Calculating Reserve Needs and Costs in Wind Integration Studies: A Review
风电并网研究中对备用需求与成本的计算：回顾

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Background
背景

- Several wind integration studies have been performed in the United States to evaluate the grid impacts of increased levels of wind power
- One of the factors considered is whether additional reserves are required, what quantity of reserves, and what type of reserves
- Reserve needs reflect the increased variability *and* uncertainty of higher levels of wind generation

- 为评估风电比重加大对电网的影响，美国已进行多次风电并网研究
- 其中考虑的因素之一是：是否需额外增加备用，以及备用的数量与类别
- 备用需求反映出风电比重加大所带来的不稳定性与不确定性的增加

Definition of Reserves 备用的定义

- No universal definition of reserves, and many terms used, sometimes somewhat interchangeably.
- Will use the following terms for this presentation:
  - ➢ Operating reserves as global term for reserves used in operating time frame (minutes to hour) to balance load and generation and to assist with frequency control.
    - Excludes what may be needed for reactive power and/or long-term planning (i.e., capacity reserves)
  - ➢ Frequency response—provides initial response for major system disturbance (seconds).

- 备用没有通用的定义，目前使用的有多个相关术语，有时可互换.
- 本次演示将使用下列术语：
  - ➢ 运行备用是备用的统称，指在运行时段（按分钟到小时不等），用于平衡负荷与发电运行，并协助控制频率的备用。
    - 不包括无功功率和/或长期规划所需的备用（如：容量备用）
  - ➢ 频率响应——对主要系统扰动作出初始响应（按秒）。

Definition of Reserves, continued
备用的定义（续）

- Regulating reserves—Balance load and generation in faster time frame than can be met through energy markets or by most generation or demand (minute to minute)
- Load following reserves—10 minutes to a few hours for balancing load and generation
- Spinning reserves—on-line and synchronized generators capable of responding within defined, short period of time
- Non-spinning reserves—similar to spinning reserves but does not have to on-line and synchronized. Must also respond within defined but longer period of time, e.g., 10 minutes. Also called replacement reserves.

- 调节备用 —— 在短于通过能源市场或由大部分发电运行或需求所能达到的时段内，平衡负荷与发电运行（按分钟）
- 负荷跟踪备用 —— 在10分钟到数小时的时段内平衡负荷与发电运行
- 旋转备用 —— 在线与同步发电机可在指定较短时段内作出响应
- 非旋转备用 —— 与旋转备用类似，但不必在线和同步。必须在指定时段内作出响应，但要长于旋转备用，如10分钟。也被称为代备用。

Definition of Reserves, continued
备用的定义（续）

- Supplemental reserves—similar to non-spinning reserves and also does not have to on-line and synchronized. Must also respond within defined period of time, but sometimes longer period, e.g., 30 to 60 minutes.

- 补充备用 —— 与非旋转备用类似，也不必在线或同步。必须在指定时段内作出响应，但可能为较长时段，如30至60分钟。

Definition of Reserves, cont.
备用的定义（续）

- Contingency reserves—used for handling instantaneous failures (e.g., generator or transmission outages).
  - In U.S., represents the reserves needed to manage the loss of the single largest unit (generation or transmission)
  - May include combination of spinning and non-spinning reserves
  - Regions may require that at least 50% of contingency reserve is spinning
  - For instance, the single largest contingency for Minnesota is 1500 MW from a 500-kV transmission line.

- 应急备用 —— 用于应对突发事故（如发电机或输电中断）。
  - 在美国指用于控制单一最大机组损耗的备用（发电或输电）
  - 可能包括旋转与非旋转组合备用
  - 部分地区可能要求至少50%的应急备用为旋转备用
  - 例如，明尼苏达州的单一最大应急备用为1500 MW，通过500-kV传输线输电。

What Has Been Learned So Far from International Wind Integration Studies
国际风电并网研究带来的启示

- Studies have found that variations in load and wind are not strongly correlated, reducing reserve requirements
- Geographic diversity of wind helps smooth wind variability and can lower need for incremental reserves on short time scales
- Impacts of wind are relatively modest on short time scales, e.g., regulation
  - Variability of wind generally low from minute-to-minute, though not all studies agree with this
  - Regulation impacts may be higher if study definition assumes a longer scheduling time frame, or if it is assumed that generators providing regulation are slow to respond to changes in load and generation

- 研究发现负荷变化与风电之间没有密切联系，进而减少了备用要求
- 风力资源的地理差异性可帮助消弱风资源变化的影响，减少短时段内对新增备用的需求
- 风电在短时段的影响相对有限，例如：调节
  - 风资源变化按分钟计算一般较低，但有研究对此持不同看法
  - 若研究定义假设一个较长的指定时段，或假设提供调节的发电机对负荷与发电运行的变化响应迟缓，则调节的影响可能增大

What Has Been Learned So Far, cont.
国际风电并网研究带来的启示（续）

- Impact of wind more pronounced in longer time scales (hourly and multi-hourly)
  - For example, greater impact on load following
- Wind does not contribute to single largest contingency
  - Changes in aggregate wind output occur over hours, not instantaneously, so contingency reserves generally not impacted
- Wind may require different types of reserves, or a reclassification of existing reserves
  - Reserves to handle multi-hour wind ramps may be needed

- 风电的影响在较长时段内更加明显（小时间隔或多个小时间隔）
  - 例如：对负荷跟踪具有更大的影响
- 风电不会影响单一最大应急备用
  - 总体风电出力会在数小时后出现变动，而不会突然发生变化，因此应急备用通常不会受到影响
- 风电可能需要不同类型的备用，或需对现有备用进行重新分级调整
  - 可能需要用于应对数小时风电爬坡的备用

What Has Been Learned So Far, cont. 国际风电并网研究带来的启示（续）

- Wind forecasting accuracy affects level of necessary reserves, both hourly and sub-hourly level
  - Some grid operators, such as the Electric Reliability Council of Texas, are factoring wind forecasts into their need for non-spinning reserves
  - Some wind integration studies are recommending another unit commitment period besides day-ahead, such as six-hour ahead, to incorporate updated wind forecasts that will likely be more accurate the closer to the operating hour

- 风电预测准确性将影响小时间间隔和小时内必要备用的比重
  - 部分电网运营商，如德克萨斯州的电力安全委员会，在非旋转备用需求中纳入风电预测因素
  - 部分风电并网研究建议除提前一天外，增加其他机组组合预测时段，如提前6个小时，进而确保越接近运行时间，获得的最新风电预测越准确。

Study Results Should Be Viewed with Caution, as They Are Subject to Many Assumptions and Uncertainties
研究结果均基于假设和不确定因素，因此应慎重对待

- Wind forecasts in modeling based on statistical extrapolations of wind resource models, not based on “real” wind forecasts
- Production cost models run hourly and therefore don’t evaluate operating reserves (since they are sub-hourly)
- Operating reserve requirements determined statistically through analyzing wind resource time series and are typically not validated in production cost modeling
- Methodologies have changed as studies have evaluated higher levels of wind penetration and are covering larger areas

- 模型中的风电预测均基于对风资源模型的统计推测，而不是基于“真实的”风电预测
- 生产成本模型按小时运行，因此无法评估运行备用（运行备用按小时内）
- 运行备用要求通过分析风资源时间序列统计确定，通常未在生产成本模型中进行验证
- 随着研究所评估的风电比例的提高和覆盖地区的扩大，研究方法已发生变化

Early Study Methods to Quantify Reserve Needs / Costs
备用需求/成本量化的早期研究方法

- Analyzed the standard deviation of sub-hourly changes in net load (load minus wind) versus load alone for regulation and load following
- Multiply standard deviation by three to capture 99.7% of all potential instances for regulation and load following
- Approach used in GE's NYSERDA (2005) and CEC study (2007) for determining regulating reserves and in other wind integration studies
- Provides estimate of quantity of regulation and load following reserves needed (cost impacts are estimated separately)

- 针对调节与负荷跟踪备用，分析净负荷（剔除了风电与负荷能互冲的部分）小时内变化的标准偏差，而非仅负荷本身的变化
- 针对调节与负荷跟踪备用，将标准偏差乘以3，以获得所有潜在实例的99.7%
- 在通用电气参与的纽约州能源研究与开发管理局（NYSERDA）（2005年）和CEC研究（2007年）中所采用的调节备用的确定方法，也被用于其他风电并网研究
- 提供对所需调节和负荷跟踪备用数量的估算（单独估算成本影响）

Minnesota Study (2007)
明尼苏达州风电并网研究（2007）

- NREL analysis of operating wind projects showed that variability in regulation time frame (minute-to-minute) was 1-2 percent for every 100 MW of wind
- Study used 2 MW regulation requirement for every 100 MW of wind
- For combination of load and wind variability, used formula on following slide to estimate overall regulation needs…

- 再生能源实验室（NREL）对运行风电项目的分析显示，调节时段内（按分钟）每100 MW风电的变化为1-2%。
- 研究中对每100 MW风电采用2 MW调节要求。
- 针对叠加的负荷与风电变化，使用下一幻灯片中的公式，对总调节需求进行估算……

Minnesota Study (2007), cont.
明尼苏达州风电并网研究（2007）（续）

New新_Regulating调节_Requirement要求 : =

$$k \frac{\sqrt{\sigma_{Load}^2 + N(\sigma_{w100}^2)}}{}$$

Where其中

K = a factor relating regulation capacity requirement to the standard deviation of the regulation variations; assumed to be 5

K=关联调节能力要求与调节变化标准偏差的参数；设定为5

σ_{Load} = standard deviation of regulation variations from the load

σ_{Load} =负荷的调节变化标准偏差

σ_{w100} = standard deviation of the regulation variations from a 100 MW wind plant 100MW

σ_{w100} =风电厂的调节变化标准偏差

N = wind generation capacity in the scenario divided by 100

N =情景中的风力发电容量除以100

Minnesota Study, cont.
明尼苏达州风电并网研究（续）

- Load following estimated as twice the standard deviation of five-minute changes in net load
- First study to consider dynamic operating reserves to reflect hourly wind forecast errors
  - Quantity of reserves needed a function of expected wind generation during operating period
- Found that variability of wind is highest when wind capacity is in middle range of installed capacity, as wind turbines are on the steepest part of the power conversion curve.
  - Therefore, more reserves are needed for the middle range compared to times of low wind generation or high wind generation

- 负荷跟踪估值为净负荷每五分钟变化的标准偏差的两倍
- 第一次通过研究动态运行备用，反映小时间隔风电预测的误差
  - 备用的数量需将运行时段的预期风电发电量作为函数
- 研究发现，当风电容量为装机容量的中间值时，风电的变化值最高，而风力涡轮机处于动力转换曲线的最陡部分。
  - 因此，与低发电容量和高发电容量相比，发电容量为中间值时需要更多的备用

All Island Grid Study (Ireland 2007)
全岛电网研究（爱尔兰 2007）

- Study looked at two of reserves: spinning (fast response) and replacement reserves (slower response)
- Replacement reserves defined as off-line units with start-up time of under 60 minutes or online units not allocated to spinning reserves
  - Demand for replacement reserves assumed to be a function of installed wind capacity and wind forecast error over longer time periods
- Spinning reserves defined as the size of the largest on-line unit plus an additional contribution for wind generation
  - Assumed 100 MW could be provided through interconnections
  - 50 MW by interruptible load
  - Pumped storage hydro limited to 50% of reserve amount
  - Wind can provide reserves through curtailment
- Additional spinning reserves required, but largest contributor still the loss of the largest conventional generating unit

- 研究对象主要为两种备用：旋转备用（快速响应）与代备用（响应相对迟缓）
- 代备用可定义为启动时间在60分钟以内的离线机组或不属于旋转备用的在线机组
  - 将代备用需求设定为较长时段内的风电装机容量与风电预测误差的函数
- 旋转备用可定义为最大在线机组，以及风力发电附加贡献因子
  - 假定通过互联可提供100 MW
  - 可中断负荷提供50 MW
  - 抽水蓄能机组仅占备用的50%
  - 通过风电减载可提供备用
- 仍需要附加旋转备用，但最大的贡献因子依然是最大传统发电机组的损耗

Ireland, cont.
爱尔兰（续）

- Replacement reserves determined as combination of the forced outage rates of plants and an additional margin that is the 90% percentile of net load for each scenario
- Used rolling unit commitment and stochastic optimization
- Demand for replacement reserves a function of installed wind capacity and wind forecast errors
- Need for replacement reserves increased over longer time frames (e.g., multi-hour) as wind forecast errors are larger

- 代备用通过叠加每一情景中电厂的事故停机率与占净负荷90%的附加保证金确定
- 使用滚动机组组合与随机优化方法
- 将对代备用的需求作为风电装机容量与风电预测误差的函数
- 在较长时段内（如：数小时），随着风电预测误差的扩大，对代备用的需求将增加

Eastern Wind Integration Study (2010, US) 东部风电并网研究（2010，美国）

- Wind forecast uncertainty factored in for determining regulating reserve
  - Economic dispatch programs run over 5 minutes, use information from 10 minutes ago
  - Only regulating reserves can meet deviations from schedules
  - Highest variation occurs near 50% level of wind production, when 10 minute changes in output can be up or down and are located in the steepest part of the wind power output curve

- 风电预测的不确定性将作为确定调节备用的因素之一
  - 经济调度项目运行超过5分钟，所使用的信息为10分钟之前的信息
  - 仅调节备用可弥补与预定安排的偏差
  - 风电发电量达到50%时将出现最大变化，在10分钟时变化会出现波动，在风电出力曲线中位于最陡部分

Eastern Wind Integration Study (cont.)

东部风电并网研究（续）

- Similar approach used for hour-ahead wind forecast errors, but assumed deviations could be met by spinning and non-spinning reserve
  - One standard deviation of hour-ahead wind forecast error could be met by spinning reserve
  - Two standard deviations could be met by non-spinning reserves
- Model releases reserves in real-time if needed because less wind was available than predicted

- 针对每小时风电预测误差采用类似方法，但假设偏差可通过旋转或非旋转备用弥补
  - 每小时风电预测误差的一次标准偏差可通过旋转备用弥补
  - 两次标准偏差可通过非选择备用弥补
- 若可用风电量低于预测风电量，则模型可根据需要实时释放备用

Western Wind and Solar Integration Study (2010, US)
西部风电及太阳能并网研究（2010 美国）

- Calculates hourly reserve requirements based on expected wind and load levels
- Demonstrated that simple rules can be used to calculate reserve requirements with wind
  - X*wind + Y*load up to max Z of wind
  - For WestConnect (southwestern U.S.), equals 1.1% of load + 5% of wind generation up to 47% of nameplate wind.
  - Reserve requirements may be considerably higher for smaller balancing areas
- Suggested that reserves are released in unit commitment from units being dispatched down instead of being de-committed

- 根据预期风电与负荷，计算小时间隔备用要求
- 研究证明可采用简单法则计算风电备用要求
  - X*风电 + Y*高达Z的负荷
  - 就WestConnect （美国西南部）而言，等于1.1%负荷 + 5% 风力发电量（达到铭牌标定风电容量的47%）
  - 对于较小平衡区域，备用要求可能更高
- 建议从关闭的机组，而非回收的机组中，释放备用至机组组合

Recommendations
建议

- Reserve determinations should be based on the net load variability of load and wind, not on load alone or wind alone. Aggregate wind generation should be considered, not the variability of individual wind plants.
- Reserve impacts from wind generally tend to increase with time frame
  - Modest increases in sub-hourly (regulation)
  - More significant increases in hourly (load following)
- Earlier wind integration studies typically multiplied standard deviation of net load ramps by three to estimate both the hourly and sub-hourly potential reserve impacts from wind, and is probably the place to start in China. More complicated methods can be implemented later.

- 备用的确定应基于负荷与风电的净负荷变化，而不仅仅是负荷或风电的变化。同时应考虑总体风电发电量的变化，而非个别风电厂的变化。
- 通常情况下，风电的备用影响随着时段不同而增大
  - 小时内有适度增大（调节）
  - 小时间隔时有明显的增大（负荷跟踪）
- 早期的风电并网研究通常将净负荷爬坡的标准偏差乘以3，以估算风电小时间隔与小时内的备用影响。中国可将其作为目前研究的起点，并在后期逐步采用更加复杂的方法。

Recommendations, cont. 建议（续）

- Wind does not contribute to need for additional contingency reserves
- Geographic smoothing offers significant benefits and should be accounted for in determining reserve requirements
- Most reserves are currently static (i.e., do not vary) and if they do vary, change based on hourly rules, not on forecasted conditions. Dynamic reserve requirements that vary based on forecasted wind generation are increasingly being called for in recent wind integration studies

- 风电不会产生对额外应急备用的需要
- 平坦的地理环境具有巨大的优势，因此应作为确定备用要求的考虑因素
- 大部分备用通常为静态（如：不会发生改变），若需改变时，则可随时变更，而不需考虑预测情况。动态备用要求应根据预测风电发电量进行变更。近期的风电并网研究越来越多的采用动态备用要求

Recommendations, cont.
建议（续）

- Easy to be conservative and hold much more reserves than needed
  - Could also end up paying more for reserves than necessary
  - Consider relying on demand response if reserves are needed for a small number of hours per year instead of building additional generation
- Requirement for ramping reserves, load following and regulating reserves influenced by quality of wind forecast. Vital that study wind forecasts emulate real wind forecasts

- 容易过于保守，保留过多不必要的备用
  - 可能会为不必要的备用支付更多成本
  - 若仅需为每年数小时提供备用，则应根据需求响应确定，不必额外建设发电系统
- 对爬坡备用、负载跟踪备用与调节备用的要求受风电预测质量的影响。至关重要的是研究中的风电预测模仿真实风电预测

Recommendations, cont.
建议（续）

- No standard definition for reserves; requirements depend on how one defines reserves (sub-hourly and hourly). Need to clarify what reserves will be defined and how in China.
- Future reserve requirements may also vary by time horizon, as wind can be better predicted the closer to real-time operations
- Future reserve requirements may vary based on load forecasts, wind and solar forecasts, net load forecasts, uncertainty of the wind and solar forecasts and expected production and availability of conventional generation.

- 备用没有标准定义；对备用的要求应以各自对备用的定义为依据（小时内和按小时）。应清楚在中国需定义的备用，以及如何定义。
- 未来的备用要求可能根据时段不同而发生变化，因为越接近实时操作，越能对风电作出更精确的预测
- 未来的备用要求可能根据负荷预测、风电与太阳能预测、净负荷预测，风电与太阳能预测的不确定性，以及传统发电的预期产量与可用性，而进行变更

For Further Information…
更多信息……

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For Further Information, continued 更多信息（续）

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- Erik Ela等于2010年7月，在明尼苏达州明尼阿波利斯举行的IEEE能源与动力会议上所做，关于"风电并网研究中运行备用确定方法的发展"的报告。

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