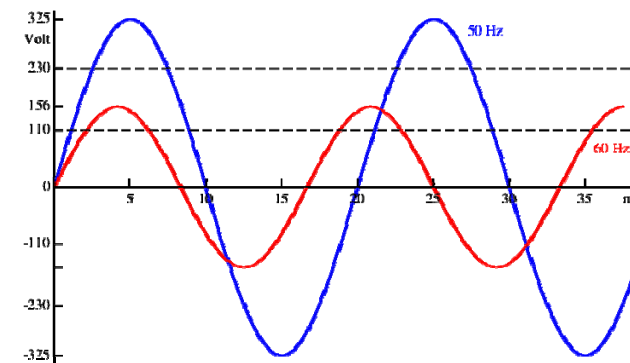


Impact of Wind Fluctuations on Frequency Dynamics and Robust Control for Ensuring Frequency Specifications

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<http://en.wikipedia.org/wiki/File:50Hz60Hz.svg>

Accommodating Wind Generation

- Variability, Intermittency
- Less forecast accuracy
- In general not dispatchable
- Reduces system inertia
- Creates burden on the traditional plants to maintain system performance

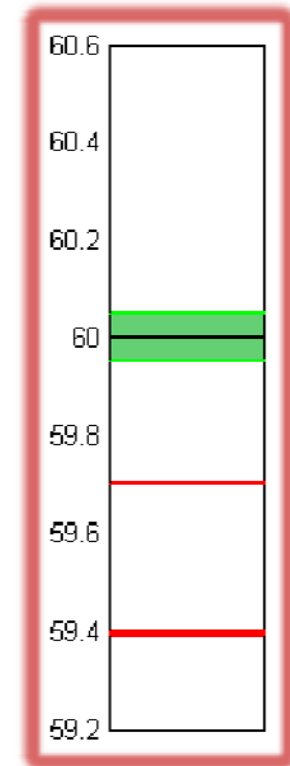


<http://windturbine-corp.com>

What is the impact of wind generation on primary frequency control (seconds to 1 min)?

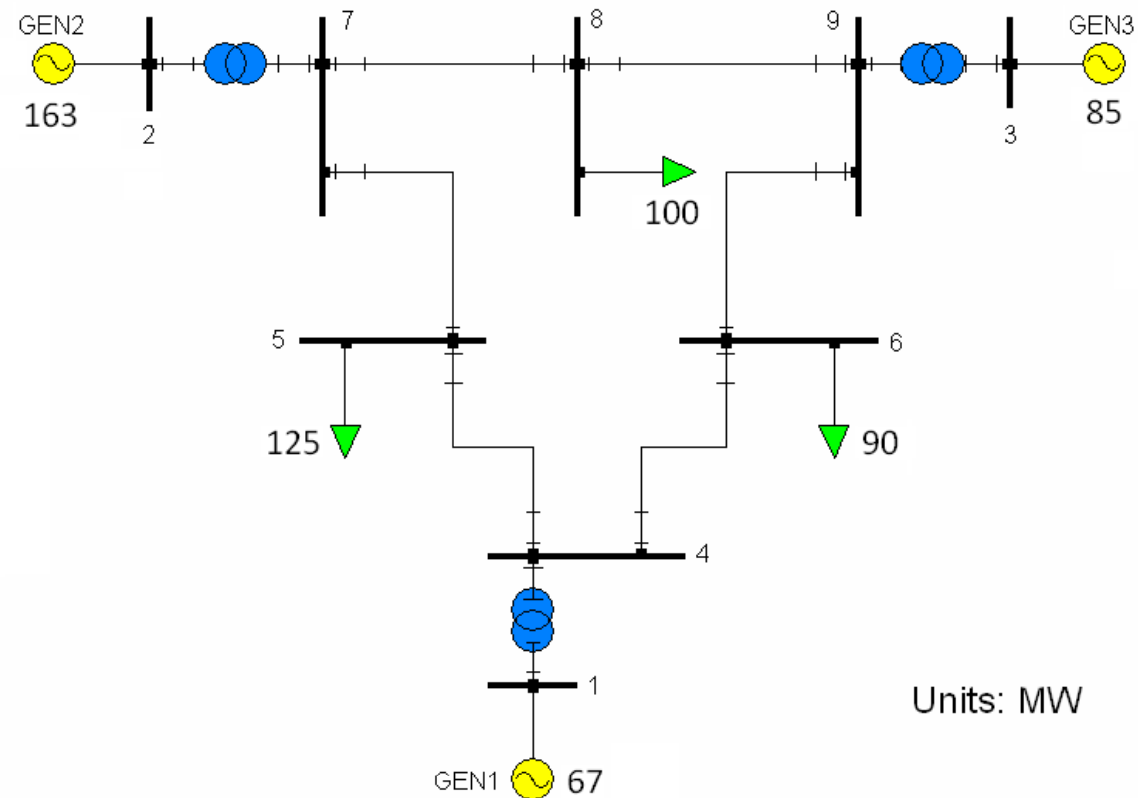
Frequency Performance Specifications

- Normal Conditions: $59.95\text{Hz} - 60.05\text{Hz}$ [1]
- Load used as a resource
 - ERCOT threshold: 59.7Hz for 20 cycles
- Under-frequency load shedding (for contingency)
 - ERCOT threshold: 59.4Hz , shed 5% load
- Future performance criteria may be different



Motivating Example

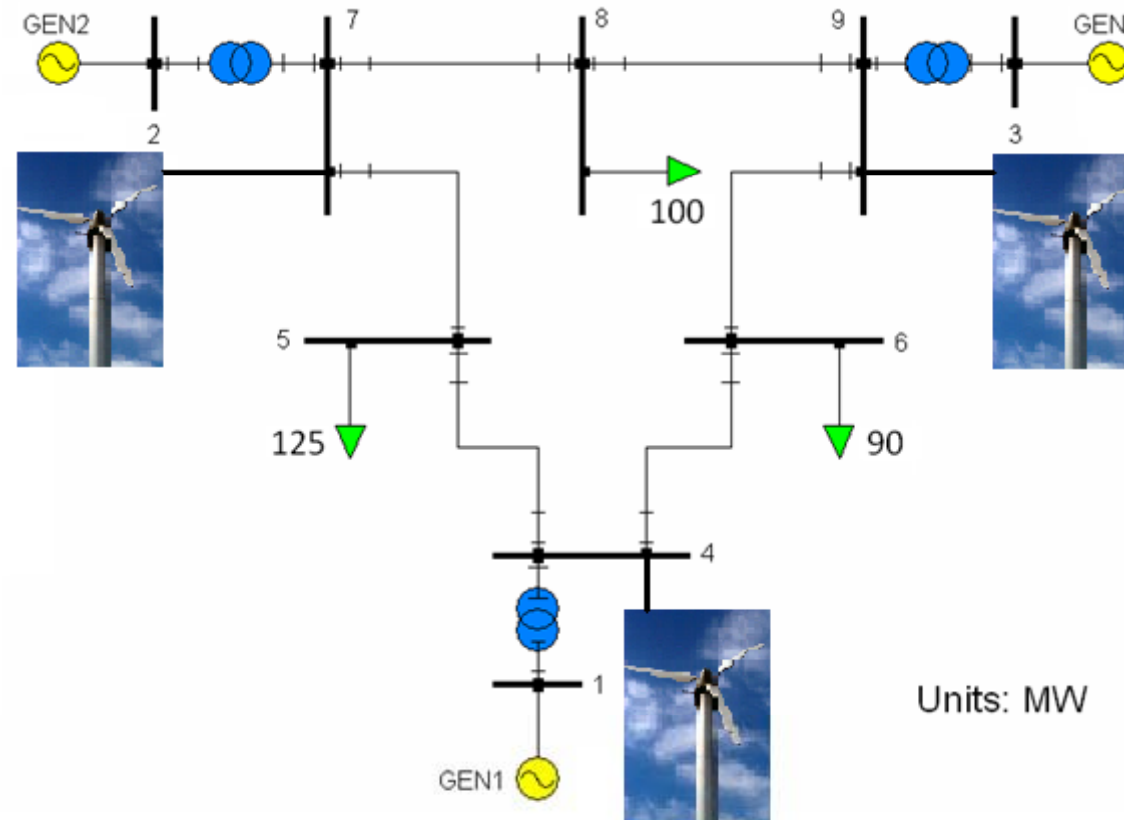
- Modified WSCC 9-Bus System^[2]



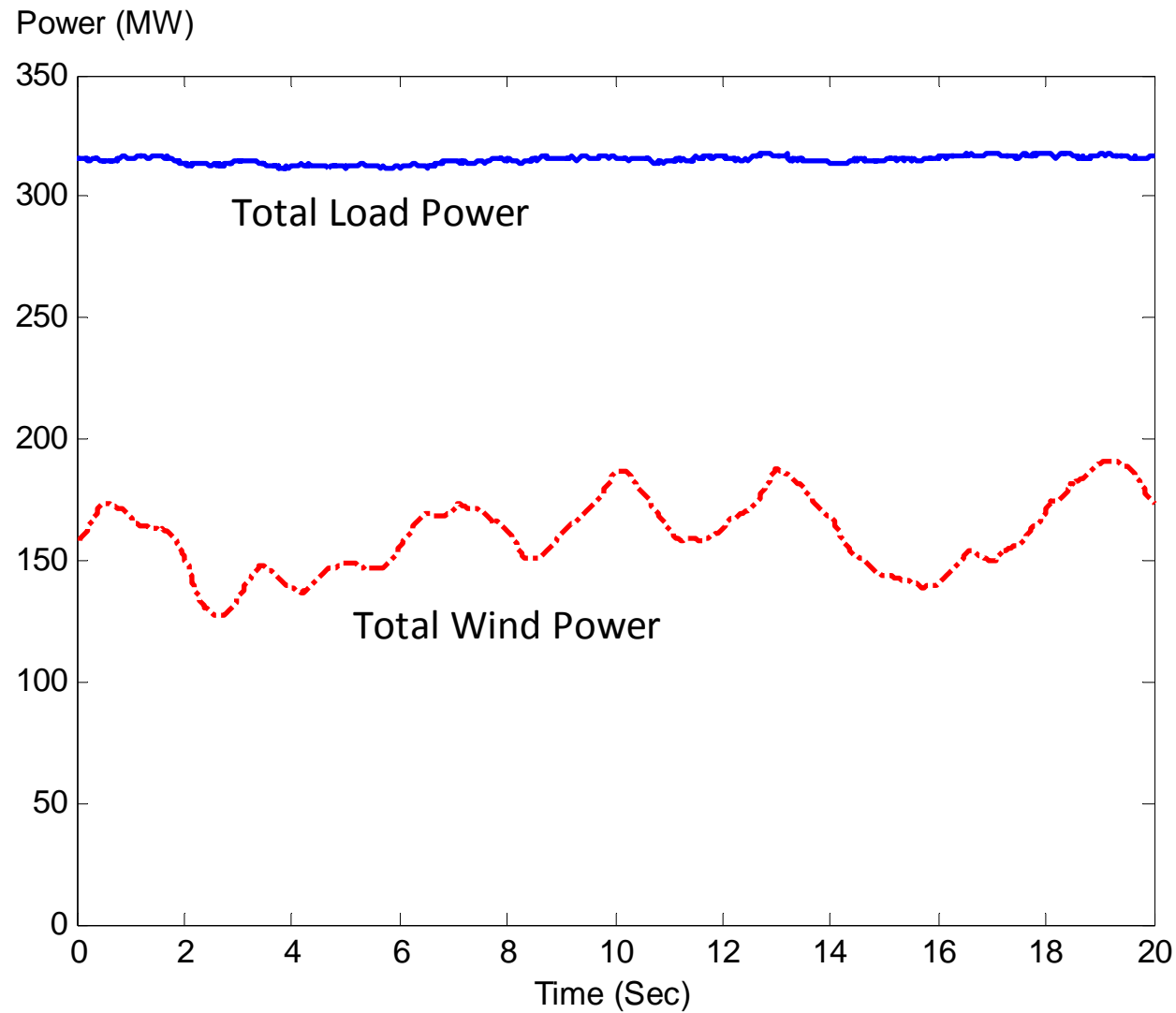
[2] P. W. Sauer and M. A. Pai, Power System Dynamics and Stability. Prentice Hall, New Jersey, 1998.

50% Wind Penetration

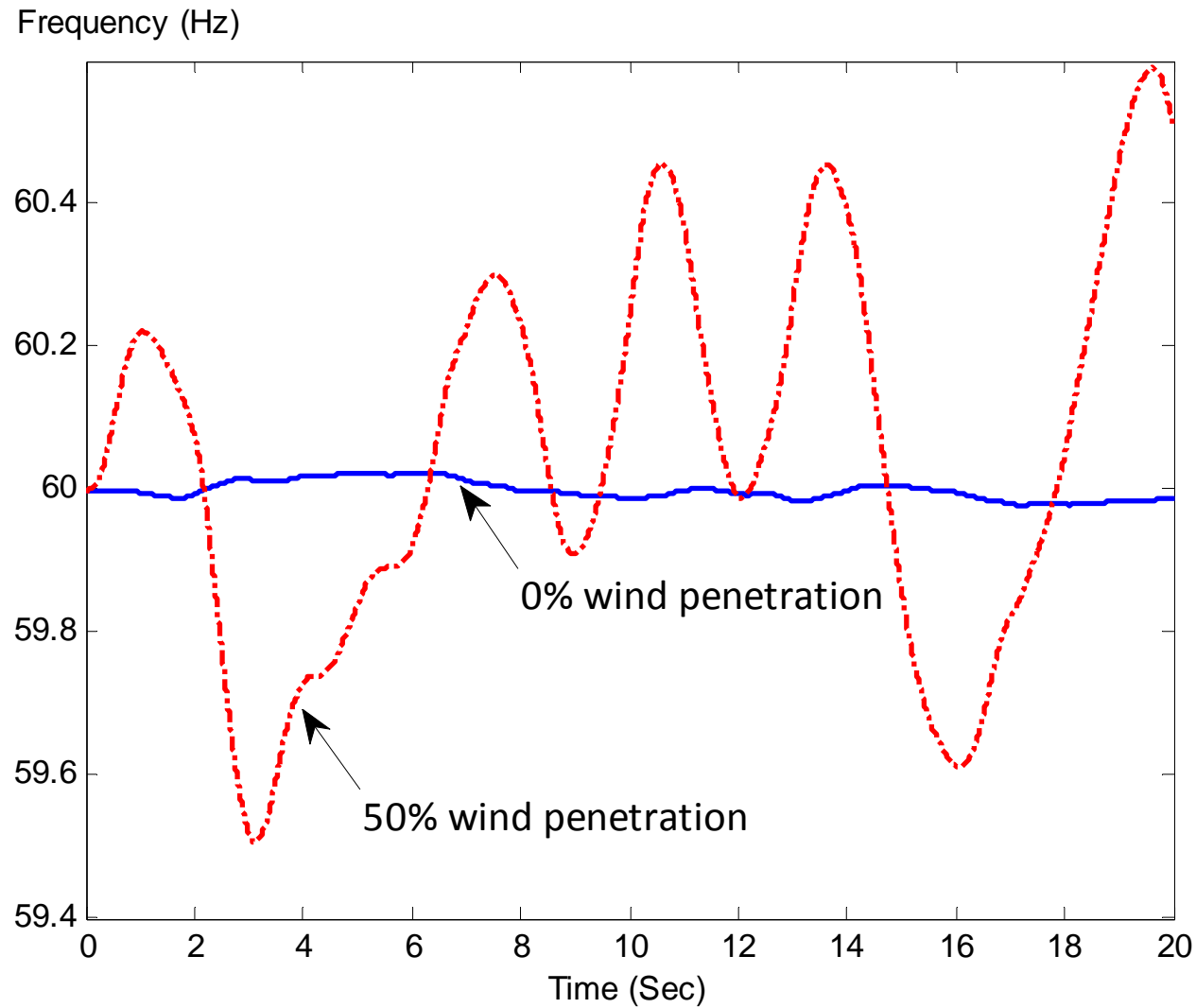
- Same amount of load; half of the traditional generation is replaced by wind generation



Load-wind generation scenario



Impact of Wind Generation



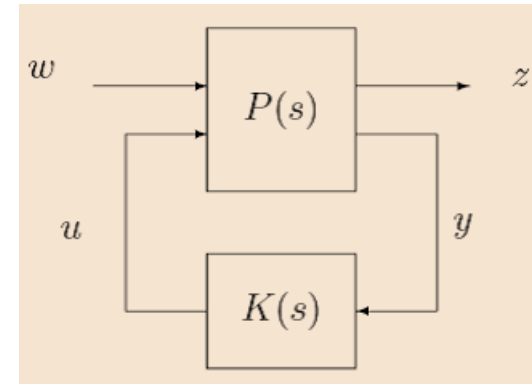
Robust Control for Frequency Regulation

- Measures must be taken to ensure frequency performance under normal conditions
 - storage
 - advanced wind turbine control
 - *advanced traditional plant (governor) control*
 - demand response, etc.

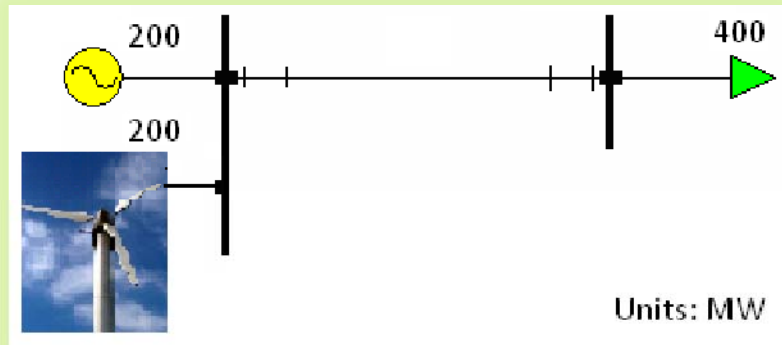
- Initial approach: Use H_∞ control theory to design controllers for the traditional plants

The H_∞ Approach

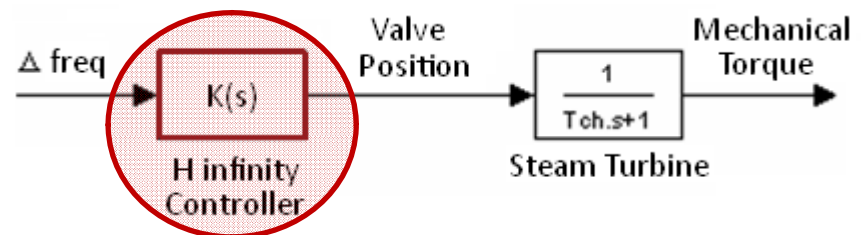
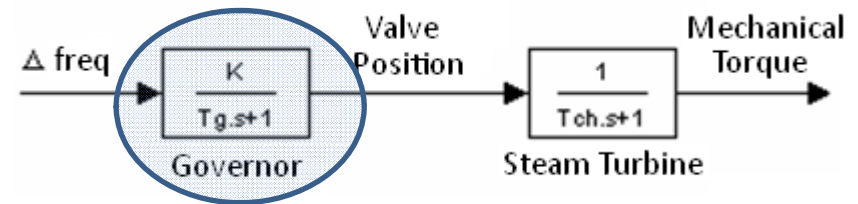
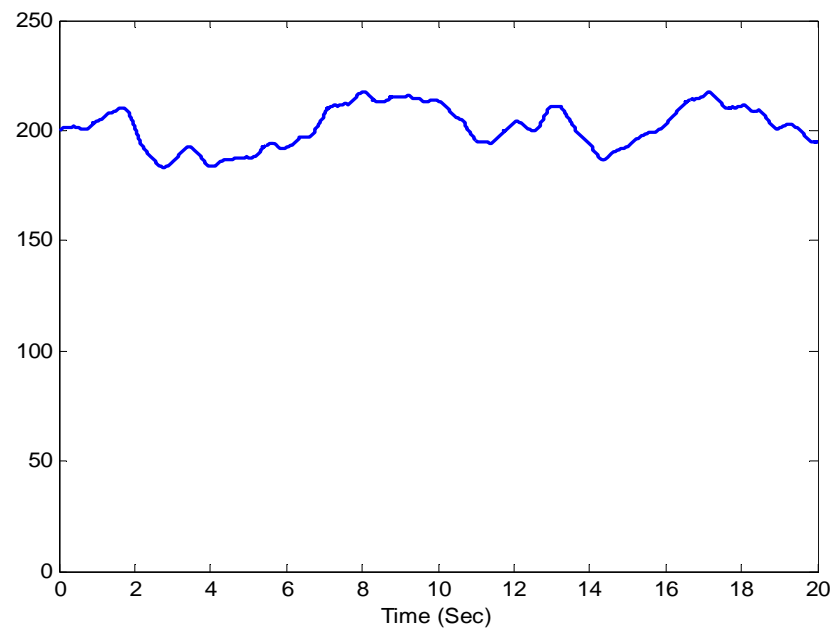
- Find a stabilizing controller K that minimizes the sensitivity from 'w' to 'z'
- Advantages
 - satisfies performance specifications
 - optimizes tradeoff between performance and control effort
 - can easily incorporate model/parameter uncertainty
 - mature software for design
- Disadvantage
 - can lead to high-order controllers, but effective model reduction techniques exist



2-bus Example

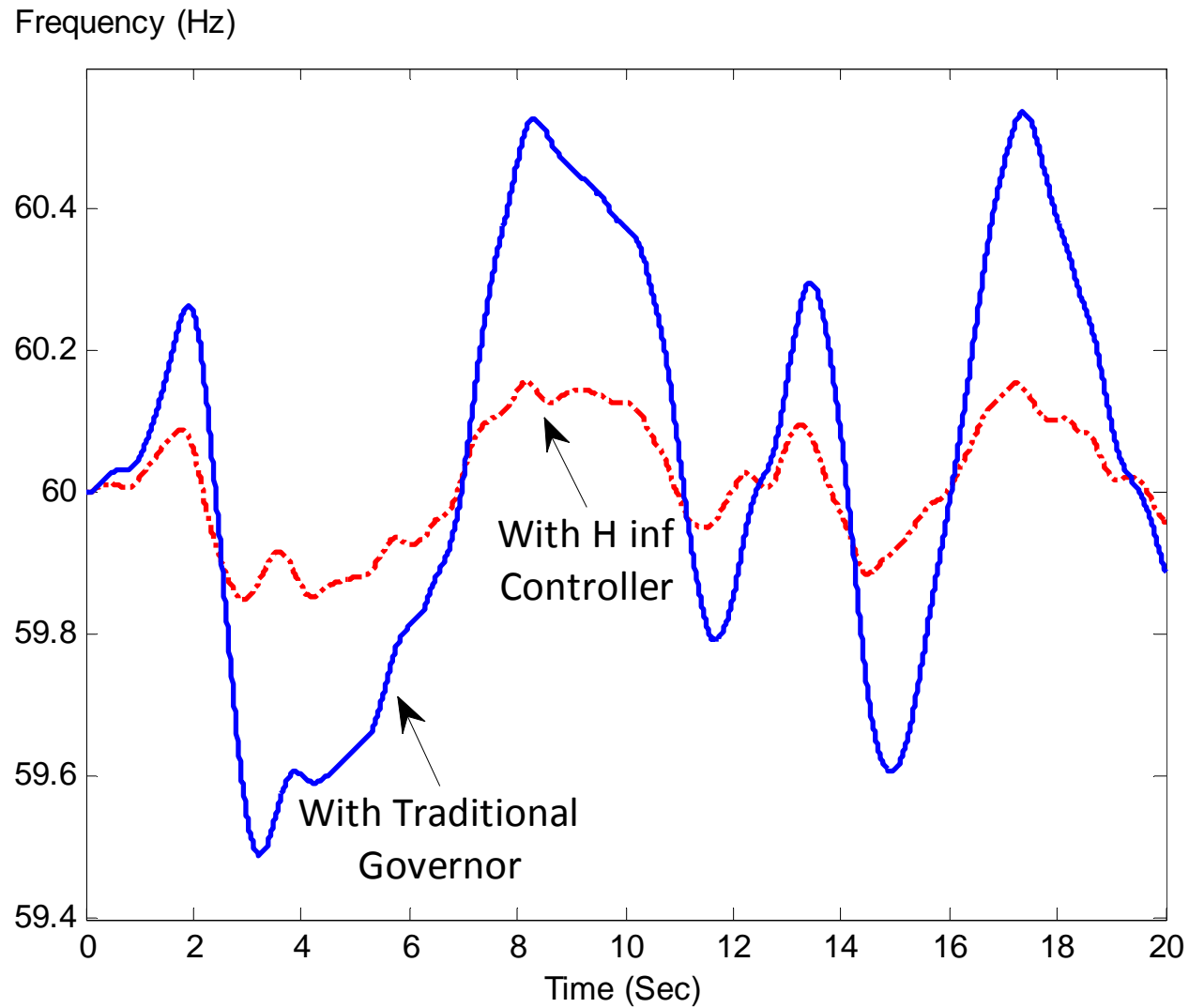


Wind Power (MW)

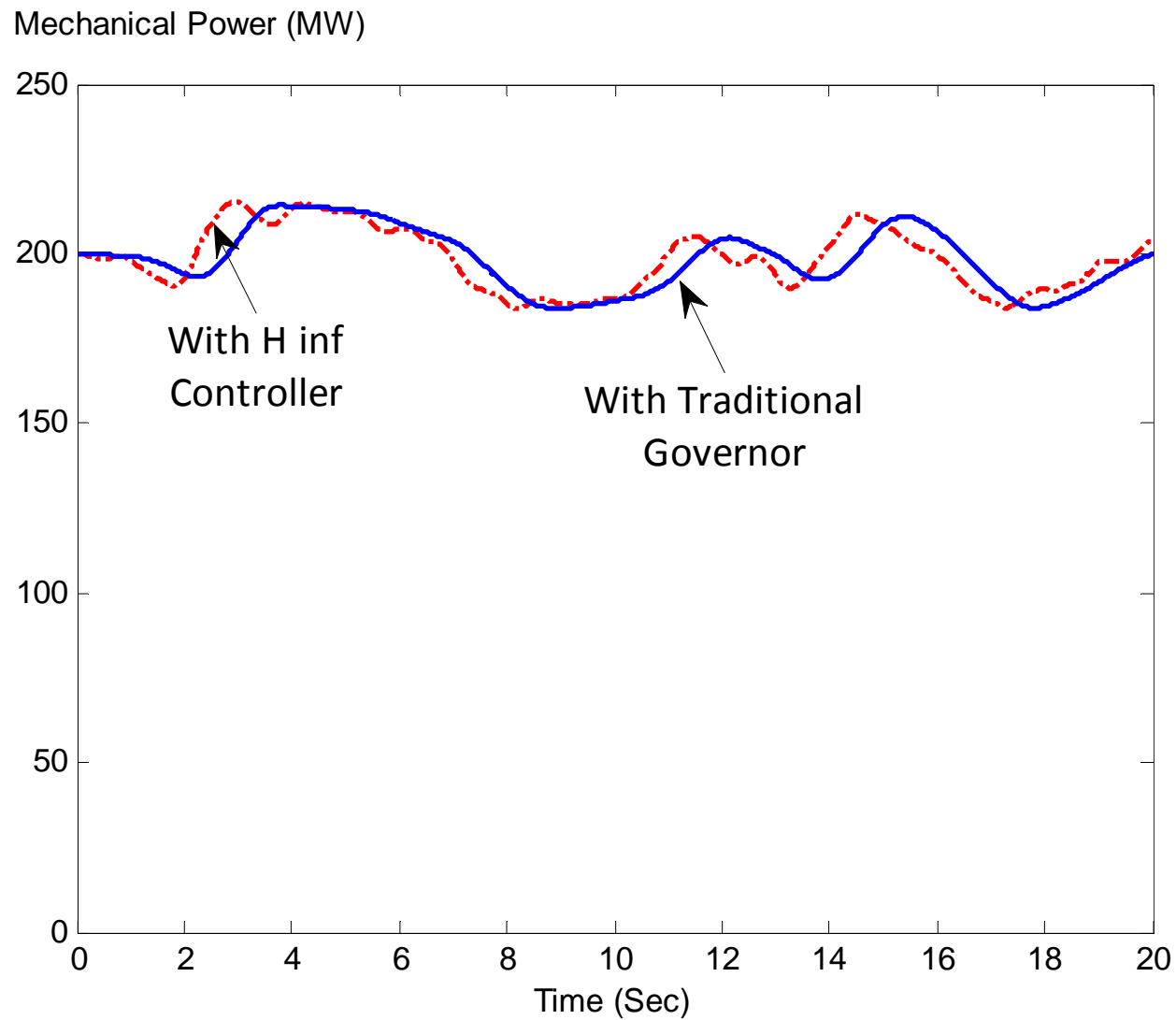


$$\frac{-124.5s - 414.8}{s^2 + 101.6s + 2523}$$

Traditional vs. H_∞ controllers



Mechanical Power



Current Research

- Decentralized control design
- Investigation of alternative control actions
 - Demand response
 - Gas-turbines
 - Storage devices
- Coordination with load-frequency control (AGC)
- Implications for system frequency specifications

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