SUBSTATION REPORT

PV Plant Enio - Capacitor Bank Webinar
2024/03/25

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1. INTRODUCTION

The objective of this report compiled by RatedPower is to describe the specifications and design for the substation of the project, Enio - Capacitor Bank Webinar.

The sizing and calculations introduced in this report are performed according to the IEC standard.

The current specifications of the project can be subject to change in the next stages of project development. The main characteristics of the project are shown in Table 1.

Table 1. A summary of the characteristics of the project

Enio - Capacitor Bank Webinar project	
Location	Spain, Illes Balears
Substation capacity	148.56 MVA
High voltage level	220.0 kV
Medium voltage level	20.0 kV
Lightning impulse withstand voltage	1050.0 kV
Rated frequency	50 Hz
Installation	Outdoor
Type of switchgear	Air-insulated switchgear
Circuit arrangement	single busbar
Step-up power transformers	2

2. SITE

2.1. Location

The 220.0/20.0 kV air-insulated substation will evacuate 148.56 MVA and it is in Illes Balears. Additional information about the location of the substation is shown in Table 2.

Table 2. The location characteristics of the project

Substation location characteristics	
City / Town	Tres Alquerias
Region	Illes Balears
Country	Tres Alquerias
Latitude	40.0
Longitude	3.8
Altitude	38.59 m a.m.s.l.

The project location is shown in Figure 1. A closer view of the region is shown in Figure 2.

Figure 1. Location of the substation in the region of Illes Balears, in Tres Alquerias

Figure 2. Closer view of the substation in the region of Illes Balears

3. DESCRIPTION OF THE SUBSTATION

The characteristics of the 220.0 kV high voltage system are shown in Table 3:

Table 3. The high voltage system characteristics

High voltage system	
Nominal system voltage	220.0 kV
System highest voltage	245.0 kV
Short-circuit level	50.0 kA
Installation	Outdoor
Insulation material	Air
Circuit arrangement	single busbar
High-voltage equipment bays	2
Output circuit levels	1

Regarding the power transformers that will raise the voltage, further characterization is given in Table 4:

Table 4. The high voltage/medium voltage system characteristics

Transformers	Voltage ratio	Rated power	Short-circuit impedance	Vector group
Num 1	220.0 / 20.0 kV	75.0 MVA	12.5 %	Ydn11
Num 2	220.0 / 20.0 kV	75.0 MVA	12.5 %	Ydn11

In total, 2 medium voltage cubicle/s will connect the PV solar plant to the electrical substation. The 20.0 kV medium voltage system´s features are delineated in Table 5:

Table 5. The medium voltage system characteristics

Medium voltage system	
Nominal system voltage	20.0 kV
System highest voltage	24.0 kV
Short-circuit level	25.0 kA
Installation	Indoor
Insulation material	SF6
Circuit arrangement for the cubicles	Single busbar
Medium voltage cubicles	2
Output feeder lines (to transformer bays)	2
Input feeder lines	15
Auxiliary cubicle	1
Metering lines	1 per cubicle

4. GENERAL CONSIDERATIONS OF THE SUBSTATION

4.1. Environmental conditions

Environmental conditions are shown in Table 6. They have been used to calculate some of the substation´s key features such as the type of insulators, the size of the buses or the value of the loads.

Table 6. The environmental conditions of the site

Environmental conditions	
Altitude	38.59 m a.m.s.l.
Maximum temperature	29.12 °C
Average temperature	17.33 °C
Minimum temperature	4.69 °C
Pollution level	Medium
Specific creepage distance	30 mm/kV
Maximum wind speed	120 km/h
Air pressure	70 daN/m^2

4.2. Short-circuit current

The short-circuit levels that have been considered in the design of the electrical substation are shown in Table 7.

Table 7. The short-circuit levels

Nominal system voltages	Short-circuit levels
220.0 kV	50.0 kA
20.0 kV	25.0 kA

4.3. Insulation coordination

The values of the insulation coordination that have been adopted to select the electrical equipment and calculate the clearance distances are presented in Table 8.

Table 8. The insulation coordination values

Insulation coordination	
Lightning impulse withstand voltage	1050 kV
Short-duration power-frequency withstand voltage (phase-to-earth)	460 kV
Short-duration power-frequency withstand voltage (phase-to-phase)	460 kV

4.4. Minimum safety distances

The safety distances are the minimum distances that should be maintained in the placement of different devices located within the perimeter of the substation field. The safety distances are made up of two values:

- The basic value which is related to the impulse withstand voltages of the substation.
- A safety zone to protect the staff during maintenance. This zone considers the likely area that would be regularly traversed by staff.

Figure 3 shows the relationship between the basic value and the safety zone for staff.

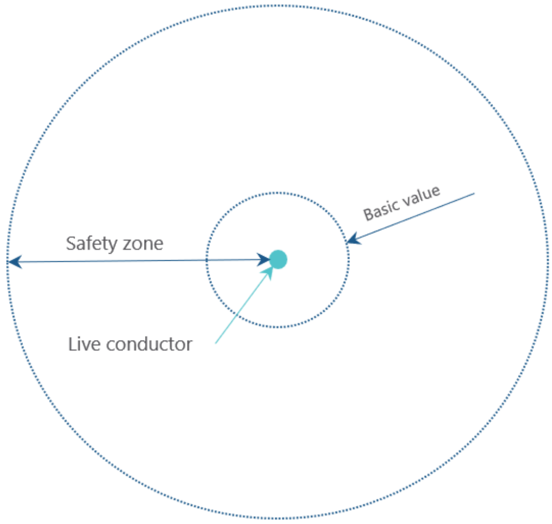

Figure 3. The safety distance is the sum of a basic value plus a safety zone

<u>Basic values</u>

After the calculation of the impulse withstand voltages, the following electrical clearances are obtained:

- Phase to earth distance: 1.9 m.
- Phase to phase distance: 2.1 m.

For these distances, the effect of the altitude over the sea level has been considered.

<u>Safety zone for staff</u>

The safety distances shall be delineated in way that facilitates the maintenance efforts of staff in the substation field. The following criteria have been adopted:

- The height of a worker with the arms raised is 2.25 m.
- The height of a worker with the arms outstretched passing above the working plane is 1.25 m.

- The length of a worker with the arms outstretched is 1.75 m.

Minimum safety distances

The conductors will be arranged to meet the following heights:

- The connection between the devices installed at the substation field will be at a height of 4.34 m above the floor.
- The buses will be at a height of 7.68 m above the floor and will be supported by outdoor post insulators.
- The outgoing lines will leave the substation at a height of 11.02 m.

The minimum safety heights of the substation are shown in Figure 4.

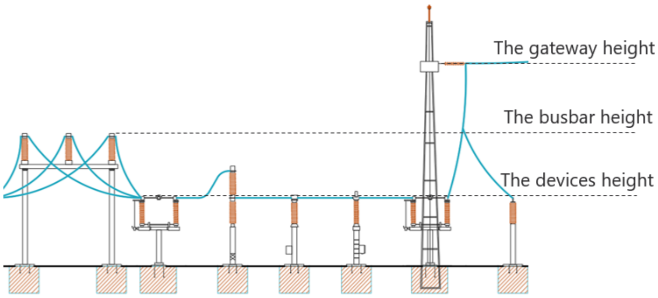

Figure 4. The minimum safety heights

The following separation parameters will be maintained in determining the location of the switchgear:

- Among the three phases of the conductor, each is separated by 3.84 m from the others.
- The bay width is 15.36 m. This is also the span of the busbar/gateway.
- An electrical device or switchgear shall keep a minimum distance of 3.84 m with an existing device in the bay direction.

The minimum safety heights of the substation are shown in Figure 5.

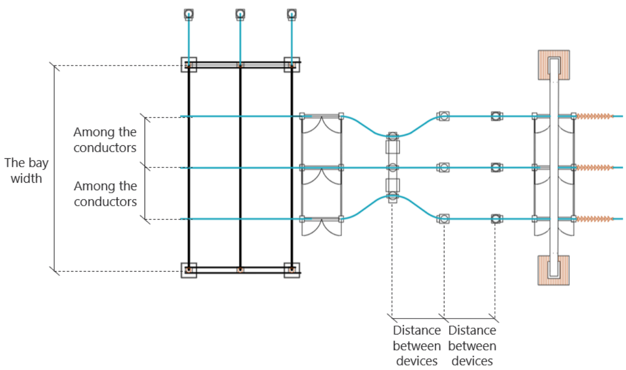

Figure 5. The minimum safety distances

Following, a summary of the distances that have been considered is presented in Table 9, Table 10, Table 11 and Table 12.

Table 9. The basic values.

Basic values	
Phase-to-earth distance	1.9 m
Phase-to-phase distance	2.1 m

Table 10. The additional distances for staff.

Safety zone for staff	
The height of a worker with the arms raised	2.25 m
The height of a worker with the arms outstretched passing above the working plane	1.25 m
The length of a worker with the arms outstretched	1.75 m

Table 11. The minimum safety distances.

Minimum safety distances	
Among the three phases of the conductor	3.84 m
The width of the bay	15.36 m
Distances between electrical devices	3.84 m

Table 12. The minimum safety heights.

Substation element	Minimum safety heights
The devices´ height	4.34 m
The busbar´s height	7.68 m
The gateway´s height	11.02 m

5. HIGH VOLTAGE SYSTEM

The 220.0/20.0 kV single busbar substation consists of 2 transformer bay/s, 1 overhead line/s and a 20.0 kV system that is made of 1 medium voltage cubicle/s to connect the PV plant to the substation.

The main equipment used to step up the voltage are:

- **Circuit breakers** that are mechanical switching devices which connect and break current circuits.

Figure 6. An example of a circuit breaker (source: ABB)

- **Disconnectors** that are used to isolate parts of the substation during maintenance. They are used to control the current that flows in the circuits. They operate when the circuit breakers are open.

Figure 7. An example of a disconnector (source: ABB)

- **Instrument transformers** that are either current or voltage transformers. They are used to reduce the current and voltage to levels that are measurable. These devices are key in enabling the protection measures that react to fault currents.

Figure 8. An example of instrument trasnformers (source: ABB)

- **Power transformers** which raise the voltage level from medium to high voltage.

Figure 9. An example of a power transformer (source: GE)

- **Grounding devices** that limit the fault currents that would flow by the neutral point of a transformer. They consist of a zig-zag transformer followed by a resistance to protect the personnel against uncommon voltage values, especially during fault conditions.

- **Surge arresters** that limit overvoltages on a system to protect the power transformer. They are placed at the end of the outgoing lines of the substation.

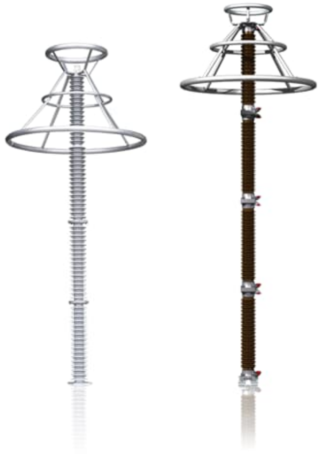

Figure 10. An example of a surge arrester (source: ABB)

- **Medium voltage cubicles**, which hold the necessary equipment connecting the PV outgoing medium voltage lines to the electrical substation.

Figure 11. An example of medium voltage cubicles (source: Ormazabal)

5.1. High-voltage equipment level - Transformer bays

The (2) transformer bays are equipped with the following devices:

- One (1) disconnector.
- One (1) circuit breaker.
- One set of three current transformers.
- Three (3) surge arresters to protect the primary winding of the power transformer.

5.2. High-voltage equipment level - Output circuit bays

The (1) outgoing line bays that leave the substation are equipped with the following devices:

- Three (3) surge arresters.
- Three (3) inductive voltage transformers.
- One (1) earthing disconnector.
- One set of three current transformers.
- One (1) circuit breaker.
- One (1) disconnector.

5.3. High-voltage equipment level - Busbar level

An inductive voltage transformer is installed on the bus position of the single busbar substation.

6. HIGH VOLTAGE EQUIPMENT - TRANSFORMER BAYS

The transformer bays connect the power transformers to the busbars of the substation. The switchgear that is placed in these bays protect the power transformers.

6.1. Disconnectors

As previously mentioned above, disconnectors are used to handle all currents that flow in the associated circuit. The main characteristics of the disconnectors that are located at the transformer bay are given in Table 13.

Table 13. The main characteristics of the disconnectors

Disconnector characteristics	
Type	Outdoor three-pole disconnector
Rated frequency	50 Hz
Nominal voltage	220.0 kV
Maximum voltage	245.0 kV
Rated normal current	2000.0 A
Rated short-circuit withstand current	50.0 kA
Rated short-circuit peak withstand current	125.0 kA

6.2. Circuit breakers

The automatic circuit breakers form an essential part of every substation. They are used to open and close circuits as needed, particularly in the case of a short-circuit. The main characteristics of these circuit breakers that are located at the transformer bay are shown in Table 14.

Table 14. The main characteristics of the circuit breakers

Circuit breaker characteristics	
Type	Outdoor three-pole on-load circuit breaker

Interrupting medium	Air
Rated frequency	50 Hz
Nominal voltage	220.0 kV
Maximum voltage	245.0 kV
Rated normal current	2000.0 A
Rated short-circuit breaking current	50.0 kA
Rated short-circuit making current	125.0 kA

6.3. Current transformers

The3 secondary windings current transformers are equipped with one winding for metering purposes and two windings for protection purposes. The main characteristics of the current transformers that are located at the transformer bay are given in Table 15.

Table 15. The main characteristics of the current transformers

Current transformer characteristics	
Type	A current transformer with three secondary windings
Rated frequency	50 Hz
Nominal voltage	220.0 kV
Maximum voltage	245.0 kV
Rated primary to secondary current ratio	250.0/5.0 - 5.0 - 5.0 A
Rated continuous thermal current	50.0 A
Rated short time thermal current	125.0 kA
Number of secondary windings	3
Accuracy class at a standard burden (First core)	15.0 VA, Cl 0.2s
Accuracy class at a standard burden (Second core)	30.0 VA, Cl 5P
Accuracy class at a standard burden (Third core)	30.0 VA, Cl 5P

6.4. Surge arresters

To protect the installations from overvoltages, surge arresters will be installed. The principal characteristics of surge arresters at the high voltage system are shown in Table 16.

Table 16. The main characteristics of the surge arrester in the HV level

Surge arrester characteristics	
Maximum voltage for insulation	245.0 kV
Rated voltage	210.0 kV
Continuous operating voltage	156.0 kV
Temporary overvoltage (10s)	218.0 kV
Switching impulse protective level	433.0 kV

Lightning impulse protective level (10kA)	494.0 kV
Lightning impulse protective level (20kA)	543.0 kV
Nominal discharge current	10.0 kA

7. HIGH VOLTAGE EQUIPMENT - OUTPUT CIRCUIT BAYS

The output circuit bays connect the substation to the grid. They are the overhead lines that leave the substation to the distribution or transmission networks.

7.1. Disconnectors

The principal characteristics of the disconnectors that are located at the output circuit are given in Table 17.

Table 17. The main characteristics of the disconnectors

Disconnector characteristics	
Type	Outdoor three-pole disconnector
Rated frequency	50 Hz
Nominal voltage	220.0 kV
Maximum voltage	245.0 kV
Rated normal current	2000.0 A
Rated short-circuit withstand current	50.0 kA
Rated short-circuit peak withstand current	125.0 kA

7.2. Circuit breakers

The main characteristics of these circuit breakers that are located at the output circuit are given in Table 18.

Table 18. The main characteristics of the circuit breakers

Circuit breaker characteristics	
Type	Outdoor three-pole on-load circuit breaker
Interrupting medium	Air
Rated frequency	50 Hz
Nominal voltage	220.0 kV
Maximum voltage	245.0 kV
Rated normal current	2000.0 A
Rated short-circuit breaking current	50.0 kA
Rated short-circuit making current	125.0 kA

7.3. Current transformers

The 3 secondary windings current transformers are equipped with one winding for metering purposes and two windings for protection purposes. The main characteristics of the current transformers that are located at the output circuit are presented in Table 19.

Table 19. The main characteristics of the current transformers

Current transformer characteristics	
Type	A current transformer with three secondary windings
Rated frequency	50 Hz
Nominal voltage	220.0 kV
Maximum voltage	245.0 kV
Rated primary to secondary current ratio	500.0/5.0-5.0-5.0 A
Rated continuous thermal current	50.0 A
Rated short time thermal current	125.0 kA
Number of secondary windings	3
Accuracy class at a standard burden (First core)	15.0 VA, Cl 0.2s
Accuracy class at a standard burden (Second core)	30.0 VA, Cl 5P
Accuracy class at a standard burden (Third core)	30.0 VA, Cl 5P

7.4. Voltage transformers

Outdoor inductive voltage transformers have been selected. The 3 secondary windings voltage transformers are equipped with one winding for metering purposes and two windings for protection purposes. They have the electrical characteristics given in Table 20.

Table 20. The main characteristics of the voltage transformers

Voltage transformer characteristics	
Type	A voltage transformer with three secondary windings
Rated frequency	50 Hz
Rated primary to secondary voltage ratio	220.0:√3 / 0.11 / 0.11 / 0.11 kV
Number of windings	3
Accuracy class at a standard burden (First core)	25.0 VA, Cl 0.2
Accuracy class at a standard burden (Second core)	100.0 VA, Cl 3P
Accuracy class at a standard burden (Third core)	100.0 VA, Cl 0.5-3P

7.5. Surge arresters

The principal characteristics of surge arresters at the beginning of the outgoing lines are shown in Table 21.

Table 21. The main characteristics of the surge arrester in the HV level

Surge arrester characteristics	
Maximum voltage for insulation	245.0 kV

Rated voltage	210.0 kV
Continuous operating voltage	156.0 kV
Temporary overvoltage (10s)	218.0 kV
Switching impulse protective level	433.0 kV
Lightning impulse protective level (10kA)	494.0 kV
Lightning impulse protective level (20kA)	543.0 kV
Nominal discharge current	10.0 kA

8. HIGH VOLTAGE EQUIPMENT - BUSBAR LEVEL

This section highlights the voltage transformer located at the busbar and the dimensions of the buses, the post insulators that will support the conductors, and the bus coupler.

This is a single busbar substation and the buses will be at a height of 7.68 m above the floor and will be supported by outdoor post insulators.

8.1. Busbar

The main characteristics of the buses are presented in Table 22.

Table 22. The parameters of the HV busbar

Design parameters	
Material	6063 aluminum tubes
External diameter	200.0 mm
Internal diameter	184.0 mm
Section of the conductor	48.25 cm2
Maximum withstand current at 85ºC	4154 A
Load current	468 A

In laying out the design parameters of the bus, the presence of a damper cable that takes up 25% of the bus weight, has been considered.

8.2. Post insulators

Post insulators are used to support high-voltage conductors in compression or cantilevered arrangements. They are mounted vertically on top of the support structure. The “c“ reference defines a cylindrical support insulator for outdoor use, made of porcelain material. Their main characteristics are shown in Table 23.

Table 23. The type of post insulators

Outdoor post insulator	
Identification code	c16_1050
Maximum withstand voltage	245.0 kV
Lightning impulse withstand voltage	1050.0 kV
Minimum bending failing load	16.0 kN

8.3. Voltage transformer

It is equipped with one winding for metering purposes and two windings for protection purposes. The voltage transformer placed on the bus position has the characteristics given in

Table 24.

Table 24. The main characteristics of the voltage transformers in the busbar level

Voltage transformer characteristics	
Type	A voltage transformer with three secondary windings
Rated frequency	50 Hz
Rated primary to secondary voltage ratio	220.0:√3 / 0.11 / 0.11 / 0.11 kV
Number of windings	3
Accuracy class at a standard burden (First core)	25.0 VA, Cl 0.2
Accuracy class at a standard burden (Second core)	100.0 VA, Cl 3P
Accuracy class at a standard burden (Third core)	100.0 VA, Cl 0.5-3P

9. HIGH VOLTAGE/MEDIUM VOLTAGE SYSTEM - POWER TRANSFORMER LEVEL

9.1. Power transformers

The power transformer raises the voltage of the medium voltage lines of the PV plant to achieve a higher efficiency in transmission or distribution lines. The principal characteristics of the power transformers are presented in Table 25.

The installed power transformer is a two-winding transformer.

Table 25. The main parameters of the power transformers

Transformers	Voltage ratio	Rated power	Short-circuit impedance	Vector group
Num 1	220.0 / 20.0 kV	75.0 MVA	12.5 %	Ydn11
Num 2	220.0 / 20.0 kV	75.0 MVA	12.5 %	Ydn11

9.2. Earthing devices

The earthing device is made of a reactance and a resistance. The earthing reactance consists of a zig-zag transformer. Their characteristics are shown in Table 26.

Table 26. The components of the grounding device

Grounding reactance and resistance characteristics	
Reactance	
Earthing current	800.0 A
Earthing reactance per phase	4.6 Ω
Fault time	10.0 s
Resistance	
Earthing resistance	14.4 Ω
Disconnector	
Rated current	3150.0 A
Current transformer	
Rated primary current	3000.0 A
Rated secondary current	5.0 A

9.3. Surge arresters

The principal characteristics of surge arresters at the medium voltage system are shown in Table 27.

Table 27. The main characteristics of the surge arrester in the MV level

Surge arrester characteristics	
Maximum voltage for insulation	24.0 kV
Rated voltage	21.0 kV
Continuous operating voltage	16.8 kV
Temporary overvoltage (10s)	21.6 kV
Switching impulse protective level	47.0 kV
Lightning impulse protective level (10kA)	54.4 kV
Lightning impulse protective level (20kA)	61.0 kV
Nominal discharge current	10.0 kA

10. MEDIUM VOLTAGE SYSTEM

A 20.0 kV system of 1 medium voltage cubicles connects the PV plant to the substation. A single busbar arrangement has been selected for the gas insulated switchgear and its characteristics are shown in Table 28.

Table 28. The main parameters of the MV busbar

Busbar characteristics	
Rated voltage	20.0 kV
Rated current	3150.0 A
Short-circuit current	25.0 kA
Rated frequency	50 Hz

The system consists of a group of medium voltage cubicles which fulfils a variety of functions that are presented in this chapter.

10.1. Cubicles for incoming lines

The incoming feeder cubicles are equipped with:

- One (1) three position earthing disconnector.
- One (1) circuit breaker.
- One set of three current transformers.

The main features of the input cubicles are shown in Table 29.

Table 29. The main components of the input cubicles

Input cubicles	
Disconnector	
Rated current	630.0 A
Circuit Breaker	
Rated current	630.0 A
Current transformer	
Rated primary current	500.0 A
Rated secondary current	5.0 A
Number of secondary windings	1
Accuracy class at a standard burden (First core)	15.0 VA, Cl 0.2s

10.2. Cubicles for outgoing lines

The outgoing feeder panels are equipped with:

- One (1) three position earthing disconnector.
- One (1) circuit breaker.

- One set of three current transformers.

The main features of the output cubicles are shown in Table 30.

Table 30. The main components of the output cubicles

Output cubicles	
Disconnector	
Rated current	3150.0 A
Circuit Breaker	
Rated current	3150.0 A
Current transformer	
Rated primary current	3000.0 A
Rated secondary current	5.0 A
Number of secondary windings	1
Accuracy class at a standard burden (First core)	15.0 VA, Cl 0.2s

10.3. Metering cubicle

The metering panels are equipped with:

- One (1) three position earthing disconnector.
- One voltage transformer.

The main features of the metering cubicles are shown in Table 31.

Table 31. The main components of the metering cubicles

Metering cubicles	
Disconnector	
Rated current	630.0 A
Voltage transformer	
Voltage ratio	20.0:√3 / 0.11/ 0.11 kV
Number of secondary windings	2
Accuracy class at a standard burden (First core)	25.0 VA, Cl 0.2
Accuracy class at a standard burden (Second core)	100.0 VA, Cl 3P

10.4. Auxiliary services' cubicle

The cubicles are designed to connect the auxiliary transformer to the system. They are equipped with:

- One (1) three position earthing disconnector.
- One (1) circuit breaker.

The main features of the cubicle for auxiliary services are shown in Table 32.

Table 32. The main components of the auxiliary services´cubicles

Auxiliary services´ cubicles	
Disconnector	
Rated current	630.0 A
Circuit Breaker	
Rated current	630.0 A
Auxiliary transformer	
Rated primary voltage	20.0 kV
Rated secondary voltage	0.4 kV
Rated power	100.0 kW

10.5. Capacitor bank cubicle

To compensate for the reactive power produced by the system, a capacitor bank is sized to improve the power factor at the output of the inverters. This automatic capacitor bank will be connected to a capacitor feeder that will be in its turn connected to the MV busbar. The capacitor feeder will be equipped with:

- One (1) three position earthing disconnector.
- One (1) circuit breaker.
- One set of three current transformers.

The characteristics of each device listed above are shown in Table 33.

Table 33. The main components of the capacitor cubicle

Capacitor bank feeder	
Disconnector	
Rated current	1250.0 A
Circuit Breaker	
Rated current	1250.0 A
Current transformer	
Rated primary current	750.0 A
Rated secondary current	5.0 A
Number of secondary windings	1
Accuracy class at a standard burden	15.0 VA, Cl 0.2s

The characteristics of one of the capacitor banks are shown in the Table 34.

Table 34. The main components of the capacitor bank

Capacitor bank
Capacitor

Rated voltage	20.0 kV
Rated voltage at capacitor input	21.5 kV
Maximum voltage at capacitor input	23.5 kV
Reactive power	16.68 MVAr
Number of capacitors	2
Detuned Reactor	
Detuned factor	7.0 %
Inductance	6.176 mH
Reactive power	-1.17 MVAr

Each capacitor bank might be compensating for reactive power of different systems. In Table 35, the capacitor's compensation per system is listed.

Table 35. Reactive power compensation per system

Capacitor Bank	Power Station	MV Lines	Power Transformer	Overhead Line
Num 1	6469.8 kVA	159.73 kVA	8887.41 kVA	0
Num 2	6377.64 kVA	110.4 kVA	8910.57 kVA	0

10.6. Cables

The cables that connect the medium voltage cubicles to the substation are characterized as shown in Table 36.

The goal when calculating the characteristics of the electrical wiring is to minimize the cable lengths and sections. The sections are selected according to the IEC 60364-5-52 and IEC 60502-2 standards.

When selecting a cable cross section, the current-carrying capacity, the voltage drop and the short-circuit current criteria are considered.

Table 36. A summary of the cable sections

Section	Conducting material	Insulation material	Installation type
630 mm2	Al	XLPE	Directly buried