



# Integrating Wind into the Grid

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Electricity from Renewables

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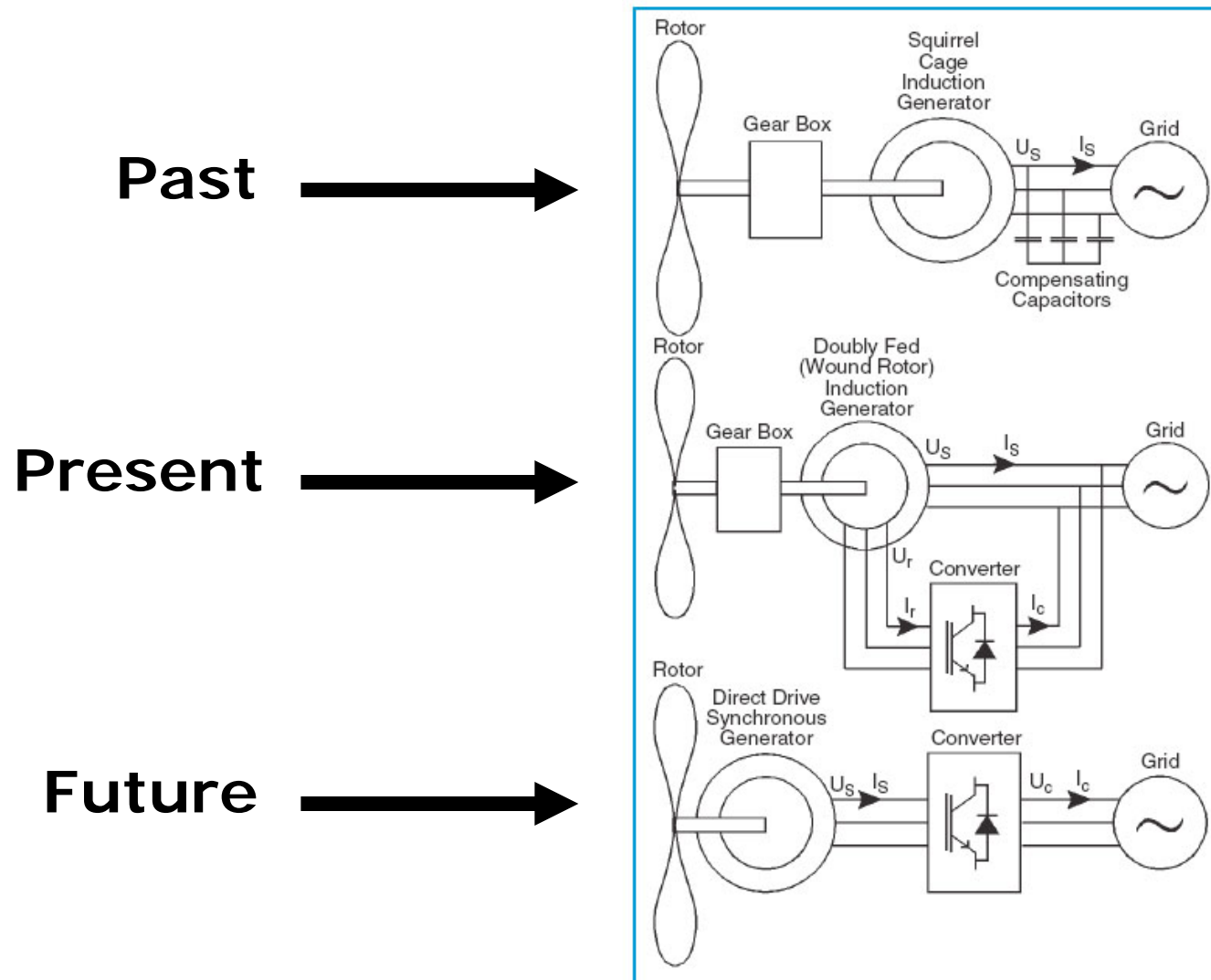


## What is UWIG?

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- Non-profit corporation established by 6 utilities in 1989 with support from EPRI and DOE/NREL
- Current membership in excess of 110, including Associate Members from wind development, equipment, and consulting community
- Focus on technical issues
- Mission: To accelerate the development and application of good engineering and operational practices supporting the appropriate integration of wind power into the electric system

# Evolution of Wind Turbine Technology



Source: IEEE Power & Energy Magazine

# How Does Wind Plant Performance Compare?

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	<u>Past</u>	<u>Present</u>	<u>Future</u>
Voltage Control	√-	√	√+
Short Circuit Contribution	√-	√	√+
Flicker	√-	√	√+
Low Voltage Ride-Through	√-	√	√+
Stability Behavior	√-	√	√+
AGC Participation	√-	√	√+

## Order 661–A Provisions

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- **LVRT**
  - Generator stays on line during a 3 phase fault for normal fault clearing time up to 9 cycles and SLG faults with delayed clearing during a voltage dip as low as .15 pu at the high side of the GSU for units in service before 2008
  - Voltage dip requirement extends to 0.0 pu in 2008
- **Reactive Power**
  - Provide power factor of +/- .95, including dynamic voltage support, if needed for safety and reliability
  - Partial dissent by Chairman Kelliher over lack of mandatory requirement, ie placing burden of proof on transmission provider
- **SCADA**
  - Provide necessary information, as agreed with transmission provider

# Wind Turbine Modeling

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- WECC Wind Generator Modeling Group
- Mission
  - Develop a set of generic (non-vendor specific), non-proprietary, positive-sequence power flow and dynamic models suitable for representation of the major commercial, utility-scale WTG technologies
  - Develop a set of best practices to represent wind plants using generic models as basic building blocks
- Model types based on characteristics of grid interface
  - Type A – conventional induction generator
  - Type B – wound rotor induction generator with variable rotor resistance
  - Type C – doubly-fed induction generator
  - Type D – full converter interface
- Model validation important requirement
- Working with IEEE, AWEA, UWIG, and industry

# Wind Plant Control Capability

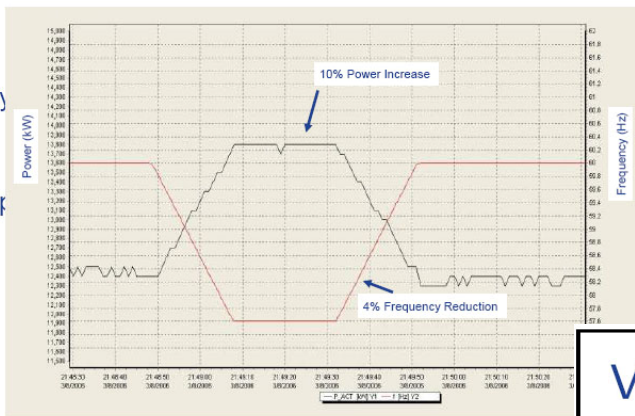
## Under-Frequency Droop Response

Settings:

90% Wind Capacity

4% Droop

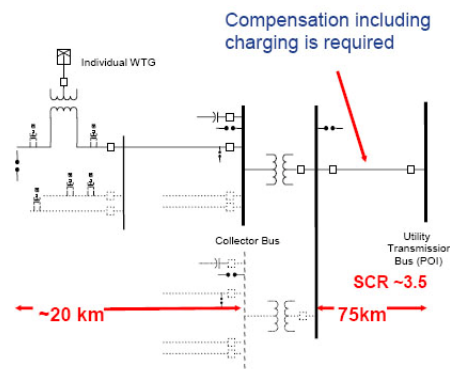
4% Frequency Step  
@0.125Hz/sec



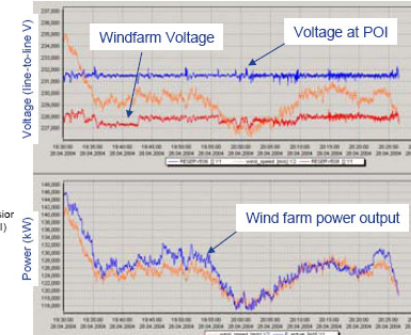
10% Increase in Farm Watts with 4% Under-frequency



## Voltage Regulation



Actual measurements from a 162MW wind farm.



Windfarm Control Minimizes Grid Voltage Fluctuations With Varying Wind Conditions



Source: GE Energy

## Interconnection Summary

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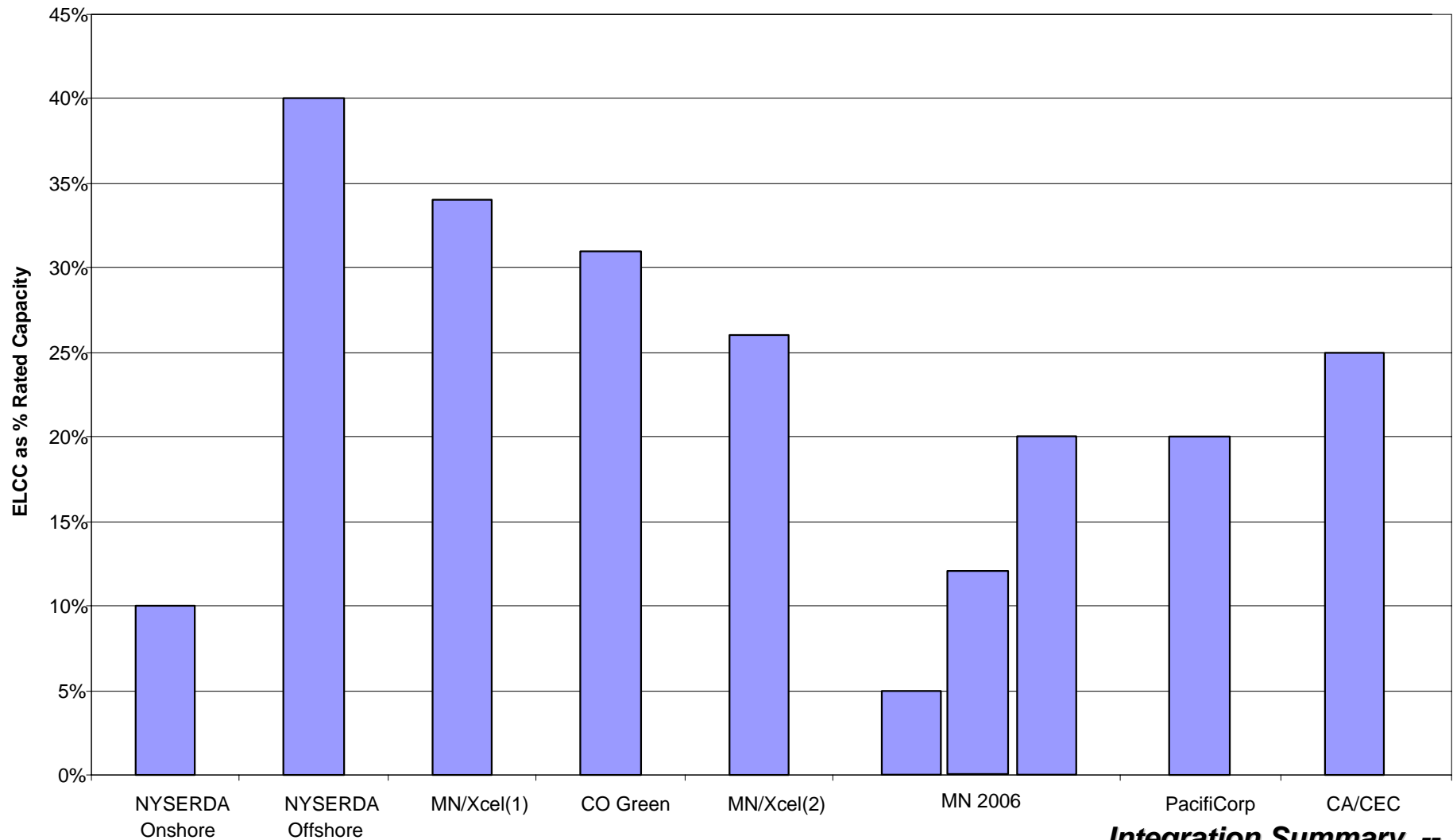
- Wind plant terminal behavior is different from conventional machines, but compatible and improving
- Better dynamic models of wind turbines required for system studies
- Increased demands will be placed on wind plant performance (LVRT, reactive control, output and ramp rate control, inertial and governor response)
- System reliability can be enhanced by wind plants

## What To Do When the Wind Doesn't Blow

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- Good question!
- Must deal with energy resource in a capacity world
- Dealt with through probabilistic reliability methods used to calculate Effective Load Carrying Capability (ELCC)
- Contribution may be large (40%) or small (<5%)
- Once the ELCC is determined, get on with the job of designing a reliable system

# Selected Capacity Values



## Won't Too Much Wind Power Cause the System to Collapse?

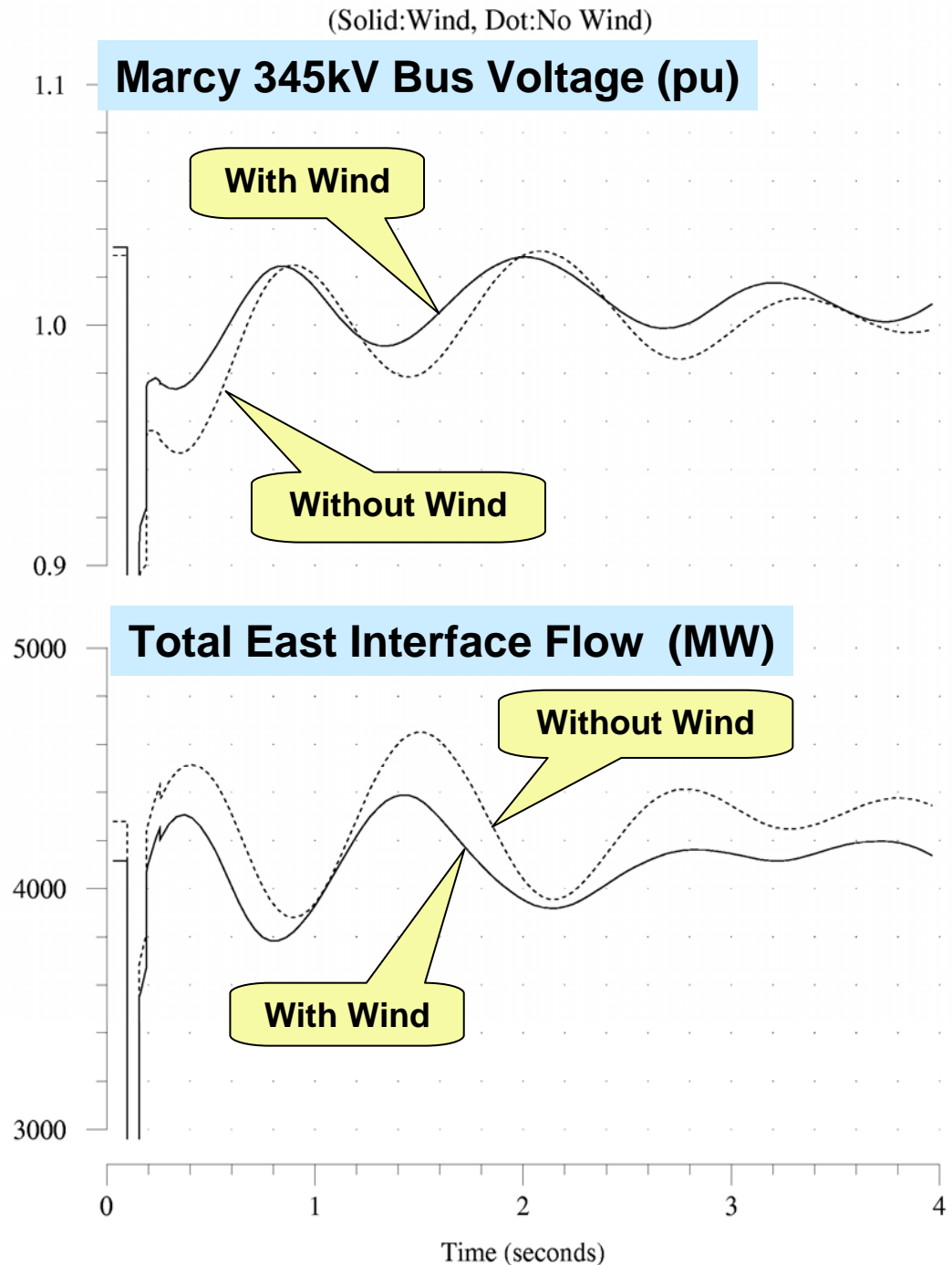
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- Often comes up as a question after a system disturbance resulting in a blackout
- Related questions about system stability are driving world-wide wind turbine and wind plant model development and verification efforts (IEEE, UWIG, WECC, manufacturers, TSOs, utilities)
- Detailed simulations of DFIGs shows that wind plants can actually aid system stability by providing LVRT and dynamic var support to reduce voltage excursions and dampen swings



## Impact of Wind Generation on System Dynamic Performance

- Fault at Marcy 345 kV bus
- Severe contingency for overall system stability
- Simulation assumes vector-controlled wind turbines
- Wind generation improves post-fault response of interconnected power grid

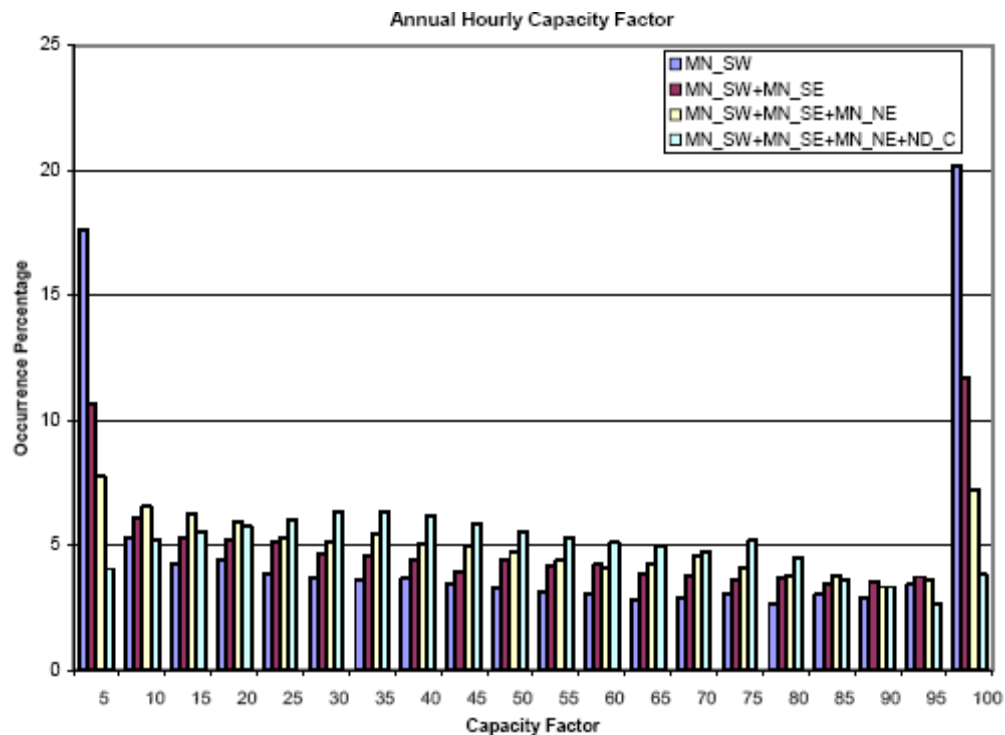


## What If the Wind Stops Blowing Everywhere at the Same Time?

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- Meso-scale wind forecasting techniques provide the answer
- Significant benefit to geographical dispersion
  - Dispersion provides smoothing in the long term
  - Aggregation provides smoothing in the short term
- Extensive modeling studies have shown no credible single contingency leading to simultaneous loss of capacity in a broad geographical region

# Aggregation Reduces Variability



Source:  
MN DOC

Annual histogram of hourly capacity factor for four levels of geographic dispersion.

# How Do You Deal with the Unpredictable Nature of the Wind?

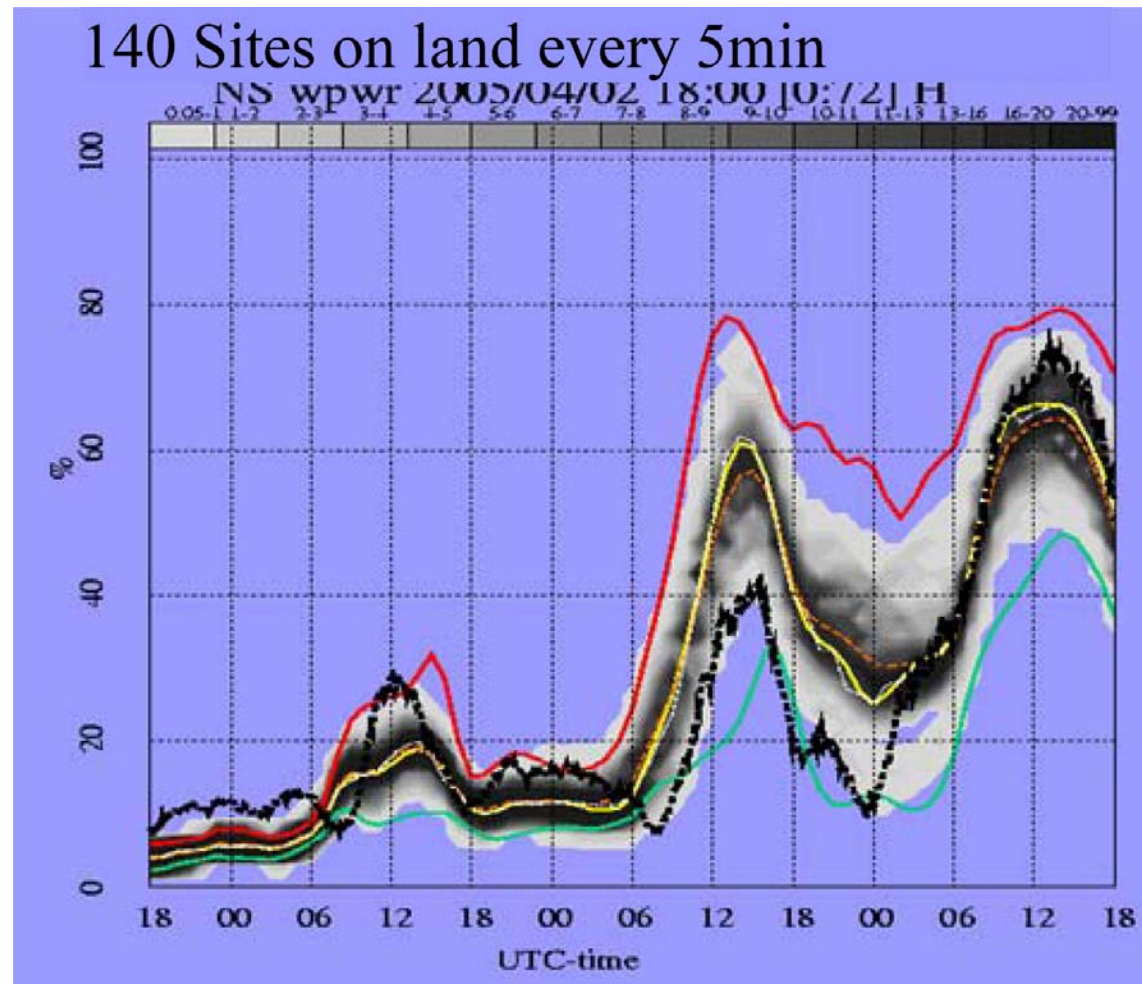
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- Again, wind forecasting provides the answer
- Wind plant output can be forecast within some margin of error, and forecasts are getting better

## Wind Plant Output Forecast Accuracy

	<u>Currently</u>	<u>5-10 Years</u>
Hour Ahead	4-6%	3-5%
Day Ahead	15-20%	10-15%

# Forecasting and Balancing Markets Reduce Impacts



## How To Deal With the Continually Changing Output of the Wind Plant

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- Wind plant output and net load variations are well characterized in sec, min, and hr time frames
- Best handled through deep, liquid real-time energy markets to financially settle schedule deviations
- At increasing (10-20%) penetration levels, small but measurable increase in regulating or ramping requirement can generally be met by existing generation with some modest cost increase
- At higher (30%+) levels, minimum load problems may appear
  - More flexible generation
  - Price responsive load or energy storage
  - Larger control areas and stronger interconnections
  - Curtailment

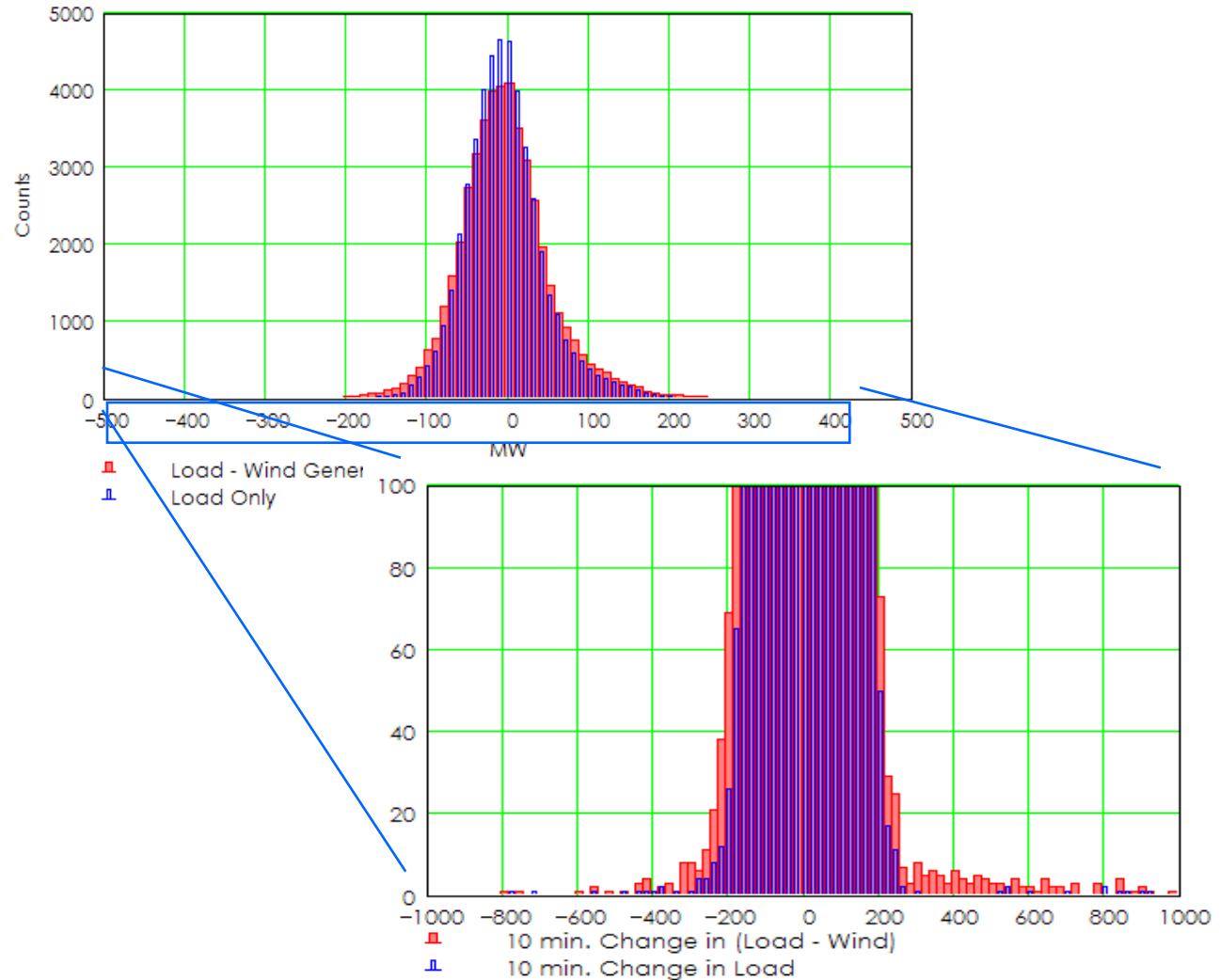
# Impacts Within the Hour

## QUESTIONS

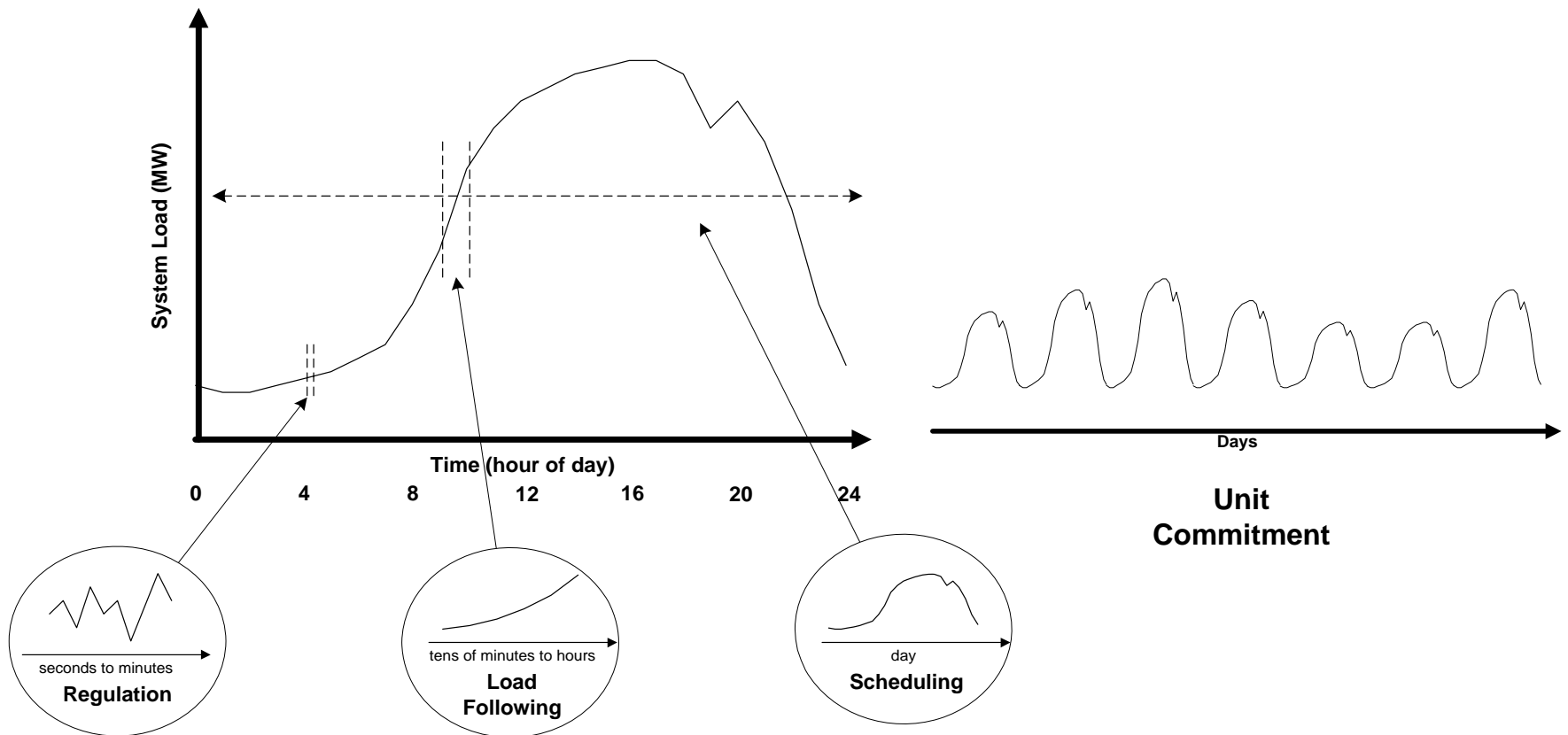
- Is control area demand more variable within the hour with wind?
- What are the consequences?

## ANSWERS

- Effect is confined mostly to “tail”
- Impact on CPS2
- Increase of 1-2 MW/min in load-following capability



# Time Scales of Interest



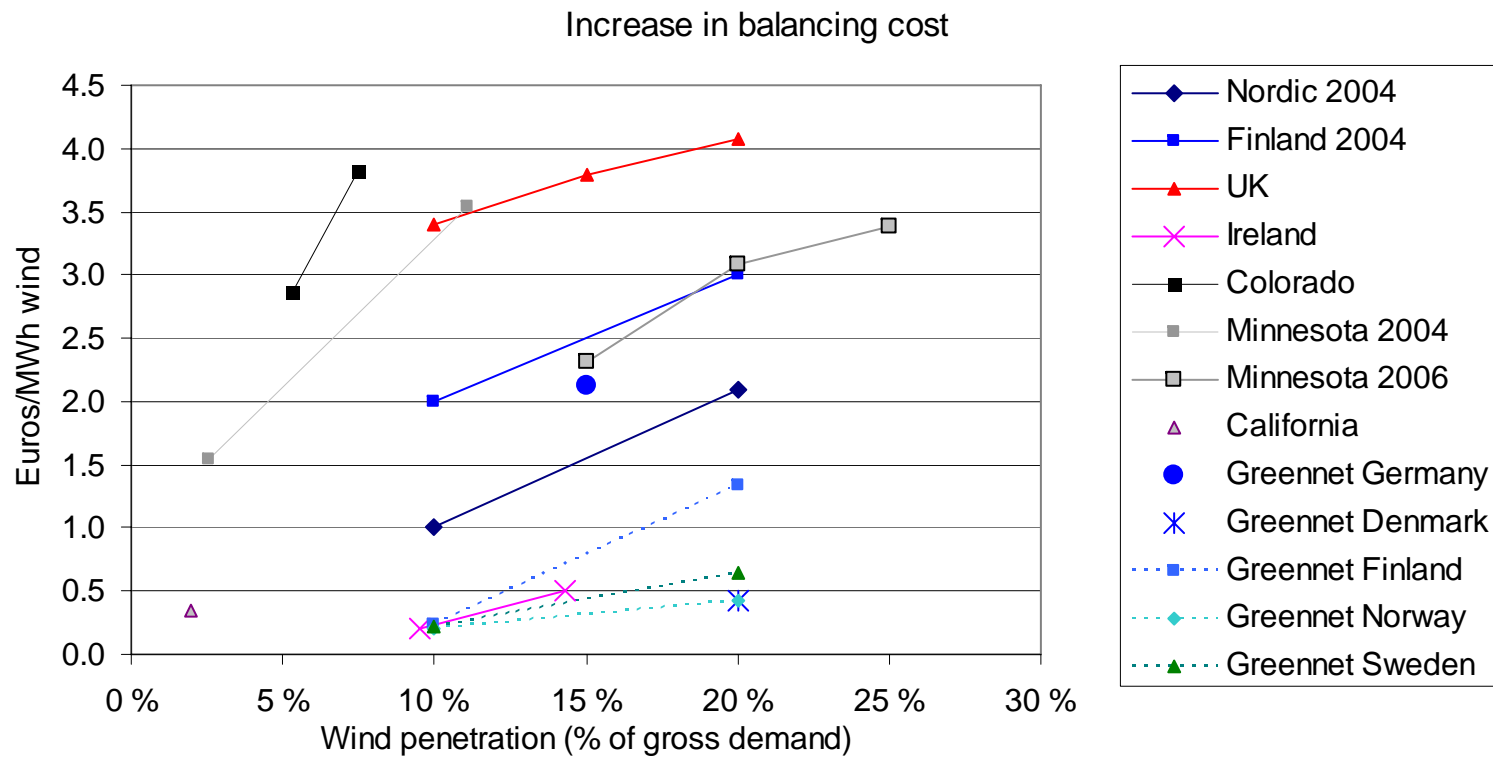


## Summary of Wind Plant Ancillary Service Costs

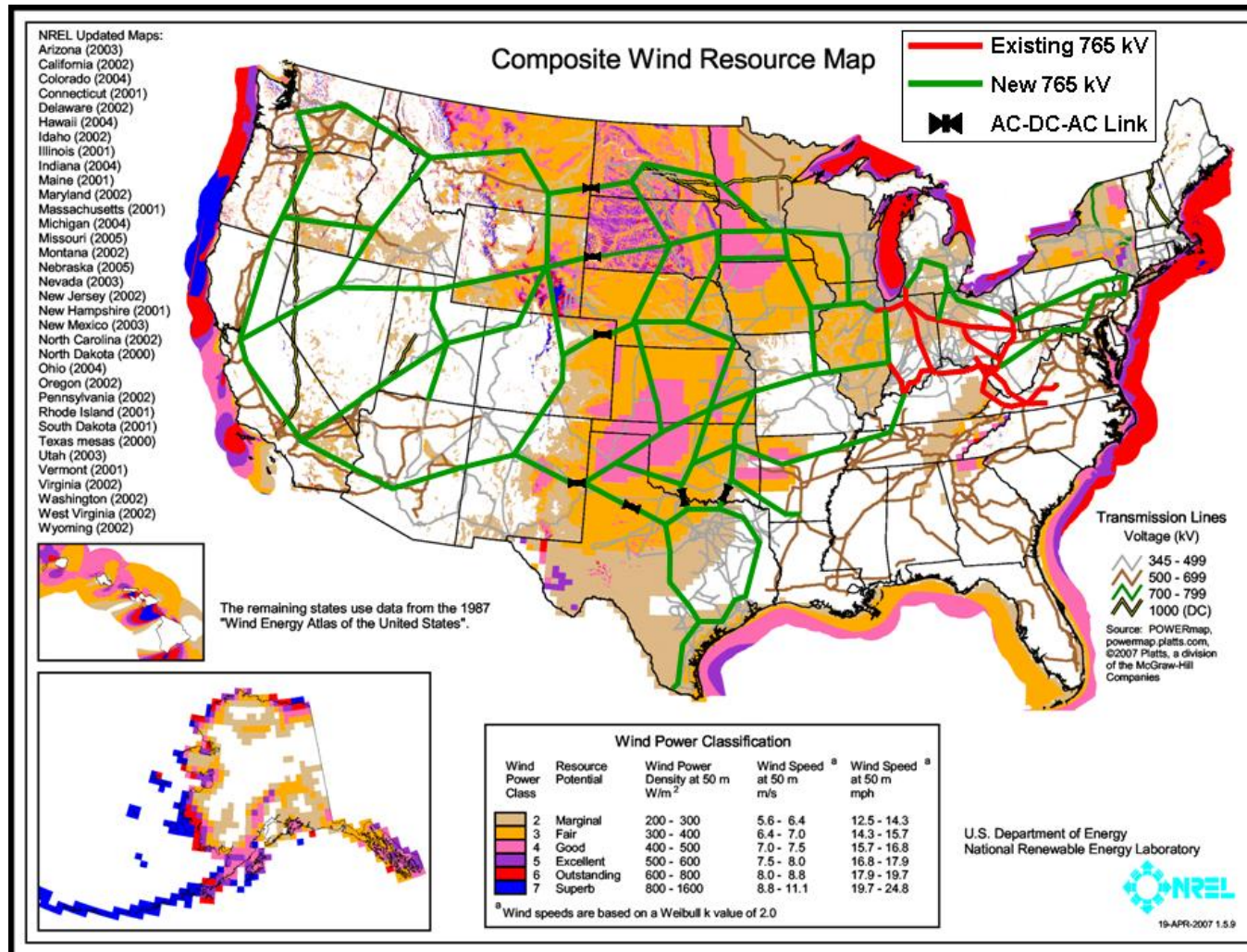
### Ancillary Services Cost Comparison

Date	Study	Wind Capacity Penetration (%)	Regulation Cost (\$/MWh)	Load Following Cost (\$/MWh)	Unit Commitment Cost (\$/MWh)	Gas Supply Cost (\$/MWh)	Total Operating Cost Impact (\$/MWh)
2002	BPA	7	.19	.28	1.00-1.80	na	1.47-2.27
2003	GRE	16.6	na	na	na	na	4.53
May '03	Xcel-UWIG	3.5	0	0.41	1.44	na	1.85
Sep '04	Xcel-MNDOC	15	0.23	na	4.37	na	4.60
July '04	CA RPS Phase III	4	0.36	na	na	na	na
June '03	We Energies	4	1.12	0.09	0.69	na	1.90
June '03	We Energies	29	1.02	0.15	1.75	na	2.92
2005	PacifiCorp	20	0	1.6	3.0	na	4.6
April '06	Xcel-PSCo	10	0.20	na	2.26	1.26	3.72
April '06	Xcel-PSCo	15	0.20	na	3.32	1.45	4.97

# Increased Balancing Cost



# Conceptual EHV Transmission Overlay



# System Planning and Operation Recommendations

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- Perform detailed wind integration studies
- Deploy more flexible generation and load technologies
- Improve wind plant output forecasting tools
- Improve grid codes and wind plant models
- Aggregate wind plant output over large regions
- Improve balancing area consolidation and ACE sharing
- Ongoing forums to share operating experience

# Transmission Planning Recommendations

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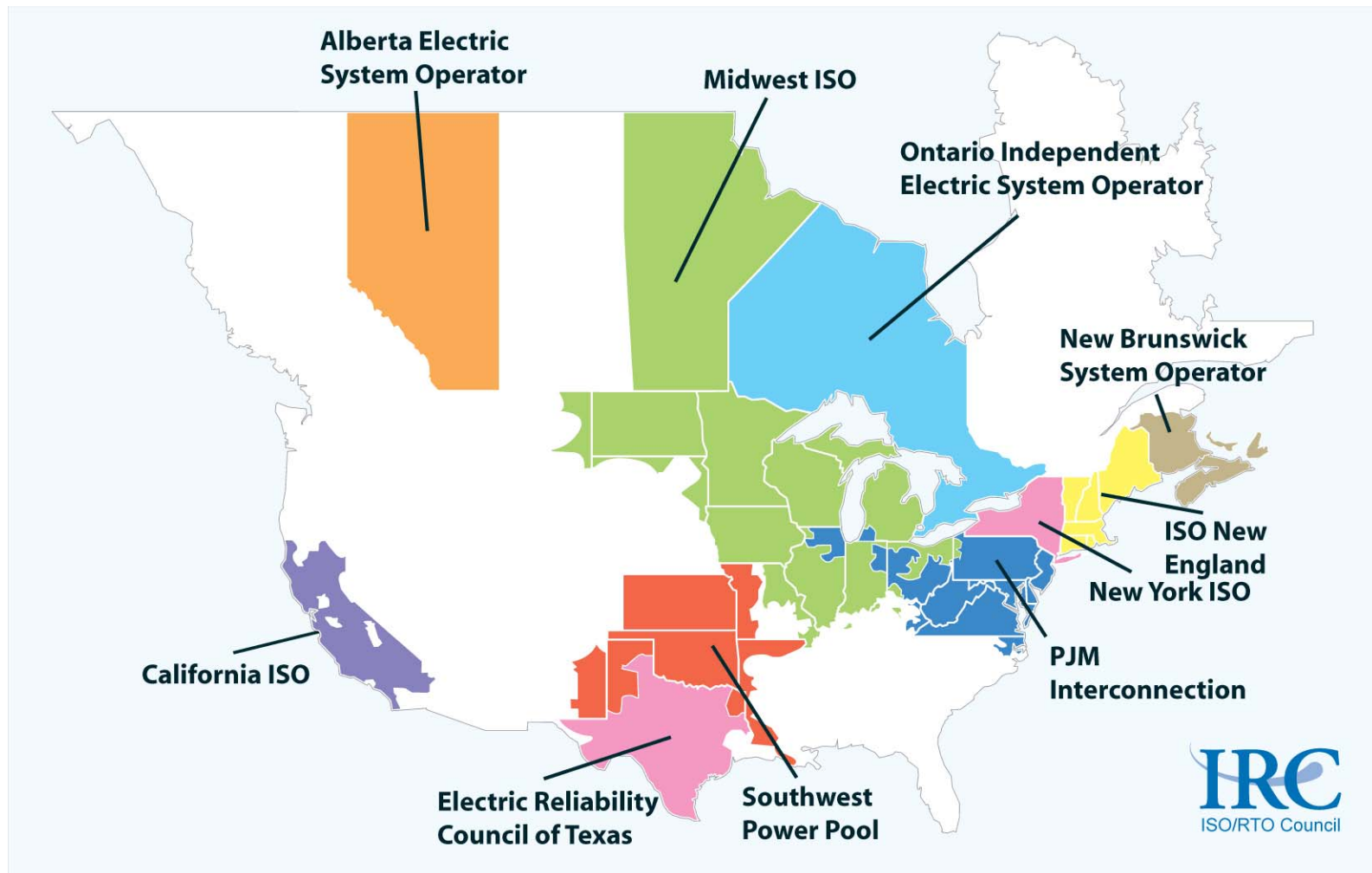
- Develop adequate transmission capacity
- Comprehensive regional planning processes
- Federal leadership in developing transmission in the national interest
- Reassessment of transmission financing approach
  - Customers in remote regions can't afford it
  - load pays in the end
- More certainty of transmission cost recovery
- More robust and flexible “smart” grid

## Market Operation and Transmission Policy Recommendations

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- Develop well-functioning real time, hour-ahead and day-ahead energy and price responsive load markets and expand access to those markets
- Adopt market rules and tariff provisions that are more appropriate to weather-driven resources
- Make better use of physically (in contrast with contractually) available transmission capacity
- Eliminate pancaked rates

# ISOs/RTOs in North America



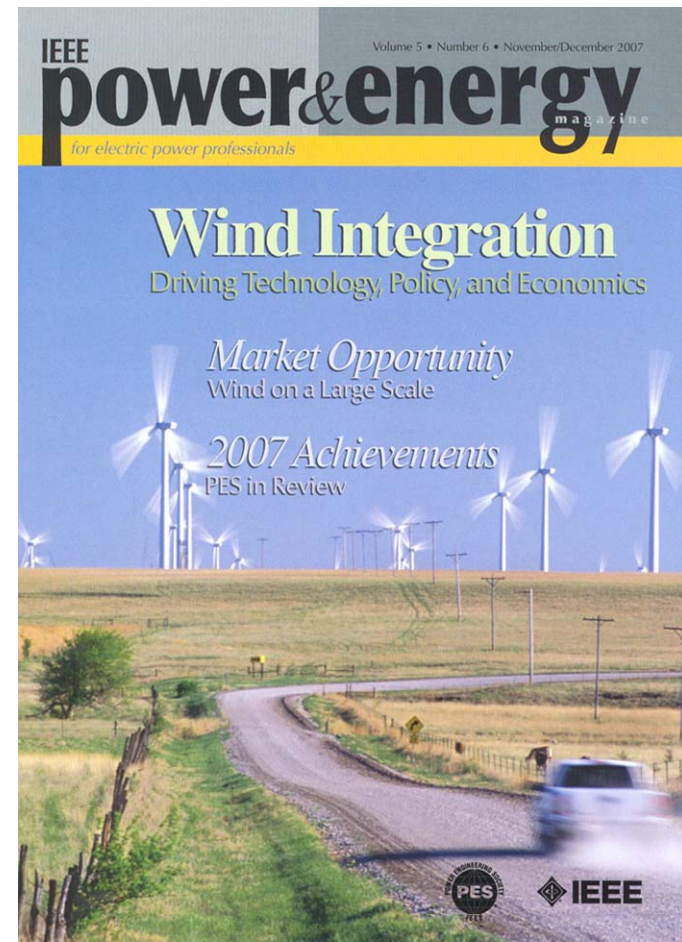
## and the conclusion is...

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- There are no fundamental technical barriers to the integration of 20% wind energy into the nation's electrical system, but...
- There needs to be a continuing evolution of system operation policy, transmission planning policy, and market development for this to be achieved.

# Wind Power Coming of Age

- IEEE PES Wind Power Coordinating Committee established 2005
  - o 6 active projects
- IEEE PES *Power & Energy Magazine* special issue on wind integration
  - o Nov-Dec 2005
  - o Nov-Dec 2007
- IEEE/NERC/AWEA/UWIG 2006 Wind Policy Symposium



## For More Information

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