ECE 333 – GREEN ELECTRIC ENERGY

7. Wind Farms and Environmental Effects

George Gross

Department of Electrical and Computer Engineering

University of Illinois at Urbana-Champaign

WIND FARMS

- A wind farm is a collection of a large number of wind turbines
- The motivation to develop wind farms is due to
  - economies of scale in site preparation and grid interconnection;
  - ability to maximize the utilization of a good wind site; and,
  - centralized access for operations and maintenance

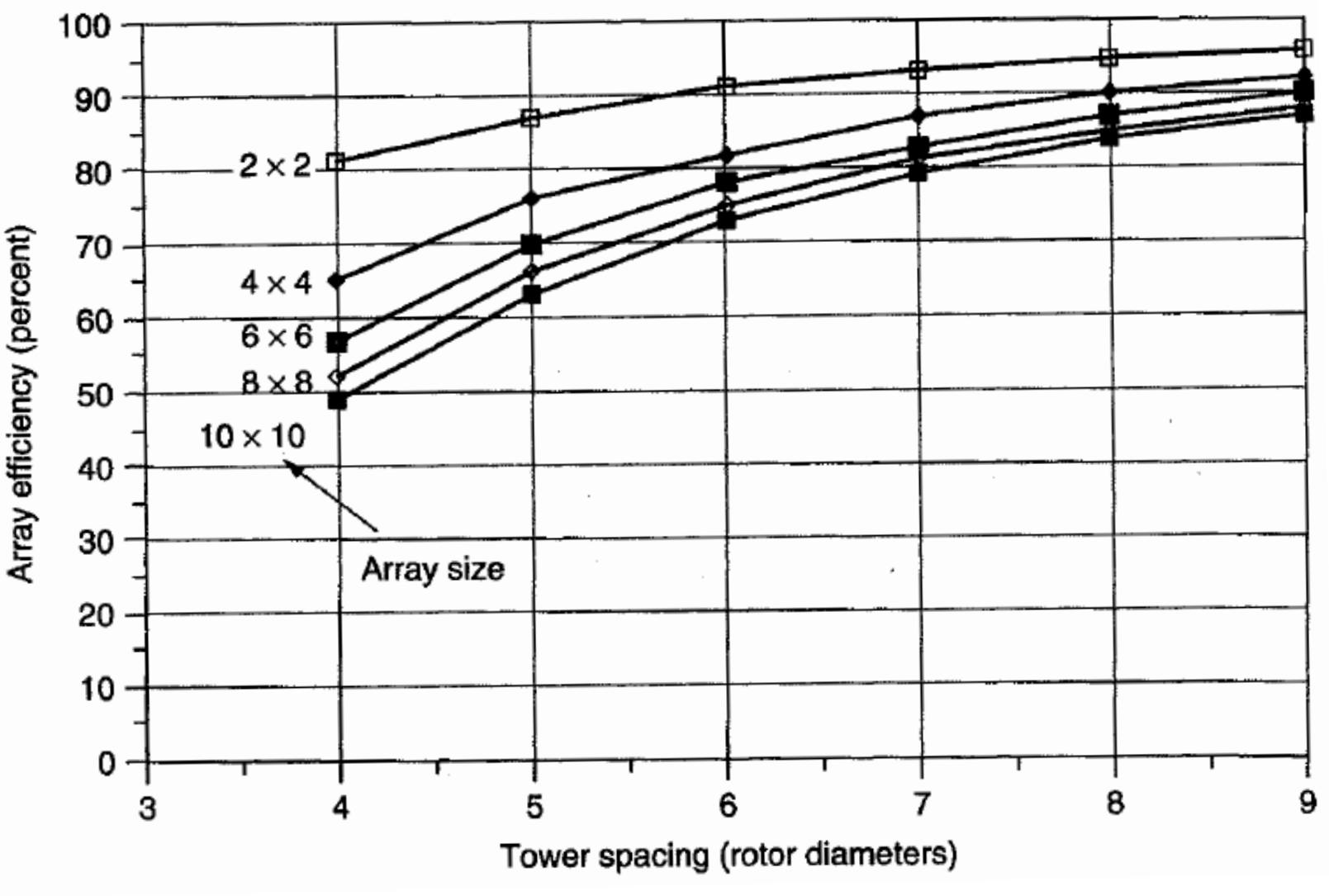
WIND TURBINE PLACEMENT

- There are serious challenges in the determination of the number and the placement of the turbines
- The wind turbines require adequate spacing so as to avoid interference with the wind used by the other turbines
- The extraction of energy as the wind passes the rotor blades reduces the wind speed and so distance behind a turbine is required for the wind speed to recover to its undisturbed value

WIND TURBINE PLACEMENT

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

WIND TURBINE PLACEMENT IMPACTS ARRAY EFFICIENCY



WIND POWER PLANT LAYOUT

- 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 rows is about 10 *rotor diameters*
- Such a layout is referred to as a $5\,d \times 10\,d$ array
- In addition, a buffer zone is added around the entire array

EXAMPLE: WIND FARM LAND REQUIREMENTS

- We consider the siting of 30 2–MW turbines each with 90–m rotor diameter using $5\,d \times 10\,d$ spacing and $10\,d$ of buffer zone around the entire array
- The total area required is

$$= \textit{array area} + \textit{buffer zone area}$$

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

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

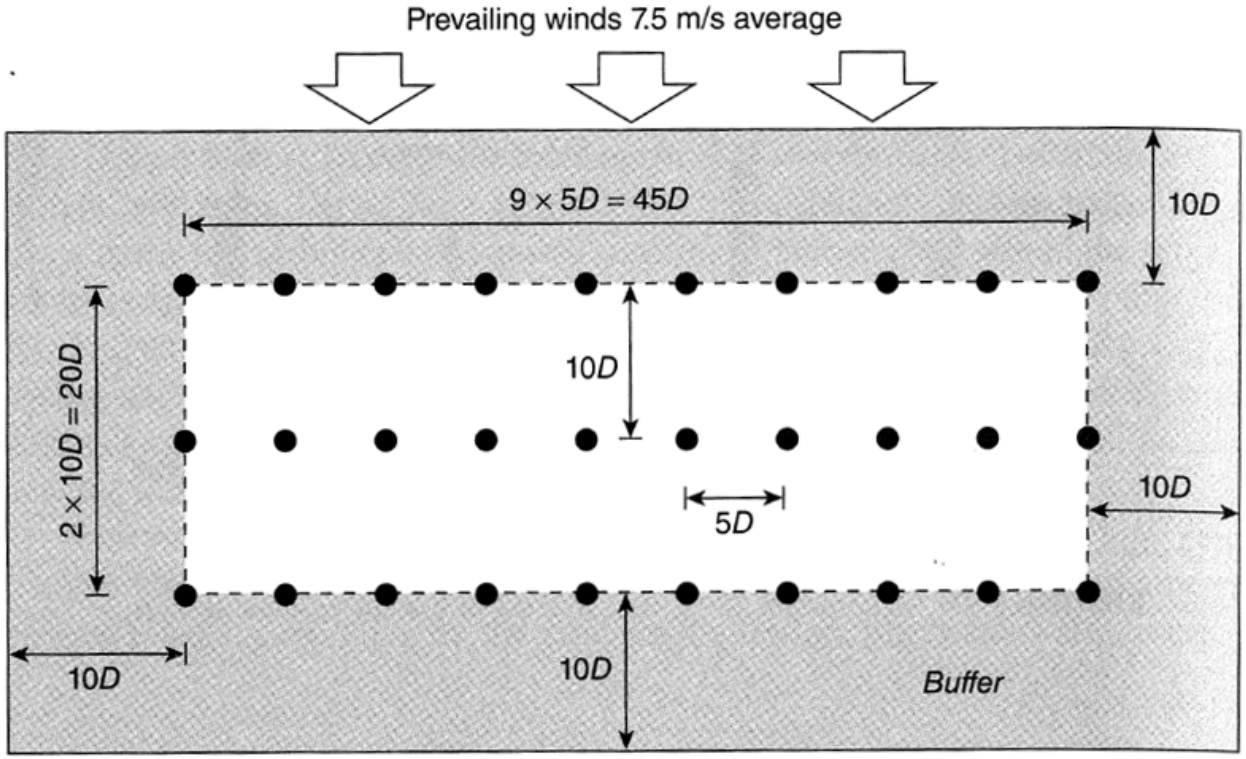
$$= 2600\,d^2$$

$$= 21.06 \times 10^6$$

EXAMPLE: WIND FARM LAND REQUIREMENTS

- The power density is

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



ENVIRONMENTAL ASPECTS

- The 2007 *US* National Academies report on the environmental aspects emphasized the beneficial impacts of wind
  - no air pollution and no CO_2 emissions
  - no water requirements
  - net decrease in pollution due to displacement of energy from fossil-fired sources

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** CO_2 emissions
- **no** radioactive waste

Can you say **no** to that?

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

ENVIRONMENTAL ASPECTS

- Wind resource is essentially free and operators try to harness as much wind as possible; however, sometimes they have no choice but to curtail wind
- Wind may impact people near wind farms due to noise and shadow flicker

NOISE AND SHADOW FLICKER

- 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 gearbox of the generator and the aerodynamic interaction of the blades with the wind
- Noise impact is, typically, moderate at $50 - 60\ dB$ within a $40\text{–}m$ distance and lower at further distances with noise at $35\text{–}45\ dB$ at a $300\text{–}m$ distance

NOISE AND SHADOW FLICKER

- The wind turbine spectrum contains frequencies with both a "hum" above $100\ Hz$ and some inaudible or barely audible low frequencies $20\ Hz$ or below
- Shadow flicker is more of an issue in high latitude countries since lower sun casts longer shadows

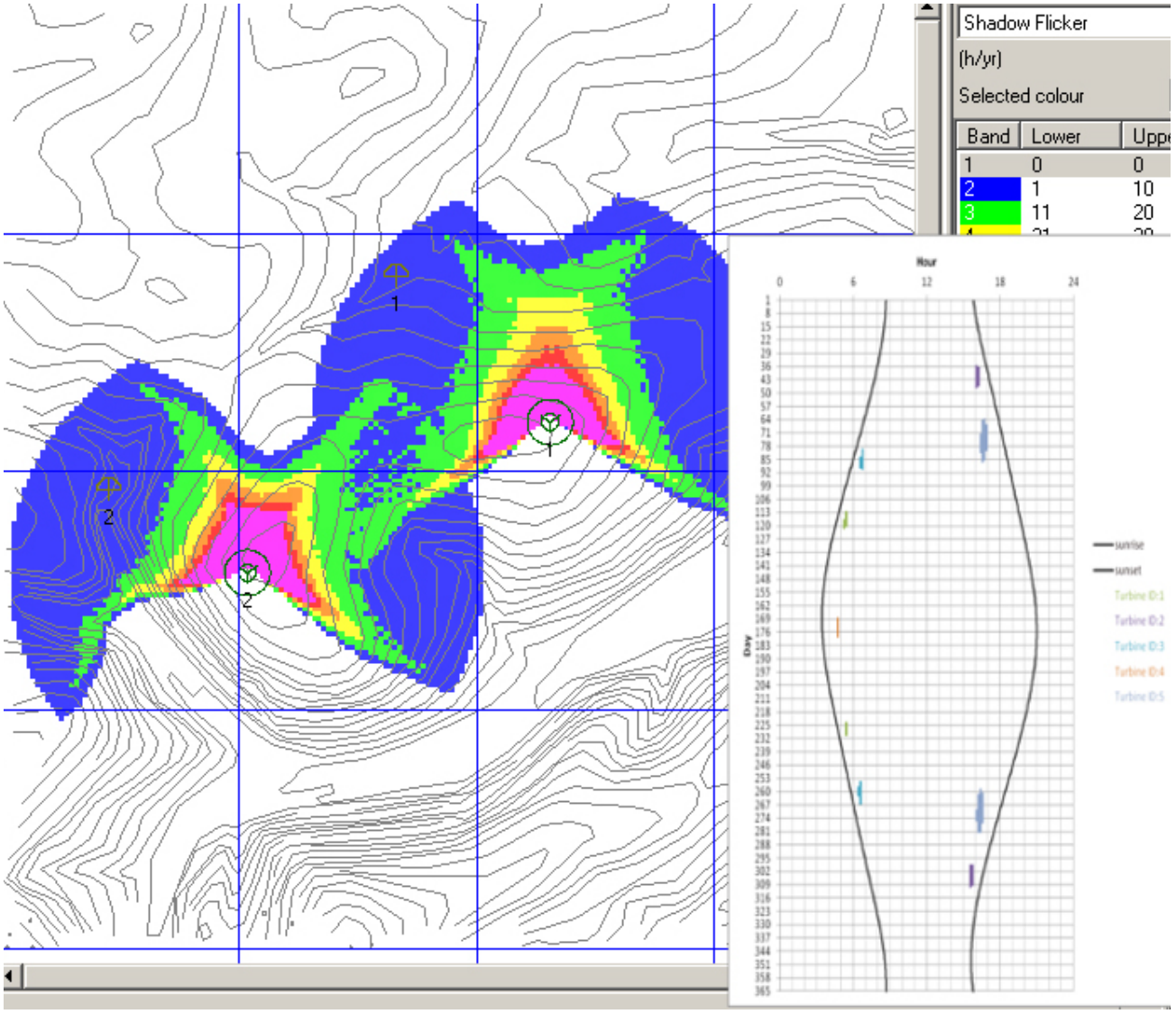
SHADOW FLICKER

- 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

https://www.youtube.com/watch?v=Mble0iUteIQ

SHADOW FLICKER



WIND TURBINES AND RADAR

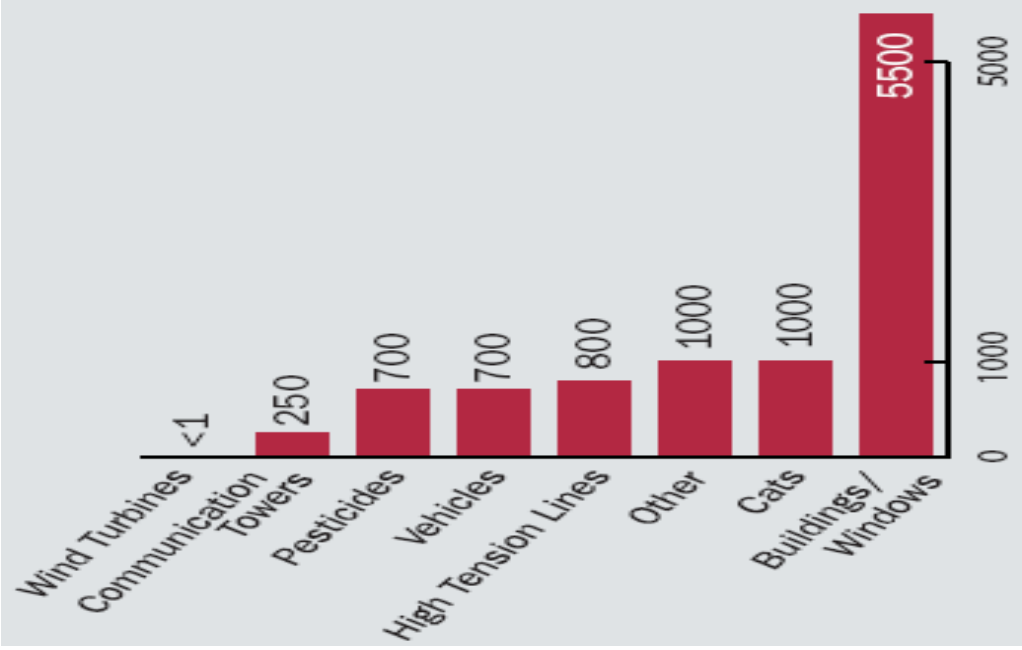
- Wind turbines impact radar through either radar shadows or Doppler returns that look like false aircraft or weather patterns
- As a result of the interference with radar, the *FAA*, *DHS*, and *DoD* have contested many proposed wind turbine sites
- There exists no fundamental constraint with respect 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

- The mitigation measures to address the possible interference, may require the wind farm to compensate for the upgrades in radar needed 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 an escrow of $\$ 15$ million to meet future requirements 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 causes of bird fatalities per 10,000 birds



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

ENVIRONMENTAL ASPECTS OF WIND ON HUMANS

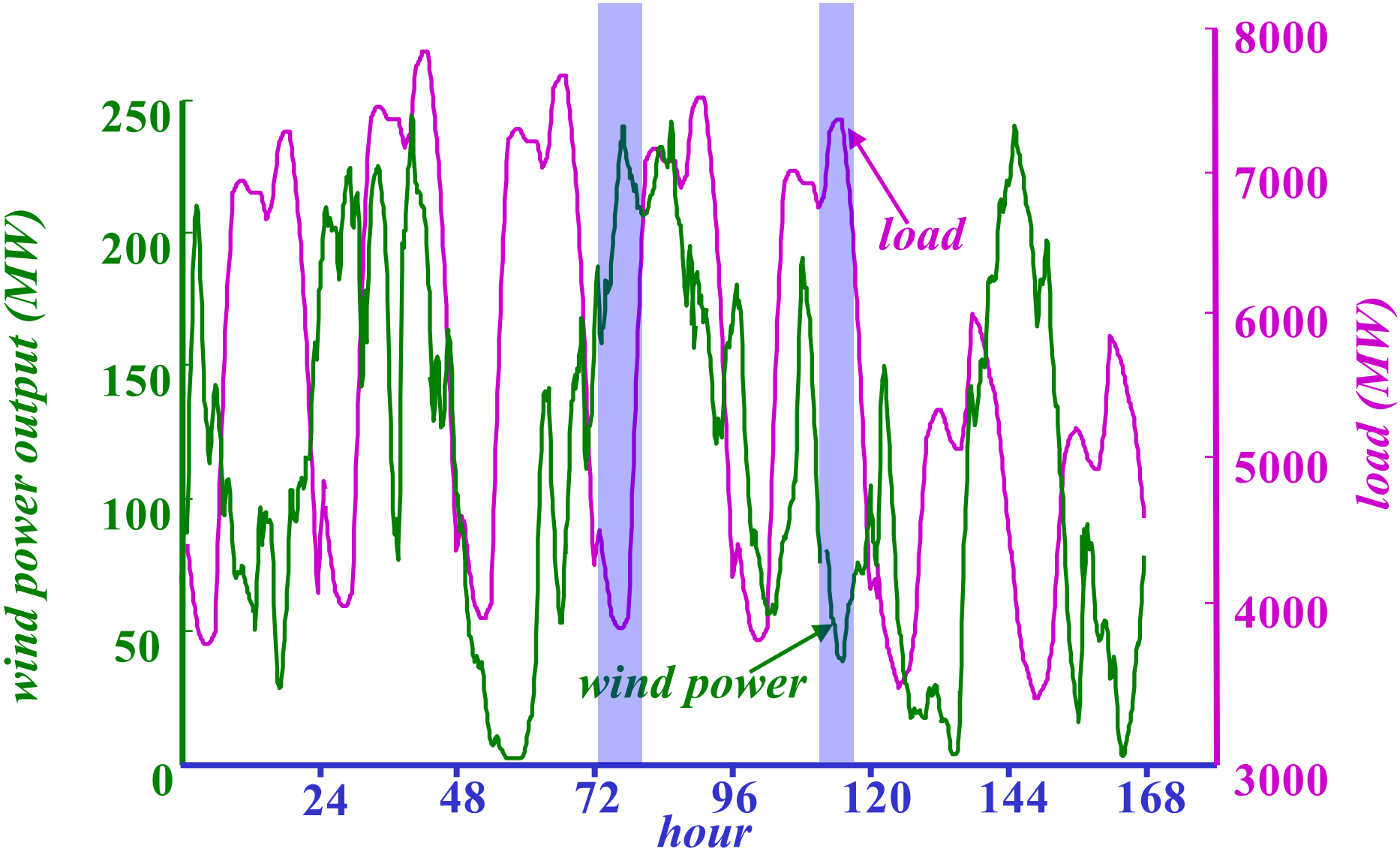
- Aesthetics is often the primary human concern about wind energy projects since beauty is often in the eyes of the beholder
- Another issue may arise from night lighting

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

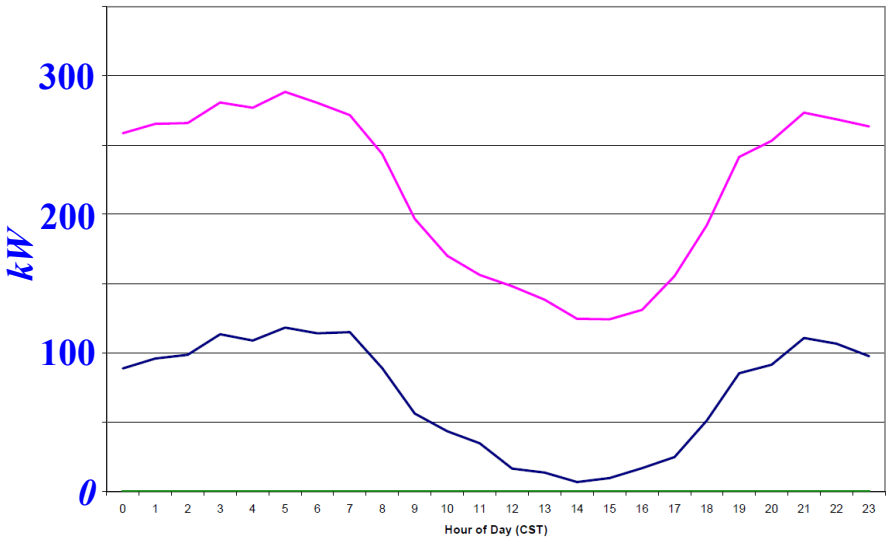
VARIATION OF WIND WITH TIME

- 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*

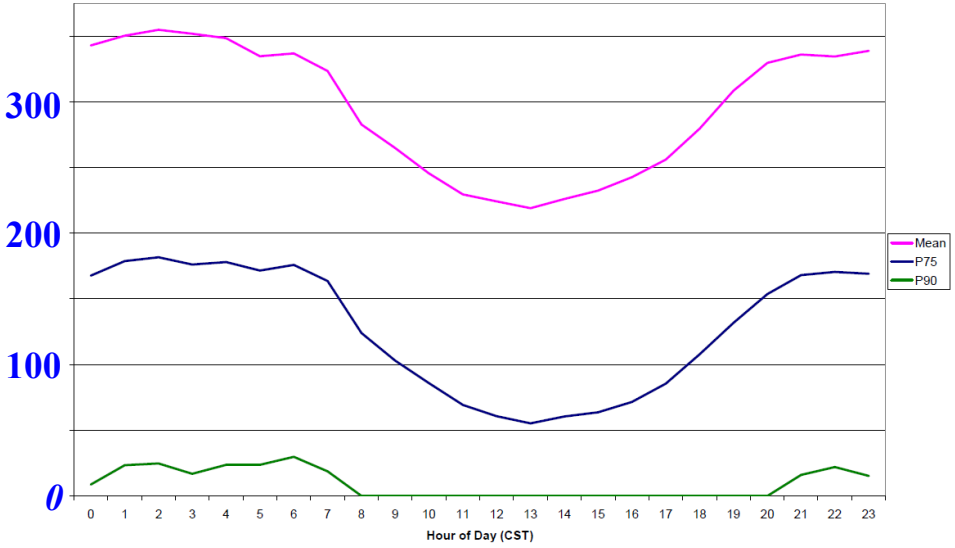
MISALIGNMENT OF WIND POWER OUTPUT AND LOAD



UPPER MIDWEST HOUR WIND VARIATIONS



August



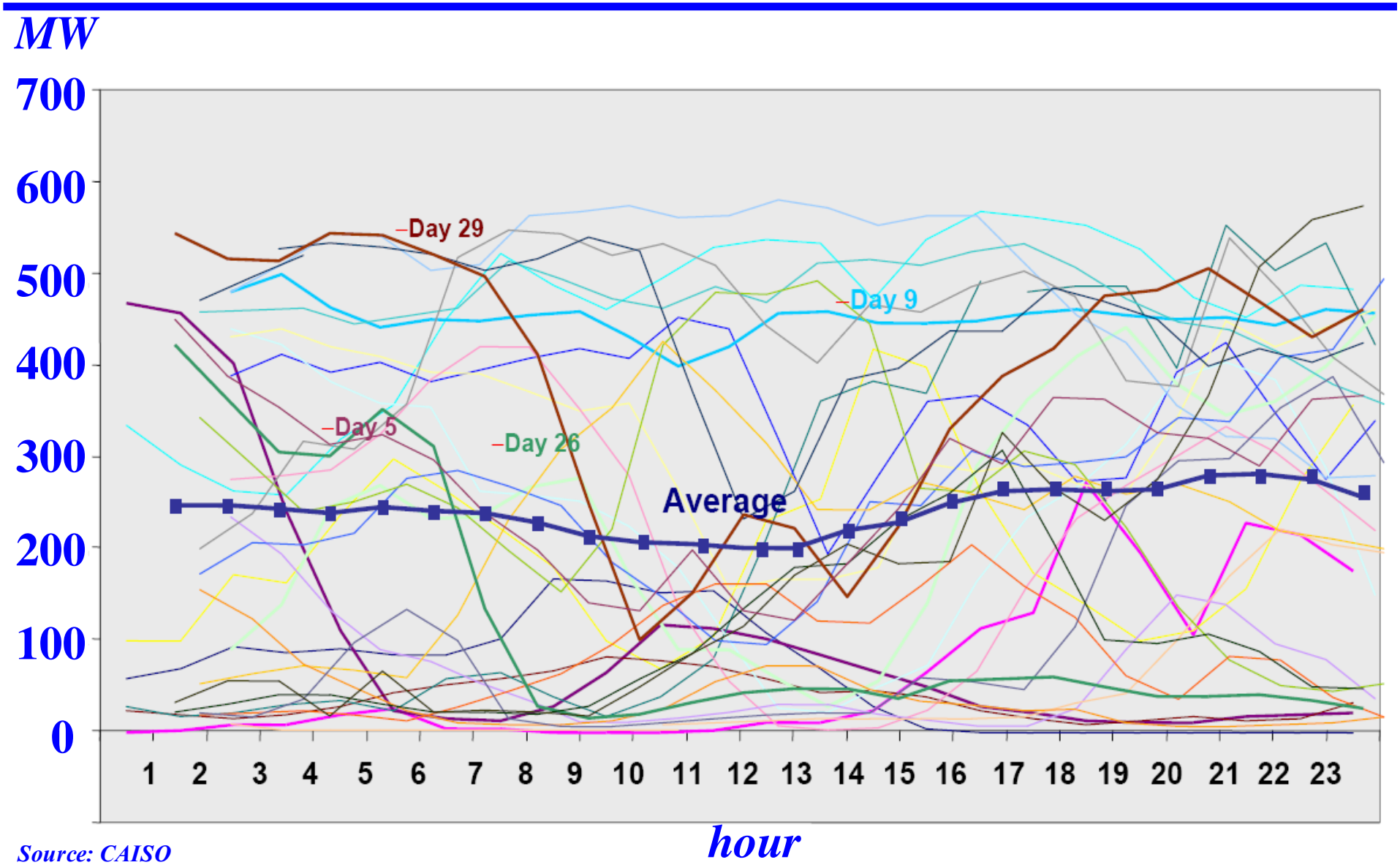
April

Source: www.uwig.org/XcelMNDOCwindcharacterization.pdf

INTEGRATION OF WIND ENERGY INTO THE POWER GRID

- 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 so as to maintain the operational reliability of the grid

CAISO APRIL 2005 DAILY WIND PATTERNS

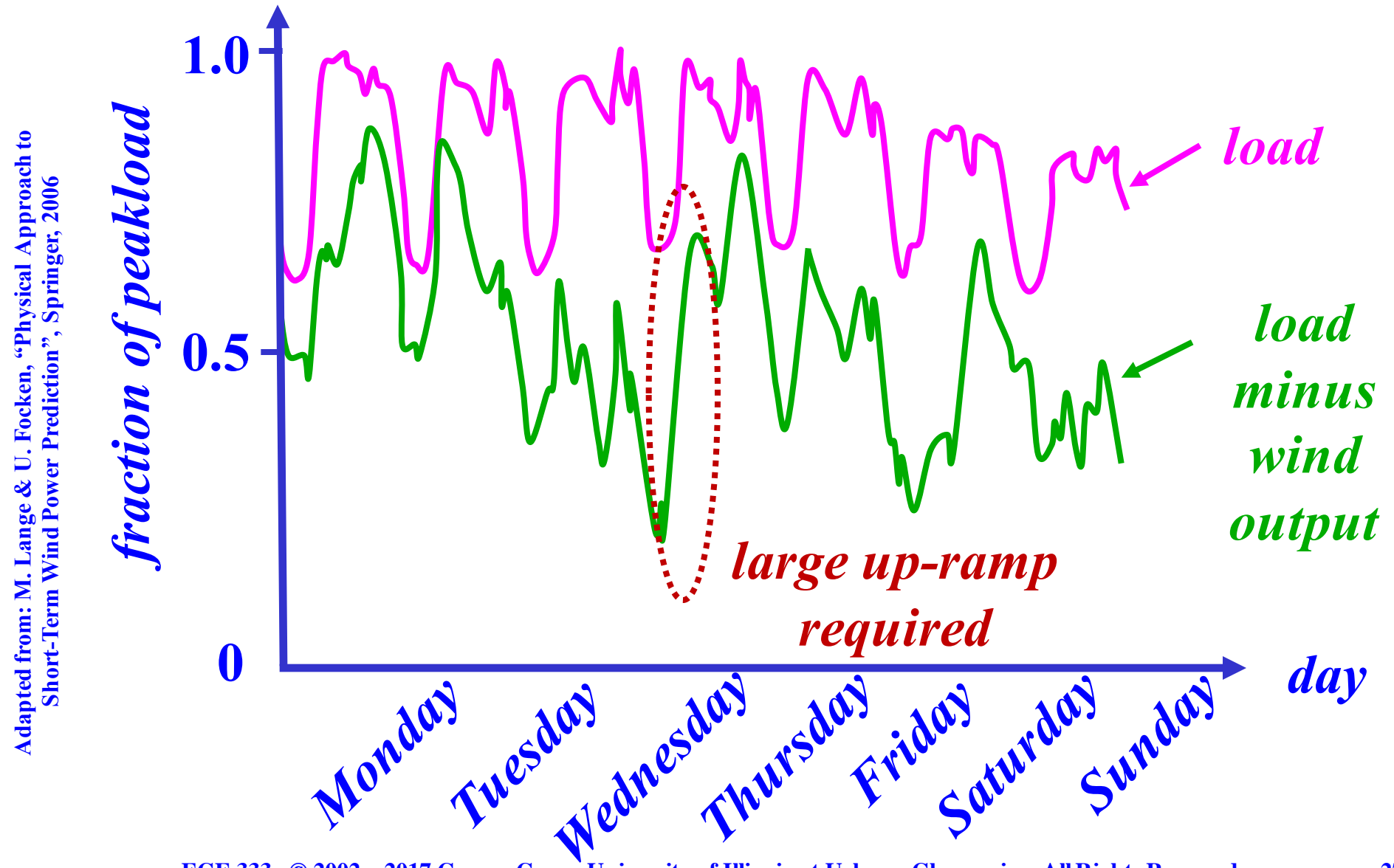


Source: CAISO

CAPACITY RESERVES AND FREQUENCY REGULATION

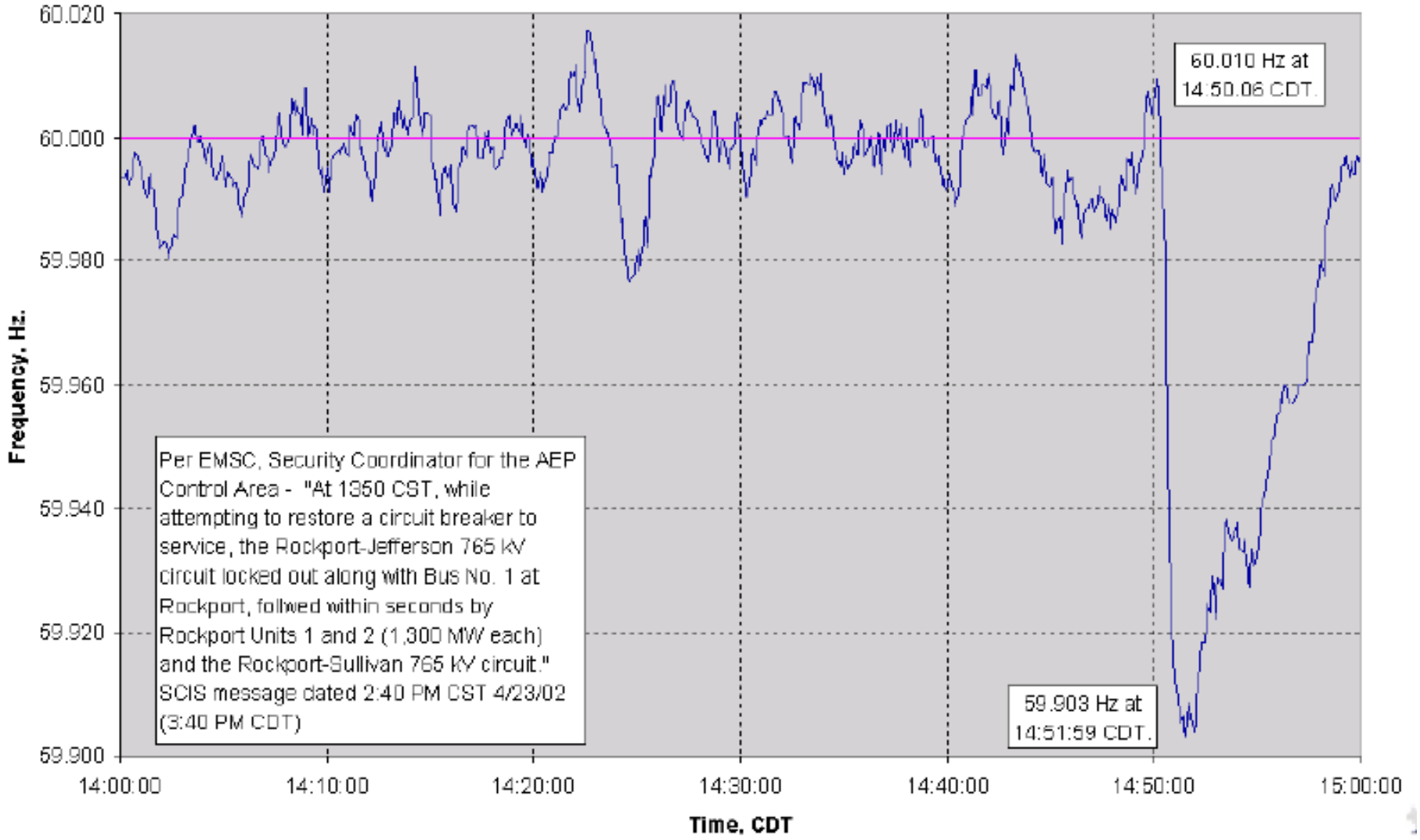
- A key need in power system operations is to ensure that power system generation exactly matches the total load plus losses at all times
- Generation shortfalls can suddenly occur because of the loss of a generator and operators must maintain sufficient reserves – generation that is on–line but not fully loaded – to account for the loss of the largest single generator in a region and other possible 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 FREQUENCY RESPONSE FOR A 2,600 – *MW* LOSS



CAPACITY RESERVES AND FREQUENCY REGULATION

- 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 major loss of generation
- Due to the limited controllability of wind resources, the operator has no choice but depend more extensively on conventional resources to supply adequate reserves and frequency regulation

