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Comparative analysis between the use of lattice towers and polygonal monopoles in SNEL SA's power grid network

[Analyse comparative entre l'usage des pylônes à treillis et ceux en monopodes polygonaux dans le réseau électrique de SNEL SA]

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Résumé

L'étude comparative relative à l'utilisation des pylônes à treillis par rapport à ceux en monopodes de forme pylygonale dans le réseau de transport à haute tension de SNEL SA, est d'une importance capitale pour déterminer les conditions de sécurité, fiabilité, exploitation et maintenance. L'intérêt majeur est de vaincre le phénomène recrudescent des actes de vandalisme tels que de vol de cornières galvanisées, boulons, conducteurs en cuivre et fil de contrepoids de terre sur les infrastructures électriques qui conduisent à l'écroulement des pylônes à treillis, et indisponibilité des lignes de transport d'énergie électrique de SNEL SA. L'usage des pylônes monopodes de forme conique offre les avantages suivants : Esthétiques, peut-être implanté en zone urbaine, faible emprise au sol, installation rapide, démontage et réutilisation possible, une journée d'installation, nombre de pièces réduit pour l'assemblage, coût de maintenance faible étalé sur plusieurs années, résistance aux actes de vandalisme, pas d'agression naturelle et impact environnemental. Le coût complet pour construire un kilomètre de ligne est de 1,25 k€/km avec un monopodes conique, contre 1 k€/km pour un pylône à treillis, engendrant ainsi une variation de coût de 20 % d'installation.

Mots-Clés : Pylônes, monopodes, sécurité et performance des infrastructures électriques, logiciel Impax, vandalisme.

Abstract

The comparative study on the use of lattice towers versus pylygonal monopods in SNEL SA's high-voltage transmission grid network is of paramount importance in determining the conditions for safety, reliability, operation and maintenance. The main aim is to overcome the growing phenomenon of vandalism, such as the theft of galvanized angle irons, bolts, copper conductors and earth counterweight wires from electrical infrastructures, leading to the collapse of lattice towers and the unavailability of SNEL SA's power transmission lines. The use of conical monopods offers the following advantages: Aesthetics, can be installed in urban areas, small footprint, rapid installation, dismantling and reuse possible, one-day installation, reduced number of parts for assembly, low maintenance costs spread over several years, resistance to vandalism, no natural aggression and environmental impact. The complete cost of building one kilometer of line is 1.25 k€/km with a conical monopole, compared with 1 k€/km for a lattice tower, resulting in an installation cost variation of 20%.

Keywords: Pylons, monopods, security and performance of electrical infrastructures, Impax software, vandalism

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1. Introduction

The introduction of this study begins by providing background information on the challenges facing the National Electricity Company (SNEL SA). Indeed, SNEL SA faces major challenges in securing, guaranteeing reliability, and ensuring a quality supply of electrical energy for its customers. Acts of vandalism targeting its high-voltage transmission infrastructure, such as the theft of essential materials, lead to collapses of pylons and prolonged interruptions of transmission lines (Btut, 1987; Ouvrier modern, 1922; Guillauneetal., 1995; Rudervall et al, 2000; Beaume, 2013; Clerfeuille & Vitel, 2000; Zu, 2023;). With a transmission network that extends over 9,189.46 km, including very high voltage direct current lines of ± 500 kV connecting Inga (SCI) to Kolwezi (SCK), it is crucial to study these phenomena to ensure reliable energy supply, especially in a context where demand reaches nearly 2.000 MW. The research area focuses on the analysis of electrical infrastructures, highlighting the reasons for this choice by the need to improve their security against acts of vandalism. These acts not only represent a threat to the reliability of the network but also a significant economic cost for the company and its users. Mining companies, in particular, adopt monopod towers to counter these acts, highlighting the need for comparative evaluation between monopod towers and lattice towers.

Real problems that require solutions include the vulnerability of lattice towers to acts of vandalism, which lead to service interruptions and high maintenance costs. The research aims to identify these challenges while exploring the advantages of monopod towers, particularly in terms of vandalism resistance and maintenance costs.

The objectives of this research are clear: to technically compare monopod and lattice towers, to identify the specific advantages of monopods, to evaluate the associated costs, and to formulate recommendations for their adoption in the SNEL SA transmission network. This will be accompanied by a study of structural engineering principles and safety standards, as lattice towers, although commonly used, present increased vulnerability.

Finally, the literature review highlights several previous studies on electricity transmission infrastructures while highlighting gaps regarding the specific impacts of vandalism and design choices. For example, a recent study (Guillaume et al., 1995) addresses the optimization of tower design without addressing their vulnerability. Similarly, the analysis (Btut, 1987) on the reliability of electrical networks does not distinguish between tower types. These gaps fully justify further investigation to offer practical and innovative solutions to improve the safety and performance of SNEL SA's electrical infrastructures.

2. Materials and methods

2.1. Presentation of the study environment

In this study, we focus on evaluating the issues related to the technique of using monopod towers compared to lattice towers and their costs. For this, we have adopted an analytical approach that starts with the examination of the geometry of monopod towers. This geometry is based on critical electrical distances, such as the distance from the ground, the balance of active conductors, and the distance between phases, as shown in figure 1. The forces induced in these structures generate internal forces and moments that are calculated in a simplified way on the supports (Bonnefille, 1976; Chanal, 2018; Kumar & Hussain, 2018; Wu et al., 2020).

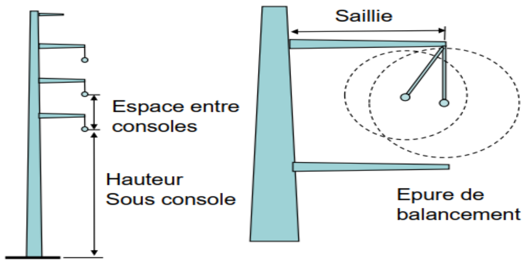


Figure 1. Geometry of the monopod flag supports (Bonnefille, 1976; Chanal, 2018; Kumar & Hussain, 2018; Wu et al., 2020)

Note: Espace entre consoles- Space between consoles; Hauteur Sous console- Height Under console; Saillie-Projection; Epure de balancement- Swinging outline.

La présente étude est qualitative dont l'approche figure 1 shows a pylon with brackets. On the left, the space between the brackets and the height under the bracket are indicated, important dimensions for stability. On the right, the projection shows how much the brackets protrude from the pylon. The swing diagram represents the possible movement of the brackets, essential to understanding how the pylon reacts to forces, such as wind, to ensure its safety and strength.

2.2 Data collection

We also studied the forces applied to the monopod supports in figure 2, which are determined by the choice of active conductors, usually supplied by customers and calculated according to national standards (Bonnefille, 1976; Ouvrier modern, 1922; Beaume, 2013; Chanal, 2018; Kumar & Hussain, 2018; Wu et al., 2020).

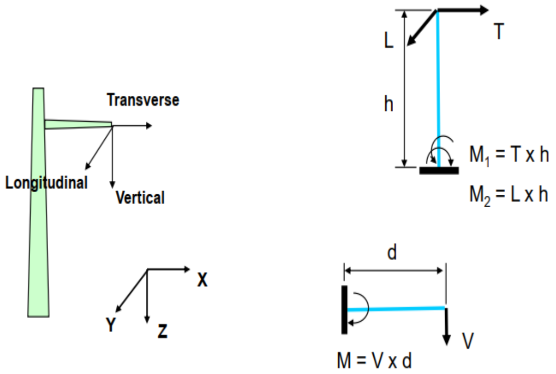


Figure 2. Diagram of forces and moments on monopod flag supports (Ouvrier modern, 1922; Beaume, 2013; Wu et al., 2020; Kumar & Hussain, 2018; Chanal, 2018; Bonnefille, 1976).

These forces can be expressed in different ways, notably by means of a mechanical load tree, which takes into account vertical, horizontal, and transverse forces and which is directly entered into a calculation program, as illustrated in figure 3 (Ouvrier modern, 1922, Zu, 2023; Chanal, 2018; Bezas et al., 2022).

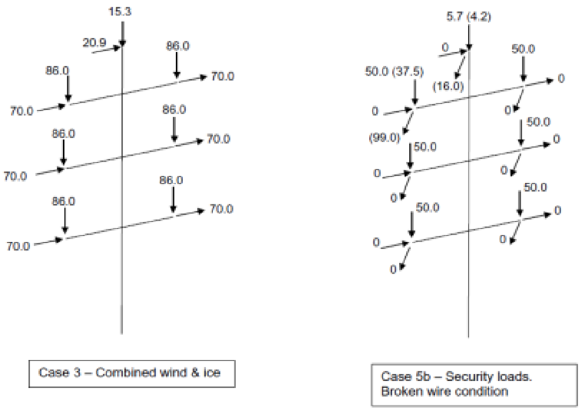


Figure 3. External Load Diagrams Case 3-Combined Wind and Ice and Case 5-Safety Loads-Broken Wire Condition (Ouvrier modern, 1922; Zu, 2023; Chanal, 2018; Bezas et al., 2022)

To assess the safety, reliability, and performance of overhead power lines on a tower, several elements must be considered. First, the span between the supports of the line is crucial, as it influences the distribution of forces exerted on the structure. Second, the conductor diameter, which defines the size of the cable used, has a direct impact on the strength, weight, and load capacity. Furthermore, it is essential to examine the pressures and wind directions for different loading scenarios in order to understand how these factors can affect the structure. The angle of the line, representing its inclination with respect to the horizontal, is also an important parameter to consider (Chanal, 2018; Bezas et al., 2022; Albavrak & Morshid, 2024).

Conductor breakage conditions are another major concern. These conditions refer to the circumstances under which the cable could break, often due to overload or material fatigue. The methods and practices used during line installation also play a determining role in the performance and durability of the cable. In addition, it is crucial to evaluate the cable tension for all possible loads to ensure that it remains within safe limits (Kumar & Hussain, 2018; Bezas et al., 2022; Li et al., 2018)

Considering all these elements, we aim to ensure efficient design and implementation of overhead power lines. Since monopod towers undergo significant deformations, it is imperative to consider the P-Δ effect, which takes into account the instability of the structure, as shown in figure 4 (Ouvrier moderne, 1922; Beaune, 2013; Zu, 2023; Batut, 1987; Chanal, 2018; Bonnefille, 1976).

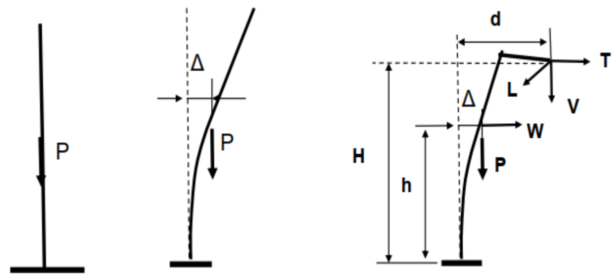


Figure 4. Diagrams of moments and applied forces (Ouvrier moderne, 1922; Beaune, 2013; Zu, 2023; Batut, 1987; Chanal, 2018; Bonnefille, 1976)

2.3. Data analysis

The applied forces and the distances involved in the calculation of moments are expressed by the following equations (Ouvrier moderne, 1922; Beaune, 2013; Zu, 2023; Batut, 1987; Chanal, 2018; Bonnefille, 1976):

$$\boldsymbol{M} = \boldsymbol{P} \times \Delta \quad (1)$$

Or :

- M : Moment (or moment of force) ;
- P : Applied force (or load) ;
- **Δ** : Perpendicular distance (or lever arm).

$$\boldsymbol{M_1} = \boldsymbol{T} \times \boldsymbol{H} + \boldsymbol{V} \times \boldsymbol{d} + \boldsymbol{W} \times \boldsymbol{h} + \boldsymbol{P} \times \Delta \quad (2)$$

Or :

- M_1 : Total moment ;

- T : Tensile force ;
- H : Height at which the tensile force is applied ;
- V : Compressive force (or other force) ;
- d : Distance at which the compressive force is applied ;
- W : Weight (or other force) ;
- h : Height at which the weight is applied ;
- P : Applied force (or load) ;
- Δ : Perpendicular distance associated with the applied force.

Regarding polygonal sections, they are subject to local deformations when considered as non-compact. To address this phenomenon, we adopt two main approaches. The first is to analyze local deformations, which involves evaluating the effects of loads applied to specific areas of the section, thus identifying potential weaknesses. The second approach focuses on the application of strength criteria, ensuring that the structural integrity of polygonal sections is maintained under various loading conditions (Wu et al., 2020; Kumar & Hussain, 2018; Chanal, 2018; Bonnefille, 1976).

We also implemented the ASCE method, which was used to establish relationships between allowable stress and the W/t ratio, where W represents the width of one side of the cross-section and t its thickness in figure 5 (Ouvrier modern, 1922; Beaume, 2013; Wu et al., 2020; Kumar & Hussain, 2018; Chanal, 2018; Bonnefille, 1976).

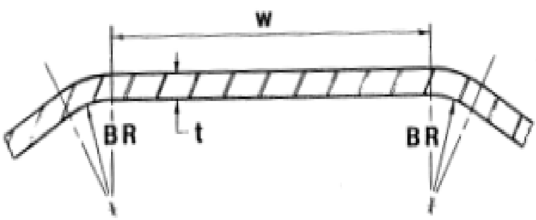


Figure 5. ASCE method (Ouvrier modern, 1922; Beaume, 2013; Wu et al., 2020; Kumar & Hussain, 2018; Chanal, 2018; Bonnefille, 1976).

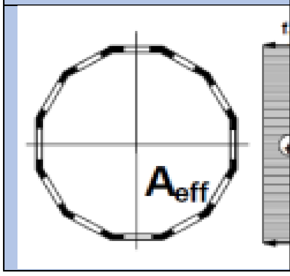
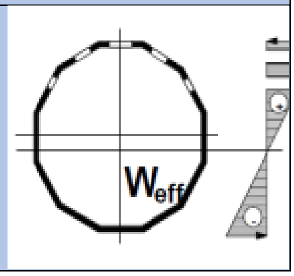
A second method, in accordance with EN 50341 in table I, is based on Eurocode 3 for non-compact sections of class 4, where the effective section characteristics are calculated using an equation defined as follows (Ouvrier modern, 1922; Beaume, 2013; Wu et al., 2020; Kumar & Hussain, 2018; Chanal, 2018; Bonnefille, 1976):

$$\frac{N_{sd}}{A_{eff}} + \frac{M_{sd}}{W_{eff}} \leq \frac{f_y}{\gamma_{M1}} \quad (3)$$

Or:

- N_{sd} : Normal service load (or normal service force) ;
- A_{eff} : Effective area (or effective section) ;
- M_{sd} : Service moment (or service bending moment) ;
- W_{eff} : Effective moment of resistance (or effective section modulus) ;
- f_y : Tensile strength (or yield strength) ;
- γ_{M1} : Partial safety factor for materials (or safety factor).

Table I. Representation of the section according to the Aeff distribution under axial force and Weff under bending moment (Ouvrier modern, 1922; Beaume, 2013; Wu et al., 2020; Kumar & Hussain, 2018; Chanal, 2018; Bonnefille, 1976)

A_{eff} under axial force	W_{eff} under the bending moment
	

Since monopod towers are more subject to deformation than lattice towers, this raises aesthetic concerns, in particular, the curvature often referred to as "banana shape." This deformation can be particularly visible when the deformation exceeds the upper diameter of the tower. According to SNEL SA standards, a deformation limit of 6% of the height of monopod towers is imposed for alignment towers, while a limit of 4.5% is set for those subjected to high angles. It is recommended that the deflection, during a second-order analysis at the ultimate limit state, does not exceed 8% of the height of the column above ground level. This attention to deformation is essential to ensure the safety and aesthetics of monopod towers in figure 6 (Ouvrier modern, 1922; Kumar & Hussain, 2018; Bezas et al., 2022; Albavrak & Morshid, 2024).

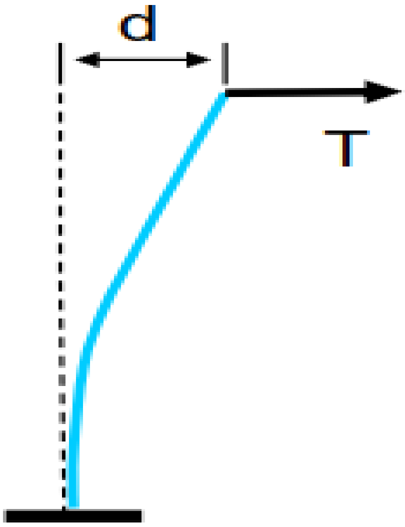


Figure 6. Diagram of the arrow of a pylon under tension (Ouvrier modern, 1922; Kumar et Hussain, 2018; Bezas et al., 2022; Albavrak & Morshid, 2024)

In tower design, stresses are evaluated by considering different types of steel. Stresses are calculated by integrating weighting factors and are compared to the yield strength or allowable buckling stress. The use of high-strength steel is crucial to reduce the weight and costs of towers (Zu, 2023; Kumar & Hussain, 2018; Bezas et al., 2022).

To optimize the design of towers, two main strategies emerge: increasing the diameter or the thickness in figure 7. It is essential to maintain a reasonable ratio between these two dimensions to avoid local deformations. Full-scale tests are performed in accordance with IEC 60652 to validate the calculation methods and manufacturing techniques. These tests consist of subjecting the tower to a load up to its design capacity, measuring the deformations, and comparing them to theoretical values (Kumar & Hussain, 2018; Bezas et al., 2022; Li et al., 2018).

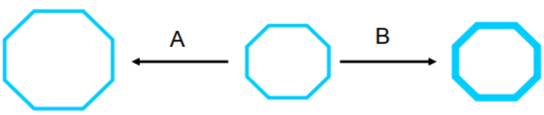


Figure 7. Section chain in hexagonal shapes by increasing the diameter or thickness (Kumar &Hussain, 2018; Bezas et al., 2022; Li et al., 2018)

To optimize the design of towers, two main strategies are considered: increasing the diameter or the thickness. Increasing the diameter is more efficient because the stress (D^2EpRe) and the stiffness (D^3EpE) depend on it. However, the weight is proportional to (D*E). It is essential to maintain a balanced ratio between diameter and thickness to avoid local deformations and improve buckling resistance (Zu, 2023; Bezas et al., 2022; Albavrak & Morshid, 2024).

Finally, we used the Impax software, a tool developed by Valmont, specifically designed for the design and analysis of electricity transmission pylons. This software, thanks to its finite element method, allows complex calculations to be performed and isostatic and hyperstatic structures to be analyzed (Ouvrier modern, 1922; Kumar & Hussain, 2018; Bezas et al., 2022; Albavrak & Morshid, 2024). By integrating geometric data and section properties, Impax facilitates the evaluation of pylons' performance, which is essential to ensure the safety and reliability of electrical infrastructures

3. Results

The 40-meter tower, supporting two 220 kV circuits and weighing 42 tonnes, meets a deformation limit of 4.5% for safety. Impax software aids in design and analysis, enhancing visualization and evaluation of mechanical properties.

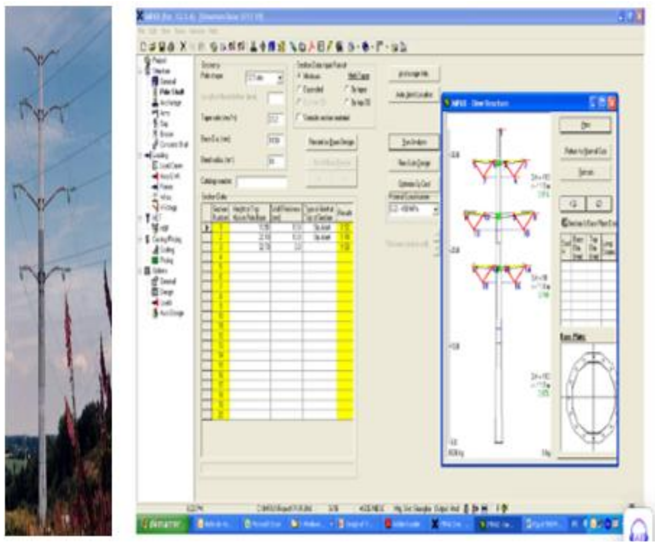


Figure 8. Double-flag pylon of two 220 kV SNEL circuits and Inserting data from the double-flag pylon into Impax

The Impax software calculates based on full-scale test results. Its diamond-shaped sole optimizes structural stresses. Figure 8 shows an interface analyzing geometric data and 2D/3D representations of double-flag towers.

Analysis results for tower design, including deflection limits for the ON1H-40, characteristics, connections, and comparisons, are in tables II to VII.

Table II. Comparison of different deflection limits: Calculations for a tower of type ON1H-40 Height 56.7 meters

Item	Version 1	Version 2	Version 3	Version 4
Deflection limit	2% Worst Load Case	4% Worst Load Case	2% Every Day Stress	4% Worst Load Case
Top deformation	1125 mm = 2%	2257 mm = 4%	995 mm = 1,8%	2029 mm = 3,6%
Type of tower steel	ASTM gr 65 448 Mpa	ASTM gr 65 448 Mpa	ASTM gr 65 448 Mpa	EN S355
Diameter	2257 mm	2100 mm	2050 mm	2200 mm
Number of elements	7	6	6	6
Thickness	22 mm to 10 mm	15 mm ro 8 mm	15 mm to 8 mm	16 mm to 8 mm
Worst stress ratio	1,94 (steel S235 would be OK)	1,02	1,00	1,01
Design governed by	Deformation	Deformation and stress	Deformation	Deformation
Tower weight	68,7 Tons	41 Tons	40,5 Tons	45,8 Tons

The 56.7-meter ON1H-40 tower's first version has a 2% deflection limit, the second 4%. Deflection ranges from 1,125 mm to 2,257 mm, with tower weights from 40.5 to 68.7 tons.

Table III. Results of the Impax software summary of the design geometry of the pole features of the double flag towe

Above ground height (m)	Ground ligne Diameter (mm)	1735.00	Pole shaft weight (kg)	15978
	Top diameter	1084.18	Shape	12 Sides
	Pole taper (mm/m)	19.5000		

The double-flag tower pole is 1,735 mm tall, weighs 15,978 kg, has a top diameter of 1,084.18 mm, and has a taper rate of 19.5 mm/m.

Table IV. Results of the Impax software summary of the design geometry of connections between sections of the double-flag tower

Connections between sections	First	Second	Third
Height above ground (m)	11.80	21.10	26.70
Type	Slip Joint	Slip Joint	Slip Joint
Overlap length (mm)	2529	2289	2145

The double-flag tower's connections include a slip joint at 11.80 meters with a 2,529 mm overlap, a 21.10-meter connection with a 2,289 mm overlap, and a 26.70-meter connection with a 2,145 mm overlap, ensuring structural integrity and load management.

Table V. Results of the Impax software summary of the design geometry of the dimensions and weight of the sections of the double flag tower

Overlap length (mm)	First	Second	Third	Fourth
Base diameter (mm)	1735.00	1576.22	1410.05	1314.18
Top diameter (mm)	1504.90	1345.55	1256.35	1084.18
Thickness (mm)	12.0000	11.0000	10.0000	8.0000
Length (m)	11.800	11.829	7.882	11.725
Weight (kg)	5749	4762	2632	2837

The double-flag tower sections include a first section with a 1,735 mm diameter and 12 mm thickness, weighing 5,749 kg; the second section weighs 4,762 kg with a 1,576 mm diameter, ensuring stability and durability.

Table VI. Results of the Impax software summary of the data analysis of the double flag pylon load points

Load point number	Mounting Height (m)	Load Height (m)	Load Eccentricity (m)	Orientation in XY plans (Degrees)	Force-X (N)	Force-Y (N)	Force-Z (N)
1	36.00	36.10	3.40	0.00	3550	20120	9090
2	36.00	36.10	3.40	180.00	3550	20120	9090
3	33.00	33.20	6.20	0.00	0	0	3500
4	29.00	29.00	0.00	0.00	17640	100010	62100
5	23.00	23.20	7.70	180.00	17640	100010	62100
6	23.00	23.20	7.70	0.00	17640	100010	62100

The double-flag tower's first load point at 36.10 meters shows an eccentricity of 3.40 meters with forces of 3,550 N (Fx), 20,120 N (Fy), and 9,090 N (Fz), critical for stability and design.

Table VII. Impax software results of the forces and moments of the double-flag pylon

Loading case cs 20 distance Force base	Mx (Nm)	My (Nm)	Resultant Mx et My (Nm)	Torsion (Nm)	Shear X-dir (N)	Shear Y-dir (N)	Resultant shear (N)	Axial (N)
36.35	0	0	0	0	0	0	0	0
36.00	5	-1	6	0	7	31	32	822
36.00	4097	-603	4122	-305	7332	40994	41644	19610
34.35	71860	-12727	72978	-306	7363	41140	41193	23562
33.00	127482	-22685	129485	-306	7389	41264	41920	26877
33.00	127513	-50977	137325	752	7426	41440	42100	31679
32.35	154468	-55808	164241	751	7437	41493	42154	33313
30.35	237643	-70721	247943	752	7472	41669	42334	38437
29.00	293995	-80829	308894	752	7500	41900	42467	41992
29.00	293986	-152342	331113	126180	25763	143967	146254	100264
28.35	387588	-169090	422867	126173	25739	143992	146274	102063
26.70	625309	-211596	660136	126173	25772	144154	146439	106546
26.70	625315	-211563	625315	126181	25740	144115	146395	106607
26.35	675771	-220570	675771	126174	25724	144140	146417	108839
24.56	934864	-266792	934864	126181	25774	144480	146761	120154
24.35	964497	-272069	964497	126177	25755	144453	146731	126942
23.00	1159610	-306860	1159610	123177	25788	144617	146898	125737
22.35	1200496	-311687	1200496	122168	62211	349321	354818	264933
21.10	1427584	-352116	1427584	122163	62154	349207	354695	267446
21.10	1864197	-429826	1864197	122161	62184	349358	354849	272015
20.35	1861194	-429795	1864194	122169	62103	349129	354610	278527
18.82	1826116	-476363	1826116	122156	62043	349002	354474	278534
18.35	2661091	-571426	2661091	122157	62026	349069	354537	290951
16.35	2824465	-600433	2824465	122159	61918	348585	354140	293441
14.35	3522090	-724237	3522090	122169	61759	348125	353560	302833
12.35	4218590	-947710	4218590	122169	61580	347434	352849	312558
11.80	4913664	-970835	4913664	61363	61470	347003	352405	322166
11.80	5104530	-1004646	5104530	61260	61480	347055	352458	324654
10.35	5104537	-1004607	5202455	122168	61363	346541	351932	325224
9.27	5607226	-1093557	5712867	122167	61260	346120	351500	339733
8.35	5980795	-1159625	6092178	122168	61167	345724	351093	350745
8.35	6299252	-1215905	6415528	122161	60992	344920	350271	356295
6.35	6989246	-1337813	7116130	122161	60748	343790	349116	367947
4.35	7676946	-1459226	7814399	122162	60489	342557	347856	379677
2.35	8362144	-1580112	8510124	122162	60214	341224	346469	391775
0.35	9044631	-1700474	9203095	122169	60046	340398	345653	403609
0.00	9163771	-1721490	9324067	122169	60046	340398	345654	405575

At 29 meters, bending moments are 293,995 Nm (Mx) and -80,829 Nm (My). At 22.35 meters, moments reach 1,200,496 Nm (Mx) and -311,687 Nm (My), indicating reinforcement needs, while shear forces at 34.35 meters are 7,363 N and 41,140 N.

Table VIII. Comparison of the Floor Area of Towers (lattice tower and monopole tower) for a 220 kV Double Circuit

220 kV Double Circuit								
		Lattice tower			Monopod tower			Monopod versus Lattice in (%)
Height below console	**Use**	**Réf. Tower**	**Size at GL**	**Floor area (m²)**	**Monopod**	**Size at GL**	**Floor area (m²)**	**Floor area**
30 m	Low-angle alignment	G4 NT B3x	6,63m x 6,63m	48,40	S2 KNT H6 Y	Diam 1,95	3,80	8%
	Medium-angle anchoring	G4 AS B3x	7,13m x 7,13m	55,921	S2 AS H6 Y	Diam 2,98	8,90	16%
	High-angle anchoring	G4 SOS1 B3x	7,13m x 7,13m	55,921	S2 AS H6 Y	Diam 3,66	13,4	24%
		160,24			**26,10**			**16%**

The console height is 30 meters for vehicle access. The G4 NT B3x tower measures 6.63 m x 6.63 m (48.40 m²), while the G4 AS B3x and G4 SOS1 B3x measure 7.13 m x 7.13 m (55.921 m²). Monopods range from 3.80 m² to 13.4 m², with lattice towers supporting larger loads. (table XIII)

Table IX. Comparison between Tubular Monopole Towers and Lattice Towers

	Monopod (tubular) towers	**Lattice towers**
	Aesthetics	Utilities
Location	Suburban areas	Campaign
Floor area	Diameter 1 m to 2 m	Square 10 m x 10 m
Installation	½ to 1 day	1 week
Number of pieces	50	> 1000 (with bolts)
Typical weight	14 tons (3T to 30 T 90 kV)	10 tons
	Resist Terrorism	No monopods
	Vandal-resistant (South Africa)	No
	Avalanche-proof (Norway, Iceland)	No
Cost of complete line per km ratio	**1.25 k€/km**	**1 k€/km**

diameter, suit suburban areas, installed in half a day to a day. Lattice towers require 10 m x 10 m space and take up to a week to install. Monopods cost 1.25 k€ per kilometer, while lattices cost 1 k€ as shown in table IX

4. Discussion

The ON1H-40 tower imposes a deformation limit of 2% for the first version and 4% for the second. Previous studies (Zhu, 2023) confirm that stricter deformation limits promote stability. A hypothesis test could be necessary to assess whether the impact of these limits on performance is significant.

The double flagpole is 1735 mm tall and has a 12-sided shape to improve strength. Research (Wu et al., 2020) shows that this design optimizes resistance to torsional forces. Further analysis could test the robustness of this configuration.

Slip joint connections are essential for the flexibility and stability of the tower. Work (Zheng & Shen, 2022) highlights that such connections improve overall performance. A hypothesis test could analyze the impact of these connections on the durability of the tower.

Tower sections vary in weight and diameter, influencing overall stability. A study (Bezas et al., 2022) suggests that cross-section optimization can reduce weight while maintaining strength. A hypothesis test could validate the effectiveness of this approach.

The applied loads present significant forces, requiring detailed evaluation. Research (Albayrak & Morshid, 2020) confirms that poorly distributed loads compromise stability. A hypothesis test could examine the effect of loads on the structure.

The measured bending moments show critical values, making the use of adequate materials imperative. Studies (Li et al., 2018) reveal that appropriate materials can enhance strength. A hypothesis test could evaluate the effectiveness of these materials under load.

Tower design, with precise specifications, is crucial for safety. Research (Zhu, 2023) indicates that monopods, although more expensive, are aesthetically pleasing. A comparative analysis could test the effectiveness of monopods versus lattice towers in different contexts.

The results of the different analyses highlight the importance of design, materials, and installation methods in ensuring the safety and performance of towers. Additional hypothesis testing could strengthen the validity of the conclusions and guide future practices in the design of similar structures

5. Conclusion

This comparative study on the use of lattice towers versus polygonal monopods in the SNEL SA high-voltage transmission network addressed several hypotheses formulated at the outset. The analysis revealed that monopod towers offer significant advantages in terms of safety, reliability, and maintenance, thus meeting the main objective of this research: to minimize the impact of vandalism on electrical infrastructure.

The results show that monopod towers, thanks to their compact and aesthetic design, allow for rapid installation and reduce maintenance costs over several years. In addition, their increased resistance to vandalism, as well as their flexibility of installation in urban environments, make them a viable alternative to lattice towers, which are often vulnerable to theft and damage. The cost assessment also revealed that, although the cost of a kilometer of line is slightly higher for monopods (€1.25k/km compared to €1k/km for lattice towers), the initial investment is offset by substantial savings in maintenance and superior durability.

This finding reinforces the idea that the choice of a tower type must take into account not only the immediate construction costs but also the long-term costs. By relating these results to previous studies on electricity transmission infrastructure, it appears that the phenomenon of vandalism is not isolated to SNEL SA. Other electricity networks around the world face similar challenges, highlighting the need to adopt innovative and sustainable solutions. These findings suggest that the increasing adoption of monopod towers could have a positive impact on the reliability of electricity networks in various contexts. In summary, this research demonstrates the need for an analytical approach to assess tower design choices in the context of electrical infrastructure safety and performance.

Recommendations

The coherence between the problem, objectives, results, and discussion reinforces the validity of this study and paves the way for practical recommendations for SNEL SA and other companies in similar contexts. The adoption of monopod towers could not only improve infrastructure safety but also contribute to a more efficient and sustainable management of electricity transmission networks.

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Conflict of Interest

The author declares no conflict of interest related to this article.

Ethical Considerations

The scope of published consent covers research on electrical infrastructure. The author must provide consent from the ethics committee or another appropriate authorization for such research

Author's Contributions

Each author played a key role in the development and finalization of the research article.

L.M.M. was responsible for drafting and preparing the original version. He also focused on data collection and analysis and validated the final version.

A.M.N. was responsible for reviewing the survey, helped improve the quality of the original version, and performed the final revision, ensuring that the article was ready for publication. He also oversaw the entire process, ensuring that all steps were followed correctly. All authors have read and approved the final version of the manuscript.

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