

# QUANTIFICATION OF THE IMPACT OF SOLAR AND WIND POWER ON POWER GRID PERFORMANCE

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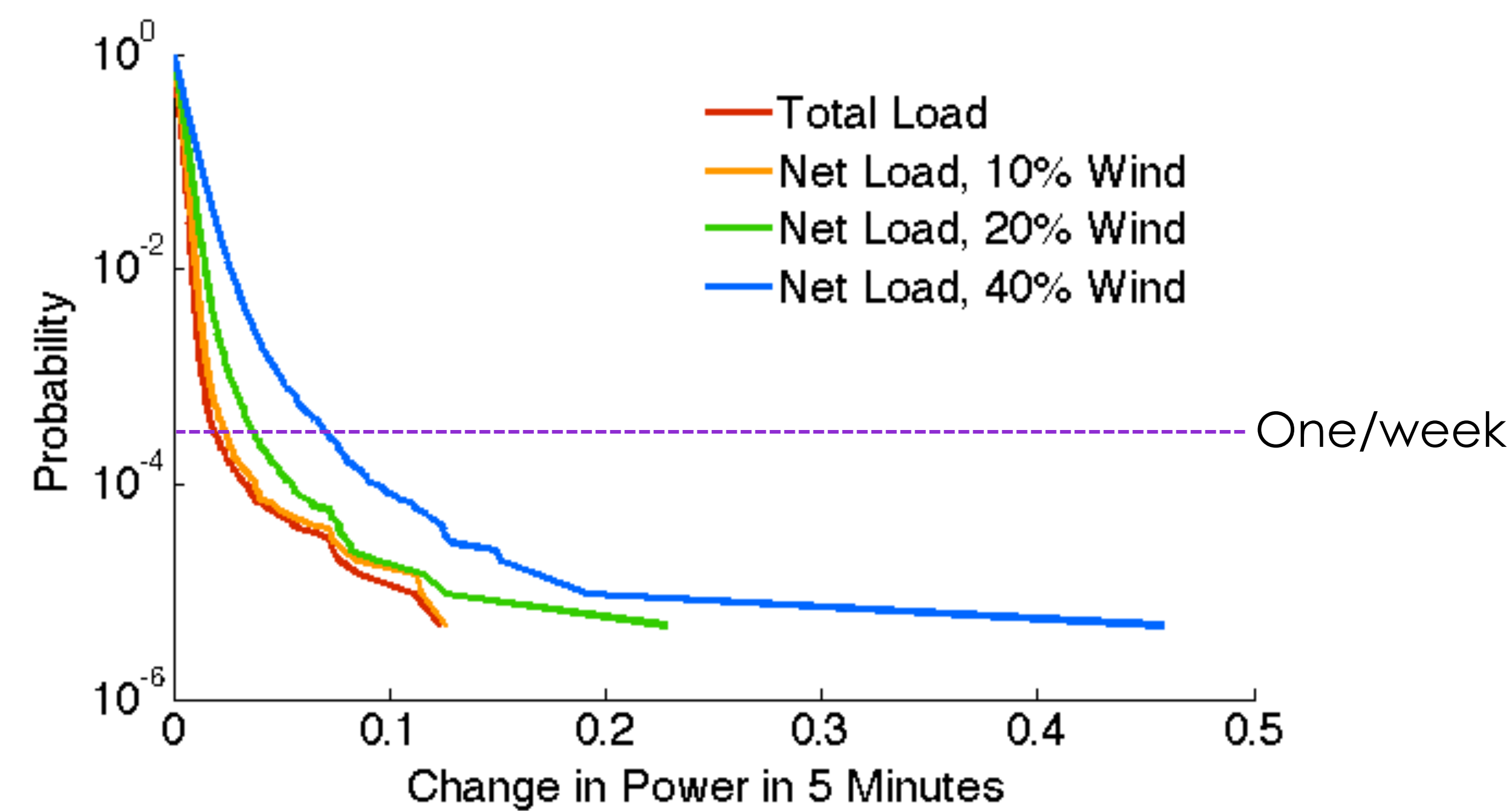
## Problem Statement

The impact of variable renewable generation on the power grid is of significant concern to utilities. Utilities must know the amount of backup generation ("regulation") needed to maintain adequate system performance amid this intermittency. Our research goals are to

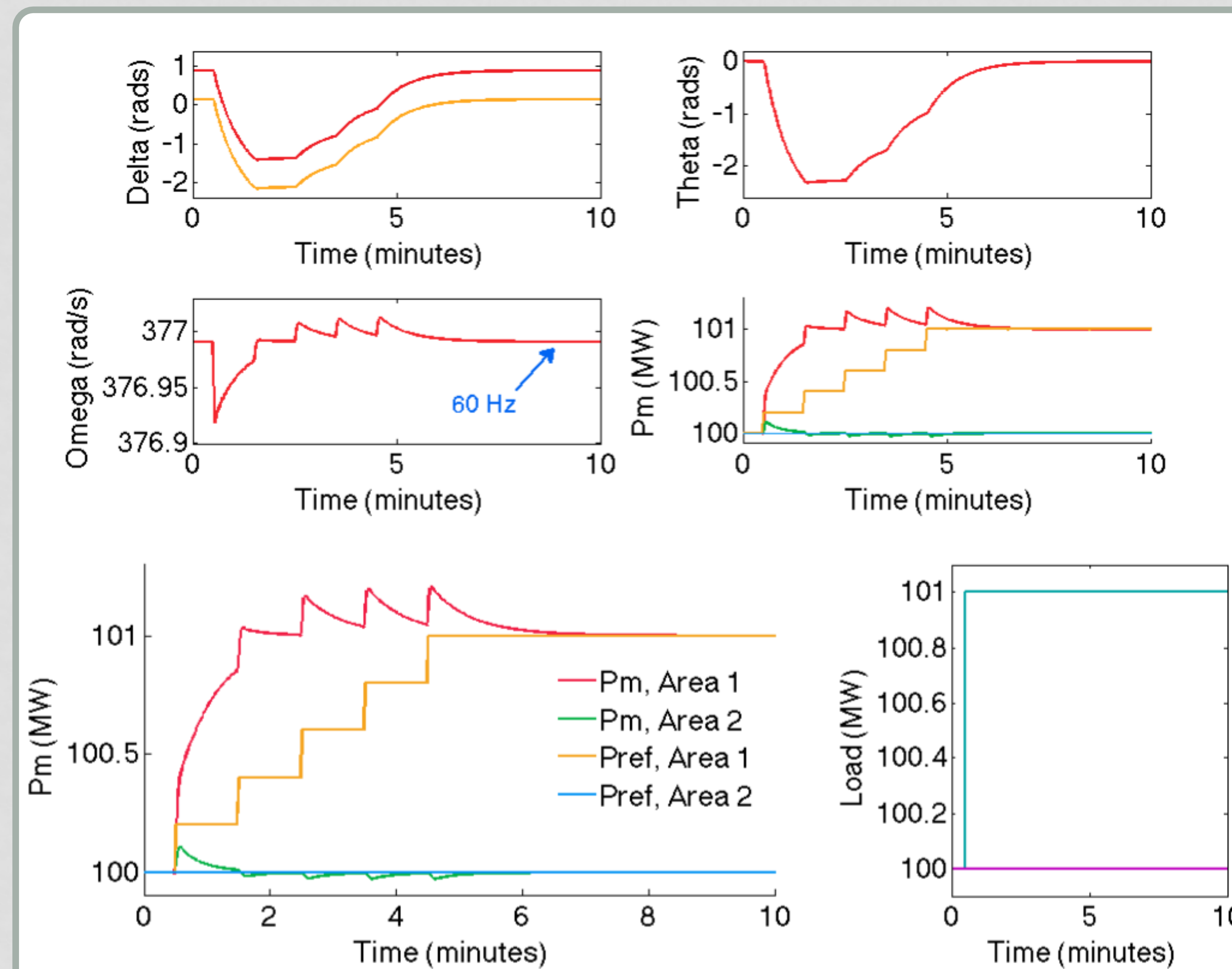
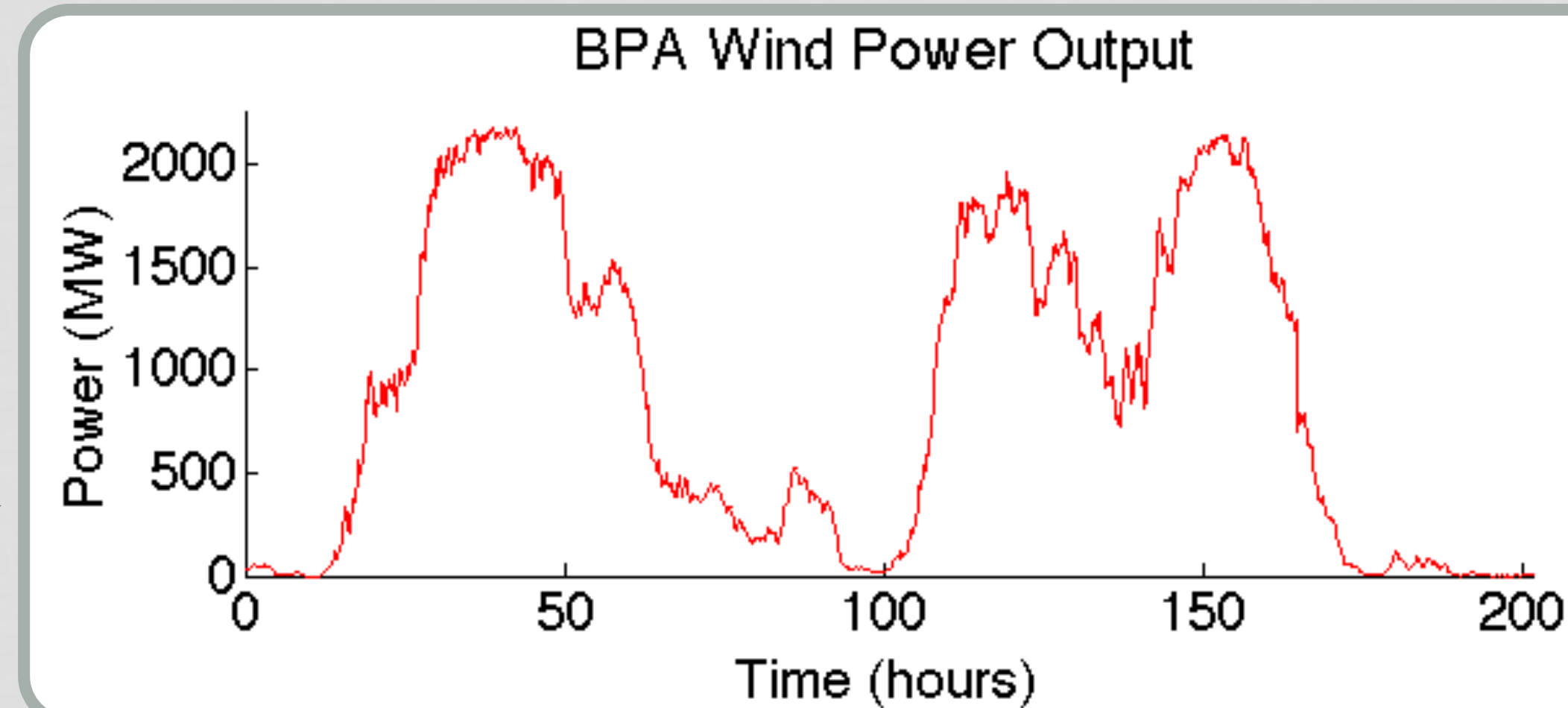
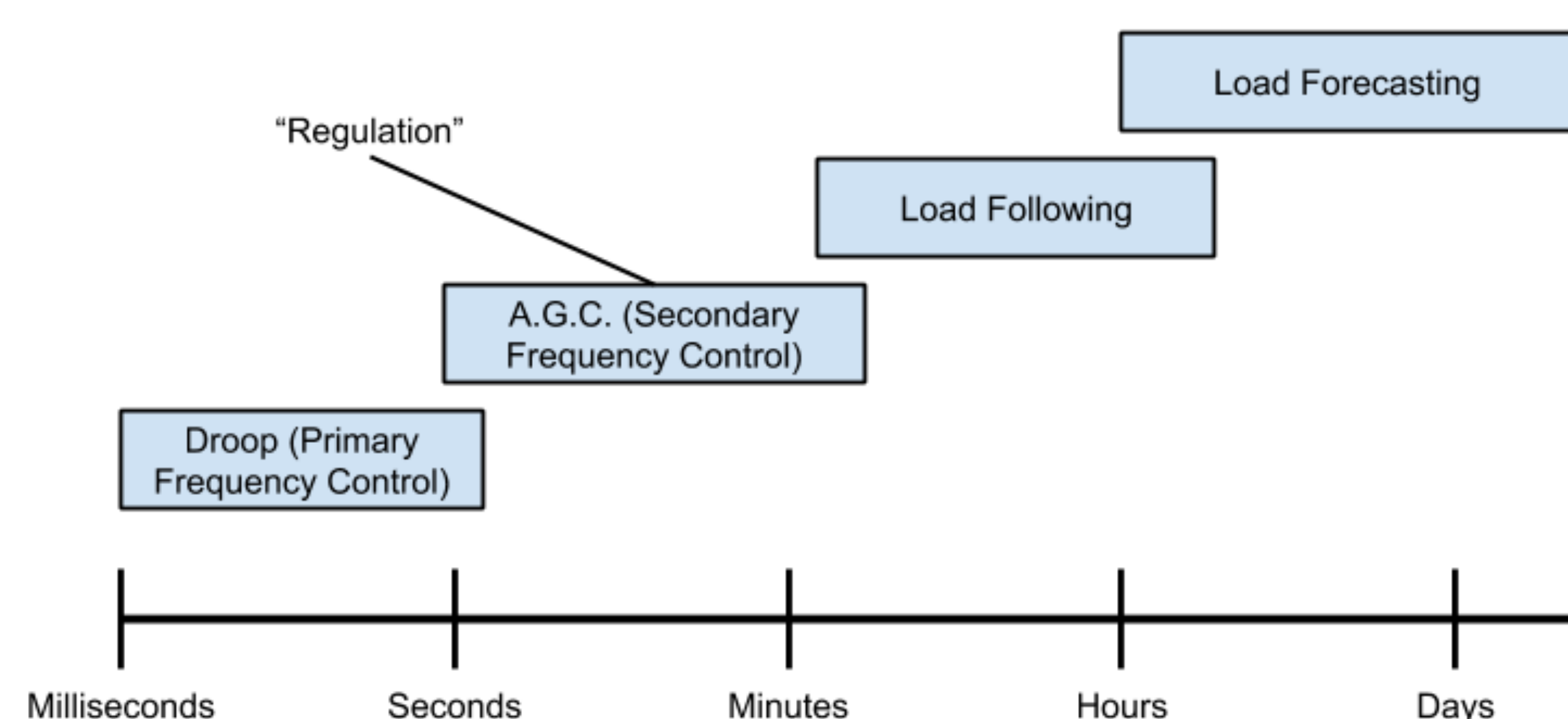
- Quantify the amount of regulation needed to maintain stability for varying wind penetration levels
- Identify how this quantity is influenced by
  - Dispatch frequency
  - Consolidation of balancing area
  - Amount of inertia

## Variability:

While load already presents some intermittency (the current use for regulation), increasing wind penetration level increases the overall variability of the net load (load-wind).



## Utility Control of Variability:



## Quantifying Frequency Performance:

$$CPS1 = (2 - CF) \cdot 100\%$$

$$CF_{minute} = \left( \frac{ACE}{-10B} \right)_{minute} \cdot \Delta F_{minute}$$

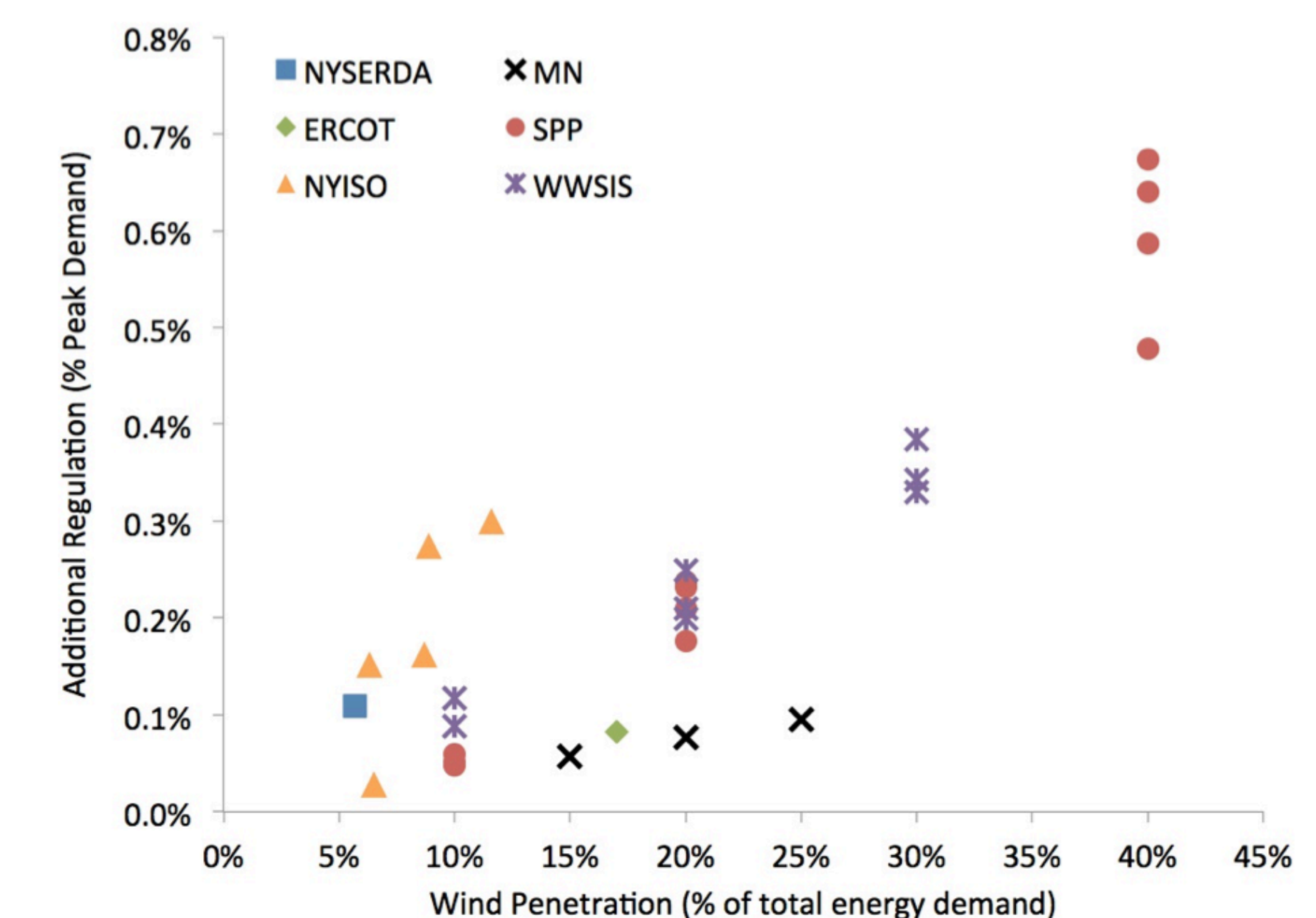
$$CPS2 = \left( 1 - \frac{Violations_{month}}{Total Periods_{month}} \right) \cdot 100\%$$

$$\left| \frac{\sum ACE}{n_{samples \text{ in } 10 \text{ minutes}}} \right| > L_{10}$$

## Dynamic Simulation:

Recently published wind studies aiming to quantify the necessary regulation tend to have two main issues:

- Limited Data: Most studies consider only 3-4 wind penetration levels, making it difficult to predict the general trend



- Lack of Dynamic Simulation: Most studies rely on unverified statistical inference of wind data to predict the necessary regulation, usually using 5 minute wind data at the highest resolution. However, this misses any performance issues on a sub-5 minute scale. Considering the intermittency of wind at sub-5 minute time scales, we expect to see performance effects on this scale, and thus instead employ a dynamic simulation model, which captures the second-to-second effects on performance.

$$P_g = P_m - D\Delta\omega - M\Delta\dot{\omega}$$

$$\dot{\delta} = \omega_0 \Delta\omega$$

$$T_g \dot{P}_m = P_{ref} + \Delta P_c - P_m - \frac{\Delta\omega}{R}$$

$$\dot{P}_c = -k \cdot ACE$$

$$[B] \Theta = P_g - P_d$$

Swing Equation: Physical Model of Generator

Droop Control

Automatic Generation Control (A.G.C.)

Algebraic Equations: Power Injection