Fiber Optic Cable Transmission Losses with Perturbation Effects

Kampanat Namngam[1*], Preecha P. Yupapin[2] and Pakkinee Chitsakul[1]

[1] *Department of Mathematics and Computer Science, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand*

[2] *Light-wave Technology Research Center (LTRC), Department of Applied Physics, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand*

**Corresponding author. E-mail: knkampan@kmitl.ac.th*

ABSTRACT

The transmission losses in a fiber optic cable hanging on an electrical power tower (EPT) in terms of cable radius of curvature is investigated. The constructed mathematical modeling is formed, relative to the cable parameters, such as sag and hanging height which can be used to design and predict the industrial cable for EPT span, based on the transmission losses with the minimum tension and cost. The stability of the analytical solution with small perturbation in terms of cable lengthening and inclined EPT is studied. The results obtained show that the transmission losses are still valid to use in transmission line within the Southeast Asia region.

Key words: Mathematical modeling, Fiber optic cable design

INTRODUCTION

Generally, types of fiber optic cables are divided into indoor and outside-plant cables. There are several types of outside-plant cables such as aerial, underground, submarine and conduit cables (Koehler, 1989; Lee and Hong, 2001), where each of them is suitably employed in different environmental conditions, i.e., different part of the world. The cable parameters such as cable length, weight, EPT span, transmission losses and the surrounding environment are commonly involved in the cable design and assembly.

The mathematical method known as calculus of variation is one of the subjects that can be used to design and optimize the fiber optic cable parameters (Allard, 1990; Mathis and Vontobel, 2000), while the least action principle is also popularly used in several subjects that the problem requires the minimum space and time variations. In this work, the aerial fiber optic cable is required to use under Thailand environment where the optimum in optical power, transmission loss and installation cost are the basic requirements. The analytical solution and the small perturbation in terms of cable lengthening are studied.

MATHEMATICAL MODELING

When a fiber optic cable is hung on the EPT span, i.e., the cable is drawn by gravitational force, then the cable shape is formed into a catenary's curve. Mathematical modeling of this curve is described by using a geometrical form as shown in Figure 1 when x is an EPT half-span, y is a height of hanging cable, l is a cable length for the EPT half-span (dotted line), h is a sag and c is a distance between a minimum point of the hanging cable and ground, respectively.

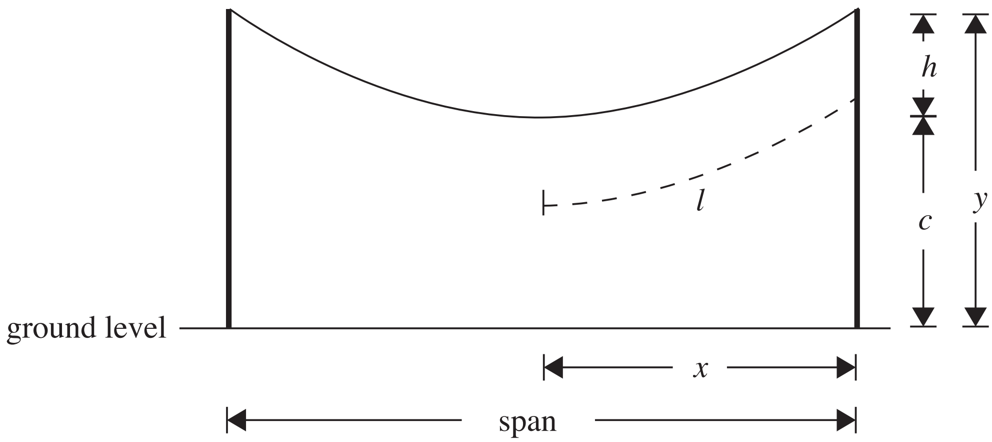

Figure 1. Schematic presentation of cable on the EPT span.

The height of hanging cable for each EPT span, which the catenary's equation is

$$y = c\cosh\left(\frac{x}{c}\right) \tag{1}$$

by Taylor's theorem

$$y = \sum_{n=0}^{\infty} \frac{1}{(2n)!} \frac{x^{2n}}{c^{2n-1}} \tag{2}$$

when x is a constant and c is a positive number, let $c = \frac{1}{a}x$ be a critical point where a is a real number, thus

$$-\sum_{n=0}^{\infty} \frac{(2n-1)}{(2n)!} a^{2n} = 0 \tag{3}$$

the solution is $a \approx 1.2$. Obviously, $y'' > 0$ for all $c > 0$ and $x \neq 0$. Therefore $c = \frac{1}{1.2}x$ is a minimum point, this value occurs at a minimum tension.

The cable macrobend loss by hanging can be expressed as Allard, 1990:

$$\gamma_{bend} = 10\log\left(\frac{\alpha+2}{2\alpha}\right)\left(\frac{\Delta}{b}\right) + 10\log R \tag{4}$$

where b is a core radius, Δ is an index elevation, R is a bend radius and α is the index profile parameter. In this problem, the transmission losses of hanging cable are considered in terms of radius of curvature, where the radius of curvature at original equal is represented by radius R. The bend loss is considered from radius of curvature, thus b, α, Δ are remiss. Let transmission loss be formed, the radius of curvature as

$$loss = 10 \log c \cdot \tag{5}$$

PERTURBATION EFFECTS

The stability of solution with small perturbation in terms of cable lengthening and the EPT are studied, when this two cases occur with installation.

Perturbation with Cable Length

The cable length for each EPT half-span forms a catenary curve is

$$l = c \sinh\left(\frac{x}{c}\right) \tag{6}$$

when the length of a fiber optic cable, l is prepared for installation for the EPT half-span x, but the EPT half-span is perturbed by δ, thus the effect for parameter, c_P is changed as equal to β. With this parameter, c_P is affected by other values with respect to analytical method (dotted line) as shown in Figure 2.

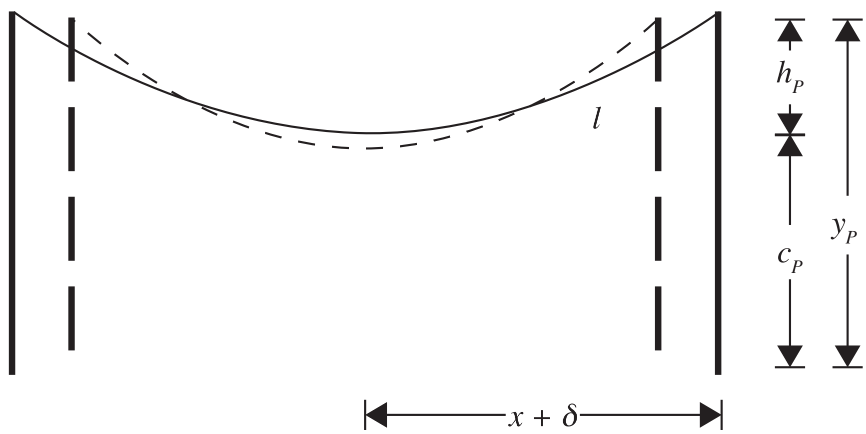

Figure 2. Schematic presentation of the cable perturbation effect.

Since the length of a cable from analytic and perturbation is equal, by using Taylor's theorem expand as

$$\sum_{n=1}^{\infty} \frac{x^{2n-1}}{(2n-1)!\, c^{2n-2}} = \sum_{n=1}^{\infty} \frac{(x+\delta)^{2n-1}}{n=1(2n-1)!\, c_P^{2n-2}} \tag{7}$$

where $c_P = c + \beta$ and $c = \frac{1}{a}x$. Varying the parameters x and δ, the solution is β for each EPT half-span, which affect other values as shown in Table 1.

The EPT span is increased but the cable length does not change. Thus the tension of cable, T is calculated in terms of percentage of change as

$$\left|\frac{T - T_P}{T}\right| \text{x } 100 = \left|\frac{wy - wy_P}{wy}\right| \text{x } 100 = \left|\frac{y - y_P}{y}\right| \text{x } 100\,. \tag{8}$$

Table 1. Results of small perturbation of the cable length.

$\delta = 0.1$

span	sag	distance	height	loop	loss	loss/length	%tension
10	3.25	4.46	7.71	2.38	6.49	0.52	0.16
20	6.63	8.62	15.25	4.96	9.35	0.37	0.04
30	10.01	12.78	22.79	7.53	11.07	0.29	0.02
40	13.38	16.95	30.33	10.11	12.29	0.24	0.01
50	16.76	21.11	37.88	12.69	13.25	0.21	0.01
60	20.14	25.28	45.42	15.26	14.03	0.19	0.00

$\delta = 0.3$

10	2.98	5.14	8.12	1.98	7.11	0.57	1.59
20	6.37	9.22	15.60	4.56	9.65	0.38	0.36
30	9.75	13.37	23.12	7.13	11.26	0.30	0.16
40	13.13	17.52	30.66	9.71	12.44	0.25	0.09
50	16.51	21.68	38.20	12.29	13.36	0.21	0.06
60	19.89	25.85	45.74	14.86	14.12	0.19	0.04

$\delta = 0.5$

10	2.68	6.05	8.73	1.58	7.82	0.62	5.16
20	6.10	9.91	16.01	4.16	9.96	0.40	1.07
30	9.49	14.00	23.49	6.73	11.46	0.30	0.45
40	12.88	18.13	31.01	9.31	12.58	0.25	0.25
50	16.26	22.28	38.54	11.89	13.48	0.21	0.16
60	19.64	26.43	46.07	14.46	14.22	0.19	0.11

Perturbation with EPT

When the EPT are inclined by angle, τ_1 with the vertical, the shape of the EPT is studied as two cases based on analytical. Where the small perturbation with the EPT occurs by symmetry shape, the first case is shown in Figure 3.

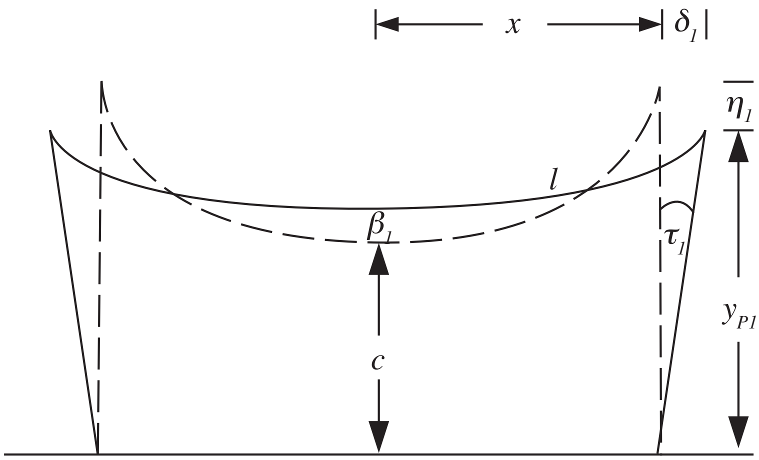

Figure 3. Schematic presentation of the cable perturbation effects (first case).

For the dotted line, the length of a cable is calculated by analytical method, and the value in this paper does not change for EPT. Thus this parameter, τ_1 affects other values as

$$y_{P1} = y \sin (90^\circ - \tau_1), \tag{9}$$

and

$$c_{P1} = c + |\beta_1|, \tag{10}$$

where

$$\beta_1 = \left| \sqrt{(y \sin (90^\circ - \tau_1))^2 - l^2} - c \right|. \tag{11}$$

Table 2. Results of small perturbation effect with EPT.

$\tau = 1^\circ$

span	sag	distance	height	loss	loss/length	%tension
10	3.37	4.17	7.54	6.20	0.49	0.02
20	6.75	8.34	15.09	9.21	0.37	0.02
30	10.12	12.51	22.63	10.97	0.29	0.02
40	13.49	16.68	30.17	12.22	0.24	0.02
50	16.87	20.85	37.72	13.19	0.21	0.02
60	20.24	25.02	45.26	13.98	0.19	0.02

$\tau = 2^{\circ}$

10	3.36	4.18	7.54	6.21	0.49	0.06
20	6.73	8.35	15.08	9.22	0.37	0.06
30	10.09	12.53	22.62	10.98	0.29	0.06
40	13.46	16.70	30.16	12.23	0.24	0.06
50	16.82	20.88	37.70	13.20	0.21	0.06
60	20.18	25.06	45.24	13.99	0.19	0.06

$\tau = 3^{\circ}$

10	3.35	4.19	7.53	6.22	0.49	0.14
20	6.70	8.37	15.07	9.23	0.37	0.14
30	10.04	12.56	22.60	10.99	0.29	0.14
40	13.39	16.75	30.14	12.24	0.24	0.14
50	16.74	20.93	37.67	13.21	0.21	0.14
60	20.09	25.12	45.20	14.00	0.19	0.14

The second case, the EPT are inclined by contrary angle with the first case, τ_2 with the vertical, shown in Figure 4.

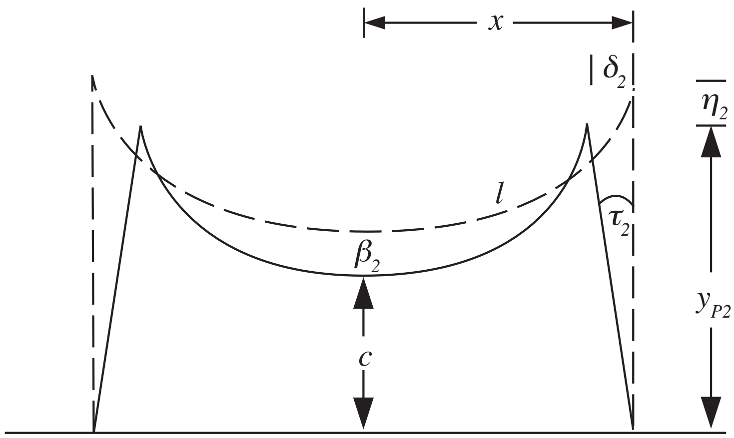

Figure 4. Schematic presentation of cable perturbation effects (second case).

The results are calculated for some small perturbation with inclined by angle, τ_2 and the EPT span, shown in Table 3.

Table 3. Results of small cable perturbation with contrary EPT.

$\tau = 1^\circ$

span	sag	distance	height	loss	loss/length	%tension
10	3.38	4.17	7.54	6.20	0.49	0.02
20	6.76	8.33	15.09	9.21	0.37	0.02
30	10.13	12.50	22.63	10.97	0.29	0.02
40	13.51	16.66	30.17	12.22	0.24	0.02
50	16.89	20.83	37.72	13.19	0.21	0.02
60	20.27	24.99	45.26	13.98	0.19	0.02

$\tau = 2^\circ$

10	3.38	4.16	7.54	6.19	0.49	0.06
20	6.76	8.32	15.08	9.20	0.37	0.06
30	10.14	12.48	22.62	10.96	0.29	0.06
40	13.52	16.64	30.16	12.21	0.24	0.06
50	16.90	20.80	37.70	13.18	0.21	0.06
60	20.28	24.96	45.24	13.97	0.19	0.06

$\tau = 3^\circ$

10	3.39	4.15	7.53	6.18	0.49	0.14
20	6.77	8.30	15.07	9.19	0.37	0.14
30	10.16	12.45	22.60	10.95	0.29	0.14
40	13.54	16.60	30.14	12.20	0.24	0.14
50	16.93	20.74	37.67	13.17	0.21	0.14
60	20.31	24.89	45.20	13.96	0.19	0.14

DISCUSSION

Cable losses are considered in respect to only the cable radius of curvature, which means the cable bend loss may be increased if including the other parameters such as b, α, Δ. The cable tension is calculated by using the minimum conditions, therefore, in general the other parameters such as fiber optic cable strength, small values of wind and temperature effects, i.e., perturbation may be involved. The result of cable perturbation is shown in Table 1. The small perturbation with cable length is increased for each EPT span, then distance between a minimum point of the hanging cable, sag, height of hanging cable, transmission losses, losses per unit length and percentage of tension are increased, while the loop storage is decreased. The EPT span is increased for each small perturbation of transmission losses, losses per unit length and tension which approach to the analytical results. Results of perturbation with EPT are shown in Tables 2 and 3, where both inclined EPT for the angles are the same for each EPT span, height of hanging cable and tension. The small perturbation from angle is increased for each span. when the distance between a minimum point of the hanging cable, transmission loss and losses per unit length are increased, while the cable sag and height of hanging are decreased. The inclined EPT by contrary angle with the previous case, the small perturbation from angle is increased for each EPT span, when the distance between a minimum point of the hanging cable, transmission losses and losses per unit length are decreased, but sag and height of hanging are increased. The EPT spans are increased for some small perturbation, transmission losses and losses per unit length that approach to the results from analytical method.

In this study, length of fiber optic cable in terms of sag, span, distance between a minimum point of the hanging cable, loop storage and height could be presented in terms of kilometer, meter, i.e., arbitrary unit (a.u.) and transmission losses could be presented in terms of decibel (dB).

CONCLUSION

In conclusion, results of catenary problem of the hanging cable is studied in terms of cable radius of curvature. The transmission losses are investigated for some EPT span, the results of analytical method with the perturbation effects for some EPT span are shown. The optimum parameters obtained have shown that the transmission losses are still valid for transmission link, with power transmission losses of 10 dB remain in the range of fiber optic cable length of 20 km.

The continuing work is focussed on the construction of the fiber optic cable that will result in the minimum installation cost and power transmission loss of cable on the EPT span within the Southeast Asia region (Thailand). The other types of fiber cables will be installed and tested. The fiber loss with lightning effects will also be investigated.

ACKNOWLEDGEMENTS

The authors wish to thank the Faculty of Science, King Mongkut's Institute of Technology Ladkrabang for providing facilities to carry out this research work.

REFERENCES

Allard, F. C. 1990. Fiber optic handbook for engineers and scientists. McGraw-Hill, New York.

Koehler, C. W. 1989. Analysis of basic position loop control systems: Conference of IEEE on Industry Applications Society Annual Meeting. Vol.2: 1656–1662.

Lee, Y. S., and S. I. Hong. 2001. A Study of maintaining control of tension for a catenary's cable. Proceeding of ISIE International Symposium on Industrial Electronics. Vol.1: 581–585.

Mathis, H., and P. O. Vontobel. 2000. Shape optimization for a rectangularly constrained small loop antenna. Proceeding of International Zurich Seminar on Broadband Communications. p.73–76.