Modeling the overhead power line post spring-damper using ADINA

A.B. Peabody[a,*], G. McClure[b]

[a]Consulting Transmission Engineer, Anchorage, AK 99516, USA
[b]McGill University, Department of Civil Engineering and Applied Mechanics, Montreal, Quebec H3A 2K6, Canada

Abstract

A new method of reducing the shock loads on electric transmission structures due to broken wires and other longitudinal disturbances was invented. It consists of a post spring-damper assembly, which replaces the standard suspension insulator assembly that supports the conductor. The concept was developed through finite element dynamic modeling using ADINA.

Keywords: Electric transmission lines; Overhead lines; Cable structures; Nonlinear analysis; Progressive failure; Damping; Analytical techniques

1. Introduction

Large-scale progressive collapses of high-voltage transmission lines, also known as cascades, have been a continuing problem for almost a century. In the great Northeast Ice Storm of January 1998 [1], Peyrot [2] concluded that there were 18 major steel tower cascades and 37 major cascades of wood structure lines. While not all structural failures result in cascades, longitudinal cascades are triggered by a failure in the structural system that maintains tension in the overhead wires. These failures are represented most simply by a broken wire. Broken wires cause dynamic loads on the towers much higher than the intact wire tensions [3,4]. Figure 1 shows a classical single-circuit 230 kV lattice steel tower. The conductor is suspended on a flexible insulator assembly composed of 12 insulators connected together with ball-and-socket joints. The post spring-damper (patents pending) shown in Fig. 2 [5], replaces the flexible insulator assembly with a relatively stiff post insulator connected to a rotary damper and torsional spring. The post insulator consists of a large diameter (around 80 mm) fiberglass composite rod covered with a silicon or EPDM (Ethylene Propylene Diene Monomer) rubber sheath. When there is a sudden longitudinal imbalance in the wire tension, for example when the conductor breaks, the wire moves longitudinally and vertically, causing the post to rotate. The rotation of the post is resisted by the torsional spring. As the base of the post rotates, the rotary damper dissipates kinetic energy. The combined action of the spring and damper reduces the impact load on the tower. The post spring-damper was developed and modeled using the finite element dynamics program ADINA [6].

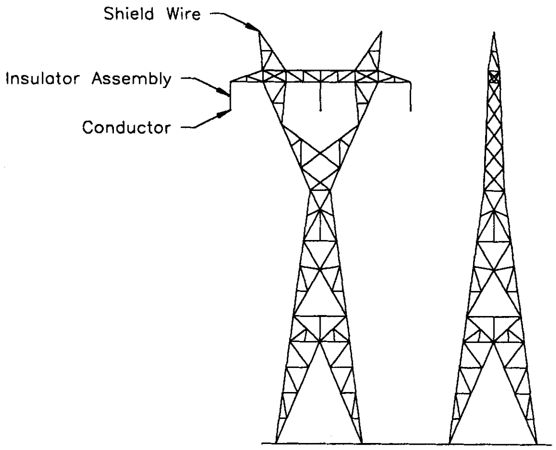

Fig. 1. 230 kV lattice steel tower.

* Corresponding author. Tel.: +1 907 345 6819; Fax: +1 907 345 6879; E-mail: apeabody@ieee.org

Computational Fluid and Solid Mechanics 2005
K.J. Bathe (Editor)

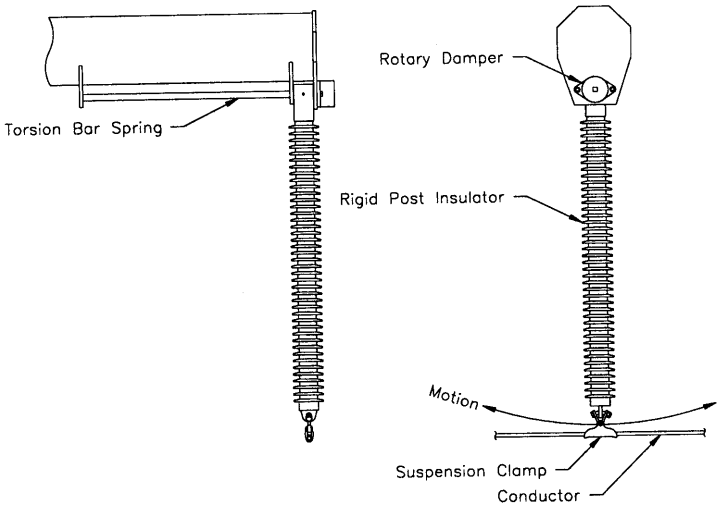

Fig. 2. Post-spring damper.

2. Tower, insulator and damper model

In this study, only the center conductor suspended from the tower shown in Fig. 1 was modeled, allowing all elements to be modeled in a 2D plane. The main action of the tower under shock loads is represented by the response of a single dynamic degree-of-freedom cantilever beam. The fundamental natural frequency of the tower alone, 3.2 Hz, was determined using both a frequency analysis and a time history analysis of the tower after plucking it with a momentary force. The tower is modeled as a linear spring and lumped effective mass (377 kN/m and 933 kg) in parallel with a viscous dashpot (5% of critical). The spring constant was determined from a static analysis and the equivalent mass from the natural frequency and spring constant. Figure 3 shows the model of the tower, post insulator and damper. The post insulator was modeled as a beam element with the properties of the fiberglass composite rod. The torsional spring and damping constants representing the spring damper were systematically varied to determine the optimum values.

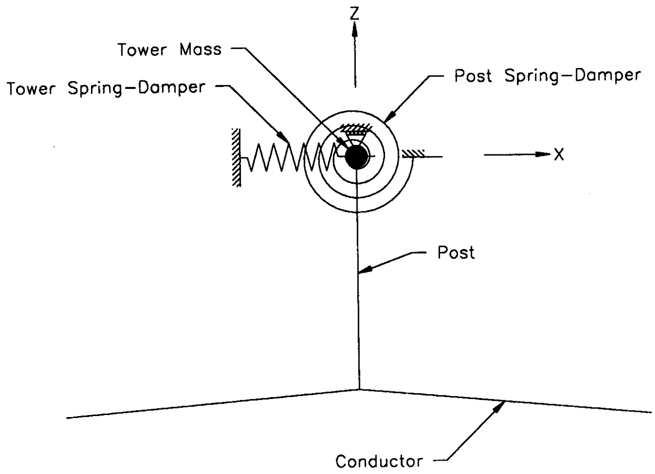

Fig. 3. Tower and post spring-damper model.

3. Conductor damping

The inherent damping of transmission conductors and shield wires can be separated into internal/structural damping and aerodynamic damping. The internal damping is complex; it is a combination of hysteretic damping within the individual cable strands, and sliding friction and contact between strands as they move past one another during cable movement. Aerodynamic damping is due to the motion of the conductor relative to the air.

3.1 Internal damping

The critical axial viscous damping, c_{cr}, for a Hookean rod is given in Eq. 1, where AE is the axial rigidity of the rod and m its mass per unit length.

$$c_{cr} = 2\sqrt{AEm} \tag{1}$$

Axial damping of 0.5% of critical damping for a rod was used for the truss elements.

3.2 Aerodynamic damping

In still air the aerodynamic damping force is given by Eq. 2 [7, p. 76] where F_d is the damping force, ρ is the air density, V_r is the velocity relative to the air, C_d is the drag coefficient and A_p is the projected area. C_d was taken as 1.25 for classical conductors stranded with round wires.

$$F_d = \frac{1}{2}\rho V_r^2 C_d A_p \tag{2}$$

4. Conductor model

Figure 4 shows the conductor model with both axial and aerodynamic damping. The aerodynamic damping was applied to the vertical motion of the conductor using the initial horizontal projected area. Figure 5 shows the spans and wires modeled. Each span of wire had 140 truss elements (2.5 m in horizontal projection).

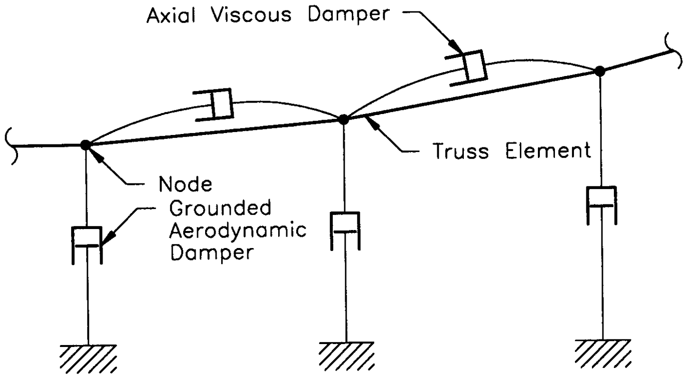

Fig. 4. Conductor model.

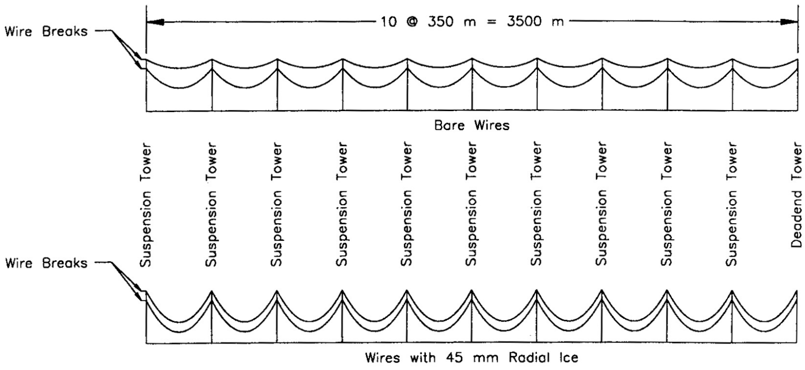

Fig. 5. Spans modeled.

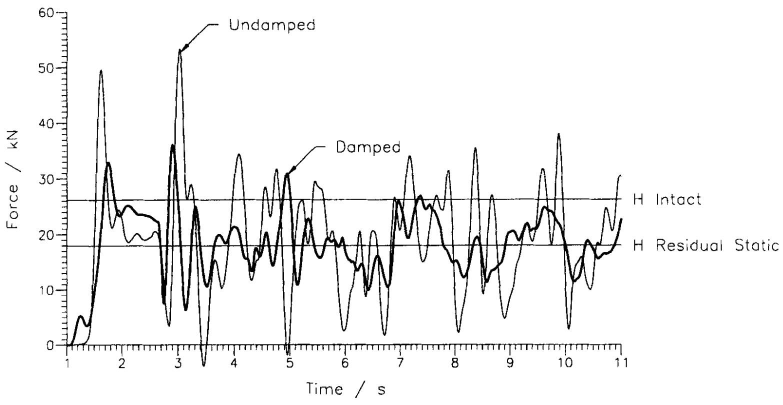

Fig. 6. Bare conductor time histories.

5. Results

Spring and damper combinations were optimized for four cases, Cardinal ACSR (aluminum conductor steel reinforced) conductor, bare and ice coated, and 7/16 EHS (extra-high strength) shield wire, bare and ice coated. In all cases, the lowest peak dynamic force was obtained with a damper only, i.e. with no rotational spring. Figure 6 shows the time histories for a bare conductor without any damping and with the optimal damper.

The horizontal component of the force on the tower is represented by *H*. The force on the tower when the line system has come to rest after a wire break is the 'residual static' force, the absolute minimum to which the peak load on the tower next to a broken wire can be reduced, without damaging the tower. Table 1 shows that the post-spring damper achieves 50–80% of this maximum possible reduction. The energy dissipated in the dampers compared to the total energy released is shown in Table 2. Most of the energy dissipation occurs at the two towers closest to the failure.

6. Conclusions

In the example discussed, the post-spring damper reduced the peak dynamic loads on the tower by 50–80% of the maximum possible reduction, while dissipating 70–90% of the total energy released by the wire break.

Acknowledgments

The authors are grateful for the financial support provided by the Natural Sciences and Engineering Research Council of Canada and Hydro-QuébecTransÉnergie.

References

[1] McClure G, Johns KC, Knoll F, Pichette G. Lessons from the ice storm of 1998, improving the structural features of Hydro-Québec's power grid. Proc of the 10th

Table 1
Percentage of maximum possible force reduction obtained

Cable	Radial ice mm	Peak tower elastic force undamped kN	Residual static horizontal tension kN	Maximum potential reduction in peak force kN	Minimum peak tower elastic force damped kN	Actual reduction in peak force kN	Reduction obtained % of maximum potential
7/16 EHS	–	37.9	14.4	23.5	18.6	19.3	82
7/16 EHS	45	112.1	64.7	47.4	75.2	36.9	79
Cardinal	–	53.2	18.0	35.2	36.0	17.2	49
Cardinal	45	156.3	81.5	74.8	105.4	50.9	68

Table 2
Total energy dissipated by damper (J)

Structure	Bare shield wire	Iced shield wire	Bare conductor	Iced conductor
Twr 1	4260	14 150	10 490	67 670
Twr 2	1530	5520	3960	23 180
Twr 3	750	2970	2670	13 680
Twr 4	400	1760	2100	8970
Twr 5	220	1100	1750	6240
Twr 6	120	730	1570	4480
Twr 7	70	510	1480	3210
Twr 8	40	380	1240	2300
Twr 9	20	290	880	1760
Twr 10	20	230	470	1200
Total energy dissipated	7430	27 640	26 610	132 690
Total energy released	8100	34 200	38 100	159 500

International Workshop on Atmospheric Icing of Structures, Brno, Czech Republic, 17–20 June 2002; Paper 9–3.

[2] Peyrot AH. Commentary on the report prepared by the structures group. In: Les conditions climatiques et l'approvisionnement en énergie (The climatic conditions and energy supply), vol. 3, Rapport de la commission scientifique et technique chargée d'analyser les événements relatifs à la tempête de verglas survenue du 5 au 9 janvier 1998. Québec: Les Publications du Québec, 1999; pp. 567–576.

[3] Govers A. On the impact of uni-directional forces on high-voltage towers following conductor-breakage. In: Proc of the International Conference on Large Electric Systems at High Tension (CIGRE), Paris, 1970; Paper 22–03.

[4] Peyrot AH, Kluge RO, and Lee JW. Longitudinal loading tests on a transmission line. Electric Power Research Institute, Palo Alto, EPRI EL-905, 1978.

[5] Peabody AB. Applying shock damping to the problem of transmission line cascades. PhD thesis, Dept. of Civil Engineering and Applied Mechanics, McGill University, Montreal, Canada 2004.

[6] ADINA (Automatic Dynamic Incremental Nonlinear Analysis), Version 8.1. Watertown, MA: ADINA R&D, Inc., 2003.

[7] Dyrbye C, Hansen SO. Wind Loads on Structures. Chichester, UK: John Wiley & Sons, Ltd, 1996.