DESIGN OF A SHORE POWER SYSTEM FOR BARCELONA'S CRUISE PIERS:

Cruise pollution study, rules analysis, design and simulation

Final Bachelor's Degree Project

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"In appreciation of my parents who in spite of difficulties are always there supporting and encouraging me to achieve my own objectives. I could not do the current project without their untiring attendance in front of any problem."

DESIGN OF A SHORE POWER SYSTEM FOR BARCELONA'S PORT CRUISE PIERS: Study about maritime pollution, rules analysis, design and simulation.

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ABSTRACT

Keywords: *pollution, cruise, ships, port, power, classification society, simulation, shore power, shore to ship, cold ironing;*

The current regulations about atmospheric pollution are, at the same time as the social responsibility, growing up because of the scientific certainty that pollution contributes on Global warming. The maritime industry such as a result of that is trying to reduce pollution from ships. Prominently, pollution from cruise ships is very polluting because of their huge power demand while they are berthed at port. Moreover, cities near big ports and their population are also an affected part.

In the current project the possibility of developing an installation to permit the shore to ship connection, also known as shore power or cold ironing, is studied for cruise piers in the Port of Barcelona. The project develops a pollution impact analysis over the port and approximated calculations of the produced emissions from cruise ships. As a result of that it is concluded that CO_2 emissions are extremely high and would be reduced in a 90 % by using shore to ship connection. In addition, the situation of the regulations related with maritime pollution has been checked to clarify its current situation and inclination.

The international standard for shore to ship connection is checked too, and it is compared with rules provided by Classification Societies. The main conclusion about that is the excessive focalization of the Classification Societies on the ship side installation. The result of that is the less effectiveness of these rules against the international standard ISO/IEC/IEEE 80005-1 because it considers shore and ship such as an entirely system.

The design statement is developed such as a result of a previous statistical study about the most typical technical characteristics of cruise ships power plant aiming to design a compatible system. The main determination of that statement is the internationalization of 6,6kV and 11kV voltages and 50 Hz and 60Hz, especially 11kV and 60 Hz for cruise ships over 200 meters length.

The basic design is composed by a main substation that supplies power to many shore stations distributed in all the cruise terminals. Different architectures for the distribution system have been proposed and tested, including a ramified system and a ring system. The simulation statement has been developed by Matlab and has achieved some general conclusions for big changes on load:

- *Bring noticeable voltage variations*
- *Produce interferences on voltage's signal in shape of harmonic distortions of high frequency.*

As a result of the analysis, monitoring of connection and disconnection shall be planed and monitoring aiming to avoid excessive voltage variations not accepted by the Classification Societies. The tested distribution systems would not work in the regulated conditions, at least with the designed composition. That is why, the best distribution system would be the common one based on individual cables for each shore station from the substation.

DISEÑO DE UNA INSTALACIÓN SHORE POWER PARA EL MUELLE DE CRUCEROS DE BARCELONA: Estudio de la contaminación, análisis de las normativas actuales, diseño y simulación en caso de fallos.

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SÍNTESIS

Palabras clave: *contaminación, crucero, puerto, electricidad, sociedades de clasificación, simulación, shore power, shore to ship, cold ironing;*

Las regulaciones y la responsabilidad social sobre la contaminación atmosférica se encuentran en un momento de gran crecimiento debido a su contribución sobre el efecto invernadero y el calentamiento global. La industria naval es un ejemplo más, en el que se intenta reducir dicha contaminación originada en los buques. De manera destacada, la demanda energética que un crucero necesita incluso estando en atracado en puerto deriva en una gran cantidad de contaminación atmosférica. Por si fuera poco, un ambiente muy contaminado no contribuye al bienestar de la propia ciudad en la que se encuentra el puerto y de sus propios habitantes.

En el presente proyecto se valora la posibilidad del desarrollo de una instalación de conexión buque-puerto conocida como "shore power","cold ironing" o "ship to ship connection" en los muelles de cruceros del puerto de Barcelona. El proyecto desarrolla un estudio actual de las normativas de contaminación en el sector marítimo así como un cálculo aproximado de las emisiones que una serie de cruceros podrían llegar a producir durante su estancia en puerto. El resultado de las emisiones de CO2 en particular resulta muy elevado y podría ser reducido en un 90% con el uso del sistema de conexión a puerto propuesto. Además se ha analizado la situación actual de las normativas marítimas sobre la contaminación, su actual situación y su tendencia.

Las normativas proporcionadas por distintas sociedades de clasificación han sido comparadas y analizadas juntamente con el standard internacional para estas instalaciones. Como resultado se deja entrever la poca efectividad o el estrecho rango

de aplicación de las normativas proporcionadas por las sociedades de clasificación frente al standard internacional ISO/IEC/IEEE 80005-1. Esto es debido básicamente a su focalización excesiva en la parte de la instalación referente al buque y su insuficiente consideración del conjunto buque-puerto como una instalación unitaria cuando estos están conectados.

En cuanto a la implementación del diseño, se ha desarrolla después de realizar un estudio completo de la normativa internacional y las normativas de las sociedades de clasificación comparándolas entre sí. La determinación de los parámetros eléctricos de la energía que suministraría la instalación y por tanto los que marcan el diseño; como son potencia, tensión y frecuencia; se han determinado mediante un estudio estadístico mediante el cual se ha llegado a la conclusión que debía diseñarse para dos tensiones distintas; 6,6 kV y 11 kV; y para dos frecuencias; 50 y 60 Hz.

Una vez diseñado el sistema basado en una subestación receptora conectada a la red nacional y una serie de estaciones de puerto, se han simulado diversos sistemas de distribución para el muelle de cruceros de Barcelona, incluyendo un sistema de distribución en anillo y uno en árbol. Estas simulaciones realizadas mediante Matlab han determinado que no serían aceptables dado el criterio de aceptación de las variaciones de tensión. En cambio se ha determinado que las grandes variaciones de carga producen:

- *Variaciones notables en la tensión;*
- *Distorsiones armónicas de frecuencia muy elevada*

Como resultado de estos hechos, los cambios de la carga del sistema deberán ser planificados i controlados en todo momento para verificar que la calidad de señal de todo el sistema se mantiene aceptable para las Sociedades de Clasificación. En cuanto al diseño, se confirma por lo tanto que con el diseño planteado no se podría conseguir el funcionamiento regulado para la instalación. Es por eso que el mejor sistema de distribución es, probablemente el más usado actualmente, basado en vías de alimentación independientes desde la subestación distribuidora del puerto.

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INTRODUCTION

Society's conscience and responsibility for environmental pollution have grown during last years as a consequence of global warming's increase in our planet. Global warming is a direct consequence of high contamination levels during last years. The main contamination type which contributes to that effect is atmospheric pollution. It is mainly caused by industry and vehicle emissions. In addition, the quality of air is getting worse because of that air pollution, leading to the appearance of pollution-related illnesses.

Most emissions are basically generated by the combustion of hydrocarbons. That chemical reaction, required in a wide range of industrial procedures, is used to transform the thermal energy obtained into mechanic or electric energy.

As a result of the importance of electric energy in the present society, the electricity generation sector is one of the most contaminating sources in our planet. Owing to the general increase in air pollution originated in that sector and aiming to reduce hydrocarbon's use, technical experts and scientists have anticipated the need to optimize all electric systems and power sources.

The energy sector includes a wide range of different industries and scopes. Particularly, the maritime industry contains a wide variety of environments such as ships, ports or off-shore structures. These environments have specific characteristics that must be considered.

For example, one vessel is constructed due to transport a concrete object, people or substance, through big water mass like a sea or an ocean. That ship is going to be isolated from the civilisation the major part of its live because in the middle of the ocean there is no else power source further than hydrocarbons. As a consequence, reducing air pollution coming from the maritime industry supposes a big challenge for engineers, experts and scientists. Specially, that problem is more serious when it big floating amount of steel, berths in any port keeping its enormous generators working to maintain the power source in all the ship.

The air pollution generated by the ship's generators in that case, is more worrying because it affects directly to the population living close to any port. The problem is aggravated when that ship is a huge luxury floating city such a cruise vessel, which needs a very high power supply to satisfy passengers' power requirements and allow ship's operations.

Then, it is not difficult to imagine that the exposed problem is a serious one. Because of its importance, international governments and international standards are trying to improve more and more the situation by creating restrictive rules about air pollution.

Moreover, many important ports are developing new technologies aiming to reduce or suppress emissions from ships. These technologies, consist basically on the possibility of connecting ships on port, and substitute their main power source, generators, for a power source provided from the shore by a shore to ship connection. As a result of that, air pollution will be supressed or reduced in a big measure while ships are at berth.

Project objectives

During the last decade, Barcelona's harbour has become an international recognised port for cruise ships in the Mediterranean Sea. Because of that, its capacity for that kind of ships has been increased such as the emission fumes that ships can produce. According to these facts, and thinking in a future sustainable harbour, the objectives of that project are:

- Compile and analyse pollution rules and directives, including global contamination and maritime industry.

- Analyse Barcelona's Cruise Harbour, identifying its maritime traffic, moulding cruise ship's generator loads in port and calculating emission's fumes levels from cruise ships.

- Analyse the actual situation of shore power, including most important classification societies and their rules, international standards and guidelines. Five classification societies are going to be analysed at least.

- Design the basic electric installation necessary to offer shore to ship connection in Barcelona's Cruise Harbour.

- Design two different distribution systems for the installation and simulate steady state, load flow, changes in load and failure conditions in all of them.

Motivations

The final step needed to be an official graduated engineer is that project. Firstly, I did not want to spend so much time in it, but finally, I thought that this document can be a kind of presentation document to entry in labour world and I strongly wanted to be proud of it.

Project's topic has been mainly recommended for my tutor because of his knowledge about my devotion for ship's power plant. Since I started to study at the college I had a kind of favouritism for subjects with electrical main topic. Then, I decided that my final project would be about maritime power industry or something related with that theme.

I do not know if my likely for electric theme has been promoted for my father, who had worked the major part of his live in an electric company, or it has grown in me by myself. The only think that I know for sure is that I very like the engineering world, specially designing things. That can be summarized in my satisfaction feeling after finding a good solution to solve a particular problem. That is the main reason because I tried to have the possibility of developing a project of this type instead of choosing other topics that might not be enough interesting for me.

Moreover, the multidisciplinary orientation of the proposed topic by my tutor, encouraged me to learn a huge amount of new concepts and to learn using Matlab for electrical purposes.

Methodology and sources

First of all, aiming to develop that project, rules and standards of five Classification societies have been consulted and analysed such a starting point. These societies are:

- American Bureau of Shipping (ABS)
- Bureau Veritas (BV)
- Det Norske Veritas (DNV)
- Lloyd's Register of Shipping (LR)
- RINA

In addition, some other Electrical International Standards (IEC, IEEE, ISO) have been consulted for electrical design owing to the close relation that they have with Classification rules and some references included in these ship standards. All of these rules about shore to ship connection have been summarized and compared in their related project's section. As a result of that, an analysis about the actual situation of onshore power and its safety degree had been developed.

During the design stage, some calculations have been done due to make an accurate dimensioning of all the elements. The final designs, result of that step, have been done for presentation by AutoCAD and are included in the current project.

Finally, simulation procedures have been developed by Matlab, particularly with System Power System tools, to analyse installation's behaviour.

1 BARCELONA'S HARBOUR

Barcelona's harbour has been a referent port in the Mediterranean Sea since it was constructed because of its continuous improvement on installations and the continuous infrastructure expansion it has developed.

Among these improvements, cruise pier ones are the most important developments. That part of the port, has very new and technological passenger terminals and in addition, two basic advantages comparing it with other international ports. First, the very effective port's management system that it use. The second advantage is its security, safety and logistic special means applied to cruise's maritime traffic.

These means contributed to improve Barcelona's image such as international European cruise harbour inside Mediterranean Sea. In that way, as a consequence of its total guarantee, many ship owners and their cruise lines decided to consider Barcelona's harbour as a very important port call for their cruise lines. All that global development has been achieved by a strengthen collaboration between the city and the port due to increase economy at Barcelona.

The port is also, an important member inside the Association of Mediterranean Cruise Ports (*MEDcruise).* That association set up in 1996 has the following objectives:

- Promoting cruise ship's sector in the Mediterranean Sea and adjacent seas;
- Contributing to its members in shape of some type of benefits such communication, development and logistics;

In addition, many private investors made important inversions in specific terminals or services, increasing in that way, Barcelona's harbour value and its installations and at the same time, local economy. In the Annexes A and B of the current project the importance of the cruise port of Barcelona within Mediterranean ports is showed.

Figure 1: *Barcelona's cruise harbor logo (at the left) and MEDCRUISE logo (at the right)*

1.1 Installations

Cruise shore installations are very big and are adapted to support a huge traffic and a wide volume of passengers. In particular, it has a total capacity for nine cruises at the same time in the port, divided in two main piers. In the following section, main characteristics of that shore areas and its terminals are going to be described. After that, a map of cruise shore areas of the port is included due to make their situation clear and totally understandable inside the global port.

1.1.1 Adossat Pier

The first pier, the main one and the most crowded, is called ***Adossat*** pier. It is located parallel from the coast and the only way to access in it, is using a bridge that joins this shore with the rest of the port. It includes four terminals which are showed below:

Figure 2: *Adossat Pier, Terminal B*

Figure 3: *Adossat Pier, Terminal B*

Figure 4: *Adossat Pier, Terminal C*

Figure 5: *Adossat Pier, Terminal D - Palacruceros*

Figure 6: *Adossat Pier, Terminal A,B,C and D*

1.1.2 Barcelona Pier (WTCB)

The other one, which is called ***Barcelona*** pier, is not exclusive dedicated to cruise traffic, but contributes to hold the total capacity of the port, nine cruises. It is located on World Trade Center's environment and is the only cruise pier that can hold long cruise stays in the port.

Figure 7: *WTCB Pier*

That wharf, as it can be seen in the last picture, can hold a total capacity of 5 cruises, but all these piers are not designed exclusively for that use. South and North piers were exclusively designed for that use. Otherwise, Z pier and East pier hadn´t been designed for that exclusive use.

Z pier is a "multipurpose" pier, because it was a ferry terminal in its beginning, but nowadays it is a reformed terminal which can hold ferry and cruise ships.
East pier is not designed to dock cruise ships in it. That space has the main utility of permitting port authorities to have such an extra pier to reorganise the docked ships in case it would be needed. In addition, if it would be necessary, that pier will be used to dock cruise ships when the port would be at its full capacity.

1.1.3 Situation

Barcelona's harbor is very big and has lot of piers and areas for varieties of ships and purposes. Due to make clear the situation of the installations described in the last sections, and the situation related with Barcelona's city, a global map of the port is included in the following source:

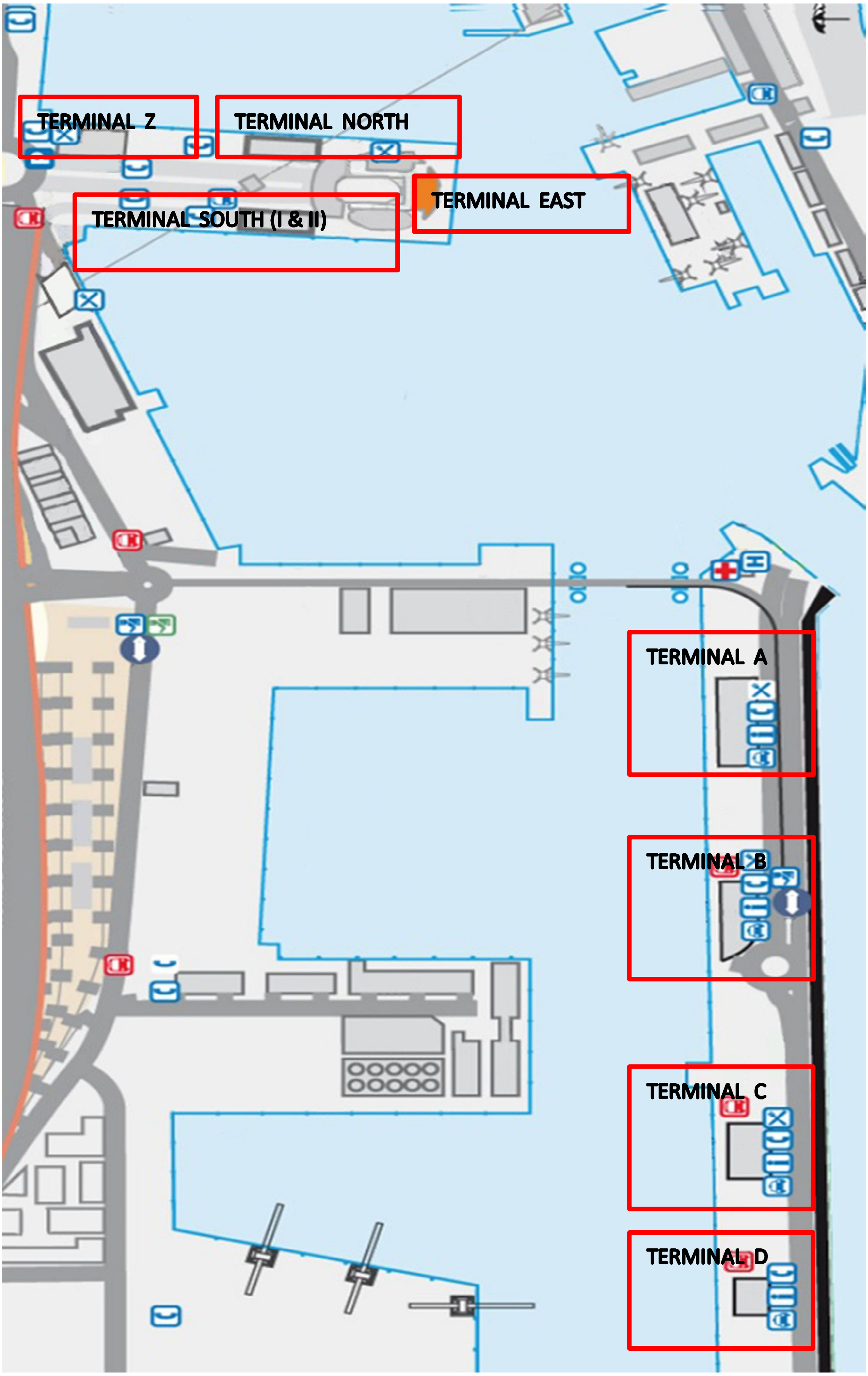

Figure 8: *Barcelona's cruise piers map*

1.1.4 Technical characteristics

Main characteristics of each terminal have been collected in the following table, in which making a comparison between all the terminals is easier:

Terminal	Docking length (m)	Ship's length (m)	Turnaround (pax)	Use
A	700	No limit	4500	Big cruises
B	700	No limit	4500	Big cruises
C	630	No limit	3800	Big cruises
D	630	No limit	4500	Big cruises
N	230	169	800	Medium &small cruises
S	430	253	1400	Medium & small cruises
E	160	205	1500	Not habitual use
Z	No data; Maritime terminal for ferry's equipped with cruise passenger means			Not habitual use

Table 1: *Barcelona cruise terminals technical characteristics*

2 AIR POLLUTION

2.1 Air's pollution current situation

Air pollution has damaged our planet since petroleum derivatives started to be used as a way to produce energy. Emissions coming from combustion reaction, and the associated air pollution that it generate, have been increased such an exponential way, becoming actually a very worrying topic because of its negative consequences. These bad effects are:

- Global warming
- Air pollution and air's poor quality because of an excessive content of toxic fumes
- Health problems related with air components
- Acid rain depending on the geographical area and its air's quality

As a result of that, many countries joined in a global compromise, called Kyoto Protocol, aimed to reduce global air pollution in all their territories. That protocol included some restrictions for each country divided in three following stages, based in an Emission Trading Scheme. The objective of that Protocol was to create a determinative level of worry over industries that should force them to invest on improving their installations with green technologies instead of buying new emission rights.

But, it was not as effective as all the members thought because of the main weakness of the protocol, the irregular participation of world countries. Some countries didn't join in the protocol and some others exited from it in the second stage. Then, the possibility of losing important companies for each economy was very heavy to skip. As a result of that, the emission rights prices were not enough expensive to force investments in industrial green technologies.

As it was mentioned previously, air pollution comes from many types of industries and sectors. These contamination origins are showed in the next graph by sources. In addition, as it can be seen in the same graph, the major part of gas emissions come from energy supply sector, transport sector and industry. It is difficult to develop global regulations for all the pollution sources at the same time.

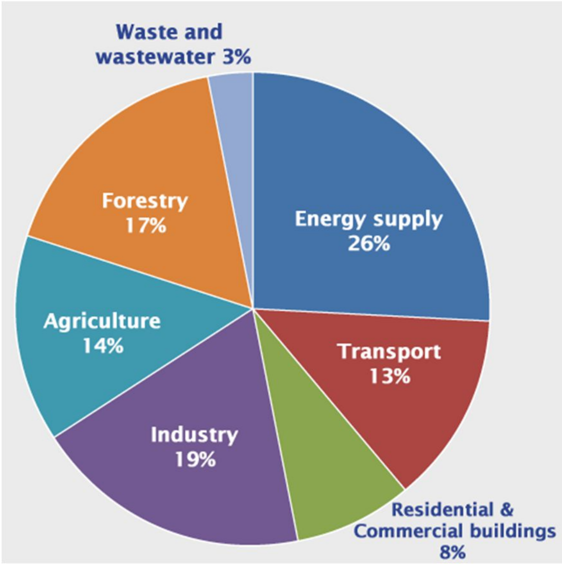

Figure 9: *Percentage diagram about Global Greenhouse Gas Emissions by source, retrieved from United States Environmental Protection Agency;*

That is why, the knowledge of how to control that contamination comes from each particular industry and its technical experts, who can work together with the specific organization, which is responsible of that area or industry, and contribute to develop effective rules and regulations.

2.2 Air's pollution coming from maritime activity

Maritime transport has always been an efficient type of transport if we consider the relation between transport operation's efficiency and the associated air pollution, generated by fuel combustion. That is the main reason why maritime transport is the most used way to trade products around the world.

Owing to marine's industry increase during last times, fuel consume percentages has been increased as a direct consequence of that growth. As a result, society started to consider combustion fumes coming from that sector, as a very important fact to keep the environment and release global warming.

Air pollution coming from ships, is composed by different type of toxic fumes that have been analysed and regulated by some international organisations. These gases are:

- Sulphur Dioxide (SO_x)
- Nitrogen Oxides (NO_x)

- Volatile Organic Compounds (*VOCs*)
- Particulate Matter (*PM*)
- Carbon Dioxide (CO_2)

The International Maritime Organisation (IMO) is the main responsible of all the global aspects related with maritime international transport. That organisation is also the assigned entity in charge of developing environmental protection measures inside the maritime industry due to reduce pollution from ships. These means are collected in the MARPOL Convention, which contains many regulations and six technical annexes. As it is known, each annex contains a different kind of pollution coming from ships. Aiming to analyse air pollution coming from ships and its regulations, next section is focused in the *Annex VI (Prevention of Air Pollution from Ships).*

2.3 MARPOL's Annex VI (Prevention of Air Pollution from Ships)

The sixth MARPOL annex, called "Prevention of Air Pollution from Ships", include measures to regulate all the toxic fumes that contribute to increase maritime air pollution. It was adopted on September 1997 and entered into force on 19 May 2005. The most relevant characteristics of that annex are exposed in the following sections. The information contained in the following sections is not as complete as the official regulations because it tries to be very clear, focused on the most important points and not so heavy to read.

2.3.1 Application

The regulations of that annex shall apply to all the ships, except in the situations described in some other regulations contained in the same annex. Generally these exceptions can be divided in two types, the general exceptions and the particular exceptions owing to each particular emission gas. Particular exceptions are going to be exposed in other sections related to each type of emission gas, but general exceptions are exposed in the following point.

2.3.2 General exceptions and exemptions

This annex and its regulations shall not apply to:

- Any emission necessary for keep the security and the safety of the ship and life at sea;
- Any emission generated as a result of ship's damage or its equipment;

- Ships purposed to develop ship emission reduction, control technologies and engine design programs. These ships can obtain a conduct trial by the Administration, allowing them not to respect the regulations of that annex. Trials have particular durations depending on its cylinder displacement and are included in *Regulation 3;*

2.3.3 Control of emissions from ships

In particular, all that regulations for emission control, are included in chapter III ***"Requirements for control of emissions from ships"***. In the following steps, all the regulations included in that chapter and based on the control of a specific gas are going to be analysed.

2.3.4 Ozone Depleting Substances

Ozone emissions are covered by the ***12th regulation of the chapter*** and applicable from 2010-07-01 for all permanently sealed equipment with refrigerant charging connections or potentially removable components containing ozone depleting substances. That regulation, mainly prohibit the deliberate emissions except if these emissions do not include minimal releases with the recycling of an ozone depleting substance. In particular two types of these emissions are regulated:

- Installations which contain *ozone depleting substances except hydro chlorofluorocarbons* shall be prohibited in the following cases:
  - On ships built on or after 19 May 2005;
  - On ships built before 19 May 2005 which have a contractual delivery date of the equipment to the ship on or after the mentioned date;

- Installations which contain *hydro-chlorofluorocarbons* shall be prohibited:
  - On ships built on or after 1 January 2020;
  - On ships built before 1 January 2020 which have a contractual delivery date of the equipment to the ship on or after the mentioned date;

2.3.5 Nitrogen Oxides (NO_x)

Nitrogen Oxides emissions are covered by the ***13th regulation of the chapter,*** applicable from 2010-07-01 for all marine diesel engines with a power output of more than 130 kW used in a ship and engines with higher power outputs that undergoes a major conversion. The major exception is that this regulation does not apply to marine diesel engines that are used or designed to use only in emergencies.

The main requirements of that regulation are divided in ***Tier I and Tier II.*** The main difference between them is its application date over construction or installation of the engine on the ship.

2.3.5.1 TIER I

Application: operation of marine diesel engines which are installed on a ship constructed *on or after 1 January 2000 and prior to 1 January 2011.*

Regulation: The operation of these engines is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) coming from these engines is not exceeding limits showed in table 2.

Crankshaft revolutions (rpm)	Emission limit of nitrogen (g/kWh)
n<130	17,0
130≤n<2000	$45 \cdot n^{(-0.2)}$
n≤ 2000	9,8

Table 2: *Tier's I emission limits of nitrogen depending on the rated engine speed (crankshaft revolutions per minute);*

2.3.5.2 TIER II

Application: operation of marine diesel engines which are installed on a ship constructed *on or after 1 January 2011.*

Regulation: The operation of these engines is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) coming from these engines is not exceeding limits showed in table 3.

Crankshaft revolutions (rpm)	Emission limit of nitrogen (g/kWh)
n<130	14,4
130≤n<2000	$44 \cdot n^{(-0.23)}$
n≤2000	7,7

Table 3: *Tier's II emission limits of nitrogen depending on the rated engine speed (crankshaft revolutions per minute);*

2.3.6 Sulphur Oxides (SO_x) and Particulate Matter (PM)

Sulphur Oxides emissions are covered by the ***14th regulation of chapter III,*** applicable from 2010-07-01 for all marine diesel engines installed in ships, excluding general exceptions and exemptions. The main content of that regulation is the Sulphur limit content that any fuel oil used on board shall not exceed. These limits are showed in table 4.

Periode	Sulphur content (m/m)
Previous 1 January 2012	4,50%
On and after 1 January 2012	3,50%
On and after 1 January 2020	0,50%

Table 4: *Sulphur limit content for marine fuels*

The worldwide average Sulphur content of residual fuel oil supplied for use on board ships shall be monitored taking into account guidelines developed by the Organization (MEPC.192(61)*, 2010 Guidelines for monitoring the worldwide average Sulphur content of fuel oils supplied for use on board ships).*

2.4 Emission Control Areas (ECAs)

These are some areas, in where the adoption of special obligatory measures for emissions from ships have been implemented aiming to prevent, reduce and control air pollution from NO_x, SO_x and particulate matter. In addition, the designation of an area such as ECA, aims to prevent and attend adverse impacts on human health. The designation of that areas starts with a formal proposal that has to be submitted to the Organization by the interested parties. The proposal shall include some aspects such as area, type of emission, a description of risks for the environment and population and other specific information. All that information necessary to submit de proposal is included in *section 3 of Appendix III – "Criteria for designation of an emission control area"* and it is summarized in the *Annex C* of the present project.

The special requirements and emission levels that each control area must comply are included in particular sections of ***regulation 13.6 and regulation 14.3.*** All these regulations related with all these specific areas are, as it can be imagined, more restrictive than the general regulations.

2.4.1 Regulation 13.6 (NO_x) - TIER III

Application: operation of marine diesel engines which are installed on a ship and are going to produce emissions in an emission control area (ECA) designated for Tier III NO_x control under paragraph 6 of this regulation.

Regulation: The operation of these engines is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) coming from these engines is not exceeding limits showed in table 5.

Crankshaft revolutions (rpm)	Emission limit of nitrogen (g/kWh)
n<130	3,4
130≤n<2000	$9 \cdot n^{(-0.2)}$
n≤2000	2,0

Table 5: *Tier's III emission limits of nitrogen depending on the rated engine speed (crankshaft revolutions per minute);*

Exception: These emission limits shall not apply to:

- A marine diesel engine installed on a ship with a length less than 24 meters when it has been designed only for recreational purposes.
- A marine diesel engine installed on a ship with a combined nameplate diesel engine propulsion power of less than 750 kW, if it is demonstrated by the Administration that it cannot comply with the standards.
- A marine diesel engine installed on a ship constructed prior to 1 January 2021 of less than 500 gross tonnage and with a length of 24 meters or over when it has been designed only for recreational purposes.

Location: for the purposes of this regulation, emission control areas shall be:

- The North American area, described by the coordinates provided in appendix VII of this current MARPOL's Annex;
- The United States Caribbean Sea area, described by the coordinates provided in Appendix VII of this Annex;
- Any other sea area, including any port area, designated by the Organization in accordance with the mentioned criteria;

2.4.2 Regulation 14.3 (SO_x)

A Emission control area in where Sulphur emissions are controlled, is mentioned as SECA (SO_x Emission Control Area).The particular requirements for SO_x emissions from ships in a ECA, stablish Sulphur contents for fuel oil used on board. These contents are showed in table 6 and shall not be exceed.

Periode	Sulphur content (m/m)
Previous 1 July 2010	1,50%
On and after 1 January 2010	1,10%
On and after 1 January 2015	0,10%

Table 6: *Sulphur limit content for marine fuels in SECAs*

There is one exception for ships built on or before 1 August 2011 that are powered by propulsion boilers that were no originally designed for continued operation on marine distillate fuel or natural gas. These ships shall not apply the present regulation prior to 1 January and operating in the North American and United States Caribbean Sea areas, as they are described in the appendix III of the annex.

For the purpose of this regulation, Emission Control Areas shall be the same zones in which regulation 13.6 is applied, with one more additive area:

- The Baltic Sea area as defined in regulation 1.11.2 of Annex I and the North Sea as defined in regulation 1.14.6 of Annex V;

2.5 Directive 2005/33/EC of the European Parliament

That directive of 6 July 2005, which modify the previous directive 1999/32/EC, follow the way adopted by the MEPC developing Annex VI of the MARPOL. The directive aims to achieve levels of air quality without risks for human health and the environment. Among all the emissions, in this case, Sulphur emissions are the main objective in two principal ways.

- Member States shall not allow using heavy fuel oils within their territory if their Sulphur content exceeds 1% by mass. However, there are some exceptions about combustion plants included.
- Member States shall not allow to use marine fuels in the areas of their territorial seas, exclusive economic zones and pollution control zones that are not considered SECA if the Sulphur content of those fuels exceeds 1,5%by mass.
- Member States, with effect from 1 January 2010, shall be sure that the following ships do not use marine fuels with a Sulphur content exceeding 0,1% by mass:
  - Inland waterway vessels
  - Ships at berth in Community ports, allowing them, sufficient time to complete any necessary fuel-changeover operation but under control.

As it can be seen in the last point exposed of the directive, ships at berth have a big problem to use marine fuel. That is the main purpose of that directive. Make docking at port difficult for the most polluting ships. In addition, that directive has a very interesting exception in which ships that use prohibited fuels with a Sulphur content over the limit, shall not apply the prohibition only if these vessels and the port have shore to ship connection technologies installed and they are going to use it during their staying, and their generators are going to be turned off.

2.6 Regulations over Barcelona's harbour

Barcelona area and consequently the Mediterranean Sea are not yet considered such as ECA or SECA. At this point, once all air pollution regulations have been analysed, it can be concluded that over Barcelona's harbour and over ships that usually do port calls in it, the following requirements shall be achieved:

1. Owing to the Directive 2005/33/EC, ships cannot use a marine fuel with a Sulphur content exceeding 0,1% by mass, at berth, and 1,5 while they are inside Spain's territorial sea. Such an exception, if they are going to use shore to ship connection in port, the first requirement limit at berth, shall not be applied.

2. NO_x emission levels are regulated by Tier I and II. The value of these limits depends on ship's rated engine speed as it is exposed in the corresponding section. Tier III is excluded for Barcelona's harbour because it is not yet considered such as Emission Control Area.

3. Installations which contain Ozone depleting substances except hydro chlorofluorocarbons shall be prohibited in the exposed situations.

4. CO_2 emissions are not controlled in the maritime sector by the mentioned Kyoto Protocol. In that case, depends on ships fleet and its owner.

2.7 Emission levels calculation

Aiming to study emissions from ships at berth in port, first of all, we shall determinate the basic conditioning factors for fuel's combustion. Auxiliary Engines are the main producer of emissions while ships are at berth in port, because they produce electricity for hoteling services and other activities. Then, all the conditioning factors for studying emissions from ships are basically three:

- Auxiliary Engine's size;
- Engine's or electricity loads needed at berth;
- Type of fuel used;

The last factor and the most important, is the type of fuel used. Engine's size and load needed at berth are factors difficult to quantify and hard to relate with their generated emissions. In addition, these data is difficult to obtain due to ship's owners privacy. In the following section a pollution analysis by components and a comparison between using heavy fuels with high Sulphur content, fuels with 0,1% Sulphur content and shore connection at the European Union is developed. All data showed in it, was extracted from an official study about Ship's pollution while they are berthed at port, *reference [5].*

2.7.1 In the European Union

2.7.1.1 NO_x, SO_x, VOC and PM

First of all to make a good comparison, the emission factors for Auxiliary Engines at berth should be determined. Extracting data from the mentioned study the following chart shows the emission factors for each polluting component in function of the produced power. In that chart there is a useful comparative between the emissions using high Sulphur content fuel and low Sulphur content fuel. That comparative is showed down in table 7.

	NO_x (g/kWh)	SO_2 (g/kWh)	*VOC* (g/kWh)	*PM* (g/kWh)
Emission factors from AE engines using 2,7% Sulphur fuel;	12,47	12,30	0,40	0,80
Emission factors from AE engines using 0,1% Sulphur fuel;	11,8	0,46	0,40	0,30

Table 7: *Emission factors for Auxiliary Engines at berth, g/kWh of electricity*

As it can be seen, the main objective of the directive, reducing a big range of SO_x emissions, has been achieved. But, having knowledge about the main exception of the European Directive related with shore-side electricity use, it is important to know the effectiveness of the emission reduction by using these technologies. The first step of that, was modelling the emissions coming from electricity generation. The mentioned study, from a particular model and European Union electricity production data, developed average emission factors for electricity generation in 2010. These average factors are showed in the table 8:

	NO_x (g/kWh)	SO_2 (g/kWh)	*VOC* (g/kWh)	*PM* (g/kWh)
Emission factors for electricity generation;	0,35	0,46	0,02	0,03

Table 8: *Average emission factors for EU25 electricity production*

Collecting data from last two charts exposed, a comparative between the emissions using Auxiliary Engines or using shore-side electricity have been constructed. In that way, through the difference between them, the reduction efficiency has been obtained. The result of that data is showed in the next two tables, table 9 and table 10:

Pollution average	NO_x (g/kWh)	SO_2 (g/kWh)	*VOC* (g/kWh)	*PM* (g/kWh)
(A)Using Auxiliary Engines	12,47	12,30	0,40	0,80

(B)Using Electricity production by Shore-ship	0,35	0,46	0,02	0,03
(A-B)Emission reduction using Shore -ship	12,12	11,84	0,38	0,77
Emission reduction (%)	97,2	96,3	95	96,2

Table 9: *Emission reduction when using shore side electricity instead if Auxiliary Engines g/kWh of electricity using 2,7% Sulphur fuel;*

Pollution average	NO_x **(g/kWh)**	SO_2 **(g/kWh)**	**VOC (g/kWh)**	**PM (g/kWh)**
(A)Using Auxiliary Engines	11,8	0,46	0,40	0,30
(B)Using Electricity production by Shore-ship	0,35	0,46	0,02	0,03
(A-B)Emission reduction using Shore -ship	11,41	0	0,38	0,27
Emission reduction (%)	96,7	0	95	90

Table 10: *Emission reduction when using shore side electricity instead if Auxiliary Engines g/kWh of electricity using 0,1% Sulphur fuel;*

To calculate emission reductions per berth, as it can be seen in the results, time and power demand of electricity are needed to convert the averages in real values. In the mentioned study, they obtained absolute values by assuming three different sizes of engine, a shore-side electricity utilization at berths of 70% of the total staying time and the use of two particular types of fuel for the engines, using 2.7%sulphur Residual Oil (RO) and engines using 0.1% Marine Distillate (MD).

2.7.1.2 Other Emissions

The real impact on emissions depends in all the cases on the electricity production method used to substitute for the AEs. Average emissions of CO_2, CO, CH_4 and N_2O were determined in the mentioned study for electricity produced across the European Union and compared with auxiliary diesel engines emission levels. The result is showed in the following table 11:

Average	CO_2 **(g/kWh)**	**CO (g/kWh)**	CH_4 **(g/kWh)**	N_2O **(g/kWh)**
Electricity production (across EU)	330	0,0125	0,028	0,014
Auxiliary Diesel engines (AE)	720	1,3	0,01	0,031

Table 11: *Comparison between average emission factors for EU25 electricity production and for Auxiliary Diesel engines*

In addition, combustion engines generate a high level of noise and vibrations on board a ship. These aspects can only be eliminated by switching them off.

2.7.2 In Barcelona's cruise harbor

A cruise traffic register from Barcelona's harbor had been consulted to compile all cruise ships that docked in the port during 2013. The main purpose of that was calculating how much emissions use to produce cruise harbor in Barcelona during one day in the worst situation. That situation is supposed to be when the biggest cruise ships that usually do port calls in Barcelona would be at the same time at berth in port.

On the way to develop that analysis, some sources have been used:

- Emission data from last section (EU)
- Cruise traffic register during 2013
- Power demand modelling

First of all, to obtain an estimated value for power demand, the area under the daily power demand curve (exposed in the next chapter) developed for the worst day or most possible polluting day, shall be determined. That step, has been implemented by the integration method based on trapezium's areas. That area is showed in the following figure 10 such as a representation:

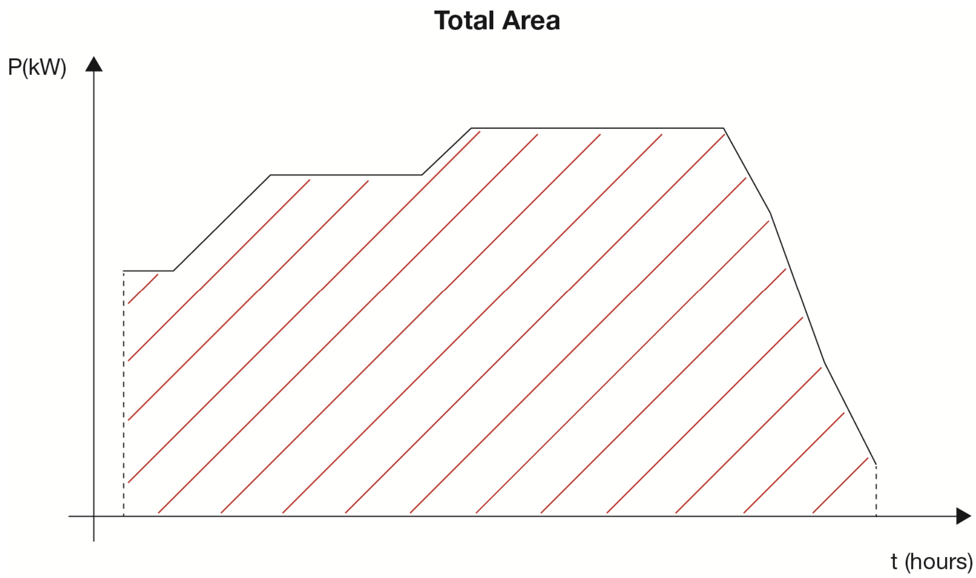

Figure 10: *Total Area under the daily power demand curve used to estimate total power supply during the most polluting day in the port;*

The result of that calculus is 957930,35 kW. We don't need to use time for calculating the emissions because that power value is a result of the integration during the time. Once the total power consumption during one day is known, the last step is multiplying it with all the averages exposed in the last section aiming to obtain estimated values for each emission from ships.

As a result of that, the following chart was developed:

Type of emission	Quantity (kg)
SO_x	11303,6
NO_2	440,65
VOC	383,17
PM	287,38
CO_2	689709,85
CO	1245,31
CH_4	9,58
N_2O	29,7

Table 12: *Estimated values for emission quantities divided in each type of component during the most possible polluting day from cruise ships at Barcelona's cruise harbour;*

2.8 Results evaluation

Everybody knows the big amount of CO_2 that combustion engines produce. In cruise ships case, as it can be seen in table 12, the quantity of CO_2 emissions is very high and it is only an estimated value for the worst possible day. Sulphur emissions, are the other big type of emissions that they can produce.

The considered situation may never occur, but it stablishes an estimated value for the limits at where the emission levels can be. Probably a common value for these emissions or the average emissions at Barcelona's harbour would be between 40% and 70% of the obtained values due to the variety of cruise ships that do port calls in it and because of the daily demand curve. That curve is calculated with the power peak values for hoteling, but it is not going to maintain that power during all the day. In addition, the power demand is going to variate along the year because of the seasons and the most demanded months by the passengers such it can be seen in the following figure 11:

***Figure 11**: Annual variation of passenger traffic through Barcelona cruise terminals during 2014 and the current 2015;*

But, the not depending data that we can obtain is the relative importance of each emission from the total. These percentages are showed in the next source, table 13.

Type of emission	Percentage (%)
SO_x	1,607
NO_2	0,063
VOC	0,054
PM	0,041
CO_2	98,052

CO	0,177
CH_4	0,001
N_2O	0,004

Table 13: *Estimated values for emission percentages*

From last chart, the supremacy of CO_2 emissions is completely confirmed, once again. Maritime Industry is permitting that amount of emissions and only some companies or fleet owners are following social responsibility means, developing or investing in new and more sustainable systems to reduce these emissions.

An example of that pollution responsibility is Maersk Line, the shipping company responsible for around 1 percent of global emissions. It saved a big amount of money on fuel over 2013 by reducing carbon dioxide outputs from its fleet by 12%. That was achieved because of the implementation of new investments and initiatives such as:

- Slower journeys to optimize fuel consume
- Increase ship's port calls to maximize their capacity use
- Upgrade existing ships
- Deploy new and more efficient vessels

Checking the results obtained for the emission reduction as a result of using shore to ship connection instead of auxiliary engines, the conclusion is very clear. Using shore to ship connection reduces emission levels more than 90% comparing it with using auxiliary engines such as it can be seen in table 10.

3 SHORE POWER, THE SOLUTION

The solution for air pollution in ports is, as it was described previously, the shore to ship connection. It is refereed with different names depending on the country you would be or the classification society that is classifying the ship. In order to avoid future confusions, these names are showed next:

- *Cold ironing - High Voltage Connection Systems*
- *High voltage shore connection*
- *Electrical Shore Connections*
- *On-shore Power Supplies*
- *Shore-side electricity*

The simplified principle of operation is clear, ship's generators would be turned off during any ship will berth at any harbour that would have these new technologies installed. Nowadays, Classification Societies for ships are improving their standard rules and developing new ones about these systems, because of the rising importance of that technology.

In addition, the European Parliament has published some recommendations for the promotion of shore-side electricity for use by ships at berth in EU ports due to reduce air pollution concentration near population.

3.1 European Parliament means

3.1.1 Directive 2003/96/EC

That directive was developed for covering the taxation of energy products and electricity. One of the main objectives of that directive is to allow all member states to cut tax rates on electricity provided to any vessel at berth in their ports. In that way, low prices of electricity taxation join in the global means to make using shore connection at berth in port an interesting possibility for ship's owner.

3.1.2 Recommendation 2006/339/EC

The main objective of that recommendation is to induce Member States to consider the installation of shore-side electricity for use by ships at berth in ports. In special, in ports where air pollution levels are exceeding limits, developing in that way bad air's quality and all the associated problems. In addition noise pollution is considered too. The recommendation emphasizes that consideration in ports where residential areas are near.

3.2 Barcelona's shore-side installation requirements of service

The first step in any design procedure is deciding which are going to be the final characteristics or specifications of the final product. In the present case, to develop the design of an electrical installation, the previous main aspects that must be considered are:

- Voltage
- Frequency
- Power demand
- Number of consumers
- National grid characteristics and environmental conditions

Cruise ships that used to dock in Barcelona's harbor shall be the starting point of consideration for deciding voltage, frequency and power demand; but the privacy of cruise ships data makes it impossible. Then, to study all these aspects, references [21], [22], [23] and [24] have been used because of their data collection about cruise ships at berth, especially in San Francisco's port.

3.3 Voltage

Cruise ships are designed to use a determinative voltage among a huge range of voltages depending on its designer, constructor and country where they were constructed. Ship's length and passenger's capacity are a determinative factor for its voltage system too. Based on San Francisco's port study about cruise ships at berth, the percentage graphs had been developed such as figure 12 and 13:

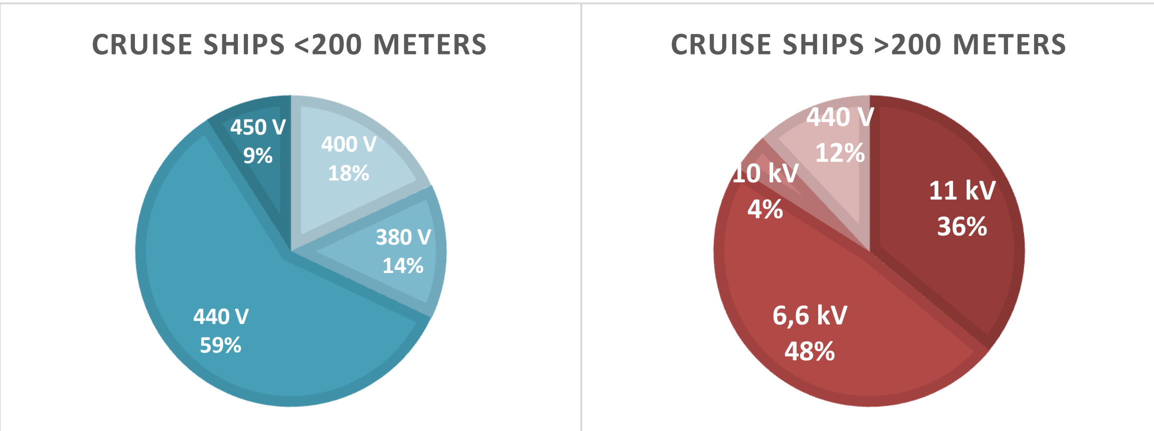

Figure 12: *Voltage percentage graphs depending on cruise ships length*

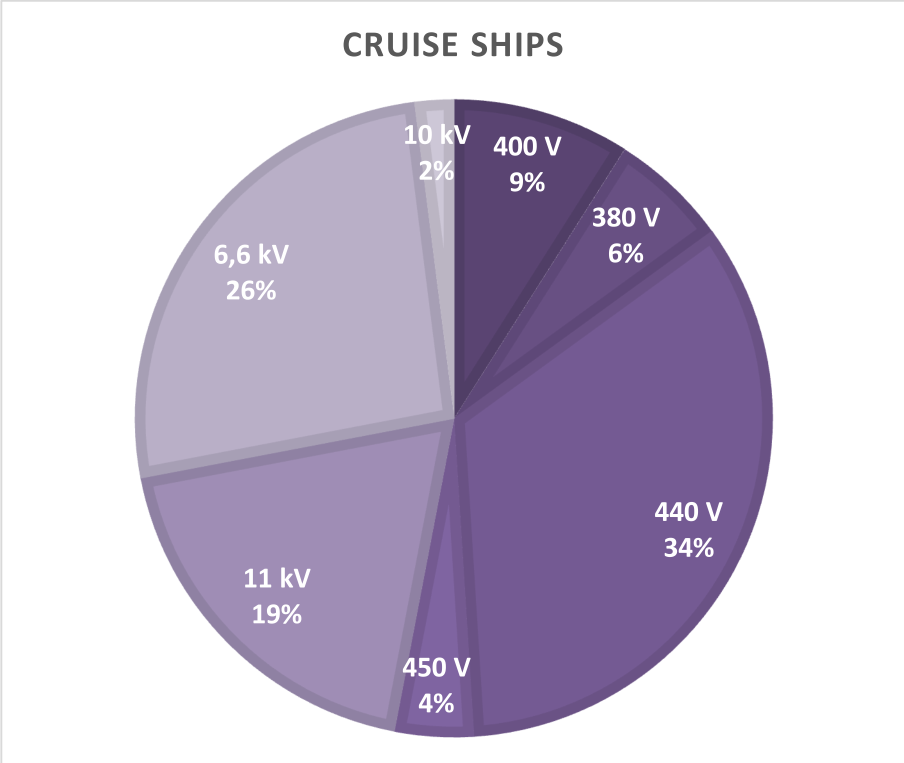

Figure 13: *Voltage percentage global graph*

Then, as it can be seen in the last graphs, choosing a determinate voltage is not possible because there are many different nominal voltages in cruise ships.

Because of that, the design determination for voltage is not based on a unique voltage. The best solution is installing some systems due to allow the global installation supply energy within the particular voltage range. In that way, all the cruise ships could use shore side electricity with any problem of compatibility. Voltage ranges obtained as a result of that study are mainly two, one medium voltage and one low voltage range. Owing to design, only medium voltage range is going to be considered. These main voltage ranges are:

- Medium voltage: **6,6kV – 11kV**
- Low voltage: **380V –450V**

3.4 Frequency

Frequency is easier to determinate compared with voltage. In that case, only two standard frequencies are used; the European frequency, 50Hz, and the American frequency, 60 Hz. Applying it to cruise ships, it seems that for over 200 meters ships only 60 Hz is used. The percentages of frequency used on board ships are showed in the next graphs represented on figure 14 and 15:

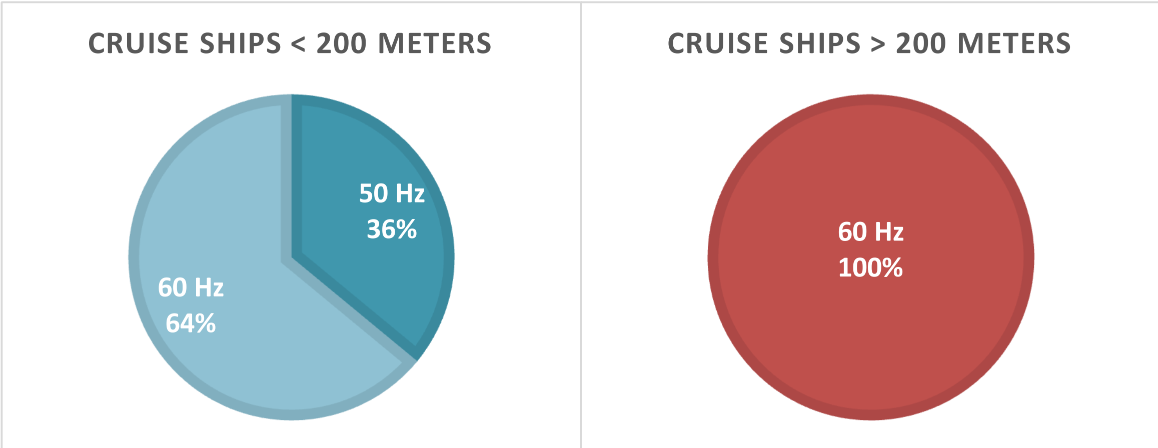

Figure 14: *Frequency percentage graphs depending on cruise ships*

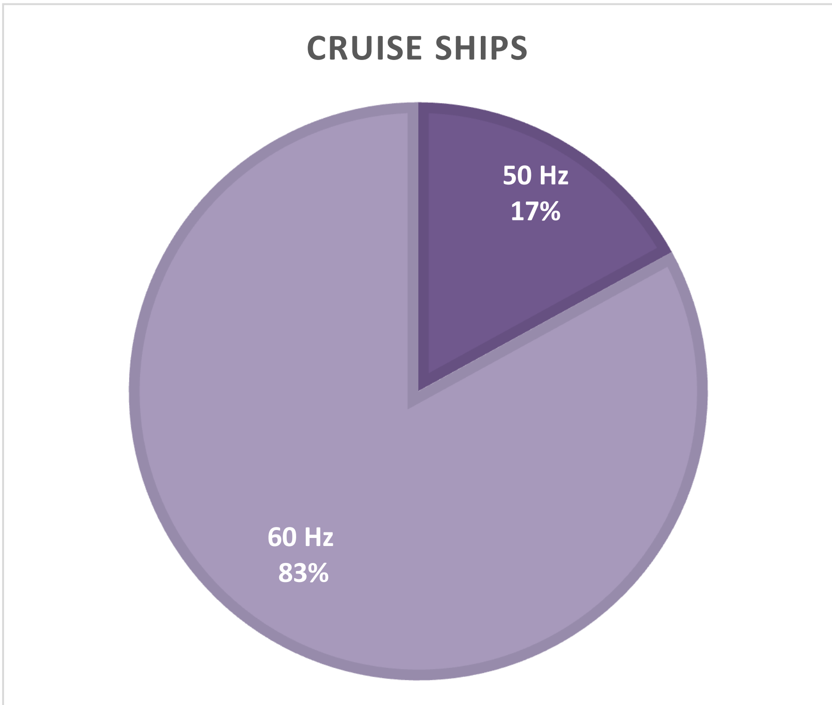

Figure 15: *Frequency percentage global graph*

In that case, 60 Hz is the most used frequency on board. But Barcelona`s port is considered the first international port for cruise ships within Mediterranean Sea, so in the way to keep that consideration, the installation shall be able to supply energy in **both frequencies**. In addition, the national grid of Spain, supplies energy at 50 Hz of frequency. That is why the design solution must consider the inclusion of frequency converters.

3.5 Power demand at berth

3.5.1 Modelling

Knowing how much power cruise ships demand at berth in port, and how much total power capacity on board they have, is very difficult. The main reason is the privacy protection of ship's owners over their ship's data.

The initial point of the research of that project was developing a power model for cruise ships, allowing the prediction of their load at berth. Power that they demand in port is used to be called "Hoteling Power Demand". As it had been mentioned, due to the high degree of data protection, an experimental model had been developed. Main steps of the modelling process have been:

1. Data collection; As a result of an extended research, a complete data collection about hoteling power peak values during the connection in San Francisco's port for all type of ships was found. Related studies were the main data source. *(References [21] and [24])*

2. Once, hoteling power demand was found, an elaborated data chart had been developed completing technical specifications of each cruise that appears in the study. That chart is included in the Annexes of the project.

3. With all these information, some hoteling power demand models had been done by the relation between how much power a cruise ship demand for hoteling and one characteristic of that ship. As a result of using regression methods, and testing them by analysing their dispersion factor, the following models have been obtained:

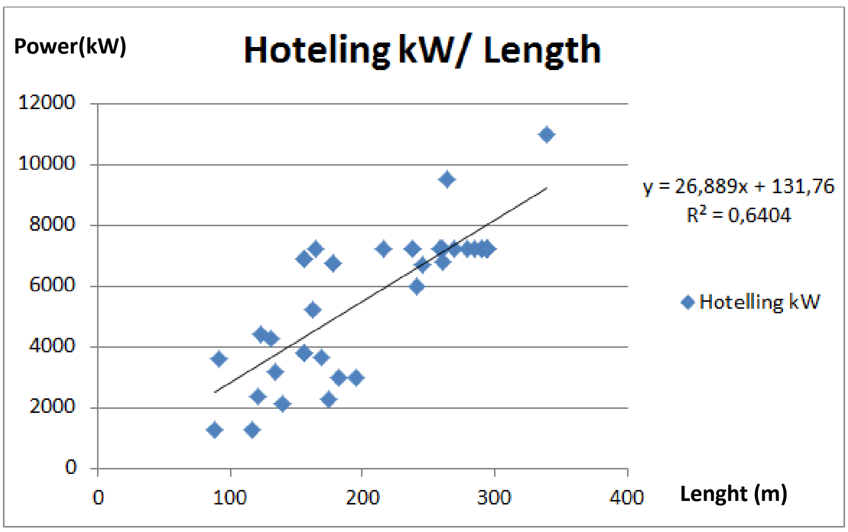

Figure 16: *Model 1 Hoteling/Length, dispersion factor 0,8, by linear regression;*

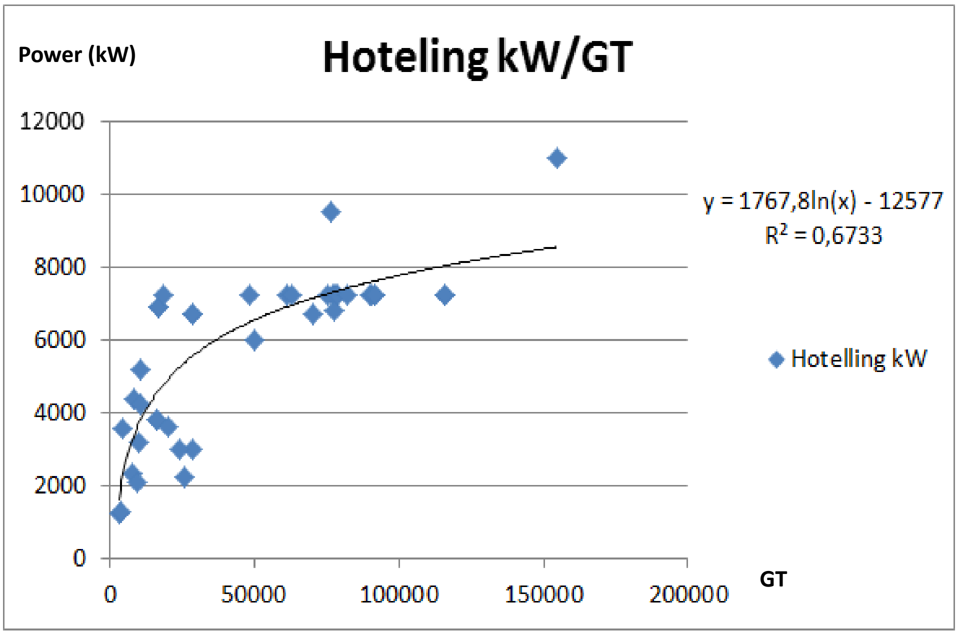

Figure 17: *Model 2 Hoteling/Gross tonnage, dispersion factor 0,82, by logarithmic regression;*

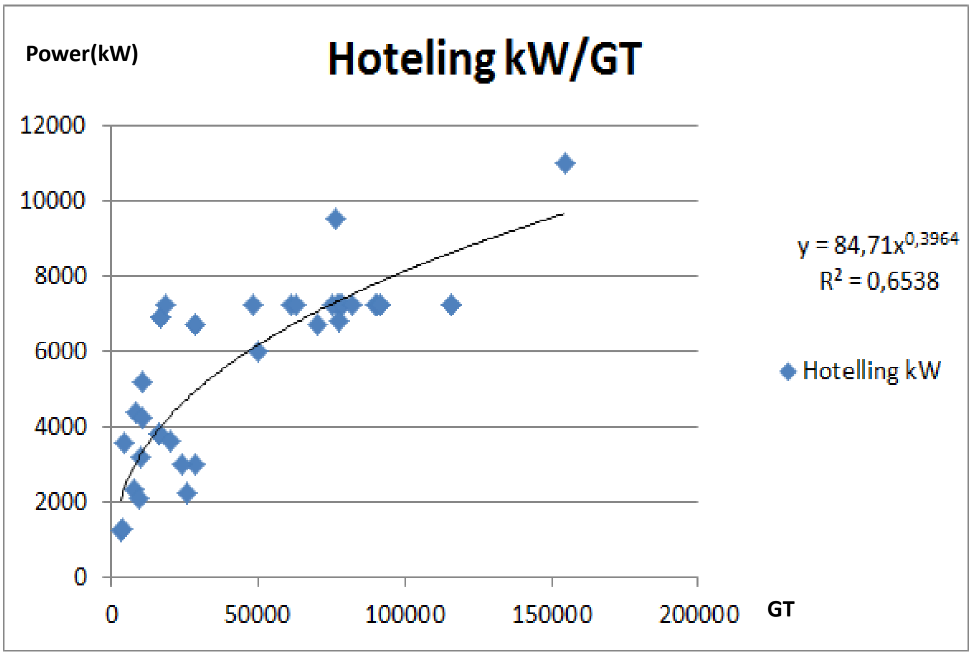

Figure 18: *Model 3 Hoteling/Gross tonnage, dispersion factor 0,808, by potential regression;*

Finally after comparing all the models, the logarithmic regression between hoteling power demand and gross tonnage seems to be the one who has the higher dispersion factor. Otherwise, looking the situation of each point in all the diagrams, it can be deduced that the real tendency of hoteling demand is divided in two parts, and the biggest ships are usually far from the tendency curve such as exceptional consumers.

Obtaining a perfect regression is difficult because it is not a proportional increase. For that reason and for practical use all the models are going to be considered to calculate the total demand in Barcelona's cruise piers.

3.5.2 Daily Power Curve

Once models had been developed, hoteling power demand can be approached for all cruise ships and for any existing harbor. In Barcelona's case, the traffic study mentioned in previous chapters of the current project had been used to approach the common daily schedule of the biggest cruise ships that usually do port calls in the city. These cruise ships are listed below in table 14.

Ship's name	**Length (m)**	**Gross tonnage(ton)**
OASIS OF THE SEAS	361	225282
LIBERTY OF THE SEAS	339	160000
INDEPENDENCE OF THE SEAS	339	160000
REGAL PRINCESS	330	142000
NORWEIGAN EPIC	330	155000
MSC SPLENDIDA	333	133500
MSC FANTASIA	333	138000
CELEBRITY EQUINOX	315	122000

***Table 14:** Biggest cruise ships characteristics;*

In the way to obtain a daily power demand curve, length and gross tonnage of these cruise ships were used to substitute the variables in the obtained model equations. As a result of that, the power demand for each cruise ship had been approached. That power results are showed in the following table 15:

Ship's name	Hotelling (kW) By Length (liniar tendence)	Hotelling (kW) by Gross tonnage (logarithmic tendence)	Hotelling (kW) By Gross tonnage (potential tendence)
OASIS OF THE SEAS	9838,6	9211,3	11213,8
LIBERTY OF THE SEAS	9247,1	8606,4	9791,4
INDEPENDENCE OF THE SEAS	9247,1	8606,4	9791,4
REGAL PRINCESS	9005,1	8395,4	9339
NORWEIGAN EPIC	9005,1	8550,2	9669
MSC SPLENDIDA	9085,7	8286,3	9113,2
MSC FANTASIA	9085,7	8344,9	9233,8
CELEBRITY EQUINOX	8601,7	8127	8793,6

Table 15: *Biggest cruise ships estimated peak demand for hoteling service*

The last step was the implementation of a daily curve based on ship's schedule to represent that consume during the day. The considered schedule had been summarized in table 16, showed next:

Ship's name	Arrival Time	Departure Time
OASIS OF THE SEAS	5:00 AM	7:00 PM
LIBERTY OF THE SEAS	5:00 AM	5:00 PM
INDEPENDENCE OF THE SEAS	7:00 AM	7:00 PM
REGAL PRINCESS	5:00 AM	7:00 PM
NORWEIGAN EPIC	5:00 AM	6:00 PM
MSC SPLENDIDA	8:00 AM	6:00 PM
MSC FANTASIA	12:00 AM	6:00 PM
CELEBRITY EQUINOX	5:00 AM	5:00 PM

Table 16: *Biggest cruise ships habitual schedule*

As a result of the entirely procedure, the following daily power demand curves for hoteling services have been developed by using the three different equation models proposed:

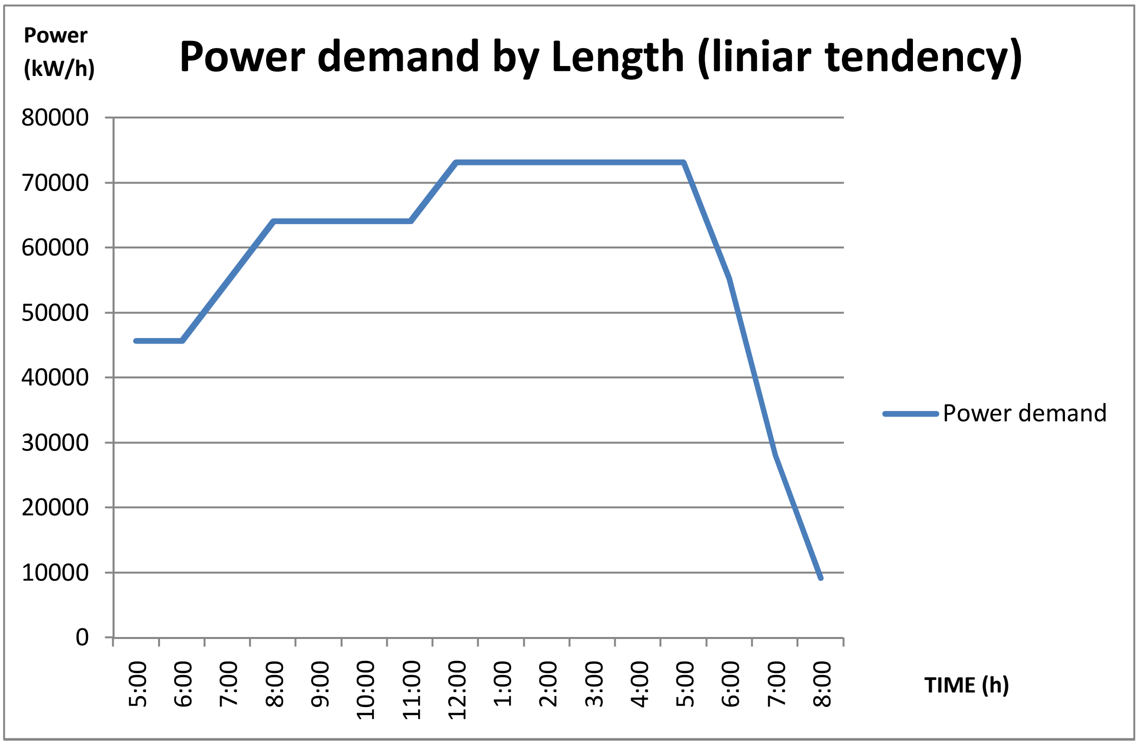

Figure 19: *Daily power demand curve developed by model 1;*

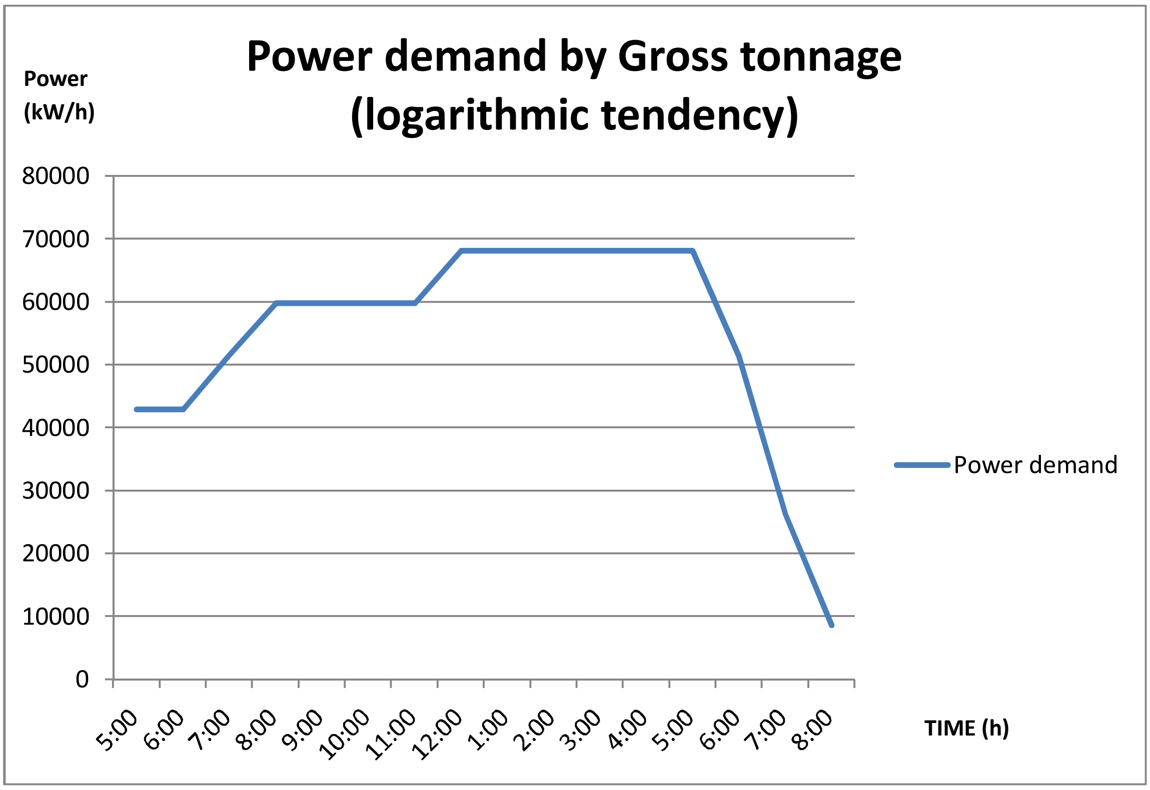

Figure 20: *Daily power demand curve developed by model 2;*

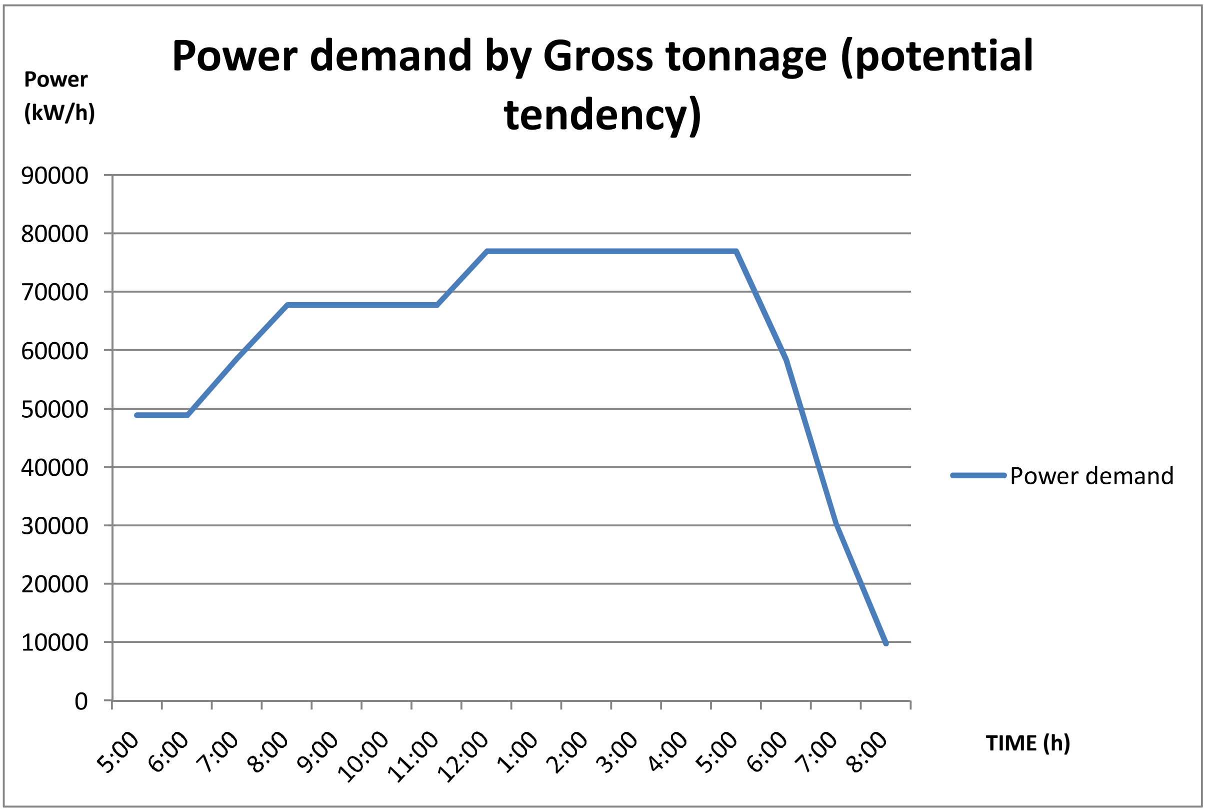

Figure 21: *Daily power demand curve developed by model 3;*

Analysing the daily power curves obtained and the power demand values for each cruise ship, it is easy to observe that the last model, showed in figure 21, has the higher peak values. This is the main reason to choose that model, based in gross tonnage and developed by potential tendency. Choosing that model, the dimensioning of the installation may be over dimensioned, but this is better than dimensioning it for lower power demand, in which case, it may not be enough for supply all the consumers.

3.6 Number of cruise ships

Barcelona's cruise piers, described in a previous chapter, have the total capacity of 9 cruise ships at the same time. Due to one of these piers is an "extra" pier for maneuverability the installation design is going to consider 8 simultaneous consumers. In addition, as it have been described in the previous sections, versatility for all the connection points must be considered in terms of frequency and voltage.

According to the utility and the length capacity of each wharf, Adossat Pier connection points are going to be designed to supply higher power than Barcelona Pier connection points.

3.7 National grid characteristics

Spain's national grid has been studied at Barcelona's harbor area to get knowledge about how the distribution system is constructed and which electrical characteristics it has. As it has been said in previous sections, Spain's national grid works at 50Hz of frequency, but it is necessary to know which are the closest substations and the closest distribution systems, their voltage and their morphology. Grid's characteristics are showed in table 17:

	National grid
Frequency	50 Hz
Transport voltage	220 KV
Phases	3

Table 17: *National grid characteristics*

4 SHORE POWER RULES ANALYSIS

First, before designing, rules and standards of Classification Societies and International standards for shore-side electricity shall be checked. In that way, all the components or parts of the complete installation are going to be isolated aiming to analyse them with their own additional requirements and rules. As it was mentioned in the project objectives, this statement is going to be developed by comparing some different rules and standards.

4.1 Rules and standards

The study developed in the current project, have been done using the following rules:

- *ABS- High Voltage Shore Connections*
- *BV- Rules for the Classification of Steel Ships (Part C – Chapter 2- Section 3)*
- *DNV- Electrical Shore Connections*
- *LR- Rules and regulations for the classification of ships (Part 7- Chapter13)*
- *RINA- Rules for the classification of ships (Part F-Chapter 13- Section 15)*
- *ISO/IEC/IEEE 80005-1 High Voltage Shore Connection (HVSC) Systems – General requirements*

4.2 Installation's main composition requirements

In a simplified point of view, and according to the International Standard **IEC/ISO/IEEE 80005-1**, installation design shall be based in a generic architecture showed in the next block diagram:

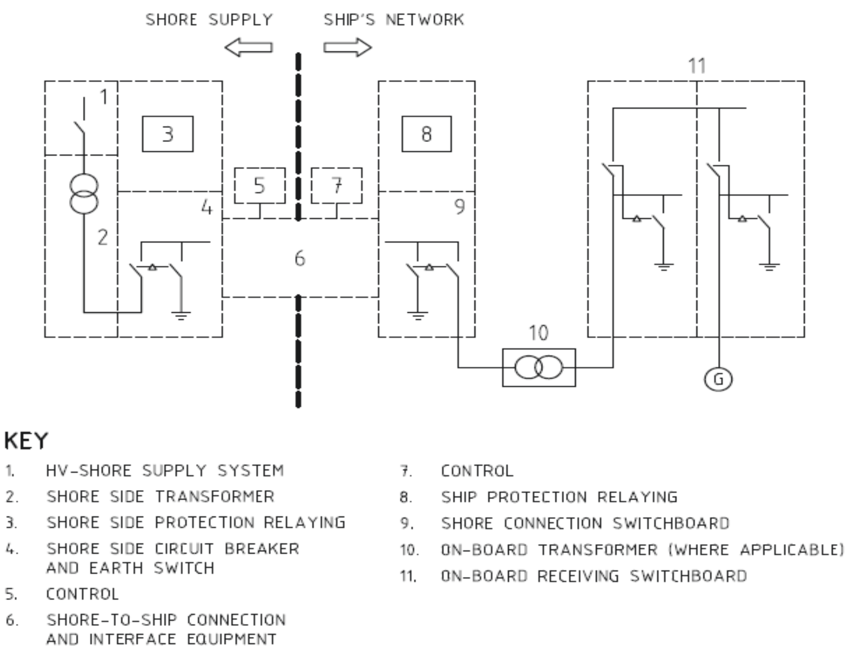

Figure 22: *Main composition of the installation; ISO/IEC/IEEE 80005-1;*

In addition, complementary requirements for high-voltage shore connection systems are provided in the annex C of the international standard in case cruise ships are going to use the shore connection. The following layout, figure 23, summarizes the additional information on architecture's morphology provided by that annex:

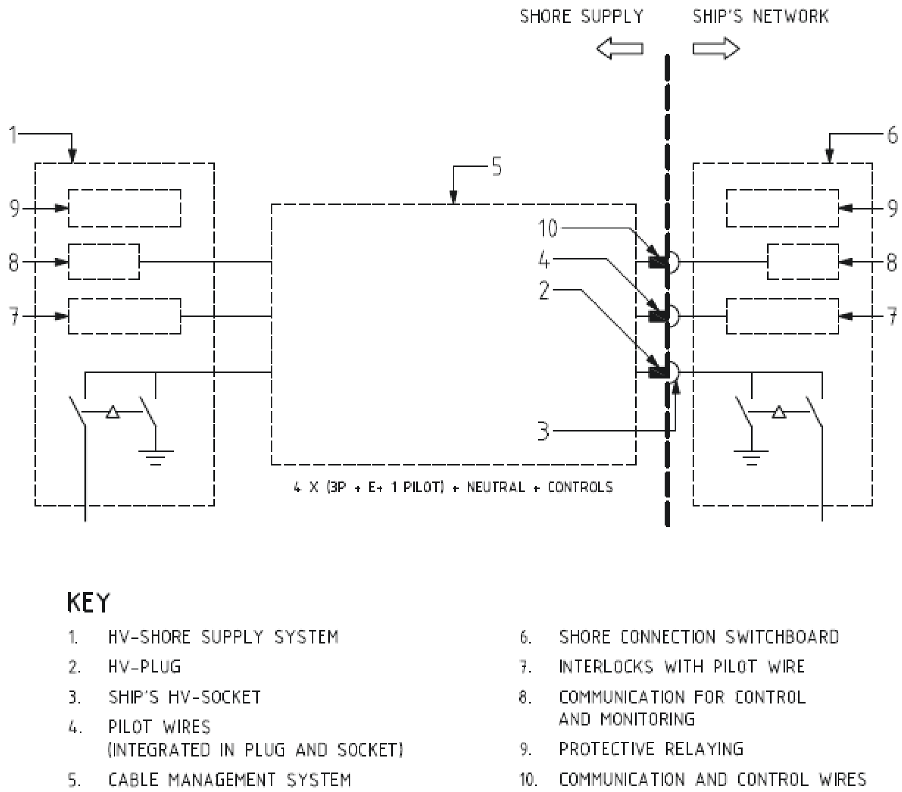

Figure 23: *Additional diagram for cruise ships; ISO/IEC/IEEE 80005-1, Annex C;*

The international standard is the unique rule that provides layouts and some useful diagrams for designing shore connection installations. The rest of the checked rules do not include any visual source for general installation's composition.

The importance of these sources in any rule is very important because it provides a generic idea about the composition, preventing at the same time big design mistakes and not wasting time developing incorrect designs. These two last layouts, figure 22 and 23, are going to be strongly considered during the design statement which is going to be developed in the next chapter.

4.3 Quality of power

The energy supplied from shore to ships shall be able to maintain a certain quality parameters, such as voltage, frequency and harmonic distortion. After checking all the rules, only the international standard and Lloyd's Register rules cover quality of power requirements. Both values use to be very similar, but international standard requirements are little more restrictive than Lloyd's. All these requirements are provided in the next summary:

1. Voltage and frequency tolerances
    a. Frequency shall not exceed the continuous tolerances +-5% between no load and nominal rating;
    b. Voltage at shore supply connection point, shall not exceed voltage increase of 6% of nominal voltage for no load conditions;
    c. Voltage at shore supply connection point, shall not exceed voltage drop of -3,5% of nominal voltage for rated load conditions;
2. Voltage and frequency transients
    a. Voltage an frequency response at shore connection when it would be subjected to an appropriate range of step changes in load, shall be defined and documented;
    b. Maximum step change in load expected when the connection would be done, shall be defined and documented for each ship;
    c. Comparison between the transient levels shall be done to verify that the limits will not be exceeded:
        i. Voltage transient ranges +20% and -15%
        ii. Frequency transient ranges +-10%
3. Harmonic distortion for no load conditions, shall not exceed the following limits:
    a. 3% for individual harmonic
    b. 5% for total harmonic distortion
4. Permanent variations for load conditions
    a. Voltage +6 and -10%
    b. Frequency +-5%

4.4 General requirements

The international standard for High voltage (HV) shore supply establish that in order to standardize these installations and link nominal voltage in different ports, HV connections shall be provided with a nominal voltage of 6,6 kV A.C and/ or 11 kV A.C, always galvanically separated from the shore distribution system. Otherwise, if some ships use to repeat itinerary at the same ports and their dedicated berths, other IEC voltage nominal values may be considered.

Finally, at the connection point, looking at the socket/connector face, the phase sequence shall be L1-L2-L3 or A-B-C or R-S-T and the system shall be balanced. Phase sequence rotation diagram shall be fixed at its location and phasors must rotate counter clockwise in reference to fixed observer.

4.5 Compatibility assessment before connection

Before connecting any ship to shore HV supply, a compatibility checking shall be performed to verify the possibility of connection between the two parts. That assessment, which is a common requirement in all the analysed rules, is not covered by all of them. Only ISO/IEC/IEEE standard, RINA and Lloyd's, include the compatibility checking procedure.

In addition, according to Lloyd's Rules, the owner is the main responsible of doing the compatibility assessment before arriving to an enabled shore connection port.

In the following source, table 18, a comparison between the different checking aspects from the mentioned rules has been developed:

Compatibility requirements	**ISO/IEC/IEEE**	**Lloyd's**	**RINA**
Compliance with the requirements of the IEC/ISO/IEEE standard and any deviations from the recommendations;	√	X	X
Minimum prospective short-circuit current;	√	X	X
Maximum prospective short-circuit current;	√	√	√
Nominal ratings of the shore supply, ship to shore connection and ship connection;	√	√	√
Any de-rating for cable coiling or other factors;	√	X	X
Acceptable voltage variations at ship switchboards between no-load and nominal rating;	√	X	√
Steady state and transient ship load demands when connected to a HV shore supply, HV shore supply response to step changes in load;	√	X	√
System study and calculations;	√	X	X

Verification of ship equipment impulse withstand voltage;	√	X	√
Compatibility of shore and ship side control voltages, where applicable;	√	√	√
Compatibility of communication link;	√	√	√
Distribution system compatibility assessment (shore power transformer neutral earthing);	√	√	√
Functioning of ship earth fault protection, monitoring and alarms when connected to a HVSC supply;	√	√	√
Sufficient cable length;	√	X	√
Compatibility of safety circuits, in accordance with the rule;	√	√	√
Total harmonic distortion (THD);	√	X	X
Consideration of hazardous areas, where applicable;	√	X	√
Consideration of electrochemical corrosion due to equipotential bonding;	√	X	X
Utility interconnection requirements for load transfer parallel connection; and equipotential bond monitoring;	√	X	√
Emergency Shut-Down requirements;	X	√	X
Rated current or apparent power;	X	√	X
Quality of power supply;	X	√	√
Minimum supply apparent power or current Capacity;	X	√	X
Isolation;	X	√	X

Table 18: *Compatibility assessment, requirements comparison*

As a result of that comparison, a compatibility assessment based on all the analysed rules had been developed trying to include all the important aspects that some of them may not pay attention on. In addition, the redaction of each point had been done with a clear and understandable vocabulary and if it were necessary, with a higher extension. That complete assessment shall include

1. Minimum and maximum prospective short-circuit current;
2. Nominal ratings of shore supply, ship to shore connection and ship connection, including frequency, voltage, quality of power supply and rated current or apparent power;
3. Any de-rating for cable coiling or other factors;
4. Acceptable voltage variations at ship switchboards between no-load and nominal rating;
5. Steady state and transient ship load demands when connected to a HV shore supply, HV shore supply response to step changes in load;
6. System study and calculations mentioned in a previous section;
7. Verification of ship equipment impulse withstand voltage;
8. Compatibility of communication link;
9. Distribution system compatibility assessment (shore power transformer neutral earthing) and equipotential bond monitoring;
10. Functioning of ship earth fault protection, monitoring and alarms when connected to a HVSC supply and compatibility of safety circuits;
11. Sufficient cable length;
12. Total harmonic distortion (THD);
13. Consideration of hazardous areas, where applicable;
14. Consideration of electrochemical corrosion due to equipotential bonding;
15. Utility interconnection requirements for load transfer parallel connection;
16. Emergency Shut-Down requirements;
17. Isolation;

4.6 Conversion equipment

For transformers design and equipment, the requirements are more complete than other components or aspects of the installation. For semiconductors converters, requirements have not been developed further than construction in order to be in compliance with the respective IEC rule. The comparison between the implicated rules is showed in table 19:

Conversion equipment requirements	ISO/IEC/IEEE	DNV	RINA
Transformers shall be of the separate winding type for primary and secondary side. The secondary side shall be star-configuration with neutral bushings (Dyn).	√	X	X
The temperature of supply-transformer windings shall be monitored. In the event of over temperature, an alarm signal shall be transmitted to the ship using the data-communication link.	√	X	√
Short circuit protection for each supply transformer shall be provided by circuit-breakers or fuses in the primary circuit and by a circuit breaker in the secondary.	√	X	X
Overload protection shall be provided for the primary and secondary circuit. In the event of overload, an alarm signal shall be activated to warn relevant duty personnel.	√	X	X
Where provided, converting equipment for connecting HV shore supplies to a ship electrical distribution system shall be constructed in accordance with IEC 60076 for transformers and IEC 60146-1 series for semiconductor convertors.	√	X	X
The protection for electrical equipment shall be in accordance with IEC 61936-1, as applicable.	√	X	X
A cooling system shall be installed for transformers on shore. Whether by air or with liquid, an alarm shall be initiated when the cooling medium exceeds a predetermined temperature and/or flow limits.	√	X	X
The transformer shall include overvoltage protection,	X	√	X
If necessary, means are to be provided to reduce transformer current in-rush and/or to prevent the starting of large motors, or the connection of other large loads, when an HV supply system is connected.	X	X	√

Table 19: *Conversion equipment, requirements comparison*

To sum up the last chart, conversion equipment requirements that shall be considered at the design statement are basically divided in four types:

1. Constructive requirements based on IEC international standards:
   a. Transformers shall be constructed in accordance with IEC 60076
   b. Semiconductors shall be constructed in accordance with IEC 60146-1
   c. The protection for electrical equipment shall be in accordance with IEC 61936-1

2. Main requirements of the transformer (Type and configuration) :
   a. Shall be of the **separate winding type for primary and secondary side**. The **secondary side shall be star-configuration with neutral bushings (Dyn).**

3. Transformer equipment:
   a. **A cooling system shall be installed for transformers on shore.** Whether by air or with liquid, an alarm shall be initiated when the cooling medium exceeds a predetermined temperature and/or flow limits.

4. Protections and safety requirements:
   a. **The temperature of supply-transformer windings shall be monitored**. In the event of over temperature, an alarm signal shall be transmitted to the ship using the data-communication link.
   b. **Short circuit protection for each supply transformer** shall be provided by circuit-breakers or fuses in the primary circuit and by a circuit breaker in the secondary.
   c. **Overload protection** shall be provided for the primary and secondary circuit.
   d. **Overvoltage protection** shall be provided for the primary and secondary circuit.

In addition to these last four basic groups of requirements, alarm and data communication system shall be considered. It is only completely covered by the international standard which requires a data communication system between the ship and the shore. By this system, alarms from onshore protection equipment shall be transmitted to the ship. Related with transformers, shore transformer high-temperature alarm shall be transmitted.

In the ABS rules, onboard transformers are well covered, but not onshore transformers. The unique requirements about onshore transformers are very generic recommendations without big utility. That is because the ABS rule does not cover onshore systems furthermore than interface equipment.

4.7 Galvanic isolation

Safety measures are always important in all the electrical installations. A galvanic isolation is such a good measure or system to increase that safety. In particular, only the international standard, DNV and RINA mention in their rules some regulations for that aspect. The comparative between them is showed below in table 20:

Regulations and requirements	**ISO/IEC/IEEE**	**DNV**	**RINA**
Galvanic separation is to be provided between the on-shore and on-board systems.	√	√	√
Each ship shall be provided with a dedicated HV shore supply installation which is galvanically isolated from other connected ships and consumers. This may not be required where a HV shore supply is dedicated to supply only ships which have galvanic isolation on board.	√	√	X
When the isolation is performed by a transformer, this shall have separate windings for the primary and the secondary side.	X	√	X
It is recommended that If a power transformer is installed on shore, the transformer shall include overvoltage protection, protecting the vessel against lightning impulse over voltages.	X	√	X

Table 20: *Galvanic isolation, requirements comparison*

Summarizing last chart, main requirements that are going to be considered for galvanic isolation are:

1. Providing a galvanic separation between each ship and each power supply on shore.

2. If that isolation will be performed by a transformer, this shall have:
   a. Separate windings for the primary and the secondary side
   b. Overvoltage protection.

4.8 Neutral earthing resistor

The earthing resistor is one of the most important safety systems within the installation. The unique rules that include some requirements for this protection system are the international standard and DNV. In table 21 their requirements are compared:

Requirement or regulation	ISO/IEEE/IEC	DNV
The neutral point of the HVSC system transformer feeding the shore-to-ship power receptacles shall be earthed: a) through a neutral earthing resistor; or b) where frequency conversion of the shore supply is required, either through a neutral earthing resistor or through an earthing transformer with resistor on the primary side that provides an equivalent earth fault impedance.	√	X
If the system is earthed through a neutral earthing resistor, its rating in amperes shall not be less 1,25 times the preliminary system charging current. The rating shall be minimum 25 A continuous.	√	X
Where an equivalent earth fault impedance is chosen when frequency conversion of the shore supply is required, studies should be conducted to verify effectiveness.	√	X
The continuity of the neutral earthing resistor shall be continuously monitored. In the event of loss of continuity the shore side circuit breaker shall be tripped.	√	√
An earth fault shall not create a step or touch voltage exceeding 30 V at any location in the shore to ship power system.	√	X
The shore side transformer star point shall be earthed, through a neutral earthing resistor **of 540 ohms** continuous rated, and bonded only to the shipside.	√ (annex C)	X

Table 21: *Neutral earthing resistor, requirements comparison*

The main requirement extracted from the comparison is that the neutral point of the Shore power feeding transformer shall be earthed through a neutral earthing resistor.

In case frequency conversion of the shore supply would be required, it can be earthed though the same system or using an earthing transformer with resistor on the primary side that provides an equivalent earth fault impedance to the system. Such as numerical requirements, the following summarized requirements are important to be considered:

- Neutral earthing resistor rating shall not be less than 1,25 times the preliminary current in amperes.
- An earth fault shall not create a step voltage exceeding 30 V at any location of the system.
- The neutral star point of the shore side transformer shall be earthed, through a neutral earthing resistor of 540 ohms continuous rated and bonded only to shipside.

Last requirement, the only common requirement and the only one from DNV, is that the neutral earthing resistor shall be continuously monitored to verify the bonding between shore and ship. If it would be any loss of bonding or continuity of the system, the shore circuit breaker shall be activated.

Such an informative note from 2009, the international standard provides that the typical cruise ship HV distribution systems are earthed though a high resistance earthing resistor that are installed on each of the ship's generators neutral points. By using that system, the earth fault current can be limited according to the size of the resistor while on the shore.

4.9 Equipotential bonding

The maintenance and monitoring of the equipotential bonding between shore earthing electrode and ship's hull is a very important aspect of the design statement. That aspect is only directly covered by the following rules, which are compared in table 22:

Regulations and requirements	ISO/IEC/IEEE	ABS	RINA	BV
An equipotential bonding between the ship's hull and shore earthing electrode shall be established.	√	√	√	√

An interlock is provided such that the HV shore connection cannot be established until the equipotential bonding has been established. An interlock arrangement is to be provided such that the loss of equipotential bonding is to result in the disconnection of the HV shore power.	X	√	√	X
Arrangements are to be provided so that when the shore connection is established, the resulting system grounding onboard is to be compatible with the vessel's original electrical system grounding philosophy. Integrity of the equipotential bonding is to be continuously checked as a part of the ship shore safety system.	X	√	√	X
The voltage rating of electrical equipment insulation materials is to be appropriate to the system grounding method, taking into consideration the fact that the insulation material will be subjected to 3 times higher voltage under single phase ground fault condition.	X	√	X	X

Table 22: *Equipotential bonding, requirements comparison*

As a result of that comparison, a complete requirement guide based on all the analysed rules had been developed trying to include all the important aspects that some of them not include. The complete requirements for equipotential bonding shall be:

1. An equipotential bonding between the ship's hull and shore earthing electrode shall be established

2. An interlock is provided such that the HV shore connection cannot be established until the equipotential bonding has been established. Interlock arrangement is to be provided such that the loss of equipotential bonding is to result in the disconnection of the HV shore power.

3. Arrangements are to be provided so that when the shore connection is established, the resulting system grounding onboard is to be compatible with the vessel's original electrical system grounding philosophy.

4. Integrity of the equipotential bonding is to be continuously checked as a part of the ship shore safety system.

5. The voltage rating of electrical equipment insulation materials is to be appropriate to the system grounding method, taking into consideration the fact that the insulation material will be subjected to 3 times higher voltage under single phase ground fault condition.

4.10 Short circuit protection onshore

Interlocking some protection measures is basically to guarantee personal's safety in all the port's environment. That is the main reason why paying attention on this step is very important. Including short circuit protections such circuit breakers is basic in design statement. All the requirements collected from all the previous mentioned rules, are compared in table 23, which is showed next:

Regulations or requirements	**ISO/IEC/IEEE**	**DNV**	**ABS**	**BV**	**RINA**
The prospective short-circuit contribution level from the HV shore distribution system shall be limited by the shore side system to 16 KA rms; (for general ships)	√	X	X	X	X
Electrical system/equipment shall be rated for minimum of 16 kA rms for 1 s, and 40 kA peak	√	X	X	X	X
The maximum short-circuit current is 25 kA / 1 s and a maximum peak short-circuit current of 63 kA.	√ (annex C)	X	X	X	X
The prospective short-circuit contribution level from the HV shore distribution system shall be limited by the shore-sided system to 25 kA rms; (for cruise ships)	√ (annex C)	X	X	X	X
The rated short-circuit making capacity of the circuit breaker is not to be less than the prospective peak value of the short-circuit current. The rated short-circuit breaking capacity of the circuit breaker is not to be less than the maximum prospective symmetrical short-circuit current.	X	X	√	√	X

All circuit breakers and cables used for the electrical shore connection shall be rated for the prospective short circuit currents that may appear at their location in the installation.	X	✓	X	X	X
Interlocks shall be provided in switchboards against simultaneously feeding from the ship's own generators and the electrical shore connection when the parallel connected short circuit power exceeds the switchboards' short circuit strength.	X	✓	X	X	X
A short time parallel feeding as a "make before break" arrangement is accepted when arranged with automatic disconnection of one of the parallel feeders within 30 s.	X	✓	X	X	X
Shore connection HV circuit breaker is to be equipped with low voltage protection (LVP).	X	X	X	X	X
In calculating the maximum prospective short-circuit current, the source of current is to include the maximum number of generators which can be simultaneously connected the shore supply contribution and the maximum number of motors which are normally simultaneously connected in the system.	X	X	X	X	✓
Protection against short-circuit currents is to be provided by circuit-breakers or fuses.	X	X	X	✓	X

The calculations may take into account any arrangements that: • prevent permanent parallel connection of high voltage shore supply with ship sources of electrical power and/or, • restrict the number of ship generators operating during parallel connection to transfer load, • restrict load to be connected.	X	X	X	X	√

Table 23: *Short circuit protection, requirements comparison*

After analysing all these rules it is easy to conclude that each rule or each classification society tries to cover short circuit protection in a basic way. The truth of it, is that only the international standard covers in an accurate way this section. As it can be seen in the chart, the ISO/IEC/IEEE standard has some regulations for generic ships contained in the main body of the rule. In addition it contains some concrete requirements for some type of ships such as cruise ships. These changes depending on the ship, are collected in table 24:

Rate		***Generic ships***	***Cruise ships***
*Prospective short-circuit contribution level shall be limited by the shore side system **to:***		***16 KA rms***	***25 kA rms***
Minimum	*Short-circuit current shall be of:*	***16 kA / 1 s***	X
	Peak short-circuit current shall be of:	***40 kA***	X
Maximum	*Short-circuit current shall be of:*	X	***25 kA / 1** s*
	Peak short-circuit current shall be of:	X	***63 kA.***

Table 24: *Summary chart for short circuit protection numerical requirements*

The remaining rules, are only covering short-circuit aspects in their general electric rules but not in the specific shore power rule or guide. For example, Bureau Veritas is only including short and general rules that are not enough meaning by their own self.

4.11 Circuit breakers and safety interlocks

Circuit breakers and switches, the mainly protection devices, shall be designed with accuracy and with a guarantee that they would work and would be activated in the exact situation. The next chart shows a comparison between all the rules and its requirements about circuit breakers and switches:

Requirements	**ISO/IEC/IEEE**	**ABS**	**BV**	**DNV**	**LR**	**RINA**
In order to have the installation isolated before it is earthed, the circuit-breaker, disconnector and earthing switch shall be interlocked in accordance with the requirements of IEC 62271-200.	√	√	√	√	√	√
HV shore connection circuit breaker is to be remotely operated.	√	√	X	X	X	√
The rated making capacity of the circuit breaker and the earthing switch shall not be less than the prospective peak value of the short-circuit current (IP) calculated in accordance with IEC 61363-1.	√	√	X	√	X	X
The rated short-circuit breaking capacity of the circuit-breaker shall not be less than the maximum prospective symmetrical short-circuit current (IAC(0,5T)) calculated in accordance with IEC 61363-1.	√	√	X	√	X	X
Short circuit protection for each supply transformer shall be provided by circuit-breakers or fuses in the primary circuit and by a circuit breaker in the secondary.	√	X	X	X	X	X
The continuity of the neutral earthing resistor shall be continuously monitored. In the event of loss of continuity the shore side circuit breaker shall be tripped.	√	X	X	√	X	X

The HV circuit-breaker on the secondary side of the transformer shall open all insulated poles in the event of the following conditions:							
a)	overcurrent including short-circuit,	✓	✓	✓	✓	✓	✓
b)	over-voltage/ under-voltage	✓	✗	✗	✗	✓	✓
c)	reverse power	✓	✗	✗	✗	✓	✓
d)	over frequency	✓	✗	✗	✗	✗	✓
In order to satisfy the last requirement, at least the following protective devices, or equivalent protective measures, shall be provided:							
d)	synchrocheck (25) or voltage sensing device (84) (for dead bus verification)	✓	✗	✗	✗	✗	✓
e)	undervoltage (27)	✓	✗	✗	✓	✗	✓
f)	reverse power (32)	✓	✗	✗	✓	✗	✓
g)	load unbalance, negative phase sequence overcurrent (46)	✓	✗	✗	✓	✗	✗
h)	instantaneous overcurrent (50)	✓	✗	✗	✓	✗	✓
i)	phase time overcurrent (51)	✓	✗	✗	✓	✗	✓
j)	earth fault overcurrent (51G)	✓	✗	✗	✓	✗	✓
k)	overvoltage (59)	✓	✗	✗	✗	✗	✓
l)	directional phase overcurrent (67)	✓	✗	✗	✓	✗	✓
m)	Phase sequence voltage (47)	✗	✗	✗	✗	✗	✓
n)	Overload (49)	✗	✗	✗	✗	✗	✓

o)	Frequency (under and over) (81)	X	X	X	X	X	√
(Standard device designation numbers are shown in brackets above, as per IEEE Std C37.2™)							
The protection systems shall be provided with battery back-up adequate for at least 30 min. Upon failure of the battery charging or activation of the back-up system, an alarm shall be communicated to the ship.		√	X	X	X	X	X
Arrangements shall be provided so that the circuit-breakers cannot be closed when any of the following conditions exist:							
a)	one of the earthing switches is closed (shore-side/ship-side);	√	X	X	√	X	√
b)	the pilot contact circuit is not established;	√	√	X	√	X	√
c)	emergency stop facilities are activated;	√	√	X	√	X	√
d)	ship or shore control, alarm or safety system self-monitoring diagnostics detect an error that would affect safe connection;	√	X	X	√	X	√
e)	the communication link between shore and ship is not operational, where applicable;	√	X	X	√	X	√
f)	the permission from the ship is not activated;	√	√	X	X	X	X
g)	the HV supply is not present;	√	√	X	X	X	√
h)	equipotential bonding is not established (via equipotential bond monitoring relays)	√	√	X	X	X	X

i)	An error within the HV connection system that could pose an unacceptable risk to the safesupply of shoreside power to the vessel;	X	√	X	X	X	√
j)	An earth fault;	X	X	X	X	X	√

Table 25: *Circuit breakers and safety interlocks, requirements comparison*

Summarizing the content of that comparison, we can conclude that circuit breaker and switches rules can be very complete such as the international standard or RINA, or very incomplete. Incomplete rules provide requirements for these systems, but not in their specific rule. They make reference to their general electric rules for classification of ships. That is the case of Bureau Veritas, its rules for that section only provide a general requirement.

4.12 Interface equipment

4.12.1 Sockets and plugs

The interface equipment is very important within onshore power installations. The huge amount of power that is going to be supplied to a ship, is very dangerous because of its high voltage. This is the main reason why the connection equipment shall be able to guarantee the safety of the personal who manipulate the interface elements, the safety of the ship and the safety of onshore equipment. In that way, the requirements for connection and interface equipment are generally covered in different levels of accuracy, by all the rules due to guarantee high safety levels during the power supply and at the procedures of connection and disconnection.

The first elements to consider are the mainly interface equipment, the plug and the socket. These elements are going to be the main contact systems between the ship and the shore. Requirements for plug and socket have been compared in table 26:

Requirements	**ISO/IEC/IEEE**	**ABS**	**BV**	**DNV**	**LR**	**RINA**
Plugs and sockets are to be protected from dust, moisture and condensation while not in use.	√	√	X	X	X	X

The minimum protection rating of plugs and sockets is to be **IP66**.	X	√	X	X	X	X
The plug and socket system shall be of a type tested design, suitable for marine use.	X	X	X	√	X	X
Plugs and socket-outlets shall be in accordance to **IEC 62613-1 and IEC 62613-2** or a relevant National Standard. *(IEC 62613: Plugs, socket-outlets and ship couplers for high-voltage shore connection systems (HVSC Systems): Part 1: General requirements. Part 2: Dimensional compatibility and interchangeability requirements for accessories to be used by various types of ship.)*	√	X	X	X	√	X
Plugs and socket-outlet connection shall be in areas where personnel will be protected in the event of an arc flash as a result of an internal fault in the plug and/or socket-outlet by barrier and access control measures.	√	X	X	X	√	X
Each plug shall be fitted with pilot contacts for continuity verification of the safety circuit.	√	X	X	X	X	√
The plug and socket-outlet arrangement is to be fitted with a mechanical securing device that locks the connection in engaged position. In addition, they are to be designed so that an incorrect connection cannot be made.	√	X	X	X	X	√
The **shore-side** of the connection cable is to be fitted **by plug(s).** The plug body is to protect all contacts. Cable connections may be permanently connected on shore to suitable terminations.	X	X	X	X	X	√

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The **shipside** of the connection cable is to be fitted **with connector(s).** Cable connections may be permanently connected on board to suitable terminations.	X	X	X	X	X	√
Cable extensions are not permitted.	X	X	X	X	X	√
The earthing contacts are to make contact before the live contact pins do when inserting a plug.	X	X	X	X	X	√
Plugs are to be designed so that no strain is transmitted to the terminals and contacts. The contacts are only to be subjected to the mechanical load which is necessary to ensure satisfactory contact pressure, also when connecting and disconnecting.	√	X	X	X	X	√
Each plug and socket-outlet is to have a permanent, durable and readable nameplate with the following information: • Manufacturer's name and trademark; • type designation; • applicable rated values; The nameplates are to be readable during normal service.	X	X	X	X	X	√

Table 26: *Sockets and plugs, requirements comparison*

After analysing all these requirements, the accuracy degree and the coverage depends on which rule is considered. As it can be seen in the last chart, the international standard is the one who has the widest coverage. RINA has also a very good coverage, having similar criteria against the international standard.

All these requirements have been unified in the next summary aiming to make their application clear and emphasizing the most important points. Plugs and sockets shall be in accordance with the next summarized requirements:

- **Protection**; plugs and sockets are to be protected from dust, moisture and condensation while not in use. The minimum protection rating of plugs and sockets is to be **IP66.**

- **Construction and dimensioning**; Plugs and socket-outlets shall be in accordance to **IEC 62613-1 and IEC 62613-2.**

- **Location**; plugs and socket-outlet connection shall be in areas where personnel will be protected in the event of an arc flash.

- **Pilot contacts**; Each plug shall be fitted with pilot contacts for continuity verification of the safety circuit.

- **No additional strains**; Plugs are to be designed so that no strain is transmitted to the terminals and contacts.
- **Security device**; plug and socket-outlet arrangement is to be fitted with a mechanical securing device that locks the connection in engaged position.

- **Nameplate**; Each plug and socket-outlet is to have a permanent, durable and readable nameplate with the following information:
    - Manufacturer's name and trademark;
    - Type designation;
    - Applicable rated values;

- **Connection contact**; earthing contacts are to make contact before the live contact pins do when inserting a plug.

It is important to analyse graphic sources of each rule to make a better idea of how complete they are. Only two of them provide us with useful visual sources about plugs and sockets: ABS and the international standard.

ABS, shows the following diagram for socket's outlet arrangement:

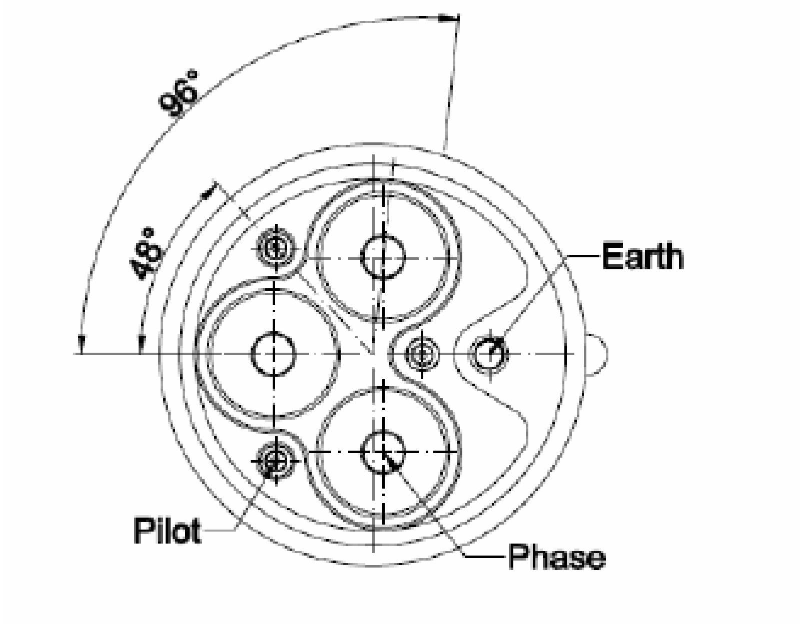
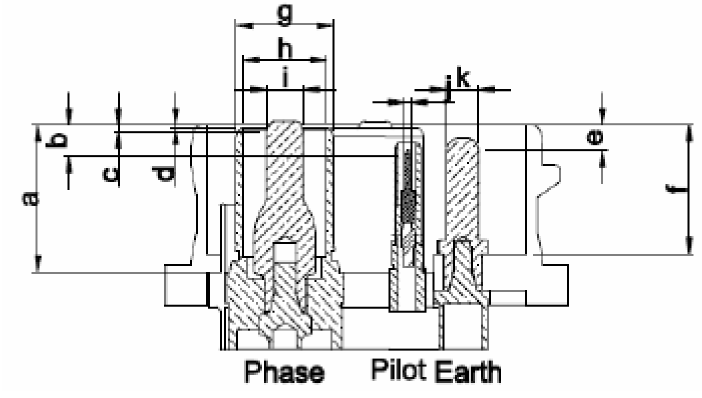


Figure 24: *Socket's arrangement by ABS*

In addition, they provide figure 25 for dimensions:

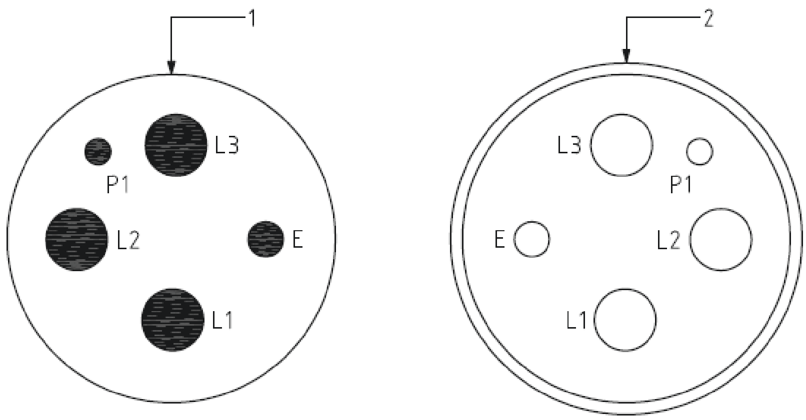


Symbol	Name	Dimension
a	Insulator depth	64
b	Contact pilot	13,8
c	Contact phase	3,4
d	Top insulator	1,4
e	Contact earth	11,1
f	Tounge depth	56
g	Insulator outside Ø	42,5
h	Insulator inside Ø	36,5
i	Phase Ø	16
j	Pilot Ø	3
k	Earth Ø	14
l	Partition phases Ø	72
m	Partition pilots Ø	84
n	Partition earth Ø	105
o	Insulator Ø	119,6
p	Plug inside Ø	140
q	Plug outside Ø	154,5
r	Plug outside + nose	162
s	Partition pilot Ø	36

Figure 25: *Socket's dimensions by ABS*

On the other side, the international standard, 80005-1, particularly the annex 3 for cruise ships, provides us with a similar diagram about the socket and its components.

The rule requires that general arrangement of that connector shall be in according to the next source, represented on figure 26:



KEY

1. POWER PLUG FACE (SHORE SIDE PLUG)
2. SOCKET OUTLET FACE (SHIP SIDE SOCKET)

E. EARTH

P1. PILOT LINE 1 (USED FOR GROUND CHECK)

L1. PHASE A - PHASE R

L2. PHASE B - PHASE S

L3. PHASE C - PHASE T

Figure 26: Connector pin assignment by the standard 80005-1

Moreover it stablish that each 3-phase HV plug or socket-outlet shall have:

a) 3 phase current carrying contacts, (L1, L2, L3);

b) one earth contact;

c) one pilot contact for ground-check monitoring;

Joining both sources, the idea that the requirements pretend to regulate is clearly understandable. Graphic sources are very important for plugs and sockets. That is why the specific IEC rules for plugs and sockets are mentioned by Lloyd's Register in its own rule.

4.12.2 Cable

Cable requirements are basically a group of regulations that use to be different between classification societies. They use to approve their own type of cable and its characteristics. Requirements for cables from each classification society are compared in table 27, which is showed next:

Requirements	ISO/IEC/IEEE	ABS	BV	DNV	LR	RINA
Non-fixed HV cables are to be constructed and tested to recognized standard acceptable to ABS.	X	√	X	X	X	X
A flexible shore connection cable can be arranged either on board the vessel or situated at key.	X	X	X	√	X	X
High voltage cables are to be readily identifiable by suitable marking.	√	√	X	√	X	X
The flexible cable shall be terminated close to the ship's side, and not be used as a part of the fixed cable installation in the vessel.	X	X	X	√	X	X
All cables installed on board shall be DNV type approved.	X	X	X	√	X	X
Cables shall be at least of a flame-retardant type in accordance with the requirements given in IEC 60332-1-2.	√	X	X	X	X	√
The outer sheath shall be oil-resistant and resistant to sea air, seawater, solar radiation (UV) and shall be non-hygroscopic.	√	X	X	X	X	√
The temperature class shall be at least 90 °C, insulation, in accordance with Annex A. The maximum operating temperature shall not exceed 95 °C, taking into account any heating effects (e.g. as a result of cable coiling).	√	X	X	X	X	X
The insulation temperature class is to be at least 85°C.	X	X	X	X	X	√
Correction factor for ambient air temperatures above 45 °C shall be taken into account (see IEC 60092-201:1994, Table 7).	√	X	X	X	X	X

Control and monitoring cables shall be at least of a flame retardant type in accordance with the requirements of IEC 60332-1-2. The environmental requirements for the sheath shall be the same as described for the ship to shore connection cable.	√	X	X	X	X	X
Size, quantity and rating of cables shall be sufficient to meet the maximum power rating and voltage that the terminal can supply to the ship.	√	X	X	X	X	X
Connection Equipment power cables are to be Type Approved in accordance with LR's *Type Approval System Test Specification Number 3* or, alternatively, surveyed by the Surveyors during manufacture and testing to assess compliance with the particular section of the rules, and application of an acceptable quality management system.	X	X	X	X	√	X

Table 27: *Cable, requirements comparison*

As it was known before analysing last chart, requirements for cables are very diverse, in order to summarize requirements about cable type or cable characteristics, a new chart was developed. That source is showed below such as table 28:

Rule	**Type**	**Outer sheath**	**Temperature class**
ISO/IEC/IEEE	At least of a flame-retardant type (IEC 60332-1-2).	Oil-resistant, resistant to sea air, seawater, solar radiation (UV) and shall be non-hygroscopic.	At least 90 °C isolation. The maximum operating temperature shall not exceed 95 °C.
ABS	Constructed and tested to recognized standard acceptable to ABS.		

BV	In accordance with IEC publications.		
DNV	Type Approval Programme No. 6-827.13: *Flexible Electrical Cables for ships/high speed, light craft and naval surface craft*		
LR	In accordance with IEC publications.		
RINA	At least of a flame-retardant type (IEC 60332-1-2).	Oil-resistant, resistant to sea air, seawater, solar radiation (UV) and shall be non-hygroscopic	At least 85 °C isolation.

Table 28: *Summary of type requirements for cable*

Once again, the international standard is the most complete rule for covering cables in an onshore power installation. For cable requirements published by classification societies, RINA is the most complete one. It shows very similar criteria in comparison with the international standard.

Such an informative note from 2009, the international standard provides that cruise ships typically utilize four power 3-phases couplers, each rated 500 A, and one neutral single pole connector rated 250 A.

4.12.3 Cable handling

The flexible cable that shall be used for the connection cannot be managed such a rope. It is very important to handle the cable during the connection to avoid extra strains over it and develop a correct use. In addition, the effectiveness of that system will help on maintenance, making it easier and cheaper. Handling requirements are compared in table 29.

Requirements	**ISO/IEC/IEEE**	**ABS**	**BV**	**DNV**	**LR**	**RINA**
A cable handling system must be arranged.	X	X	X	✓	X	X

The cable management system is to allow extending cable and retracting cable without causing undue stress to the cable.	√	√	X	X	X	X
There shall be installed equipment enabling efficient cable handling and connection.	X	X	X	√	X	X
The cable management system shall give alarm at high cable tension to a manned position. At high high tension, the shore connection shall be automatically disconnected. Automatic release of the plug and socket connection is not required.	X	X	X	√	X	X
Handling of plug and socket outlets shall be possible only when the associated earthing switch is closed.	√	X	X	X	X	X
Connection Equipment cable reels, cranes and/or gantries used to manage, handle or adjust connection cables, plugs and/or socket-outlets, are to be designed and manufactured in accordance with applicable LR Rules or a marine standard acceptable to LR.	X	X	X	X	√	X
The ship to shore connection cable installation and operation are to be arranged to provide adequate movement compensation, cable guidance, anchoring and positioning of the cable during normal planned ship to shore connection conditions.	X	X	X	X	X	√
Connection Equipment support and management arrangements, including those for control engineering arrangements, are to be arranged not to apply damaging forces or tension to correctly applied equipment. Support arrangements are to ensure that the weight of connected cable is not borne by cable end terminations or connections.	X	X	X	X	√	X

Table 29: *Cable handling, requirements comparison*

After comparing all the requirements for handling, a summary have been developed for practical application:

- A cable handling system must be arranged.
- It shall allow extending cable and retracting cable without causing undue stress to the cable.
- The cable management system shall give alarm at high cable tension to a manned position.
- Connection Equipment cable reels, cranes and/or gantries used to manage, handle or adjust connection cables, plugs and/or socket-outlets, are to be designed and manufactured in accordance with applicable LR Rules or a marine standard acceptable to LR. About these elements, only Lloyd's Register mentions some construction and design requirements.
- Be sure that the handling system is supporting all the weight loads that were considered during its design.

4.12.4 Management

Cables, plugs and sockets shall have a management system to assist the connection procedure. That system is going to include safety procedures, management equipment and protection systems such as switches and interlocks. The regulations aiming to guarantee the safety of operation are compared in table 30 which is showed next:

Requirements	**ISO/IEC/IEEE**	**ABS**	**BV**	**DNV**	**LR**	**RINA**
Socket-outlets and inlets shall be interlocked with the earth switch so that plugs or connectors cannot be inserted or withdrawn without the earthing switch in the closed position.	√	X	X	X	X	√
The current-carrying capacity of the earth contact shall be at least equal to the rated current of the other main contacts.	√	X	X	X	X	√

The power plugs as well as the neutral plug shall be fitted with fail-safe limit switches that are activated only when the plug and socket-outlet are properly mated. These fail safe limit switches shall be part of, and activate the emergency shutdown, if the plug is moved from the mated position while live.	√ (annexC)	X	X	X	X	X
Connection between the neutral and ship's hull shall be robust and durable for proper bonding.	√ (annexC)	X	X	X	X	X
Interlock between the plug and the shore connection circuit breaker is to be provided such that the plug can be disengaged only after the shore connection circuit breaker has been opened.	√	√	X	√	X	X
Connections with external electrical power supply arrangements are to be designed to prevent damage to the ship structure or Connection Equipment cable reels, cranes and/or gantries as a result of the connections separating in the event of the ship leaving a berth inadvertently or as a result of high cable tension for other reasons	X	X	X	X	√	X

Interlocking with earthing switches is to be arranged to ensure that the HV power contacts remain earthed until: • all connections are made, • the communication link is operational, • self-monitoring properties of ship or shore alarm, control and safety systems detect that no failure would affect safe connections, and • the permission from ship and shore is activated.	X	X	X	X	X	√
Each plug shall be fitted with pilot contacts for continuity verification of the safety circuit.	√	√	X	X	X	√
An interlock, which prevents plugging and unplugging of the HV plug and socket outlet arrangements while they are energized, is to be provided.	√	√	√	X	X	X
Opening, or release, of the plug and socket may be a manual operation.	X	X	X	√	√	X

Table 30*: Interface management, requirements comparison*

Classification societies are, once again, not well covering this type of equipment with the exception of RINA. The requirements about safety measures and the interface equipment are basically to guarantee the safety of the connection procedure and the personal. In particular, the interlocking system to prevent plugging and unplugging while the connection is energized, is very curious, because some rules require an interlock without specifying which type and others specify which type of interlock, a circuit breaker.

After analysing all the requirements, the summary for designing these systems are:

- **Earth switch;** plugs or connectors cannot be inserted or withdrawn without the earthing switch in the closed position. In addition, RINA amplify the situations on which that switch shall remain closed until the connection is made, the communicational link is operational, there are not any failures and the permission from ship and shore is activated.
- **Earth contact capacity**; shall be at least equal to the rated current of the other main contacts.
- **Fail-safe limit switches**; that will be activated only when the plug and socket-outlet will be properly mated. If the plug will be moved from the mated position, it will activate the emergency shutdown.
- **Interlocking protection**;
    - A Circuit breaker shall be installed between the plug and the shore. The plug can be disengaged only after the shore connection circuit breaker has been opened.
- **Pilot contacts**; plugs shall be fitted with pilot contacts for continuity verification of the safety circuit.
- **Plug actions**; Opening, or release, of the plug and socket may be a manual operation.

4.13 Location and construction

Due to increase safety in onshore installations, the major part of the rules, mention some requirements to be in account of about location and installation. These requirements are compared in table 31:

Requirements	**ISO/IEC/IEEE**	**ABS**	**LR**	**DNV**	**RINA**
HVSC equipment shall be installed in access controlled spaces.	√	√	X	X	√
When determining the location of the HVSC system, the full range of cargo, bunkering and other utility operations shall be considered, including: *1. The cargo handling and mooring equipment in use on the ship and shore, and the areas that must be clear for their operation;*	√	X	√	X	√

2. Traffic management considerations;	√	X	√	X	√
3. Personnel safety measures, such as physical barriers to prevent unauthorized personnel access to HVSC equipment or the cable management equipment;	√	√	√	X	√
4. Presence of hazardous areas	√	X	X	X	√
The shore connection switchboard is to be located in a compartment that is sheltered from the weather. HV shore cables are to enter this compartment through a temporary opening with weather tight arrangements	X	√	X	X	X
Higher voltage equipment is not to be combined with low voltage equipment in the same enclosure, unless safety measures are taken.	X	√	X	X	X
High voltage cables are to be installed on cable trays or equivalent when they are provided with a continuous metallic sheath or armor which is effectively bonded to earth; otherwise, they are to be installed for their entire length in metallic casings effectively bonded to earth.	X	√	X	X	X
Appropriate arrangements are to be provided for storage of removable HVSC equipment when not in use.	X	√	X	X	X
At all locations from where the electrical shore connection or cable management system may be controlled, the following alarms and controls shall be available: — high and high high tension of the flexible cable — loss of shore power — emergency disconnection — activation of protective functions as earth fault, overcurrent and short circuit	X	X	X	√	X

Table 31: *Location and construction, requirements comparison*

4.14 System study and calculations

The shore-connected electrical system shall be evaluated in many points of its complete working behaviour during design statement. These are the main and the first important requirements on which all the international standards are based. These points or these calculations are only covered in an extended way by the international standard ISO/IEC/IEEE for shore side and ship side, and by Lloyd's Register Rules only for ship side. The ISO/IEC/IEEE design aspects mentioned for shore side are included in table 32 which is showed next:

Design aspect	**ISO/IEC/IEEE**
The electrical load during shore connection;	√
For shore supply installations, a maximum and minimum prospective short circuit current for visiting ships shall be defined and used for calculations.	√
For ships, a maximum and minimum prospective short circuit current for visiting ships shall be defined and used for calculations.	√
The calculations may take into account any arrangements that prevent parallel connection of HV shore supplies with ship sources of electrical power;	√
The calculations may take into account any arrangements that restrict the number of ship generators operating during parallel connection to transfer load;	√
The calculations may take into account any arrangements that restrict load to be connected;	√
System charging (capacitive) current for shore and ship;	√
This system charging current calculation shall consider the shore power system and the expected ship power including the on line generator(s);	√
Shore power transformer neutral earthing resistor analysis and earth fault limiting requirements for earthed high voltage connections;	√
Transient overvoltage protection analysis;	√

Connections, including control, alarm and safety systems and data communication links;	√
Emergency Shut-Down requirements;	√
Nominal ratings of the shore supply, ship to shore connection and ship connection;	√
Reference to protection system design, including protection characteristics for the Connection Circuit-Breaker;	√
Minimum supply apparent power or current capacity;	√
Isolation;	√

Table 32: *System study and calculations, requirements comparison*

These calculated values shall be used to select suitably rated shore connection equipment and to allow the selection and setting of protective devices. The final results of these calculations shall be made available to all involved parties.

Documented alternative proposals with the objective to limit the parallel connection to short times may be considered where permitted by the relevant authorities and the parties involved.

4.15 Protection against moisture and condensation

Such as a general requirement, effective means shall be provided to prevent accumulation of moisture and condensation, even if equipment is idle for appreciable periods. That requirement shall be applied to all the shore equipment, and it is very important applied to the connection equipment.

4.16 Results evaluation

After developing the previous sections of the current chapter, the general results of the analysis can be concluded in the interaction between the studied rules.

First of all, as it can be seen in all sections of the chapter, the international standard IEC/IEEE/ISO 80005-1 is the most complete document to take notice before designing a shore to ship system at any port. It provides good and specific requirements for this type of systems and what is most important, the recognition from the major part of the Classification Society rules such as a valid rule to be approved by their standards. Then, designing a Shore Power installation under the mentioned international standard is a guarantee to be approved by some Classification Societies, but not all of them consider the standard as a valid rule.

Classification Societies use to consider shore power installations such as additional classes and, as a result of that, additional class approval is needed. Moreover, their rules use to cover only the installation onboard ships. Some of them provide some requirements which are a little bit confusing owing to their relativity. These few requirements about onshore are related to the limit between shore installation and ship's installation. That is the most confusing aspect in Classification Societies rules, the interface between both sides.

That confusion is normal. The major part provides initial notes about the range of application of their rules in which the uncovering of shore side installation is mentioned. Otherwise it is hard to provide requirements about interface equipment, because of its presence in both sides, within mention shore side.

Moreover all these general facts about the compared rules, individual commentaries for each rule can be mentioned excluding the already mentioned IS0/IEC/IEEE standard. The worst compared rule or the most incomplete rule is developed by Bureau Veritas. All the rules provide a particular and extended chapter or section for covering the shore power additional class. Bureau Veritas provide some general requirements mixed in its general electrical rules and reference its high voltage section such as the reference section. Otherwise, the best and most complete requirements provided by Classification Societies, are provided by RINA. Lloyd's Register rules are very complete, but just according to ship side and interface equipment, and that is why it is ranked such as the fourth rule.

All the mentioned aspects are exposed comparing all the rules in general aspects are showed in table 33. In addition, class notation for their additional class is provided.

RULE			APPLICATION		IEC CONSIDERATION
Ranking	**Rule**	**Class Notation**	**Ship side**	**Shore Side**	
1	RINA	HVSC	√	√	√
2	DNV	SHORE POWER	√	√	√
3	ABS	HVSC	√	X	√
4	LLOYD'S REGISTER	OPS	√	X	√
5	BUREAU VERITAS	X	√	X	X

Table 33: *General comparison between classification rules*

The international standard is the most complete, but there are some important requirements provided from the rest of the rules that should be added to the standard. These requirements are showed along the chapter in all the comparison charts.

Anyway, the ISO/IEC/IEEE 80005-1 is the referent because its consideration by the Classification Societies.

5 DESIGN

Developing an entirely distribution installation for shore power is always a complex procedure because of its two steps, design and construction. In that project only design had been evaluated and developed; construction is not developed in it. Only the basic elements of the installation are going to be accurately designed, aiming to make good simulation models.

5.1 General criteria and system's composition

The criterion which is going to be used to design the system, have been basically exposed in previous sections. In that section, all these ideas are going to be collected and applied during design statement.

First of all, analysing the requirements of service and general rules for shore power, we decided that the simplified blocks architecture is going to be represented by the next layout:

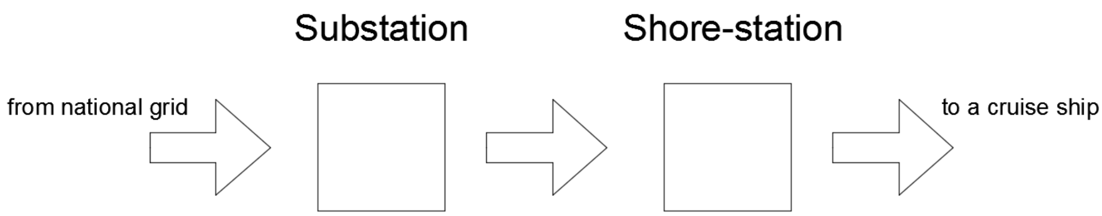


Figure 27: *Simplified block layout of the system*

It is going to be composed by a substation; which is going to receive the energy from the national grid, at 220 kV and 50 Hz, and is going to control the main transformation of the power and the distribution onshore. This substation is going to reduce voltage from 220 kV to 25 kV by a transformer. Frequency is going to be kept at 50 Hz.

The substation is going to supply the energy to the different shore stations, once for connection point, which are going to be located very near from that point. These substations are going to be basically composed by two different transformers, allowing the installation supply power at 6,6 kV or 11 kV, and one frequency converter permitting the connection at 60 Hz.

The idea of distributing power onshore at 25 kV may seem unreasonable, because it can be transformed directly to 11 kV at the substation and distributed at this voltage.

But the higher the voltage is, the more effective the power transmission is along the system. That is the main reason to use 25 kV for distributing power onshore.

The power supply designed for all the substations was in first instance a unified power equal for each of them, and equivalent to 12 MW. Finally, it was decided that only the terminals located at the Adossat Pier were going to be designed with this total power.

Otherwise, Barcelona's Pier is going to be designed with 8 MW for each connection point owing to their dimensions which not allow the biggest cruise ships berth in it.

After analysing the criterion and the main design ideas, the installation should be basically divided in the following sections:

- Connection with the national grid;
- Substation;
- Shore station;
- Distribution system and cable calculations;
- Interface equipment;

5.2 Connection with the national grid

Obviously, to develop that system we need to find one power source that would be able to supply the required power. In that case, the best option is choosing national grid such as the main supply source.

As it was previously mentioned in past sections, the Spanish high voltage grid used to transport power along big distances, works with 220 kV of voltage, 3 phases and 50 Hz of frequency. Aiming to guarantee power supply, the energy is used to be distributed by ring distribution architectures. In that way in case of possible faults or accidents the power supply would be continuous and without interruption for the consumers, because the consumption system or load is connected to the grid by two points and it can be supplied by two different incomings.

As a result of that, the substation shall have two connection points to the national high voltage grid.

5.3 Substation

As it was described in past sections of the current chapter, the power is going to be supplied to the substation by the national high voltage grid at 220 Kv and 50 Hz of frequency. Both connection points are going to be connected with two different bars.

From that bars power is going to pass through a transformer which is going to transform power voltage from 220kV to 25kV. Then a couple of bars are going to control the distribution of 25Kv power by its switchboard and its corresponding cells.

The substation is feed with high voltage power, because of that it shall have high protection systems to verify the safety of the personal and global system. The elements that compose the substation are accurately exposed in the following sections.

According to the place where the substation is going to be placed and aiming a higher safety degree, the 220kV Park is going to be composed by a group of armored cabins isolated with SF6. The corresponding layouts of the substation are included at the end of the project with the reference *SUBSTATION DESIGN, 220kV Part and 25kV Part.*

5.3.1 Substation's Transformers 220kV/25kV

The transformers considered for the current design, shall be star configuration with neutral bushings for the primary side such as the national distribution system at 220kV. The secondary side shall be, in accordance with national distribution standards, delta configuration. Distribution at 25 kV is not commonly used, but in Catalonia it is a standardized distribution voltage.

5.3.2 Measurement equipment

There are some measurement equipment that shall be installed aiming to have control and measure of all the system's working all the time. These elements are:

- Current transformers. They shall be installed at the beginning of the system aiming to control the incoming current in each instant. It is usually to install 4 transformers of this type for each phase.

- Voltage transformers. Such as current transformers, they are installed first aiming to control the incoming voltage.

5.3.3 Control elements

Aiming to have means to interrupt the supply in case of possible failures, the system shall have the following elements:

- Switches
- Circuit breakers
- Earthing systems

- Auto-valves

Circuit breakers shall be opened when the protection system will detect faults and dangerous conditions for the installation and for the safety of the personnel. Most of them are going to be included inside the armored cabins.

5.4 Shore-stations

The main function of the shore-stations proposed for the system is to adapt the power characteristics such as voltage and frequency to the used system on board the cruise ship to make it compatible. Some ships do not need to connect to a shore power supply compatible with their power plant in terms of voltage, because they have a transformer between their connection point on board and the main switchboard at the power plant.

The power parameters election for designing the system is determining for which ships will use the shore power system. The developed study for determining the most used voltages and frequencies was successful and it is in the way of the requirements analysed in the last chapter. According to the international standard HV connections shall be provided with a nominal voltage of 6,6 kV A.C and/ or 11 kV A.C. Otherwise, if some ships use to repeat itinerary at the same ports and their dedicated berths, other IEC voltage nominal values may be considered. This means that to design an installation to provide voltages not equal to 6,6kV or 11kV, it first pass a specific testing and checking by the IEC.

Then, the shore station is going to be supplied by one connection point at 25kV and 50Hz, that is going to be connected to another switchboard and it corresponding bar. From that bar, depending on the distribution architecture, one exit connection is going to leave from the shore-station to supply other shore stations or to be supplied in case of failure at the other connection point.

Aiming to be in compliance with the exposed facts, in all the shore-stations two transformers are going to be installed, one of 25/11 kV and one of 25/6,6 kV. The station would use a transformer among these two depending on cruise ships' voltage. In addition, these transformers shall be of the separate winding type for primary and secondary side. The secondary side shall be star-configuration with neutral bushings (Dyn).

Measurement equipment are going to be installed before the transformers aiming to measure the power demand that cruise ships will consume while they will be connected with the shore to ship connection. That equipment is basically, a current transformer and a voltage transformer.

To make the system versatile, a frequency converter shall be installed after transformers outlet to guarantee a very probable frequency of 60 Hz according to the high percentage of ships that use this frequency. In addition, the inclusion of a harmonic filter shall be considered owing to the frequency converter possible power distortions.The corresponding layouts of the substation are included at the end of the project with the reference *SHORESTATION DESIGN.*

According to the proposed distribution, there are two types of shore-stations for the current case, Adossat Pier stations and Barcelona Pier stations.

5.4.1 Adossat Pier shore-stations

This type of shore-station, present for Terminals A,B,C and D, is the biggest one in power terms. It is designed thinking on a peak of power of 12 MW. For that reason its elements shall be dimensioned with the following criteria.

- Transformer A (25/11kV)
- Transformer B (25/6,6 kV)
- Frequency converter

5.4.2 Barcelona Pier shore-stations

This type of shore-station, present for Terminals on Barcelona Pier, lower rated than Adossat Pier terminals. It is designed thinking on a peak of power of 8 MW. For that reason its elements shall be dimensioned with the following criteria:

- Transformer A (25/11kV)
- Transformer B (25/6,6 kV)
- Frequency converter

5.4.3 Transformer's protections

According to the analysed rules the following protections shall be installed:

- Short circuit protection for each supply transformer shall be provided by circuit-breakers or fuses in the primary circuit and by a circuit breaker in the secondary;
- Overvoltage protection; such as auto-valves;
- Overload protection in the primary circuit and in the secondary

In addition temperature of both windings shall be monitored with a temperature sensor. Cooling medium temperature shall be monitored too, an alarm shall be initiated when the cooling medium exceeds a predetermined temperature and/or flow limits.

5.4.4 Protections

The following protections shall be installed (*Standard device designation numbers are shown in brackets above, as per IEEE Std C37.2™)*

- Synchrocheck (25) or voltage sensing device (84) for dead bus verification
- Under-voltage (27)
- Reverse power (32)
- Load unbalance, negative phase sequence overcurrent (46)
- Instantaneous overcurrent (50)
- Phase time overcurrent(51)
- Earth fault overcurrent (51G)
- Overvoltage (59)
- Directional phase overcurrent (67)
- Phase sequence voltage (47)
- Overload(49)
- Frequency (under and over) (81)

Circuit breakers shall open as a result of not correct conditions detected by any of the mentioned protection devices.

5.4.5 Shore solutions

Actually, there are some companies that have developed their own shore-stations such as a close unit. They offer the entire shore-station for each particular purpose according to voltage, frequency and power compatibility.

Some of these products are offered by:

- Schneider Electric
- ABB
- Siemens

This type of product is very interesting because the company adapt the product for each particular case and port including all the protection, power, communication and management systems.

5.5 Distribution systems or architectures

To supply power to the different shore stations from the substation two different architectures have been chosen. Designing and checking different distribution systems aims to analyse the degree of dependability in all the connection points in front possible electrical or mechanical faults that would interrupt the power provision. Otherwise, the behavior of power's quality will be simulated in the next chapter due to predict possible reactions from faults in random points of the system.

The proposed architectures are the following:

- **Architecture 1**; based in two basically ramifications from the substation to four shore-stations each. On the one hand, that distribution system is the most efficient system looking it from cable cost point of view. This is the design that requires less cable length that will consequently save considerable money to invest in the project. On the other hand, the design won't be able to keep the power supply to all the cruise ships in case one fault would occur in one point along the main distribution conductor.

- **Architecture 2**; based in a combination between the first proposed architecture and one ring architecture. The ring architecture is going to perform de main distribution for Adossat Pier terminals and for Barcelona Pier ramification.
  This architecture offers the possibility of supplying power to Adossat Pier's terminals by two different ways. It makes the system very reliable in effectiveness terms.

Aiming to know how much cable length is necessary to adapt the installation to the real structure, a harbor model must be done.

That model had been developed by using a combination of Google maps and AutoCAD 2015. The main procedure was very simple, by using a screenshot of port's shape took from Google Maps, and inserting it in AutoCAD. The last step was tracing piers contour, and join them. The last step was scaling that sketch to a correct standard scale. One draft has been developed for each of the proposed architectures on the mentioned 2D model in AutoCAD. These drafts are showed at the final of the project with the measurement of all the distances that cable should be tended on. The reference for these layouts is *DISTRIBUTION ARCHITECTURES, Architecture 1 and Architecture 2.*

5.6 Fixed Cable calculations

The election of the cable is very important to keep the safety of the installation and to make it efficient. The effectiveness of the power transmission depends basically on the accuracy degree of that point. First of all, once basic architectures of the installation are decided, it is important to know cable length in all the stretches of the installation. In that way, aiming to obtain these data, the mentioned scaled drafts from Barcelona's cruise piers had been used to have reliable measurements. After that, all the designed stations had been situated with the objective of measuring length between them.

According to the project and the port, the cable installation is going to be undergrounded inside tubes. Moreover, next parameters are going to be considered and used for all the calculations:

Variables used for cable calculations	
Voltage (V)	25 kV
Conductor material	Copper
Electric resistivity (ρ)	0,01724 Ω·mm^2 / m
Voltage drop (ΔV) *(required drop)*	3,5%
cos Ø	0,8

Table 34: *Cable design parameters;*

5.6.1 Architecture 1

5.6.1.1 Calculations

The proposed architecture can be divided in two simplified parts according to the pier which they are supplying power to. The architecture of these two parts is simplified in the next layouts, figure 28,29,30 and 31:

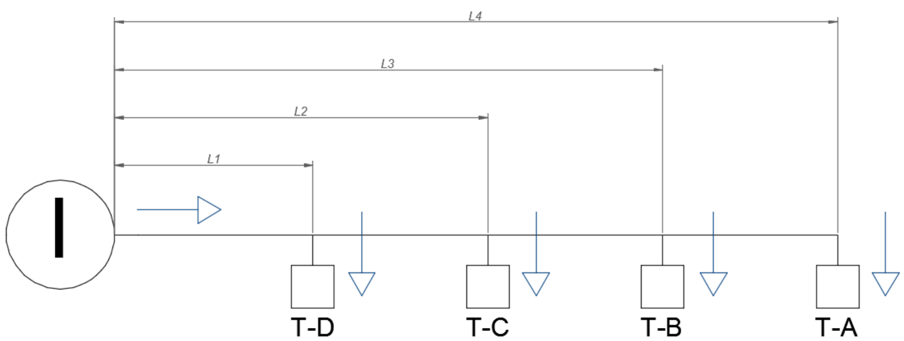


Figure 28: *Layout about Adossat Pier supplying, which is going to be called such as part 1 of the current architecture;*

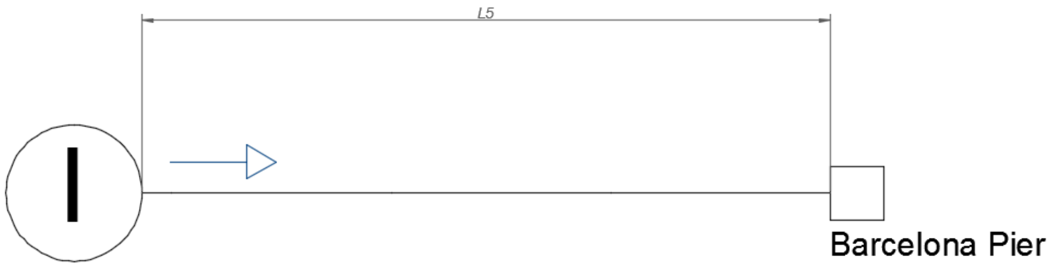


Figure 29: *Layout about Barcelona pier distribution line, which is included in the called part 2 of the current architecture;*

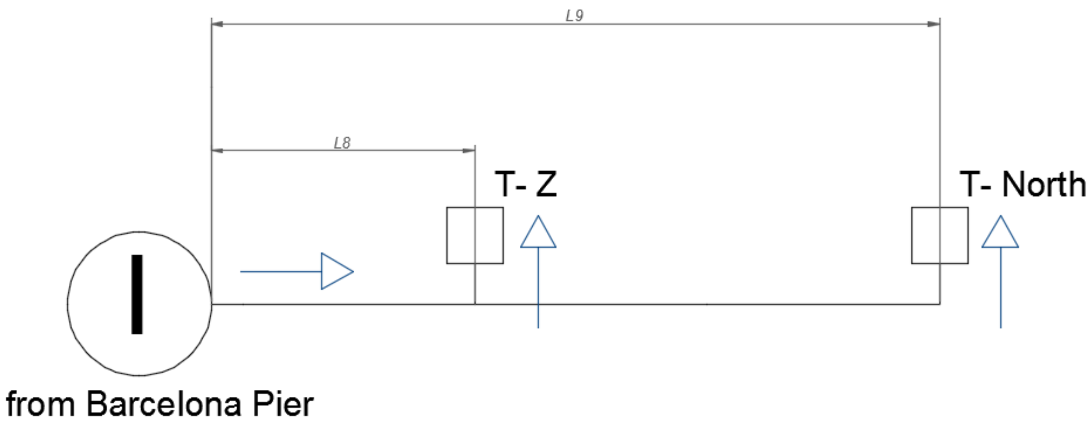


Figure 30: *Layout about one of the distribution lines of Barcelona Pier, included in the mentioned part 2 of the current architecture;*

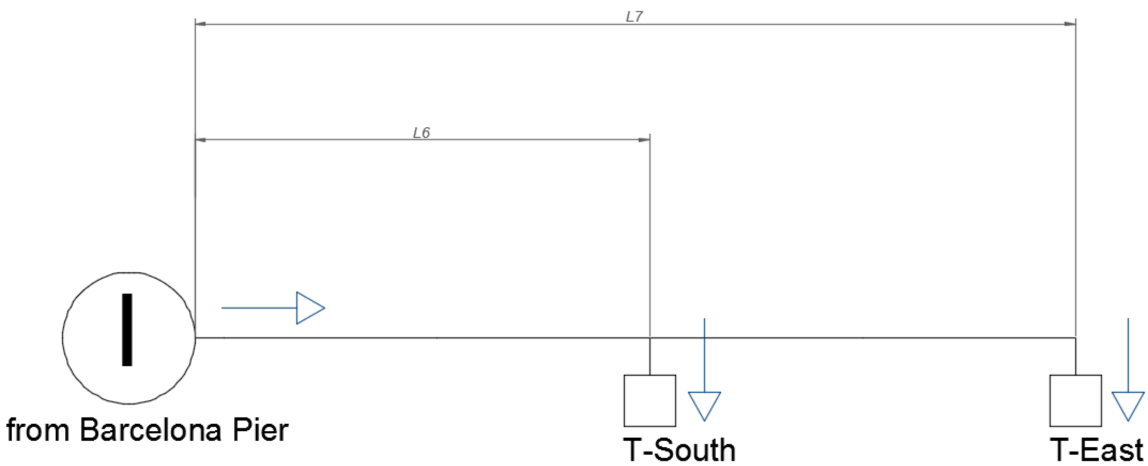


Figure 31: *Layout about one of the distribution lines of Barcelona Pier, included in the mentioned part 2 of the current architecture;*

To be sure that the result will be accurate for that use, *equation 1* shall be used to calculate the maximum current that is going to pass through the conductor:

$$I = \frac{P}{\sqrt{3} \cdot V \cdot \cos \emptyset} \quad ; \qquad [Equation\ 1]$$

The results obtained for current on both parts of the first architecture are showed in table 35:

	Part 1 (Adossat Pier)	Part 2 (Barcelona Pier)		
		L5	*L6,L7*	*L8,L9*
Maximum current (A)	1385,64	923,76	461,88	416,88

Table 35: *Maximum currents for architecture 1*

For calculating the optimized cable section for both parts of this architecture, catalogues of trademark cables have been consulted to determine the standard sections and the maximum current they can support. These options are included in table 36. If no units are specified for current and section, Amperes and mm^2 shall be considered.

Trade denomination	Supplier	Section	$\mathbf{I_{admissible}}$	Insulation	TºC
EPROTENAX COMPACT (EC)	PRYSMIAN	300	500	HEPR	105ºC
		400	565		
		500	650		
		630	730		
VOLTALENE (V)	PRYSMIAN	300	460	XLPE	90ºC
		400	520		
		500	605		
		630	675		

Table 36: *Selected cables for the system;*

Current values are very high. Then, some cables shall be used at the same time. After that, the voltage drop criterion shall be verified to be sure that the chosen cables have a voltage drop less or equal than the required value. For developing that validation next *equation 2* was used:

$$S = \frac{100 \cdot \rho}{V^2 \cdot \Delta V} \cdot \sum_{i=1}^{n} l_i \cdot P_i \qquad ; \qquad [Equation\ 2]$$

According to the main composition of the installation exposed at the beginning of the current chapter, power consume of each ship is going to be considered equal to **12 MW**, for Adossat Pier connection points, and **8 MW**, for Barcelona Pier connection points.

The rest of data necessary to make the calculation, cable length measures obtained from the mentioned draft are collected in tables 37 and 38:

Stretches of cable for part 1 (Adossat Pier)	
L1	1315,42 m
L2	1716,06 m
L3	2007,77 m
L4	2480,05 m

Table 37: *Stretches of cable for part 1 (Adossat Pier)*

Stretches of cable for part 2 (Barcelona WTCB Pier)	
L5	2410,24m
L6	509,53 m
L7	662,95 m
L8	163,22 m
L9	314,61 m

Table 38: *Stretches of cable for part 2 (Barcelona WTCB Pier)*

The voltage drop validation has been developed for many different combinations. These combination options and their validation are exposed in chart 39, which is showed next:

Stretch	Type	Section	Nº	I_{unit}	I_{total}	ΔV
L1	EC	630	2	730	1460	√
	EC	300	3	500	1500	√
	V	400	3	520	1560	√
L5	EC	300	2	500	1000	√
	EC	400	2	565	1130	√
	V	400	2	520	1040	√
L6,L7	EC	500	1	650	650	√
	EC	400	1	565	565	√
	V	500	1	605	605	√
L8,L9	EC	500	1	650	650	√
	EC	400	1	565	565	√
	V	500	1	605	605	√

Table 39: *Evaluated combinations of cable and its voltage drop validation;*

According to the chosen conditions and the supplier information, undergrounded cable admissible current shall be corrected depending on its undergrounding depth. The data provided in all the charts is for an undergrounded cable at 1 meter depth. Depending on depth the correction factors included in the annex shall be considered. In the current architecture the maximum correction factor value has been considered, equal to 0,89. The final cable election and its characteristics are included in table 40.

Stretch	Type	Section	Units	I_{unit}	$I_{admissible}$	$I_{corrected}$
L1	EC	400	3	730	1560	1388,4
L5	EC	400	2	565	1130	1005,7
L6,L7	EC	500	1	650	650	578
L8,L9	EC	500	1	650	650	578

Table 40: *Final cable solutions and their corrected admissible current because of undergrounded worst case;*

5.6.1.2 Cable technical characteristics

The technical characteristics for the chosen cable are showed in table 41:

Section	Units	Total section	Capacity (μF/km)	Resistance (Ω/km)	Reactance (Ω/km)
400	3	1600	0,646	0,066	0,095
400	2	800	0,646	0,066	0,095
500	1	500	0,737	0,054	0,092
500	1	500	0,737	0,054	0,092

Table 41: *Technical data about the chosen cables;*

Applying last data to the proposed stretches of cable, the following data contained in table 42 will be the result:

Stretch	Capacity (μF/km)	Resistance (Ω/km)	Inductance (H/km)
L1	1,938	0,198	$0{,}9071\cdot10^{-3}$
L5	1,292	0,132	$0{,}604\cdot10^{-3}$
L6,L7	0,737	0,054	$0{,}292\cdot10^{-3}$
L8,L9	0,737	0,054	$0{,}292\cdot10^{-3}$

Table 42: *Technical data for the proposed stretches of cable;*

5.6.2 Architecture 2

5.6.2.1 Calculations

Such as it is done in the first architecture, this proposed architecture can be divided in two simplified parts according once again, to the pier which they are supplying power to. The main difference is that in the first architecture there wasn't any interaction between them and in that distribution system, the second part is supplied by the first part. Aiming to simplify the procedure and the connection between them, the first part is represented in figure 32.

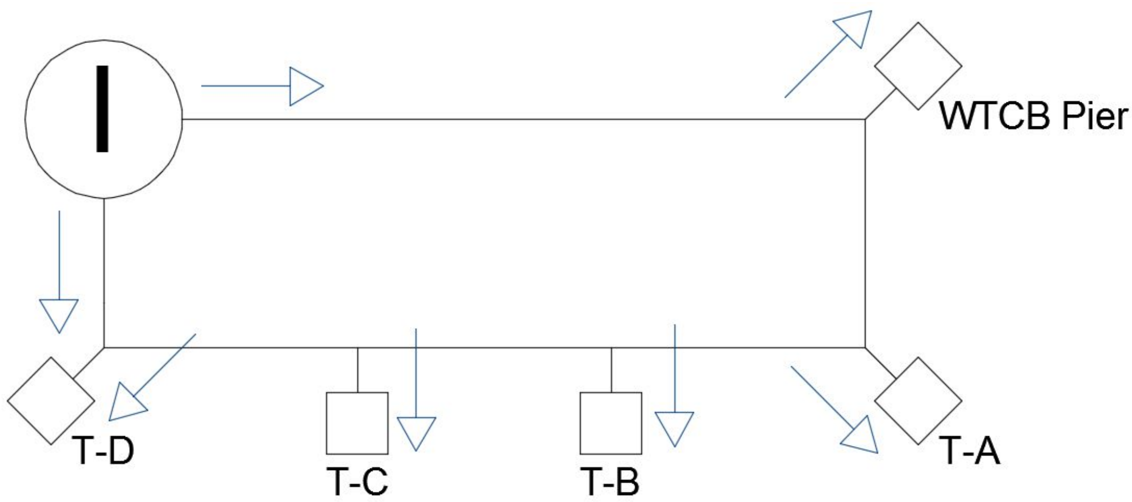


Figure 32: *Simplified block layout of the system (I);*

Figure 32 can be also simplified to make easier the calculus procedure. The simplified result is showed next in figure 33:

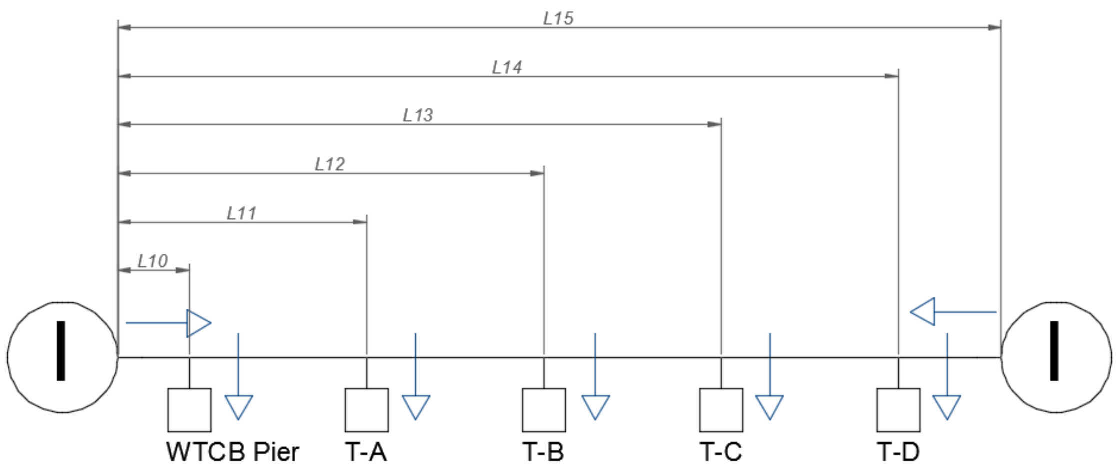


Figure 33: *Simplified block layout of the system (II); made simplifying figure 32;*

For calculating the optimized cable section for this architecture, the first data that we shall obtain is the point along the installation in which voltage drop is minimal. In the way to calculate that point equations 3 and 4 shall be used:

$$P_I = \sum_{i=1}^{n} P_i - \frac{\sum_{i=l}^{n}(l_i \cdot P_i)}{L} \quad ; \qquad [Equation\ 3]$$

$$P_{II} = \sum_{i=1}^{n} P_i - P_I = \frac{\sum_{i=l}^{n}(l_i \cdot P_i)}{L} \quad ; \qquad [Equation\ 4]$$

According to the requirements recently exposed in this section, power consume of each ship is going to be considered the same, and equal to **12 MW**, for Adossat Pier connection points, and **8 MW**, for Barcelona Pier connection points. But with this architecture the WTCB consumer is equal to 4 ships, because it is the point of connection with *Barcelona* pier. For that reason the power consumed by that consumer had been considered equal to four times the power considered for one unique ship docked in that pier. Cable length measures obtained from the corresponding draft are collected in table 43:

Stretches of cable for the ring part	
L9	1395,36 m
L10	2611,15 m
L11	3083,43 m
L12	3365,14 m
L13	3765,98 m
L14 or LT	5081,40 m

Table 43: *Stretches of cable for the ring part of the current architecture;*

The result obtained using this procedure is that the point in where the voltage drop is minimal, is Terminal A. The power supply from each way during normal working is showed in the next figure:

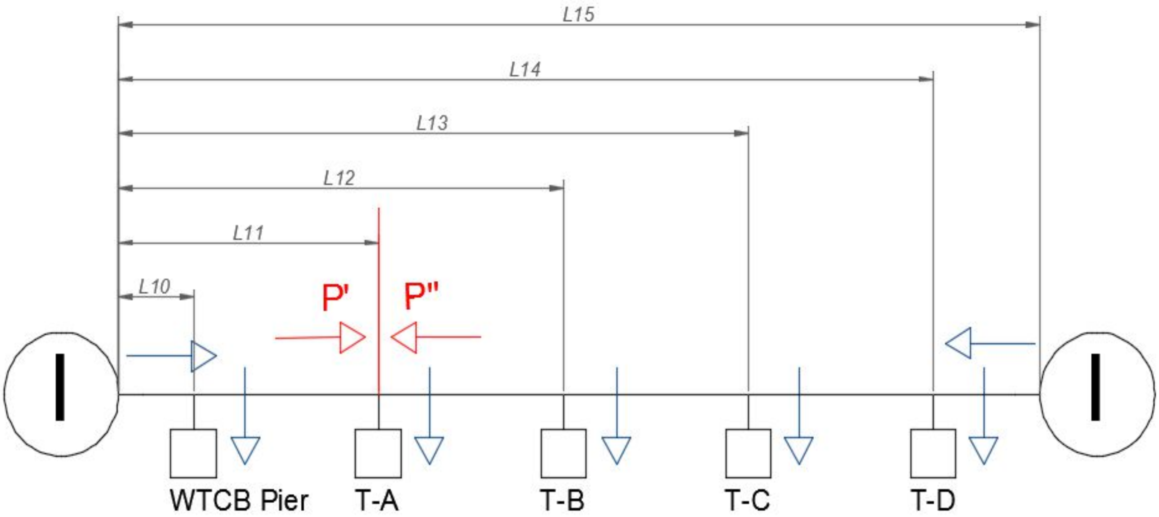


Figure 34: *Simplified block layout of the current distribution and interpretation about the calculations of P' and P'';*

These two power supplies can be decomposed in the following values included in table 44:

	Total P	P at Terminal A
P' (MW)	40,924	8,924
P'' (MW)	39,075	3,075

Table 44: *General distribution of power and particular distribution that supplies Terminal A;*

Once that point is known, for calculating the current, the method is the same used for the first architecture, but taking the corresponding values of P' or P'' depending on the way it is going to be calculated. Results obtained for current are showed in table 45; which is showed next:

	by P'	*by P''*
Maximum current (A)	1181,38	1128,02

Table 45: *Results for maximum current during close ring supply;*

These values for current are calculated considering a close ring working. But this architecture is thought to work such as opened ring and in case of faults or problems in a random point of the system it can be modified to supply power to that point because each shore station has two connection ways to the substation. Considering the worst case, in which the fault would be just between the substation and the first shore station, the maximum current would be 2309,40 A. That fault case is showed in the next figure:

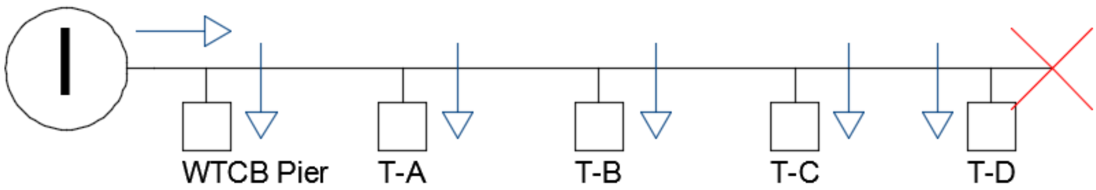


Figure 35: *Layout of the fault case mentioned in one extreme of the system;*

Considering a fault in one extreme terminal would be solved by the own protections of the shore station, in that case Terminal D. Then it is going to be considered only for simulations. But, the design is going to be based on the possible case showed in figure 35. The installation will probably support a arround 50% of the calculated current with the ring distribution part closed.

For the Barcelona Pier supplying line, the architecture is the same used in the first architecture model excepting the length of L5 which in that case is going to be called L5*. The calculation model and the procedure is exactly the same but using the new length mentioned. Table 38, is repeated below such as table 46 with the mentioned change:

Stretches of cable for part 2 (Barcelona WTCB Pier)	
L5*	*959,39m*
L6	509,53 m
L7	662,95 m
L8	163,22 m
L9	314,61 m

Table 46: *Stretches of cable for Barcelona Pier distribution lines in the current architecture;*

The voltage drop validation has been developed for many different combinations. These combination options and their validation are exposed in chart 39, which is showed next:

Stretch	Type	Section	Nº	$I_{admissible}$	Itotal	ΔV
L1 (ring system)	EC	630	4	730	2920	√
	EC	400	5	565	2825	√
	V	630	4	675	2700	√
L5*	EC	300	2	500	1000	√
	EC	400	2	565	1130	√
	V	400	2	520	1040	√
L6,L7	EC	500	1	650	650	√
	EC	400	1	565	565	√
	V	500	1	605	605	√
L8,L9	EC	500	1	650	650	√
	EC	400	1	565	565	√
	V	500	1	605	605	√

Table 47: *Evaluated combinations of cable and its voltage drop validation;*

According to the chosen conditions and the supplier information, undergrounded cable admissible current shall be corrected depending on its undergrounding depth. The data provided in all the charts is for an undergrounded cable at 1 meter depth. Depending on depth the correction factors included in the annex shall be considered. In the current architecture the maximum correction factor value has been considered, equal to 0,89. The final cable election and its characteristics are included in table 48.

Stretch	Type	Section	Units	I_{unit}	$I_{admissible}$	$I_{corrected}$
L1	EC	630	4	730	2920	2598,8
L5	EC	400	2	565	1130	1005,7
L6,L7	EC	500	1	650	650	578
L8,L9	EC	500	1	650	650	578

Table 48: *Final cable solutions and their corrected admissible current because of undergrounded worst case;*

5.6.2.2 Cable election

The technical characteristics for the chosen cable are showed in table 49:

Section	Units	Total section	Capacity (µF/km)	Resistance (Ω/km)	Reactance Ωkm)
630	4	2520	0,793	0,046	0,089
400	2	800	0,646	0,066	0,095
500	1	500	0,737	0,054	0,092
500	1	500	0,737	0,054	0,092

Table 49: *Technical data about the chosen cables;*

Applying last data to the proposed stretches of cable, the following data contained in table 42 will be the result:

Stretch	Capacity (µF/km)	Resistance (Ω/km)	Inductance (Ω/km)
L1	3,172	0,184	$1{,}133 \cdot 10^{-3}$
L5	1,292	0,132	$6{,}04 \cdot 10^{-4}$
L6,L7	0,737	0,054	$2{,}92 \cdot 10^{-4}$
L8,L9	0,737	0,054	$2{,}92 \cdot 10^{-4}$

Table 50: *Technical data for the proposed stretches of cable;*

5.7 Connection cable

5.7.1 Calculations

According to the proposed design, and the two possible shore stations, there will be two different parameters to calculate. The following variables have been used to calculate the main criterion for selecting the cable following the same procedure used in the last section:

Variables used for calculating cable section		
Voltage (V)		11 kV
		6 kV
Conductor material		Copper
Electric resistivity (ρ)		0,01724 Ω·mm^2 / m
Voltage drop (ΔV)		3,5%
Considered length		40 m
Power	**Adossat Pier Terminals**	12 MW
	Barcelona Pier Terminals	8 MW

Table 51: *Cable design parameters;*

The obtained results for current are showed in table 52, which is shoed next:

	Adossat Pier Terminals		***Barcelona Pier Terminals***	
	6,6 kV	***11 kV***	***6,6 kV***	***11 kV***
Maximum current (A)	1312,15	787,3	874,77	524,86

Table 52: *Results for maximum current;*

5.7.2 Cable election

Connection cable shall be, such as it can be imagined, flexible and very resistant aiming the handling procedure during connection and disconnection with any problem. According to the informative Annex A of the international standard for shore connection, it should have the following characteristics:

- The insulating compounds of the cable should be extruded cross-linked solid dielectric, designated as **EPR, HF EPR, HEPR or HF HEPR** in IEC 60092-351 or IEEE Std 1580.
- An isolation temperature of 90ºC.
- Be **flexible** in accordance with of the following references:
  - Class 5 of IEC 60228
  - Table 11 of IEEE Std 1580™-2001
- Be **plain or metal-coated** copper conductors
- The cables should be constituted as follows:
  - Power cores with copper conductors; that should be laid up with earth cores with copper conductors and semiconducting layer.
  - Conductor screen
  - Insulation
  - Insulation screen
- The neutral cables are constituted as follows:
  - Core with copper conductor,
  - Insulation
  - Outer sheath.

These last exposed characteristics are the main important. More details about each component are provided in the mentioned Annex.

For shore to ship cables, there are some trademarks specialized in that utility. But the major part of these them, are shore to ship cables for low voltages that are not acceptable or the current design. In the way to be in compliance with the exposed information, and the results of the last section the following trademark cables have been considered:

Trade denomination	Supplier	Section	$I_{admissible}$	Insulation	TºC
MMV-VFD Power Cable (Three conductor)	NEXANS AMERCABLE	159	389	EPR	90ºC
		189	432		
		227	456		
PANZERFLEX-L FO (Three conductor)	CAVOTEC	150	404	EPR	90ºC
		185	461		
Red Jumper Cable (One conductor)	NEXANS AMERCABLE	127	445	EPR	90ºC
		177	550		
		253	690		

Table 53: *Selected cables for the system;*

According to the particular characteristics and recommendations of each cable, the chosen cable is the MMV-VFD of *Nexans Amercable.* The validation has been developed for some combinations. These options are exposed in table 54:

Terminal	Type	Section	Nº	I_{unit}	$I_{admissible}$	ΔV
12MW	MMV-VFD	227	3	456	1368	√
	MMV-VFD	159	4	389	1556	√
8MW	MMV-VFD	227	2	456	912	√
	MMV-VFD	159	3	389	1167	√

Table 54: *Evaluated combinations of cable and its voltage drop validation;*

The final cable election and its characteristics are showed in table 55:

Terminal	Type	Section	Nº	I_{unit}	$I_{admissible}$
12MW	MMV-VFD	159	4	389	1556
8MW	MMV-VFD	159	3	389	1167

Table 55: *Final cable solutions*

;

For the flexible shore to ship connection cable technical data, such as resistance or capacitance is not going to be included. That is because for the simulation models it is not going to be considered. The cable is not as long as the calculated cables for the distribution system.

6 SIMULATION AND TESTING

Once the system is designed for two different distribution systems, the last step is to test these models to analyse their behaviour in some situations. To develop the current chapter the software that has been used is Matlab. The procedure to simulate installation's behaviour depends on the effectiveness of reproducing a good model in the Simulink space. After that, simulations have been developed for the following aspects:

- Steady State
- Load flow
- Connection and disconnection reactions
- Fault situations

6.1 Simulink's models

A model had been developed for each of the proposed architectures. These models are composed with the following elements:

- Supplying source
- Substation's transformer
- Pi line model for the transmission line
- Shore station's transformer
- Load
- Measurement equipment

In the following pages the final composition of each model can be seen. For each of them, different conditions have been implemented aiming to obtain a very complete analysis. These conditions are summarized in the following list:

- CASE-A; based on the initial model at maximum power demand
- CASE-B; based on the initial model but applying different loads that makes the load distribution not as regular as in case A. These loads are the following:
    - 12MW for terminal A
    - 9MW for terminal C
    - 8MW for terminal B and Z
    - 6MW for terminal D and South
    - 5MW for terminal North
    - 4MW for terminal East

- CASE-C; Based on the disconnection of some loads during the simulation
- CASE-D; Based on the connection of some loads during the simulation
- CASE-E; Based on the simulation of a three-phase fault in one load;

6.2 Test conditions

Aiming to test the systems, variations about the quality of power shall be verified. The international standard provides that a comparison between the transient levels shall be done to achieve the verification. The result of that comparison shall not be exceeded the following limits for voltage and frequency:

i. Voltage transient ranges +20% and -15%
ii. Frequency transient ranges +-10%

For power quality for permanent load conditions, the ISO/IEC/IEEE doesn't provide more data. Otherwise, Classification Societies use to provide the following limits:

i. Voltage ranges +6% and -10%
ii. Frequency +5% and -5%

Applying the mentioned requirements to the designed voltages, voltage measurements shall be between the following values:

Design voltage (V)	Range (V)
220000	233200 ~ 198000
25000	26500 ~ 22500
11000	11660 ~ 9900

Table 56: *Acceptable ranges for voltage*

The simulation time used for all the models is 0,2 seconds and the analysis mode is discrete. These options were chosen due to the precision of the results and the quality of the obtained diagrams.

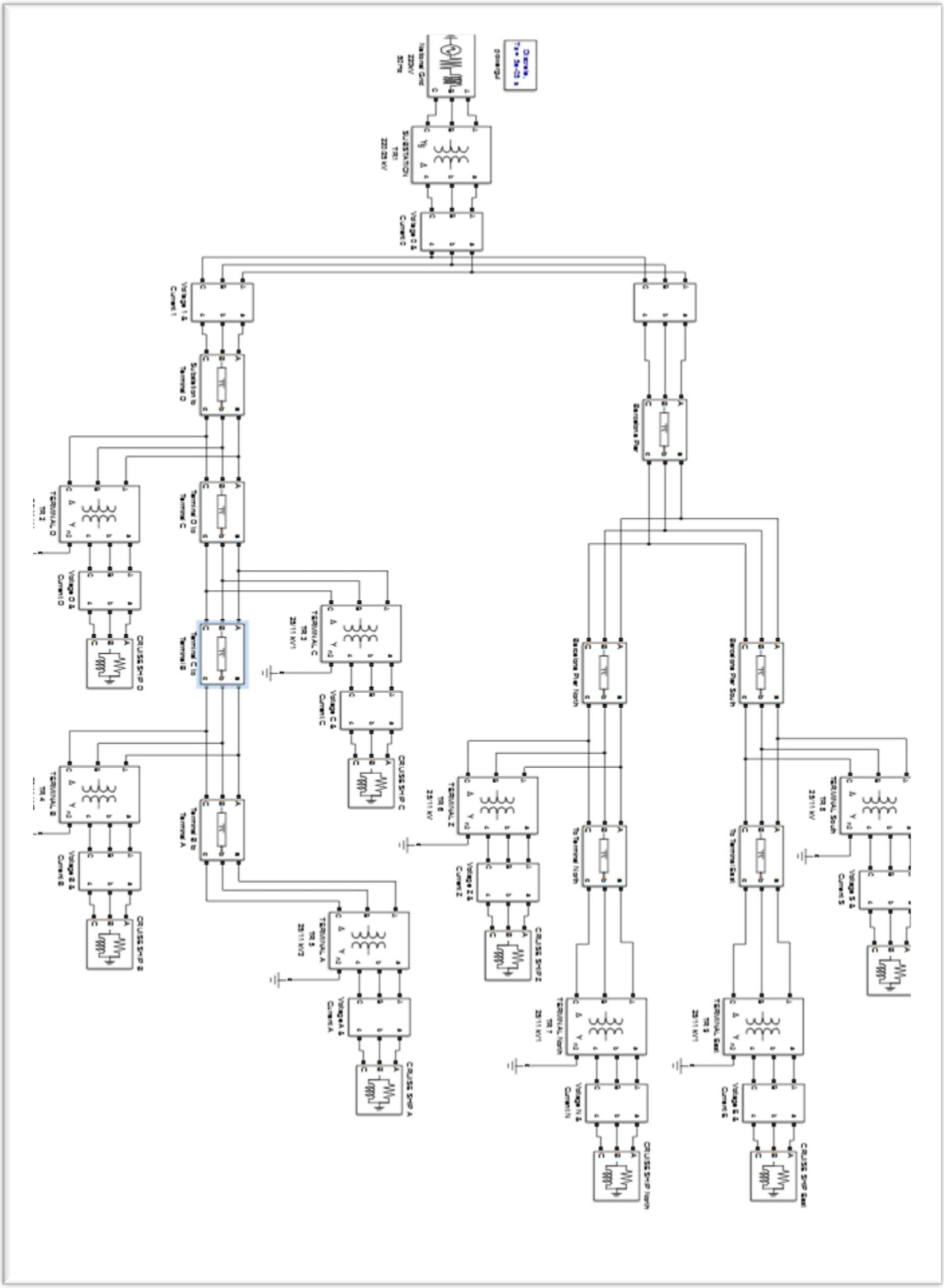


Figure 36: *Matlab model for architecture 1 (The quality of the screenshot is not as well as others but main blocks and the architecture can be seen);*

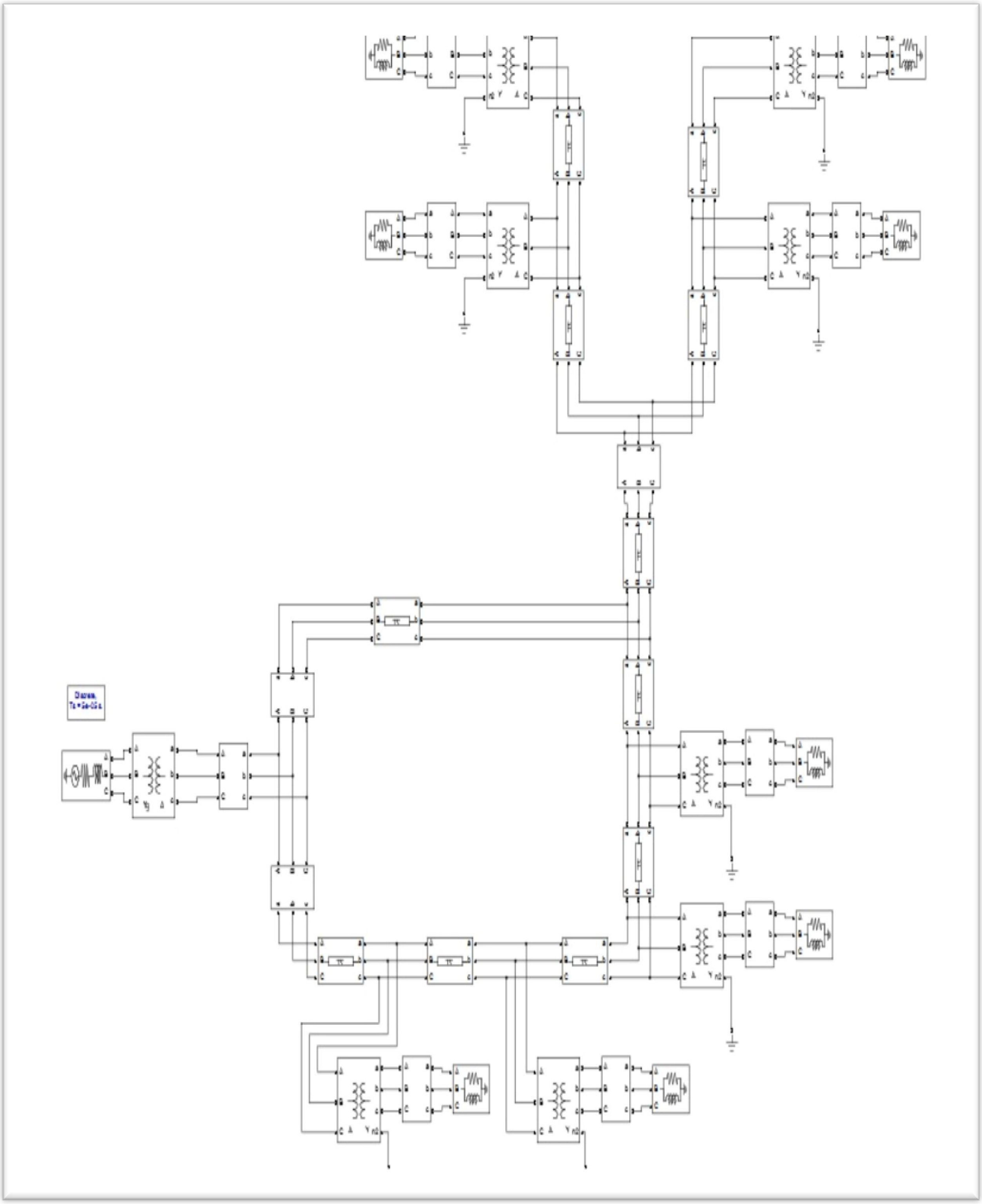


Figure 37: *Matlab model for architecture 2 (The quality of the screenshot is not as well as others but main blocks and the architecture can be seen);*

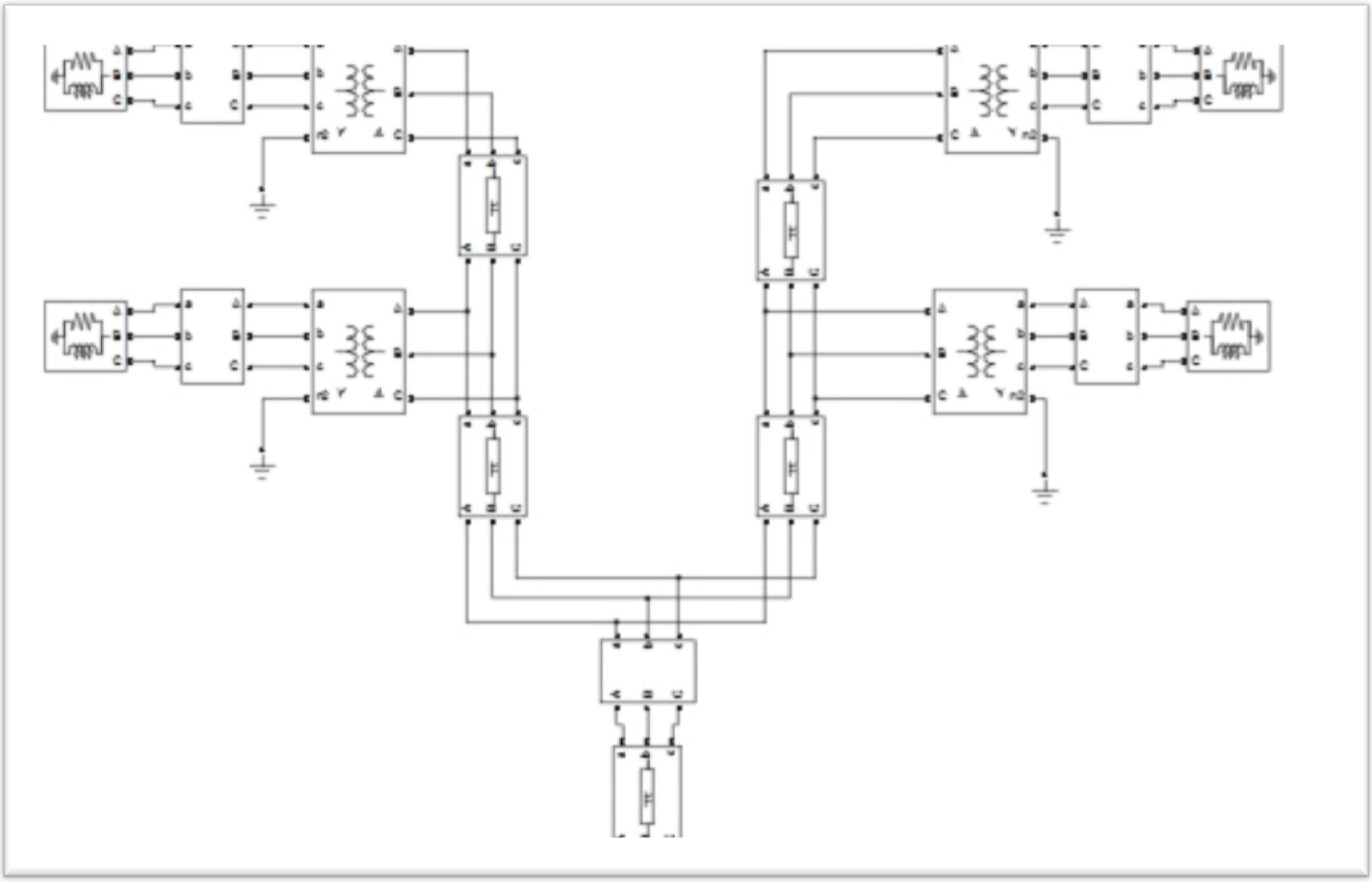


Figure 38: *Detail 1 from figure 37;*

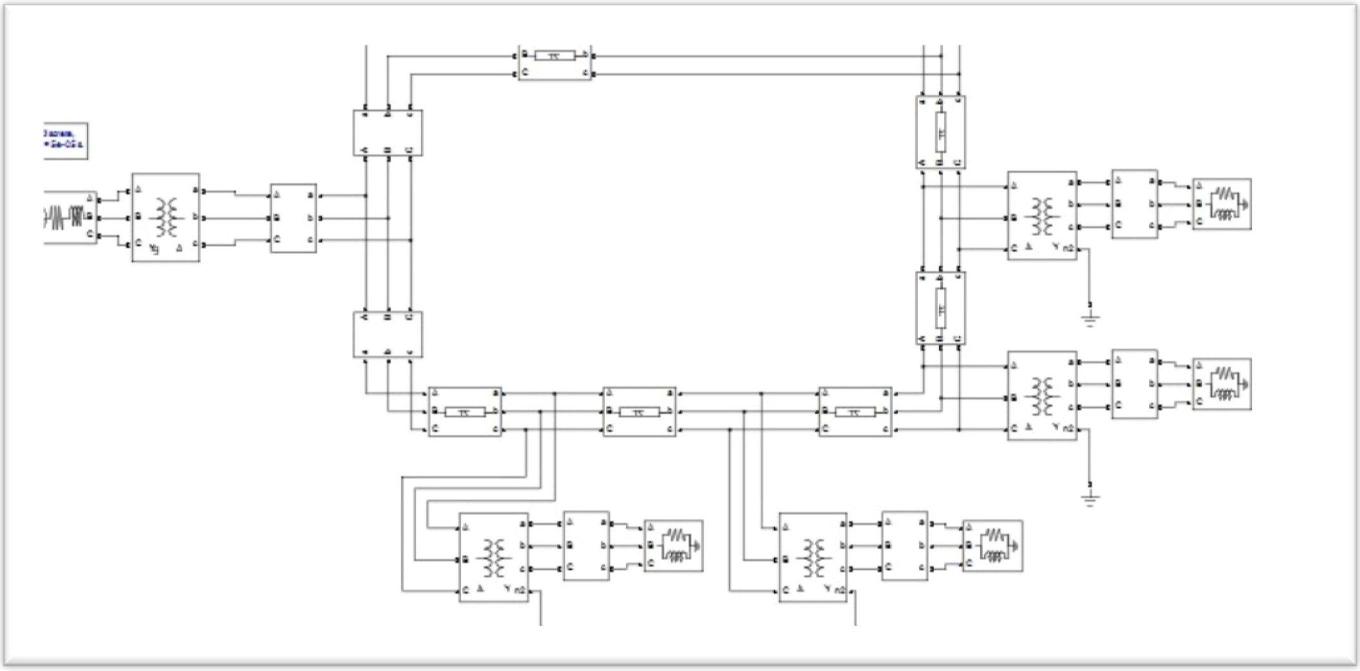


Figure 39; *Detail 2 from figure 37;*

6.3 Architecture 1

6.3.1 Steady State Analysis

The steady state analysis is the first calculation that should be simulated in any model. For the current architecture based on case A, the results of the verifications are:

- Barcelona Pier terminals have acceptable voltages
- Adossat Pier terminals have lower voltages than the acceptable -10%
- Voltage supplied by the substation has high not acceptable voltages

Otherwise, when the load distribution is such as the mentioned random combination, according to case B, all the shore stations have an acceptable voltage for the service excepting the supplied voltage by the substation which is over the limit of 26500 V with a voltage of 29000 V more less. In the following figures all the obtained values for case A and case B are showed:

```
 1:  'U AB: Voltage S &Current S'  =      10048.25 V    10.52°
 2:  'U BC: Voltage S &Current S'  =      10048.96 V  -109.49°
 3:  'U CA: Voltage S &Current S'  =      10047.29 V   130.51°
 4:  'U AB: Voltage N &Current N'  =      10063.09 V    10.56°
 5:  'U BC: Voltage N &Current N'  =      10063.80 V  -109.45°
 6:  'U CA: Voltage N &Current N'  =      10062.12 V   130.55°
 7:  'U AB: Voltage E &Current E'  =      10044.57 V    10.51°
 8:  'U BC: Voltage E &Current E'  =      10045.28 V  -109.50°
 9:  'U CA: Voltage E &Current E'  =      10043.60 V   130.50°
10:  'U AB: Voltage D &Current D'  =       9290.73 V     6.98°
11:  'U BC: Voltage D &Current D'  =       9291.40 V  -113.03°
12:  'U CA: Voltage D &Current D'  =       9289.54 V   126.97°
13:  'U AB: Voltage C &Current C'  =       9210.10 V     6.93°
14:  'U BC: Voltage C &Current C'  =       9210.77 V  -113.08°
15:  'U CA: Voltage C &Current C'  =       9208.83 V   126.92°
16:  'U AB: Voltage B &Current B'  =       9181.51 V     6.84°
17:  'U BC: Voltage B &Current B'  =       9183.96 V  -113.03°
18:  'U CA: Voltage B &Current B'  =       9199.88 V   126.89°
19:  'U AB: Voltage A &Current A'  =       9153.07 V     6.83°
20:  'U BC: Voltage A &Current A'  =       9155.52 V  -113.05°
21:  'U CA: Voltage A &Current A'  =       9171.39 V   126.88°
22:  'U AB: Voltage 2 &Current 2'  =      27535.90 V    -9.78°
23:  'U BC: Voltage 2 &Current 2'  =      27540.49 V  -129.78°
24:  'U CA: Voltage 2 &Current 2'  =      27537.84 V   110.21°
25:  'U AB: Voltage 1 &Current 1'  =      27535.90 V    -9.78°
26:  'U BC: Voltage 1 &Current 1'  =      27540.49 V  -129.78°
27:  'U CA: Voltage 1 &Current 1'  =      27537.84 V   110.21°
28:  'U AB: Voltage 0 &Current 0'  =      27535.90 V    -9.78°
29:  'U BC: Voltage 0 &Current 0'  =      27540.49 V  -129.78°
30:  'U CA: Voltage 0 &Current 0'  =      27537.84 V   110.21°
31:  'U AB: Voltage Z &Current Z'  =      10066.73 V    10.57°
32:  'U BC: Voltage Z &Current Z'  =      10067.44 V  -109.44°
33:  'U CA: Voltage Z &Current Z'  =      10065.76 V   130.57°
```

```
 1:  'U AB: Voltage S &Current S'  =      11190.92 V    14.09°
 2:  'U BC: Voltage S &Current S'  =      11191.67 V  -105.92°
 3:  'U CA: Voltage S &Current S'  =      11190.19 V   134.08°
 4:  'U AB: Voltage N &Current N'  =      11420.74 V    15.22°
 5:  'U BC: Voltage N &Current N'  =      11421.51 V  -104.79°
 6:  'U CA: Voltage N &Current N'  =      11420.00 V   135.21°
 7:  'U AB: Voltage E &Current E'  =      11633.51 V    16.33°
 8:  'U BC: Voltage E &Current E'  =      11634.29 V  -103.68°
 9:  'U CA: Voltage E &Current E'  =      11632.75 V   136.32°
10:  'U AB: Voltage D &Current D'  =      11165.75 V    14.18°
11:  'U BC: Voltage D &Current D'  =      11166.53 V  -105.83°
12:  'U CA: Voltage D &Current D'  =      11164.77 V   134.17°
13:  'U AB: Voltage C &Current C'  =      10457.75 V    11.07°
14:  'U BC: Voltage C &Current C'  =      10458.49 V  -108.94°
15:  'U CA: Voltage C &Current C'  =      10456.75 V   131.07°
16:  'U AB: Voltage B &Current B'  =      10633.96 V    11.97°
17:  'U BC: Voltage B &Current B'  =      10635.91 V  -107.92°
18:  'U CA: Voltage B &Current B'  =      10652.25 V   132.02°
19:  'U AB: Voltage A &Current A'  =       9817.69 V     8.25°
20:  'U BC: Voltage A &Current A'  =       9819.48 V  -111.64°
21:  'U CA: Voltage A &Current A'  =       9834.57 V   128.30°
22:  'U AB: Voltage 2 &Current 2'  =      29249.59 V    -8.33°
23:  'U BC: Voltage 2 &Current 2'  =      29253.46 V  -128.33°
24:  'U CA: Voltage 2 &Current 2'  =      29251.54 V   111.67°
25:  'U AB: Voltage 1 &Current 1'  =      29249.59 V    -8.33°
26:  'U BC: Voltage 1 &Current 1'  =      29253.46 V  -128.33°
27:  'U CA: Voltage 1 &Current 1'  =      29251.54 V   111.67°
28:  'U AB: Voltage 0 &Current 0'  =      29249.59 V    -8.33°
29:  'U BC: Voltage 0 &Current 0'  =      29253.46 V  -128.33°
30:  'U CA: Voltage 0 &Current 0'  =      29251.54 V   111.67°
31:  'U AB: Voltage Z &Current Z'  =      10775.67 V    12.05°
32:  'U BC: Voltage Z &Current Z'  =      10776.39 V  -107.96°
33:  'U CA: Voltage Z &Current Z'  =      10774.97 V   132.04°
```

Figure 40: *Steady state analysis for case A (left) and for case B (right)*

6.3.2 Connection and disconnection reactions

Case C and Case D have been developed by using programmed circuit breakers in terminals D and Z, with an determined action time.

The reaction produced because of the disconnection shows a little increase of voltages in all the system, but it keeps a similar behaviour comparing it with case B.

The most noticeable reaction is produced during connection situation. Particularly in the time environment after the connection, voltage experiences a generalized voltage increase comparing it with the base case studied with the steady state analysis. The highest voltage increase is produced on the supplied power by the substation.

In the most particular case, such it was mentioned case D, monitoring phase to phase voltages shows a noticeable transient change mixed with harmonic distortion what is showed in next figures about Adossat Pier voltages:

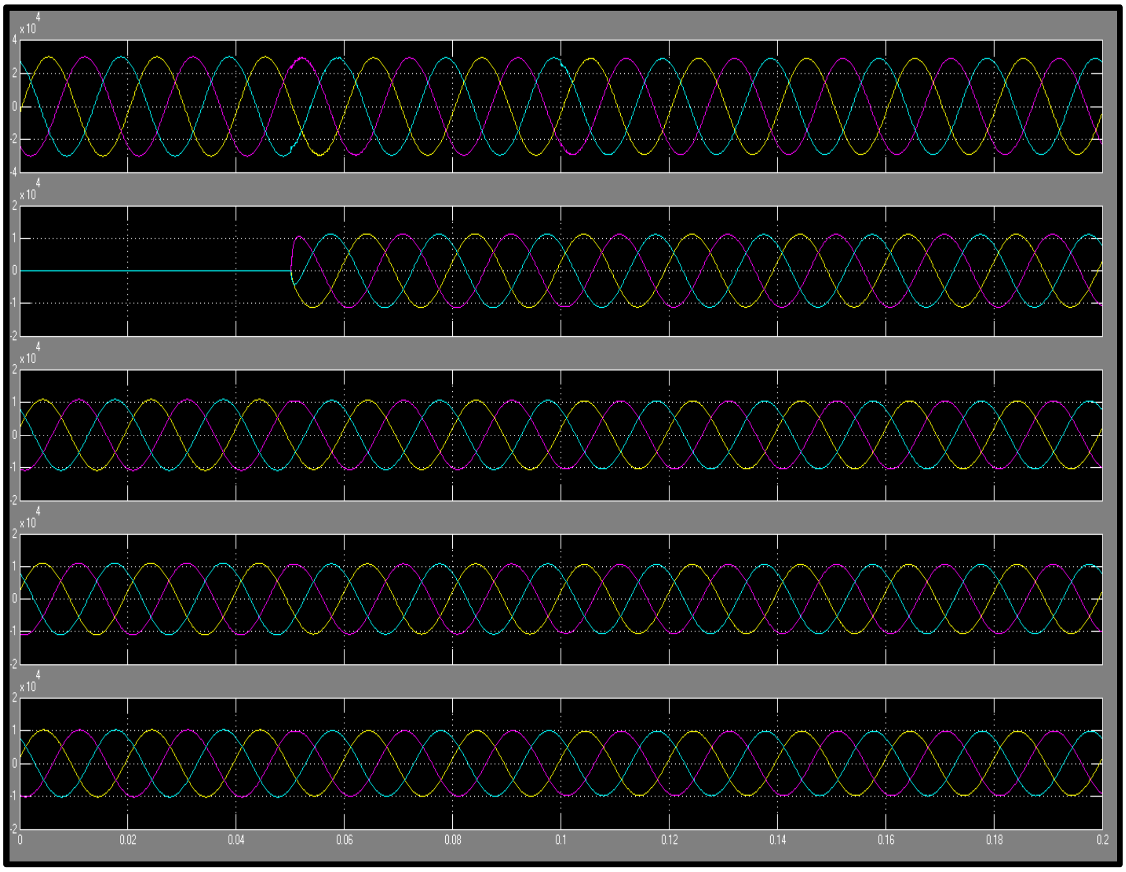


Figure 41: *Voltage three-phase measurements for supplying voltage to Adossat Pier, Terminal D, C, B and A;*

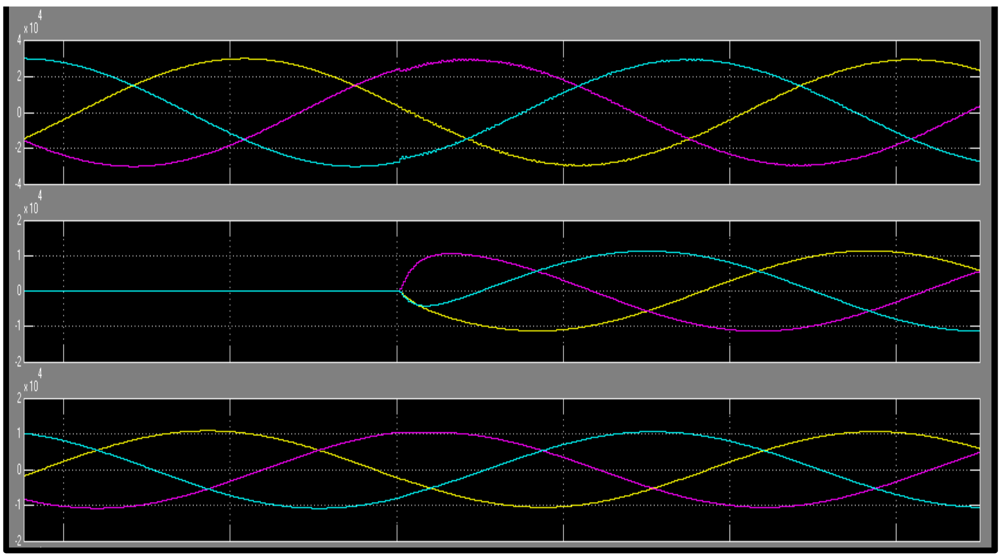


Figure 42: *Detail from figure 41 for the first three measurements;*

In the last figure, figure 42, the harmonic distortion can be seen such as little details after the connection point in the simulation. The same monitoring result is obtained for Barcelona Pier but with it corresponding relative voltages for each terminal and the global Pier.

6.3.3 Fault situation

A fault has been programmed for cruise ships berthed on terminal D and terminal Z. for the second 0,08. In addition aiming not to affect the rest of the system, a circuit breaker has been included before the fault. That circuit breaker is programmed for opening or disconnecting the terminal from the rest of the system at the second 0,1.

The less time passes between the faulting time and the disconnection time, the more distortions the system and the other terminals experience. These distortions can be harmonic distortions or resolution faults of the software, anyway they incline to rise. In addition the supplied power by the substation experiences a little voltage transient that reduces the voltage, but after that it increases the value over the initial value.

For all the terminals of the system, the negative transient is also experienced, but after it, voltage values recover their initial values. In the next figures it can be seen with the marked details:

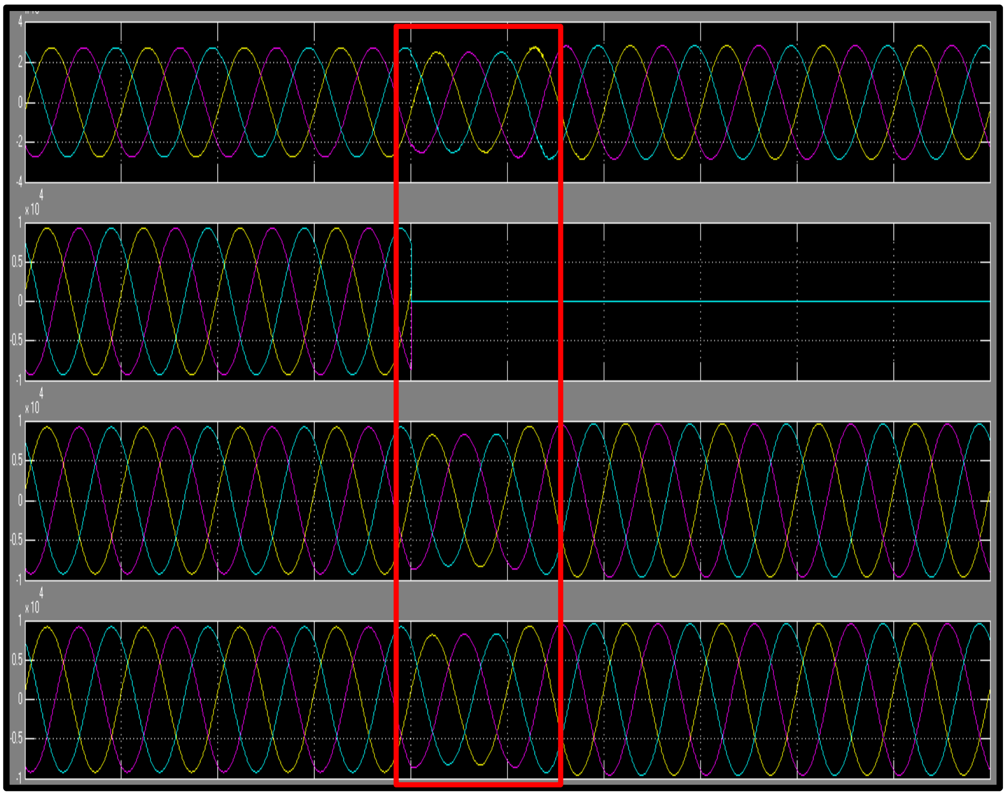


Figure 43: *Fault case measurements for supplying voltage to Adossat Pier, Terminal D (which is the faulted terminal), C and B;*

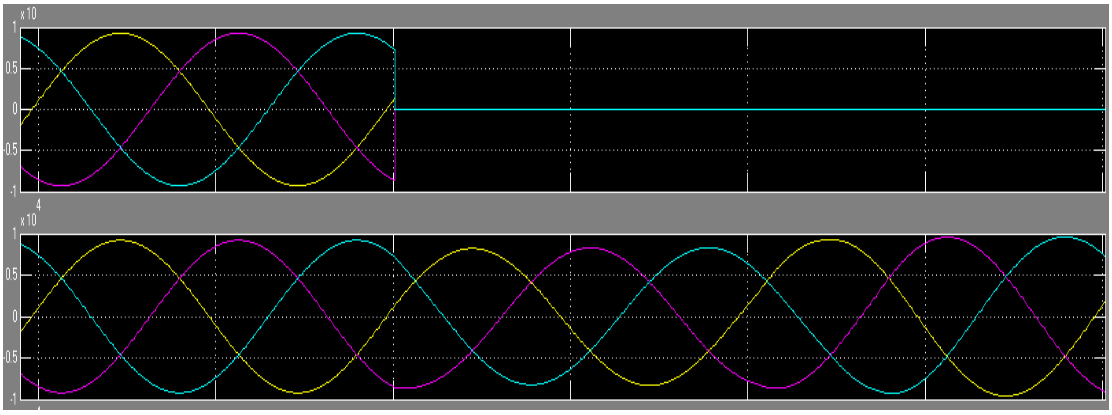


Figure 45: *Detail from figure 43 for Terminal D voltage measurement (up) and Terminal C. In the last one the red area shows the transient reduction of voltage;*

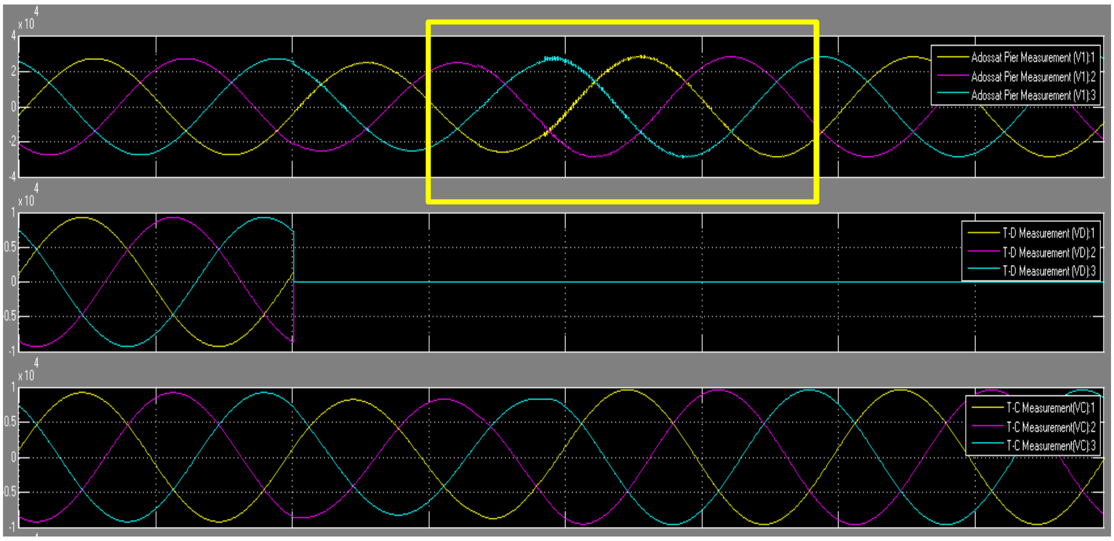


Figure 44: *Fault case measurements for supplying voltage to Adossat Pier, Terminal D and C; In that case the opening time of the circuit breaker was reduced, what increased harmonic distortions (yellow area);*

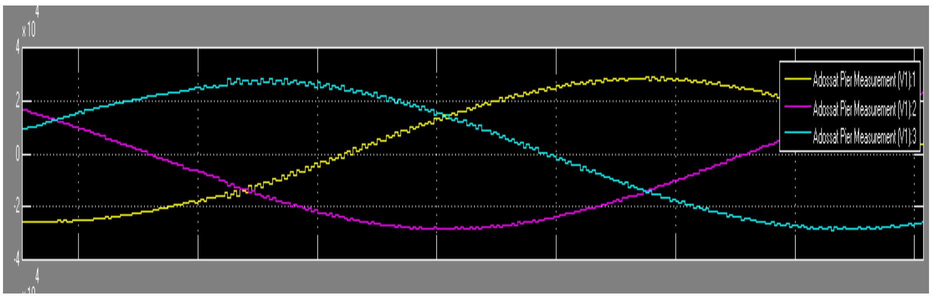


Figure 46: *Detail from the yellow area of the figure 45;*

6.3.4 Load Flow

The load flow analysis for all the proposed cases and situations shows a correct flow for the proposed cruise ship loads. These results are included in the annexes because they are correct and without unexpected variations.

6.4 Architecture 2

6.4.1 Steady State

The steady state analysis is the first calculation that should be simulated in any model. For the current architecture based on case A, the results of the verifications are:

- Barcelona Pier terminals have lower voltages than the acceptable -10%
- Adossat Pier terminals have lower voltages than the acceptable -10%
- Voltage supplied by the substation has high not acceptable voltages.

Otherwise, when the load distribution is such as the mentioned random combination, according to case B, all the shore stations have an acceptable voltage for the service excepting the supplied voltage by the substation which is over the limit of 26500 V with a voltage of 29000 V more less.

6.4.2 Connection and disconnection reactions

Case C and Case D have been developed by using programmed circuit breakers in terminals D and Barcelona Pier, with all its terminals, with a determined action time.

The reaction produced by the first disconnection shows a little increase of voltages in all the system, but it keeps a similar behaviour comparing it with case B. The most noticeable reaction is produced during disconnection of Barcelona Pier, which is equal to disconnect four terminals at the same time.

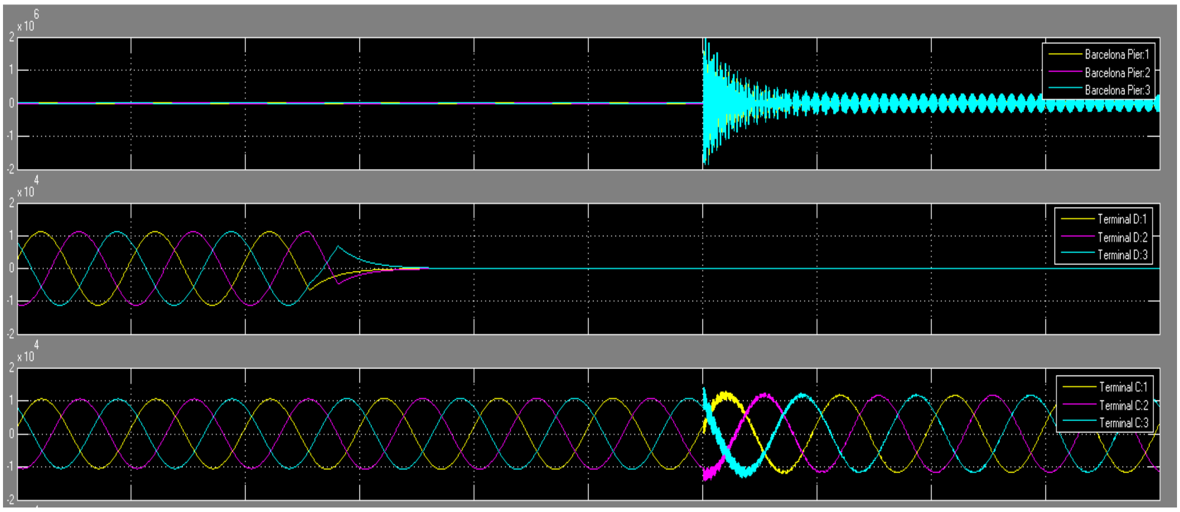


Figure 47: *Voltage measurement of Barcelona Pier, Terminal D and Terminal C respectively; the harmonic distortion produced in C (down) because of the disconnection of Barcelona Pier (up) can be seen.*

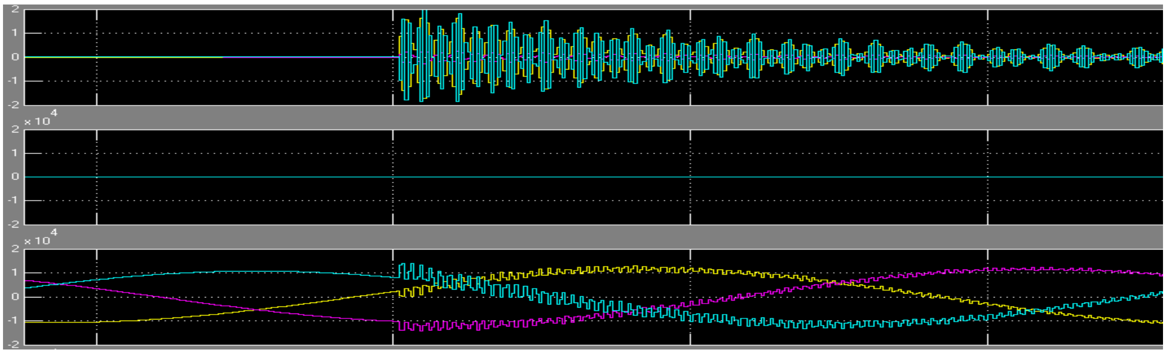


Figure 48: *Detail of the harmonic distortions mentioned on figure 47;*

For case D, connection of terminal D and Barcelona Pier, particularly in the time environment after the connection, voltage experiences a generalized little voltage reduction comparing it with the base case studied with the steady state analysis. The connection produces a noticeable harmonic distortion in the connected Barcelona Pier.

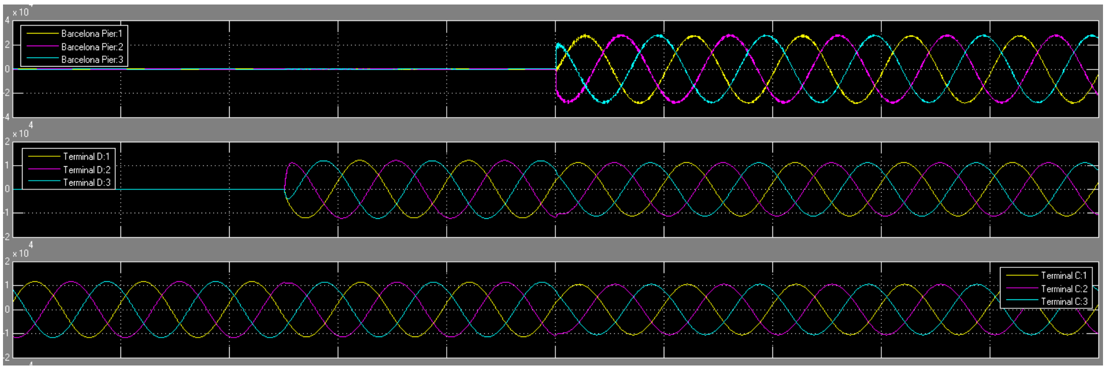


Figure 49: *Voltage measurement of Barcelona Pier, Terminal D and Terminal C respectively; the harmonic distortion after the connection of Barcelona Pier in its own signal can be seen (up);*

6.4.3 Fault situation

A fault has been programmed for cruise ships berthed on terminal D and terminal Z in two different models aiming to compare the behaviour of voltage measures. The fault was set at the second 0,08 and the circuit breaker at the second 0,1.

The less time passes between the faulting time and the disconnection time, the more harmonic distortions the system and the other terminals experience. Otherwise, it produces a higher level of harmonic distortion.

The rest of the terminals of Barcelona Pier experiences a permanent reduction on voltage that can be seen in figure 50.

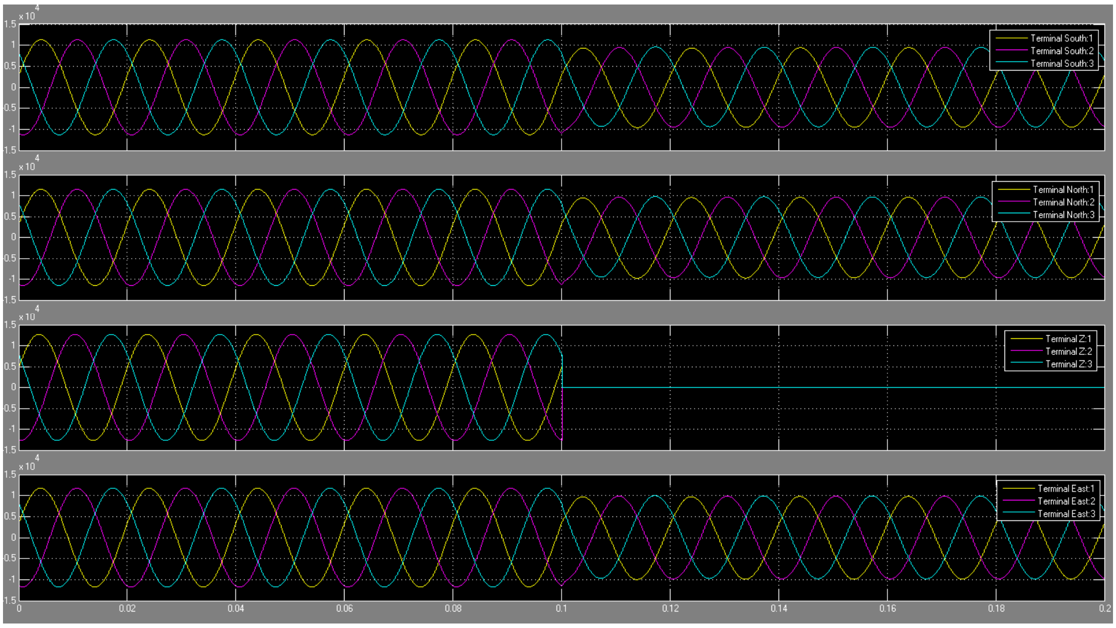


Figure 50: *Voltage measurement of Barcelona Pier, Terminal D and Terminal C respectively; the harmonic distortion produced in C (down) because of the disconnection of Barcelona Pier (up) can be seen;*

6.4.4 Load Flow

The load flow analysis for all the proposed cases and situations shows a correct flow for the proposed cruise ship loads. These results are included in the annexes because they are correct and without unexpected variations.

7 CONCLUSIONS

Barcelona is a very recognised city in all over the world owing to many factors such as culture, business, weather and history. These factors convert the city on a referent point for tourists and such as consequence cruise lines decide to include Barcelona's port in their habitual offer. By the way, port calls are having an increasing tendency in time. An increase on maritime traffic would be beneficious for the city and for the country, but if some effective means to reduce pollution will not be provided, it would trigger on a degeneration of city's weather and environment.

MARPOL Annexes and national laws are increasing the restrictions over some type of emissions but CO_2 is not as regulated as these emissions. It is difficult, and hard to regulate, strongly after the actual situation of Kyoto protocol but some means should be developed to reduce CO_2 pollution coming from ships. It may not be possible in all type of ships because of the amount of business that depend on the maritime traffic, but it may be controlled in a more restrictive way for cruise ships. If that means would not be possible, benefits or privileges could be awarded for ship owners that will invest and develop new less-polluting systems in their fleet. Moreover, the concession of these benefits would contribute in their corporative social responsibility, increasing at the same time their cruise line image for people.

The shore to ship connection is such as it has been exposed during the current project, a very effective way to reduce pollution from ships in port, particularly it can reduce emission levels more than 90% comparing it with using auxiliary engines. It may require big investments to develop the entirely project and construct it but, it will provide new benefits for the exploitation manager and as a consequence for the local economy by providing power to cruise ships. In addition the European Union is trying to make using shore to ship connection easier for all the involved parts by its recommendations and directives.

The shore side system is hard to design owing to the big demand of power that cruise ships use to need. Specially, it is hard to design a distribution system for many of that cruise ships because all the connection points should offer the same versatility in front of different on board power plants.

After testing the developed models with Matlab, it can be concluded that the proposed models are not acceptable for Classification Societies due to their voltage variations. If the requirements provided by them would be a little bit more permissive, the system will be probably accepted. Moreover, the tested distribution systems are very sensitive to big load changes such it was showed with Barcelona Pier connection and disconnection. The transient variations are inside the provided ranges and the voltage recovers its initial value very fast making that point acceptable by the Societies. These types of distribution systems need some harmonic filters to compensate the harmonic distortions that were showed in the simulation chapter.

Connection and disconnection procedure in that type of systems use to be progressive and keeping a parallel power supply with the shore to ship connection and the on board engines. A procedure to connect and disconnect a new cruise ship shall be monitored and controlled, and a technical procedure should be developed to avoid unacceptable distortions and voltage drops.

In addition, the inclusion of a ramification supplied by a ring distribution is not probably the best option because the total power that this ramification demands could bring some problems such as voltage variations in case of faults in it. As a result of that, the best distribution system for that type of installations based on the project, would be one based on individual cables from the substation to each shore station.

Current variations are very noticeable, but such as Classification Societies provide in their rules and knowing power's behaviour, paying attention to voltage and frequency and knowing to which loads the system will have to supply energy, is enough to control power's quality.

Regulations and requirements provided by the Classification Societies are not enough yet. The International Standard ISO/IEC/IEEE 80005-1 is the only rule that makes a good and complete approach of shore side and ship side considering requirements for all the complete system and not considering only one side of it. I guess that actually they are probably developing new and best classification rules for shore to ship connection due to its increasing importance and the reinforcement of pollution regulations.

8 REFERENCES

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9 ANNEXES

9.1 ANNEX A- MEDcruise countries and ports

Croatia	Cyprus	Egypt	France	Georgia
Gibraltar	Greece	Italy	Malta	Monaco
Montenegro	Portugal	Romania	Russia	Slovenia
Spain	Syria	Tunisia	Turkey	Ukraine

Table 57: *Annex A- Countries represented in MEDcruise*

WEST MED	Alicante	Azores	Balearic Islands	Barcelona
	Cagliari	Cartagena	Castellón	Ceuta
	Civitavecchia	French Riviera Ports	Genoa	Gibraltar
	Huelva	La Spezia	Lisbon	Livorno
	Madeira Ports	Málaga	Marseille	Messina
	Monaco	Motril-Granada	Naples	North Sardinian Ports
	Palamós	Palermo	Portimao	Portoferraio
	Savona	Sète	Tarragona	Tenerife Ports
	Toulon-Var-Provence	Tunisian Ports	Valencia	Valletta
ADRIATIC	Bari	Brindisi	Corfu	Dubrovnik/Korcula
	Koper	Kotor	Ravenna	Rijeka
	Sibenik	Split	Trieste	Venice
	Zadar			
EAST MED	Alanya	Cyprus Ports	Egyptian Ports	Heraklion
	Igoumenitsa	Kavala	Kusadasi/Bodrum/Antalya	Lattakia
	Mersin	Patras	Piraeus	Souda/Chania
	Thessaloniki	Volos		
BLACK SEA	Batumi	Constantza	Odessa	Rize
	Sevastopol	Sinop	Sochi	

Table 58: *MEDcruise ports*

9.2 ANNEX B- Barcelona's cruise harbour situation within Medcruise

No	Port	Total Pax. 2013	Cruise Passengers Concentration				
			2013	2012	2011	2010	2009
1	Barcelona	2.599.232	9,62%	9,29%	9,88%	9,77%	9,85%
2	Civitavecchia	2.538.259	9,39%	9,23%	9,59%	8,08%	8,25%
3	Venice	1.815.823	6,72%	6,85%	6,64%	6,72%	6,51%
4	Balearic Islands	1.541.376	5,70%	5,17%	5,98%	6,43%	5,67%
5	Piraeus	1.302.581	4,82%	4,62%	5,53%	4,76%	5,59%
Major 5 - SUM		**9.797.271**	**36,26%**	**35,17%**	**37,63%**	**35,77%**	**35,87%**
6	Marseille	1.188.031	4,40%	3,43%	3,01%	2,91%	2,89%
7	Naples	1.175.018	4,35%	5,00%	4,83%	4,74%	5,29%
8	Dubrovnik/Korcula	1.136.503	4,21%	3,79%	3,76%	3,89%	4,13%
9	Genoa	1.050.085	3,89%	3,08%	2,97%	3,58%	3,07%
10	Savona	939.038	3,48%	3,12%	3,53%	3,25%	3,25%
Major 10 - SUM		**15.285.946**	**56,57%**	**53,59%**	**55,72%**	**54,13%**	**54,49%**
11	Tenerife Ports	794.151	2,94%	3,42%	3,08%	3,08%	2,66%
12	Kusadasi/Bodrum/ Antalya	780.804	2,89%	3,00%	3,02%	2,75%	2,84%
13	Corfu	744.651	2,76%	2,53%	2,31%	2,48%	2,30%
14	Livorno	736.516	2,73%	4,00%	3,66%	3,42%	3,64%
15	French Riviera Ports	613.218	2,27%	2,71%	2,48%	2,79%	3,41%
16	Bari	604.781	2,24%	2,39%	2,18%	2,11%	2,60%
17	Lisbon	558.040	2,07%	2,02%	1,87%	1,86%	1,90%
18	Tunisian Ports	511.065	1,89%	2,04%	1,17%	3,72%	3,44%
19	Messina	501.316	1,86%	1,69%	1,86%	1,56%	1,16%
20	Madeira Ports	482.112	1,78%	2,29%	2,02%	2,05%	2,00%
Major 20 - SUM		**21.612.600**	**79,99%**	**79,67%**	**79,37%**	**79,96%**	**80,44%**

Table 59: *Major 20 Medcruise ports – Cruise pax. concentration*

9.3 ANNEX C- Criteria for ECA's designation

As it is mentioned in chapter 3 of the main project, the proposal that all the interested parties must submit to the Administration, shall include concrete information details. The following points expose these requirements:

1. A clear definition of the proposed area of application, what shall include detailed coordinates, references and the area marked in draft;
2. The type or types of emission(s) that is or are being proposed for control;
3. A description of the human populations and environmental areas at risk from the impacts of ship emissions;
4. An assessment that emissions from ships operating in the proposed area of application are contributing to air pollution concentration levels;
5. Relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk;
6. Ship's traffic in the proposed Emission Control Area, including the patterns and density of such traffic;
7. A description of the control measures taken by the proposing Party or Parties to regulate NO_x, SO_x and particulate matter emissions with the consideration of regulations 13 and 14 of Annex VI;
8. The relative costs of reducing emissions from ships when compared with land based controls, and the economic impacts on shipping engaged in international trade.

Otherwise the final delimitation of the geographical limits of an Emission Control Area will be based on the relevant criteria outlined above, including emissions and deposition from ships navigating in the proposed area, traffic patterns and density, and wind conditions.

9.4 ANNEX E- Cruise data chart from San Francisco's study

Name	IMO	Gross tonnage	Length (m)	Passengers	Hotelling kW
NATIONAL GEOGRAPHIC ENDEAVOUR	6611863	3132	88	110	1280
ISLAND SKY	8802894	4280	91	114	3600
SEA CLOUD II	9171292	3849	117	96	1290
VISTAMAR	8701193	7498	121	330	2360
HANSEATIC	9000168	8378	123	184	4400
OCEAN MAJESTY	6602898	10417	131	535	4260
SEABOURN PRIDE	8707343	9975	134	204	3200
SPIRIT OF ADVENTURE	7904889	9570	139	470	2112
SILVER CLOUD	8903923	16927	156	296	6912
SILVER WIND	8903935	16927	156	315	6912
DELPHIN	7347536	16331	156	590	3816
VAN GOGH	7359400	16331	156	650	3816
OCEAN MONARCH	5282627	10545	162	503	5220
ASTORIA	8000214	18591	164	500	7240
DISCOVERY	7108514	20186	169	600	3636
COSTA MARINA	6910544	25441	174	1025	2265
BLACK WATCH	7108930	28668	178	758	6740
BOUDICCA	7218395	28388	178	1022	6740
SILVER SHADOW	9192167	28258	182	388	3000
MAXIM GORKIY	6810627	24220	195	650	3000
SEVEN SEAS MARINER	9210139	48075	216	769	7250
VOLENDAM	9156515	61214	238	1440	7250
AMSTEDAM	9188037	62735	238	1380	7250
ASUKA II	8806204	50142	241	960	6000
PACIFIC DAWN	8521232	70285	245	1900	6700
NORWEGIAN SUN	9218131	78309	258	2350	7250
NORWEGIAN SKY	9128532	77104	259	2450	7250

SUN PRINCESS	9000259	77441	261	2342	7250
DAWN PRINCESS	9103996	77441	261	2342	6800
CELEBRITY MERCURY	9106302	76522	264	1896	9500
NORWEGIAN SPIRIT	9141065	75338	269	3760	7250
VISION OF THE SEAS	9116876	78340	279	2416	7250
OOESTERDAM	9221281	81769	285	1968	7250
SAPHIRE PRINCESS	9228186	115875	290	3100	7250
DIAMOND PRINCESS	9228198	115875	290	2600	7250
RADIANCE OF THE SEAS	9195195	90090	293	2100	7250
CELEBRITY SUMMIT	9192387	90280	294	2499	7250
NORWEGIAN STAR	9195157	91740	294	2240	7250
CORAL PRINCESS	9229659	91627	294	3178	7250
INDEPENDENCE OF THE SEAS	9349681	154407	339	4375	11000

Table 60: *Cruise data list*

9.5 ANNEX- Cable additional information

9.5.1 Correction factors depending on cable depth construction

Depth (m)	Correction coefficient
1,25	0,98
1,50	0,96
1,75	0,94
2	0,93
2,50	0,91
3,00	0,89

Table 61: *Correction coefficient depending on cable depth construction*

9.5.2 Cable disposition

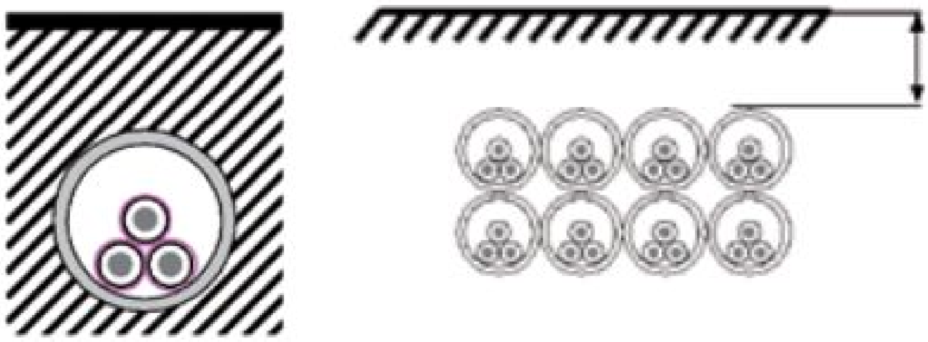

Figure 51: *Construction cable representation*

9.6 ANNEX- Drafts

In the following pages, all the mentioned drafts in chapter5 about the electrical design and its composition are included. They follow the next order:

- *SUBSTATION DESIGN, 220kV Part*
- *SUBSTATION DESIGN, 25kV Part*
- *SHORE STATION DESIGN*
- *DISTRIBUTION ARCHITECTURES, Architecture 1*
- *DISTRIBUTION ARCHITECTURES, Architecture 2*

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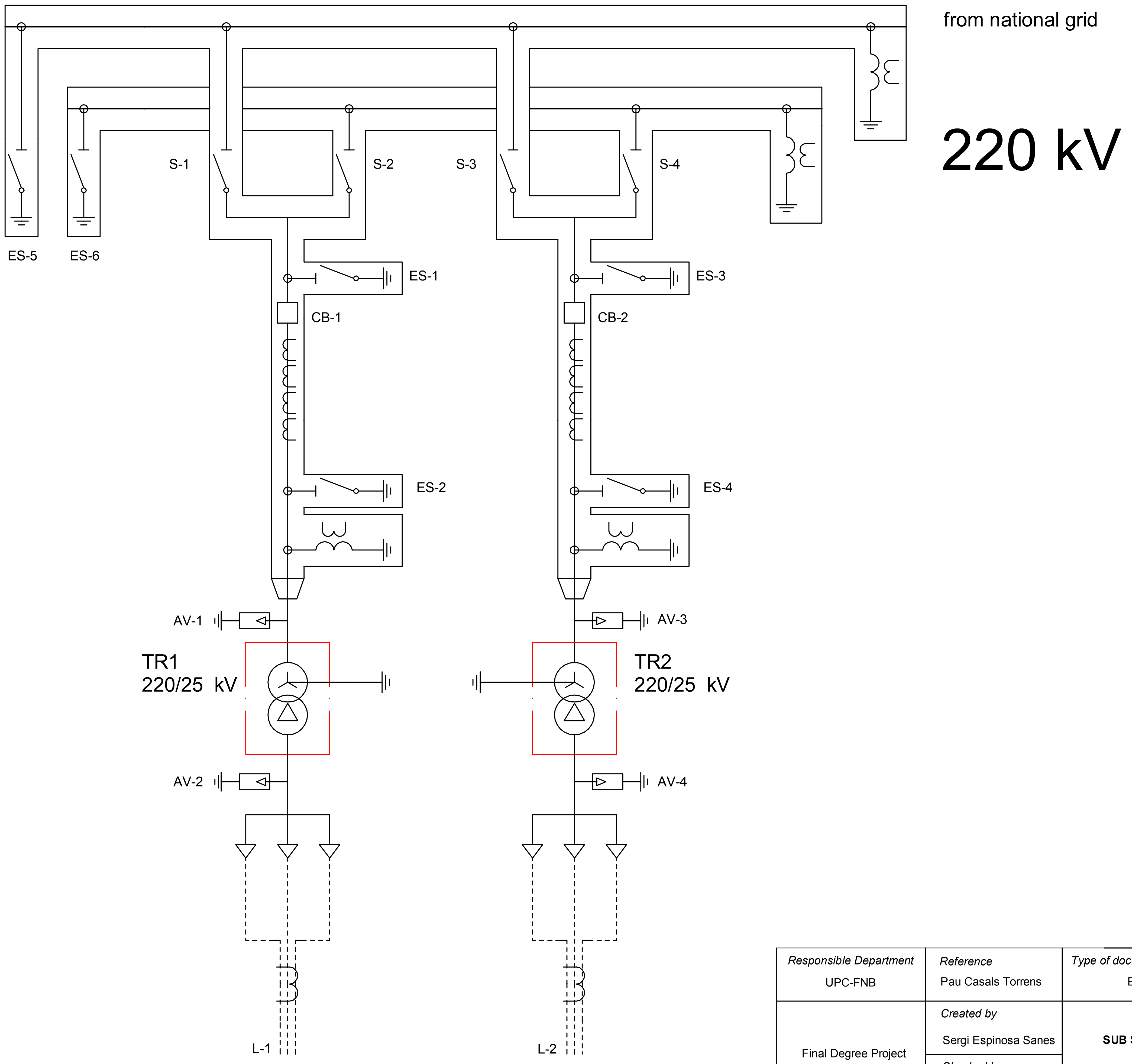
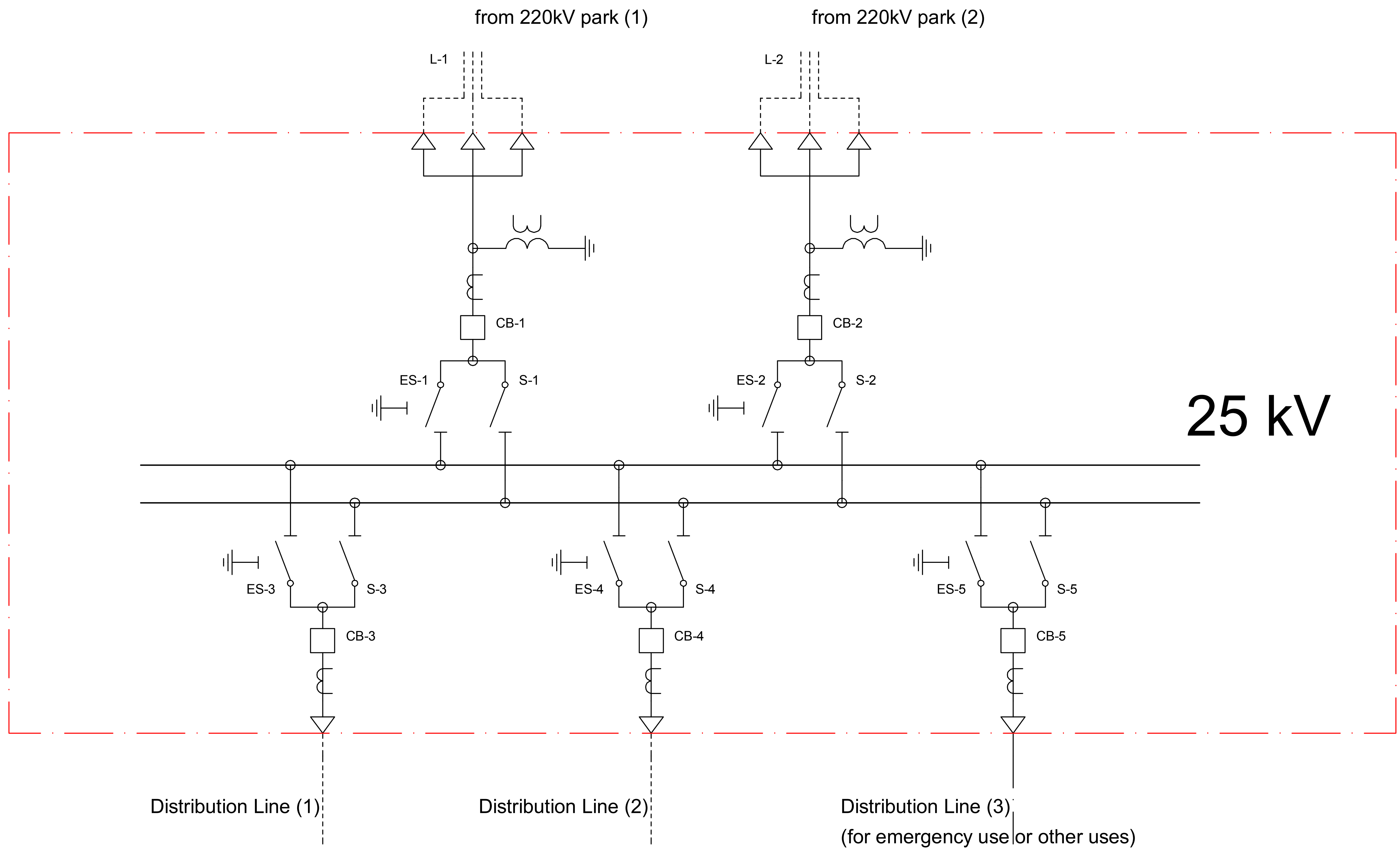


Responsible Department UPC-FNB	*Reference* Pau Casals Torrens	*Type of document* Electrical Layout	*Document situation* Edited
Final Degree Project	*Created by* Sergi Espinosa Sanes *Checked by* Sergi Espinosa Sanes	**SUB STATION DESIGN** 220 kV Part	**Single-line diagram** Edition date: 2015-07-9 · Language: English · *Page*: 1/2



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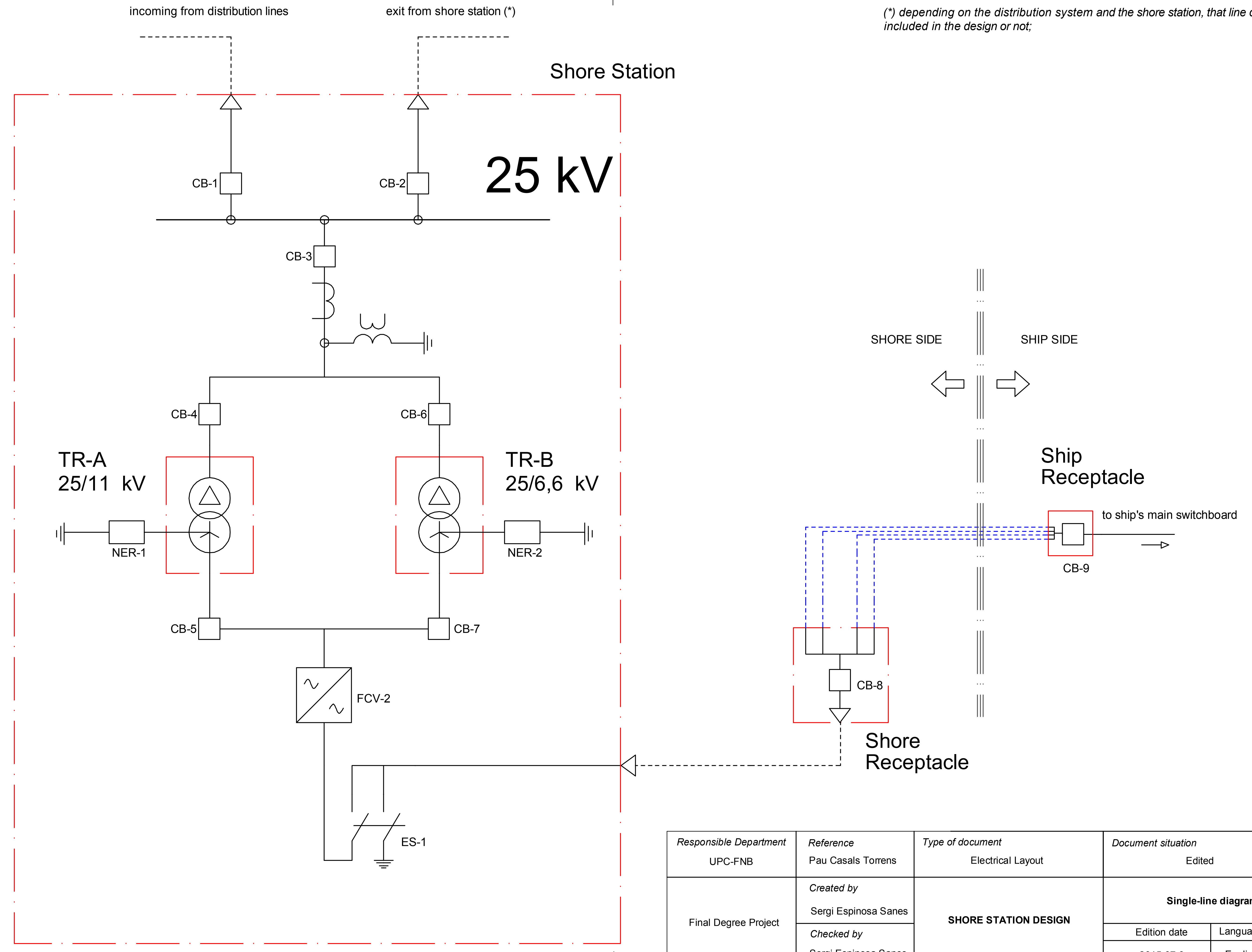
Final Degree Project	Created by Sergi Espinosa Sanes Checked by Sergi Espinosa Sanes	**SUB STATION DESIGN** 25 kV Part	**Single-line diagram**		
			Edition date	Language	Page
			2015-07-9	English	2/2

(*) depending on the distribution system and the shore station, that line can be included in the design or not;



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Final Degree Project	*Created by* Sergi Espinosa Sanes	**SHORE STATION DESIGN**	**Single-line diagram**		
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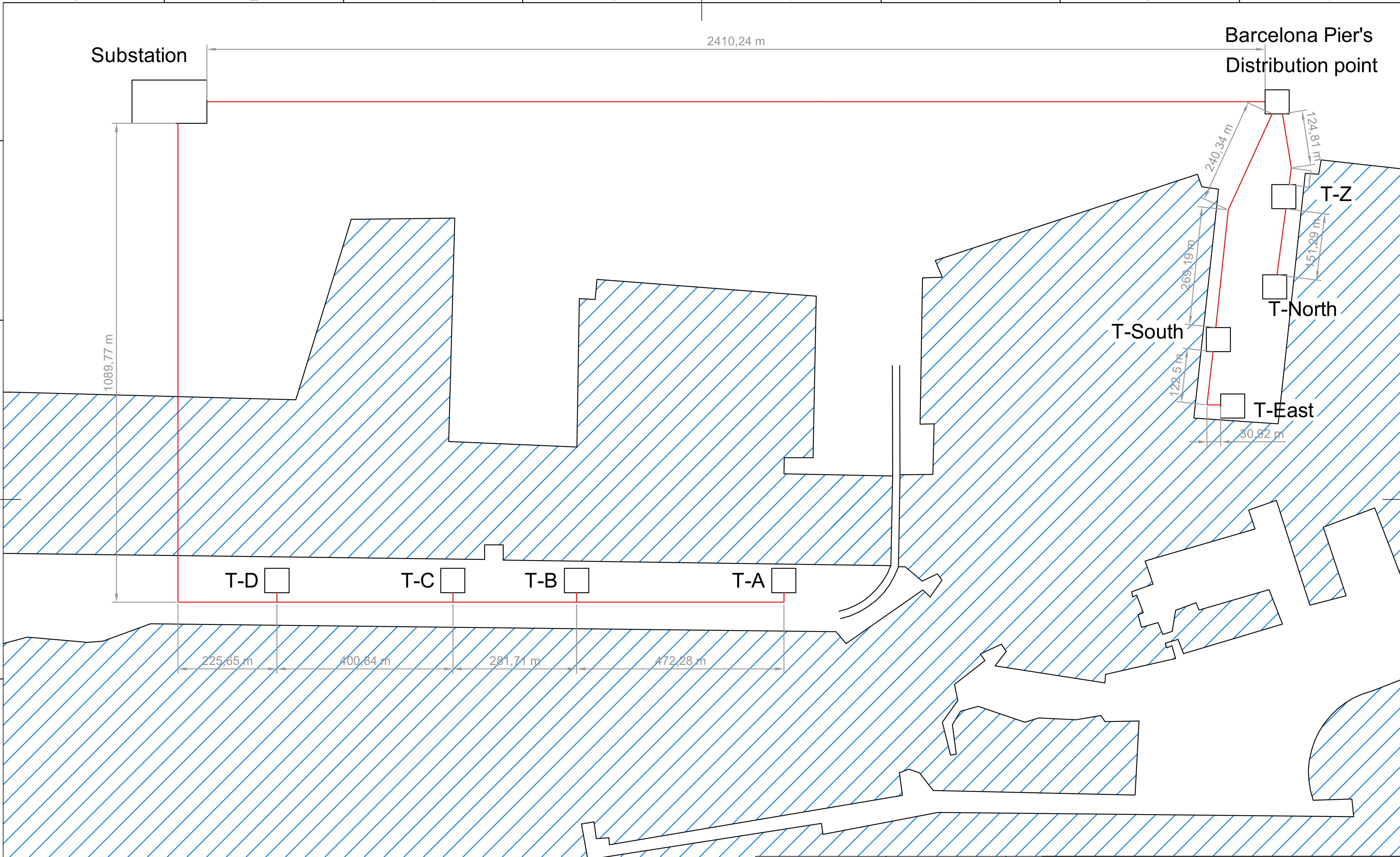

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UPC-FNB	Pau Casals Torrens	Electrical Layout	Edited
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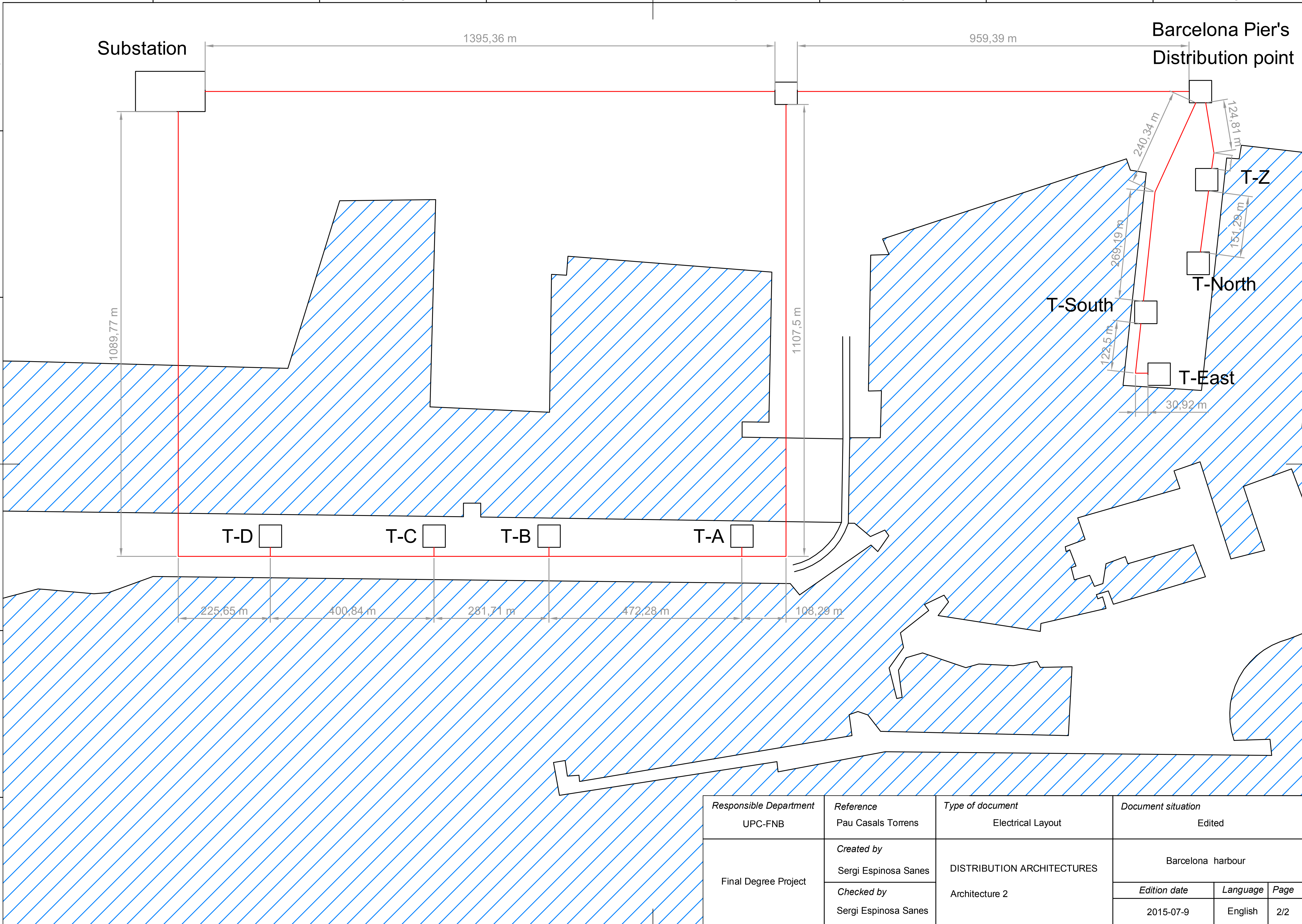

Responsible Department UPC-FNB	*Reference* Pau Casals Torrens	*Type of document* Electrical Layout	*Document situation* Edited
Final Degree Project	*Created by* Sergi Espinosa Sanes *Checked by* Sergi Espinosa Sanes	DISTRIBUTION ARCHITECTURES Architecture 2	Barcelona harbour *Edition date* 2015-07-9 / *Language* English / *Page* 2/2