Conductor Dynamics – Practical Information for Design Engineers

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Background:

Transmission line design engineers are required to gain a practical understanding of foundations, structures, fittings, insulators and conductors. In addition they need to understand AC systems, protection, and controls. Also required are minors in real estate, law, and public relations. Long life for the transmission system also requires a background in aerodynamics, structure mechanics, and the interaction between the wind and the obstructions we place in its path. There are no other structures as large and as flexible as a transmission line. There are extreme dynamics challenges. Overhead system dynamics is still under investigation by researchers. There are areas where the scientific and engineering consensus has been reached. Ice galloping is still poorly understood and there is no engineering consensus on preventing galloping. This discussion attempts to provide practical advice for ensuring a transmission line design is reasonably well-engineered against excessive damage from dynamic phenomena.

History:

Interaction between wind and structures surely vexed the earliest humans as they constructed the first bridges and other structures. Wind has been harvested as an energy source since before recorded history. New problems emerged when we started stringing wire across the countryside. Early telegraph wires were reported to "sing". This was soon followed by reports of strange looking breaks we now recognize as fatigue fractures.

In 1923, George Stockbridge, a transmission engineer with Southern California Edison, invented the first reliable vibration damper. Since then, conductor motion control has grown into a large industry. The technology development is also driven by commercial interests which should be considered when designing a transmission line.

Protection from Aeolian vibration is reasonably well-understood, and a competitive market provides several effective options. To date, there is no scientific or engineering consensus on preventing ice galloping. Expensive damage occurs every winter. Galloping counter-measures are commercially available, but most have unresolved issues.

Conductor Motion: Types and Countermeasures

Aeolian Vibration

Aeolian vibration is a high-frequency, low amplitude vibration excited by smooth and steady wind. Damage can occur in a matter of hours or days, but in most cases it is years or decades before the hidden damage is serious enough to cause a conductor failure. Early warning signs include problems with loosening hardware, and rust streaks from attachments where the galvanizing is worked away by motion. Fortunately, this type of motion is well-understood, and there are recent IEEE and CIGRE publications that cover the subject well.

For countermeasures, the Stockbridge damper is still the most common protection device. The cost is sufficiently low that dampers are well-advised if there is any doubt about the possibility of damage due to Aeolian vibration. Tension limits incorporated into the National Electric Safety Code (NESC) are directed at vibration prevention, but the experts agree that tension limits alone are insufficient. Many conductors installed below the NESC tension limits have failed due to fatigue. Other important factors are the local climate and terrain. The best predictor of Aeolian vibration is the history of fatigue damage to nearby transmission lines.

The power needed to cause damage from Aeolian vibration is tiny: on the order of one watt is sufficient to damage a typical 1000 ft span. We spend far more energy just breathing than the energy required to vibrate a long conductor span.

Wake-Induced Oscillation

Sub-conductors in bundled configurations can oscillate if the down-wind sub-conductor encounters the wake of the up-wind sub-conductor. Early bundled conductor installations suffered from fatigue failures at rigid bundle spacers. Two countermeasures were quickly adopted: increasing the sub-conductor is not ideal for corona performance, but the aerodynamics consideration trumps corona as more distance allows the wake to dissipate and have less of an effect on the down-wind sub-conductor. Also effective is increasing the compliance in the spacer to avoid localized bending of the conductor. Rubber-lined clamps are now common. Spacer/dampers have articulating arms to provide even more compliance. Spacer/dampers also provide distributed damping, and Stockbridge dampers are no longer needed at the span ends.

Blow-out

Steady and gusty winds will deflect the conductor from its rest condition. Blow-out must be considered for electrical clearances, and the structure loads need to include the forces from wind drag on the conductor. Blow-out may be reduced by higher tensions, shorter spans, and smaller diameter conductors. Blow-out is not considered harmful.

Buffeting

Gusting winds can cause large conductor displacements. Fortunately, wind gusts tend to arrive randomly, and therefore do not cause build-up of motion that is typical of resonances. Similar to blow-out, buffeting is rarely harmful, but must be considered in electrical clearances and structure loads.

Ice Galloping

Ice galloping is the result of an aerodynamic instability caused by an unfortunate coincidence of a torsional (twisting) resonant mode occurring at a similar frequency as a transverse (up-down) resonant mode for a span. In a cross wind, the ice deposit forms an oval shape, which will generate variable lift as the conductor responds to wind forces. Most spans are aerodynamically stable, meaning that the lift forces occur at a frequency that does not match a resonance in the transverse vibration modes.

We lack understanding to develop engineering rules to prevent the type of aerodynamic instability that makes a transmission span prone to gallop when ice and wind conditions are conducive. With luck, the design will be stable, but luck is not a good engineering strategy.

The power transferred during a galloping event is in the kW range – strong winds generate a lot of force, and the resonant coupling of two vibration modes is relatively efficient for converting the wind energy to kinetic energy in the span.

Popular counter-measures include:

- Torsional detuning devices. These work if the line is known to gallop, but should not be considered unless the span is known to gallop. Applying a torsional detuner to a stable line is unnecessary at best, and at worst can cause a stable span to become unstable.
- Air flow spoilers are proven, but need to cover approximately one-third of the span. Ice and wind loads on the spoilers increase the structure loads. Spoilers target both the aerodynamic and structural mechanics elements of galloping. Wind flow over part of the span is modified enough to prevent its participation in galloping. There is also a twisting action similar to a torsional detuner.
- Twisted-pair (TP) and oval conductor. TP conductor was developed as a counter-measure for Aeolian vibration, but it was soon observed to have anti-galloping properties. There are downsides: TP has a reputation for being difficult to install. TP and oval cross-sections are more prone to corona than the equal-kcmil round conductor.
- Phase spacers are long fiberglass rods that clamp to the conductors to maintain spacing if the line starts to gallop. Spacers also reduce the occurrence of clashing, where adjacent phases contact and cause an electrical fault. Spacers will also detune lines that are prone to gallop.

Commercial Considerations

The conductor dynamics market is dysfunctional for several reasons. A long-standing issue is "free" consulting by the damper manufacturers. Independent consultants cannot compete, and it is therefore difficult to find advice that is free of commercial considerations. The easy QC tests (dimensions, weight, coating thickness, etc) are not direct measures of how well a damper works.

Price competition has not worked in the vibration damper industry. The manufacturing cost is dominated by the purchase price per pound for the metal. There is a built-in incentive to make dampers as light as possible, but mass is needed to respond at the mission-critical lower end of the frequency range. R&D and testing are expensive, and bring the additional cost of recognizing that mass is necessary for good performance. Absent the necessary R&D and testing capability, it is easy to make a damper that looks correct but does not work. Dampers are one item where a low-bid procurement strategy is unwise.

Some non-commercial advice for transmission design engineers:

- Talk to several manufacturers, and consider all advice offered. Who demonstrates the best technical expertise? Who has R&D and testing capability? Do they have experience in your region (remember local conditions are a large factor)? An offer of a plant visit or audit is a sure sign that the supplier wants you to understand what they are offering.
- Talk to peers in your organization or neighbors in the same area. What happened to local lines historically? The past is a pretty good predictor of the performance of similar lines.

- Talk to line crew members. Engineers go to the conferences, but the crews have boots on the ground and most are keen observers of what works and what causes problems. Most have valuable information to share if they know you are interested.
- Demand design information and test reports. Test reports should be much younger than the drinking age, and should reflect the professionalism of the testing organization. You will quickly recognize who is in it for the fast profit and who is in for the long term. Ask for performance charts. Better yet, hire an independent lab to do some testing and see if the manufacturer is doing their homework.
- Be assertive with procurement organizations. They need your expertise, or else they will evaluate only cost in bid evaluations. The engineer is blamed when things go wrong, and that gives the engineer the right and the duty to spend what is necessary to ensure reliability and long life.