Sag and Tension Evaluation of a 330kV Overhead Transmission Line Network for Upland and Level land Topographies.

Crescent O. Omeje, Roland Uhunmwangho

Abstract: The objective of this research paper is to evaluate the effects of sag and tension on a 330kV transmission line network for equal and unequal level topographies. The selected upland for this study in Nigeria is the Asaba-Onitsha 330kV overhead transmission line network in the South-East while a level land topography from New Haven transmission network in Enugu to Abakaliki injection substation in Ebonyi state was considered in the Sag and Tension analysis. The resultant effect of increased temperature above the ambient value on the conductor span length and on the sag was presented. Simulation was carried out on the sag equation at different stages of temperature increase with corresponding changes in the span length for different wind loading. All simulation was carried out in Matlab 7.14.

Keywords: Conductor –ground clearance, Sag, Span length, Transmission lines, Tension.

1 INTRODUCTION

Transmission lines are physical structures that are installed in the natural environment. These structures are designed and positioned in a way to minimize power loss and guarantee safety to life. An ideal transmission line must be safe, reliable and efficient with reduced over-stressed line conductors during stringing [1]. In the overall design of a transmission line network, excessive sag is always avoided so that a minimum vertical clearance is maintained between the overhead line conductors and the ground [2]. This ground clearance is very significant to avoid power failure and explosive short circuit of the line conductors during wind actions. In power system network, the transmission lines and substations play a major role in the conveyance of generated power to the end users. Therefore appropriate modelling of these lines is very pivotal in the design and erection of the transmission line network. Traditionally, the overhead line conductors usually take the shape of a catenary due to sag as illustrated in Figure 1 for a level ground operation. Sag is the vertical distance formed between the point where the line is joined to the tower and the lowest point on the base line [3]. Sag is very essential in the minimization of tension for stringed overhead transmission line conductors. In different reported literatures, it is proven that an inverse relationship exists between sag and tension [4]. A maximum tension on the stringed line conductors necessitates low sag which may result in a total collapse or snap of the line conductor. Conversely, a high magnitude of sag implies a minimum tension. A situation that involves higher sag with minimum tension will undoubtedly require more overhead line conductor with a consequential increase in the cost of conductor [5]. Temperature and wind impacts on sag and tension of All Aluminium Alloyed Conductor (AAAC) for equal level topology have been presented in [6]. In this reference, the line support was considered on equal level topology and no comparative analysis was carried out for upland topology. The minimum ambient temperature applied was 5°C which is below the minimum ambient temperature for the selected area in Nigeria. In [7], the effect of sag on transmission line was analysed based on the factors affecting sag in a transmission line. No emphasis was made on unequal ground level and temperature variations. This paper is therefore aimed at evaluating the sag and tension of a 330kV overhead transmission line conductors for the Asaba-Onitsha 330kV overhead transmission line network in the South-East region in Nigeria. A level land topography from New Haven transmission network in Enugu to Abakaliki injection substation in Ebonyi state was considered in the Sag and Tension analysis. The variation in sag as a result of increase in temperature and conductor span length is also evaluated in this paper and a comparison was made in terms of sag variation with tension for the upland and level land topology.

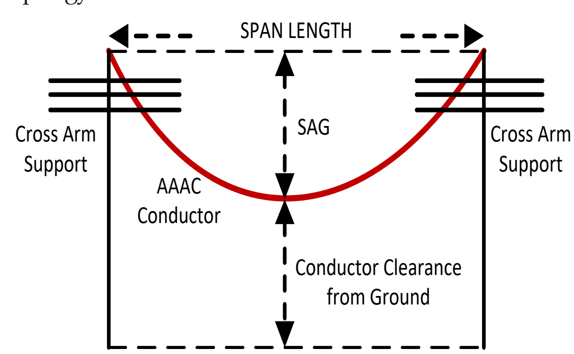

Figure 1: A Catenary with Conductor clearance.

2 AMBIENT TEMPERATURES FOR LEVEL AND UPLAND TOPOGRAPHIES

The level land topographies considered in this research work are the New-Haven transmission line network in Enugu and the Abakaliki injection substation. The ambient mean daily temperature of the two selected areas with their seasonal temperature variations were considered in the sag

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calculation. According to a meteorological report, Enugu has an average daily ambient temperature of 20.7°C (80.1°F) [8]. The area is characterized by two seasons which are the rainy season and the dry season. Another weather condition that affects the city is the Harmattan. A dusty trade wind that lasts between November through February [8]. During the dry season, the temperature is always high with an occasioned wind pressure. This condition invariably leads to the expansion of the overhead conductor span length with an increased magnitude of sag and reduced tension on the line conductor. In Abakaliki, the ambient temperature varies from 18.33°C (65°F) to 31.67°C (89°F) and is rarely below 14.44°C (58°F) or above 33.33°C (92°F) [9]. Similar to the weather condition in Enugu, seasonal variation with temperature also affects the Abakaliki overhead transmission line conductor and the rate of increase in sag. The increase in the overhead conductor span length with respect to temperature change is given by equation (1).

$$L_2 = L_1\left(1 + \alpha_{AAAC}(t_2 - t_1)\right) \qquad (1)$$

Where: L_2 = Increased length of the transmission Line Conductor.
L_1 = Original length of the transmission Line Conductor.
α_{AAAC} = Coefficient of thermal expansion of All Aluminium Alloyed Conductor.
t_2 = Final temperature of the conductor after thermal expansion.
t_1 = Initial or ambient temperature of the conductor before thermal expansion.

The selected upland in Nigeria for this research paper is the Asaba-Onitsha 330kV overhead transmission line. The average ambient temperature of Onitsha is 27°C (80.6°F) [10]. This temperature varies annually by 3.5°C (38.3°F) and rises during the dry season which affects the magnitude of sag and tension acting on the overhead transmission line. The driest months are December and January. The overhead line conductors within this period of the month are affected by a high wind loading which exert more pressure on the conductor.

2.1 Sag Calculations for Level land Topography

Sag calculation for the level land topography is achieved using Figures 2 and 3. The weight of conductor AOB suspended freely between equal level supports A and B is $\frac{WL}{2}$. The vertical displacement δ represents the sag. The sag equation is obtained by taking moments of forces about point B in Figure 3 as presented in equation (2).

$$H \times \delta = \frac{WL}{2} \times \frac{L}{4} = \frac{WL^2}{8} \qquad (2)$$

$$\delta = \frac{WL^2}{8H} \qquad (3)$$

In equation (3), it is obvious that the sag in a freely suspended overhead transmission line conductor is directly proportional to the weight per unit length of the conductor and to the square of the span length. It is also inversely proportional to the horizontal tension H. Taking into account the deflection effect of wind loading with respect to the vertical loading, the resultant sag obtained becomes a deflected sag due to wind pressure. The angle of deflection θ of the conductor from the vertical displacement as derived from Figure 2 is given by (4).

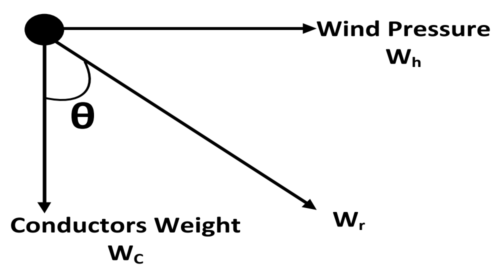

Figure 2: Wind Loading and Conductor Weight.

$$\tan\theta = \frac{W_h}{W_c} \qquad (4)$$

The deflected sag with wind loading is given by equation (5).

$$\delta' = \frac{W_r L^2}{8H} \qquad (5)$$

$$\text{Where: } W_r = \sqrt{W_c^2 + W_h^2} \qquad (6)$$

I. W_c is the conductors own weight per unit length acting vertically downwards
II. W_h is the wind loading per unit length acting horizontally and perpendicular to the line conductor.

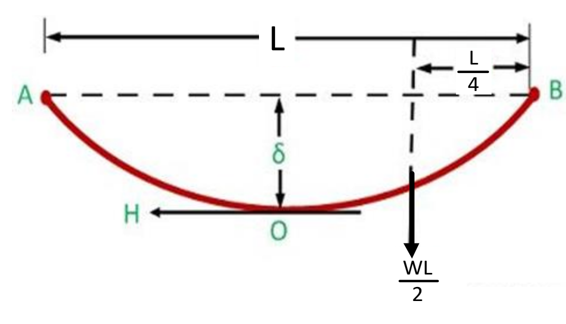

Figure 3: An Overhead line conductor (AOB) on a Level Topography.

2.2 Sag Calculations for Upland Topography.

When two transmission line supports are not on equal levels due to river separation as observed in Asaba-Onitsha overhead bridge or in a hilly area, the conductors suspended between the two supports will be at unequal levels. Figure 4 shows a conductor suspended between two supports A and B at unequal level. The lowest point on the

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conductor is O. The sags δ_1 and δ_2 are obtained by taking moments separately about points A and B. Taking moment of force about point A gives rise to equation (7).

$$T \times \delta_1 = \frac{WX_1}{2} \times X_1 = \frac{WX_1^{\,2}}{2} \quad (7)$$

$$\delta_1 = \frac{WX_1^{\,2}}{2T} \quad (8)$$

Similarly, taking moment of force about point B gives rise to equation (9).

$$T \times \delta_2 = \frac{WX_2}{2} \times X_2 = \frac{WX_2^{\,2}}{2} \quad (9)$$

$$\delta_2 = \frac{WX_2^{\,2}}{2T} \quad (10)$$

$$X_2 + X_1 = L \quad (11)$$

$$\delta_2 - \delta_1 = \frac{W\left(X_2^{\,2} - X_1^{\,2}\right)}{2T} = \frac{W(X_2 + X_1)(X_2 - X_1)}{2T} \quad (12)$$

$$\delta_2 - \delta_1 = h = \frac{W \times L\,(X_2 - X_1)}{2T} \quad (13)$$

The magnitudes of X_1 and X_2 need to be determined so that the exact values of the sags from points A and B can be evaluated. Rearranging equation (13) gives rise to equation (14)

$$X_2 - X_1 = \frac{2Th}{WL} \quad (14)$$

For simulation purposes, the expressions for X_1 and X_2 in terms of T, h, W, and L are solved simultaneously using equations (11) and (14) to give equations (15) and (16) .

$$X_1 = \frac{L}{2} - \frac{Th}{WL} \quad (15)$$

$$X_2 = \frac{L}{2} + \frac{Th}{WL} \quad (16)$$

The effect of wind on the conductors when positioned in upland topography is always very enormous since wind pressure increases with height or altitude [11]. Therefore, the deflected sags for an overhead conductor affected by wind are given by equations (17) and (18).

$$\delta_1{}' = \frac{W_r X_1^{\,2}}{2T} \quad (17)$$

$$\delta_2{}' = \frac{W_r X_2^{\,2}}{2T} \quad (18)$$

Where: $W_r = \sqrt{W_c^2 + W_h^2}$ (19)

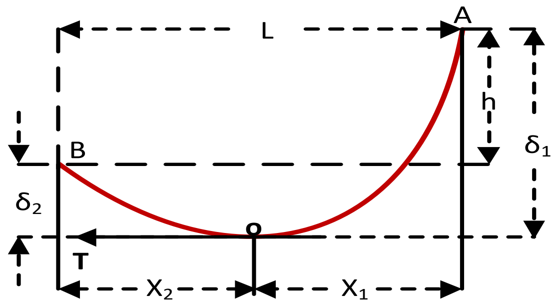

Figure 4: An Overhead line conductor (AOB) on Upland Topography.

2.3 Conductor Clearance from Ground.

An adequate clearance of a conductor from the ground under all loading conditions must be maintained for safety purposes. The conductor distance from ground level depends upon the magnitude of the transmission line voltage. The approximate value of conductor clearance is presented in equation (20) in accordance with [12].

$G_c = 6m + 0.01m\ per\ kV$. (20).

The statutory regulations of a country govern the choice of minimum ground clearances depending upon the location and weather conditions. In India, a clearance of 17 feet (5.18m) is provided for 33kV line and for every additional 33kV or part thereof, one foot (0.3048m) clearance is provided.

For a 132kV line, the ground clearance is given by $132 = 33 + 3 \times 33 = 5.18 + 3 \times 0.3048 = 6.1m\ (20ft)$.

For a 330 kV line, the ground clearance is given by $330 = 33 + 9 \times 33 = 5.18 + 9 \times 0.3048 = 7.923m\ (25.987ft)$. This implies that the level at which overhead line conductor sags must not exceed the prescribed clearance from the ground level to avert electrical hazard on humans. Similarly, an increase in sag beyond the prescribed ground clearance level may lead to a short circuit of the conductors during a heavy wind loading.

3 SIMULATION RESULTS AND DISCUSSION

The results realized in this paper were achieved with the parameters in table 1. The effects of rise in conductors span length with temperature on the sag and tension are reflected in the simulation results. The impact of wind pressure on the conductors is also presented. In Figure 5, the effects of temperature variation with negligible wind pressure on the sag and tension of the overhead line conductor for a level land topography is presented. The result indicated that as the temperature is varied with a negligible wind pressure of $0\ \mathrm{Nm}^{-2}$, the tension exerted on the conductor decreased in the follwing sequence: [2000; 1500; 1250; 1000; 750; 500] N whereas the sag on the overhead line conductor increased in the sequence [0.5445;

0.7260; 0.8712; 1.089; 1.452; 2.178] m . The increase in sag is a consequence of temperature change from ambient value leading to a slight thermal expansion of the conductor span length. In Figures 6 and 7, the effect of height difference between towers for unequal level (upland) topography with respect to changes in the sags at varied temperature and negligible pressure from the wind was presented. The magnitude of sag increased as the tension decreased. It is observed that for the same tension values the sag differs in magnitudes. This is due to the obvious height difference between the two towers that support the overhead line conductors. In Figure 8, a wind pressure of 150 Nm^{-2} was applied on the overhead line conductors. It is observed that the magnitude of tension changed with the wind pressure to support the variation in sag values. The magnitude of sag increase in Figuire 8 is in the sequence of [1.156; 1.444; 1.926; 2.889; 3.852; 5.778] m which is almost twice the values obtained in Figure 5. Therefore under this condition, more tension is needed on the stringed conductor in Figure 6 to avert the dangerous effect of short-circuit that may arise from conductor swinging during a high wind. In Figures 9 and 10, it is evident that as a wind pressure of 150 Nm^{-2} is exerted on the overhead line conductor, the tension on the line increased and subsequently decreased in proportion to the increase in sag. The rate of increase in sag values for the upland topography is indicative of the height difference between towers and their distance of separation. The deflected angle during wind loading on the overhead line conductor is plotted in Figure 11. This plot shows that the critical deflection angle occurs at 45^0 which implies that deviation from this value can lead to a dangerous sway of the conductor which may give rise to an explosive short circuit.

Table 1 Simulation Parameters

Overhead Conductor Parameter (AAAC)	**Values**
Ambient Temperature (°C)	20.7 and 30.5
Transmission Voltage (kV)	330
Frequency of transmission (Hz)	50
Overhead conductor spacing between towers (m)	300
Wind pressure Nm^{-2}	0 and 150
Assumed Varying Temperature (°C)	50, 55, 60, 65, 70
Assumed Varying Span Length (m)	60, 70, 80, 90, 100
Coefficient of Thermal expansivity ($^0C^{-1}$)	19×10^{-6}
Assumed height difference between Towers (m)	10

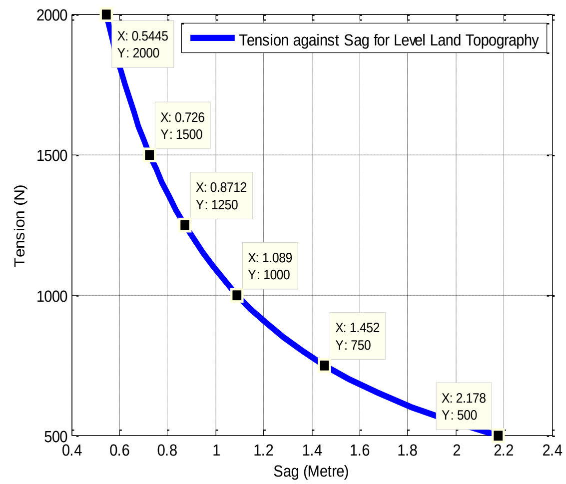

Figure 5 A plot of Tension against Sag(δ) at varied temperature with wind pressure=0 N/m² for a Level land.

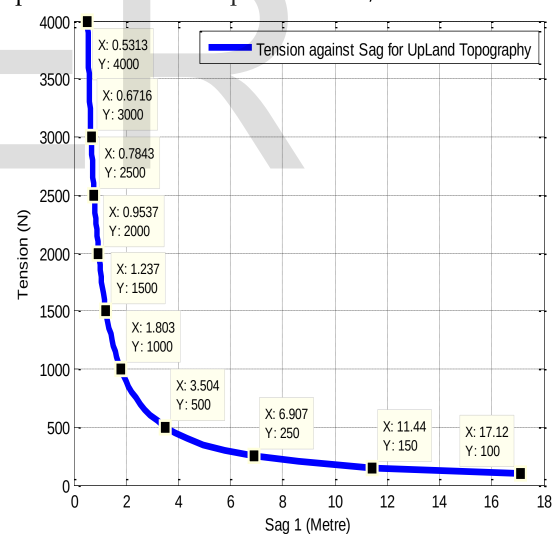

Figure 6 A plot of Tension against Sag 1(δ_1) at varied temperature with wind pressure=0 N/m² for an Upland.

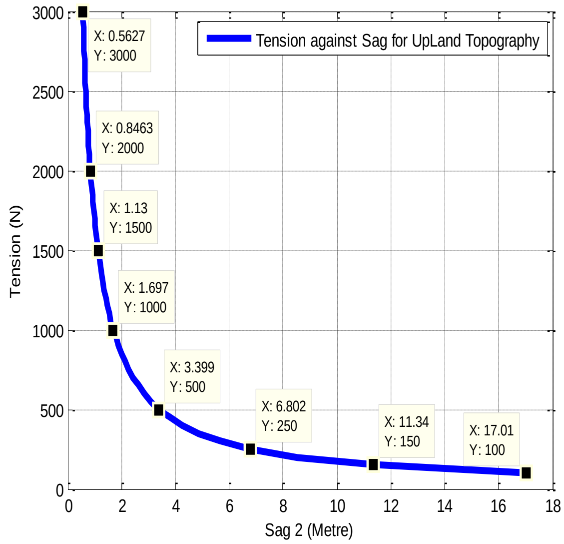

Figure 7 A plot of Tension against Sag 2 (δ_2) at varied temperature with wind pressure=0 N/m² for an Upland.

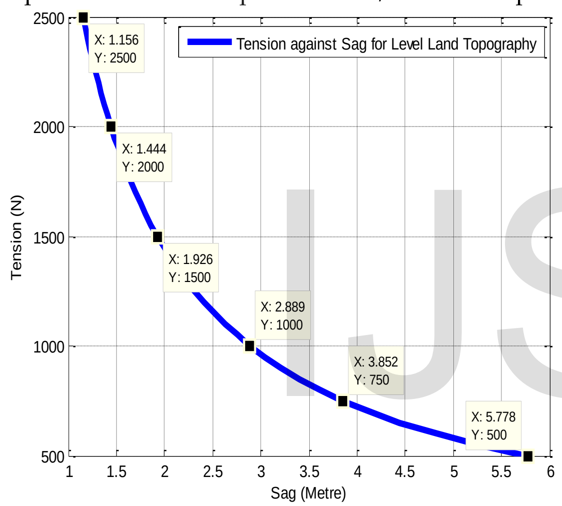

Figure 8 A plot of Tension against Sag (δ') at varied temperature with wind pressure=150 N/m² for a level land.

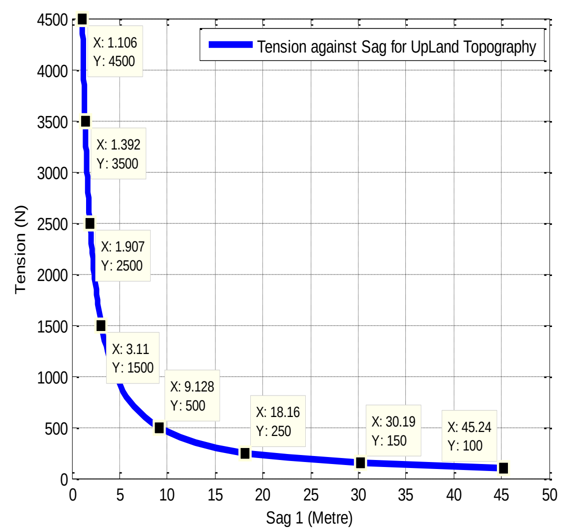

Figure 9 A plot of Tension against Sag 1 ($\delta_1{}'$) at varied temperature with wind pressure=150 N/m² for an Upland Topography.

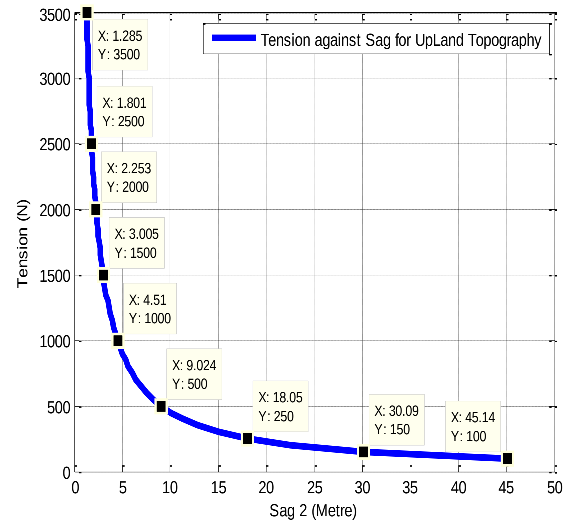

Figure 10 A plot of Tension against Sag 2 ($\delta_2{}'$) at varied temperature with wind pressure=150 N/m² for an Upland Topography.

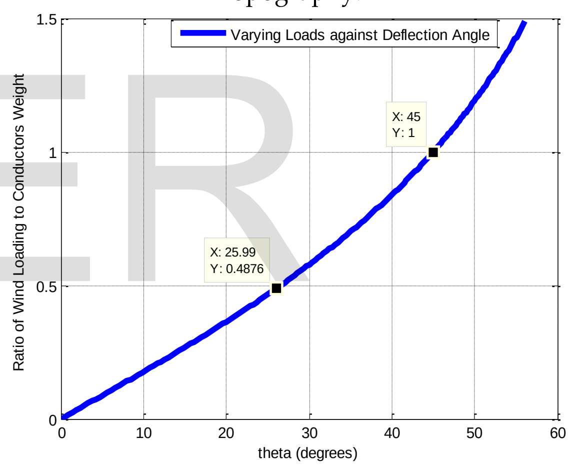

Figure 11 Varying Load $\frac{W_h}{W_c}$ against Deflection Angle for a Level land Topography.

4 CONCLUSION

This paper was able to analyse the effects of sag and tension variation on a level land and upland topographies. Temperature and wind pressure with height difference between towers for upland topography was considered in this analysis. The simulation results obtained showed that at minimum temperature and negligible wind pressure which occurs during the rainy season, the overhead line conductor (AAAC) contracts. This results to a low value of sag for both level land and upland topography. The seasonal variations for the two selected areas of study equally showed that the magnitude of sag increase is much greater during the dry season due to the increased temperature and wind pressure that is exerted on the conductor. This increase in sag affects the conductor to ground clearance which must be within the range of a value that conforms to equation 20. It is also evident from the simulation waveforms that the difference in the values of sags ($\delta_1\delta_2$) and ($\delta_1'\delta_2'$) for the high tower and the lower tower for upland topography is due to the height difference between the towers. This research has therefore shown that at severe weather condition the sag on overhead line conductor increases greatly with a decrease in tension. This implies that a routine check and proper stringing of the overhead line conductor is needed to avert the destructive effect of short circuit on the conductor during a phase swing.

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