OVERHEAD LINE REPORT

PV Plant Webinar Amperecloud
2024/10/29

Prepared for: Amperecloud

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1. INTRODUCTION

The objective of this report compiled by RatedPower is to describe the specifications and design of the overhead line of the project in Spain, Andalucía.

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

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

Webinar Amperecloud project	
Location	Spain, Andalucía
Substation capacity	35.53 MVA
High voltage level	132.0 kV
Rated frequency	50 Hz
Substation installation	Outdoor
Type of switchgear	Air-insulated switchgear
Type of line	transmission

This overhead line will evacuate the capacity generated by the plant to the grid.

2. SITE

2.1. Location

The 132.0kV overhead line will carry 35.53MVA from the plant's interconnection facility in Andalucía to the point of interconnection. Additional information about the location of the substation and the start of the line is shown in Table 2.

Table 2. The location characteristics of the project

Substation location characteristics	
City / Town	Carboneras
Region	Andalucía
Country	Carboneras
Latitude	37.0
Longitude	-2.0
Altitude	204.79 m a.m.s.l.

The overhead line is crossing the plant; hence, a buffer zone of width 10.0 m needs to be applied.

3. DESCRIPTION OF THE OVERHEAD LINE

The general characteristics of the 132.0kV overhead line are shown in Table 3:

Table 3. The overhead line general characteristics

Line characteristics	
Nominal system voltage	132.0 kV
System highest voltage	145.0 kV
Capacity	35.53 MVA
Frequency	50 Hz
Length	2073.54 m
Overhead line type	transmission
Circuit arrangement	Simplex
Sub-conductor number	1
Number of earth wires	1
Phase conductor type	250-A1/S1A
Suspension insulator type	long rod
Tension insulator type	long rod
Tower type	MV Single fork
Number of towers	11

In total, 11 towers will carry the transmission conductors to the point of the interconnection. The coordinates of each tower in UTM are listed in Table 4:

Table 4. The towers' coordinates.

Tower	X	Y	Z
Tower 1	585474.694	4093641.273	211.464
Tower 2	585482.9	4093646.231	210.931
Tower 3	585598.801	4093701.025	218.264
Tower 4	585842.592	4093742.563	217.45
Tower 5	586037.625	4093775.793	228.445
Tower 6	586242.409	4093810.684	226.559
Tower 7	586534.959	4093860.53	207.949
Tower 8	586788.502	4093903.729	185.595
Tower 9	587061.024	4093903.809	187.744
Tower 10	587314.08	4093903.883	203.549

Tower 11	587509.405	4093859.61	217.076

4. GENERAL CONSIDERATIONS OF THE OVERHEAD LINE

4.1. Environmental conditions

Environmental conditions are shown in Table 5. They have been used to calculate some of the overhead line´s key components such as the type of the conductor and insulator, the catenaries of both the phase conductor and the earth wire, as well as the tower forces.

Table 5. The environmental conditions of the site

Environmental conditions	
Altitude	204.79 m a.m.s.l.
Maximum temperature	85°C
Average temperature	15°C
Minimum temperature	-5°C
Pollution level	Medium
Specific creepage distance	20mm/kV
Maximum wind speed	120 km/h
Maximum ice thickness	30 mm
Maximum ice density	900 kg/m^3

4.2. Insulation coordination

The values of the insulation coordination that have been adopted to select the insulator and calculate the clearance distances are presented in Table 6.

Table 6. The insulation coordination values

Insulation coordination	
Fast-front overvoltage	498.8kV
Slow-front overvoltage	373.5kV
Power frequency voltage	216.8kV
Statistical slow-front voltage	189.4kV

4.3. Minimum clearances

The minimum clearances are embodied in two main clearances:

- An electrical clearance between phase conductors as well as between phase conductor and earth wire.
- An electrical clearance between a phase conductor and objects at earth potential. In this case the towers.

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

- Phase to earth distance: 1.2 m.
- Phase to phase distance: 1.4 m.

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

4.4. Mid-span clearances

The minimum mid-span clearances are calculated based on the electrical minimum clearances values and are designed to avoid flashovers between the conductors under any wind action. These clearances are of two values:

- Phase to earth mid-span distance.
- phase to phase mid-span distance.

The maximum clearances per block of the line are presented in Table 7.

Table 7. Maximum mid-span clearances

Block	Phase-phase mid-span clearance [m]	Phase-earth mid-span clearance[m]
Block 1	1.12	0.97
Block 2	2.04	1.89
Block 3	3.32	3.17
Block 4	3.42	3.27
Block 5	3.11	2.96

4.5. Minimum safety distances

The safety distances are the minimum distances that should be maintained in the placement of phase conductors within the perimeter of the overhead line. The safety distances are made up of two values:

- The distance to ground value which is related to the phase to earth clearance of the line. It represents the minimum distance between the lowest phase conductor and the ground. Hence, the bottom phase conductor's lowest point must be at a minimum of 6.2 m from the ground.
- The distance to object value is the minimum safety distance between the line and a possible object presence along the line. Hence, the conductors and the towers mustn't be close to a building by more than 11.2 m.

The minimum safety distances of the overhead line are shown in Figure 1.

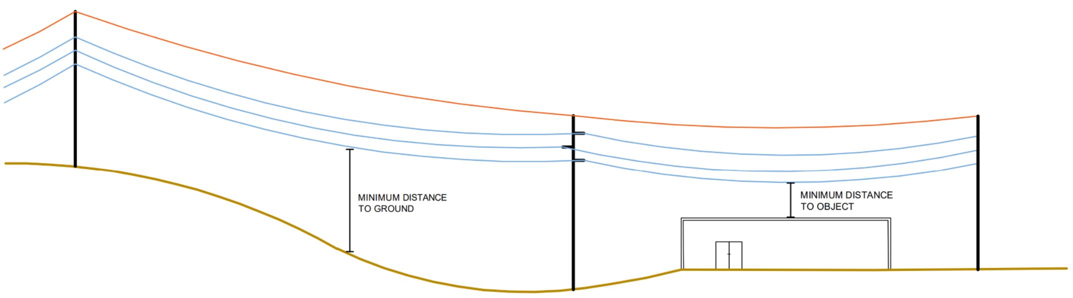

Figure 1. The minimum safety distances

4.6. Minimum clearances summary

Following, a summary of the distances that have been considered is presented in Table 8.

Table 8. The Line's clearances.

Basic values	
Phase-to-earth distance	1.2 m
Phase-to-phase distance	1.4 m
Distance to ground	6.2 m
Distance to object	11.2 m

5. LINE CHARACTERESTICS

The 132.0kV transmission line has a Simplex circuit arrangement to carry a capacity of 35.53MVA. The line is 2073.54 m long and it consists of 5 blocks defining the deviations of the line.

5.1. Blocks

The line's blocks are presented in Table 9 along with their corresponding ruling spans, their start and end towers location and their total lengths.

Table 9. The blocks of the line

Block	Start coordinates	End coordinates	Ruling span[m]	Length[m]
Block 1	{585,474.7; 4,093,641.3}	{585,482.9; 4,093,646.2}	9.59	9.59
Block 2	{585,482.9; 4,093,646.2}	{585,598.8; 4,093,701}	128.20	128.20
Block 3	{585,598.8; 4,093,701}	{586,788.5; 4,093,903.7}	249.26	1206.85
Block 4	{586,788.5; 4,093,903.7}	{587,314.1; 4,093,903.9}	263.33	525.58
Block 5	{587,314.1; 4,093,903.9}	{587,509.4; 4,093,859.6}	200.28	200.28

5.2. Towers

The overhead line has 11 towers in total, 5 of them are suspension towers, 4 are angle towers and two dead end towers. The tension towers are the towers that are spotted in a straight corridor and the angle towers are the towers that have more tension caused by a deflection of the line.

The type of the tower in this line is a MV Single fork with a Simplex circuit arrangement. The selected tower is represented in Figure 2.

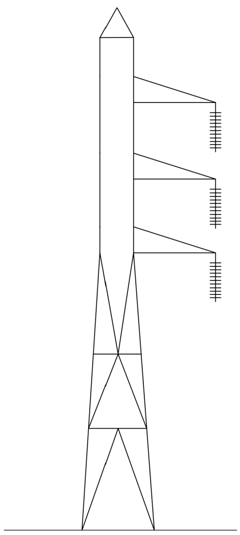

Figure 2. Illustration of the line's tower

5.3. Conductors

The 132.0kV phase conductor that was selected for the line is of type 250-A1/S1A, the electrical consideration consists of the voltage gradient, the maximum admissible current and the maximum voltage drop consideration. its characteristics are shown in Table 10.

Table 10. The conductor's characteristics

Conductor's characteristics	
Designation	250-A1/S1A
Composition	Al x Steel
Stranding	22x7
Total diameter	21.6 mm
Unitary mass	0.8806 Kg/m
Maximum load	68720 N
Section	2.74 cm2
Resistivity	0.03 Ω.mm
Elasticity	67.7 ·10^3 N/mm²
Resistance [AC]	0.15 Ω/km
Maximum admissible current	0.708 kA
Voltage gradient	11.63 kV/cm

Moreover, the line has a bundle arrangement of one conductor per phase.

The length of the line's conductor is 2063.06 m.

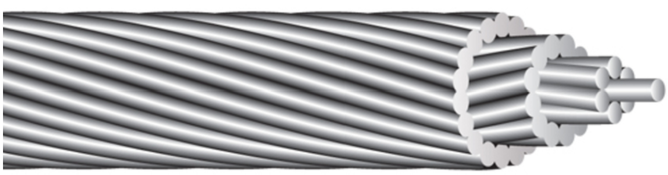

Figure 3. Illustration of the line's conductor [source: Southwire]

5.4. Earth wires

The 132.0kV overhead line is protected by 1 earth wire(s) of type OPGW-2S 1/48B1 (0/165-213.7), its characteristics are shown in Table 11

Table 11. The earth wire

Earth wire's characteristics

Designation	OPGW-2S 1/48B1 (0/165-213.7)
Number of fibers	48
Total diameter	17.2 mm
Unitary mass	0.7960 Kg/m
Maximum load	106300.00 N
Section	1.65 cm2
Thermal expansion	0.000016 °C−1
Elasticity	10.9 ·10^4 N/mm²
Resistance [AC]	0.27 Ω/km
Short-circuit capacity	213.70 kA²/s-1

The total length of the earth wire(s) is 2075.75 m.

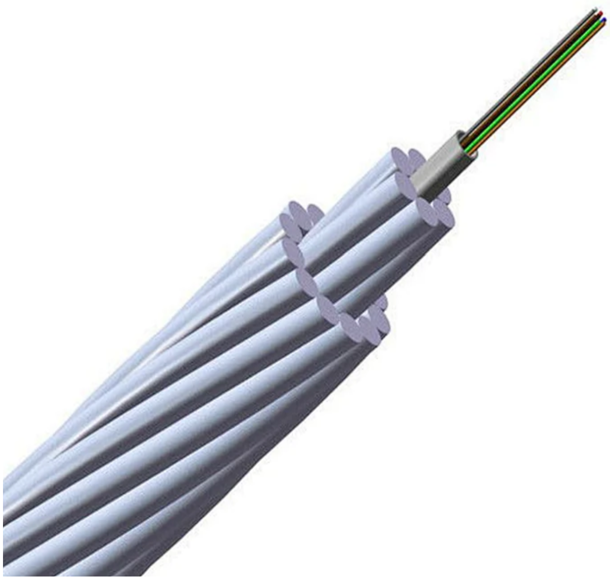

Figure 4. Illustration of the line's earth wire [source: Faso]

5.5. Insulators

The 132.0kV overhead line's conductor is insulated by a 1 insulator(s) per phase of type long rod for the suspension towers, and of type long rod for the tension towers. The selected insulators withstand both the required lightening and wet withstand voltages.

The total mass of the long rod insulators is not calculated.

The characteristics of the suspension insulator are shown in Table 12.

Table 12. The suspension insulator's characteristics

Suspension insulator's characteristics

Designation	U160BS
Length	1.46 m
Total diameter	280.0 mm
Total mass	62.00 Kg
Minimum failing load	160000.0 N
Number of elements	10
Lightning impulse	760.0kV
Wet withstand voltage	345.0kV
Minimum creepage	3.15 m

The characteristics of the tension insulator are shown in Table 13.

Table 13. The tension insulator's characteristics

Tension insulator's characteristics	
Designation	U160BS
Length	1.46 m
Total diameter	280.0 mm
Total mass	62.00 Kg
Minimum failing load	160000.0 N
Number of elements	10
Lightning impulse	760.0kV
Wet withstand voltage	345.0kV
Minimum creepage	3.15 m

Figure 5. Illustration of the line's insulator [source: NGK]

6. ELECTRICAL CALCULATIONS

The equivalent circuit of the 132.0kV overhead line is represented by the nominal PI circuit; the representation is shown in Figure 6. The electrical performance is determined by the resistance, the inductance, and the capacitance. In the following sub-sections, the electrical properties of the line are presented assuming a balanced three-phase current.

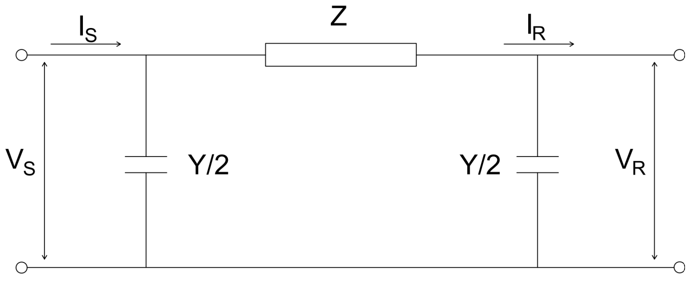

Figure 6. Pi model

6.1. Resistance

The electrical resistance is one of the most important properties that determine the optimization of an overhead line. The dc resistance of this line is calculated based on the conductor's resistance and characteristics. The resulting resistance is 0.30Ω.

6.2. Inductance

The inductance gives an idea on the performance of the line, its calculation considers the bundle of the conductor, and it depends on the geometry of the tower. For the tower geometry of this line and the conductor's characteristics, the calculated inductance is 0.003H.

Hence, the inductive reactance corresponds to 0.82 Ω.

6.3. Impedance

The positive sequence impedance is represented as a complex number from the reactance and resistance. The resulting impedance is 0.88 Ω.

Similarly, the zero-sequence impedance of the line representing the zero-sequence resistance and reactance is 2.48 Ω.

6.4. Capacitance

The capacitance in the overhead line is responsible for generating reactive power for system requirements. The capacitance formed among the phase conductors and earth is distributed along the whole line's conductors. The capacitance is calculated based on the height of the conductor to the ground and it depends on its circuit arrangement.

Accordingly, the susceptance results in 5.97 ·10-6 S.

6.5. Electrical parameters summary

The main electrical parameters of the 132.0kV line are presented in Table 14

Table 14. The electrical parameters of the line

Electrical parameters

Resistance	0.30 Ω
Inductance	0.003 H
Inductive reactance	0.82 Ω
Positive-sequence impedance	0.88 Ω
Zero-sequence impedance	2.48 Ω
Capacitance	0.0190 ·10-6 F
Susceptance	5.97 ·10-6 S

6.6. Power factor

The power factor at the receiving end of the overhead line was calculated based on the Pi model considering the voltage and current at the receiving end. The resulting power factor is shown in Table 15.

6.7. Voltage drop

Due to the electrical parameters mainly resistance, inductance and capacitance, the voltage drop of the 2073.54 m transmission line is calculated with respect to the Pi model considering the voltage at the receiving end.

The voltage at the receiving end is calculated based on the surge impedance and the propagation constant, which results in 131.9kV.

Therefore, the voltage drop is 0.1kV and the corresponding voltage drop percentage is 0.062 %. A summary of the voltage drop results are presented in Table 15.

Table 15. Voltage drop results

Voltage drop results	
Maximum voltage	132.0 kV
Voltage at receiving end	131.9 kV
Voltage drop	0.1 kV
Voltage drop percent	0.062 %
Power factor	1.000

6.8. Corona effect

The corona phenomena happens when the electrical field reaches the critical surface gradient of the conductor. This is characterized by a minimum phase to neutral voltage called the critical disruptive voltage that is require for corona effect to occur.

The overhead line has a critical disruptive voltage of 162.2kV under wet conditions, as the maximum voltage of the line is 132.0kV this means that the corona effect will not occur.

6.9. Losses

The overhead line’s losses are the Ohmic ones and those caused by the corona effect, if occurred, following is the details of both losses.

- *Joule losses:*

The Ohmic losses are the main losses that occur in the conductors of the line. The calculation of the Joule loss considers the power at the receiving and sending ends, it results in 0.022 MW.

- *Corona loss:*

The corona effect will not occur as the nominal voltage is lower than the critical voltage.

Table 16. The main line losses

Losses	
Joule losses	0.022MW
Corona Losses	0.0MW

7. MECHANICAL CALCULATIONS

The mechanical calculations of the line cover the conductor and insulator's selection, the loads on both the conductor and earth wire, and their catenaries throughout the line. In the following sections, the different mechanical results will be introduced.

7.1. Conductor

The mechanical considerations to select the conductor are related to the tensile strength that the conductor must handle under different operation conditions. The summary of the 250-A1/S1A conductor's mechanical considerations is shown in Table 17.

Table 17. The mechanical characteristics of the conductor

Conductor's Mechanical characteristics	
Conductor's designation	250-A1/S1A
Section	2.74 cm2
Maximum load	68720 N

7.2. Load

The weight, wind, and ice loads per unit length on the conductor are calculated for different load hypothesis The hypotheses that are considered are the following:

- *Maximum temperature:* With a temperature of 85°C and a maximum load percentage of 70%.
- *Minimum temperature:* With a temperature of -5°C, an ice thickness of 30 mm, an ice density of 900 kg/m3, and a maximum load percentage of 70%.
- *Maximum wind*: with a temperature of 10°C, a wind speed of 33.3m/s, and a maximum load percentage of 70%.
- *Everyday stress (EDS):* with a temperature of 15°C and a maximum load percentage of 22%.
- *Heavy load:* with a temperature of -5°C, a wind speed of 23.3 m/s, an ice thickness of 30 mm, an ice density of 900 kg/m3, and a maximum load percentage of 70%.

In Table 18 the different loads per unit length on the phase conductor are presented for the different hypothesis listed above.

Table 18. The loads per unit length on the phase conductor

Load	Maximum temperature	Minimum temperature	Maximum wind	EDS	Heavy load
Weight load	8.6 N/m	8.6 N/m	8.6 N/m	8.6 N/m	8.6 N/m
--	--	14.7 N/m	--	8.3 N/m	Ice load

43.0 N/m	--	43.0 N/m	Total load	8.6 N/m

In Table 19 the different loads on the earth wire are presented for the different hypothesis listed above.

Table 19. The loads per unit length on the earth wire

Load	Maximum temperature	Minimum temperature	Maximum wind	EDS	Heavy load
Weight load	7.8 N/m	7.8 N/m	7.8 N/m	7.8 N/m	7.8 N/m
Wind load	--	--	11.7 N/m	--	6.6 N/m
Ice load	--	39.3 N/m	--	--	39.3 N/m
Total load	8.6 N/m	51.6 N/m	17.0 N/m	8.6 N/m	52.3 N/m

7.3. Insulator

When selecting the insulators of the line, the load of the conductors on the said insulators, suspension, tension, and dead-end insulators is respected. The minimum failing load of the insulators withstands the conductor load on them; hence, the calculated number of insulators per phase is 1.

The characteristics of the different line insulators are presented in Table 20.

Table 20. The mechanical characteristics of the insulators

Mechanical characteristic	Suspension insulator	Tension insulator	Dead-end
Designation	U160BS	U160BS	U160BS
Minimum failing load	160000.0	160000.0	160000.0
Total load	54539.7	77913.8	77913.8

7.4. Spans

The different spans of the line are presented below, the weight and wind spans are calculated based on the span lengths and the catenaries of each span. In Table 21 all the spans are listed.

One or more spans could not match the predefined target span, the span(s) had to be adjusted automatically.

Table 21. The spans of the line

Span	Span length	Wind span	Weight span

number	[m]	[m]	[m]
Span 1	9.59	4.79	106.74
Span 2	128.20	68.89	117.63
Span 3	247.30	187.75	234.35
Span 4	197.84	222.57	193.77
Span 5	207.74	202.79	217.73
Span 6	296.77	252.25	333.27
Span 7	257.20	276.98	298.60
Span 8	272.52	264.86	176.39
Span 9	253.06	262.79	234.74
Span 10	200.28	226.67	201.96

The representation of the span length, wind span, and weight span is shown in Figure 7.

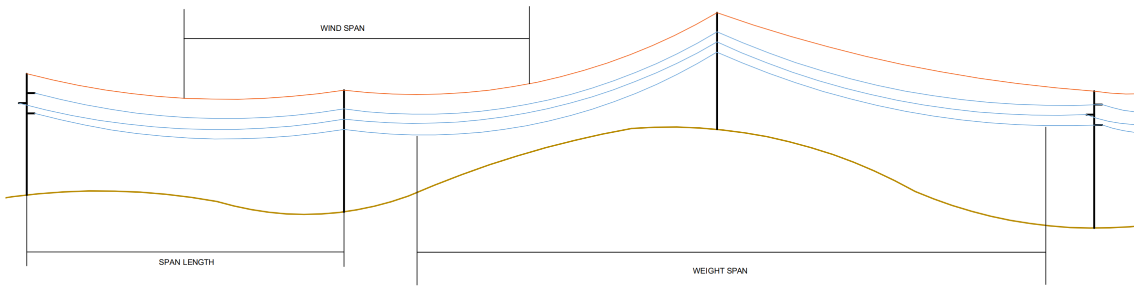

Figure 7. Illustration of the span's types

- *Swing angle:*

  Under specific weather conditions where the wind exceeds a certain speed, the suspension insulators will swing upon the wind direction. The swing angle is important to consider when calculating the mid-span clearances between the conductors as well as when determining the towers' top geometry.

  For the tension towers, only the swinging of the conductors is considered when calculating the swing angle.

  In Table 22 the maximum swing angles per block are presented.

Table 22. The insulators' swing angles

Block	Swing angle
Block 1	45.3°
Block 2	53.5°
Block 3	68.0°

Block 4	68.0°
Block 5	61.9°

7.5. Catenaries

- *Phase conductor catenary*

The catenary of the conductors is a crucial step in the overhead line mechanical calculation. The catenary results for the phase conductor present the maximum horizontal tension and the corresponding maximum sags for the different hypothesis introduced above per block. The results are presented in Table 23

Table 23. The phase conductor's catenaries

Block	Ruling span	Max. Temp. Sag [m]	Max. Temp. Tension [daN]	Minimum Temp. Sag[m]	Minimum Temp. Tension [daN]	Everyday stress Sag[m]	Everyday stress Tension [daN]	Max. wind Sag[m]	Max. wind Tension [daN]	Heavy load Sag[m]	Heavy load Tension [daN]
Block 1	9.6	0.07	67	0.01	2291	0.00	1512	0.00	1703	0.01	2292
Block 2	128.2	2.59	660	2.57	3979	1.13	1512	0.81	2110	2.55	4005
Block 3	249.3	11.34	842	11.97	4768	8.35	1142	4.73	2014	11.86	4810
Block 4	263.3	9.51	837	9.98	4767	7.28	1092	4.05	1961	9.89	4810
Block 5	200.3	4.87	868	5.29	4774	2.87	1472	1.84	2296	5.25	4810

- *Earth wire catenary*

The catenaries of the earth wire(s) are represented by the maximum sags under the different load hypothesis and the horizontal tension for each block. The results of the catenary are presented in Table 24.

Table 24. The earth wire's catenaries

Block	Ruling span	Max. Temp. Sag [m]	Max. Temp. Tension [daN]	Minimum Temp. Sag[m]	Minimum Temp. Tension [daN]	Everyday stress Sag[m]	Everyday stress Tension [daN]	Max. wind Sag[m]	Max. wind Tension [daN]	Heavy load Sag[m]	Heavy load Tension [daN]
Block 1	9.6	0.11	86	0.03	2064	0.01	1472	0.01	1615	0.03	2065
Block 2	128.2	2.26	713	2.61	3720	1.06	1513	0.82	1959	2.60	3738
Block 3	249.3	10.03	861	11.47	4546	7.54	1146	4.69	1840	11.39	4576
Block 4	263.3	8.51	853	9.61	4560	6.62	1095	4.05	1791	9.54	4592

Block 5	200.3	4.32	907	5.27	4495	2.66	1475	1.86	2108	5.24	4521

8. TOWER GEOMETRY

8.1. Tower description

The tower selected for this 132.0kV line is of type MV Single fork with a top shape of 2. The tower is Simplex that has 1 earth wire(s).

8.2. Tower geometry

The dimensions of the tower's top geometry were calculated based on the phase to phase and phase to earth clearances. It might be that some market standard towers (C Atorinillada tower) or none were found to match the calculated towers; hence, the dimensions presented below might include towers that were calculated by the model representing bigger dimensions than those standardized.

The presented results presented in Table 25 represent the biggest tower in each block of the line. Also, the illustration of the tower is in Figure 8.

Table 25. The tower's geometry

Block	Tower type	a	b	c	d
Block 1	2	1.73	2.45	1.73	2.27
Block 2	2	2.29	3.57	2.29	3.39
Block 3	2	2.98	3.57	2.98	2.83
Block 4	2	2.97	4.10	2.97	2.82
Block 5	2	2.37	3.74	2.37	3.56

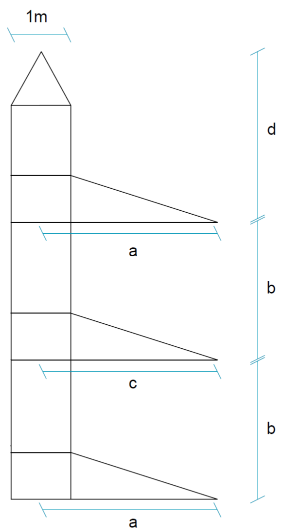

Figure 8. Illustration of tower's top geometry

9. TOWER'S CALCULATION

This section highlights the calculation of the overhead line towers' forces. The forces were calculated upon four special load hypotheses.

9.1. Hypotheses

The hypotheses that were considered in the towers' forces calculation are as follow:

- *Maximum wind* [H1]: The temperature is considered as 10°C, the wind speed at 120km/h and a 100% dead-end longitudinal load.
- *Maximum ice* [H2]: The temperature is considered as -5°C with an ice thickness of 30 mm and ice density of 900 kg/m3 and a dead longitudinal load of 100%.
- *Unbalance* [H3]: The temperature is considered as -5°C with an ice thickness of 30 mm and ice density of 900 kg/m3, a suspension longitudinal load of 15% and a tension longitudinal load of 50%.
- *Conductor break* [H4]: The temperature is considered as -5°C with an ice thickness of 30 mm and ice density of 900 kg/m3, a suspension longitudinal load of 50%, and a tension and dead-end longitudinal loads of 100%.

9.2. Forces on phase conductor

The results of the towers forces are shown in Table 26. The results represent the maximum vertical, transversal, and longitudinal forces at the phase conductors per block.

Table 26. Forces at phase conductors

Block	H1 Vert. [daN]	H1 Trans. [daN]	H1 Long. [daN]	H2 Vert. [daN]	H2 Trans. [daN]	H2 Long. [daN]	H3 Vert. [daN]	H3 Trans. [daN]	H3 Long. [daN]	H4 Vert. [daN]	H4 Trans. [daN]	H4 Long. [daN]
Block 1	480	295	1703	727	321	2292	729	319	3974	729	319	1987
Block 2	441	834	0	1333	1199	0	1331	1190	4724	1331	1190	2362
Block 3	456	834	0	1785	1199	0	1781	1190	4751	1781	1190	2376
Block 4	247	805	0	1271	1071	0	1273	1062	4751	1273	1062	2376
Block 5	287	805	2296	1164	1071	4810	1164	1062	4774	1164	1062	2372

9.3. Forces on earth wire

The results of the towers forces are shown in Table 27. The results represent the maximum vertical, transversal, and longitudinal forces at the earth wire(s) per block.

Table 27. Forces at earth wire

Block	H1 Vert. [daN]	H1 Trans. [daN]	H1 Long. [daN]	H2 Vert. [daN]	H2 Trans. [daN]	H2 Long. [daN]	H3 Vert. [daN]	H3 Trans. [daN]	H3 Long. [daN]	H4 Vert. [daN]	H4 Trans. [daN]	H4 Long. [daN]

Block 1	379	275	1703	553	321	2292	554	319	3974	554	319	1987
Block 2	288	779	0	1106	1199	0	1104	1190	4724	1104	1190	2362
Block 3	357	779	0	1574	1199	0	1571	1190	4751	1571	1190	2376
Block 4	153	738	0	1105	1071	0	1106	1062	4751	1106	1062	2376
Block 5	205	738	2296	951	1071	4810	952	1062	4774	952	1062	2372