

LVRT conformity proofing for wind farms via validated WEC models

通过验证过的风电机组模型检验风电场低电压穿越符合性



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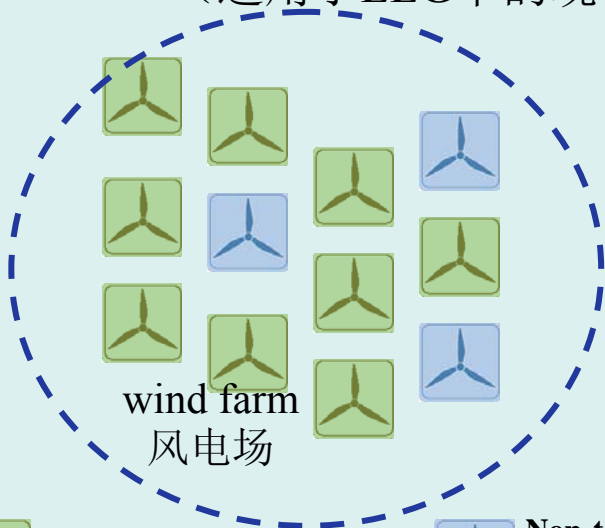
Forschungsgemeinschaft
für Elektrische Anlagen
und Stromwirtschaft e.V.

General Alternative Approaches


一般替代方法

1. “Pars-Pro-Toto” “以部分代替整体”

- Testify conformity of single WEC types via measurement
通过测量验证个别风电机组类型的符合性
- Declare (proportionate) conformity of entire wind farm if (partially) consisting of testified WEC types
如果风电场(部分地)包含验证过风电机组类型, 则表示整个风电场(成比例的)的符合性
(applied in EEG for existing installations; option in PVVC)
(适用于EEG中的现存设施; PVVC中的可选择)



→ 75% conformity of wind farm
风电场75%的符合性

 Testified WEC type
验证过风电机组类型

 Non-testified WEC type
未验证的风电机组类型

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(applied in EEG for existing installations; option in PVVC)
(适用于EEG中的现存设施; PVVC中的可选项)

2. **Simulation via WEC models** 通过风电机组模型进行仿真

- Testify conformity of single WEC types via measurement
通过测量验证个别风电机组类型的符合性
- Validate simulation models of these WEC types
验证这些风电机组类型的仿真模型
- Test conformity via comprehensive wind farm simulation
通过全面的风电场仿真检验符合性
(applied in German Medium Voltage Directive; option in PVVC)
(在德国中压电网规范中应用; PVVC中的可选择)

General approaches – Comparison

一般方法-比较

Pars Pro Toto 以部分代替整体

- + Low effort since based on single WECs' conformity
由于基于单台风电机组的一致性故易于实现
- + Most suitable for “mixed” wind farms, consisting of different types of WECs
特别适合由不同类型的风电机组组成的“混合型”风电场
- Approach is fully neglecting dynamical feedbacks between WECs and other assets in the wind farm
此方法完全忽略风电场中风电机组和其它设备间的动态反馈
- the evidence of the farm's conformity can not be testified in terms of the entity's response to failures
对故障的整体反应方面不能证明风电场的符合性

Simulation via validated WEC models
通过校验过的风电机组模型进行仿真

- + Approach takes into account dynamic interaction between WECs and other assets in the wind farm
此方法考虑了风电场中风电机组和其他设备间的动态影响
- + Wind farm's conformity can be proofed in terms of the entity's behaviour
从整体角度检验了风电场的符合性
- Additional competences required with respect to grid calculation and model porting
电网计算和建模需要附加功能
- “Mixed” wind farms with WECs of different manufactures may cause difficulties due to confidentiality issues with regard to WEC models
由不同厂家的风电机组组成的“混合型”风电场可能会遇到风电机组模型保密的难题

Objection can be met by adapted processes
应用过程会遇到的障碍

Simulation provides most reliable conformity test
仿真方法可提供更可靠的符合性测试

Agenda提纲

- Regulative Framework 体系框架
- General Approaches for Wind Farm Conformity Testing
风电场符合性测试的一般方法
 - Pars Pro Toto 以部分代替整体
 - Simulation via validated WEC models
通过验证过的风电机组模型进行仿真
- **Simulation via Validated WEC Models**
通过验证过的风电机组模型进行仿真
 - **Scope of simulation** 仿真范围
 - **Required model characteristics** 要求的模型特点
 - **Validation process** 验证程序
 - **Wind farm simulation and certification Process**
风电场仿真和认证程序
- Secondary Aspects – Existing Installations
次要方面-现有设备
- Conclusion 结论

Simulation – Scope of models

仿真 - 模型范围

Normal operation 正常运行

- ✓ **Active Power Control** – simple model of setpoints and step responses (depending on **primary energy supply** and frequency)
有功功率控制– 设定值控制和阶跃响应的简单模型(取决于**主电源**和频率)
- ✓ **Reactive Power Control** – simple model of setpoints and step responses ($\cos \phi$ (P); Q (U))
无功功率控制– 设定值控制和阶跃响应的简单模型 ($\cos \phi$ (P); Q (U))
- ✓ **System perturbations (harmonics)** – calculation according to IEC 60400-21
系统扰动(谐波) – 根据 IEC 60400-21 计算
- ✓ **Mode of (re-)connection** – static behaviour; no model required
(重)并网模式–静态特性; 无需模型

Failure mode (Voltage dip)

故障模式(电压跌落)

- ! **LVRT behaviour** – failure detection, response to voltage dips (no disconnection) and dynamic behaviour of reactive and short circuit current
! 低电压穿越动作– 故障检测, 对电压跌落的反应(不脱网)及无功和短路电流的动态特性

→ **Separate models for different modes applicable**
对不同的应用模式分别建立模型

Simulation – WEC models characteristics

仿真– 风电机组模型特点

- Models must feature all relevant responses of WEC with respect to considered grid code
模型必须体现应用的并网导则中风电机组的所有相关反应
- Voltage and current characteristics should be represented as alternation effective values
电压电流特性以交流有效值表示
- For normal operation and three-phase failures, the calculation of the positive sequence system is sufficient
对于正常运行和三相故障，只计算正序系统即可
- For two-phase failures the calculation of the negative sequence system is required
对于两相故障需要计算负序系统
- Hence, the detection of the kind of failure mode is crucial
因此，判定故障类型很关键

Simulation – Physical vs. Blackbox Models

仿真–物理模型vs. 黑盒子模型

Validation

确认

Physical Model 物理模型

(block diagram or program code (e.g. MATLAB))

(流程图或程序代码(比如MATLAB))

- + Certifier or expert, respectively, can reconstruct plausibility of WEC responses
认证方或专家能分别再现风电机组反应
- + Certifier or expert, respectively, may compile model due to selective needs for further calculation or proofing
认证方或专家鉴于进一步计算及试验的需要可以分别对模型进行编辑
- Model will/may not be handed out to third parties
模型不可交予第三方

Blackbox Model 黑盒子模型

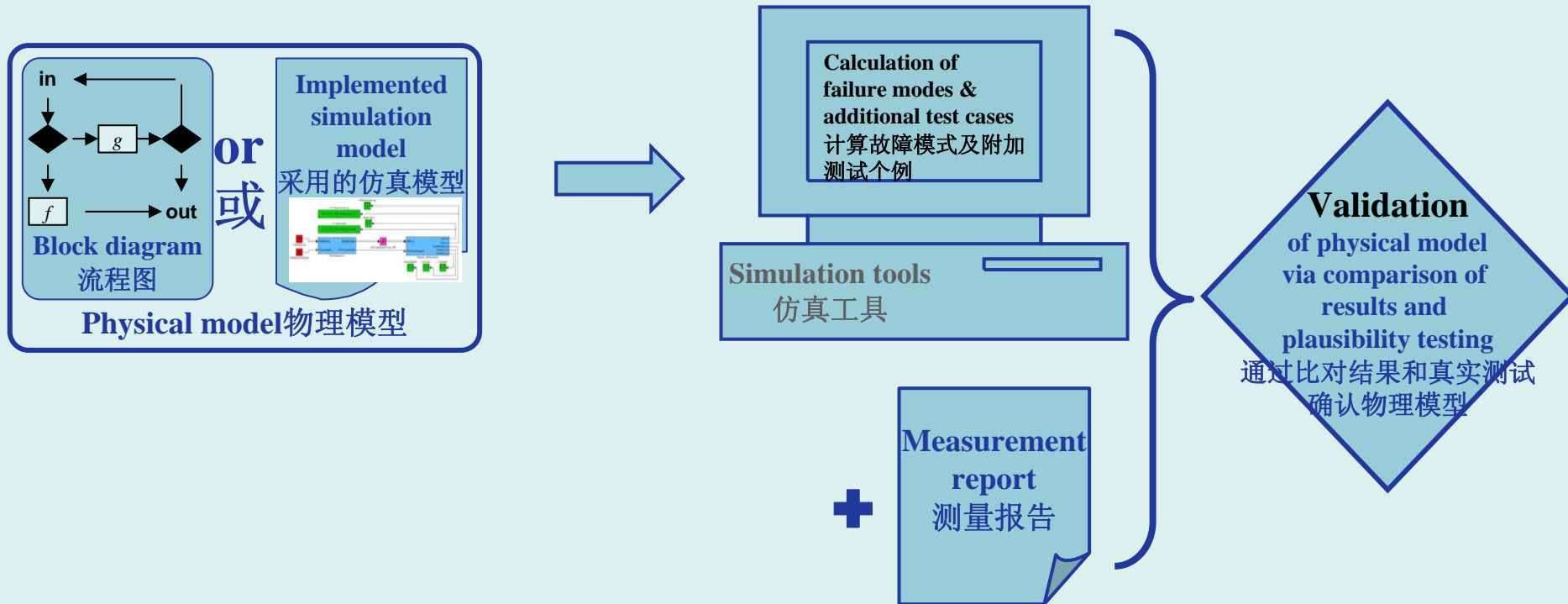
(encapsulated code) (封装代码)

- + Validated model can be handed out to third parties
验证过的模型可交予第三方
- + Different model formats may be validated for different calculation / simulation tools
不同的模型形式可能适用于不同的计算/仿真工具
- Model does not provide insight into plausible structure
模型不能体现真实的结构
- Model is not capable for extended proof by certifier / expert by means of adjusted calculations or monitoring of critical parameters
认证方或专家不能使用模型通过调整计算或监控关键参数来扩展检验范围

Validation of physical **and** blackbox model required !
必须检验物理及黑盒子模型

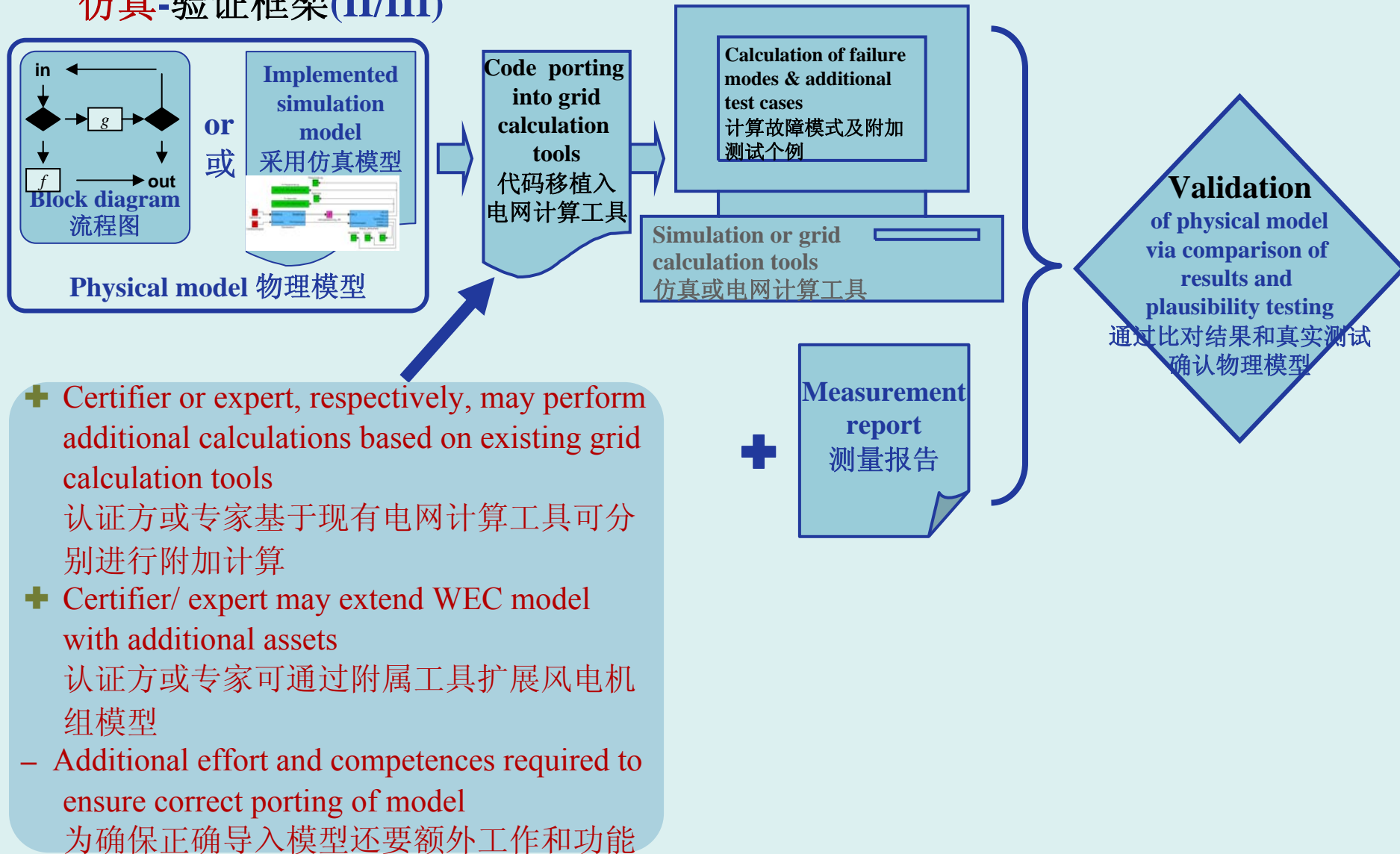
Simulation – Validation framework (I/III)

仿真-验证的架构(I/III)



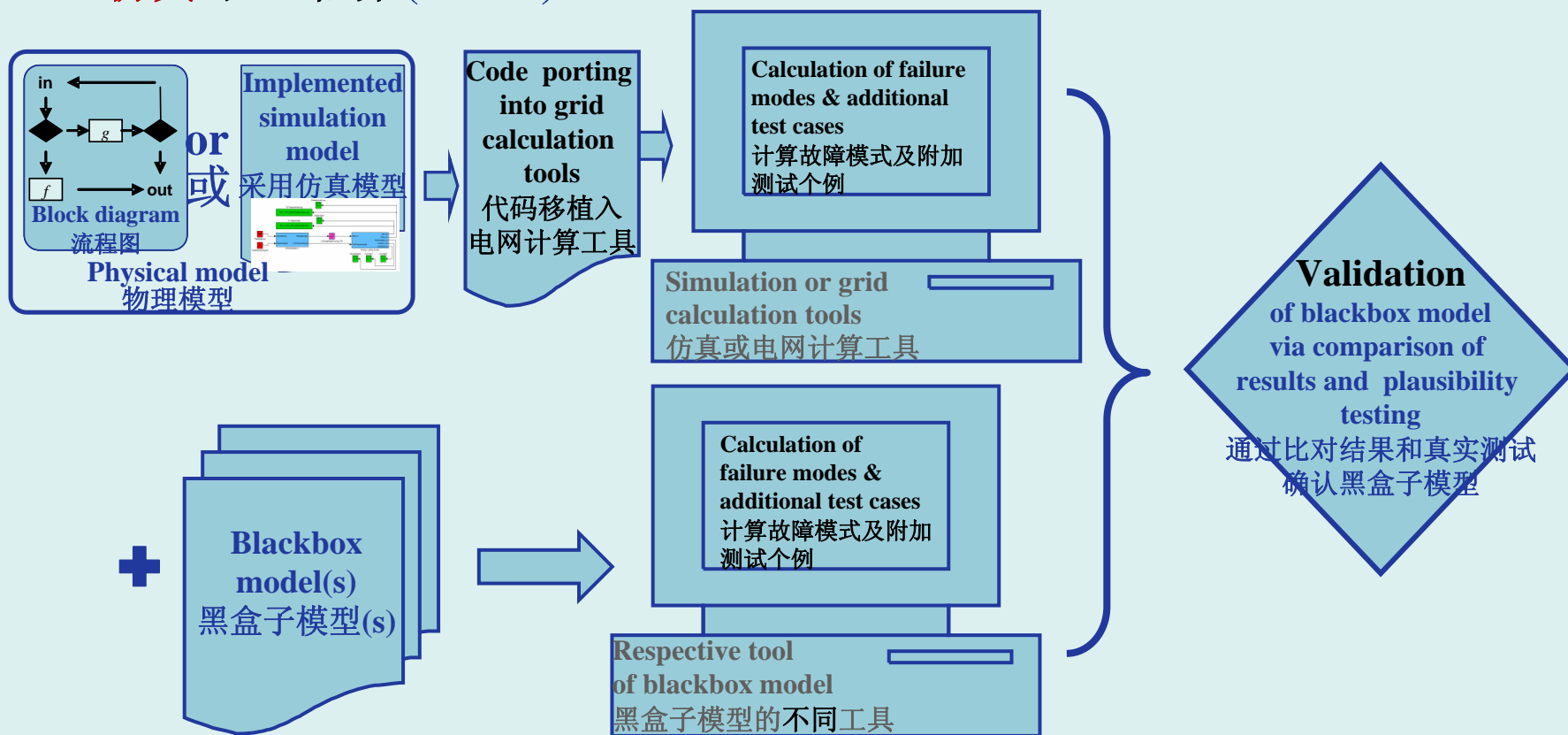
Simulation – Validation framework (II/III)

仿真-验证框架(II/III)



Simulation – Validation framework (III/III)

仿真-验证框架(III/III)



Physical **and** blackbox model validated; 物理及黑盒子模型验证;
Blackbox model available for subsequent wind farm simulation
黑盒子模型可用于后续的风电场仿真

Simulation – Validation basics

仿真– 验证基础

- Calculation of WEC response to voltage dips must utilize same reactances X_1 , X_2 like in field test measurements
计算风电机组对电压跌落反应时，必须使用与现场测试相同的电抗 X_1 、 X_2
- Additional sources of errors due to simulation must be considered for 对于以下量，必须考虑由仿真引起的附加误差
 - Active Power 有功功率
 - Reactive power 无功功率
 - Reactive current 无功电流
- Additional deviations between calculation results of physical and blackbox model should be accepted
物理模型和黑盒子模型计算结果之间的附加偏差应能接受
- Certifier or assigned expert should apply additional test cases in order to proof plausibility of WEC model
认证方或指定专家应进行附加测试以检验风电机组模型的可信性

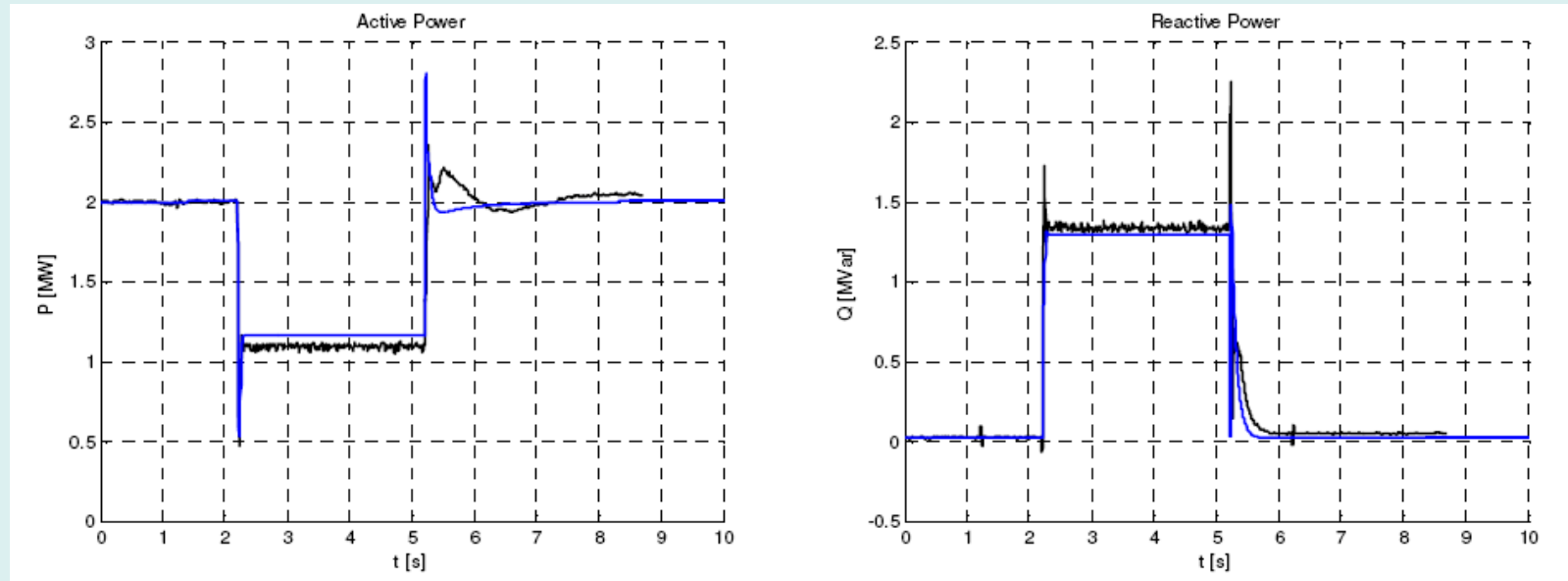
Simulation – Error considerations

仿真– 误差因素

Example: Comparison between field test measurement and simulation
(here: 50% voltage dip; 100% P_N ; MATLAB Simulink); measurement; simulation

例如：现场测试和仿真结果对比

(此处：50% 电压跌落; 100% P_N ; MATLAB Simulink); 测量值; 仿真值



Tolerances should be error-time dependent, e.g.

容许误差取决于故障-时间，例如

$\Delta P, \Delta Q \leq 0,05 P_N$ if error duration > 2 s ,

如果故障持续时间 > 2 s

$\Delta P, \Delta Q \leq 0,10 P_N$ if $0,1$ s \leq error duration ≤ 2 s

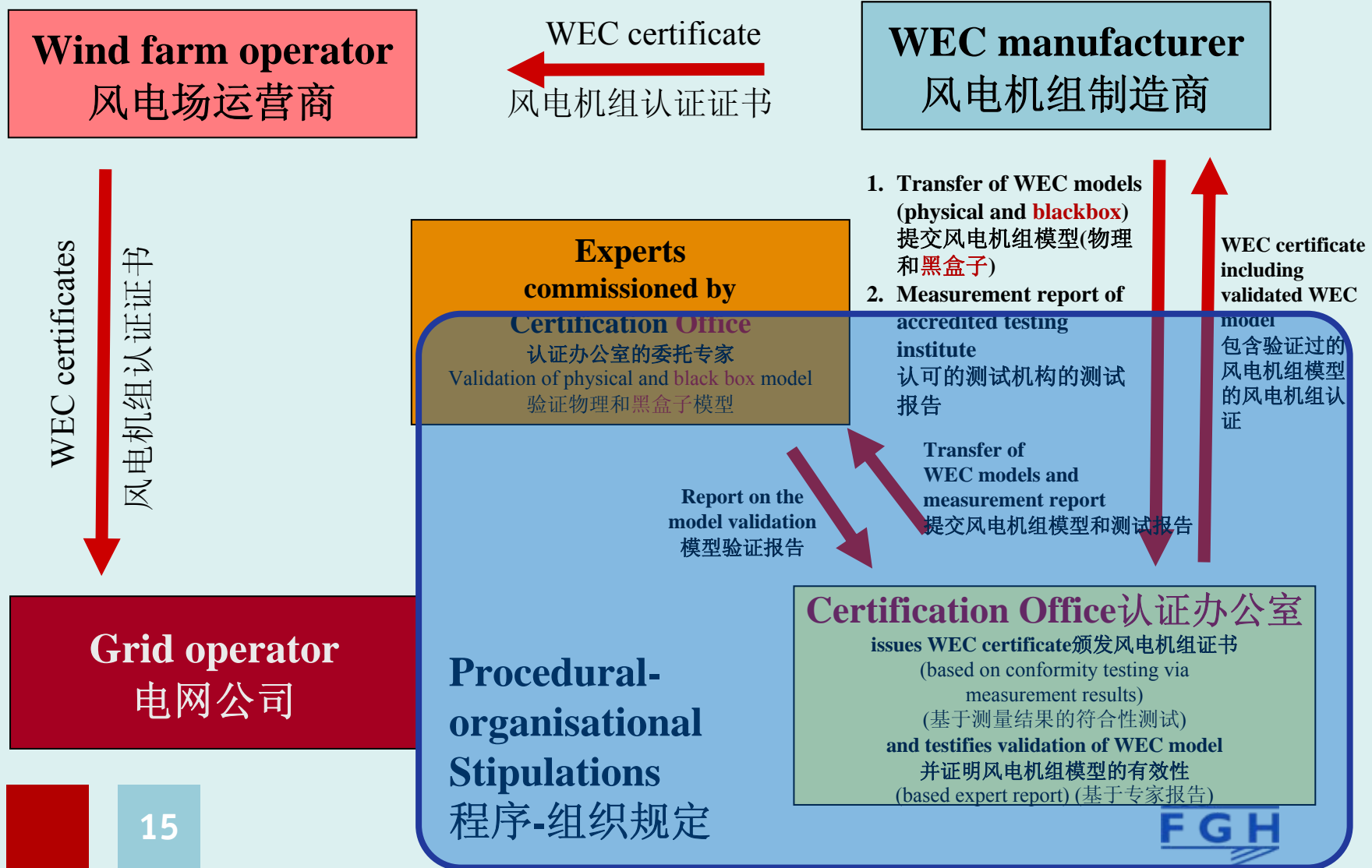
如果 0.1 s \leq 故障持续时间 ≤ 2 s

$\Delta P, \Delta Q \leq 0,20 P_N$ if $0,01$ s \leq error duration $\leq 0,1$ s

如果 0.01 s \leq 故障持续时间 ≤ 0.1 s

General process for single WEC certification including model validation

包含模型验证的风电机组认证的一般过程



Simulation – Procedural-organisational stipulations of validation process – with respect to certifier and experts

仿真 – 验证过程对认证方及专家的程序-组织规定

1. Certifier and experts must provide competences in WEC control (mainly electrical parts) and its mapping to block diagrams and/or simulation software.
认证方及专家必须有风电机组控制(主要是电气部分)及并将其映射至流程图和/或仿真软件的能力。
2. To enable most effective evaluation of WEC model it should be ported into dynamic grid calculation tools, e.g. MATLAB Simulink → PSD → INTEGRAL for subsequent wind farm simulation; respective knowledge in code porting must be available.
为有效评估风电机组模型以及后续风电场仿真的需要，风电机组模型应导入电网动态仿真软件，例如Matlab Simulink→PSD→INTEGRAL。必须具备相应的代码移植知识。
3. Validation process must include additional test cases to proof the the model validation. A solely comparison of field test measurement results is not sufficient.
验证过程必须包含附加测试以检验模型的有效性。仅与现场测试结果进行比较是不够的。

Simulation – Procedural-organisational stipulations of validation process – with respect to certifier and experts

仿真 – 验证过程对认证人及专家的程序-组织规定

4. Blackbox models are required for different software environments (due to mixed wind farms with different manufactures → different types of black-box models may have to be merged in a wind farm simulation). Certifier or expert must provide several calculation tools and respective competences.

黑盒子模型对于不同的软件环境是必须的(由于混合型风电场包含不同厂家的风电机组 → 不同类型的黑盒子模型有可能集成在同一个风电场仿真中)。认证方或专家必须有几种功能不同的计算工具和相关的功能。

5. Certifier and expert must provide highest confidentiality on validated physical models (utilisation and storage).

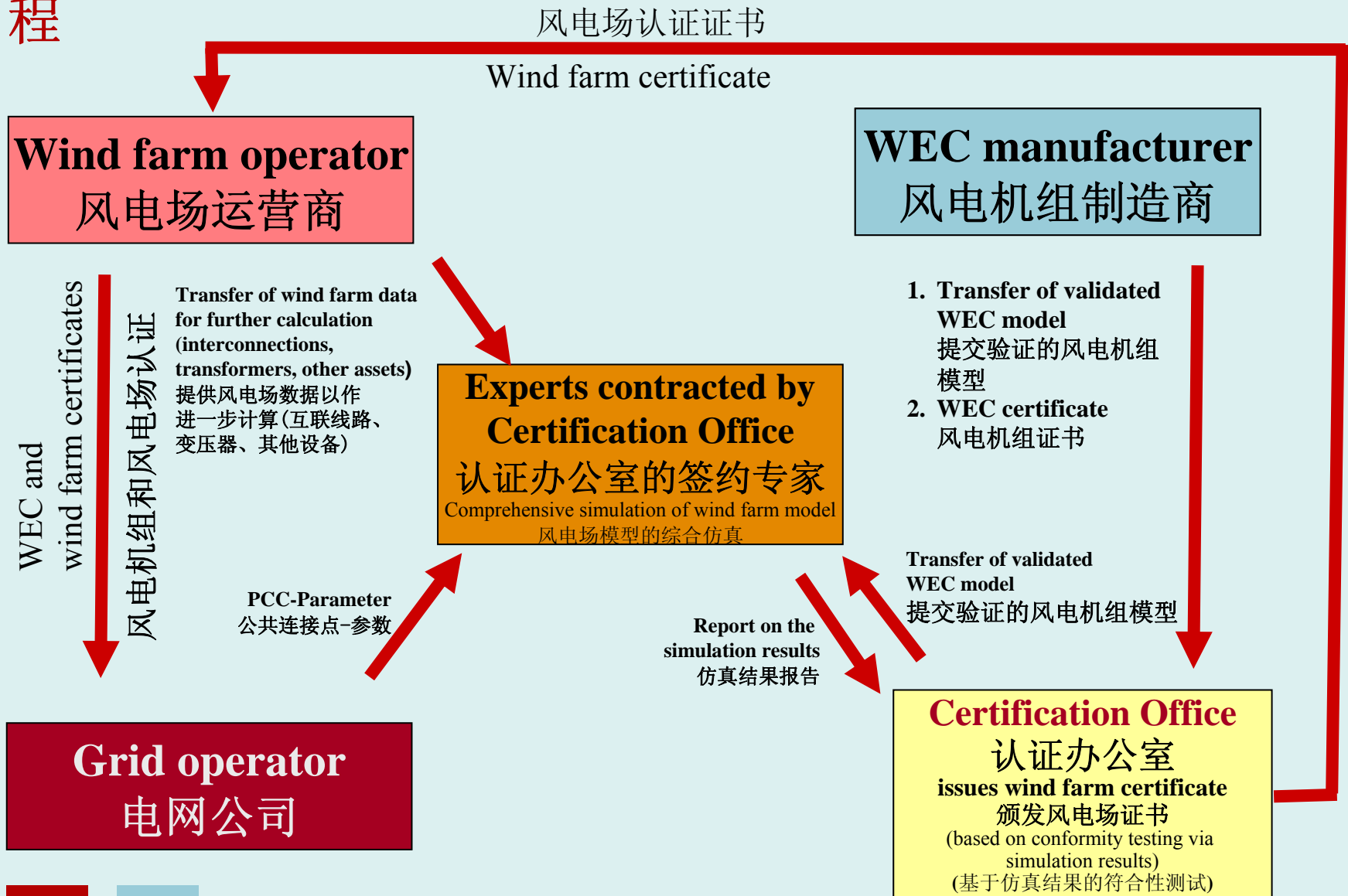
认证方及专家必须对验证过的物理模型高度保密(使用及存储)。

Simulation – wind farm conformity testing

仿真 - 风电场符合性测试

- Wind farm calculation may be based on either validated black box models or validated physical models (if applicable to grid calculation tools via prior porting)
基于验证过的黑盒子模型或物理模型进行风电场计算(可适用于经过事先移植的电网计算工具)
- Wind farm data (interconnections, transformers, other assets) have to be provided by wind farm operator
风电场数据(互联线、变压器、其他设备)必须由风电场运营商提供
- Data on point of common coupling (PCC), e.g. short-circuit power and impedance angle, has to be provided by grid operator
公共连接点的数据，比如短路容量和阻抗角必须由电网公司提供
- Additional sources of errors due to simulation should be considered by respective grid codes
由仿真引起的附加误差应在对应的电网导则中予以考虑

General process for wind farm certification via WEC models 通过风电机组模型进行风电场认证的一般过程



Wind farm conformity testing – Status Quo at FGH

风电场符合性测试 – FGH现状

- Certificate for grid code conformity needed for new wind farm installations \geq 1MW after 01-01-2009 (with transition periods – based on Medium Voltage Directive and EEG)
2009年1月1日后对装机容量 \geq 1MW 的新风电场进行必需的并网导则符合性认证(过渡期内-基于中压电网规范和可再生能源法进行)
- German wind power associations (FGW) are developing joint directives for the validation and simulation processes as well as for the certification itself
德国风力发电协会正在制定关于验证和仿真程序以及认证本身的指导书
- FGH is running a prototype process on validation and wind farm certification with a renowned German WEC manufacturer
FGH与德国著名的风电机组制造商之间开展样机验证及风电场认证合作
- FGH Certification Office seeks for the accreditation to issue respective wind farm certificates in March 2009
FGH认证办公室正努力在2009年3月获得颁发风电场认证书的资质
- Based on the generic framework, FGH can provide a complete consultancy on the questions of wind farm conformity testing
基于通用框架，FGH可以提供风电场符合性测试相关问题的全面咨询

Secondary aspects – conformity testing of existing installations

(here: provisions according to German EEG)

次要方面– 对现存设备进行符合性测试

(此处:根据德国可再生能源法的规定)

Restricted scope on subset of electrical characteristics for included WECs:

范围局限在包括风电机组在内的设备的电气特性

1. LVRT test (disabled disconnection only – no dynamic reactive current control)
低电压穿越测试(仅保证不脱网—没有动态无功电流控制)
2. Reduction of active power for frequency variations $50,2 \text{ Hz} \leq f \leq 51,0 \text{ Hz}$
当频率在 $50.2 \text{ Hz} \leq f \leq 51.0 \text{ Hz}$ 之间 变化时降低有功功率
3. No supply of reactive power later than 500 ms after voltage dips $\leq 85\% U_N$
当电压跌落至 $\leq 85\%U_n$ 持续 500 ms 后不再提供无功功率
4. No disconnection for frequency $47,5 \text{ Hz} \leq f \leq 51,0 \text{ Hz}$
当频率在 $47.5 \text{ Hz} \leq f \leq 51.0 \text{ Hz}$ 之间时不能脱网
5. Blocking of automated re-coupling on request of grid operator
电网公司有相关要求时应阻止风电机组自动并网

Certification of wind farm conformity is based on a pars pro toto approach with respect to the included WEC types.

风电场符合性认证以部分代替整体的方法为基础并与包含的风电机组类型有关。

Conclusion 结论

- Wind farm conformity testing is most appropriate via simulation with validated WEC models
通过验证过的风电机组模型进行仿真是进行风电场符合性测试的最适宜方法
- Validation should be based on physical models to ensure plausibility proof
验证必须基于物理模型进行以确保检验的可信性
- Additional blackbox model validation provides flexibility for further simulations in mixed wind farms or additional calculations
附加的黑盒子模型验证提供了对混合型风电场进行进一步仿真或额外计算的灵活性
- Certification bodies and commissioned experts must provide high competences in simulation and grid calculation
认证机构与委托专家必须具备很强的仿真及电网计算能力

Thank you for your attention !

I'm pleased to answer any questions.

谢 谢 !