Real Power Modulation of a Wind Turbine Using Wide-Area PMU Feedback

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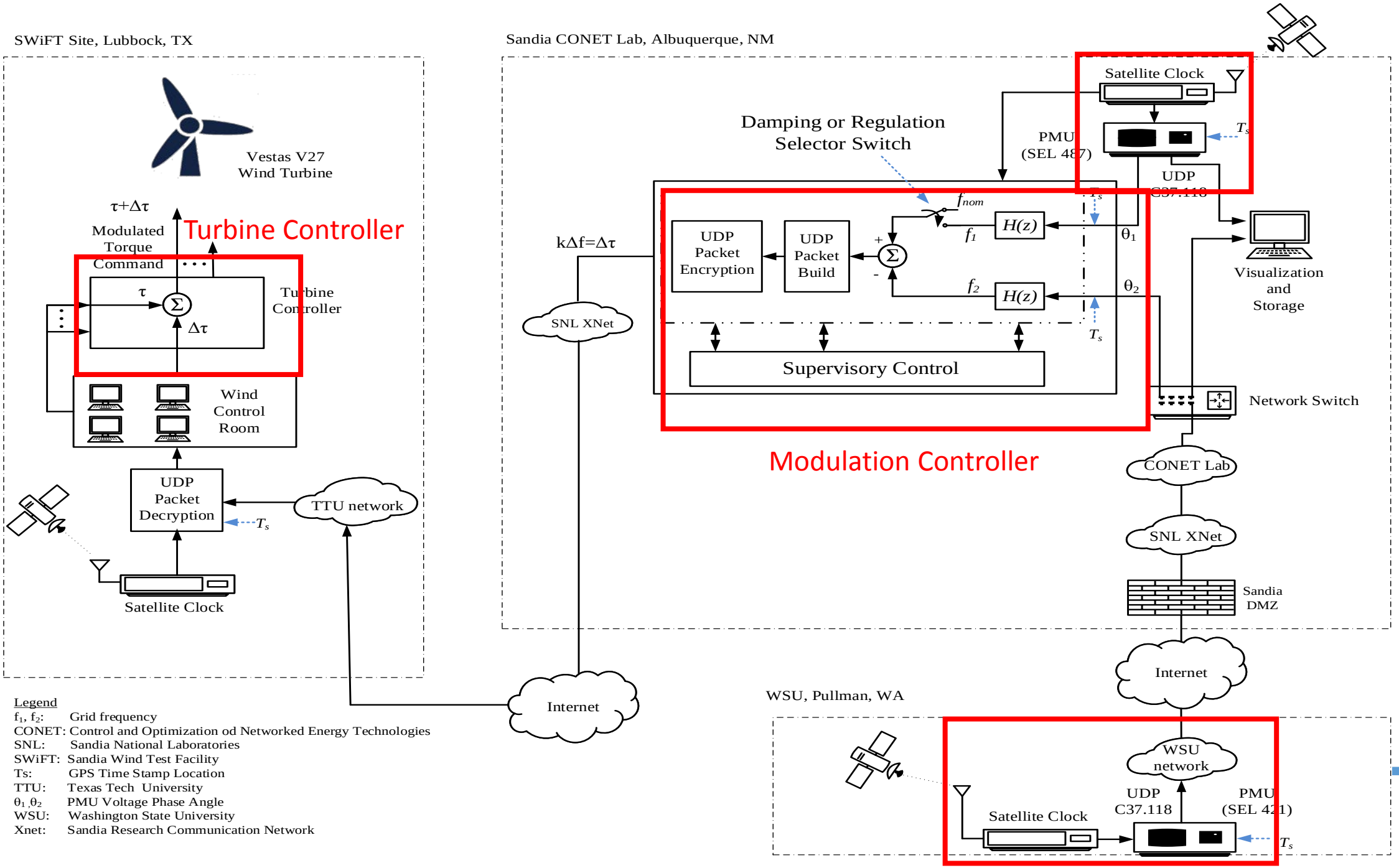
Big Picture

- Overall objective: Build a prototype, demonstration system that can utilize spinning inertia (energy storage) of a wind turbine to “give and take” real power to grid
  - In appropriate frequency band (approx 0.1 to 2 Hz)
  - Using PMU feedback in real time
  - Proportional to (but opposing) grid frequency deviations
  - DOE SBV between Sandia and NIRE (Lubbock, TX)



Legend
f_1, f_2: Grid frequency
CONET: Control and Optimization od Networked Energy Technologies
SNL: Sandia National Laboratories
SWiFT: Sandia Wind Test Facility
Ts: GPS Time Stamp Location
TTU: Texas Tech University
θ_1 ,θ_2 PMU Voltage Phase Angle
WSU: Washington State University
Xnet: Sandia Research Communication Network

Background

- Building on work of the Sandia/BPA PDCI modulation project
  - B. Pierre *et al.*, "Supervisory system for a wide area damping controller using PDCI modulation and real-time PMU feedback," *2016 IEEE Power and Energy Society General Meeting (PESGM)*, 2016.
  - B. J. Pierre *et al.*, "Open-loop testing results for the pacific DC intertie wide area damping controller," *2017 IEEE Manchester PowerTech*, 2017.
  - R. Guttromson, I. Gravagne, J. White, J. Berg, F. Wilches-Bernal, and C. Hansen, "SAND2018-772151: Use of Wind Turbine Kinetic Energy to Supply Transmission Level Services," Sandia National Laborotories, Albuquerque, NM, March, 2018.
  - T. Knuppel, J. Nielen, K. Jensen, A. Dixon, J. Ostergard, “Power Oscillation Damping Controller for Wind Power Plant Utilizing Wind Turbine Inertia as Energy Storage,” *2011 IEEE Power and Energy Society General Meeting*, 2011.

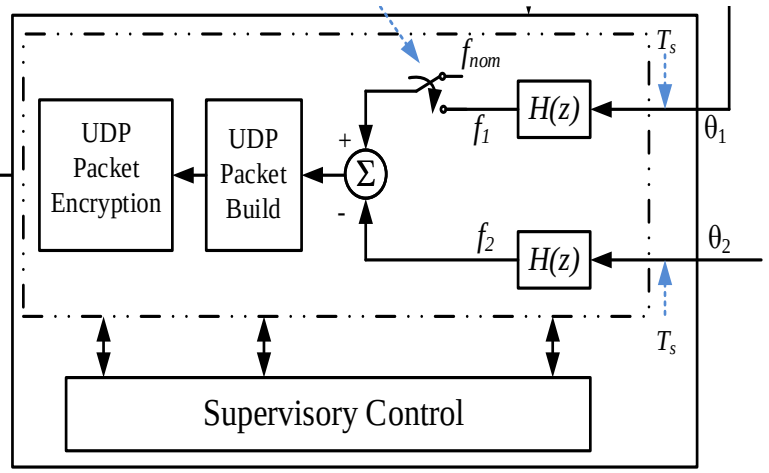
Experimental Setup: PMUs

- PMUs
  1. SEL 421 located at Washington State U (Pullman, WA), with GPS clock.
  2. SEL 487 Located at Sandia Labs, with GPS clock.
- Both PMUs transmitting C37.118-2015, “UDP_S”, 60 msg/s (WSU using public internet)
- Both on western grid

Experimental Setup: Modulation Controller

- Modulation controller is the design prototype for PDCI (resides at Sandia “CONET” lab)
- LabView-based RT OS
- Two operational modes

$$mod = k\Delta f$$



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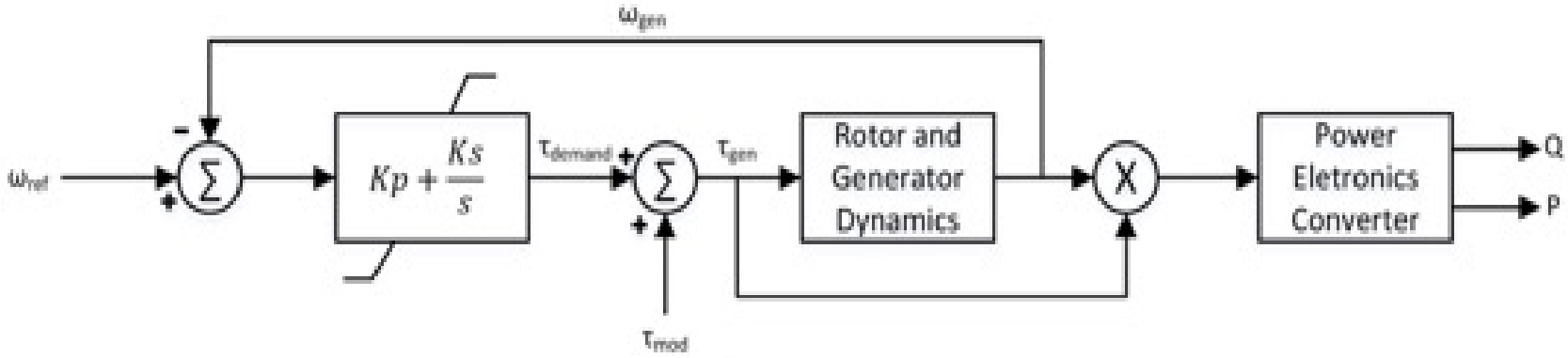
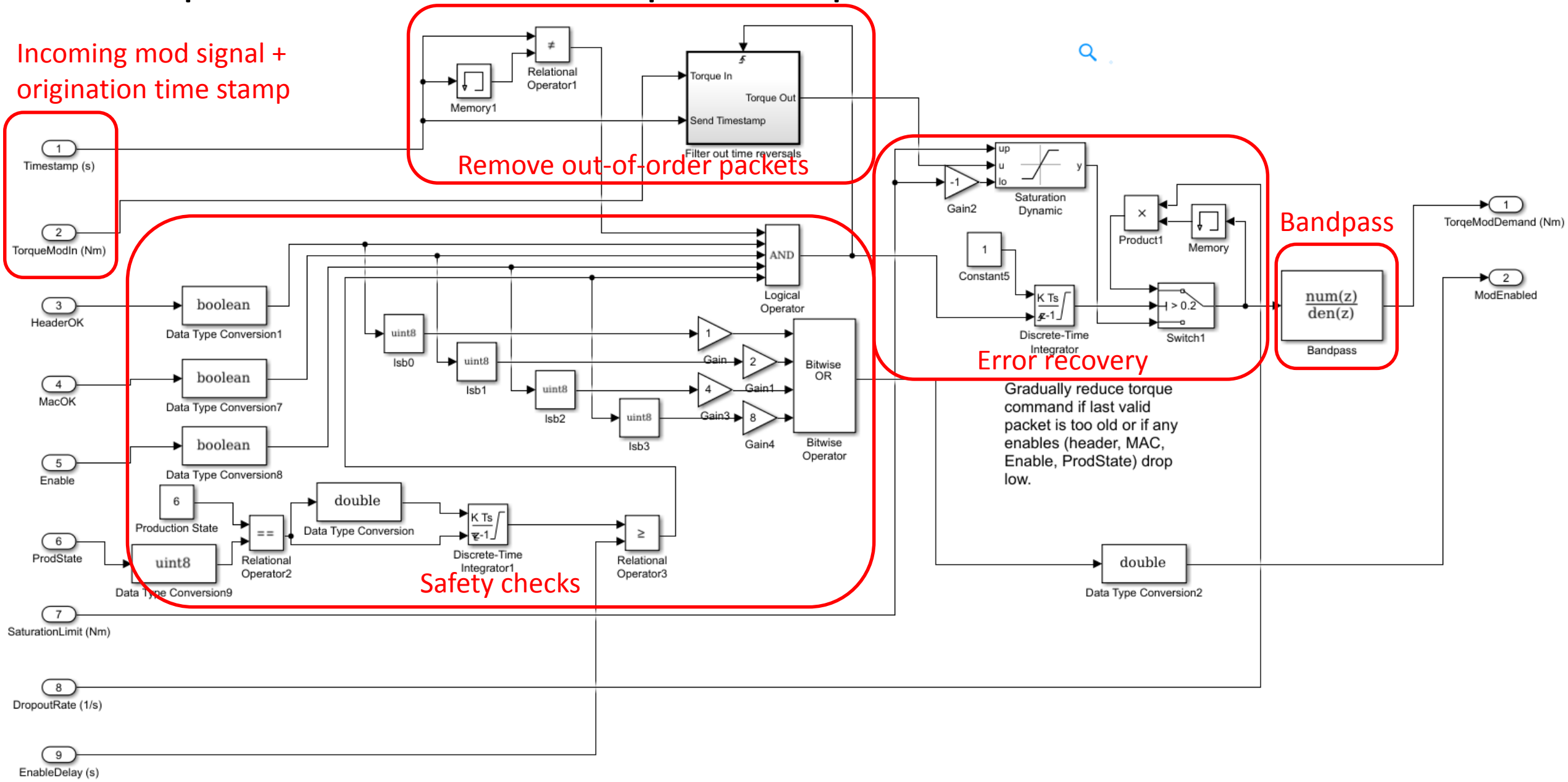
Experimental Setup: Turbine Controller

- Modified the turbine speed controller to accept “torque modulation” input

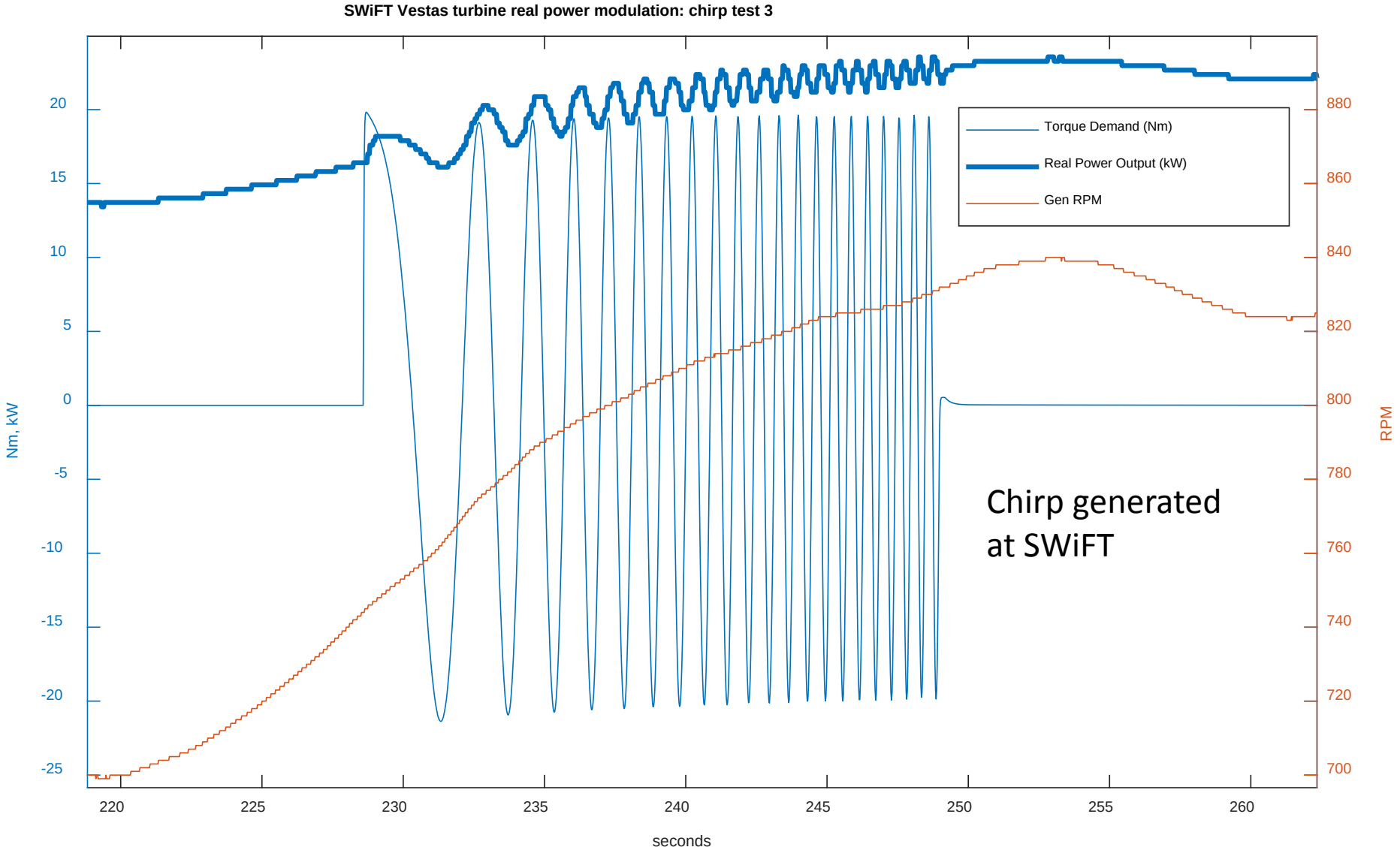


ω_{ref}	Reference rotor and generator speed
ω_{gen}	Speed of rotor and generator
τ_{demand}	Torque Demand from wind turbine controller
τ_{mod}	Torque modulation from wide-area controller
τ_{gen}	Torque to generator applied to rotor

Experimental Setup: Torque Modulator



Chirp Test 1



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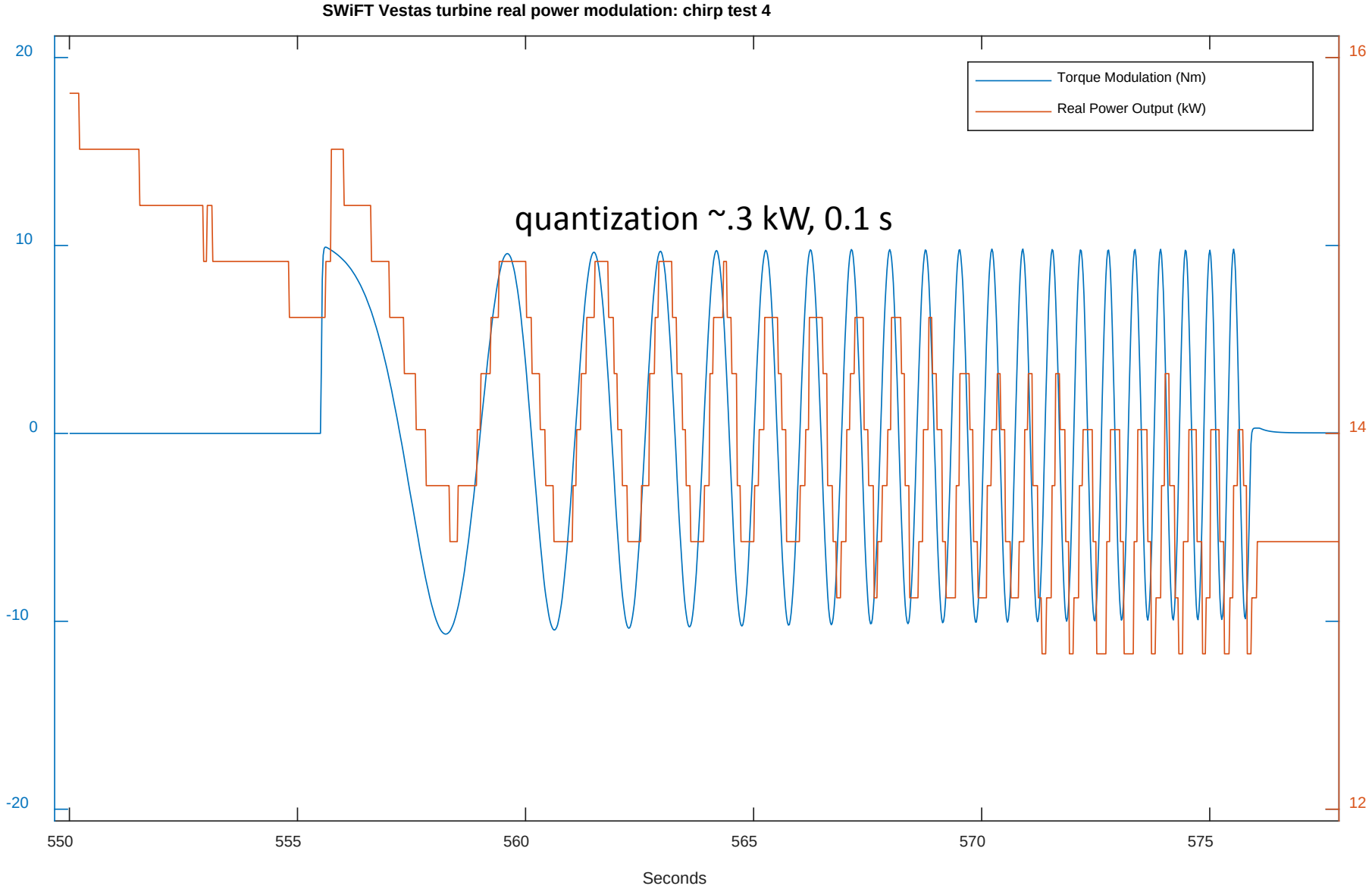
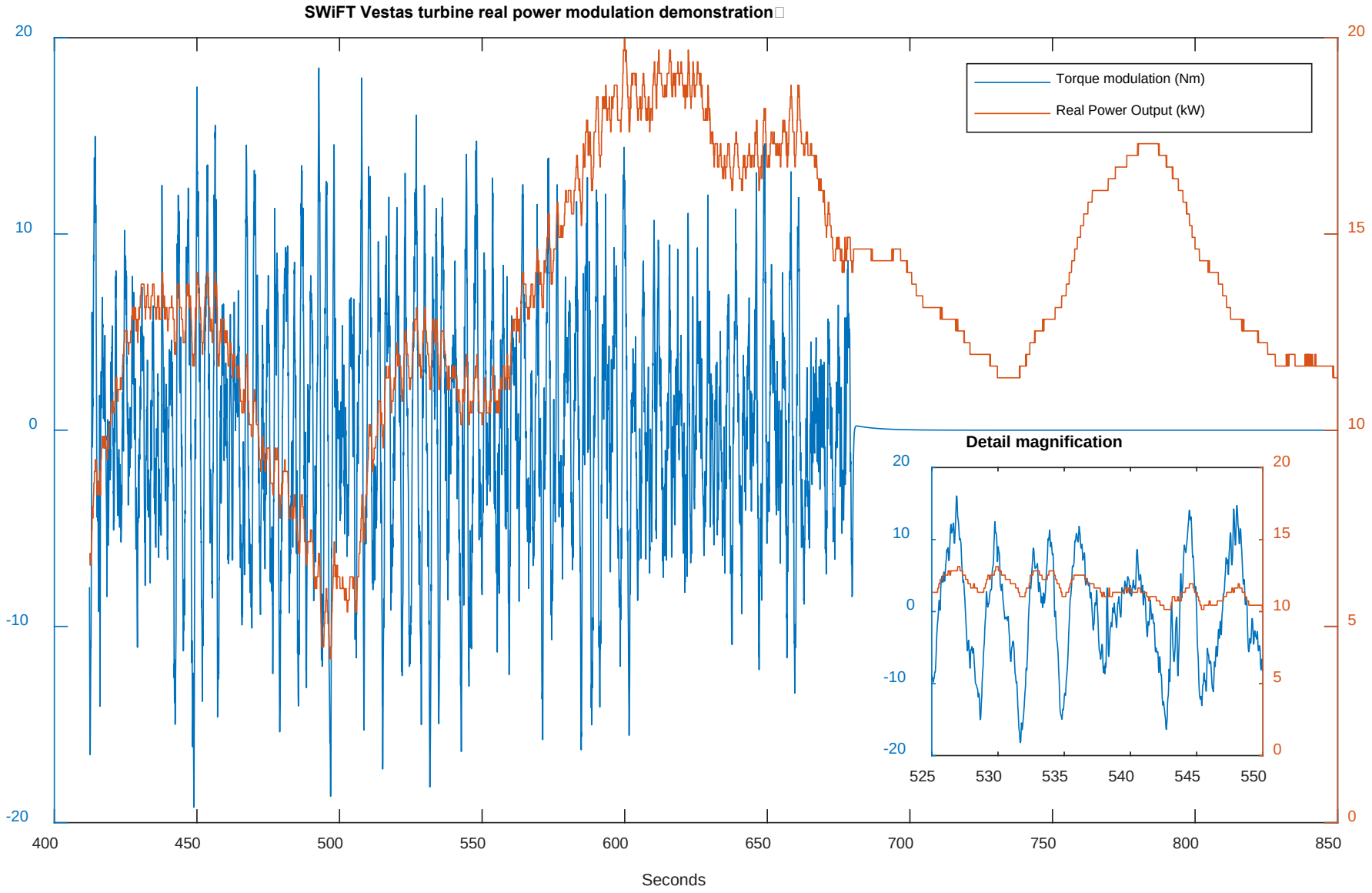
Chirp Test 2


SWiFT Vestas turbine real power modulation: chirp test 4
Torque Modulation (Nm)
Real Power Output (kW)
quantization ~.3 kW, 0.1 s
20
10
0
-10
-20
16
14
12
550
555
560
565
570
575
Seconds



Wide area differential mode

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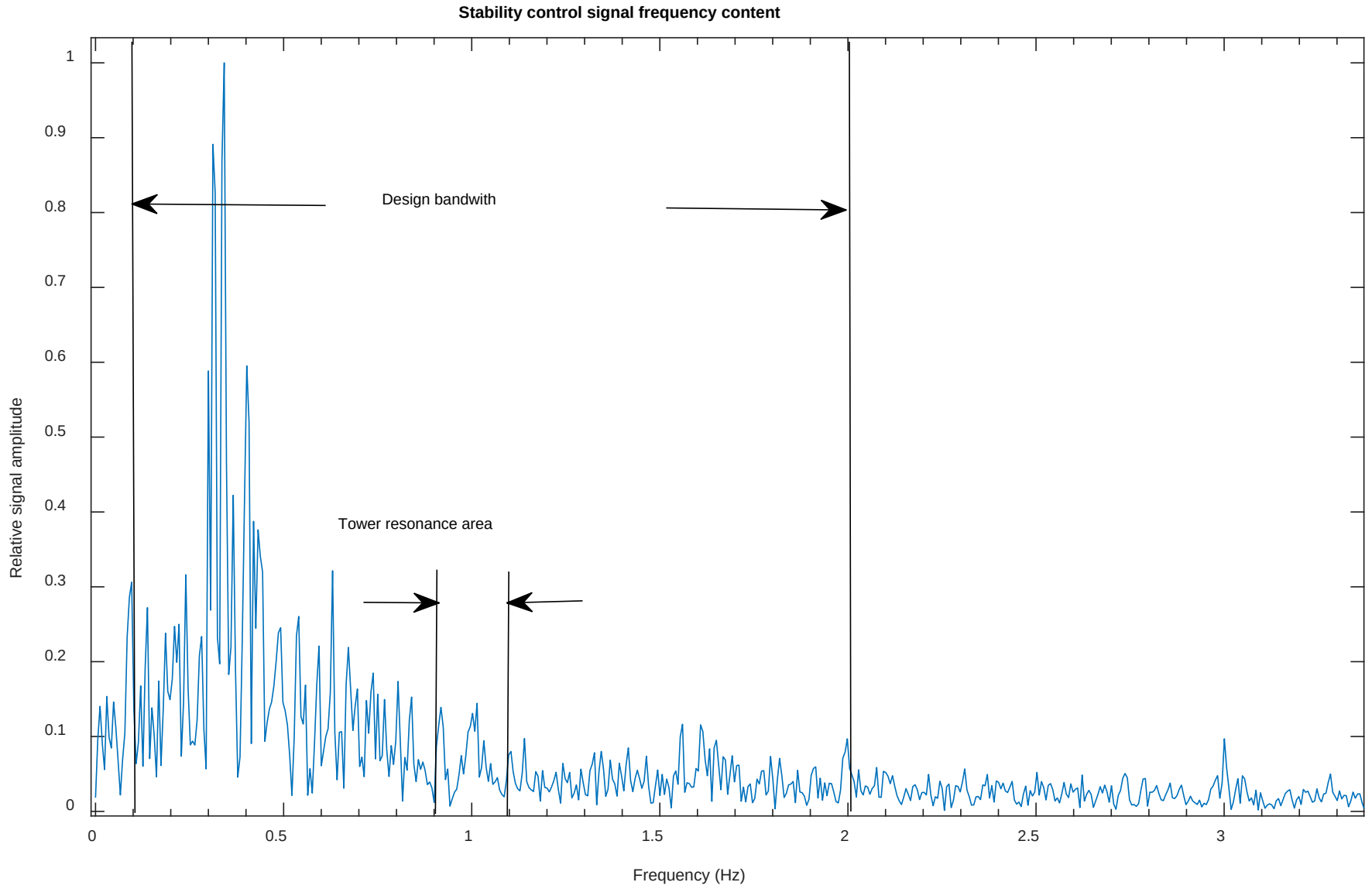
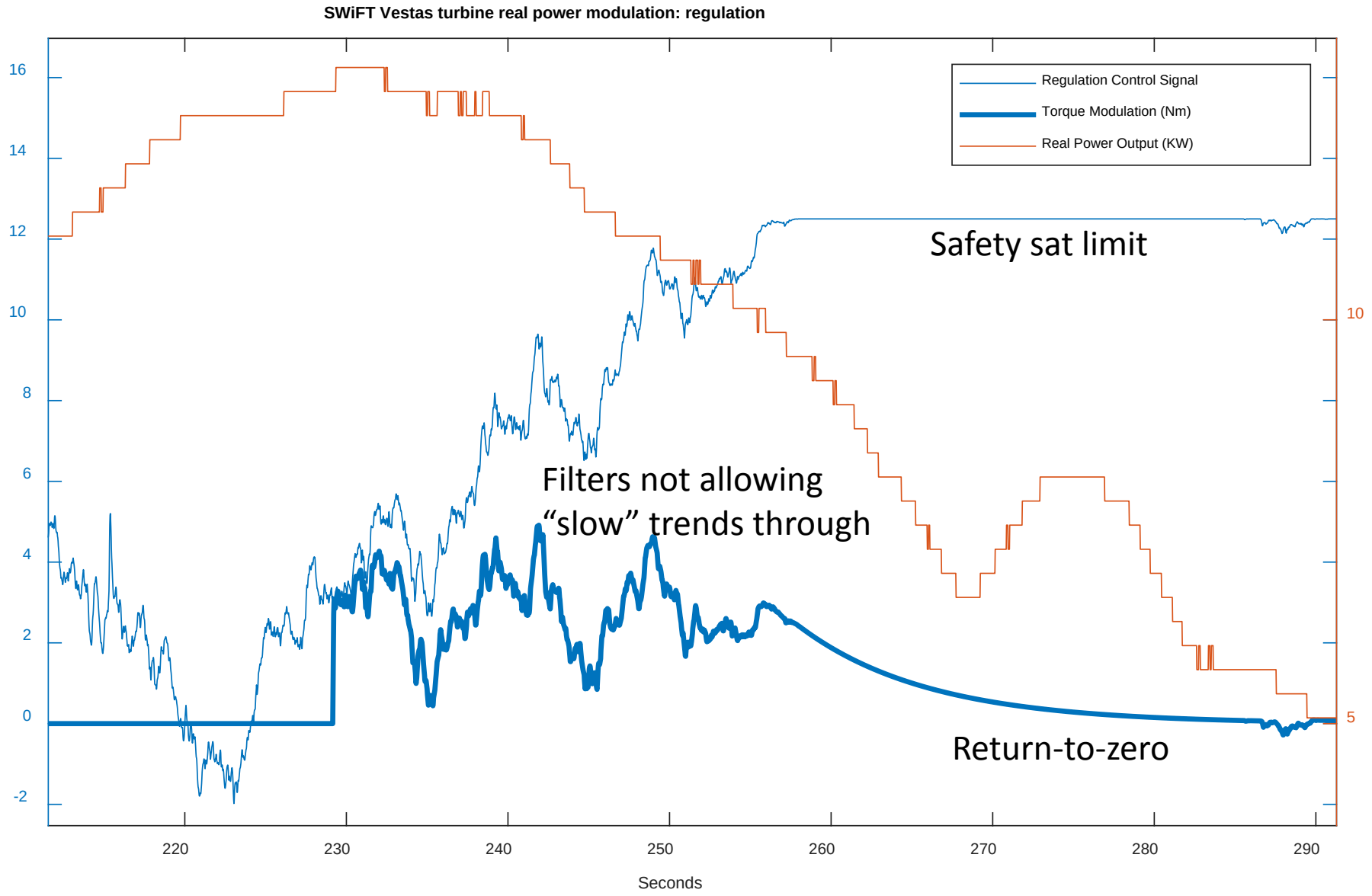
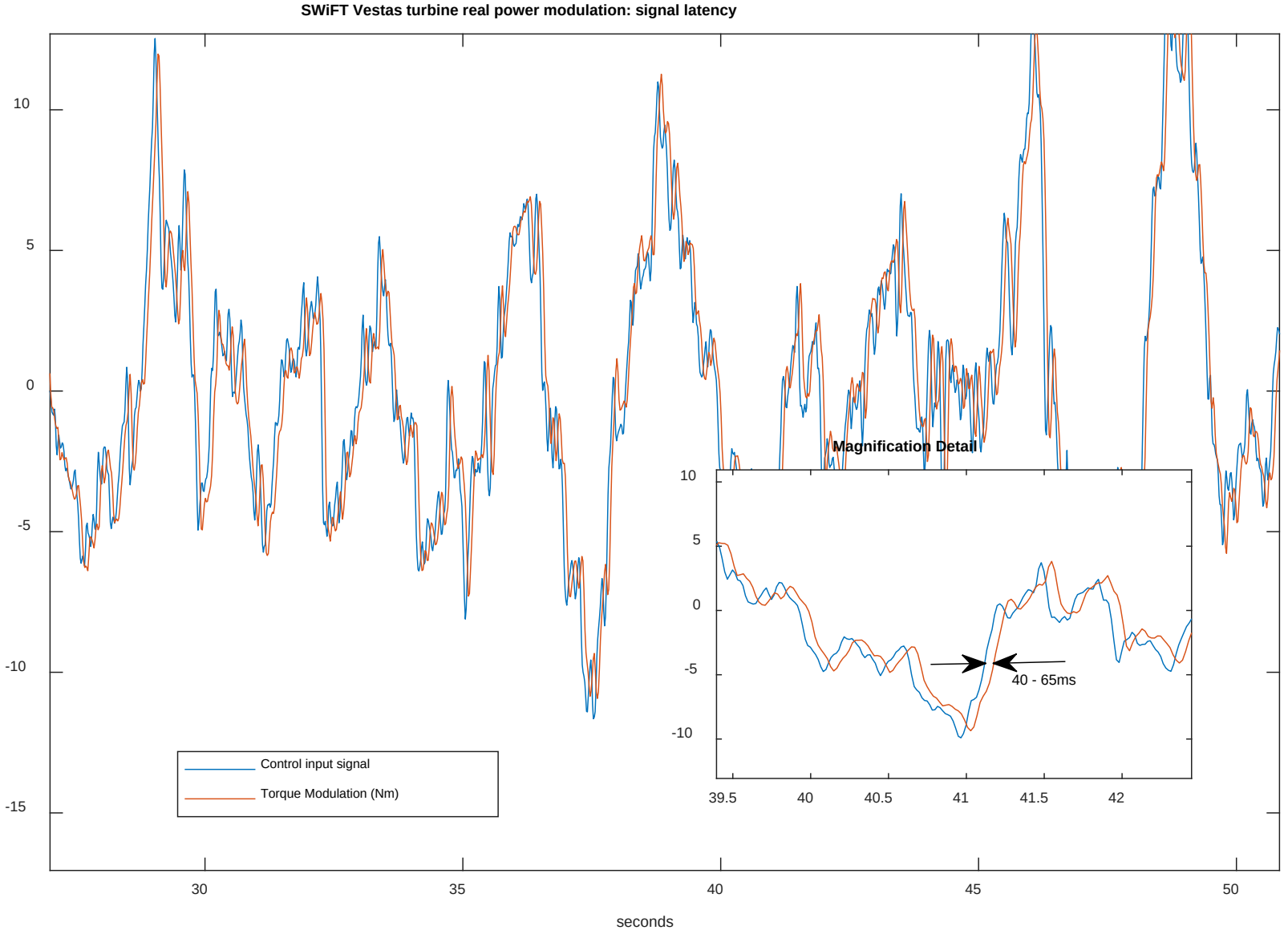


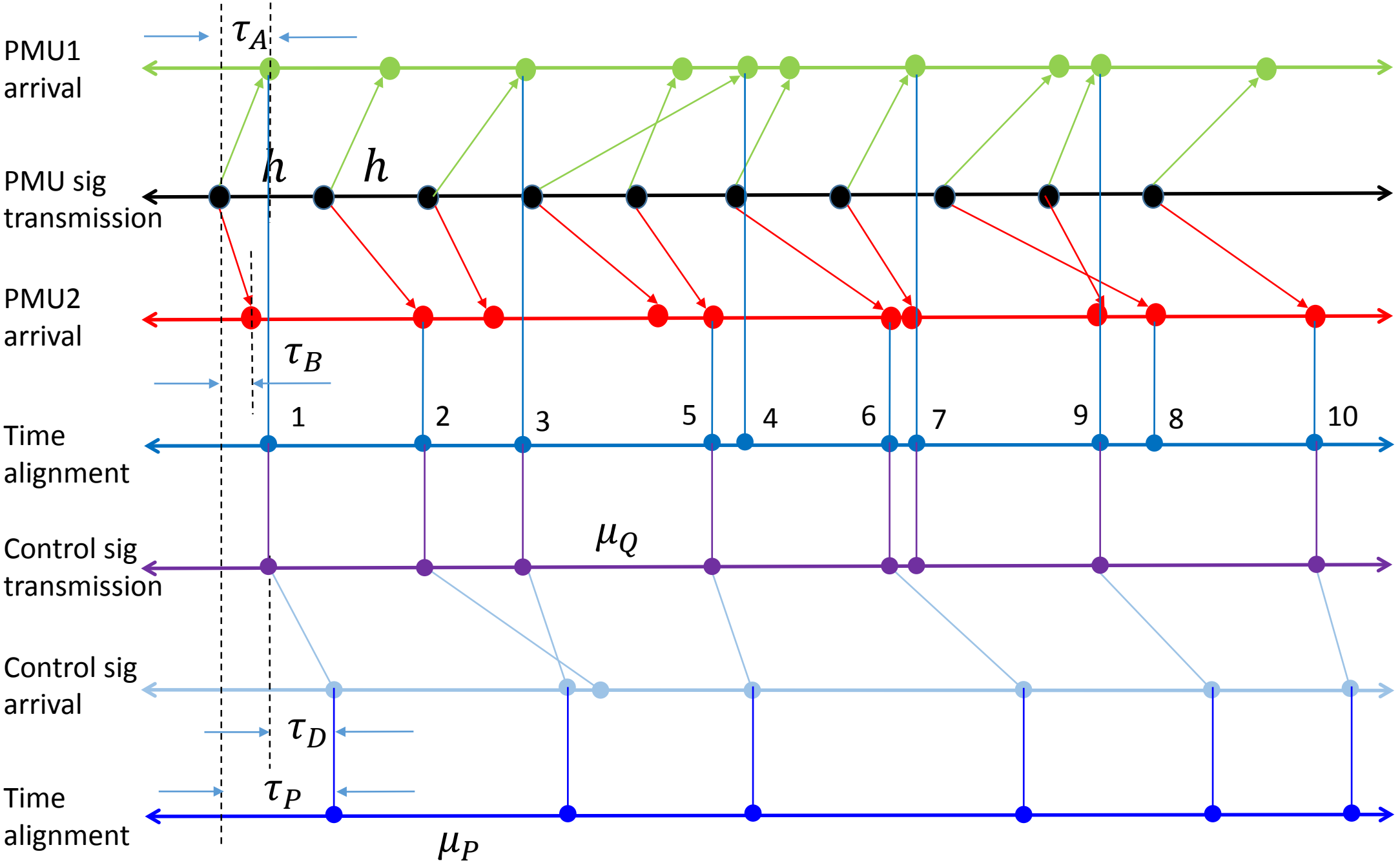
Wide area frequency content

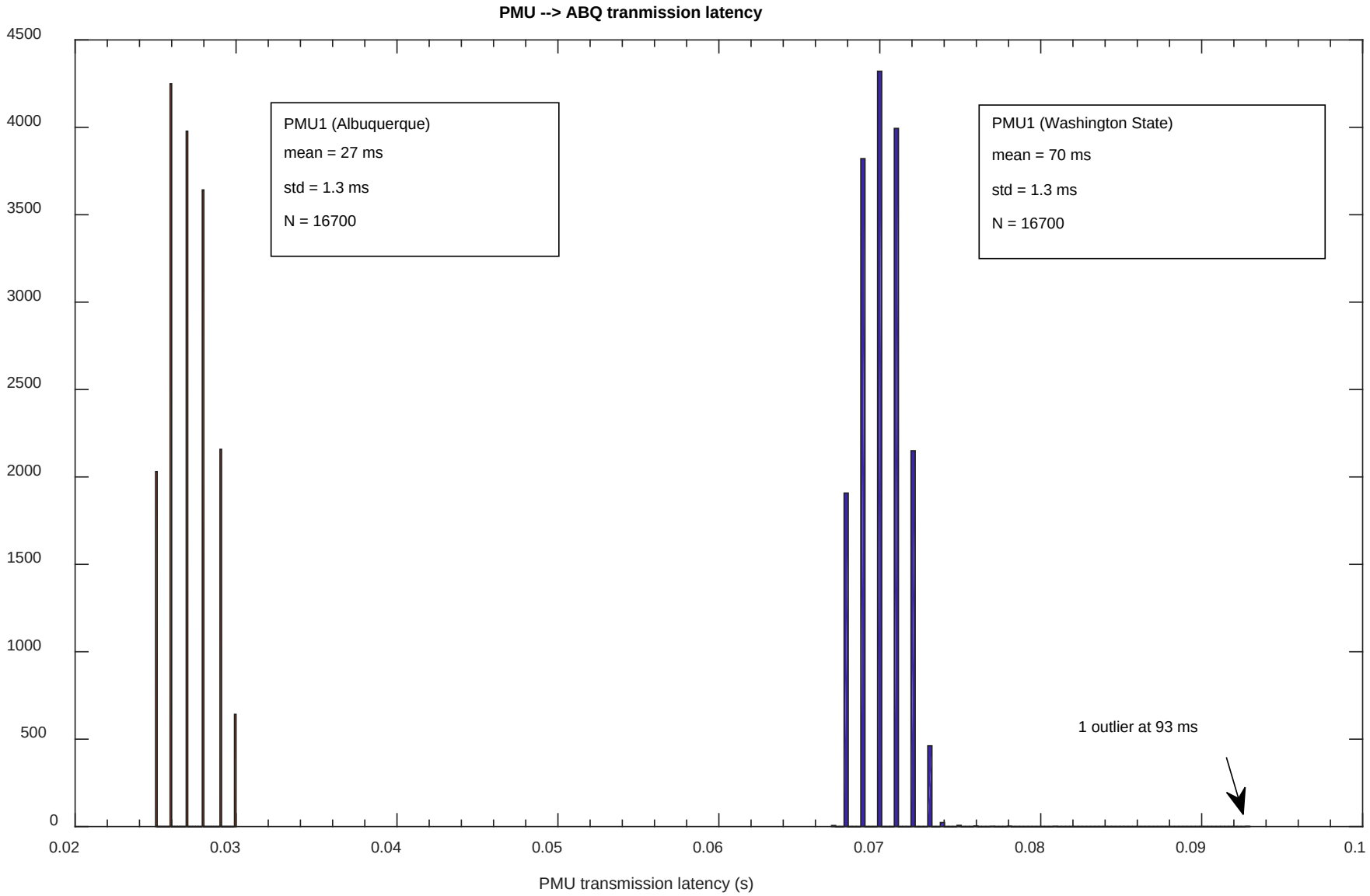


Frequency regulation mode



Signal Latency


PMU1 arrival
PMU sig transmission
PMU2 arrival
Time alignment
Control sig transmission
Control sig arrival
Time alignment
τ_A
τ_B
τ_D
τ_P
h
h
μ_Q
μ_P
1
2
3
5
4
6
7
9
8
10



PMU transmission delay

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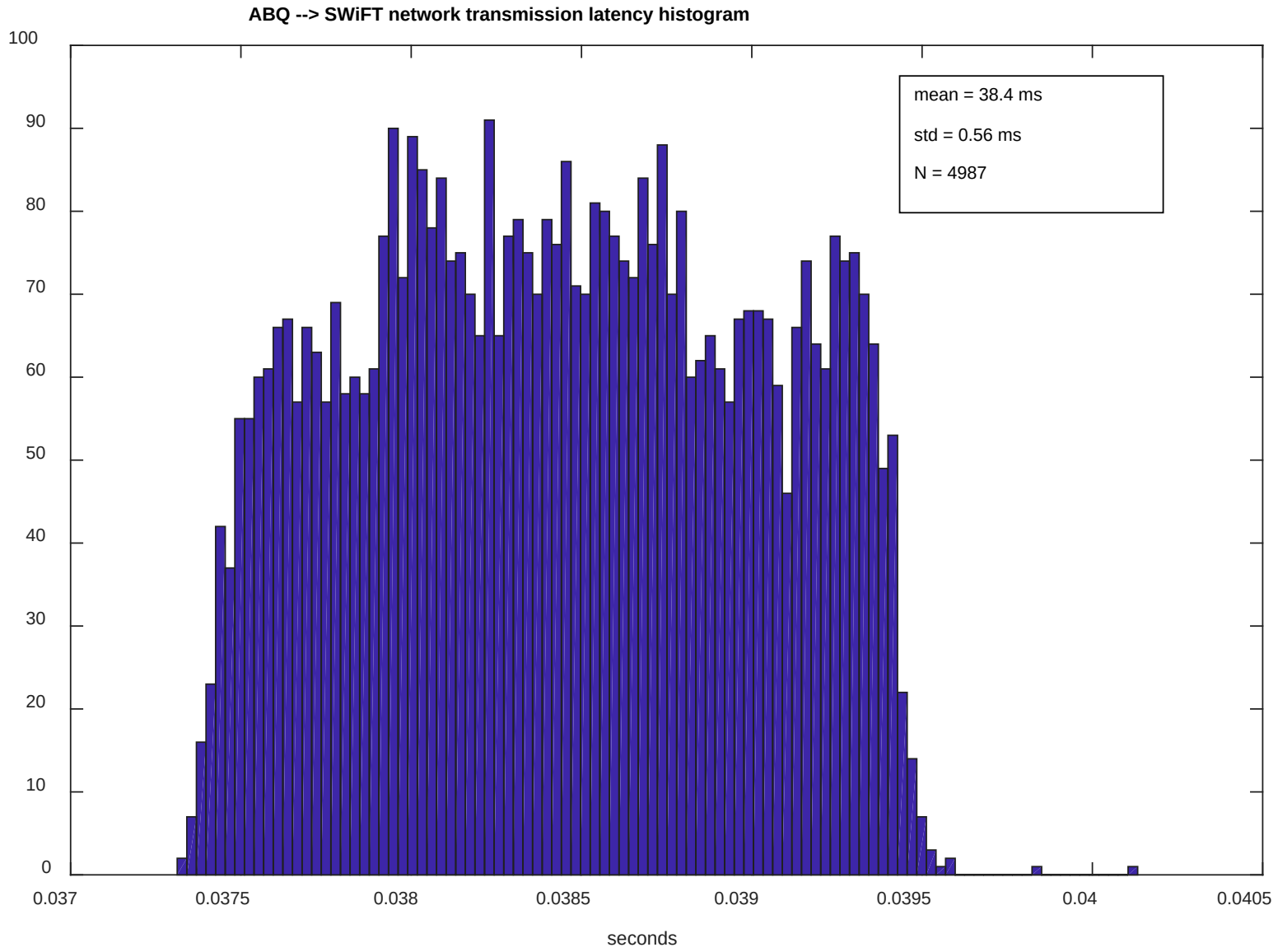

Control signal transmission delay

Q: How'd you get transmissions in/out of Sandia so quickly?
A: X-net

A word on comm security

- Message Authentication Coding (MAC) using SHA-256 w/ pre-share key

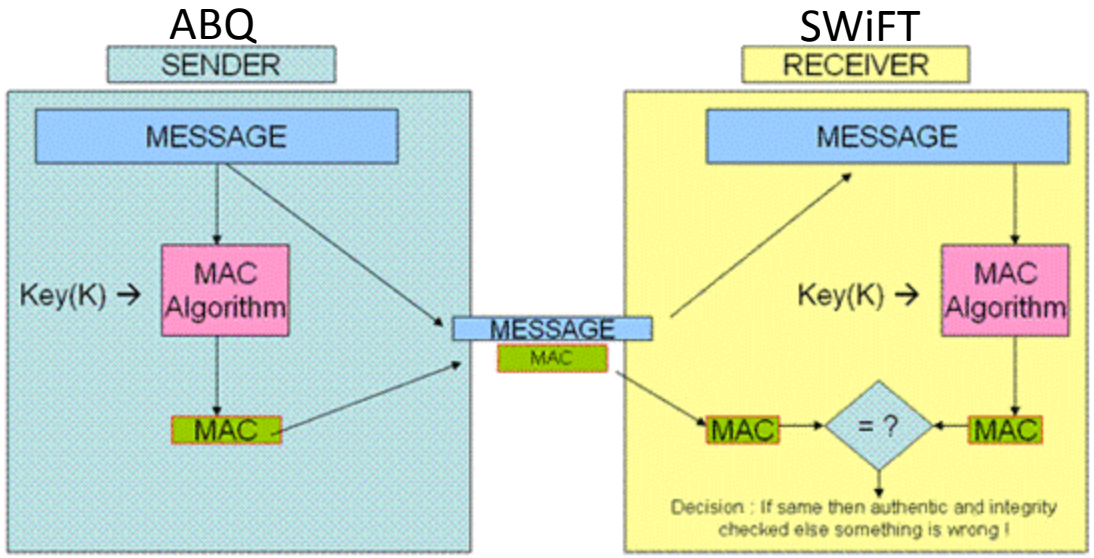

Illustration of Message Authentication Code Process (www.sqa.org.uk)

Conclusions, future work

- It is possible to modulate the real power output of a wind turbine with zero "spill" using real-time PMU feedback.
  - Wind operators can provide grid services ("Wind helps grid!")
  - Within appropriate frequency band
- Challenges remain:
  - Need better measurement of power output (PMU at tower)
  - Analysis of overall phase margin complicated (filters, delays, sampling, quantization...)
  - Freq regulation mode needs more thinking
  - Explore larger (much larger?) modulation limits
  - Can it be scaled up?
  - Ongoing question of cybersecurity for PMU comm

Acknowledgements

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