Adaptive Wide-Area Damping Control Using Transfer Function Model Derived from Ring-down Measurements

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Outline

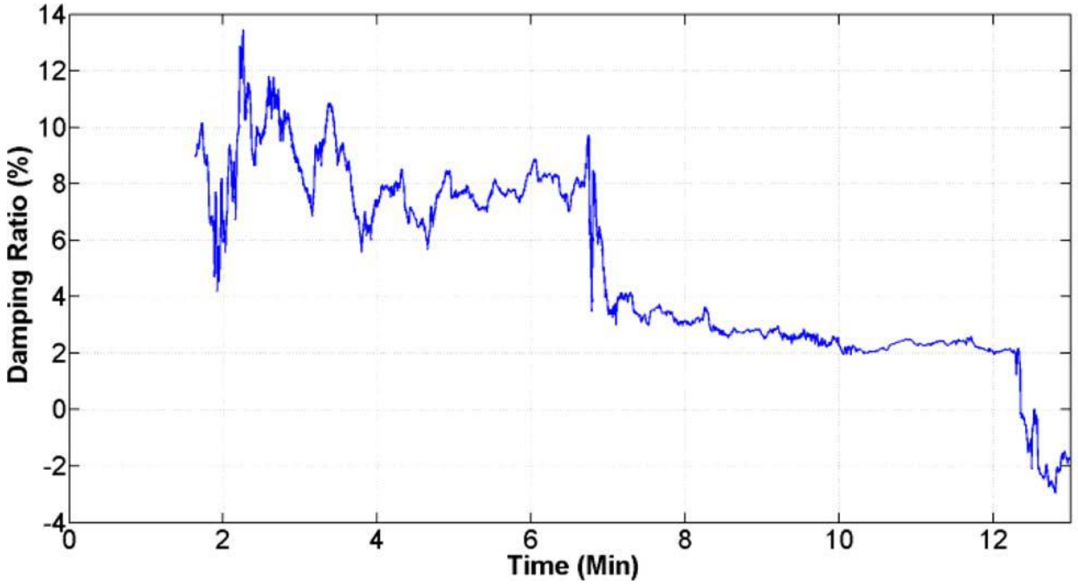
- Wide-area damping control (WADC) design approach
  - Full dynamic model v.s. Measurement-driven model
- WADC design using measurement-driven approach
- Case study on two area – four machine system
- Demo on UTK hardware testbed
- Summary

Damping Ratio Variations During Operation

- **Varying operating condition + damping controller with fixed parameters --> inadequate damping ratio in some cases**

North-South Mode on August 10, 1996 [1]

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

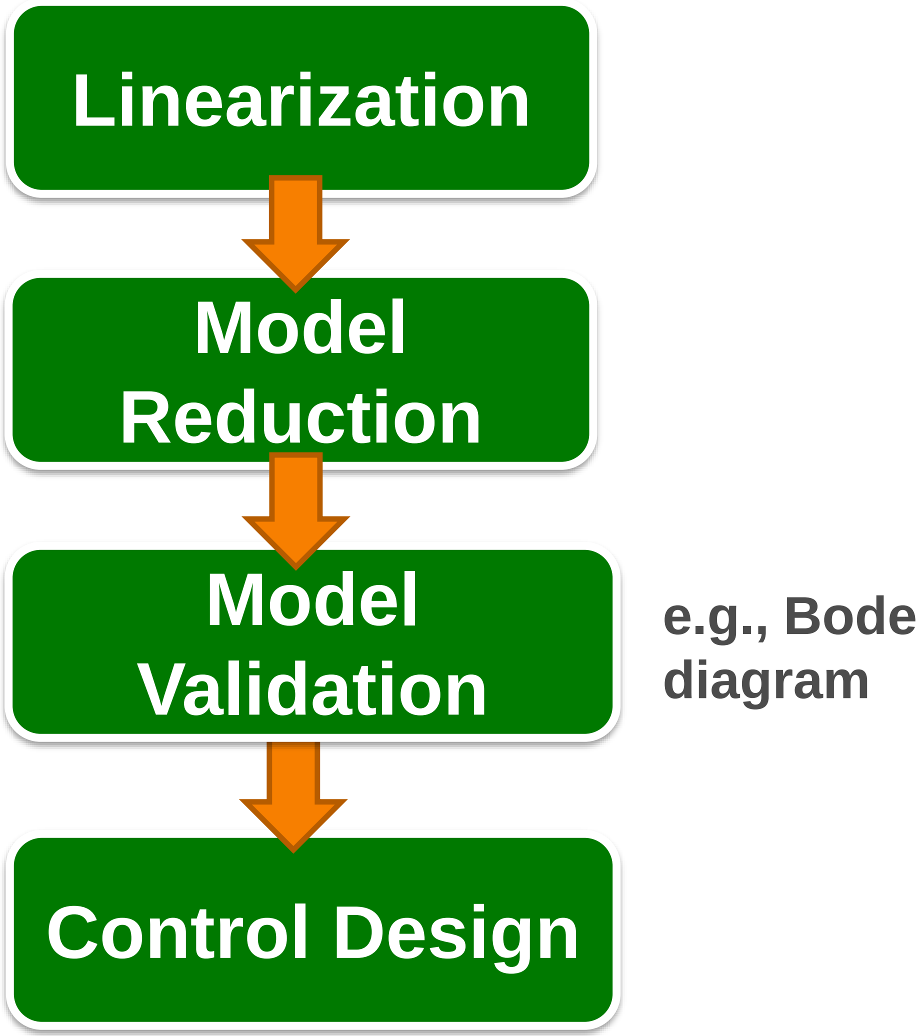


Damping ratio estimation [2]

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.
2. Source of figures: Sarmadi, S. Arash Nezam, and Vaithianathan Venkatasubramanian. "Electromechanical Mode Estimation Using Recursive Adaptive Stochastic Subspace Identification." IEEE Transactions on Power Systems 29.1 (2014) 349 - 358.

Full Dynamic Model v.s. Measurement-Driven Model

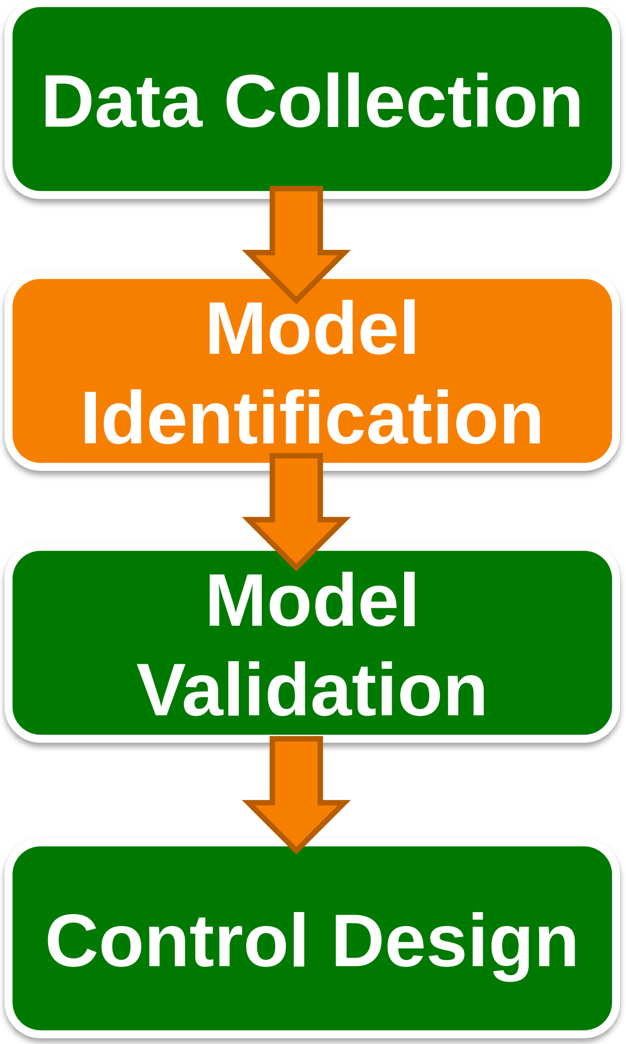
- Based on a linearization of the system circuit model around a operating point
- Designed WADC usually cannot perform as expected if operating condition changes
- Model itself may not be able to include sufficient details to be accurate, e.g., the large number of loads, etc.



Using full dynamic model

Full Dynamic Model v.s. Measurement-Driven Model

- Does not rely on circuit model
- More accurate
- Easy to reflect changes in system
- Could be made adaptive.



Using measurement-driven model

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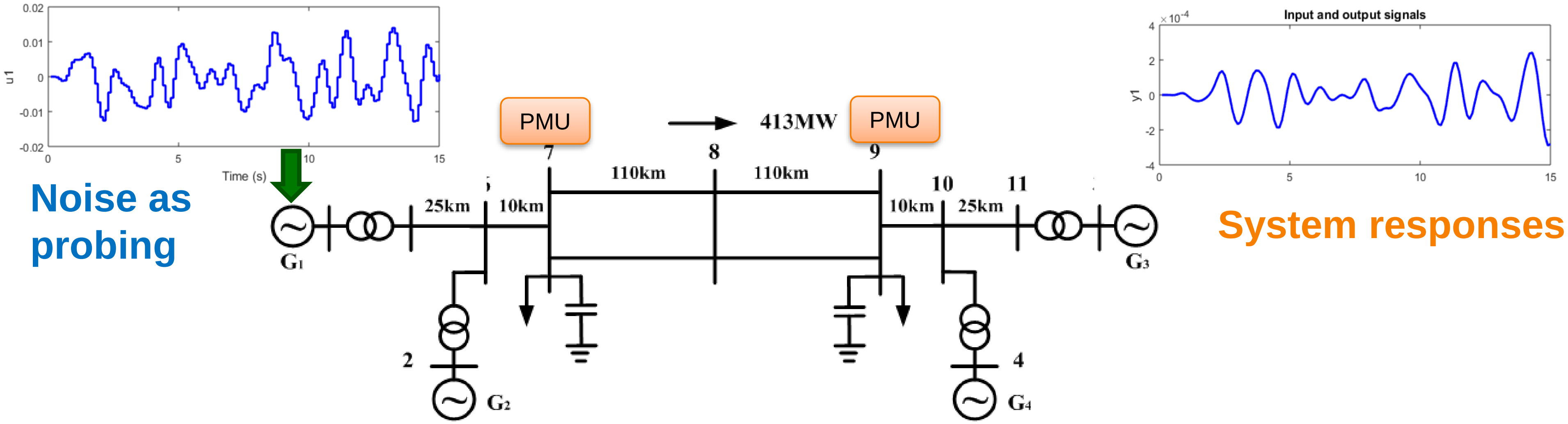
Measurement-driven Model Identification Using Probing Data

- Probing signal type: noise, step, or pulse, etc.
- Model type: State space model, auto-regressive exogenous(ARX), etc.



Noise

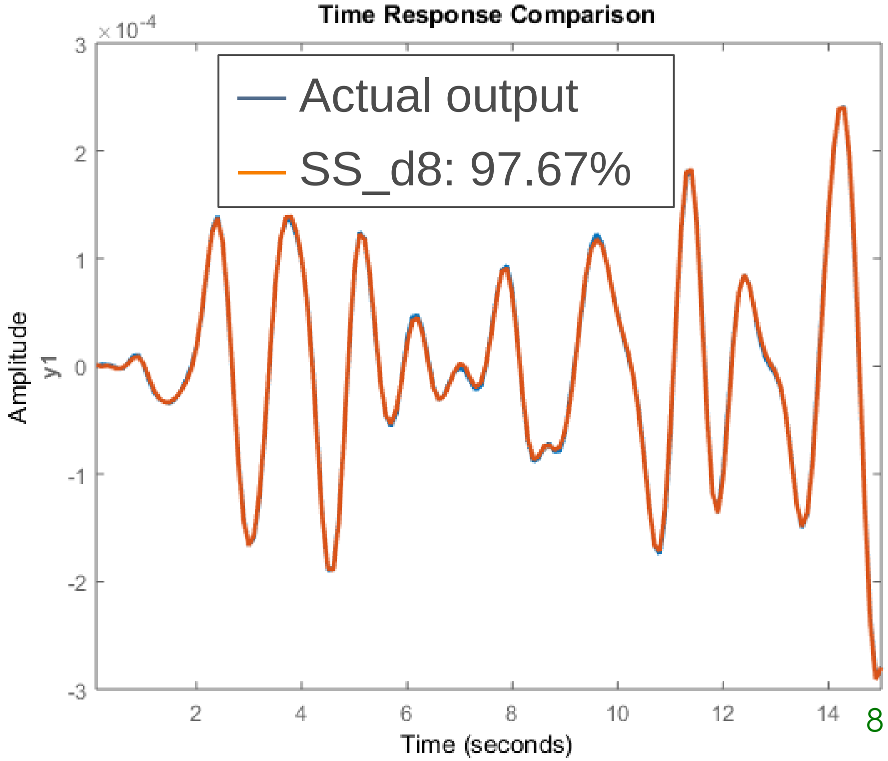
Measurement-driven model
e.g., State space model,
Transfer function model, etc.

⋮

System responses

Measurement-driven Model Validation

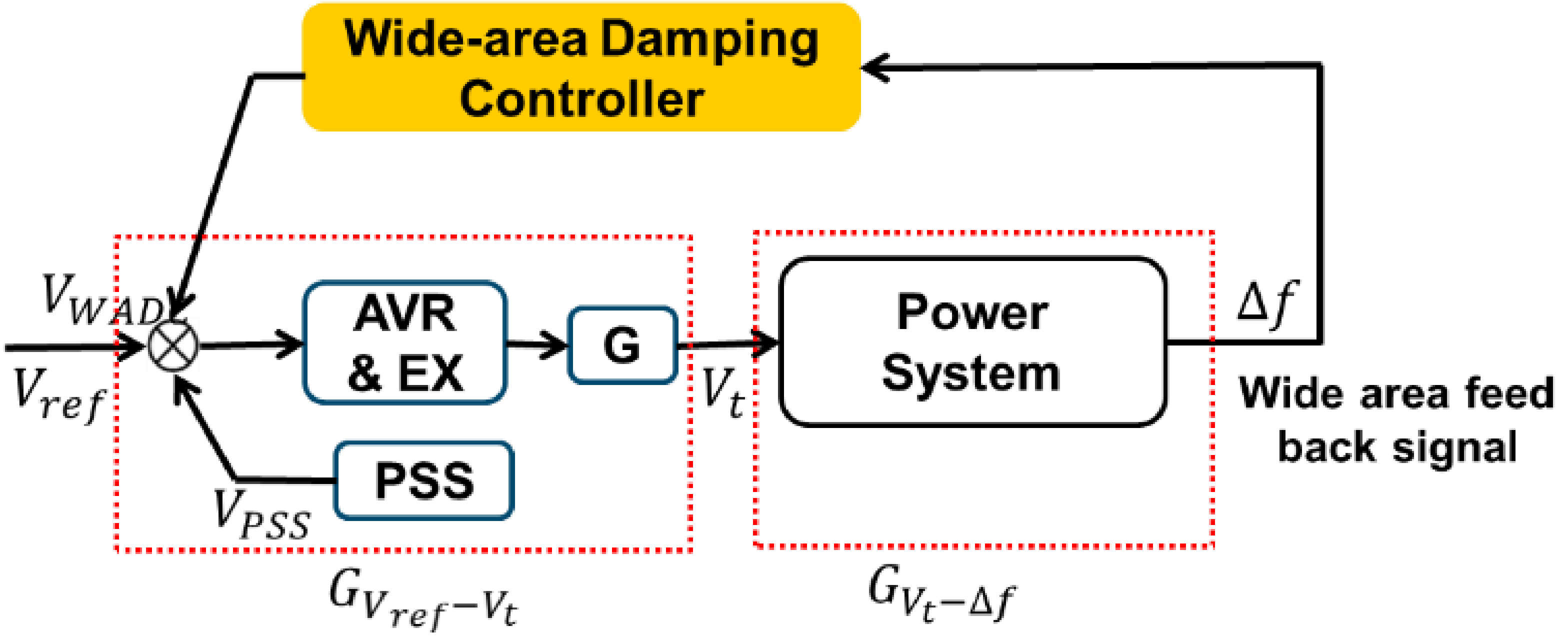
- Time-domain validation: compare real system output and identified model output (Curve fitness)
- Frequency domain validation: Compare eigenvalues (frequency and damping) of the identified model and Prony analysis results



State Space Order = 8		Prony analysis results	
Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
1.1445	20.37	1.1273	21.15
0.6071	8.38	0.6073	6.84

Measurement-driven Model Identification Using Ring-down Data

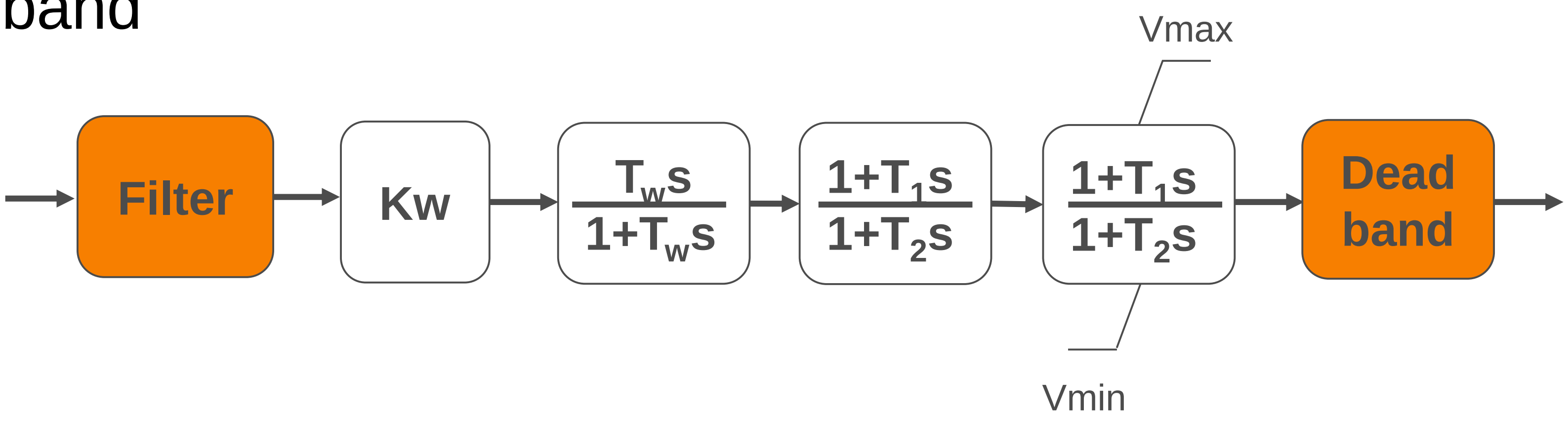
- Closed-loop system, online identification
  - Transfer function between Vref and Vt is already known
  - Transfer function between Vt and Δf can be identified using ring-down measurements



Source: EPRI report: Oscillation damping control using measurement-driven transfer function model

WADC Design Based on Residue Angle

- Lead-lag structure employed
  - T_w = 5~20 s
  - T_1 and T_2 are determined by residue angle
  - Kw is determined by the target damping ratio
  - Filter: eliminate impacts of other modes
  - Deadband



Source: A. Magdy, A. Sallam, and J. Mccalley, "Damping controller design for power system oscillations using global signals," *IEEE Transaction on Power Systems*, vol. 11, no. 2, pp. 767-773, May. 1996.

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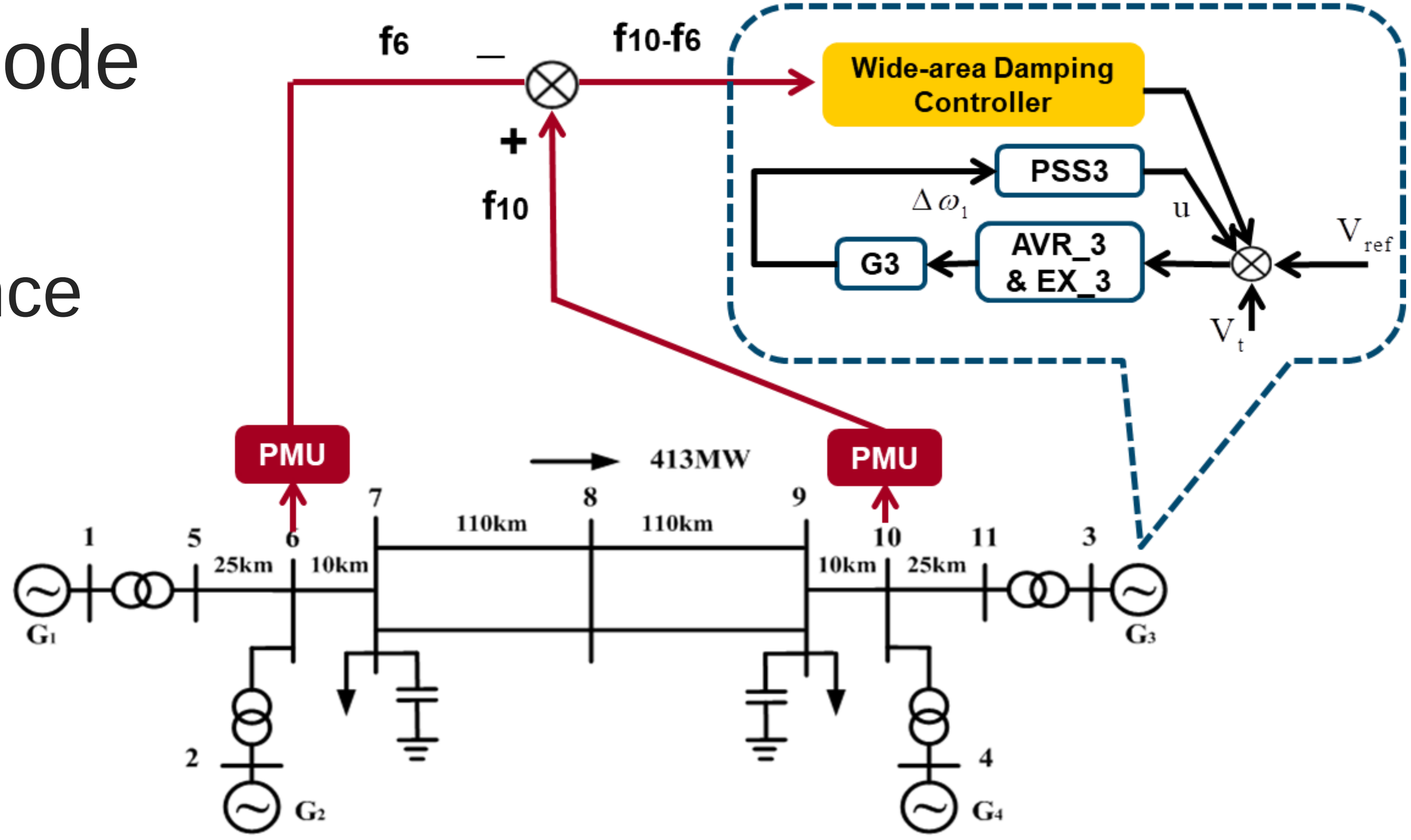
Case Study on two area – four machine System

- Inter-area oscillation mode
- WADC input signal
  - Bus frequency difference between two areas
- WADC location
  - Gen #3



Case Study on two area – four machine System

- Operating condition 1: original
- Operating condition 2: original + consecutive events (line trip, load condition, etc.)

Oscillation mode under different operation conditions

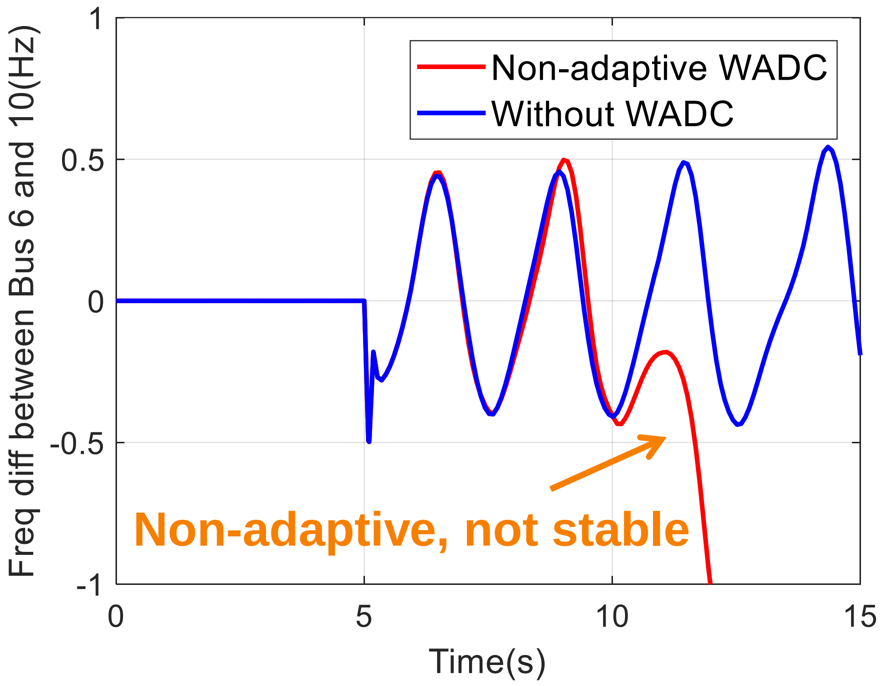
	Oscillation frequency (Hz)	Damping ratio (%)
Operating condition 1	0.603	5.66
Operating condition 2	0.494	0.81

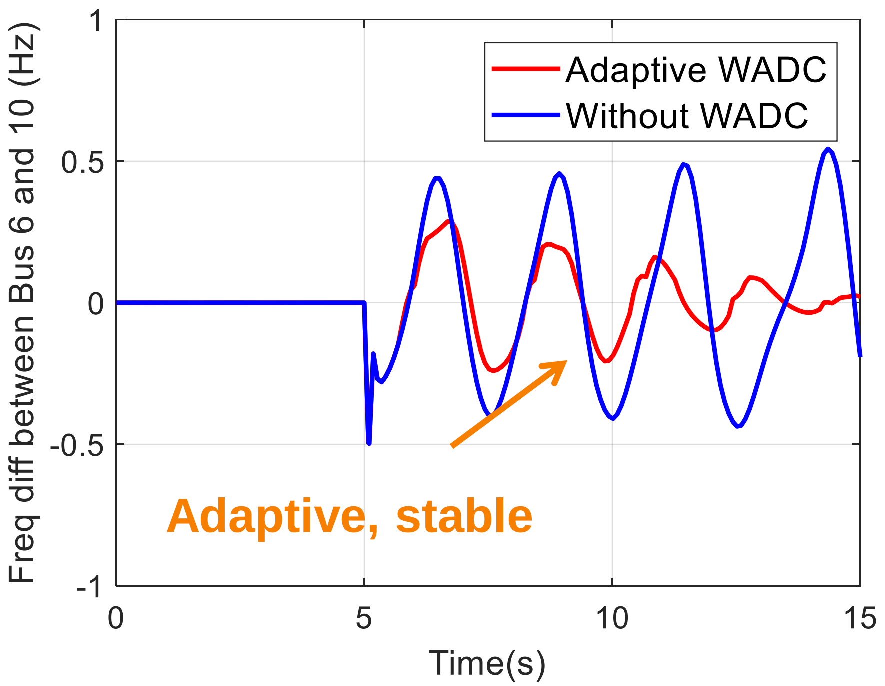
WADC parameters under different operation conditions

	Kw	T1	T2
Operating condition 1	2.138	0.5748	0.1220
Operating condition 2	1.414	0.4104	0.2533

Case Study on two area – four machine System

- Apply temporary three-phase fault on tieline under operating condition 2 to compare non-adaptive and adaptive WADC
  - Non-adaptive WADC: tuned under condition 1
  - Adaptive WADC: tuned under condition 2





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Demonstration on UTK Hardware Testbed

- CURENT HTB is a unique testing platform to emulate large-scale power systems
- Interconnecting modular and reprogrammable power electronic converters in a reconfigurable structure
- Currently, the reduced WECC system is emulated.

Control and visualization

Front row

- Areas 1 and 4
- Transmission line cabinet 1
- Physical inductor cabinet
- PMU cabinet

Middle row

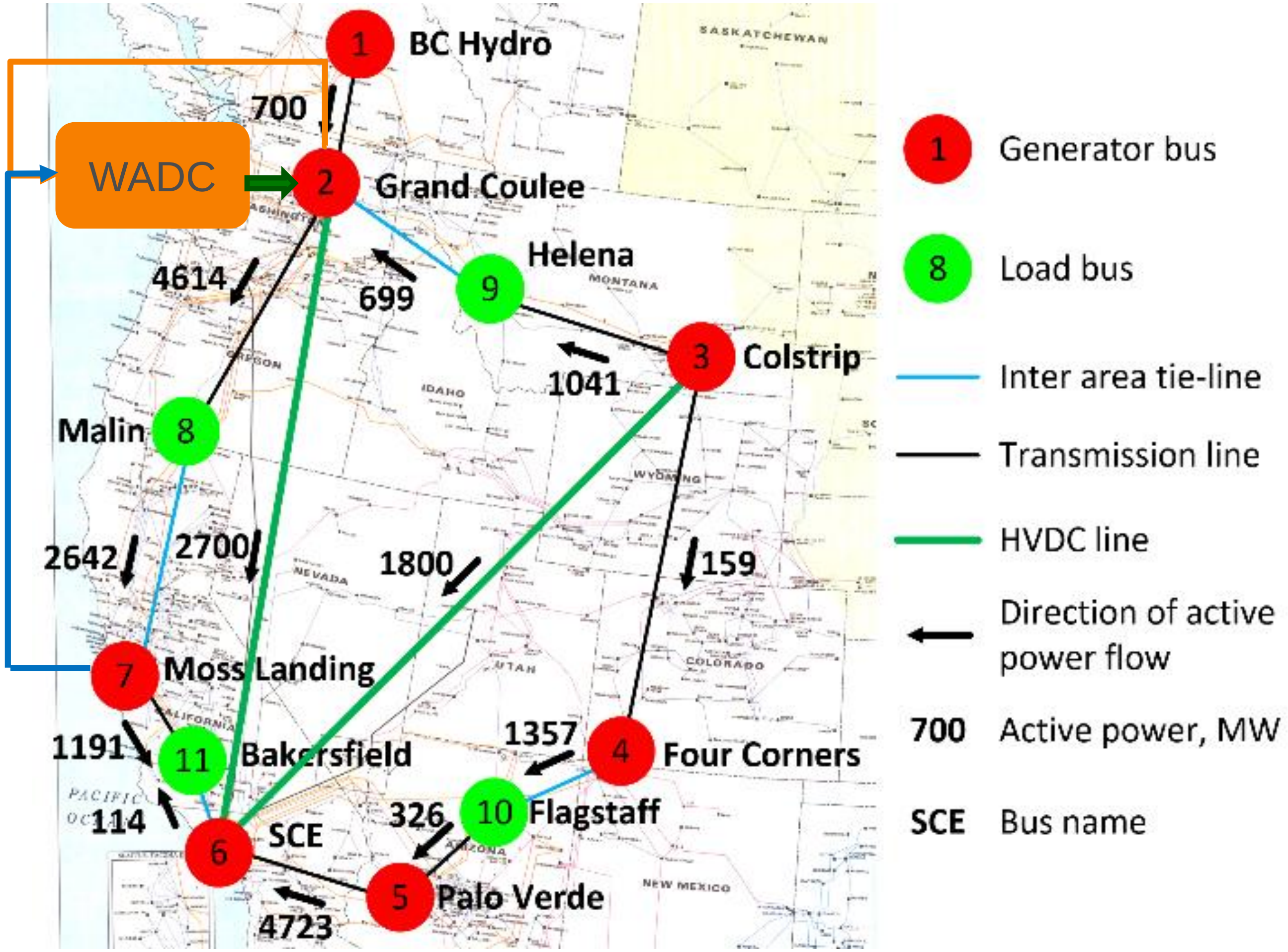
- Areas 2 and 3
- Transmission line cabinet 2

Back row

- 2 cabinets for Multi-terminal HVDC system
- 1 wind farm cabinet

Demonstration on UTK Hardware Testbed

- Reduced WECC model with 60% renewable
- WADC on Gen 2 using bus frequency difference as feedback

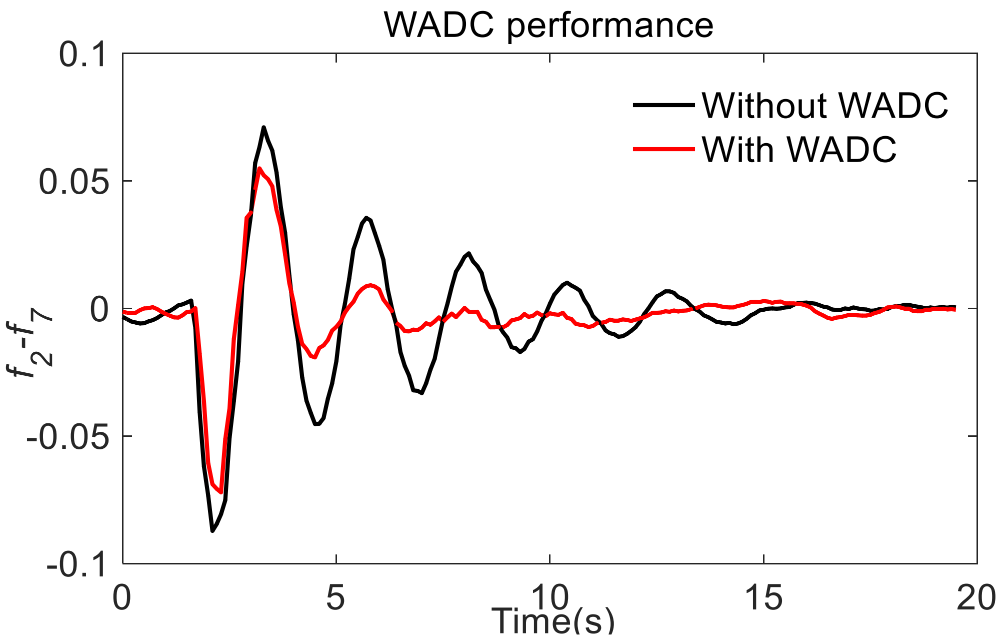


WADC parameters under Winter/Summer case

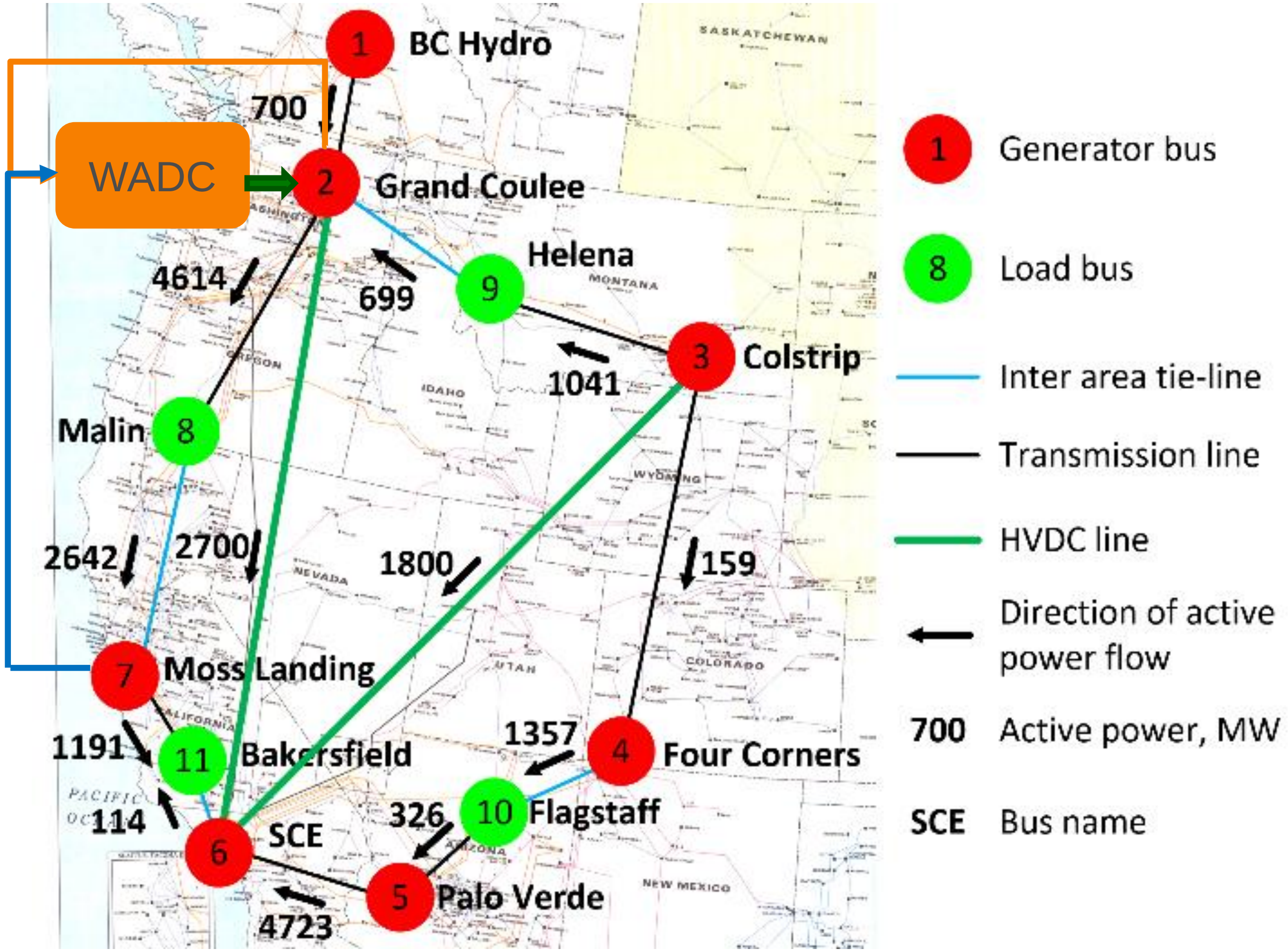
	Kw	T1	T2
Winter	21.18	0.302	0.302
Summer	7.20	0.399	0.235

Demonstration on UTK Hardware Testbed

- WADC is tuned for summer case



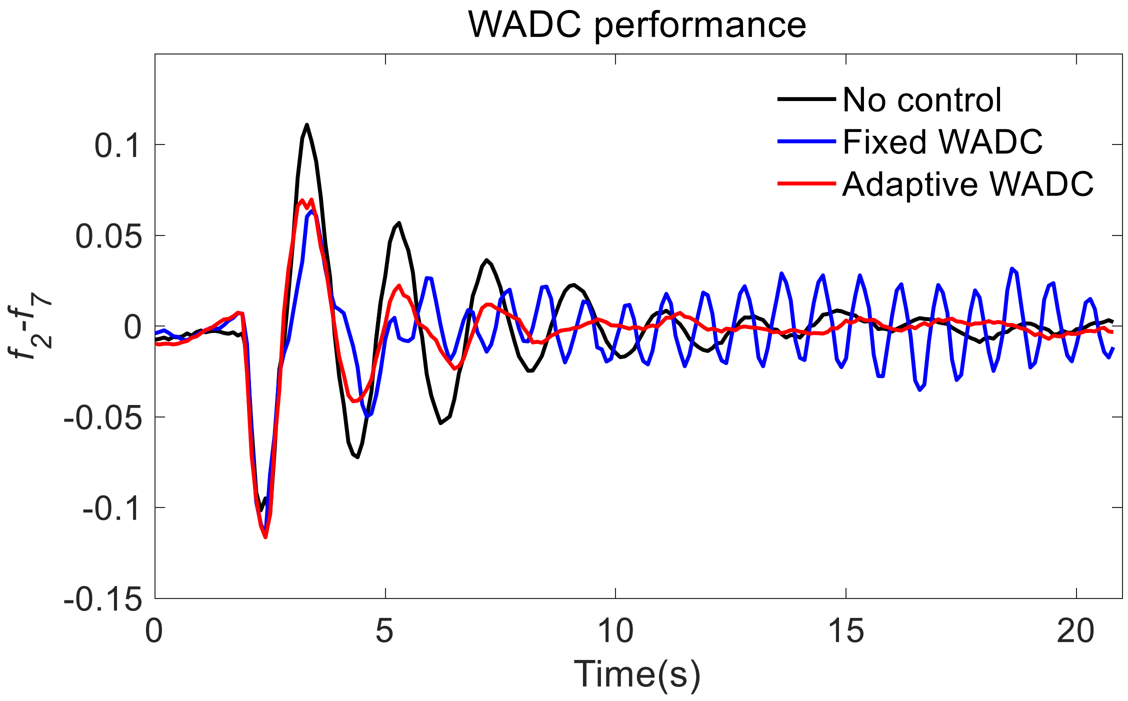
WADC performance



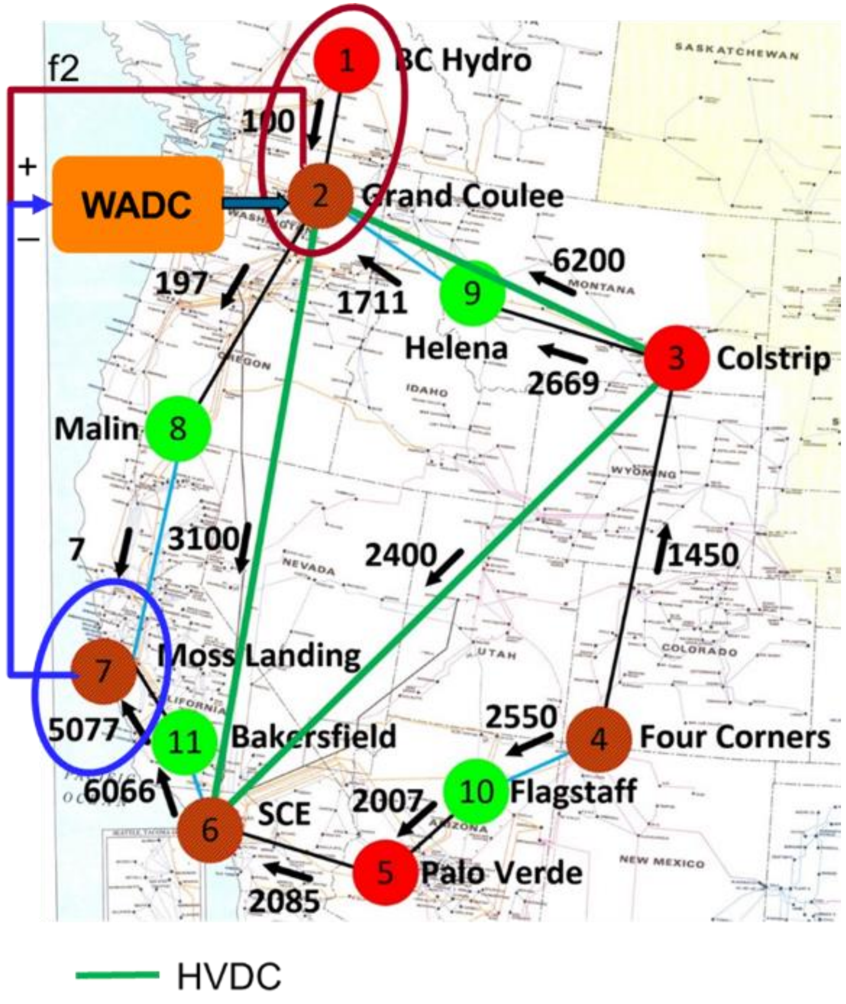
WECC Summer case

Demonstration on UTK Hardware Testbed

- Non-adaptive WADC is tuned for summer case, tested in winter case
- Adaptive WADC is tuned for winter case



WADC performance



WECC winter case

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Conclusion

- A measurement-driven approach to design WADC, does not rely on full system dynamic model.
- Adaptive WADC to accommodate variations in operating conditions, providing better control effect.
- Validated on two area – four machine system and demonstrated on UTK’s hardware testbed on reduced WECC system.
- Next steps
    - Case study with EPRI members: NYPA, Terna (TSO in Italy), Saudi Electric
    - RTDS/OPAL-RT hardware-in-the-loop test

Acknowledgements

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