Adaptive Wide-Area Damping Controller Using Transfer Function Model Derived from Measurements: Case Studies on Realistic Power Grid Models

Presented by Lin Zhu

NASPI WG Meeting
San Diego, CA
April 15-17, 2019

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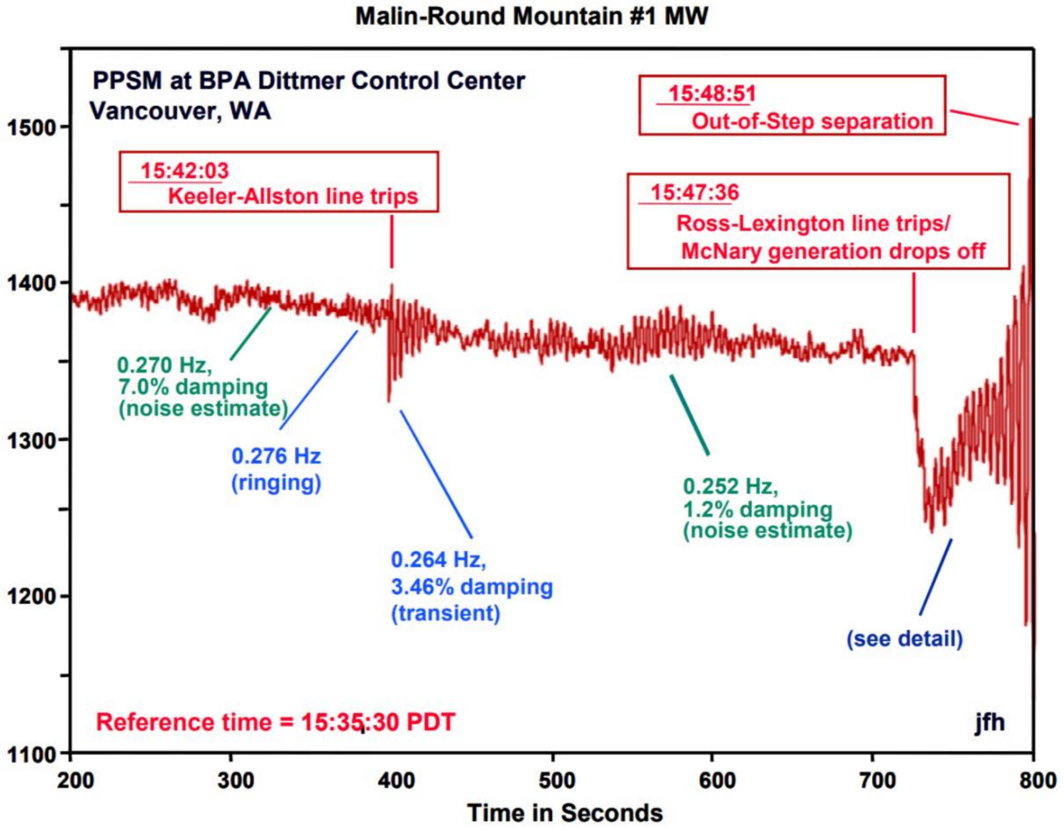
Outline

- Motivation
- WADC Design Using Measurement-Driven Approach
- Case Studies on Realistic Grid Models
  - New York State Grid Model
  - Terna (TSO in Italy) Grid Model
  - SEC (Saudi) Grid Model
- Summary

Motivation

- Decreasing and inadequate damping during cascading events.
- Adaptive wide-area damping control is desirable.



North-South Mode on August 10, 1996

Time/Event	Frequency	Damping
10:52:19 (brake insertion)	0.285Hz	8.4%
14:52:37 (John Day-Marion)	0.264Hz	3.7%
15:42:03 (Keeler-Allston)	0.264Hz	3.5%
15:47:40 (oscillation startup)	0.238 Hz	-3.1%
15:48:50 (oscillation finish)	0.216 Hz	-6.3%

Table and Figure Source:

1. J. F. Hauer and J. W. Burns, "Roadmap to monitor data collected during the WSCC breakup of August 10, 1996," in PNNL-19459, Pacific Northwest National Laboratory, Richland, WA, USA.

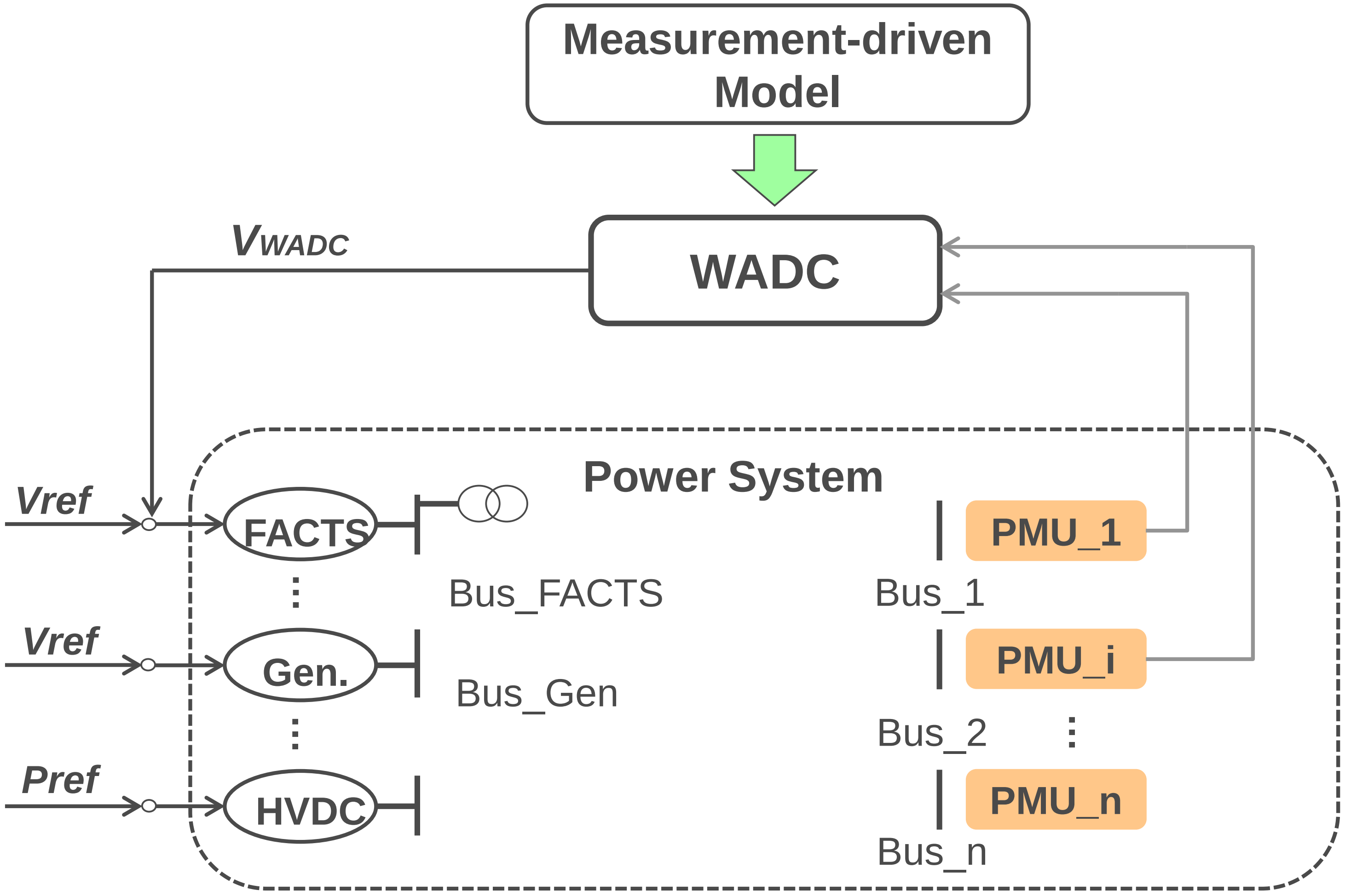
Planning Model Based v.s. Meas.-Driven Approach

- Measurement-driven approach
  - Build a simple, low order transfer function model to depict system oscillatory behavior for damping controller design

	System Planning Model	Measurement-driven Model
Model size	Large (~70,000 bus for EI) High order	Simple Low order
Model accuracy	Low (if not well validated)	High (for damping controller design)
Model update rate	Every year (typically)	Every 5 minutes
Track operating condition variation	Not easy	Easy
Adaptive damping control	Not easy	Easy

Adaptive Wide-Area Damping Controller Design

- Build measurement-driven model to capture current operating condition
- Adaptively adjust WADC parameters for the current operating condition



Adaptive Wide-area Damping Controller

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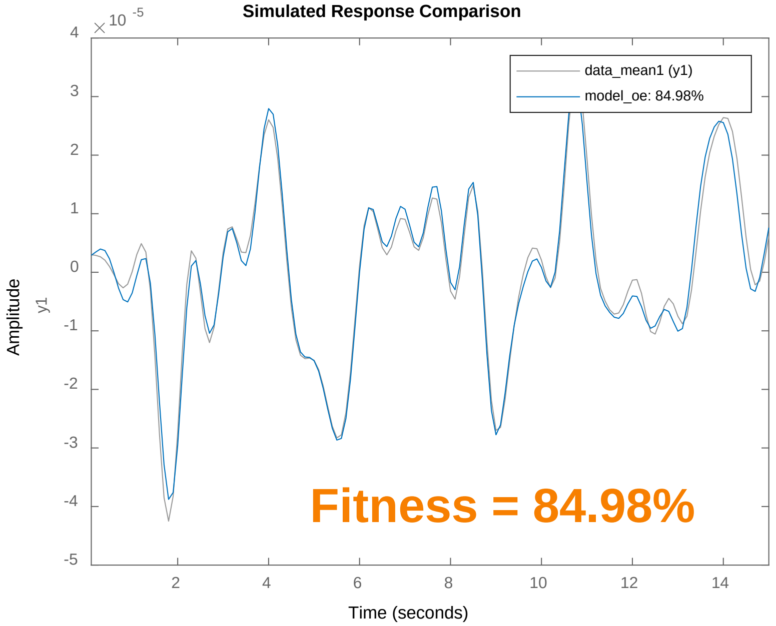
Measurement-driven Model Identification and Validation

- Model Identification: Using ring-down or probing measurements.
- Model validation: Check fitness index; Compare damping ratios, oscillation frequencies, residue magnitude, and residue angle.

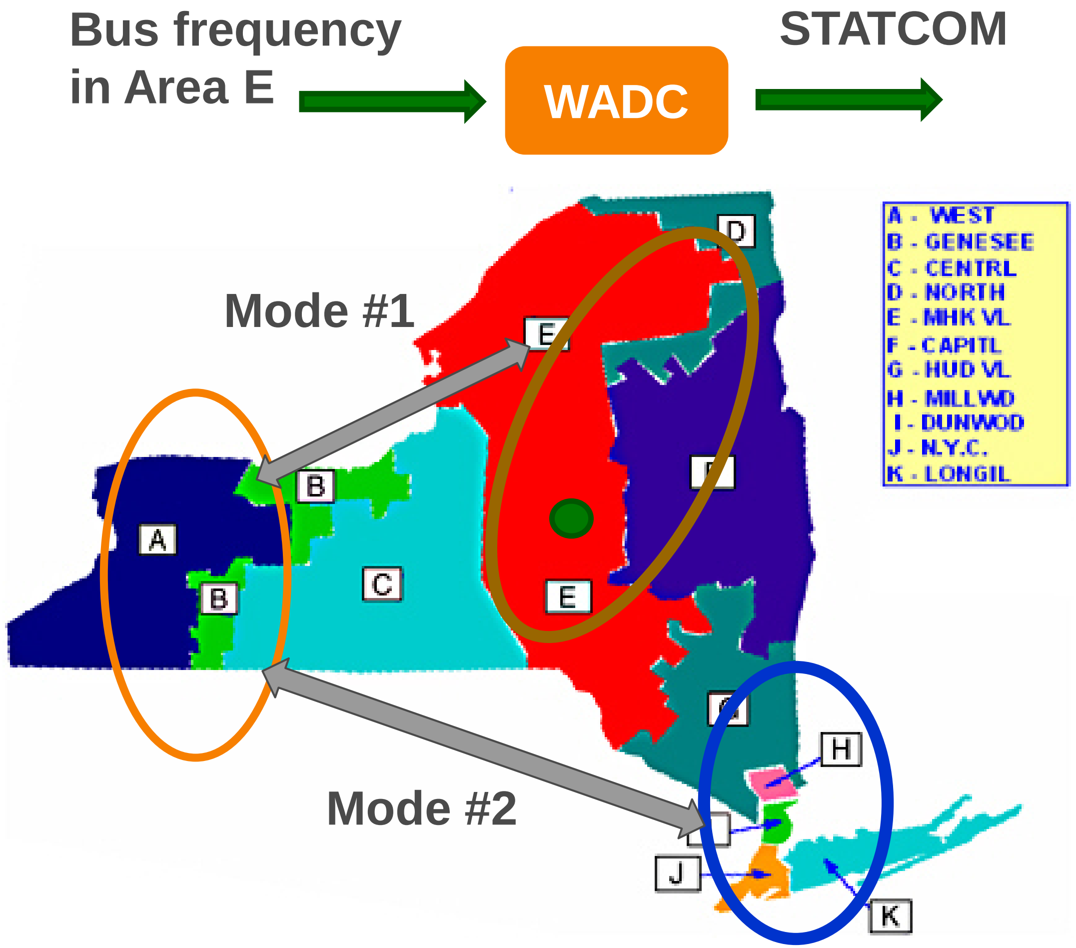


Model Identification Results

Order	Fitness Index(%)	Oscillation frequency(Hz)	Damping ratio(%)	Residue Mag.	Residue angle (deg.)
4	77.33	0.2652	16.09	0.0009	117.87
5	84.98	0.2781	19.62	0.0013	139.15
6	76.25	0.2566	23.70	0.0014	101.95
7	85.36	0.2765	17.52	0.0011	136.63
8	75.76	0.2956	8.88	0.0007	159.70
9	85.31	0.2801	18.84	0.0013	142.52

NYPA Case Study (1/3)

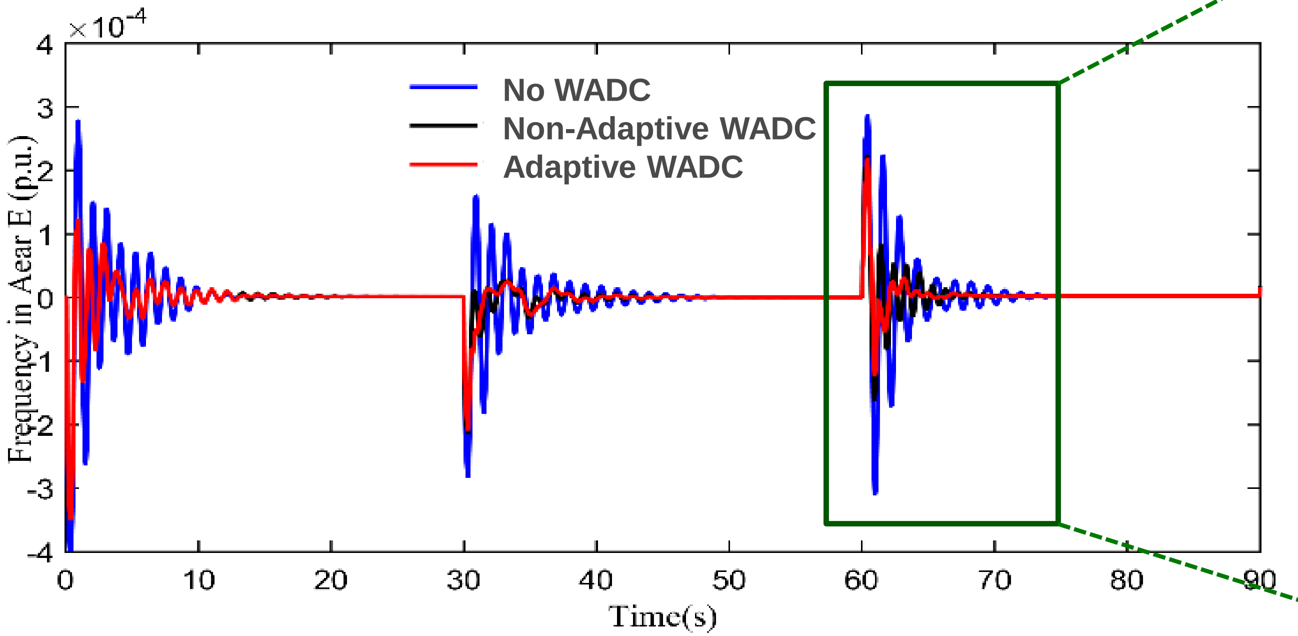
- 2019 NYISO planning models (Spring, Summer and Winter)
- Modal analysis: Identified coherent groups and dominant modes
- Feedback signal/Actuator: Bus frequency/STATCOM in Area E.
- Demonstrating adaptive performance of WADC
  - ❑ Cascading events
  - ❑ Seasonal operating condition variations

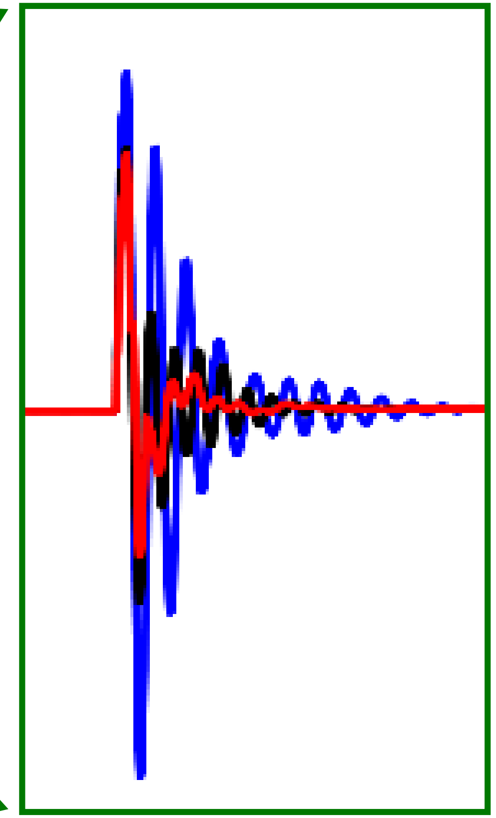


Area map of New York State grid (Source: NYISO)

NYPA Case Study (2/3)

- Cascading events
  - Create operating conditions via multi-line trip disturbances.
  - Using ring-down data to build the model





Control effect: Adaptive v.s. Non-adaptive

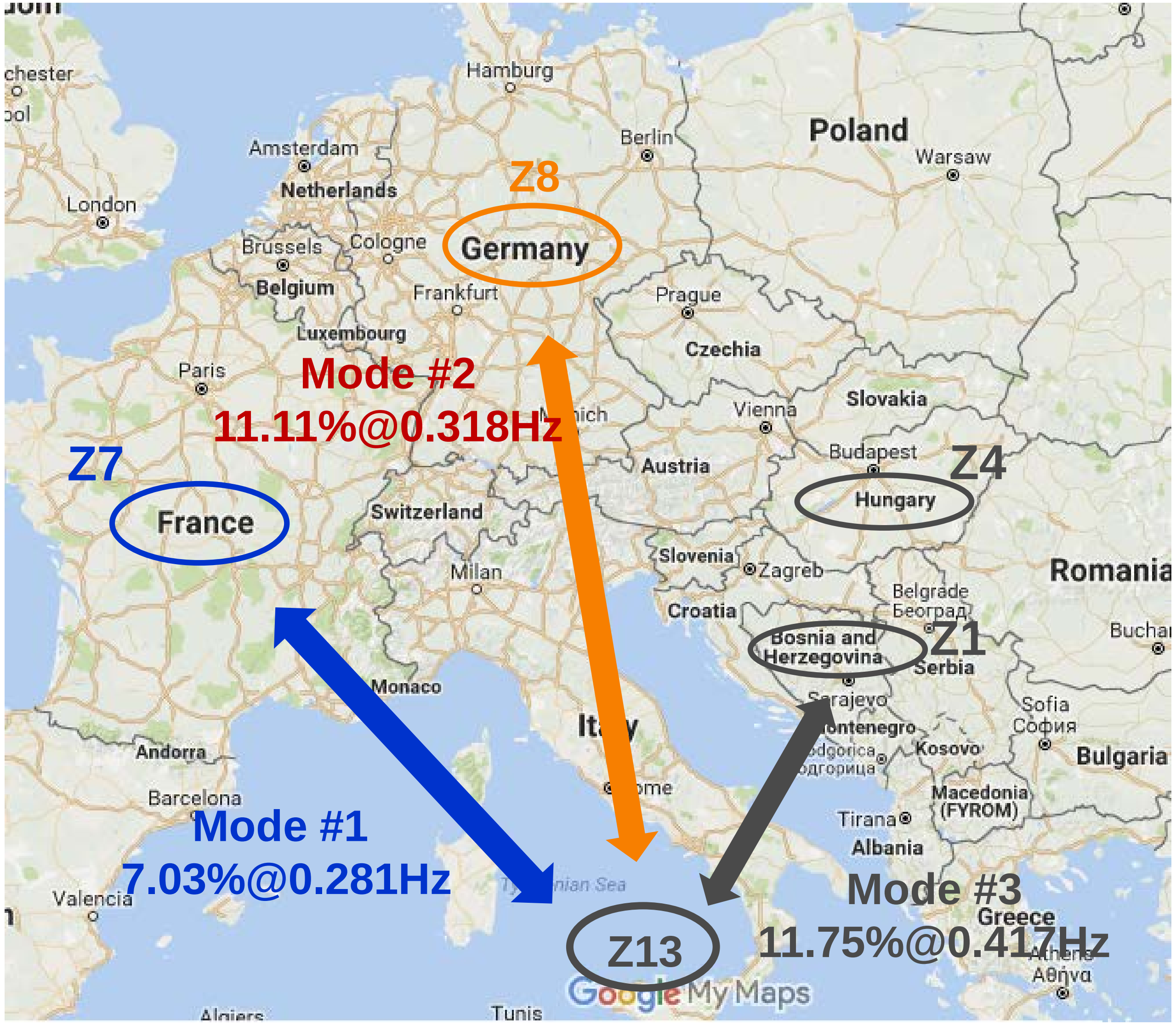
NYPA Case Study (3/3)

- Seasonal operating condition variations
  - Adaptive WADC: WADC tuned based on each case separately
  - Non-adaptive WADC: WADC tuned based on winter case

Case	WADC	Damping Ratio Improvement of Mode #1	Damping Ratio Improvement of Mode #2
Winter	Non-Adaptive	+7.85%	+4.47%
	Adaptive	+7.85%	+4.47%
Summer	Non-adaptive	+5.38%	+6.82%
	Adaptive	+7.00%	+7.23%
Spring	Non-adaptive	+5.65 %	+1.63%
	Adaptive	+7.33%	+6.25%

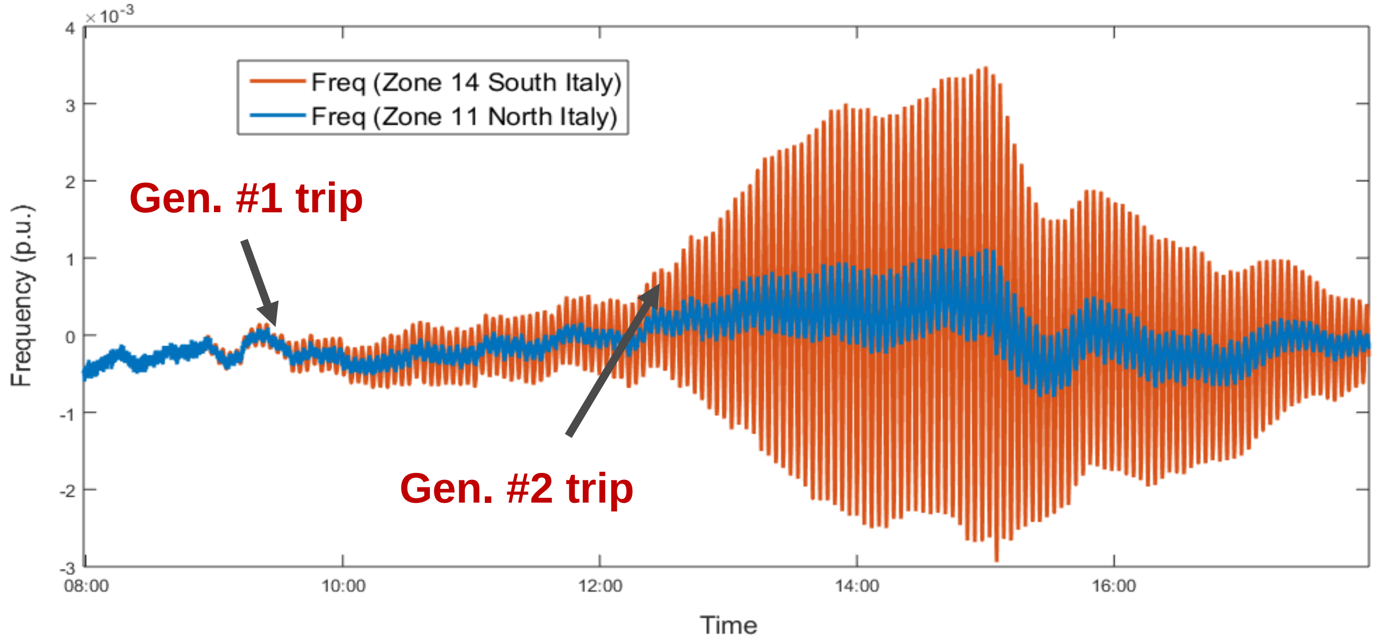
Terna Case Study (1/3)

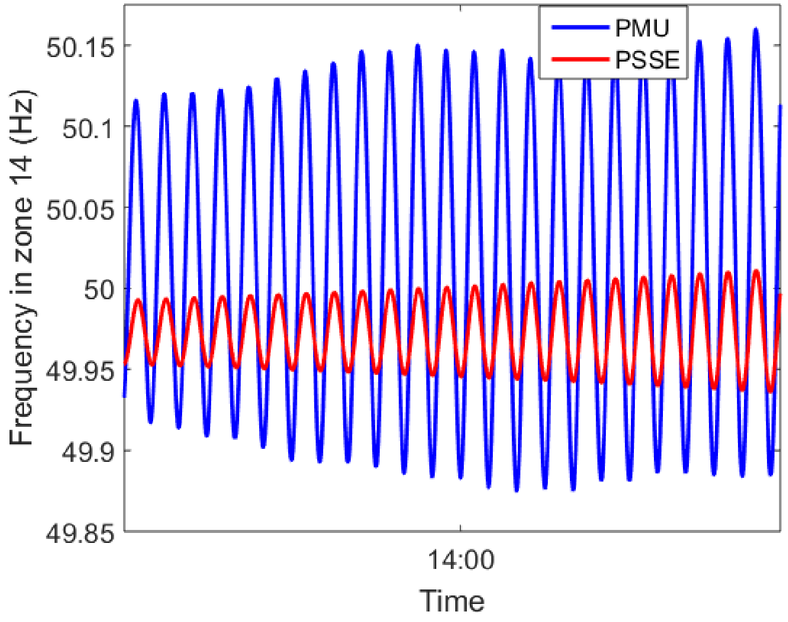
- Model provided by Terna
- Modal analysis: Italy-France mode in Terna model
- Observation signal selection:
  - ❑ PMU1 South Italy
  - ❑ PMU2 North Italy (France area is optimal)
- Actuators: Two synchronous condensers in South Italy



Terna Case Study (2/3)

- Realistic oscillation event in Dec. 2017
  - PMU measurements provided by Terna
  - Two consecutive generator trip events
  - Growing oscillation: ~0.292Hz



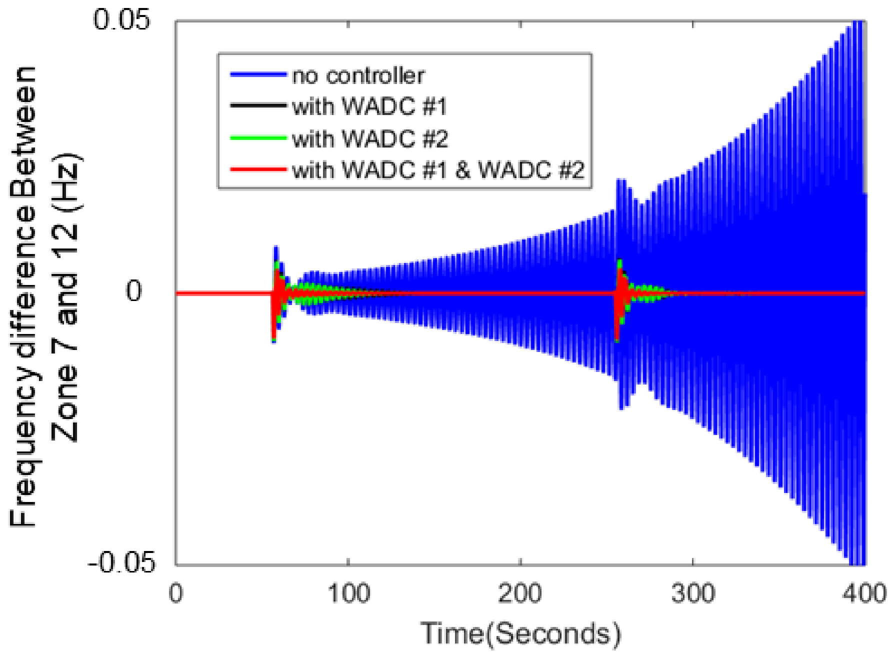


PMU:
Frequency: 0.293Hz
Damping ratio: -1.062%

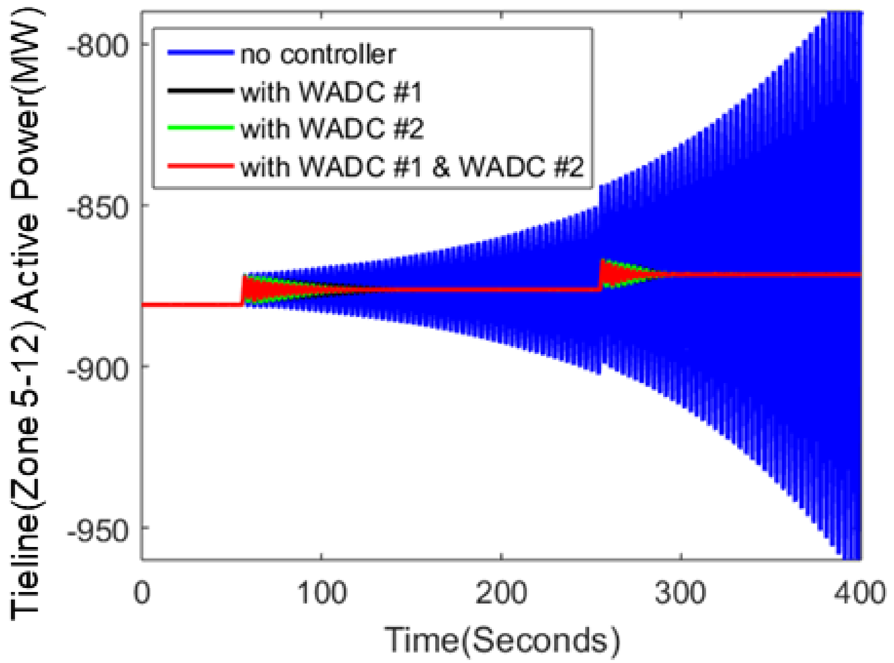
PSS/E:
Frequency: 0.293Hz
Damping ratio: -0.410%

Terna Case Study (3/3)

- Two WADCs are designed using ring-down measurements
- The growing oscillations can be damped by WADCs



Bus Frequency Difference between South and North Italy



Tie-line active Power

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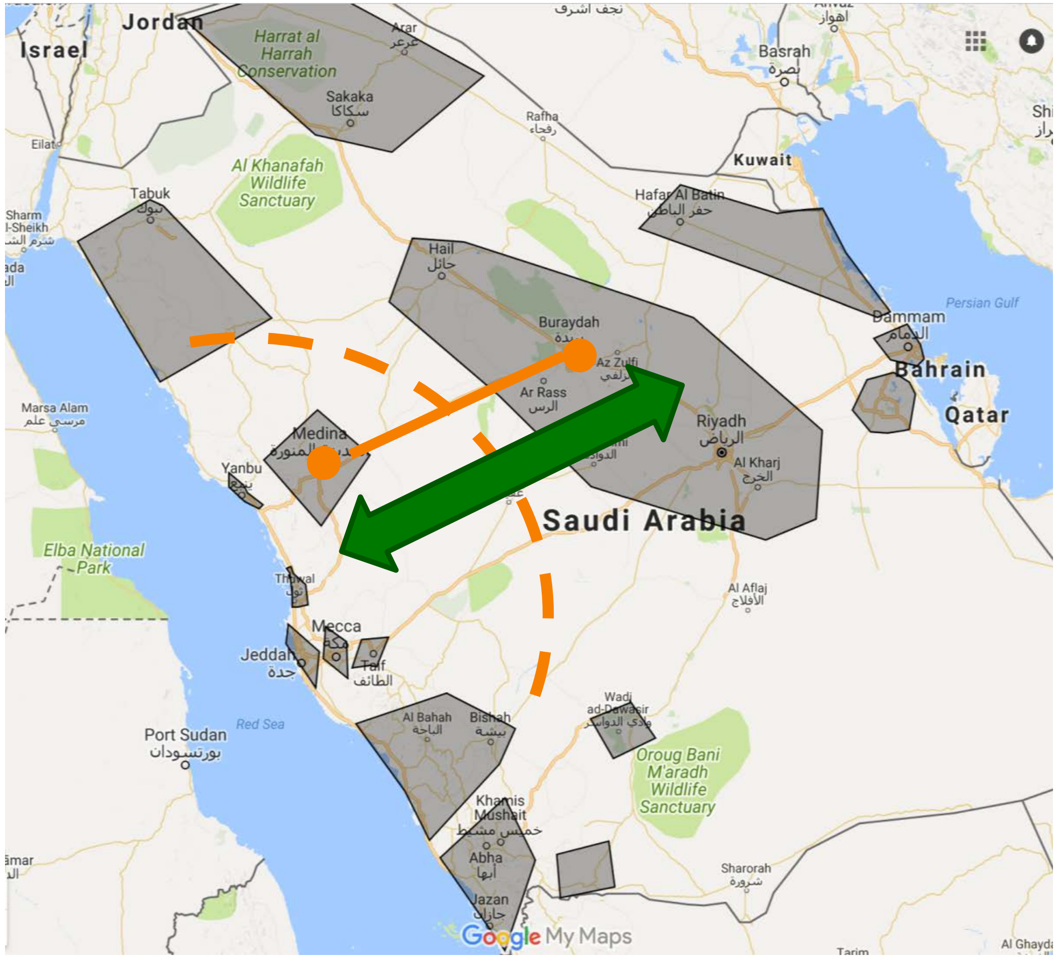
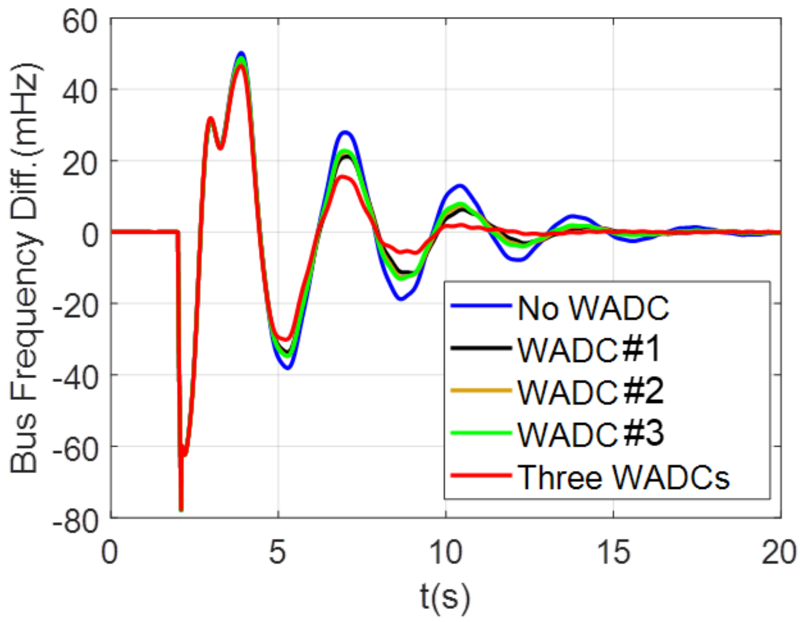
SEC Case Study (1/2)



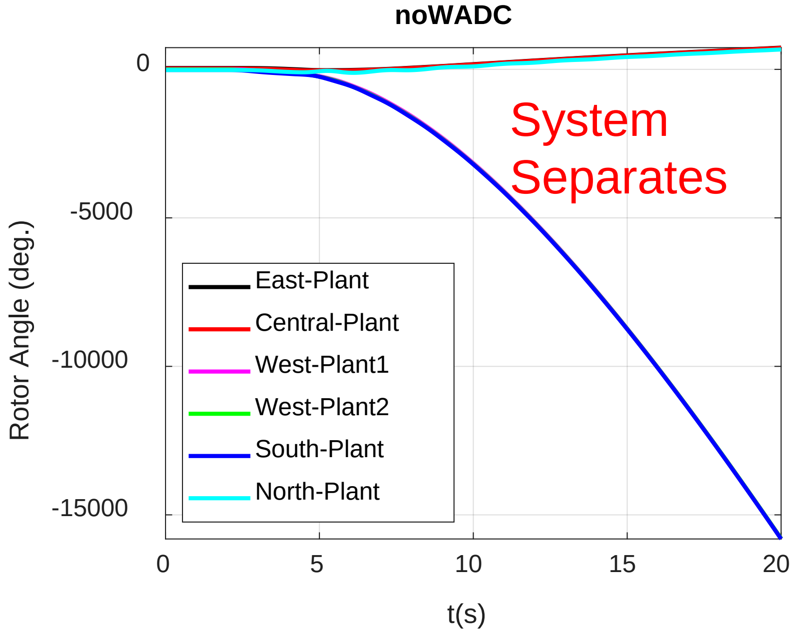
- Target mode: est/south v.s. central/east
- Observation signal:
  - ❑ Bus frequency between west and central
- Actuators:
  - ❑ SVCs
  - ❑ Generator governors in west/south
  - ❑ Generator exciters in west/south
- Improve damping ratio and transient stability simultaneously
  - ❑ Three incidents since 2015 that resulted in tripping tie-line between west and central – system separation

SEC Case Study (2/2)

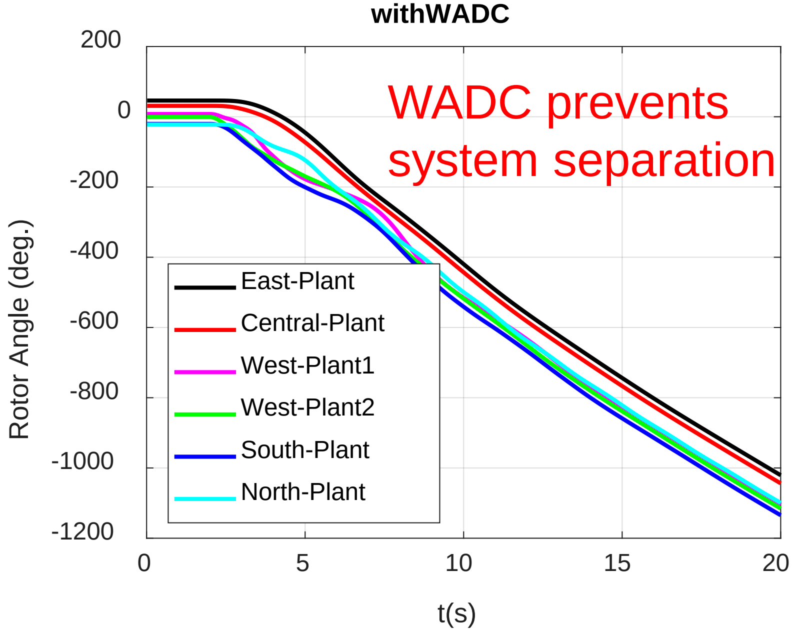
- Improve damping ratio and transient stability simultaneously
  - ❑ Temporary fault on tieline between West and Central
  - ❑ Large generation trip in west: ~2 GW



Damping Control Effect (Actuators: Exciters)



Rotor Angle (No WADC)



Rotor Angle (with WADCs)

Summary

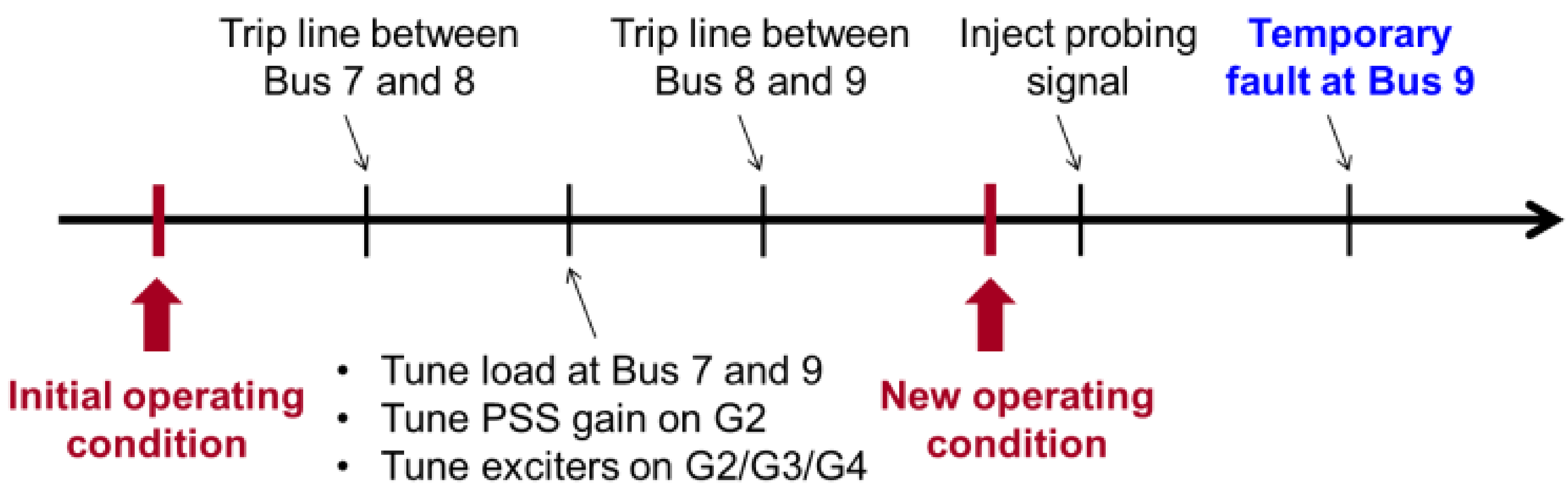
- A measurement-driven approach to design WADC, does not rely on full system dynamic model.
  - Model Identification using ring-down or probing measurements.
  - Model validation in time-domain and frequency domain
- Adaptive WADC to accommodate variations in operating conditions, providing better control effect.
- Validated in three realistic large power grid models: NYPA, Terna and SEC.
- Next steps
  - RTDS/OPAL-RT hardware-in-the-loop test

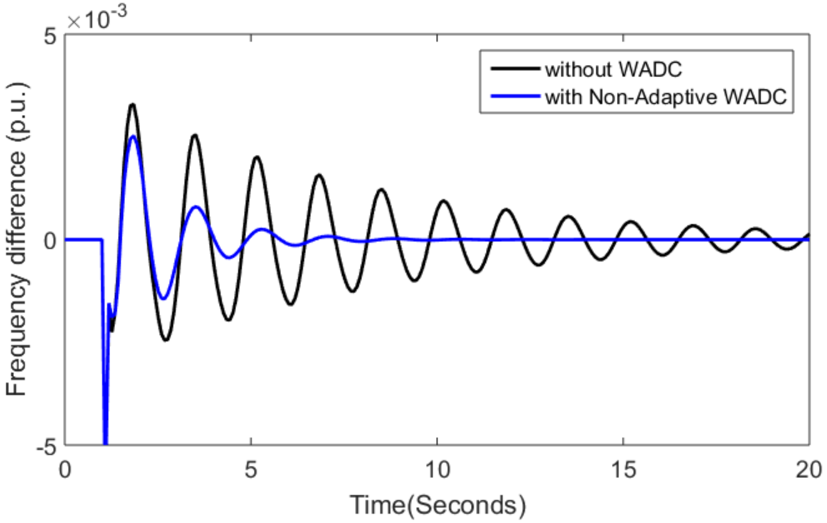
Acknowledgements

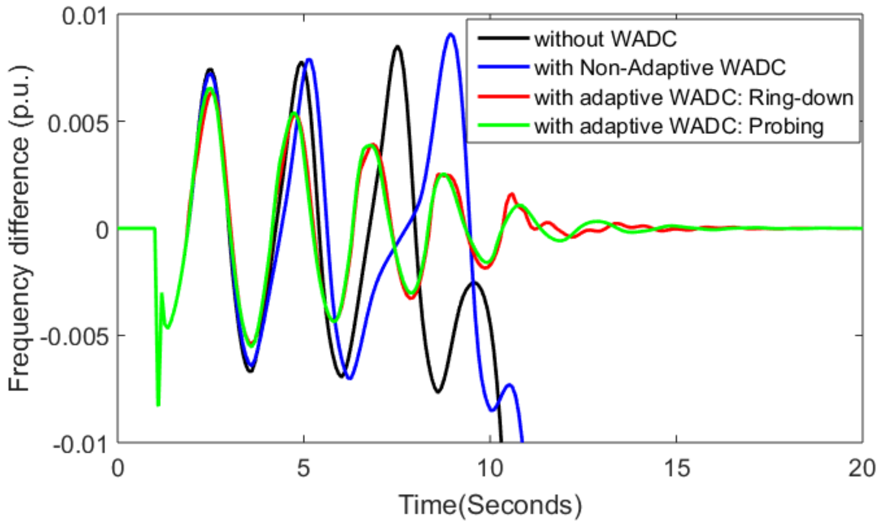
- This work was supported primarily by Electric Power Research Institute(EPRI), New York Power Authority (NYPA), Terna (Italian TSO) and Saudi Electricity Company (SEC).

- This work made use of Engineering Research Center Shared Facilities supported by the Engineering Research Center Program of the National Science Foundation and DOE under NSF Award Number EEC-1041877 and the CURENT Industry Partnership Program.

Backup: Case Study on Two-area Four-machine System

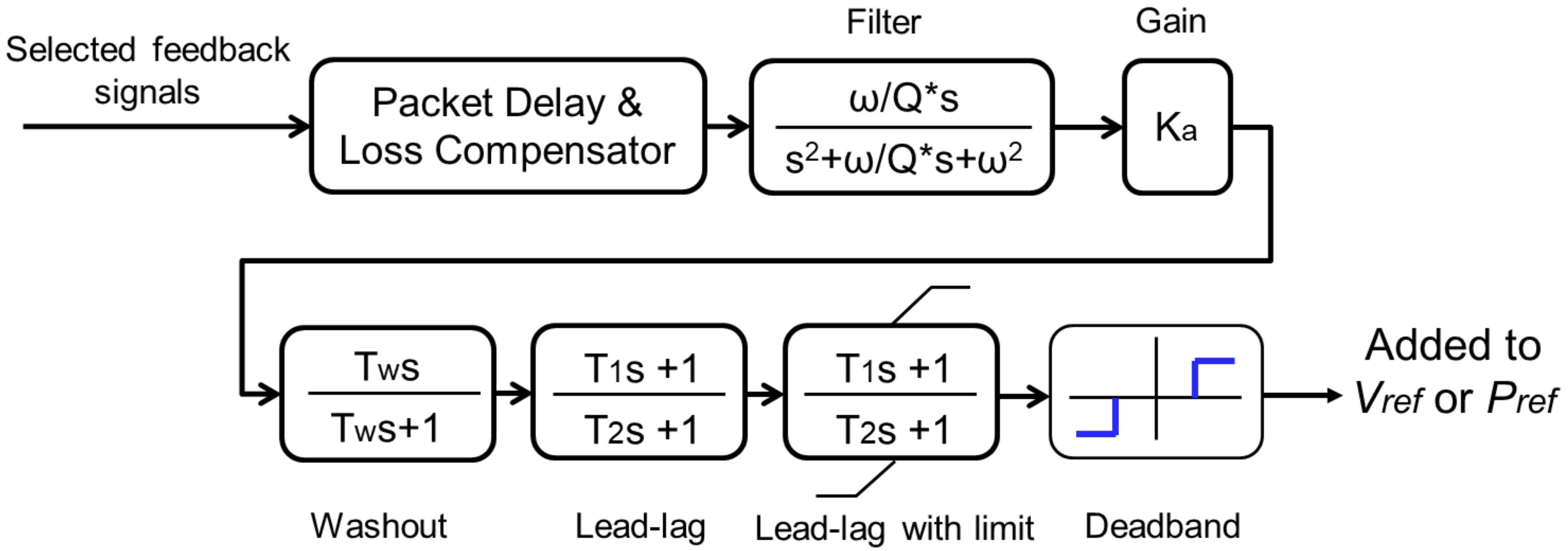






Backup: Adaptive Wide-Area Damping Controller Structure

- Lead-lag structure is employed
- Adjust T_1, T_2 , K_a and ω based on the identified model



WADC Based on Lead-lag Structure