海上风电场运行尾流评估
及对平价大基地微观选址的启示

Wake Assessments of Operating Offshore Wind Farm and Its Instruction on Micro-Sitting of Large-scale Zero-subsidy Wind Power Bases

2020.10 Beijing China

*数据来源CWEA2019，统计数据截止2019年底
The statistics comes from CWEA2019, according to the end of 2019

	2015Y	2016Y	2017Y	2018Y	2019Y
新增装机New	36	59	118	173	249
累计装机Accumulated	103	163	281	454	703

新增装机New　累计装机Accumulated

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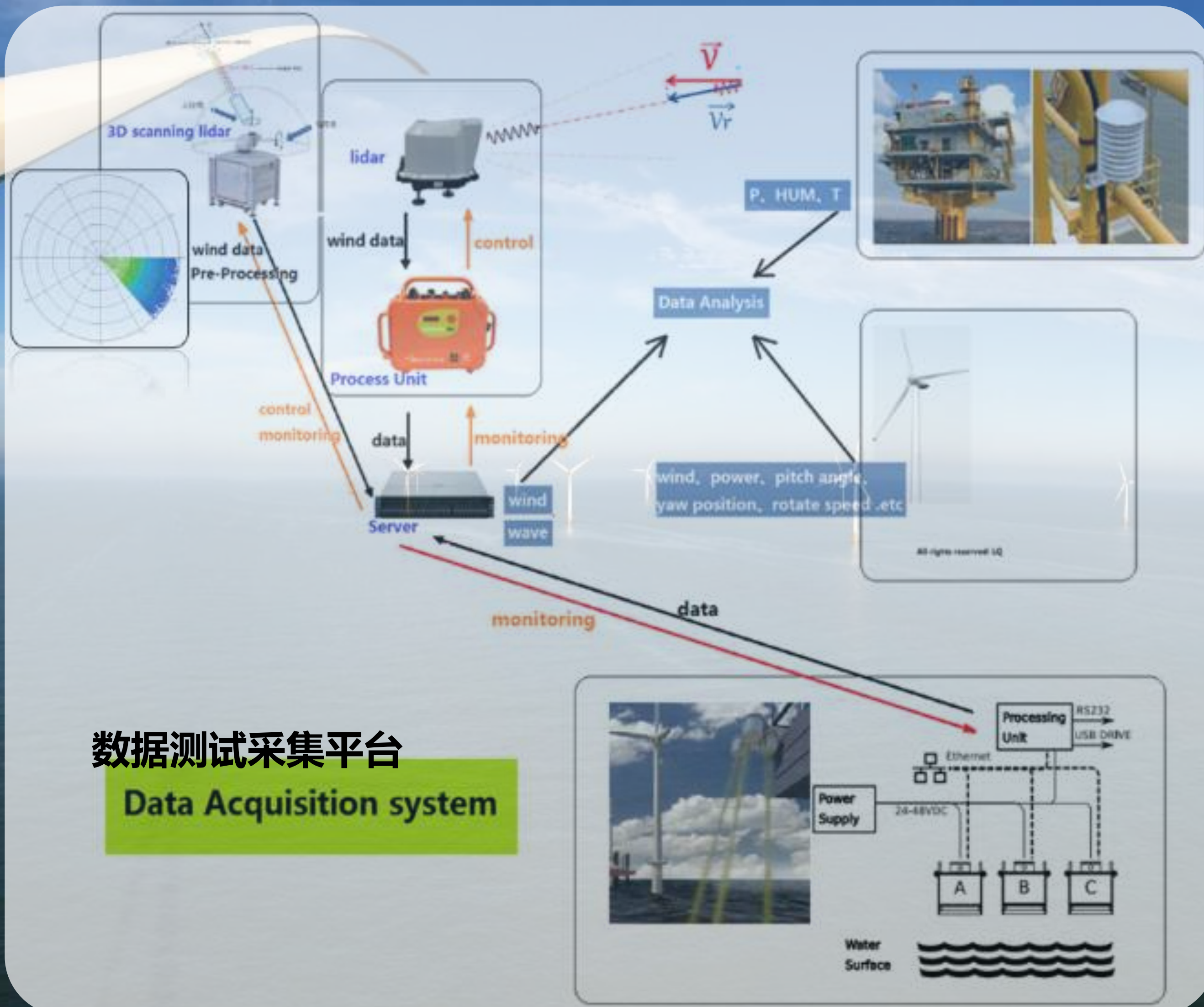
2.909GW

41.4%

基于江苏某风场的后评估项目
Post-evaluation platform based on an OWF* in Jiangsu province



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*OWF (Offshore Wind Farm)

海上风电场运行尾流评估流程

Procedures of wake Assessments on Operating OWFs

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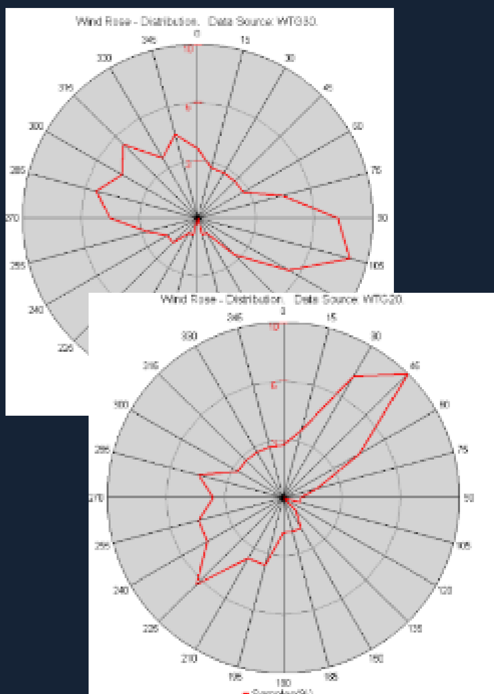
step1风机偏航角校准
Calibration of WTGs yaw position angle(Force geographic north is zero)
↓↓↓
step2风机功率曲线测试，NTF函数测试
Testing of Power-Curve and nacelle NTF-function
↓↓↓
step3运行SCADA数据清洗
Cleaning of SCADA data
↓↓↓
step4运行工况分类（风机工况、环境工况）
Classification of operating scenarios
↓↓↓
step5数据分析
Data analysis
↓↓↓
step6实测数据vs数值计算
Operating data vs. numerical computation

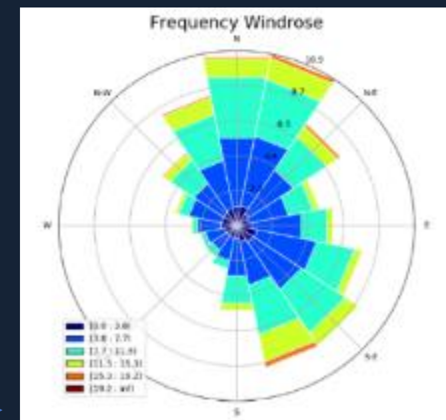
step1：风机偏航角校准
Calibration of WTGs yaw position angle(Geographic north is zero)



原始SCADA风玫瑰
Windrose in SCADA

BeiDou Satellite System

approach



校准后全场SCADA风玫瑰
Windrose after calibration

step2：风机功率曲线测试，NTF函数测试
Testing of Power-Curve and nacelle NTF-function

- 实测功率曲线用于评估机组性能及风电场后评估电量测算

The measured power curve is used to evaluate the performance of the WTGs and AEP production calculation in post-evaluation

- NTF函数用于通过机舱测风还原每台风机在自由流扇区下叶轮前入流风速

NTF is used to calculate the free flow speed in front of the turbine rotor in free flow sectors

step3：运行SCADA数据清洗
Cleaning of SCADA data

包括但不限于风机故障、停机维护、降功率运行以及风电场限电等工况需要被剔除
scenarios like turbine failure， maintenance, reduced power operation and gird limiting should be excluded

step4：运行工况分类（风机工况、环境工况）
Classification of operating scenarios

热稳定度分级
Thermal stability

	frequency
A:Extremely Unstable	26.3%
B:Moderately Unstable	0.0%
C:Slightly Unstable	0.0%
D:Neutral	20.4%
E:Slightly Stable selected	**35.5%**
F:Moderately Stable	9.1%
G:Extremely Stable	8.6%

运行尾流评估结论分享1 功率分布
Conclusion1 based on operating SCADA data: power distribution

- 在风电场年均风速下的后排功率损失可达50%

The wake loss in the down wind fields can reach up to 50% under the average wind speed of OWF.

- 缓冲区从在可显著提升之后第一台风机的发电功率

The existing of the wake buffer zones can increasing the first turbine row’s power significantly,.

运行尾流评估结论分享2 尾流分布
Conclusion2 based on operating SCADA data: wake distribution

- 通过12排以上实际风场的运行数据，结合现阶段大量模拟和风洞试验结果，风电场整体的尾流分布情况，后排功率不会无限制降低，而会达到一个“尾流平衡点”

By analyzing the operating SCADA data of actual OWF with more than 12 rows, combined with the result of a large number of simulation and wind tunnel testing results, the distribution of wake factor in the down wind fields may reach a "wake balance" point, after which the wake factor will stay nearly the same.

运行尾流评估结论分享3 全尾流与偏尾流

Conclusion3 based on operating SCADA data: full wake influence vs. partial wake influence

- 入流风向从94.5°全尾流向偏尾流变化至102.5°，风电机组功率提升显著

The inflow angle changes from full wake influence sector(94.5°) to partial wake influence sectors(94.5°~102.5°), the power production of WTGs increases rapidly.

- 准确的前期测风评估更显至关重要，避免全尾流方向入流

Accurate pre-assessment is even more critical when it comes to the avoidance of full wake situation.

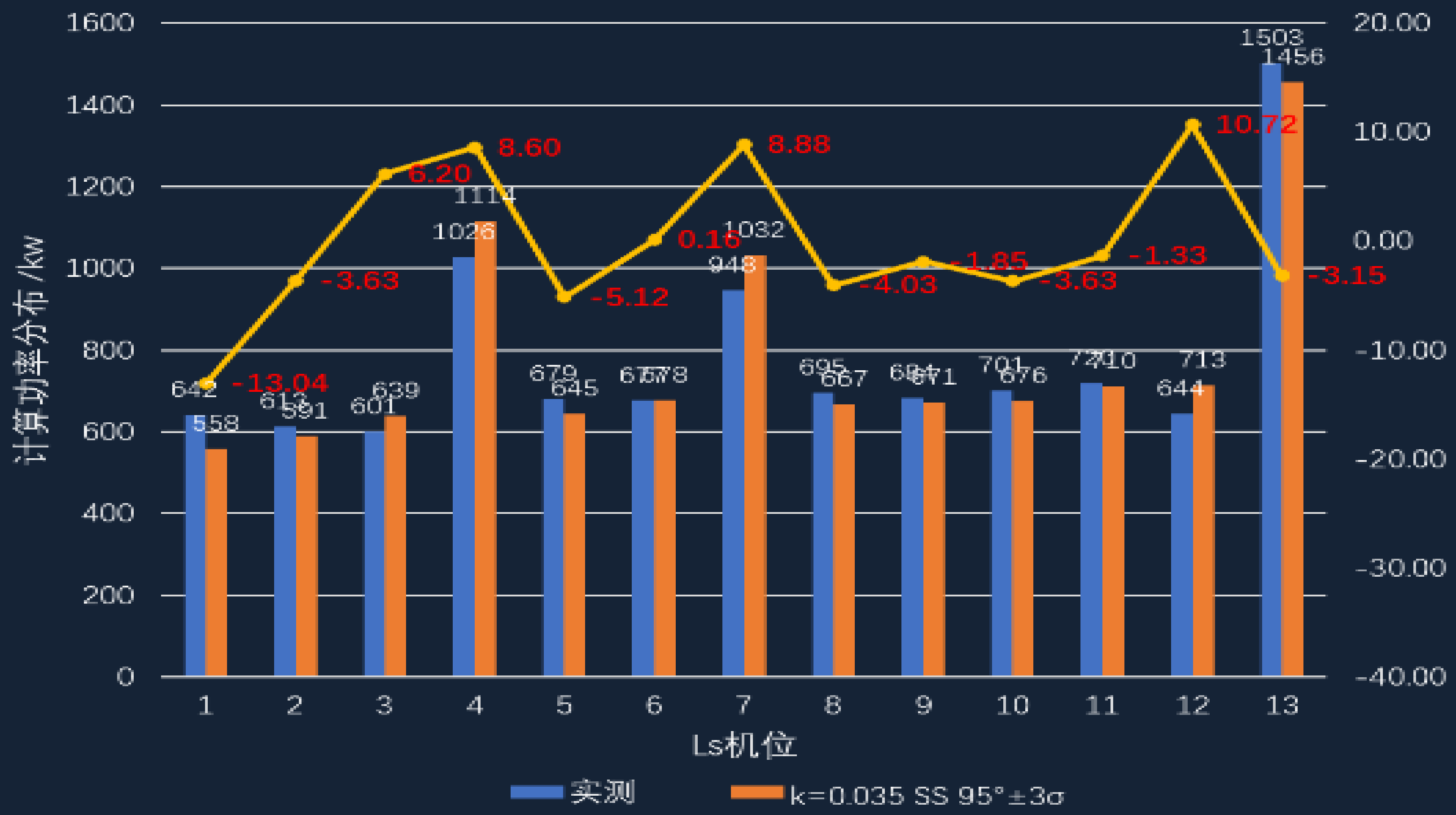
探索 尾流监测及控制技术
Technology Exploration: wake detection and control

- ➢ 基于控制雷达的尾流监测
  Wake detection based on TC lidar

- ✓ 极端全尾流工况下的偏航尾流控制
  Yaw control technology in extreme full wake situation

- ✓ 偏航尾流工况下降低偏航误差
  Reducing the yaw misalignment in partial wake situation

step6：实测数据vs数值计算
Operating data vs. numerical computation



基于计算的设计优化探讨1：机组选择及不同容量风电场尾流

Discussion1 based on computational results: WTG selection and wake loss of different OWF with different capacity

- 大基地开发模式下风电场尾流带来的能量损失可能高达20%，传统单机发电性能最优的机组选型路线可能“失效”

The wake loss in large scaled OWFs can reach more than 20%, as a result larger Cp of WTG brings larger Ct and the total wind farm AEP can be reduced due to higher wake loss and at the same time increasing the turbine loads.

基于计算的设计优化探讨2： 大基地风电场边界规划

Discussion2 based on computational results: shape of wind farm boundary

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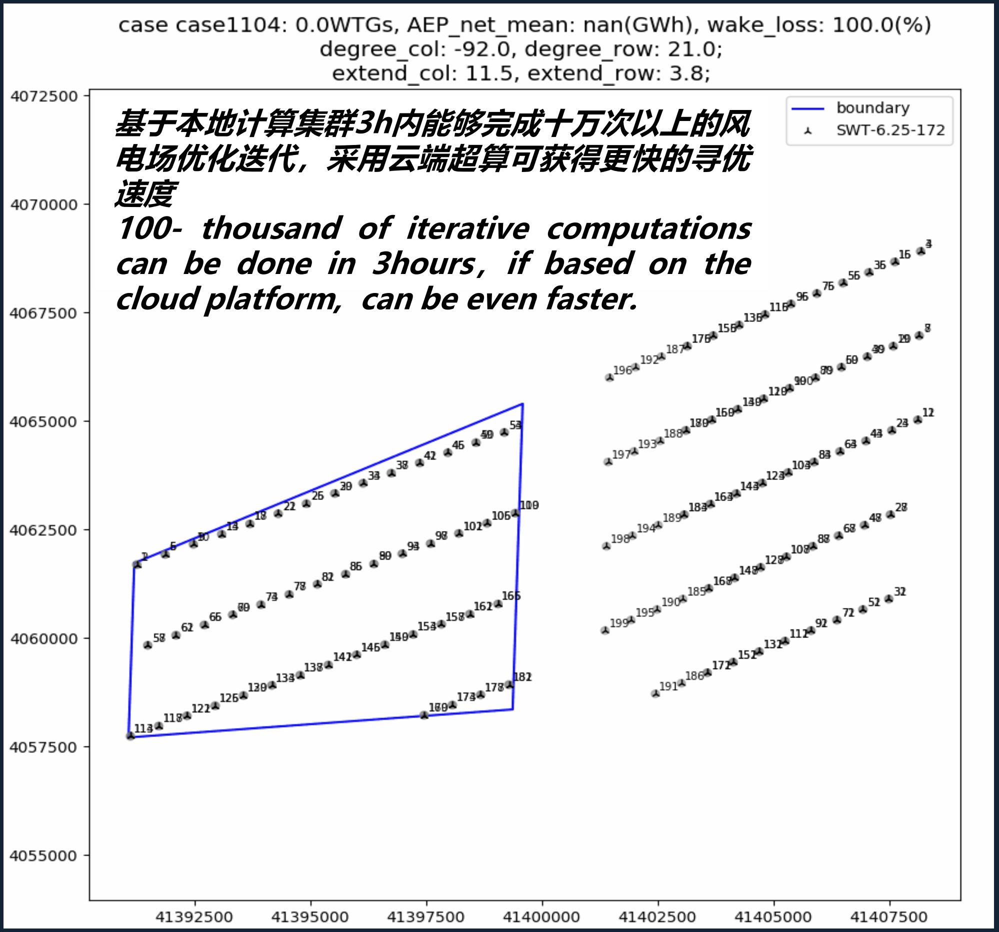
- 风电场大基地边界形状构建，边界形状的确立需要综合考虑场内尾流损失和风电场尾流恢复条件

The shape of the large scaled OWF’s boundary is also a factor. Both wake velocity deficit and wake recovery condition in the wind farm should be considered.

探索 大规模计算机寻优迭代
Exploration: Large-scale computer optimization iteration

- 大基地全场容量1GW以上，风电场覆盖面积超160km^2，机位数100以上，传统的工程师手排机位方案比选无法获得最优机位方案

In large scaled OWFs with capacity of more than 1GW, the total wind field area can reach more than 160km^2, and hundreds of WTGs need to be optimized in the best position combination. Large-scale computational optimization should be proposed.



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Acknowledgment

国内现阶段缺少大型风电场的实际运行经验，对大型海上风电场ABL大气边界层变化进而引起的风电场年均风速变化，以及如阻塞效应等都缺乏量化评估，对后期大基地的风场发电量评估存在较大不确定性。

At present, as a result of lacking the experience of running large scaled OWFs in China, there is less evidence in blockage effect and change of wind farm inflow speed because of ABL change. This raises a great number of uncertainty when it comes to the evaluation of large scaled OWF’s AEP production.

展望 Outlook

受限于一期项目风电场容量，项目二期将展开对滨海北H2，亚洲最大已建单体风电场的后评估计划，将重点关注研究大型海上风电场尾流效应，以及如阻塞效应、ABL（大气边界层）改变等引起的风电场发电量损失

Due to the capacity limitation of project step1, we have made plan of project step2 to conduct post-evaluation in BinHaiBei H2 OWF which is the biggest in operation OWF in Asia till now. And power losses come from the wake effect, the blockage effect and change of ABL in large scaled OWF will be our first priority to be studied.

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