



Role of Markets, Balancing Authority Areas, and Transmission in Integration 风电接入中的市场角色、平衡权限区域和输电

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

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Collaborative Effort

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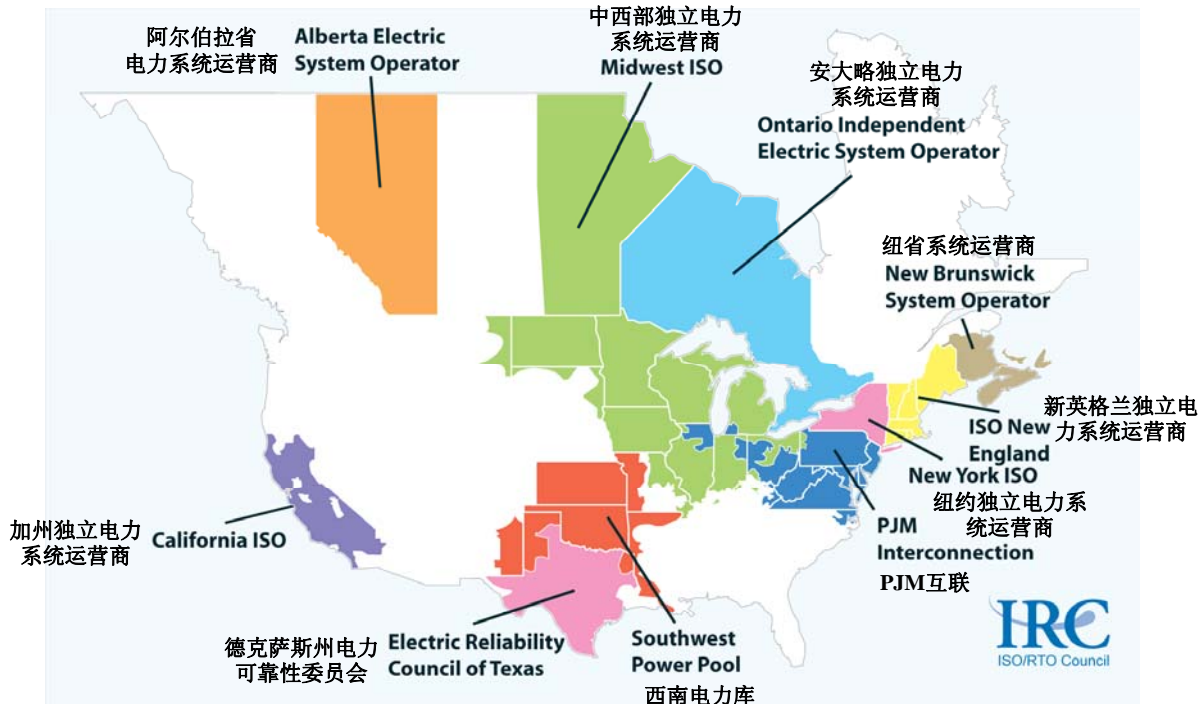
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- ◆ Introduction
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- ◆ Sample of Current US Market Design and Operation with Variable Renewable Resources
- ◆ 当前含有波动性可再生能源的美国市场设计与运行样板
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- ◆ Traditional markets designed for traditional generation
- ◆ 设计用于传统电源的传统型电力市场
- ◆ Additional considerations for variable generation
- ◆ 对于波动电源需额外考虑的因素
 - Increased variability and uncertainty
 - 新增的波动性和不确定性
 - Need for additional reserve capacity
 - 需要额外的备用容量
 - Dispatch with marginal price of zero
 - 零边际价格调度
 - Profit motive to operate with negative LMP
 - 运行于负节点边际电价的驱动因素
- ◆ Develop insights into future needs based on present experience
- ◆ 基于目前的经验，深入了解未来需求

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Sample of Current US Market Design and Operation with Variable Resources 美国当前含波动能源的市场设计与运行案例

- ◆ Common characteristics of regional markets
 - Sub-hourly energy markets
 - Co-optimized ancillary service markets
 - Large systems with aggregation benefits for generation and load
- ◆ PJM
 - Operates in 13 states and DC
 - 163,000 MW generating capacity
 - DA and RT energy and AS markets and capacity market
 - Centralized wind power forecast
 - Negative price offers allowed
- ◆ 区域市场的共同特征
 - 小时内能量市场
 - 协作优化的辅助服务市场
 - 大系统，对于电源和负荷均有好处
- ◆ PJM
 - 运行范围覆盖13个州和华盛顿特区
 - 发电容量163,000 MW
 - 日前和实时能源市场、辅助服务市场、容量市场
 - 集中风电功率预测
 - 允许使用负价格报价

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- ◆ ISO-NE
 - DA and RT LMP energy markets
 - A/S market and 3 yr forward capacity market
 - Peak load 28,000 MW
 - 150 MW wind currently on-line
- ◆ NYISO
 - DA and RT markets
 - A/S and capacity markets
 - 33,000 MW peak load
 - Centralized wind forecast
- ◆ ISO-NE
 - 日前和实时节点变价电价（LMP）能量市场
 - 辅助服务市场和3年远期容量市场
 - 高峰负荷 28,000 MW
 - 目前风电并网容量为150MW
- ◆ NYISO
 - 日前和 实时市场
 - 辅助服务市场和容量市场
 - 高峰负荷33,000 MW
 - 集中风电功率预测

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- ◆ ERCOT
 - 63,000 MW peak load
 - 9,000 MW of wind capacity
 - Evolving LMP market design
 - A/S Markets
 - Ramp rate limitations
- ◆ CAISO
 - DA and RT LMP based markets
 - A/S markets
 - Wind forecasted hour ahead
 - 3,000 MW of wind
- ◆ ERCOT
 - 高峰负荷63,000 MW
 - 风电容量9,000 MW
 - 改进节点边际电价市场设计
 - 辅助服务市场
 - 爬坡率限制
- ◆ CAISO
 - 基于日前和 实时节点边际电价的电力市场
 - 辅助服务市场
 - 小时前风功率预测
 - 风电容量3,000 MW

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PJM:

Day-ahead transmission security and reserve adequacy assessments.
Not currently used as input into day-ahead markets.

NYISO

Evaluating levels of generation committed in the day-ahead market compared to forecasted load.
Real-time wind forecast integrated into real-time commitment and dispatch.

Midwest ISO

Reliability unit commitment.
Transmission outage coordination.
Transmission security.
Peak load analysis and potential impact of wind ramps on flowgates.

ERCOT

80% exceedance forecast used for day-ahead commitment planning.
Amount of installed capacity considered for acquiring regulation reserves.
Wind and load forecast error considered for procuring non-spinning reserves.

PJM:

日前输电安全和备用充裕度评价。
目前不作为日前市场的输入。

NYISO:

对照预测负荷，评估日前市场的开机水平。
实时风能预测与实时安排和调度相结合。

Midwest ISO:

开机安排可靠性。
输电中断协调。
输电安全。
高峰负荷分析和风电爬坡率对潮流的潜在影响。

ERCOT:

日前开机安排规划采用准确率超过80%的预测。
为了确定备用容量，需要考虑装机容量。
为了确定非旋转备用容量，需要考虑风能和负荷的预测误差。

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◆ PJM:

- Plants must be able to accept electronic basepoint signals
电厂必须能够接收电子基点信号。
- During constrained operations, PJM will redispatch all resources on a cost-effective basis according to each resource's bid curve
当运行受限时，PJM会根据各类电源的竞价曲线、并以经济最优为基准对所有电源进行再调度。
- Will send a desired MW basepoint to plants
向电厂发送所需要的MW基点信号。
 - any curtailments should be achieved within 15 minutes or PJM must be notified
任何消减必须在15分钟内实现，否则必须告知PJM。

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▶ NYISO

- Plants must be able to accept electronic basepoint signals
电厂必须能够接收电子基点信号。
- During constrained operations, wind plants must follow the re-dispatch signal and meet the basepoint output limit within 5 minutes
当运行受限时，风电场必须依照再调度信号，并在5分钟内达到基点输出限值。
- Penalties for non-compliance equal to MW above basepoint multiplied by the regulation clearing price
违规罚金数额等于超出基本点的MW数乘以 监管结算价格
- 3% error is allowed
允许3%的误差

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◆ Bi-lateral markets

- stand-alone balancing areas
- tend to saturate with renewables sooner
- stand-alone provider tends to have a smaller pool of dispatchable resources available to manage the renewable integration
- often limited by hourly scheduling protocols
- may not make full use of load response to provide ancillary services
- increasing efforts to develop wind integration charges which are allocated to the renewable provider.

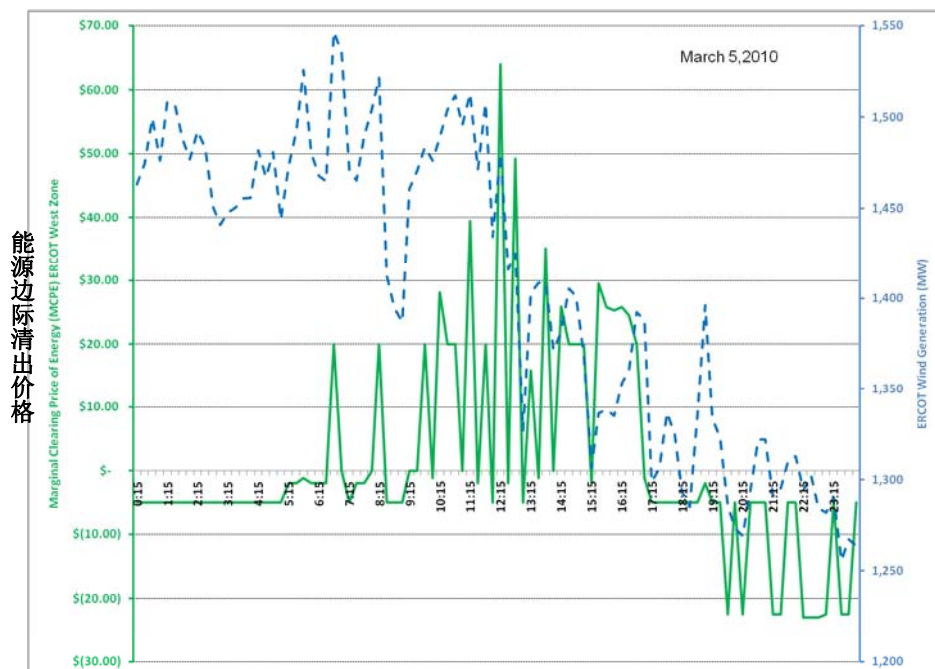
◆ 双向市场

- 独立平衡区域。
- 可再生能源不久将趋于饱和。
- 独立业主趋于采用更小的可用调度电源库来对可再生能源接入进行管理。
- 通常受小时级安排协议的约束。
- 可能没有充分利用 负荷响应来提供辅助服务。
- 不断致力于完善划拨给可再生能源开发商的风电接入费用。

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- ◆ Energy Market Prices and Price Volatility with Renewable Energy
 - When renewable energy generation is high and loads are low, energy prices can go low or negative
 - Negative prices serve to establish a measure of the opportunity cost associated with a lack of dispatch flexibility
 - If prices become too depressed, to the point that average prices do not cover the variable operating costs of the generator, these resources will exit the market, jeopardizing resource adequacy and reliability
 - Conventional energy resources with sufficient flexibility are likely to be profitable and to contribute significantly to the ability to reliably integrate high levels of renewable resource
- ◆ 含可再生能源的能源市场价格和价格波动
 - 当可再生能源发电出力较高而负荷较小时，能源价格较低甚至可能为负值。
 - 负电价用于建立量测手段，用于确定与调度灵活性缺乏相关的机会成本。
 - 如果价格太低，以至于评价电价无法涵盖电源的可变运行成本，则这些电源将退出市场，这将危及能源充裕度和可靠性。
 - 具有足够灵活性的常规能源通常利润较高，且对大规模可再生能源的可靠接入具有很大的贡献。

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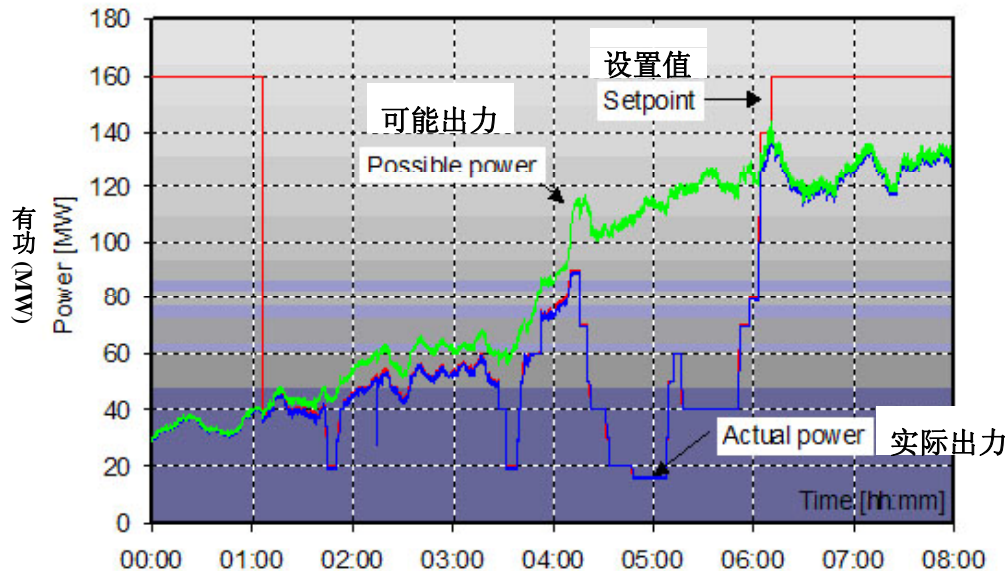
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- ◆ Role of Capacity Markets - How to Keep Conventional Generators in the Market
 - An energy-only market, or energy plus ancillary services market, can lead to stable long-term prices and the ability of generators to recover fixed costs and provide sufficient capacity for adequate reliability
 - Growing body of evidence that a well designed forward capacity market operating in a parallel and coordinated fashion with an energy market can lead to a more stable market operation and reliable system operation in the long term
 - The jury is still out on this issue
- ◆ 容量市场的作用—如何维持市场中的常规电源。
 - 单一能源市场，或是能源加辅助服务市场，通常带来价格的长期稳定和发电机补偿器其固定成本的能力，并为保证可靠性而提供足够的容量。
 - 越来越多的证据表明，从长远来看，一个设计合理的远期容量市场与能源市场并行，可以使市场的运行更为稳定、可靠的。
 - 在这个问题上还没有引起注意。

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- ◆ Role of Ancillary Service Markets – Do We Have What It Takes?
 - An A/S similar to but slower than supplemental operating reserve may be required with high renewable penetration
 - A/S procurement should vary by season and time of day to match wind output patterns and minimize cost
 - Allow wind power plants to participate in providing A/S
 - » They can provide spinning reserve and regulating reserve
 - » During certain times it may be economic for wind plants to provide these services even if with holding energy to do so
- ◆ 辅助服务市场的作用—我们是否得到了其能实现的价值？
 - 辅助服务与附加运行备用类似，但比它慢，当系统中可再生能源接入比例较高时可能需要。
 - 辅助服务的购买应该随季节和时段而变化，从而使之与风电出力水平相匹配，并实现成本最小化。
 - 允许风电场参与提供辅助服务。
 - » 风电场可以提供热备用和调节备用
 - » 在某些特定时刻，由风电场来提供这些服务可能是经济的，即使需要浪费一些能源。

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- ◆ Co-optimization of Energy and Ancillary Service Markets – What’s It All About
 - Co-optimization works by having generators submit offers to supply energy and each of the ancillary services
 - Co-optimization assigns and prices energy and ancillary services simultaneous in dispatch or unit commitment
 - Resources that need advanced commitment such as some forms of storage, demand response, or resources with operating restrictions could be assigned outside of the co-optimization.
 - NYISO recently changed its market rules to exempt storage that is supplying regulation from having to be co-optimized into the energy market
- ◆ 能源市场与辅助市场的协调优化—是什么？
 - 协调优化是指让发电机提交电力供应计划以及各自的辅助服务。
 - 协调优化同时对调度或开机安排中的能源和辅助服务进行分配和定价。
 - 对于需要事先安排的资源（如某些类型的储能、需求响应），或存在运行约束的资源，这些资源可以不参与协调优化。
 - NYISO最近对其市场规则进行了修改，取消了关于提供调节的储能必须参与协调优化才能进入能源市场的这一规定。

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- ◆ **Overcoming Current Market Design Deficiencies - What Role Should Price Responsive Load and Demand Response Markets Play**
克服当前市场设计的不足—价格响应型负荷和需求响应市场应该起到什么样的作用？
 - Demand response for peak reduction, ancillary service supply, and simply as price responsive load is a growing but underutilized resource
针对削减峰荷、辅助服务供应以及价格响应型负荷的需求响应属于正在发展、但尚未被充分利用的资源。
 - Create rules and infrastructure that encourage and facilitate the participation of price-responsive demand and storage resources in the market and consider their specific characteristics
制定新条例、建设基础设施，以促进和推动价格响应型负荷和储能参与到市场中来，并考虑它们它们的独特性。

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- ◆ **Role of Wind Forecasting in Markets**
风功率预测在市场中的作用
 - Using the wind power forecasts in the day-ahead market would generally produce a more efficient result
在日前市场中应用风功率预测能够得到更为有效的结果。
 - With the current process, prices would eventually incentivize wind generators to participate in the day-ahead market, with virtual trading following.
按照目前的形势，最终会因为价格原因而希望风机参与到日前市场，虚拟交易跟踪。
 - Likely that market operators will need to seek increased unit commit and de-commit authority in the future
如果那样的话，市场运行人员以后需要寻求增加机组安排和回收权限。

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- ◆ Incentivizing Flexibility in Organized Markets: How Much is There and How Do We Access It
 - Current generally sufficient level of flexibility will be challenged as variable generation saturation increases
 - The threshold can be estimated as roughly correlated to the “traditional” variability inherent in the diurnal supply pattern.
 - Flexibility challenges may lead stakeholders to establish minimum aggregate flexibility measures and requirements
 - These steps will help manage costs and reliability as the percentage of variable generation increases
- ◆ 激励市场组织的灵活性：程度如何，如何实现。
 - 随着可变电源饱和程度的上升，当前充足的灵活性水平将会面临挑战。
 - 通过日间供电模式固有的传统变化性可以粗略地评估其极限。
 - 灵活性挑战可能会促使利益相关者建立最小的集合灵活性措施和要求。
 - 这些措施有助于在波动电源比例逐渐升高的过程中管理成本和可靠性。

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- ◆ New Market Products and Changes Required
- ◆ 所需要的市场新产品和变化：
 - Ramping - if the ramping capacity of the marginal generators is insufficient, there is likely a need to create a new ramping product
 - 爬坡—如果边际电源的爬坡容量不足，则很可能需要引入新的爬坡电源。
 - An additional reserve service, similar to supplemental operating reserve but slower and cheaper, may be required if the energy market alone cannot accommodate the large but infrequent drops in generation expected
 - 如果电力市场本身无法应对发电容量大幅、且很罕见的跌落，则可能需要引入额外的备用服务。备用服务与附加运行备用类似，但是相对更慢、也更便宜。

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- ◆ Energy Storage: How Do Markets Access the Value and How Do Owners Maximize It
 - The economic incentive provided to energy storage through price arbitrage, in large amounts, could help
 - » smooth out the price duration curve in wholesale markets
 - » provide additional capacity at system peaks
 - » increase the system load factor
 - In wholesale markets with capacity and ancillary service market constructs, energy storage may also be able to capture cash flows from:
 - » Provision of reliability value
 - » Provision of ancillary services
- ◆ 储能：市场如何获得其价值，业主如何使它最大化
 - 通过价格套利的经济手段来激励储能，大量地，可能有帮助
 - » 平滑趸售市场的价格曲线
 - » 在系统高峰负荷期提供额外的容量
 - » 提高系统负荷因数
 - 在含容量和辅助服务市场构成的趸售市场中，储能通过以下方式同样可能获得现金流：
 - » 可靠度条款
 - » 辅助服务条款

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- ◆ Seams Issues: How Important Are They and What Can We Do About Them
 - Seams between energy markets can be mitigated or eliminated through
 - » consolidation of balancing areas
 - » implementing procedures to share reserves
 - » dynamically scheduling energy between balancing areas
 - Interregional transmission planning coordination as proposed by EIPC or WECC addresses some deficiencies associated with multiple independent planning authorities
 - Cost allocation for transmission facilities that span multiple states or regions remains an unresolved question
- ◆ 衔接问题 — 他们的重要性，我们能做什么
 - 电力市场间的衔接问题可以通过以下方式缓解或是消除：
 - » 平衡区域的合并
 - » 备用共享的实施步骤
 - » 平衡区域间的电力动态调度
 - EIPC 或 WECC提出的区域间传输规划协调，解决了与多个独立规划机构相关的某些不足问题。
 - 跨多个州或区域的输电设施的成本分摊是一个尚未解决的问题。

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- ◆ Will Current Congestion Management Techniques Be Adequate for a High Renewables Future
 - Transmission currently a limiting factor in development of renewable generation. Transmission is required to:
 - » deliver renewable generation to load centers
 - » allow system balancing across large regions to reduce the need for ancillary services within the hour
 - Analysis of transmission capacity improvements should account for the needs of:
 - » renewable generation,
 - » flexible generation and other complementary technologies required to cost-effectively maintain system reliability
 - LMP generally considered most efficient means of managing transmission congestion
- ◆ 未来大量可再生能源接入时，当前的阻塞管理技术是否够用？
 - 当前的输电水平制约着可再生能源的发展，输电系统应该能够：
 - » 将可再生能源发电的电力输送至负荷中心。
 - » 允许大区域在大区域范围内进行电力平衡，以减少对小时内辅助服务的需求。
 - 分析如何提高输送容量时，应该说明对以下的需求：
 - » 可再生能源发电
 - » 灵活发电和其他辅助技术，用于最经济的维持系统可靠性
 - 节点边际价格（LMP）通常被认为是进行输电阻塞管理的最有效方法。

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- ◆ System evolution considering needs of renewable energy
 - Need to embrace technological changes and think more flexibly about various aspects of markets and operations
 - Demand traditionally considered inflexible, but with Smart Grid technologies paired with transparent prices from markets, demand can respond to price
 - “co-optimization” of energy and ancillary service markets which can be done faster and better with continued computing advances, blended with variable resource forecasting, can provide a probabilistic SCUC of resources day-ahead and intra-day that can help minimize schedule deviations in real-time
 - Technological advances can help integrate variable resources into the well understood and established principles of markets and operations
- ◆ 考虑可再生能源需求的系统发展
 - 需要涉及技术变革、以及更为灵活的看待市场与运行的各个方面。
 - 通常认为传统的负荷需求不具有灵活性。但是智能电网技术以及相应市场透明电价制度，负荷需求能够对电价做出响应。
 - 随着计算机技术的不断进步，能源和辅助服务市场的“协调优化”能够运行得更快、更好。协调优化与波动电源功率预测相结合，能够给出电源的日前和日内安全约束机组组合（SCUC），有助于实时最小化安排容量偏差。
 - 技术的进步有助于更好的帮助波动电源融入市场和运行的已有理论中。

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Wind Generation Contribution to Resource Adequacy

风力发电对能源充足性的贡献

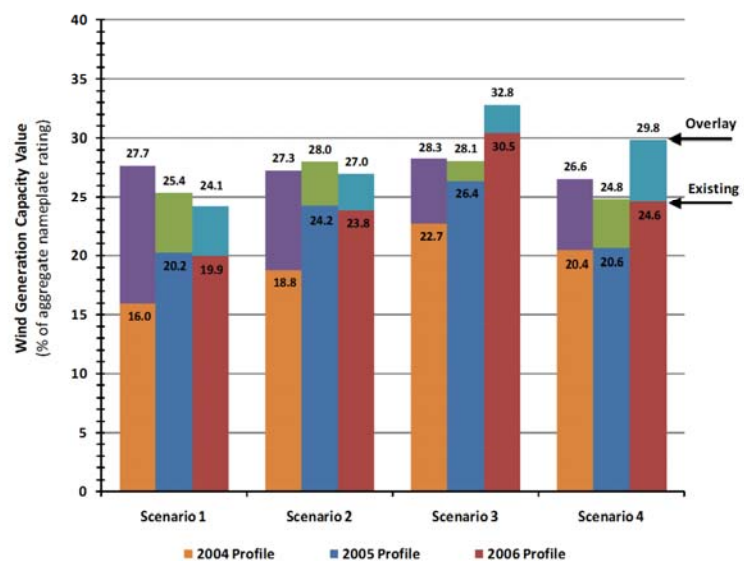
- ◆ LOLE analysis of the Eastern Interconnection with wind generation and the transmission overlays as developed in this study show the Effective Load Carrying Capability of the wind generation to range from 24.1% to 32.8% of the rated installed capacity.
- ◆ The transmission overlays increase the ELCC of wind generation anywhere from a few to almost 10 percentage points (e.g. 18% to 28%).
- ◆ The ELCC of Wind can vary greatly geographically depending on which historical load and wind profiles are being studied. Inter-annual variations were observed; however, these variations were much smaller than had been observed in previous studies (e.g. Minnesota 2006).
- ◆ The LOLE analysis performed for this study shows that the existing transmission network in the Eastern Interconnection contributes roughly 50,000 MW of capacity benefits. With the transmission overlays developed for the wind scenarios in this study, the benefit is increased by up to 8500 MW.
- ◆ 本研究对含风电接入的东部互联系统以及输电网覆盖区域的所做LOLE分析表明，风电的有效负荷承载能力（ELCC）在其额定装机容量的24.1%-32.8%之间。
- ◆ 输电的覆盖范围能够提升风电的ELCC，从很小增到接近10% (比如 18% to 28%)。
- ◆ 风电的ELCC 会因地理位置的不同而产生很大的变化，主要取决于研究中采用了哪些历史负荷数据和风数据。对年内变化进行了观察；但是这些变化要远小于之前的研究中观测到的值。(如Minnesota 2006)。
- ◆ 本研究所做的LOLE 分析表明，东部互联系统中现有的输电网大概贡献了50,000 MW 的容量效益。在本研究中为风电情景扩展的输电网覆盖范围内，其容量效益增至 8500 MW。

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Transmission Overlay Effects on Wind Generation Capacity Value

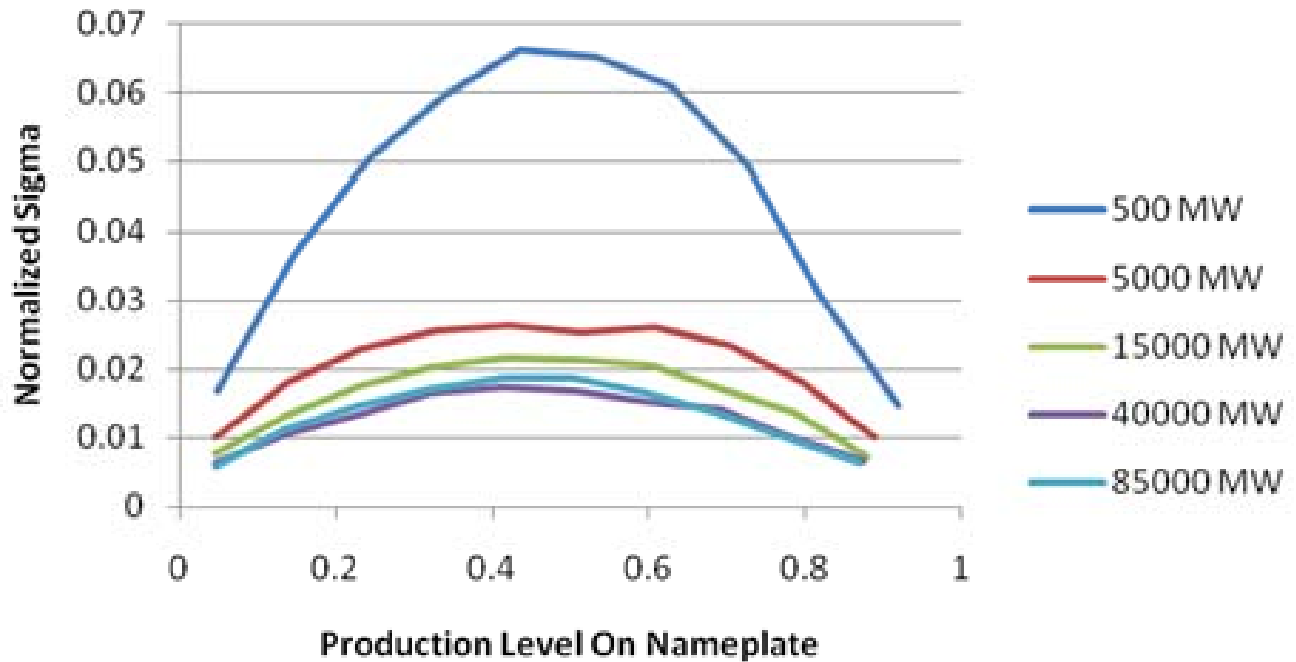
输电覆盖区对风电容量置信度的影响

- ◆ Overlay increases capacity value of wind generation by a few to almost 10%
- ◆ 输电覆盖区能够将风电容量置信度从很小增加到接近10%。
- ◆ Some inter-annual variability, although smaller than observed in some previous studies
- ◆ 存在一定的年际波动，但是远小于之前研究所观测的水平。
- ◆ Difference between ELCC with overlay and 20% is conventional generation that could be deferred



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Normalized 10 Min. Variability for 5 Regional Groups



Additional Transmission Benefits

额外的输电效益

- ◆ Long-distance transmission overlays (especially HVDC) can
 - Make regional markets larger and more competitive
 - Aggregate variable generation across large regions
 - Deliver ancillary services where they are needed
 - Increase capacity value of variable generation
 - Increase the robustness of the system
 - Potentially increase the utilization of the underlying AC system
- ◆ 长距离输电覆盖区 (尤其是HVDC) 能够:
 - 使区域市场变得更大、更加复杂。
 - 在更大范围内汇集波动电源。
 - 在需要的地方提供 辅助服务。
 - 增加波动电机的容量置信度。
 - 增强系统的鲁棒性。
 - 可能提高对基础性交流系统的利用率。

- ◆ Evolutionary market design changes will assist in integrating large amounts of variable renewables in the future:
 - Larger balancing areas
 - Sub-hourly energy markets
 - Flexible generation
 - Price responsive load
 - Centralized wind forecasting
 - A few new ancillary services
 - Transmission is essential
- ◆ 改进的市场设计变化有助于未来接入大量的波动性可再生能源电源。
 - 更大的平衡区域
 - 小时内源市场
 - 柔性发电
 - 价格响应型负荷
 - 集中风功率预测
 - 一些新型的辅助服务
 - 输电是基础

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