

ROSEI SUMMIT 2023

Frequency Shaping Control for Low Inertia Power Systems

Enrique Mallada

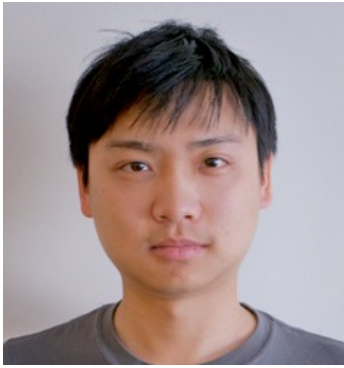
Associate Professor, ECE, JHU

January 18, 2023

Acknowledgements



Yan Jiang



Hancheng Min



Eliza Cohn



Petr Vorobev



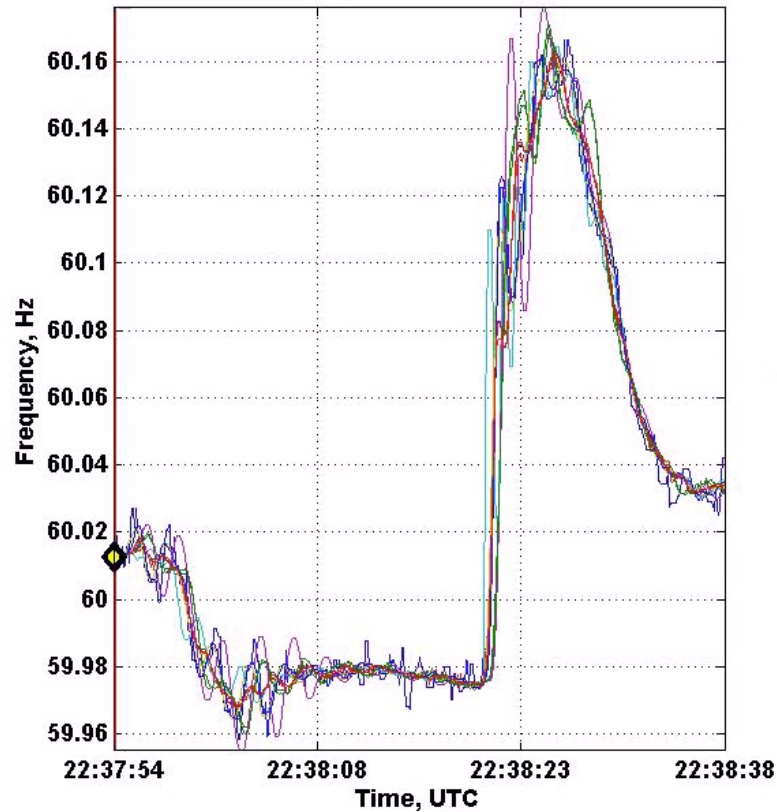
Richard Pates



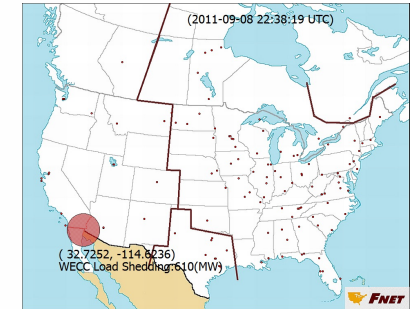
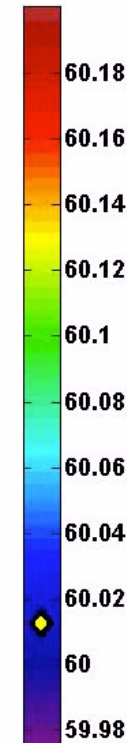
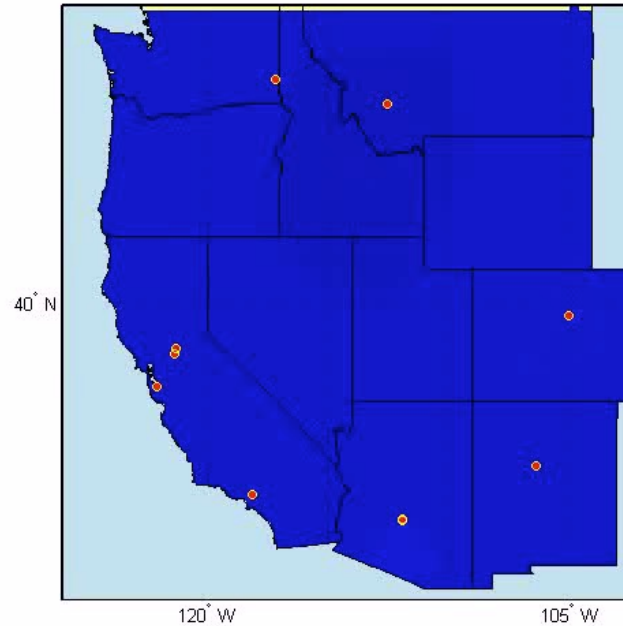
Fernando Paganini



Frequency Control

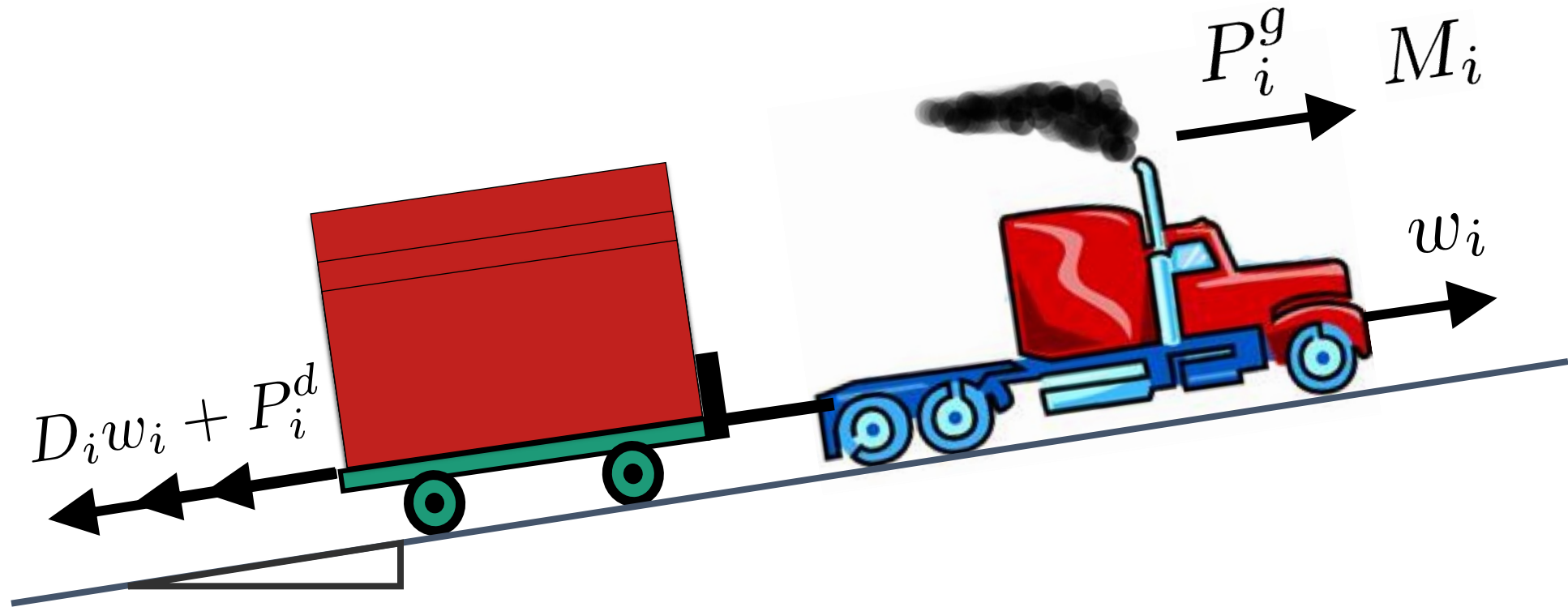


FNET Data Display [9/8/2011 Southwest Blackout]
Time: 22:37:54.0 UTC 60.0125 Hz



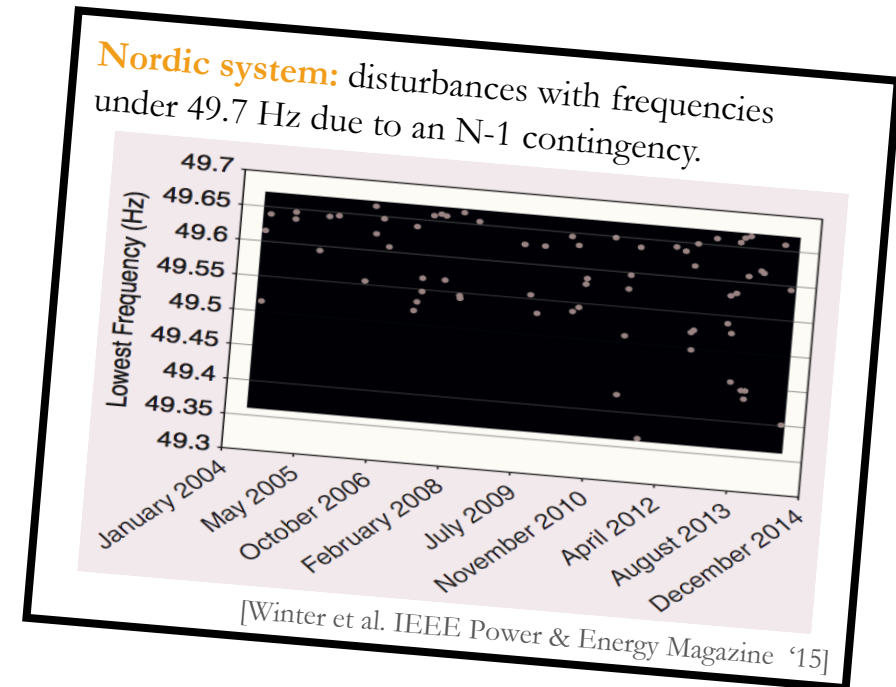
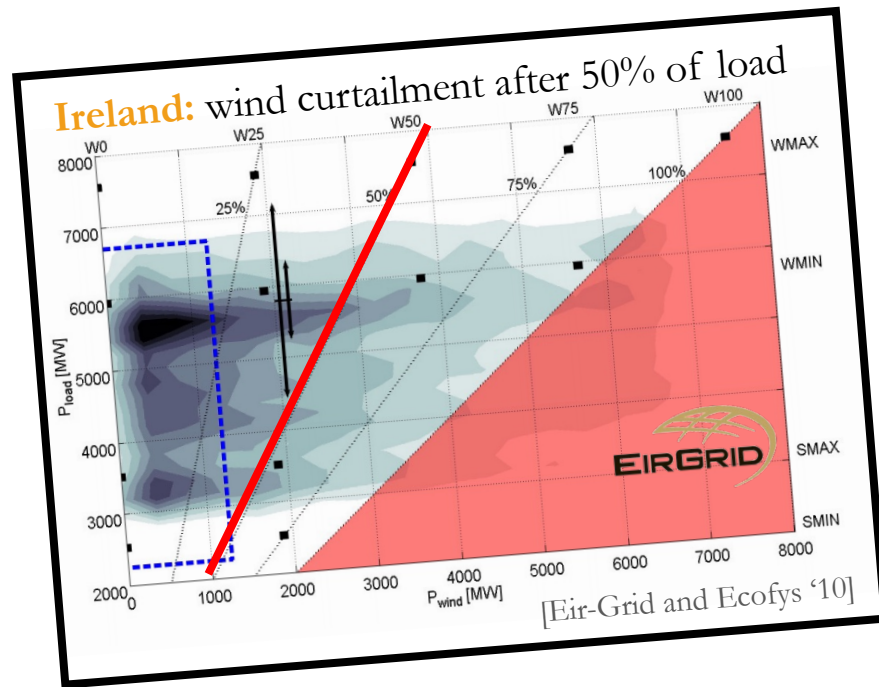
Goal: Maintain **frequency** close to the nominal (60/50 Hz)

Mechanical Analogue



Goal: Maintain **speed** close to the nominal (60/50 Hz)

Low Inertia = Dynamic Degradation



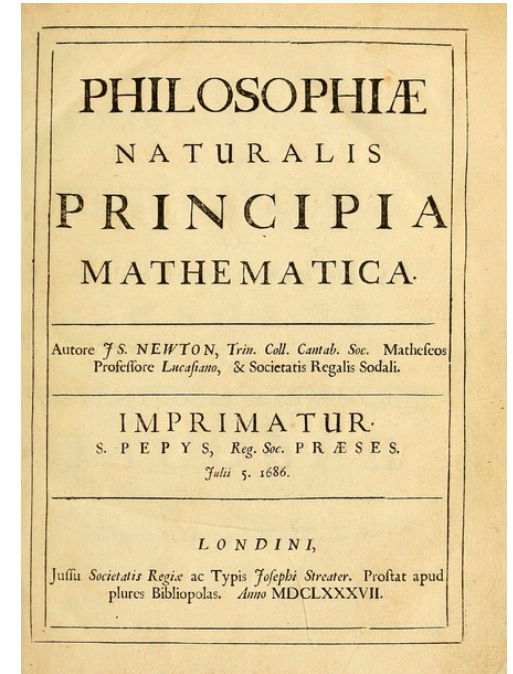
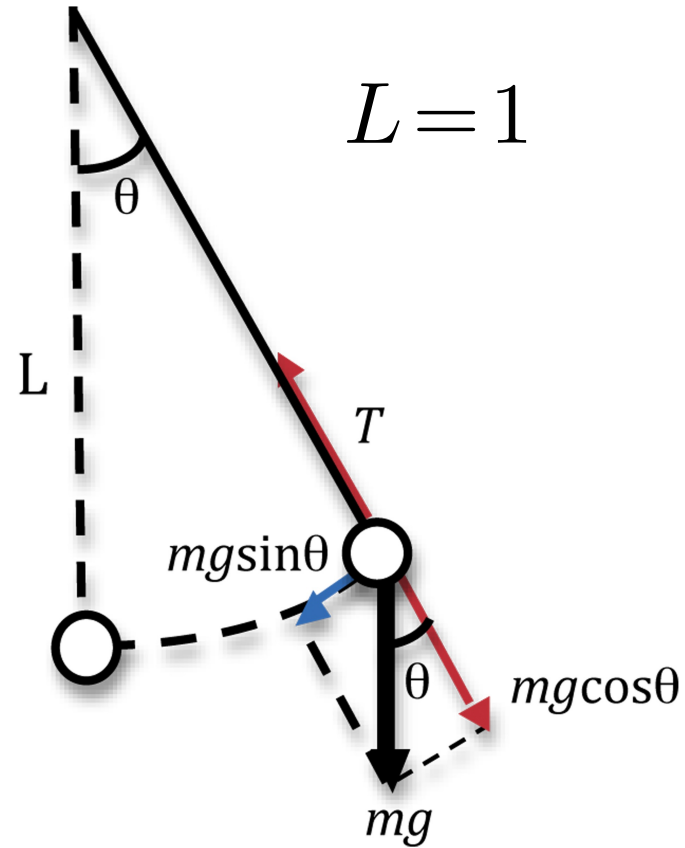
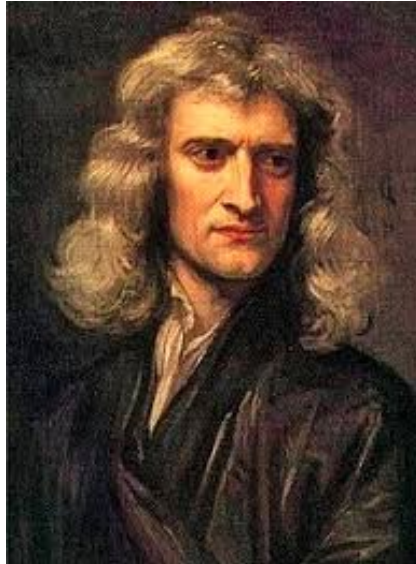
In the United States:



“While the three [contiguous] U.S. interconnections currently exhibit adequate frequency response performance above their interconnection frequency response obligations, there has been a significant decline in the frequency response performance of the Western and Eastern Interconnections,” FERC said.

[FERC, Nov. 16]

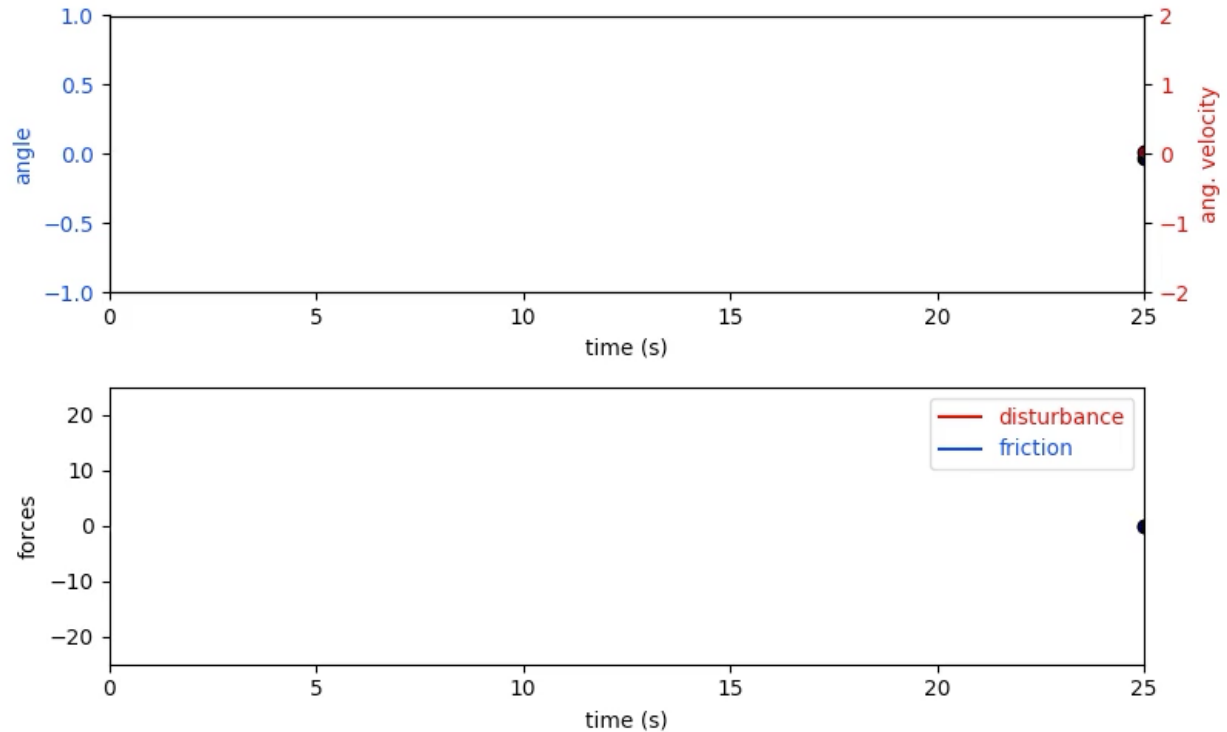
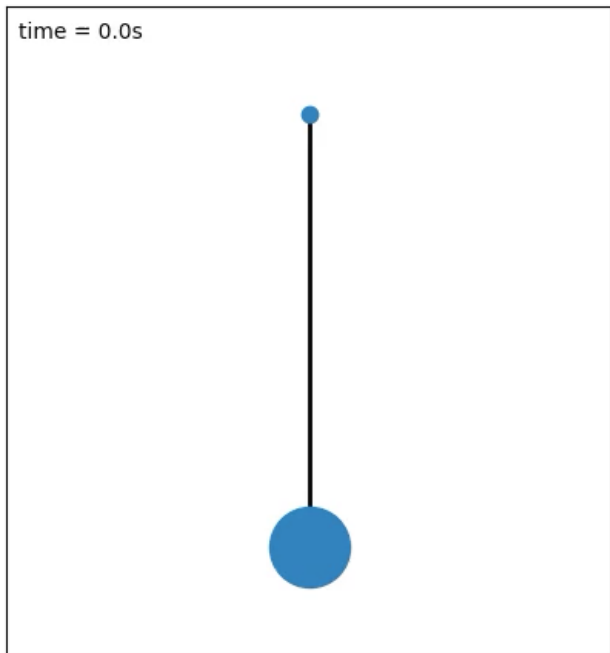
Merits and Trade-offs of Inertia



$$\ddot{\theta} = -\frac{d}{m}\dot{\theta} - g \sin \theta + \frac{f}{m}$$

Merits and Trade-offs of Inertia

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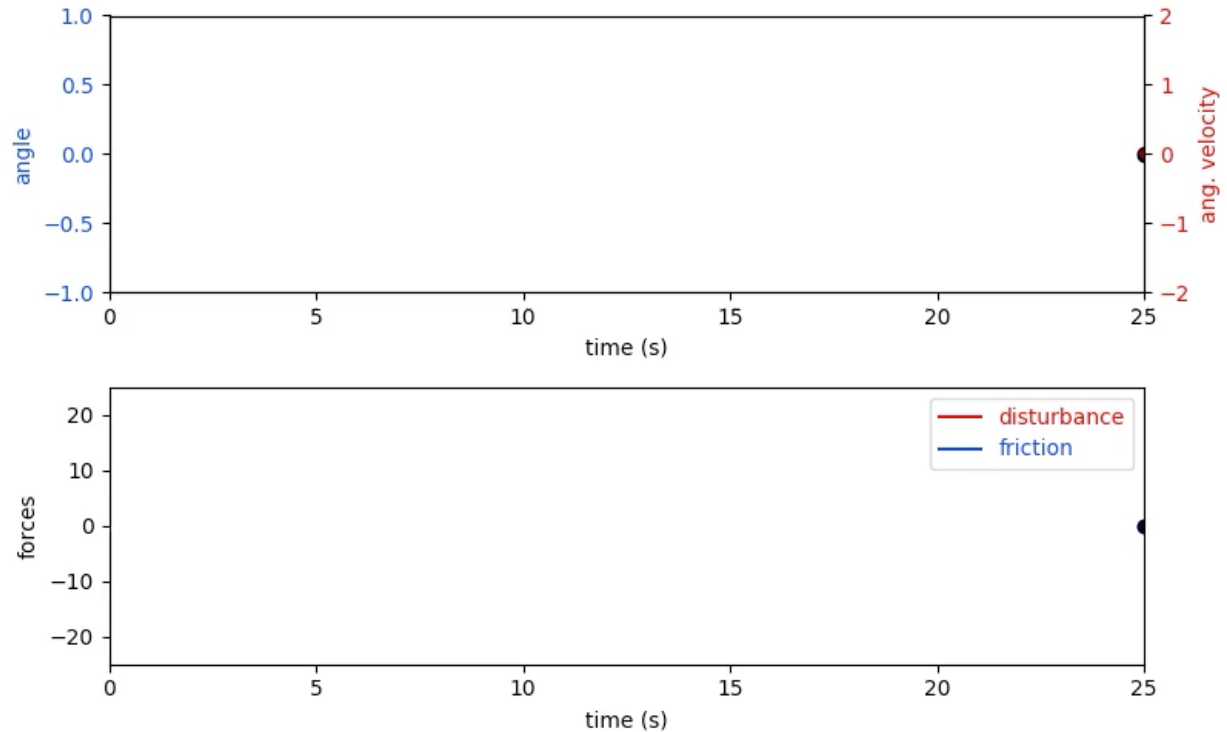
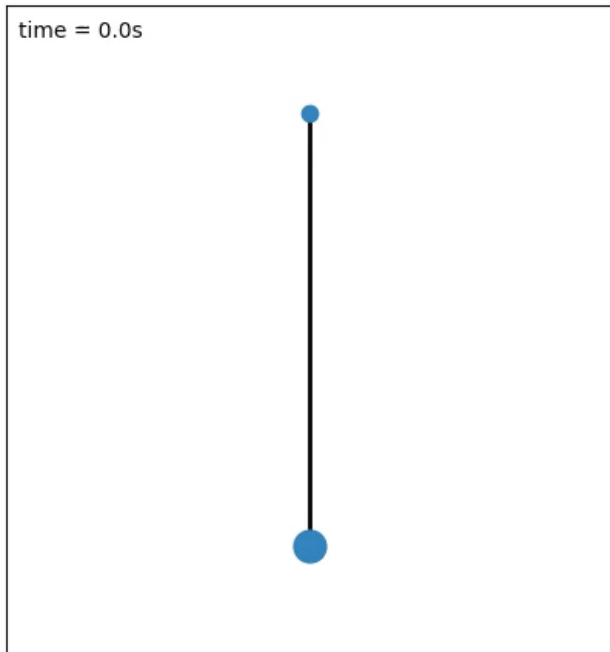


Pros: Provides natural disturbance rejection

Cons: Hard to regain steady-state

Merits and Trade-offs of **Low** Inertia

$$\ddot{\theta} = -\frac{d}{m}\dot{\theta} - g \sin \theta + \frac{f}{m}$$

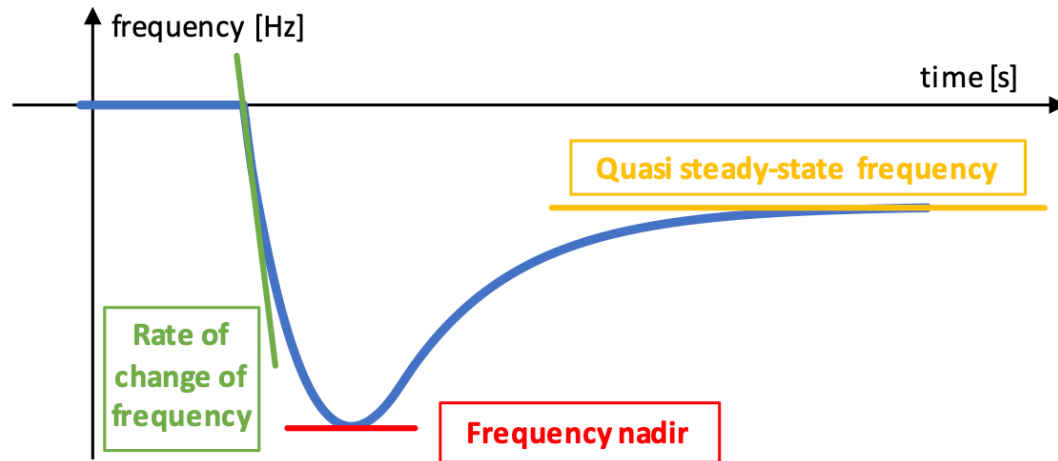


Cons: Susceptible to disturbances

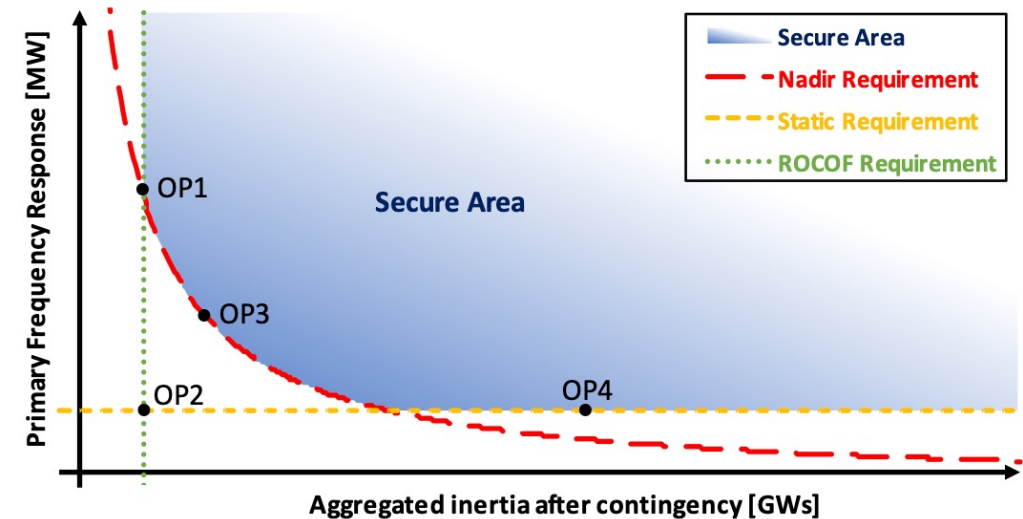
Pros: Regains steady-state faster

Freq. Control: Importance of Inertia

Frequency response to disturbance



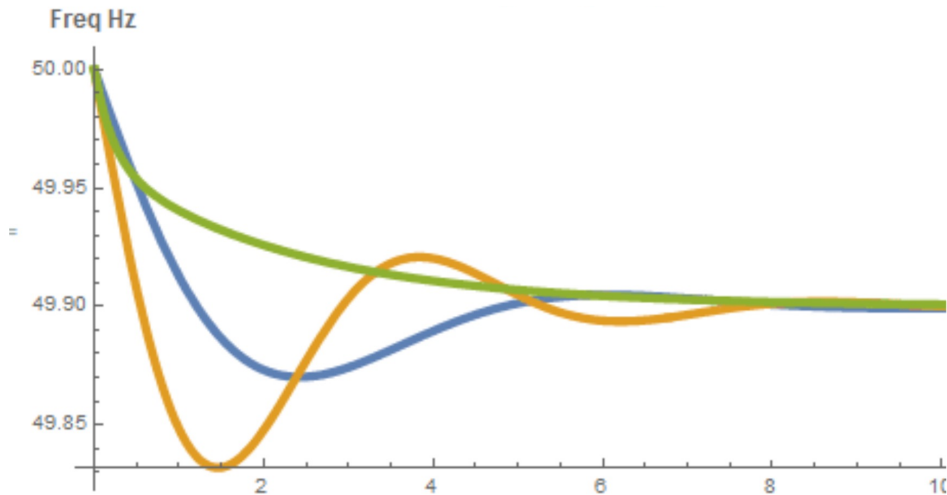
Frequency response security map



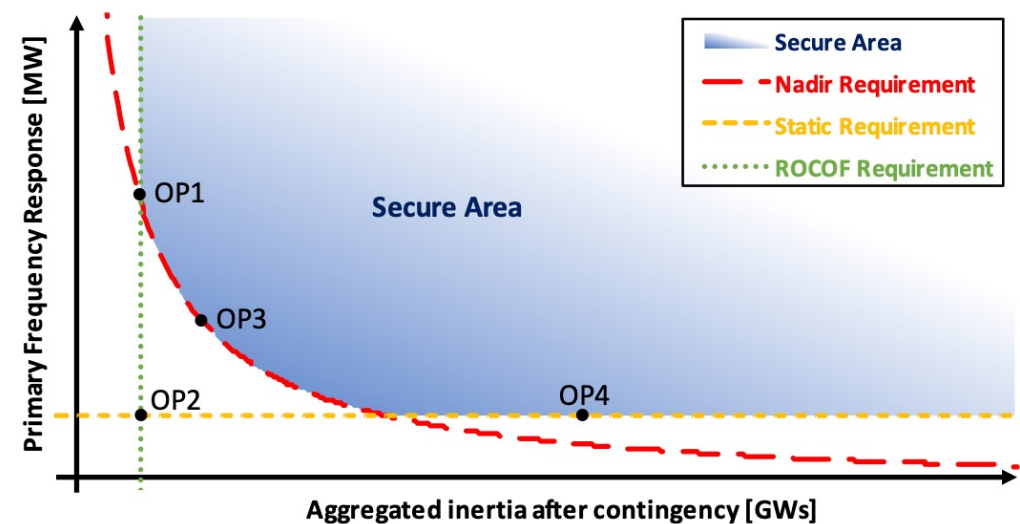
S. Püschel-Løvgreen and P. Mancarella, "Mapping the frequency response adequacy of the Australian national electricity market," *2017 Australasian Universities Power Engineering Conference (AUPEC)*, Melbourne, VIC, Australia, 2017.

Freq. Control: Importance of Inertia

Low inertia frequency response

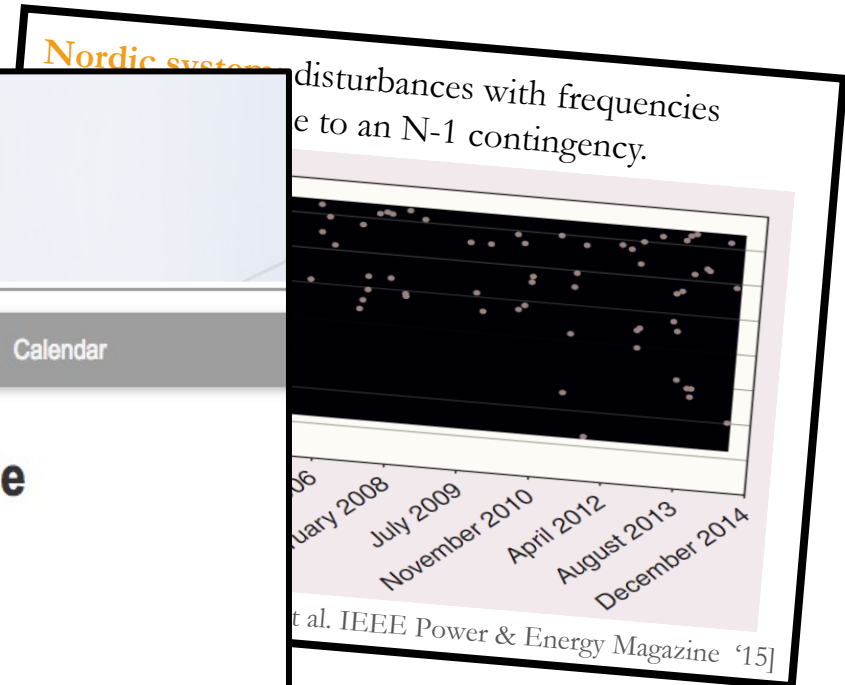
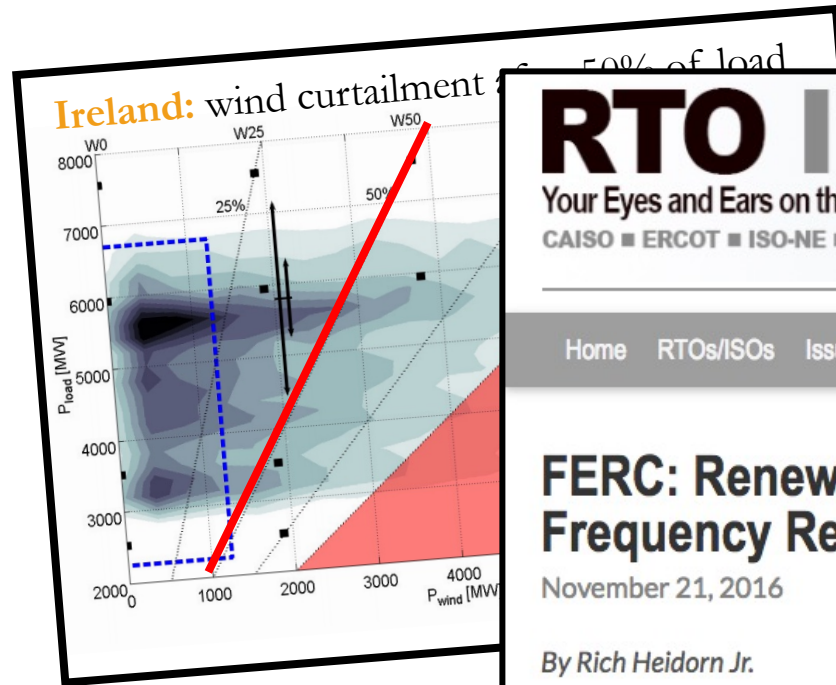


Frequency response security map



S. Püschel-Løvgreen and P. Mancarella, "Mapping the frequency response adequacy of the Australian national electricity market," 2017 Australasian Universities Power Engineering Conference (AUPEC), Melbourne, VIC, Australia, 2017.

Low Inertia = Dynamic Degradation



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FERC: Renewables Must Provide Frequency Response

November 21, 2016

By Rich Heidorn Jr.

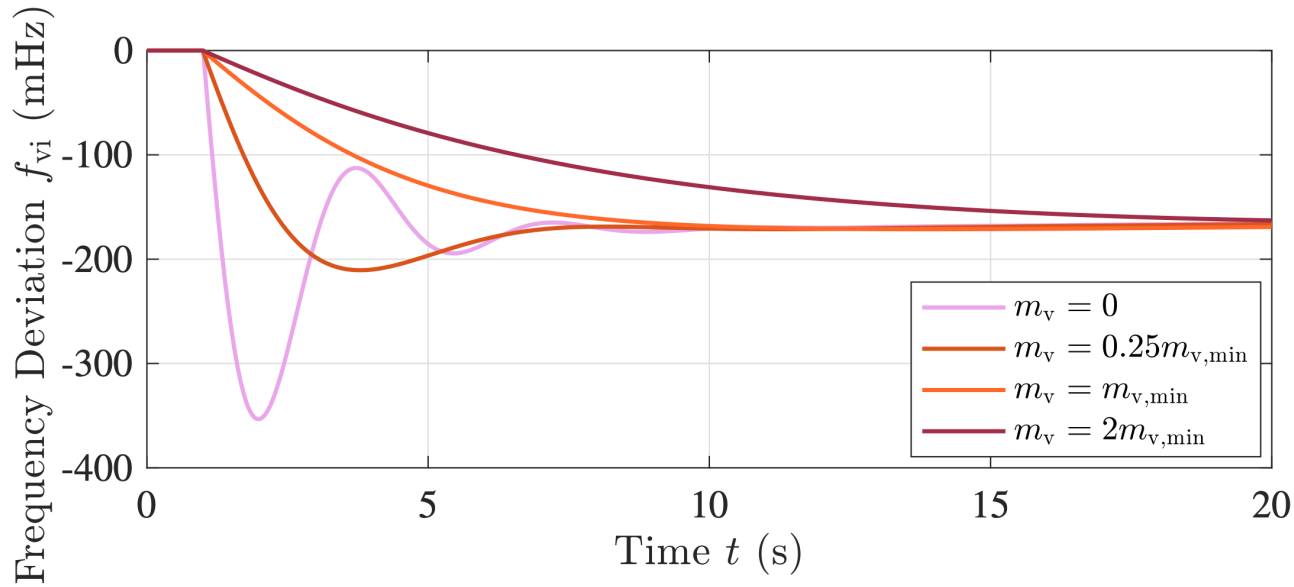
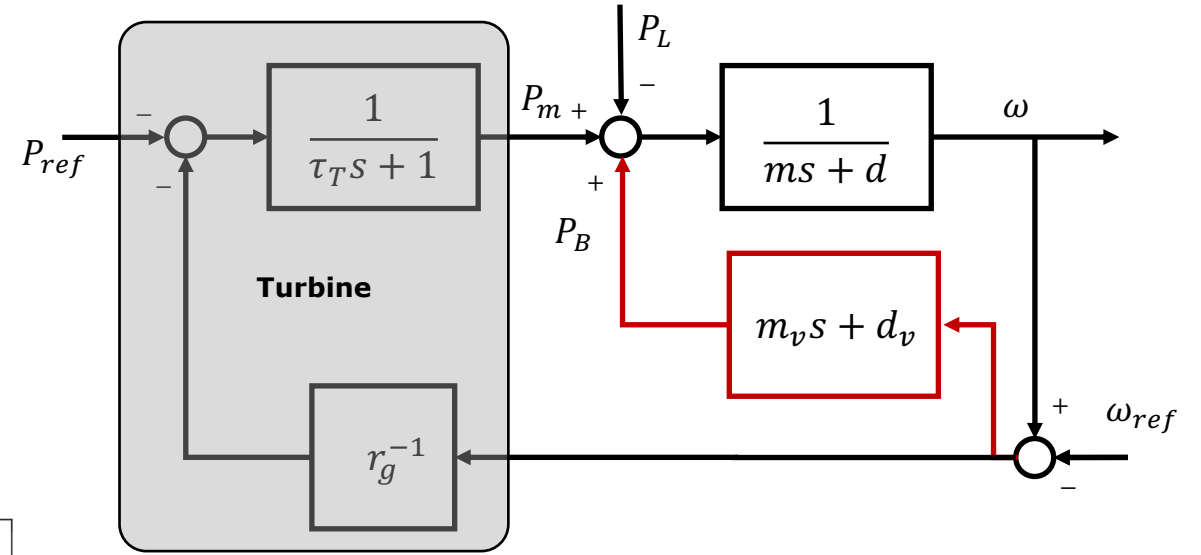
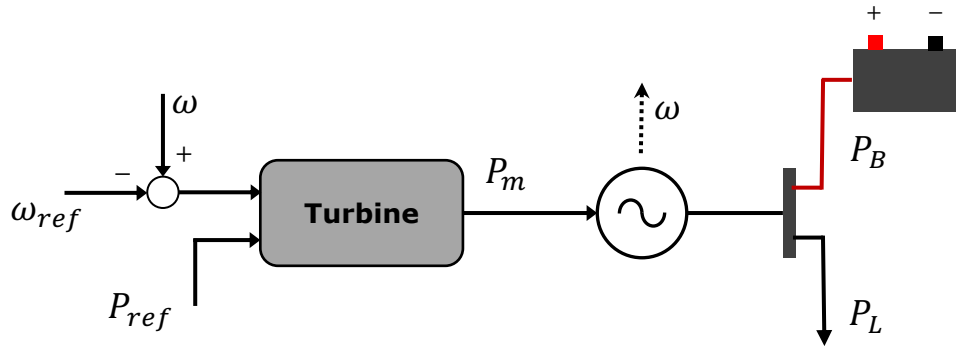
In a rulemaking reflecting both reliability concerns and the technological advances of renewable generators, FERC on Thursday proposed revising the *pro forma* Large Generator Interconnection Agreement (LGIA) and Small Generator Interconnection Agreement (SGIA) to require all newly interconnecting facilities to install and enable primary frequency response capability (RM16-6).

In the US

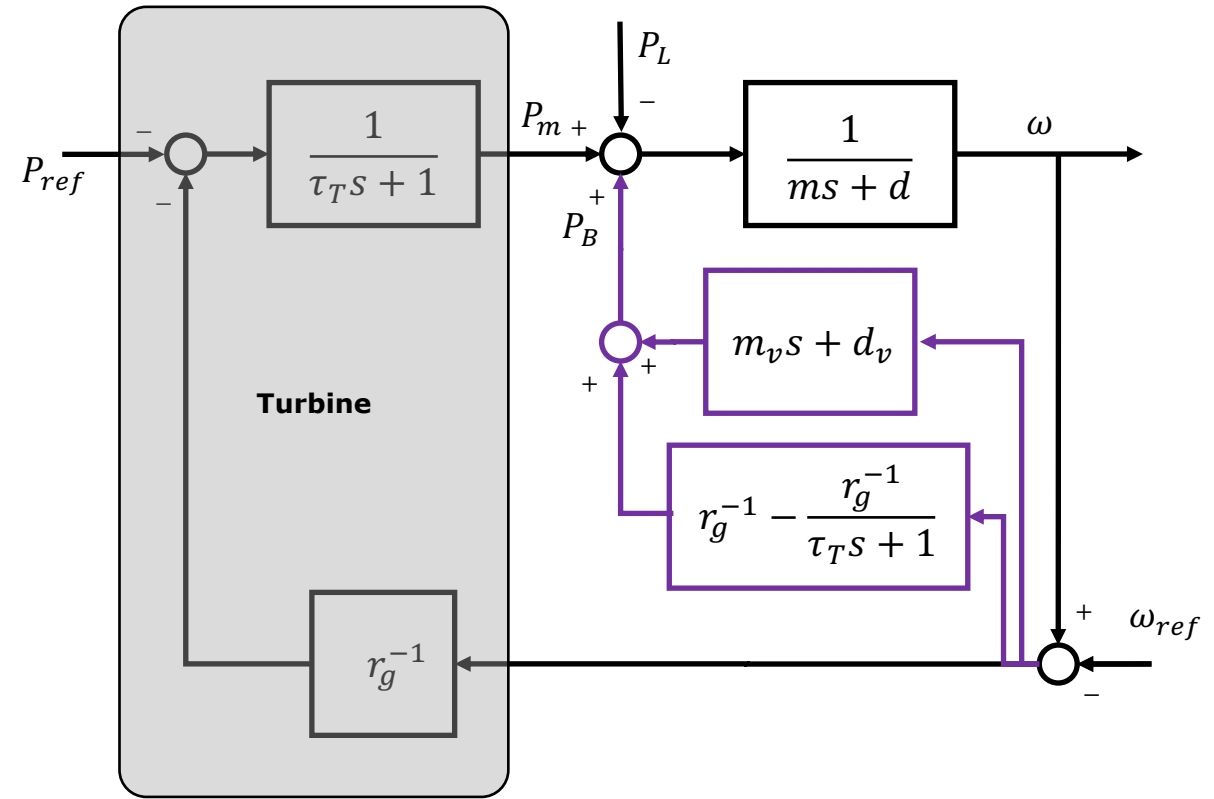
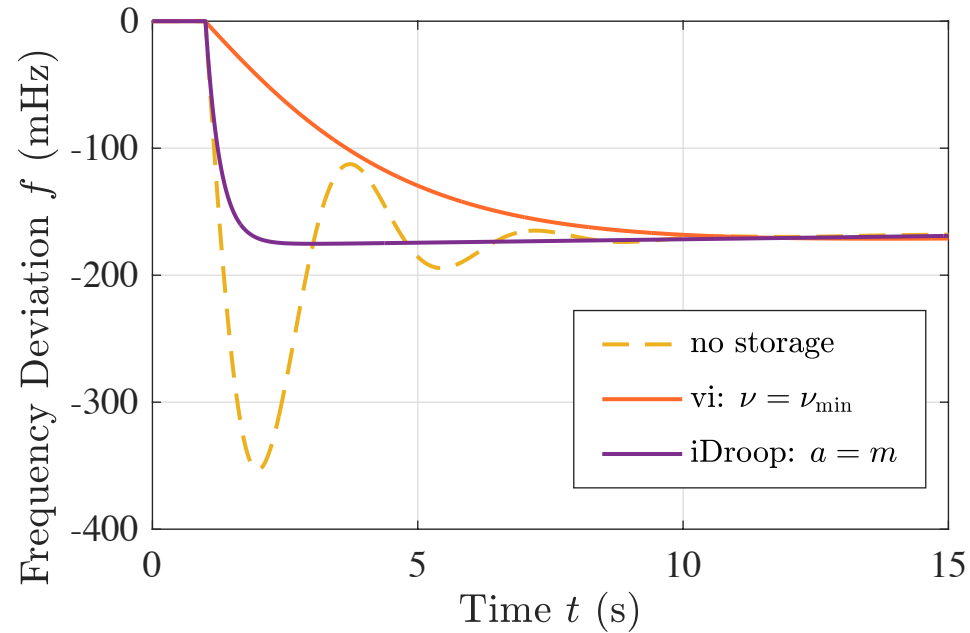
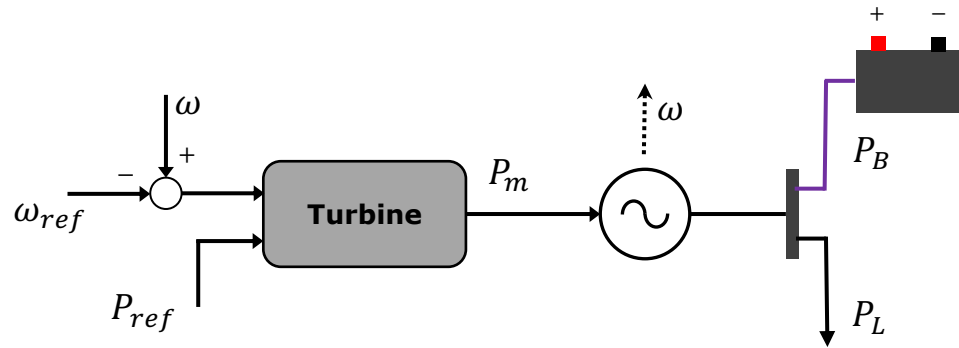
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[FERC, Nov. 16]

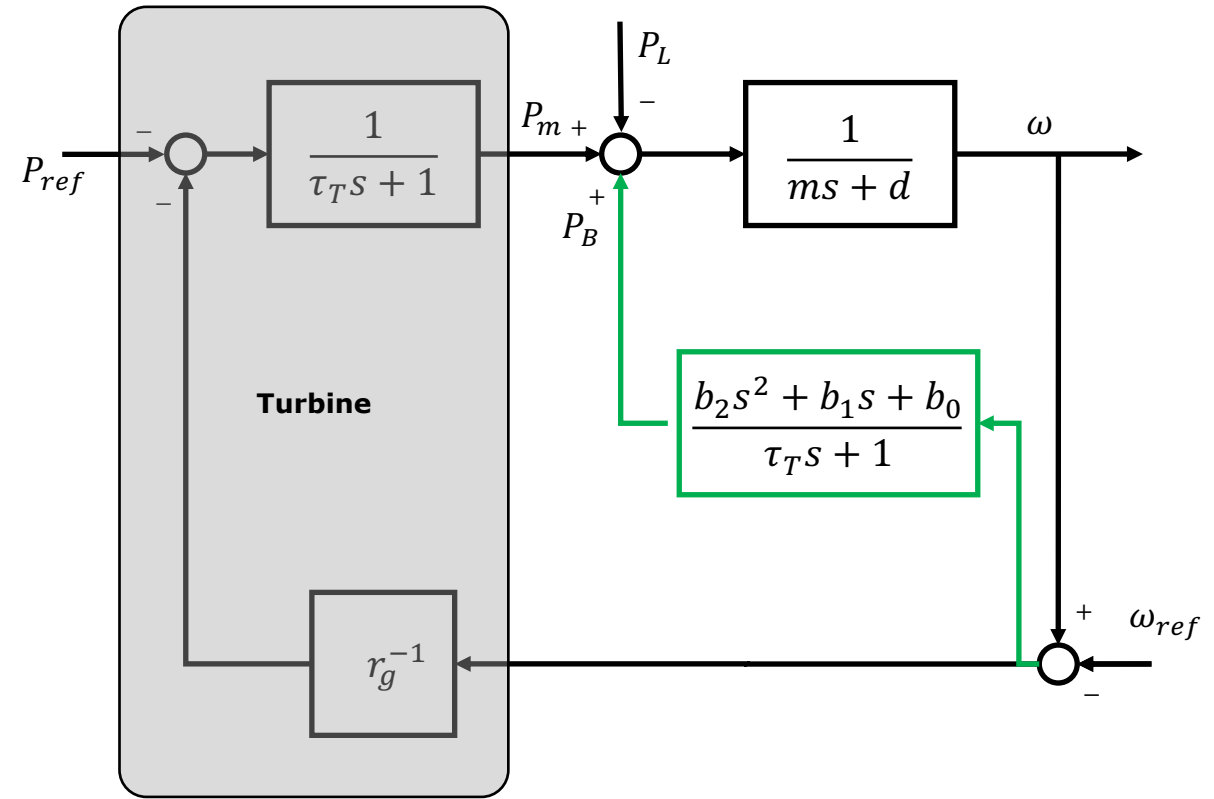
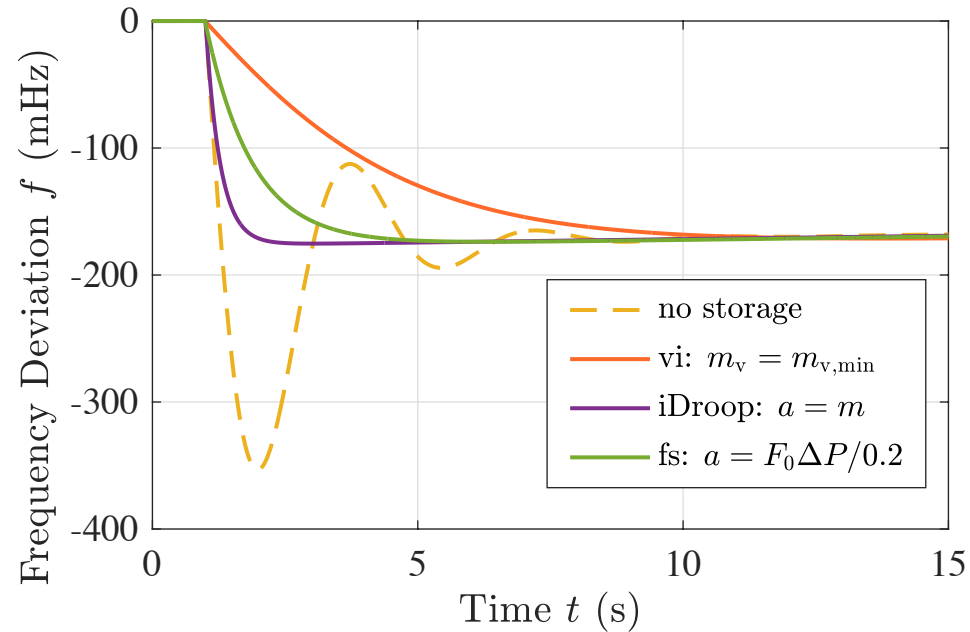
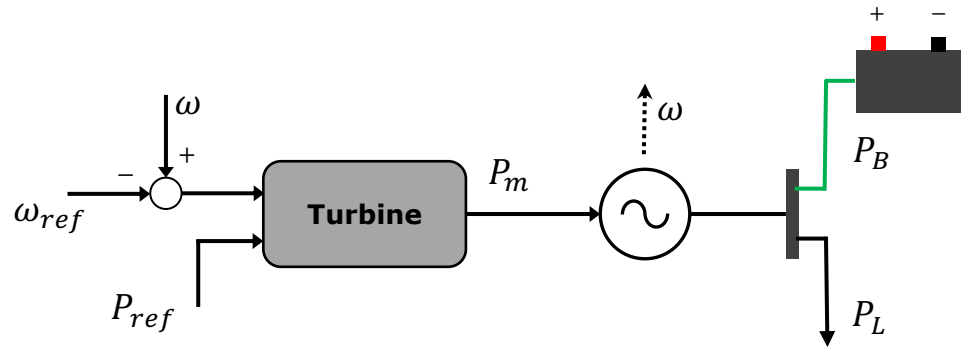
Frequency control by storage units



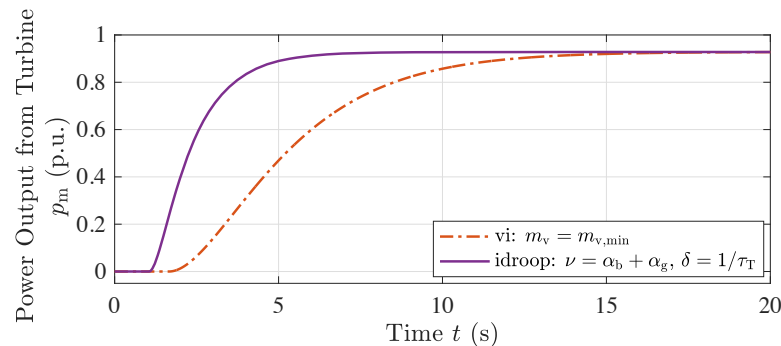
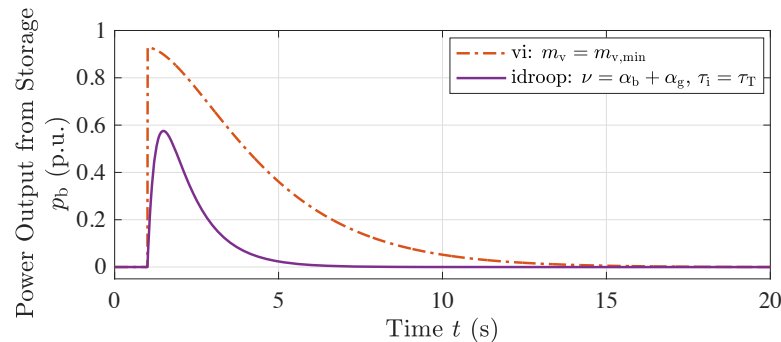
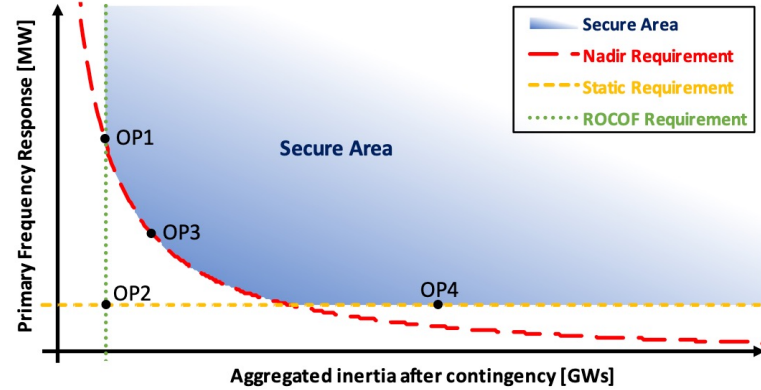
A new approach: *frequency shaping* control



A new approach: *frequency shaping* control



Frequency shaping control: advantages



- Separate tuning for **each performance metric**
- Optimal use of energy storage power and energy capacity
- Storage units and turbines complement each other
- Frequency security can be certified with **algebraic calculations**
- No need to run dynamic simulations for every configuration

Other talks from group members



- 2:45 pm, **Dhananjay Anand:**
Testing and validation of inverter-based grid support functions



- 3:25 pm, **Hancheng Min:**
Learning coherent clusters for modeling and analysis of power system dynamics



- 3:40 pm, **Rajni Bansal:**
Efficient storage integration in electricity markets

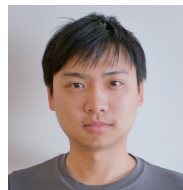
Thanks!

Related Publications:

- Paganini and M, “Global analysis of synchronization performance for power systems: bridging the theory-practice gap,” **IEEE TAC 2020**
- Jiang, Pates, M, “Dynamic Droop Control for Low Inertia Power Systems,” **IEEE TAC 2021**
- Jiang, Cohn, Vorobev, M “Storage-Based Frequency Shaping Control,” **IEEE TPS 2021**
- Min, Paganini, M, “Accurate Reduced Order Models for Coherent Synchronous Generators,” **L-CSS 2020**



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