American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-10, pp-23-29
www.ajer.org
Research Paper Open Access

Estimation of Sag by the Influence of Altitude Parameter

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ABSTRACT: *In this paper, transmission line sag is studied by direct effect of altitude parameter. More precise result is achieved when the measurement is performed considering the height of the overhead transmission lines from ground. Barometrical data from American standard atmosphere is used to carry this study. The complete form of mathematical sag expression is considered here, in presence of ice coting and wind pressure. Study is performed for both cases, when the supports are equal and unequal levels. Numerical calculations are performed in Matlab®.*

Keywords -*Transmission lines, Sag, Quintic polynomial, Quartic polynomial, Altitude function, Matlab.*

I. INTRODUCTION

In a simple definition, the vertical distance between the points of supports and the lowest point of the transmission line is referred as dip or sag. It is not possible to install the electric cables without any sag even though we wish to do so because of its acting downward weight. This sag is in practice, allowed to form to prevent the conductors from break due to the excessive tension.

Thus the sag has become a frequently handled parameter in power systems. The conventional mathematical expressions of sag are involved with the ice coating and the wind pressure [1]. This pressure again varies by the altitude or height. Some useful barometric formulae are available with different variables including the altitude. These equations are generally used to find out the barometric pressure and hence the sag of the overhead power transmission lines. But in this paper, the sag is studied considering the altitude directly.

II. CONVENTIONAL MEASUREMENT OF SAG

It is considered that the supports are at unequal levels (Fig. 1). The transmission lines are assumed with ice coating and influenced by wind pressure. Then the mathematical form [1] of sag at the support of lower level, can be expressed by (1)

$$S_l = \frac{W_r}{2T}\left(\frac{l}{2} - \frac{Th}{W_r l}\right)^2 \tag{1}$$

Expression of sag at the support of upper level, is given by (2).

$$S_u = \frac{W_r}{2T}\left(\frac{l}{2} + \frac{Th}{W_r l}\right)^2 \tag{2}$$

Where, T is the tension in the conductor. The span length is l. Difference between the two supports is h. Resultant weight per unit length of the conductor is denoted by W_r .

The resultant weight is occurred because of the weight of conductor itself, ice coating and the wind flow. Thus $W_r$is given by (3).

$$W_r = [(W_c + W_i)^2 + W_w^2]^{1/2} \tag{3}$$

W_c, W_i and W_w in Eq. (3) denote the weight per unit length of the conductor, weight of ice for unit length and wind force per unit length respectively.

Weight of ice per unit length can again be written as:

$$W_i = \pi t \rho_i (D + t) \tag{4}$$

$\rho_i$is the density of ice. Diameter of the conductor is *D* and *t* for the thickness of ice coating. Finally wind force per unit length is calculated using (5), where *P* is the wind pressure [1].

$$W_w = P(D + 2t) \tag{5}$$

If the supports are exactly at equal level (h = 0) or almost at equal level ($h \approx 0$) then Eq. (1) and Eq. (2) are reduced in a single formula. In that case the sag *S* becomes [1]:

$$S = \frac{W_r l^2}{8T} \tag{6}$$

A schematic diagram is shown in Fig. 1 to illustrate the involved parameters of sag formation.

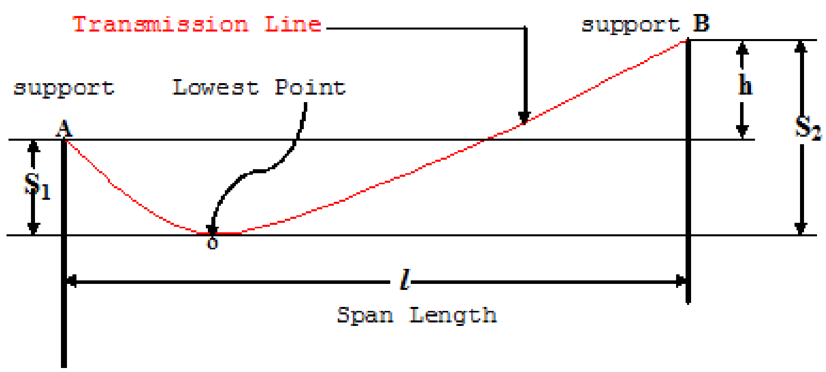

Fig.1. Formation of sag at unequal supports

These mathematical expressions [Eq. (1), Eq. (2) and Eq. (6)] are generally used for the conventional measurement of sag. The wind pressure *P* is in practice, calculated by some sort of barometric formulae.

This is of course a correct process but the problem is that those barometric formulae may have many variables [2]. So it would be better if the sag expressions can have only the altitude parameter, for the barometric estimation. This altitude is the height of the overhead power transmission lines. In the next section, sag is studied in this direction.

III. MEASUREMENT USING THE ALTITUDE PARAMETER

Many theoretical and experimental works have been done on sag calculation and later sag was calculated from GPS measurements [3]. But up to this time no research had been conducted to calculate the sag directly by altitude measurement system. Let us consider the variation of wind pressure with respect to the height. According to the information provided by American Standard Atmosphere [2], this variation follows the Height (H) and Pressure vector (P), as below.

H = [0 11 20 32 47 51 71] in Km

P = [101.33 22.63 5.48 0.87 0.11 0.07 0.004] in KPa

This data set is widely used to get the overview of the wind pressure for certain altitude levels. The variation of wind pressure with altitude and the standard deviation of wind pressure are observed in Matlab. For this purpose, the corresponding code is written in Matlab, which is shown below.

Code for wind pressure variation and standard deviation calculation

```
% observe barometric data and find standard deviation of wind pressure
%
% P and H are row vectors
%
H = [0 11 20 32 47 51 71]; % height in Km
P = [101.33 22.63 5.48 0.87 0.11 0.07 0.004]; % wind pressure in KPa
%
figure;
axis('normal')
box 'on'
grid 'off'
zoom 'off'
barh(H,P,1.5) % horizontal bar diagram
xlabel('Wind Pressure (in KPa)')
ylabel('Height (in Km)')
xlim([0 110])
text(50,5,'Pressure at Sea Level')
legend('Wind Pressure','Location','NorthEast');
%
% find standard deviation of wind pressure
%
M = mean(P); % mean of wind pressure
%
N1=P(:,1); s1=round(abs(N1-M)); % standard deviation of P at zero level
N2=P(:,2); s2=round(abs(N2-M));
N3=P(:,3); s3=round(abs(N3-M));
N4=P(:,4); s4=round(abs(N4-M));
N5=P(:,5); s5=round(abs(N5-M));
N6=P(:,6); s6=round(abs(N6-M));
N7=P(:,7); s7=round(abs(N7-M)); % standard deviation of P at 71 Km
%
S = [s1 s2 s3 s4 s5 s6 s7] % standard deviation for seven altitude levels
%
figure;
bar(S)
ylabel('Standard deviation of wind pressure')
%
str1=['at H = 0; std = ',num2str(s1)];
str2=['at H = 11 Km; std = ',num2str(s2)];
str3=['at H = 20 Km; std = ',num2str(s3)];
str4=['at H = 32 Km; std = ',num2str(s4)];
str5=['at H = 47 Km; std = ',num2str(s5)];
str6=['at H = 51 Km; std = ',num2str(s6)];
str7=['at H = 71 Km; std = ',num2str(s7)];
%
text(0.6,86,str1);
text(2,25,str2,'rotation',90);
text(3,25,str3,'rotation',90);
text(4,25,str4,'rotation',90);
text(5,25,str5,'rotation',90);
text(6,25,str6,'rotation',90);
text(7,25,str7,'rotation',90);
%
```

Wind pressure at different altitude levels and standard deviation of wind pressure are illustrated on bar diagrams in Fig. 2 and Fig. 3 respectively.

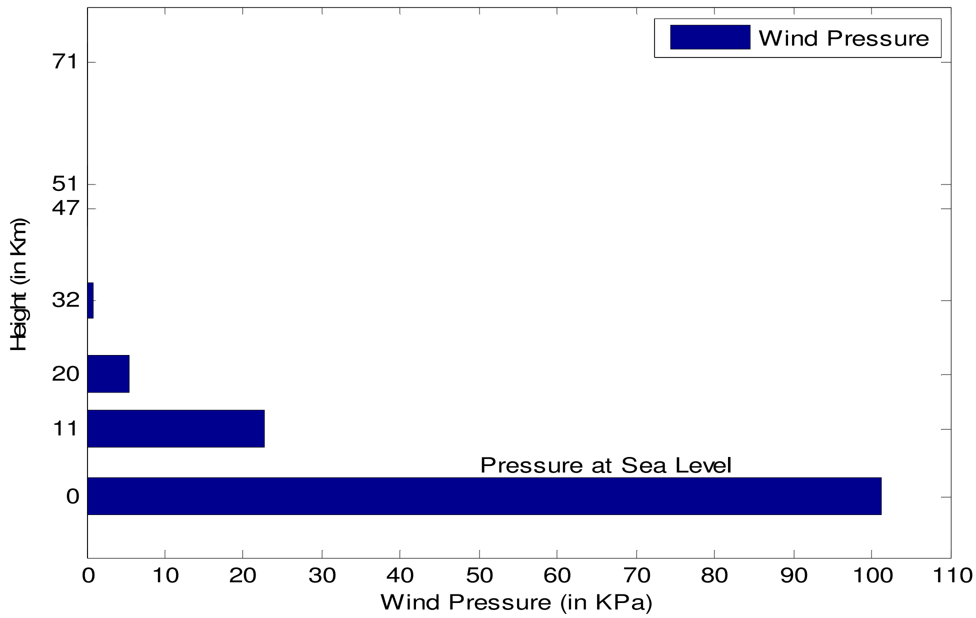

Fig. 2. Wind pressure variation with altitude

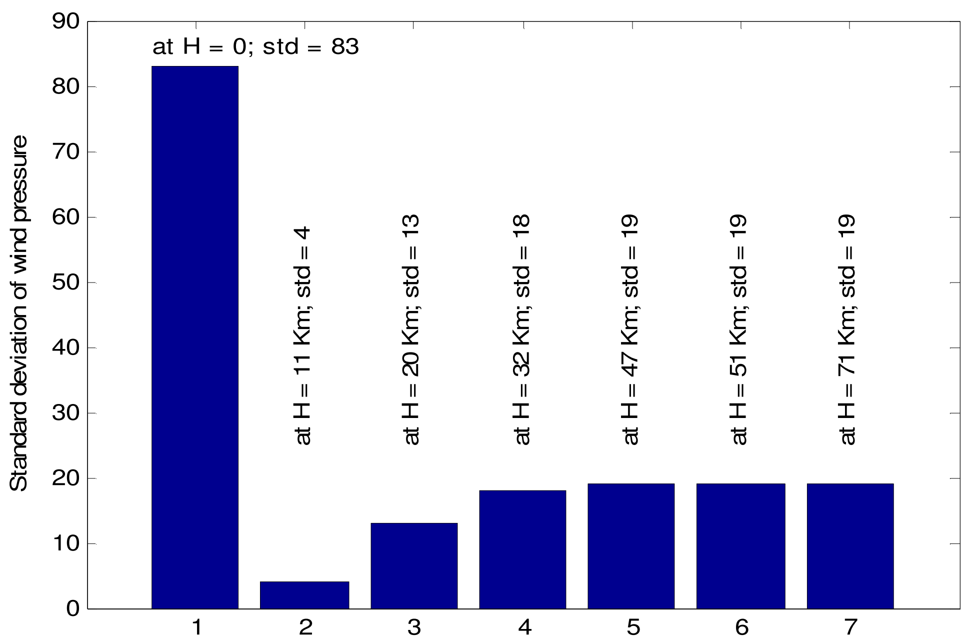

Fig. 3. Standard deviation of wind pressure for seven altitude levels

From figure 3, it is obvious that almost every cases, the standard deviations are too high. So it is not a good idea to consider the average of wind pressure at the desired level, where the overhead transmission lines are installed. This problem could be solved with a quintic polynomial, which is established by curve fitting method in Matlab.

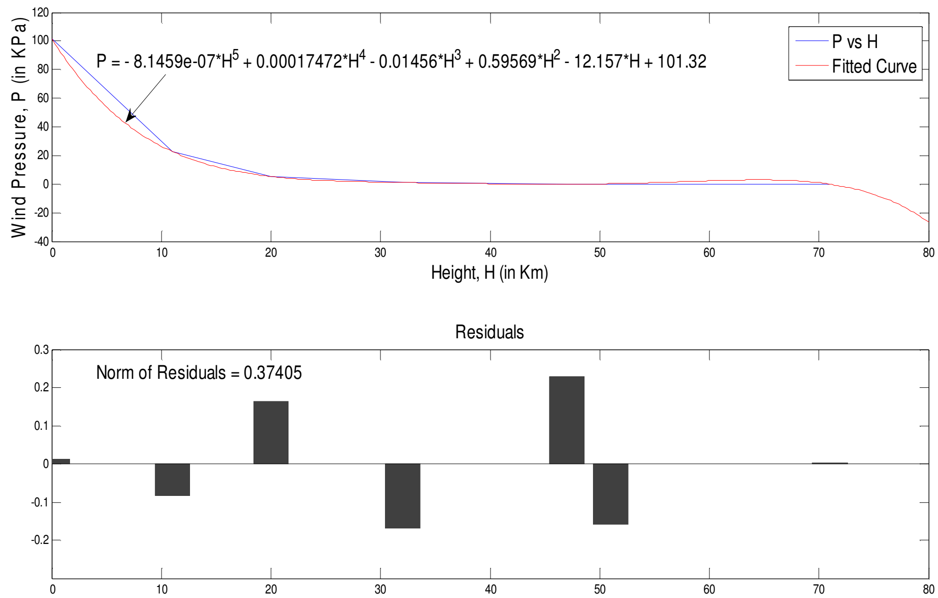

Fig. 4. Fitted wind pressure for fifth degree

The residuals are found as below.

Residuals = [0.013 -0.084 0.164 -0.169 0.230 -0.157 0.004]

Hence the curve fitting leads to achieve (7).

$$\alpha(H) \approx 100.32 - 12.16\, H + 0.60\, H^2 - 0.015\, H^3 + 0.0002 H^4 - 0.0000008\, H^5 \tag{7}$$

Thus $\alpha(H)$ forms a quintic polynomial, where the leading coefficient is -0.0000008 and the leading term is $-0.0000008\, H^5$. This polynomial implies that higher the power of altitude, its coefficient becomes smaller.

This Altitude function $\alpha(H)$ can directly be used to measure the wind pressure *P*, only using the height from the ground to the overhead power transmission lines.

Eq. (5) can now be given in terms of $\alpha(H)$ as:

$$W_w = (D + 2t) * \alpha(H) \tag{8}$$

The resultant weight, using Eq. (8) stands as:

$$W_r = [(W_c + W_i)^2 + \{(D + 2t) * \alpha(H)\}^2]^{1/2} \tag{9}$$

Finally the mathematical expression of sag in Eq. (6) becomes:

$$S = \frac{l^2}{8T}[(W_c + W_i)^2 + \{(D + 2t) * \alpha(H)\}^2]^{1/2} \tag{10}$$

Eq. (10) allows to express Eq. (1) and Eq. (2) as below.

$$S_1 = \frac{[(W_c+W_i)^2+\{(D+2t)*\alpha(H)\}^2]^{1/2}}{2T}\left(\frac{l}{2} - \frac{Th}{l*[(W_c+W_i)^2+\{(D+2t)*\alpha(H)\}^2]^{1/2}}\right)^2 \tag{11}$$

$$S_2 = \frac{[(W_c+W_i)^2+\{(D+2t)*\alpha(H)\}^2]^{1/2}}{2T}\left(\frac{l}{2}+\frac{Th}{l*[(W_c+W_i)^2+\{(D+2t)*\alpha(H)\}^2]^{1/2}}\right)^2 \quad (12)$$

Eq. (11) and Eq. (12) are the desired expressions of sag. Where $S_1$the sag at support of is lower level and S_2 is the sag at support of upper level. These equations are perfectly able to calculate sag by the direct effect of altitude function $\alpha(H)$.

IV. ESPECIAL CONDITION

For the minimum height that is at the sea level, $\alpha(H)$ is reduced as:

$$\alpha(H) = \lim_{H\to 0} \alpha(H) \approx 100.32 \text{ KPa} \quad (13)$$

But it is important to note that wind pressure does not follow the conventional barometric formulae above 32 Km from the sea level [3]. This is true both for the case of standard temperature lapse rate as zero or nonzero. As a result, the study of measurement is limited up to this level. But in practice, it is not a problem at all. Because the installed transmission lines are much lower than that level, even in the hilly places.

However, the rate of change of wind pressure with respect to height becomes:

$$\frac{d\alpha(H)}{dH} = -12.16 + 1.2\,H - 0.05\,H^2 + 0.0008\,H^3 - 0.000004\,H^4 \quad (14)$$

Thus Eq. (14) is a quartic polynomial when the rate of change of wind pressure with respect to the height of the transmission line is considered. It is observed from Fig. 5.

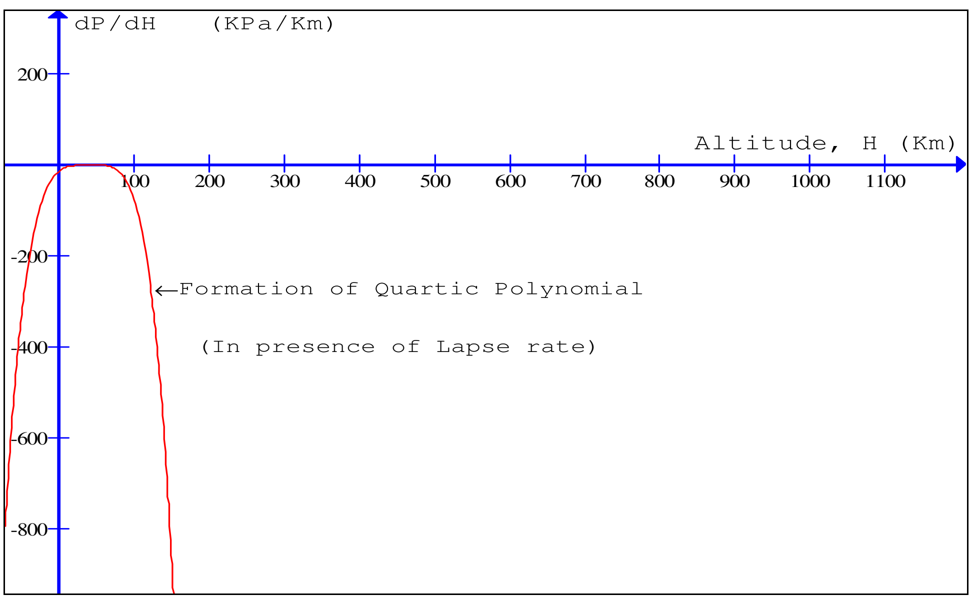

Fig. 5. Formation of quartic polynomial from quintic form

From Eq. (7), it is obvious that when we consider the height of the transmission lines at the sea level then H is to be considered zero. Thus $\alpha(H)$ becomes:

$\alpha(H = 0) \approx 100.32$ KPa

$\alpha(H = 11\,Km) = 22$ KPa; Almost same as in vector P

As a same manner, for desired level (where the transmission line is installed), the corresponding wind pressure can be obtained, for the altitude range $0 \leq H < 32$.

V. CONCLUSION

Conventional sag has been studied by influence of the height of overhead transmission lines. This study is more convenient for sag calculation for any types of sag formation. In special case, the quintic polynomial has been reduced on its limiting value same as the wind pressure at sea level. This allows to have a single constant of the altitude function. The quintic polynomial was turned into a quartic polynomial when the rate of change of wind pressure near to the overhead transmission lines is considered. This approach can be used when the altitude is below 32 kilometers. The measurement is valid for both conditions when the supports are at equal and unequal levels.

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