Extracting of Sagging Profile of Overhead Power Transmission Line Via Image Processing

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***Abstract*—Sagging of the conductor in transmission line has a vital role in the safety, reliability and efficiency of power transmission. Transmission lines must be designed to guarantee the maximum static loading capacity. This is done by maintaining the minimum vertical clearance between the cables and the ground. However, the increase of the cable length between two tower, leads to the high cost of material and electrical energy loss, as well as increasing the possibility of intervention. On the other hand, reducing the line sagging induces high tension in the conductor, which may lead to damage of the conductor. To assure a safety sagging profile, an inspection is essential at the establishment and maintainance of the power transmission lines. In this paper firstly the mathematical formulation of long and heavy cables are developed. Then an image processing method is applied for inspection of cable sagging. To investigate the method a reconfigurable experimental setup is designed to provide various sagging profiles and the sagging profile is extracted via image processing and the result is compared to that of analytical method.**

***Index Terms*—Dynamic modeling, heavy cables, power lines, sagging, inspection, image processing.**

I. Introduction

Power transmission lines are in charge of delivering the power loads over long distances from power generation sources to the consumers. In transmission lines the conductor is suspended upon two successive tower and it's weight cause the sagging as shown in Fig. 1. The sagging profile of the transmission line depends on the weight per unit length of the conductor, horizontal tension in the cable and the elevation of the installation points. The environmental circumstances, such as icing, wind flow, rise in the temperature, as well as electrical current flow make the conductor to stretch, which leads to an increase in the cable sagging. A highly loaded transmission line in the summer can sag much more than the same line in winter. Sagging can lower a conductor to an unsafe height above the earth. Thus, knowing the sagging behavior of conductor is of great importance in the design stage and life time of the conductor. By accurately measuring the sagging of the conductor, the core temperature of the conductor can be measured accordingly [1] and once the sagging and temperature are obtained the current carrying capacity of the line can be calculated [2]. The profile of the sagging cable can be measured directly using coordinating based methods such as image processing, laser technology, GPS and tilt sensors. It also may be calculated by measuring the tension, temperature and the surrounding magnetic field of the conductor using sensors [3] [4] [5], and correlating the measured parameters to the cable sagging.

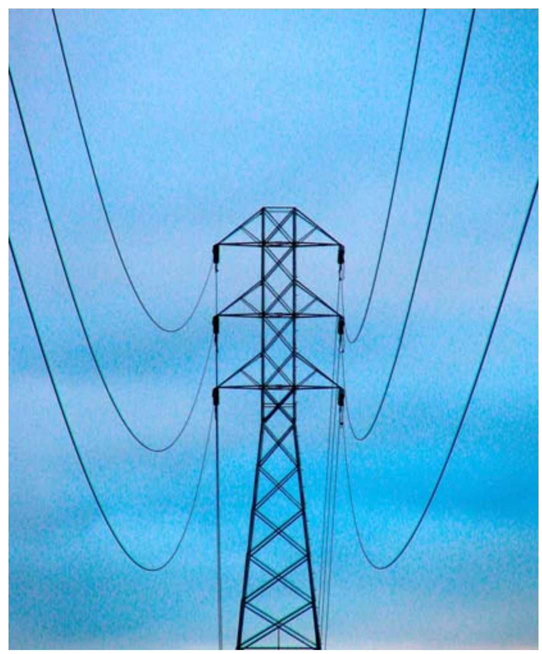

Fig. 1. Sagging Phenomena in Power Transmission line

In [6] the average height variation of the conductor line is measured by associating the sagging to the measured variation in the amplitude of the signal propagating between power line carrier station. The other existing method uses power donuts to measure sag and tension of the conductor based on conductor inclination and its specifications. The power donut can measures the inclination of the sagging cable with 0.05 degrees accuracy and 0.01 degree resolution with an operating temperature between -40 to 70 centigrade degrees [7]. The global positioning system for measuring the sagging of the conductor is proposed in [8], and [9]. The proposed method uses two GPS receiver and the accuracy of the method is in the range of 19.6 cm 70% of times [8].

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In [10], the sagging profile is introduced via interferometers based on the inclination measurements. The system is equipped with a transmitter to communicate the information of the sagging profile. In [11] the current induced on a high resistance grounded wire near the HV conductor is used to measure E-Field at the vicinity of the conductor, in order to evaluate the sagging profile [12]. In [5]Uniaxial MF sensor mounted at the support tower synchronized with current-transformer (CT) measurement at the substation is used to estimate the symmetrical sag and motion in all conductors. The results of this study proves the viability of the proposed approach within 2.6% deviation for current and 1% for sag comparing with the measurement done by Ammeter and Vernier Caliper. One other method is based on the relation of the cable tension and sagging profile. in [13] Sagging clearance is indirectly measured by the tension of the conductor. In [14] on-line monitoring of temperature and sag in 400KV power transmission line has successfully been implemented by a novel device using Fiber Bragg Grating (FBG) sensors. Laser technology is another method to measure and monitor the line sagging [15]. The method provides a point to point measuring system and can be applied to visually locate the lowest point of the conductor. Except the FBG technology, which is quite expensive, none of the aforementioned methods provide an explicit method to measure the sagging profile of the cable. The methods are point to point measurements system which implicitly calculate the sagging profile. The image processing method is proposed in this paper as a promising solution to directly extract the sagging profile. This paper is devoted to dynamic formulation and the experimental examination of the method and discusses the upcoming issues relating to the application of the method in practice.

II. Static Analysis of a Hinged Cable

In the sagging problem a uniform flexible chord with predefined mass and length is suspended at two ends. Fig. 2 shows a sagging profile in which the end points of the cord is represented by A and B. The chord may be a chain, string, rope or a conductor in transmission lines. As the paper deals with the cable transmitting power in high voltage power lines, the cord is considered as a cable. The fixing points of the cable ends may be at the different vertical level and horizontal distance with respect to each other. The shape of the sagging cable is refereed to, as catenary in literatures. The procedure applied to the sagging of the cable considered in this paper is to extract a mathematical expression for the sagging profile of the cable with respect to the above mentioned geometric and tension parameters.

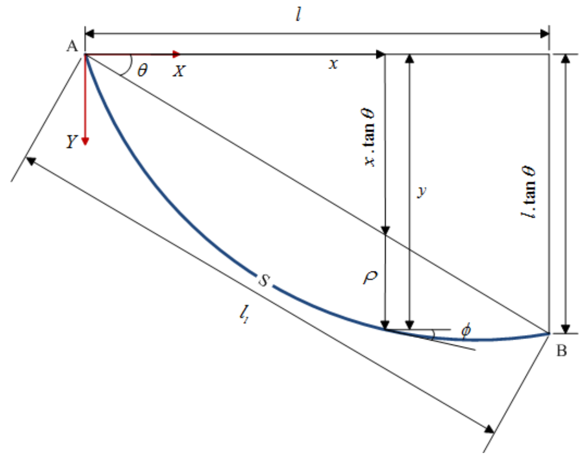

Fig. 2. Suspended cord

To derive the sagging profile of a uniform cable with the length of S a coordinate system is assigned to the origin at the point A. The positive direction of the Y axis of the coordinate system is along the gravity force and the cable length increases along the axis X. The cord span is defined as the line connecting the two supporting ends of the cable, represented by l_l and the angle of the span line with respect to horizontal axis is measured as θ. the position of the any point belonging to the cord may be denoted in cartesian coordinates, by (x, y) with respect to the assigned frame. The other alternative method for representing cable profile is to use body coordinate, (s, ϕ). In which, the first component ,s, represents the cable length beginning at the outset of the cable, point A and ending to a specified point on the cable. The other component, ϕ, is the angle of the cable profile at the specified point with respect to the horizontal line. The governing equation of the cable is extracted by considering an infinitesimal element of the cable as shown in Fig. 3. By neglecting the shear and the moment forces acting on the sectional area of the segment, the only forces are the gravity and internal tension of the cable.

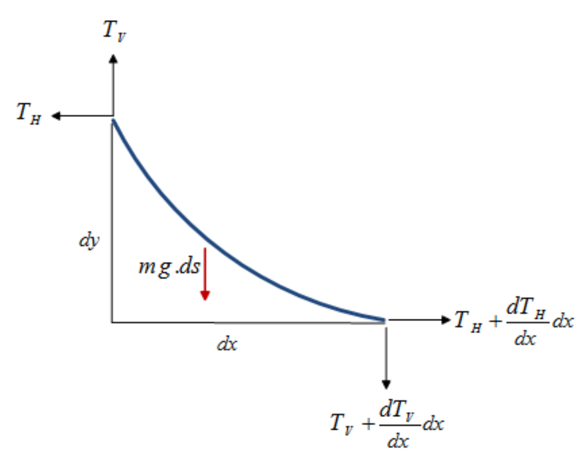

Fig. 3. Infinitesimal cable segment

Writing the equation of force balance along the coordinate axes yields:

$$\sum F_X = 0 \rightarrow \frac{dT_H}{dx} = 0 \tag{1}$$

$$\sum F_Y = 0 \rightarrow \frac{dT_V}{dx} = -mg\frac{ds}{dx} \tag{2}$$

In which, the first equation shows that the horizontal cable tension is constant over the cable profile. As the tension force is alone the cable profile the relation between the horizontal and vertical component is as follows:

$$T_V = T_H\frac{dy}{dx} \tag{3}$$

The infinitesimal length of the cable can be obtained as follow:

$$\frac{ds}{dx} = \sqrt{1+(\frac{dy}{dx})^2} \tag{4}$$

Substituting (3) and (4) into (2) the differential equation of the cable profile is obtained as follows:

$$\frac{d^2y}{dx^2} + \frac{mg}{T_H}\left[1+\left(\frac{dy}{dx}\right)^2\right]^{1/2} = 0 \tag{5}$$

Using the boundary condition into equation (5) the mathematical model of the cable profile is obtained as:

$$y(x) = \frac{T_H}{mg}\left\{\cosh(\alpha+\beta) - \cosh\left(\alpha+\beta\left(1-2\frac{x}{l}\right)\right)\right\} \tag{6}$$

where, α and β are nondimensional parameters which are defined as:

$$\alpha = \sinh^{-1}\left(\tan\theta\frac{\beta}{\sinh\beta}\right) \tag{7}$$

$$\beta = \frac{mgl}{2T_H} \tag{8}$$

Combining the above equationss and integrating along the cable length the cable length is derived as a function of x.

$$s(x) = \frac{T_H}{mg}\left(\sinh(\alpha+\beta) - \sinh\left(\alpha+\beta\left(1-2\frac{x}{l}\right)\right)\right) \tag{9}$$

using this equation the horizontal component of the cable tension T_H is obtained as:

$$T_H = \frac{mgS}{2\tan(\theta)}\tanh(\beta) \tag{10}$$

This equation has three solution, the first solution is zero for T_H and the other two solutions have the same magnitude with opposite sign. As the tension of the cable is not zero and it cannot be negative, just the positive solution is considered as the right answer.

III. Experimental Setup

The experimental setup consist of a fixed $1m \times 1m$ square frame with linear guides mounting along two perpendicular sides of the frame. A uniform cable with length of 1.28 meter is fixed to railing at both ends. The ends of the cable are attached two the railing via revolute joints and the cable is free to rotate at two ends. The linear guides provides the capability to set the ends of the cable at different elevation and span with respect to each other. Two circular disk are attached to the ends of the cable with the centers at both ends. As the background color of the experiment is white, the color of the disk and the cable itself is chosen in a manner to provide suitable contrast with respect to the background. To have a picture of the cable profile a camera is fixed and calibrated with respect to the frame. Fig. 4 shows an overview of the experimental setup in which the frame is fixed to a base. The image resolution of the camera is 640×480, using a predefined rectangular shape at the center of the frame the scaling factor is obtained. Knowing the coordinates of the cable points in pixel, length coordinate of the points is calculated. The parameters of the experiment is provided in the table I.

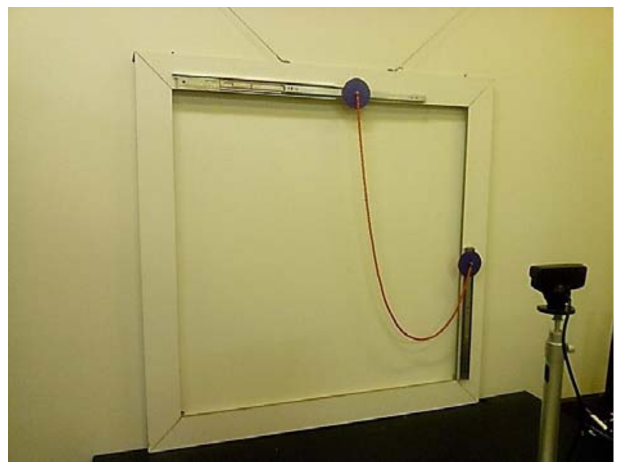

Fig. 4. Experimental Setup

TABLE I
Parameters of the Experiment

Mass/Length	Length	Scalling Factor	Cable Diameter
0.136 Kgr/m	1.28m	486.5 Pixel/m	0.01 m

The first step for obtaining the coordinates of the point on the cable is to extract the cable profile. Doing so, for a specific configuration of the cable the profile of the cable is extracted from the image taken as it is shown in Fig 5. Referring to the figure it is clear that the image processing procedure has not extracted the shape of the cable entirely. The reliability of the method is based on the brightness of the surrounding environments and the contrast of the cable itself with respect to the background.

Fig. 5. Binary Image of the Extracted Cable Profile

IV. Discussion of the results

To obtain the coordinates of the cable profile, the binary image of the extracted profile is used. As it is clear form the Fig5, due to the thickness of the cable, for a specific length along the cable several points may be considered as the representative of the cable coordinates. Thus the midpoint along the thickness is considered as the coordinate of the cable profile. As the profile of the Fig 5 has not a uniform thickness, the calculated profile is not a smooth curve. To compare the results of the image processing procedure with that analytical method, the obtained profile of the either methods is shown in Fig 6. As it is clear there is some deviations between the extracted profile at the either sides of the bottom point the cable.

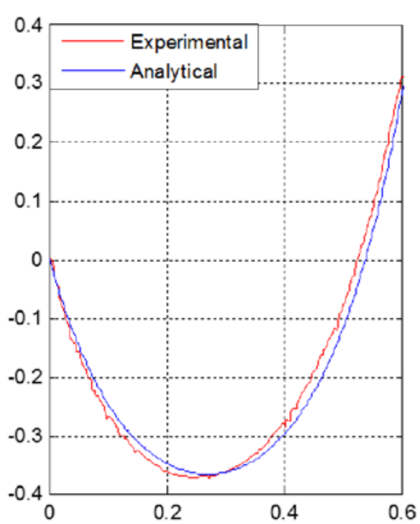

Fig. 6. Comparision of Experimental Results and Analytical Solution

To clarify the obtained result the error curve between the analytical profile and experimental is shown in Fig7. Referring to the figure the maximum magnitude of the error is about 0.045 of the cable length. As it is clear the minimum error is around the lowest level of the cable profile and it increase along the cable length at either sides, until it reaches the vicinity of anchor points of the cable. By moving along the cable length at the either sides of the bottom point the inclination of the cable profile is increased which leads to the section area of the cable to be increased along the vertical direction. Thus the number of points representing the profile of the cable increases, so there would be much more deviations in these regions.

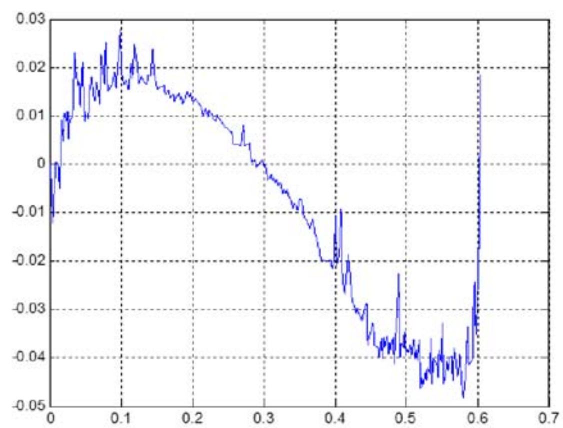

Fig. 7. Error Curve

As the extracted profile of the cable via image processing is not a smooth curve the results is not applicable to measure the length of the cable directly. Thus an smooth curve is to be fitted to the data in order to calculate the cable length. To fit a curve to the experimental data of the cable profile the analytical non-dimensional equation (3) is examined. Inducing 400 points of the cable profile extracted via the image processing method, into the equation (6) the experimental-analytical solution of the cable profile is obtained. The parameters of the experimental-analytical profile is listed as the table II.

To compare the results of different solution the obtained sagging profile of the three methods is provided in Fig. 8. As shown in 8 the experimental-analytical solution approximately lies within the region of the two other solution. Using the dimensional parameters of the experimental-analytical solution the arc length of the sagging cable can be calculated using the (9).

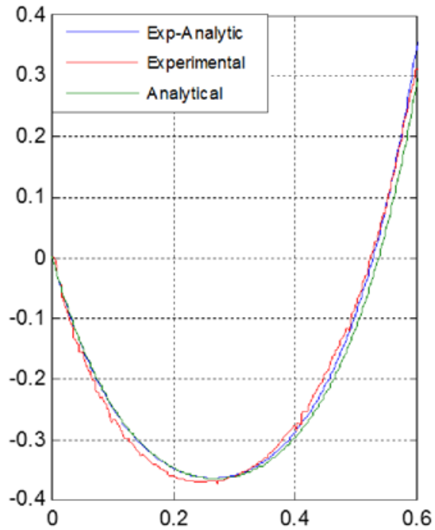

Fig. 8. Analytical, Experimental and Experimental-Analytical Solution

TABLE II
NONDIMENSIONL PARAMETERS

Method	a	b
Analytical	0.2474	2.2248
Experimental-Analytical	0.2880	2.283

V. CONCLUSIONS

In this paper the implementation of image processing method for extracting the sagging profile is investigated. Comparison of the experimental results with that of analytical method for the shape of catenary, confirms that the image processing approach is a promising approach to obtain the profile and the lowest level of a sagging conductor. As the method extract the coordinates of the cable points directly it is much tractable campier to explicit method of measuring the sag, such as magnetic field based method or force sensing which are also prone to high voltage in transmission line. Using the method, the coordinates of the entire cable profile is extracted and the cable length can be measured accordingly, rather than point to point coordinating method, such as laser technology, tilt sensors and GPS in which a collection of sensory data is to be analyzed in order to calculate the shape of the sagging profile.

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