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# WORK SPECIFICATION FOR THE CONSTRUCTION OF 33KV OVERHEAD LINES ACROSS A LAGOON USING EQUAL LEVEL DEAD-END LATTICE TOWER SUPPORTS

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## ABSTRACT

***Bare overhead distribution conductors are typically flexible and uniform in weight along their lengths. This weight causes the span to form a catenary (sag) which changes with conductor temperature, ice, wind loading and time. This catenary is capable of tripping circuits because it often results to short circuit and damage power system equipment with attendant loss of revenue to utility company. This paper presents a case study of 33kV overhead line construction crossing a 200m wide 'Lagoon' which requires minimum sag-tension design and estimation of Dead-End Lattice Tower weight specification that would determine weight of Tower foundation. These two parameters were obtained using the standard mathematical equations and the specifications for Aluminium Conductor Steel Reinforce (ACSR). The results of various Parameters evaluated in this research work are presented and discussed. The Sag and Tower weight results were applied to the proposed project which was successfully completed and commissioned.***

***Keywords***: *Aluminium Conductor, Catenary, Dead-End, Lattice Tower, Tripping Circuits, Parameters, Overhead Lines, Sag-Tension, Tower Weight, Tower Foundation, Steel Reinforce, Specifications.*

## 1. INTRODUCTION

In electrical power distribution networks, electricity supply is made available by utility companies from nearby transmission substations via the use of High Tension (HT) supports strung with Aluminium Conductors. Typical source-station ranges from 30MVA 132/33kV to 100MVA 132/33kV power Transformer in Nigeria. The acceptable span of 33kV line stringing between two High Tension Supports is about 50m for concrete poles, while the Aluminium conductors used for the overhead line to distribute the electric supply are usually of different types depending on the user's choice and area of application.

Aluminium Conductor is a physical medium used to transmit or distribute electrical energy from one place to other. It is an important component of overhead and underground electrical transmission and distribution systems. The choice of conductor depends on the cost and efficiency. A Typical conductor has the following features [1]

1. High electrical conductivity.
2. High tensile strength so that it can withstand mechanical stresses.
3. Low specific gravity i.e. weight/unit volume.
4. Low cost of installation without sacrificing other factors.

Aluminium Conductors are preferred over copper due to the following reasons.

1. It costs less than copper to produce.
2. It offers larger diameter for the same amount of current which reduced corona.

Very common Aluminium conductors used as overhead lines include [1,2]

1. All Aluminium Conductor (AAC)
2. Aluminium Conductor Aluminium Reinforce (ACAR)
3. All Aluminium Alloy Conductor (AAAC)
4. Aluminium Conductor Steel Reinforced (ACSR)
5. Aluminium Conductor Composite Core (ACCC)

The choice of conductor type and size has a major impact on transmission/distribution line design and subsequent financial returns. For any given project, however, this choice is often limited to a narrow set that conform to specified criteria, including, but not limited to, [2,3]:

1. Electrical load requirements
2. Load growth projections

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3. Network voltage requirement and/or accessible voltage ranges.
4. Support structure requirements, limitations and/or the availability of extant infrastructure such as towers for transmission lines and concrete poles for distribution lines.
5. Environmental Considerations.
6. Regulatory Statutes.

Transmission lines do not connect between their supporting towers/poles in a straight line. The Shape formed by a line strung between the two supports is called catenary [1, 2, 3]. If the line is much tensioned, sag will be minimized and there is possibility of line snapping. But if the line is much sagged, it will increase the quantity of conductor used and hence increasing the cost of the project. A reasonable sag level is allowed, to prevent too much tension on the line [3 – 6].

## 2. ALUMINIUM CONDUCTOR SAGGING AND TENSIONING

In Nigeria, most power Utilities use AAC Conductor at 33kV, 11kV and 0.415 kV voltage levels for stringing overhead lines. While the primary function of the conductor is to transfer electrical load, it must also be strong enough to support its own weight as well as any other weight (or Stress) caused by ice, wind and pole movement [2, 3]. Other causes of conductor sag include Age of conductor, conductor load per unit length (span), conductor tension and level of supporting towers/poles [4]. Conductor sag to some degree can be mitigated by installing the conductor at a higher initial tension but higher tensions tend to increase the conductor's susceptibility to premature fatigue failure due to Aeolian vibration. For this reason, most conductors are installed at relatively low catenary constant [1 – 3]. Some conductor types/sizes adopt larger sags with imposed loads or high temperatures than others. This can impact span length and support structure combination dramatically. The choice of conductor, based on its sag and tension characteristics, have a large impact on overall project costs.

## 3. CATENARY PARAMETERS AND EQUATIONS IN TWO EQUAL LEVEL SUPPORTS

### 3.1 Sag and Tension

The catenary of 33kV overhead line between two supports erected about the same level is shown in Figure 1.0 [3]. The conductor catenary is very nearly a parabolic shape defined by the conductor's weight per unit length (W) and the Horizontal tension (H). The sag of the conductor (D) is a function of W, H, span length (l), and the difference in elevation between the span supports.

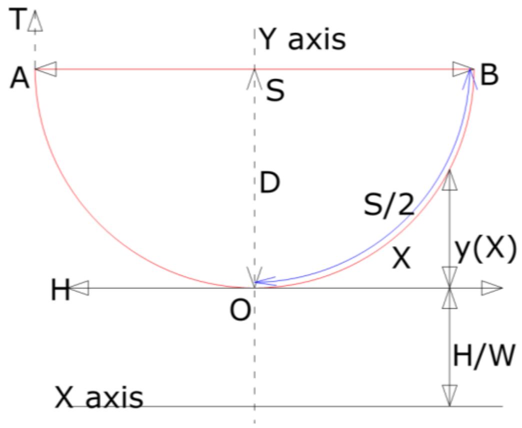


*Figure 1: The catenary curve for the two level supports*

The catenary equation for a conductor between supports is expressed in terms of the horizontal distance (x) from the lowest point (or vertex) of the catenary to a point on the catenary that is y(x) above the vertex, is given as [2,3].

$$\boldsymbol{y}(x) = \frac{H}{W}\left[\cosh\left(\frac{W.x}{H}\right) - 1\right] \cong \frac{wx^2}{2H} \qquad (1)$$

The expression on the right side of equation (1) is an approximate parabolic equation based upon the first term of the MacLaurin expansion of the hyperbolic cosine. The approximate parabolic equation is valid [2] if:

$$\frac{x^2w^2}{12H^2} \leq 1 \qquad (2)$$

Where,

W is the weight per unit Length of conductor, H is the Horizontal Tension in the conductor

For a level span with the vertex in the centre, sag (D) is found by substituting $x = \frac{s}{2}$ in equation (1). The exact catenary and approximate parabolic equation for sag is

$$D = \frac{H}{W}\left[\cosh\left(\frac{WS}{2H}\right) - 1\right] \cong \frac{WS^2}{8H} \qquad (3)$$

Where

S is the Length of span

The ratio $\frac{H}{W}$, is commonly referred to as the catenary constant, C. An increase in the catenary constant causes the catenary curve to become shallower and the sag to decrease. The catenary varies as a function of conductor temperature, ice and wind loading and time [1, 2, 3]. The Catenary constant typically has a value in the range 500 – 2000 meters for most transmission catenaries under most conditions [2]. The approximate or parabolic expression is sufficiently accurate if the sag is less than 5% of the span length [3]. The horizontal component of tension, H, as measured at the vertex is the same at all points within the catenary, but the total tension increases as the support points are approached, due to added vertical components [2]. Given a level span at the supports, the vertical component V of tension is equal to one half of the weight of the conductor as [2, 3]:

$$V = \frac{WL}{2} = H\sin\text{h}\left[\frac{WS}{2H}\right] \quad (4)$$

At the end of level supports, the conductor tension is the vector sum of the horizontal and vertical tension given as [1, 2],

$$T^2 = H^2 + \left(\frac{W \cdot L}{2}\right)^2 \quad (5)$$

Using equations (4) and (5)

$$T = H\sqrt{1 + \sinh^2\left(\frac{WS}{2H}\right)} = H\cosh\left(\frac{WS}{2H}\right) \quad (6)$$

Relating total tension to sag in a level support, the equation becomes

$$T = H + W\left(\frac{H}{W}\cosh\left(\frac{WS}{2H}\right) - \frac{H}{w}\right) \quad (7)$$

Relating equations (3) and (7)

$$T = H + WD \quad (8)$$

Equation (8) implies that at the ends of the level support, the conductor tension T is equal to the horizontal component plus the conductor weight per unit length W multiplied by the Sag (D).

### 3.2. Conductor Length Estimation

Applying calculus to the catenary equation allows the calculation of the conductor length L(x) measured along the conductor from the lowest point of the catenary in either direction. The equation for catenary length between the support is given as [3],

$$L(x) = \frac{H}{W} Sinh\left(\frac{wx}{H}\right) \cong x\left(1 + \frac{x^2w^2}{6H^2}\right) \quad (9)$$

For a two-level support, the conductor length corresponding to $x = \frac{s}{2}$, is half of the total conductor length Las shown in equation (10) [3]

$$L = \frac{(2H)}{W}\sinh\left(\frac{sw}{2H}\right) \cong S\left(1 + \frac{S^2W^2}{24H^2}\right) \quad (10)$$

The parabolic equation for conductor length can also be expressed as a function of Sag (D) by substituting the Sag parabolic equation i.e. equation (3) [3];

$$L = S + \frac{8D^2}{3S} \quad (11)$$

The conductor slack is defined as the difference between the conductor Length L and span Length S. The parabolic equation for slack may be found from equations (3), (10) and (11) as in equation (12) [3];

$$L - S = S^3\left(\frac{w^2}{24H^2}\right) = D^2\left(\frac{8}{3s}\right) \quad (12)$$

Equation (11) can be rearranged to obtain an equation showing the dependence of sag D on slack $L - S$ as,

$$D = \sqrt{\frac{3S(L-S)}{8}} \quad (13)$$

### 3.3 The Wind Load and Effective Conductor Weight

In a situation where the environment is tense with wind pressure that is above normal wind and blowing with ice presence, it is important to obtain wind load ($W_w$) and effective conductor weight ($W_{eff}$) as shown in equations (14) and (15) respectively [1,7];

$$\text{Wind Load (Ww)} = \frac{P(2K + x)}{1000}\ \text{N/M} \quad (14)$$

Effective conductor Weight ($W_{eff}$) is given by:

$$W_{eff} = \sqrt{[wt.of\ conductor]^2 + \frac{(wind\ load)^2}{g^2}}\ \text{kg/m} \quad (15)$$

Where: P is the Wind pressure in N/m$^2$, K is the Radial thickness of ice in mm, X is the conductor diameter in mm and V is the wind speed in m/s. The wind pressure (P) and design wind speed ($V_s$) are obtainable using equations (16) and (17) respectively [7],

$$Wind\ Pressure\ (P) = 0.613\, V_s^{\,2} \quad (16)$$

$$Design\ Wind\ Speed\ (Vs) = V \times S_1 \times S_2 \times S_3 \quad (17)$$

Where, $V_s$ is the Design wind speed, V is the wind speed, $S_1$ is the Topography factor; 1.0 for normal sites, $S_2$ is the Ground roughness; $0.5 \le x \le 1.3$ and $S_3$ is the Security factor; usually 1.0.

## 4. DESCRIPTION OF CASE STUDY

A customer of Electricity Distribution Company, located in Badagry area of Lagos - Nigeria, desiredto install a 1 MVA,33/0.415 kV Transformer with a construction of 4 spans of overhead lines strung with Aluminium conductor. Between the second and third spans is a Lagoon with an approximate distance of 200m. To complete the project, it is required to install Lattice Towers at the two ends of Lagoon through which the overhead line can be strung. Therefore, overhead sag, tower height, conductor weight and tower foundation designs are required to be carried out.

### 4.1 Estimation of Catenary Parameters for an Equal Level Supports

(i) Parameter Specifications

Aluminium Conductor Steel Reinforced ACSR type A1/S1A conductors IEC 61089 standard is recommended for construction of the overhead lines. The ACSR parameter specifications are as follows [8].

1. Nominal cross-sectional area of Aluminium = 160 mm$^2$
2. Steel Cross-sectional Area = 8.89 mm$^2$
3. Total Cross-sectional Area of selected ACSR (sum of 1 and 2 above) = 168.89 mm$^2$
4. Approximate overall Diameter = 16.8 mm
5. Approximate Overall Weight = 509.3 kg/km
6. Maximum DC Resistance at 20 $^o$C = 0.18 Ω /km
7. Rated Strength = 36.18 kN
8. Electrical Resistivity at 20 $^o$ C = 0.028264 $\mu\Omega$m

9. Temperature coefficient of resistance = 0.00403 /$^o$C
10. Density at 20 $^o$ C = 2.703 kg/m$^3$
11. Coefficient of Linear Expansion = 23 x 10$^{-6}$ /$^o$C
12. Final Modulus of Elasticity = 68000MPa
13. Coefficient of Linear Expansion for Galvanised steel = 11.5 x 10 $^{-6}$ /$^o$C
14. Density of steel at 20$^o$ C = 7.80kg/m$^3$
15. Proposed Height of Tower = 18m

(ii) Sag Calculation without wind or ice environmental conditions

Length or span of the overhead line S (Across Lagoon water) = 200m

Weight of conductor (W) = 509.3kg/km = 0.5093kg/m

Acceleration due to gravity (g) = 9.81m/s$^2$

Tension on Conductor ($W_I$) =Weight x Acceleration due to gravity (18)

= 0.5093 x 9.81 = 4.99N

Rated strength (Tension) of conductor = 36.18kN = 36180N

$$\text{Working Tension} = \frac{Rated\ Strength}{Safety\ factor} \quad (19)$$

Safety factor = 2 was used because the conductor tension shall not exceed 50% of its breaking load [7]. Using equation (19),

$$\text{Working Tension} = \frac{36180}{2} = 18090\text{N}$$

Therefore, Using equation (3) above,

$$\text{Sag (D)} = \frac{4.99 \times 200^2}{8 \times 18090} = 1.38\text{meters}$$

Using equation (12), conductor slack (L-S) is obtained as

$$\text{Conductor} = (1.38)2 \times \frac{8}{3 \times 200} = 0.025$$

= 2.5 % of span Length

(iii) Sag calculation with Wind and Ice environmental condition

Given that, the design wind speed V= 8.06m/s, $S_1$ = 1, $S_2$ = 0.99 (using [8]) and $S_3$ = 1

the design wind speed $V_S$ from equation (17) is

$V_S$ =8.06 x 1 x 0.99 x 1 = 7.98 m/s

The wind pressure, from equation (16)

Wind pressure (P)= 0.613 x 7.98$^2$ = 39.04 N/m$^2$

However, in the climate of Nigeria, there is no ice at all. Therefore the wind load ($W_w$) from equation (14) with y=0, is

$$W_w = 39.04\ [2x0 + \frac{16.8}{1000}] = 0.66\ \text{N/m}$$

Substituting weight of conductor stated in the list of specifications for 160 mm$^2$ ACSR Conductor, the estimated Wind Load and acceleration due to gravity in equation (15) gives the effective weight of conductor $W_{eff}$ as

$$W_{eff} = \sqrt{0.5093^2 + \frac{0.66^2}{9.81^2}} = 0.51\ \text{kg/m}$$

Using equation (17), Tension on conductor ($W_{eff1}$) becomes,

$W_{eff1}$ = 0.51 x 9.81 = 5.0N

With $W_{eff1}$ = 5.0 N, S = 200m and H = 18090N in equation (3) gives Sag (D) as

$$D = \frac{5 \times 200^2}{8 \times 18090} = 1.38\text{m}$$

The summary results of sag parameters calculation are shown on Table 1 below.

*Table 1: Summary Results of Sag Parameters Calculation*

| S/N | Parameters | Calculated Value |
|---|---|---|
| 1 | Tension on conductor (WI) | 4.99 N |
| 2 | Rated Strength of Conductor | 36.18 Kn |
| 3 | Working Tension | 18090 N |
| 4 | Sag (D) [without wind or Ice environmental conditions] | 1.38 m |
| 5 | Conductor slack (L-S) | 2.5% of span Length |
| 6 | Design Wind Speed (Vs) | 7.98 m/s |
| 7 | Wind Pressure (P) | 39.04 N/m2 |
| 8 | Wind Load (Ww) | 0.66 N/m |
| 9 | Effective weight of conductor (Weff) | 0.51 kg/m |
| 10 | Sag (D) [with wind and Ice environmental conditions] | 1.38 m |

### 4.2 Estimation of Dead-End Lattice Tower Weight

Size of MS (mild steel) Angle Iron Selected = 45 x 45 x 4 mm

Considering mild steel for its light weight.

The Approximate weight of MS iron per meter = 2.7 kg/m [9].

*Tower stand:*

Proposed height of the tower excluding base = 18 meters

Total Number of stand required = 4

Therefore, Total length of iron = 4 x 18

= 72 meters

Total weight, ($A_T$) = 72 x 2.7 = 194.4 kg (without Braces)

*Tower Braces:*

Approximately 24 Braces per side from average of several sample pictures of lattice tower of similar structure.

Total length is obtained by adding 25% of approximate number of braces per side to account for extra braces requirement

∴Total length of Braces per side ≅ 30 meters

Total length of Braces for 4 sides ≅ 30 x 4 = 120 meters

Size of MS Angle Iron Selected for Braces = 35 x 35 x 4 mm
Approximate weight of MS iron per meter = 2.1 kg/m [9].
Therefore, Total weight ($B_T$) = 2.1 x 120 meters= 252 kg

*Dead-end Tower Cross arm*:
Standard Cross arm length for a 33kV line is 2.75 m (9ft).
Total length of arm = [Both receiving and sending end] = 2.75 m x 2 = 5.5m
Size of MS (mild steel) Angle Iron Selected = 45 x 45 x 4 mm
The Approximate weight of MS iron per meter = 2.7kg/m [9].
∴ Total weight of cross arm (**$C_T$**)= 5.5 x 2.7 = 14.85kg

*Cross Arm Braces:*
4 braces are required for each side of tower to support cross arm
Therefore, Braces for Length the cross arm = 4 x 2 meter = 8 meters
Size of cross arm = 45 x 45 x 4 mm
The Approximate weight of MS iron per meter = 2.7 kg/m [9].
∴ Total weight of cross arm braces, **$D_T$** = 8 x 2.7 = 21.6 kg

*Nut and Bolt:* 5/8" -11 x 2 ASTM F3125 Grade A325 Hot Dipped Galvanized Steel Structural Bolt w/A563 DH Nut-Nap is Specified [10].
Parameters of specification:
Head: Hex
Diameter: 5/8"
Grade: A325
Thread Size: 11
Length: 2"
Product Weight: 0.37 lbs
Thread Type: cut
Thread Length: 1"
From the 30 braces per side stated earlier above,
Since each brace requires 2 Nuts and Bolts, then
30 Braces will have = 30 x 2 = 60 Nuts and Bolts per side
Total Bolt and nut for the 4 sides of the Tower = 60x 4 = 240 Nuts and Bolts
Nut for cross arm = 10 for each arm
Nuts for the 2 sides of cross arm = 10 x 2 = 20
Total Number of Nuts, Approximately = 240 +20 = 260
The specified values above i.e. Length, Diameter, Thread Size and Head Type in calculating total weight ($E_T$) of the bolts & nuts and washers using online calculator [11] is obtained to be 55.34 kg .
Therefore, $E_T$ = 55.34 kg
Weight of Aluminium Conductor is negligible

Total weight of the Tower = $A_T + B_T + C_T + D_T + E_T$
= 194.4 + 252 + 14.85 + 21.6 +55.34
= 538.19 kg ≈ 538.2 kg
The summary results of dead-end lattice tower and components weights evaluation are shown in Table 2 below.

*Table 2: Summary Results of Dead-End Lattice Tower and Components Weights Evaluation*

| S/N | Parameters | Calculated Value |
|---|---|---|
| 1. | Weight of Tower Stand | 194.4 kg |
| 2. | Tower Braces | 252 kg |
| 3. | Dead-End Tower Cross arm | 14.85 kg |
| 4. | Cross arm braces | 21.6 kg |
| 5. | Nuts & Bolts | 55.34 kg |
| | Total weight of Dead-End Lattice Tower | 538.2 kg |

## 5. RESULTS AND DISCUSSION

The Dead-end Tower expected to be used based on estimated parameters is shown in Figure 2, the results of Sag calculations and other associated parameters used to prepare the designed 33kV overhead lines are shown in Figure 3. It can be seen that the sag and conductor slack calculated for the overhead lines, on consideration that no serious wind is blowing in the environment, both have the same value of 1.38 meters and 2.5% of span length respectively with sag values when the environments were considered as normal atmospheric pressure and without ices as it is found in the Nigerian environment. This implies that the average wind parameters for Lagoons in Lagos-Nigeria has minimal sagging effect on overhead lines constructed across it.

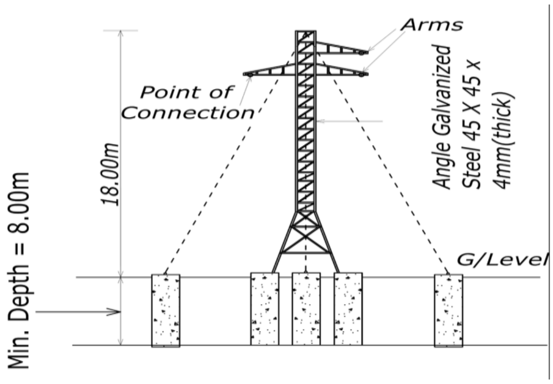


*Figure 2: Front view of dead end tower*

Also, the slack values of 0.025 estimated (i.e. 2.5% of span length) is accurate because one of the literatures reviewed relayed that slack not greater than 5% of span length is allowed and recommended in overhead line stringing regardless of voltage level [3].
The newly constructed lines T-off near a 15MVA 33/11kV injection substation. Thus, when the newly

constructed 1MVA 33/0.415kV substation is finally energized, the load will be operating an approximate short distance of 265m which will definitely measure lower value of Total harmonic distortion [12] which automatically leads to reduction in Technical losses [13]. Hence, marginal cost of Transmission or Distribution expansion is achieved [14]. Also, commissioning of such substation will have impact on sub-grid allocated distributable generation capacity or allocated parts of generation capacity [15].

Furthermore, the approximate total weight of the specified dead-end Tower estimated to be 538.2kg per tower, is a value that determines the expected calculated weight of Tower foundation by structural Engineers. This civil engineering foundation weight will be designed greater than the tower weight since the civil foundation will be carrying the weight of the Tower.

Finally, for the project to be executed, Tower height of 18m, Sag Value 1.3< Sag <2m and Tower Weight value of 535 < Tower Weight < 550 kg are recommended and specified.

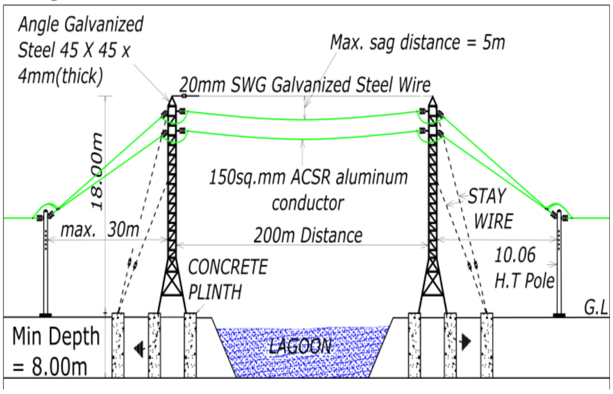


*Figure 3: Side view of designed 33kV overhead line*

## 6. CONCLUSION

Aluminium Conductor as a means of making electric power available to distribution companies from a transmission company has been discussed including its properties. The theory of Sag and Tension in equal Level supports has also been extensively presented. A practical project of a 33kV overhead line which is required to cross a 200m Lagoon (a span) was used as case study. Sag and catenary parameters required for the overhead construction were calculated. The obtained results are presented and discussed accordingly. The presentation also includes estimation of total weight of a dead-end tower, which will in turn determine the weight of the civil Engineering design for the Tower foundation. Thus, heights of Tower, Sag and weight of the Tower values have been specified for the project execution. These specified parameters were applied to the proposed project construction and it was successfully commissioned.

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