The Importance of System Dynamic Modeling for Small Wind Turbines

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Why Am I Here? What Is My Objective?

- To convince you that system dynamic modeling of small wind turbines is very important, if not imperative.

  - ***System***[*]: a set of connected things forming a complex whole.
  - ***Dynamics***[*]: a branch of classical mechanics concerned with the study of forces and their effect on motion.

❖ paraphrased from Wikipedia

The “Typical” Tower System Design Approach

- Turbine Designer
  - Define operating conditions, such as cut-in, cut-out, design wind speed.
  - Define configuration-specific geometry, such as the yaw interface.
  - Calculate tower top loads, usually from IEC 61400-2.
- Tower Designer
  - Invoke TIA-222-G-4* and other standards (AISC, ASCE, AASHTO, etc.).
  - Structural analysis.
  - Optimization (top/base geometry, segmentation, erection, climbing, etc.).
  - Final configuration definition: geometry and foundation loads.
- Foundation Designer
  - Invoke TIA-222-G-4 and other standards (ACI-318, AISC, IBC, etc.).
  - Attempt innovation???
  - Define geometry, reinforcement, concrete specifications.
  - Accommodate installation provisions.

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* Structural Standards for Steel Antenna Towers and Antenna Supporting Structures- Addendum 4 (Small Wind Turbine Support Structures), 2014

Fundamentally, “Typical” Approach Is a Static-Strength Design

- Regardless of whether the loads are based on dynamic analysis or the simplified method.
- Check for tower-turbine resonance.
  - Risk of incorrectly estimating tower natural frequency.
  - Example: rotor at 60 RPM (1/sec) with 1 Hz tower natural frequency.
- TIA-222-G-4 does call for a simplified fatigue analysis.
  - Fatigue is not a worrisome issue because ultimate strength design methods are conservative.

What Is Missing in the “Typical” Design Approach?

- System (turbine + tower) response.
  - Impulsive loads on the tower.
    - Unsteady winds.
    - Change of direction.
    - Inertial loads of the turbine.
  - Rotor-tower-tail coupling.

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Field Experience

- Skystream 3.7: towers of 35’, 60’, 63’ tall.
  - 80,000 hours testing.
  - 97 mph; stable; well damped.
  - [Skystream Video]

Field Experience

- Pika T701(Tail 1): 65‘ tower.
  - 84 mph; excessive deflections; minimally damped.
  - [Video T701 Old Tail]
  - T701 with original tail tested at Colby, KS test site [(Colby Video)]
  - Tower failure during SWCC testing [(Failed Tower).]

Field Experience

- Pika T701 (Tail 2): 53’ tower.
  - 104 mph; stable; adequate damping.
  - [Video T701 New Tail]
  - FAST-instigated changes.
    - Center-of-gravity, tail area, tail length, controls.

Attempts at Validation

- FAST does not replicate the observed behavior of the Pika T701 (Tail 1).
- FAST did instigate changes that improved the performance.
  - Center-of-gravity, tail area, tail length, controls.

* FAST: An aeroelastic computer-aided engineering (CAE) tool for horizontal axis wind turbines, https://nwtc.nrel.gov/FAST.

Conclusions

- System dynamic analysis:
  - Is especially important for new SWT designs.
  - Can inform the SWT design process in important ways.
  - Is not expensive in the overall scheme of SWT development.
- FAST needs work.

Recommendations

- Develop a FAST version that simultaneously models SWTs with towers and tails.

- Validate with field test data and calibrate as necessary.
  - This effort is of value to the entire SWT industry.

- The Distributed Wind community needs to strongly encourage DOE to follow up on the investments already made in SWT innovations.

- NREL is best capable of the necessary testing, analysis, and validation.

More to Come

- Pika T701Case Study
- What is FAST? How is it Used? How Much Does It Cost?