Lessons from (Transmission Line) Failures

May the lessons be learned from the failures made by other people more often than not!

The presentation will describe a number of transmission line structural failures that the author has studied in detail. The objective is to recognize that the devil is in the details, vendors do not always provide quality guidance, things fail for reasons we typically don’t address and some failures are more problematic than others. Throughout, the audience should learn what the root causes of failures can be and therefore where to put more attention in order to reduce the number of failures and the impact of failures on systems that he/she has designed.
Contents

• Understanding root causes
• The devil is in the details
• Vendors don’t always provide quality guidance
• Things fail for reasons we don’t address
• Some failures are more problematic than others
The thing about failures...

- You can study them poorly and learn nothing
- If studied properly, you will learn things…
  - that you did not expect to learn – every time!
  - that you cannot learn by other means

- There is lots of drama to distract you from what matters. Recognize the drama and ignore it.
- There are lots of reasons to not be given the opportunity to study the failure.
Root Causes

- Anomaly
  - Anything (ANYTHING!) that is different from everything else
  - It takes an anomaly to start a failure
  - It takes an anomaly to stop a failure
- Slack
  - The wires between support structures dictate the nature of the failure – which structures will fall and in what manner.
Slack

• The length of the wire in a span minus the distance between the wire’s end points
• basically: \( \text{Slack} = \frac{\text{span}^3}{24} \times C^2 \)

  • Long spans >>> lots of slack; short span >>> no slack
  • Loose wires >>> lots of slack; tight wires >>> no slack

• As slack is removed, tension rises exponentially
The UNIT Curve illustrates Slack

When Slack is small and a change in the slack occurs, the tension changes radically (in the dashed box).

So... a failure occurs (something moves), the slack changes.

The impact on the system depends on how much slack compared to how much was needed to accommodate the movement thus defining the change in tension that will occur.

To understand the failure, figure out where the wires caused things to go.
Example: The Lack of Slack

- In 3 places on the 27.5 kV short span line, the bolted, wave seat clamps snapped in tension at about 60% of vendor’s declared capacity.
- Lab tests confirmed the weakness with this conductor installed even at room temperature.
Vendor Guidance
Poor clamp design for the local conditions

• Triggers:
  – The ONE THING that caused the event:
  – Conductor tension failure at clamp face
    • No-radius clamp seat design, large departure angles with high tension under large ice load (big departure angle + high tension)
The Devil is in the Details
Lightning Damage to OHGW:
Preform Fatigue Failure at Anchors
The Consequences

• **At the same tower site:**
  
  • Broke a poorly designed cable anchor.
    • No circuit loss, no risk to persons, $40K to fix
  
  • Loss of a replacement tower (Hinged Tower)
    • 3 months to replace, $50M+ revenue loss, risk to life, loss of reputation
  
  • Loss of second replacement tower
    • 4 months to reinstate circuit, $100M lost revenue
    • 2 years to replace tower, $20M
A Failure of Understanding the Intent

- Standardized substation structure
  - Various uses, one use required 6 anchor bolts
  - >>> standard foundation, 36” drilled pier because this was in common use at the design time (1970s)
  - 1987: proposed most uses of structure could use 18” pier
  - Substation site / project: no 36” drill available anymore
    - Found and used 42” drill
  - Shallow foundations to be insulated
    - Construction process debacle.

- A COMPLETE WASTE OF $$$$
Further Reading:

• ASCE Manual 74, Appendix on Failure Investigations

• Structural Engineering of Transmission Lines
  Catchpole and Fife, 2013
Questions