UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Industrial Engineering

Project for the Evacuation and Transmission Power Lines of the Offshore Wind Farm Spinnaker of 360 MW

End of Degree Project

Bachelor's Degree in Industrial Engineering

AUTHOR: Lazaro Novella, Alejandro

Tutor: Pineda Sánchez, Manuel

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ACADEMIC YEAR: 2022/2023

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ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

SPINNAKER OFFSHORE WIND FARM

ELECTRICAL DESIGN

July 2023

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

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July 2023

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1. Introduction

1.1 Object of the document

The purpose of this document is to present to the lecturers committee at UPV the project "SPINNAKER Offshore Wind Farm Electrical Design" and its connection to the grid.

The SPINNAKER offshore wind farm is located in the North Atlantic marine demarcation, off the coast of the province of Lugo. The park is located entirely within the High Potential Wind Energy Zone (ZAPER) NOR-5, as identified in the Maritime Spatial Management Plans (POEMs).

The wind farm consists of 24 wind turbines of 15 MW of unitary power, which means a total installed power of 360 MW. The wind turbines are installed on floating platforms and are connected to each other to form a power transmission line, distributed in six different arrays of 4 WTG´s each one. From this position, by means of marine/land power evacuation lines, they discharge the energy generated to the marine substation situated 10 km away from the transition joint bay, then an onshore line connects the TJB to the grid.

The document will include the sizing of the cables between the aerogenerators, between the aerogenerators to the marine substation, from the marine substation to the transition joint bay and then to the land substation. These calculations will be done by Alejandro Lázaro Novella. The layout and the displacement of the aerogenerators has been decided by other members of the teams.

1.2 Project Justification

The project has several justifications that make it a feasible and desirable solution to the energy needs of the region. Firstly, the offshore wind farm will be able to generate a substantial amount of clean and renewable energy. The region has a high potential for wind energy, and offshore wind farms are proven to be more efficient in harnessing wind power. The proposed wind farm has a planned capacity of 360 MW, which can power 480.000 households annually.

Secondly, the offshore wind farm can significantly reduce carbon emissions. The project will contribute towards the region's target of reducing greenhouse gas emissions. The offshore wind farm will offset a significant amount of carbon emissions that would otherwise be produced by traditional power generation sources such as coal and natural gas.

Thirdly, the offshore wind farm will create employment opportunities and contribute to the economic development of the region. The project will require a significant investment, and the construction and maintenance of the wind farm will provide employment opportunities to the local community. Furthermore, the project will generate revenue for the region through the sale of electricity and associated services.

Lastly, the offshore wind farm will contribute to the energy security of the region. The region currently relies on imported energy sources, which can be volatile in terms of supply and price. The offshore wind farm will provide a stable and reliable source of energy, reducing the region's dependence on imported energy sources.

In conclusion, the proposed offshore wind farm project has significant justifications that make it a feasible and desirable solution to the energy needs of the region. The project will generate clean and renewable energy, reduce carbon emissions, create employment opportunities, contribute to the economic development of the region, and enhance energy security.

1.2.1 Fit of the project

With the development of the SPINNAKER offshore wind farm project, a significant contribution is being made to meeting the 2021-2030 Energy and Climate Change Policy objectives in terms of emissions reduction and energy transition; and the National Integrated Energy and Climate Plan (PNIEC), in which renewable energies are the basis for the development of the energy transition, whose target is set at 50 GW of installed wind power capacity by 2030.

Spain published the draft of the National Integrated Energy and Climate Plan 2021-2030 whose objective is to facilitate and update compliance with the main binding targets for the EU in 2030, taking into account the agendas and timetables established in the European Commission, the Climate Change Convention (Paris Agreement) and the UN (Sustainable Development Goals), and which are set out below:

- 23% reduction of greenhouse gas (GHG) emissions compared to 1990.
- 42% of renewables over final energy use.
- 39.5% improvement in energy efficiency.
- 74% of renewable energy in electricity generation.

One of the main ways to achieve these results lies in the substitution of fossil fuels, which account for most of the greenhouse gas emissions in Galicia. Due to this, the SPINNAKER offshore wind farm represents an excellent opportunity to materialize the national energy transition policy. In line with the above, it is worth mentioning the real need to cover the energy generated by the coal-fired thermal power plants which are in the process of closing in the community, as is the case of the plant in Meirama (Cerceda) and the As Pontes power plant.

The Spinnaker offshore wind farm would add 360 MW of installed renewable power. Taking into account the above, according to data from 2021, the total installed renewable power in Galicia is 7780 MW. With the implementation of the project in question, a continuous growth would be ensured in addition to expanding the supply of renewable energy available for consumption.

There are many instruments that contribute to the development of offshore wind power, as mentioned in this first section. The following are some of the directives, strategies and plans that are considered to be of importance:

- Within the European scope are the following:
    - Directive (EU) 2018/2001: As mentioned in Article 194, "The promotion of renewable energies is one of the objectives of the European Union's energy policy. This Directive pursues that objective."
    - European Offshore Renewable Energy Strategy (European Commission in November 2020), which proposes to increase Europe's offshore wind energy production capacity from its current level to at least 60 GW by 2030 and 300 GW by 2050.
    - European Strategic Energy Technology Plan (SETPlan): Aims to improve new technologies and reduce costs by coordinating national research efforts and helping to fund projects.
        - Blue Growth Strategy (European Commission, 2012): Highlights the potential and the need to prioritize blue energy (from the sea), since according to forecasts in 2030 offshore wind could surpass onshore wind by 2030.
        - European Green Pact: The aim is to turn marine renewables into an even greater opportunity for clean energy, high quality employment, sustainable growth and international competitiveness.
- Within the national scope:

- National Integrated Energy and Climate Plan 2021-2030 (PNIEC): The same is demanded by the European Union to each State in order to determine the degree of joint compliance with the well-known "winter package" regarding renewable energies and to establish actions to correct possible deviations.

- Maritime Space Management Plans; which, as its name suggests, is a system for managing the different maritime spaces according to the activities that take place in them. It has different management plans depending on the demarcation. In this case, the demarcation to be used is the North Atlantic marine.

- Offshore wind and marine energy roadmap in Spain: It is in line with the European Union Strategy on offshore renewable energies and seeks to make Spain a European reference pole for technological development and an international reference in industrial capacities, a compatible and sustainable offshore wind development and to establish a state framework for the deployment of offshore renewable energies.

- Sectoral Agenda for the Wind Industry (Ministry of Industry, Trade and Tourism, 2019): Offshore wind is presented as a priority for the leadership of the wind industry in Spain. The priority nature of simplifying regulations and administrative procedures is mentioned.

2. References

2.1 Standards and codes

- Royal Decree 1565/2012, of November 19, which regulates and modifies certain aspects related to the activity of electricity production under special regime.

- Law 15/2012, of December 27, on fiscal measures for energy sustainability.

- Royal Decree-Law 2/2013, of February 1, on urgent measures in the electric system and the financial sector.

- Law 24/2013, of December 26, on the Electric Sector.

- Royal Decree 413/2014, of June 6, which regulates the activity of electricity production from renewable energy sources, cogeneration, and waste.

- Royal Decree 1028/2007, of July 20, establishing the administrative procedure for the processing of applications for authorization of electricity generation facilities in territorial waters.

- Royal Decree 842/2002, of August 2, approving the Electrotechnical Regulation for low voltage.

- Royal Decree 223/2008, of February 15, approving the Regulation on technical conditions and safety guarantees in high voltage power lines and its complementary technical instructions ITC-LAT 01 to 09.

- Royal Decree 337/2014, of May 9, approving the Regulation on technical conditions and safety guarantees in high voltage electrical installations and its complementary technical instructions ITC-RAT 01 to 23.

- Coastal Law 22/1988, of July 28.

- Law 2/2013, of May 29, on protection and sustainable use of the coastline and modification of Coastal Law 22/1988, of July 28.
- Legislative Royal Decree 1/2008, of January 11, approving the consolidated text of the Law on Environmental Impact Assessment of projects.
- Legislative Royal Decree 1175/1991, of September 28, approving the rates and the instruction of the Tax on Economic Activities.
- Law 27/2014, of November 27, on Corporate Income Tax.
- Law 3/1985, of March 18, on Metrology.
- International standard IEC 61400-3, relating to wind turbines.
- UNE standards of mandatory compliance.
- Order of December 19, 1997, which develops certain aspects of Royal Decree 2019/1991, of December 26, which organizes and regulates the electricity production market.
- Royal Decree 2018/1997, of December 26, approving the Regulation on measuring points for electricity consumption and transit.
- Order of April 12, 1999, which issues the Complementary Technical Instructions to the Regulation on measuring points for electricity consumption and transit.
- Royal Decree 385/2002, of April 28, amending Royal Decree 2018/1997, of December 26, approving the Regulation on measuring points for electricity consumption and transit.
- Royal Decree 1955/2000, of December 1, which regulates the activities of transport, distribution, commercialization, supply, and authorization procedures for electricity installations.
- Royal Decree-Law 1/2012, of January 27, which suspends the pre-allocation procedures for remuneration and eliminates economic incentives for new electricity installations using cogeneration, renewable energy sources, and waste.
- IEC 61400: This international standard establishes design and construction requirements for wind turbines. It includes several standards related to wind turbines, such as IEC 61400-1 for general design, IEC 61400-2 for load design, and IEC 61400-3 for structural design.
- IEC 61400-22: This standard is specific to offshore wind farms. It defines design and construction requirements for offshore wind farms, including the installation and maintenance of wind turbines, support structures, substations, and transmission lines.
- IEC 61803: This standard establishes design and construction requirements for high-voltage cables and transmission lines. It includes information on material selection, installation methods, and testing.
- IEC 60909: This standard establishes methods for calculating short-circuits in electrical systems. It includes information on evaluating short-circuit currents, calculating impedances, and selecting protective devices.
- IEC 60050: This standard establishes common terminology and definitions used in the electrical industry.

- Royal Decree 223/2008 of February 15, 2008, approving the Regulation on technical conditions and safety guarantees in high voltage power lines and its complementary technical instructions. Correction of errors of Royal Decree 223/2008 of February 15 (BOE 174. July 19, 2008). Corrigendum to Royal Decree 223/2008 of February 15, 2008 (BOE 120. 17 May 2008).

- Royal Decree 337/2014, of May 9, approving the Regulation on technical conditions and safety guarantees in high voltage electrical installations and its Complementary Technical Instructions ITC-RAT 01 to 23. Correction of errors (Royal Decree 337/2014, May 9)., which approves the regulation on technical conditions and safety guarantees in high voltage electrical and its complementary technical instructions ITC-RAT 01 to 23 (BOE 09.06.14).

- IEC 60287 "Electrical calculations. Calculation of ampacity".

- IEC 60949 "Calculation of thermally permissible short-circuit current".

- IEC 60909 "Short-circuit currents in three-phase alternating current systems".

In addition to these international standards, there may be national standards that apply to the design and construction of wind farms. For example, in Spain, the UNE-EN 50341 standard applies to wind farms, and the UNE 21186 standard applies to the installation of overhead high-voltage lines.

3. Project definition and specifications

3.1 Introduction

Subsequently, the state of the art is defined for each of the technologies that make up the electrical interconnection cable between wind turbines, the offshore substation, marine cable for electrical evacuation, sea-land transition, onshore substation and land line. Once the state of the art has been defined with the corresponding comparisons between technologies, we proceed with the selection of the particular technology for each element, justifying the selection in view of what is indicated in the description of the different technologies.

3.2 Wind turbines layout

The site selected for this project is located within one of the priority use areas (ZUPER) established by the Maritime Space Management Plans (POEM), specifically in the area known as NOR-5 in the Cantabrian Sea. The industrial estate is located on the coast of Lugo.

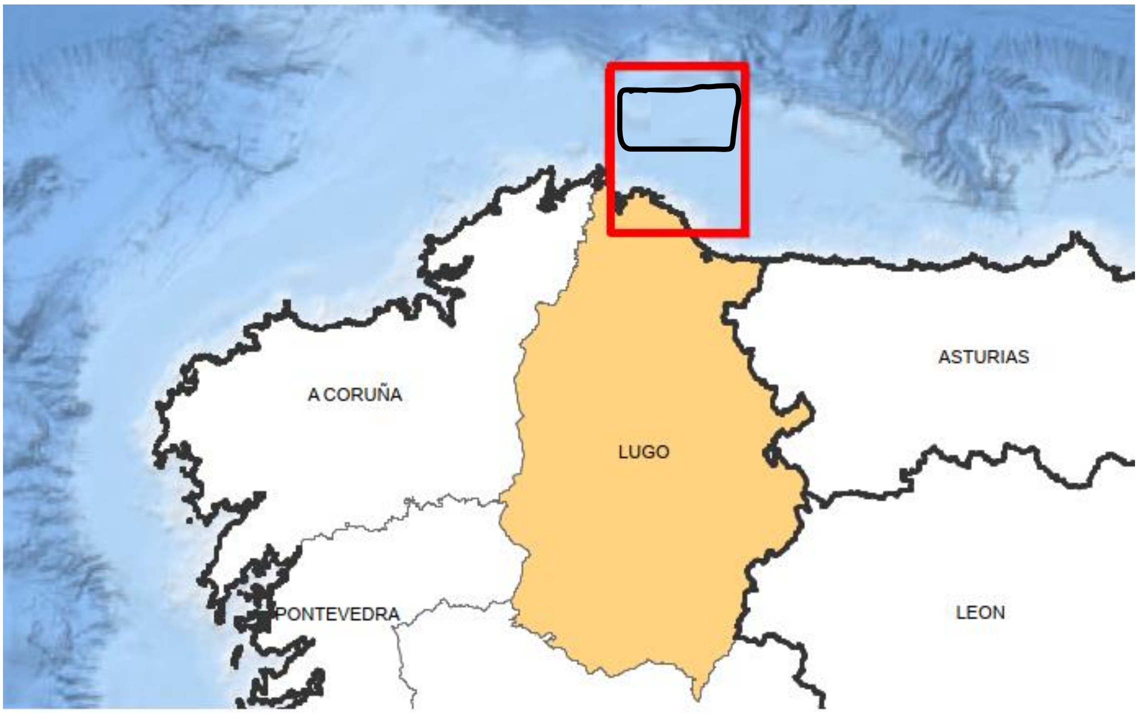


Figure 1: Map Layout

The criteria followed and the reasons for ultimately choosing this location are defined in Annex I and summarized as follows:

- High wind resource, with average speeds between 8 and 10 m/s.
- It is located in a suitable area "with constraints" according to the Regulations of the Strategic Environmental Study of the Spanish Coastline for the installation of Offshore Wind Farms.
- Optimal depths for the structures, with an average of 40 meters.
- Minimum distance from the coast of 8 km.
- Respecting environmental resources and fishing activities.
- Proximity to ports and shipyards.
- Possibility of electrical evacuation for the installed capacity at the land Substation electrical substation (220 kV).

3.2.1 Wind turbines model selection

The selection of the wind turbine model, as mentioned at the beginning of this chapter, is a fundamental part of the wind resource production study, since the wind turbine is responsible for transforming the kinetic energy of the wind into electrical energy. The study of the wind resource has been carried out separately by other members of the team, they decided to implement the model called V236-15MW from Vestas manufacturer.

For this purpose, the model of a generic 15 MW wind turbine with the following main characteristics will be considered:

GENERIC WIND TURBINE MODEL OF 15 MW	
Clase IEC	I, S
Nominal Power	15 MW
Rotor Diameter	**236 m**
Blade length	115,5 m
Swept area	43,742 m2

The distance between each wind turbine and its next connected wind turbine must be a minimum of 5 times the rotor diameter, in this case we have 236 m what makes a separation of 1180 m, it is very important to define the length to use in order to make effective calculations. Other consideration that must be take into account should be the separation between the different arrays, being the distance between them of 12 times the rotor diameter.

Power losses: The calculation of power generated by integrating the power curve of the turbine with the corresponding Weibull distribution of wind in the area corresponds to the gross value of production. To obtain the net energy production, this value needs to be adjusted for various loss factors. The following reference values are provided:

- Electrical losses, approximately 3-5%
- Losses due to unavailability, around 3%
- Blade contamination, around 1%
- Hysteresis of high winds, estimated at around 0.5%
- Wake effect losses, of significant importance in offshore wind farms, on the order of 10%

3.2.2 Layout study and optimization

The wind turbine layout study maximizes wind farm production and reduces wake losses generated between the rows of wind turbines, thus improving energy production performance.

In this phase of the project, different turbine layout alternatives have been analyzed within the wind farm location polygon. All of them consider 24 machines, separated by distances of 5D (5 times the diameter) for turbines of the same alignment; being the distance between alignments of 12D (12 times the diameter).

Of the various alternatives studied, the one with the highest energy production was selected. In this turbine layout, the rows of wind turbines are arranged parallel to the line that delimits the polygon in the western part of the wind farm. This consideration implies a slight increase in the distance between wind turbines and marine substation in some arrays. It should also be noted that the use of space is greater in this alternative.

3.3 Wind farm Design

Offshore wind farms are increasingly being developed to harness renewable energy from wind resources. The efficient transmission of this energy from the offshore platforms to the onshore grid requires careful planning and design. One crucial aspect is the selection of an appropriate voltage level for the power transmission lines. In this context, the decision to employ a voltage of 220 kV between the marine substation platform and the transition joint bay will be explained.

The choice of 220 kV as the operating voltage for the offshore lines is driven by several factors. Firstly, it strikes a balance between transmission efficiency and equipment costs. Higher voltage levels, such as 400 kV, offer better transmission efficiency due to reduced losses but come with increased equipment and infrastructure expenses. In contrast, a lower voltage level like 66 kV may lead to higher transmission losses. Therefore, 220 kV represents a practical compromise for this project.

Additionally, the availability and compatibility of equipment play a vital role in the decision-making process. The existing transformer in the substation onshore operates at 220/400 kV, making 220 kV an appropriate choice for seamless integration and compatibility with the onshore infrastructure. This decision allows for the efficient transfer of electrical power from the offshore wind farm to the existing grid system, minimizing additional investment in new equipment and ensuring operational reliability.

In conclusion, the selection of 220 kV as the operating voltage for the offshore power transmission lines between the marine substation platform and the transition joint bay offers a balanced approach in terms of transmission efficiency, equipment compatibility, and overall cost-effectiveness. This choice ensures the seamless integration of the offshore wind farm into the existing onshore grid system, facilitating the sustainable utilization of renewable energy resources.

Nevertheless, the idea of using a HVDC electrical design has been considered, deep research has been made in order to choose the best way to evacuate the energy produced. The following statements resume properly the most important facts:

- DC cables have a longer service life than AC cables.
- The power electronics allow a high control of active and reactive power, which enables a greater involvement of wind farms in voltage control.
- Compared to AC, a DC cable of the same size carries more energy.
- Direction and magnitude of power can be controlled.
- HVDC does not transfer short-circuit currents (the converter blocks them).
- Asynchronous connection (frequency can be different at either end), allowing more advanced control schemes in converters.
- Transmission distance is not limited by losses.

These are good points to defend the use of HVDC system, but we also can find other justifications that makes it less appropriate in our case:

- Produces large amounts of harmonics which necessitates the use of large filters.
- Does not provide an independent control above the active and reactive power.

Furthermore, that last reason is one of the most important considerations to take into account, because we have to accomplish straight specifications to be able to connect our system to the existent grid. This consideration will be deeply explained in other sections of this project.

3.3.1 Marine Substation

3.4.1.1 Introduction

A substation is that part of an electric power generation, transmission and distribution system that transforms low voltage to high voltage or vice versa. Within an offshore wind farm, an offshore substation can be defined as that structure supported by a fixed or floating platform (depending on the bathymetry) that collects energy from the wind turbines through the interconnection cables and transforms the voltage from medium voltage to high voltage in order to transfer the electrical energy through the power evacuation cables to the onshore connection point. This is done in order to reduce losses and even to ensure the viability of the project. Its main functions are reduced to the following:

- Transform voltage to enable power to be transported over long distances.
- Collect energy from interconnecting cables.
- Reduce the total cable cross-section.
- Regulate and control the exporting capacity: emergency stops, shutdowns, etc.

Figure 2: Marine Substation

3.4.1.2 Substation Components

As for the usual layout of a marine substation, the following single-line diagram is available as an overview summary:

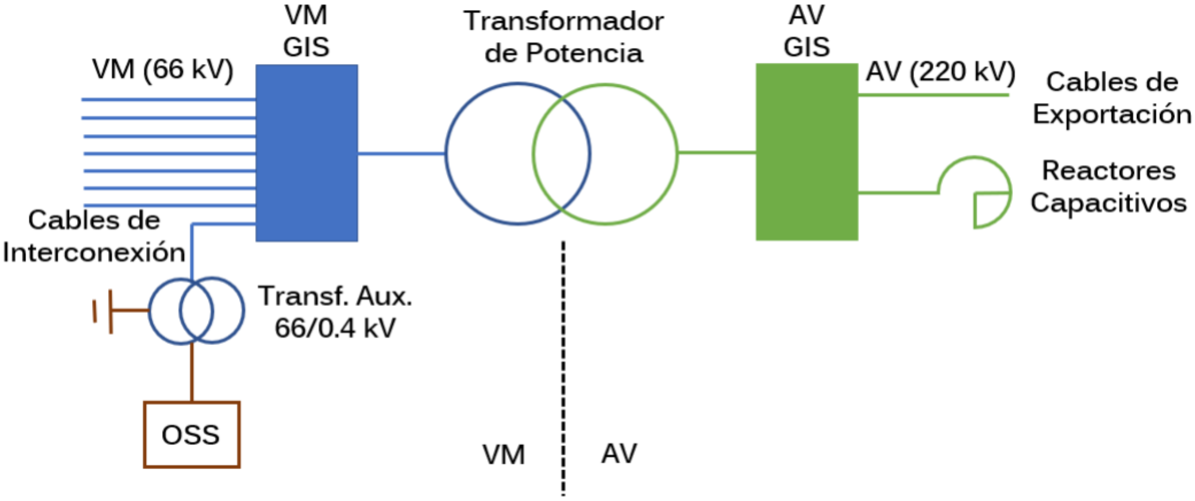


Figure 3: Substation Diagram

Firstly, we considered the interconnection cables between the wind turbines that reach the substation and increase its voltage through a power transformer to a enough high voltage to ensure that losses to the shore are not a problem for the evacuation designing. Capacitive reactors are those that reduce losses due to reactive power generated on the AC line, and a study should be carried out to confirm the need for them. In the following, each of the components will be defined, without including the cables, as they have their own corresponding section:

- VM and AV GIS: Gas insulated systems are those units which house components and circuits in a single, compact size gas tank. They are rooms which, depending on the voltage, have different dimensions and lifting aids. The gas used for insulation is Sulphur Hexafluoride (SF6) since it is non-toxic and has excellent electrical properties. However, its strong greenhouse effect must be taken into account.
- Power transformer: The most important and reliable equipment in an offshore wind farm. It allows the increase from medium to high voltage in order to minimise losses in the evacuation cable. Typically, two power transformers of between 55%-65% of the total capacity are used. The main components are components are shown below:

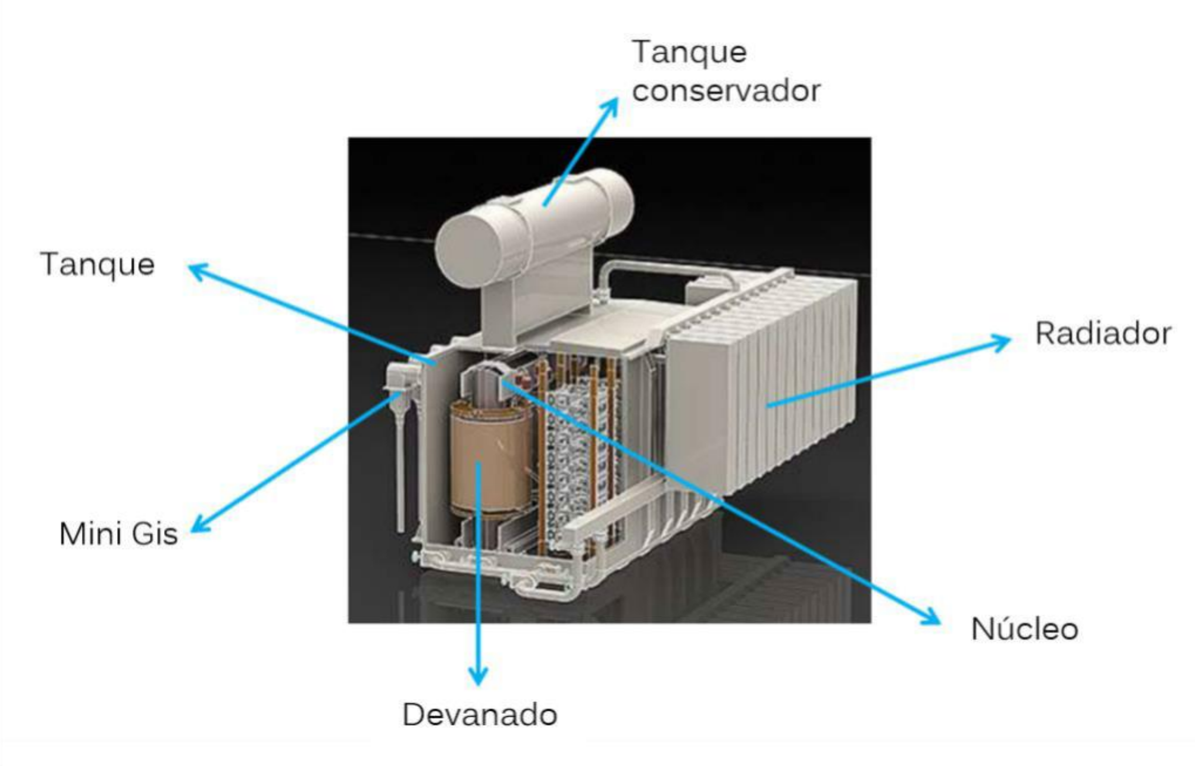


Figure 4: Key parts of a transformer. Own source

- Capacitive reactors: Inductors which are used for the purpose of compensating capacitive reactive power generated by long, low-load transmission lines or underground cables. generated by long, low-load transmission lines or underground cables.

These GIS systems, power transformers and capacitive reactors account for around 60/70% of the space available in an offshore substation. As for the rest of the percentage, there are different auxiliary elements:

- Control rooms: High voltage (grid management), medium voltage (wind farm management) and low voltage (auxiliary systems).
- HVAC: Refers to the ventilation and air-conditioning systems present in most of the rooms.
- Drainage: Rainwater, diesel, sump tanks...
- Auxiliary transformer and earthing.
- Diesel system corresponding to different equipment such as HVAC, fire pumps, cranes and others.
- Fire-fighting system: heliport, sump tanks, generators, electrical rooms. A choice should be made between foam, water or inert gas as extinguishing method.
- Water system: cooling, cleaning and firefighting.
- Communications, SCADA (Supervisory Control and Data Acquisition).
- Heliport.

- Shelter and welfare: emergency shelter area and may also include showers, working areas, drinking water, etc.
- Access and egress: jetties, evacuation routes, davits and liferafts.
- Cranes.
- Cable deck.
- Navigation aid systems, VTMS (vessel traffic management system).
- Lighting.
- Batteries (Shut down and restore marine substation).

3.3.1 Electrical Evacuation Cable

The main characteristic of a submarine power cable lies in its greater insulation and robustness in order to better withstand the effects of the environment in which it will work. In the offshore industry, it generally works in three-phase, this is a three-core cable in which the three conductor cores are located. There are other alternatives for evacuation in direct current, although only when the distance to the coast is very long and this technology allows a more efficient transport of the energy.

This section refers to the electrical evacuation system by which the energy will be transported to the Kook Substation. To this end, the interconnection cables between the different wind turbines will have to be defined, as well as the marine cable for electrical evacuation which will terminate the underwater section once it reaches the transition joint bay where it will become a land line.

In an offshore wind farm we can differentiate between two types of submarine cables:

- Interconnection cables between wind turbines: These are cables that connect several turbines together to form a row or array, which, for the power of the installed wind turbine, connects an approximate maximum of 5 wind turbines on a single circuit. This typology also includes (if necessary) the interconnection cables between the turbine closest to the substation and the the lift-to-float substation itself.
- Electrical evacuation cables: These are responsible for transmitting the power from the wind farm to the onshore connection point where the buried transition joint bay will be located. Where the transition between the submarine cables and the terrestrial cables will be made.
  between the submarine and terrestrial cables.

Figure 5: Submarine cable layouts. Own source

3.3.1 Transition Joint Bay

The transition chamber is a buried room in which the link between cables of different technologies is made, in this case between submarine cables (three-pole cables) and terrestrial cables (single-pole cables).

The offshore transmission lines terminate at the TJB, where the cables are securely connected to the onshore infrastructure. The cable termination process involves the preparation, insulation, and termination of the cable ends, ensuring a reliable electrical connection between the offshore and onshore cables. The cable jointing procedure within the TJB involves connecting the offshore and onshore cables. Specialized cable joints are utilized to establish a secure and robust electrical connection, capable of withstanding the environmental and operational conditions present in the TJB.

After the cable transition is complete, comprehensive testing and commissioning procedures are conducted to verify the integrity and performance of the jointed cables. Various electrical tests, including insulation resistance, high voltage withstand, and partial discharge measurements, are performed to ensure the reliability and safety of the cable connection.

The TJB is subject to various environmental factors that must be carefully addressed during the design and operation stages. These considerations include:

- Marine Environment: The TJB is located in proximity to the shore, making it susceptible to marine conditions such as saltwater exposure, tidal effects, and corrosion. Appropriate measures, such as the selection of corrosion-resistant materials and protective coatings, must be implemented to mitigate the potential impact of the marine environment on the TJB and its cable transition section.

- Seismic Stability: Seismic events, including earthquakes, can pose a significant risk to the TJB's structural integrity. The section should discuss the design strategies employed to ensure the TJB's seismic stability, including foundation design, reinforcement measures, and seismic monitoring systems.

Safety and Maintenance: Safety considerations and regular maintenance are essential to ensure the reliable and safe operation of the TJB. The section should highlight:

- Safety Measures: The TJB should be equipped with safety features such as fire detection and suppression systems, emergency shutdown mechanisms, and personnel protection measures. These precautions are necessary to safeguard personnel, equipment, and the environment.

- Maintenance Strategies: The TJB requires regular maintenance to prevent equipment failures and optimize performance. The section should address the planned maintenance activities, including routine inspections, cable condition monitoring, and preventive maintenance practices.

The designs of these chambers may differ according to the number of splices to be made and the dimensions of the cables. Their functions are defined in the following points:

- Mechanical fixing of power cables.
- Interface joint between submarine and terrestrial power cables
- Earthing point

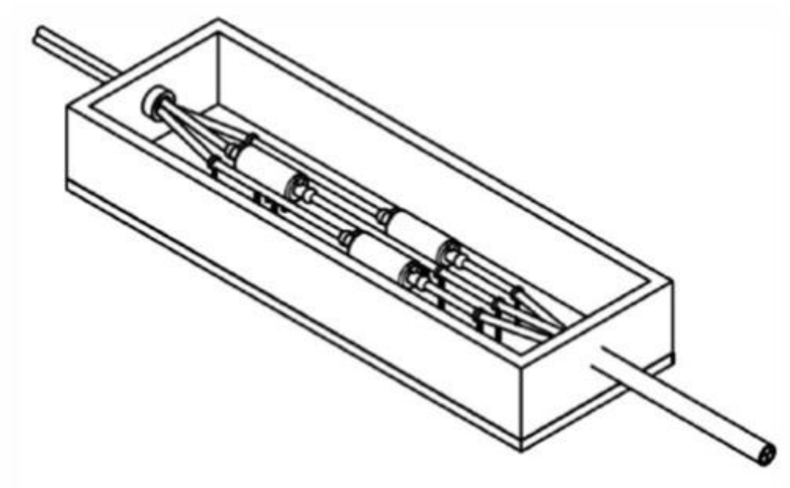


Figure 6: Diagram of the TJB

3.3.1 Onshore Line

Electrical installations can be assembled with overhead and underground transmission lines. These lines form the overland evacuation scheme from the transition chamber to the booster substation. Both options present different opportunities and the project conditions must be studied in order to select the most viable option.

3.3.4.1 Underground line

An underground power line is an infrastructure for the transmission of electrical energy by means of underground cables. This undergrounding is carried out by means of a trench and causes an increase in costs compared to overhead lines, even tripling their value, as the deployment of means for their assembly is much higher.

However, as they are buried, they do not interfere with the landscape of the environment in which they are located and guarantee greater safety. Two other major advantages of this type of transmission would be, on the one hand, that underground power lines are designed for minimum maintenance, and on the other hand, that underground power lines lose less voltage compared to overhead lines, offering a longer reach and a higher voltage drop than overhead lines.

The cables shall be properly shielded and protected against corrosion caused by the ground and the environment where they are installed or by erratic currents and shall have sufficient mechanical strength to withstand the stresses to which they may be subjected. Their main characteristics are:

COMPOSICIÓN:

1 **Conductor:** cuerda taponada de hilos de aluminio de sección circular compactados clase 2K según IEC 60228.
2 **Semiconductora interna:** capa extruida de material conductor.
3 **Aislamiento:** polietileno reticulado (XLPE).
4 **Semiconductora externa:** capa extrusionada de material conductor.
5 **Pantalla metálica:** hilos de cobre en hélice con cinta de cobre a contraespira.
6 **Obturación longitudinal de la pantalla:** cinta semiconductora hinchante.
7 **Estanqueidad radial:** cinta de aluminio solapada y termopegada a la cubierta.
8 **Cubierta:** poliolefina tipo ST7 no propagadora de la llama (S) con capa exterior semiconductora extruida conjuntamente con la cubierta.

Figure 7: UDG cable example

5.1.1 Offshore Line

Submarine power transmission lines play a crucial role in interconnecting offshore wind farms, facilitating the efficient transport of electricity generated by the wind turbines (WT). These underwater cables form a vital link between the individual turbines and the onshore electrical grid, enabling the integration of renewable energy into the existing power infrastructure.

In an offshore wind farm, the interconnection lines are responsible for collecting the electricity generated by each WT and consolidating it for transmission to the mainland. Typically, these submarine cables are designed to withstand the challenging marine environment, including factors such as water pressure, temperature fluctuations, and potential mechanical stresses.

To ensure the efficient evacuation of power from the wind farm, there is typically one cable connecting the last WT of each array to a submarine substation. This substation acts as a central hub for the wind farm, where the electrical energy from multiple WTs is combined and transformed to a higher voltage suitable for long-distance transmission. The submarine cable from each array serves as a backbone to deliver the power to the substation, minimizing energy losses and maximizing the overall system efficiency.

Once the power is consolidated at the submarine substation, it needs to be transported to the onshore electrical grid, often located at a considerable distance from the wind farm. For distances of around 20 kilometers, it is common to have two submarine power transmission lines for redundancy and increased reliability. These lines, designed with high-capacity conductors and advanced insulation, carry the electricity from the substation to the onshore grid connection point.

The submarine transmission lines for this 20-kilometer stretch are engineered to minimize power losses and maintain the stability and quality of the electricity during transit. These cables undergo rigorous testing and adhere to strict industry standards to ensure their reliability and longevity in the harsh marine environment.

Overall, submarine power transmission lines form the backbone of offshore wind farm infrastructure, enabling the efficient and reliable transport of renewable energy from the wind turbines to the onshore grid. They are designed with specialized features to withstand marine conditions and maximize the overall efficiency of the offshore wind energy system.

Figure 8: Offshore cable example

Going a little deeper into its internal configuration and starting to explain from one of the cores outwards, first we find the conductor, which can be made of copper or aluminium which will vary its conductive properties and price significantly, then there is a small black screen of semiconductor material in order to confine the electric field of the current, followed by a light-coloured thermal insulation, in most cases, as in the picture, it is an XLPE insulation, a polymeric layer with great thermal properties that ends in another semiconductor screen like the previous one and finally a double aluminium and polymeric sheath whose purpose is to insulate the conductor from the entry of water. To provide continuity, a filler material of plastic origin is used for the cable's physical properties and strength. Finally, in order to insulate the cable from water and to protect it from physical stresses, the armouring is made up of different layers, both metallic and polymeric.

In addition, between the left and upper core, the communication cable can be seen. It is a fibre optic cable due to its light weight and its innocuousness to the effects of electric and magnetic fields.

This whole set of layers makes the cable very robust, making its weight per unit length much greater than that of a terrestrial or aerial cable, and above all it influences its handling, complicating it due to its rigidity and the need for large turning angles, which can be limiting on certain occasions.

5.1.1 Transformers

Transformers play a fundamental role in electrical power systems by facilitating voltage conversion, ensuring efficient power transmission, and enabling the integration of various energy sources. This section provides an overview of the utility, importance, and key characteristics of transformers in general. Additionally, it explores the specific application of transformers in the context of an offshore wind farm, including the voltage conversion from 0.69 kV to 66 kV for each wind turbine and the subsequent conversion from 66 kV to 220 kV in the marine substation.

Transformers are primarily used for voltage conversion, allowing power to be efficiently transmitted over long distances. They step up or step down the voltage level, depending on the requirements of the electrical system, ensuring compatibility between different components and enabling the integration of diverse energy sources.

Transformers contribute to efficient power transmission by minimizing transmission losses. By operating at higher voltage levels, transformers reduce the current flowing through the transmission lines, resulting in lower resistive losses and improved overall system efficiency.

Transformers help maintain grid stability and ensure high power quality by regulating voltage levels and controlling reactive power flow. They mitigate voltage fluctuations, harmonics, and other disturbances, thus enhancing the reliability and performance of the electrical network.

Within our offshore wind farm, individual wind turbines require transformers to convert the voltage generated by the turbines from the low voltage of approximately 0.69 kV to a higher voltage of 66 kV. These transformers serve the following purposes:

- Voltage Elevation: The wind turbine transformers step up the voltage to facilitate efficient power transmission from the wind turbines to the central collection point, minimizing transmission losses over the long distances between turbines.

- Turbine Interconnection: By converting the voltage to a standardized level of 66 kV, the wind turbine transformers enable the parallel interconnection of multiple turbines, forming a high-voltage array for effective power collection.

In the marine substation of the offshore wind farm, transformers are utilized to further convert the voltage from 66 kV to 220 kV before the power is transmitted via offshore transmission lines. These transformers serve the following purposes:

- Grid Connection: The substation transformers step up the voltage from the 66 kV generated by the wind turbines to a higher voltage of 220 kV, enabling efficient power transfer to the onshore grid through the offshore transmission lines.

- System Integration: The substation transformers facilitate the integration of the offshore wind farm with the onshore power grid by adapting the voltage levels to match the requirements of the grid infrastructure.

Figure 9: Example of transformer

In order to compare transformers, we should focus on some important characteristics of transformers:

- Efficiency: Transformers should exhibit high efficiency to minimize energy losses during voltage conversion. Modern transformers employ advanced materials and designs to achieve optimal efficiency levels, reducing environmental impact and operating costs.

- Reliability: Transformers must demonstrate high reliability to ensure continuous and uninterrupted power supply. Robust insulation systems, effective cooling mechanisms, and rigorous maintenance protocols contribute to transformer reliability.

- Load Flexibility: Transformers should be designed to handle variable loads and accommodate fluctuations in power demand. They should possess appropriate load-carrying capabilities while maintaining voltage stability and power quality.

- Safety: Transformers require comprehensive safety features to protect personnel and equipment. Safety measures include temperature monitoring, fault detection systems, and protective devices to ensure safe operation during abnormal conditions.

3.3.1 Land Substation

An electrical substation is a node for interconnecting circuits, either directly or by transformation to connect networks. Electrical substations are installations responsible for carrying out transformations of voltage, frequency, number of phases or connections of two or more circuits.

To enable connection to the transmission grid, an onshore electrical substation will be installed to receive the energy produced at the offshore wind farm. This substation shall be installed as an annex or in the vicinity of the access point to the transmission grid. The transmission grid which, in this case, is assumed to be the Kook substation located within the municipality of Viveiro in the province of Lugo at a distance of approximately 8 km from the coast. This assumption will be taken for the rest of the technical description.

The presence of the transformer within the land substation is of significant importance in the integration of offshore wind farms. It enables a seamless connection between the offshore and onshore electrical systems and ensures the efficient transmission of renewable energy generated offshore to consumers on land. The transformer plays a vital role in maximizing the potential of offshore wind farms and contributes to the decarbonization of the energy sector.

The land substation with its transformer is a crucial component in the integration of offshore wind farms into the onshore power grid. By facilitating the voltage conversion from 220 kV to 400 kV, the transformer enhances the efficiency, stability, and scalability of the grid. It enables the seamless integration of renewable energy generated offshore, supporting the transition to a cleaner and more sustainable energy future.

Figure 10: Image of Substation

It should be clarified that the substation is used to raise the voltage with the help of a transformer. In the event that no voltage boosting is necessary, a transformer will be built in order to link the installation in question with the substation owned by REE. The substation may be an indoor armoured technology substation of the GIS type or a conventional outdoor AIS type substation.

4. Objective

The calculation in the annex refers to the 66 kV collector network, starting from the inner terminals of the substation or transformer substation entrance cubicles to the inner terminals of the transformer substations. It is considered that the wind turbine switchgear will be supplied by the wind turbine manufacturer.

The total installed capacity of the wind farm is 360 MW.

The studies that will be carried out are:

- Study of the cable design and electrical calculations for interconnections between multiple aerogenerators in an offshore wind farm.
- Develop a design for the interconnections between the aerogenerators and a marine substation.
- Design the offshore connections to a transition joint bay on the shore.
- Design an onshore line from the transition joint bay to a substation on land.
- A report detailing the cable design and electrical calculations for the interconnections between the aerogenerators and the marine substation.

There will be drawings and specifications for:

- the interconnections between the aerogenerators and the marine substation.
- the offshore connections to the transition joint bay on the shore.

- the onshore line from the transition joint bay to the substation on land.

Project Boundaries:

The project will focus on the cable design and electrical calculations for the interconnections between the aerogenerators and the marine substation, as well as the connections to the transition joint bay and the onshore substation.

The project will not include the design of the aerogenerators themselves, the marine substation, or the onshore substation beyond the connection points.

The project will not include construction or installation of the cables or connections but will provide guidance for these activities based on the design and specifications developed.

5. Design Criteria and Input Data

The following criteria has been considered for the calculations and design of the 66 kV collection system:

- Collection system nominal voltage: 66 kV
- Underground lines
- Direct buried cable in trench, trefoil configuration
- Maximum 1 circuit per trench
- Cable reel length 1,000 m
- Fault duration considered: 0.5 seconds.
- Collection system design power factor: 0.95
- Maximum power demand of 360 MVA with power factor 0.95.
- Distribution voltage 66 kV and 220 kV.
- Maximum voltage drops of 5%.
- 3 electrical lines required. System should be able to work in N and N-1 conditions with maximum load demand (loading of cables should not exceed 100%). System should be able to work in N-2 conditions with a limitation of the power demand.
- Maximum permissible loading of cables 105% under N and N-1 operating conditions.
- Soil thermal resistivity:
  - Onshore line 3 Km/W (considered as equivalent design value, including dry-out effect of terrain)
  - Offshore line 2 (2,2 in the cable connecting the array to the marine substation) Km/W (considered as equivalent design value, including dry-out effect of terrain)
  - Transition between offshore and onshore line 2.5 Km/W (considered as equivalent design value, including dry-out effect of terrain)
- Ground temperature (approved values by Neom in follow-up meetings in the absence of site tests)
  - Onshore line 40ºC
  - Offshore line 20ºC
- Cable depth
  - Onshore line laying depth of 1 m for simulations
  - Offshore line laying depth in seabed of 1 m for simulations
- Offshore line spacing between group centres of three-phase circuits 50 m.
- Onshore line spacing between group centres of three-phase circuits 7.5 m.
- The length used for the calculation has been increased by 5% from layout measurements.
- All lines are going to be operating simultaneously.
- Considered conductor cross-sectional areas (all available in the market according to several manufacturers, ABB is our manufacturer):

  - Onshore line 95, 120, 150, 185, 240, 300, 400, 500, 630 mm^2
  - Offshore line 95, 120, 150, 185, 240, 300, 400, 500, 630 mm^2
- Copper conductor material
- Metallic sheath/screen cross-sectional area enough to withstand single-phase to ground fault.
- XLPE insulation and withstand operating temperature of 90ºC.
- Maximum fault clearance time for cable sizing 1 s. For three-phase short-circuit.
- 50 m extra considered for the entrance and exit to the WTG.
- Conditions of the HDD duct for the onshore-offshore transitions and offshore cable:
  - Wet scenario
    - Soil thermal resistivity 1 Km/W
    - Ground temperature 20ºC
    - Duct depth 40m from upper soil layer.
    - Water-filled HDD duct
  - Dry scenario
    - Soil thermal resistivity 2 Km/W
    - Ground temperature 20ºC
    - Duct depth 25m from upper soil layer.
    - Dry HDD duct
  - Seabed scenario (submarine cable laid on top of soil but will end up partially buried due to sea currents):
    - Soil thermal resistivity 1 Km/W
    - Ground temperature 20ºC
    - Laying depth 1m from upper soil layer
    - Directly buried
  - Coast scenario:
    - Soil thermal resistivity 2 Km/W
    - Ground temperature 40ºC
    - Laying depth 1m from upper soil layer
    - Directly buried

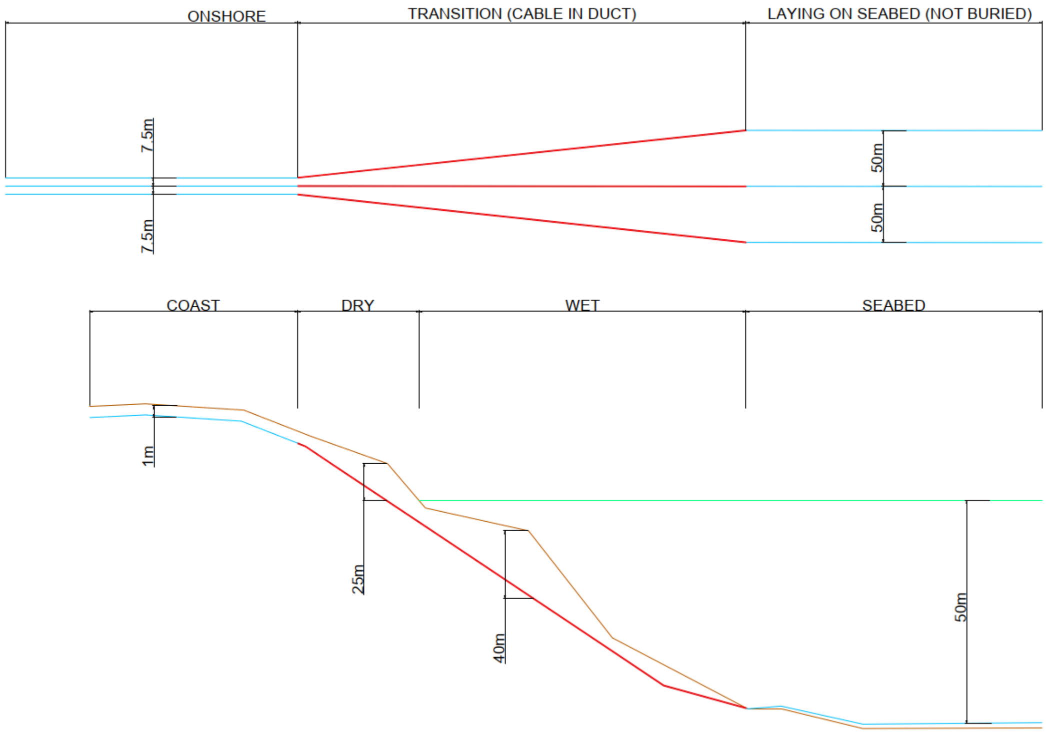
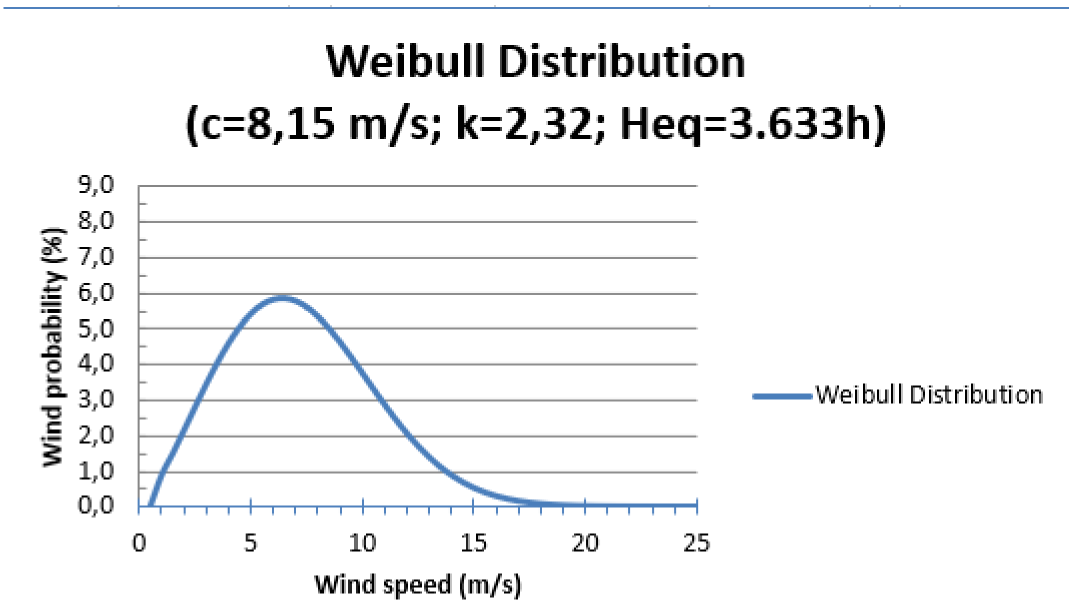


Figure 11: Offshore Scenarios Diagram

As design values the following are considered:

- Maximum voltage drop: 5% for 66 kV collection system.
- Maximum power losses: 3% for 66 kV collection system cables.

The wind data considered (Weibull Parameters) is stated below. Weibull parameters are indicated from two different sources. For the calculation only one of them Is selected (Vortex source):



- Scale factor (c) 8.15 m/s
- Shape factor (k) 2,32

- Annual equivalent hours 3.633 h

Moreover, our intention is to connect the wind farm to the grid, so we are owed to follow some stric specifications. Studying the static simulations in order to accomplish two different behaviours of the WTGs depending on the grid requirements for each moment. It is necessary to define a Station Control that, besides from withstanding a p.u. level, and a power factor at the entrance of the grid, we study the System behaviour when the WTGs are working on inductive and on capacitive mode.

The grid is connected to other generation and transmission systems, so it could happen that the reactive power has to be compensated, sometimes feeding sometimes absorbing. In resume, our wind farm should be able to maintain the specifications working on both methods.

5.1 DigSilent Design

DigSilent Power Factory is a widely recognized and extensively used software package specifically designed for power system analysis. It offers a range of powerful features and functionalities that enable engineers and researchers to model, simulate, and analyse various aspects of electrical power systems. The software's versatility and robustness make it an invaluable tool for conducting comprehensive studies and assessments related to power system planning, operation, and optimization.

The utility of the DigSilent Power Factory software lies in its ability to handle complex power system models and simulate various operational scenarios with high precision and efficiency. It allows users to accurately represent and analyse components such as generators, transformers, transmission lines, and distribution networks. Additionally, it incorporates advanced algorithms for load flow analysis, short circuit calculations, dynamic simulations, stability analysis, and harmonic studies.

Additionally, it is worth noting that the Spanish electrical grid authorities have stringent requirements and specifications for approving wind farm projects. To ensure compliance with these specifications, the use of advanced software tools is mandatory. DigSilent Power Factory is one of the three approved software options recommended by the Spanish electrical grid authorities.

By utilizing DigSilent Power Factory, I can confidently demonstrate that my project aligns with the grid specifications and meets the necessary criteria for approval. The software's capabilities enable me to accurately model and analyze the proposed wind farm, taking into account various factors such as grid integration, power flow, voltage stability, and fault analysis. This ensures that my calculations and simulations align with the requirements set by the Spanish electrical grid, ultimately increasing the likelihood of project acceptance and successful integration into the national power system.

5.1.1 System Model

Before entering into the calculations, it is important to recognize every component of the system and the code that is referenced to. Anyway, we will remember important components once they appear.

Here are some components that should be interesting to take into account for next sections:

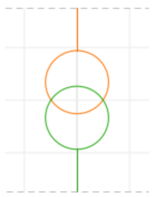


Figure 12: Transformer

Figure 13: Wind Turbine Generator (WTG)

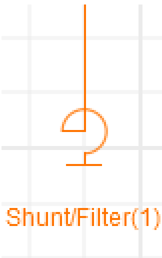


Figure 14: Shunt of Reactive Power RL

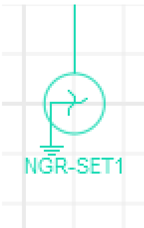


Figure 15: Grounding

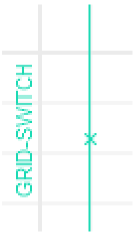
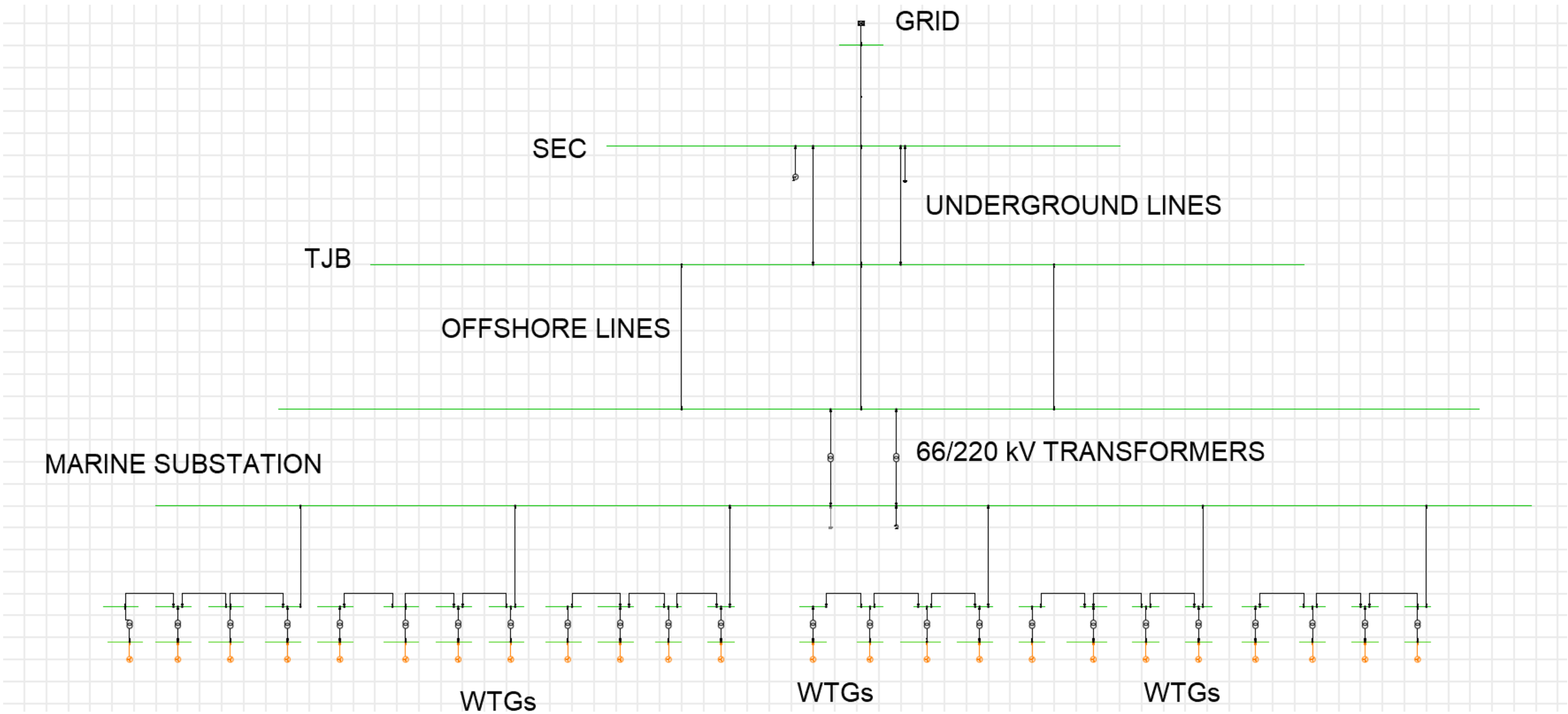


Figure 16: Grid Switch

The following diagram corresponds to our system:


GRID
SEC
UNDERGROUND LINES
TJB
OFFSHORE LINES
66/220 kV TRANSFORMERS
MARINE SUBSTATION
WTGs
WTGs
WTGs

Furthermore, it is necessary to clarify the nomenclature used for each busbar/terminal in order to understand the results below:

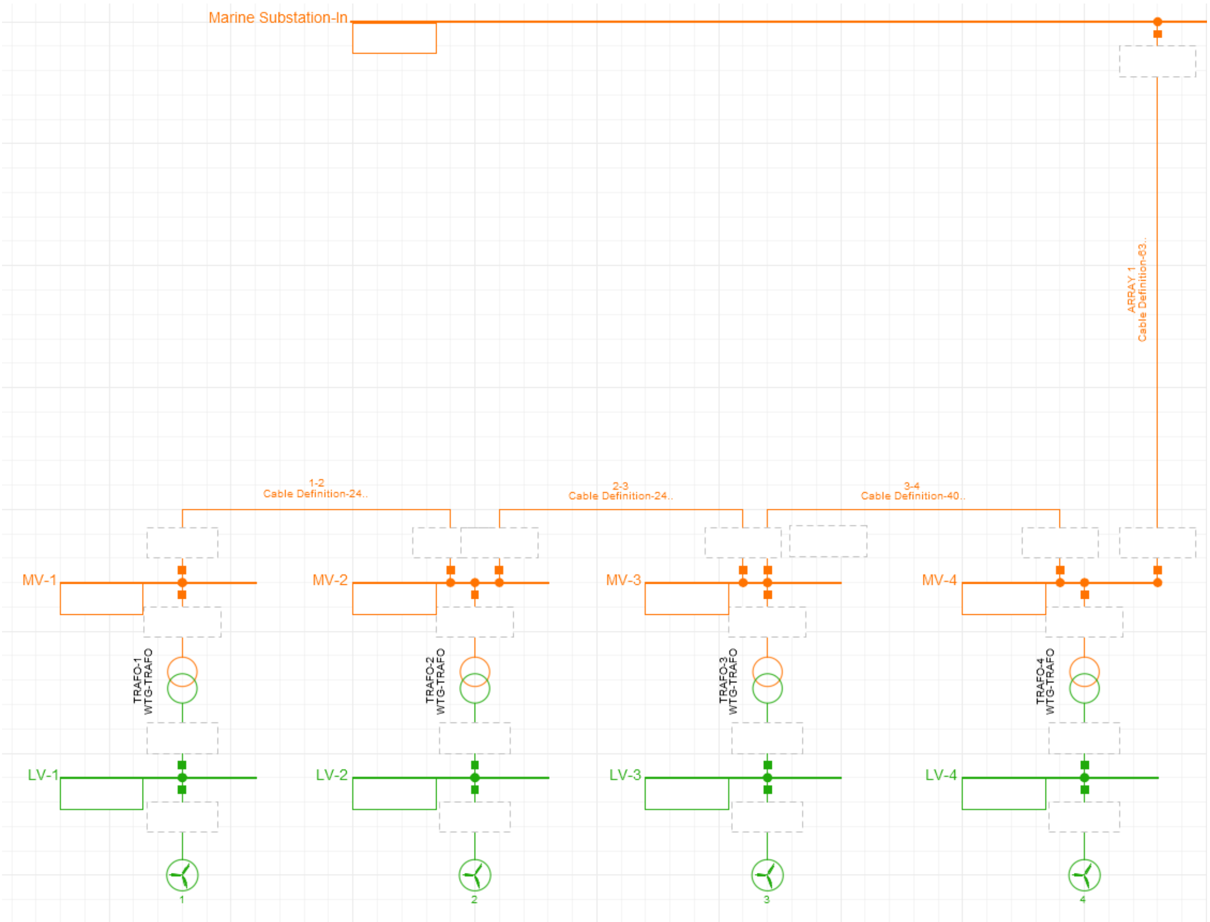


Figure 17: Diagram of the collection system

- LV-: Represents the Low Voltage side that belongs to the transformer of the wind turbine generator, its voltage is 0,69 kV. Each wind turbine has one of these.
- MV-: Represents the Medium Voltage (actually it is High Voltage) side that belongs to the transformer of the wind turbine generator, its voltage is 66 kV. Each wind turbine has one of these.
- Marine Substation-In: This busbar is the point where all the arrays are connected with.

6. Calculations

6.1 General Description

A total of 6 arrays have been planned to evacuate the energy generated by the WTGs, which means that all the 24 WTG units will be connected to one marine substation.

The following tables show the distribution of WTGs to the intermediate marine substation:

Array Nº	WTGs	Nº of WTGs	Unit Power (MW)	Total Power (MW)
1	**1-2-3-4**	4	15	60
2	**5-6-7-8**	4	15	60
3	**9-10-11-12**	4	15	60
4	**13-14-15-16**	4	15	60
5	**17-18-19-20**	4	15	60
6	**21-22-23-24**	4	15	60

Table 18: WTG Connection Distribution

6.2 Cable Ampacity

In this chapter the 66 kV and 220 kV system is studied with the selected cable for the final power generation scenario of 360 MW. Both the onshore and offshore cables are studied to evaluate their ampacity. The onshore cable has been calculated in two different ways to compare results, while the offshore cable has been evaluated only through software due to lack of manufacturer data for the specified cable:

- Onshore cable:
    - Ampacity through correction factors
    - Ampacity through software simulation (DigSILENT)
- Offshore cable:
    - Ampacity through software simulation (DigSILENT)

6.2.1 Offshore cable 66 kV

For the current rating of the offshore cable, the study has been developed using DigSILENT PowerFactory 2023 simulations. The current rating is performed in Seabed scenario. Installation conditions at marine substation arrivals are assumed to be the same for all the arrays and covered by the scenario below.

These are the conditions for the interconnection cables between the wind turbines:

Ambient temperature	20,	degC
Dry soil thermal resistivity	2,	K.m/W
Medium mean temperature	45,	degC
Solar radiation intensity	1,	W/m^2
Critical temperature of soil	25,	degC

Figure 19: Ambient Conditions (seabed)

The conditions for the interconnection cables between the wind turbines and the marine substation change in one parameter as shown below:

Dry soil thermal resistivity	2,2	K.m/W

Figure 20: Ambient Conditions (last WT-MS)

The tables below will show the results for each WTG behaviour (inductive and capacitive) as we explained in chapter 5. Design Criteria:

Capacitive:

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
1	1-2	240	480	138	28,78
	2-3	240	480	276	57,57
	3-4	400	590	415	70,30
	4-MS	630	715	555	77,56

Figure 21: Loading Array nº1.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
2	5-6	240	480	138	28,78
	6-7	240	480	276	57,58
	7-8	400	590	415	70,31
	8-MS	630	715	554	77,53

Figure 22: Loading Array nº2.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
3	9-10	240	480	138	28,80
	10-11	240	480	277	57,61
	11-12	400	590	415	70,35
	12-MS	630	715	554	77,46

Figure 23: Loading Array nº3.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
4	13-14	240	480	138	28,80
	14-15	240	480	277	57,61
	15-16	400	590	415	70,35
	16-MS	630	715	554	77,46

Figure 24: Loading Array nº4.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
5	17-18	240	480	138	28,78
	18-19	240	480	276	57,58
	19-20	400	590	415	70,31
	20-MS	630	715	554	77,53

Figure 25: Loading Array nº5.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
6	21-22	240	480	138	28,78
	22-23	240	480	276	57,57
	23-24	400	590	415	70,30
	24-MS	630	715	555	77,56

Figure 26: Loading Array nº6.

*MS is the reference for Marine Substation.

Inductive:

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
1	1-2	240	480	137	29,565
	2-3	240	480	273	59,143
	3-4	400	590	410	80,263
	4-MS	630	715	548	77,468

Figure 27: Loading Array nº1.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
2	5-6	240	480	136	29,572
	6-7	240	480	273	59,158
	7-8	400	590	410	80,283
	8-MS	630	715	548	77,422

Figure 28: Loading Array nº2.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
3	9-10	240	480	137	29,585
	10-11	240	480	273	59,182
	11-12	400	590	410	80,317
	12-MS	630	715	548	77,362

Figure 29: Loading Array nº3.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
4	13-14	240	480	137	29,585
	14-15	240	480	273	59,182
	15-16	400	590	410	80,317
	16-MS	630	715	548	77,362

Figure 30: Loading Array nº4.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
5	17-18	240	480	136	29,572
	18-19	240	480	273	59,158
	19-20	400	590	410	80,283
	20-MS	630	715	548	77,422

Figure 31: Loading Array nº5.

Array nº	Section	S (mm2)	Izc (A)	I (A)	Loading (%)
6	21-22	240	480	137	29,565
	22-23	240	480	273	59,143
	23-24	400	590	410	80,263
	24-MS	630	715	548	77,468

Figure 32: Loading Array nº6.

In conclusion, ampacity calculations for offshore transmission lines of 66 kV are crucial for ensuring the safe and efficient operation of electrical systems in offshore wind farms. These calculations consider the unique behaviors of wind turbines, including both capacitive and inductive characteristics, to accurately determine the current flow and assess its impact on the line's thermal performance. The use of correction factors, including derating factors obtained through software simulations, allows for a comprehensive assessment of the transmission line's thermal characteristics.

6.2.2 Offshore cable 220 kV

For the current rating of the offshore cable, the study has been developed using DigSILENT PowerFactory 2023 simulations. The current rating is performed in 4 different scenarios (Coast, Dry, Wet, Seabed). Installation conditions at island and mainland arrivals are assumed to be the same and covered by the scenarios below.

This line sections present all of the following scenarios, despite this information, we will modelate the system in PowerFactory with the worst possible scenario, that will let us be sure that our installations are safe for the equipment and people.

Installation conditions

The calculation will be carried out in 4 different scenarios. The procedure consists of creating the following scenarios, we will obtain a new ampacity (Iz´) different from the one on the catalogue. Then we calculate the Derating Factor (Iz´/Iz) an apply it or we can change directly the nominal current instead.

- Coast scenario:
  - Soil thermal resistivity 2 Km/W
  - Ground temperature 40ºC
  - Laying depth 1m from upper soil layer

    - Directly buried
- Dry scenario:
    - Soil thermal resistivity 2 Km/W
    - Ground temperature 25ºC
    - Duct depth 25m from upper soil layer
    - Dry HDD plastic duct
- Wet scenario:
    - Soil thermal resistivity 1 Km/W
    - Ground temperature 25ºC
    - Duct depth 40m from upper soil layer
    - Water-filled HDD plastic duct
- Seabed scenario (submarine cable laid on top of soil but will end up partially buried due to sea currents):
    - Soil thermal resistivity 1 Km/W
    - Ground temperature 25ºC
    - Laying depth 1m from upper soil layer
    - Directly buried

<u>Cable Modelling</u>

The 1x3x500mm^2 Cu cable has been created introducing in the software the following information.

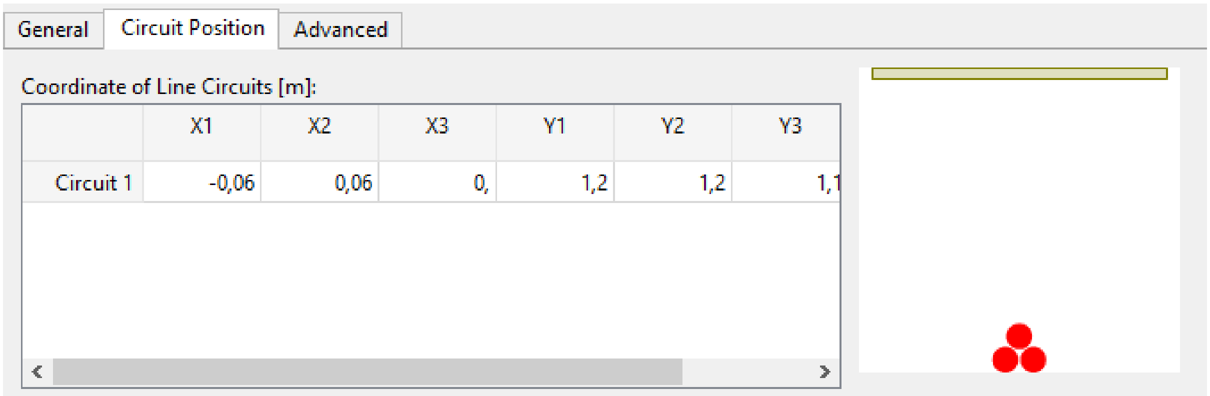


Figure 33. Cable Modelling in DigSILENT PowerFactory 2022 (Conductor coordinates). Own source

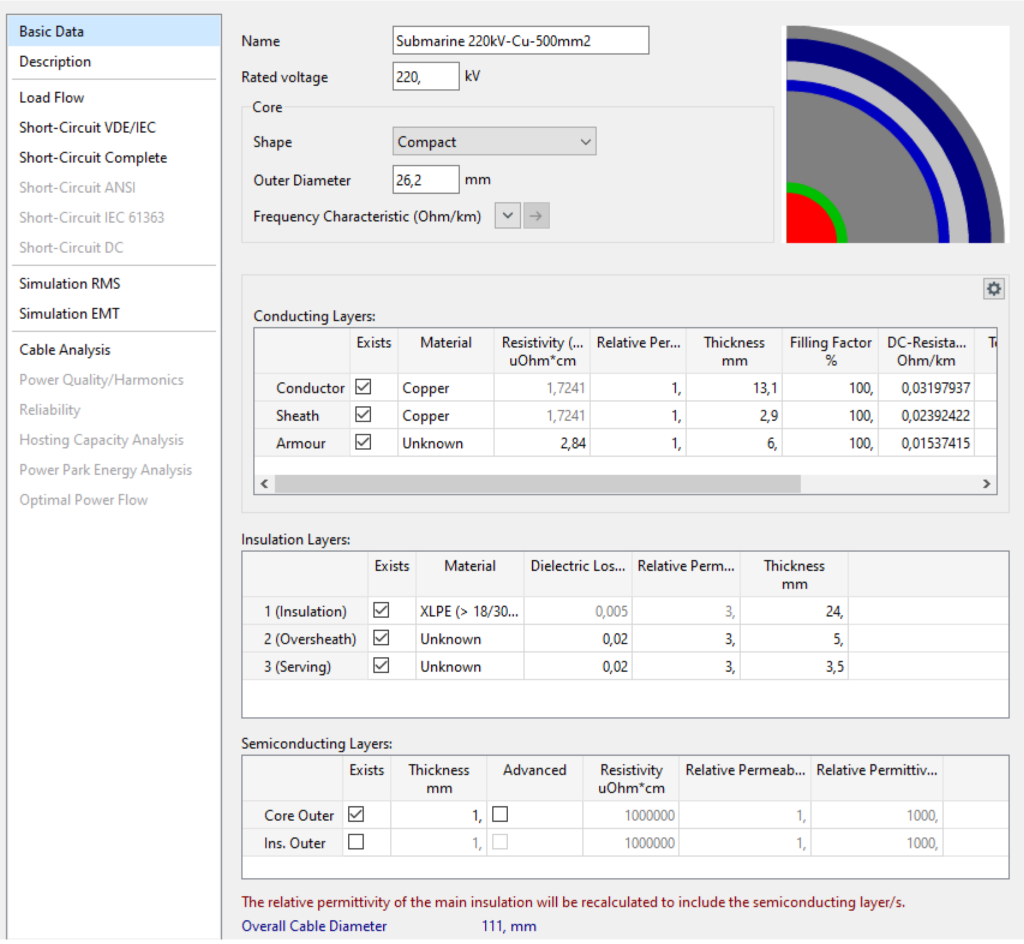


Figure 34. Cable Modelling in DigSILENT PowerFactory 2022 (General). Own source

__Wet scenario__

- Soil thermal resistivity 1 Km/W
- Ground temperature 25ºC
- Duct depth 20m from upper soil layer
- Water-filled HDD plastic duct

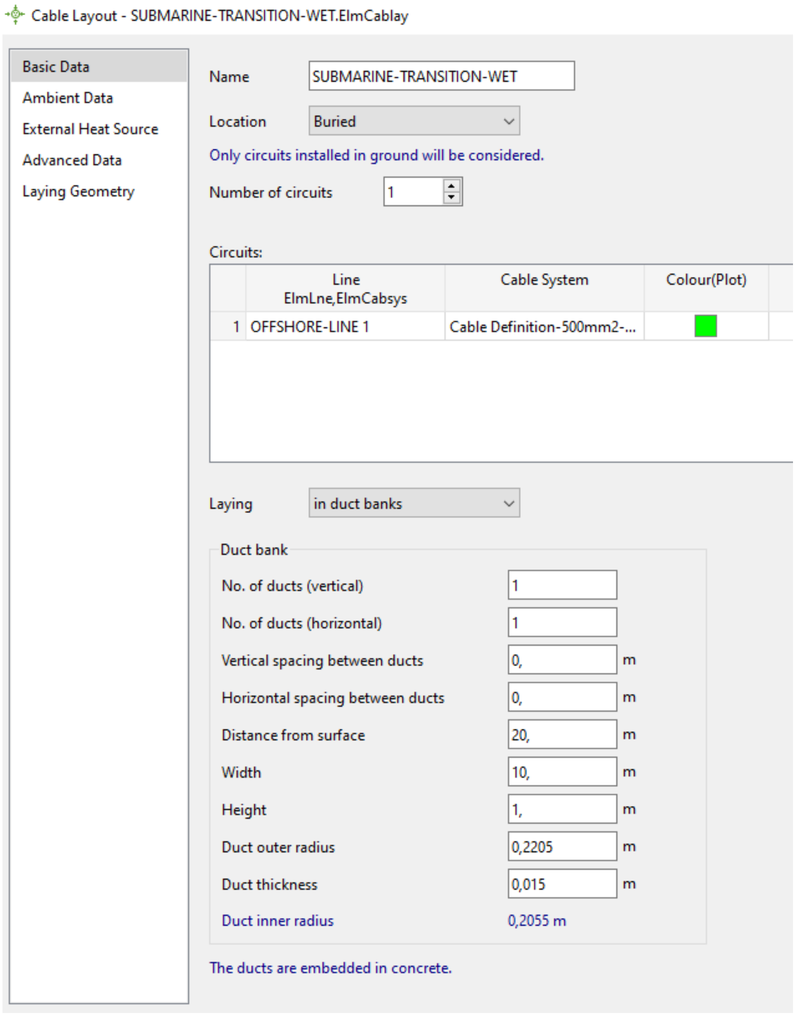


Figure 35. Installation conditions in wet scenario (Basic data). Own source

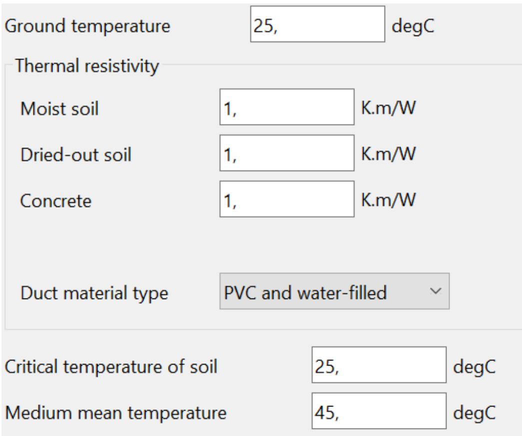


Figure 36. Installation conditions in wet scenario (Ambient data). Own source

- <u>*Dry scenario*</u>
  - Soil thermal resistivity 2 Km/W
  - Ground temperature 25ºC
  - Duct depth 1m from upper soil layer
  - Dry HDD plastic duct

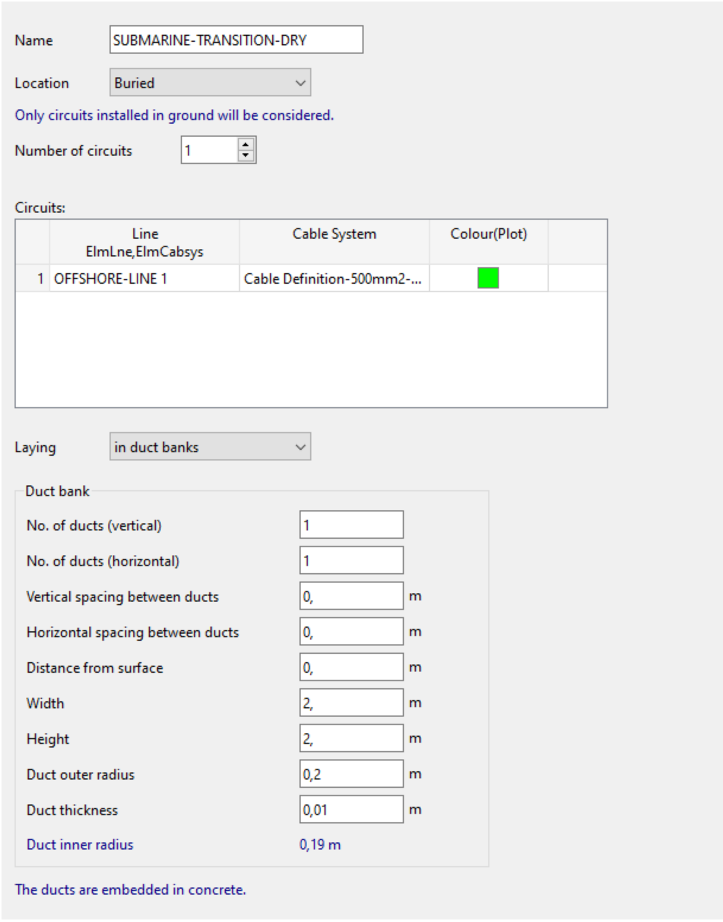


Figure 37. Installation conditions in dry scenario (Basic data). Own source

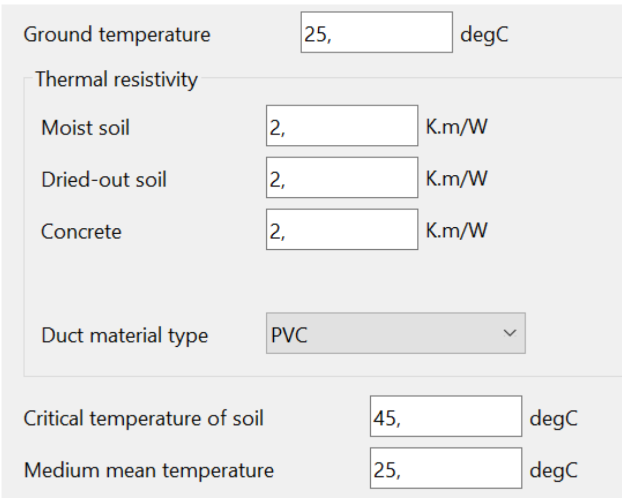


Figure 38. Installation conditions in dry scenario (Ambient data). Own source

- *Seabed scenario*
    - Soil thermal resistivity 1 Km/W
    - Ground temperature 25ºC
    - Laying depth 1m from upper soil layer
    - Directly buried

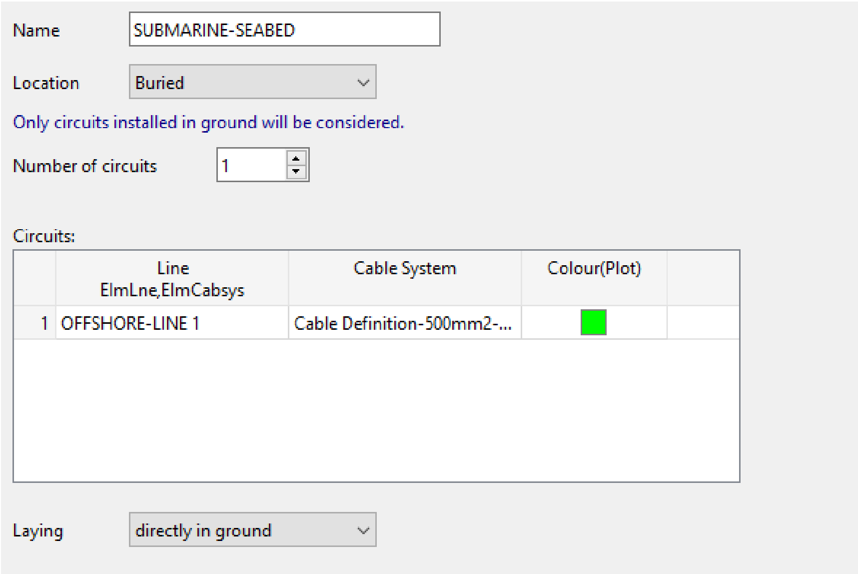


Figure 39: Installation conditions in seabed scenario (Basic data). Own source

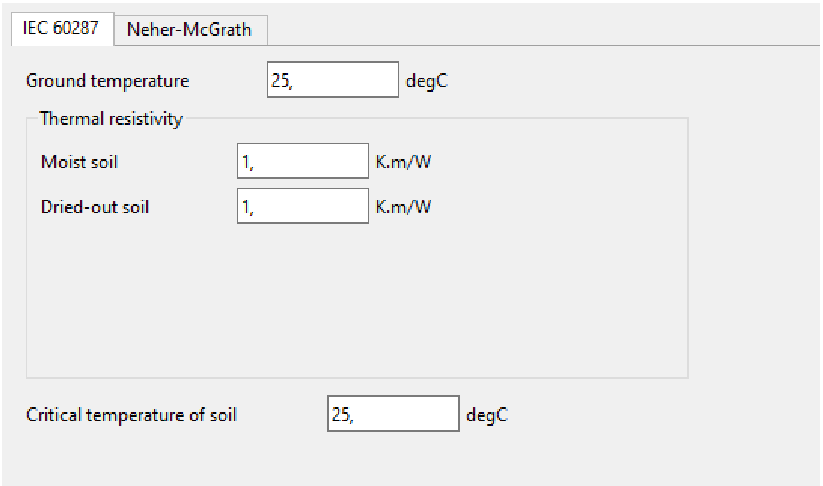


Figure 40: Installation conditions in seabed scenario (Ambient data). Own source

- <u>*Mainland coast scenario*</u>
    - Soil thermal resistivity 2 Km/W
    - Ground temperature 40ºC
    - Laying depth 1m from upper soil layer
    - Directly buried

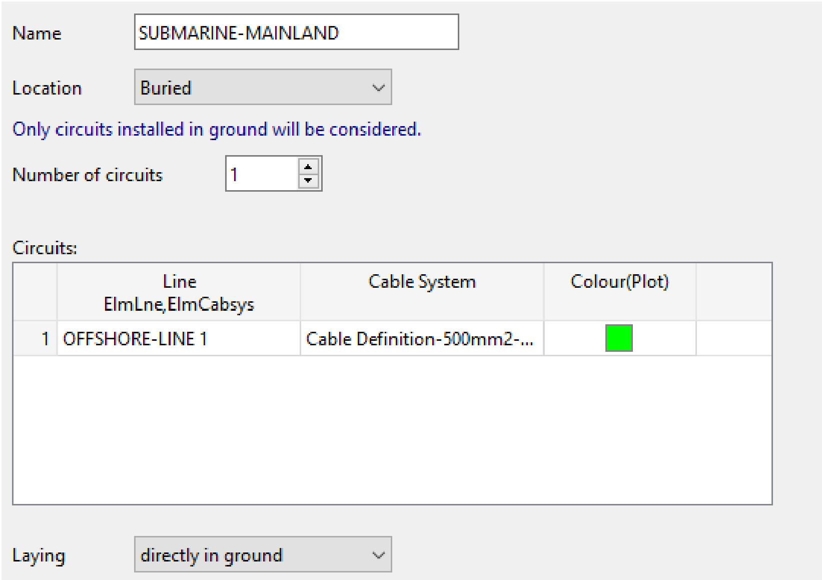


Figure 41: Installation conditions in mainland coast scenario (Basic data). Own source

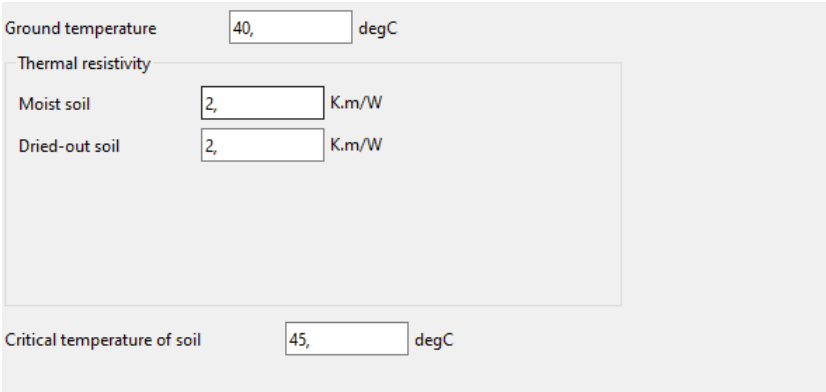


Figure 42: Installation conditions in mainland coast scenario (Ambient data). Own source

For the calculation it is considered that the metallic sheath is grounded at both ends of cables (both onshore and offshore cable. Therefore, groundings will be carried out at each transition joint bay, each WT and for marine substation.

But we should notice that not all the scenarios have the same layout, for instance, both transitions wet and dry are very short sections (maximum of 500 m), they take place in the entrance of the TJB (dry transition) and in the exit of the marine substation (wet transition). The rest of the length should be calculate for both remaining scenarios (Seabed and Mainland).

Capacitive:

DigSILENT PowerFactory 2022 Simulation									
Maximum estimated Current (A)		950 A							
Selected cable		1x3x500mm2 Cu							
Scenarios	Conditions Operation	**Wet**		**Dry**		**Seabed**		**Mainland-Coast**	
		Loading (%)	**Current (A)**	**Loading (%)**	**Current (A)**	**Loading (%)**	**Current (A)**	**Loading (%)**	**Current (A)**
	N	66,78	324	49,94	324	40,66	324	68,03	324

	N-1	92,64	487	74,87	487	60,97	487	101,8	487

Inductive:

As we did before, we do the same calculations for the Inductive behaviour of the Wind Turbines Generators:

DigSILENT PowerFactory 2022 Simulation									
Maximum estimated Current (A)		950 A							
Selected cable		1x3x500mm2 Cu							
Scenarios	Conditions Operation	Wet		Dry		Seabed		Mainland-Coast	
		Loading (%)	Current (A)	Loading (%)	Current (A)	Loading (%)	Current (A)	Loading (%)	Current (A)
	N	67,832	327	57,335	327	41,28	327	68,23	327
	N-1	93,93	491	85,672	491	61,73	491	102,3	491

There is fact remarkable to tell about, when the wet transition takes place in the N-1 scenario we can appreciate that the load level overpasses the 105%, it is an acceptable result, because this transition has been calculated for 10 km, when actually it does not reach the 100 m.

Therefore, the cable ampacity is valid for the installation according to this procedure. It is important to remember that it is acceptable a loading % above 100%, up to 105%, due to the fluctuations of the wind production, the cables are not going to be operating all the time at this loading, so we can exceed that 5% extra, what helps Scenario N-1.

6.2.3 Onshore cable 220 kV

We should clarify that we will have the following section, the characteristics of them are the following:

- First section: Underground Line from Transition Joint Bay to Land Substation. Maximum length 9 km.

The manufacturers provide us with onshore cable characteristics for 220 kV, so we are able to make the calculations applying the correction factors, otherwise we only have the DigSilent software calculations. We will do both to compare the accuracy of the different methods.

6.2.3.1 Ampacity calculation through application of correction factors

For the current rating of the onshore cable, the study has been developed using two methods of calculation (correction factor stated by the manufacturer and DigSILENT PowerFactory 2022 simulations). This chapter presents the results obtained using correction factors.

For the cable model, a national manufacturer has been selected with the following cable characteristics and ampacities. The selected cables are copper conductors with XLPE insulation following IEC-60502-2 regulation with copper wires for the metallic sheath. The onshore cables considered are single-core cable of 220 kV:

Rating factor for ground temperature

Table 7

Rating factor for laying depth	
Laying depth, m	Rating factor
0.50	1.10
0.70	1.05
0.90	1.01
1.00	1.00
1.20	0.98
1.50	0.95

Table 8

Rating factor for ground temperature								
Conductor temperature, °C	Ground temperature, °C							
	10	15	20	25	30	35	40	45
90	1.07	1.04	1	0.96	0.93	0.89	0.84	0.80
65	1.11	1.05	1	0.94	0.88	0.82	[illegible]	0.66

Table 9

Rating factor for ground thermal resistivity							
Thermal resistivity, Km/W	0.7	1.0	1.2	1.5	2.0	2.5	3.0
Rating factor	1.14	1.00	0.93	0.84	0.74	0.67	0.61

Table 7 Laying depth correction factors. Source: ABB XLPE Land Cable Systems Catalogue

Table 8 Soil temperature correction factors. Source: ABB XLPE Land Cable Systems Catalogue

Table 9 Soil Thermal resistivity correction factors. Source: ABB XLPE Land Cable Systems Catalogue

Table 4

Rated voltage 110-500 kV, copper conductor – 95 mm² screen									Segmental conductor for 1200 mm² or higher							
Cross section con-ductor	Cables in Ground								Cables in Air							
	Flat formation ●●●				Trefoil formation				Flat formation ●●●				Trefoil formation			
	Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends		Cross bonded		Both ends	
mm²	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C	65°C	90°C
300	530	640	440	535	505	610	480	580	600	805	500	685	525	710	500	685
400	600	720	485	595	575	690	540	650	680	915	565	775	605	820	575	785
500	685	825	530	650	655	785	600	730	790	1060	625	860	695	945	650	895
630	780	940	570	705	740	890	660	810	[illegible]	1235	685	950	800	1085	735	1010
800	870	1055	610	755	825	995	720	885	1045	1415	745	1040	905	1235	815	1130
1000	960	1165	645	800	900	1095	770	950	1175	1590	800	1125	1005	1380	895	1245
1200	1115	1345	690	860	1060	1280	855	1055	1395	1880	880	1240	1210	1650	1025	1425
1400	1205	1455	715	890	1145	1385	895	1110	1530	2065	920	1300	1320	1800	1090	1525
1600	1280	1550	735	920	1215	1470	930	1155	1655	2235	960	1355	1420	1940	1150	1615
2000	1410	1705	765	955	1320	1605	980	1220	1845	2500	1000	1425	1565	2145	1230	1740
2500	1540	1875	795	1000	1445	1755	1025	1285	2095	2845	1065	1515	1750	2410	1330	1890

The ampacities of the table above are indicated for an ambient ground temperature of 20ºC, 1 m laying depth and a soil thermal resistivity of 1 Km/W. Since these conditions are not the ones of the project, the "Current Carrying Capacity" is converted to the appropriate conditions".

The distance referred to in the table above is the distance between cable edges.

The correction factors applied to convert the ampacity to the project's conditions are the following:

Iz (A) Conductor ampacity for project's installation conditions

$$I_z = I_{ad} \cdot C_d \cdot C_t \cdot C_p \cdot C_r$$

Where:

- Iad (A) – Maximum allowable current through conductor
- Cd (p.u.) – Grouping factor
- Ct (p.u.) – Soil temperature factor
- Cp (p.u.) – Installation depth factor

- Cr (p.u.) – Soil thermal resistivity factor

Grouping factor (Cd)

The selected factors are the following:

- C_d = 1.00 – 1 circuit per trench

Soil temperature factor (Ct)

The cable carrying capacity is indicated by the selected manufacturer for a 20 ºC soil temperature. Therefore, for a ground temperature of 40ºC, the soil temperature factor used is Ct = 0.84.

Installation depth factor (Cp)

The cable depth considered is 1 m to the bottom part of the cables. The manufacturer conditions indicate the current carrying capacity of the cables for an installation depth of 1 m. Therefore, the installation depth factor is considered as Cp = 1.

Soil thermal resistivity factor (Cr)

The soil thermal resistivity has been estimated as 3 Km/W (includes the dry-out effect of the terrain). Therefore, the soil thermal resistivity factor Cr = 0.61.

Izc (A) Corrected conductor's ampacity for project's installation conditions

The calculation for the loading of each line is indicated below:

$$Izc_{\%} = \frac{I}{Iz * ct * cr * cp * cd} * 100$$

Where:

- Izc% (%): Loading of cable.
- I (A): Current at nominal power through each line.
- Iz (A): Allowable current through conductor.
- ct (p.u.) – Soil temperature factor
- cr (p.u.) – Soil thermal resistivity factor
- cp (p.u.) – Installation depth factor
- cd (p.u.) – Grouping factor

The total correction factors are included in the following result tables.

Applying the coefficients described above, the maximum ampacity and the cable loading for the sections described at the beginning of this chapter are the following:

Table 1 Onshore Correction Factors Cable Design 66kVC. Source: Own elaboration

Correction factors calculation		
Underground Cable	Selected cable	3x1x630mm2 Cu
	Manufacturer Ampacity (A)	810
	Correction factor	0.5124

	Corrected Ampacity (A)	415,044
	Maximum Current Expected Inductive	476
	Maximum Current Expected Capacitive	491
	Loading (%) Ind.	114,7
	Loading (%) Ind.	118,3

As it does not fit the ampacity criteria through software simulation and pointing out we wish the 630mm2 cable in order to limit the costs, it would be crucial studying the ampacity of the underground lines through the software.

As seen in the table above, the values obtained applying the correction factors are over the 100% loading. Therefore, the cable ampacity is not valid for this installation according to this procedure.

6.2.3.2 Ampacity calculation through software simulation

In addition, and to obtain more detailed results of the cable performance in the installation, a simulation with DigSILENT PowerFactory 2022 has been carried out.

Calculations are performed considering a copper sheath.

Cable Modelling

The 3x1x630mm^2 Cu cable has been created introducing in the software the following information.

Table 28

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross-section of screen	Outer diameter of cable	Cable weight (Al-conductor)	Cable weight (Cu-conductor)	Capacitance	Charging current per phase at 50 Hz	Inductance (trefoil)	Inductance (flat)	Surge impedance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km	mH/km	Ω
Single-core cables, nominal voltage 220 kV (U_m = 245 kV)												
500	26.2	24.0	77.6	185	94.0	8.3	11.4	0.14	5.8	0.44	0.60	40.2
630	29.8	23.0	79.2	185	95.8	8.8	12.7	0.16	6.4	0.42	0.58	36.4
800	33.7	23.0	83.1	185	100.3	9.7	14.7	0.17	6.9	0.41	0.56	33.8
1000	37.9	23.0	87.3	185	104.9	10.7	16.9	0.19	7.4	0.39	0.54	31.3
1200	42.8	23.0	93.8	185	111.8	12.0	19.4	0.21	8.2	0.38	0.52	28.8
1400	46.4	23.0	97.4	185	115.6	12.9	21.6	0.22	8.7	0.37	0.51	27.3
1600	49.8	23.0	100.8	185	119.2	13.8	23.7	0.23	9.1	0.36	0.50	26.0
2000	54.4	23.0	105.4	185	124.2	15.4	27.8	0.24	9.7	0.35	0.49	24.5
2500	62.0	23.0	113.0	185	132.4	17.6	33.1	0.27	10.6	0.34	0.47	22.3

Table 28 Onshore cable characteristics 220 kV. Source: ABB XLPE Land Cable Systems Catalogue

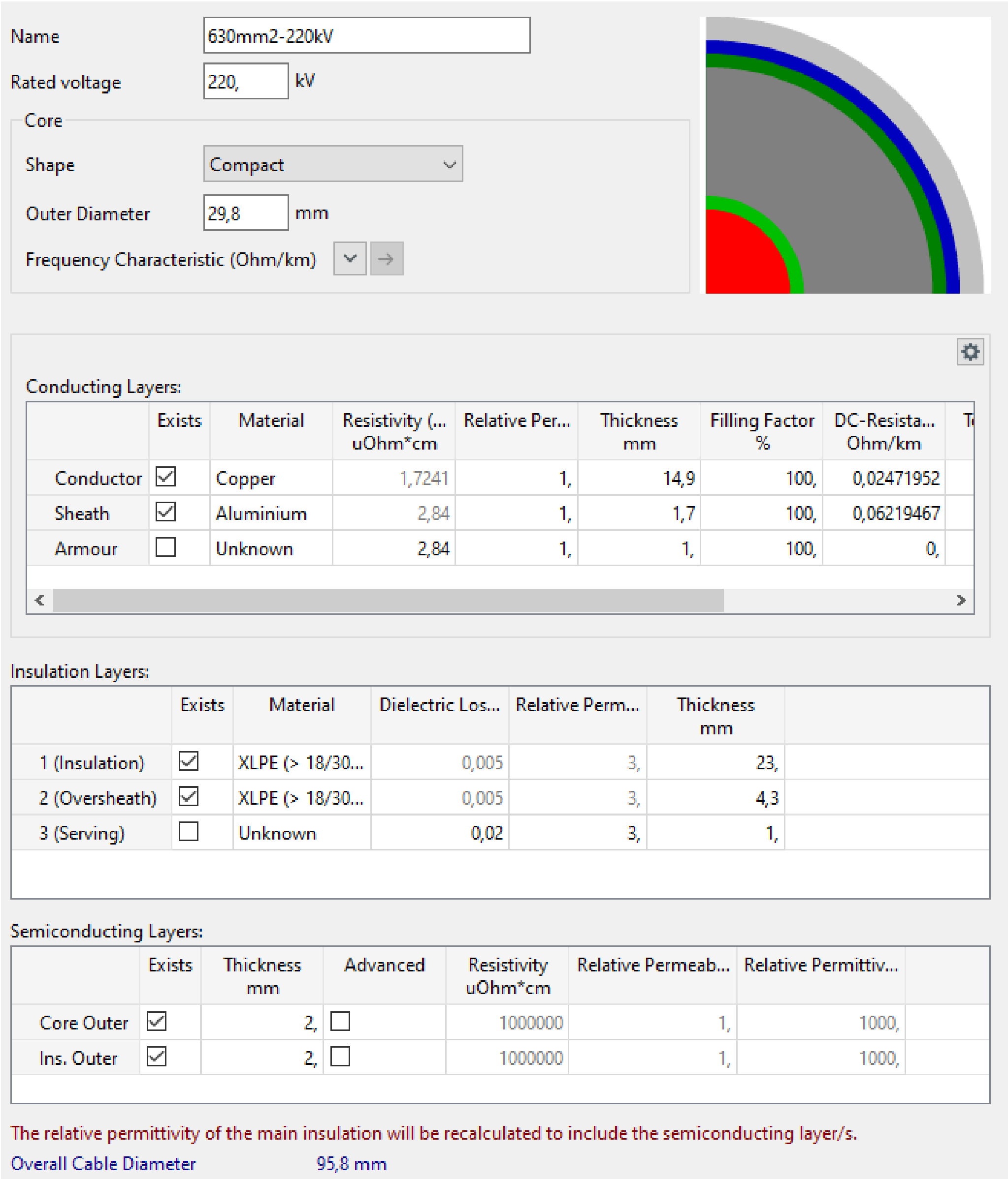


Figure 43. Cable Modelling in DigSILENT PowerFactory 2022. Own source

<u>Installation conditions</u>

The installation conditions have been obtained from the following design criteria:

- Ground temperature: 40ºC
- Thermal resistivity: 3 Km/W
- Installation depth: 1 m

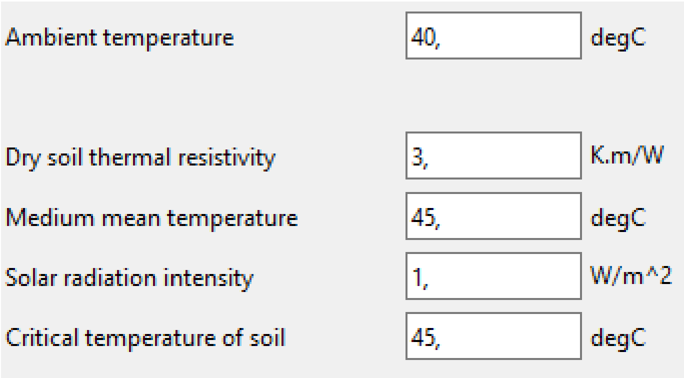


Figure 44. Installation conditions in DigSILENT PowerFactory 2022 (Ground temperature a thermal resistivity). Own source

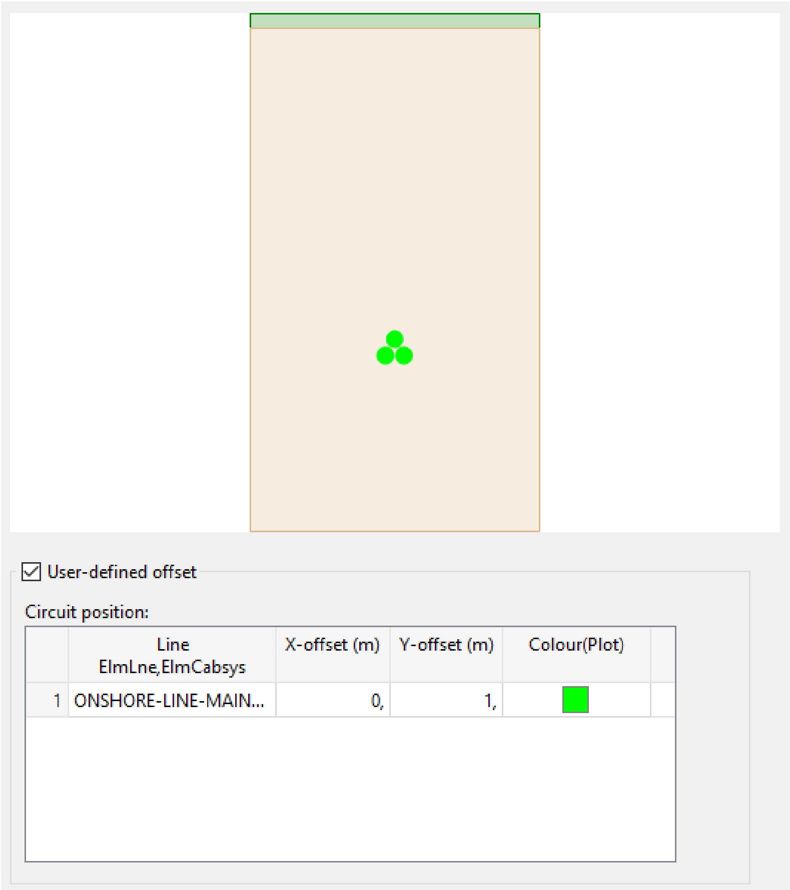


Figure 45. Installation conditions in DigSILENT PowerFactory 2022 (Installation Depth). Own source

The results obtained are summarised in the following table:

DigSILENT PowerFactory 2022 Simulation		
Maximum estimated Current (A)		491
Underground Cable (6.1 km)	Selected cable	3x1x630mm2 Cu
	Calculated Ampacity (A)	725
	Loading (%)	67,75

As seen above, the values obtained using the DigSILENT PowerFactory 2022 Simulation are below the 100% loading. Therefore, the cable ampacity is valid for this installation according to this procedure.

6.3 Drop Voltage Calculation

The equations for the voltage drop calculations are cited below:

$$dUT = \left(\frac{\sqrt{3}}{1000}\right) * (I * L) * \left(\frac{1}{10 * U}\right) * (Rt * \cos\varphi + X * sen\varphi)$$

Where:

- dU(%) T: Percentage voltage drop
- I (A): Current through each line
- L (m): Line length
- U (kV): Nominal voltage
- Rt (ohm/km): Resistance of each line at maximum operating temperature Tf
- X (ohm/km): Cable reactance
- cosφ: Power factor

$$UTi = dUTi + dUT_{i-1}$$

Where:

- U(%) Ti: Cumulative percentage voltage drop.
- dU(%) Ti: Percentage voltage drop of studied line
- dU(%) Ti-1: Percentage voltage drop of previous line.

In our project that has been modelated with the software DigSilent (Power Factory) we are able to induce our system to work in a specific operating point, the grid has several rules in order to get our Wind Farm connected, here in Spain it is controlled the reactive power, power factor as well as drop voltage (p.u. level). Working with this software allow us to define these parameters named. Nevertheless, the Spinnaker Wind Farm will enter to the grid with 1.00 p.u. but these does not necessarily means that in other points we do not have any drop voltage, so let´s focus on each busbar the level of p.u. that we are working on.

Now we are prepared to understand the values obtained:

During the transmission of electrical power over a transmission line, a voltage drop occurs due to the resistance and reactance of the line. The voltage drop is proportional to the current flowing through the line and its impedance. To compensate this drop and maintain proper voltage levels at the point of load, step-up transformers are used.

The step-up transformer increases the voltage before transmission through the transmission line. This counteracts some of the voltage drop and ensures that the voltage at the point of load is sufficient to supply the electrical devices adequately.

The obtained results for the capacitive behaviour are the following:

Maximum voltage of all terminals p.u.	Minimum voltage of all terminals p.u.	Maximum Loading %
1,000	0,968	85,6

The obtained results for the inductive behaviour are the following:

Maximum voltage of all terminals p.u.	Minimum voltage of all terminals p.u.	Maximum Loading %
1,011	0,993	82,2

The maximum voltage drop experimented by the system does not overpass the established limit of 5%. Both behaviours are considered valid for drop voltage criteria.

The whole system levels of p.u. in each terminal are shown in the calculation annex with load flow calculations. The maximum loading showed is referred to the load of transformers and wind turbines.

6.4 Power Losses Calculation

The common equation used for the power losses calculation in each cable is the following:

$$\text{Pj T} = 3 * (Rt) * \left(\frac{L}{1000}\right) * I^2$$

Where:

- Pj (W)T: Power losses in each line at cable maximum operating temperature.
- Rt (ohm/km): Resistance of each line at maximum operating temperature Tf.
- L (m): Line length.
- I (A): Current flowing through line.

The summary of results after the study of power losses exposes the following information:

For capacitive behaviour:

Generators, Nominal Active Power MW	Losses, Active Power MW
360,0	4,4

Losses, Active Power (load) MW
3,3

Losses, Active Power (no load) MW
1,1

External Networks, Active Power MW
-355,6

In the other hand, here are the results for inductive behaviour:

Generators, Nominal Active Power MW	Losses, Active Power MW
360,0	3,9

Losses, Active Power (load) MW
2,8

Losses, Active Power (no load) MW
1,1

External Networks, Active Power MW
-356,1

6.5 Load Flow

In the context of a project, the load flow calculation section holds significant importance in the design of electrical lines. The calculation of load flow enables to assess the steady-state behavior of the power system and make informed decisions for line design. By analyzing power flow and voltage levels, this section provides crucial insights into voltage regulation, identification of potential bottlenecks, and determination of appropriate line ratings, conductor sizes, and reactive power compensation requirements. Accurate load flow calculations empower designers to optimize the efficiency, reliability, and safety of the electrical lines within the project, ensuring seamless integration and operation within the power system.

For the design of the collection system then steady state is studied considering 100% of the production capacity of the WTGs and a power factor of 0.95 in the collection system MV cables of 66 kV. The WTG transformer considered has a nominal power of 20 MVA and it's considered losses are the following:

- No-load losses at nominal voltage: 5 kW
- Load losses at nominal voltage: 100 kW

The following equations describe the recurrent procedure followed for the power losses, loading of cables and voltage drops obtained in the collection system.

- **Q (kVAr) – Reactive Power**

$$Q = \frac{P}{cos\varphi} \cdot \sin\varphi$$

Where:

- P (kW) – Active power
- cosφ – Power factor, estimated as 0,95 for the calculations.

- Ip (A) – Active Current

$$I_p = \frac{P}{(\sqrt{3} \cdot U)}$$

Where:

- P (kW) – Active power
- U (kV) – Voltage

Then:

- **Iq (A) – Reactive Current**

$$\mathbf{I_q = \frac{Q}{(\sqrt{3} \cdot U)}}$$

Where:

- Q (kVAr) – Reactive power
- U (kV) – Voltage

Rt(Ω/km) – Resistance at conductor's operating temperature

Resistance has been considered at the maximum operating temperature with DigSILENT software for every calculation.

The calculations have been carried out for a 100% generation, power factor of 0.95 at each turbine and an operating temperature of the conductors equal to its maximum temperature (90ºC).

6.6 Short-Circuit Analysis

7.5.1 Basis

The data used for the calculations is the following:

General data

- Fault clearance time: 0.5 seconds.
- Neutral grounding reactor at 66 kV side. Limitation of the single-phase to ground fault at 3 kA.
- Maximum three-phase and single phase to ground short-circuit at 220 kV bars of SEC substation:
  - 100 kA
  - X/R ratio of 10

Network description

The evacuation of the generated Energy is carried out as follows:

- The WTGs are connected to the intermediate 0,69/66 kV transformers.

- The 66 kV offshore lines are all single circuit.
- In the 66/220 kV intermediate marine substation the voltage is increase from 66 kV to 220 kV, from where three 220 kV lines exit carrying the energy to the 220/4000 kV SEC substation.
- 220 kV side of SEC substation is considered as the POI.

7.5.2 Results

Three-phase short-circuit.

The following has been considered:

- The WTG contribution is approximately 2.5 times its rated current.
- With the 3-phase short circuit results the selected cable sizes and conductors are verified and checked, as well as the required withstand short-circuit value for the WTG switchgears.
- Fault clearance time: 0.5 seconds.

The results with the maximum thermal and dynamic short-circuit currents obtained at the WTG MV switchgears and at each line section are included in the annex of this document. According to the results, the maximum short-circuit current experienced in the MV WTG switchgears does not exceed 60kA. The minimum short-circuit capacity of the switchgears is as follows:

For capacitive behaviour:

3-phase short-circuit capacity in switchgears			
Maximum Ik”III according	Minimum Ik”III capacity required (kA) – 1 s.	Maximum Ip according to results (kA)	Minimum Ip capacity required (kA)
<60 kA	60kA	<90 kA	90kA

For inductive behaviour:

3-phase short-circuit capacity in switchgears			
Maximum Ik”III according	Minimum Ik”III capacity required (kA) – 1 s.	Maximum Ip according to results (kA)	Minimum Ip capacity required (kA)
<50 kA	50kA	<80 kA	80kA

Where:

- Ik”III (kA): 3-phase short-circuit permanent current.
- Ip (kA): 3-phase short-circuit peak current.

The verification of withstand of the selected cables to the short-circuit currents experienced in the system is shown below. The recommendation is to design the protection equipment focusing on the most critical scenario, in this case the capacitive behaviour.

$$I_{AD}^2 \cdot t = K^2 \cdot S^2 \cdot \ln(\frac{\theta_f + \beta}{\theta_i + \beta})$$

Where:

- IAD (A): Adiabatic short-circuit current.
- t (s): Short-circuit duration
- K (A·s1/2/mm2): Conductor material constant
- S (mm2): Cross-sectional area of the conductor
- θf (ºC): Final temperature
- θi (ºC): Initial temperature
- β: Inverse of the temperature variation coefficient of the resistance

To obtain the value of K the following equation is used:

$$K = \sqrt{\frac{\sigma_c \cdot (\beta + 20) \cdot 10^{-12}}{\rho_{20}}}$$

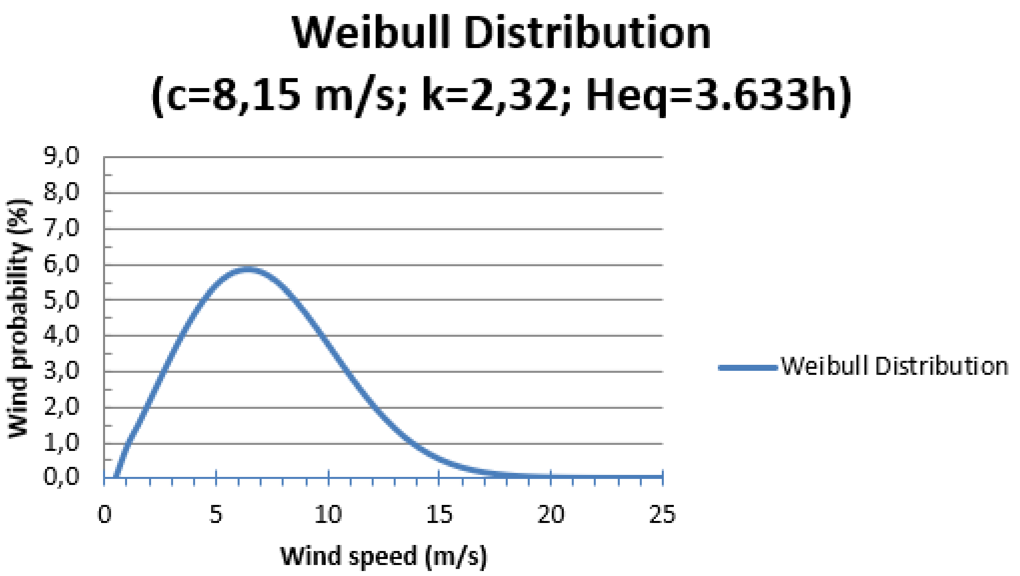
According to the results, the maximum short-circuits current experienced through the conductor, as well as the minimum short-circuit capacity of the selected cables and conductors is less than the withstand values of each cable:

For both behaviours we obtained these values:

3-phase short-circuit capacity in cables and conductors		
Cable Size	Maximum Ik"l (kA)	Withstand Ik"l (kA)
240	28	32,5 (0,5s)
400	30,5	54 (0,5s)
500 (MS-TJB)	7,695	67,56 (0,5s)
630 (offshore)	28	84,9 (0,5s)
630 (UDG)	12,149	72,85 (0,5s)

6.7 Energy Losses

The Weibull distribution considered is defined by the following figure:



The wind data considered (Weibull Parameters) is stated below:

- Scale factor (c) 8.15 m/s
- Shape factor (k) 2,32
- Annual equivalent hours 3,633 h

The energy losses have been calculated for a maximum operating temperature of the cable/conductor. Which means that the results are on the safety side and the real energy losses will be lower.

Energy Losses Summary		
Energy Generated	**Total Losses (MWh)**	**Anual Energy Loss TºC ideal (MWh) (%)**
1307033,76 MWh	**6188,32 MWh**	**0,47**

6.8 Reactive Power

The reactive power reserves of synchronous generators in transmission networks are used to control the voltages at specific nodes in the system and/or to control the reactive power exchange with neighbouring network zones. In *PowerFactory*'s load flow calculation, the voltage regulator of the generators has a voltage setpoint which can be set manually or from an Automatic Station Controller. This Automatic Station Controller combines several sources of reactive power to control the voltage at a given bus. In this case the relative contribution of each reactive power source is defined in the Station Controller dialog.

To carry out the reactive study, a "Station Control" controller is defined to control the reactive power of all the wind turbines at the same time. Then, carrying out the load flow we see how the reactive power injected by each turbine is modified to achieve the power factor defined in the controller.

- WIND FARM WORKING AT LOW LOAD:

At no load (no active power generation), the reactive character of the wind farm will be the result of the capacitive generated by the underground cables and overhead lines, and the little inductive consumed by the wind turbine and substation transformers. This usually results in a capacitive character.

- WIND FARM WORKING AT NOMINAL LOAD:

As active power generation increases to rated power, underground cables and overhead lines as well as wind turbine and substation transformers consume more inductive power. The reactive power control of the wind turbines will try to compensate for reactive power at the PCC level to meet the reactive requirements at the PCC.

5.1.1 Design criteria

The following criteria has been considered for the calculations:

- Reactive power limitations at each WTG according to considered WTG model.
- Maximum reactive power of the WTG 7 MVAr.

5.1.1 Point of interconnection (POI) requirements

The POI requirements for a single generator unit (SGU) and Powe Park Modules (PPM) are the following:

Considering the POI requirements and the considered reactive power capability of the WTGs the following scenario is studied:

- Maximum active power output per WTG.
- Voltage at POI 1.0 pu.
- Calculation for 0.95 capacitive and inductive power factor.

It is considered that the wind farm is cable of working at the reactive power requirements below 20% of the active power due to the considered individual WTG reactive power capability. Therefore, only the scenario at 100% generation is included in this report.

6.9 Earthing Design

6.9.1 Introduction

Earthing design is a crucial aspect of any engineering project involving electrical systems, as it ensures the safety of personnel and equipment by providing a low impedance path for fault currents to flow. In this chapter, the earthing design of a transition joint bay between offshore and onshore cables is defined.

The transition joint bay is a critical component of the project, as it serves as a connection point between the offshore and onshore cables. Due to the high fault current levels expected, it is essential to ensure that the earthing design is adequate to protect against potential faults and reduce the risk of damage to equipment and harm to personnel.

In this context, the earthing design should consider factors such as step voltages and grounding resistance. Touch voltages are only studied on top of the manhole covers given that there are no additional possible touch points expected in the area, in other words, there will not be any metallic element with any possibility for people to get in contact with it other than the manhole covers.

There are three different components that should be considered for earthing design:

- Wind Turbines: The earthing system for wind turbines plays a crucial role in safeguarding personnel, equipment, and the environment from electrical hazards. It involves establishing a low-resistance path to the ground to effectively dissipate fault currents and minimize the risk of electrical shock or damage. This system considers factors such as the wind turbine structure, electrical equipment, lightning protection, and grounding methods. By implementing a robust and well-designed earthing system, we can ensure the reliable operation of the wind turbines and mitigate potential electrical disturbances or failures.

- Marine Substation: The marine substation serves as a vital hub for power collection and transmission within the offshore wind farm. To guarantee its operational integrity and safety, an appropriate earthing system must be implemented. This system establishes a low-resistance path for fault currents and provides effective grounding for electrical equipment, such as transformers, switchgear, and control systems. By properly grounding the marine substation, we can minimize the risk of electrical hazards, optimize system performance, and facilitate efficient fault detection and isolation.

- Transition Joint Bay: The transition joint bay, buried in the shore, serves as a crucial connection point between the offshore and onshore electrical systems. An effective earthing system for this component is essential to ensure the reliable transfer of power and maintain system stability. This system involves the proper grounding of cables, connectors, and associated equipment, considering factors such as soil resistivity, fault currents, and electromagnetic interference. By establishing a robust earthing system for the transition joint bay, we can minimize power losses, mitigate electromagnetic interference, and ensure a secure and efficient energy transfer between the offshore wind farm and the onshore grid.

The grounding calculations have been performed with the software XGSLab. The grounding study covers the individual resistance of each WT, the split factor, the current injected in the WTGs when a default takes place in the collection system. Then, it is supposed a 3kA default in the Transition Joint Bay, where the Touch & Step Voltages have been studied.

6.9.2 Design criteria

The following design criteria parameters have been considered for the design:

- Fault Current: 3 kA will be considered.
- Fault Duration: 1s will be considered.
- Earthing rods: 2 m length steel rods with copper covering, 16 mm of diameter.
- Horizontal electrodes: Made of copper, section of 120 mm^2 bare cable.
- Soil Resistivity: 500 Ωm is estimated. This value is not obtained through soil measurements but approved by Neom for the design given the lack of information from the site.
- Earthing impedance: Must be lower than 5 Ω as a whole system considering the copper conductors inside the trench.

A grounding conductor shall be installed between transition joint bay and power generation plant interconnection both grounding systems.

For the calculations of step voltages and its assessment of compliance the limits are defined according to IEC Std 80-2013:

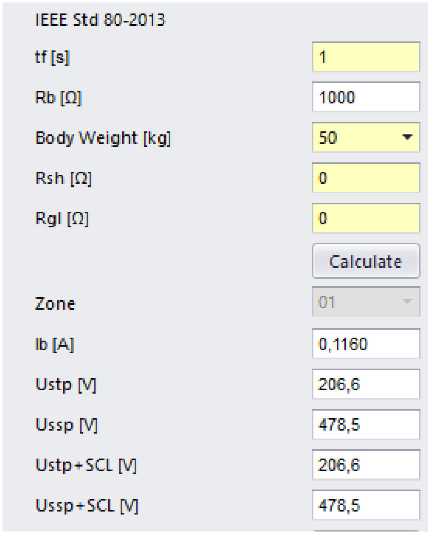


Figure 46. Step and touch voltage limits calculations according to IEC Std 80-2013. Source Own elaboration

- Fault clearance time: 1s is considered.
- Body resistance: 1000Ω per norm definition.
- Body weight: 50 kg.
- Shoe resistance 0 Ω.
- Glove resistance 0 Ω.

The figure below shows the calculation process followed in the software for the step and touch voltage limits calculation:

The maximum step voltage allowed is 478.5 V, while the maximum touch voltage allowed is 206.6 V.

No resistance from shoes or gloves is considered in order to study the worst-case scenario and stay on the safety side.

For the earthing calculation of the wind turbines generators, it is necessary to design the individual grounding system (represented in the figure below). Normally, we should carry out quite number of tests to measure the resistivity of the ground zone, the ideal performance should be one test per wind turbine, but in this project, we assume the same resistivity to sum up and in fact, the same grounding system for all the wind turbines.

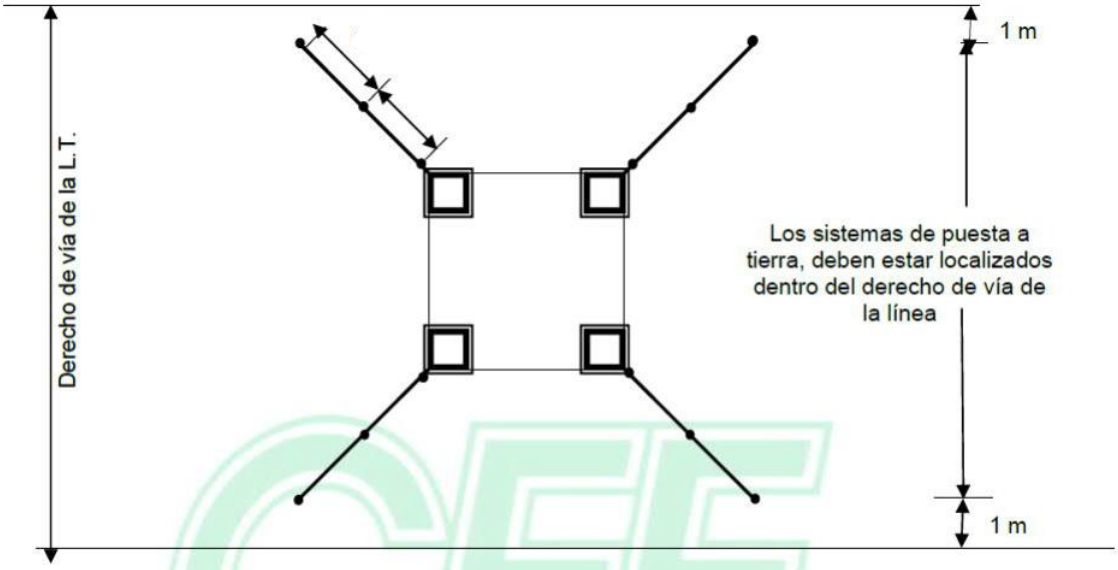


Figure 47. Grounding system for wind turbines. Source Own elaboration

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CHAPTER

2

Technical documents

ELECTRICAL CALCULATIONS ANNEX

July 2023

Índice

1. Drop Voltage & Load Flow Results

1.1. Capacitive Behaviour

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-1	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-1	2-Winding Transformer	15,0	-5,7	0,934	13,862	83,3
1	Static Generator	15,0	-5,7	0,934	13,862	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-2	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-2	2-Winding Transformer	15,0	-5,7	0,934	13,865	83,3
2	Static Generator	15,0	-5,7	0,934	13,865	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-3	0,7	0,969	0,7	7,4

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-3	2-Winding Transformer	15,0	-5,7	0,934	13,870	83,3
3	Static Generator	15,0	-5,7	0,934	13,870	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-4	0,7	0,968	0,7	7,3

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-4	2-Winding Transformer	15,0	-5,7	0,934	13,876	83,3
4	Static Generator	15,0	-5,7	0,934	13,876	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-5	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-5	2-Winding Transformer	15,0	-5,7	0,934	13,863	83,3
5	Static Generator	15,0	-5,7	0,934	13,863	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-6	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-6	2-Winding Transformer	15,0	-5,7	0,934	13,866	83,3
6	Static Generator	15,0	-5,7	0,934	13,866	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-7	0,7	0,968	0,7	7,4

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-7	2-Winding Transformer	15,0	-5,7	0,934	13,871	83,3
7	Static Generator	15,0	-5,7	0,934	13,871	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-8	0,7	0,968	0,7	7,3

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-8	2-Winding Transformer	15,0	-5,7	0,934	13,877	83,4
8	Static Generator	15,0	-5,7	0,934	13,877	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-9	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-9	2-Winding Transformer	15,0	-5,7	0,934	13,865	83,3
9	Static Generator	15,0	-5,7	0,934	13,865	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-10	0,7	0,969	0,7	7,4

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-10	2-Winding Transformer	15,0	-5,7	0,934	13,867	83,3
10	Static Generator	15,0	-5,7	0,934	13,867	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-11	0,7	0,968	0,7	7,4

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-11	2-Winding Transformer	15,0	-5,7	0,934	13,873	83,3
11	Static Generator	15,0	-5,7	0,934	13,873	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-12	0,7	0,968	0,7	7,3

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-12	2-Winding Transformer	15,0	-5,7	0,934	13,879	83,4
12	Static Generator	15,0	-5,7	0,934	13,879	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-13	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-13	2-Winding Transformer	15,0	-5,7	0,934	13,865	83,3
13	Static Generator	15,0	-5,7	0,934	13,865	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-14	0,7	0,969	0,7	7,4

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-14	2-Winding Transformer	15,0	-5,7	0,934	13,867	83,3
14	Static Generator	15,0	-5,7	0,934	13,867	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-15	0,7	0,968	0,7	7,4

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-15	2-Winding Transformer	15,0	-5,7	0,934	13,873	83,3
15	Static Generator	15,0	-5,7	0,934	13,873	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-16	0,7	0,968	0,7	7,3

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-16	2-Winding Transformer	15,0	-5,7	0,934	13,879	83,4
	16	Static Generator	15,0	-5,7	0,934	13,879	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-17	0,7	0,969	0,7	7,5

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-17	2-Winding Transformer	15,0	-5,7	0,934	13,863	83,3
	17	Static Generator	15,0	-5,7	0,934	13,863	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-18	0,7	0,969	0,7	7,5

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-18	2-Winding Transformer	15,0	-5,7	0,934	13,866	83,3
	18	Static Generator	15,0	-5,7	0,934	13,866	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-19	0,7	0,968	0,7	7,4

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-19	2-Winding Transformer	15,0	-5,7	0,934	13,871	83,3
	19	Static Generator	15,0	-5,7	0,934	13,871	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-20	0,7	0,968	0,7	7,3

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-20	2-Winding Transformer	15,0	-5,7	0,934	13,877	83,4
20	Static Generator	15,0	-5,7	0,934	13,877	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-21	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-21	2-Winding Transformer	15,0	-5,7	0,934	13,862	83,3
21	Static Generator	15,0	-5,7	0,934	13,862	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-22	0,7	0,969	0,7	7,5

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-22	2-Winding Transformer	15,0	-5,7	0,934	13,865	83,3
22	Static Generator	15,0	-5,7	0,934	13,865	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-23	0,7	0,969	0,7	7,4

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-23	2-Winding Transformer	15,0	-5,7	0,934	13,870	83,3
23	Static Generator	15,0	-5,7	0,934	13,870	85,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-24	0,7	0,968	0,7	7,3

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-24	2-Winding Transformer	15,0	-5,7	0,934	13,876	83,3
24	Static Generator	15,0	-5,7	0,934	13,876	85,6

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-1	66,0		0,992		65,5		3,9	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	TRAFO-1	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3	
	1-2	Line	14,9	-7,1	0,904	0,146	31,5	

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-2	66,0		0,992		65,5		3,8	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	TRAFO-2	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3	
	1-2	Line	-14,9	6,6	-0,914	0,144	31,5	
	2-3	Line	29,9	-13,7	0,909	0,290	62,7	

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-3	66,0		0,992	65,5		3,8	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-3	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	2-3	Line	-29,9	13,3	-0,913	0,288	62,7
	3-4	Line	44,8	-20,4	0,910	0,434	85,0

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-4	66,0		0,991	65,4		3,7	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-4	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	3-4	Line	-44,8	20,0	-0,913	0,432	85,0
	ARRAY 1	Line	59,7	-27,0	0,911	0,578	81,7

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-5	66,0		0,992	65,5		3,9	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-5	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	5-6	Line	14,9	-7,1	0,904	0,146	31,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-6	66,0	0,992	65,5	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-6	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
6-7	Line	29,9	-13,7	0,909	0,290	62,7
5-6	Line	-14,9	6,6	-0,914	0,144	31,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-7	66,0	0,992	65,5	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-7	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
6-7	Line	-29,9	13,3	-0,913	0,288	62,7
8-9	Line	44,8	-20,4	0,910	0,434	85,0

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-8	66,0	0,991	65,4	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-8	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,4
8-9	Line	-44,8	20,0	-0,913	0,433	85,0
ARRAY 2	Line	59,7	-27,0	0,911	0,578	81,7

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-9	66,0	0,992	65,5	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-9	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
9-10	Line	14,9	-7,1	0,904	0,146	31,5

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-10	66,0		0,992	65,5		3,8	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-10	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	9-10	Line	-14,9	6,6	-0,914	0,144	31,5
	10-11	Line	29,9	-13,7	0,909	0,290	62,8

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-11	66,0		0,992	65,5		3,7	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-11	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	11-12	Line	44,8	-20,4	0,910	0,434	85,0
	10-11	Line	-29,9	13,3	-0,913	0,288	62,8

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-12	66,0		0,991	65,4		3,6	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-12	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,4
	11-12	Line	-44,8	20,0	-0,913	0,433	85,0
	ARRAY 3	Line	59,7	-27,0	0,911	0,578	81,7

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-13	66,0		0,992	65,5		3,8	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-13	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	13-14	Line	14,9	-7,1	0,904	0,146	31,5

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-14	66,0		0,992	65,5		3,8	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-14	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	13-14	Line	-14,9	6,6	-0,914	0,144	31,5
	14-15	Line	29,9	-13,7	0,909	0,290	62,8

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-15	66,0		0,992	65,5		3,7	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-15	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
	15-16	Line	44,8	-20,4	0,910	0,434	85,0

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-16	66,0	0,991	65,4	3,6

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-16	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,4
15-16	Line	-44,8	20,0	-0,913	0,433	85,0
ARRAY 4	Line	59,7	-27,0	0,911	0,578	81,7

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-17	66,0	0,992	65,5	3,9

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-17	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
17-18	Line	14,9	-7,1	0,904	0,146	31,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-18	66,0	0,992	65,5	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-18	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
18-19	Line	29,9	-13,7	0,909	0,290	62,7
17-18	Line	-14,9	6,6	-0,914	0,144	31,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-19	66,0	0,992	65,5	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-19	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
18-19	Line	-29,9	13,3	-0,913	0,288	62,7
19-20	Line	44,8	-20,4	0,910	0,434	85,0

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-20	66,0	0,991	65,4	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-20	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,4
19-20	Line	-44,8	20,0	-0,913	0,433	85,0
ARRAY 5	Line	59,7	-27,0	0,911	0,578	81,7

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-21	66,0	0,992	65,5	3,9

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-21	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
21-22	Line	14,9	-7,1	0,904	0,146	31,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-22	66,0	0,992	65,5	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-22	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
22-23	Line	29,9	-13,7	0,909	0,290	62,7
21-22	Line	-14,9	6,6	-0,914	0,144	31,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-23	66,0	0,992	65,5	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-23	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
22-23	Line	-29,9	13,3	-0,913	0,288	62,7

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	23-24	Line	44,8	-20,4	0,910	0,434	85,0

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-24	66,0	0,991	65,4	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-24	2-Winding Transformer	-14,9	7,1	-0,904	0,146	83,3
23-24	Line	-44,8	20,0	-0,913	0,432	85,0
ARRAY 6	Line	59,7	-27,0	0,911	0,578	81,7

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
Marine Substation-In	66,0	0,991	65,4	3,6

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
ARRAY 6	Line	-59,6	26,3	-0,915	0,575	81,7
Shunt/Filter	Shunt/Filter	0,0	0,0	1,000	0,000	
ARRAY 4	Line	-59,7	26,6	-0,913	0,577	81,7
TRAFO-SET1(2)	2-Winding Transformer	178,9	-103,8	0,865	1,826	48,8
Shunt/Filter(1)	Shunt/Filter	-0,0	49,1	-0,000	0,433	
ARRAY 1	Line	-59,6	26,3	-0,915	0,575	81,7
ARRAY 5	Line	-59,6	26,4	-0,915	0,576	81,7
ARRAY 2	Line	-59,6	26,4	-0,915	0,576	81,7
TRAFO-SET1(1)	2-Winding Transformer	178,9	-103,8	0,865	1,826	48,8
ARRAY 3	Line	-59,7	26,6	-0,913	0,577	81,7

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
Marine Substation-Out	220,0		1,000	220,1		0,4	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-SET1(1)	2-Winding Transformer	-178,7	119,3	-0,832	0,564	48,8
	OFFSHORE-LINE 2	Line	119,1	-79,5	0,832	0,376	47,3
	OFFSHORE-LINE 3	Line	119,1	-79,5	0,832	0,376	47,3
	OFFSHORE-LINE 1	Line	119,1	-79,5	0,832	0,376	47,3
	TRAFO-SET1(2)	2-Winding Transformer	-178,7	119,3	-0,832	0,564	48,8

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
TJB	220,0		1,000	220,1		0,2	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	UDG-1	Line	178,2	-81,5	0,909	0,514	70,8
	UDG2	Line	178,2	-81,5	0,909	0,514	70,8
	OFFSHORE-LINE 1	Line	-118,8	54,3	-0,909	0,343	47,3
	OFFSHORE-LINE 2	Line	-118,8	54,3	-0,909	0,343	47,3
	OFFSHORE-LINE 3	Line	-118,8	54,3	-0,909	0,343	47,3

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
SEC	220,0		1,000	220,0		0,0	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	GRID-SWITCH	Breaker/Switch	355,6	-116,9	0,950	0,982	0,0
	CB-SET1	Shunt/Filter	0,0	0,0	1,000	0,000	
	NGR-SET1	NEC/NER	0,0	0,0	1,000	0,000	
	UDG-1	Line	-177,8	58,4	-0,950	0,491	70,8
	UDG2	Line	-177,8	58,4	-0,950	0,491	70,8

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
SUBESTACION	220,0		1,000	220,0		0,0	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	External Grid	External Grid	-355,6	116,9	-0,950	0,982	
	GRID-SWITCH	Breaker/Switch	-355,6	116,9	-0,950	0,982	0,0

For the capacitive behaviour, the following results had been obtained:

1.2. Inductive Behaviour

For the inductive behaviour, the following results had been obtained:

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
LV-1	0,7		1,011	0,7		7,1	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-1	2-Winding Transformer	15,0	3,5	0,974	12,758	76,2
	1	Static Generator	15,0	3,5	0,974	12,758	82,2

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
LV-2	0,7		1,010	0,7		7,1	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-2	2-Winding Transformer	15,0	3,5	0,974	12,763	76,3
	2	Static Generator	15,0	3,5	0,974	12,763	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-3	0,7	1,009	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-3	2-Winding Transformer	15,0	3,5	0,974	12,774	76,3
3	Static Generator	15,0	3,5	0,974	12,774	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-4	0,7	1,008	0,7	7,0

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-4	2-Winding Transformer	15,0	3,5	0,974	12,787	76,4
4	Static Generator	15,0	3,5	0,974	12,787	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-5	0,7	1,010	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-5	2-Winding Transformer	15,0	3,5	0,974	12,761	76,3
5	Static Generator	15,0	3,5	0,974	12,761	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-6	0,7	1,010	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-6	2-Winding Transformer	15,0	3,5	0,974	12,766	76,3
6	Static Generator	15,0	3,5	0,974	12,766	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-7	0,7	1,009	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-7	2-Winding Transformer	15,0	3,5	0,974	12,776	76,3
7	Static Generator	15,0	3,5	0,974	12,776	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-8	0,7	1,008	0,7	7,0

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-8	2-Winding Transformer	15,0	3,5	0,974	12,790	76,4
8	Static Generator	15,0	3,5	0,974	12,790	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-9	0,7	1,010	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-9	2-Winding Transformer	15,0	3,5	0,974	12,766	76,3
9	Static Generator	15,0	3,5	0,974	12,766	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-10	0,7	1,010	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-10	2-Winding Transformer	15,0	3,5	0,974	12,771	76,3
10	Static Generator	15,0	3,5	0,974	12,771	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-11	0,7	1,009	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-11	2-Winding Transformer	15,0	3,5	0,974	12,781	76,4
11	Static Generator	15,0	3,5	0,974	12,781	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-12	0,7	1,008	0,7	7,0

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-12	2-Winding Transformer	15,0	3,5	0,974	12,795	76,5
12	Static Generator	15,0	3,5	0,974	12,795	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-13	0,7	1,010	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-13	2-Winding Transformer	15,0	3,5	0,974	12,766	76,3
13	Static Generator	15,0	3,5	0,974	12,766	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-14	0,7	1,010	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-14	2-Winding Transformer	15,0	3,5	0,974	12,771	76,3
14	Static Generator	15,0	3,5	0,974	12,771	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-15	0,7	1,009	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-15	2-Winding Transformer	15,0	3,5	0,974	12,781	76,4
15	Static Generator	15,0	3,5	0,974	12,781	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-16	0,7	1,008	0,7	7,0

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-16	2-Winding Transformer	15,0	3,5	0,974	12,795	76,5
	16	Static Generator	15,0	3,5	0,974	12,795	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-17	0,7	1,010	0,7	7,1

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-17	2-Winding Transformer	15,0	3,5	0,974	12,761	76,3
	17	Static Generator	15,0	3,5	0,974	12,761	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-18	0,7	1,010	0,7	7,1

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-18	2-Winding Transformer	15,0	3,5	0,974	12,766	76,3
	18	Static Generator	15,0	3,5	0,974	12,766	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-19	0,7	1,009	0,7	7,1

	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-19	2-Winding Transformer	15,0	3,5	0,974	12,776	76,3
	19	Static Generator	15,0	3,5	0,974	12,776	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-20	0,7	1,008	0,7	7,0

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-20	2-Winding Transformer	15,0	3,5	0,974	12,790	76,4
20	Static Generator	15,0	3,5	0,974	12,790	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-21	0,7	1,011	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-21	2-Winding Transformer	15,0	3,5	0,974	12,758	76,2
21	Static Generator	15,0	3,5	0,974	12,758	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-22	0,7	1,010	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-22	2-Winding Transformer	15,0	3,5	0,974	12,763	76,3
22	Static Generator	15,0	3,5	0,974	12,763	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-23	0,7	1,009	0,7	7,1

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-23	2-Winding Transformer	15,0	3,5	0,974	12,774	76,3
23	Static Generator	15,0	3,5	0,974	12,774	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
LV-24	0,7	1,008	0,7	7,0

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-24	2-Winding Transformer	15,0	3,5	0,974	12,787	76,4
24	Static Generator	15,0	3,5	0,974	12,787	82,2

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-1	66,0	0,996	65,8	3,8

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-1	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,2
1-2	Line	15,0	2,4	0,988	0,133	28,9

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-3	66,0	0,995	65,7	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-3	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
2-3	Line	-29,9	-5,5	-0,983	0,267	57,8
3-4	Line	44,8	7,9	0,985	0,400	78,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-4	66,0	0,994	65,6	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-4	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,4
3-4	Line	-44,8	-8,3	-0,983	0,401	78,5
ARRAY 1	Line	59,7	10,6	0,985	0,534	75,7

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-5	66,0	0,996	65,7	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-5	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
5-6	Line	15,0	2,4	0,988	0,133	28,9

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-6	66,0	0,996	65,7	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-6	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
6-7	Line	29,9	5,1	0,986	0,267	57,8
5-6	Line	-14,9	-2,8	-0,983	0,134	28,9

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-7	66,0	0,995	65,7	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-7	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
6-7	Line	-29,9	-5,5	-0,983	0,267	57,8
8-9	Line	44,8	7,9	0,985	0,400	78,5

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-8	66,0	0,994	65,6	3,6

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-8	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,4
8-9	Line	-44,8	-8,3	-0,983	0,401	78,5
ARRAY 2	Line	59,7	10,6	0,985	0,534	75,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-9	66,0	0,996	65,7	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-9	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
9-10	Line	15,0	2,4	0,988	0,133	28,9

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg
MV-10	66,0	0,995	65,7	3,7

Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
TRAFO-10	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
9-10	Line	-14,9	-2,8	-0,983	0,134	28,9
10-11	Line	29,9	5,1	0,986	0,267	57,9

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-11	66,0		0,994	65,6		3,7	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-11	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,4
	11-12	Line	44,8	7,9	0,985	0,400	78,5
	10-11	Line	-29,9	-5,5	-0,983	0,267	57,9
Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-12	66,0		0,993	65,6		3,6	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-12	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,5
	11-12	Line	-44,8	-8,3	-0,983	0,401	78,5
	ARRAY 3	Line	59,7	10,6	0,985	0,534	75,6

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-13	66,0		0,996		65,7		3,7	
	Name	Element type	Active Power MW		Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-13	2-Winding Transformer	-15,0		-2,4	-0,988	0,133	76,3
	13-14	Line	15,0		2,4	0,988	0,133	28,9

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-14	66,0		0,995		65,7		3,7	
	Name	Element type	Active Power MW		Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-14	2-Winding Transformer	-15,0		-2,4	-0,988	0,133	76,3
	13-14	Line	-14,9		-2,8	-0,983	0,134	28,9
	14-15	Line	29,9		5,1	0,986	0,267	57,9

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-15	66,0		0,994		65,6		3,7	
	Name	Element type	Active Power MW		Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-15	2-Winding Transformer	-15,0		-2,4	-0,988	0,133	76,4
	15-16	Line	44,8		7,9	0,985	0,400	78,5

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-16	66,0		0,993		65,6		3,6	
	Name		Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-16		2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,5
	15-16		Line	-44,8	-8,3	-0,983	0,401	78,5
	ARRAY 4		Line	59,7	10,6	0,985	0,534	75,6

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-17	66,0		0,996		65,7		3,7	
	Name		Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-17		2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
	17-18		Line	15,0	2,4	0,988	0,133	28,9

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-18	66,0		0,996		65,7		3,7	
	Name		Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-18		2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
	18-19		Line	29,9	5,1	0,986	0,267	57,8
	17-18		Line	-14,9	-2,8	-0,983	0,134	28,9

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
IV-19	66,0		0,995		65,7		3,7	
	Name		Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %
	TRAFO-19		2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3
	18-19		Line	-29,9	-5,5	-0,983	0,267	57,8
	19-20		Line	44,8	7,9	0,985	0,400	78,5

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-20	66,0		0,994		65,6		3,6	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	TRAFO-20	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,4	
	19-20	Line	-44,8	-8,3	-0,983	0,401	78,5	
	ARRAY 5	Line	59,7	10,6	0,985	0,534	75,6	

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-21	66,0		0,996		65,8		3,8	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	TRAFO-21	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,2	
	21-22	Line	15,0	2,4	0,988	0,133	28,9	

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-22	66,0		0,996		65,7		3,7	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	TRAFO-22	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3	
	22-23	Line	29,9	5,1	0,986	0,267	57,8	
	21-22	Line	-14,9	-2,8	-0,983	0,134	28,9	

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
MV-23	66,0		0,995		65,7		3,7	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	TRAFO-23	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,3	
	22-23	Line	-29,9	-5,5	-0,983	0,267	57,8	

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg		
MV-24	66,0	0,994	65,6	3,7		
	Name	**Element type**	**Active Power MW**	**Reactive Power Mvar**	**Power Factor -**	**Current, Magnitude kA**	**Loading %**
	TRAFO-24	2-Winding Transformer	-15,0	-2,4	-0,988	0,133	76,4
	23-24	Line	-44,8	-8,3	-0,983	0,401	78,5
	ARRAY 6	Line	59,7	10,6	0,985	0,534	75,7

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg		
Marine Substation-In	66,0	0,993	65,5	3,6		
	Name	**Element type**	**Active Power MW**	**Reactive Power Mvar**	**Power Factor -**	**Current, Magnitude kA**	**Loading %**
	ARRAY 6	Line	-59,7	-11,4	-0,982	0,536	75,7
	Shunt/Filter	Shunt/Filter	0,0	0,0	1,000	0,000	
	ARRAY 4	Line	-59,7	-11,1	-0,983	0,535	75,6
	TRAFO-SET1(2)	2-Winding Transformer	179,1	9,2	0,999	1,580	41,1
	Shunt/Filter(1)	Shunt/Filter	-0,0	49,3	-0,000	0,434	
	ARRAY 1	Line	-59,7	-11,4	-0,982	0,536	75,7
	ARRAY 5	Line	-59,7	-11,3	-0,983	0,535	75,6
	ARRAY 2	Line	-59,7	-11,3	-0,983	0,535	75,6
	TRAFO-SET1(1)	2-Winding Transformer	179,1	9,2	0,999	1,580	41,1
	ARRAY 3	Line	-59,7	-11,1	-0,983	0,535	75,6

Terminal	Nominal Line-Line Voltage kV	Voltage, Magnitude p.u.	Line-Line Voltage, Magnitude kV	Voltage, Angle deg		
Marine Substation-Out	220,0	1,004	220,8	0,3		
	Name	**Element type**	**Active Power MW**	**Reactive Power Mvar**	**Power Factor -**	**Current, Magnitude kA**	**Loading %**
	TRAFO-SET1(1)	2-Winding Transformer	-178,9	2,8	-1,000	0,468	41,1
	OFFSHORE-LINE 2	Line	119,2	-1,8	1,000	0,312	40,0
	OFFSHORE-LINE 3	Line	119,2	-1,8	1,000	0,312	40,0
	OFFSHORE-LINE 1	Line	119,2	-1,8	1,000	0,312	40,0
	TRAFO-SET1(2)	2-Winding Transformer	-178,9	2,8	-1,000	0,468	41,1

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
TJB	220,0		1,002		220,5		0,1	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	UDG-1	Line	178,5	35,4	0,981	0,476	67,7	
	UDG2	Line	178,5	35,4	0,981	0,476	67,7	
	OFFSHORE-LINE 1	Line	-119,0	-23,6	-0,981	0,318	40,0	
	OFFSHORE-LINE 2	Line	-119,0	-23,6	-0,981	0,318	40,0	
	OFFSHORE-LINE 3	Line	-119,0	-23,6	-0,981	0,318	40,0	

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
SEC	220,0		1,000		220,0		-0,0	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	GRID-SWITCH	Breaker/Switch	356,1	117,0	0,950	0,984	0,0	
	CB-SET1	Shunt/Filter	0,0	0,0	1,000	0,000		
	NGR-SET1	NEC/NER	0,0	0,0	1,000	0,000		
	UDG-1	Line	-178,0	-58,5	-0,950	0,492	67,7	
	UDG2	Line	-178,0	-58,5	-0,950	0,492	67,7	

Terminal	Nominal Line-Line Voltage kV		Voltage, Magnitude p.u.		Line-Line Voltage, Magnitude kV		Voltage, Angle deg	
SUBESTACION	220,0		1,000		220,0		0,0	
	Name	Element type	Active Power MW	Reactive Power Mvar	Power Factor -	Current, Magnitude kA	Loading %	
	External Grid	External Grid	-356,1	-117,0	-0,950	0,984		
	GRID-SWITCH	Breaker/Switch	-356,1	-117,0	-0,950	0,984	0,0	

2. Short-Circuit Results

Short-Circuit Summary Currents	
HIGUEST VALUE IN COLLECTION SYSTEM (66kV)	Isym_m=33,245 kA Iasym_m=48,011 kA Ipeak_m=81,935 kA

MARINE SUBSTATION-IN	Isym_m=35,049 kA Iasym_m=53,478 kA Ipeak_m=90,135 kA
MARINE SUBSTATION-OUT	Isym_m=23,085 kA Iasym_m=30,755 kA Ipeak_m=53,377 kA
TRANSITION JOINT BAY	Isym_m=24,299 kA Iasym_m=33,276 kA Ipeak_m=57,437 kA
SUBSTATION	Isym_m=28,243 kA Iasym_m=37,730 kA Ipeak_m=64,453 kA

3. Power Losses Resume

3.1. Capacitive Behaviour

POWER LOSSES SUMMARY	
LINES	LOSS (MW)
1-2, 5-6, 9-10, 13-14, 17-18, 21-22	0,060
2-3, 6-7, 10-11, 14-15, 18-19, 22-23	0,025
3-4, 7-8, 11-12, 15-16, 19-20, 23-24	0,048
4-MS, 8-MS, 12-MS, 16-MS, 20-MS, 24-MS	0,080
OFFSHORE LINES	0,305
UNDERGROUND LINES	0,332
0,69/66 kV TRANSFORMERS	0,048
66/220 kV TRANSFORMERS	0,248

3.2. Inductive Behaviour

POWER LOSSES SUMMARY	
LINES	LOSS (MW)
1-2, 5-6, 9-10, 13-14, 17-18, 21-22	0,05
2-3, 6-7, 10-11, 14-15, 18-19, 22-23	0,021
3-4, 7-8, 11-12, 15-16, 19-20, 23-24	0,041
4-MS, 8-MS, 12-MS, 16-MS, 20-MS, 24-MS	0,068
OFFSHORE LINES	0,264
UNDERGROUND LINES	0,427
0,69/66 kV TRANSFORMERS	0,041
66/220 kV TRANSFORMERS	0,23

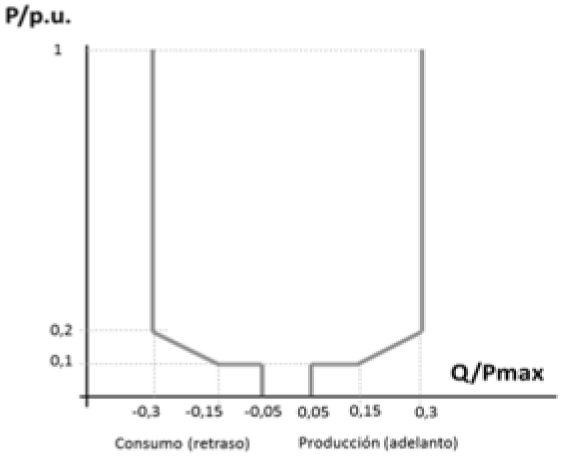
4. Energy Losses Results

v (m/s)	p (%)	h/año	P (kW)	E (MWh)	Pj (kW) T	Ej (MWh) T
3,0	3,447	293,79	202,2	1461,46	0,44	0,13
3,5	4,049	345,11	463,7	3885,37	2,30	0,80
4,0	4,588	391,09	801,1	7577,24	6,88	2,69
4,5	5,046	430,13	1224,9	12725,57	16,09	6,92
5,0	5,408	460,97	1740,3	19370,74	32,48	14,97
5,5	5,664	482,74	2370,9	27647,75	60,32	29,12
6,0	5,807	494,98	3115,9	37291,15	104,26	51,61
6,5	5,839	497,67	3993,2	48113,27	171,43	85,32
7,0	5,763	491,19	5009,6	59671,36	270,25	132,74
7,5	5,588	476,28	6176,5	71483,04	411,78	196,12
8,0	5,326	453,99	7478,7	82699,48	605,66	274,96
8,5	4,994	425,63	8845,6	91935,20	850,66	362,06
9,0	4,606	392,60	10160,5	97650,98	1127,38	442,61
9,5	4,181	356,41	11372,0	99449,28	1418,82	505,68
10,0	3,737	318,49	12497,1	97875,78	1721,59	548,32
10,5	3,287	280,21	13446,3	92823,42	2001,70	560,89
11,0	2,848	242,74	14141,5	84685,29	2221,51	539,25

11,5	2,429	207,07	14505,2	74151,39	2341,49	484,85
12,0	2,041	173,95	14579,9	62621,23	2366,57	411,66
12,5	1,688	143,90	14579,9	51805,34	2366,57	340,56
13,0	1,375	117,24	14579,9	42206,36	2366,57	277,46
13,5	1,104	94,06	14579,9	33863,24	2366,57	222,61
14,0	0,872	74,32	14579,9	26755,80	2366,57	175,89
14,5	0,678	57,83	14579,9	20817,68	2366,57	136,85
15,0	0,520	44,30	14579,9	15949,78	2366,57	104,85
15,5	0,392	33,42	14579,9	12032,72	2366,57	79,10
16,0	0,291	24,83	14579,9	8937,92	2366,57	58,76
16,5	0,213	18,16	14579,9	6536,52	2366,57	42,97
17,0	0,153	13,07	14579,9	4706,16	2366,57	30,94
17,5	0,109	9,27	14579,9	3335,54	2366,57	21,93
18,0	0,076	6,46	14579,9	2327,11	2366,57	15,30
18,5	0,052	4,44	14579,9	1598,02	2366,57	10,51
19,0	0,035	3,00	14579,9	1080,02	2366,57	7,10
19,5	0,023	2,00	14579,9	718,35	2366,57	4,72
20,0	0,015	1,31	14579,9	470,17	2366,57	3,09
20,5	0,010	0,84	14579,9	302,79	2366,57	1,99
21,0	0,006	0,53	14574,8	191,79	2364,84	1,26
21,5	0,004	0,33	14435,6	118,39	2318,26	0,77
22,0	0,002	0,20	14077,0	70,74	2200,58	0,45
22,5	0,001	0,12	13526,5	40,96	2026,42	0,25
23,0	0,001	0,07	12871,0	23,09	1829,20	0,13
23,5	0,000	0,04	12359,3	12,93	1682,83	0,07
24,0	0,000	0,02	11982,1	7,19	1579,10	0,04
24,5	0,000	0,01	11755,4	3,98	1518,48	0,02
25,0	0,000	0,01	11643,3	2,18	1488,97	0,01

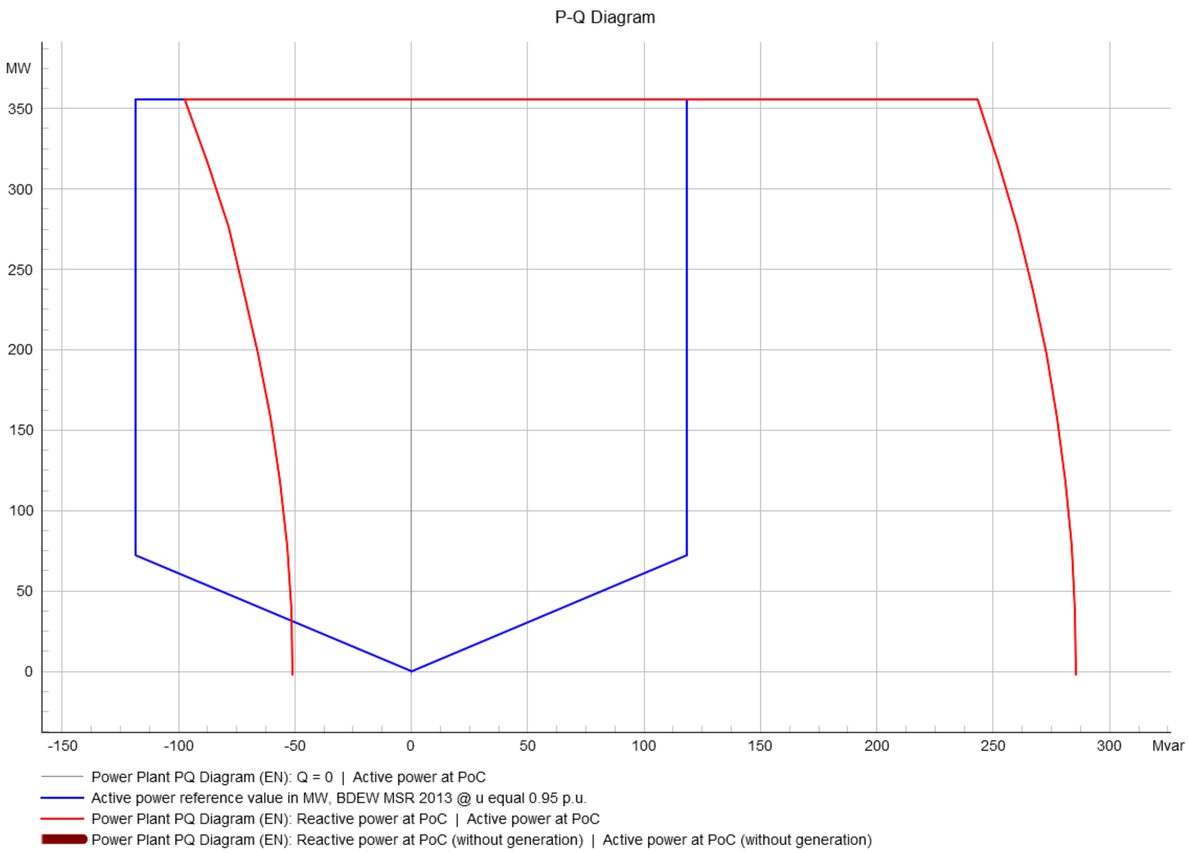
5. Reactive Study

To make possible the connection to the grid, our curve P-Q should involve the curve on the slack node (reference node). The Spanish code has the following requirements where depending of the % of load our wind farm is working on we should be consuming or generating a % of reactive to the grid over the maximum power.

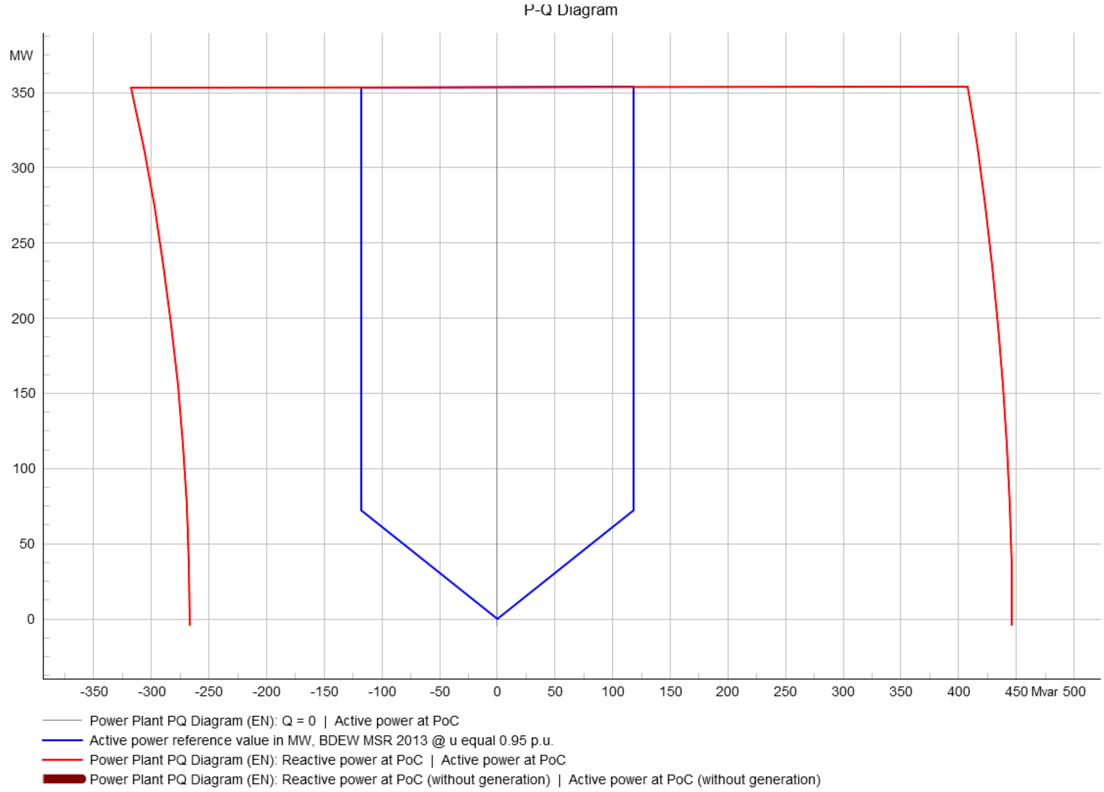


Indeed, the blue curve has not the same shape as the established before, due to software specifications we only assure the reactive requirements for loads between 100-10%

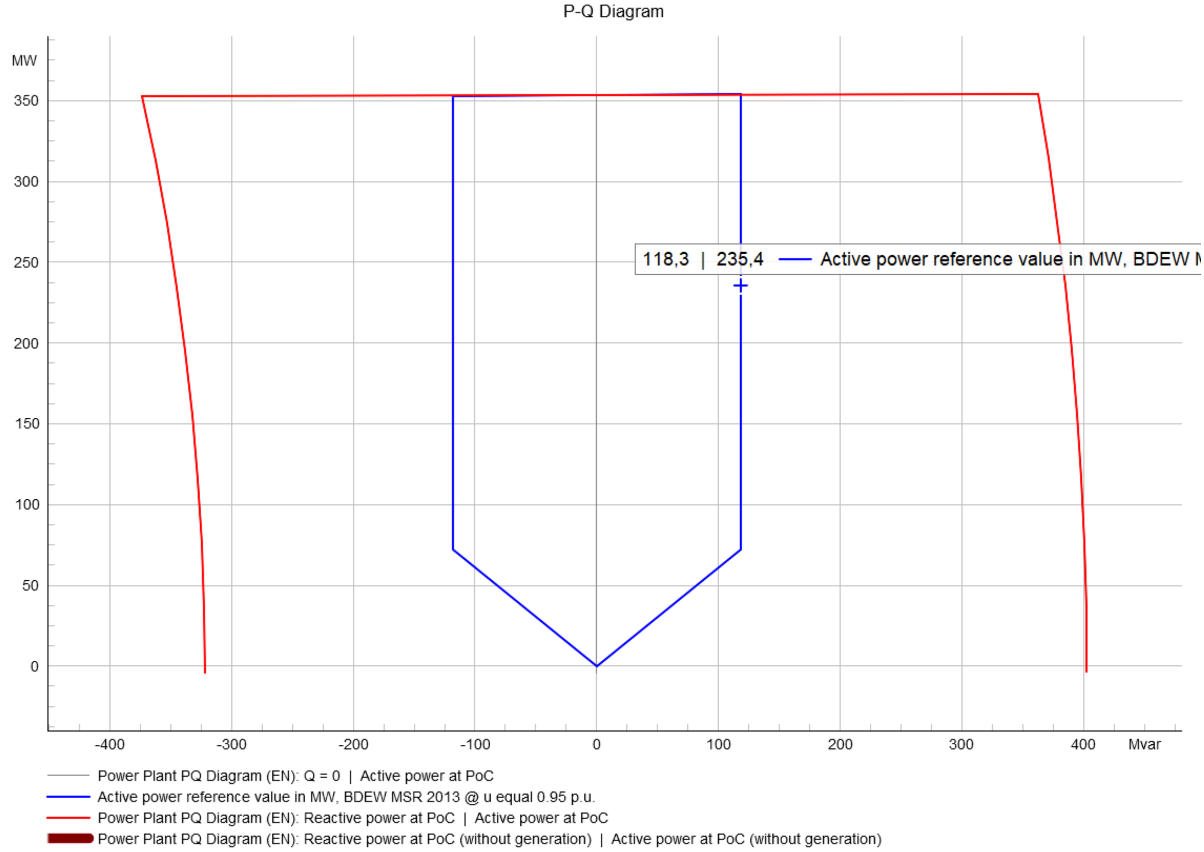
The next image corresponds to an unbalanced reactive model, not ours:



At first sight we obtained the following graphic, without any compensation connected to the system. The following graphic reflects the reactive production of our system, we can appreciatte it fits the requirements (not studying the 10%-0%) although the generation/consumption of reactive is a bit unbalanced.



One optimal solution could be adding a capacitor bank of 50 MVA. The obtained graphic is:



Obtaining a more balanced reactive compensation. We can assume that the Spinnaker Wind Farm is able for consuming and for generating reactive power, working on inductive or capacitive behaviour. Important to remember that these studies are static simulations, these is just a moment of performance.

6. Earthing Calculations

6.1. Individual Resistance for Wind Turbines

The individual resistance obtained with this grounding design is 34,1 Ω. This value could be considered as too high, although the regulations limit values of individual resistance in land up to 10Ω, the value offshore could be incremented. But here there is no consideration of the bare copper conductor going out to the next wind turbine, what would make a lower resistance, and lower split factor. For the calculations it has been considered the following values, but in the reality, all of them will decrease a bit as we advanced into the array. For each array, here are each resistance according to the position on the array considered:

WTG	WTG EARTHING RESISTANCE (Ω)
1st	29,3
2nd	24,1
3rd	21,7
4th	17,3

6.2. Split factor

Once the grounding system is checked, the next step is to calculate the global resistance of the wind farm, the software XGSLab has some limitations in order to import the real system or even with the accuracy of the results.

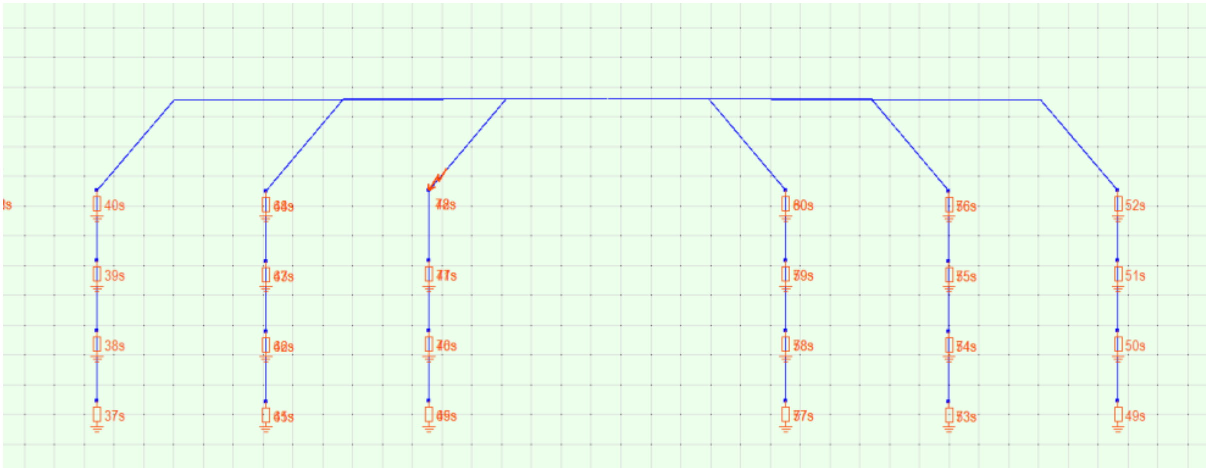


Figure 1. Diagram Earthing Software calculation. Source Own elaboration

We can appreciate where the default is injected (lightning symbol), and also it is shown the consideration of the individual resistances in parallel. The values obtained for each Wind Turbine considering a default current of 1 kA are the following:

WTG	WTG EARTHING RESISTANCE	GLOBAL RESISTANCE FROM WTG (Ω)	INJECTED CURRENT AT EACH WT (A)
1	29,3	2,301	78,53
2	24,1	1,699	70,49
3	21,7	1,319	60,78
4	17,3	1,207	69,77
5	29,3	4,07	138,91
6	24,1	3,52	146,06
7	21,7	2,625	120,97
8	17,3	1,907	110,23
9	29,3	4,379	149,45
10	24,1	3,813	158,22
11	21,7	2,787	128,43
12	17,3	1,879	108,61
13	29,3	4,379	149,45
14	24,1	3,813	158,22

15	21,7	2,787	128,43
16	17,3	1,879	108,61
17	29,3	4,07	138,91
18	24,1	3,52	146,06
19	21,7	2,625	120,97
20	17,3	1,907	110,23
21	29,3	2,301	78,53
22	24,1	1,699	70,49
23	21,7	1,319	60,78
24	17,3	1,207	69,77

6.3. Touch and Step Voltages for TJB

In this section the calculations and results are shown. The figure below shows the model of the grounding grid implemented in the software for the simulation.

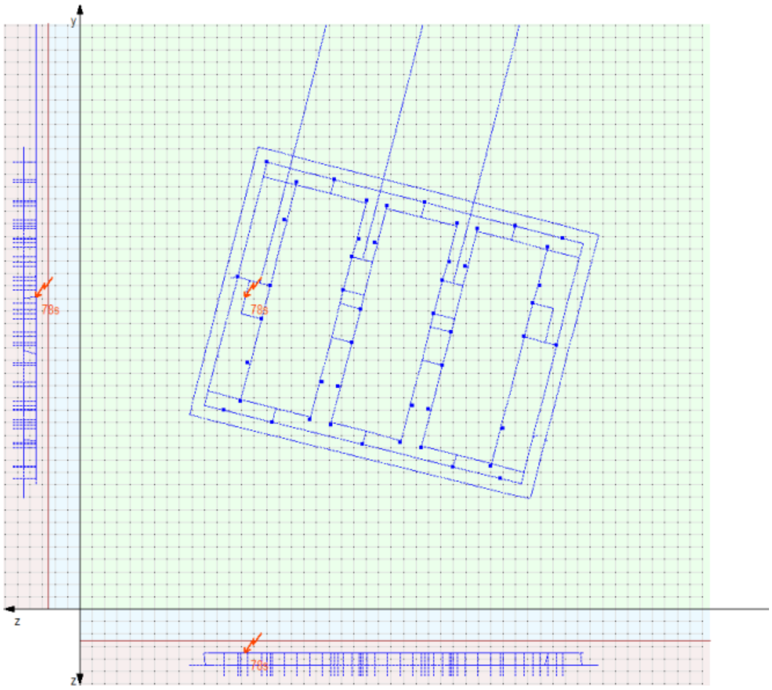


Figure 2. Grounding system model for TJB in software. Source Own elaboration

The composition of the grounding grid is the following:

- Individual ring surrounding each of the transition joint bays buried at 1m depth.
- First external ring surrounding all the 3 transitions buried at 1m depth and separated 1m from the individual rings of each transition joint bay.
- Second external ring surrounding the first external ring at 2m depth and separated 1m from the first external ring.
- Grounding rods connected throughout the layout of the horizontal electrodes.
- Bare copper conductors which will be installed inside the onshore trenches.

With this design and the soil electrical resistivity of 500 Ωm, the resistance obtained through software is 1.13 Ω.

Additionally, the following figures show the results for the earth potential and the touch and step voltages obtained in the surroundings of the transition joint bays during a single phase to ground fault of 3 kA.

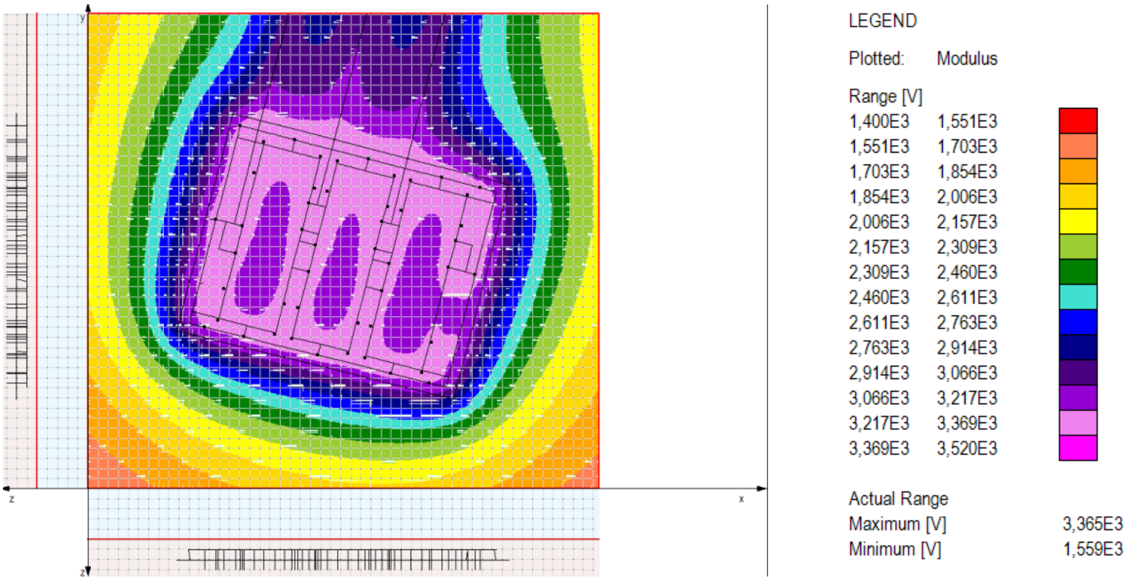


Figure 3. Earth Potential obtained with XGSLab. Source Own elaboration

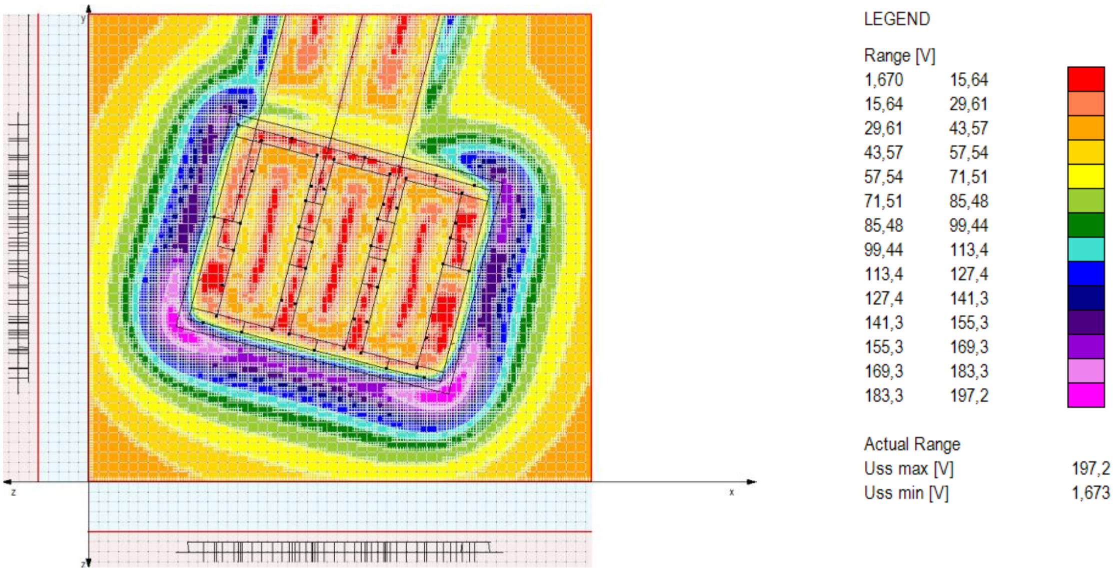


Figure 4. Step voltages obtained with XGSLab. Source Own elaboration

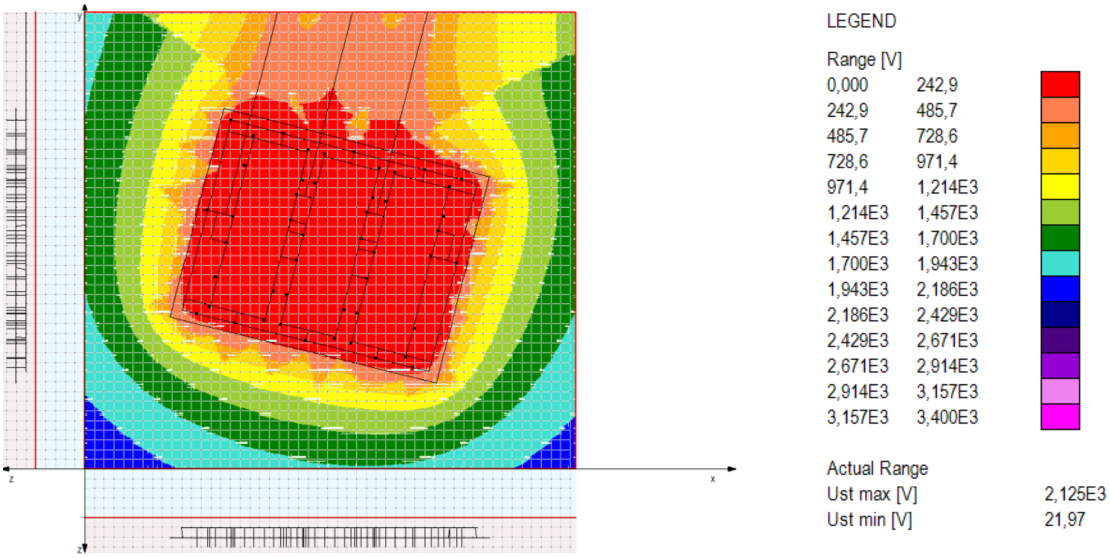


Figure 5. Touch voltages obtained with XGSLab. Source Own elaboration

The results show that the step voltages in the studied area are always below the limits defined by the norm. So, it can be said that the grounding design meets the requirements for step voltages.

On the other hand, the touch voltages exceed the limits in some areas, but since the possible touch voltage (a contact occurring) are only expected 1m around the manholes, and in these areas the touch voltages are below the limits, it can also be said that the grounding design meets the requirements of the norm for touch voltages.

The figure below shows the areas where the touch voltages are below the limits. Since the manholes are covered by this area, the expected touch voltages will not exceed the limits.

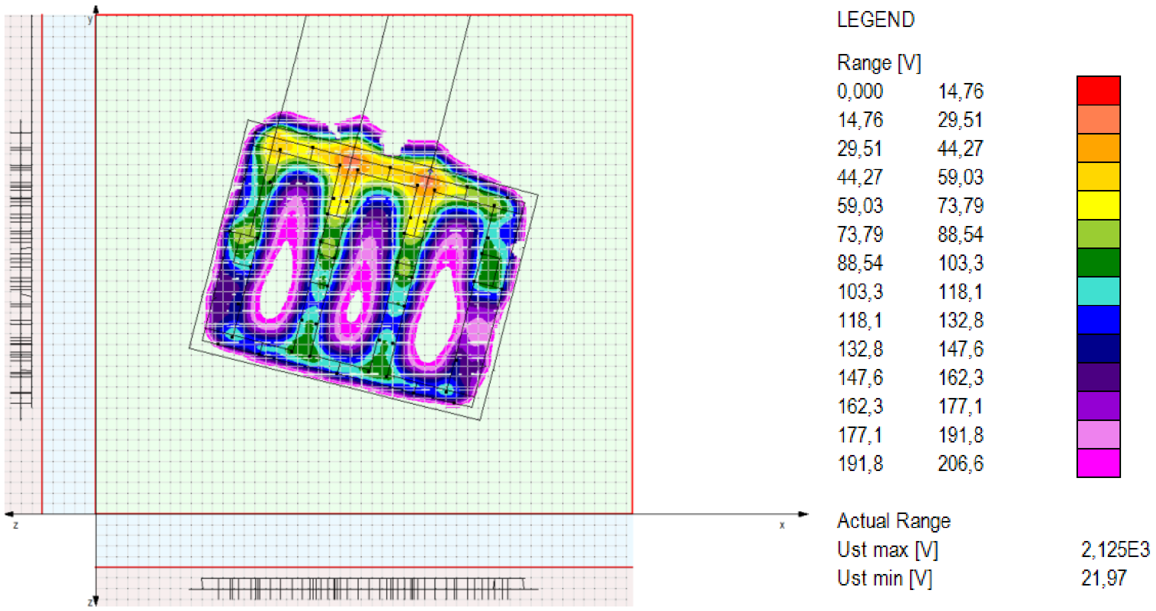


Figure 6. Acceptable touch voltage areas with XGSLab. Source Own elaboration

It is important to be noted that if any additional metallic elements are to be installed in the proximity of the transition joint bays which could create a possible contact point, the grounding system should be analysed to verify that the touch voltages created do not exceed the limits defined by the norm.

Additionally, the length of the grounding electrodes from the onshore trench will influence the grounding resistance as well as the touch and step voltages.

As a summary the maximum touch and step voltages expected are the following:

Table 1 Touch and step voltage summary. Source: Own elaboration

Voltage	Maximum	Permissible
Step voltage (V)	197.2	478.5
Touch voltage (V)	162.3	206.6

To analyze the permissible step and touch voltages considering a shoe resistance of 2000 Ω, and additional calculation is performed with the corresponding graphical representations.

The figure below shows the calculation process followed in the software for the step and touch voltage limits considering a shoe resistance of 2000 Ω (which is a more likely scenario):

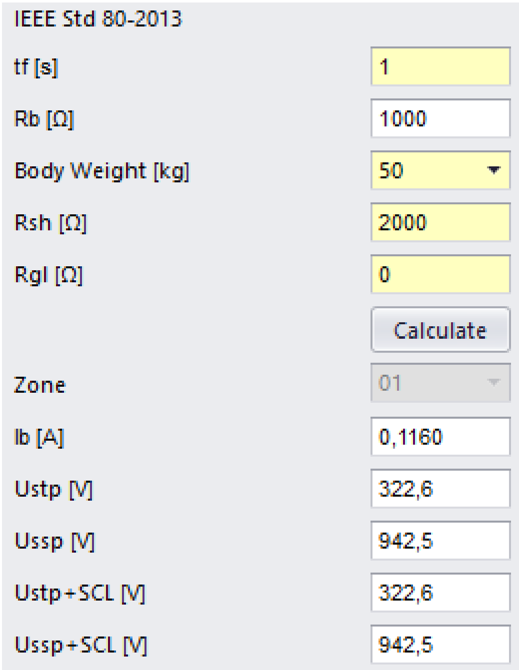


Figure 7. Step and touch voltage limits calculations with shoe resistance according to IEC Std 80-2013. Source Own elaboration

With these increase limits, the touch voltages would be acceptable in a greater area. The figure below shows the areas where the touch voltages are below the limits considering a shoe resistance. Since the manholes are covered by this area, the expected touch voltages will not exceed the limits.

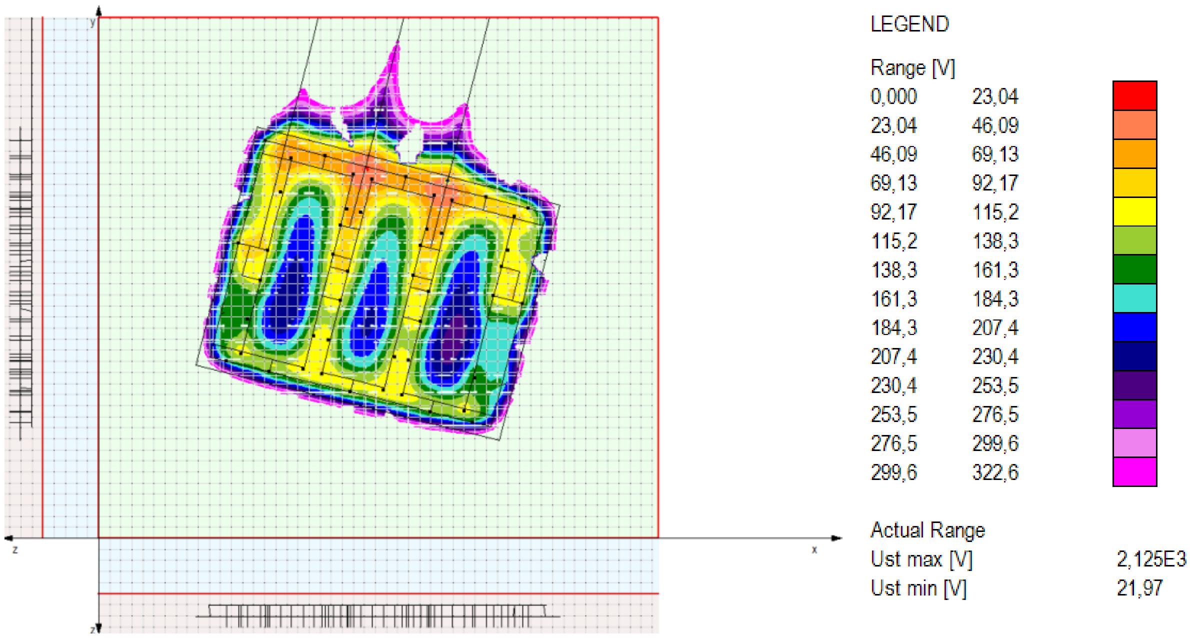


Figure 8. Acceptable touch voltage areas with XGSLab. Source Own elaboration

The figure above shows the areas where the touch voltages are below the limits considering a shoe resistance (322.6 V).

Furthermore, and to improve the performance of the grounding system, an additional horizontal electrode buried at 1m depth and located on top of each of the transition bays is proposed. This improvement for the grounding system is not required but left as a possibility in case some of the design criteria considered are modified. The figure below includes the 3 additional electrodes.

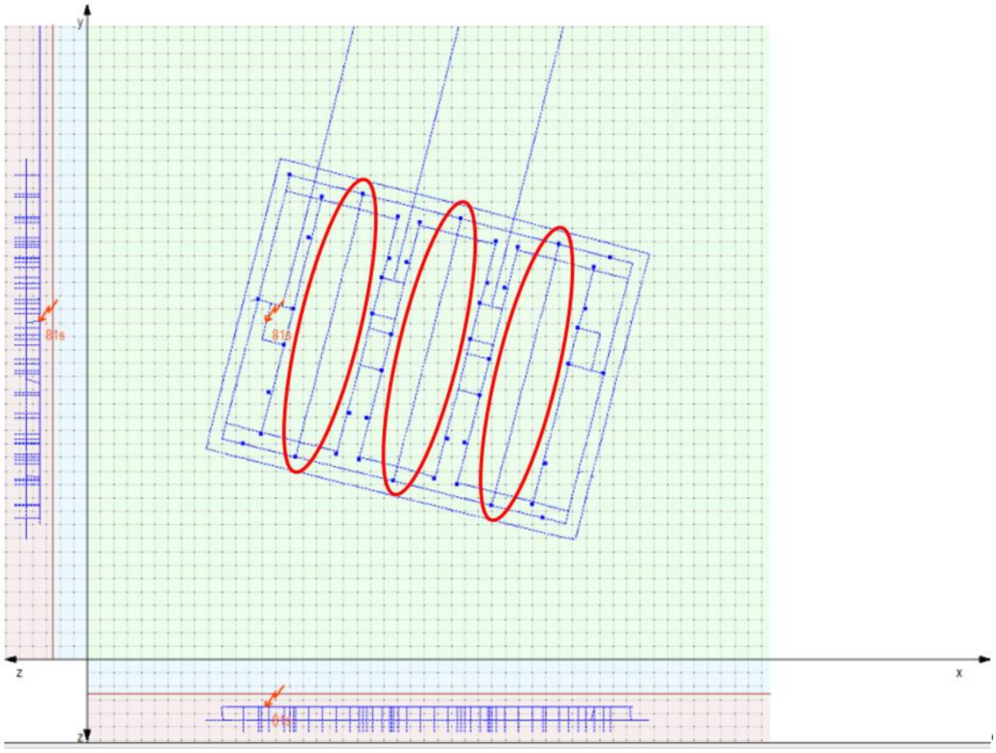


Figure 9. Additional Grounding system modelled in software for better performance. Source Own elaboration

With this additional electrode, the touch voltages are significantly improved per the following results/figures:

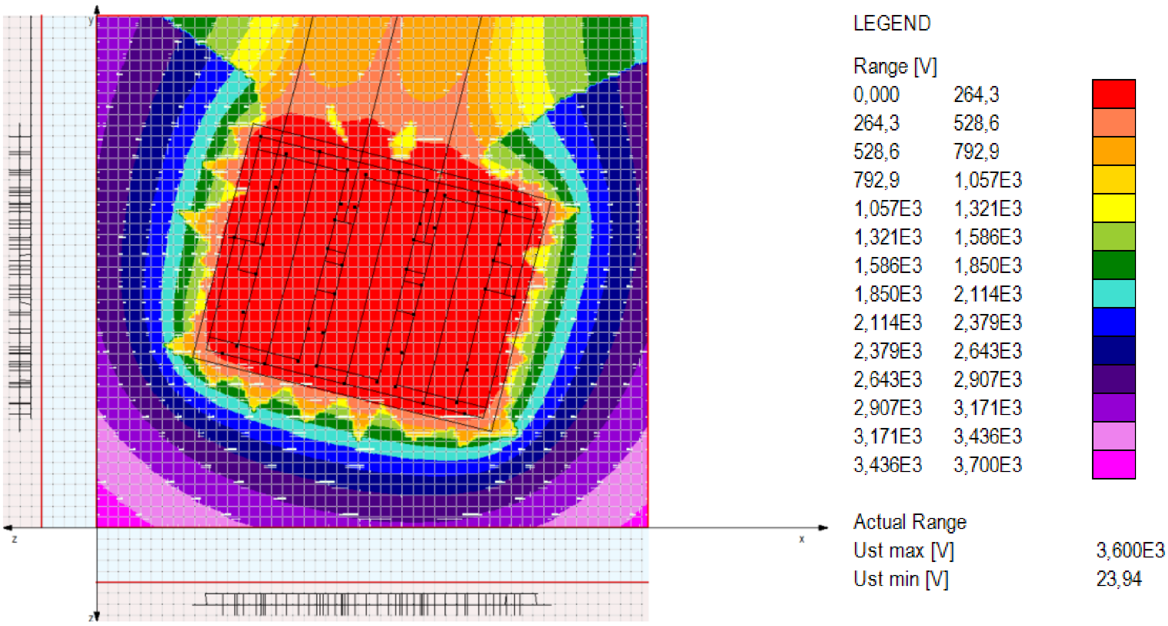


Figure 10. Touch voltages obtained with additional electrode with XGSLab . Source Own elaboration

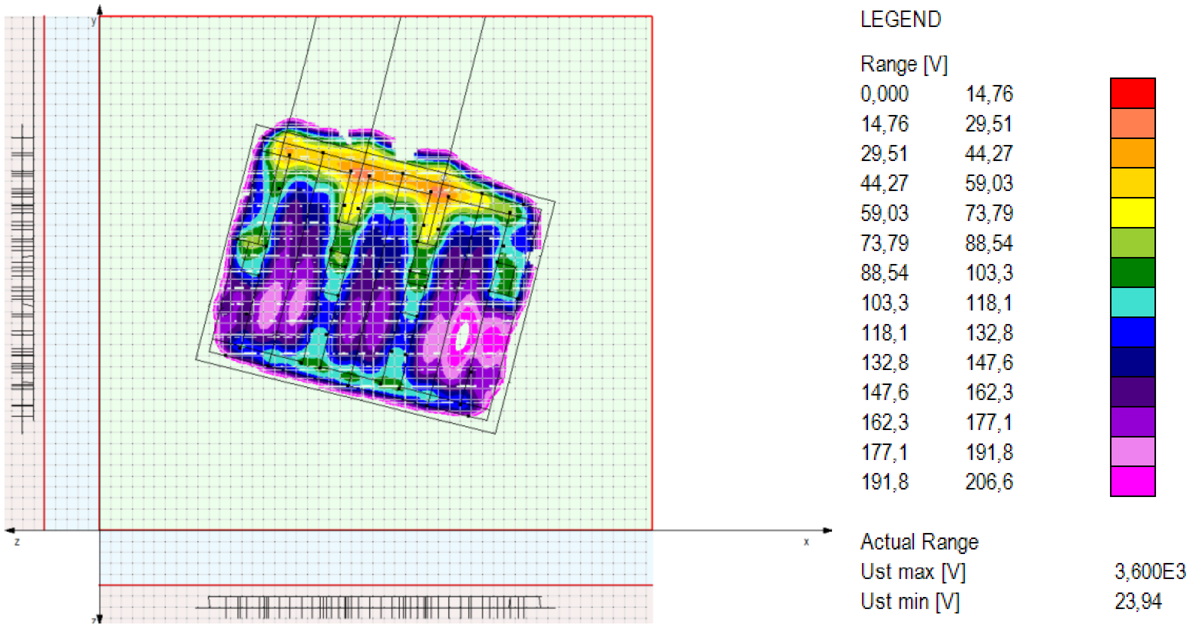


Figure 11. Acceptable touch voltage areas with additional electrode with XGSLab. Source Own elaboration

The figure above shows the areas where the touch voltages are below the limits without considering a shoe resistance (206.6 V).

It can be seen how the area where the touch voltages do not exceed the limits defined by the norm is increase, improving the grounding system design. No touch voltages above the limits are expected to occur given that there is no possible contact with metallic elements which could be subjected to dangerous induced voltages.

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CHAPTER

3

Technical documents

BUDGET ANNEX

July 2023

Índice

1. GENERAL BUDGET

1.1. Trenches & Cable Ducts

1. TRENCHES AND CABLE DUCTS IN THE GROUND					
Nº	Description	Unit	Measure	Unit Price (€)	*Total Amount (€)*
1	Excavations, HDPE ducts, signage plates, and cable protection.	U	1	1.276.670,00	*1.276.670,00*
2	Interconnection manhole for marine cable - land cable measuring 3.5 x 3.85 x 2,00 in reinforced concrete, fully completed.	U	3	9.000,00	*27.000,00*
TOTAL	TRENCHES & CABLE DUCTS				*6.356.000,00*

1.2. Engineering & Design

2. ENGINEERING & DESIGN					
Nº	Description	Unit	Measure	Unit Price (€)	*Total Amount (€)*
1	Software License	U	1	6.000,00	*6.000,00*
2	Engineering Design	h	300	100,00	*30.000,00*

TOTAL	ENGINEERING & DESIGN	*36.000,00*

1.3. Wind Turbines

3. WIND TURBINES					
Nº	Description	Unit	Measure	Unit Price (€)	*Total Amount (€)*
1	Vestas WT: V236-15.0 MW	U	24	13.200.000,00	*316.800.000,00*
2	Transport and installation of the wind turbines from the shipment point to the designated location.	U	24	700.000,00	*16.800.000,00*
3	Supply and installation unit for a meteorological tower, including support, base, weather sensors, control panel, lightning protection, evacuation line, and grounding network.	U	1	40.000,00	*40.000,00*
TOTAL	WIND TURBINES				*333.640.000,00*

1.4. Electrical Infrastructure

4. ELECTRICAL INFRASTRUCTURE					
Nº	Description	Unit	Measure	Unit Price (€)	*Total Amount (€)*
1	Wiring, transportation, and installation of a 66 kV submarine power line.	U	1	179.600.000,00	*179.600.000,00*
2	Wiring, transportation, and installation of 220 kV submarine power line	U	3	700.000,00	*2.100.000,00*

3	Wiring, transportation, and installation of 220 kV underground power line and fiber optic cable.	U	1	40.000,00	*40.000,00*
4	Grounding System	U	1	60.000,00	*60.000,00*
5	Substation building and necessary elements.	U	1	7.000.000,00	*7.000.000,00*
6	Transport and installation of the building.	U	1	5.000.000,00	*5.000.000,00*
7	50 MVAr and 66 kV capacitor bank.	U	1	150.000,00	*150.000,00*
8	66/220 kV 440 MVA power transformer.	U	2	500.000,00	*1.000.000,00*
9	Switchgear, cells, and switches (including disconnectors, current transformers, and voltage transformers) for 66 kV.	U	2	1.250.000,00	*2.500.000,00*
10	Switchgear, cells, and switches (including disconnectors, current transformers, and voltage transformers) for 0,69 kV.	U	24	1.450.000,00	*34.800.000,00*
11	Auxiliary power transformer cell.	U	24	60.000,00	*1.440.000,00*
12	Other items (panels, lighting, solenoid valves, etc.).	U	1	80.000,00	*80.000,00*
13	Auxiliary equipment.	U	1	5.500,00	*5.500,00*
14	Protection relay set.	U	1	44.000,00	*44.000,00*
15	Measurement equipment.	U	1	4.200,00	*4.200,00*
TOTAL	ELECTRICAL INFRASTRUCTURE				*233.823.700,00*

1.5. Medium Voltage Trenches & Cables & Grounding

4. MEDIUM VOLTAGE TRENCHES & CABLES					
Nº	Description	Unit	Measure	Unit Price (€)	*Total Amount (€)*

1	Execution and supply of materials necessary for the construction of a **Cable Trench for 1 MV circuit**, 1 FO cable and earthing conductor on the side of roads or cross country. Including excavation with mechanical machinery loading and transport of products to place of use or landfill. Includes compaction of the base, supply and placement of sand backfill over the MV cables and backfill compacted with the selected soil from the excavation.	U	11.250	18,79	*211,00*
2	Execution and supply of materials necessary for the construction of a Cable Trench for 2 MV circuit, 1 FO cable and earthing conductor on the side of roads or cross country. Including excavation with mechanical machinery (backhoe, hammer, etc.) loading and transport of products to place of use or landfill. Includes compaction of the base, supply and placement of sand backfill over the MV cables and backfill compacted with the selected soil from the excavation	U	24	700.000,00	*16.800.000,00*
			CABLES		
3	Supply and laying of single conductor 66 kV Cu with XLPE insulation and screen. 1x240mm2. Includes proportional part joints and repercussion of terminals (material+assembly) connecting wind turbine cells or substation cells for type cable. Completely installed and connected according to standards and specifications, and in accordance with drawings.	m	15.360	50.000,00	*768.000.000,00*
4	Supply and laying of single conductor 66 kV Cu with XLPE insulation and screen. 1x400mm2. Includes proportional part joints and repercussion of terminals	M	7.680	54.000,00	*414.720.000,00*

	(material+assembly) connecting wind turbine cells or substation cells for type cable. Completely installed and connected according to standards and specifications, and in accordance with drawings.				
5	Supply and laying of single conductor 66 kV Cu with XLPE insulation and screen. 1x630mm2. Includes proportional part joints and repercussion of terminals (material+assembly) connecting wind turbine cells or substation cells for type cable. Completely installed and connected according to standards and specifications, and in accordance with drawings.	m	9.200	58.000,00	*533.600.000*
	GROUNDING				
7	Supply and Installation of rods, 16 mm of diameter single conductor copper conductor for grounding in MV trenches,	m	192	2.500,00	*480.000,00*
8	Supply and Installation of wind turbine grounding system with 120 mm² single conductor - soft drawn bare copper conductor, and connection to the grounding network, including laying of the conductor in trench, p/p of aluminothermic welding from each wind turbine, grounding rods if necessary, small material and connection, carried out according to the wind turbine specifications, standards and drawings.	m	61.200,00	7.000,00	*428.400.000,00*
TOTAL	MV TRENCHES & CABLES				*1.183.253.600,00*
TOTAL	GROUNDING				*428.880.000,00*

1.6. Health & Safety Study

6. *HEALTH & SAFETY STUDY*					
Nº	Description	Unit	Measure	Unit Price (€)	*Total Amount (€)*

1	Health & Safety Study	U	1	6.356.000,00	*6.356.000,00*
TOTAL	HEALTH & SAFETY STUDY				*6.356.000,00*

2. Budget Summary

1	*TRENCHES & CABLE DUCTS*	*6.356.000,00*
2	ENGINEERING & DESIGN	*36.000,00*
3	WIND TURBINES	*333.640.000,00*
4	ELECTRICAL INFRASTRUCTURE	*233.823.700,00*
5	MV TRENCHES & CABLES	*1.183.253.600,00*
6	GROUNDING	*428.880.000,00*
7	HEALTH & SAFETY STUDY	*6.356.000,00*

AMOUNT OF MATERIAL EXECUTION	*2.192.345.300,00 €*
13 % GENERAL COSTS	*285.004.889,00 €*
6 % INDUSTRIAL BENEFITS	*131.540.718,00 €*
AMOUNT EXECUTION	*2.608.890.907,00 €*
21 % IVA	*547.867.090,47 €*
CONTRACT AMOUNT	*3.156.757.997,47 €*

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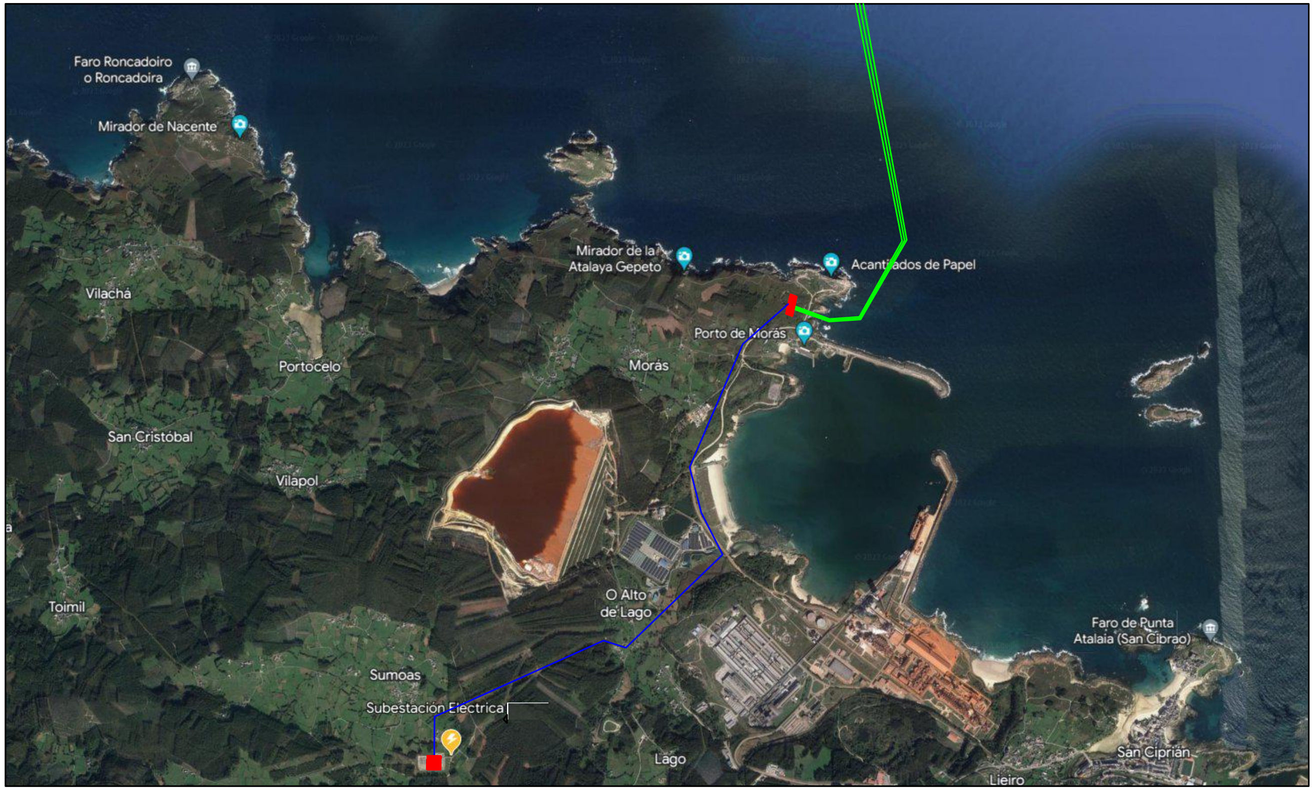
CHAPTER

4

Technical documents

MAPS ANNEX

July 2023



LEGEND

INTERCONNECTION CABLE BETWEEN TJB & MARINE SUBSTATION	ONSHORE LINE
TRANSITION JOINT BAY	LAND SUBSTATION 220/400 kV

CONTAINS INFORMATION FOR THE DESIGN OF STRUCTURES, SYSTEMS OR COMPONENTS................................ YES ☒ NO ☐

VERIFICATION N/A ☐ SUP. ☒ VERIFIER L1 ☐ L2 ☐

REV.	Date	Drawn	Prepared	Checked	Approved	DESCRIPTION

Owner :

Clasification : ELECTRIC

Type : GRAPHICS

File : PLANE

No :

SPINNAKER WIND FARM

FIRST EDITION:

Drawn	Prep.	Check.	Appr.

Client :

Author : ALEJANDRO LÁZARO NOVELLA

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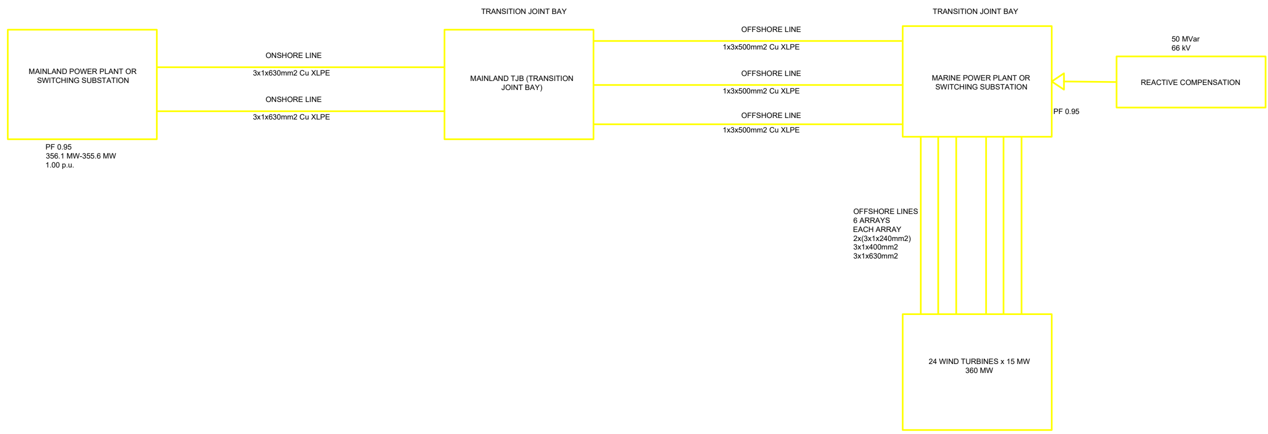
WIND FARM TO MAINLAND INTERCONNECTION DIAGRAM



-THE NORMAL OPERATION OF THE SYSTEM WILL BE WITH THE THREE LINES CONNECTED AND OPERATING AT ALL TIMES.

-THE SYSTEM MUST BE ABLE TO WITHSTAND THE MAXIMUM POWER DEMAND (100% OF LOAD) WITH ONE OF THE CABLES BEING OUT OF SERVICE.

-AT THE LAST AND FIRST 30m OF THE ONSHORE LINE THE CABLE WILL BE MAKING A LOOP TO PROVIDE SPARE CABLE AT BOTH ENDS IN CASE IT IS NEED TO CARRY OUT ANY ADDITIONAL CONNECTION OR SPLICE (SEE DETAILS ON MV TRENCH DRAWING FOR DETAILS ON LOOP TECHNIQUE).

CONTAINS INFORMATION FOR THE DESIGN OF STRUCTURES, SYSTEMS OR COMPONENTS................................ YES ☒ NO ☐
VERIFICATION N/A ☐ SUP. ☒ VERIFIER L1 ☐ L2 ☐

REV.	Date	Drawn	Prepared	Checked	Approved	DESCRIPTION

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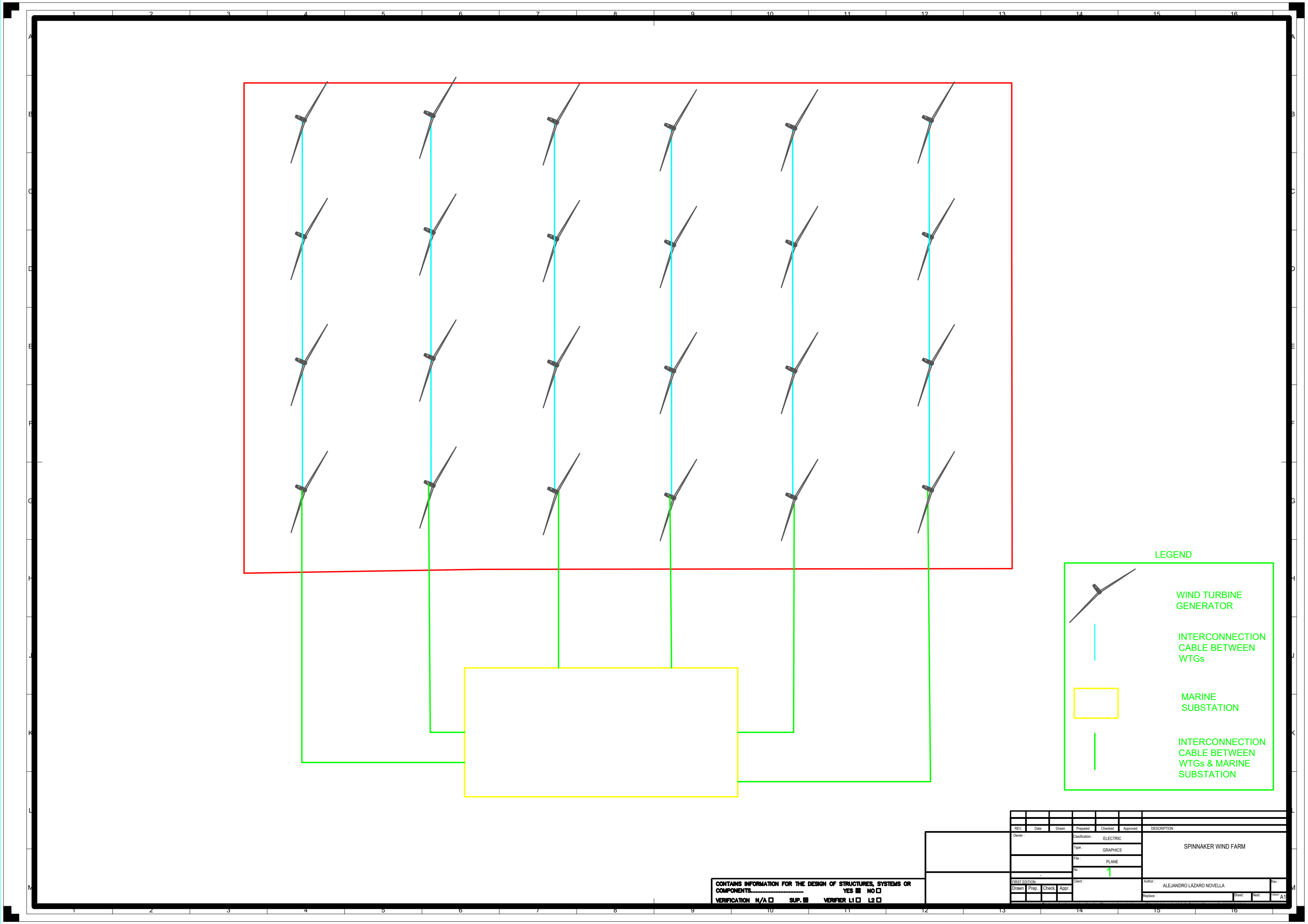
	Type : GRAPHICS	
	File : PLANE	
-	No :	
FIRST EDITION: Drawn / Prep. / Check. / Appr.	Client :	Author : ALEJANDRO LÁZARO NOVELLA; Rev :
		Replace : ; Sheet: ; Next: ; FORMAT: A1


LEGEND
WIND TURBINE GENERATOR
INTERCONNECTION CABLE BETWEEN WTGs
MARINE SUBSTATION
INTERCONNECTION CABLE BETWEEN WTGs & MARINE SUBSTATION
CONTAINS INFORMATION FOR THE DESIGN OF STRUCTURES, SYSTEMS OR COMPONENTS.............................. YES ☒ NO ☐
VERIFICATION N/A ☐ SUP. ☒ VERIFIER L1 ☐ L2 ☐
REV. Date Drawn Prepared Checked Approved DESCRIPTION
Owner :
Clasification : ELECTRIC
Type : GRAPHICS
File : PLANE
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Author : ALEJANDRO LÁZARO NOVELLA
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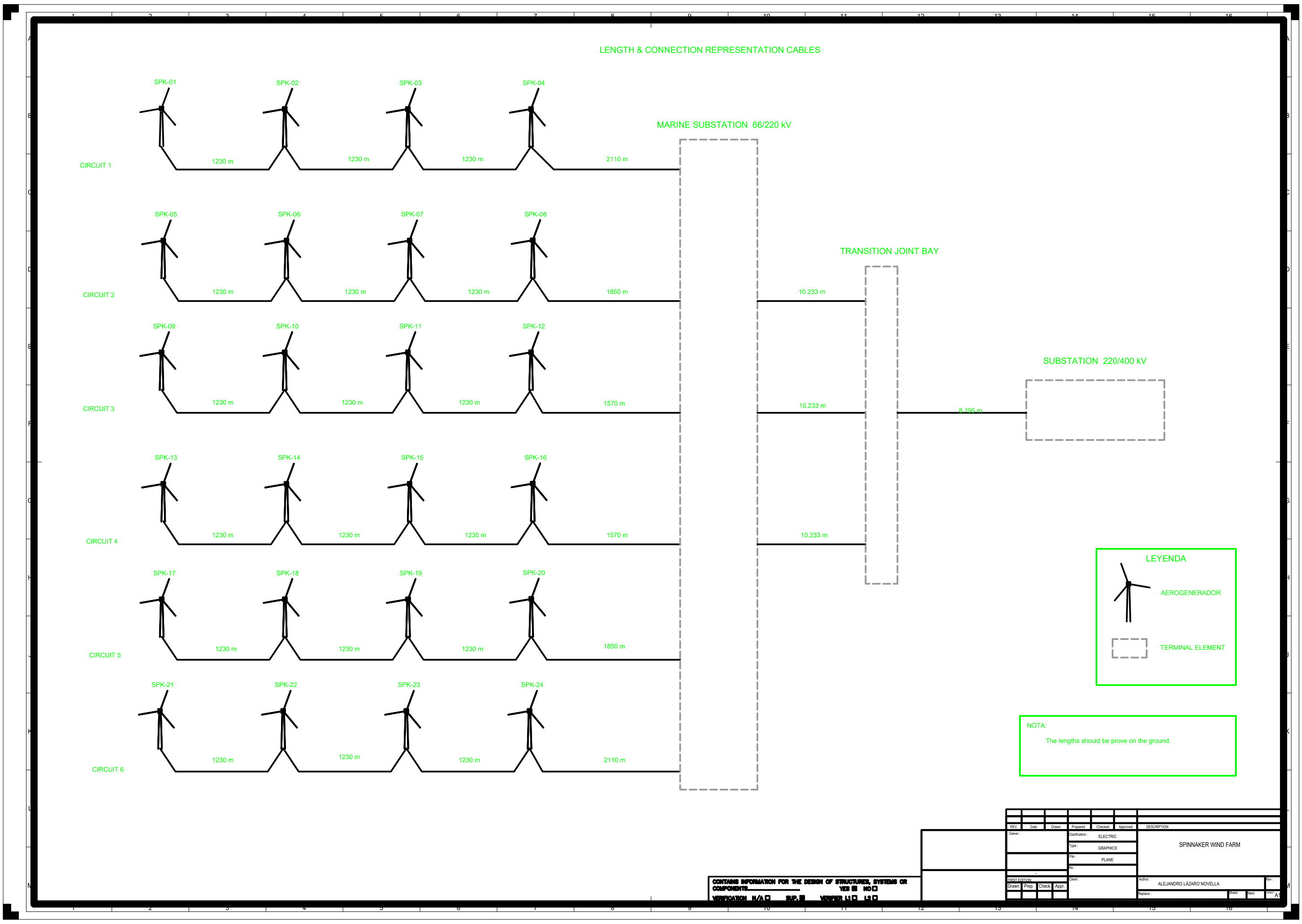
LENGTH & CONNECTION REPRESENTATION CABLES
MARINE SUBSTATION 66/220 kV
TRANSITION JOINT BAY
SUBSTATION 220/400 kV
CIRCUIT 1
SPK-01
SPK-02
SPK-03
SPK-04
1230 m
1230 m
1230 m
2110 m
CIRCUIT 2
SPK-05
SPK-06
SPK-07
SPK-08
1230 m
1230 m
1230 m
1850 m
10.233 m
CIRCUIT 3
SPK-09
SPK-10
SPK-11
SPK-12
1230 m
1230 m
1230 m
1570 m
10.233 m
8.195 m
CIRCUIT 4
SPK-13
SPK-14
SPK-15
SPK-16
1230 m
1230 m
1230 m
1570 m
10.233 m
CIRCUIT 5
SPK-17
SPK-18
SPK-19
SPK-20
1230 m
1230 m
1230 m
1850 m
CIRCUIT 6
SPK-21
SPK-22
SPK-23
SPK-24
1230 m
1230 m
1230 m
2110 m
LEYENDA
AEROGENERADOR
TERMINAL ELEMENT
NOTA:
The lengths should be prove on the ground.
CONTAINS INFORMATION FOR THE DESIGN OF STRUCTURES, SYSTEMS OR COMPONENTS.............................. YES NO
VERIFICATION N/A SUP. VERIFIER L1 L2
REV. Date Drawn Prepared Checked Approved DESCRIPTION
Owner :
Clasification : ELECTRIC
Type : GRAPHICS
File : PLANE
No :
FIRST EDITION:
Drawn Prep. Check. Appr.
Client :
SPINNAKER WIND FARM
Author : ALEJANDRO LÁZARO NOVELLA
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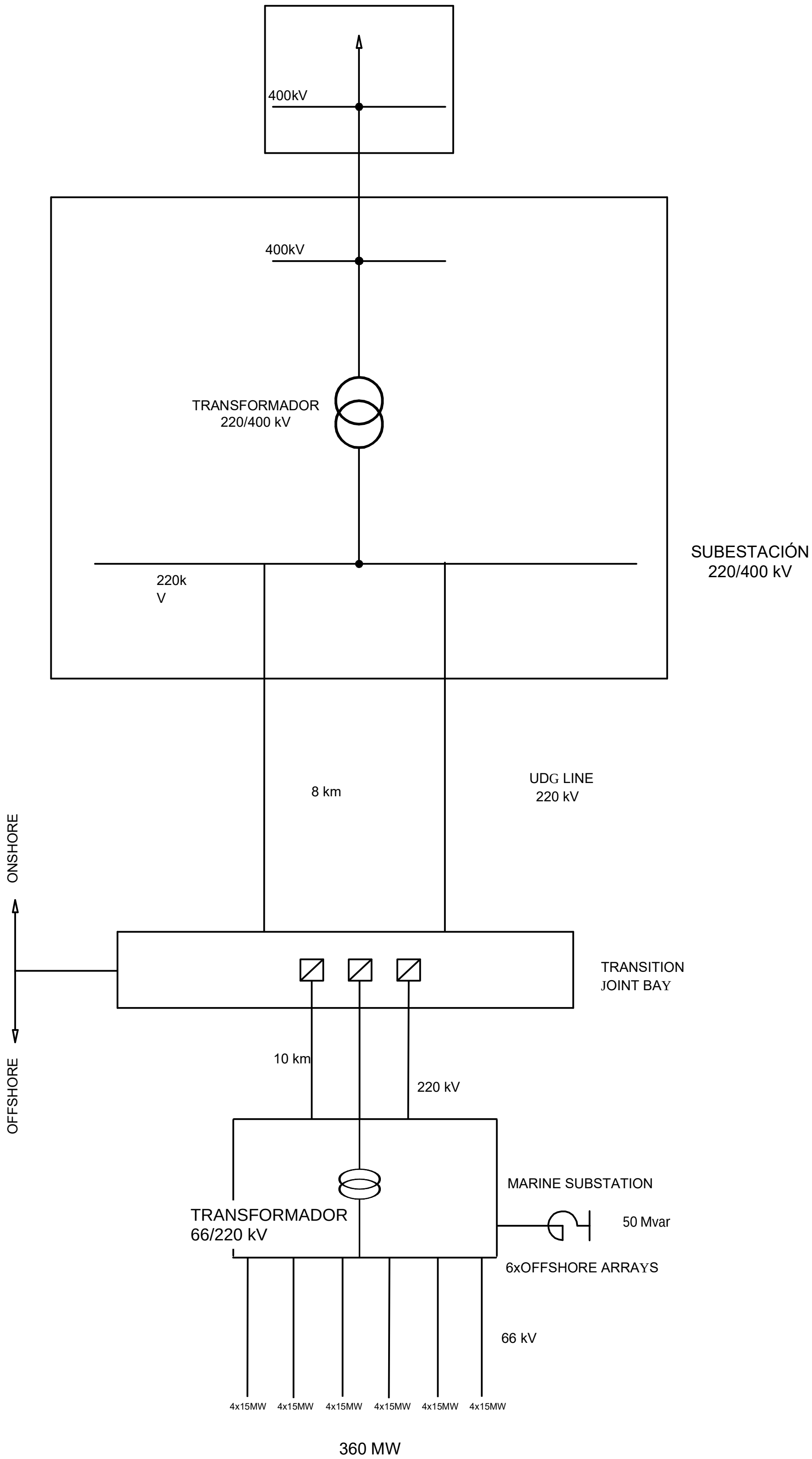

400kV
400kV
TRANSFORMADOR
220/400 kV
SUBESTACIÓN
220/400 kV
220k
V
8 km
UDG LINE
220 kV
ONSHORE
OFFSHORE
TRANSITION
JOINT BAY
10 km
220 kV
MARINE SUBSTATION
TRANSFORMADOR
66/220 kV
50 Mvar
6xOFFSHORE ARRAYS
66 kV
4x15MW
4x15MW
4x15MW
4x15MW
4x15MW
4x15MW
360 MW

XLPE Submarine Cable Systems
Attachment to XLPE Land Cable Systems - User´s Guide

Rev 5

Power and productivity
for a better world™

CONTENT

XLPE Submarine Cable Systems

To make sure you have the latest version of this brochure, have a look at www.abb.com/cables

CURRENT RATING FOR XLPE SUBMARINE CABLE SYSTEMS

The XLPE cable should at least have a conductor cross section adequate to meet the system requirements for power transmission capacity. The cost of energy losses can be reduced by using larger conductor.

Load losses in XLPE cables are primarily due to the ohmic losses in the conductor and the metallic screen. XLPE cables can be loaded continuously to a conductor temperature of 90°C.

The dielectric losses of XLPE insulation are present also at no load. Those losses depend on the operation voltage applied and shall be considered above 100 kV.

Dielectric losses in XLPE cables are lower than for EPR and fluid-filled cables.

The current rating of submarine cables follows the same rules as for land cables. However there are some differences:

– Three-core submarine cables usually have steel wire armour. Single-core cables have non-magnetic armour.
– Single-core cables can be laid separated or close. Close laying gives lower losses. Separation eliminates mutual heating but means higher losses in the armour. The induced current in the armour can be high, up to the same value as in the conductor.

Single-core cable with lead sheath and wire armour

Three-core cable with optic fibers, lead sheath and wire armour

Continuous current ratings for three-core submarine cables are given in Tables 33-34 and for single-core cables in Tables 35-36. The continuous current ratings are calculated according to IEC 60287 series of standards and with the following conditions:

– One three-core cable or one three-phase group of single-core cables
– Temperature in sea bed 20°C
– Laying depth in sea bed 1.0 m
– Sea bed thermal resistivity 1.0 K x m/W

Rating factors for sea bed temperature - see Tables 7-11 in the brochure “XLPE Land Cable Systems - User’s guide”.

Current rating for three-core submarine cables with steel wire armour

Table 33

10-90 kV XLPE 3-core cables		
Cross section mm²	Copper conductor	Aluminium conductor
	A	A
95	300	235
120	340	265
150	375	300
185	420	335
240	480	385
300	530	430
400	590	485
500	655	540
630	715	600
800	775	660
1000	825	720

Table 34

100-300 kV XLPE 3-core cables		
Cross section mm²	Copper conductor	Aluminium conductor
	A	A
300	530	430
400	590	485
500	655	540
630	715	600
800	775	660
1000	825	720

CURRENT RATING FOR XLPE SUBMARINE CABLE SYSTEMS

Current rating for single-core submarine cables

Table 35

Cross section Cu conductor	Rated voltage 10 - 90 kV	
	Wide spacing	Close spacing
mm²	A	A
95	410	315
120	465	355
150	520	395
185	585	435
240	670	495
300	750	545
400	840	610
500	940	670
630	1050	740
800	1160	805
1000	1265	870

Table 36

Cross section Cu conductor	Rated voltage 100 - 420 kV	
	Wide spacing	Close spacing
mm²	A	A
185	580	445
240	670	505
300	750	560
400	845	620
500	950	690
630	1065	760
800	1180	830
1000	1290	895

Note 1: Calculations were performed assuming single layer of 5 mm copper armour wire.
Note 2: Aluminium cables (conductor made of aluminum and armouring made of aluminium alloy) will have a rating of 75 to 80 % for the same conductor area.
Note 3: The rating data given in the above tables should be regarded as indicative only.
Note 4: Cross sections larger than 1000 mm² can be offered on request.

Single-core cables with lead sheath

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance ●●●
mm²	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km

Table 37

Single-core cables, nominal voltage 220 kV (Um = 245 kV)										
500	26.2	24.0	77.6	2.9	111.0	19.1	29.3	0.14	5.8	1.42
630	29.8	23.0	79.2	3.0	112.8	20.0	31.2	0.16	6.4	1.40
800	33.7	23.0	83.1	3.1	117.5	21.9	34.5	0.17	6.9	1.37
1000	37.9	23.0	87.3	3.1	121.9	23.5	37.7	0.19	7.4	1.35
1200	41.2	23.0	90.6	3.1	125.2	24.8	40.4	0.20	7.8	1.33
1400	44.4	23.0	93.8	3.1	128.6	26.1	43.2	0.21	8.2	1.32
1600	47.4	23.0	96.8	3.1	131.8	27.5	46.0	0.22	8.6	1.31

Table 38

Single-core cables, nominal voltage 275 kV (Um = 300 kV)										
500	26.2	26.0	81.6	3.0	115.2	20.5	31.1	0.14	6.8	1.42
630	29.8	24.0	81.2	3.0	114.8	20.6	31.8	0.16	7.7	1.40
800	33.7	24.0	85.1	3.1	119.5	22.5	35.2	0.17	8.3	1.37
1000	37.9	24.0	89.3	3.1	123.9	24.1	38.4	0.18	9.0	1.35
1200	41.2	24.0	92.6	3.1	127.4	25.5	41.6	0.19	9.5	1.33
1400	44.4	24.0	95.8	3.1	130.6	26.8	44.4	0.20	10.0	1.32
1600	47.4	24.0	98.8	3.1	133.8	28.1	47.2	0.21	10.4	1.31

Table 39

Single-core cables, nominal voltage 330 kV (Um = 362 kV)										
630	29.8	28.0	89.2	3.1	123.4	23.3	35.2	0.14	8.8	1.40
800	33.7	27.0	91.1	3.1	125.9	24.3	37.5	0.15	9.7	1.37
1000	37.9	26.0	93.3	3.1	128.1	25.3	39.9	0.17	10.7	1.35
1200	41.2	25.0	94.6	3.1	129.4	26.1	42.0	0.18	11.1	1.33
1400	44.4	25.0	97.8	3.1	132.8	27.4	44.9	0.19	11.6	1.32
1600	47.4	25.0	100.8	3.1	135.8	28.7	47.7	0.20	12.1	1.31

Table 40

Single-core cables, nominal voltage 400 kV (Um = 420 kV)										
630	29.8	32.0	98.2	3.1	132.8	26.1	38.8	0.13	9.6	1.40
800	33.7	30.0	98.1	3.1	133.1	26.5	40.2	0.15	10.7	1.37
1000	37.9	29.0	100.3	3.1	135.3	27.5	42.6	0.16	11.7	1.35
1200	41.2	27.0	99.6	3.1	134.6	27.7	44.0	0.18	12.9	1.33
1400	44.4	27.0	102.8	3.1	138.0	29.0	46.9	0.19	13.5	1.32
1600	47.4	27.0	105.8	3.1	141.0	30.4	49.7	0.19	14.1	1.31

TECHNICAL DATA FOR XLPE SUBMARINE CABLE SYSTEMS

Three-core cables with copper wire screen

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross section of screen	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km

Table 41

Three-core cables, nominal voltage 10 kV (Um = 12 kV)										
70	9.6	3.4	18.8	16	80.7	13.7	15.0	0.31	0.6	0.41
95	11.2	3.4	20.4	16	84.2	14.4	16.2	0.34	0.6	0.39
120	12.6	3.4	21.8	16	87.2	14.9	17.2	0.37	0.7	0.37
150	14.2	3.4	23.4	16	90.6	15.7	18.5	0.40	0.7	0.36
185	15.8	3.4	25.0	16	94.1	16.5	19.9	0.44	0.8	0.35
240	18.1	3.4	27.3	16	99.1	17.7	22.2	0.48	0.9	0.33
300	20.4	3.4	29.6	16	104.0	18.9	24.5	0.53	1.0	0.32
400	23.2	3.4	32.4	16	110.1	20.8	28.2	0.59	1.1	0.31
500	26.2	3.4	35.8	16	117.4	22.7	32.1	0.66	1.2	0.30

Table 42

Three-core cables, nominal voltage 20 kV (Um = 24 kV)										
70	9.6	5.5	23.0	16	89.8	15.1	16.4	0.21	0.8	0.44
95	11.2	5.5	24.6	16	93.2	15.8	17.6	0.23	0.9	0.41
120	12.6	5.5	26.0	16	96.2	16.6	18.8	0.25	0.9	0.40
150	14.2	5.5	27.6	16	99.7	17.3	20.1	0.27	1.0	0.38
185	15.8	5.5	29.2	16	103.2	18.2	21.6	0.29	1.1	0.37
240	18.1	5.5	31.5	16	108.1	19.3	23.7	0.32	1.2	0.35
300	20.4	5.5	33.8	16	113.1	20.6	26.2	0.35	1.3	0.34
400	23.2	5.5	36.6	16	119.1	22.5	29.9	0.39	1.4	0.33
500	26.2	5.5	40.0	16	126.5	24.5	33.8	0.43	1.6	0.32
630	29.8	5.5	43.6	16	134.3	26.7	38.5	0.48	1.7	0.31

Table 43

Three-core cables, nominal voltage 30 kV (Um = 36 kV)										
70	9.6	8.0	28.0	16	100.6	16.9	18.2	0.16	0.9	0.46
95	11.2	8.0	29.6	16	104.0	17.7	19.5	0.18	1.0	0.44
120	12.6	8.0	31.0	16	107.0	18.4	20.7	0.19	1.0	0.42
150	14.2	8.0	32.6	16	110.5	19.3	22.1	0.21	1.1	0.41
185	15.8	8.0	34.2	16	114.0	20.1	23.6	0.22	1.2	0.39
240	18.1	8.0	36.5	16	118.9	21.4	25.9	0.24	1.3	0.38
300	20.4	8.0	38.8	16	123.9	22.6	28.2	0.26	1.4	0.36
400	23.2	8.0	41.6	16	129.9	24.6	32.0	0.29	1.6	0.35
500	26.2	8.0	45.0	16	137.3	26.7	36.0	0.32	1.7	0.34
630	29.8	8.0	48.6	16	145.1	29.2	40.9	0.35	1.9	0.32
800	33.7	8.0	52.5	16	154.4	32.2	47.2	0.38	2.1	0.31

TECHNICAL DATA FOR XLPE SUBMARINE CABLE SYSTEMS

Three-core cables with lead sheath

Table 44

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm^2	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km
Three-core cables, nominal voltage 45 kV (Um = 52 kV)										
95	11.2	8.0	29.6	1.3	109.0	19.1	20.8	0.18	1.5	0.43
120	12.6	8.0	31.0	1.3	112.0	20.0	22.3	0.19	1.6	0.42
150	14.2	8.0	32.6	1.4	116.0	21.6	24.4	0.21	1.6	0.40
185	15.8	8.0	34.2	1.4	119.0	22.7	26.2	0.22	1.8	0.39
240	18.1	8.0	36.5	1.5	124.0	25.0	29.5	0.24	2.0	0.37
300	20.4	8.0	38.8	1.6	130.0	27.3	32.9	0.26	2.2	0.36
400	23.2	8.0	41.6	1.7	136.0	30.4	37.9	0.29	2.3	0.35
500	26.2	8.0	45.0	1.8	144.0	33.8	43.2	0.32	2.6	0.33
630	29.8	8.0	48.6	1.9	152.0	37.8	49.7	0.35	2.9	0.32
800	33.7	8.0	52.5	2.1	162.0	43.5	58.6	0.38	3.1	0.31
1000	37.9	8.0	57.3	2.2	173.0	49.3	68.1	0.42	3.5	0.30

Table 45

Three-core cables, nominal voltage 66 kV (Um = 72.5 kV)										
95	11.2	9.0	31.6	1.3	113.0	19.8	21.6	0.17	2.0	0.44
120	12.6	9.0	33.0	1.4	116.0	21.6	23.8	0.18	2.1	0.43
150	14.2	9.0	34.6	1.4	120.0	22.9	25.7	0.19	2.3	0.41
185	15.8	9.0	36.2	1.4	124.0	24.5	28.0	0.20	2.4	0.40
240	18.1	9.0	38.5	1.6	129.0	26.8	31.3	0.22	2.6	0.38
300	20.4	9.0	40.8	1.6	134.0	28.7	34.3	0.24	2.8	0.37
400	23.2	9.0	43.6	1.7	141.0	31.7	39.2	0.26	3.1	0.35
500	26.2	9.0	47.0	1.9	149.0	36.0	45.4	0.29	3.5	0.34
630	29.8	9.0	50.6	2.0	157.0	40.1	52.0	0.32	3.7	0.33
800	33.7	9.0	54.5	2.1	167.0	45.1	60.1	0.35	4.1	0.32
1000	37.9	9.0	59.3	2.3	178.0	51.8	70.7	0.38	4.6	0.31

Table 46

Three-core cables, nominal voltage 110 kV (Um = 123 kV)										
185	15.8	16.0	50.2	2.0	156.0	37.4	40.9	0.14	2.8	0.46
240	18.1	15.0	50.5	2.0	157.0	38.0	42.5	0.15	3.0	0.43
300	20.4	14.0	50.8	2.0	157.0	38.5	44.1	0.17	3.5	0.41
400	23.2	13.0	51.6	2.0	159.0	39.7	47.2	0.20	3.9	0.38
500	26.2	13.0	55.0	2.1	167.0	43.6	53.0	0.22	4.3	0.37
630	29.8	13.0	58.6	2.3	176.0	48.8	60.7	0.24	4.7	0.36
800	33.7	13.0	62.5	2.4	185.0	54.4	69.5	0.26	5.2	0.34
1000	37.9	13.0	67.3	2.6	197.0	61.6	80.5	0.28	5.6	0.33

TECHNICAL DATA FOR XLPE SUBMARINE CABLE SYSTEMS

Three-core cables with lead sheath

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm^2	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km

Table 47

Three-core cables, nominal voltage 132 kV (Um = 145 kV)										
185	15.8	18.0	54.2	2.1	165.0	41.4	44.9	0.13	3.0	0.47
240	18.1	17.0	54.5	2.1	166.0	41.8	46.3	0.14	3.4	0.44
300	20.4	16.0	54.8	2.1	167.0	42.4	48.0	0.16	3.8	0.42
400	23.2	15.0	55.6	2.1	168.0	43.6	51.1	0.18	4.3	0.40
500	26.2	15.0	59.0	2.3	176.0	48.6	58.0	0.20	4.6	0.38
630	29.8	15.0	62.6	2.4	185.0	53.3	65.2	0.21	5.1	0.37
800	33.7	15.0	66.5	2.5	194.0	59.0	74.0	0.23	5.6	0.36
1000	37.9	15.0	71.3	2.7	206.0	66.6	85.4	0.25	6.1	0.35

Table 48

Three-core cables, nominal voltage 150 kV (Um = 170 kV)										
240	18.1	21.0	62.5	2.4	184.0	51.1	55.5	0.13	3.4	0.47
300	20.4	20.0	62.8	2.4	185.0	51.7	57.3	0.14	3.7	0.44
400	23.2	19.0	63.6	2.4	187.0	52.9	60.5	0.15	4.1	0.42
500	26.2	18.0	65.0	2.5	190.0	55.7	65.1	0.17	4.7	0.40
630	29.8	17.0	66.6	2.5	194.0	57.8	69.7	0.19	5.3	0.38
800	33.7	17.0	70.5	2.7	204.0	64.7	79.8	0.21	5.7	0.37
1000	37.9	17.0	75.3	2.8	215.0	71.6	90.5	0.23	6.3	0.36

Table 49

Three-core cables, nominal voltage 220 kV (Um = 245 kV)										
500	26.2	24.0	77.6	2.9	219.0	71.8	81.3	0.14	5.7	0.43
630	29.8	23.0	79.2	3.0	224.0	74.9	86.7	0.16	6.4	0.41
800	33.7	23.0	83.1	3.1	234.0	80.2	95.3	0.17	6.9	0.40
1000	37.9	23.0	87.3	3.1	241.0	85.1	104.0	0.19	7.4	0.38

Table 50

Three-core cables, nominal voltage 275 kV (Um = 300 kV)										
500	26.2	26.0	81.6	2.9	229.0	75.3	84.7	0.14	6.8	0.44
630	29.8	24.0	81.2	3.0	228.0	77.0	88.9	0.16	7.7	0.42
800	33.7	24.0	85.1	3.1	237.0	82.5	97.6	0.17	8.3	0.40
1000	37.9	24.0	89.3	3.1	247.0	87.4	106.3	0.18	9.0	0.39

Notes

Notes

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CONTENT

XLPE Submarine Cable Systems

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CURRENT RATING FOR XLPE SUBMARINE CABLE SYSTEMS

The XLPE cable should at least have a conductor cross section adequate to meet the system requirements for power transmission capacity. The cost of energy losses can be reduced by using larger conductor.

Load losses in XLPE cables are primarily due to the ohmic losses in the conductor and the metallic screen. XLPE cables can be loaded continuously to a conductor temperature of 90°C.

The dielectric losses of XLPE insulation are present also at no load. Those losses depend on the operation voltage applied and shall be considered above 100 kV.

Dielectric losses in XLPE cables are lower than for EPR and fluid-filled cables.

The current rating of submarine cables follows the same rules as for land cables. However there are some differences:

– Three-core submarine cables usually have steel wire armour. Single-core cables have non-magnetic armour.
– Single-core cables can be laid separated or close. Close laying gives lower losses. Separation eliminates mutual heating but means higher losses in the armour. The induced current in the armour can be high, up to the same value as in the conductor.

Single-core cable with lead sheath and wire armour

Three-core cable with optic fibers, lead sheath and wire armour

Continuous current ratings for three-core submarine cables are given in Tables 33-34 and for single-core cables in Tables 35-36. The continuous current ratings are calculated according to IEC 60287 series of standards and with the following conditions:

– One three-core cable or one three-phase group of single-core cables
– Temperature in sea bed 20°C
– Laying depth in sea bed 1.0 m
– Sea bed thermal resistivity 1.0 K x m/W

Rating factors for sea bed temperature - see Tables 7-11 in the brochure “XLPE Land Cable Systems - User’s guide”.

Current rating for three-core submarine cables with steel wire armour

Table 33

10-90 kV XLPE 3-core cables		
Cross section mm²	Copper conductor A	Aluminium conductor A
95	300	235
120	340	265
150	375	300
185	420	335
240	480	385
300	530	430
400	590	485
500	655	540
630	715	600
800	775	660
1000	825	720

Table 34

100-300 kV XLPE 3-core cables		
Cross section mm²	Copper conductor A	Aluminium conductor A
300	530	430
400	590	485
500	655	540
630	715	600
800	775	660
1000	825	720

CURRENT RATING FOR XLPE SUBMARINE CABLE SYSTEMS

Current rating for single-core submarine cables

Table 35

Cross section Cu conductor	Rated voltage 10 - 90 kV	
	Wide spacing	Close spacing
mm²	A	A
95	410	315
120	465	355
150	520	395
185	585	435
240	670	495
300	750	545
400	840	610
500	940	670
630	1050	740
800	1160	805
1000	1265	870

Table 36

Cross section Cu conductor	Rated voltage 100 - 420 kV	
	Wide spacing	Close spacing
mm²	A	A
185	580	445
240	670	505
300	750	560
400	845	620
500	950	690
630	1065	760
800	1180	830
1000	1290	895

Note 1: Calculations were performed assuming single layer of 5 mm copper armour wire.
Note 2: Aluminium cables (conductor made of aluminum and armouring made of aluminium alloy) will have a rating of 75 to 80 % for the same conductor area.
Note 3: The rating data given in the above tables should be regarded as indicative only.
Note 4: Cross sections larger than 1000 mm² can be offered on request.

TECHNICAL DATA FOR XLPE SUBMARINE CABLE SYSTEMS

Single-core cables with lead sheath

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance ●●●
mm²	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km

Table 37

Single-core cables, nominal voltage 220 kV (Um = 245 kV)										
500	26.2	24.0	77.6	2.9	111.0	19.1	29.3	0.14	5.8	1.42
630	29.8	23.0	79.2	3.0	112.8	20.0	31.2	0.16	6.4	1.40
800	33.7	23.0	83.1	3.1	117.5	21.9	34.5	0.17	6.9	1.37
1000	37.9	23.0	87.3	3.1	121.9	23.5	37.7	0.19	7.4	1.35
1200	41.2	23.0	90.6	3.1	125.2	24.8	40.4	0.20	7.8	1.33
1400	44.4	23.0	93.8	3.1	128.6	26.1	43.2	0.21	8.2	1.32
1600	47.4	23.0	96.8	3.1	131.8	27.5	46.0	0.22	8.6	1.31

Table 38

Single-core cables, nominal voltage 275 kV (Um = 300 kV)										
500	26.2	26.0	81.6	3.0	115.2	20.5	31.1	0.14	6.8	1.42
630	29.8	24.0	81.2	3.0	114.8	20.6	31.8	0.16	7.7	1.40
800	33.7	24.0	85.1	3.1	119.5	22.5	35.2	0.17	8.3	1.37
1000	37.9	24.0	89.3	3.1	123.9	24.1	38.4	0.18	9.0	1.35
1200	41.2	24.0	92.6	3.1	127.4	25.5	41.6	0.19	9.5	1.33
1400	44.4	24.0	95.8	3.1	130.6	26.8	44.4	0.20	10.0	1.32
1600	47.4	24.0	98.8	3.1	133.8	28.1	47.2	0.21	10.4	1.31

Table 39

Single-core cables, nominal voltage 330 kV (Um = 362 kV)										
630	29.8	28.0	89.2	3.1	123.4	23.3	35.2	0.14	8.8	1.40
800	33.7	27.0	91.1	3.1	125.9	24.3	37.5	0.15	9.7	1.37
1000	37.9	26.0	93.3	3.1	128.1	25.3	39.9	0.17	10.7	1.35
1200	41.2	25.0	94.6	3.1	129.4	26.1	42.0	0.18	11.1	1.33
1400	44.4	25.0	97.8	3.1	132.8	27.4	44.9	0.19	11.6	1.32
1600	47.4	25.0	100.8	3.1	135.8	28.7	47.7	0.20	12.1	1.31

Table 40

Single-core cables, nominal voltage 400 kV (Um = 420 kV)										
630	29.8	32.0	98.2	3.1	132.8	26.1	38.8	0.13	9.6	1.40
800	33.7	30.0	98.1	3.1	133.1	26.5	40.2	0.15	10.7	1.37
1000	37.9	29.0	100.3	3.1	135.3	27.5	42.6	0.16	11.7	1.35
1200	41.2	27.0	99.6	3.1	134.6	27.7	44.0	0.18	12.9	1.33
1400	44.4	27.0	102.8	3.1	138.0	29.0	46.9	0.19	13.5	1.32
1600	47.4	27.0	105.8	3.1	141.0	30.4	49.7	0.19	14.1	1.31

TECHNICAL DATA FOR XLPE SUBMARINE CABLE SYSTEMS

Three-core cables with copper wire screen

Table 41

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross section of screen	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km
Three-core cables, nominal voltage 10 kV (Um = 12 kV)										
70	9.6	3.4	18.8	16	80.7	13.7	15.0	0.31	0.6	0.41
95	11.2	3.4	20.4	16	84.2	14.4	16.2	0.34	0.6	0.39
120	12.6	3.4	21.8	16	87.2	14.9	17.2	0.37	0.7	0.37
150	14.2	3.4	23.4	16	90.6	15.7	18.5	0.40	0.7	0.36
185	15.8	3.4	25.0	16	94.1	16.5	19.9	0.44	0.8	0.35
240	18.1	3.4	27.3	16	99.1	17.7	22.2	0.48	0.9	0.33
300	20.4	3.4	29.6	16	104.0	18.9	24.5	0.53	1.0	0.32
400	23.2	3.4	32.4	16	110.1	20.8	28.2	0.59	1.1	0.31
500	26.2	3.4	35.8	16	117.4	22.7	32.1	0.66	1.2	0.30

Table 42

Three-core cables, nominal voltage 20 kV (Um = 24 kV)										
70	9.6	5.5	23.0	16	89.8	15.1	16.4	0.21	0.8	0.44
95	11.2	5.5	24.6	16	93.2	15.8	17.6	0.23	0.9	0.41
120	12.6	5.5	26.0	16	96.2	16.6	18.8	0.25	0.9	0.40
150	14.2	5.5	27.6	16	99.7	17.3	20.1	0.27	1.0	0.38
185	15.8	5.5	29.2	16	103.2	18.2	21.6	0.29	1.1	0.37
240	18.1	5.5	31.5	16	108.1	19.3	23.7	0.32	1.2	0.35
300	20.4	5.5	33.8	16	113.1	20.6	26.2	0.35	1.3	0.34
400	23.2	5.5	36.6	16	119.1	22.5	29.9	0.39	1.4	0.33
500	26.2	5.5	40.0	16	126.5	24.5	33.8	0.43	1.6	0.32
630	29.8	5.5	43.6	16	134.3	26.7	38.5	0.48	1.7	0.31

Table 43

Three-core cables, nominal voltage 30 kV (Um = 36 kV)										
70	9.6	8.0	28.0	16	100.6	16.9	18.2	0.16	0.9	0.46
95	11.2	8.0	29.6	16	104.0	17.7	19.5	0.18	1.0	0.44
120	12.6	8.0	31.0	16	107.0	18.4	20.7	0.19	1.0	0.42
150	14.2	8.0	32.6	16	110.5	19.3	22.1	0.21	1.1	0.41
185	15.8	8.0	34.2	16	114.0	20.1	23.6	0.22	1.2	0.39
240	18.1	8.0	36.5	16	118.9	21.4	25.9	0.24	1.3	0.38
300	20.4	8.0	38.8	16	123.9	22.6	28.2	0.26	1.4	0.36
400	23.2	8.0	41.6	16	129.9	24.6	32.0	0.29	1.6	0.35
500	26.2	8.0	45.0	16	137.3	26.7	36.0	0.32	1.7	0.34
630	29.8	8.0	48.6	16	145.1	29.2	40.9	0.35	1.9	0.32
800	33.7	8.0	52.5	16	154.4	32.2	47.2	0.38	2.1	0.31

Three-core cables with lead sheath

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm^2	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km

Table 44

Three-core cables, nominal voltage 45 kV (Um = 52 kV)										
95	11.2	8.0	29.6	1.3	109.0	19.1	20.8	0.18	1.5	0.43
120	12.6	8.0	31.0	1.3	112.0	20.0	22.3	0.19	1.6	0.42
150	14.2	8.0	32.6	1.4	116.0	21.6	24.4	0.21	1.6	0.40
185	15.8	8.0	34.2	1.4	119.0	22.7	26.2	0.22	1.8	0.39
240	18.1	8.0	36.5	1.5	124.0	25.0	29.5	0.24	2.0	0.37
300	20.4	8.0	38.8	1.6	130.0	27.3	32.9	0.26	2.2	0.36
400	23.2	8.0	41.6	1.7	136.0	30.4	37.9	0.29	2.3	0.35
500	26.2	8.0	45.0	1.8	144.0	33.8	43.2	0.32	2.6	0.33
630	29.8	8.0	48.6	1.9	152.0	37.8	49.7	0.35	2.9	0.32
800	33.7	8.0	52.5	2.1	162.0	43.5	58.6	0.38	3.1	0.31
1000	37.9	8.0	57.3	2.2	173.0	49.3	68.1	0.42	3.5	0.30

Table 45

Three-core cables, nominal voltage 66 kV (Um = 72.5 kV)										
95	11.2	9.0	31.6	1.3	113.0	19.8	21.6	0.17	2.0	0.44
120	12.6	9.0	33.0	1.4	116.0	21.6	23.8	0.18	2.1	0.43
150	14.2	9.0	34.6	1.4	120.0	22.9	25.7	0.19	2.3	0.41
185	15.8	9.0	36.2	1.4	124.0	24.5	28.0	0.20	2.4	0.40
240	18.1	9.0	38.5	1.6	129.0	26.8	31.3	0.22	2.6	0.38
300	20.4	9.0	40.8	1.6	134.0	28.7	34.3	0.24	2.8	0.37
400	23.2	9.0	43.6	1.7	141.0	31.7	39.2	0.26	3.1	0.35
500	26.2	9.0	47.0	1.9	149.0	36.0	45.4	0.29	3.5	0.34
630	29.8	9.0	50.6	2.0	157.0	40.1	52.0	0.32	3.7	0.33
800	33.7	9.0	54.5	2.1	167.0	45.1	60.1	0.35	4.1	0.32
1000	37.9	9.0	59.3	2.3	178.0	51.8	70.7	0.38	4.6	0.31

Table 46

Three-core cables, nominal voltage 110 kV (Um = 123 kV)										
185	15.8	16.0	50.2	2.0	156.0	37.4	40.9	0.14	2.8	0.46
240	18.1	15.0	50.5	2.0	157.0	38.0	42.5	0.15	3.0	0.43
300	20.4	14.0	50.8	2.0	157.0	38.5	44.1	0.17	3.5	0.41
400	23.2	13.0	51.6	2.0	159.0	39.7	47.2	0.20	3.9	0.38
500	26.2	13.0	55.0	2.1	167.0	43.6	53.0	0.22	4.3	0.37
630	29.8	13.0	58.6	2.3	176.0	48.8	60.7	0.24	4.7	0.36
800	33.7	13.0	62.5	2.4	185.0	54.4	69.5	0.26	5.2	0.34
1000	37.9	13.0	67.3	2.6	197.0	61.6	80.5	0.28	5.6	0.33

TECHNICAL DATA FOR XLPE SUBMARINE CABLE SYSTEMS

Three-core cables with lead sheath

Cross-section of con-ductor	Diameter of con-ductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capaci-tance	Charging current per phase at 50 Hz	Inductance
mm²	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km

Table 47

Three-core cables, nominal voltage 132 kV (Um = 145 kV)										
185	15.8	18.0	54.2	2.1	165.0	41.4	44.9	0.13	3.0	0.47
240	18.1	17.0	54.5	2.1	166.0	41.8	46.3	0.14	3.4	0.44
300	20.4	16.0	54.8	2.1	167.0	42.4	48.0	0.16	3.8	0.42
400	23.2	15.0	55.6	2.1	168.0	43.6	51.1	0.18	4.3	0.40
500	26.2	15.0	59.0	2.3	176.0	48.6	58.0	0.20	4.6	0.38
630	29.8	15.0	62.6	2.4	185.0	53.3	65.2	0.21	5.1	0.37
800	33.7	15.0	66.5	2.5	194.0	59.0	74.0	0.23	5.6	0.36
1000	37.9	15.0	71.3	2.7	206.0	66.6	85.4	0.25	6.1	0.35

Table 48

Three-core cables, nominal voltage 150 kV (Um = 170 kV)										
240	18.1	21.0	62.5	2.4	184.0	51.1	55.5	0.13	3.4	0.47
300	20.4	20.0	62.8	2.4	185.0	51.7	57.3	0.14	3.7	0.44
400	23.2	19.0	63.6	2.4	187.0	52.9	60.5	0.15	4.1	0.42
500	26.2	18.0	65.0	2.5	190.0	55.7	65.1	0.17	4.7	0.40
630	29.8	17.0	66.6	2.5	194.0	57.8	69.7	0.19	5.3	0.38
800	33.7	17.0	70.5	2.7	204.0	64.7	79.8	0.21	5.7	0.37
1000	37.9	17.0	75.3	2.8	215.0	71.6	90.5	0.23	6.3	0.36

Table 49

Three-core cables, nominal voltage 220 kV (Um = 245 kV)										
500	26.2	24.0	77.6	2.9	219.0	71.8	81.3	0.14	5.7	0.43
630	29.8	23.0	79.2	3.0	224.0	74.9	86.7	0.16	6.4	0.41
800	33.7	23.0	83.1	3.1	234.0	80.2	95.3	0.17	6.9	0.40
1000	37.9	23.0	87.3	3.1	241.0	85.1	104.0	0.19	7.4	0.38

Table 50

Three-core cables, nominal voltage 275 kV (Um = 300 kV)										
500	26.2	26.0	81.6	2.9	229.0	75.3	84.7	0.14	6.8	0.44
630	29.8	24.0	81.2	3.0	228.0	77.0	88.9	0.16	7.7	0.42
800	33.7	24.0	85.1	3.1	237.0	82.5	97.6	0.17	8.3	0.40
1000	37.9	24.0	89.3	3.1	247.0	87.4	106.3	0.18	9.0	0.39

Notes

Notes

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2010-04, 2GM 5007 -sub GB rev5

V236-15.0 MW™

Wind. It means the world to us.™

Vestas®

Determined to lead offshore wind forward

We are driven by an ambition to power the clean energy future of our world. Offshore wind is pivotal to hitting that target. So we have been busy innova-ting, for the future of our industry and the future of our world.

The V236-15.0 MW™ is the culmination of that innovation. World-class technology shaped by industry-leading experience, onshore and offshore. It is built for a ground-breaking world: efficiently designed, globally applicable and engineered for peak performance. It is Vestas powering the future.

A strong foundation

We are battle-hardened. Over 40 years of turbine development expertise and over 25 years delivering projects offshore has given us some hard-earned lessons. Together with our partners, we have installed and maintained turbines in frozen tundras, in tropical trade winds, and in tsunami-stricken waters. From the installment of 500 kW turbines at Tunoe Knob in 1995 to the 9 MW platform turbines in operation today, we have been pushing boundaries offshore for more than 25 years. This experience has enabled us to hand-pick what works. It takes experience to know, and our lessons learned are fused into the core of Vestas' nextgeneration offshore platform.


Vestas

Introducing the V236-15.0 MW™

Advanced platform based on proven system designs
The V236-15.0 MW™ is built on proven, world-class technology. Drawing the best from our EnVentus and 9 MW platforms, the V236-15.0 MW™ is a continuation of proven results. Advanced system designs, such as our efficient geared drivetrain, our CubePower converter, and our Control System 8000, are integrated and optimised for our next-generation offshore platform. Due to the common technical design principles, V236-15.0 MW™ benefits directly from accumulated experience, development and scale synergies of the onshore and offshore business.

Designed for competitive project development
We are collaborative by nature, working with partners to offer a turbine made for the realities of project development, where every component matters. V236-15.0 MW™ is configured to strike the balance between energy production performance and number of turbines required at park level, while utilising advanced control and damping systems to optimise foundation requirements. The gearbox-based drivetrain offers a balanced, scalable, and efficient technology platform from which to enable the future growth of offshore wind.

Leading energy production at scale
Powered by a swept area of 43,742 m^2, the V236-15.0 MW™ moves the boundaries of offshore wind energy production forward. A single turbine is capable of producing up to 80GWh/year depending on site-specific conditions.
The 115.5m blades drive a capacity factor of over 60%, ensuring that fewer turbines enable greater annual energy production than ever before. Globally applicable, the turbine is designed for high wind conditions and rated to withstand IEC 1 extreme wind conditions up to 50 m/s and IEC T up to 57 m/s.

Safe and certain throughout project lifetimes
Vestas' rigorous testing standards guides the development of all of our turbines. The V236-15.0 MW™ is subject to the same stringent testing protocol. The V236-15.0 MW™ has a design lifetime of 30 years with the option to extend depending on project specific conditions. Strict quality control and life testing processes identify potential failure modes and mechanisms before they occur. The nacelle is ergonomically designed to make it easier for maintenance crews to gain access, reducing time spent offshore on service while maximising turbine uptime.
Our understanding of service needs, including in nascent segments such as floating offshore wind, has informed our design of the V236-15.0 MW™.

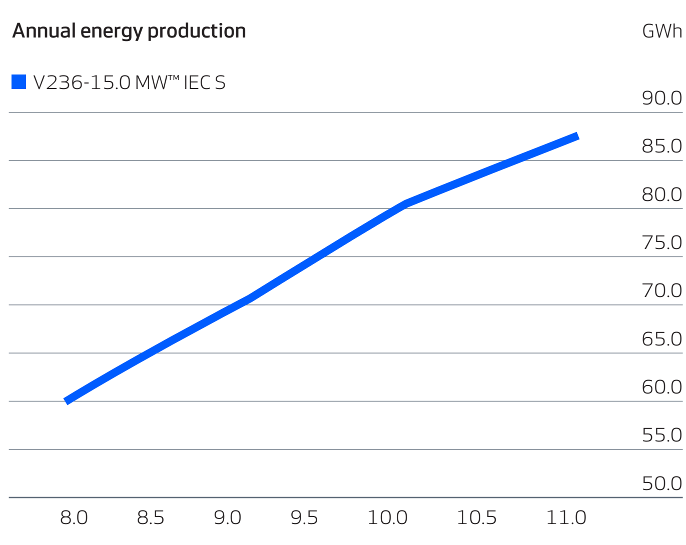
We've installed over 8,5 GW of turbines, **offshore.**

V236-15.0 MW™ IEC S

The V236-15.0 MW™ is built on proven, world-class technology and engineered for efficiency in offshore environments around the world.

Power regulation	Pitch regulated with variable speed
Operating data	
Rated power	15,000kW
Cut-in wind speed	3m/s
Cut-out wind speed	31m/s
Wind class	IEC S or S,T
Standard operating temperature range from -15°C to +23°C* with a de-rating interval from +23°C to +45°C	
* High ambient temperature variant available	
Sound power	
Maximum	115.3dB(A)
Rotor	
Rotor diameter	236m
Swept area	43,742m²
Aerodynamic brake	three blades full feathering
Electrical	
Frequency	50/60Hz
Converter	full scale
Gearbox	
Type	medium speed
Tower	
Hub heights	site-specific

Annual energy production



Assumptions
One wind turbine, 100% availability, 0% losses, k factor = 2,
Standard air density = 1.225, wind speed at hub height

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04/2023-EN