, more sensibility and an easier adjust, than the overcurrent relays. It is based in the impedance measure, so when the impedance is lower than the load then takes action.
- **Switchgear fault protection relay.** These relays check, at short intervals, in the event of the aperture of itself, avoiding faults at opening, closing, low load or of neutral current.

Description	ANSI	IEC 60617	Description	ANSI	IEC 60617
Overspeed relay	12	$\omega >$	Inverse time earth fault overcurrent relay	51G	$I\perp >$
Underspeed relay	14	$\omega <$	Definite time earth fault overcurrent relay	51N	$I\perp >$
Distance relay	21	$Z <$	Voltage restrained/controlled overcurrent relay	51V	$U\nearrow I >$
Overtemperature relay	26	$\theta >$	Power factor relay	55	$\cos\varphi >$
Undervoltage relay	27	$U<$	Overvoltage relay	59	$U>$
Directional overpower relay	32	$\rightarrow P >$	Neutral point displacement relay	59N	$U_{rsd} >$
Underpower relay	37	$P <$	Earth-fault relay	64	$I\perp >$
Undercurrent relay	37	$I <$	Directional overcurrent relay	67	$\rightarrow I >$
Negative sequence relay	46	$I_2 >$	Directional earth fault relay	67N	$\rightarrow I\perp >$
Negative sequence voltage relay	47	$U_2 >$	Phase angle relay	78	$\varphi >$

Figure 17. ANSI & IEC Relay Symbol.

2.15.2. Substation busbar and types of configuration

An electrical bus bar is defined as a conductor used for collecting electric power from the incoming feeders and distributes them to the outgoing feeders. It is a type of electrical junction in which all the incoming and outgoing electrical current meets. Thus, the electrical bus bar collects the electric power at one location.

The bus bar system consists the isolator and the circuit breaker. On the occurrence of a fault, the circuit breaker is tripped off and the faulty section of the busbar is easily disconnected from the circuit. Some different types of electrical busbar arrangements are:

- **Single Bus-Bar Arrangement**. The arrangement of such type of system is very simple and easy. The system has only one bus bar along with the switch. The advantages of single bus bar are the cost, maintenance, and its simplicity. But provide low flexibility and the circuit breaker and isolating switches are used. The isolator disconnects the faulty section of the busbar, hence protects the system from a complete shutdown.
- **Single Bus-Bar Arrangement with Bus Sectionalized.** The circuit breaker and isolating switches are used. The isolator disconnects the faulty section of the busbar, hence protects the system from complete shutdown. The advantages are that the faulty section is removed without affecting the continuity of the supply, the maintenance of the section does not disturb the supply. However, the system uses the additional circuit breaker and isolator which increases the cost of the system.

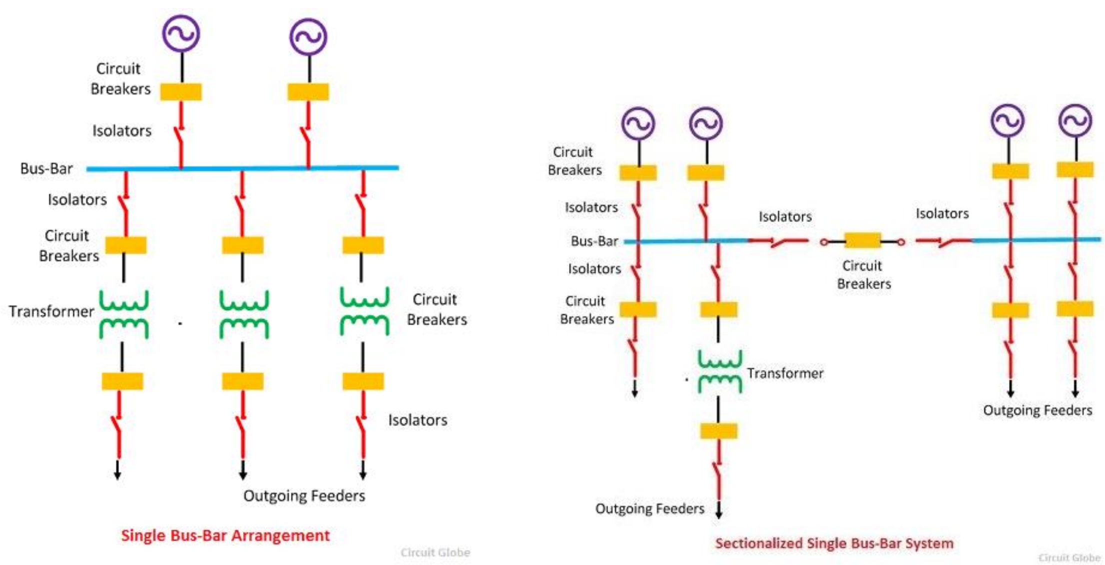


Figure 18. by circuitglobe.com

- **Main and Transfer Bus Arrangement.** The busbar arrangement uses bus coupler which connects the isolating switches and circuit breaker to the busbar. The bus coupler is also used for transferring the load from one bus to another in case of overloading. The continuity of the supply remains same even in the fault. Some advantages are that when the fault occurs on any of the buses the entire load is shifted to another bus, the repair and maintenance are easy and cheap, the potential of the bus is used for the operation of the relay, and the load can easily be shifted on any of the buses. Nevertheless, is expensive and the fault on any of the bus would cause the complete shutdown on the whole substation.
- **Double Bus Double Breaker Arrangement**. This type of arrangement requires two busbars and two circuit breakers. It does not require any additional equipment like bus coupler and switch. The advantages of Double Bus Double Breaker are that this arrangement provides the maximum reliability and flexibility in the supply and the continuity of the supply remains same because the load is transferrable from one bus to another on the occurrence of the fault. And the main disadvantages of double bus Double breaker are the cost of the system, and their maintenance cost is high.

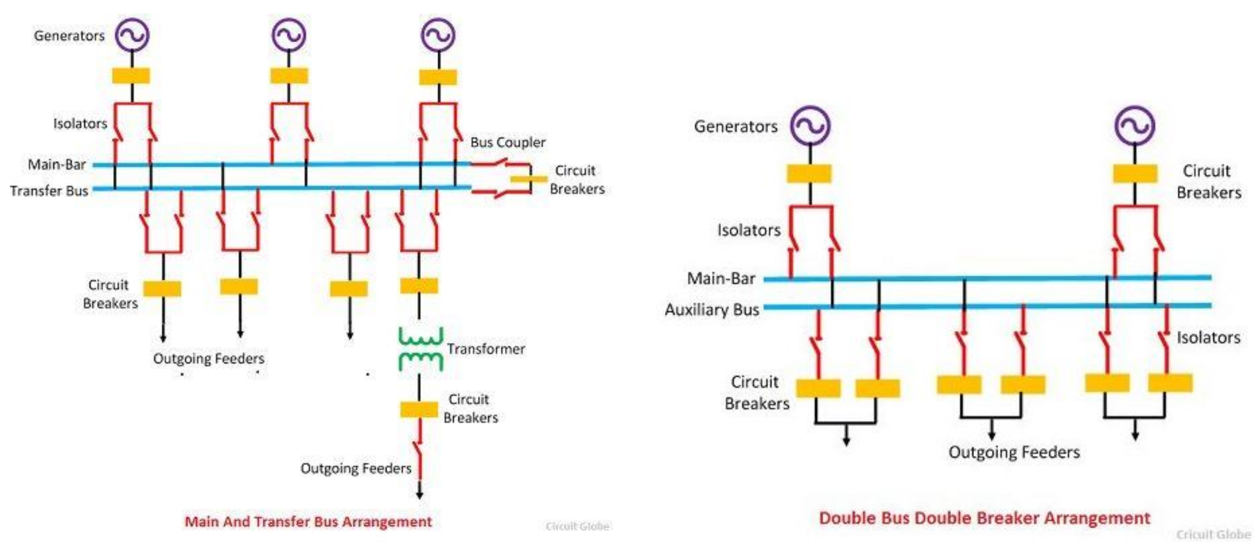


Figure 19. by circuitglobe.com

- **Sectionalized Double Bus Bar Arrangement**. The sectionalized main bus bar is used along with the auxiliary bus bar. Any section of the busbar removes from the circuit for maintenance and it is connected to any of the auxiliary bus bars.
- **One and a Half Breaker Arrangement.** In this arrangement, three circuit breakers are required for two circuits. Each circuit of the bus bar uses the one and a half circuit breaker. Such type of arrangement is preferred in large stations where power handled per circuit is large.

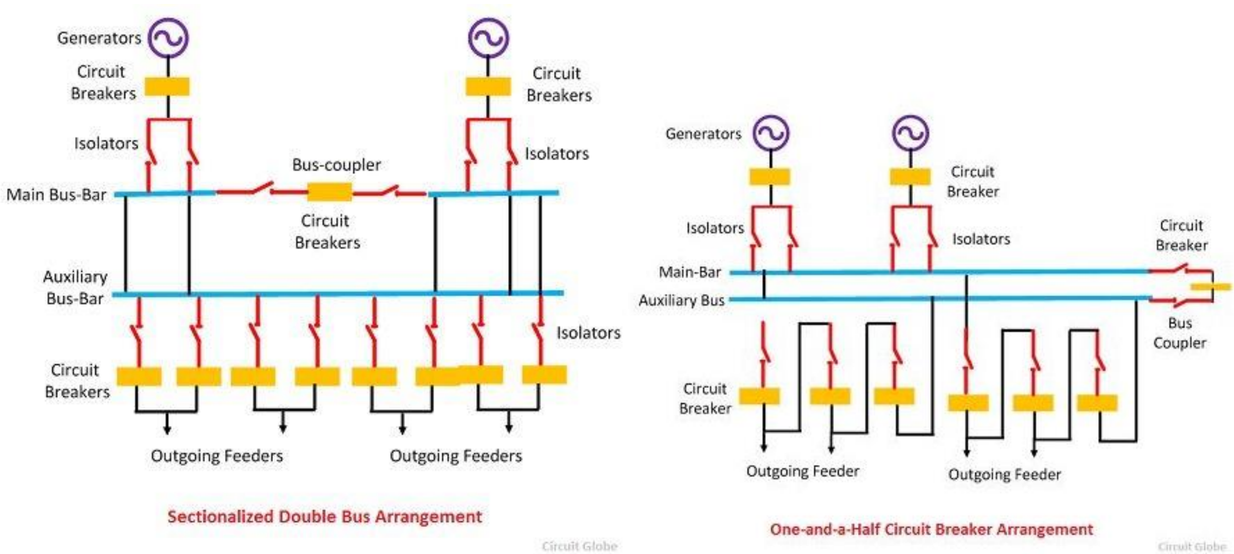


Figure 20. by circuitglobe.com

- **Ring Main Arrangement.** In such type of arrangement, the end of the bus bar is connected back to the starting point of the bus to form a ring. The advantages are that can provide two paths for the supply. Thus, the fault will not affect their working. The fault is localized for the particular section, the whole circuit is not affected by the fault. The circuit breaker can be maintained without interrupting the supply. On the other hand, some difficulties occur with the addition of the new circuit, and overloading occurs on the system if any of the circuit breakers is opened.

- **Mesh Arrangement**. In such type of arrangement, the circuit breakers are installed in the mesh formed by the buses. The circuit is tapped from the node point of the mesh. Such type of bus arrangement is controlled by four circuit breakers. When a fault occurs on any section, two circuit breakers must open, resulting in the opening of the mesh. Such type of arrangement provides security against bus-bar fault but lacks switching facility. It is preferred for substations having many circuits.

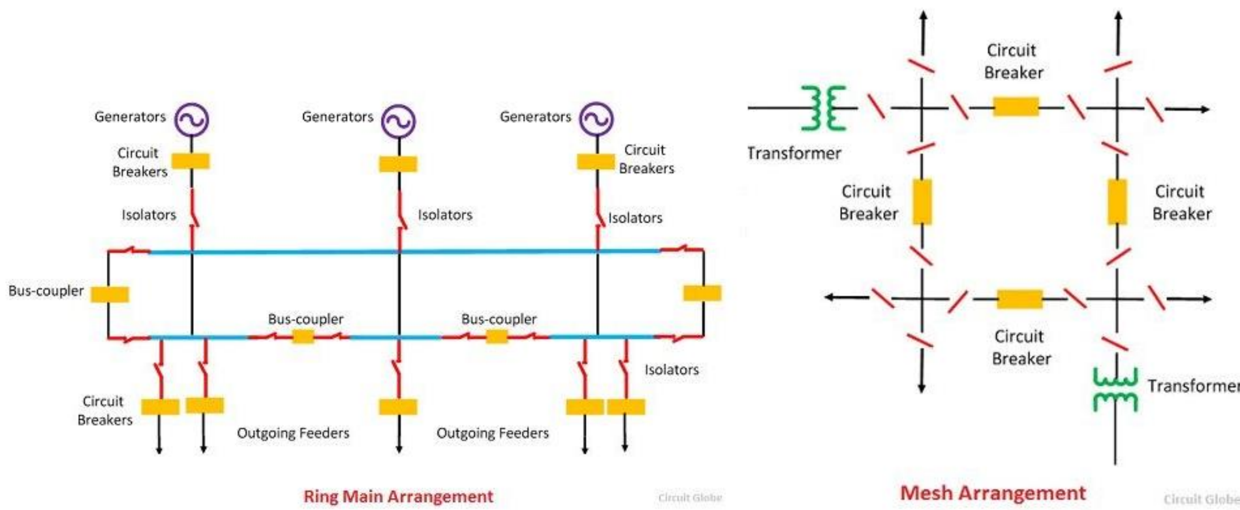


Illustration 1. Busbars arrangements.

2.15.3. Switches

These are the elements whose function is to open or close a circuit, in normal operating conditions or in the case of faults and short circuits when the intensity is between 30 and 50 times its rated intensity in continuous service.

Consequently, the most important factor is the power of short circuit (at the point of installation) to be protected, and not the rated intensity that will hold in normal operating mode. Another significant factor to select the switch, is the duration of the fault. The bigger the short-circuit, the greater thermal and electrodynamic stress affecting our switch, so the duration of the arc extinction in our switch It will be decisive.

The closing and opening contacts of the switch are confined inside of a camera that, among other functions, collects an atmosphere that depending on the type is classified in:

- **Air breaker:** Only used in medium voltage due to the low dielectric properties of air. The principle on operation is based on the magnetic blowout leads the arch to an elongation which reduce its dielectric rigidity and provokes its extinction.
- **Large volume of oil:** This type of switch is no longer manufactured due to the its elevated size, but they are still operating in some old substations. These switches consist of a large container of oil in which two pairs of contacts, per phase, have been arranged. In the vessel circulates the arc during its extinction process, and due to the characteristics of the oil and to the pressure that is created, it is incite the elimination of the arc caused by the short circuit.
- **Small volume of oil:** It is the evolution of the previous type with minor dimensions. This type of device consists of a manufactured disconnection chamber of insulating material. Inside of which it evaporates a small volume of oil, increasing the required pressure for the blowing out of the arch.
- **No-load breaker:** It is only applicable in medium voltage. With this method you get a rapid extinction of the arc which facilitates the evacuation of ionized molecules, allowing the disconnection with petite separation between the contacts. The maintenance will be limited since there is no element that becomes carbonized during a short circuit, like oil, and therefore could leave any residues throughout its decomposition.

In order to maneuver the contacts with the required high speed, different drive systems are used, such as (springs, hydraulic, pneumatic, etc.).

The initiating elements of the opening and closing maneuvers are generally coils, which release the locking arm when it is energized by an auxiliary voltage, normally 125 V DC

According to whether the closing and opening maneuver is independent for each pole, or common to the three poles, the switches are classified into unipolar or tripolar.

The closing and firing coils, together with the spring tensioning motors, auxiliary contacts of the switch, alarm contacts, are housed in the cabinets of the control switch.

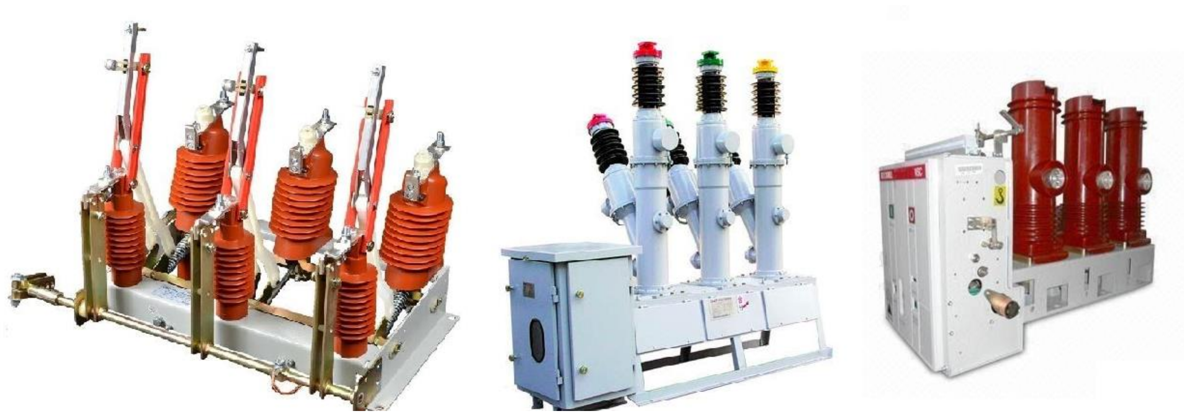


Figure 21. Air, oil and no-load switches, by electricaplicada.com

2.15.4. Disconnectors

The disconnectors have as mission to isolate sections of the circuit of a substation in a visible way, so it provides full security, at the time of maneuver with the circuit, before a possible maintenance, substitution or inspection tasks. These do not have a breaker chamber, so they cannot maneuver under load, they can only be opened with the assurance that no current circulates in them. Although in closed operating position, they must withstand rated currents of circuits and overcurrents or short-circuit currents for a specified time.

Since they do not maneuver under load, nor are speed restrictions during the of maneuver, its construction is very simple, being limited to conductive blades that connect or interrupt the circuit. The blades are supported on insulators and manually operated or by an electric motor. The motor and the driving crank, together with the auxiliary contacts are included in a control cabinet that is located at an accessible height for the operator.

Since the disconnector must be placed at a higher height for reasons of security, it is necessary to install a mechanical coupling mechanism between the cabinet and the blades. The disconnectors can be unipolar or tripolar according whether the maneuver of the three poles is independent or simultaneous.

There are multiple constructive solutions of disconnectors, for a determined rated voltage and current, being possible to distinguish the following types:

- **Rotating blades disconnectors:** The constitution of these elements is very simple, consisting of a base or rigid metal frame (where are supported the rest of the elements), two insulators or porcelain supports, a fixed contact (or contact clip), and a mobile contact or rotating blade (these two last elements mounted on each one of the porcelain insulators).
- **Sliding blade disconnectors**: With a similar structure to that of the rotating blades disconnectors described above, they have the advantage of requiring less space in their maneuvers since the blades move longitudinally, so it can be installed in narrower places. However, given their type of blade displacement, these disconnectors have a disconnection capacity 70% lower than the previous ones.
- **Central rotating column disconnectors:** This type of disconnector is used in outdoor substations with a higher voltage than 30kV. It consists of three columns located on the same plane. The two exterior columns are rigidly mounted on a metal support, of laminated profiles, and they are the responsible for holding the fixed contacts. The central column is responsible for opening or closing the circuit by a rotary movement on its own axis. This rotation will be activated through rods or controlled mechanisms of its cabinet, located in the metallic base at a manageable height for the operator.

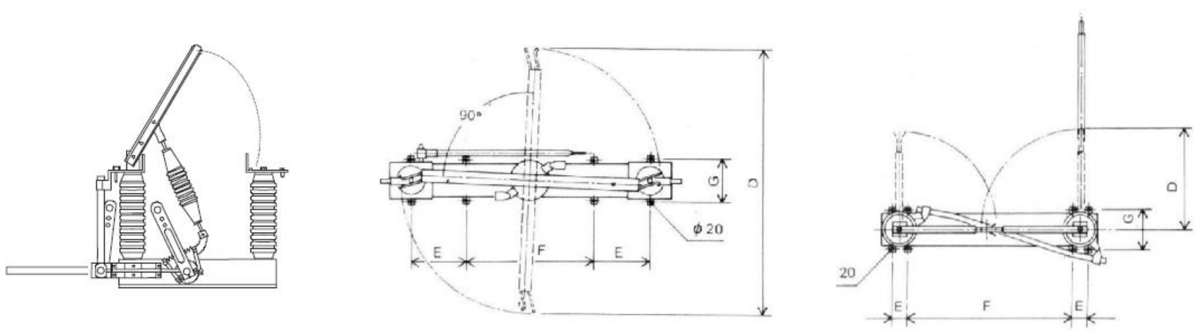


Figure 22.Sliding and rotating disconnectors by google images.

- **Disconnectors with two rotating columns:** The disconnector has two rotating columns instead of three like the central rotating column model, being these two rotating columns and carriers of solidarity blades, which rotate towards the same side. In this case you get a single break point at the halfway between the two columns. The field of application of this disconnector is in outdoor installations with service voltages up to 110 kV.

- **Pantograph disconnectors:** The blade is replaced by a pantograph system supported on a single column of insulators. The "closed" position is achieved by the lengthening of the pantograph until it reaches the conductor to which the disconnector is connected. The opening is produced by the retracting of the pantograph to its initial position. These disconnectors are available for service voltages between 132 and 400 kV.

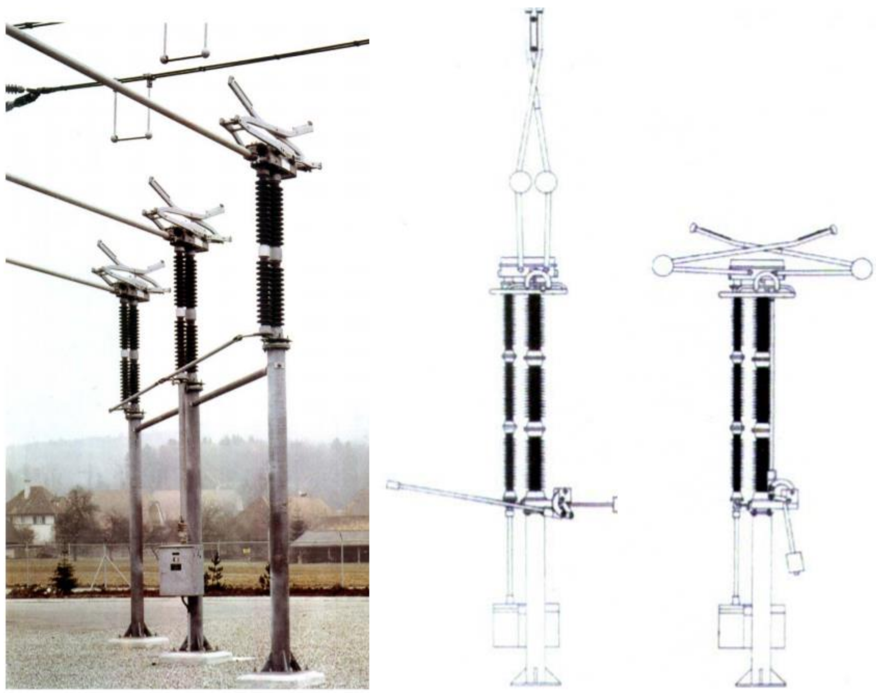


Figure 23. Pantograph disconnector by frlp.utn.edu.ar.

2.15.5. Measuring transformers

In order to control the energy exchanges in the electrical system, it is necessary to continuously measure the electrical state in a large number of points its electric state of those points on the network.

In the practice, the instantaneously and simultaneous vector measurement (module, direction and sense) of the tension and the current, defines the electrical state of a point in the system. In fact, it is measured at the output of each of the power plants and at each point of consumption, in addition to the entry and exit of each of the lines that converge in each transformer and distribution substation.

These measures have an economic objective, knowing exactly how much each company generates and how much each client consumes (being sometimes some client companies of others, according to what generating plants are in operation) for billing purposes.

There is also another point, because it must pay attention to not overload the lines, the failures that occur in the network and to optimize the generation and distribution, making them possible in the most economical and safe way.

The measurement transformers are specially designed to measure, they are electrical machines equipped with a primary and secondary taking advantage of the electromagnetic properties of alternating current to transform power.

The function of a measurement transformer is to provide accurate inputs to the protection, control and measurement systems, including the fiscal measurement. These functions require a high degree of accuracy and reliability of the measurement transformers, to guaranteeing the correct operation of the protection systems and the accurate measurement.

As with all transformers, the measuring transformer must be isolate and conveniently separate circuits from each other and from the outside. So, the primary and secondary windings must be isolated each loop of the next so when the current crosses them neatly one after the other and not all at once. In the case of copper wires, with a continuous coating of insulating enamel, we already have a first insulation between turns that will then be reinforced with successive layers of paper. If not, it would be necessary to proceed to its isolation, as it is done in the case of strips and nude tapes that are isolated with covers. The paper impregnated with insulating gas SF6 or oil is much better insulator than paper only.

To isolate one winding from another one also resorts to impregnated paper or resin in some cases. This same type of isolation is given to the nucleus with respect to each one of the windings. The insulation of the device against the environment is achieved with oil and porcelain in outdoor and resin-based epoxide in the internal service. Some outdoor devices are insulated in resin cycloaliphatic

The form and quality of insulation depends in each case on multiple factors, being the principal the value of the voltage that exists between the two extremes to be isolated. In this case it should be kept in mind that the relationship between insulator thickness and applied voltage is not linear, so it is not true that at double voltage applied double thickness of insulator to interpose, but we will have to stick to what in each case corresponds to the dielectric nature.

Within the measurement transformers we can distinguish in:

- **Current transformers:** The current transformer is intended to provide on a much smaller scale, in the secondary, a proportional magnitude of the current that passes through the primary. It is a through-line transformer, where the current passes through the toroidal core where it is transformed into the secondary current. The current is measured by inserting the measuring device into the same point of the line where you want to measure. So, the intensity that goes through the line crosses the whole amperometric measuring device. The transformers have two primary terminals, the electrical resistance between these two terminals is always very small, so under normal conditions the potential difference between them is negligible, of the order of mV.

  The primary can pass one or more times through the nucleus according to whether the intensity is enough to magnetize him.

  The secondary can be used for different uses such as for the measurement of current in quantities close to the rated. At high values it reaches the saturation and for low values lose precision. They are used as a measure of different magnitudes of current in the installation. Another use is the protection, this is a secondary designed to measure, with precision, high currents (up to about twenty times the rated), depending on the model, without variation of the precision. On the contrary, to low power measurements for lacks of precision. That is why it is used for protections intended for detecting overcurrents and derivatives from them. The secondary can be assigned to the fiscal measure, where the secondary is similar to the measurement but with an iron core that confer it, greater precision, the ability to maintain this for much lower compared to normal measurement. They are used to give signal to the charging equipment.

- **Inductive voltage transformers:** The voltage transformers are connected between two points to different potential between each other. These two points are both at different potential than earth, or one of them is directly grounded. We call the first type V and the second type U. From the constructive and electrical point of view the more rational are the U-type voltage transformers, but in certain three-phase measures can be performed using two type V voltage transformers instead of three type U, which gives those some economic advantage. However, from at 52 kV it is very rare to find type V voltage transformers.

  Voltage transformers normally carry a single core on in which they are rolled tightly between one and three secondaries and one primary. The secondaries have the order of hundreds of turns and between their ends are measured hundreds of volts. Regarding to earth, they should be isolated at 3 or 4 kV. Unlike the current transformers, voltage transformers do not require a different magnetic core for each secondary, so you can associate several windings to the same core.

  In U-type apparatus, the core and one of the edges of each one of the windings are rigidly grounded, just like all other metallic parts of the device. However, with the V-type, in the primary, each one of the ends of this one is isolated from the other to the rated voltage of the network.

  In the voltage transformers rectangular cores, of two columns are used, sometimes due to space problems, armored cores. The electromagnetic characteristics of these cores are inferior to those of the toroidal cores used in the current transformers, due to the air gaps and inserts between plates

  The inductive voltage transformers support minor voltages that the capacitive voltage transformers, but provide better results in the field of precision, so they are usually preferred for measurement.

- **Capacitive voltage transformers:** They were devised from the possibility of reducing voltages by another method than electromagnetic. For this, it was thought of connecting several capacitors in series, and applying one determined voltage between the first and the last, each of them remaining charged to a partial voltage, proportional to its capacity. The sum of all the partial stresses will obviously be the total. Being all the capacitors of equal capacity, we get a capacitive divider.

  The capacitive voltage transformer includes a column of capacitors with an intermediate voltage tap, that is, a capacitive divider and an inductive voltage transformer, which is connected to the outlet. That socket is chosen at a voltage such that, the inductive voltage transformer could be of economic construction.

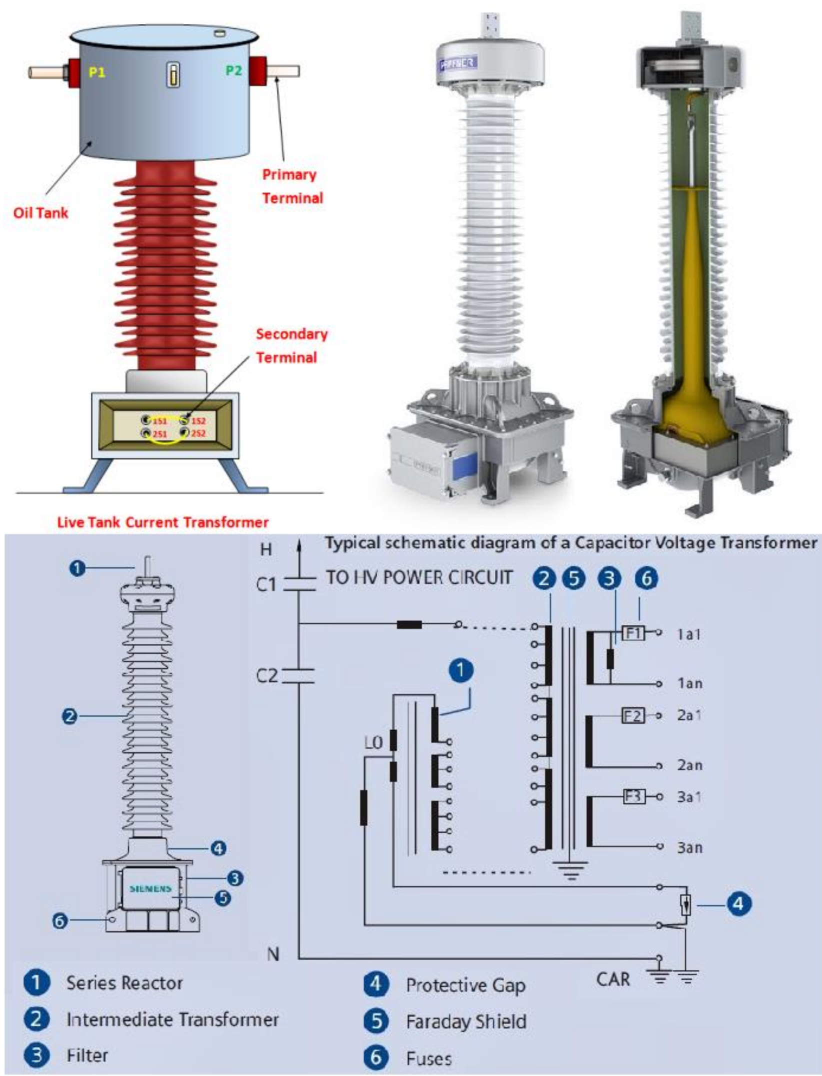


Figure 24. Measurement transformers by studyelectrical.com

2.15.6. Lightning Arresters or lightning rods

These are electrical devices formed by groups of non-linear resistive elements and blasting devices that limit the amplitude of the overvoltage caused by atmospheric discharges, operation of switches or power oscillations. An effective protection device should have three main characteristics:

- To behave as an insulator while the applied voltage does not exceed a certain default value.
- To become a driver when the voltage reaches that value.
- To earth the current wave produced by the surge wave.

Once the overvoltage has disappeared and the normal voltage has been restored, the protective device must be able to interrupt the current. The lightning rods comply with the following functions:

- To download surges when their magnitude reaches the value of the disruptive designed voltage.
- To earth the discharge currents produced by the surges.
- The discharge currents must disappear when the surges disappear.
- They must not operate with temporary, low frequency overvoltages.
- The residual voltage must be less than the voltage that the devices that they protect.

The lightning rods must be permanently connected to the circuits that they protect and start operating at the moment when the overvoltage reaches an approved value, higher than the maximum voltage of the system. During an overvoltage, the gaps of the air gaps are produced, and the resulting current is limited by the resistances to small values, until in one of the times that the current wave passes through zero, then the blasters interrupt the current finally.

It is observed that once the shockwave starts it starts to grow reaching a point where the air gap, of the blaster, starts to ionize and continue increasing the voltage until reaches a certain potential value, at the moment when the arc between the terminals of the blaster is produced. On the other hand, during the download of the overvoltage in the non-linear resistance, a current flow with a maximum value of current that fixes the maximum discharge capacity of energy through the lightning rod, without it suffering any deterioration.

When lightning rods must also limit the overvoltages that cause the operation of switches, the blusters include a magnetic blowing that fulfills two functions, extinguishes the formed arc faster, and it opposes greater resistance to re-ignitions.

Figure 25. Lightning Arrester by indiamart.com.

2.15.7. Line traps

The blocking coils are elements that may be present in a High voltage park. These elements will be necessary when the substation has a communication system known as PLC (Power Line Carrier).

The blocking coils are therefore a high voltage element but in fact, they are part of the communication system. The PLC system is a communication system that takes advantage of the high-voltage connection line, that connects two substations, to establish a link and perform the exchange of data and signals. The system makes use of the same high-voltage line for the transmission of teleprotection, voice and data. The system generally uses frequencies in the range of 30 to 500 kHz. The high voltage line PLC is formed by the following equipment:

- Blocking coil.
- Coupling Capacitors.
- Coupling Unit.
- High Frequency Cable
- PLC terminal.

The blocking coils are connected in series in the high voltage lines. Its impedance must be negligible at the industrial frequency in such a way that it does not disturb the energy transmission, but it must be relatively high for any band of frequency used for communication by PLC.

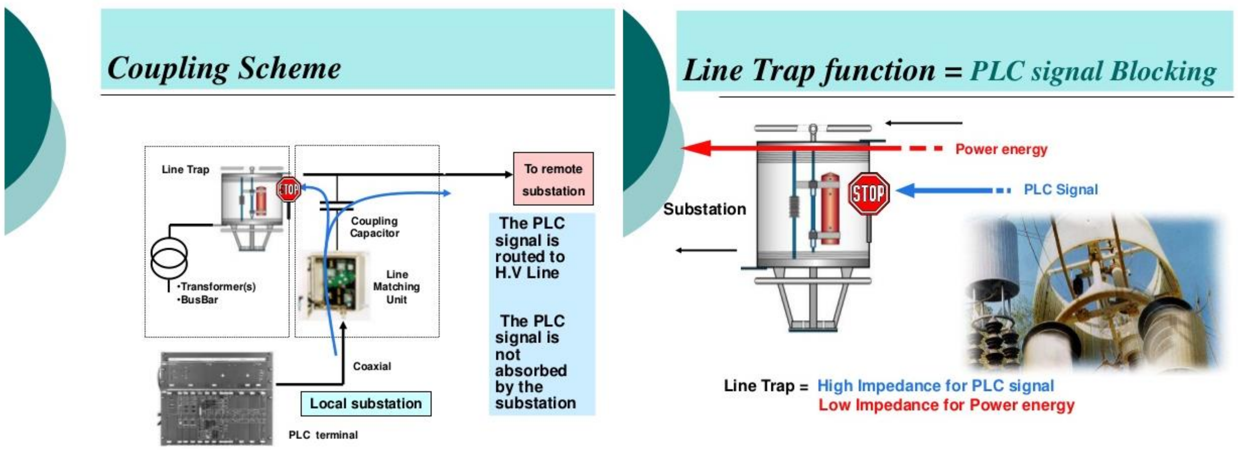


Figure 26. Way of operation and scheme by: slideshare.net/vishu_angira/power-line-carrier-communication-plcc.

The blocking coils basically consist of a main coil with a protective element and usually one of tuning. The main coil is an inductance, which allows the passage of the industrial frequency current of the transmission line or circuit, while the protective equipment protects the coil against possible transient overvoltages.

The tuning equipment serves to obtain a relatively high impedance for one or more frequencies or frequency bands and thus prevent their passage into the substation, decoupling it from the carrier wave.

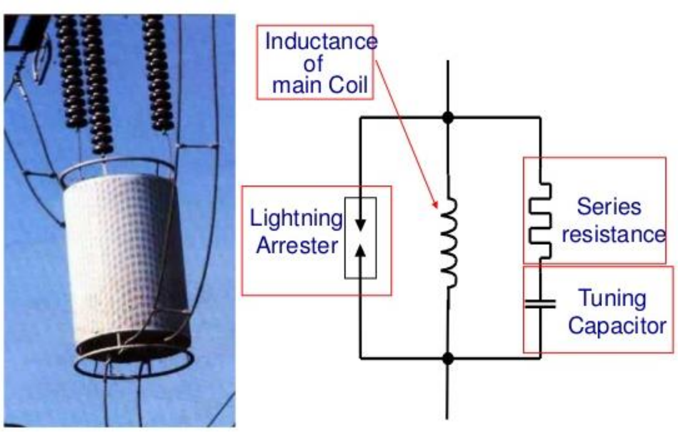


Figure 27. Source Vishwesh Sharma slides.

2.16. General outline

The substation will be GIS type with a double bar configuration in the high and medium voltage. In the HV with transversal coupling, and longitudinal and transversal coupling in MV. The substation will be constituted by an underground building of two floors, its dimensions are 60 x 60 m. The second floor is the basement that will house the cables for the connection between cells and the arrival of the lines, with a free height of 2.5m. The GIS cell room will have a free height of about 6.5 m above the level of the floor.

At one end of the building there will be a Control Room where will locate the control equipment, protections, measurement, communications and the cabins and electrical panels for the powering of the auxiliary systems.

In the cell area of the 220 kV GIS, the power and control cables instrumentation will run through ditches made in the ground of the main floor by ladder trays (cable ladder systems).

Two rooms will be available for the exclusive use of transformers where only these and their refrigeration equipment will be disposed.

Below the floor, of the rooms of the transformers, it will assemble a tramex grid to facilitate the transit of the workers in their assemblage and maintenance,

In the control and auxiliary services rooms, it will be installed a false floor with the ladder trays for the power, control and instrumentation cables. In addition, the control room will have an air conditioning system.

Additionally, the building will be equipped with the necessary auxiliary facilities, such as lighting, sockets, fire-fighting system and anti-intrusion system.

2.17. Analisys of the topology

As general criteria to design the substation layout, for the electrical topology of the installation, it will be considered:

- Installation costs: Which is it influenced by the number of switches per circuit, the number of disconnectors, and the switchgear to measure and control the substation.

- Ease of operation and maneuver: The possibilities to interconnect circuits, and a possible ampliation for the future.

- Reliability, analyzing the continuity of the service during contingencies, such as: Circuit failure, bus bar failures, switch maintenance or circuit breaker failure.

2.18. High voltage configuration 220 kV system:

For our configuration we have chosen the double bar electric topology, it is a set of two main bars where in each position of the circuit it has two bar disconnectors to allow the connection of a part of the circuit to either of the two bars.

It also has a bus coupling switch, whose mission is to allow the transfer of a circuit from one bar to the other maintaining the voltage of it, thanks to the action of the bar disconnectors.

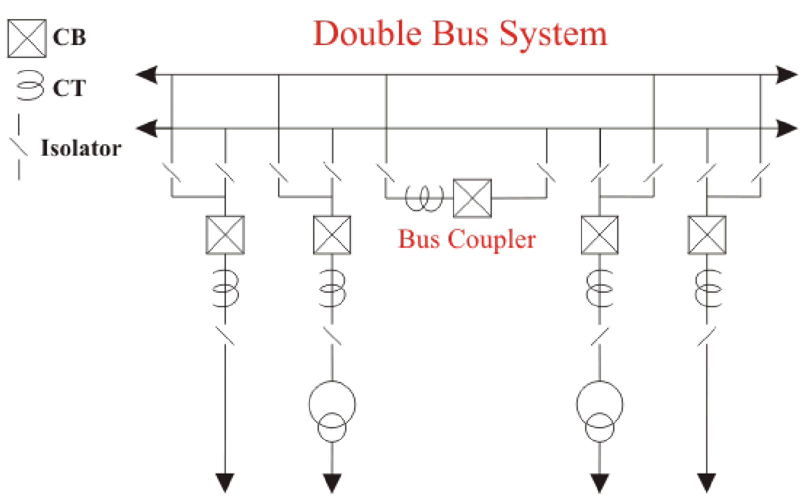


Figure 28.https://www.electrical4u.com/electrical-bus-system-and-electrical-substation-layout/

It will be taken into account the adjustment of the needed protections with a high level of sensitivity, in order to avoid the complete shutdown of the substation during a fault.

Then we can make an analysis of the configuration based on the criteria of the previous design:

- Installation costs. The total cost of this provision is relatively high. Each position consists of at least four disconnectors. In addition, it is the coupling switch will be necessary.

- Ease of operation and maneuver. This scheme allows flexibility in the operation of the substation. The two bars can act in as independent, which allows to isolate any of the bars without giving discharge in any of the positions. On the other hand, it is possible to extend the substation without altering initial the scheme.

- Reliability. With short circuits in any of the positions, it allows to isolate the defect in one of the bars without stopping the whole substation In these circumstances, however, if a fault occur again in any of the healthy positions, the substation will be out of service.

From the previous analysis it is clear that this provision is adequate to substations with medium responsibility, and therefore, it suits the characteristics of a distribution substation.

2.19. Medium voltage configuration 20 kV system.

A similar configuration to the double bar will be used, although in this case, the flexibility of exploitation it is improved. Each line position can be connected to any of the two bars. As a novelty, there are switches for the transverse coupling on the bars, allowing electrical separation of the circuits connected to each one of the half-bars. In this way, we have 4 independent bars, maximizing the maneuverability of the installation.

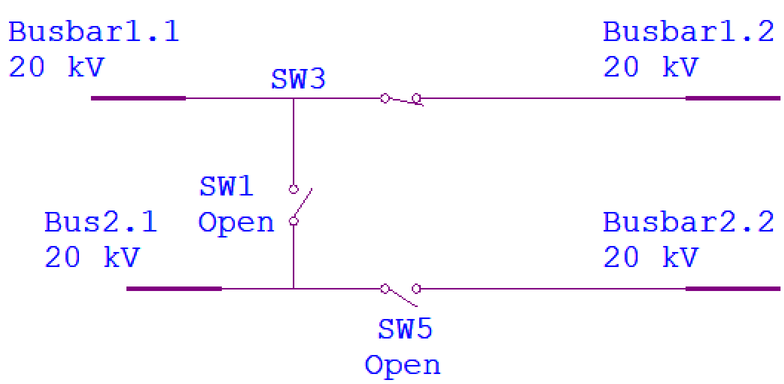


Figure 29. Busbar set up (ETAP simulation.)

2.20. Wonted configuration at operation

The following figure shows the usual way of exploiting the installation. It should be noted that under normal conditions, the transformers supply in different bars of the distribution network, getting this way to reduce the risk of propagation of faults to the entire distribution network.

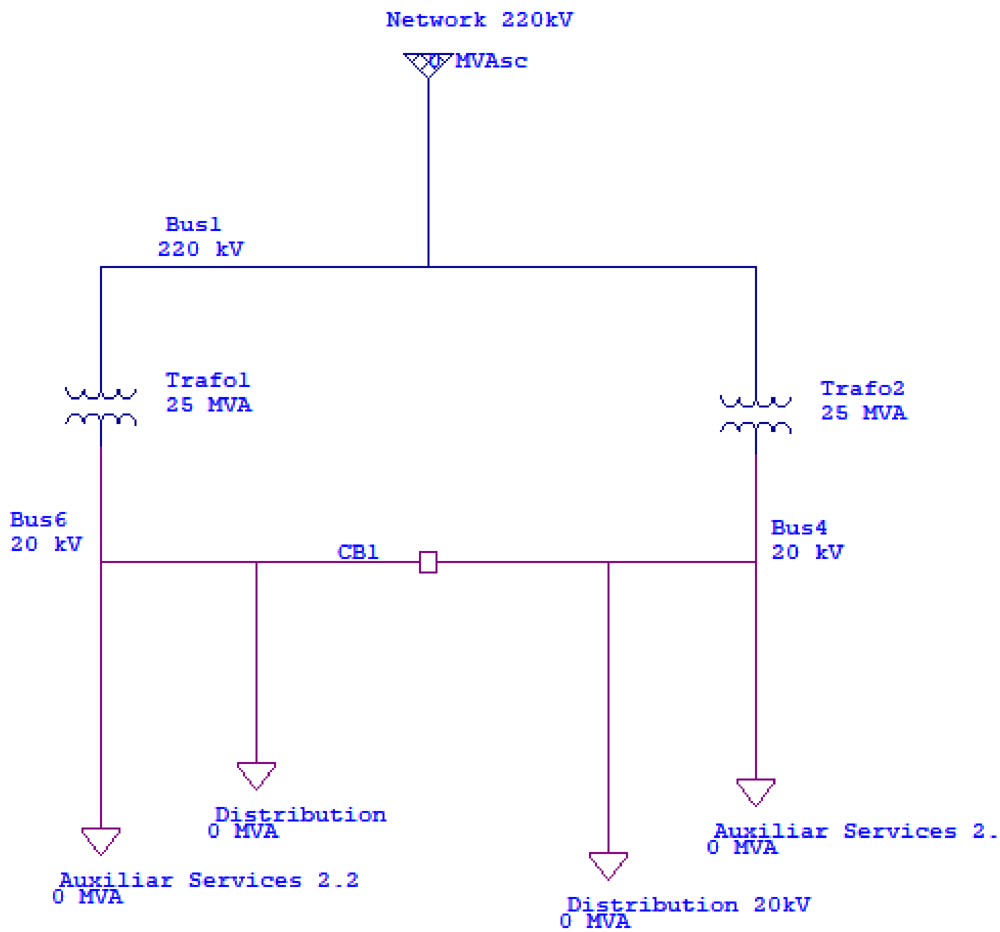


Figure 30. Normal functioning (simulated in ETAP).

3.SETUP AND INSTALLATION FEATURES

INDEX: SETUP AND INSTALLATION FEATURES

3. SETUP AND INSTALLATION FEATURES

3.1. Equipment at HV:

- Four (4) line positions, which collect each line corresponding to the substations interconnected with ours and Parque Central, Alameda, Fuente de San Luis I, Fuente de San Luis II.
- Two (2) transformer positions.
- One (1) coupling position.
- One (1) measuring position with the earthing of the bars.

After the GIS cells we it can be found the power transformers.

3.2. Transformers, from HV to MV, and from MV to LV.

- Two (2) transformers with load regulation of transformation ratio 220 ± 9x1.5% / 20 kV, 25 MVA, ONAF.
- Two (2) transformers with load regulation of transformation ratio 20 kV/ 400 V, 630 kV.

3.3. Equipment at MV:

There are 22 positions, each one corresponds to a different cell, we can distinguish:

- Thirty-two (10) line positions.
- Two (2) transformer positions.
- Two (2) auxiliary transformer positions.
- Two (2) transversal coupling positions.
- Two (2) longitudinal coupling position.
- Two (2) line positions for capacitor banks
- Two (2) measurement positions.

In addition to the cells of high and medium voltage the following equipment will be installed at the substation:

- The control equipment and protections for control, protection, signaling and command at the local level.
- The necessary equipment for control, protection and supervision of the substation through a centralized system.
- Transmission and communications equipment with the maneuver room with the room control of the substation.
- Equipment auxiliary services.
- Capacitor batteries.

3.4. Detailed description of the HV equipment:

It details the equipment that it will be installed in the cells according to the functionality of each one within the substation:

3.4.1. Line cell (4):

- One (1) three-pole switch, 1250 A, 50 kA, encapsulated in SF6 including the support structure, manufactured and tested according to IEC 62271-100.
- One (1) current transformer per phase, consisting of four secondaries each one, 1000 / 5-5-5-5, of them three will be destined to protection 30 VA 5P20, another destined to measurement and invoicing 20VA, cl. 0.2, encapsulated in SF6, manufactured and tested according to IEC 60044-1.
- One (1) voltage transformer per phase, consisting of three secondaries, $(220/\sqrt{3})$ / $(0.11/\sqrt{3})$, $\frac{0.11}{\sqrt{3}}, \frac{0.11}{\sqrt{3}}$ kV, 1º secondary intended for and 20 VA billing, cl.0.2 and 2º and third 3º for protection 30 VA, 3P, encapsulated in SF6, manufactured and tested according to IEC60044-2.
- Two (2) three-phase disconnectors encapsulated in SF6, including supporting structures, manufactured and tested according to IEC 62271-102.
- Two (2) three phase earthing disconnectors encapsulated in SF6, manufactured and tested according to IEC 62271-102.

3.4.2. Transformer cell (2):

- One (1) three-pole switch, 1250 A, 50 kA, encapsulated in SF6, including the supporting structure, manufactured and tested according to IEC 62271-100.
- One (1) current transformer per phase, each one consisting of four secondaries, 800/5-5-5-5, three will be destined to protection 30 VA, 5P20, one will measure and bill 10VA, cl 0.2, encapsulated in SF6, manufactured and tested according to IEC 60044-1.
- Two (2) three-phase disconnectors encapsulated in SF6, including supporting structures, manufactured and tested according to IEC 62271-102.
- Two (2) three phase earthing disconnectors encapsulated in SF6, manufactured and tested according to IEC 62271-102.

3.4.3. Measurement Cell (1):

- Two (2) voltage transformer, one per bar and per phase, consisting of three secondaries, $(220/\sqrt{3})$ / $(0.11/\sqrt{3},, \frac{0.11}{\sqrt{3}}, \frac{0.11}{\sqrt{3}}$ kV, the first to measure 30 VA, cl. 0.5, the second and third to protect 50 VA, 3P. Encapsulated in SF6, manufactured and tested according to IEC 60044-2.
- Two (2) three-phase to earth disconnectors encapsulated in SF6, one per bar, manufactured and tested according to IEC 62271-102.

3.4.4. Coupling cell (1):

- One (1) three-pole switch, 2000 A, 50 kA, encapsulated in SF6, including supporting structure, manufactured and tested according to IEC 62271-100.
- One (1) current transformer per phase, each one consisting of four secondary, 3000 / 5-5-5-5, of which three will be destined to protection 30 VA, 5P20, one will be allocated to measure and bill 30VA, cl. 0.2 encapsulated in SF6, manufactured and tested according to IEC 60044-1.

3.5. Detailed description at the MV equipment:

Similarly, at the HV equipment, it will describe the installed equipment at the cells.

3.5.1. Line cell (10):

- One (1) three-pole switch, 630 A, 31.5 kA, no-load breaking, drive by motor, manufactured and tested according to IEC 62271-200.
- One (1) current transformer per phase, each consisting of two secondary, 630 / 5-5, where one will be destined to measure 15 VA, 0.2 s, and the other one will be destined to protect 15VA, 5P20, manufactured and tested according to IEC 62271-200.
- One (1) current toroid transformer per phase, used for protection, 50/1, manufactured and tested according to IEC 62271-200.
- Two (2) three-phase no-load disconnector, motorized control, manufactured and tested according to IEC 62271-200.
- One (1) no-load three-phase disconnector, to-earth motorized control. Manufactured and tested according to IEC 62271-200.

3.5.2. Measurement Cell (2):

- One (1) voltage transformer, per bar and per phase, each one consisting of three secondaries, $(220/\sqrt{3})\ /\ (0.11/\sqrt{3},, \frac{0.11}{\sqrt{3}}, \frac{0.11}{\sqrt{3}}$ kV, first secondary designed to measure, cl. 0.5 and other two secondaries to protect, 3P.

3.5.3. Auxiliary transformer cell (2):

- One (1) three-pole switch, 630 A, 31.5 kA, no-load cut, drive by motor, manufactured and tested according to IEC 62271-200.
- One (1) current transformer per phase, each one consisting of two secondaries, 630 / 5-5, where one will be destined to measure cl. 0.2, 15 VA, and the other to protect, 5P20, 15VA, 5P20, manufactured and tested according to IEC 62271- 200.
- One (1) toroidal current transformer per phase, used for protection, 50/1, manufactured and tested according to IEC 62271-200.

- Two (2) three-phase no-load disconnectors, motorized control, manufactured and tested according to IEC 62271-200.
- One (1) three-phase no-load disconnectors, motorized control, earthed, manufactured and tested according to IEC 62271-200.

3.5.4. Transformer cell (2):

- One (1) three-pole switch, 2000 A, 31.5 kA, no-load breaking, drive by motor, manufactured and tested according to IEC 62271-200.
- One (1) current transformer per phase, each consisting of three secondary, 2000 / 5-5-5, where one will be destined to measure 15 VA, cl.0.2, the two others will be destined to protect 15VA, 5P20. Manufactured and tested according to IEC 62271-200.
- Two (2) three-phase no-load breaking interrupters, motorized control. Manufactured and tested according to IEC 62271-200.
- One (1) three-phase no-load cut-off switch, motorized earthing type. Manufactured and tested according to IEC 62271-200.

3.5.5. Longitudinal coupling cell (2):

- Two (1) three-pole switches, 2000 A, 31.5 kA, no-load breaking, with motorized driving, manufactured and tested according to IEC 62271-200.
- Two (2) three-phase no-load interrupters, motorized driving, manufactured and tested according to IEC 62271-200.
- Two (2) three-phase no-load disconnectors, motorized earthing, manufactured and tested according to IEC 62271-200.

3.5.6. Transverse coupling cell (2):

- One (1) three-pole switch, 2000 A, 31.5 kA, no-load breaking, drive by motor, manufactured and tested according to IEC 62271-200.
- Two (2) three-phase no-load breaking interrupters, motorized driving, manufactured and tested according to IEC 62271-200.

- One (1) three-phase no-load breaking switch, motorized, earthed class, manufactured and tested according to IEC 62271-200.

3.5.7. Capacitor battery (2):

- One (1) three-pole switch, 630 A, 31.5 kA, no-load cutting-off type, drive by motor, manufactured and tested according to IEC 62271-200.
- One (1) current transformer per phase, each one consisting of two secondaries, 630 / 5-5, one destined to measure cl.0.2, 15 VA, and the other designed to protect 15VA, 5P20. Manufactured and tested according to IEC 62271- 200.
- Two (2) three-phase no-load breaking disconnectors, motorized driving, manufactured and tested according to IEC 62271-200.
- One (1) three-phase no-load disconnectors switch, to-earth motorized type. Manufactured and tested according to IEC 62271-200.

3.6. Charasteristics of the facility, data specification.

3.6.1. HV Armored Cells

As we previously commented, there will be four (4) high voltage armored cells for the line positions, two (2) for the transformer positions, one (1) coupling cell, and one (1) for measurement. The following paragraph describes the characteristics of the switchgear within each of the cells.

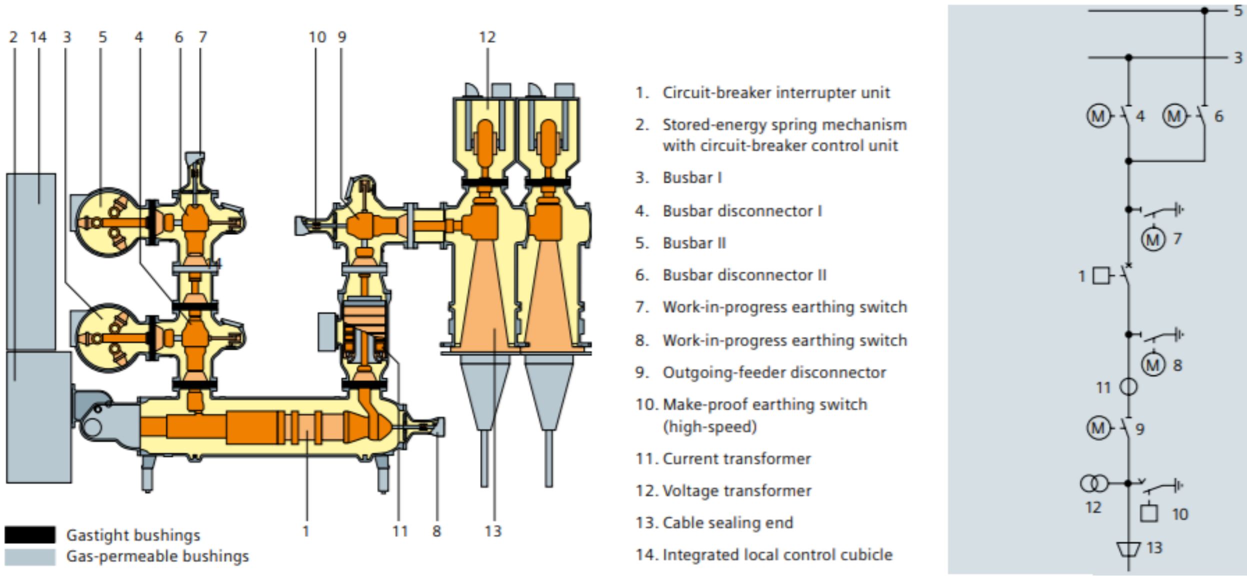


Figure 31. Scheme of the GIS cell. By Siemens manual: https://www.energy.siemens.com/nl/pool/hq/power-transmission/high-voltage-substations/gas-insulated-switchgear/8dn9-switchgear-up-to-245-kv/downloads/GIS-8DN9-Ds-e.pdf

3.6.1.1. Circuit breaker interrupter unit

The switches must comply the following characteristics:

• Number of poles	3
• Unipolar control type	
• Interior Installation	
• Type	SF6
• Service voltage	220 kV
• Maximum service voltage	245 kV
• Frequency assigned	50 Hz
• Rigidly earthed neutral system	
• Voltage assigned to industrial frequency (1 min)	
o To earth and between poles	460kV
o Through the insulation distance	530 kV
• Voltage assigned to the lighting impulse (1,2 / 50 μs)	
o To earth and between poles	1050 kV peek
o Through the insulation distance	1200 peek
• Breaking power capacity in no-load lines	125 A

- Breaking power capacity at no-load cables 250 A
- Switching cameras by pole 1
- Rated current during short duration 50 kA
- Dynamic current (2.5Icc) 125 kA
- Short circuit duration 3 s
- Assigned rated intensity:
  - Line switch 1250 A
  - Transformer switch 2000 A
  - Coupling switch 2000 A
- First pole factor 1,3
- Rated switching sequence, IEC O-0.3 s-CO-3 min-CO
- Total breaking time during in short-circuit 3 cycles
- Drive:
  - Type: Accumulation of energy by spring and motorized in DC
  - Designed to recover fast unipolar or tripolar reclosing.
  - Quantity: One (1) per pole

The switches of H.V. will be of three phaseSF6, single-pole, spring-loaded and with motorized commands in DC. Its mechanical characteristics will be those defined as class M2 in CEI 62271-100, that is, switches with frequent maneuvers and with limited maintenance.

Its mechanical characteristics will be those defined as class M2 in CEI 62271- 100, that is, switches with frequent maneuvers and with limited maintenance. Regarding of breaking capacitive currents, they will be class C2 according to IEC 62271-100, This means that there is very low probability of re-ignition at the breaking of capacitive currents. They will be designed both for cutting the whole short circuit current and for maneuvering no-load lines and / or small inductive currents.

They will be designed to carry out unipolar or tripolar fast reclosing through external equipment. Each pole of the switch will have a position indicator.

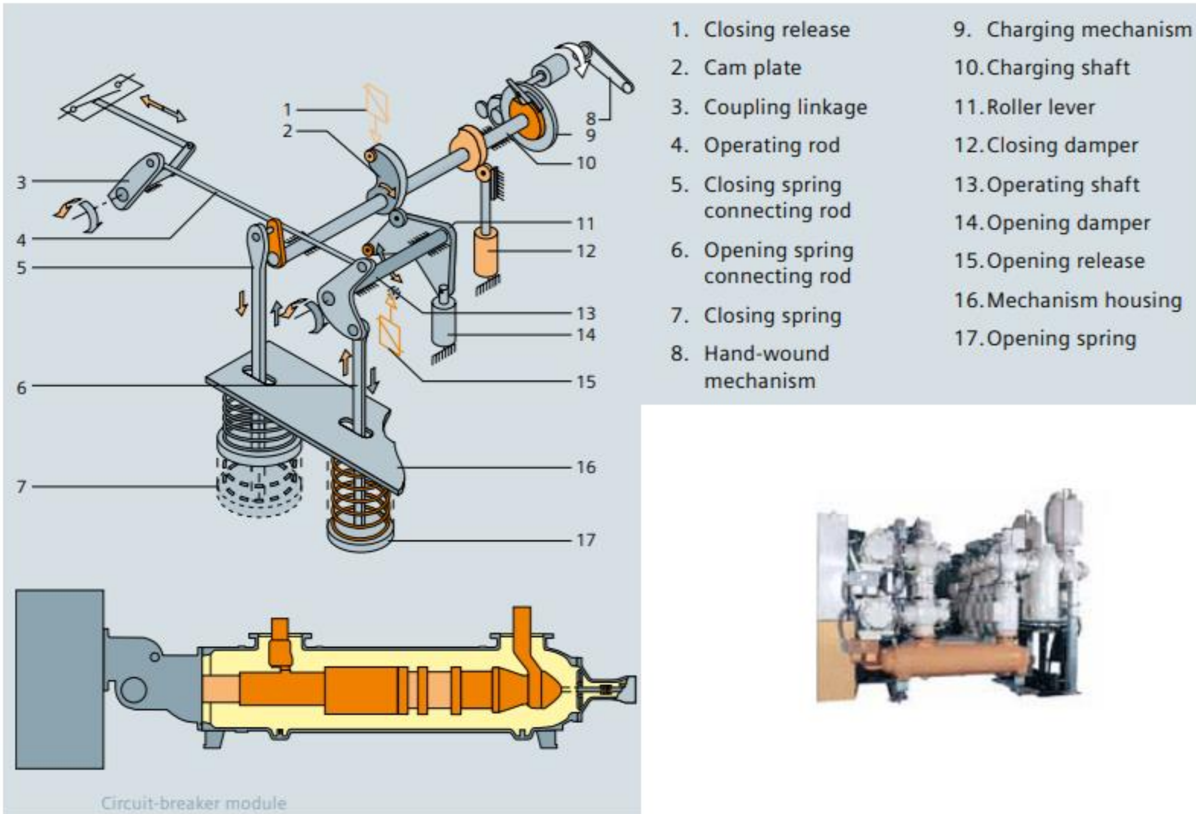


Figure 32. Circuit breaker module by SIEMENS catalogue.

All the elements of the circuit-breaker that are subjected to the current flow of the short circuit, must withstand the thermal effects of this current for 3 s. Likewise, they must withstand without deterioration the electrodynamic effects produced by the peek value of the current.

The opening and closing maneuvers of all the switches can be carried out in the following ways:

- Local electrical control, from the drive cabinet located or from the control panel.
- Manual maneuver (slow), from the control.

Both closing and opening orders must be blocked if the switch is in the desired order. An "anti-pumping" relay per pole must be provided in the closing circuit, to prevent the repetition of the closing maneuver in the case of a maintained order.

None anti-pumping relays will be installed in the opening circuit, to allow the safe switching of the switch by means of the appropriate regulation of the path of its auxiliary contacts.

The opening maneuver will have priority over the closing maneuver, but it will not be executed until the closing maneuver, once started, has been completed, that is, until the closing of the main contacts has occurred. It is planned to order automatic opening switch in the event that some phase does not complete the operation of closing and opening (pole mismatch).

The charge of the spring will be carried out by an electric motor of 125 V direct current, also manually. The manual spring load will be with the help of a crank, which when inserted into the actuator housing will block automatically the feeding at the automatic motor.

The spring charging motor and its auxiliary electrical equipment will work satisfactorily for all the nominal voltage supply values between 85% and 115% of the nominal supply voltage of the closing device. The spring can be loaded automatically in any position of the switch, open or closed.

Each pole will have one opening coil and two trip coils. The reels will work satisfactorily at 125 V DC for all nominal voltage values between 70% and 115%.

3.6.1.2. Busbar disconnector

The installed disconnectors have the following characteristics:

• Number of poles	3
• Interior Installation	
• Type	SF6
• Voltage at service	220 kV
• Maximum service voltage	245 kV
• Frequency assigned	50 Hz
• V assigned to industrial frequency (1 min)	
o To earth and between poles	460 kV
o Through the insulation distance	530 kV
• V assigned to lighting impulse (1,2/50µs)	
o To earth and between poles	1050 kV peek
o Through the insulation distance	1200 peek
• Assigned rated current of short duration	50 kA

- Dynamic intensity (2.5Icc) 125 kA
- Duration of short circuit 1 s
- Rated nominal intensity
  - Line disconnector 1250 A
  - Transformer switch 2000 A
  - Coupling switch 2000 A
- Drive:
- Main blades and earthing blades:
  - Electric motor type 125 V DC
  - Permissible voltage range 70 ÷ 110%

The disconnectors are designed to operate in continuous service on its rated intensity, so the heating over the ambient temperature do not exceed the maximum values indicated in the

Table 3 of the IEC 60694 standard. The disconnectors will be able to withstand the stresses without mechanical damage and thermal factors produced with the peak value of the short-circuit rated current and for the short-time rated current during 1 sec. is according to the specifics in the IEC Standard 62271-121.

The radio-interference level (RIV) will be in accordance with section 6.3 of the IEC 60694 standard. The 4 earthing disconnectors closest to the entrances and exits of the substation, will be from fast earthing.

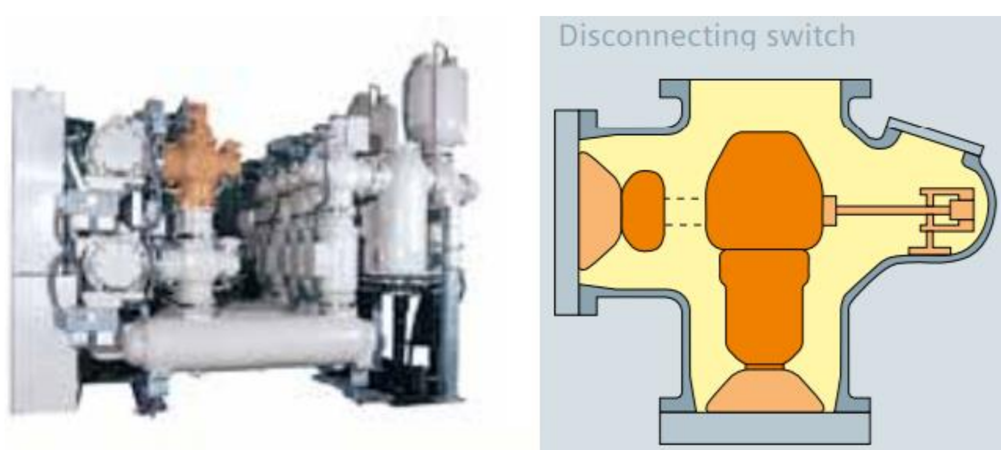


Figure 33.Disconnector, by siemens catalogue.

3.6.1.3. Measuring and protection transformers

It will distinguish between measurement and protection current transformers or measuring and protection voltage transformers

3.6.1.3.1. Measuring and protection current transformers:

- Interior installation
- SF6 insulation type
- Rated voltage 220 kV
- Rated maximum voltage 245 kV
- Frequency assigned 50 Hz
- Number of secondary
  - Line position 4
  - Transformer position 4
  - Coupling position 4
- Transformation ratio
  - Line position 1000 / 5-5-5-5 A
  - Transformer position 800 / 5-5-5-5 A
  - Coupling position 2000 / 5-5-5-5 A
- Power and precision class
- First (1º), second(2º) and third(3º) secondary (protection)
  - Line position 30 VA, 5P20
  - Transformer position 30 VA, 5P20
  - Coupling position 30 VA, 5P20
- Fourth secondary (measurement and billing)
  - Line position 20 VA, CL. 0.2s
  - Transformer position 20 VA, CL. 0.2s
  - Coupling position 20 VA, CL. 0.2s
- Supported voltage assigned to the impulse, primary winding lighting type 1050 kV peek
- Supported voltage assigned to the industrial frequency of the primary winding 460 kV
- Supported voltage assigned to the industrial frequency of the secondary windings 3 kV

- Supported voltage assigned between turns — 4.5 kV peek
- Short circuit current thermal limit — 50 kA for 1 s
- Dynamic short circuit current limit — 125 kA peek
- Rated thermal limit intensity — 1,2 In
- Permanent overvoltage factor — 1

Current transformers will be designed to not exceed the heating limits indicated in section 4.6 of the IEC 60044-1 Standard. The current transformers will be able to withstand without damage, the thermal and mechanical stresses produced by the specified short-circuit currents

Measuring current transformers must not exceed the limits of the intensity and lag error indicated in section 11.2 of the IEC standard 60044-1.

Protection current transformers shall not exceed limits of error of intensity, phase shift and compound error indicated in section 12.3 of the IEC 60044-1 Standard.

3.6.1.3.2. Measuring and protection voltage transformers:

- Interior Installation
- Type — SF6
- Rated voltage — 220 kV
- Maximum service voltage between phases — 245 kV
- Assigned frequency — 50 Hz
- Number of secondary
  - Line position — 3
  - Measurement position — 3
- Transformation relation
  - Line position — $(220/\sqrt{3})\ /\ (0.11/\sqrt{3})\ , \frac{0.11}{\sqrt{3}}, \frac{0.11}{\sqrt{3}}\ \text{kV}$
  - Measurement position — $(220/\sqrt{3})\ /\ (0.11/\sqrt{3})\ , \frac{0.11}{\sqrt{3}}, \frac{0.11}{\sqrt{3}}\ \text{kV}$
- Power and precision class
- First secondary (measurement and billing)
  - Line position — 20 VA, CL. 0.2
  - Measuring position — 30 VA, CL. 0.5

- Second and third secondary (protection)
  - Line position 30 VA, 3P
  - Measuring position 50 VA, 5P20
- Rated voltage factor:
  - In continuous service 1,2
  - In maximum of 30 sec. 1,5
- Supported voltage assigned to the lightning type pulse of the primary winding 1050 kV crest
- Supported voltage assigned to the frequency of the primary winding: 460 kV
- Supported voltage assigned to the frequency of the secondary windings, and between each of these and earth: 2kV

The voltage transformers will be designed to not exceed the limits of heating; indicated in IEC 60044-2 Standard.

Measuring voltage transformers shall not exceed the limits of the voltage and phase shift error indicated in section 12.2 of the IEC 60044-2 Standard.

Voltage transformers for protection must not exceed limits of the voltage error and the shift phase indicated in section 13.2 of the IEC Standard 60044-2.

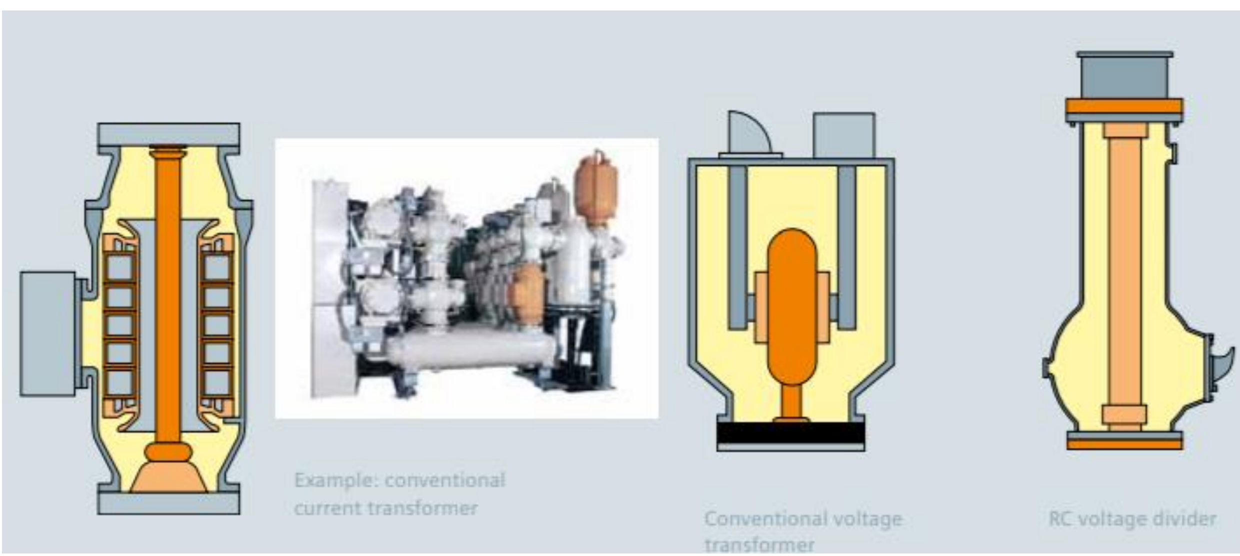


Figure 34.Current and voltage transformer.

3.6.1.4. Busbar

The main parameters for the designing of the busbars are:

- Double bar configuration
- SF6 Armored Type
- Neutral state Rigid to ground
- Rated service voltage 220 kV
- Highest rated voltage for the material 245 kV
- Voltage assigned to industrial frequency (1 min)
  - To earth and between poles 460 kV
  - Through the insulation distance 530 kV
- Voltage assigned to impulse type ray (1,2 / 50 μs)
  - To earth and between poles 1050 kV crest
  - Through the insulation distance 200 kV crest
- Rated intensity of short duration 50 kA
- Dynamic intensity 125 kA crest
- Duration of short circuit 1s

3.6.1.5. HV terminals

The installed terminals have the following characteristics:

- Type HV GIS / TRF
- Rated service voltage 220 kV
- Highest assigned voltage for the material 245 kV
- Voltage assigned to the lightning impulse 1050 kV peek
- No-load voltaje:
  - U0 127 kV
  - 1.5U0 190 kV
  - 2U0 254 kV
- Frequency assigned 50 Hz
- Isolation level
- The voltage tests comply with the requirements of the IEC 62067 standard. The dimensions and weight are within the established ranges in the IEC 60859 standard.

3.6.2. MV Cells

As previously discussed, there will be (10) ten line cells, two (2) cells for the main transformers, two (2) cells of the auxiliary transformers, two (2) condenser battery cells, two (2) measurement cells, two (2) transverse coupling cells and finally, one (2) longitudinal coupling cell. The following describes the characteristics of the equipment to be installed in each one of the cells.

Figure 35. From the catalogue of Siemens: https://w3.siemens.com/powerdistribution/global/SiteCollectionDocuments/en/mv/switchgear/gas-insulated/8djh/catalogue-8djh_en.pdf

3.6.2.1. Switches

• Number of poles	3
• Unipolar control type	
• Interior installation	
• No-load breaking type	
• Operating voltage	20 kV
• Maximum service voltage	24 kV
• Frequency assigned	50 Hz
• Rigidly earthed neutral system	
• Isolation level:	
o Voltage assigned to effective industrial frequency	(1 min)
o Voltage assigned to lightning type pulse (1.2 / 50 μs)	125 kV crest
• No-load breaking capacity	125 A

- Breaking capacity of the capacitor bank 400 A
- No-load breaking capacity of cables 250 A
- Assigned rated current of short duration 31.5 kA
- Dynamic intensity (2.5Icc) 78.75 kA
- Short circuit duration 3 s
- Rated nominal current
  - Line switch 630 A
  - Auxiliary transformer switch 630 A
  - Main transformer switch 2000 A
  - Longitudinal coupling switch 2000 A
  - Transverse coupling switch 2000 A
  - capacitor battery switch 630 A
- Electric endurance E2
- Mechanical endurance M2 (1000 maneuvers)
- Nominal switching sequence, IEC O-0.3 sec-CO-15 sec-CO
- Drive:
  - Type: Motorized control, with 125 V DC power supply, charging time of springs less than 15 sec., 2 opening coils at voltage emission, one closing coil and one (1) undervoltage coil.
  - Quantity One (1) per pole

Internal resistance arc is accredited by the tests carried out complying with the criteria of the IEC 62271-200 standard. Visual state indicators of the switchgear through synoptic diagrams and visual indicators of the presence or absence of tension.

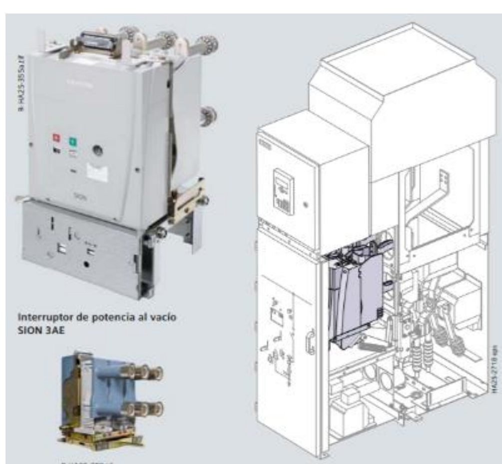


Figure 36. Switch unit from Siemens catalogue

3.6.2.2. Disconnectors

The supplied disconnectors have the following characteristics:

- Number of poles 3
- Unipolar control type
- Interior Installation
- Vacuum breaking Type
- Operating voltage 20 kV
- Maximum service voltage 24 kV
- Frequency assigned 50 Hz
- Neutral system rigidly earthed
- Isolation level:
  - Voltage assigned to the industrial frequency (1 min) 50 kV
  - Voltage assigned to the lighting pulse type (1.2 / 50 μs) 125 kV crest
- Assigned nominal intensity of short duration 31.5 kA
- Dynamic intensity (2.5Icc) 78.75 kA
- Short circuit duration 3 s
- Rated nominal current
  - Line disconnector 2000 A
  - Auxiliary transformer switch 2000 A
  - Main transformer switch 2000 A
  - Longitudinal coupling switch 2000 A
  - Transverse coupling switch 2000 A
  - Capacitor battery disconnector 2000 A
- Electric endurance E0
- Drive:
  - Type: Motorized control, with 125 V DC power supply
  - Quantity One (1) per pole

For manual operation, close clockwise and open in the reverse direction. Independent levers for the disconnector and the earthing switch.

3.6.2.3. Measuring and protection transformers

As before, we can distinguish between measuring and protection current transformers and measuring and protection voltage transformers. The following describes the designing characteristics of the transformers.

Figure 37. Current transformer from Siemens catalogue.

3.6.2.3.1. Measuring and protection current transformers:

• Interior Installation	
• Rated voltage	20 kV
• Rated maximum voltage	24 kV
• Assigned frequency	50 Hz
• Number of secondaries	
o Line position	3
o Auxiliary transformer position	3
o Main transformer position	3
o Capacitor battery position	3
• Transformation ratio	
o Line position	150-300 / 5-5-5
o Auxiliary transformer position	150-300 / 5-5-5
o Main transformer position	1000-2000 / 5-5-5
o Capacitor battery position	150-300 / 5-5-5

- Power and precision class
- First secondary (measurement)
    - Line position 25 VA, CL. 0.5
    - Auxiliar transformer position 25 VA, CL. 0.5
    - Main transformer position 25 VA, CL. 0.5
    - Capacitor battery position 25 VA, CL. 0.5
- Second secondary (protection)
    - Line position 25 VA, 5P20
    - Auxiliar transformer position 25 VA, 5P20
    - Main transformer position 25 VA, 5P20
    - Capacitor battery position 25 VA, 5P20
- Third secondary (protection)
    - Line position 25 VA, 5P20
    - Auxiliary transformer position 25 VA, 5P20
    - Main transformer position 25 VA, 5P20
    - Capacitor battery position 25 VA, 5P20
- Isolation level 0.72 kV
- Short circuit thermal limit intensity for 1s 31.5 kA
- Short-circuit dynamic limit current 78.75 kA peek
- Rated thermal limit intensity 1,2 In
- Permanent overvoltage factor 1

Figure 38.Current and voltage transformer units from Siemens catalogue.

3.6.2.3.2. Measuring and protection voltage transformers:

• Interior. installation	
• Rated nominal voltage	20 kV
• Maximum voltage service between phases	24 kV
• Frequency assigned	50 Hz
• Number of secondaries	
o Measurement position	3
• Relation of transformation	
o Measurement position kV	
• Power and precision class	
o First secondary (measurement)	
▪ Measurement position	25 VA, CL. 0.5
o Second secondary (protection)	
▪ Measurement position	25 VA, 3P
o Third secondary (protection)	
▪ Measurement position	25 VA, 3P
• Rated voltage factor:	
• In continuous service	1,2
• Rated service every 8 h	1.9
• Insulation level	0.72 kV

Figure 39. Voltage transformer from Siemens catalogue.

3.6.2.4. Busbars

The basic parameters for the design of the busbar of M.T. of the substation are:

• Double bar configuration	
• Type of insulation:	Copper, SF6
• Neutral state: Rigidly earthed	
• Rated operating voltage	20 kV
• Rated maximum voltage for the material	24 kV
• Isolation level	
o Assigned voltage for the industrial frequency (1 min)	50 kA
o Assigned voltage to the lightning type impulse (1.2 / 50 μs)	125 kA
• Maximum current in permanence	2000 A
• Rated current at short duration	31.5 kA
• Dynamic current	78.75 kA crest
• Duration of short circuit	1 s

3.6.2.5. Voltage terminals

The terminals to connect the wires at M.V., with the cells, are already provided all together with the cell, so the choice is already determined according to the type of wire, during its construction.

3.6.3. Capacitor batteries

The reactive power compensation in MV is directly related to the different aspects that contribute to the technical management at transport and distribution networks. They are:

- Quality of the supply: Consists on the increase of the voltage levels in the bar sets at the transformer stations and in the end of the lines.
- Operating cost optimization of the facility: The decrease of reactive power, and therefore, the reduction in apparent power leads to two aspects of strong technical relevance:
  - Reduction of the losses
  - The increase in the performance of transformers and installations
- Reduction of the economic cost of energy.

For the proper dimensioning of the power of the capacitor batteries, the power is analyzed starting from the nominal power of the substation, 50 MVA, and the power factor that we want to correct in our substation. In our case we will dimension the batteries for a $\cos\phi = 0.99$, starting from $\cos\phi = 0.85$. With this data the power will be:

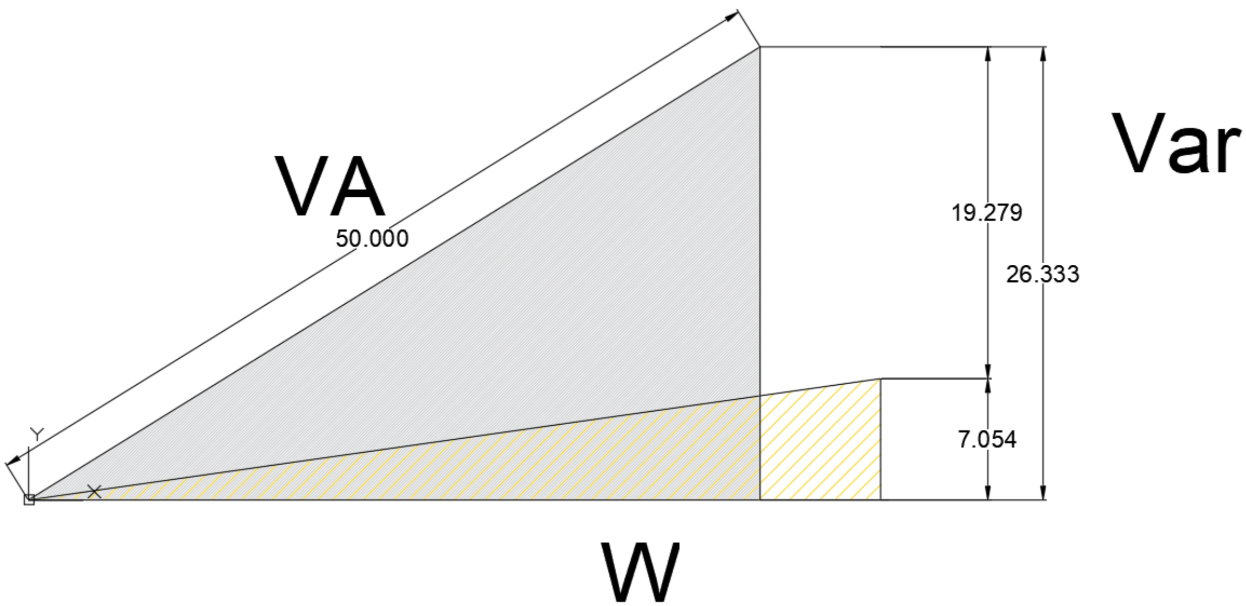


Figure 40.Power triangles in AutoCad.

Then the power of the batteries must be 19.28 Mvar. Contrasting different models, we finally install by group of capacitors (available from 300 kvar to 12000 Mvar) capacitors. We can put 9600 Mvar, in each battery (two batteries). And the way of connecting our capacitor banks will be double star since this arrangement allows us to achieve the desired power starting from standard capacitors. This form of connection is shown in the following figure:

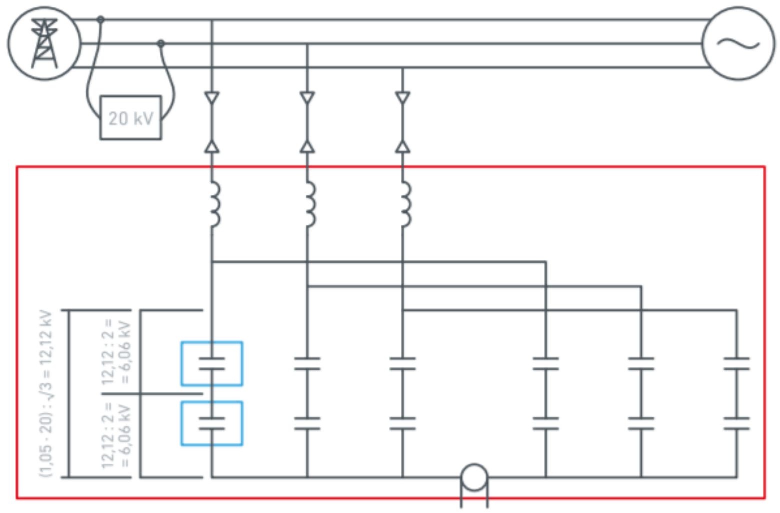
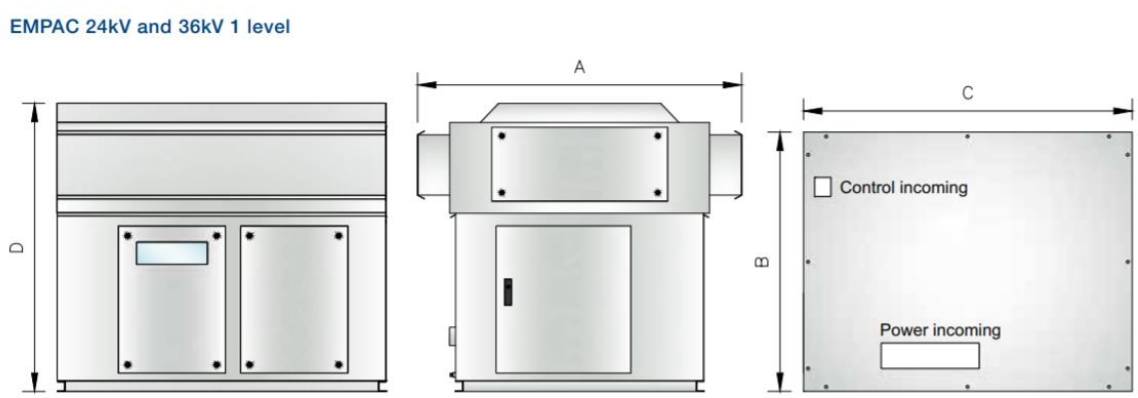


Figure 41.Double star arrangement by Circutor: http://circutor.com/docs/MitjaTensio_EN_Cat.pdf

Making use of the previous connection form and the power that will be needed The following equipment will be installed: Three (6) capacitor banks with the following characteristics:

- Manufacturer: ABB
- Model EMPAC w/o CB 24 kV 1 level
- Single-phase configuration in double star
- Interior Installation
- Frequency 50 Hz
- Degree of protection IP 23
- Nominal voltage 20 kV
- Maximum voltage 24 kV



3.6.4. Power transformers

Power transformers are a fundamental part of the substation since they are responsible for providing the necessary power for the supply of the loads that are demanded at a lower voltage level for an easier and safer handling.

3.6.4.1. General characteristics

There will be two three-phase transformers, ABB brand, with windings submerged in mineral oil, and designed for indoor installations.

The Transformers will have a power of 25 MVA each one, and the voltage levels will be of 220 ± 9 * 1.5% / 20 kV.

The electrical design of the transformers will be made according to the standard UNE-EN 60076-3. The transformers will comply with the tolerances indicated in the standard UNE-EN 60076-1, regarding the parameters:

- Total losses
- Partial losses
- Transformation ratio
- Short circuit impedance (between primary and secondary).
- No-load current.

The transformers will be designed for external short circuit according to the standard UNE-EN 60076-5, guaranteeing in any case, with the proposed design, the expected functionality for the transformer, in dynamic and thermal effects during the different types of short circuit and foreseen duration, and for each one of the transformer windings.

The use of additional internal ballasts will not be allowed, in order to increase the short circuit impedance between windings. Epoxy resin will be used to achieve a greater mechanical reinforcement of the windings.

The cooling of the transformers will be forced by fans connected to these to avoid overheating and therefore increase their performance.

At least one (1) additional fan will be supplied to the required number, which it will be considered as a reserve, although it will be in operation at the assigned power. Each fan must admit the possibility of being fed individually, regardless of whether they can be grouped together.

For ONAF cooling, the fans must be connected to the radiators with elastic neoprene or silentblock joints.

The transformer with stationary fans must permanently admit 75 % of its assigned power.

At following the designing constraints, construction details and accessories are being clarified.

Figure 42.Power transformer for interior, by SIEMENS.

3.6.4.2. Constructive details

3.6.4.2.1. Windings

In each transformer will be available a single primary and secondary winding.

The windings must be electrolytic copper conductors, free of impurities, isolated with paper, and as soon as possible, without welding.

The materials used must be insoluble and chemically inactive in hot oil bath. The use of insulating wooden supports will not be accepted.

The coils and the core, completely assembled, must be vacuum dried and immediately afterwards, it will be impregnated with dielectric oil to ensure the elimination of humidity and air from the insulating materials.

3.6.4.2.2. Terminals

The terminals will be pluggable. Considering the nominal and short circuit currents, the manufacturer shall confirm the thermal and dynamic capability of the offered terminals.

All bushing insulators must be gas and oil tight.

The terminals belonging to the primary and secondary, both for phase and for neutral when applied, they should preferably be identical to each other respectively, regardless of whether a transformer is housed in any of them intensity. This will facilitate the existence of a single terminal per voltage level as replacement.

Two (2) terminals will be perfectly protected by insulating caps, teflon type or similar, which will be supplied by the manufacturer, indicating the physical and electrical characteristics of such caps, which will present a maximum material voltage and identical insulation level used in the design of the tertiary winding. The connection type of the terminal will be threaded.

The other two (2) terminals will be used to close the triangle by means of a suitable board supplied by the bidder, who will be equipotentially connected to the cover of the transformer, although the design will allow the possibility of external connection to the general network of the designated substation.

The marking of the terminals and taps will be done following the recommendations of the UNE 20158 standard.

The transformer cover shall bear terminal identification plates with the following notation:

- Primary terminals: 1U, 1V, 1W, 1N.
- Secondary terminals: 2U, 2V, 2W, 2N.

The location of the terminals will be in a way that just looking from the H.V. side and from left to right, the terminals are identified as 1U, 1V and 1W, and looking from the low voltage side from left to right, the terminals will be identified as 2W, 2V, 2U. For the nominal primary voltage of 220 kV, the terminals will be pluggable, oil-oil with lateral output. The bushings offered will dispose of maneuver overvoltage type tests for (850 kV).

3.6.4.2.3. Tank

The transformer tank will be built with steel plates, of low percentage of carbon, suitable for welding and reinforced with steel profiles. The tank must form a single body, not subdivided. No welded joint or bell construction will be accepted. The joints of the sheets must resist hot oil. Inside the box should be provided the necessary guides to maintain the core, its windings, and the right direction to be introduced or extracted. Between the coiled core and the bottom of the box, a space must be adjusted to collect the sediments.

The lid of the tank must be bolted and should be designed to avoid water deposits on the external surface, and allow the gas and air bubbles to be directed towards the Buchholz relay In addition to the overpressure valves or as a base system for the mechanical protection, rupture discs can be used to achieve selectivity. As a secondary protection, the use of a sudden pressure relay is not desirable, unless the bidder justifies the need thereof.

The tank will be prepared with a minimum of two (2) terminals to earth it, located at two opposite ends of the lower part thereof, and prepared for copper conductor. The supplied staple will also permit the connection to earth, with a looping shape.

3.6.4.2.4. Expansion tank

The offered oil preservation system will be free with desiccators, not admitting the use of elastic membrane or air balloon.

The tank will preferably be fastened with brackets to the transformer tank, on top, in order to minimize the surface occupied in the plant. It will be prepared for whole vacuuming.

The capacity of the preservative deposit will be such, that the level of oil, in no case, will be lower below the level of the Buchholz relay floats (difference of temperature to be considered 120 ° C). In the same way, it will allow the established overload according to the UNE 20110 standard without spilling oil through the conservator.

If 220 kV oil adapter boxes are used, the tank will have three independent and watertight sections, corresponding to the tank of the transformer, tap changer and the aforementioned oil boxes. Each section will have a filler cap, a drain valve, a valve to separate the tank and the corresponding tank, a magnetic level indicator with two contacts alarm (level 1) and two alarm contacts (level 2), both by minimum level of oil, as well as an optical level indicator.

For the rest of the cases, it will have two sections, one for tank and another for the on-load tap-changer, the requirements for accessories are identical.

Each independent enclosure in the conservatory deposit will have an air dryer with silicagel; one for the deposit of the tank, one for the oil adapter boxes, when they exist, and another for the deposit of the tap changer.

All of them will incorporate an elongated glass window that allows to see all its contents, and will be located at a suitable altitude above ground level, with a maximum of 1.5 meters

3.6.4.2.5. Oil

The oil must be of paraffinic or naphthenic type, it has to be defined in the supply phase, and meet the requirements imposed by the UNE-EN 60296 standard. In its chemical composition it will not contain inhibitory substances, according to the established in the previous standard.

The amount of oil to be supplied will contemplate the oil necessary for the transformer, including the tank, expansion tank, refrigeration equipment, insulators and, where necessary, a reserve of approximately 5 % of the net volume of oil.

The oil will be supplied with the transformer and packaged separately in steel drums hermetically sealed and sealed off from the refinery, since the transformer will be transported without oil, the bidder will dictate the adequate procedure to transport.

The design of the compatible transformer will be highly valued for oils with a very high combustion point, above 300 ºC, as well as the use of lower volume of oil as possible.

None of the gases, H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO and CO_2, should reach concentrations (in p.p.m.) of 250, 150, 150, 250, 150, 1,000 and 10,000 respectively; The monthly increased concentration values of $H_2 + CH_4 + C_2H_6 + C_2H_4 + C_2H_2$, should not be higher than 5%.

If these values are not met, the guarantee will be considered extended until determine the causes that cause the latent defect and correct them, along with the additional consequences indicated in the contract document of the order.

3.6.4.2.6. Valves

The transformer will have the following valves:

Two (2) filtering valves on opposite sides of the tank and upper part and lower. The filtering valves must guarantee a minimum flow of 12,000 l / hour and nominal diameter DN80.

Two (2) valves for taking oil samples with fast connection, at middle and lower height of the tank. Internal sleeve is not allowed neither the positioning of both valves on the bottom. It will be supplied a male connector and a 3 meters length sleeve.

One (1) valve for total emptying in the lower part of the tank, diameter nominal DN80.

One (1) valve for the connection with the dissolved gas analyzer equipment.

A fast oil draining valve, located at the base of the transformer, of remoting operation, with electric and manual mechanism. It will indicate the maximum evacuation flow of such valve. The size of the valve it must not increase significantly the overall dimensions of the transformer.

The 220 kV oil adapter box will house the following valves:

- One (1) filling valve
- One (1) drain valve
- One (1) connection valve for the preserved tank.
- One (1) valve for connection for the dissolved gas analyzer equipment.
- One (1) sampling valve with fast connection.

The isolation valves of the tank and the radiators or tank and the aero-cooling will be independent and will not be welded to the tank or the cooling pipe. They will have an indicator of open/close state and for the cooling ONAF will be placed in the own tank.

3.6.4.2.7. Protections

The following protections will be used for the transformer:

A Buchholz relay for the tank, and in case of using oil adapter boxes, another that collects the oil from the three terminals, in the common pipe attached to the three pipes, associated with each box through a three-way valve or system. Similarly, there will be separation between the pipes of the Buchholz relays towards the cooling. The pipeline connection must be provided with a removable section to assemble the Buchholz relay. Such section must be provided with valves on either side.

The Buchholz relay will preferably be brand TRAFO UNIÓN or EMB, anti-seismic and with one (1) alarm contact and two (2) trigger. The bidder will indicate the maximum acceleration in the three directions below which the reliable and safe operation of the relay.

It should be perfectly level. The linking pipe will have a slope of not less than 8% to facilitate the flow of gas to the cooling deposit, with the proper minimum diameters according to the capability of the transformer. The pipe it will start from the highest point with the oil. Between the tank and the Buchholz relay an elastic reel will be available.

The transformer will house a socket for the gases and oil samples for each Buchholz relay installed, at man height and through a glass vessel. Two valves will be installed to isolate the glass vessel allowing it to be easily removable.

An oil thermometer, preferably AKM brand, will be supplied four sets of contacts, with alarm functions of level 1 and level 2 by temperature of oil and start/stop of the refrigeration equipment.

A thermal image relay will be supplied, preferably of AKM brand and a Bushing current transformer in the central phase of the primary and secondary, four contact games, with alarm functions of level 1 and level 2 by temperature of winding and running and stopping the cooling equipment.

As a variant, both thermometer and thermal image relays will have additionally analog output (0-5 mA) for remote indication.

A platinum resistance PT-100 will be supplied for remote indication of the oil temperature, by an analog signal (0-5 mA).

The probes of thermometers and thermal image relays will be protected with a removable sheet metal enclosure. A reserve probe will be left for oil thermometer.

The thermal image relays and the thermometer will be housed in a hot galvanized cabinet and painted with glass lid and attached to the tank.

This cabinet will have a thermostat and heating resistance. It will also have single-phase circuit protected by a magneto-thermal switch, alarm contacts, properly connected to terminals, to feed the dissolved gas analyzer equipment.

The location will be such that they can be easily observed from the ground, and it will have a convenient scale.

The scales will be graduated in centigrade degrees, the opening and closing hysteresis of the auxiliary contacts will be indicated, by means of a suitable plate, as well as with the alarm levels (levels 1 and 2) recommended by the manufacturer, according to the outcome of the heating test.

3.6.5. Cables

For the selection of the cables for our substation, it will be necessary to size them through the pertinent calculation taking into account the correction factor to each disposition. since each cable will be arranged in a different way and in different terrain conditions, depending on their location and its functionality.

The values of the correction factors are established according to the tables of the UNE 20435 standard for those calculations referring to high voltage cables. For medium voltage cables, the appropriate procedures have been followed as established in the RLAT ("Regulation of High Voltage Lines").

As a method of calculation, several ways can be used, such as:

- Maximum admissible current
- Maximum allowable short-circuit current
- Voltage drop

These last two will be disregarded, since the distances are short and therefore the voltage drop will be negligible for the selection of the cable, and for the short circuit current, the manufacturer catalogue offers short circuit currents much more above than the calculated, then they will not be decisive in the election neither.

These calculations are made on the calculations section, regarding the cable diameter calculations. From the calculations and comparing the choices between different manufacturers it is obtained the final choice of the type of cable with its own characteristics. We must differentiate between high voltage and medium voltage cables, breaking down into the different types of cables that will be installed according to its functionality within the substation.

3.6.5.1. High voltage cables

3.6.5.1.1. General characteristics

The high voltage cables will be found buried reaching the basement of our substation where they will be subject to the wall, flanged and bolted to it, being totally fixed. The cables will be three-polar, with a cross-section of 400 mm2, separated by a distance of 0.25m 1 tray per line, until the arrival at the basement, where the connections with the GIS cells will be made.

Figure 43. XLPE and tray disposition by the manufacturer.

The high voltage cables of the transformers will run through the high voltage GIS cells directly to the transformer terminals through the basement to avoid perforations in the walls of the rooms of the transformers.

3.6.5.1.2. Constructive details

With the previously calculated current, and contrasting such current with the manufacturer, the following cable is finally selected:

- Manufacturer ESTRALIN
- Conductor material
    - Al to transformers
    - Cu from lines
- Insulation XLPE
- Cover Graphite polyolefin
- Section:
    - Line cable 1 1200 mm2
    - Transformer cable 500 mm2
- Capacitance, μF / km
    - Line cable 0.19 μF / km
    - Transformer cable 0.13 μF / km
- Inductance, mH / km
    - Line cable 0.29 mH / km
    - Transformer cable 0.45 mH / km
- Rated voltage 220 kV
- Rated current, A
    - Line cable range 755-820 A
    - Transformer cable range 555-595 A
- Maximum short-circuit current, kA
    - Line cable 113.4 kA
    - Transformer cable 71.5 kA
- Maximum admitted effort, kN
    - Line cable 36 kN
    - Transformer cable 15 kN

Manufacturing and testing follow the following rules:

- Fire non-propagation tests IEC 60332-1 / 3, EN 50266.
- Halogenic gas determination tests IEC 60754-1, EN 50267-2-1.
- Tests to determine the acidity degree IEC 60754-2, EN 50267-2-2- / 3.
- Smoke capacity tests IEC 61034, EN 50268.

3.6.5.2. Medium Voltage Cables

3.6.5.2.1. General characteristics

The medium voltage cables will be arranged in the basement of the substation whose exclusive use will be for these cables all together with the ingoings of the high voltage cables.

They will be arranged in trays subject to wall and floor by means of straps which allow their handling and at the same time the stability against vibrations during the steady state service or faults.

There will be a total of six trays with two conductors for each one, or vice versa, without one diameter of separation between them and 0.3m between trays, and 0.20m to the wall.

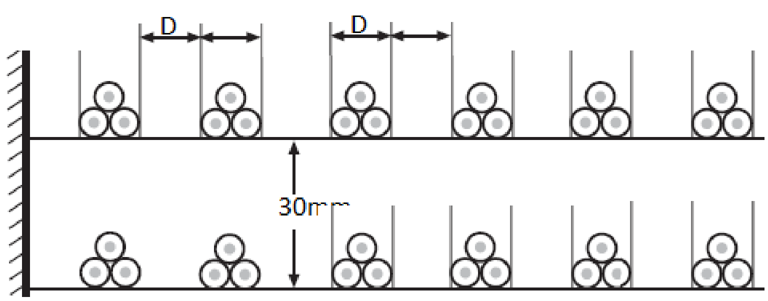


Figure 44. MV tray disposition.

The correction values will be established according to the tables of the Regulation of High Voltage Lines (RLAT) and explained in detail at the calculation annex.

3.6.5.2.2. Constructive details

By contrasting the intensities previously calculated with the manufacturer, there is the possibility of adjusting the nominal currents to the different sections.

However, the short circuit current in the smaller sections like those of cogeneration cables or auxiliary transformers will comply with the theoretical calculated in the calculation annex current of 29.3 kA, then two three-polar cable of 150 mm2 sections will be chosen from the ESTRALIN manufacturer.

With the previously calculated current, and contrasting such current with the manufacturer, the following cable is finally selected:

- Manufacturer — ESTRALIN
  - Conductor material — Aluminum
- Insulation — XLPE
- Cover — Graphite polyolefin
- Section: — 150mm2
- Capacitance, μF / km
  - Line cable — 0.434 μF / km
- Inductance, Ω / km
  - Line cable — 0.105 Ω / km
- Rated voltage — 20 kV
- Rated current, A
  - Line cable — 457 A
- Maximum short-circuit current, kA
  - Line cable — 17.5 kA
- Maximum admitted effort, kN
  - Line cable — 9.25 kN

Manufacturing and testing follow the following rules:

- Fire non-propagation tests IEC 60502-2, EN 50265-1.
- Halogen gas determination tests IEC 60754-1, EN 50267-2-1.
- Tests to determine the degree of acidity IEC 60754-2, EN 50267-2-2- / 3.
- Smoke capacity tests IEC 61034, EN 50268

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Figure 45. 20kV aluminum cable.

3.6.6. Auxiliary Systems

Apart from other secondary functions, the auxiliary services constitute the power supply of the command, control and protection systems of the substations; Therefore, they must be designed with the objective of maintaining its own reliability of the main elements of these systems.

The fundamental design criteria of the auxiliary services system must be guaranteeing the energy necessary supply for the installation, even when there are some failures in the system itself or in the sources that feed it since it will have extra batteries (in the case of direct current auxiliary services) with sufficient capacity to supply the loads during a certain time until the total recovery for the normal performance of the system.

For the auxiliary services design, we will contemplate the following sections where it is mentioned the descriptions and characteristics of the installed equipment.

3.6.6.1. Auxiliary Services of A.C.

The auxiliary services of the substation will be equipped with an automatic switching system for the feeder, and other components for its monitoring and surveillance that will house the automatism box of the feeder under minimum voltage.

This automatism aims to provide the continuous supply of auxiliary services by the use of switches. It is the responsible for starting at the generator set, which will feed the auxiliary services. bars in the event of total voltage failure, thus assuming the emergency supply role.

To provide these auxiliary services of 400/230 V A.C. we have choosen two cast resin encapsulated transformers of 630 kVA each one. These transformers will be installed inside the MV room and will connect their corresponding cells of 20 kV through three unipolar aluminum cables with dry insulation, capable of withstand the rated and short circuit current. In addition, these transformers will feed, in low voltage, the AC Auxiliary Service Main Board (ASMB.AC).

The main function of the ASMB.AC is to provide energy to:

- Chargers of the 125 C.C. V batteries
- Chargers of the 48 C.C. V batteries
- Continuous current batteries
- Lighting and power
- Cooling
- On-load regulator
- The panel for communication distribution
- The auxiliar substation

The auxiliary services windings of 400/230 V A.C. will be of 0.6 / 1 kV, and for these unipolar cables will be prohibited the use of hoses.

The chosen sections will comply with the current density and will be oversized to avoid voltage drops. It will be performed a posterior analysis to the winding path to check and verify that the voltage drop is not higher than 5% and the isolation tolerate the short circuit current density for 1 second.

The protection of these transformers is guaranteed both in high and low voltage lane through a circuit breaker.

3.6.6.1.1. Auxiliary Service Transformers

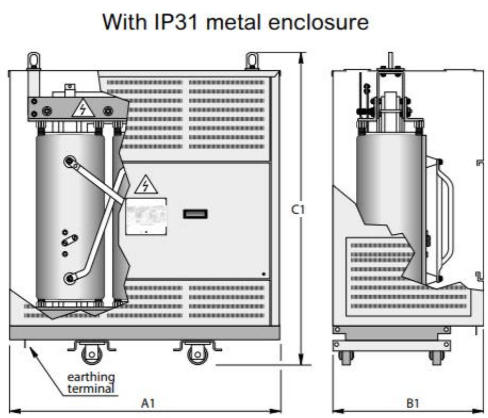
Auxiliary service transformers will be connected to their respective cells destined for auxiliary services, at M.T.

These transformers will have the purpose of feeding the A.C. auxiliary service facilities for the launching of the standard loads of the substation.

The auxiliary services windings of 400/230 V A.C. will be of 0.6 / 1 kV, and for these unipolar cables will be prohibited the use of hoses.

There will be two transformers (one per cell for these auxiliary services) and will have the following characteristics:

- Three-phase transformer submerged in cast resin
- Nominal power 630 kVA
- primary voltage 20 kV
- Secondary voltages 400 V
- Short-circuit voltage 6%
- connection Triangle / Star
- connection group Dyn11



Rated power (kVA)		630
Without enclosure IP00		
Dimensions (mm)	-A	1500
	-B	800
	-C	1640
	-D	670
	-E	795
Total weight (kg)		1920
With IP31 metal enclosure		
Dimensions (mm)	-A1	1800
	-B1	1020
	-C1	2050
Weight enclosure (kg)		210
Total weight (kg)		2130

Power kVA	630
Primary voltage Secondary voltage	20kV 400 to 433V between phases, 231 to 250V phase to neutral (at no load)
HV insulation level	24kV for 20kV
HV tapping range	± 2.5 % and/or ± 5 %
Vector group	Dyn 11, Dyn 5, Dyn 1 (other vector groups upon request)
No-load losses (w) Load losses at 75°C (w) Load losses at 120°C (w)	1100 6390 7100
Impedance voltage (%)	6
Acoustic Level dB(A): - power L_{WA} - pressure L_{PA} (1m)	 62 49

Figure 46. Assembly of the Schneider catalogue: http://download.schneider-electric.com/files?p_Doc_Ref=NRJED315663EN&p_EnDocType=Catalog&p_File_Name=Trihal%20Catalog_NRJED315663EN_030418.pdf

3.6.6.2. Auxiliary services of D.C.

For the direct current voltage, we will dispose of two battery-rectifier equipment of 125 V D.C. fed from the the AC Auxiliary Service Main Board (ASMB.AC).
In addition, two 48 V.D.C. output battery-rectifier units will be installed, also fed from the ASMB.AC.

3.6.6.2.1. Accumulator batteries

An electric accumulator, also known as a battery, is a device that stores energy in a chemical form and returns it in electric form. These have the capability to recharge itself so that its cycle is reversible (loading and unloading).

The operation of the accumulator is based on the reversible process of reduction oxidation (Redox) During this, one part is oxidized losing electrons and another part it is reduced by gaining electrons. The batteries chosen for both voltage levels: 125 V D.C. and 48 V D.C. will be of Nickel-Cadmium technology.

They consist of positive plates (cathode) of nickel hydroxide and negative plates (anode) of cadmium, using as an electrolyte potassium hydroxide.

The chemical reaction of loading and unloading these batteries is:

$$Cd\ (s) + 2\ HO^-\ (ac) \rightarrow Cd(OH)_2\ (s) + 2\ e^-$$
$$2\ Ni(OH)_3\ (s) + 2\ e^- \rightarrow 2\ Ni(OH)_2\ (s) + 2\ HO^-\ (ac)$$

Figure 47. Reaction Ni-Cd

These batteries require less maintenance than the lead ones, admitting deeper shocks. On the other hand, there is no hydrogen released during the loading process, which eases its installation inside metal cabinets and there is no need for venting the expulsion gases.

The capacity of the batteries is measured in Ah, which corresponds to the amount of energy that you can supply under certain conditions.

Reducing the temperature will reduce the capacity of the batteries, however, a high temperature could reduce the life of the batteries, which is about 20 and 30 years.

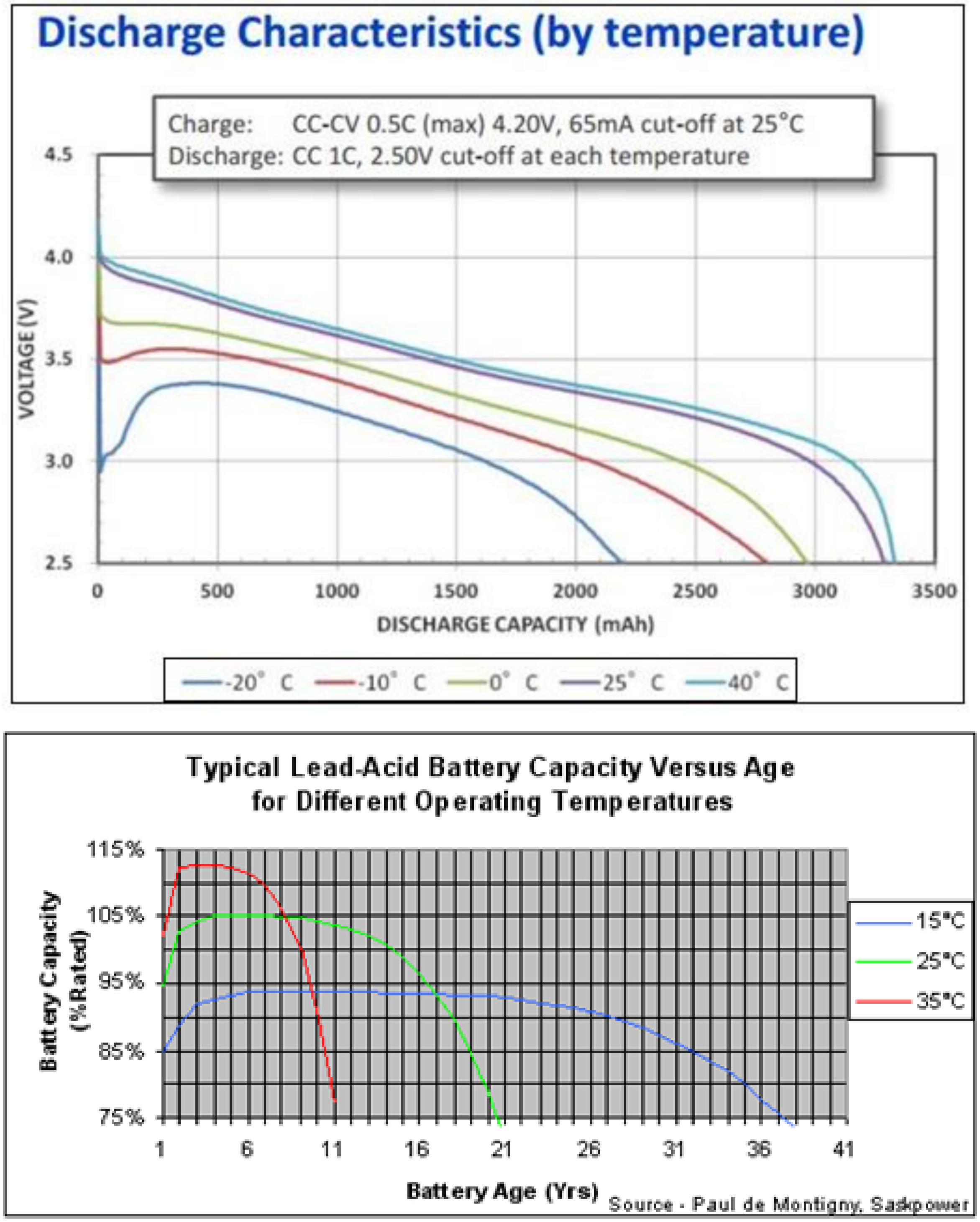


Figure 48. Performance of the batteries depending on the temperature by renobat.eu

So, nickel-cadmium batteries will be chosen, after calculations (take a look the calculation annex), we will choose 95 cells and 335 Ah capacity for 125 D.C. and 48 D.C. with a of 5 hours discharge time.

Discharge time (Hours)	5h
Battery	Ni-Cd Open
Operation temperature (°C)	25
Operation voltage (VDC)	125V – 48V
Voltage tolerance (rec)	-10% / +10%
Tensión de carga de las baterías (V)	1,45-1.7 V/cell
Current I_1 (A)	25A: Absorption charge
Current I_2 (A)	85A: Bulk charge
Number of cells at 125V:	95 cells
Capacity of the cells at 125V:	335 Ah
Number of cells at 48C:	37 cells
Capacity of the cells at 48V:	335 Ah

Figure 49. Battery summary.

Cell Type	C_5 Ah	Hours		
		10	8	5
KPL11P	11	1.07	1.33	2.08
KPL310P	310	30.2	37.4	58.6
KPL335P	335	32.6	40.4	63.3

Cell Type	C_5 Ah	Cell Dimension			Approx Cell Wt	Electrolyte	Terminals
		L (mm)	W (mm)	H (mm)	(KG)	Volume (Litres)	
KPL335P	335	156	165	401	16.8	4.8	2XM20

Figure 50. Battery properties.

3.6.6.2.2. Chargers

They constitute the direct current sources, possess the capability of increasing the voltage. The charge current is measured in proportion of the corresponding current to the usual capacity for discharge, being 0,2C the most standard among nickel-cadmium battery manufacturers. To avoid the deterioration of the plates, it will not be permitted to exceed these values, in the same way, that lower values would lead to longer recharging times.

According to the manufacturer, the final charge voltage must be between 1.45 and 1.7 V/element. At the end of the charging process there is a strong gasification of the electrolyte result in water loss and temperature rise, proportional to the final voltage. Therefore, a compromise must be reached between the recharge degree and the required maintenance

The chargers will dispose the following charge regimes that can be selected either remotely or manually from the own frame, which houses the batteries:

- Flotation: The charger feeds the DC system with a slightly higher voltage than the rated system, providing the battery with a current that compensate its auto discharge. Such flotation voltage is around 1.4V/element in the case of Ni-Cd batteries, that means, 1 mA for each Ah rated battery capacity.

.

- Fast charging: This charging regime aims to replenish the capacity transmitted to the continuous system after a discharge. It will reach a final voltage of 1.45 to 1.5 V/element, at this moment the charger switches to the flotation charge. Then it remains constant until it reaches a load of the 80% of the discharged capacity. From this instant the system automatically switches to flotation mode.

  This regime does not permit to fill the 100% of the capacity, since a greater charge voltage would be needed, more than the admitted maximum by the continuous system. In such a case it would be necessary to apply a charge deep with isolated consumption.

- Deep load: This load is carried out with a voltage of 1.65 to 1.7 V/element, so it cannot feed the system due to overcoming the maximums acceptable tensions. It should be done at least once a year or twice a year, aiming to replenish the 100% of the battery's capacity and increase its useful life.

The useful life according to manufacturers in good condition of exploitation and charging is approximately 20 years. The tests and manufacturing will be subjected to the provisions in the IEC 60146 standard. Therefore, the chargers are the following:

• Manufacturer	AEG-SAFT
• Model	RCS
• Units	2
• Type	6 pulses
• Capacity:	10-500 A

3.6.6.2.3. C.C. Main board

• Manufacturer	AEG-SAFT
• Model	PC
• Busbar units	2

3.6.6.2.4. Housing charasteristics:

• Material	Steel sheets
• Thickness	2mm
• Smooth finish surface	
• Dimensions (l x a x p)	645x2046x745 mm
• Protection degree	IP 65
• Finish colour	BEIGE, RAL 1015

The tests and manufacturing will be subject to the provisions of the IEC 60439 standard.

3.6.6.3. Lighting

The different devices, both electronic and the switchgear, need a power source for its operation in addition of the required illumination. The substations must be equipped with lighting so that the personnel of operation, maintenance and monitoring can develop their respective work. The lighting has as main purpose:

- Safety during the equipment operation
- Transit without danger
- Equipment inspection
- Maintenance or repair works

The lighting of the substation will be provided from the auxiliary services of alternating current since they are considered normal loads.

In the event of emergency lighting, as this will be necessary in case of system failure, will be fed from the continuous power auxiliary services of 125 V.
At the following table it will resume the number of luminaires necessaries for the lighting of the substations. It will be respected the minimum level of light according with the standards.

Normal lighting		Emergency lighting	
Ptotal	10944W	**Ptotal**	468W
Number of lum.	72	Number of emergency light	59

At the calculation annex it will be dispose all the calculations, standards and formulas for the design.

3.6.7. Protection, control, measurement and communication systems

The substation will have the possibility of being operated remotely, so it will be provided with a remote-control system, which will collect the signals, alarms and measurements of the installation for its transmission to remote operation centres.

From the remote-control system, it will be given the orders for the closing and opening of the switches and disconnectors by means of electric control, as well as, the replacement of protections differentials, command relays, etc.

The information to be transmitted will be treated and prepared by the integrated control system and the transmission will be carried out with optic fibre optic. The communication equipment will be fed from the 48 V C.C. and it will be installed in one of the cabinets of the control room of the building.

As it was previously mentioned the telecommunication technology will be of fibre optic. The remote-control systems and telecommunications will transmit the information of:

- Measures (I, U, P, Q)
- Billing (kVARh, kWh)
- Alarms
- Instructions: The substation receives this signal from the outside
- Status signs: indicate the operation state of the elements at the substation: opened or closed switch, state of the disconnectors, etc.

3.6.7.1. Protection system

The protections must protect coordinating each one of the elements and equipment that make up our substation and therefore is meshed with others, it is part of the electrical system so for that, you should have a global knowledge of operation of the electrical system in order to design the combined protections with the automation systems which directly affect the dynamic operation of the electrical system.

Depending on the position, some protections or others will be used. The described protections are differentiated for each position.

3.6.7.1.1. Line position

Tabla 1. Line position protection 220 kV

PROTECTION	PROTECTION FUNCTIONS
MAIN PROTECTION	- LINE DIFERENTIAL (87L) * - DISTANCE (21) * - DIRECTIONAL OVERCURRENT GROUND PROTECTION (67N) - LOCATOR (LOC) - OSCILLOGRAPHIC (OSC)
SECUNDARY PROTECTION	- DISTANCE (21) - DIRECTIONAL OVERCURRENT GROUND PROTECTION (67N) - LOCATOR (LOC) - OSCILLOGRAPHIC (OSC)
SWITCH PROTECTION	- BREAKER FAILURE (50S-62) - SYNCHRONISM (25/25-AR) - MINIMUM VOLTAGE (27) - POLE DISCORDANCE (2) - OSCILLOGRAPHIC (OSC)

3.6.7.1.2. Coupling position 220 kV

Tabla 2. Coupling position protection 220 kV

PROTECTION	PROTECTION FUNCTIONS
MAIN PROTECTION	- DISTANCE (21) * - LOCATOR (LOC) - OSCILLOGRAPHIC (OSC)
SECUNDARY PROTECTION	- DISTANCE (21) - LOCATOR (LOC) - OSCILLOGRAPHIC (OSC)
SWITCH PROTECTION	- BREAKER FAILURE (50S-62) - SYNCHRONISM (25/25-AR) - MINIMUM VOLTAGE (27) - POLE DISCORDANCE (2) - OSCILLOGRAPHIC (OSC)

3.6.7.1.3. Transformer position 220/20 kV

Tabla 3. Transformer position protection 220/20 kV

PROTECTION	PROTECTION FUNCTIONS
MAIN PROTECTION 220 kV	- LINE DIFERENTIAL (87T) - INSTANTANEOUS PHASE OVERCURRENT (50) - TEMPORIZED PHASE OVERCURRENT (51) - TEMPORIZED PHASE OVERCURRENT GROUND PROTECTION (51N) - OSCILLOGRAPHIC (OSC)
SECUNDARY PROTECTION 220 kV	- LINE DIFERENTIAL (87T) - INSTANTANEOUS PHASE OVERCURRENT (50) - TEMPORIZED PHASE OVERCURRENT (51) - TEMPORIZED PHASE OVERCURRENT GROUND PROTECTION (51N) - OSCILLOGRAPHIC (OSC)
SWITCH PROTECTION	- BREAKER FAILURE (50S-62) - SYNCHRONISM (25/25-AR) - OSCILLOGRAPHIC (OSC)
TRANSFORMER PROTECTION 220/20 kV	- BUCHHOLZ (63B) - BUCHHOLZ JANSEN (63B) - PRESSURE RELIEF (63L) - MAGNETIC LEVEL TRANSFORMER (63NT) - MAGNETIC REGULATOR TRANSFORMER (63NR) - TEMPERATURE (26T) - THERMIC IMAGE (49)
EARTHED THREE-PHASE REACTANCE PROTECCION 20 kV	- BUCHHOLZ (63B) - BUCHHOLZ JANSEN (63B) - TEMPERATURE (26T)
MAIN PROTECTION 20 kV	- TEMPORIZED PHASE OVERCURRENT (51) - TEMPORIZED PHASE OVERCURRENT GROUND PROTECTION (51N)
SWITCH PROTECTION 20 kV	- BREAKER FAILURE (50S-62) - OSCILLOGRAPHIC (OSC)
EARTHED REACTANCE MAIN PROTECTION 20 kV	- TEMPORIZED PHASE OVERCURRENT GROUND PROTECTION (51N) - OSCILLOGRAPHIC (OSC)

3.6.7.1.4. Line position 20 kV

Tabla 4.Line position

PROTECTION	PROTECTION FUNCTIONS
LINE PROTECTION	- INSTANTANEOUS PHASE OVERCURRENT (50) - TEMPORIZED PHASE OVERCURRENT (51) - GROUND DIRECTIONAL OVERCURRENT (67N) - RECLOSER (79)
SECUNDARY PROTECTION	- DISTANCE (21) - DIRECTIONAL OVERCURRENT GROUND PROTECTION (67N) - LOCATOR (LOC) - OSCILLOGRAPHIC (OSC)
SWITCH PROTECTION	- BREAKER FAILURE (50S-62) - SYNCHRONISM (25/25-AR) - MINIMUM VOLTAGE (27) - POLE DISCORDANCE (2) - OSCILLOGRAPHIC (OSC)

For the installation of the protection system we will be dispose of the following equipment and protection:

- Six (6) local control cabinets will be provided in a way that facilitates the equipment maintenance, with degree of protection IP55, IK10 and NEMA12. RITTAL manufacturer, model VX25. Dimensions (l x to x p), mm 1200 x 2200 x 600, manufactured and tested according to UNE-EN-60439-1 standards. Material sheet steel of colour RAL 7035, and 2 mm thickness.

- Six (6) oscilloperturbographs, model e DRTS (type TRANSCOPE 82170) of the manufacturer ISATEST, one for each relay frame, with capacity for 10 analog signals and 12 digital signals, based on the IEC 61850 standard.
- Breaker failure protection, model SIPROTEC 5 of SIEMENS, type 7VK87, which integrates, among other functions, automatic reclosing function and synchrocheck for line protection applications with 1-pole and 3-pole tripping, circuit-breaker failure protection for 1-pole and 3-pole tripping, control, synchrocheck and switchgear interlocking protection, voltage controller for transformers, arc protection, and voltage protection.

- Transformer Differential Protection – SIPROTEC 7UT82. Main function 1 differential protection function (standard or auto transformer) with additional stabilization; up to 2 ground fault differential protection functions.
- SIPROTEC 7SJ85 differential bar protection.
- Stopping or opening time delay protection, SIPROTEC 5, SIEMENS, type 7DS5002-5JE52.
- SIEMENS frequency protection, type SIPROTEC 7SJ82.
- Reclosing equipment, monopole and three-pole, in combination with line protections. SIEMENS, model 7DS5225-5DE29.
- SIEMENS SIPROTEC 5 tripping equipment as standardized by REE.
- A set of fiber optic connections and the needed accesories to connect the previous equipment with the fiber optic junction boxes.

All protections are digital and will allow full test for all functions still during ordinary service. All protections will allow the connection via bus communications, for adjustments and data extraction, (recording of incidents, oscillography, etc.) dialoguing directly with the control system of the substation.

The protections enable to program from the engineering station located on the centralized control level.

The protections must comply with the protection general standards of the spanish peninsular electric system.

Each of the evacuation line must be equipped with a double protection system with double communication system, being able to guarantee the instantaneous and selective clearance of possible short circuits, so it can be cleared even if they appear during the failure of one protection system or one communication system.

As we declared before for the recording of disturbances in the substation, six (6) integrated oscilloperturbographs in the relay frames. Each relay frame will include:

One (1) oscilloperturbograph type DRTS (model TRANSCOPE 82170) with with capacity for 10 analog signals and 12 digital signals, based on the IEC 61850 standard communication module.

3.6.7.2. Control system

It will have a complete, programmable, redundant control system. This system will be connected to the control cabinets locally as well as to the protection cabinets, allowing the automation, supervision and control of all the substation.

SIPROTEC 5 includes all bay level control and supervision functions that are required for efficient operation of the switchgear. The large, freely configurable graphics display for control diagrams is available for convenient local control.

Operating actions, such as start switching sequences or displaying the message list, can be called up via the function keys. The required security is guaranteed by the key switches for local/remote and interlocked/uninterlocked switchover.

Protection and control functions access the same logical elements. From the perspective of switching devices, protection and control are treated with equal priority.

The system will have a gateway of communication with each one of the elements, and It will contain the following functional units:

- Three (3) local control cabinets provided to simplifie the equipment maintenance, with degree of protection IP55, IK10 and NEMA12. RITTAL manufacturer, model VX25. Dimensions (l x t x p), mm 1200 x 2200 x 600, manufactured and tested according to UNE-EN-60439-1 standards. Material sheet steel of 2 mm colour RAL 7035.
- Complete automation and interface units for control, automation and supervision of all 220 kV equipment. Manufacturer Siemens, model SIPROTEC 7KE85.
- Unit similar to the previous one, for command, automation and supervision of the subsidiary services of the substation. Manufacturer Siemens, model SIPROTEC 7KE85.

  It must also incorporate the necessary services of:

  - Fire protection
  - Antiintrusive
  - Lighting

These automation units must have the sufficient processing capacity to allow the handling of all the necessary equipment with the following times. This data is in accordance with the IEC standadrs and facilited by ENDESA:

- Maximum data refresh time on the screen: 10 ms.
- Maximum data adquisition time for analog signals : 500 ms.
- Maximum refresh time of the changing variables periodically measured will be below than 1s.
- Maximum refresh time of a changing state of the digital variables periodically measured, will be below than 500 ms.
- Maximum time to change an image on the screen: 500 ms.
- Maximum time to precess the logic signals: 100 ms.
- Maximum execution time of any order randomly chosen by the operator: 10 ms.
- Event sequencer resolution time: 1 ms.

Man-machine interface units for operation functions. Manufacturer SIEMENS, model DIGSI 5. Manufacturing and testing standards IEC 60253-5.

CPU units and plasma screens, both for personal control of the substation as for the storage of the data collected in the substation database,SIEMENS manufacturer DIGSI 5 configuration.

3.6.7.3. Measurement system

It is necessary to measure the currents, voltages and powers in the substation in both high and medium voltage bars to be able to notice anomalies in the equipment or in the system, therefore we will need a system for measuring the following characteristics:

Measuring converters, of SIEMENS, modular unit type SIPROTEC 5.01 class UT85 , manufactured and tested according to IEC 60253-5 standard.

It will be installed commercial measurement systems mounted within the measurement cabinets, according to the current regulation of measurement consumption points and transits of electric power approved by “ el Real Decreto 1110/2007” (August 24).

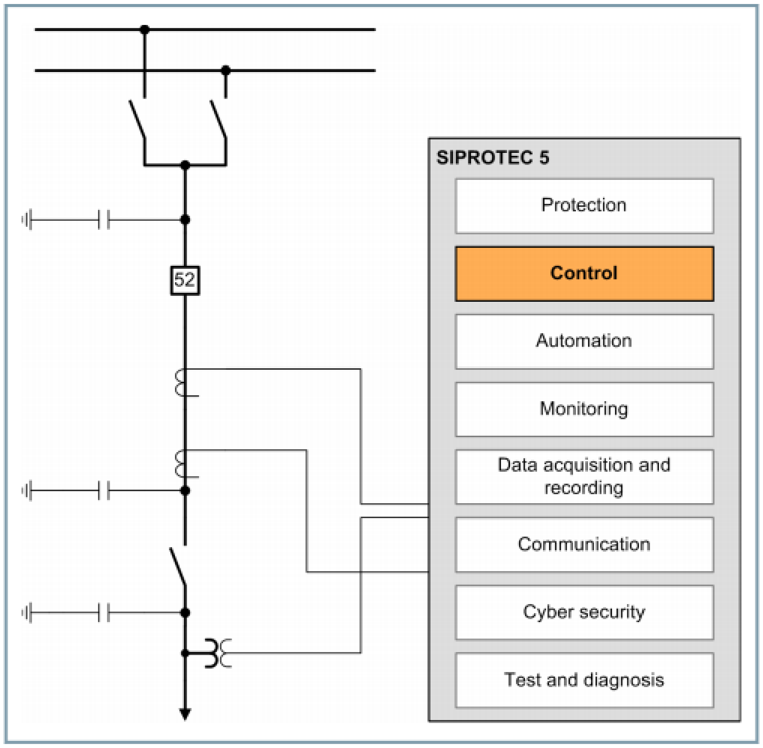


Ilustración. Scheme of the function integration with SIPROTEC 5, Siemens catalogue. https://www.automation.siemens.com/tip-static/dlc/en/Energy-Automation-for-Medium-Voltage/Catalog_SIPROTEC_5_Protection.pdf

3.6.7.4. Communication system

For the communication between substations will dispose of:

- One (1) cabinet with four optical distributors will be included for the interconnection with the substations. With degree of protection IP55, IK10 and NEMA12. RITTAL manufacturer, model VX25. Dimensions (l x t x p), mm 1200 x 2200 x 600, manufactured and tested according to UNE-EN-60439-1 standards. Material sheet steel of 2 mm colour RAL 7035.

- One (1) optical distributor cabinet, RITTAL manufacturer, model VX25. Dimensions (l x t x p), mm 1200 x 2200 x 600, manufactured and tested according to UNE-EN-60439-1 standards. Material sheet steel of 2 mm colour RAL 7035.

These communications will be made through fiber optic cable since it allows a superior data transmission, speed and reliability, at the transmission.

For the internal communications of the substation, it will be disposed an Ethernet network where it will be connected the desktop computers of the substation and the authorized staff laptops.

3.6.7.5. Earthing network

The installation will be endowed with an underground mesh at 1-meter depth respect to the surface at the passable basement and another grid below 1 meter of the surface. Its objective is to reduce the step and contact voltage to admissible values by the regulation, both for people who circulate inside as well as outside of the installation.

According to the MIE-RAT in its ITC-13, all non-active metallic elements of the substation will be connected to the lower ground mesh. They will connect:

- Frames
- Enclosures
- Metal doors
- Perimetral closing
- Slabs
- Foundations
- Footing pillars
- Screens
- Metal tanks and benches
- Etcetera.

Both the earthing service and the protection ground will share the same earthing electrode. consequently, it will be connected at this one too:

- Neutral of power transformers
- Neutral of the three-phase earthing reactances
- Neutral of the measurement transformer
- Insulated conductor screens
- Automatic valves

3.6.7.6. Ventilation

According to the specific standards forced ventilation will be carried out for technical reasons. The main reasons are the type of construction (underground), the use of batteries, the type of switchgear (GIS), and the size of the power transformers (25KVA).

Inside the technical rooms the permitted maximum temperature will be 40 ° C since this is the temperature limit during the gear operation, but for the regular operation It will be operating around 25 ° C.

According to the specific standards forced ventilation will be carried out for safety and technical reasons, for instance the construction placement (underground), the use of batteries, the type of switchgear (GIS), and the size of the power transformers (25KVA).

The ventilation system will consist of centrifugal or axial extractors. We can make an estimate calculation of the air volume needed for the refrigeration that will allows us to obtain the number of needed extractors. The necessary power of ventilation will be calculated at the calculation annex.

Figure 51.Selected model, Helix axial 37, of the CHICLOSA manufacturer.

4. CALCULATION REPORT

INDEX -CALCULATION REPORT

4. CALCULATION REPORT

The electrical study that is set out below determines the main characteristics that all the elements of the substation must meet.

To establish the theoretical basis of the calculations, and determine the electrical design of the substation, it has taken into account the UNESA recommendations, and the Complementary Technique Instruction MIE-RAT 13, specifically the Regulation on Technical Conditions and Safety Power Plants, Substations and Transformation Centers [6].

The preliminary design of the installation has been made considering the expected conditions of the connection point of the network. In the construction project they will ratify the starting data for the installation calculations.

As much as for the M.V. and H.V. cells., as for the substation protections, and the earthing network, it is necessary to carry out some previous calculations for the correct dimensioning.

4.1.1. Input data

In the current phase of the construction of the Substation, it has been contemplated the assembly of two transformers of 220/20 KV of 25 MVA, with charge regulation in the high voltage side.

All calculations have been made taking the total power of the system considering that the rated power of each transformer with mixed cooling ONAN / ONAF, is 25 MVA.

Transformers:

- Nominal power 25MVA
- Short-circuit reactance 13%

4.2. Rated current

The substation consists of four lines with a voltage of 220 kV and two power transformers in of 25 MVA each one with relation of transformation of 220 ± 9 * 1.5% / 20 kV.

The transport capacity of the 220 kV lines for our calculations is the rated power of the transformers, 25MVA, each one.

It must withhold the rated current of the transformer, by a safe margin of 20%:

$$In = 1.2\ x\ \frac{Sn}{\sqrt{3} \times Un}$$

4.2.1. Rated current at 220 kV

Using the previous formula at 220kV:

$$In = 1.2\ x\ \frac{Sn}{\sqrt{3} \times Un} = \frac{25\ x\ 10^6}{\sqrt{3} \times 220\ x\ 10^3} = 78.73\ A$$

4.2.2. Rated current at 20 kV

We proceed as before but with 20kV:

$$In = \ 1.2\ x\ \frac{Sn}{\sqrt{3} \times Un} = 1.2\ x\ \frac{25\ x\ 10^6}{\sqrt{3} \times 20\ x\ 10^3} = 866.025\ A$$

4.2.3. Rated current at 400 V

In this case the rated power corresponds with the auxiliary service power transformer, which is 630 KVA each one:

$$In = 1.2\ x\ \frac{Sn}{\sqrt{3} \times Un} = \frac{630\ x\ 10^3}{\sqrt{3} \times 400} = 1091.192\ A$$

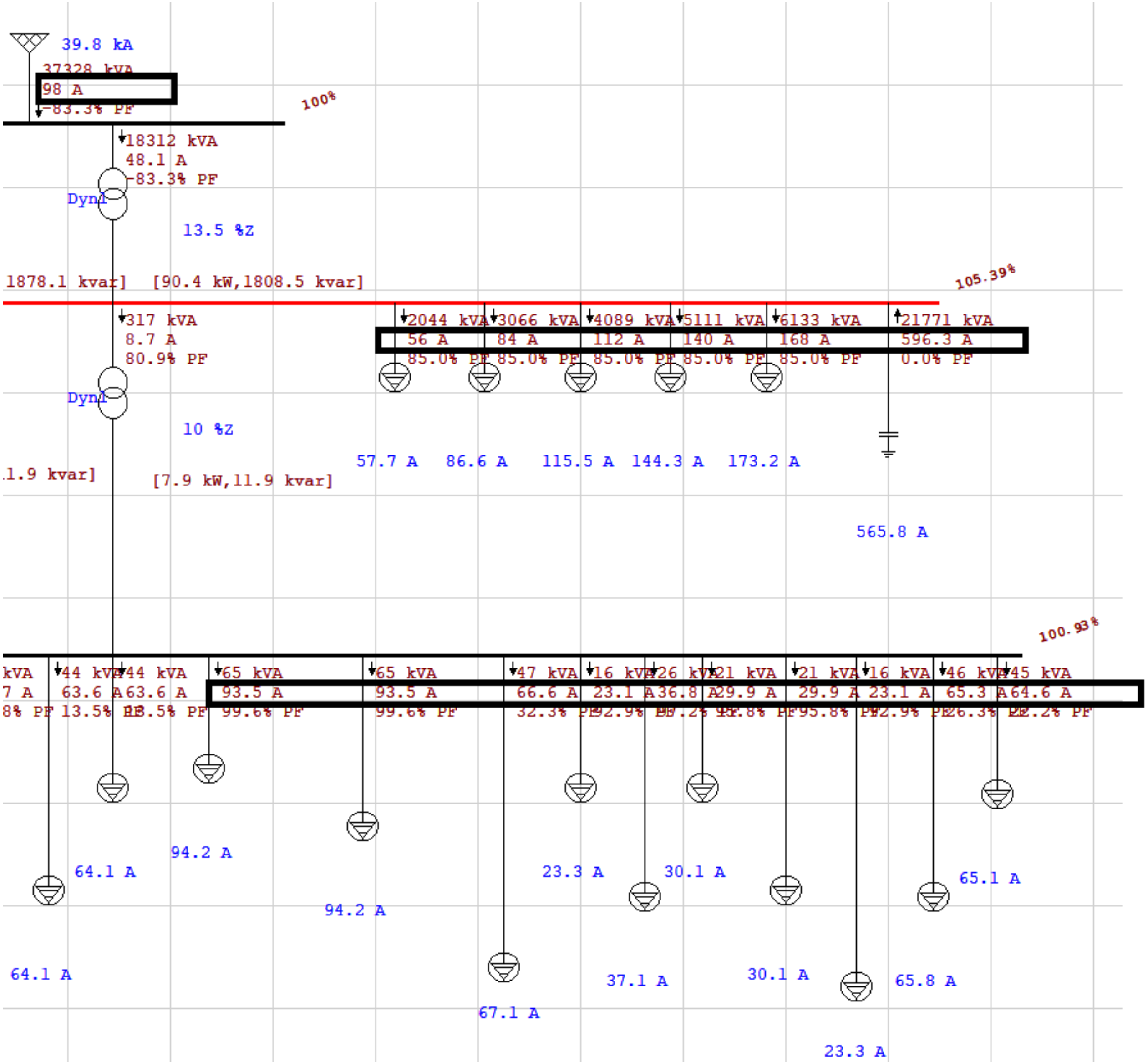


Figure 52. The different In simulated in ETAP.

SIMULATION	MODELED FOR	VERIFICATION
In=98A/4 lines	In=78.73A/1 line	✓
In=50A-600A	In=866A	✓
In=20A-95A	In=1091.19A	✓

Figure 53. Rated current comparation.

4.3.Short-circuit currents

In this section will be calculated the short-circuit currents, in the most critical points of the substation.

The following cases will be studied:

- Short-circuit three-phase in bars of 220 kV
- Three-phase short circuit in bars of 20 kV
- Three-phase short circuit in auxiliary service bars

Only three-phase short-circuits will be calculated since they are the ones that origin the highest short-circuit currents.

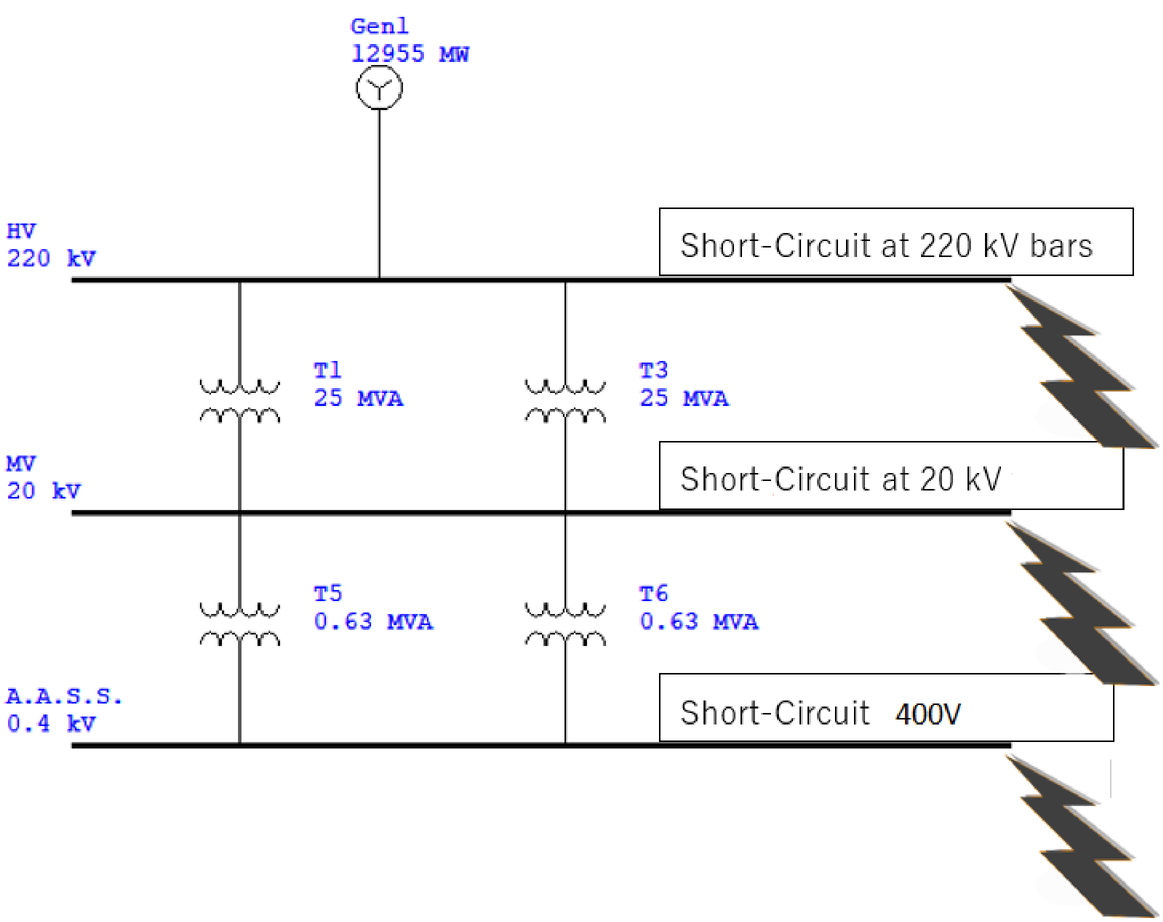


Figure 54. Short circuit at bars.

4.3.1. Three-phase short circuit at 220 kV bars

Normally we can ask to the supplying company for the energy at the connection point of the substation. In our case we will suppose, for the calculation, of the data extracted at the BOE standards.

According with the BOE num. 51 (01/03/2005) page 7429, point 3.2.1 Short Circuit Power. The designing values of the connected installations of the transport network will be at least of 50kA at 400kV and 40 kA at 220kV.

From these data, the short-circuit currents in bars will be calculated, due to is the point where the electrical demand is greater. The three-phase short-circuit current is calculated from the following formula:

$$Icc = 40\ kA$$

$$Scc = \sqrt{3} \times Un\ x\ Icc = 15242.047\ MVA$$

4.3.2. Three-phase short circuit at 20 kV bars

Once the short-circuit power is known at certain point in the system, the Thevenin equivalent circuit of the network can be calculated at that point. The nominal power of each transformer 25 MVA will be taken as the power basis.

$$Zth\ = \frac{Ub^2}{Scc} = \frac{(20\ x\ 10^3)^2}{15242.047\ x\ 10^6} = 0.0262\ \Omega$$

Once the equivalent impedance of the network has been calculated, the transformers impedances are calculated, taking into account, that the two power transformers of the substation are identical. From the technical information of the transformers, Ucc=13.5%.

$$ZT1\ = ZT2\ = \frac{Ub^2\ x\ Ucc}{Sb} = \frac{0.135\ x\ (20\ x\ 10^3)^2}{50\ x\ 10^6} = 1.08\ \Omega$$

The equivalent impedance of both transformers, results from calculating their parallel impedance:

$$ZTr = \frac{ZT1 \ x \, ZT2}{ZT1 + ZT2} = \frac{1.08}{2} = 0.54 \, \Omega$$

The equivalent impedance of the network and the transformers:

$$ZT = ZTr + Zth = 0.026 + 0.54 = 0.5662 \, \Omega$$

Finally, the short-circuit current is calculated:

$$Scc = \frac{Un^2}{Z} = \frac{(20 \, x \, 10^3)^2}{0.5662} = 706.464 \, MVA$$

$$Icc = \frac{Scc}{\sqrt{3} \times Un} = \frac{706.464 \, x \, 10^6}{\sqrt{3} \times 20 \, x \, 10^3} = 20.393 \, kA$$

4.3.3. Three-phase short circuit at auxiliary service bars

In this case, for the calculation of the equivalent impedance, in addition to the network impedances and the transformer impedances, we need to consider the impedances of the auxiliary services transformers.

With the short circuit voltage of the data sheets of the auxiliary services transformers, Ucc=6%, the impedance of the network in 400 V is calculated in the following way:

$$Zth = \frac{Ub^2}{Scc} = \frac{(400)^2}{15242.047 \, x \, 10^6} = 1.0497 \ x \, 10^{-5} \ \Omega$$

The impedance of the power transformers results:

$$ZT1 = ZT2 = \frac{Ub^2 \, x \, Ucc}{Sb} = \frac{0.135x \, (400)^2}{25x \, 10^6} = 8.64 \, x \ 10^{-4} \ \Omega$$

Therefore, the equivalent impedance of the two transformers will be obtained by calculating the parallel between both:

$$ZTr = \frac{ZT1 \ x \ ZT2}{ZT1 \ + \ ZT2} = \frac{8.64 \ x \ 10^{-4}}{2} = 4.32 \ x \ 10^{-4} \, \Omega$$

The impedance of the auxiliary service transformers, taking as base power the rated power of such transformers (630 kVA), is calculated as:

$$ZSA1 \ = ZSA2 \ = \frac{Ub^2 \ x \ Ucc}{Sb} = \frac{0.06 \ x \ (400)^2}{630 \ x \ 10^3} = 15.238x \ 10^{-3} \, \Omega$$

Therefore, the equivalent impedance of the two transformers will be obtained by calculating the parallel between both:

$$ZSA = \frac{ZSA1 \ x \ ZSA2}{ZSA1 \ + \ ZSA2} = \frac{15.238x \ 10^{-3}}{2} = 7.619 \ x \ 10^{-3} \, \Omega$$

Finally, the equivalent impedance of the network, of the power transformers and the auxiliary service transformer results:

$$ZT \ = ZTr + Zth + ZSA \ = \ 4.32 \ x \ 10^{-4} \ + \ 1.0497 \ x \ 10^{-5} \ + 7.619 \ x \ 10^{-3} \ = 8.061 \ x \ 10^{-3} \ \Omega$$

Finally, the short-circuit current is calculated:

$$Scc \ = \frac{Un^2}{ZT} = \frac{(400)^2}{8.061 \ x \ 10^{-3}} = 19.847 \ MVA$$

$$Icc \ = \frac{Scc}{\sqrt{3} \times Un} = \frac{19.847 \ x \ 10^6}{\sqrt{3} \times 400} = 28.647 \ kA$$

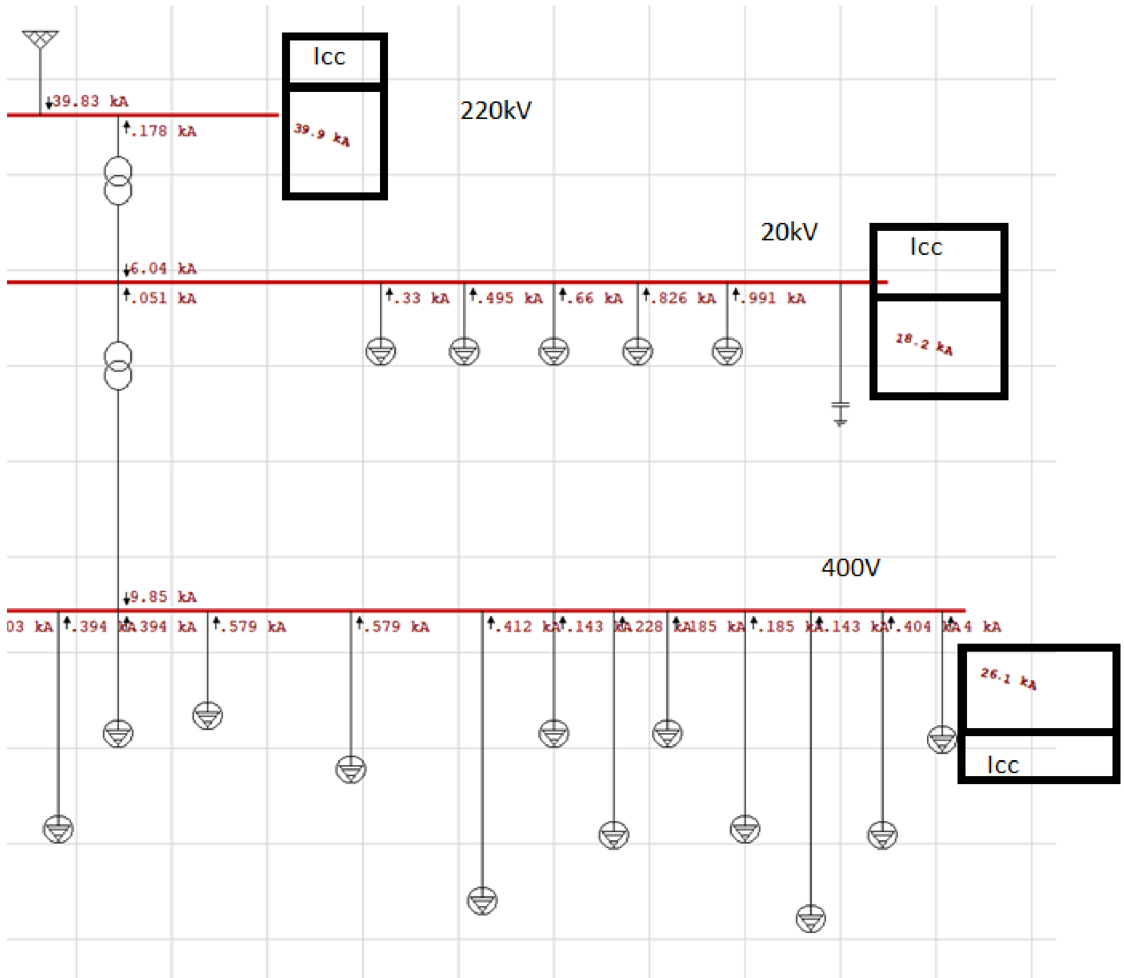


Figure 55. Simulated short circuit values at ETAP.

SIMULATION	MODELED FOR:	VERIFICATION
Icc=39.9kA	Icc=40kA	✓
Icc=18.2kA	Icc=20.393kA	✓
Icc=26.1kA	Icc=28.647kA	✓

4.4. Cables

From the of rated current and short circuit calculations of the preceding section above and applying the appropriate correction we will calculate the necessary cross sections of the conductors. Finally, the standard section will be chosen from the manufacturer's catalog, and all the conductors will be made of aluminum, XLPE.

4.4.1. 220 kV cables

The 220 kV conductors connect the outputs of the transformer cells with the primary of the power transformers. The installation method of them will be implemented in concrete canalizations.

The regulation of High Voltage Lines does not offer instructions about the correction factors applicable to conductors with higher insulation voltages than 18/30 kV. However, for example at the catalogue the cross section of (500 mm2) meets a rated current of 734 A which is about 9 times higher than the rated current calculated. Even for the coupling cells its thick enough.

The cables will meet the specified currents at the rated and short-circuit current calculation, that is to say that at least will comply:

In >=	78.73A
Icc>=	40kA

Our delimitation is the short circuit current we need to at least 40kA. Then for 500mm2 it can withhold, during 1s, 47kA of short circuit current.

Sección nominal	mm²	400	500	630	800	1000	1200
Intensidad max admissible en el aire[5] Cu	A	800	908	1031	1160	1281	1380
Al		641	734	841	955	1071	1174
Intensidad max admissible en el aire[6] Cu	A	796	884	977	1063	1136	1232
Al		658	743	836	927	1013	1101

Figure 56.. 220kV ESTRALIN cable properties.

Corriente admisible de cortocircuito durante un segundo por el conductor								
Sección del conductor, mm^2	400	500	630	800	1000	1200	1600	2000
conductor de cobre	57,2	71,5	90,1	114,4	14	172,8	230	288
conductor de aluminio	37,6	47	59,2	75,2	93, 1	114,3	152	190

Figure 57.220kV ESTRALIN cable S-C properties.

4.4.2. 20 kV cables

The 20 kV conductors connect the secondaries of the power transformers with the medium voltage cells. The installation arrangement will be implemented in concrete canalizations, and the cables will meet the specified currents at the rated current calculation, that is to say that at least will comply, without the K factors correction:

In >=	866A
Icc>=	20.4kA

Características técnicas del cable de polietileno reticulado para la tensión de 20 kV

Sección nominal	mm^2	50	70	95	120	150	185	240	300	400	500	630	800	1000	1200
Sección de la pantalla[1]	mm^2	16	16	16	16	25	25	25	25	35	35	35	35	35	50
Espesor del aislamiento	mm	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5
Espesor de la cubierta	mm	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,7	2,7	2,9	2,9	2,9
Diametro exterior[2]	mm	31,6	33,3	34,9	36,4	37,7	39,6	41,8	44,1	47,5	50,5	54,0	58,6	62,4	67,6
Peso aprox.[2] Al conductor	kg/km	849	953	1073	1185	1386	1537	1751	1981	2455	2815	3277	3899	4557	5568
Peso aprox.[2] Cu conductor	kg/km	1158	1386	1660	1927	2314	2681	3236	3838	4930	5908	7192	8848	10744	13197
Radio mínimo de curvatura	cm	48	50	52	55	57	60	63	66	72	76	si	88	94	101
Esfuerzos adicionales de tendido Al conductor	κN	1,5	2,1	2,85	3,60	4,50	5,55	7,20	9,00	12,0	15,0	18,9	24,0	30,0	36,0
Esfuerzos adicionales de tendido Cu conductor	κN	2,5	3,5	4,75	6,00	7,50	9,25	12,0	15,0	20,0	25,0	31,5	40,0	50,0	60,0
Intensidad max admissible en el aire[2] (trefoil) Cu	A	261	325	394	453	512	585	687	786	903	1036	1182	1336	1468	1555
Intensidad max admissible en el aire[2] (trefoil) Al	A	203	252	306	352	398	457	537	616	717	830	960	1104	1236	1340
Intensidad max admissible en el aire[2] (flat) Cu	A	298	371	450	517	577	657	764	868	965	1088	1221	1359	1500	1509
Intensidad max admissible en el aire[2] (flat) Al	A	232	289	351	404	454	519	608	694	788	902	1028	1165	1304	1352

Figure 58. 20kV XLPE Al cable models, from ESTRALIN catalogue.

Since the insulation voltage of the cable will be less than 30 kV, it will meet what is indicated in the standards and their complementary technical instructions.
In this case, the applicable correction factors will be:

- Operation temperature. The average temperature inside the substation is estimated around 25ºC. This temperature must be increased in 15 K, corresponding to the installation mode in reviewable channels, in agreement with ITC-LAT 06. Therefore, the correction factor will be 1.00, since 40ºC is the designed temperature of the conductors.

Tabla 14. Factor de corrección, F, para temperatura del aire distinta de 40 °C

Temperatura de servicio, θ_s, en ºC	Temperatura ambiente, θ_a, en ºC										
	10	15	20	25	30	35	40	45	50	55	60
105	1,21	1,18	1,14	1,11	1,07	1,04	1	0,96	0,92	0,88	0,83
90	1,27	1,23	1,18	1,14	1,10	1,05	1	0,95	0,89	0,84	0,78
70	1,41	1,35	1,29	1,23	1,16	1,08	1	0,91	0,82	0,71	0,58
65	1,48	1,41	1,34	1,27	1,18	1,10	1	0,89	0,78	0,63	0,45

$$F = \sqrt{\frac{\theta_s - \theta_a}{\theta_s - 40}}$$

Table 1.Temperature correction.

- Grouping of two three-polar cable laid on trays continuous, with restricted air circulation, and a separation between the cables equivalent to the diameter length. According to table 15 of the ITC-LAT 06, the correction factor will be 0.81, for two cable terminations and the maximum number of trays, 6 and vice versa.

By the number of cells, we will probably need to exploit all the available space.

Tabla 15. Cables tripolares o ternos de cables unipolares tendidos sobre bandejas continuas (la circulación del aire es restringida), con separación entre cables igual a un diámetro d

Número de Bandejas	Factor de corrección: Número de cables tripolares o ternos unipolares				
	1	2	3	6	9
1	0,95	0,90	0,88	0,85	0,84
2	0,90	0,85	0,83	0,81	0,80
3	0,88	0,83	0,81	0,79	0,78
6	0,86	0,81	0,79	0,77	0,76

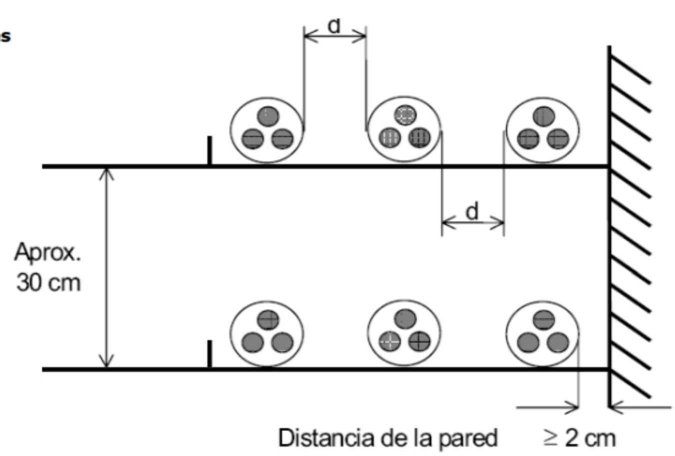


Table 2. Arrangement correction.

The permanent maximum intensity on the conductors of the same phase will be:

$$I = \left(\prod_{i}^{n} Fi \right) x\ In = 1\ x\ 0.81\ x\ 866.025 = 701.48\ A$$

Each 185 mm2 section of Al XLPE cable will withhold 457 A, so in total 914 A in nominal operation.

We can also take a tripolar cable of 500mm2 and 830 A, but it would be more expensive if we supose the price in basis of the cross section:

$$\frac{Px}{Sx} = cte \qquad\qquad \frac{P400}{S400} = \frac{2\ x\ P150}{2\ x\ S150}$$

So, the section of 400mm2 is 0.3333% more expensive than two sections of 185 mm2.

$$\frac{P400}{2\ x\ P150} = 1.3333$$

For the short circuit solicitation, the minimum section, according to the short circuit calculation, can be calculated with the following expression:

$$\frac{Icc}{S} = \frac{K}{\sqrt{tcc}}$$

Tabla 26. Densidad máxima admisible de corriente de cortocircuito, en A/mm², para conductores de aluminio

Tipo de aislamiento	Δθ* (K)	Duración del cortocircuito, tcc, en segundos									
		0,1	0,2	0,3	0,5	0,6	1,0	1,5	2,0	2,5	3,0
PVC:											
sección ≤ 300 mm²	90	240	170	138	107	98	76	62	53	48	43
sección > 300 mm²	70	215	152	124	96	87	68	55	48	43	39
XLPE, EPR y HEPR	160	298	211	172	133	122	94	77	66	59	54
HEPR Uo/U≤ 18/30 kV	145	281	199	162	126	115	89	73	63	56	51

* Δθ es la diferencia entre la temperatura de servicio permanente y la temperatura de cortocircuito.

Table 3.K value for short-circuit.

Where tcc is the time to dissipate the fault (0.5 s) and K is a parameter that is extracted from the regulation. For the isolation of crosslinked polyethylene, K takes the value of 133.

Then for two cables, the minimum section will be:

$$S = \frac{Icc\ x\ \sqrt{tcc}}{K} = \frac{20.393\ x\ 10^3\ x\ \sqrt{0.5}}{133} = 108.42\ mm^2$$

For the sort circuit cross-section, the solicitation is smaller than the rated previously calculated.

$$Sn = 2\ x\ 150mm^2 = 300mm^2\ >\ 108.42\ mm^2 = Ssc$$

Therefore, the section of each unipolar conductor will be 185 mm2, 457 A, and will be necessary in total two three-polar cables.

Corriente admisible de un segundo														
Sección del conductor mm²	50	70	95	120	150	185	240	300	400	500	630	800	1000	1200
Conductor de cobre	7,15	1,00	13,6	17,2	21,5	26,5	34,3	42,9	57,2	71,5	90,1	114,4	143,0	172,8
Conductor de aluminio	4,7	6,6	8,9	11,3	14,2	17,5	22,7	28,2	37,6	47,0	59,2	75,2	93,9	114,3

Figure 59. 20kV. ESTRALIN cable properties.

According to the manufacturer the cable can withhold a short circuit current of 14.2 kA, as we have 2 we comply all the required specifications. For the coupling cells we will dispose of the double current, so we will take the double section, 4 three-polar cables with 150mm2.

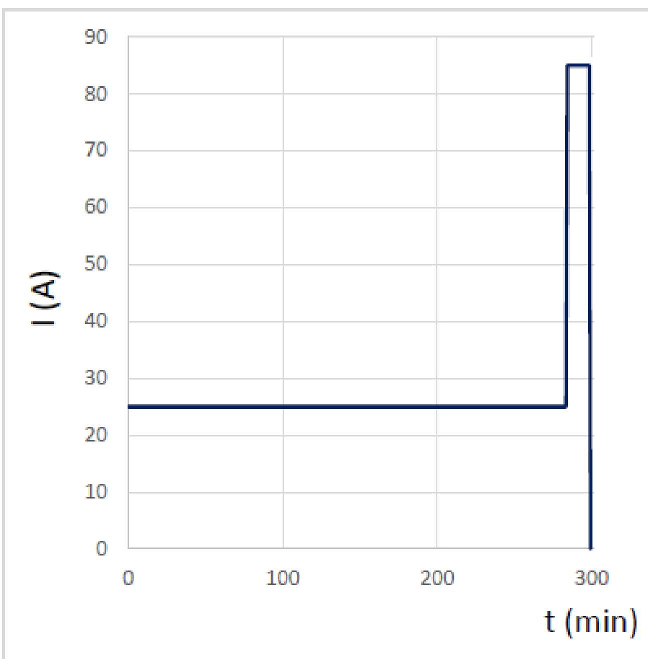
4.5.Capacitor batteries

The dimensioning of the rectifier-battery equipment is made from the following system data:
- Battery charge diagram. It represents the current provided by the battery throughout the time after losing the supplying charge.
- Permanent maximum intensity that the charger must provide.
- Nominal voltage. Maximum/minimum allowable tension during loading and
during battery discharge.

4.5.1. Capacitor batteries: 125 VCC

Then is carried out the sizing of battery nickel-cadmium (125 Vc.c.) equipment.

The solicitation diagram corresponds to the following substation consumption:



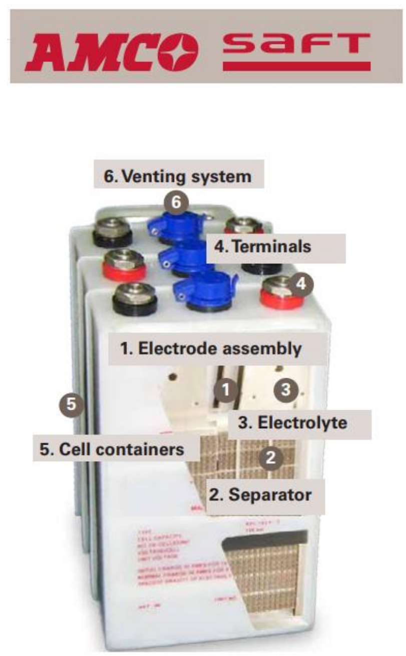


Figure 60. Charging profile in our battery model.

Subsequently, the required autonomy is approximately of 5 hours, and the tension of the system is 125 V, admitting variations of +10% (137.5 V), and -15% (106 V).

The number of elements of the battery is determined first from the floating tension, whose value will be the permanent voltage that the must withhold the equipment, so it should be close to the nominal. In this case:

- A nominal system voltage (125 V)
- Uf the floating tension per element (1.45 V / element)

The final admissible discharge voltage per element is:

$$N^{o}\ Cells = Umáx/Ucharge = 1{,}1 \times 125/1{,}45 = 94{,}83\ cells \rightarrow 95\ cells$$

$$U_{\text{ending-discharge}} = Umin/Nº\ Cells = 0{,}9 \times 125/95 = 1{,}18\ V/cells$$

This value is much higher than the final nominal discharge voltage of the battery (1 V) so the selected battery is valid.

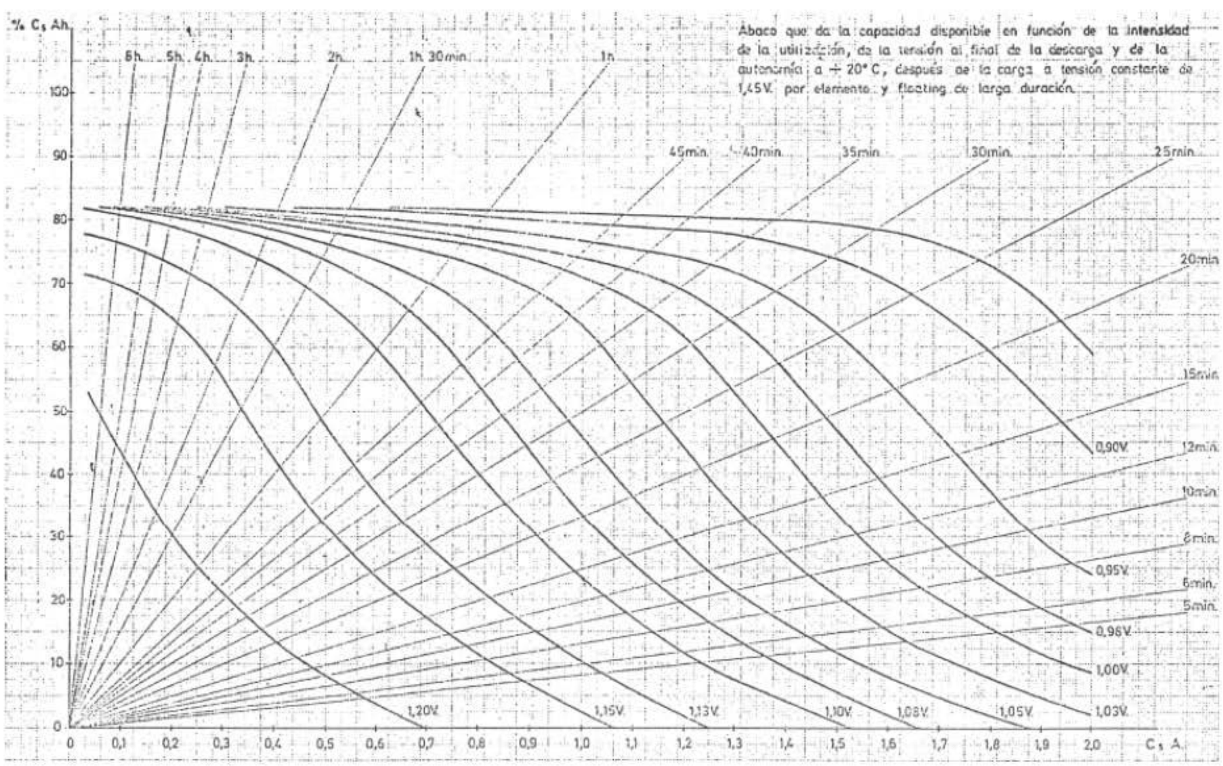


Figura 47.- Curvas típicas de descarga de elementos de níquel-cadmio

Figure 61. Ni-Cd discharge curves A-efficiency.

Then, the needed capacity for the batteries is:

$C1=25\times(4\times60+30)/60)=112.5\text{Ah}$	$C2=85\times(30/60)=42.5\ Ah$
$\eta1=68\%$: $\text{C1real}=\text{C1}/\eta1=165.44\text{Ah}$	$\eta2=28\%$: $\text{C2real}=\text{C2}/\eta2=151.78\text{Ah}$
$Ctotal=C1\text{real}+C2\text{real}=317.225Ah$ →	$\text{C}=335\ Ah$

We choose in the tables of the manufacturer for 1.14V/cell, and we select the next value in the table of the manufacturer→ 335 Ah

4.5.2. Capacitor batteries: 48VCC

- A nominal system voltage (48 V)
- Uf the floating tension per element (1.45 V / element)

The final admissible discharge voltage per element is:

$$N^{\circ}\ Cells=Umáx/U\text{charge}=1{,}1\times48/1{,}45=36.41\ cells\rightarrow37\ cells$$

$$U_{\text{endind-discharge}}=Umin/Nº\ Cells=0{,}9\times48/37=1{,}168\ V/cells$$

This value is much higher than the final nominal discharge voltage of the battery (1 V) so the selected battery is valid

Similarly, as before, the needed capacity for the batteries is:

$C1=25\times(4\times60+30)/60)=112.5\text{Ah}$	$C2=85\times(30/60)=42.5\ Ah$
$\eta1=68\%$: $\text{C1real}=\text{C1}/\eta1=165.44\text{Ah}$	$\eta2=28\%$: $\text{C2real}=\text{C2}/\eta2=151.78\text{Ah}$
$Ctotal=C1\text{real}+C2\text{real}=317.225Ah$ →	$\text{C}=335\ Ah$

L Range

Final voltage: 1.14 V/cell

Performance for fully charged cells

Available Amperes at + 20°C

Cell Type	C_5 Ah	Hours						
		10	8	5	3	2	1.5	1
KPL11P	11	1.07	1.33	2.08	3.26	4.18	4.78	5.61
KPL18P	18	1.75	2.17	3.40	5.33	6.84	7.82	9.17
KPL25P	25	2.44	3.02	4.73	7.40	9.50	10.9	12.7
KPL32P	32	3.12	3.86	6.05	9.48	12.2	13.9	16.3
KPL39P	39	3.80	4.71	7.37	11.5	14.8	16.9	19.9
KPL45P	45	4.38	5.43	8.51	13.3	17.1	19.5	22.9
KPL52P	52	5.07	6.27	9.83	15.4	19.8	22.6	26.5
KPL58P	58	5.65	7.00	11.0	17.2	22.0	25.2	29.6
KPL69P	69	6.72	8.32	13.0	20.4	26.2	30.0	35.2
KPL75P	75	7.31	9.05	14.2	22.2	28.5	32.6	38.2
KPL80P	80	7.79	9.65	15.1	23.7	30.4	34.7	40.8
KPL88P	88	8.57	10.6	16.6	26.1	33.4	38.2	44.9
KPL94P	94	9.16	11.3	17.8	27.8	35.7	40.8	47.9
KPL100P	100	9.74	12.1	18.9	29.6	38.0	43.4	51.0
KPL115P	115	11.2	13.9	21.7	34.1	43.7	49.9	58.6
KPL125P	125	12.2	15.1	23.6	37.0	47.5	54.3	63.7
KPL135P	135	13.2	16.3	25.5	40.0	51.3	58.6	68.8
KPL145P	145	14.1	17.5	27.4	42.9	55.1	63.0	73.9
KPL155P	155	15.1	18.7	29.3	45.9	58.9	67.3	79.0
KPL165P	165	16.1	19.9	31.2	48.9	62.7	71.6	84.1
KPL177P	177	17.2	21.4	33.5	52.4	67.3	76.9	90.2
KPL191P	191	18.6	23.0	36.1	56.6	72.6	82.9	97.3
KPL205P	205	20.0	24.7	38.8	60.7	77.9	89.0	104
KPL216P	216	21.0	26.1	40.8	64.0	82.1	93.8	110
KPL230P	230	22.4	27.7	43.5	68.1	87.4	99.9	117
KPL240P	240	23.4	29.0	45.4	71.1	91.2	104	122
KPL256P	256	24.9	30.9	48.4	75.8	97.3	111	130
KPL265P	265	25.8	32.0	50.1	78.5	101	115	135
KPL282P	282	27.5	34.0	53.3	83.5	107	122	144
KPL290P	290	28.3	35.0	54.8	85.9	110	126	148
KPL310P	310	30.2	37.4	58.6	91.8	118	135	158
KPL335P	335	32.6	40.4	63.3	99.2	127	145	171

Figure 62. catalogue of the manufacturer AMCOSAFT, for further information: amcosaft.com/sites/default/files/document_repo/AMCO%20Saft%20KP%20Range_final%20web_0.pdf

4.6. Isolation level

The isolation of the equipment used in the H.V. at which is referenced in the RCE ITC-12, should be adapted to the standardized values shown in the UNE 21 062 standard, except in special cases duly justified by the installation designer. The normalized values of the nominal insulation levels of the H.V. apparatus, defined by the rated supported voltages for different types of dielectric stresses, are show in the tables 1, 2 and 3 gathered in three groups according to the maximum value of the material voltage.

- Group A: Voltage greater than 1 kV and less than 52 kV.
- Group B: Voltage equal to or greater than 52 kV and less than 300 kV.
- Group C: Voltage equal to or greater than 300 kV.

4.6.1. HV cells

In line with this instruction, the isolation level of this substation belongs to the Group B, with voltage equal to or greater than 52 kV and less than 300 kV, since it has 220 kV of rated voltage. In this voltage range the choice, of insulation level, should be made mainly in function of the lightning and short-time surges at industrial frequency, which they can withhold.

Below are the tables belonging to the MIE-RAT 13, where it is established the insulation levels values to meet with the substation equipment.

Highest voltage for the material	Rated voltage supported during lighting impulse test (shock wave)	Short-time rated voltage supported at industrial frequency
kV rms	kV peek	kV rms
245	650 750 850 950 **1050**	275 325 360 395 **460**

Table 4. Insulation levels for high voltage equipment, up to 300 kV

4.6.2. MV cells

Similarly, as stated above for this range of voltages the choice of insulation level should be made mainly as a function of lightning and short-time surges at industrial frequency, which they can withhold.

Highest voltage for the material	Rated voltage supported during lighting impulse test (shock wave)	Short-time rated voltage supported at industrial frequency
kV rms	kV peek	kV rms
24	95 **125**	***50***

Table 5.Insulation levels for high voltage equipment, up to 52 kV

4.7.Geotechnical report

4.7.1. Introduction

The following study is essential to size our grounding network since the voltage levels to be considered as allowable depend on the soil characteristics where it will be placed. Another useful aspect of this report will be the awareness of the soil on which our substation is going to be based on,

The field work and the results of the tests carried out on samples and controls obtained of them permit to obtain accurate information of the conformation and geotechnical characterization of the subsoil.

For our case we will dispose of the inform realize by the itc (Technic Institute of the Construction) and provided by the University of Alicante in its website (https://web.ua.es/estudio-geotecnico/doc/full/Informe_completo_2.pdf). We can obtain some comparable values for our project. For our purpose this should be enough but in a real project we should perform the required tests in our location and get precise values.

4.7.2. Object of the geotechnical report

The study aims to identify and locate the different levels that constitute the subsoil of the area, interpreting their interrelation and verifying possible causes that may be the cause for the construction instability, always under the perspective of soil mechanics.

In the same way, the parameters and geotechnical characteristics that will be determined allow to analyze the interaction between the soil and foundation structure, predicting the presumed behavior of the different foundation models which are considered suitable for the planned structure.

4.7.3. Recognition of the soil and other tasks

The fieldworks carried out for the geotechnical characterization have been based on:

- Field survey.
- Three endurance tests using Dynamic Penetrometer, continuously performed until the obtained rejection, with different shocks and extractions. The used penetrometer will meet all the requirements of homologation according to the UNE 103801 standard.
- Sampling "in situ" both on the surface and in the depths required for analysis.

With the samples of the witnesses recovered in the surveys, the following laboratory tests:

- Granulometric analysis by sieving (UNE 103 101: 95)
- Determinations of Atterberg limits (UNE 103 103: 94 and 103 104: 93)
- Determinations of bulk density (UNE 103 301: 94)
- Determinations of natural humidity (UNE 103 300: 93)
- Swelling pressure (UNE 103 602: 96)

The following table shows the values of the calculated and estimated parameters for each of the established geotechnical levels, according to the tests carried out in-situ and over recovered samples. It also may be used in the structure calculation of the substation.

The tested samples, and the obtained results are summarized in the following table:

PARÁMETROS GEOTÉCNICOS CALCULADOS Y ESTIMADOS						
NIVEL	NIVEL I	NIVEL II Entre 3.5-4.0 y 8.0 m		NIVEL III Entre 8.0 y 17-19 m		NIVEL IV
PROFUNDIDAD	Entre 1.0 y 4.0 m	Subnivel IIa Limos arcillosos	Subnivel IIb Arenas limosas	Subnivel IIIa Limos rojizos	Subnivel IIIb Limos claros	A partir de 17-19 m
Peso específico de partículas g/cm^{3}	2.690	2.670		2.675	2.705	2.705
Peso específico seco g/cm^{3}	1.65 **2.00** (*)	1.55	1.65	1.72	1.85	2.30
Peso específico aparente g/cm^{3}	1.88 **2.14**	1.97	2.03	2.08	2.17	2.45
Peso específico saturado g/cm^{3}	2.04 **2.26**	1.97	2.03	2.08	2.17	2.45
Peso específico sumergido g/cm^{3}	1.04 **1.26**	0.97	1.03	1.08	1.17	1.45
Porosidad (%)	38.7 **25.7**	41.9	38.2	35.7	31.6	15.0
Grado de saturación (%)	59.7 **53.0**	saturado		saturado	saturado	saturado
Índice de poros	0.630 **0.345**	0.723	0.618	0.555	0.462	0.176
Humedad (%)	14.0 **6.8**	> 27.0	> 23.5	> 21.0	> 17.0	> 6.5
Ángulo de resistencia interna º	20 - 24 **30 - 33**	18 - 22	19 - 23	20 - 25	25 - 30	33 - 40
Cohesión Kg/cm^{2}	0.15 - 0.25	0.00 - 0.15	0.00 (nula)	0.30 - 0.60	0.50 - 1.5	0.00 (nula)
Resistencia a compresión simple k/cm^{2}	--	0.30	--	0.92 - 1.04	5.4	--
Módulo de deformación k/cm^{2} (2)	80 - 120 **200 - 300**	30 - 50	20 - 40	80 - 160	300 - 550	1000 - 2000
Coeficiente de balasto kg/m^{3} (1)(2)	3.5 - 5.0 **5.0 - 9.0**	1.2 - 2.5	1.0 - 2.0	3.5 - 6.0	7.5 - 10.0	12.0 - 18.0
Contenido de sulfatos (mg/kg)	733.4 - 793.3	529.5 - 818.6		608.9		--

(1) PARA PLACA DE 1 PIE^{2}
(2) EN LOS NIVELES GRANULARES LOS VALORES DE MÓDULO DE DEFORMACIÓN Y COEFICIENTE DE BALASTO HAN SIDO MINORADOS POR ENCONTRARSE SUMERGIDOS BAJO EL NIVEL FREÁTICO
(*) LOS VALORES QUE SE MUESTRAN EN AZUL CORREPONSEN A LAS INTERCALACIONES ARENOSAS Y ARENOGRAVOSAS

Figure 63. Samples and characteristic of the soil.

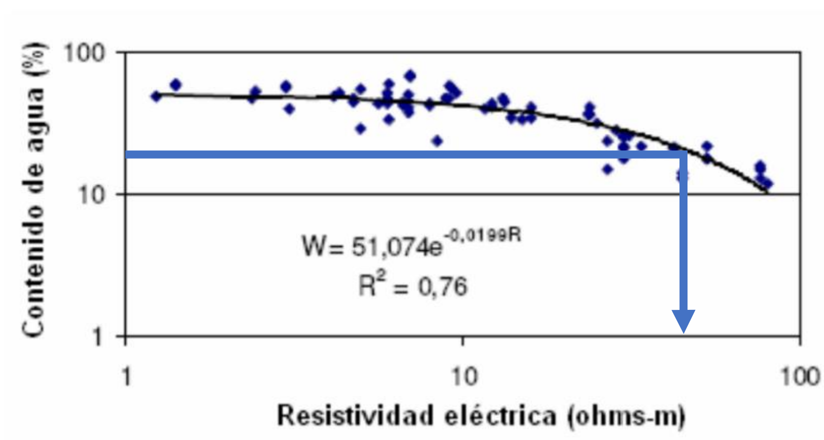
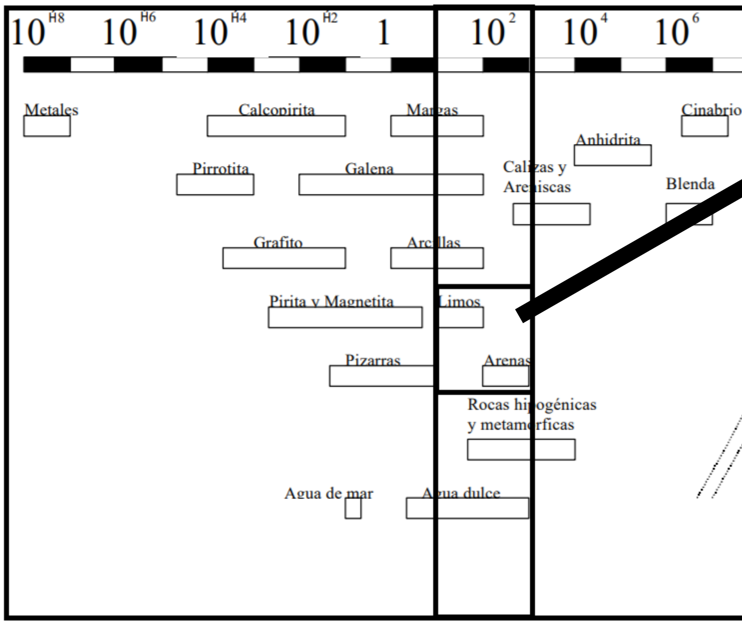


Figure 64. Relation between electric resistivity of the soil and its and humidity.

In regarding with the humidity we can observ that at 4m-17m beneath of the surface we got limo as soil composition, with an humidity of 23-27%. If we look in the previous graphic we can expect an electric resistivity of 60/80 Ω/m more or less.

And if we take a look for the standard soil resitivities of the figure 48, we can observe that the expected values should be between 20-100 Ω/m.



Naturaleza de lterreno	Resistividad Ohmios-m
Terreno pantanoso	Hasta 30
Limo	20 a 100
Humus	10 a 150
Turba Húmeda	5 a 100
Arcilla Plástica	50
Margas y arcillas compactas	100 a 200
Margas de jurásico	30 a 40
Arena arcillosa	50 a 500
Arena silícea	200 a 3000
Suelo pedregoso cubierto de césped	300 a 500
Suelo pedregoso desnudo	1500 a 3000
Caliza blanda	100 a 300
Caliza compacta	1000 a 5000
Caliza agrietada	500 a 1000
Pizarra	50 a 300
Rocas de mica y cuarzo	800
Granito y gres procedentes de alteración	1500 a 10000
Granito y gres muy alterados	100 a 600

Figure 65. Extract of Orellana 1982, "Resistivity values in different soils and rocks"

4.8. Earthing network

The main function of the earth grid is draining the discharge current or earth fault, ensuring a uniformed potential distribution in the protected area, reducing the contact voltages up to safe values.

In the case of an earth fault, only a percentage of the current is drained through the mesh, since a part is distributed by the grounding systems of the transmission and distribution lines (which are interconnected with the mesh of the substation).

The use of the grounding grid has two objectives, to provide a means to dissipate the currents to ground, without exceeding the operation limits at the equipment and to ensure that any person who could be in the vicinity or in contact with the grounded equipment does not suffer an electric shock. The requirements which must met, a grounding grid, are the following:

According to the MIE-RAT, ITC-13, all non-active metallic elements of the substation will be connected to the lower ground mesh. They will connect:

- Racks
- Enclosures
- Metal doors
- Perimetric closing
- Forged
- Foundations
- Pillars shoes
- Screens
- Metal tanks and benches

Both the service grounding and the protection ground will share the same ground electrode. Then they will be connected to this one:

- Power transformers and measuring transformer neutral point
- Three-phase earthing reactance neutral point
- Insulated conductor screens
- Automatic valves

It must have such resistance, that the system can be considered solidly earthed. The variation in resistance, due to environmental changes, should be insignificant so that the ground fault current, at any time, would be able to trigger the protections.

The wave impedance must be of low value for the easy passage of the atmospheric discharges. It must conduct the fault currents without causing potential dangerous gradients between their neighboring points. When the fault current circulates up to the maximum established fault time, there should not exist excessive heating. Furthermore, it must be a corrosion resistant material.

With the end of meeting acceptable contact and step voltages the substation will be doted of an earthing mesh of cupper cable buried 1 m below of the bracing beams level, while outside of the underground substation another grid must be buried, at 9 m of the surface level, forming the grid which is extended beneath the building.

To calculate the earthing network, we will base our calculus on the higher three-phase short-circuit current, ,40 kA.

Although the earthing network must take into account the single-phase short-circuit currents, we design the three-phase earthing network since this is the worst case in the event of a short circuit.

4.8.1. Input data

For the calculation and sizing of our grounding network, we will start with the input data that we have, as the short-circuit current already calculated, the surface that we need to protect against the fault and the characteristics of the terrain shown and analyzed in a geotechnical report.

Recommended clearing time equal to 500 ms, according with IEEE Std. 80 -2000 standard, “IEEE Guide for Safety in A.C. Substation Grounding”.

The general data of the network:

• Nominal frequency	50 Hz
• Room Temperature	40 ºC
• Clearance fault time	0.5 s
• Short circuit current	40kA

4.8.1.1. Field data

Although it is necessary to perform the Wenner method to measure the soil resistivity, and then perform the eathing grid calculations, taking into account the soil samples we will suposse the resitivity.

• Surface layer	
o Type of material	Concrete
o Thickness of the surface layer	0.2 m
o Resistivity	3000 $\Omega \cdot m$
• First layer	
o Type of land	Silt
o Thickness	4 m
o Resistivity	60-70 $\Omega \cdot m$
• Second layer	
o Type of land	Silty sand
o Thickness	4 m
o Resistivity	70-80 $\Omega \cdot m$
• Third layer	
o Type of land	Red silt
o Thickness	10 m
o Resistivity	90-100 $\Omega \cdot m$

4.8.1.2. Line data

• Voltage levels	220/20 kV
• Level at where the fault is calculated	220 kV
• Short-circuit current (Icc)	40 kA
• Fault current (Ig)	28 kA

Since the voltage installation is greater than 100 kV, is rigidly earthed to the neutral, and in addition we are using the three-phase short circuit current value instead of the one-phase, according to the MIE- RAT 13, we can reduce at 70% the grounding current value:

$$Ig = IG\ x\ 0.7 = 28\ kA$$

Two conductors rise from the mesh to the surface; thus, the intensity is divided by two.

$$If = \frac{Ig}{2} = 14\ kA$$

• Corrected fault current (If)	14 kA

4.8.1.3. Conductor data

• Cross section of the conductors	240 mm2.
• Diameter of the conductor	17.48mm
• A current density of Cu of	160 A / mm²
• A short circuit current (Ic)	20 kA

4.8.1.4. Geometric data of the substation

In the calculation, the dimensions of the plant will be considered enlarged by 1 meter per side, in order to cover the entire covered area by the substation and its accesses.

• Larger side of the mesh	60+2 m
• Minor side of the mesh	60+2 m
• Area	3600m2
• r_{AREA}	33.851m
• Depth of the mesh conductors	h =1 y 9 m
• Thickness of the surface layer	hs = 0.2m
• Grid side	s = 2m
• Number of grids	31

Longitudinal conductor	31 x 62 = 1922 m
Transversal conductor	31 x 62 = 1922 m
Total length	= **3844 m**

4.8.2. Earthing calculus methodology

The design of the earthing network of our installation presents two degrees of freedom. One is the grid length, and the second is the number of spikes.

The objective of the calculation is to minimize the total length of the conductors and pikes to be used, obtaining the most economic and efficient design.

Taking into account the above criteria, an iterative process is started, which start with a reasonable grid side of mesh, without considering the existence of ground spikes, and then the step and contact voltages are calculated. If the permissible voltages of step and contact, spikes are added. If this measure is ineffective, the process starts again, reducing the side mesh.

4.8.3. Step and contact voltages

In accordance with the IEC standards, the step voltage is defined as the difference of potential between the points on the ground surface, separated by a distance of one step, 1 m, in the direction of the maximum potential gradient.

Similarly, it defines the contact voltage as the potential difference between the grounding metallic structure and the grounding point of the surface at 1 m of distance in the direction of the maximum potential gradient.

In the grounding calculation it is essential to know the voltage that a person would be submitted if he or she were in the facility at the time of occurrence an earth fault.

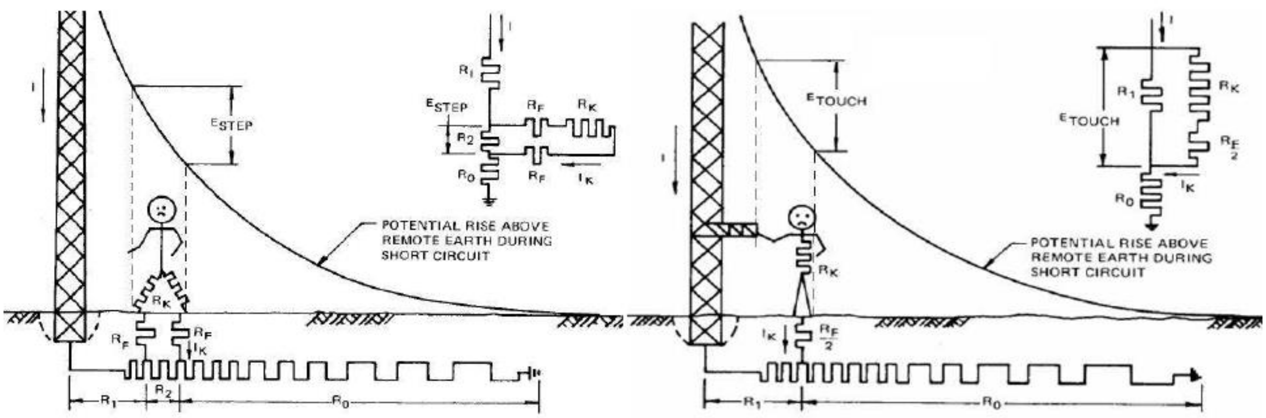


Figure 66. Contact and step voltage. By IEC standard.

The person constitutes a potential divisor among all the resistors which intervene in the circuit, so the subject is not subjected to the totality of the step or contact voltage existing at the installation, but to a fraction of the same, which constitutes the so-called step voltage or applied contact.

The applied step voltage is the fraction of the current of the step voltage which is directly applicable to the feet of a man, estimating the resistance of the human body of 1000 ohms.
On the other hand, the applied contact voltage is the voltage that results directly applicable to the human body, estimating again 1000 ohms of resistance in the human body.

The applied step and contact voltages establish a maximum limit of voltage. In all cases must be respected the maximum levels of step and contact voltage calculated using the relationships detailed in the following section.

4.8.4. Calculation of the grounding resistance. (MIE-RAT 13)

The earth resistance of the electrode, which depends on its shape and dimensions and of the soil resistivity, is calculated by:

$$R = \frac{\rho}{4\,x\,r} + \frac{\rho}{L} = \frac{70}{4\,x\,33.851} + \frac{70}{1560} = 0.5534\ \Omega$$

- R = earthing electrode resistance in ohms.
- L = length in meters of the pike, and in the mesh is the total length of buried conductors.
- r = radius in meters of a circle of the same surface the area covered by the mesh.

R is an excellent value for H.V. grids. Now we calculate the elevation grid voltage:

$$Um = If\ x\ Rm = 14\ x\ 10^3 = 7747.6\ V$$

4.8.5. Calculation of the earthing cross section, MIE-RAT 13-3.1.

This section shall be enough so when the maximum current flows through, in case of defect or atmospheric discharge, the conductors will not meet a temperature close to fusion, nor endanger their splices and connections.

For dimensioning purpose of the sections, the minimum considered time for the fault duration, at the frequency of the network, will be one second, and must not be exceeded the following current densities:

$$\boldsymbol{\rho \mathrm{Cu} \leq 160\ \mathrm{A} / \mathrm{mm2}}$$
$$\rho \mathrm{Ac} \leq 60\ \mathrm{A} / \mathrm{mm2}$$

$$Sc \geq \frac{IG}{\rho cu\ x\ 1.2} = \frac{20\ x\ 10^3}{160\ x\ 1.2} = 104.16\ mm^2$$

So, we take a greater section for our design, (that much bigger targeting the contact voltage):

$$\mathbf{Sdcu = 240mm2} \geq 104.16\ \mathrm{mm}^2 = \mathrm{Scu}$$

4.8.6. Admissible contact and step voltages calculation, MIE-RAT 13

The permissible step and contact voltages are the values that must not be exceeded at any point of the substation for the safety of the people who circulate through it.

The maximum values admitted by the MIE-RAT 13 for these parameters are in function of the ground resistivity on its surface, and the fault duration.

Step voltage:

$$Vp = \frac{10\ x\ k}{t^n}\ x\ \left(1 + \frac{6\ x\ \rho s}{1000}\right) = \frac{10\ x\ 72}{0.5^1}\ x\ \left(1 + \frac{6\ x\ 3000}{1000}\right) = 27360\ V$$

Contact voltage:

$$Vc = \frac{k}{t^n}\ x\ \left(1 + \frac{1.5\ x\ \rho s}{1000}\right) = \frac{72}{0.5^1}\ x\ \left(1 + \frac{1.5\ x\ 3000}{1000}\right) = 792\ V$$

Since the clearing time of the fault is less than 0.9 s, K = 72 and n = 1.

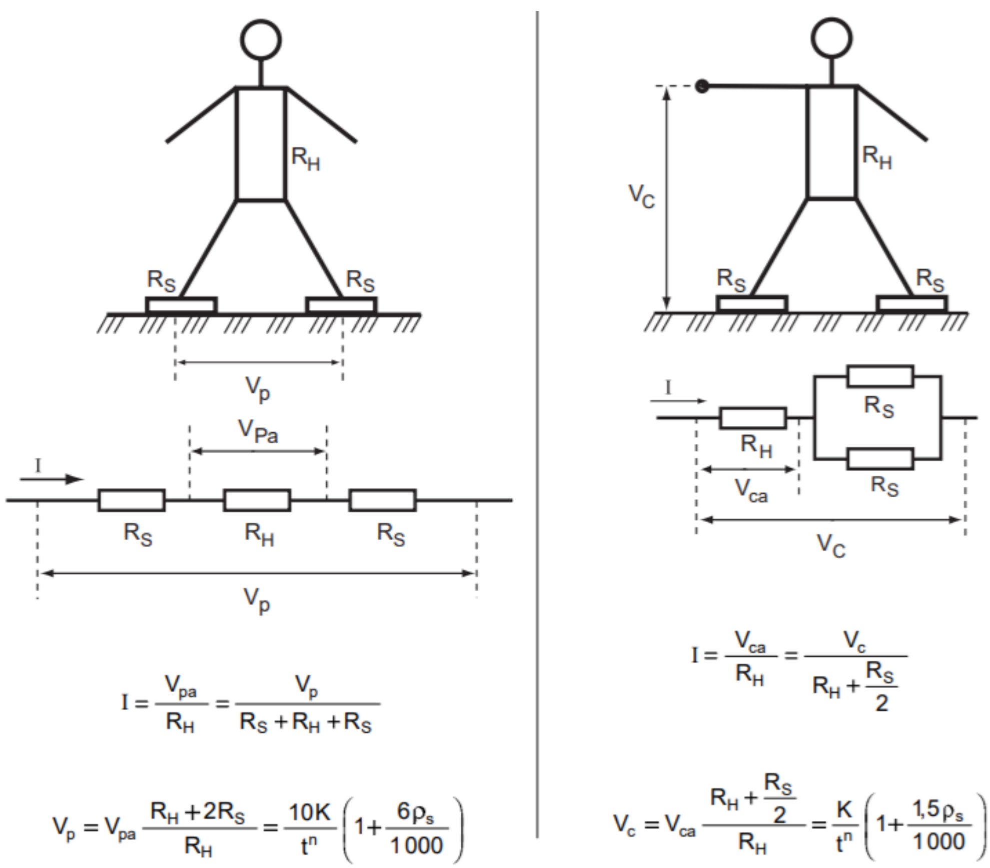


Figure 67. Contact and step voltage, equivalent impedance.

When one foot is on the threshold pavement and the other on the ground without it. In this case, the step voltage formula is:

$$Vp = \frac{10\ x\ k}{t^n}\ x\ \left(1 + \frac{3\ x\ \rho s + 3\ x\ \rho s}{1000}\right) = \frac{10\ x\ 72}{0.5^1}\ x\left(1 + \frac{3\ x\ 3000 + 3\ \mathrm{x}\ 70}{1000}\right) = 14702.4\ V$$

And outside of the substation, bare soil, ρ =70 Ω (not corrected):

Step voltage:

$$\mathrm{Vp} = \frac{10\ \mathrm{x\ k}}{\mathrm{t^n}}\ \mathrm{x}\ \left(1 + \frac{6\ \mathrm{x}\ \rho\mathrm{s}}{1000}\right) = \frac{10\ \mathrm{x}\ 72}{0.5^1}\ \mathrm{x}\ \left(1 + \frac{6\ \mathrm{x}\ 70}{1000}\right) = 2044.8\ \mathrm{V}$$

Contact voltage:

$$\mathrm{Vc} = \frac{\mathrm{k}}{\mathrm{t^n}}\ \mathrm{x}\ \left(1 + \frac{1.5\ \mathrm{x}\ \rho\mathrm{s}}{1000}\right) = \frac{72}{0.5^1}\ \mathrm{x}\ \left(1 + \frac{1.5\ \mathrm{x}\ 70}{1000}\right) = 159.12\ \mathrm{V}$$

4.8.7. Calculation of the step and contact voltage, at the installation.

After obtaining the admissible step and contact voltages for the substation, we will continue studying the voltages that appear on the surface of the same.

So that the calculated earthing mesh would be valid, the obtained voltages must be less than the admissible.

The step and contact voltages are estimated at the most unfavorable points, being these, the corner of the rectangular grounding mesh in a homogeneous resistivity ground.

4.8.7.1. Step voltage

The step voltage which will be calculated will be the one that appears between the corner surface of the network and 1 m away diagonally away from it, since it is the point of greatest gradient voltage, therefore is the most unfavorable.

The maximum predictable step voltage occurs at the periphery of the mesh, its value is calculated by the following expression:

$$Up = \frac{ks\ x\ ki\ x\ \rho\ x\ If}{L} = \ 1041.27\ V$$

Where:

- Up is the voltage between the mesh and the field 1 meter outside of the grid
- If is the fault current.
- ρ is the resistivity of the terrain outside of the grid.
- L is the length of the buried conductor.
- ks = geometric factor.
- ki = correction factor for diffused current density and corner effect.

$$\mathrm{ks} = \frac{1}{\pi}\ \mathrm{x}\ \left[\frac{1}{2\ \mathrm{x}\ \mathrm{h}} + \frac{1}{\mathrm{D}\ \mathrm{x}\ \mathrm{h}} + \frac{1}{\mathrm{D}}(1 - 0.5^{\mathrm{n}-2})\ \right] = 0.47746$$

$$\mathrm{ki} = 0.656\ + 0.172\ \mathrm{x}\ \mathrm{n} = 5.988$$

Where:

- D = Separation between parallel conductors. [m]
- h = Depth of the conductor (mesh).
- n = Number of parallel conductors of mesh. For rectangular meshes, take the greatest value from both directions, longitudinal and transverse.

Up = 1041.27 V ≤ 27360 V = Vp_Adm

We compare the maximum admissible step voltage of 2044.8V, with the calculated, and it is much bigger than the calculated value of 368.774 V.

4.8.7.2. Contact voltaje

It is calculated by the expression:

$$Uc = \frac{km\ x\ ki\ x\ \rho\ x\ If}{L} = \frac{0.2831\ x\ 5.988\ x\ 70\ x\ 20\ 000}{3844} \ = \ 617.523\ V$$

$$km = \frac{1}{2\pi}\ x\ \left[ln\left(\frac{D^2}{16\ x\ h\ x\ dc} + \frac{(\ D + 2\ x\ h)^2}{8\ x\ D\ x\ dc} - \frac{h}{4\ x\ dc}\right) + \frac{kii}{kh}\ x\ ln\left(\frac{8}{\pi(2n-1)}\right)\right] = 0.283$$

$$ki = 0.656\ + 0.172\ x\ n = 5.988$$

$$kh = \sqrt{1 + \frac{h}{h0}} = 1.4142 \qquad kii = \frac{1}{(2n)^{2/n}} = \ 0.766$$

Where:

- h : Depth of the grid
- D: sides separation of the grid
- n: Conductors in one direction, not need to correct the value for a square disposition.
- dc: conductor diameter, for 150mm2, D = 6.91mm.

Uc =617.523 V ≤ 792 V = Vc_Adm

4.8.7.3. Validation

To check if the sizing of our mesh is correct, we will compare the obtained values of maximum admissible tensions according to the MIE RAT 13:

	Step voltage (V)	Contact voltage (V)
MIE-RAT 13	27360	792
Predicted values	1041.27	617.523
Verification	☑	☑

As can be seen in the table, the admissible values for the MIE-RAT 13 are superior to those found by the calculation in our substation during possible faults or derivations to ground.

4.8.8. Report and comments.

Both the step voltages and the calculated contact voltages are lower than the maximum permissible step and contact voltages according to the MIE-RAT 13, so the of the grounding installation design of the substation is checked.

According to the MIE-RAT 13 after the installation has been built, the tests "in situ" the necessary corrections will be arranged if it would be necessary.

On the other hand, as the ground wires of the lines will be connected to the earthing network, a substantial part of the earth fault current drifts outward from thereof. And this effect supposes a reduction of the fault current value which drains through the installation electrode and therefore there will exist lower step and contact voltages.

4.9. Minimum distances

The current "Regulation on Power Plants, Substations and Centers Transformation "[6] in section 3 of the MIE-RAT-12, specifies the rules to determinate the minimum distances to voltage points.

The distances, in any case, will always be higher than those specified in such norm, which are included in the following table:

The existing "Regulation on Power Plants, Substations and Transformation Centers "[6] in section 3 of the MIE-RAT-12, specifies that the rules for the minimum distances are not valid for altitudes higher than 100 m.

The distances, in any case, will always be higher than those specified in such norm, which are included in the following table:

Rated voltage (kV)	220	20
Rated voltage at lighting impulse (kV peek)	1050	125
Minimum distance phase to ground in the air (cm)	210	22
Minimum distance between phases in the air (cm)	210	22

Table 6.Minimum distances.

The "Regulation on Power Plants, Substations and Transformation Centers" established that the minimum distances that appear in tables 4 to 7, of the MIE-RAT-12, are only valid for altitudes not exceeding 1000 meters, as in our case.

For installations that are between the 1000 and 3000 meters, these distances must be increased by 1.25% per 100 m above 1000 m.

4.9.1. 220 kV system

In accordance with the level of isolation adopted and as indicated in the Complementary Technical Instructions, MIE-RAT-12, for the voltage level at 220 kV, the minimum distances between phase-earth and between phases are 210 cm.

In the substation the distances taken between axes of phases and between axes and earth will be 400 cm for the voltage of 220 kV, higher to the minimum required.

4.9.2. 20 kV system

In the busbar connection to the 20 kV terminals of the transformer will be respected a minimum separation of 50cm for greater security. As indicated in the MIE-RAT-12 standard, the rest of the MT installation will be at the separation specified by the manufacturer that is greater than the minimum specified.

4.10. Heating and ventilation facilities

According to the standard ET/508 ''Buildings at electric substations'', ventilation devices must be provided in all the units, each different unit will have a unlike facility.

In the control room, it will be disposed the necessary air conditioning responsible for keeping the temperature of the rooms constant.

According to the code of Practice No. 101-point 6.2, for Distribution Substation Design, the height of the ventilation outlet to free air should be 2.5m above footpath or street level. The hot air outlet stream should be directed away from the personnel.

Each unit will be composed of a heating pump with evaporator and will be reversible. It is essential that in the event of a power cut (switching of auxiliary services, etc.) the equipment continue to operate without the need for manual reconnection.

Depending of the volume (1-5 kW approximately) electric radiators will be installed in the MV cells, GIS cells, and control room, thermostats, for the heating, will be included.

At the cell room 4 radiators will be installed, and due to the dimensions of the the GIS room 4 fan heaters controlled by thermostat, of 5 kW, will be installed.

Due to the kind of substation, it will have forced ventilation. For the air renewal. It will be designed the airflow and the pressure to select the adequate system.

From the ventilation practical manual, of Soler and Palau will just have to apply the following formula:

$$\mathrm{Q} = \mathrm{V} \times \mathrm{n_{ren}} = 3600\ x\ v\ x\ Sup = 60\ x\ 60\ x\ 8\ x\ 10 = 288000\ m3$$

$$\mathrm{Pd} = \frac{v^2}{16.3} = 0.552$$

Where:

- Q the airflow in m3/h.
- V is the total volume of the building.
- n_{ren} = number of renovations per hour.
- v is the velocity of the air inside of the conduct, m/s. For a compromise between the comfort and the air flow volume we will stabilised 3 m/s.

The needed diameter is too high, the standard values of diameters are between 600mm-1200mm. So, the more reasonable is to put in each room the suitable fan for its characteristics.

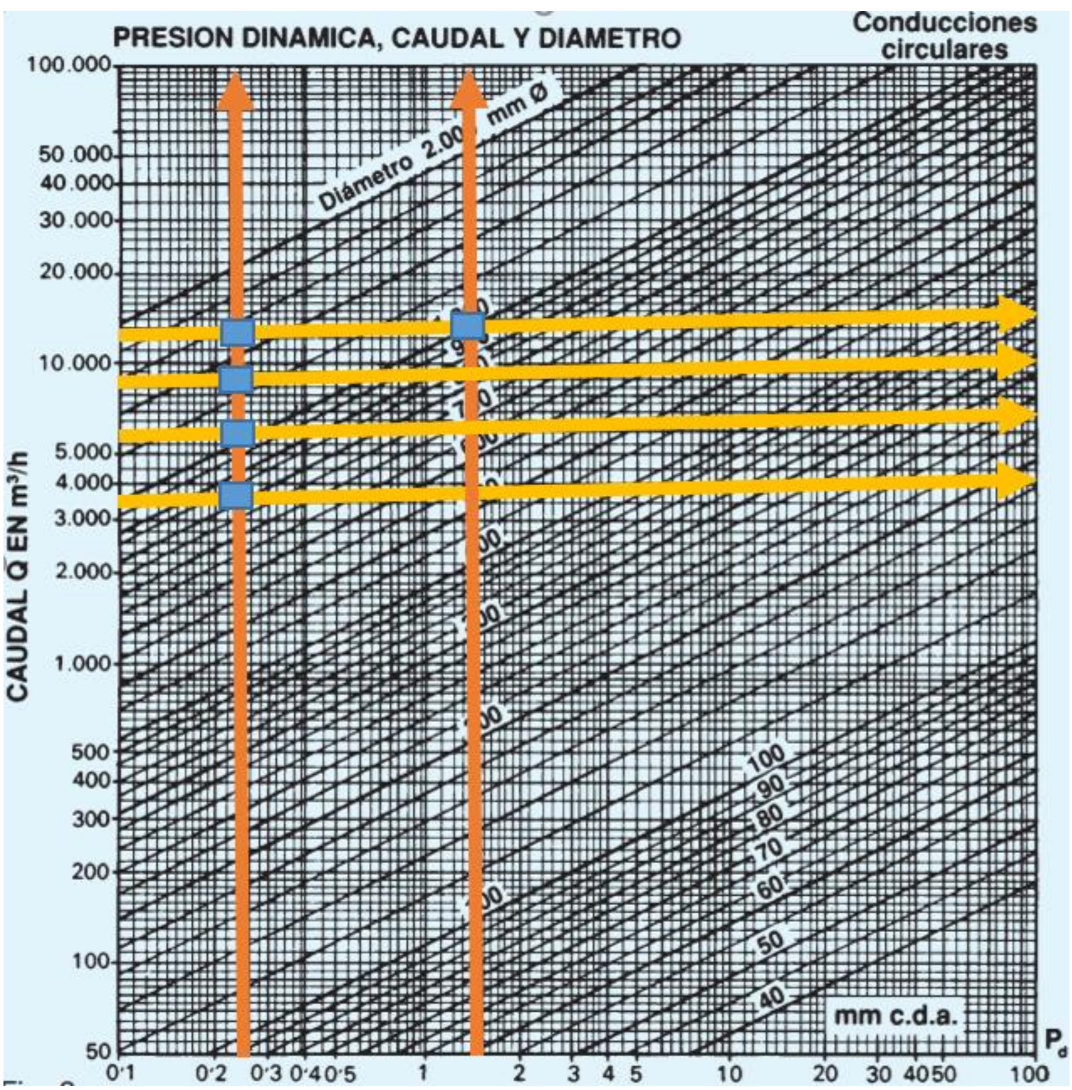


Figure 68. Diagram for the diameter calculation, from the manual of Salvador Escoda S.A.

Room	n	Vol	Q(m3/h)	vel	Pd	Diameter	Proom(W)
GIS cells	10	2700	27000	5	1.53	1000mm	1068.31
Transformer room	10	1500	15000	5	1.53	650mm	593.51
MV cells	10	2400	24000	5	1.53	1000mm	949.61
Control	10	1800	18000	2	0.25	1000mm	712.21
AASS Transformer	10	1200	12000	5	1.53	650mm	474.80
Batteries	10	1800	18000	5	1.53	800mm	712.21
Main hall	1	12000	12000	2	0.25	1000mm	474.80

Figure 69. Calculation in excel of the fun parameters.

For the calculation we have stablished a height for the air column of 10m, and for the losses we have increased the power by a 20 %. In addition, we have used 1.21 for the air density.

Room	Q(m3/h)	Q(m3/s)	Power_room(W)	HP
GIS cells	27000	7.5	1068.31	1.43
Transformer room	15000	4.2	593.51	0.80
MV cells	24000	6.7	949.61	1.27
Control	18000	5.0	712.21	0.96
AASS Transformer	12000	3.3	474.80	0.64
Batteries	18000	5.0	712.21	0.96
Main hall	12000	3.3	474.80	0.64

Figure 70. Unit transformation to contrast at the catalogue

Room	HP minimum	Q(m3/s) minimum	Power-model (HP)	Qmodel (m3/s)	Helix model	Number of funs
GIS cells	1.43	7.50	2	8.28	800-3DD	1
Transformer room	0.80	4.17	1	4.73	714-3DB	1 each room
MV cells	1.27	6.67	1.5	7.32	900-3CI	1
Control	0.96	5.00	0.75	4.27	800-3DE	1
AASS Transformer	0.64	3.33	0.75	4.27	714-3CG	1 each room
Batteries	0.96	5.00	1.5	5.53	714-4DI	1
Main hall	0.64	3.33	0.75	4.27	714-3CG	1
Total			10	54.05		9

Figure 71. Power and fans report calculation.

.

Tamaño	500				
HP Motor	0,25	0,33	0,5	0,75	1
Caudal m³/s	1,78	1,90	2,17	2,47	2,55
Hélice	3EE	3EJ	4FA	9FA	12FA

Tamaño	714						
HP Motor	0,75	1	1,5	2	3	4	5,5
Caudal m³/s	4,27	4,73	5,53	6,10	7,05	7,68	7,88
Hélice	3CG	3DB	4DI	4EE	6EJ	9FA	12FA

Tamaño	560					
HP Motor	0,25	0,33	0,5	0,75	1	1,5
Caudal m³/s	2,10	2,35	2,60	2,98	3,30	3,38
Hélice	3DA	3EA	3EJ	4FA	9FA	12FA

Tamaño	800							
HP Motor	0,75	1	1,5	2	3	4	5,5	7,5
Caudal m³/s	4,95	5,65	6,57	7,18	8,23	8,95	10,15	10,70
Hélice	3BL	3CG	3DE	3DL	4EF	4FA	9EL	12FA

Tamaño	630						
HP Motor	0,25	0,33	0,5	0,7	1	1,5	2
Caudal m³/s	2,30	2,58	3,02	3,48	3,87	4,47	4,83
Hélice	3CD	3CI	3DI	4EC	6EE	9EK	12FA

Tamaño	900							
HP Motor	1	1,5	2	3	4	5,5	7,5	10
Caudal m³/s	6,20	7,32	8,28	9,57	10,33	10,78	13,05	14,18
Hélice	3CA	3CI	3DD	3EA	3EH	3FA	6FA	12FA

Figure 72.Power and airflow for the 37-helix model.

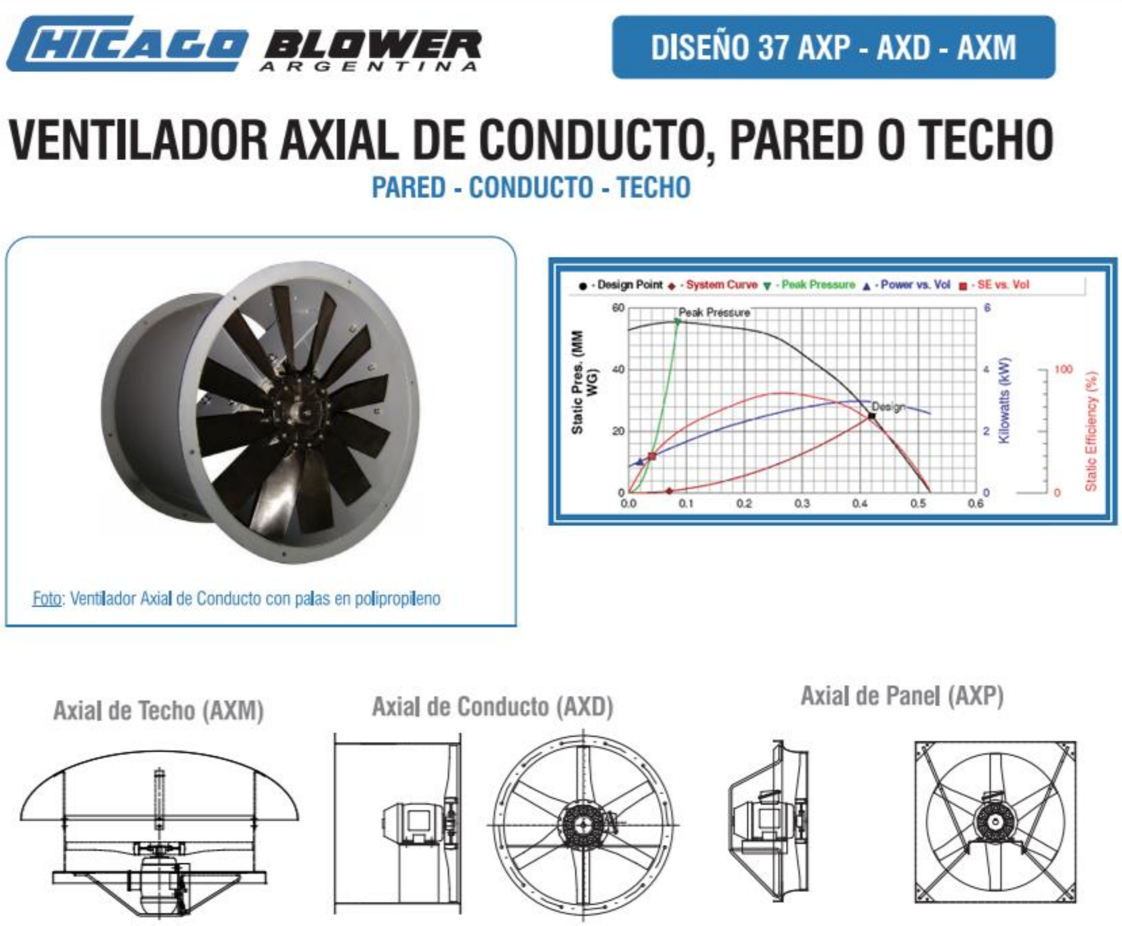


Figure 73.AXC, AXP and AXL, design 37, model of the manufacturer.

4.11. Lighting

According with the specified at the standard 3.5 of ET/RE - MA - 00007 de HCDE “Criterios Medioambientales de Diseño de subestaciones”.

For the regular operation watertight luminaires will be installed in all rooms to achieve at least a level of lighting of 150 lux, except at the control room, MV and GIS room where the level of lighting must be 300 lux.

In addition, emergency lighting will be installed providing 5 lux at the GIS, MV cells and control room, and in the other rooms will be at least 1 lux. Its activation will be automatic in case of failure of the normal lighting and will have 1 hours of autonomy.

The lighting of the substation will be provided from the auxiliary services, 400 V alternating current, since they are considered normal loads. In the event of emergency lighting, as this will be necessary in case of system failure, will be fed from the continuous power auxiliary services panel of 125 VCC.

For the calculation we have used the following formulas:

$$\text{Room Index (R.I.)} = \frac{l \times b}{h_{wc}\,(l + b)}$$

Where “***l***” is the length of the room,

“w” is the width of the room and,

h_{wc} is height between work plane i.e. Bench to Ceiling

This formula for Room Index is applicable only when room length is less than 4 times the width.

Space to Height ratio

It is the ratio of distance between adjacent luminaires (centre to centre) to their height above the working plane.

Where,

- H_m = Mounting height
- A = Total floor area
- N = No. of Luminaires

$$SHR = \frac{1}{H_m}\sqrt{\frac{A}{N}}$$

It is less than or equal to 1.

$$M.F. = \frac{\text{Lumen o/p of Lamp after some time}}{\text{Lumen o/p of Lamp when new}}$$

It is less than or equal to 1.

Typical values used for the lighting calculation are:

- 0.8 – For offices/classroom
- 0.7 – For clean Industry
- 0.6 – For dirty Industr

$$\text{Room Index (R.I.)} = \frac{l \times b}{h_{wc}\,(l + b)}$$

Room Reflectance			Room Index								
C	**W**	**F**	0.75	1	1.25	1.50	2.00	2.50	3.00	4.00	5.00
0.70	0.50	0.20	0.43	0.49	0.55	0.60	0.66	0.71	0.75	0.80	0.83
	0.30		0.35	0.41	0.47	0.52	0.59	0.65	0.69	0.75	0.78
	0.10		0.29	0.35	0.41	0.46	0.53	0.59	0.63	0.70	0.74
0.50	0.50	0.20	0.38	0.44	0.49	0.53	0.59	0.63	0.66	0.70	0.73
	0.30		0.31	0.37	0.42	0.46	0.53	0.58	0.61	0.66	0.70
	0.10		0.27	0.32	0.37	0.41	0.48	0.53	0.57	0.62	0.66
0.30	0.50	0.20	0.30	0.37	0.41	0.45	0.52	0.57	0.60	0.65	0.69
	0.30		0.28	0.33	0.38	0.41	0.47	0.51	0.54	0.59	0.62
	0.10		0.24	0.29	0.34	0.37	0.43	0.48	0.51	0.56	0.59
0.00	0.00	0.00	0.19	0.23	0.27	0.30	0.35	0.39	0.42	0.46	0.48

$$N = \frac{E \times A}{F \times n \times U.F. \times M.F.}$$

Where N = Number of luminaire required for given area

- E = Average luminance over the horizontal working plane
- A = Area of the horizontal working plane
- n = Number of lamps in each luminaire
- F = Lighting design lumens per lamp, i.e. initial bare lamp luminous flux
- UF = Utilisation factor for the horizontal working plane
- M.F. = Maintenance factor

The problem will be separated in rooms and simplified. At following it is shown the distribution and the luminosity in each room of our facility, for normal lighting:

Room	Area	Lux at working plane		Luminaires	Total	
		Minimum Lux	Lux	Power(W)	Number	Power(W)
GIS cells	22.5x15	300	354	152	8	1216
Transformer room	12.5x15(x2)	150	151		2(x2)	304(x2)
MV cells	30x10	300	337		7	1064
Control	15x15	300	321		5	760
AASS Transformer	15x10(x2)	150	183		2(x2)	304(x2)
Batteries	15x15	150	192		3	456
Main hall	30x50	150	159		15	2280
Ptotal					46	15960

Figure 74.Power and luminaires in the substation.

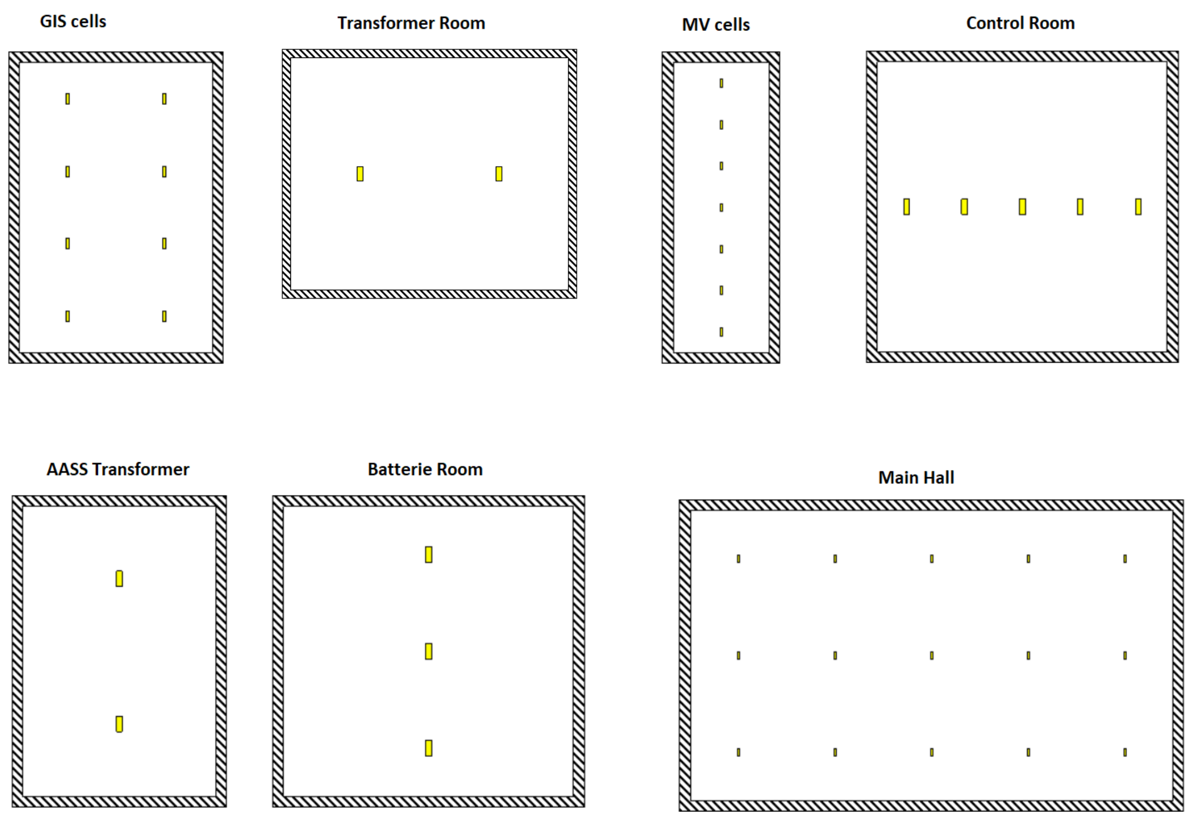


Figure 75.Luminaires distribution at normal lighting, via http://www.thornlighting.com.

Emergency lighting summary:

Room	Area	Lux at working plane		Luminaires	Total	
		Minimum Lux	Lux	Power(W)	Number	Power(W)
GIS cells	22.5x15	5	6	12	1	12
Transformer room	12.5x15(x2)	1	10		1(x2)	12(x2)
MV cells	30x10	5	7		1	12
Control	15x15	5	9		1	12
AASS Transformer	15x10(x2)	1	12		1(x2)	12(x2)
Batteries	15x15	1	7		1	12
Main hall	30x50	1	3		2	12
Ptotal					10	120

Figure 76.Power and emergency luminaires in the substation.

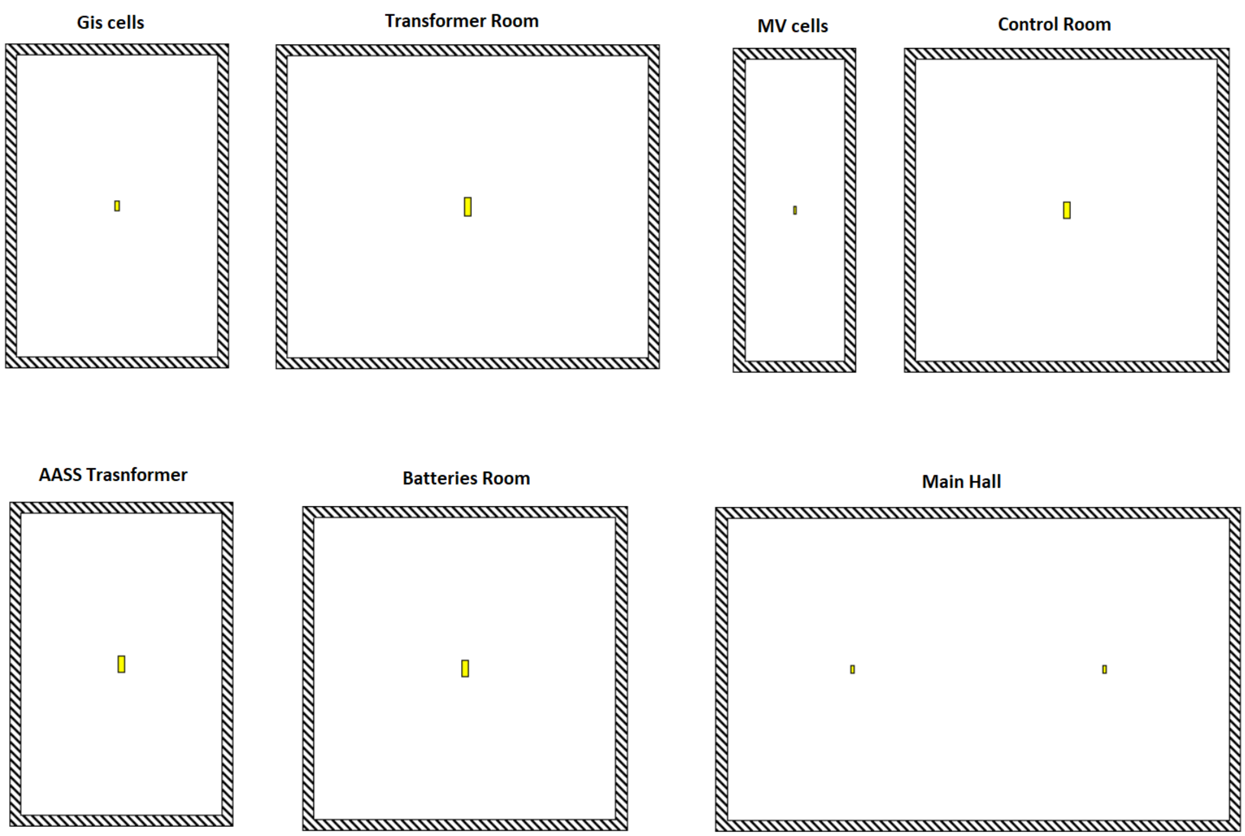


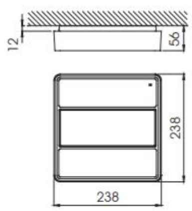
Figure 77. Emergency lighting distribution via thornlighting.com display unit.

At the next page it will be attached a resume with the luminaires and the data sheet of each model:

High-power Emergency Lighting

Atria

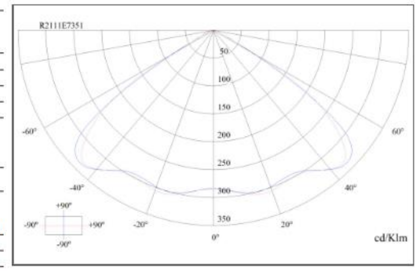
Atria Surface
Atria N48



Atria A Specifically for self-test
Atria TCA Specifically for self-test and DaisaTest system

Includes microprocessor for self-test mode operation [A] or DaisaTest centralised management system [TCA].
Fill out the reference with [A] or [TCA] depending on the model.
Example of order with open area on ceiling optical group in white colour: Atria N22 A (AT,B) / Atria N22 TCA (AT,B)

Model	Autonomy	Battery	Lumens
Non maintained:			
Atria N22 ☐	1 h	LiFePO4	1000
Atria N48 ☐	1 h	LiFePO4	2500
Atria 2N22 ☐	2 h	LiFePO4	1000
Atria 2N48 ☐	2 h	LiFePO4	2200
Atria 3N22 ☐	3 h	LiFePO4	1000
Atria 3N28 ☐	3 h	LiFePO4	1600



Model	Autonomy	Battery	Lumens Emerg.	Lumens Lum.
Maintained: (1)				
Atria P22 ☐	1 h	LiFePO4	1000	1000
Atria P48 ☐	1 h	LiFePO4	2500	1000
Atria 2P22 ☐	2 h	LiFePO4	1000	1000
Atria 2P48 ☐	2 h	LiFePO4	2200	1000
Atria 3P22 ☐	3 h	LiFePO4	1000	1000
Atria 3P28 ☐	3 h	LiFePO4	1600	1000

Atria Luminaire No battery included

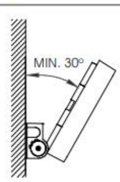
Model	Voltage	Lumens	Lamp	
Atria L22	See voltage finish	1000	MHBLED	-----
Atria L48	See voltage finish	2500	MHBLED	-----

Finishes ■ Accessories

■ Finishes

Finisf of	Description		
Optical group	Open area on ceiling	(AT)	-----
	Open area on wall	(AP)	-----
	Escape route ceilings/Walls	(EVC)	-----
Colour	Silver grey	(RAL9006)	-----
	White	(B)	-----
	Metallic grey	(GR)	-----
LED Colour	Cool white (as standard)	(-----)	-----
	Warm white (2)	(WW)	-----
	Only Maintained and Luminaire models		
Voltage:			
Self-Contained	220-230V 50/60Hz	(-----)	-----
	110-127V 50/60Hz	(110-127V)	-----
Luminaires	110-240V 50/60Hz, 170V-320V DC	(------)	-----
	24V 50/60Hz, 18-30V DC	(24V)	-----

■ Accessories

Diagram	Reference	Description	
	**KPGP Atria**	Silver grey (RAL9006)	-----
	KPB Atria	White	-----
	KPGR Atria	Metallic grey	-----
	Accessory for adjusting the angle. Suitable for installation in ceilings and walls.		

Atria Surface
Atria N48 + KPGP Atria

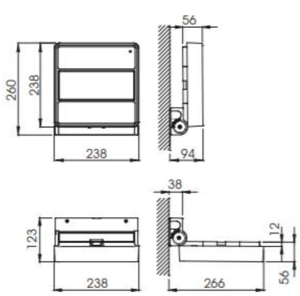


Figure 78. DASIALUX manufacturer Atria-N48 model.

THORN

HiPak Pro LED

96642987 HIPAK PRO IP66 LED18500-740 HFI-X E3 RK

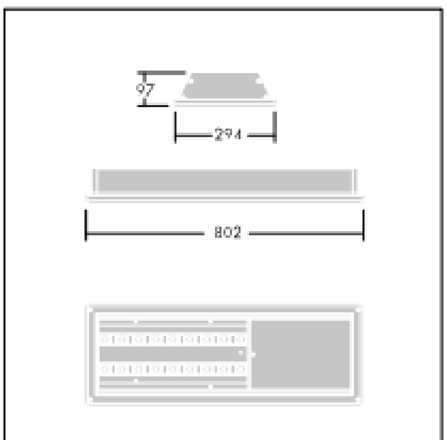
LED 152W LED_HIPP_18500	IP66	D	IK08	⏚	CE	Ta 0 +30

HiPak Pro LED

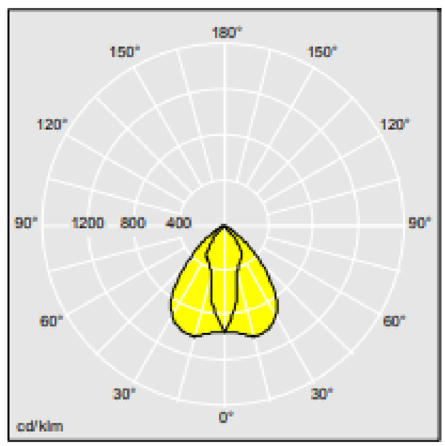
A LED High Bay luminaire with rack distribution. Electronic, DALI dimmable control gear with 3 hour, manual test, LED emergency lighting circuit. Class I electrical, IP66, IK08. Housing: anodised aluminium extrusion. End caps: die-cast aluminium (close to RAL 9006). Reflector: high grade aluminium. Front cover: polycarbonate in steel frame. Mounting kits to be ordered separately. Electrical connection via pre-fitted 2m x 6 x 1.5mm² grey cable. Complete with 4000K LED.

Dimensions: 802 x 294 x 97 mm
Total power: 152 W
Weight: 14.3 kg

TLG_HIPP_F_LEDIP66PDB.jpg



TLG_HIPP_M_LDIP66.wmf



TLG_SP_0042254.ldt

Lamp position: STD - standard
Light Source: LED
Luminaire luminous flux*: 18500 lm
Total emergency luminous flux: 500 lm
Luminaire efficacy*: 122 lm/W
Lamp efficacy: 121 lm/W
Colour Rendering Index min.: 80
Correlated colour temperature*: 4000 Kelvin
LOR: 1,00 ULOR: 0,00 DLOR: 1,00

Chromaticity tolerance (initial MacAdam)*: 3
Rated median useful life*:
50000h L80 at 35°C
Ballast: 1x HFI* Xitanium
Luminaire input power*: 152 W Lambda = 0.95
Standby Power*: 0.5 W
Charging power: 2 W
Dimming: DA2 dimmable to 1%
Maintenance category: E - Dust-proof IP5X

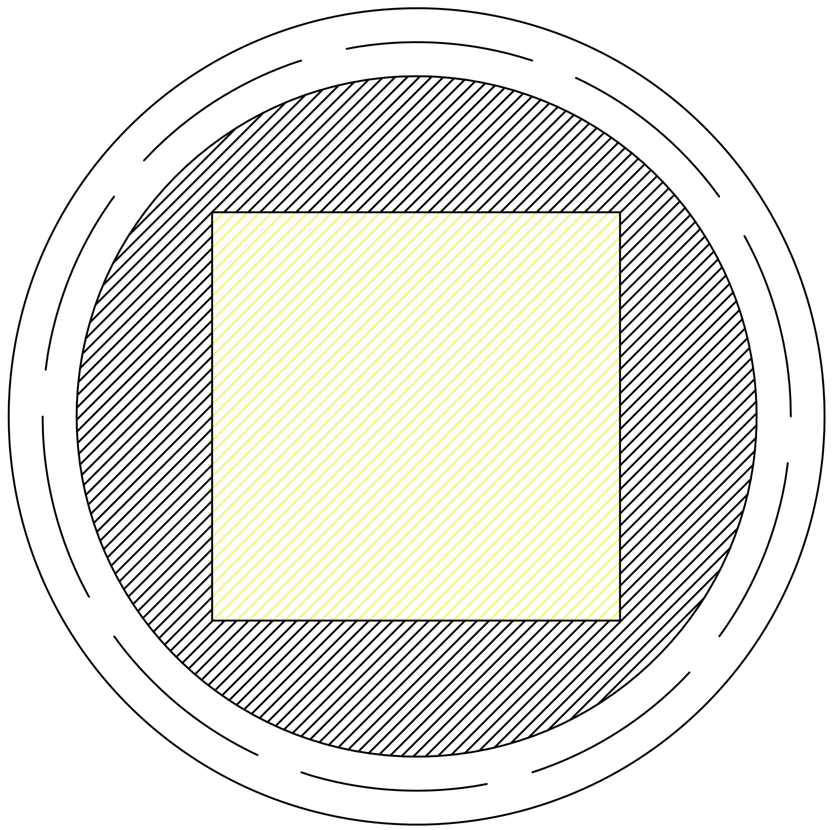
All values marked with an * are rated values. Thorn uses tried and tested components from leading suppliers, however there may be isolated instances of technology-related failures of individual LEDs during the rated product lifetime. International standards set the tolerance in initial flux and connected load at ±10%. Colour temperature is subject to a tolerance of up to +/-150 Kelvin from the nominal value. Unless stated otherwise, the values apply to an ambient temperature of 25°C.
In most products the failure of one LED point causes no functional impairment to the lighting performance of the luminaire and is therefore no reason for complaint. Unless otherwise stated all Thorn LED products are suitable for unrestricted use (rated RG0 or RG1) with regard photobiological blue light safety (IEC/EN60598-1).

Thorn Lighting is constantly developing and improving its products. The right is reserved to change specifications without prior notification or public announcement.

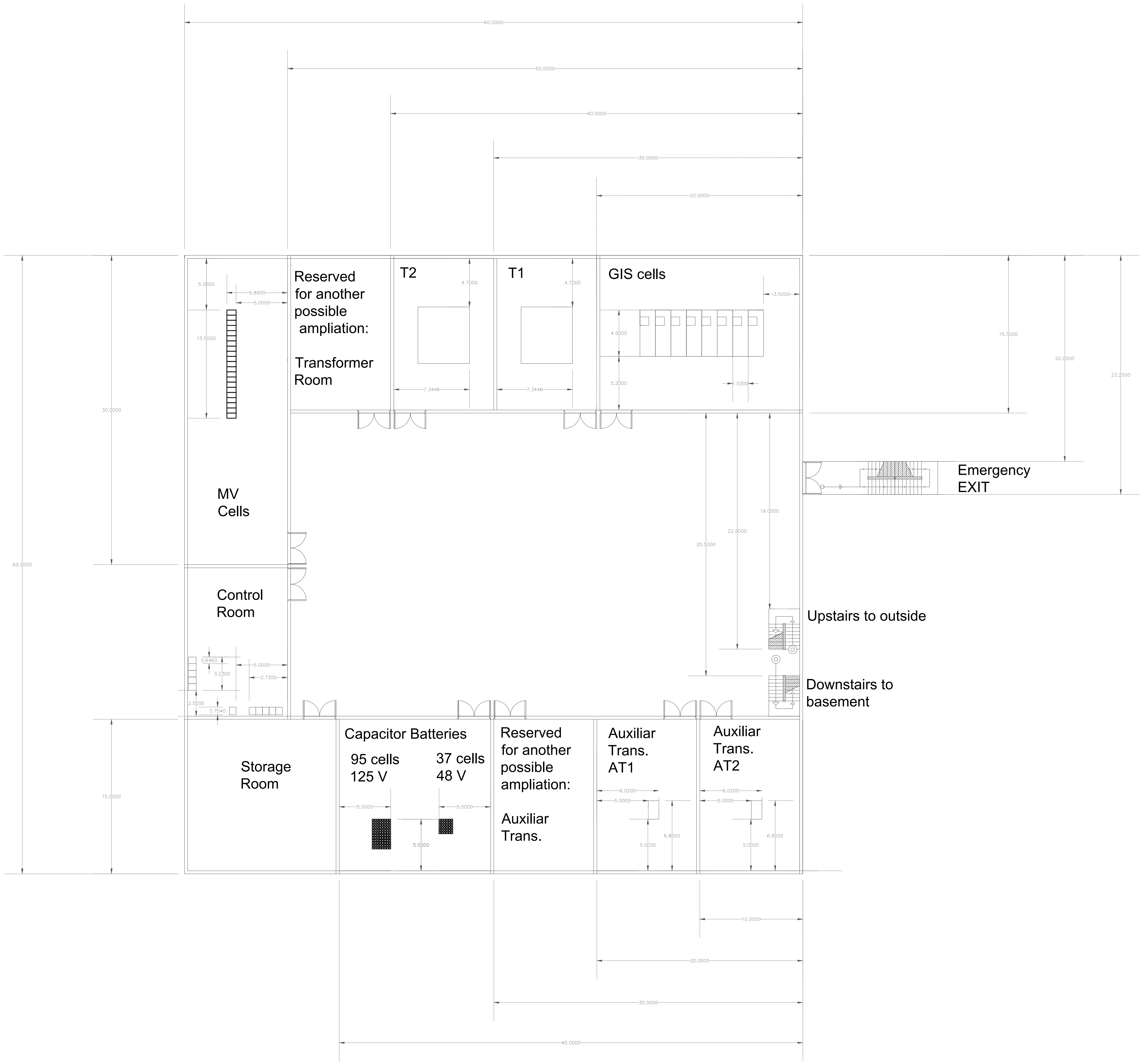
Figure 79. THORNLIGHTING manufacturer HiPak model.

5. PLANS

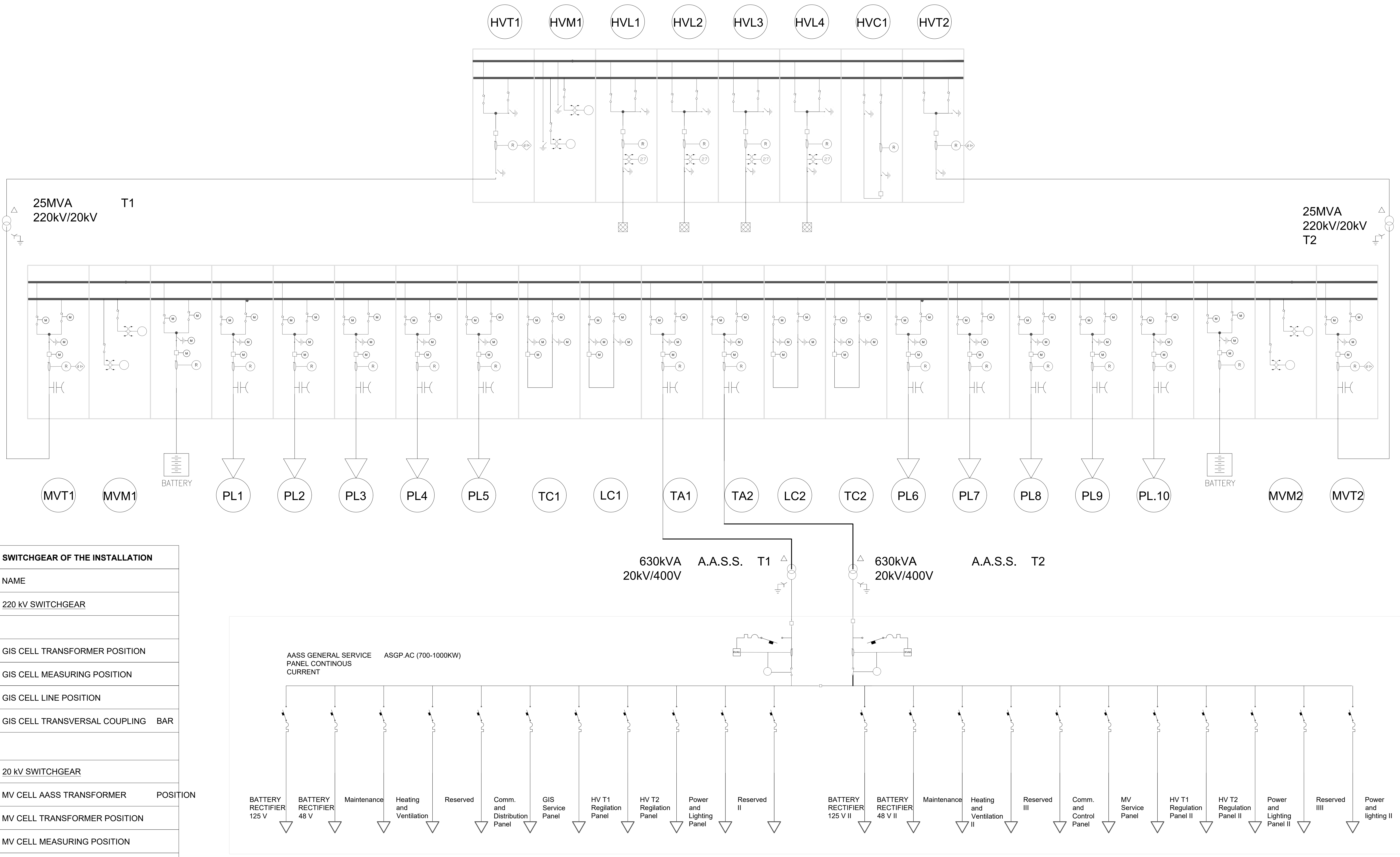
INDEX: PLANS



PLAN: LOCATION		Nº: 1	
Warsaw University of Technology	SCALE	AUTOR	ALEJANDRO RODRIGUEZ GARCIA
		TUTOR	MARIUSZ KŁOS
		DATE	09/07/2018

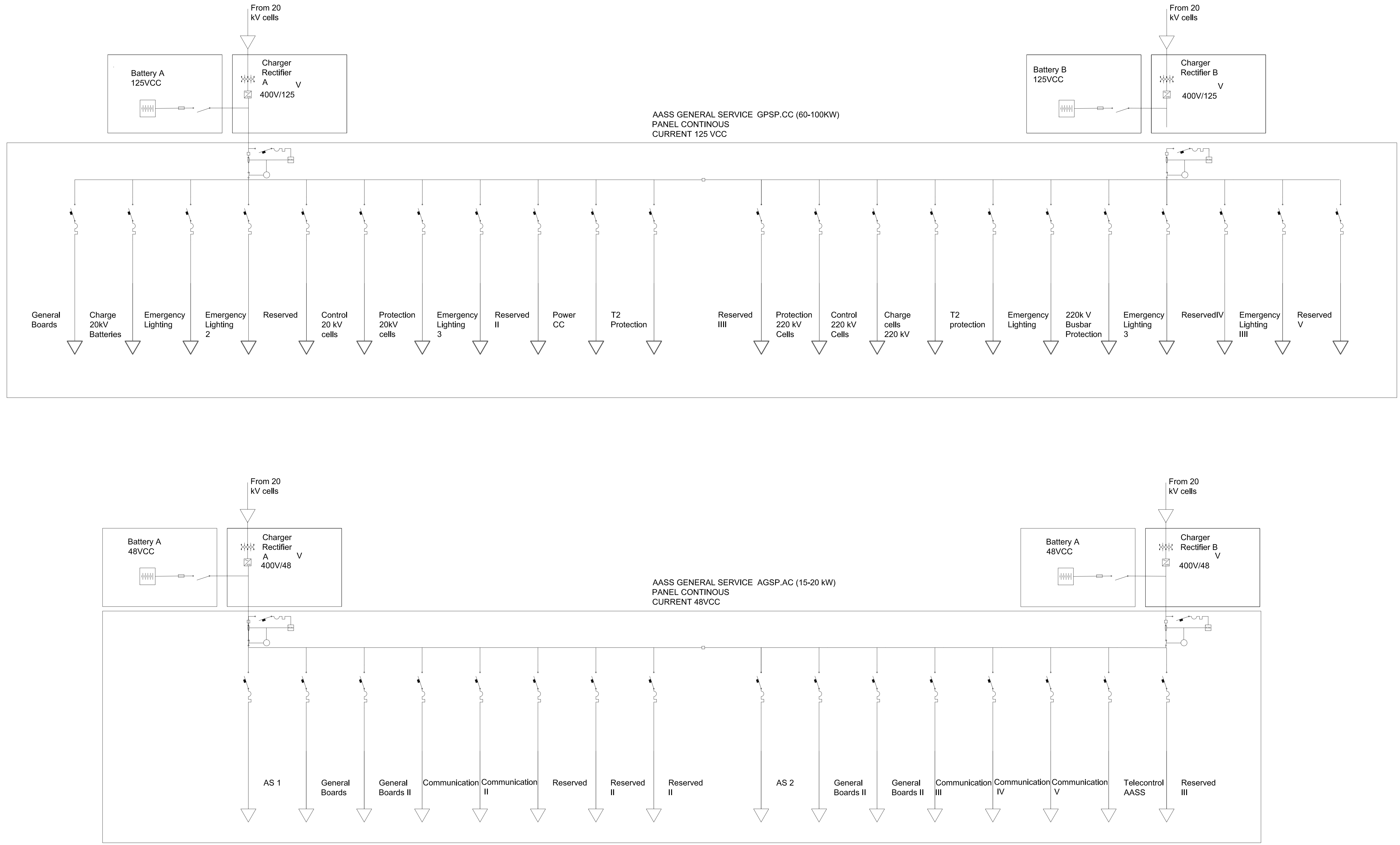


PLAN: LOCATION	Nº: 2		
Warsaw University of Technology	SCALE	AUTOR	ALEJANDRO RODRIGUEZ GARCIA
	1/400	TUTOR	MARIUSZ KŁOS
		DATE	09/07/2018

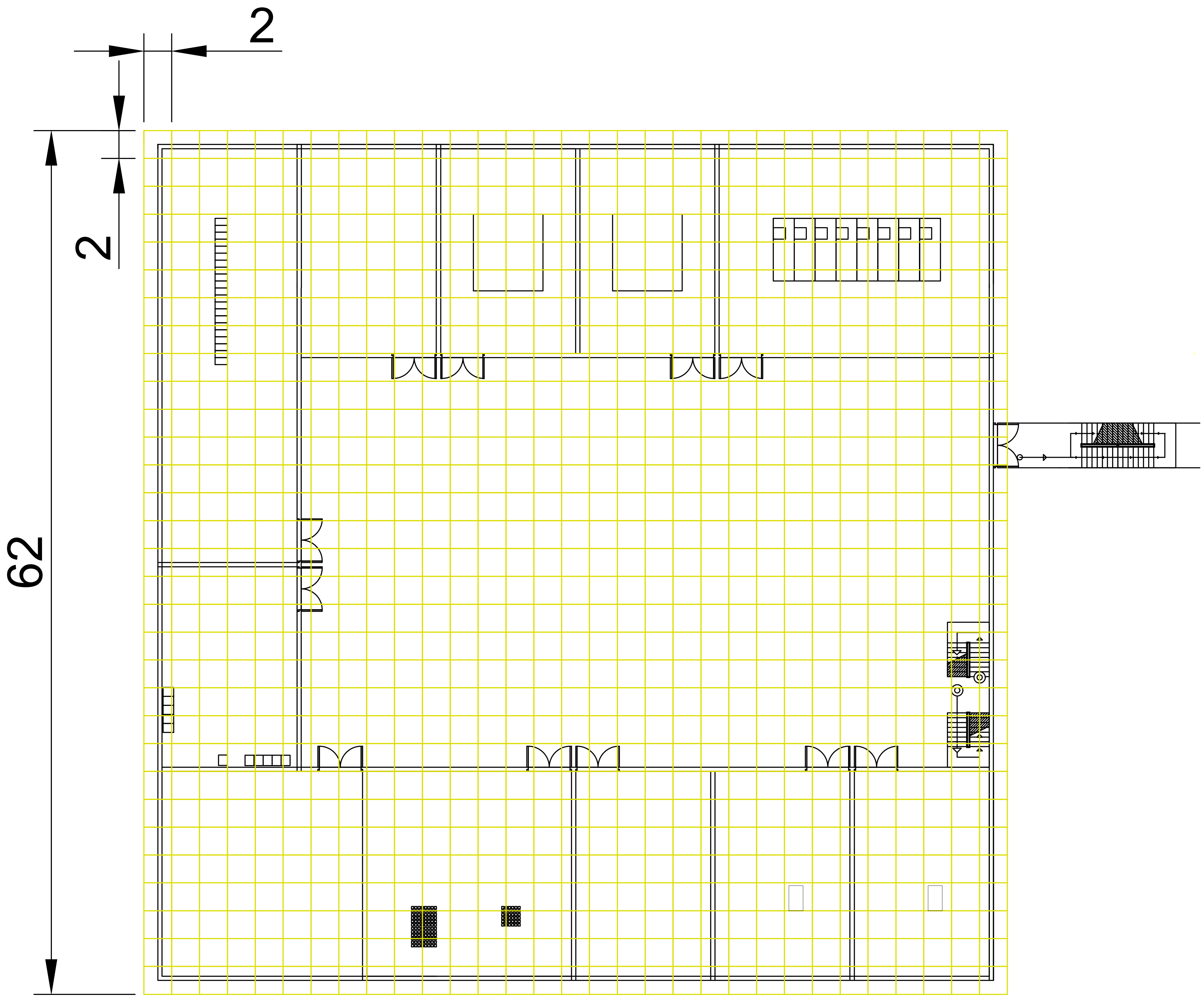


	SWITCHGEAR OF THE INSTALLATION
	NAME
HV	220 kV SWITCHGEAR
HVT	GIS CELL TRANSFORMER POSITION
HVM	GIS CELL MEASURING POSITION
HVL	GIS CELL LINE POSITION
HVC	GIS CELL TRANSVERSAL COUPLING BAR
MV	20 kV SWITCHGEAR
TA	MV CELL AASS TRANSFORMER POSITION
MVT	MV CELL TRANSFORMER POSITION
MVM	MV CELL MEASURING POSITION
PL	MV CELL LINE POSITION
TC	MV CELL TRANSVERSAL COUPLING BAR
LC	MV CELL LONGITUDINAL COUPLING BAR

PLAN: ONE-LINE DIAGRAM HV-MV	Nº: 3		
Warsaw University of Technology	SCALE	AUTOR	ALEJANDRO RODRIGUEZ GARCIA
		TUTOR	MARIUSZ KŁOS
		DATE	09/07/2018



PLAN: ONE-LINE DIAGRAM LV	Nº: 4		
Warsaw University of Technology	SCALE	AUTOR	ALEJANDRO RODRIGUEZ GARCIA
		TUTOR	MARIUSZ KŁOS
		DATE	09/07/2018



PLAN: LOCATION		Nº: 5	
Warsaw University of Technology		SCALE	AUTOR	ALEJANDRO RODRIGUEZ GARCIA
	1/500	TUTOR	MARIUSZ KŁOS
		DATE	09/07/2018

6.SIMULATION

INDEX: SIMULATION

6. Simulation on ETAP

6.1. Introduction

It is vital to contrast the calculus realized, via any capable software, in order to support the designed model by the engineer. The load flow analysis using ETAP provides reliable and accurate results. Additionally, it can be selected the calculation method and the precision or iterations for the calculations.

For this project we have implemented our model using the Electrical Transient Analyzer Program (ETAP), so with this software. we have review our model in two key parts of the project.

6.2. Power flow

The first one is the Power/Load flow analysis, which is a technique to determine the characteristics of the studied system in stable conditions. The load flow specified the margins for various contingency conditions and any overloading of the connected equipment, for large systems only +/- 5% percent of the nominal voltage is considered to be small.

Furthermore, the load flow report permits to detect and finish with the problem of undervoltage. To overcome the problem the software indicates the best place to connect the capacitor and the size. It is convenient to underline that in our system the software indicates no preference for the placement. The capacitor is calculated by the application of the following formula:

$$\textbf{Rating of Capacitor Bank (MVAr)} = \textbf{MW} * (\textbf{Tan}\ \phi_1 - \textbf{Tan}\ \phi_2)$$

Where ϕ_1 and ϕ_2 can be calculated by follow

$\text{Cos}\ \phi_1$ = Existing Power Factor

$\text{Cos}\ \phi_2$ = Required Power Factor

And for our calculations it has been defined the adaptative Newton-Raphson method, which is like the Newton-Raphson but for the first iterations uses Gauss-Seidel.

For our simulation we have compared the values of the V (%) and see the difference with or without the capacitors. As we can see in the figures, in the alarm report we can observe that with the capacitors the bus which is connected to them has an insignificant undervoltage.

On the other hand, in the case without capacitors the MV bus and the LV are in a serious undervoltage, even more than 10%, that is too much. So, in these case as we have anticipated in the calculation, it is necessary to correct the power factor with capacitors.

Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

Capacitors on

Marginal Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus8	Bus	Under Voltage	0.400	kV	0.389	97.3	3-Phase

Capacitors off

Critical Alerts Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus2	Bus	Under Voltage	20.000	kV	18.818	94.1	3-Phase
Bus8	Bus	Under Voltage	0.400	kV	0.357	89.2	3-Phase

Figure 80. Voltage behavior depending on capacitors.

6.3.Short circuit simulation

The actual systems are different than before, nowadays the character of load is severally changed. The load is drive and secured by using digital electronic controllers. For healthy and secure margins of operation the network need to be balanced and contain the fault current in the design limits. So, it is important to be secured about the calculations, both for the equipment and for the security of the people.

Generally, the transmissions networks of power systems are reaching new stressed values due to the increasing on the demand and the problems to build new substation overall, in closed and crowded places, as the cities. One of the consequences of having such stressed levels is the risk of losing stability following a disturbance.

The short circuit can appear due to a reason, usually when the insulation is broken, and within milliseconds, can increased by a hundred times its rated value of operation. The damage can be reduced till acceptable valued by using fuses breakers or other protections. In this analysis we will check if the calculation currents will match the simulated outcome of the simulation.

For the worst-case scenario, is during the 3-phase short circuit, and for the analysis all the values are similar that in our previous calculation in all the busbars, so we can argument that the values were correctly designed. And the cross sections of the cables will tolerate the current during

Short-Circuit Summary Report

3-Phase, LG, LL, LLG Fault Currents

Bus		3-Phase Fault			Line-to-Ground Fault				Line-to-Line Fault				*Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
Bus1	220.000	39.931	57.601	39.826	39.896	57.551	39.896	39.896	34.581	49.884	34.581	34.581	40.014	57.721	40.014	40.014
Bus2	20.000	18.378	46.181	12.504	15.943	40.061	15.943	15.943	15.916	39.994	15.916	15.916	17.579	44.173	17.579	17.579
Bus8	0.400	26.060	44.075	19.523	23.724	40.125	23.724	23.724	22.569	38.170	22.569	22.569	25.442	43.028	25.442	25.442

All fault currents are in rms kA. Current ip is calculated using Method C.

* LLG fault current is the larger of the two faulted line currents.

Figure 81. Short circuit values during each simulation.

6.4. Conclusion

The short circuit studies are vital for planning future expansions of power systems and it also necessary for the adequate procedure of protective system. ETAP software is a magnificent tool for system testing and simulating a different of scenarios, such as line to line fault, line to ground fault, line-line to ground fault and three phase faults. All this data is recompiled and used to define the optimum size and placement of relays and circuits breakers. In addition, the information during the faults can clarify the network voltages under the different conditions of mal functioning.

Also, it is very useful to determine the range of voltages for specified situation, for example during the loss of a load or if the transformers are saturated. Moreover, it is typically used to identify the necessity of generation, capacitive or inductive VAR support as in our case.

Finally remark that in our simulation, with the capacitors, we stay in correct values of voltage range, in this way if the load saturates the bar, at MV, there will enough margin to operate without losing the quality of the voltage and keeping the system stable.

6.5. ETAP Load Flow Report:

Buses	3
Branches	4
Generators	0
Power Grids	1
Loads	30
Load-MW	30.313
Load-Mvar	1.826
Generation-MW	30.313
Generation-Mvar	1.826
Loss-MW	0.14
Loss-Mvar	2.466
Mismatch-MW	0
Mismatch-Mvar	0

Bus ID	Nominal kV	Voltage	MW Loading
Bus1	220	100	30.313
Bus2	20	99.44	30.191
Bus8	0.4	94.74	0.49

ID	Type	kW Flow	kvar Flow	Amp Flow	% Loading
25MVA	Transf. 2W	15442	930	40.6	61.9
25MVA2	Transf. 2W	14871	896	39.1	59.6
630kVA	Transf. 2W	254	185	9.125	1.3
630kVA5	Transf. 2W	254	185	9.125	1.3

Rating	Rated kV	MW	Mvar	Amp	% PF
15175 MVA	220	30.313	1.826	79.7	99.82

ID	Rating	Rated kV	kW	kvar	Amp	% PF	% Loading	Vterm
20kV.PANNEL3	20.9 kVA	0.4	19.795	5.936	31.48	95.79	104.5	94.74
220kV.ONAF.VENT	46.5 kVA	0.4	14.846	43.534	70.07	32.28	104.5	94.74
220kV.PANNEL	20.9 kVA	0.4	19.795	5.936	31.48	95.79	104.5	94.74
CAP5	-19600 kvar	20	0	-19380	562.6	0	99.4	99.44
COMM.PANEL	20.9 kVA	0.4	19.795	5.936	31.48	95.79	104.5	94.74
CONTROL.PANEL3	20.9 kVA	0.4	19.795	5.936	31.48	95.79	104.5	94.74
HEATING	16.2 kVA	0.4	14.846	5.936	24.36	92.85	104.5	94.74
HEATING3	16.2 kVA	0.4	14.846	5.936	24.36	92.85	104.5	94.74
Lump3	2000 kVA	20	1696	1051	57.93	85	100.3	99.44
Lump5	4000 kVA	20	3392	2102	115.9	85	100.3	99.44
Lump6	5000 kVA	20	4240	2628	144.8	85	100.3	99.44
Lump7	6000 kVA	20	5089	3154	173.8	85	100.3	99.44
Lump8	3000 kVA	20	2544	1577	86.9	85	100.3	99.44
Lump15	2000 kVA	20	1696	1051	57.93	85	100.3	99.44
Lump16	4000 kVA	20	3392	2102	115.9	85	100.3	99.44
Lump17	5000 kVA	20	4240	2628	144.8	85	100.3	99.44
Lump18	1000 kVA	20	848	526	28.97	85	100.3	99.44
Lump19	3000 kVA	20	2544	1577	86.9	85	100.3	99.44
OTHER PANELS	45.6 kVA	0.4	11.877	43.534	68.75	26.32	104.5	94.74
PCI.PANNEL	11.7 kVA	0.4	9.898	5.936	17.58	85.76	104.5	94.74
POWER	16.2 kVA	0.4	14.846	5.936	24.36	92.85	104.5	94.74
PROT.SEC	45.1 kVA	0.4	9.898	43.534	68.01	22.17	104.5	94.74
RECT.BAT.125V	65.3 kVA	0.4	64.335	5.936	98.43	99.58	104.5	94.74
RECT.BAT.125V2	65.3 kVA	0.4	64.335	5.936	98.43	99.58	104.5	94.74
RECT.BAT.125V7	65.3 kVA	0.4	64.335	5.936	98.43	99.58	104.5	94.74
RECT.BAT.125V8	65.3 kVA	0.4	64.335	5.936	98.43	99.58	104.5	94.74
SERVICE	44 kVA	0.4	1.175	43.534	66.35	2.7	104.5	94.74
T1.REG	44.4 kVA	0.4	5.939	43.534	66.94	13.52	104.5	94.74
T2.REG	44.4 kVA	0.4	5.939	43.534	66.94	13.52	104.5	94.74
VENTILATION	25.7 kVA	0.4	24.744	5.936	38.77	97.24	104.5	94.74
VENTILATION3	25.7 kVA	0.4	24.744	5.936	38.77	97.24	104.5	94.74

Project:	**ETAP**	Page: 1
Location:	12.6.0H	Date: 13-07-2018
Contract:		SN:
Engineer:	Study Case: SC	Revision: Base
Filename: 1141		Config.: Normal

SHORT- CIRCUIT REPORT

Fault at bus: **Bus1**

Nominal kV = 220.000

Voltage c Factor = 1.10 (User-Defined)

Contribution		**3-Phase Fault**		**Line-To-Ground Fault**					**Positive & Zero Sequence Impedances Looking into "From Bus"**			
From Bus	To Bus	%V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
Bus1	Total	0.00	39.930	0.00	99.79	100.29	39.896	39.896	7.07E-001	1.49E-001	7.11E-001	1.43E-001
Bus2	Bus1	32.19	0.184	68.51	69.39	100.00	0.123	0.000	1.39E+001	1.56E+002		
Bus2	Bus1	32.19	0.178	68.51	69.39	100.00	0.119	0.000	1.43E+001	1.62E+002		
U10	Bus1	100.00	39.826	100.00	100.00	100.00	39.826	39.896	7.11E-001	1.43E-001	7.11E-001	1.43E-001
Bus8	Bus2	48.49	0.035	93.11	65.68	92.13	0.020	0.000	2.00E+003	6.37E+003		
Bus8	Bus2	48.49	0.035	93.11	65.68	92.13	0.020	0.000	2.00E+003	6.37E+003		
Lump3	Bus2	100.00	0.224	100.00	100.00	100.00	0.129	0.000	9.57E+001	9.57E+002		

Lump5	Bus2	100.00	0.448	100.00	100.00	100.00	0.258	0.000	4.78E+001	4.78E+002
Lump6	Bus2	100.00	0.560	100.00	100.00	100.00	0.323	0.000	3.83E+001	3.83E+002
Lump7	Bus2	100.00	0.672	100.00	100.00	100.00	0.388	0.000	3.19E+001	3.19E+002
Lump8	Bus2	100.00	0.336	100.00	100.00	100.00	0.194	0.000	6.38E+001	6.38E+002
Lump15	Bus2	100.00	0.224	100.00	100.00	100.00	0.129	0.000	9.57E+001	9.57E+002
Lump16	Bus2	100.00	0.448	100.00	100.00	100.00	0.258	0.000	4.78E+001	4.78E+002
Lump17	Bus2	100.00	0.560	100.00	100.00	100.00	0.323	0.000	3.83E+001	3.83E+002
Lump18	Bus2	100.00	0.112	100.00	100.00	100.00	0.065	0.000	2.85E+002	1.90E+003
Lump19	Bus2	100.00	0.336	100.00	100.00	100.00	0.194	0.000	6.38E+001	6.38E+002

		3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	:	39.930	39.896	34.581	40.013
Peak Current (kA), Method C	:	57.600	57.550	49.883	57.719
Breaking Current (kA, rms, symm)	:	39.896	34.581	40.013	
Steady State Current (kA, rms)	:	39.826	39.896	34.581	40.013

# Indicates a fault current contribution from a three-winding transformer
* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer

Fault at bus: **Bus2**

Nominal kV = 20.000

Voltage c Factor = 1.10 (User-Defined)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus	To Bus	% V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
Bus2	Total	0.00	18.165	0.00	108.46	106.29	15.720	15.720	1.52E+000	1.74E+001	1.28E+000	2.56E+001
Bus1	Bus2	99.27	6.253	100.37 *	100.00	99.02	6.273	7.998	3.91E+000	5.06E+001	2.52E+000	5.03E+001
Bus1	Bus2	99.27	6.038	100.37 *	100.00	99.02	6.058	7.723	4.05E+000	5.24E+001	2.61E+000	5.21E+001
Bus8	Bus2	24.34	0.051	70.60	68.94	100.00	0.030	0.000	2.66E+003	5.60E+003		
Bus8	Bus2	24.34	0.051	70.60	68.94	100.00	0.030	0.000	2.66E+003	5.60E+003		
Lump3	Bus2	100.00	0.330	100.00	100.00	100.00	0.191	0.000	9.57E+001	9.57E+002		
Lump5	Bus2	100.00	0.660	100.00	100.00	100.00	0.381	0.000	4.78E+001	4.78E+002		
Lump6	Bus2	100.00	0.826	100.00	100.00	100.00	0.476	0.000	3.83E+001	3.83E+002		
Lump7	Bus2	100.00	0.991	100.00	100.00	100.00	0.572	0.000	3.19E+001	3.19E+002		
Lump8	Bus2	100.00	0.495	100.00	100.00	100.00	0.286	0.000	6.38E+001	6.38E+002		
Lump15	Bus2	100.00	0.330	100.00	100.00	100.00	0.191	0.000	9.57E+001	9.57E+002		
Lump16	Bus2	100.00	0.660	100.00	100.00	100.00	0.381	0.000	4.78E+001	4.78E+002		
Lump17	Bus2	100.00	0.826	100.00	100.00	100.00	0.476	0.000	3.83E+001	3.83E+002		
Lump18	Bus2	100.00	0.165	100.00	100.00	100.00	0.095	0.000	2.85E+002	1.90E+003		
Lump19	Bus2	100.00	0.495	100.00	100.00	100.00	0.286	0.000	6.38E+001	6.38E+002		
U10	Bus1	100.00	1.117	100.00	100.00	100.00	0.558	0.000	7.11E-001	1.43E-001	7.11E-001	1.43E-001
20kV.PANNEL3	Bus8	100.00	0.147	100.00	100.00	100.00	0.074	0.000	3.17E+004	7.55E+004		
220kV.ONAF.VENT	Bus8	100.00	0.328	100.00	100.00	100.00	0.164	0.000	1.42E+004	3.39E+004		
220kV.PANNEL	Bus8	100.00	0.147	100.00	100.00	100.00	0.074	0.000	3.17E+004	7.55E+004		

COMM.PANEL	Bus8	100.00	0.147	100.00	100.00	100.00	0.074	0.000	3.17E+004	7.55E+004
CONTROL.PANEL3	Bus8	100.00	0.147	100.00	100.00	100.00	0.074	0.000	3.17E+004	7.55E+004
HEATING	Bus8	100.00	0.114	100.00	100.00	100.00	0.057	0.000	4.10E+004	9.76E+004
HEATING3	Bus8	100.00	0.114	100.00	100.00	100.00	0.057	0.000	4.10E+004	9.76E+004
OTHER PANELS	Bus8	100.00	0.322	100.00	100.00	100.00	0.161	0.000	1.45E+004	3.46E+004
PCI.PANNEL	Bus8	100.00	0.082	100.00	100.00	100.00	0.041	0.000	5.68E+004	1.35E+005
POWER	Bus8	100.00	0.114	100.00	100.00	100.00	0.057	0.000	4.10E+004	9.76E+004
PROT.SEC	Bus8	100.00	0.318	100.00	100.00	100.00	0.159	0.000	1.47E+004	3.49E+004
RECT.BAT.125V	Bus8	100.00	0.461	100.00	100.00	100.00	0.230	0.000	1.01E+004	2.41E+004
RECT.BAT.125V2	Bus8	100.00	0.461	100.00	100.00	100.00	0.230	0.000	1.01E+004	2.41E+004
RECT.BAT.125V7	Bus8	100.00	0.461	100.00	100.00	100.00	0.230	0.000	1.01E+004	2.41E+004
RECT.BAT.125V8	Bus8	100.00	0.461	100.00	100.00	100.00	0.230	0.000	1.01E+004	2.41E+004
SERVICE	Bus8	100.00	0.311	100.00	100.00	100.00	0.155	0.000	1.50E+004	3.58E+004

(Cont.)

Fault at bus: **Bus2**

Nominal kV = 20.000

Voltage c Factor = 1.10 (User-Defined)

Contribution		**3-Phase Fault**		**Line-To-Ground Fault**					**Positive & Zero Sequence Impedances Looking into "From Bus"**			
From Bus	To Bus	% V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
T1.REG	Bus8	100.00	0.313	100.00	100.00	100.00	0.157	0.000	1.49E+004	3.55E+004		
T2.REG	Bus8	100.00	0.313	100.00	100.00	100.00	0.157	0.000	1.49E+004	3.55E+004		
VENTILATION	Bus8	100.00	0.181	100.00	100.00	100.00	0.091	0.000	2.58E+004	6.13E+004		
VENTILATION3	Bus8	100.00	0.181	100.00	100.00	100.00	0.091	0.000	2.58E+004	6.13E+004		

		3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	:	18.165	15.720	15.732	17.362

Peak Current (kA), Method C	:	45.658	39.513	39.541	43.640
Breaking Current (kA, rms, symm)	:	15.720	15.732	17.362	
Steady State Current (kA, rms)	:	12.291	15.720	15.732	17.362

\# Indicates a fault current contribution from a three-winding transformer
* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer

Fault at bus: **Bus8**

Nominal kV = 0.400

Voltage c Factor = 1.05 (User-Defined)

Contribution		**3-Phase Fault**		**Line-To-Ground Fault**					**Positive & Zero Sequence Impedances Looking into "From Bus"**			
From Bus	To Bus	% V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
Bus8	Total	0.00	26.056	0.00	103.15	106.41	23.722	23.722	2.96E+002	5.01E+002	4.18E+002	6.27E+002
Bus2	Bus 8	97.99	9.848	98.80	100.00	99.40	9.929	11.861				
							*		8.39E+002	1.29E+003	8.37E+002	1.25E+003
Bus2	Bus 8	97.99	9.848	98.80	100.00	99.40	9.929	11.861				

				*	8.39E+002	1.29E+003	8.37E+002	1.25E+003				
20kV.PANNEL3	Bus8	100.00	0.185	100.00	100.00		100.00		0.112	0.000	3.17E+004	7.55E+004
220kV.ONAF.VENT	Bus8	100.00	0.412	100.00	100.00		100.00		0.250	0.000	1.42E+004	3.39E+004
220kV.PANNEL	Bus8	100.00	0.185	100.00	100.00		100.00		0.112	0.000	3.17E+004	7.55E+004
COMM.PANEL	Bus8	100.00	0.185	100.00	100.00		100.00		0.112	0.000	3.17E+004	7.55E+004
CONTROL.PANEL3	Bus8	100.00	0.185	100.00	100.00		100.00		0.112	0.000	3.17E+004	7.55E+004
HEATING	Bus8	100.00	0.143	100.00	100.00		100.00		0.087	0.000	4.10E+004	9.76E+004
HEATING3	Bus8	100.00	0.143	100.00	100.00		100.00		0.087	0.000	4.10E+004	9.76E+004
OTHER PANELS	Bus8	100.00	0.404	100.00	100.00		100.00		0.245	0.000	1.45E+004	3.46E+004
PCI.PANNEL	Bus8	100.00	0.103	100.00	100.00		100.00		0.063	0.000	5.68E+004	1.35E+005
POWER	Bus8	100.00	0.143	100.00	100.00		100.00		0.087	0.000	4.10E+004	9.76E+004
PROT.SEC	Bus8	100.00	0.400	100.00	100.00		100.00		0.243	0.000	1.47E+004	3.49E+004
RECT.BAT.125V	Bus8	100.00	0.579	100.00	100.00		100.00		0.351	0.000	1.01E+004	2.41E+004
RECT.BAT.125V2	Bus8	100.00	0.579	100.00	100.00		100.00		0.351	0.000	1.01E+004	2.41E+004
RECT.BAT.125V7	Bus8	100.00	0.579	100.00	100.00		100.00		0.351	0.000	1.01E+004	2.41E+004
RECT.BAT.125V8	Bus8	100.00	0.579	100.00	100.00		100.00		0.351	0.000	1.01E+004	2.41E+004
SERVICE	Bus8	100.00	0.390	100.00	100.00		100.00		0.237	0.000	1.50E+004	3.58E+004
T1.REG	Bus8	100.00	0.394	100.00	100.00		100.00		0.239	0.000	1.49E+004	3.55E+004
T2.REG	Bus8	100.00	0.394	100.00	100.00		100.00		0.239	0.000	1.49E+004	3.55E+004
VENTILATION	Bus8	100.00	0.228	100.00	100.00		100.00		0.138	0.000	2.58E+004	6.13E+004
VENTILATION3	Bus8	100.00	0.228	100.00	100.00		100.00		0.138	0.000	2.58E+004	6.13E+004
Bus1	Bus2	99.96	0.136	100.01	99.98		99.97		0.072	0.000		
				*	7.80E+002	8.00E+002						
Bus1	Bus2	99.96	0.132	100.01	99.98		99.97		0.069	0.000		
				*	8.07E+002	8.28E+002						
Lump3	Bus2	100.00	0.007	100.00	100.00		100.00		0.004	0.000	9.57E+001	9.57E+002
Lump5	Bus2	100.00	0.014	100.00	100.00		100.00		0.008	0.000	4.78E+001	4.78E+002
Lump6	Bus2	100.00	0.018	100.00	100.00		100.00		0.009	0.000	3.83E+001	3.83E+002
Lump7	Bus2	100.00	0.022	100.00	100.00		100.00		0.011	0.000	3.19E+001	3.19E+002
Lump8	Bus2	100.00	0.011	100.00	100.00		100.00		0.006	0.000	6.38E+001	6.38E+002
Lump15	Bus2	100.00	0.007	100.00	100.00		100.00		0.004	0.000	9.57E+001	9.57E+002
Lump16	Bus2	100.00	0.014	100.00	100.00		100.00		0.008	0.000	4.78E+001	4.78E+002

(Cont.)

Fault at bus: **Bus8**

Nominal kV = 0.400

Voltage c Factor = 1.05 (User-Defined)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus	To Bus	% V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
ID	ID	From Bus	Symm. rms	Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
Lump17	Bus 2	100.00	0.018	100.00	100.00	100.00	0.009	0.000	3.83E +001	3.83E +002		
Lump18	Bus 2	100.00	0.004	100.00	100.00	100.00	0.002	0.000	2.85E +002	1.90E +003		
Lump19	Bus 2	100.00	0.011	100.00	100.00	100.00	0.006	0.000	6.38E +001	6.38E +002		

		3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	:	26.056	23.722	22.565	25.439
Peak Current (kA), Method C	:	44.070	40.122	38.166	43.026
Breaking Current (kA, rms, symm)	:	23.722	22.565	25.439	
Steady State Current (kA, rms)	:	19.514	23.722	22.565	25.439

\# Indicates a fault current contribution from a three-winding transformer

* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer

Load flow simulation, capacitors on

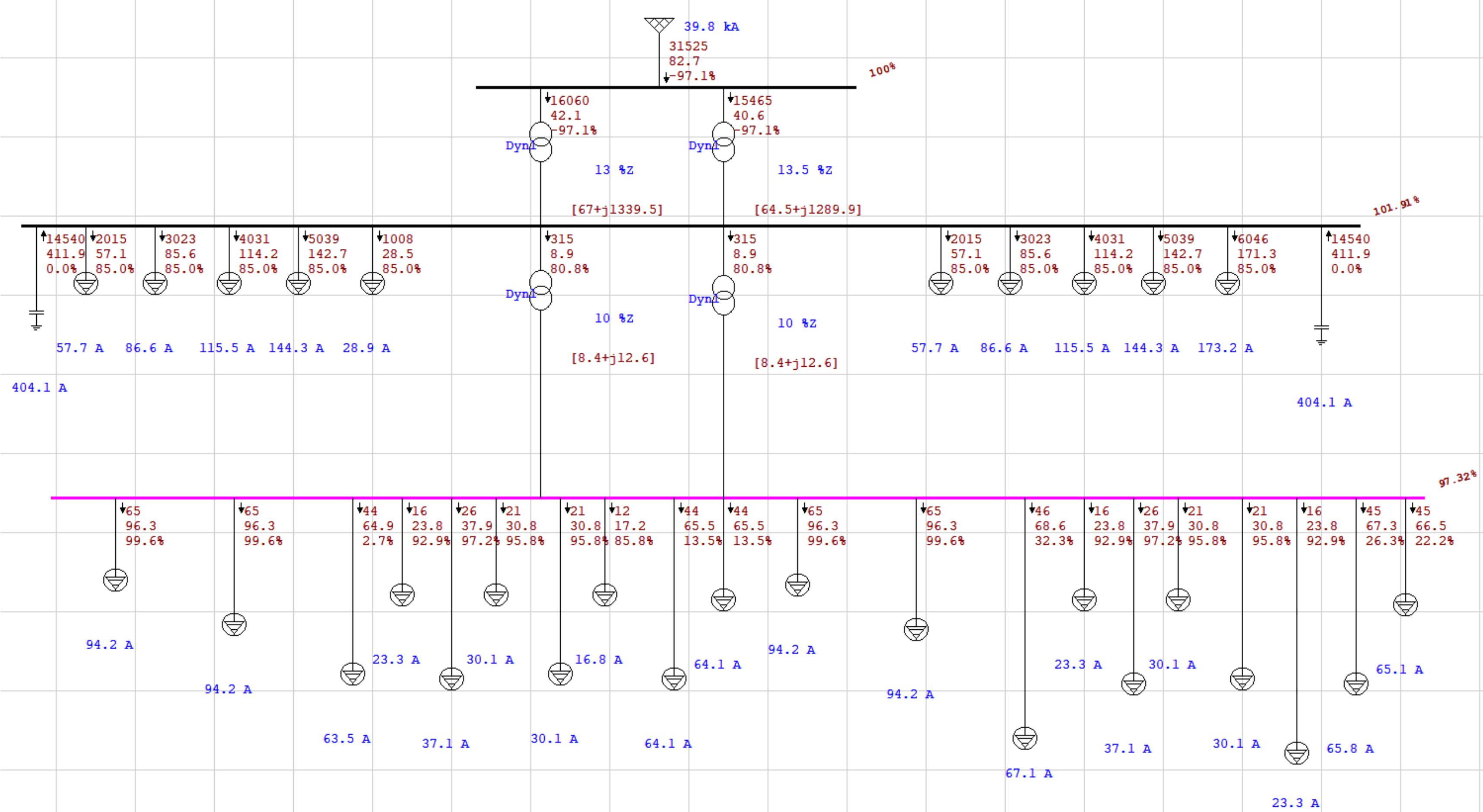


Figure 82.Power Flow simulation.

Load flow simulation capacitors off

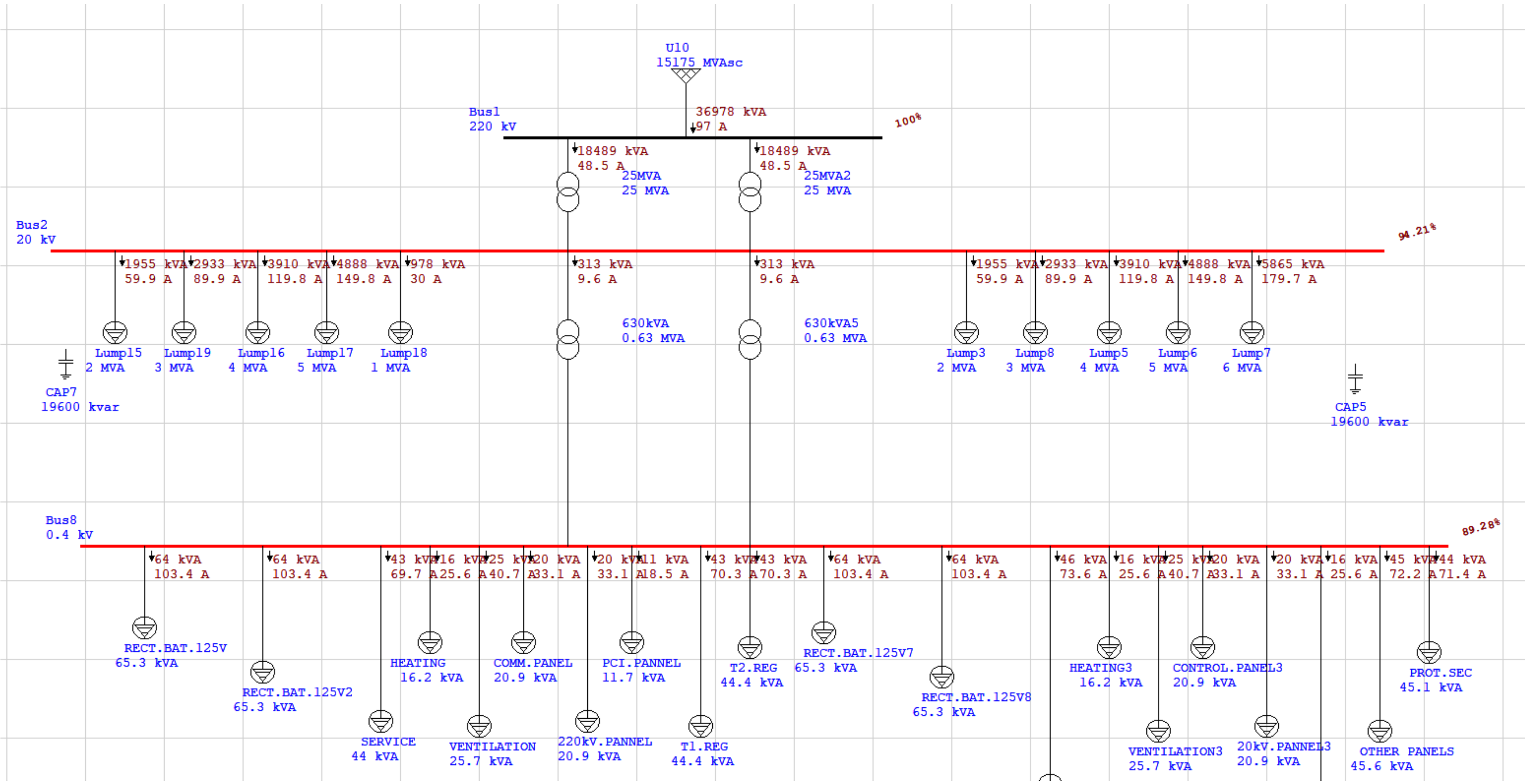


Figure 83. Simulatoin with no capacitors.

Short Circuit simulation.

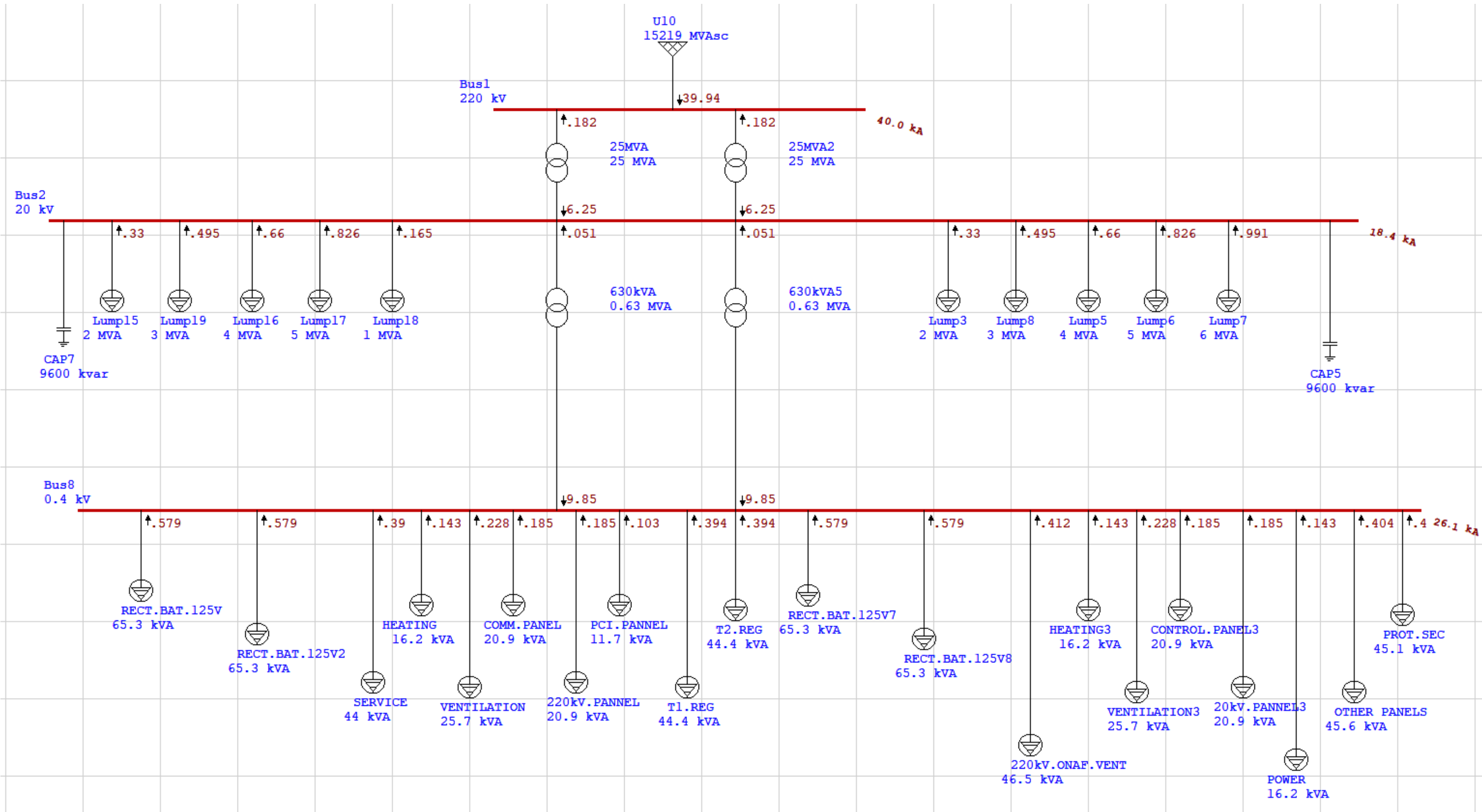


Figure 84. Short circuit simulation.

7. ECONOMIC STUDY

INDEX: SIMULATION

7. Introduction and structure.

The elaboration of this project would be an approximation from the point of view that the data recompiled for this section. The information has been taken from the websites of manufacturers and from the documentation found, of the other similar projects, about construction and installation of other facilities. It is remarkable to say that many budgets that were found, of the same equipment, could differ by a 100% of their rated value depending on the source. Investigating that variation there was published several articles indicating that many times the manufacturers increase the prize in the web even doubling it, from the real prices

In any case. the budget is structured with the breakdown of each part that compose it, and then it shows a general resume of the total budget.

In this way it will be possible to analyze, at the end of the budget, each relationship between the price and quantity that some of the equipment means. This therefore each unit will draw attention to their importance within the role of the substation.

7.1.CIVIL WORK

	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
LAND MOVEMENT				
Grubbing, clearing and cleaning of the land with extraction of it and the transport to an authorized landfill.	m2	1.23	3844	4728.12
Opencast excavation by mechanics means including the withdrawal of it. Does not include load and transportation.	m3	2.25	34596	77841
Excavation of ditches in compacted terrain by mechanical means. Does not include load and transportation.	m3	6.7	1609	10780.3
Extended filling and earth compaction by mechanical means until a degree of compaction of 95% normal proctor is achieved, without land contribution.	m3	6.6	1573	10381.8
Land transport to the landfill, in a distance less than 20 km, including round trip and the load of these.	m3	7.63	34596	263967.5
TOTAL				***367698.7***

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
FOUNDATIONS				
Concrete in mass HM-20 N / mm2, soft consistency, Tmax 20 mm, for normal environment, for the cleaning and leveling of foundation funds.	m3	83	219	18177
Formwork and stripping with loose wood in pads, ditches, beams and pile caps, considering 4 postures According to NTE-EME.	m2	11	1773	19503
Reinforced concrete HA-25 N / mm2, soft consistency, for pads and foundation ditches filling. Even armor poured by manual means, vibration and placement. According to NTE-CSZ and EHE standards	m3	119.7	265	31720.5
Concrete floor of 30 cm. Made with concrete HA-20N / mm2, elaborated in work armed with mesh of 49x51x15 extended and compacted with piston. According to NTE-RSS and EHE.	m2	20.3	3546	71983.8
TOTAL				***141384.3***
STRUCTURE				
Laminated steel S-275-JR, in rolled hot sections for beams, pillars and by welding joints according to NTE-EAS / EAV standards.	Kg	1.2	135200	162240 0
Reinforced concrete HA-25 N / mm2, Tmax 20 mm soft consistency, wood formwork, poured with boom-crane, vibrated and placed. According to NTE-EME and EHE standards.	m3	496	1642.6	814729.6 0
Reticular slab with 5 cm of compression layer of concrete HA-25 / P / 201, reinforcement of holes, formwork and stripping, without impact on pillars. According to norms NTE-EHR, EFHE and EHE.	m2	51.56	3191.37	164547.0372
TOTAL				***1141516.637***

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
PAVEMENT				
Mosaic micro grain-interior flooring Solana S.A. type VA-CUTILE fabricated according to norm UNE 127020 of 40 x 40 cm. In light and dark color, properly polished from the factory tests before the slip / slip according to brand AENOR.	m3	35	1773	62055
TOTAL				***62055***
ALUMINUM WOODWORKING				
Metal fire door 1.50 x 2.10 m, homologated, constituted with two galvanized steel sheets, 0.80 mm thickness and an intermediate chamber of non-insulating material on a galvanized steel sheet frame of 1.20 mm thickness. Finished in oven-cured epoxy paint.	ud	496	5	2480
Metal fire door 5 x 3.65m double pivoting door, approved EI 2-60-C5, constituted of two 0.80 mm electro-galvanized steel plates, of thickness, and intermediate chamber of fireproof material on a steel sheet fence galvanized, 1.20 mm thick. Finished in epoxy paint polymerized in the oven.	ud	877.5	6	5265
TOTAL				***7745***

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
TRAMEX				
Stainless steel grating (tramex), brand Meiser, with anti-slipper finished.	m2	58.5	30	1755
TOTAL				***1755***
LIGHTING				
Supply and installation of the sealed luminaire model HiPak of the manufacturer THORN. 152 W. IP65 protection rating, with insulation class I. Lamp and equipment auxiliary connection. Transportation, assembly and commissioning. All according to regulations valid.	ud	70	72	5040
Supply and installation of the sealed luminaire model N-48 of the manufacturer ATRIA. For emergency with 12 W. IP67 protection rating, with insulation class I. Lamp and equipment auxiliary connection. Transportation, assembly and commissioning. All according to regulations valid.	ud	496	59	29264
Supply of the AUTONOMOUS EMERGENCY EQUIPMENT AND SIGNALLING IN A WATERCASE BOX. Fully equipped with lamps and power strips Connection. Assembly, testing and commissioning. All perfectly installed, connected and operating according to current regulations.	ud	70	4	280
Supply and placement of PVC corrugated pipe of 180 mm diameter inside the trench for the channeling of electrical circuits during the work.	m	3.3	75	247.5
TOTAL				***34831.5***

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
SECURITY				
Supply and location of the operation unit to allow maneuvers with the sufficient protection of personnel during the execution of maneuvers and operations of maintenance. Compound: Pair of asbestos gloves A lever of action Plates and signaling bands Order book Transportation and location of everything is included the set, testing and commissioning Everything done according to current regulations.	ud	579	1	579
TOTAL				***579***
VARIOUS				
Quality control	ud	6600	1	6600 0
Archeological following	ud	5654	1	5654 0
Geotechnical study	ud	9500	1	9500 0
Detail engineering at civil work	ud	6700	1	6700 0
Working topography	ud	3232	1	3232
TOTAL				***28454***
TOTAL CIVIL WORK				***3058477.837***

7.2. 220 KV cells.

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
220 kV CELLS				
Double bar armored cell line SF6 220 KV Each line cell includes: SF6 switch SF6 disconnector Intensity transformer 220 KV inductive voltage transformer	ud	420000	4	1680000 0
Double bar transformer armored cell SF6 20 KV Each transformer cell includes: SF6 switch SF6 disconnector Intensity transformer	ud	360000	2	720000
Double bar measuring armored cell SF6 220 KV Each measurement cell includes: Inductive voltage transformer 220 KV SF6 disconnector	ud	120000	1	120000 0
Double bar armored cell coupling SF6 220 KV Each coupling cell includes: SF6 switch SF6 disconnector Intensity transformer	ud	170000	1	170000 0
Assembly and accessories	ud	9000	1	9000
TOTAL 220 kV CELLS				***2699000***

7.3. 20 KV cells

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
20 kV CELLS				
Double bar armored cell line, SF6, 20 KV Each line cell includes: Switch 3 Disconnector 3 Current transformer 3 Toroidal transformer	ud	37500	22	825000
Double bar transformer armored cell, SF6, 20 KV Each transformer cell includes: Switch 3 Disconnector 3 Current transformer 3 Toroidal transformer 50/1 A	ud	46000	2	92000
Double bar measurement armored, SF6, 20 KV Each measurement cell includes: Inductive voltage transformer 220 KV Disconnector	ud	18000	2	36000 0
Double bar armored transversal coupling, SF6, cell 20 KV Each coupling cell includes: Switch 4 Disconnector	ud	36600	2	73200
Double bar armored longitudinal coupling, SF6, cell 20 KV Each coupling cell includes: 2 Switch 8 Disconnector	ud	35000	2	70000
Double bar capacitor battery cell, SF6, 20 KV Each coupling cell includes: Switch 3 Disconnector 3 Current transformer	ud	33500	2	67000

Double bar AASS cell, SF6, 20 KV Each coupling cell includes: Switch 3 Disconnector 3 Current transformer 3 Toroidal transformer	ud	38600	2	77200
Mounting and accesories	ud	7200	1	7200
CAPACITORS BATTERY				
ABB Manufacturer, EMPAC model, IP 23, 9600 kVar	ud	6000	2	12000
Double bar AASS cell, SF6, 20 KV Each coupling cell includes: Switch 3 Disconnector 3 Current transformer 3 Toroidal transformer	ud	38600	2	77200
TOTAL 20 kV CELLS AND CAPACITORS BATTERY				***1336800***

7.4. Power Transformers

POWER TRANSFORMERS				
Power transformer 25 MVA of transformation ratio 220 ± 9 * 1.5% / 20 KV. Brand ABB ONAF cooling, connection group YNd11	ud	250500	2	501000
Mounting and accessories	ud	15200	1	15200
TOTAL POWER TRANSFORMERS				***516200***

7.5. Cables

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
CABLE				
Cable STRALIN 220kV, Al XLPE 500mm2	ud	100	60	6000
Cable STRALIN 20kV, Al XLPE 150mm2	ud	35	230	8050
Plug terminal 220kV cell	ud	25200	6	151200
Plug terminal 20kV cell	ud	5500	22	121000
Cable laying	ud	85	290	24650
TOTAL CABLES				***310900***

7.6.Auxiliar Services

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
A.A.S.S. CC				
Ni-Cd 125 VCC battery. AMCOSAFT manufacturer. 335 Ah of capacity. Discharge time of 5h. KPL model. Fabricated according IEC 60623 standard	ud	9000	2	18000
Ni-Cd 48 VCC battery. AMCOSAFT manufacturer. 335 Ah of capacity. Discharge time of 5h. KPL model. Fabricated according IEC 60623 standard.	ud	3000	2	6000
Charger from AEG-SAFT manufacturer. Capacity until 100A. Fabricated and tested according IEC 60146 standard.	ud	2550	2	5100
Rectifier from AEG-SAFT manufacturer.400VCC. Power 1kW. Fabricated and tested according IEC 60146 standard.	ud	5200	2	10400 0
CC converter from AEG-SAFT manufacturer. Power 1kW. Fabricated and tested according IEC 60146 standard.	ud	3500	2	7000 0
CC general board from AEG-SAT. Protection IP 42. Fabricated and tested according to IEC 60439.		11000	1	11000
TOTAL				***57500***

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
A.A.S.S. AC				
CC general board from AEG-SAT. Protection IP 42. Fabricated and tested according to IEC 60439.		16700	1	16700
TOTAL				***16700***

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
SUPPLY EQUIPMENT				
Uninterrupted supply equipment of 3kW, 50Hz. From AEG-SAFT	ud	34000	2	68000 0
Mounting and accessories	ud	6300	1	12600 0
AASS POWER TRANSFORMERS				
Resin cast power transformer from Schneider-Electric of 630 kVA. Conexión group Dyn11.	ud	20000	2	20000
TOTAL				***114300***
TOTAL A.A.S.S.				***188500***

7.7.Control, Measurement, Communication, And Protection.

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
MEASUREMENT				
Measuring converters, of SIEMENS, modular unit type SIPROTEC 5.01 class UT85, manufactured and tested according to IEC 60253-5 standard.	ud	2750	50	137500
TOTAL				137500

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
CONTROL				
Local control cabin, with degree of protection IP55, IK10 and NEMA12. RITTAL manufacturer, model VX25.	ud	2500	3	7500
Man-machine interface units for automatization and operation functions. 220kV equipment. Manufacturer SIEMENS, model DIGSI 5. Manufacturing and testing standards IEC 60253-5.	ud	8200	1	8200
Man-machine interface units for operation functions. Manufacturer SIEMENS, auxiliary service equipment model DIGSI 5. Manufacturing and testing standards IEC 60253-5.	ud	4400	1	4400
Model DIGSI 5, manufacturer SIEMENS, for command, automation and supervision of the subsidiary services of the substation. Manufacturer Siemens, model SIPROTEC 7KE85. It must also incorporate the necessary services of: Fire protection Ant intrusive Lighting		6600	1	6600
CPU y screens for the staff. Manufacturer SIEMENES model of DIGSI 5		1700	3	5100
TOTAL				31800

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
PROTECTION				
Cabinet of protection. With degree of protection IP55, IK10 and NEMA12. RITTAL manufacturer, model VX25. Dimensions (l x t x p), mm 1200 x 2200 x 600, manufactured and tested according to UNE-EN-60439-1 standards. Material sheet steel of 2 mm colour RAL 7035.	ud	7550	6	45300
Oscilloperturbograph type DRTS (model TRANSCOPE 82170) with with capacity for 10 analog signals and 12 digital signals, based on the IEC 61850 standard communication module.		1100	6	6600
Breaker failure protection, model SIPROTEC 5 of SIEMENS, type 7VK87, which integrates, among other functions, automatic reclosing function and synchro check for line protection applications with 1-pole and 3-pole tripping, circuit-breaker failure protection for 1-pole and 3-pole tripping, control, synchro check and switchgear interlocking protection, voltage controller for transformers, arc protection, and voltage protection.	ud	7150	50	357500
SIPROTEC 7SJ85 differential bar protection.		6230	1	6230 0
Stopping or opening time delay protection, SIPROTEC 5, SIEMENS, type 7DS5002-5JE52.	ud	3200	6	19200
SIEMENS frequency protection, type SIPROTEC 7SJ82.		2550	1	2550

Reclosing equipment, monopole and three-pole, in combination with line protections. SIEMENS, model 7DS5225-5DE29.	ud	1600	4	6400
SIEMENS SIPROTEC 5 tripping equipment as standardized by REE.	ud	6650	4	26600
A set of fiber optic connections and equipment needed to connect the previous equipment with the fiber optic junction boxes.	ud	2553	25	63825
GPS syncronization	ud	1550	1	1550
Mounting and accesories	ud	1551	1	1551
TOTAL				537306

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
PROTECTION				
Cabinet of protection. With degree of protection IP55, IK10 and NEMA12. RITTAL manufacturer, model VX25. Dimensions (l x t x p), mm 1200 x 2200 x 600, manufactured and tested according to UNE-EN-60439-1 standards. Material sheet steel of 2 mm colour RAL 7035.	ud	7550	6	45300
Oscilloperturbograph type DRTS (model TRANSCOPE 82170) with with capacity for 10 analog signals and 12 digital signals, based on the IEC 61850 standard communication module.		1100	6	6600

Breaker failure protection, model SIPROTEC 5 of SIEMENS, type 7VK87, which integrates, among other functions, automatic reclosing function and synchro check for line protection applications with 1-pole and 3-pole tripping, circuit-breaker failure protection for 1-pole and 3-pole tripping, control, synchro check and switchgear interlocking protection, voltage controller for transformers, arc protection, and voltage protection.				
	ud	7150	50	357500
SIPROTEC 7SJ85 differential bar protection.		6230	1	6230 0
Stopping or opening time delay protection, SIPROTEC 5, SIEMENS, type 7DS5002-5JE52.	ud	3200	6	19200
SIEMENS frequency protection, type SIPROTEC 7SJ82.		2550	1	2550
Reclosing equipment, monopole and three-pole, in combination with line protections. SIEMENS, model 7DS5225-5DE29.	ud	1600	4	6400
SIEMENS SIPROTEC 5 tripping equipment as standardized by REE.	ud	6650	4	26600
A set of fiber optic connections and equipment needed to connect the previous equipment with the fiber optic junction boxes.	ud	2553	25	63825
GPS synchronization	ud	1550	1	1550
Mounting and accessories	ud	1551	1	1551
TOTAL				537306

TOTAL CONTROL MEASUREMENT AND PROTECTION	***716006***

7.8. Engeniering

DESCRIPTION	UNITS	UNT.PRC(€)	QUANTITY	PRICE(€)
PROJECT MANEGEMENT				
Construction manager	year	60000	1	60000
Civil work supervisor	year	55000	0.3	16500
TOTAL				76500
Government agencies: Including taxes of the corresponding official bodies.				90000
TOTAL ENGENIERING				166500

7.9. Health and Safety

DESCRIPTION	PRICE(€)
HEALTH AND SAFETY	
Health and safety facilities	8000
Individual protections	6000
Signalizing and narrowing	6000
Medical examination of the staff, before the work	5000
TOTAL HEALTH AND SAFETY	25000

7.10. Summary and conclusions

TOTAL HEALTH AND SAFETY	25000
TOTAL ENGENIERING	166500
TOTAL CONTROL MEASUREMENT AND PROTECTION	716006
TOTAL A.A.S.S.	188500
TOTAL CABLES	310900
TOTAL POWER TRANSFORMERS	516200
TOTAL 20 kV CELLS AND CAPACITORS BATTERY	1336800
TOTAL 220 kV CELLS	2699000
TOTAL CIVIL WORK	3058477.84
TOTAL CALCULATED	**9017383.84**

Finally, the monetary figure that would be required for the elaboration of this project amounts to NINE MILLION, SEVENTEEN THOUSAND, THREE HUNDRED AND EIGHTY-THREE POINT EIGHT FOUR EUROS.

In the prices given on the 220 kV and 20 kV cells are included all the equipment to be installed on them as current transformers, transformers voltage, switches or disconnectors.

As it can be seen in the following graph, the most significant costs are those referred to high and medium voltage cells. Although if you take into account the relationship between the quantity of equipment and the price of the same, the power transformers are the most important expense of the substation, therefore it will be dedicated a special care and supervision to each detail during the life of the substation.

Probably the substation could be designed smaller reducing this way the civil works costs. However, it was designed looking with vision for the future, so if it would be necessary it could be extensive enough to double the capacity of the station.

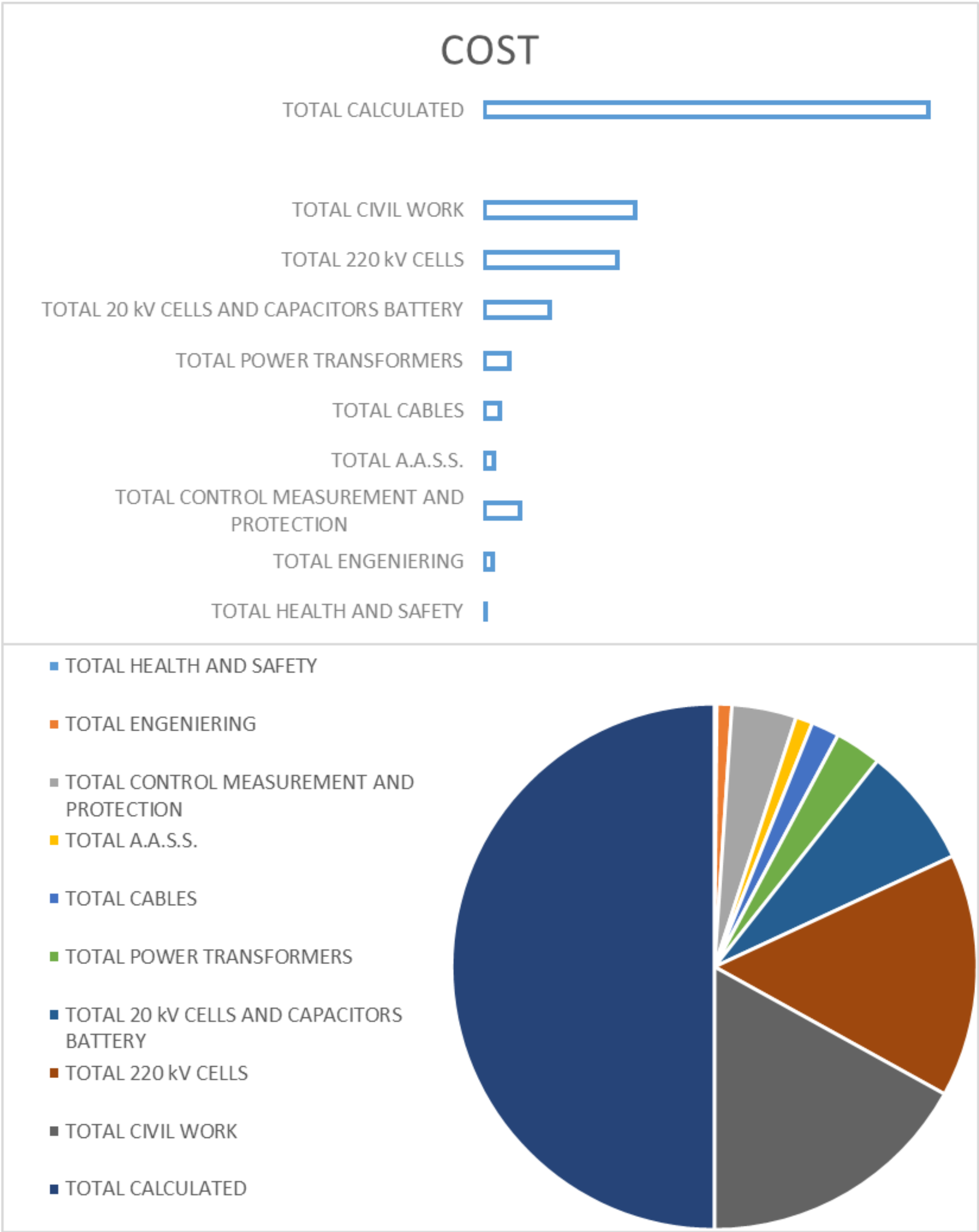


Figure 85. Graphic of each cost of the project.

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