Lessons Learned in Wind Integration
风电接入的经验教训

Renewable Energy Integration:
可再生能源接入
International Experiences and Implications for China
国际经验和对中国的启示

Beijing, China
December 2010

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UWIG
Utility Wind Integration Group

Outline of Topics
主要内容

- Lessons from Recent Studies
- Wind Forecasting
- Capacity Value
- Energy Storage
- System Stability
- System Reliability
- Conclusions and Recommendations

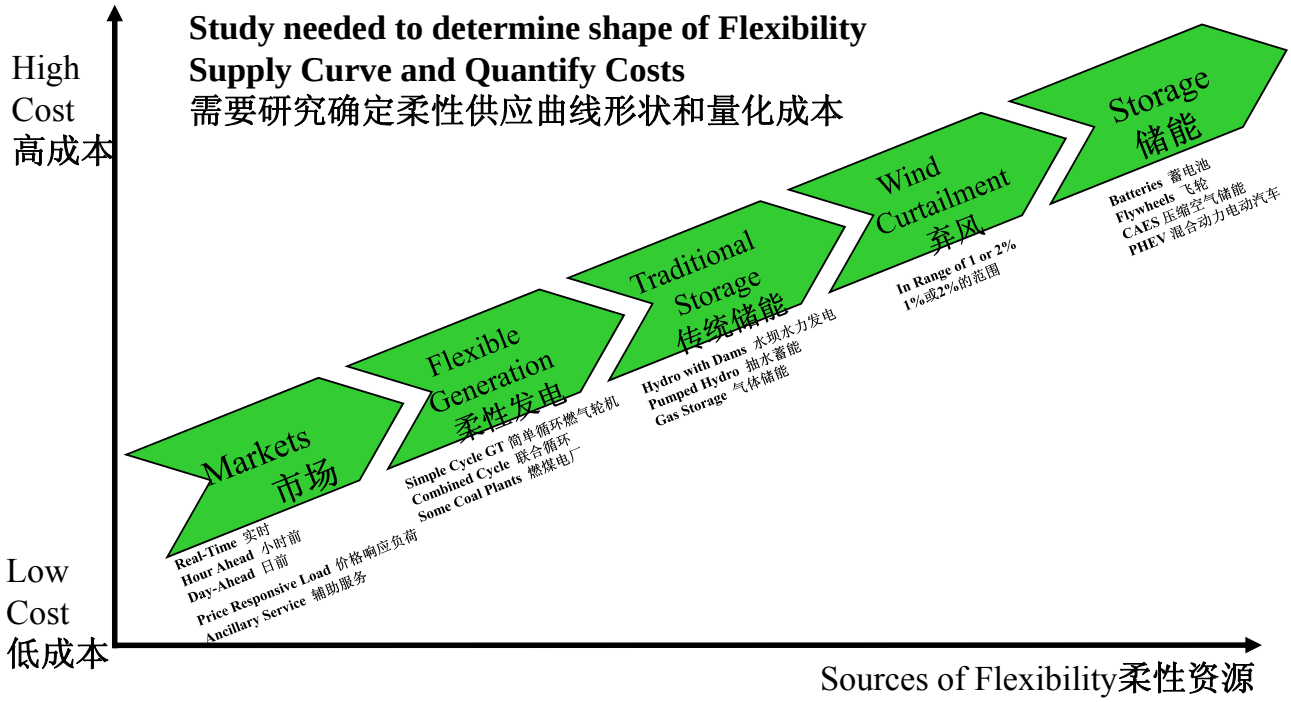
- 近期研究得到的经验教训
- 风功率预测
- 容量置信度
- 储能
- 系统稳定性
- 系统可靠性
- 结论与建议

It's All About Dealing with Variability and Uncertainty
关于处理可变性和不确定性

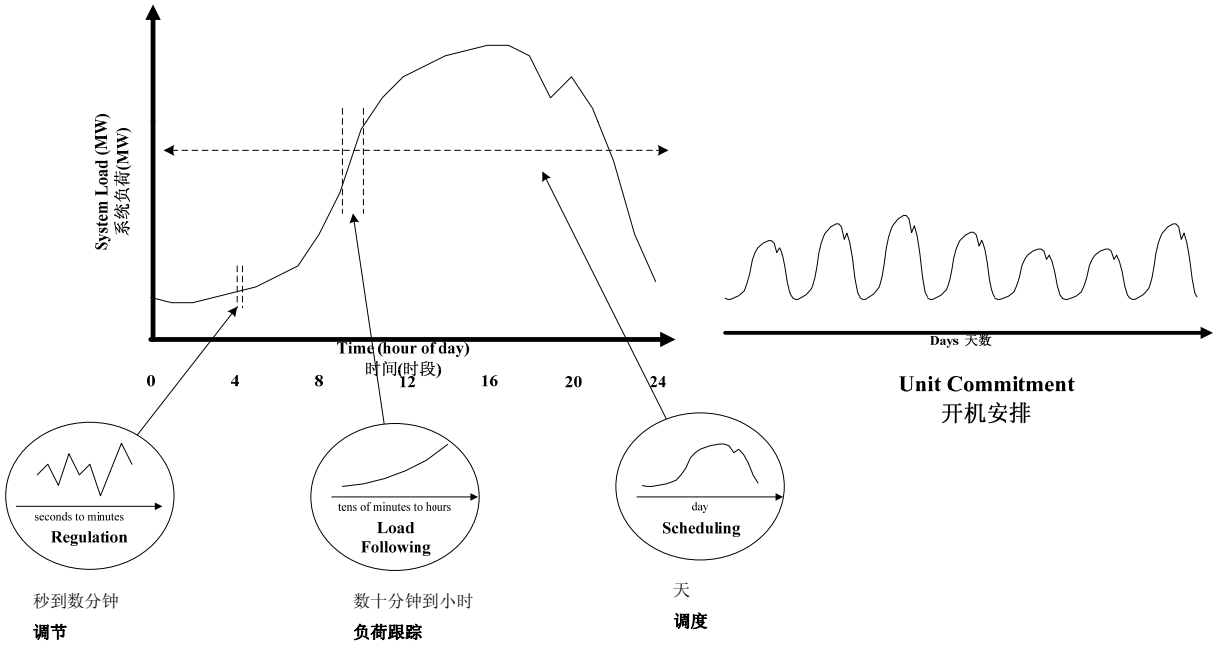
- Variability
  - Load varies by seconds, minutes, hours, by day type, and with weather
  - Supply resources may not be available or limited in capacity due to partial outages
  - Prices for power purchases or sales exhibit fluctuations
- Uncertainty
  - Operational plans are made on basis of best available forecasts of needs; some error is inherent
  - Supply side resource available with some probability (usually high)
- Key questions
  - How does wind generation affect existing variability and uncertainty
  - What are the costs associated with the changes
  - What does the future hold

- 可变性
  - 负荷每天秒钟、每分钟、每小时、每天都在波动，并随天气变化而变化。
  - 部分电源的跳闸事故会造成停电或者供电容量不足。
  - 电力买卖价格也存在波动。
- 不确定性
  - 基于可用的最佳需求预测手段来制定运行计划；但是误差是不可避免的。
  - 供电侧资源的可用率通常较高。
- 关键问题
  - 风电并网如何影响已有的可变性和不确定性
  - 与这些变化相关的成本是多少？
  - 前景如何？

Flexibility Supply Curve
柔性供应曲线



Time Scales of Interest
关注的时间尺度



Interestingly – Generators Do Not Appear To Command A Premium For Sub-Hourly Response
发电机没有因为次小时级响应获得补贴

ISO 电力系统独立运营商	Day-Ahead $/MWH 日前	Hour-Ahead $/MWH 小时前	5-Minute $/MWH 每5分钟	Average Within-Hour 5-Minute Range $/MWH
NYISO	$67.70	$64.93	$63.31	$91.18
ISO-NE	$81.38	$80.76	$81.22	$24.40
CAISO		$69.78	$68.32	$59.87
ERCOT[1]			$71.69	$40.00
MISO	$49.99	$48.62	$48.71	$67.75

1小时内和5分钟内的平均值

[1]ERCOT currently operate a 15 minute sub-hourly market rather than a 5 minute market.

ERCOT目前运行的是15分钟级的小时内市场，而不是5分钟级市场。

- *Average* day-ahead, hour-ahead, and 5-minute prices are nearly equal
  - 5-minute price is often slightly lower
  - No premium for flexible generation
- *Within hour* 5-minute price *range* is very large
  - Marginal generators receive a strong signal to move within the hour

- 天前、小时前和每5分钟的平均价格几乎是相同的。
  - 每5分钟的价格略低。
  - 对于柔性发电没有奖励。
- 各小时内的每5分钟内的价格变化范围很大。
  - 边际发电机收到一个强信号使其在一小时内动作。

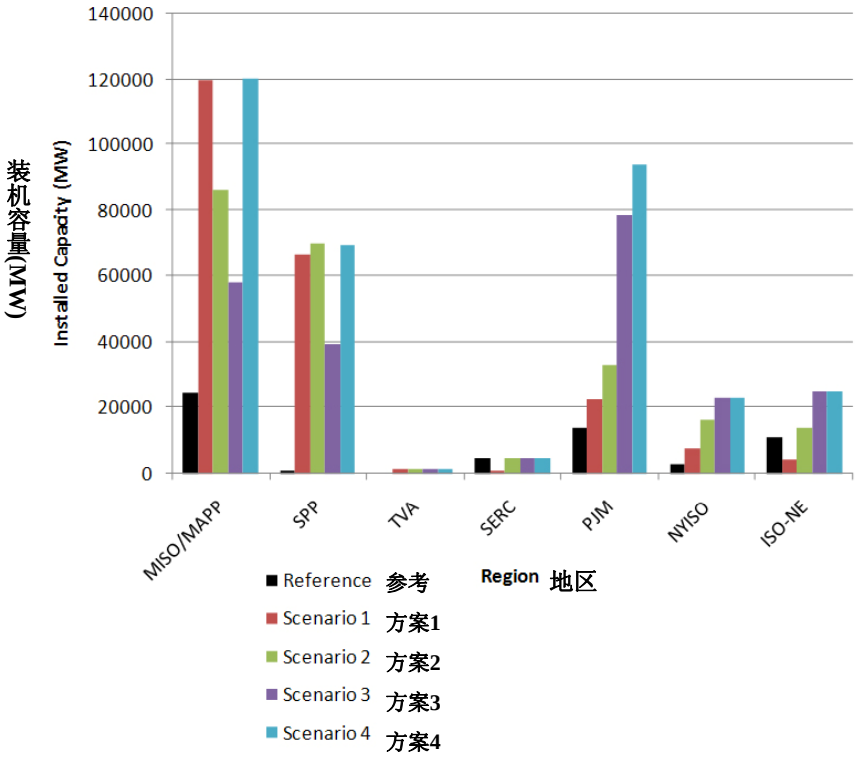
Source: Brendan Kirby, UWIG 2009 Spring Workshop

Variability is Expensive: Regulation Is The Most Expensive Ancillary Service
变化是昂贵的：调节出力是最昂贵的辅助服务

		2002	2003	2004	2005	2006	2007	2008
				Annual Average $/MW-hr				
	California (Reg = up + dn)							
调节出力	Regulation	26.9	35.5	28.7	35.2	38.5	26.1	33.4
热备用	Spin	4.3	6.4	7.9	9.9	8.4	4.5	6.0
无备用	Non-Spin	1.8	3.6	4.7	3.2	2.5	2.8	1.3
替换	Replacement	0.90	2.9	2.5	1.9	1.5	2.0	1.4
	ERCOT (Reg = up + dn)							
调节出力	Regulation		16.9	22.6	38.6	25.2	21.4	43.1
响应	Responsive		7.3	8.3	16.6	14.6	12.6	27.2
无备用	Non-Spin		3.2	1.9	6.1	4.2	3.0	4.4
	New York							
调节出力	Regulation	18.6	28.3	22.6	39.6	55.7	56.3	59.5
热备用	Spin	3.0	4.3	2.4	7.6	8.4	6.8	10.1
无备用	Non Spin	1.5	1.0	0.3	1.5	2.3	2.7	3.1
30分钟	30 Minute	1.2	1.0	0.3	0.4	0.6	0.9	1.1
	New England (Reg +"mileage")							
调节出力	Regulation			54.64	30.22	22.26	12.65	13.75
热备用	Spin					0.27	0.41	1.67
无备用	10 Minute					0.13	0.34	1.21
30分钟	30 Minute					0.01	0.09	0.06

Source: Brendan Kirby, UWIG 2009 Spring Workshop

Eastern Wind Integration and Transmission Study (EWITS) Scenarios
东部风电接入与输电研究（EWITS）方案



WWSIS Scenario Overview
WWSIS方案概览

- 2017 Study Year
- 2004, 2005, 2006 Load Shapes Escalated to 2017
- Wind and Solar Penetration Levels (% Energy)

- 研究水平年为2017
- 由2004，2005，2006的负荷曲线推测2017年的负荷水平
- 风能和太阳能接入水平(%能源)

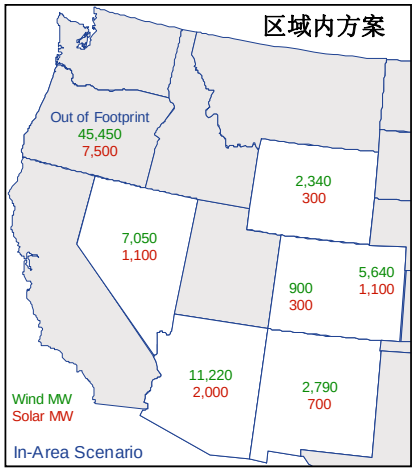
In Footprint		Rest of WECC	
Wind风能	**Solar太阳能**	**Wind风能**	**Solar太阳能**
10%	1%	10%	1%
20%	3%	10%	1%
20%	3%	20%	3%
30%	5%	20%	3%

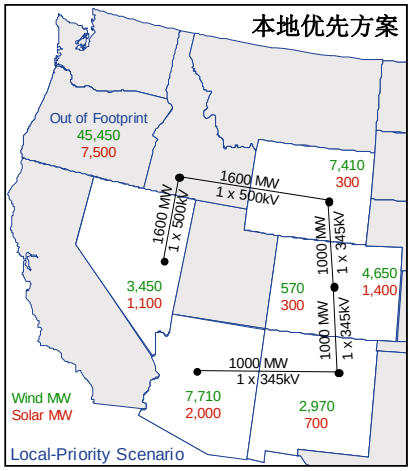
- Solar Mix
  - 70% Concentrating Solar Plant with Storage (CSP w/S)
  - 30% Photo-voltaic (PV)

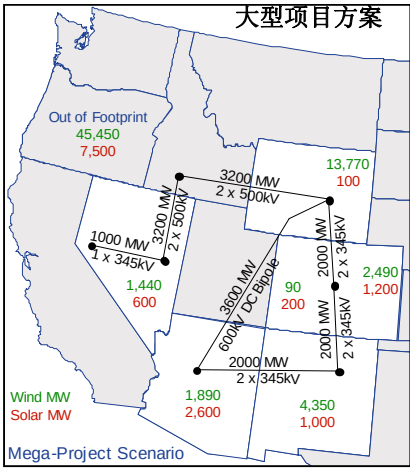
- 太阳能组合方案
  - 含储能系统的70%集中式太阳能电站（CSP w/S）
  - 30%光伏（PV）

WWSIS Capital Costs: Wind, Solar, Transmission
WWSIS 建设成本：风能、太阳能、输电

方案 Scenario	风电 Wind MW	太阳能 Solar MW	输电 Transmission (GW-mi)	风电成本 Wind Cost ($B)	太阳能成本 Solar Cost ($B)	输电成本 Transmission Cost ($B)	总成本 Total Cost ($B)	差值 Delta ($B)
In-Area	29,940	5,800	0	59.9	23.2	0.0	83.1	
Local-Priority	26,760	5,800	2,100	53.5	23.2	3.4	80.1	-3.0
Mega-Project	24,030	5,700	6,900	48.1	22.8	11.0	81.9	-1.2

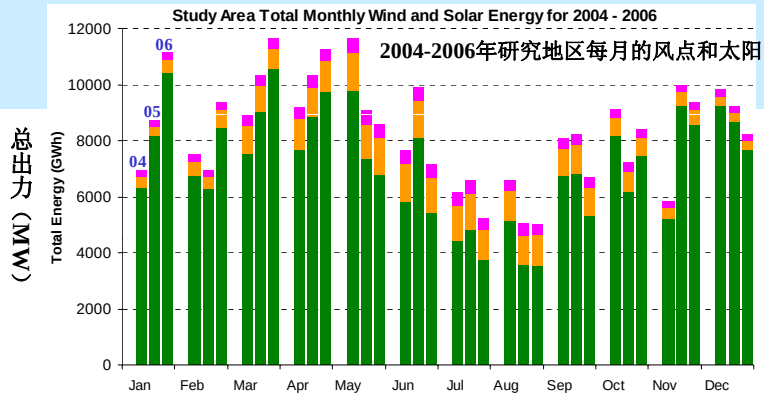


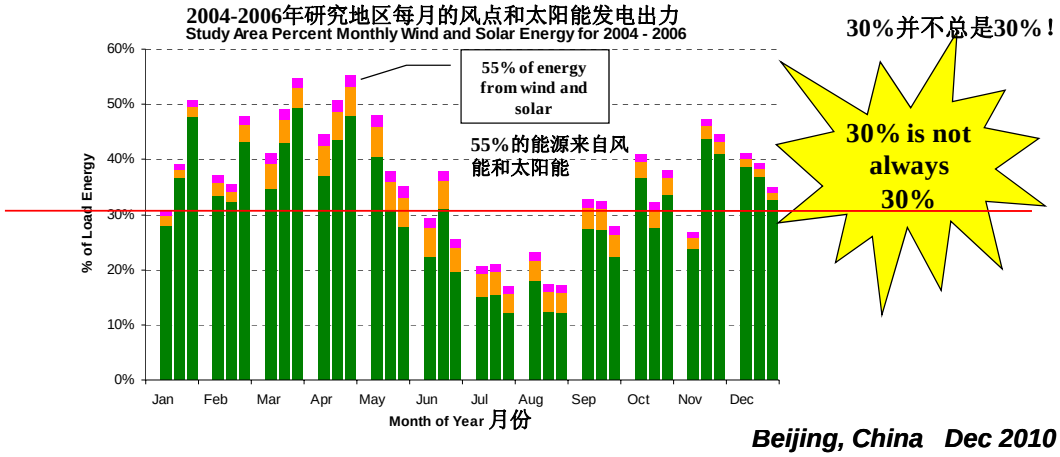




WWSIS Study Area Monthly Energy from Wind and Solar for 2004 – 2006 (30% In Area Scenario)

2004 – 2006年 WWSIS研究地区每月风点和太阳能发电出力（区域内方案：30%）



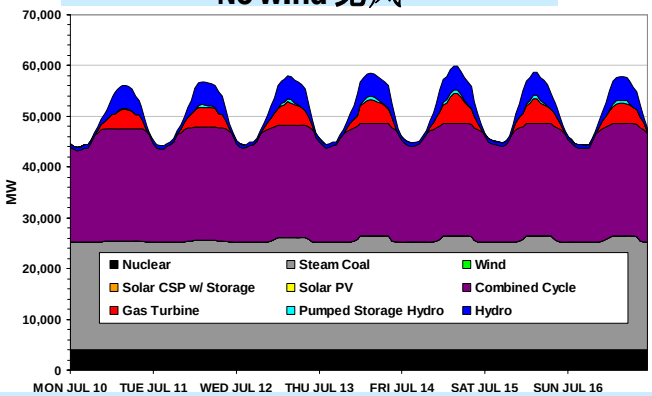


30%并不总是30%！

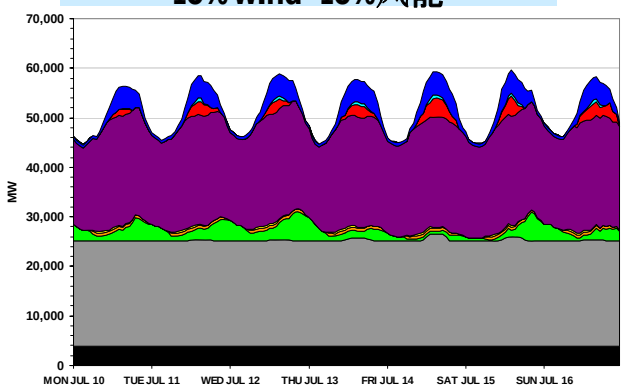
30% is not always 30%

Dispatch During a Tame Week (July) 某普通周的调度（7月）

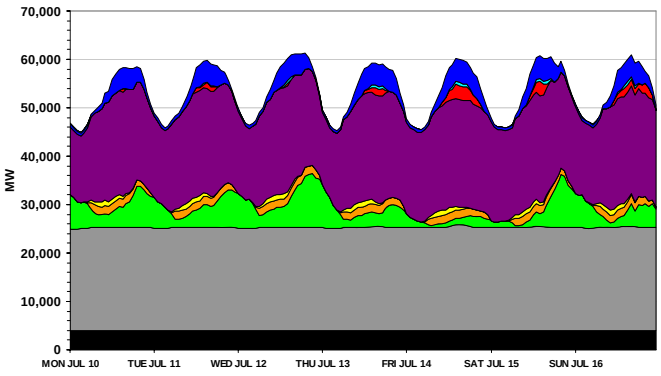
No wind 无风



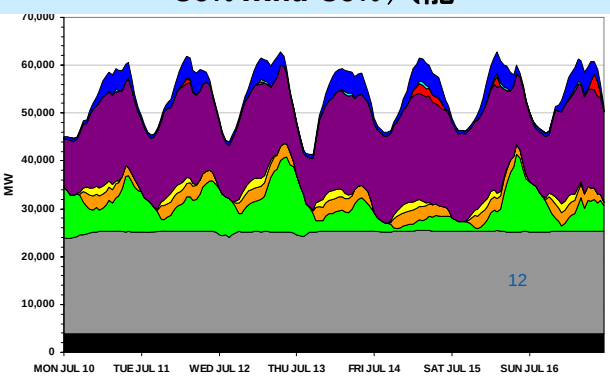
10% wind 10%风能



20% wind 20%风能

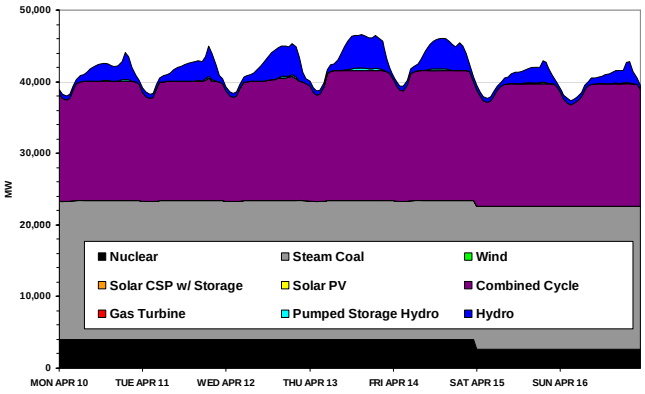


30% wind 30% 风能

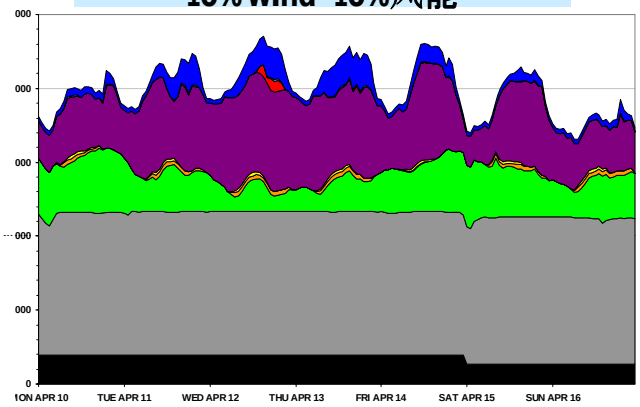


Dispatch During the Worst Week (April) 某最差周的调度(4月)

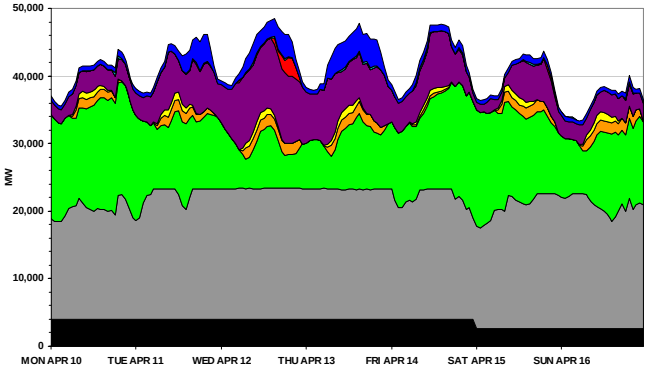
No wind 无风



10% wind 10%风能

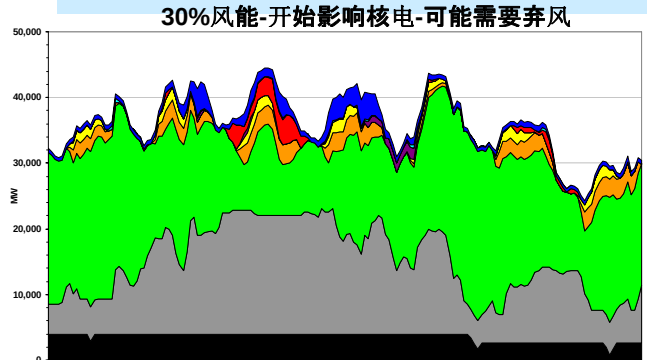


20% wind **20%风能**



30% wind – starting to impact nuclear – likely curtail wind

30%风能-开始影响核电-可能需要弃风



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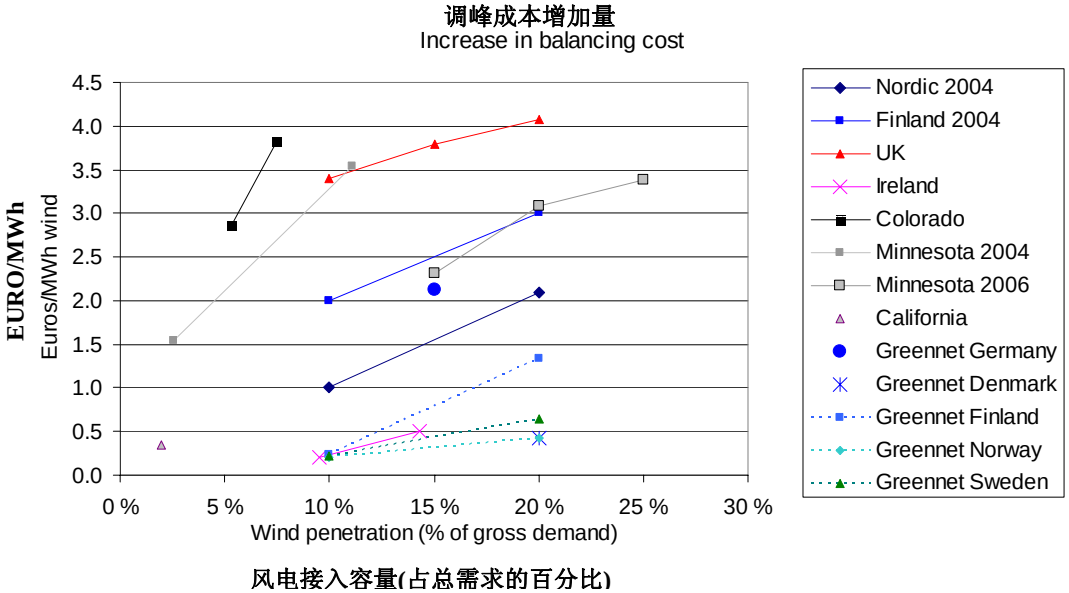
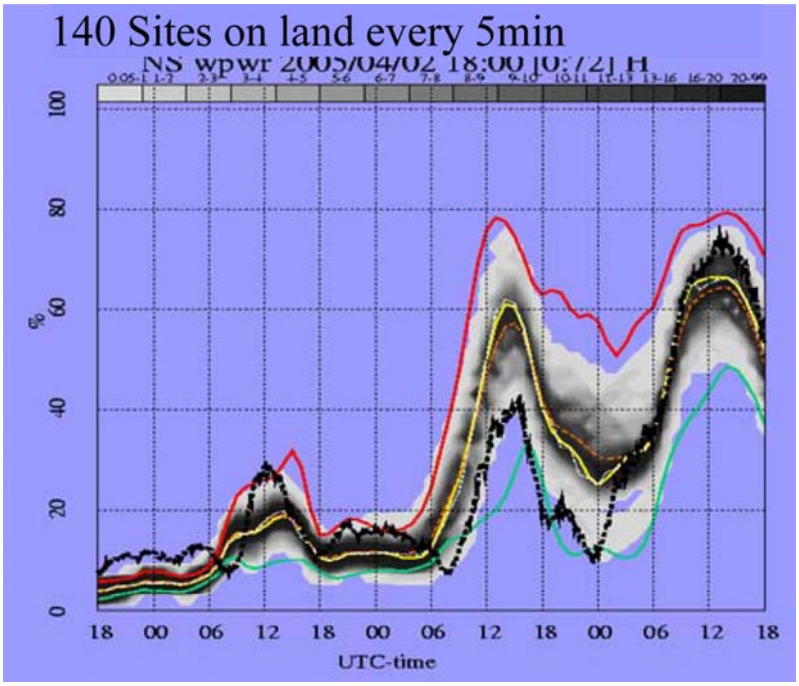
Increased Balancing Cost
增加的调峰成本



Forecasting and Balancing Markets Reduce Impacts
通过市场预测和调峰来降低影响

每5分钟地面140地点



Different Forecasts for Different Time Periods
针对不同时间尺度采用不同预测方法

- Situational awareness forecast: used for severe weather events (real-time)
- Hour ahead forecast: uses rapid update cycle to produce 10 min forecasts 4-6 hrs ahead, updated every hour
- Day ahead forecast: Hourly forecasts 2-4 days ahead, updated every 12 hours, uses national weather service models
- Nodal forecast: hourly forecast of transmission system nodal injections for managing transmission congestion
- Different performance metrics for different forecasts

- 态势感知预测：用于恶劣天气(实时)
- 小时前预测:利用快速更新周期，提前4-6小时做出10分钟预测，每小时更新。
- 天前预测：提前2-4天进行小时级预测，每12小时更新，利用国家气象服务模型
- 节点预测：对输电系统节点注入量进行小时级预测，以进行输电阻塞管理。
- 不同预测方法有不同的性能指标

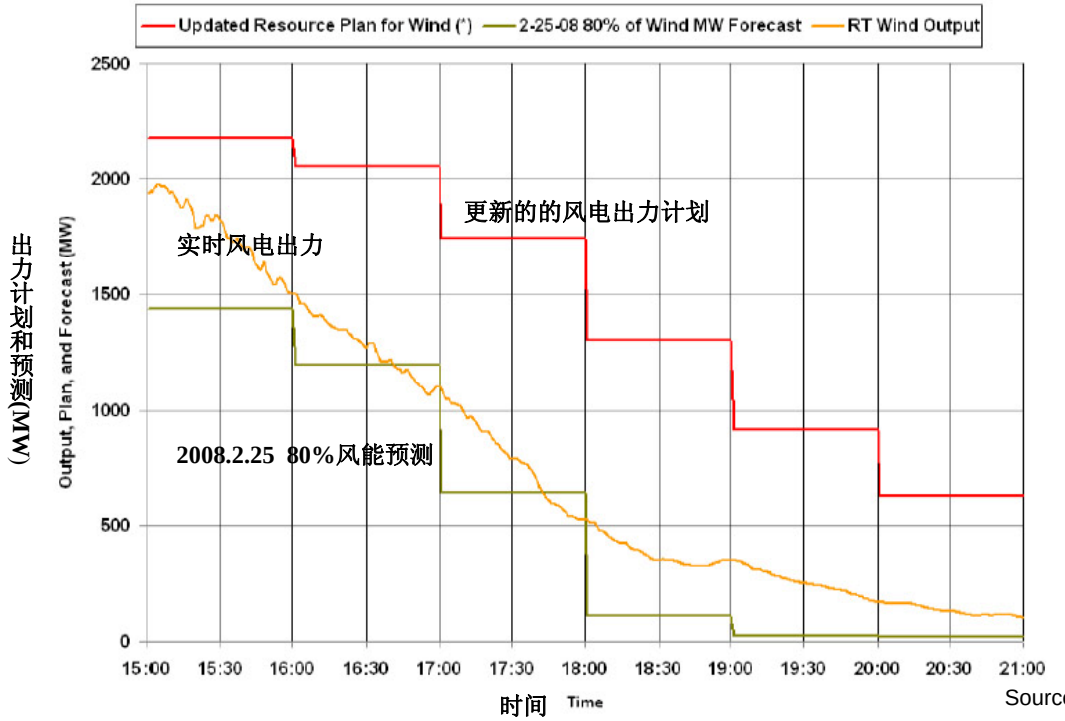
How Good is the Forecast?
预测的精确程度

- Wind plant output can be forecast within some margin of error, and forecasts are getting better
- 风电场输出能在一定误差范围内预测，并且预测技术会越来越好。

Forecast Error 预测误差

	Single Plant单个风电场	Large Region大区域
Hour Ahead 小时前		
Energy (% actual) 发电量(与实际发电量的比值)	10-15%	6-11%
Capacity (% rated) 发电出力(与额定容量的比值)	4-6%	3-6%
Day Ahead 日前		
Hourly Energy(% Actual) 每小时的发电量 (与实际发电量的比值)	25-30%	15-18%
Hourly Capacity (% Rated) 每小时平均出力(比额定容量的比值)	10-12%	6-8%

ERCOT Wind Generation – Feb. 26, 2008
ERCOT风力发电–2008.2.26



Source: ERCOT

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What If the Wind Stops Blowing Everywhere at the Same Time?
如果所有地区在同一时刻风停了该怎么办

- 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

- 中尺度风功率预测技术能够给出解决方案
- 地理分布上的分散性具有很大好处
  - 分散分布能够在长时间尺度范围内起到平滑作用。
  - 汇集能够起到短时间内的平滑作用。
- 大量建模研究表明没有任何一种单一事故会导致大区域范围同时弃风。

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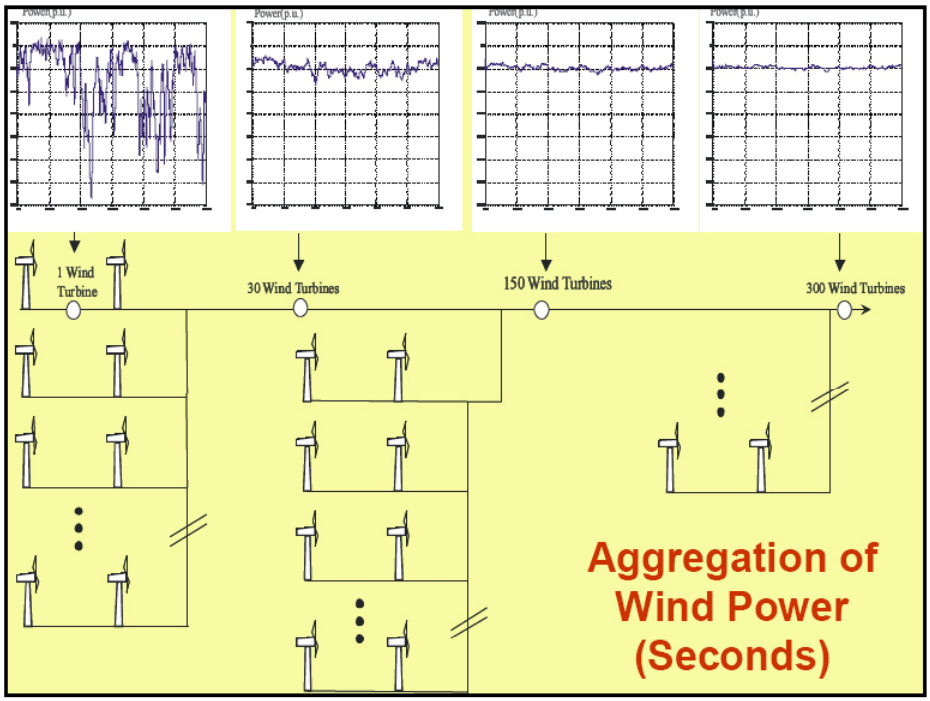
The Power of Aggregation
汇集发电



汇集发电出力

(秒)

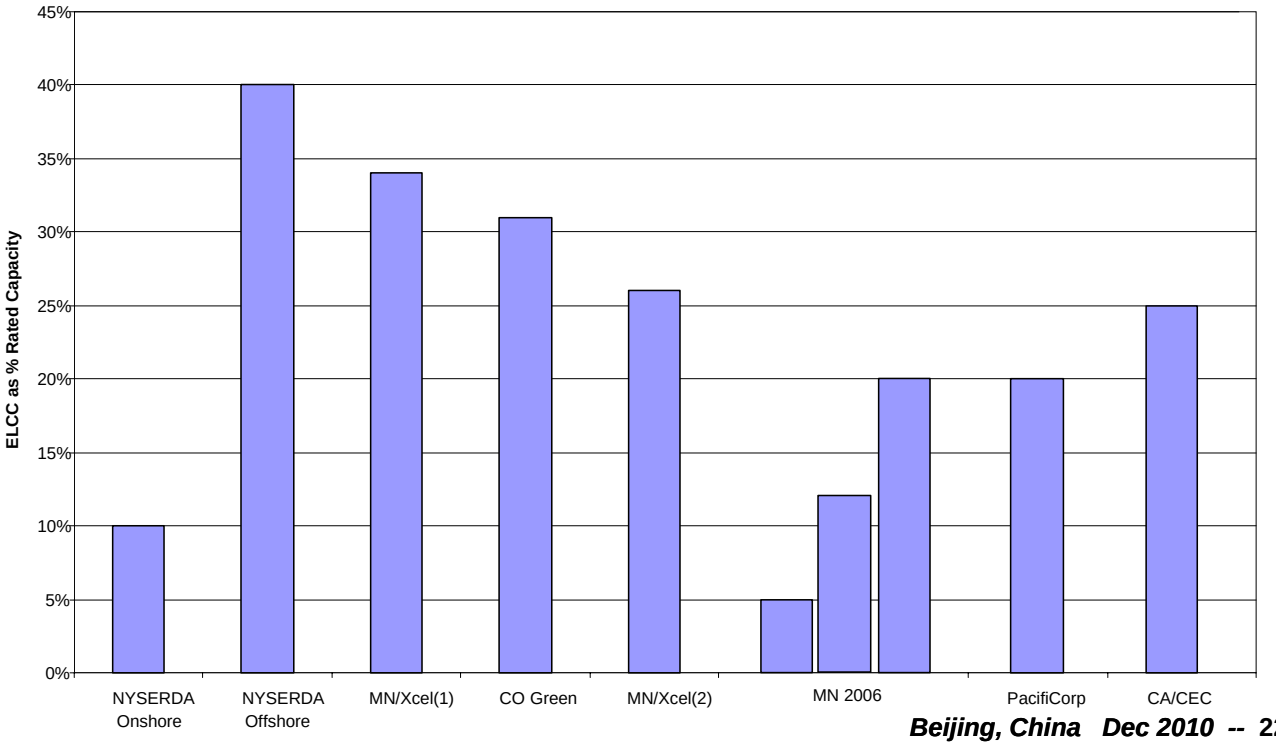
Source: Thomas Ackermann, Energynautics

What To Do When the Wind Doesn't Blow
不刮风时怎么办

- 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
- And that means adding more flexible capacity in the future!

- 好问题！
- 必须在容量概念下处理能源问题。
- 通过概率可靠性方法进行处理，该方法主要用于计算有效负荷承载能力(ELCC)。
- 贡献量可能很大(40%)，也可能很小(5%)。
- 一旦ELCC确定了，随后就可以设计一个可靠系统。
- 这意味着未来将增加更多的柔性容量。

An Energy Resource in a Capacity World
容量概念下的能源



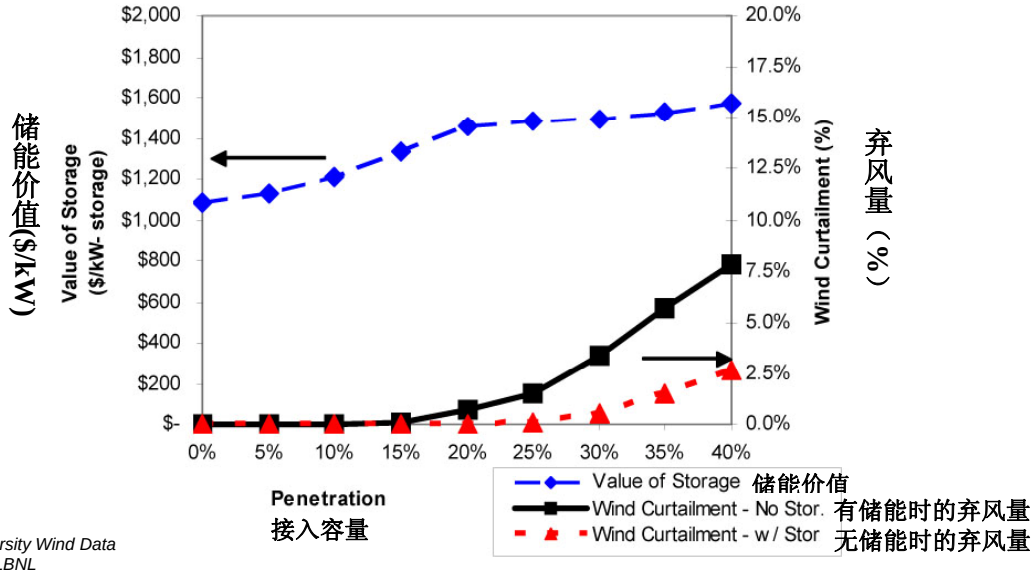
What About Energy Storage?
什么是储能？

- Valuable component of a power system, can provide many benefits
- Greatest value when operated for benefit of entire system, not dedicated to a single resource
- One of many sources of flexibility available to the system
- Expensive, and benefits accrue to different parties, i.e. generation owner, trans. system operator, power marketer
- Seldom sufficient value in revenue stream for any single party to justify the investment
- Integration studies do not show need for storage at 20% wind except possibly on small, isolated systems

- 是电力系统的重要组成部分，具有很多优点。
- 其最大价值在为一个完整的电力系统服务时得到体现，而不是服务于单一资源。
- 是系统可用的众多柔性资源中的一种。
- 成本高，但不同环节均能获益，比如发电厂、输电网运营商、电力市场组织等。
- 对于任何一个组织来说都没有足够的收益率来评价其投资效果如何。
- 并网研究表明，除非是小孤岛系统，否则风能占20%时不需要储能。

Value of Electrical Storage - Wind
储能的价值-风能

- "Medium run" ~ 80% Incumbent Generation
  "中等运行方式" ~80%的机组开机运行



High Diversity Wind Data
Source: LBNL

Won't Too Much Wind Power Cause the System to Collapse?
过多的风电是否会导致系统崩溃

- 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

- 在发生因系统故障导致黑启动这类事故时，人们经常会想到这个问题。
- 与系统稳定性相关的这些问题促使全球范围内的相关机构都致力于风电机组和风电场的模型开发和验证工作(IEEE、UWIG、WECC、制造商、 输电网运营商、供电公司) 。
- 对双馈机组进行的详细仿真表明，风电场可以通过其低电压穿越(LVRT)能力和动态无功支撑来减少电压偏差和阻尼振荡，从而提高系统的稳定性。

System Stability Case Study
系统稳定性问题案例分析

- Wind integration and interconnection study conducted by GE for NYISO, supported by NYSERDA
- Looked at impacts of 3,300 MW of wind generation on 33,000 MW peak load system (10%)
- Stability case study investigated differences in behavior with 3,300 MW of wind plant with generic doubly fed induction machines, distributed throughout the state, replacing 3,300 MW of conventional plant

- 在NYSERDA的支持下，GE为NYISO进行风电并网和互联研究。
- 分析3300MW风电对33000MW高峰负荷系统的影响。
- 稳定性案例分析研究了用3300MW风电取代3300MW常规电源时的系统特性有何不同，分析时采用的是双馈风电机组经典模型，且3300MW风电分散于整个州。

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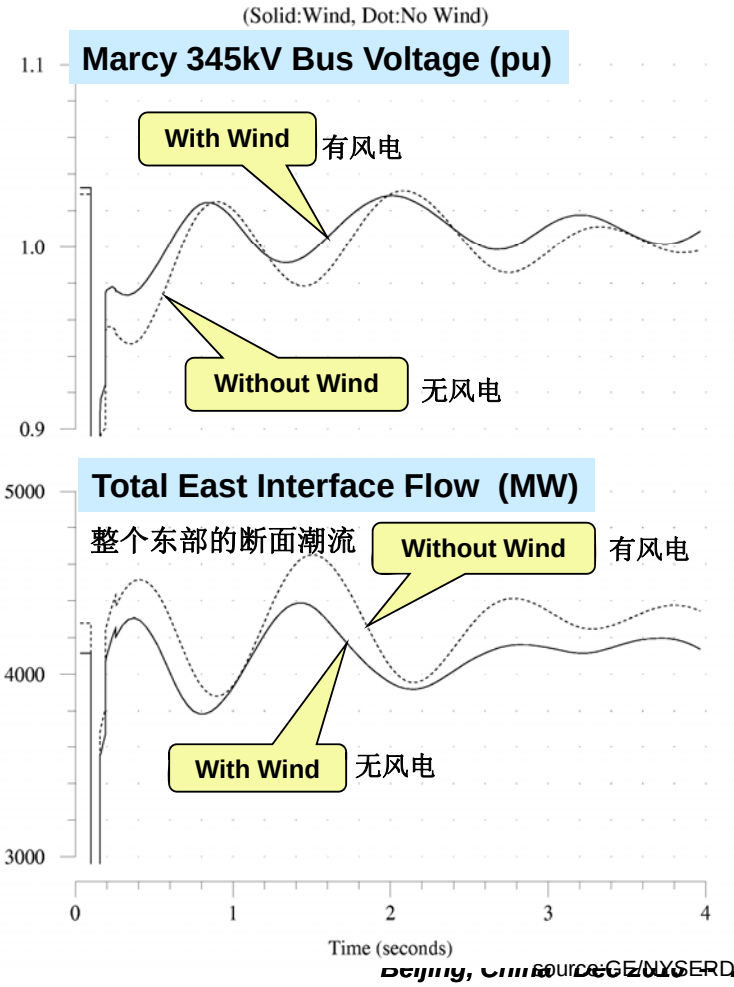
Impact of Wind Generation on System Dynamic Performance
风电对系统动态特性的影响

- Fault at Marcy 345 kV bus
  故障位置：Marcy345kV母线
- Severe contingency for overall system stability
  严重 影响整个系统的稳定性
- Simulation assumes vector-controlled wind turbines
  仿真时假定风电机组采用矢量控制
- Wind generation improves post-fault response of interconnected power grid
  风电提高了互联电网的故障后响应能力



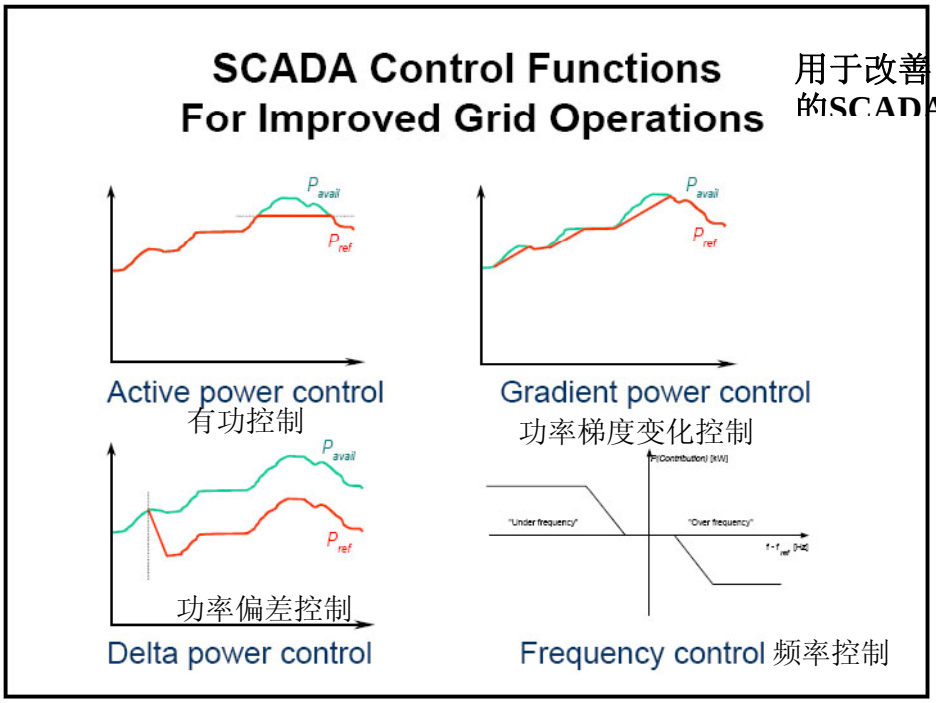
Source:GE/NYSERDA

UWIG Utility Wind Integration Group

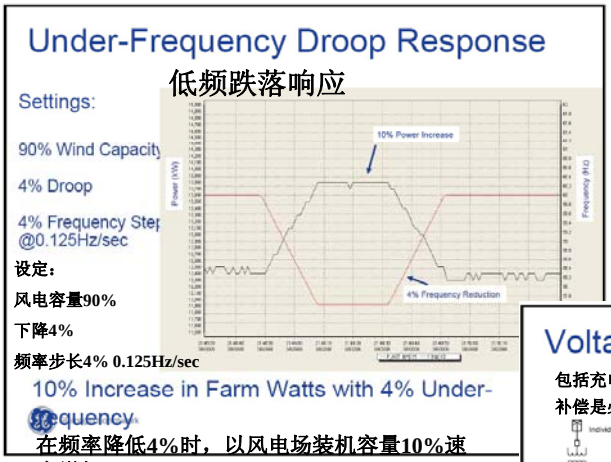
Conclusions from a Recent GE Case Study
GE近期案例分析得出的结论

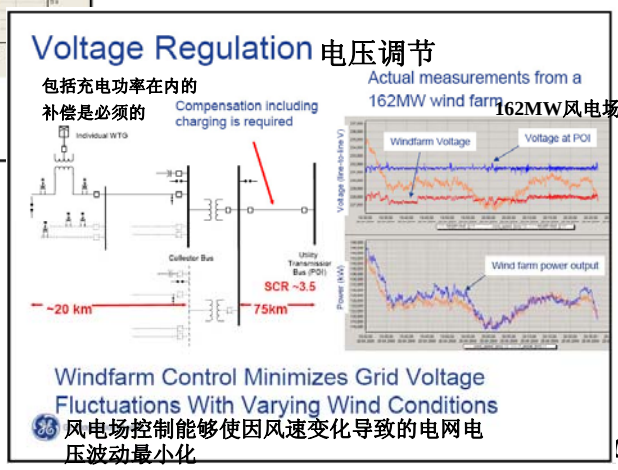
- WECC 20% Electricity from Wind Scenario
  - Systems with high wind penetration can exhibit superior frequency performance
  - Presently available wind plant controls can contribute positively to system frequency performance
  - "It is possible for systems with wind generation to experience degraded frequency performance"
  - "Statements that wind generation necessarily results in degraded frequency performance are incorrect"
- WECC 20%电力来自风电的方案
  - 风电并网容量高的电力系统具有较好的频率稳定性。
  - 目前可用的风电场控制措施有利于改善系统的频率稳定性。
  - 含风电的电力系统有可能会出现频率稳定性变差的情况。
  - "关于风电必然会导致频率稳定性变差的说法是不正确的"

Turbine Technology Advances Reduce Impacts
先进的风电机组技术能减少不利影响



Wind Plant Control Capability
风电场控制能力





Source: GE Energy

National Transmission Policy
国家的输电政策

- National policy debate stimulated by two activities:
  - Success of Texas CREZ process
  - COMPETITIVE RENEWABLE ENERGY ZONES (CREZ)
  - Growing recognition that RPS goals cannot be met without significant transmission build-out
- Three major transmission bills proposed in US Senate last year.
- All different, but all have three common elements:
  - Interconnection-wide transmission planning
  - High voltage backbone with broad cost allocation
  - Federal backstop siting authority
- Growing recognition of critical need for transmission

- 两个事件激发了关于国内政策的讨论：
  - 德克萨斯竞争性可再生能源区（CREZ）的成功建立
  - 越来越多的人们意识到，如果不对输电系统进行大范围的扩建，那么将无法完成可再生能源配额制目标。
- 美国参议院去年提出了三个主要的输电议案
- 这些议案各不相同，但都有三个共同点：
  - 大范围互联输电计划
  - 以高压输电为主干、大范围成本分摊
  - 政府支持的选址授权
- 逐渐增加对输电迫切需求的认识

NERC IVGTF Report Recommendations
NERC IVGTF 报告中的建议

- Broad based industry effort with participation of utilities, ISOs, turbine manufacturers, project developers, research organizations, consultants, trade associations
- Requested by OC/PC in recognition of the increasing large role wind power will play
- Chaired by Warren Frost, AESO with NERC staff support provided by Mark Lauby
- Just released report, which will lead to a review and likely update of NERC standards

- 以供电公司、独立系统运营商、风机制造商、项目开发商、研究机构、咨询公司、行业协会等的共同努力为基础。
- OC/PC要求认可风电将要发挥越来越重要的作用。
- 由AESO的Warren Frost 担任主席，由Mark Lauby 提供NREC人力支持。
- 刚刚发布的报告将带来对NERC标准的重新审查和更新。

The Big Enchiladas
大的墨西哥卷饼

- Dynamic models
- Grid codes
- Probabilistic planning
- Incorporating need for flexibility in G&T planning
- PHEV and DSM as sources of flexibility
- Need for forecasting
- Large balancing areas
- Faster markets
- Remove barriers to transmission

- 动态模型
- 并网导则
- 概率规划
- 关于G&T规划灵活性的协作需求
- 混合动力电动汽车(PHEV)和需求侧管理(DSM)视为灵活的资源
- 预测的必要性
- 大平衡区域
- 更为快速的市场
- 清除输电障碍

and the conclusion is…
结论是…

- There are no fundamental technical barriers and the cost is moderate for the integration of 20% wind energy into the electrical system, but …
- It will not be achieved with business as usual
- There needs to be a continuing evolution of transmission planning and system operation policy and market development for this to be achieved.

- 不存在任何技术障碍，且20%的风电接入电力系统时其成本适中，但是…
- 不能像以往那样实现商业化
- 为了实现这一目标，需要不断完善关于输电规划和系统运行的相关法规、并开拓市场。

As they say in Texas …
正如他们在Texas所说

- If all you ever do is all you ever done, then all you'll ever get is all you ever got!

如果你所做的都是你曾经做过的，那么你将得到的也只会是你曾经得到过的！

For More Information
更多信息

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