



# **ECE 333 – GREEN ELECTRIC ENERGY**

## **10. Wind Farms and Environmental Effects**

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# WIND FARMS

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- ❑ A wind farm or wind park is a collection of a large number of wind turbines
- ❑ The objectives in wind farm developments are to
  - take advantage of the *economies of scale* in site preparation and grid interconnection;
  - maximize the utilization of a good wind site;
  - utilize effectively the centralized access for operations and maintenance

# WIND TURBINE PLACEMENT

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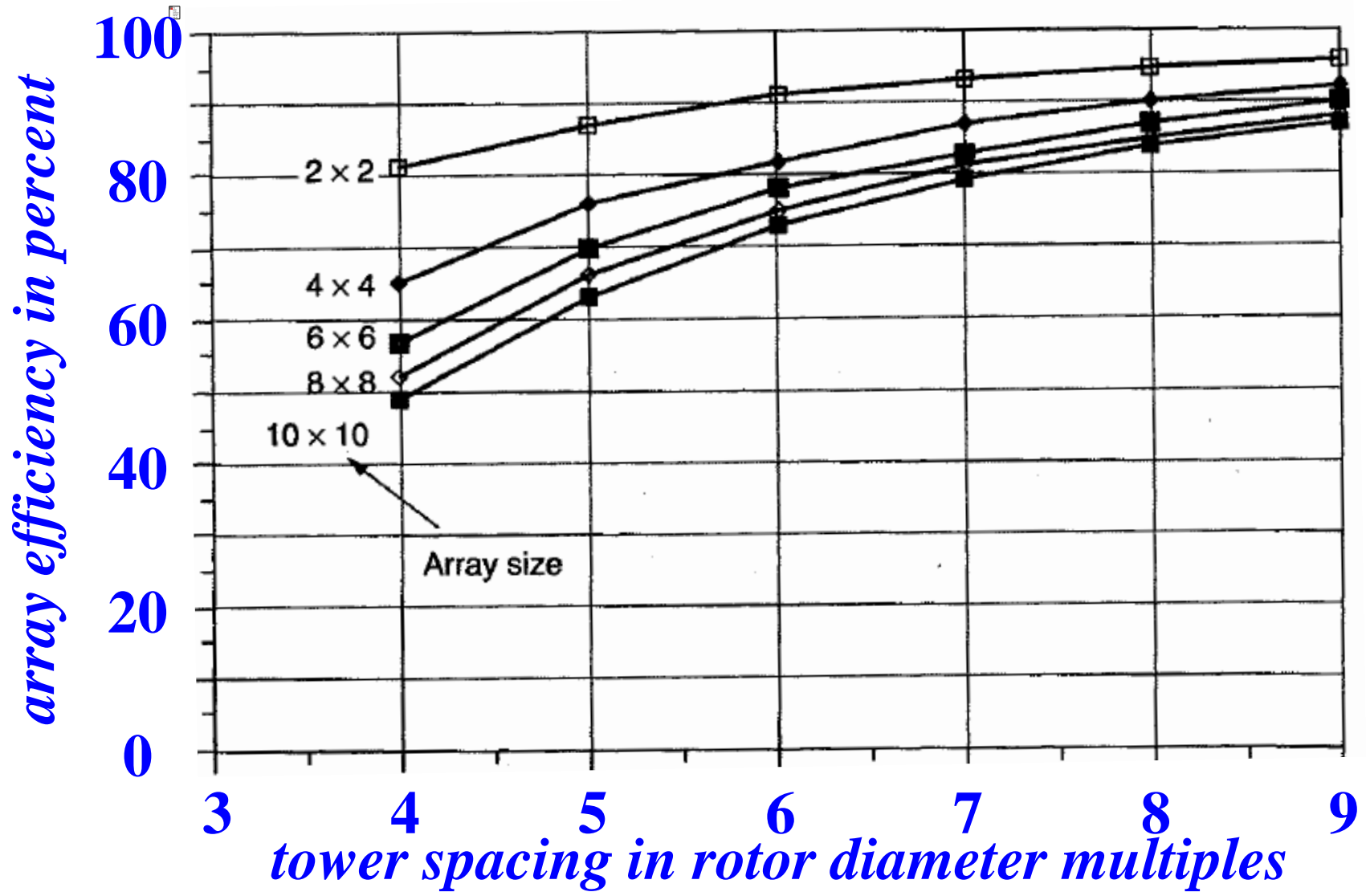
- ❑ Serious challenges arise in the determination of **the number and the placement** of the turbines
- ❑ The wind turbines require **appropriate spacing** in order to **avoid interference** with the wind used by the other, neighboring turbines
- ❑ The extraction of energy from wind passing the rotor blades reduces the wind speed and *adequate distance behind a turbine is needed* for the wind speed to return to its earlier, *undisturbed value*

# WIND TURBINE PLACEMENT

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- The appropriate placement of turbines requires consideration of some critical issues, such as
  - good, prevailing wind directions;
  - terrain irregularities;
  - siting of access roads; and
  - grid interconnection facilities

# WIND TURBINE PLACEMENT IMPACTS ARRAY EFFICIENCY



Source: Data from M. J. Grubb and N. I. Meyer, "Wind Energy: Resources, Systems and Regional Strategies," chapter 4 in Renewable Energy: Sources for Fuels and Electricity, Island Press, Washington, DC, 1993.

# WIND POWER FARM LAYOUT

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- ❑ A common layout is based on the placement of turbines in a systematic row-and-column array:
  - in each row a separation of *5 rotor diameters* is used between two turbines in a row perpendicular to the prevailing wind direction
  - spacing between two neighboring rows is roughly *10 rotor diameters*
- ❑ We refer to such a layout as a *5 d × 10 d array*
- ❑ In addition, we add *a buffer zone* around the array to lessen community impacts

# EXAMPLE: WIND FARM LAND REQUIREMENTS

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□ We consider the siting in 3 rows 30 2-MW turbines, each with 90-m rotor diameter using  $5d \times 10d$  array with a  $10d$  buffer zone around the entire array

□ The total area required is

*array area + buffer zone area*

$$= (9 \times 5d)(2 \times 10d) + 2(9 \times 5d + 20d)10d + 2(10d)(20d)$$

$$= 900d^2 + 1300d^2 + 400d^2$$

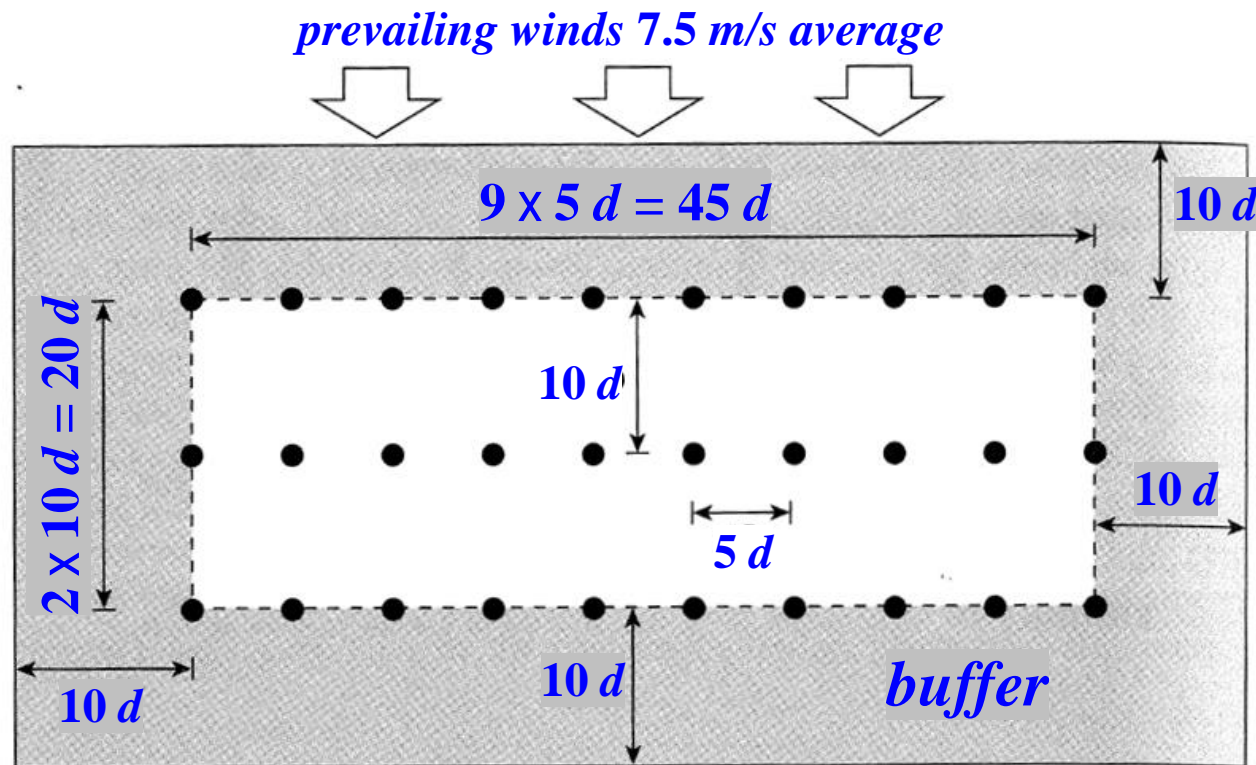
$$= 2600d^2$$

$$= 21.06 \times 10^6 m^2$$

# EXAMPLE: WIND FARM LAND REQUIREMENTS

- The power density is calculated to be

$$\frac{\textit{capacity installed}}{\textit{area required}} = \frac{60 \times 10^6 \textit{ W}}{21.06 \times 10^6 \textit{ m}^2} = 2.85 \frac{\textit{W}}{\textit{m}^2}$$





# ENVIRONMENTAL ASPECTS

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- The 2007 report by the *US* National Academies on environmental aspects emphasized the benefits of wind generation, including
  - no air pollution and no  $CO_2$  emissions
  - no water requirements
  - net decrease in pollution due to *displacement of energy from fossil-fired sources by renewable energy*

# WIND ENERGY



**no** external energy dependence

**no** energy imports

**no** fuel costs

**no** fuel price risk

**no** exploration

**no** extraction

**no** refining

**no** pipelines

**no** resource constraints

**no** CO2 emissions

**no** radioactive waste

Source: EWEA, <http://www.no-fuel.org/>

Can you say **no** to that?

# ENVIRONMENTAL ASPECTS

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- ❑ Wind resource is, in essence, free; operators try to harness as much wind energy as possible; unfortunately, sometimes they have no choice but curtail wind
- ❑ Wind may impact people near wind farms due to noise and side effects of rotor spin

# NOISE AND SHADOW FLICKER

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- ❑ Wind turbines often enhance the well being of many people, but those living nearby may be affected by **noise and shadow flicker**
- ❑ Noise comes from the **turbine gearbox and the aerodynamic blade interactions with the wind**
- ❑ Noise impact is, typically, **moderate at 50 – 60 dB** within a **40–m** distance and lower at larger distances with noise at **35–45 dB** at a **300–m** distance

# NOISE AND SHADOW FLICKER

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- The *wind turbine spectrum* contains frequencies with both a “hum” above 100  $Hz$  and some barely audible or completely inaudible low frequencies at or below 20  $Hz$
- Shadow flicker is a more severe issue in higher latitude countries due to the longer shadows cast by lower sun

# SHADOW FLICKER

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- ❑ Shadow flicker is a **visual phenomenon** produced by wind turbines and is defined as the alternating changes in light intensity that can occur at times when the **rotation of turbine blades casts moving shadows on the ground or on structures**
- ❑ Shadow flicker depends on wind direction and time of day and is, typically, limited to locations **within 10 rotor diameters of a wind project**

# SHADOW FLICKER VIDEO

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<https://www.youtube.com/watch?v=Mble0iUtelQ>

# WIND TURBINES AND RADAR

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- ❑ Wind turbines impact radar through either radar shadows or Doppler returns that resemble false aircraft or weather patterns
- ❑ As a result of the interference with radar, the *FAA*, *DHS*, and *DoD* have contested many proposed wind turbine sites
- ❑ There exists no fundamental constraint with respect to radar interference, but mitigation might require either upgrades to radar or new rules that stipulate the installation of telemetry from wind farms to the radar sites



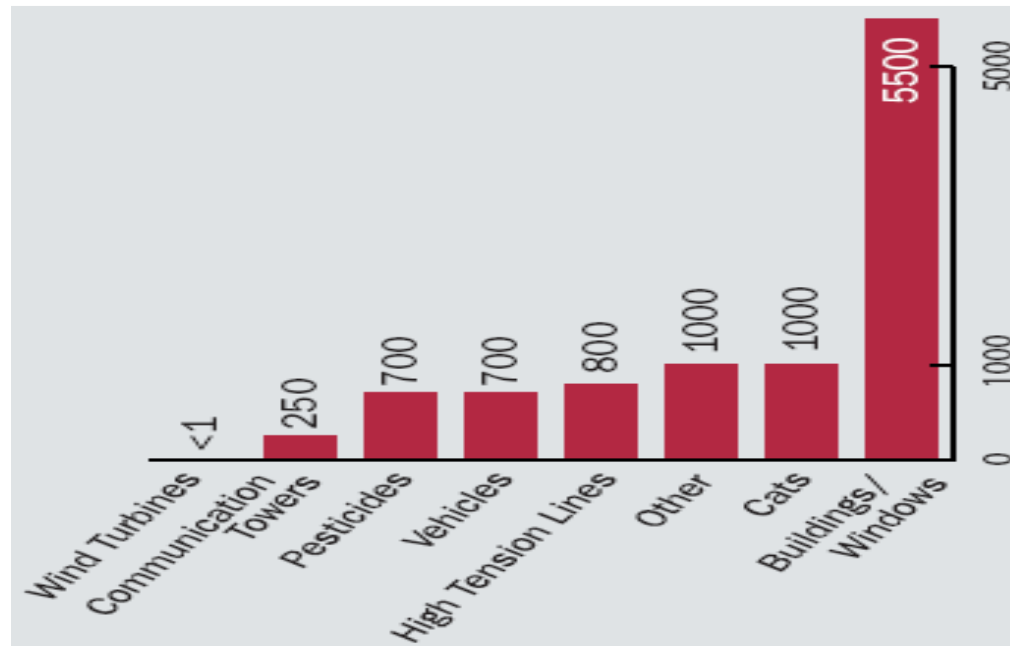
# WIND TURBINES AND RADAR

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- The mitigation measures to address the possible interference, may require the wind farm to reimburse the needed radar upgrades to overcome interference: e.g., the *Fort Cape Wind* project developer agreed to pay for \$ 1.5 million in radar equipment upgrades at the nearby military base and put in escrow an additional \$ 15 million to address any future issues that may arise

# WIND IMPACT ON BIRDS AND BATS

- ❑ Wind turbines certainly kill birds and bats, but so do other structures such as windows, which kill between 100 and 900 million birds per year
- ❑ The diagram below shows the estimated share *per* 10,000 birds of each key cause of bird fatalities



Source: Erickson, et.al, 2002. Summary of Anthropogenic Causes of Bird Mortality

# A POSSIBLE “FIX” FOR BIRD DEATH REDUCTION

- The <sup>U.S.</sup> *US Fish & Wildlife Service* estimated that for the 49,000 wind turbines located in 39 states in 2015 the range of bird fatalities from turbine collisions to be from 140,000 to 500,000 birds per year



Source: <https://arstechnica.com/science/2020/08/black-paint-on-wind-turbines-helps-prevent-bird-massacres/>

- A single 9-year study conducted at a wind farm on the Norwegian *Smøla* archipelago indicates that black paint on a single blade of a turbine may reduce the number of bird fatalities

# ENVIRONMENTAL ASPECTS OF WIND ON HUMANS

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- ❑ Aesthetics is often the primary human concern about wind energy projects, as beauty is often in the eyes of the beholder
- ❑ Another issue may arise from night lighting

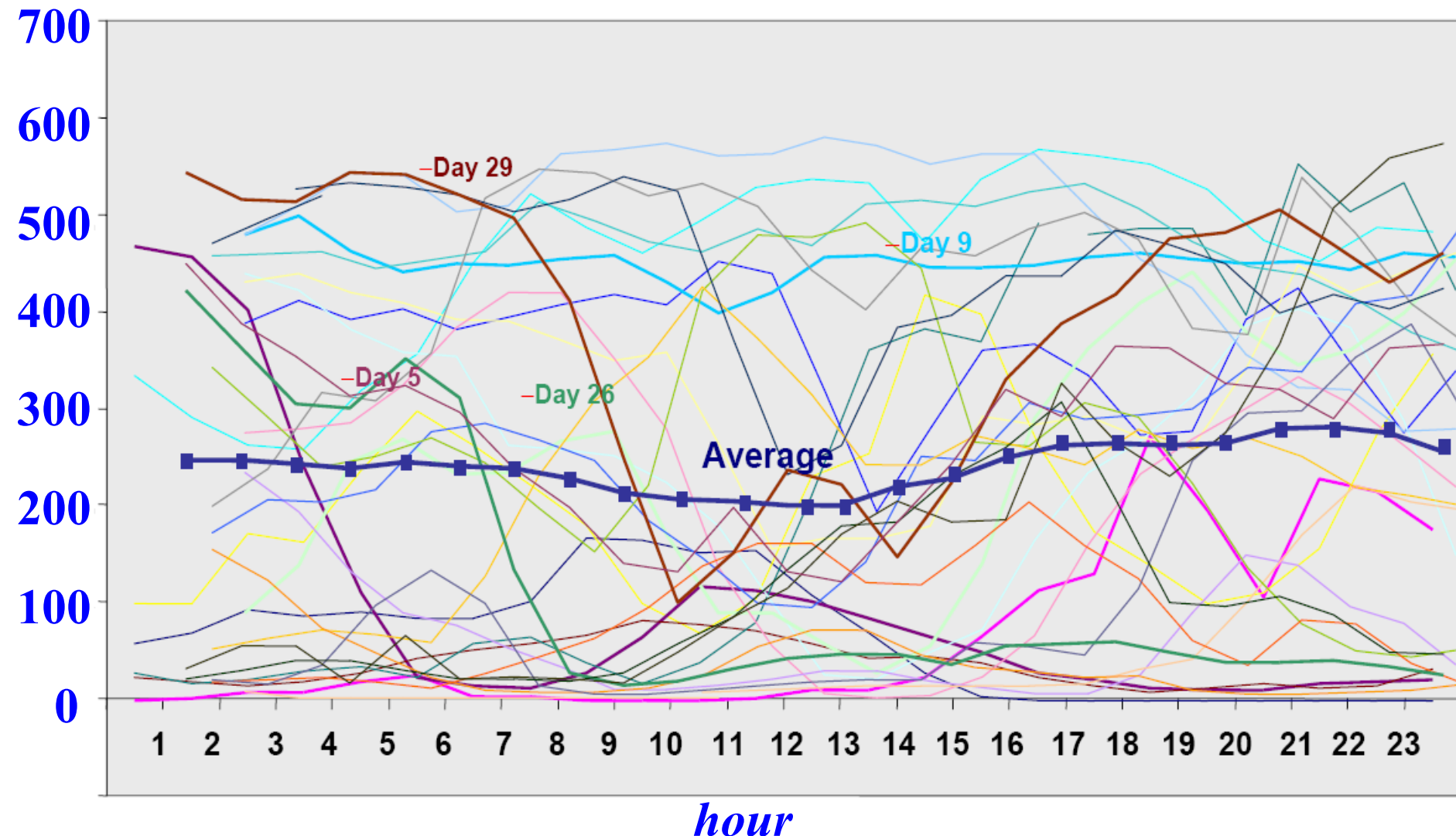


*Source: Figure 4-1 of NAS Report, Mountaineer Project 0.5 miles*

# CAISO APRIL 2005 DAILY WIND PATTERNS

MW

Source: CAISO

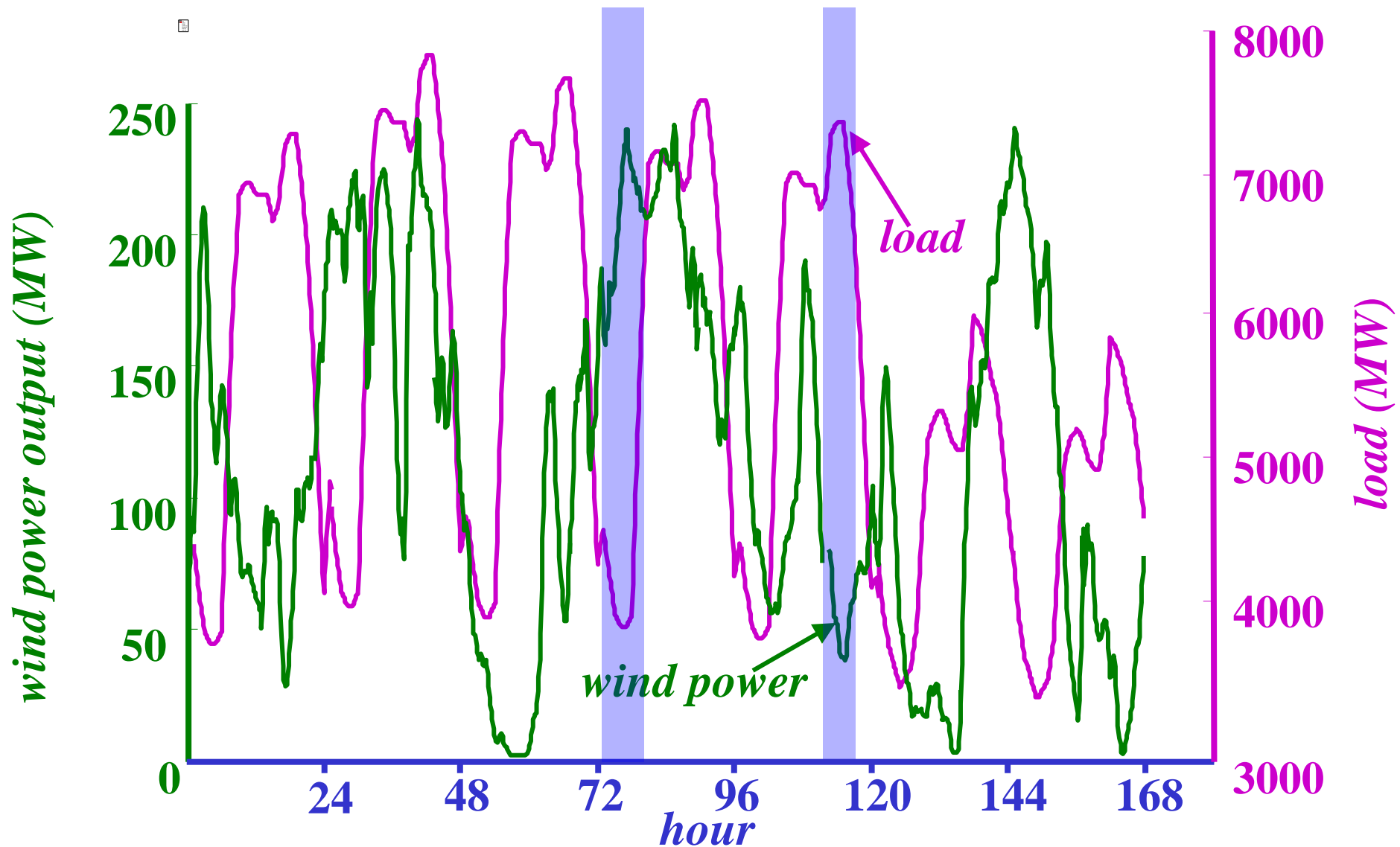


# VARIATION OF WIND OVER TIME

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- A key consideration in the effective utilization of wind is the **correlation between wind and loads**: how good is the timing of high-wind speeds *vis-à-vis* the loads that must be supplied
- Wind patterns vary quite a bit with geography – costal and mountain regions have more steady winds – and weather conditions, such as the temperature
- In the **Midwest**, the wind tends to blow the strongest when the electric load is the lowest and so there is a *virtually perfect mismatch*

# MISALIGNMENT OF WIND POWER OUTPUT AND LOAD



# INTEGRATION OF WIND ENERGY INTO THE POWER GRID

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- Wind power impacts grid operations in many ways ranging from transient and dynamic effects to steady-state power flow behavior, with voltage and frequency impacts being key concerns
- The large variability of wind requires operators to take measures to manage their impacts in order to maintain the operational reliability of the grid

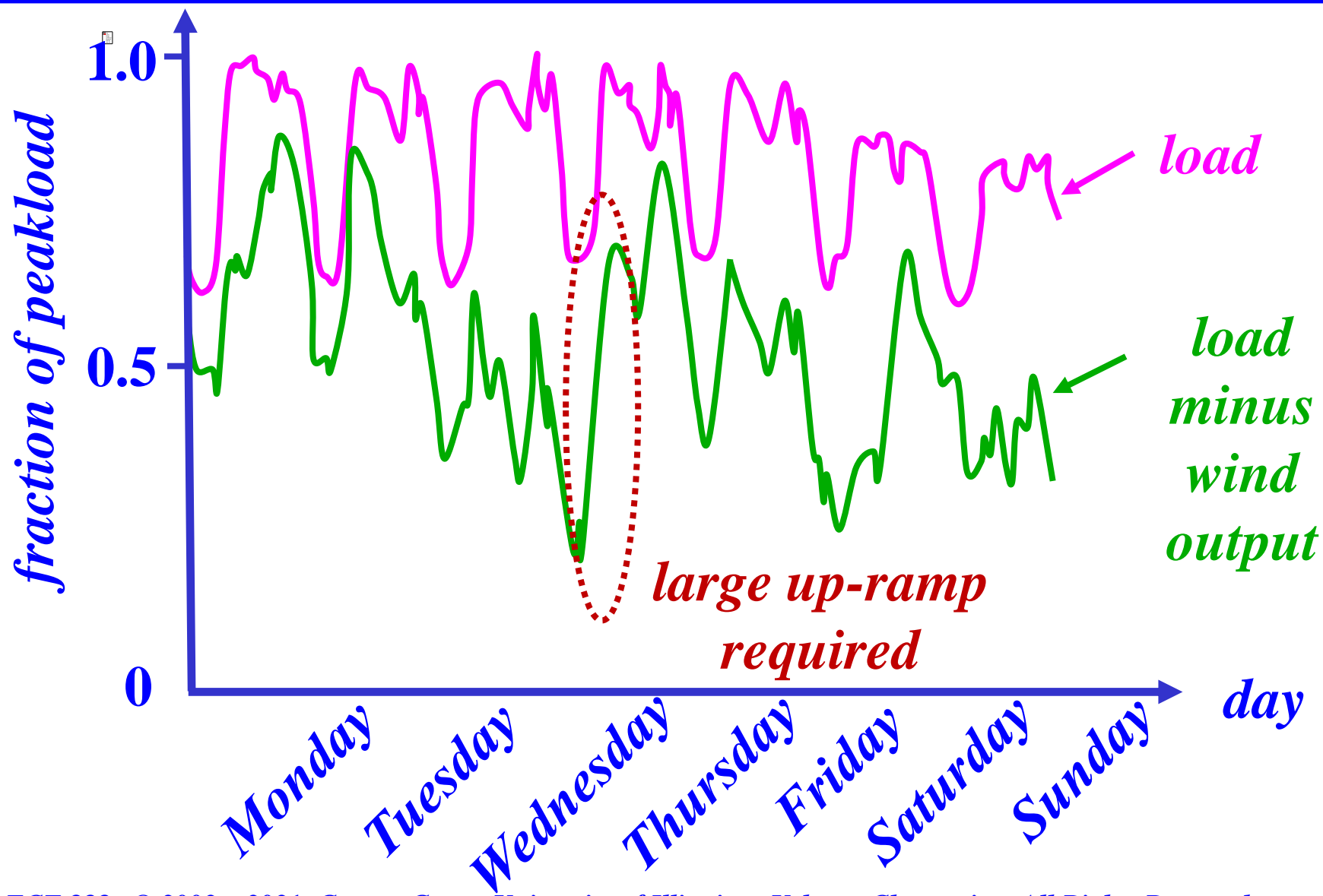


# CAPACITY RESERVES AND FREQUENCY REGULATION

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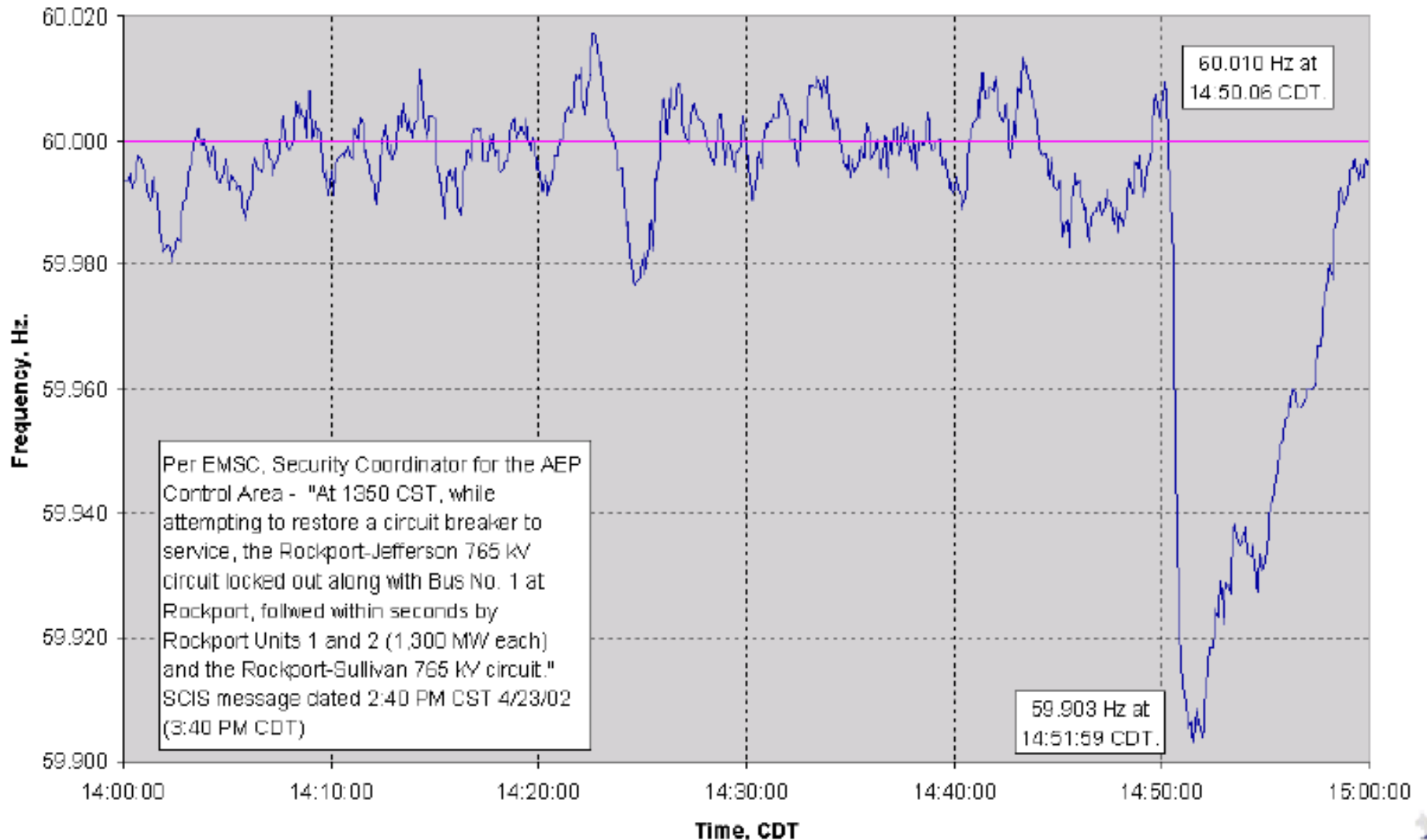
- ❑ A key need in power system operations is to ensure that power system generation exactly matches the total load plus losses **at all times**
- ❑ Generation shortfalls can suddenly occur because of the loss of a generator and operators must maintain sufficient reserves – generation that is on–line but not fully loaded – to account for **the loss of the largest single generator in a region and possibly additional contingencies**
- ❑ Moreover, the operators must ensure that the frequency in the system is maintained at its **nominal value**

# EFFECTS OF DEEP WIND PENETRATION INTEGRATED INTO THE GRID



Adapted from: M. Lange & U. Focken, "Physical Approach to Short-Term Wind Power Prediction", Springer, 2006

# EASTERN INTERCONNECT FREQUNECY RESPONSE FOR A 2,600 – MW LOSS



# CAPACITY RESERVES AND FREQUENCY REGULATION

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- As a wind turbine output varies with the cube of the wind speed, even a modest drop in the wind speed can result in a marked loss of generation
- Due to the *limited controllability* of wind resources, the operator has no choice but to depend more extensively on conventional resources to supply *adequate reserves* and around-the-clock *frequency regulation*; retirements of the conventional fossil-fired units are rapidly reducing their capacity