Wind Energy Control Solution
风能控制系统解决方案发展

罗克韦尔自动化

08. 2010

(Confidential – For Internal Use Only)

ALLEN-BRADLEY • ROCKWELL SOFTWARE

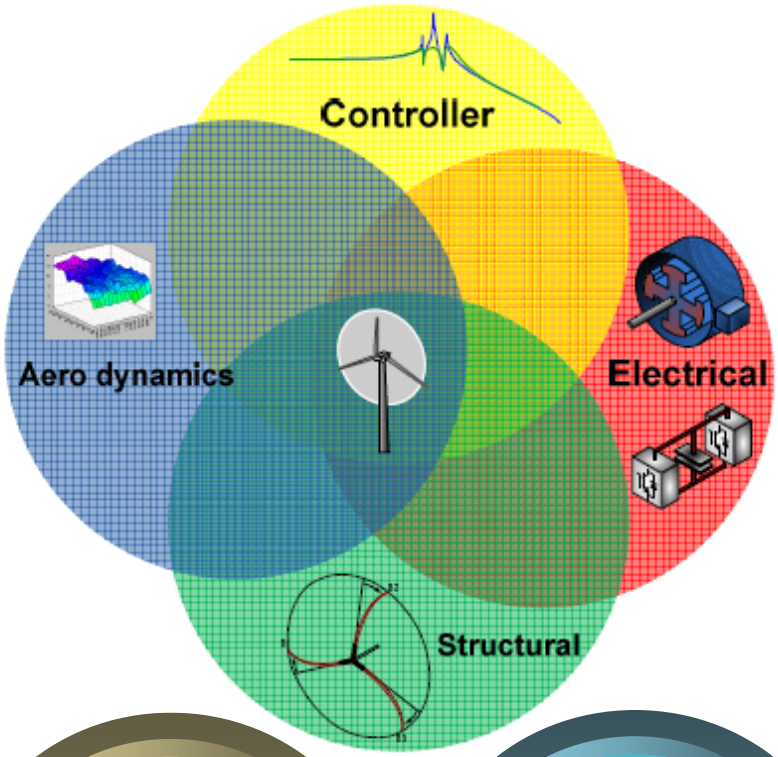
Rockwell Automation

Wind Energy Industry Trends
风能行业发展趋势

- Larger Wind Turbines & Larger Wind Farms 大型化
  - Even larger for off-shore applications 海上风电
  - More direct drive and permanent magnet generators 直驱及永磁发电机等
  - Medium Voltage Inverter Technology 中压变流器
- Moving from Product Diff. to Solution diff. including services across the whole Supply Chain 从产品到服务
  - More valuable to protect& service, Condition Monitoring 状态检测及预测维修
- Higher expectation on robust& automated Grid Integration 电网适
  - Fro age
    an

Key topics for Wind Energy& Control Solution
风能及控制系统的重要议题

IEC 61400
GCC



Germanischer
Lloyd
Certification

可靠Reliability
可用Availabili

安全
Safety

先进风机控制
Advanced
WTG Control

先进风场控制
Advanced
Wind Park
Managemen

What's the difference
高可靠、高可用性及安全的不同含义

Availability

24/7/365
Fault Tolerant
Redundant

Reliability

High MTBF

Safe

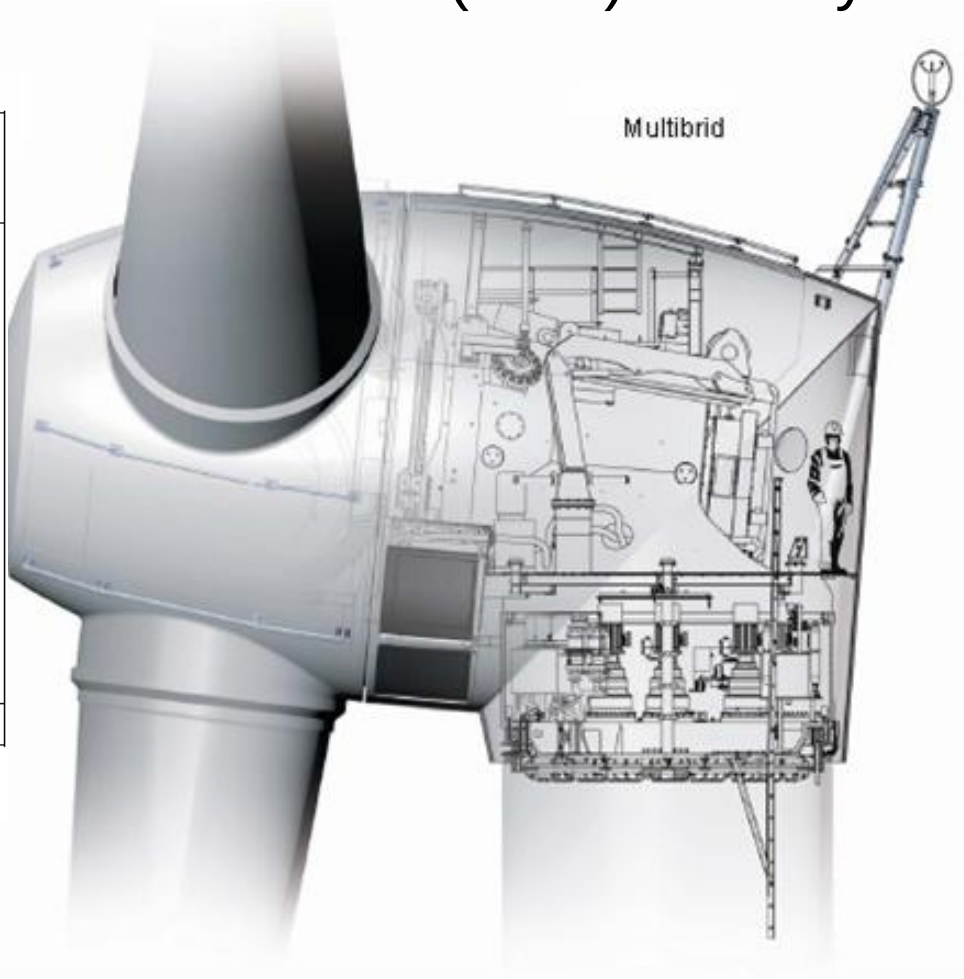
OFF
Failsafe
1001 or 1oo2
SIL3 or PL d

Why Reliability is so important?
为什么可靠性如此重要？

- Wind turbine reliability is still a problem, especially for offshore installations, says Jessica Holierhoek of the Energy research Centre of the Netherlands (ECN) recently in a wind energy forum.

Component	Onshore failure frequency (failures/year)	Reduced failure frequency (failures/year)
Shaft & Bearings	0.02	0.02
Brake	0.05	0.05
Generator	0.05	0.05
Parking Brake	0.05	0.05
Electric	0.14	0.10
Blade	0.16	0.11
Yaw System	0.23	0.15
Blade tips	0.28	0.14
Pitch Mechanism	0.28	0.14
Gearbox	0.30	0.15
Inverter	0.32	0.16
Control	0.34	0.17
Total	**2.20**	**1.28**

Table 1 Estimated yearly averaged failure rates per component category



Why Reliability for Wind Turbine Electrical& Control?
提高风机电控部分可靠性的意义

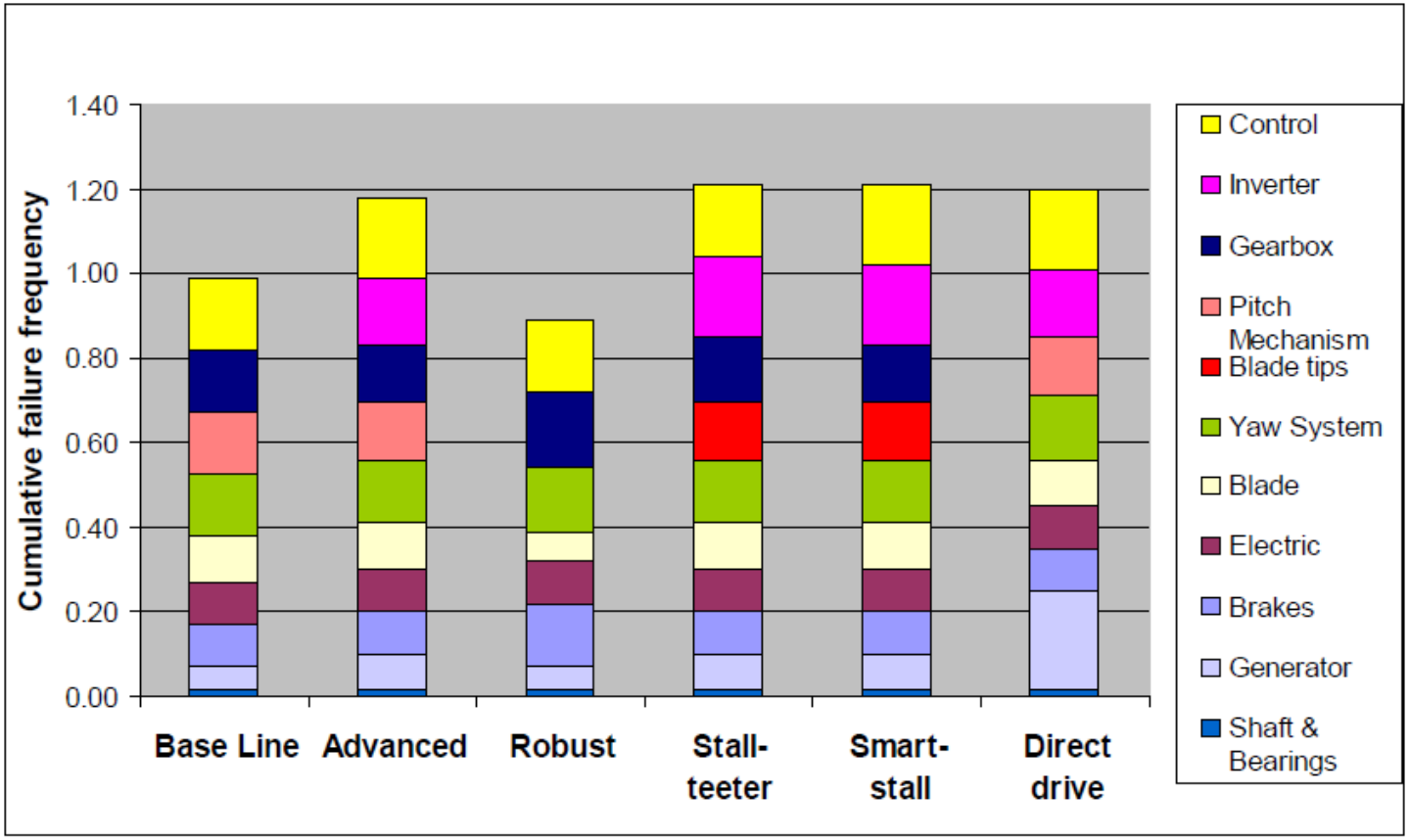
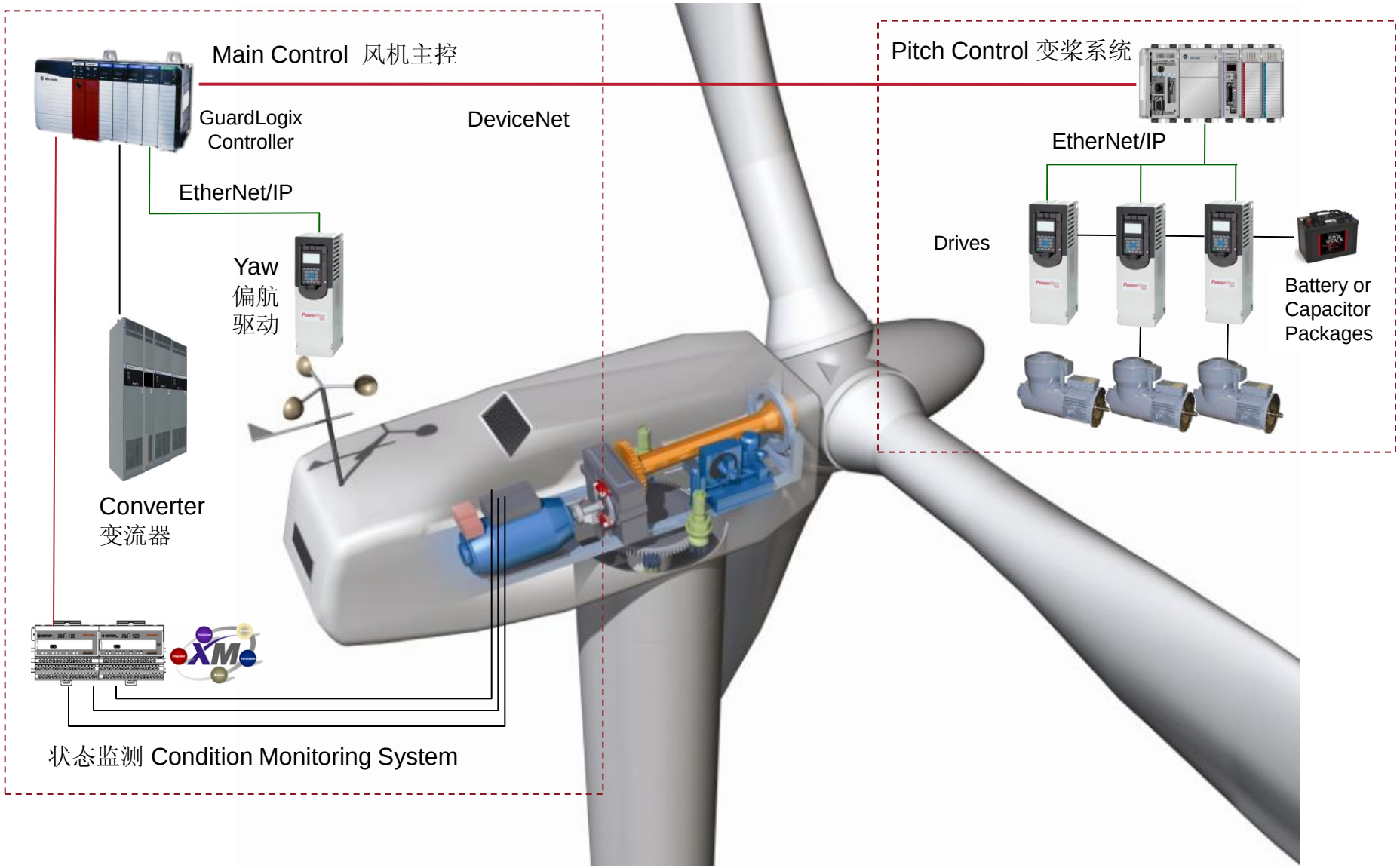


Fig. 2 Yearly (cumulative) failure frequencies of the concepts anticipated in the study

- Electrical and control system failures account for the highest percentage of failures. For the year, failures of electrical and controls systems accounted for exactly 50% of the need for wind turbine repairs. Potting of electronic printed circuit boards and reduction in the number of components are necessary for offshore conditions.

Wind Turbine Electrical& Control Solution
典型风机电控制架构



A-B platform by Rockwell Automation: Quality
A-B Quality: 高可靠性的工业控制产品

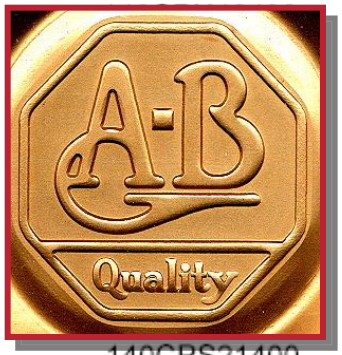
Logix
MTBF List

Catalog Number	MTBF (Hours)
1756L1M1/A	2, 064, 747
1756L1M3/A	1, 999, 574
1756IV32/A	3, 685, 760
1756IB32/A	2, 122, 885
1756IF8/A	2, 463, 018
1756IH16I/A	2, 816, 320
1756IM16I/A	7, 614, 880
1756OA16I/A	6, 045, 520
1756OB16E/A	4, 026, 880
1756OB8/A	4, 517, 760
1756OF4/A	4, 195, 776
1756PA72/B	3, 543, 423
1756PA75/A	3, 902, 080
1756A7/B	14, 202, 240
1756A10/B	10, 340, 374

This is the latest list of MTBF's: 12/16/02

2. MTBF numbers are in hours.

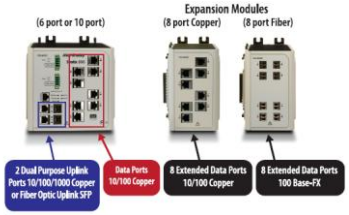
approved	mtbf rev	std	gnd benign 25 deg C	gnd benign 30 deg C
140CPU42401	0200	PCF		313253
	0200	PCF		313253
	0100	PCF		240810
	0100	PCF		218979
	0100	PCF		349886
	0100	PCF		329504
	0100	PCF		282877
	0100	PCF		200000
	0100	PCF		200000
	0100	PCF		200000
140CPS21400	0100	SGPC		267881
140CPS22400	0100	SGPC		266666

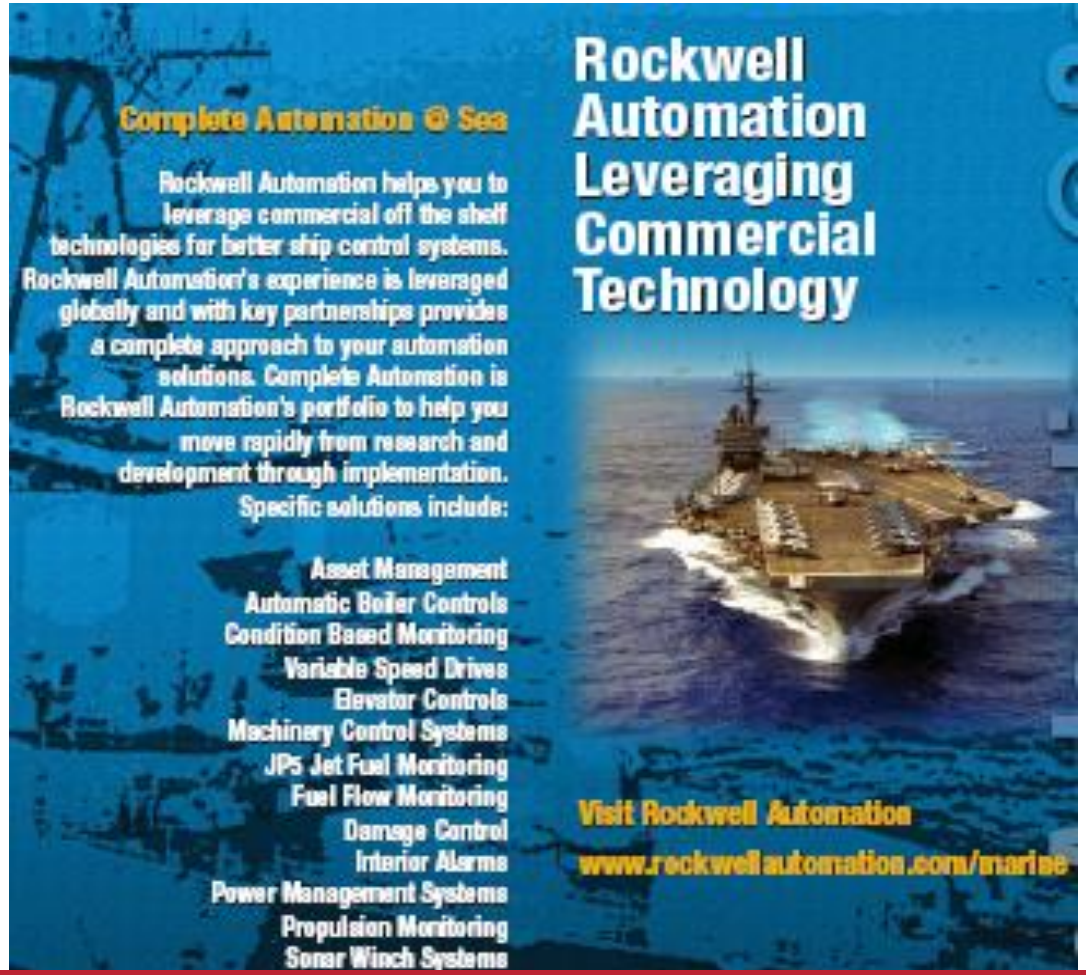


在各种硬件设备上，包括各种模块以及电源等，
Logix比其它品牌的典型工业控制产品
高出5~20倍以上的平均无故障时间(MTBF)

Allen-Bradley

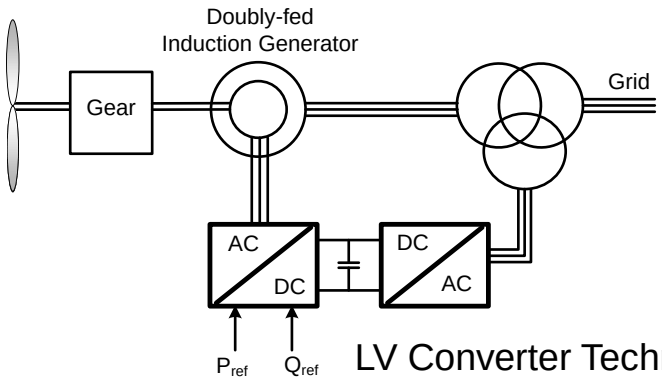
A-B platform by Rockwell Automation: Quality
A-B Quality: 高可靠性的工业控制产品



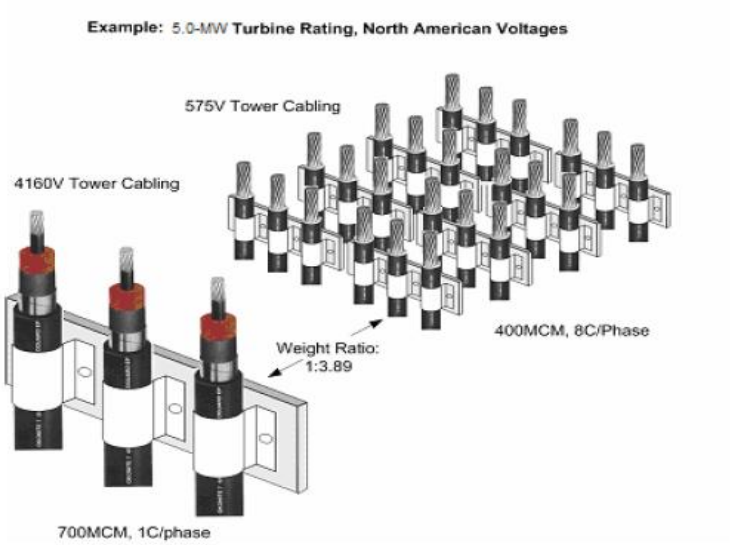


‘ The ship automation system are composed of commercial off-the-shelf (COTS) hardware and software. The hardware is based on Rockwell Automation's **Logix family and PowerFlex Family** ’

MV Converter for Large Wind Turbines (on-going)
中压变流器对于大型风机的好处

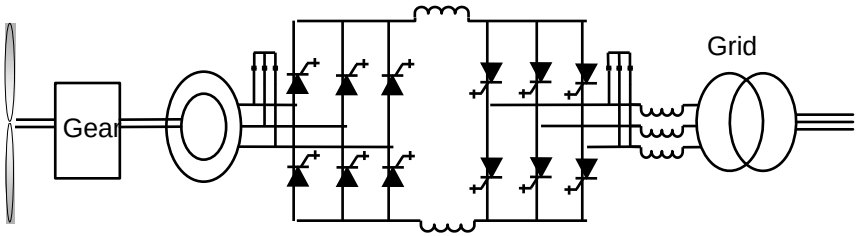


LV Converter Technology



The PowerFlex 7000 medium voltage drive uses the patented PowerCage™ with SGCT technology for easy installation and maintenance.

Full Rated MV Converter Technology



= or > 5MW ： MV is attractive

Number of conductors, connections and fewer components (SGCTs) will lower total installed costs, reduce maintenance time and increase converter reliability as Wind Turbines continue to get larger

可靠性及可用性
Reliability& Availability

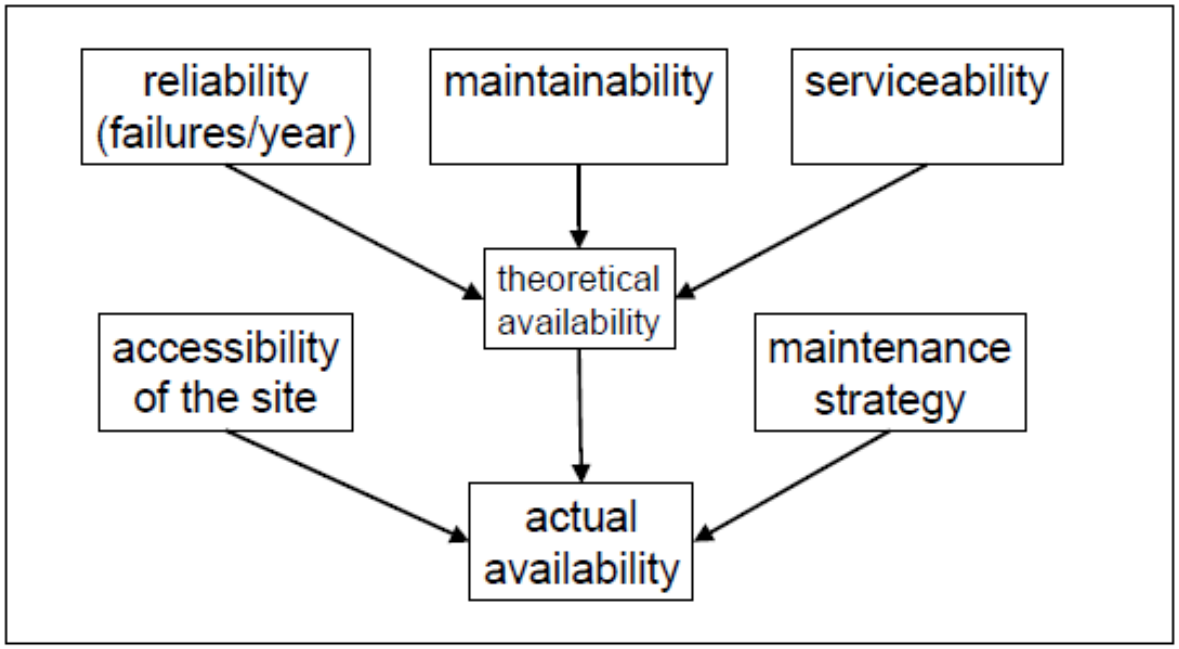
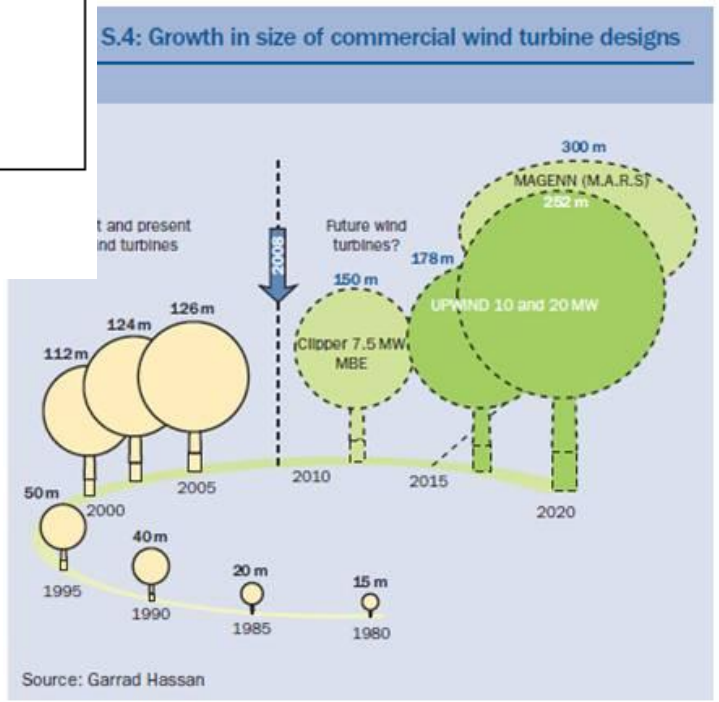
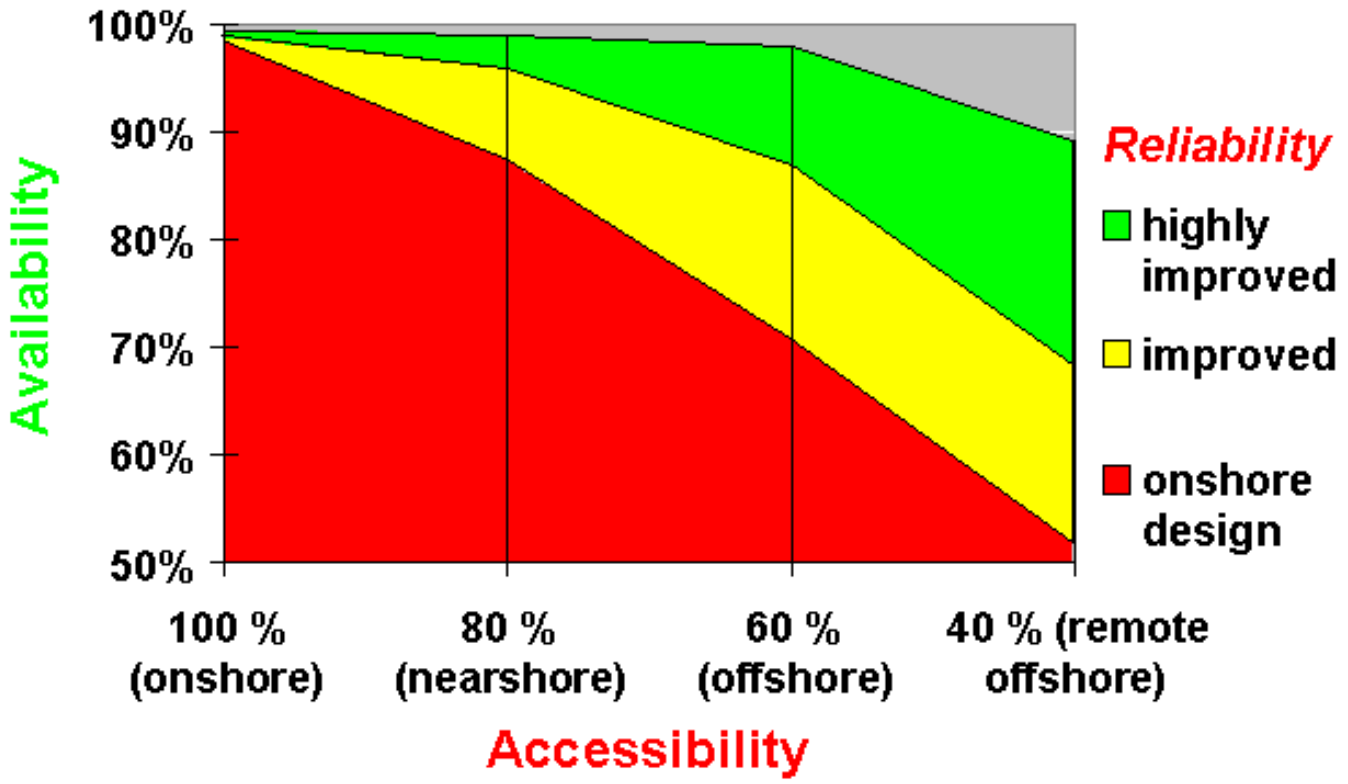


Fig. 1 Theoretical and actual availability



可靠性及可用性
Reliability& Availability



- Figure 11:

  Importance of Reliability& Availability for Offshore Wind Turbines

越来越离不开远程状态检测及预测性维护系统
CMS become more& more important

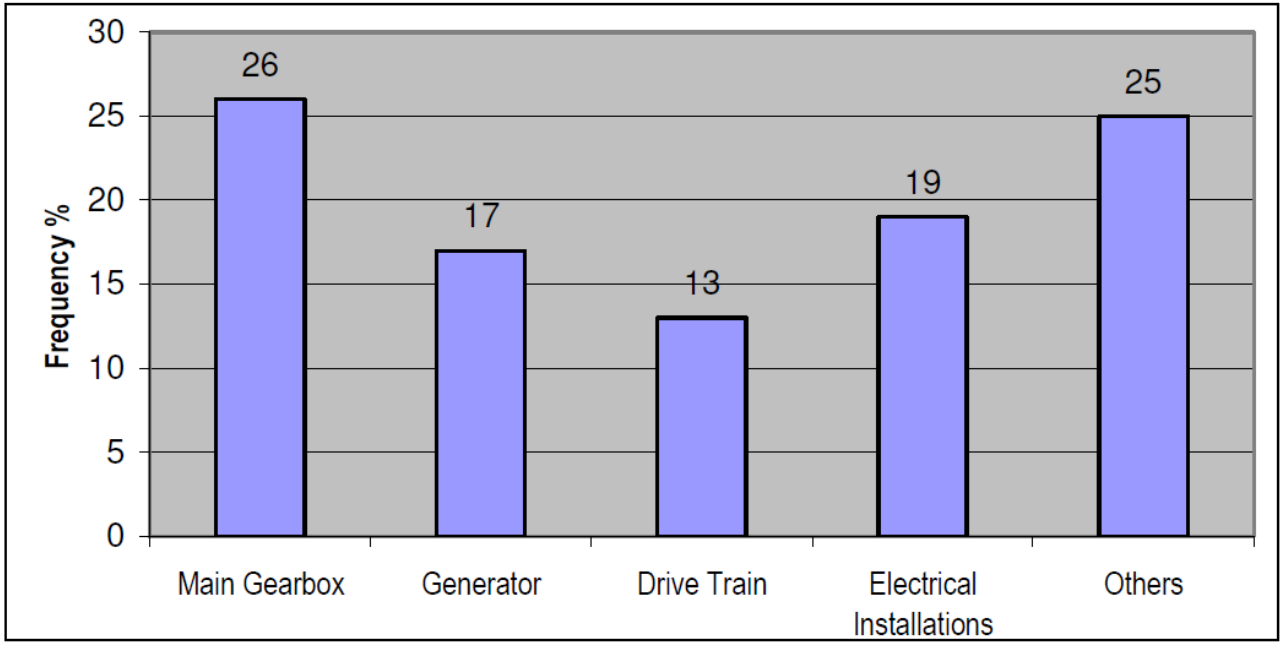
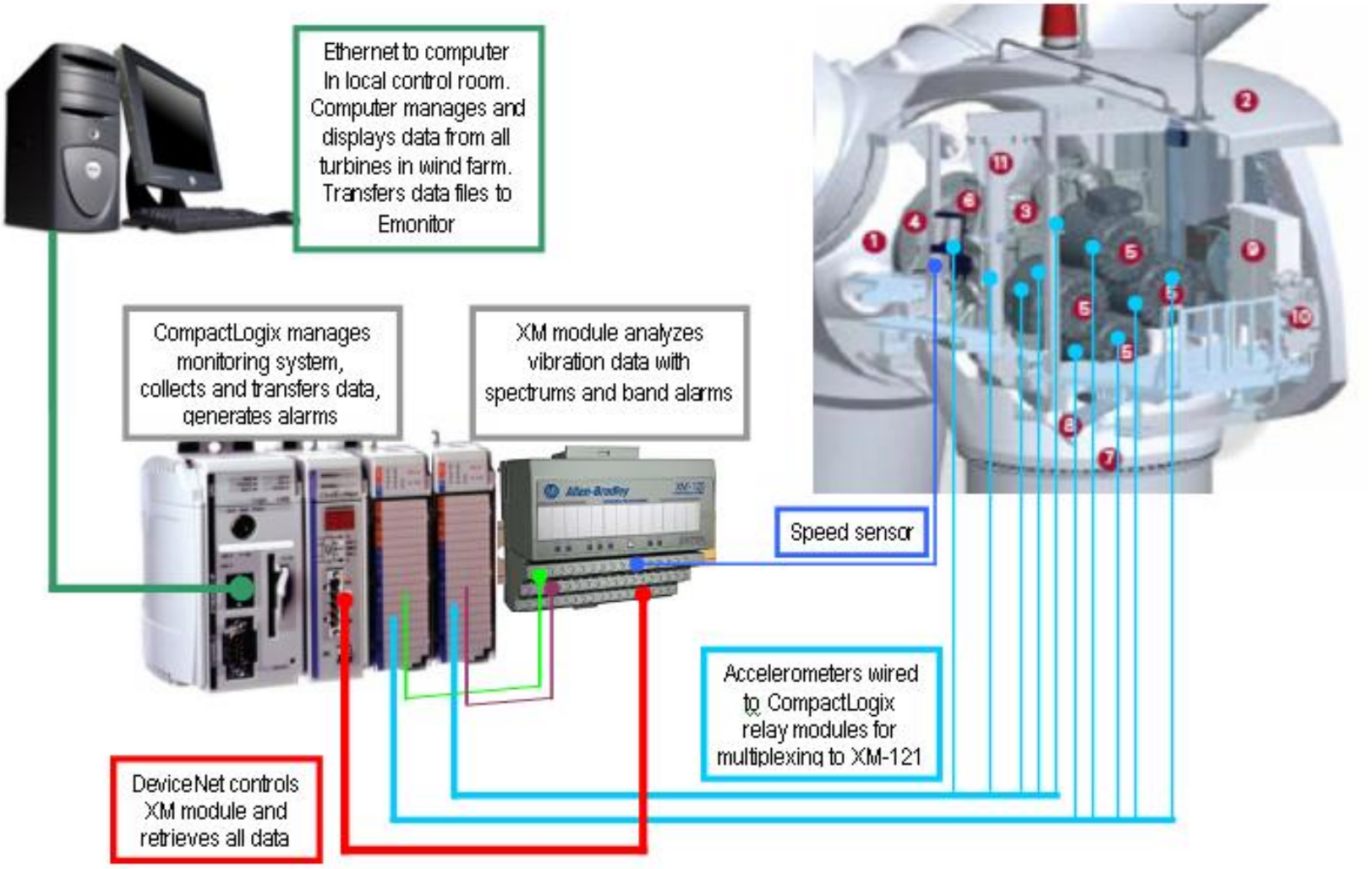


Fig. 1: Defects and damages of wind turbine components [Data base GL]

- This inspection data base shows that about 26% of all defects and damages result from the gearbox (especially bearings and toothing), about 17% from the generator (especially bearings) and about 13% from the drive train (e.g. main bearing, coupling). These results are comparable to damage statistics of insurance companies or institutes.

CMS Overview by Rockwell Automation



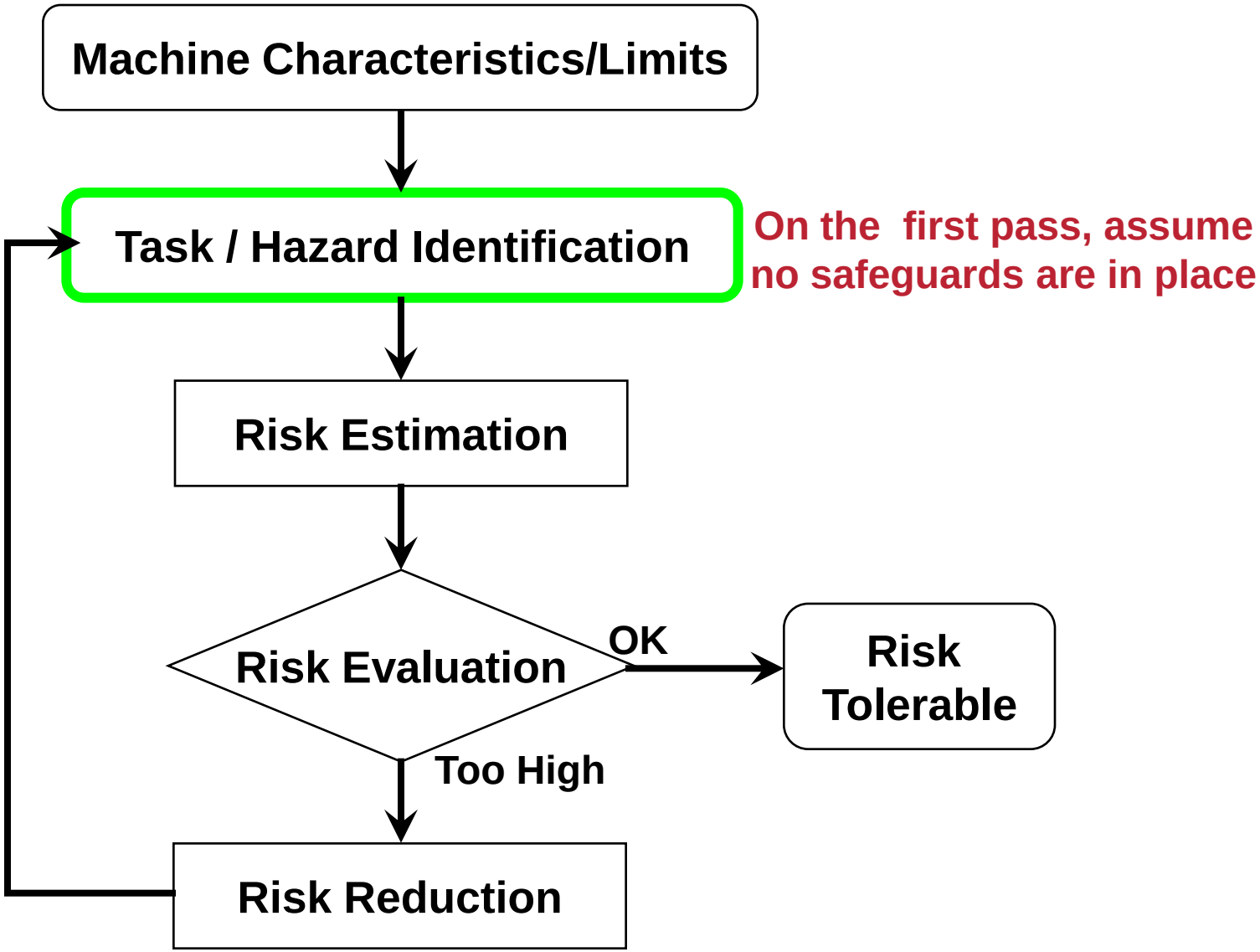
Safety is so important!
风机安全很重要！

FailSafe

- Safety basics came from IEC61400 or GL Guidelines for Certification of Wind Turbines Edition 2003
  - “The safety system shall have access to at least two mutually and totally independent braking systems” (Para 2.2.3.1.2). “By independence is meant that faults with a common cause shall rigorously be avoided in the system engineering design stage. Accordingly, the failure of a single component shall not result in the failure of more than one braking system and thus the loss of the entire safety function” (note to Para. 2.2.3.1.2). Each one of these braking systems shall fulfill the principal detailed in Para. 2.2.3.1.1. “whereby the failure of a single component which is relevant for the functioning of that independent safety system shall not lead to the failure of the safety system.” Burton, etal [10] explain how the independent braking system rule has been applied to turbines that depend solely on aerodynamic braking from individual blade pitching. “Provided the individual pitch actuators can be made independently fail‐safe and as long as the aerodynamic braking torque is always sufficient to slow the rotor down to a safe speed even if one pitch actuator has failed at the working pitch angle, then multiple actuators may be considered to be independent braking systems for this purpose.” Another way this is commonly expressed is “any single failure in the sensing or activation parts of the control system must not lead to a malfunction of the
  - systems, it is important to separate the safety aerodynamic braking function

A better way is still under development by joint-work of wind turbine makers& control vendors, syncing with related safety IEC standard.

Fundamental Process of Functional Safety Development



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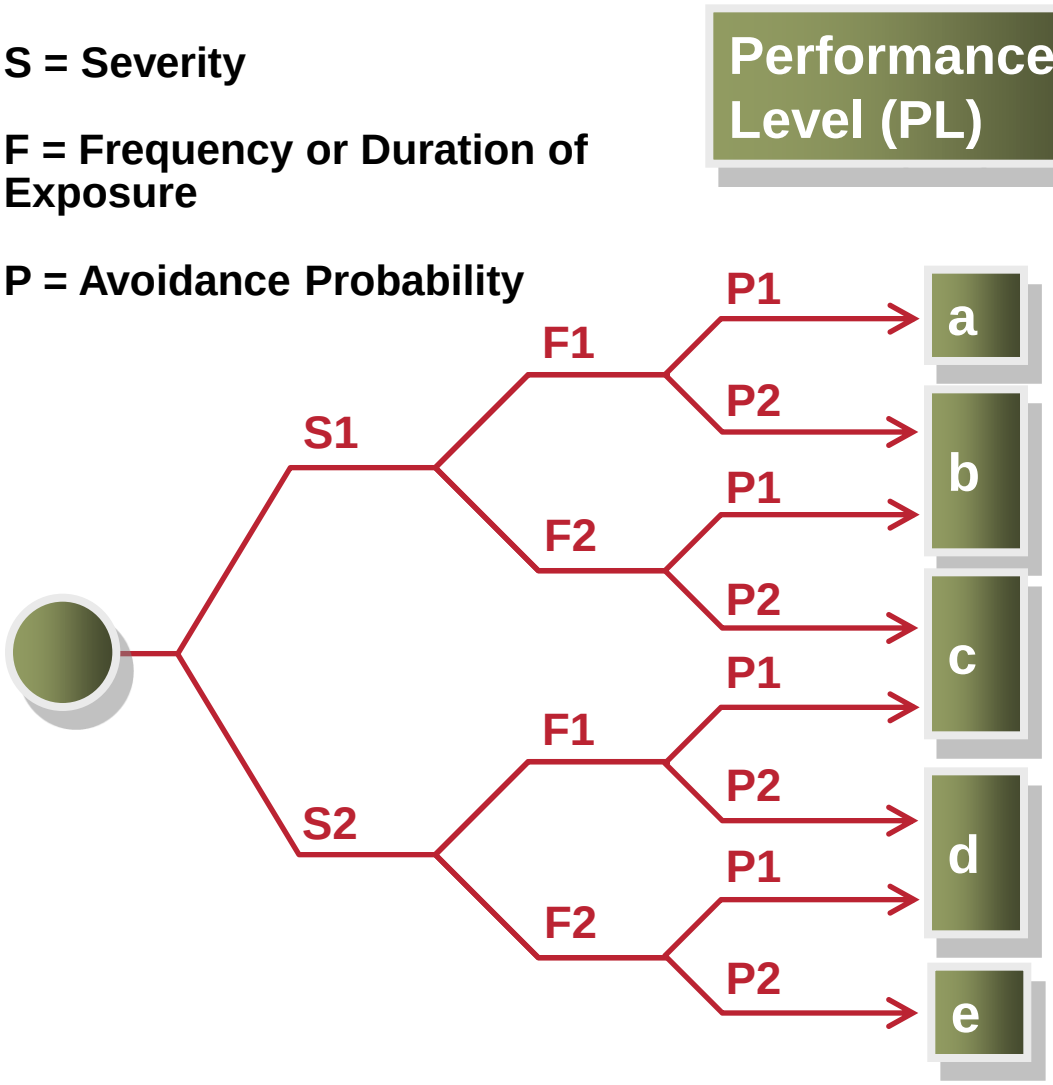
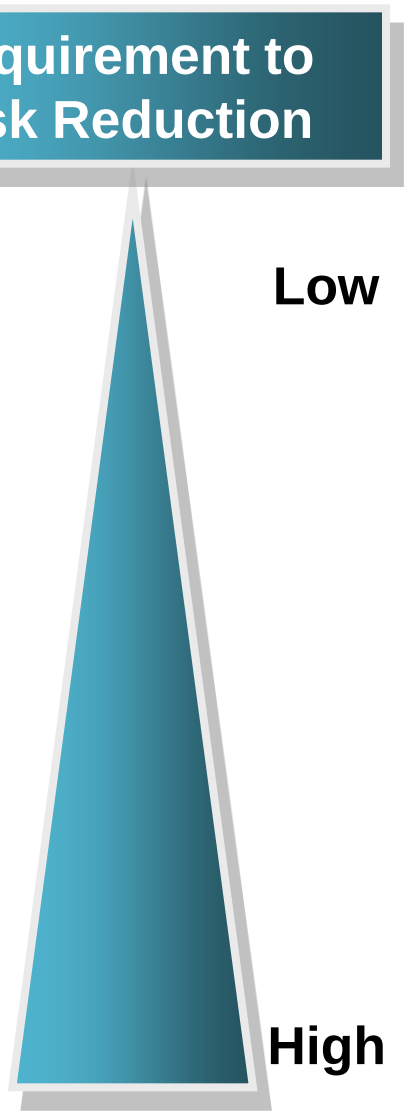
Functional Safety Standard ISO13849-1
风险评估 Risk Assessment

S = Severity

F = Frequency or Duration of Exposure

P = Avoidance Probability





Must be determined for each safety function!

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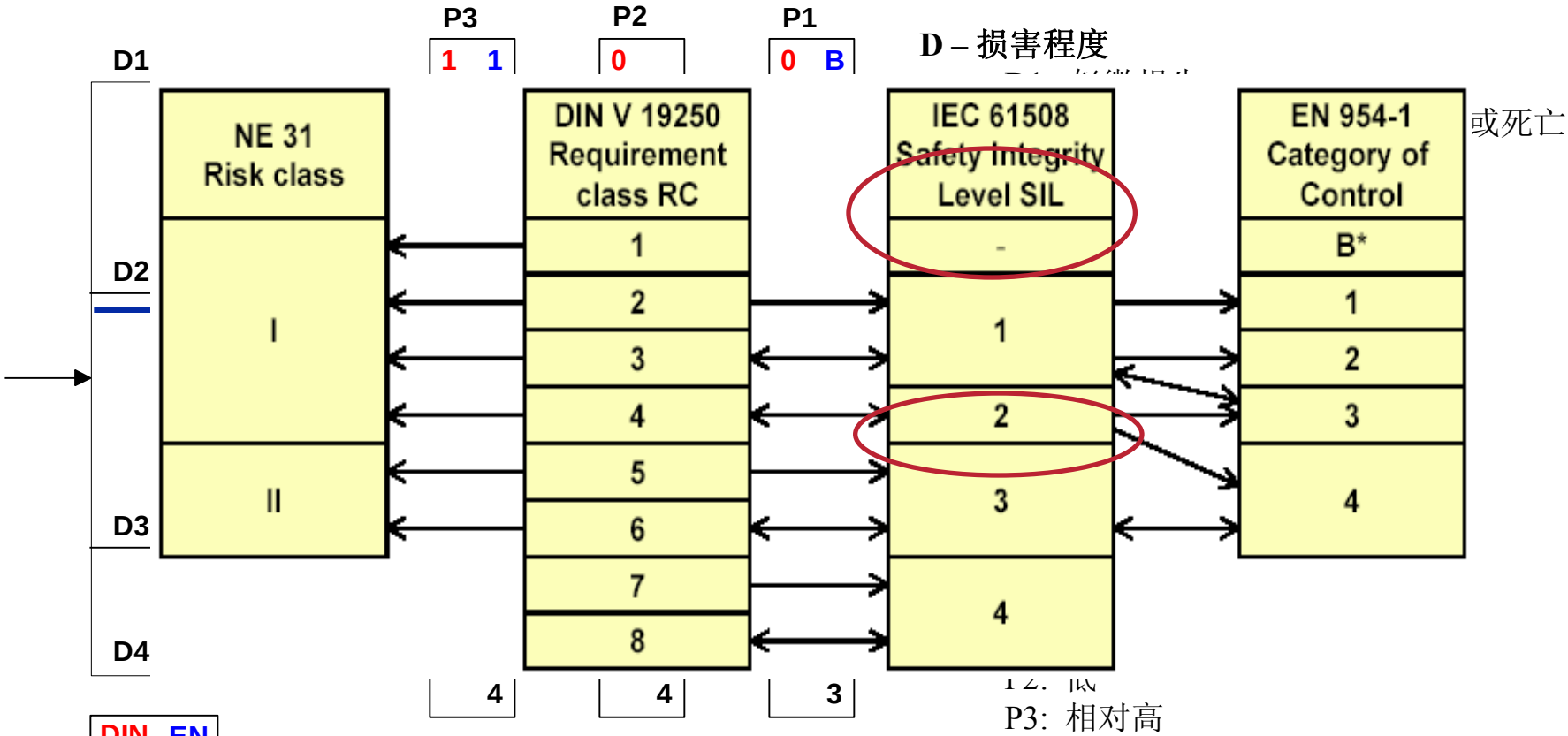
Functional Safety Standard IEC 61508 /EN0954
风险评估 Risk Assessment

摘自: TUV Product Service

危险参数:

D – 损害程度



或死亡

P3: 相对高

DIN VDE-19250 (AK) Fundamental safety aspects for measurement and control equipment

EN-954 (Category) Safety of machinery - Safety related parts of control systems

IEC 61508 (SIL) Functional safety of programmable electronic systems (PES)

Relationship between PL and SIL

Performance level (PL)	Average probability of a dangerous failure per hour [1/h]	Safety Integrity Level (SIL)
a	$\geq 10^{-5}$ to $< 10^{-4}$	No special safety requirements
b	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$	1
c	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$	1
d	$\geq 10^{-7}$ to $< 10^{-6}$	2
e	$\geq 10^{-8}$ to $< 10^{-7}$	3

Functional Safety Standard Update
安全领域国际标准更新

- **Functional Safety** is part of overall safety that depends on a system's or equipment's ability to operate correctly in response to its inputs. It marks a transition from a *qualitative* approach of applying safety to a *probabilistic* approach of applying safety.

SIL = Safety Integrity Level **PL** = Performance Level

After 2010, ISO 13849-1 will become mandatory & effective for all equipment (new and continuing construction) being approved for CE marking under the EU Machinery Directive.

IEC EN 62061 / ISO 13849-1:2006 (Machinery Sector 机器设备类别)

IEC 62061

- Relatively complex methodology
- More flexibility
- Less constraints
- Simplified modularity via subsystems
- Only applies to electrical technology

Are there complex safety functions
e.g. depending on logic decisions?
or
Will the system require complex or programmable electronics to a high level of integrity?

If the answer to either question is YES it is probably most appropriate to use
IEC 62061

ISO 13849-1: 2006

Preferred

- Simple methodology
- Builds on Categories
- More constraints
- System based
- Applies to all technologies; i.e.
  - Electrical
  - Mechanical
  - Pneumatic
  - Hydraulic

Can the system be designed simply using the designated architectures at figures 7.7 to 7.11
or
Will the system include technologies other than electrical?

If the answer to either question is YES it is probably most appropriate to use
ISO 13849-1: 2006

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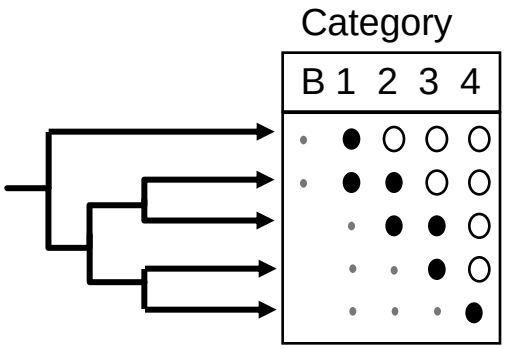
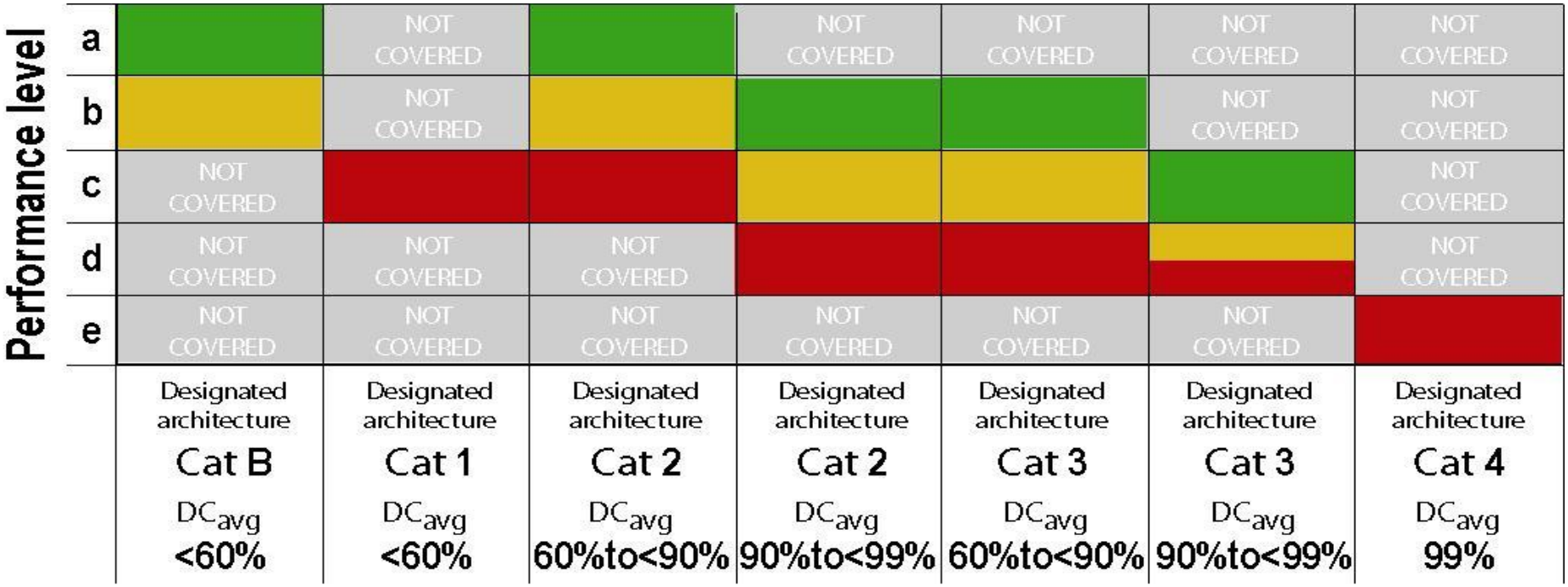
The requirement of Safety System v.s PL
安全系统要求 v.s 相应的安全等级

- Performance Level consist of three main parts:
  1. Failure rate – Mean Time To Failure (dangerous) **$MTTF_d$**
     - Three levels –
       - Low = 3 to 10 years
       - Med = 30 to 30 years
       - High = 30 to 100 years
  2. Diagnostic Coverage – **DC_{avg}**
     - Four levels –
       - None <60%
       - Low =>60% to <90%
       - Med =>90% to <99%
       - High =>99%
  3. Category – **CAT B through CAT 4**



The requirement of Safety System v.s PL
安全系统要求 v.s 相应的安全等级

To choose the most suitable combination of Structure (Category), Reliability (MTTFd) and Diagnostics (DC)



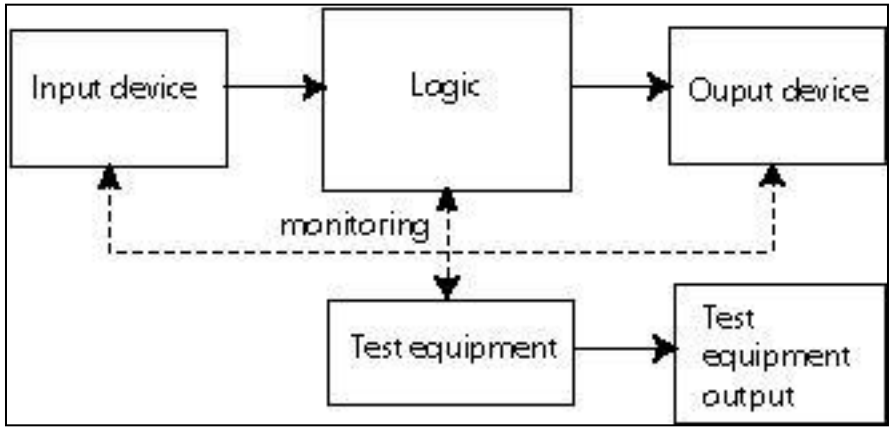
Key

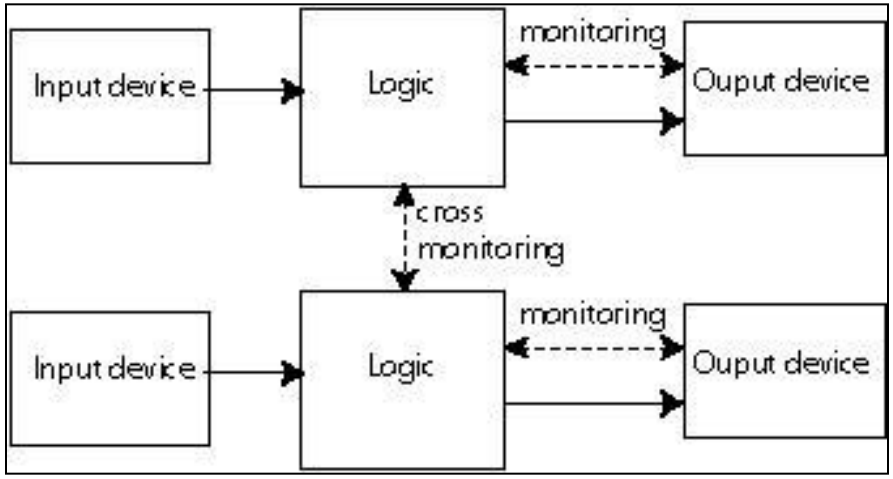
- MTTF$_d$ of each channel = from **3 years to <10 years**
- MTTF$_d$ of each channel = from **10 years to <30 years**
- MTTF$_d$ of each channel = from **30 years to <100 years**

Types of Cats (structure) Overview
4 类 Cat 安全回路简介

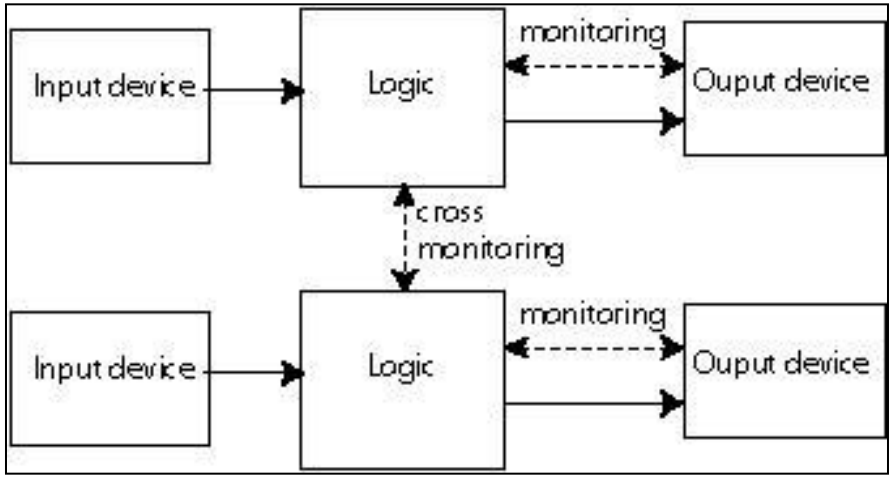
Cat B/1

Cat 2





Cat 3



Cat 4

What RA can help on wind turbine, complying with ISO 13849-1:2006 风机安全，我们如何帮助？

- TUV Certified Safety Expert work together with wind turbine makers to make risk assessment and safety system
  - In-process partnering with 3 leading wind turbine makers in Europe, Japan and US
- Plus SISTEMA, software tools, on safety system development& design
  - From TÜV W

EN ISO 13849-1

TÜV SÜD America

Software:

TÜV Recommends the open source (Free as in Free Beer) Software published by the German Occupational Safety Agency BGIA, called Sistema. It may be downloaded here:

http://www.dguv.de/bgia/en/pra/softwa/sistema/index.jsp

(Google: BGIA Sistema, look for the link titled BGIA Practical Aids: Software Assistant Sistema)

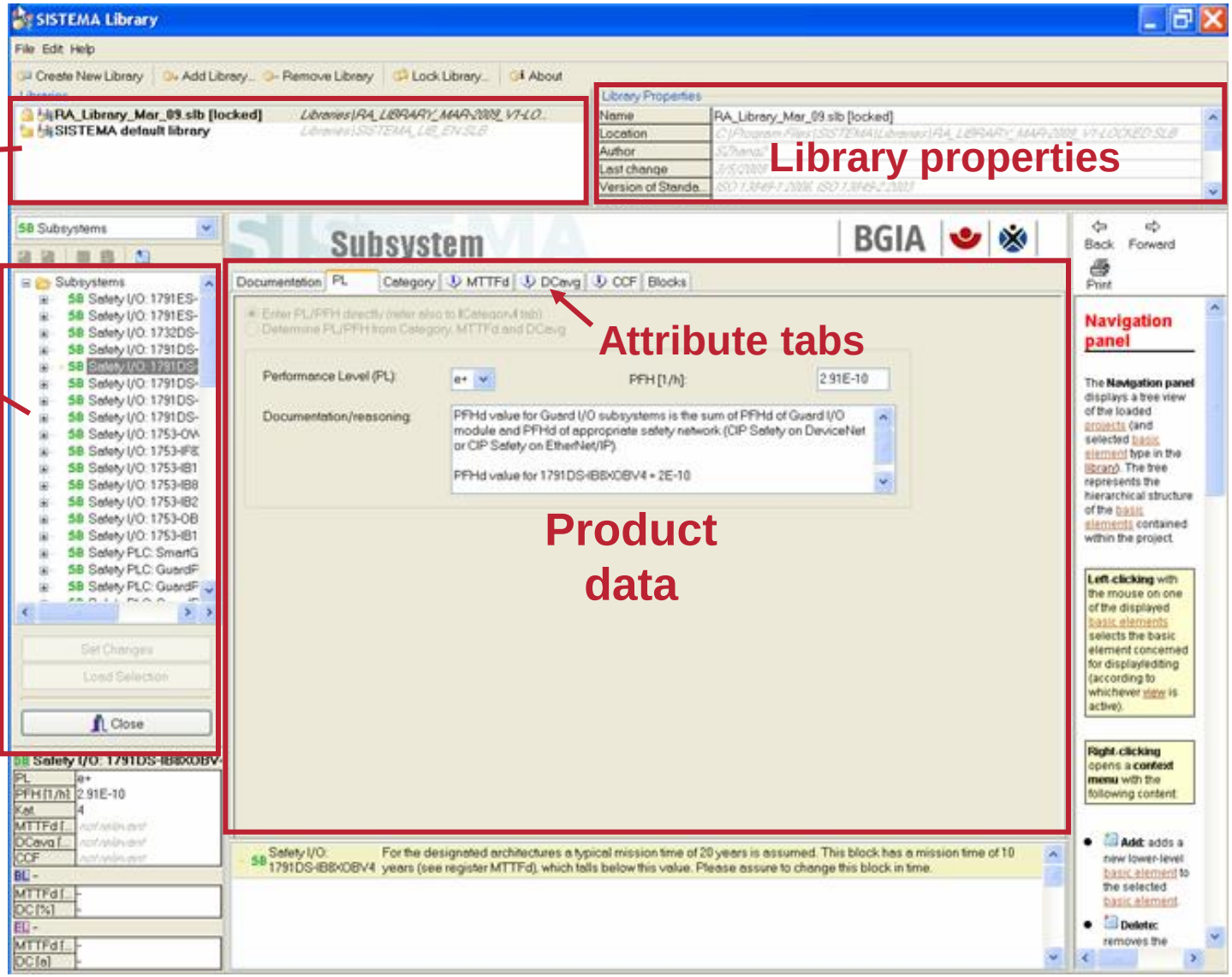
SISTEMA simplifies the PL calculation of a safety function for customers if they have access to the appropriate

SISTEMA User Interface – Library View

Library selection

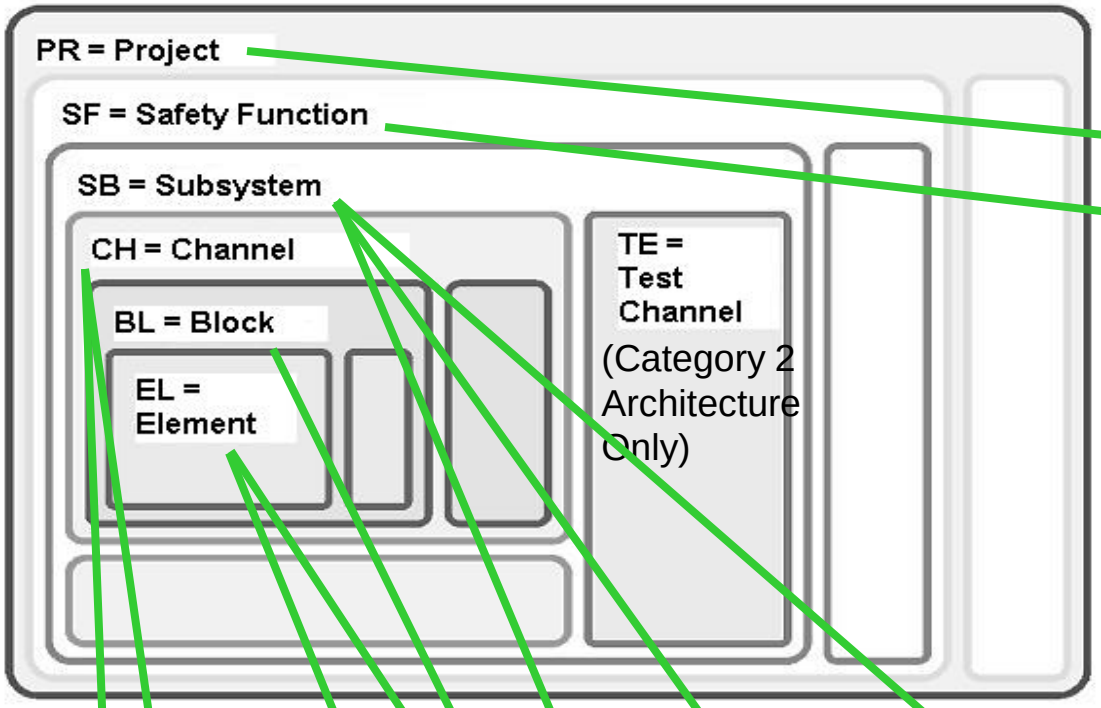
RA Product Library

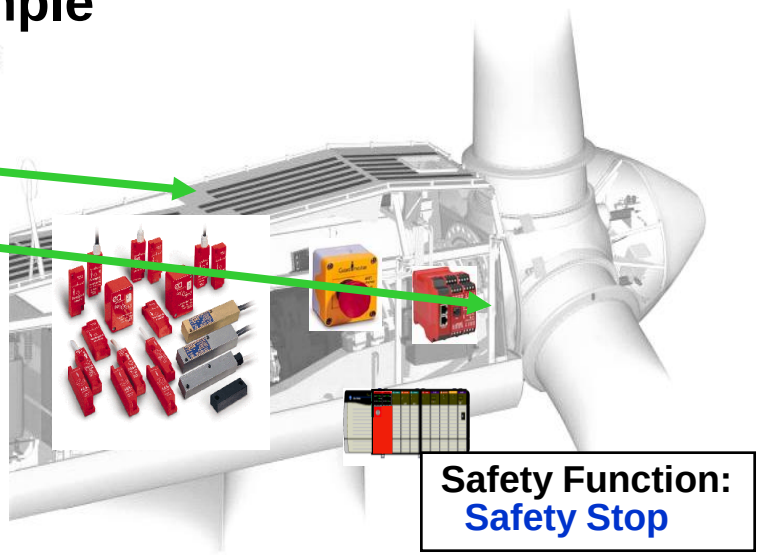
Click on the product to show details in the Product Data Window

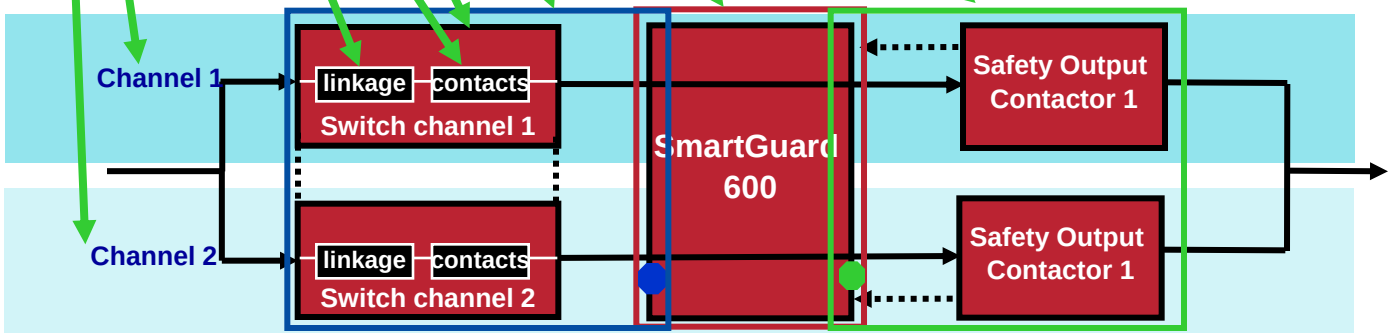


SISTEMA applied to wind turbine safety
SISTEMA 用于风机安全设计

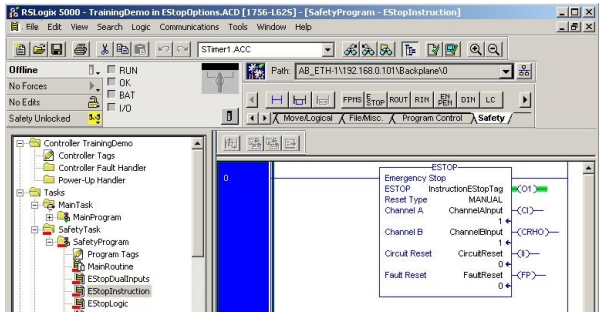
- **Relationship of 7 SISTEMA elements - example**

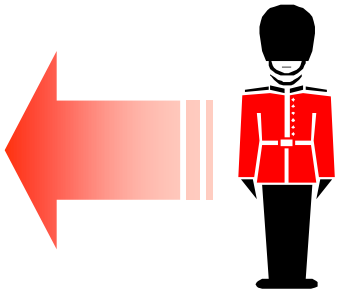


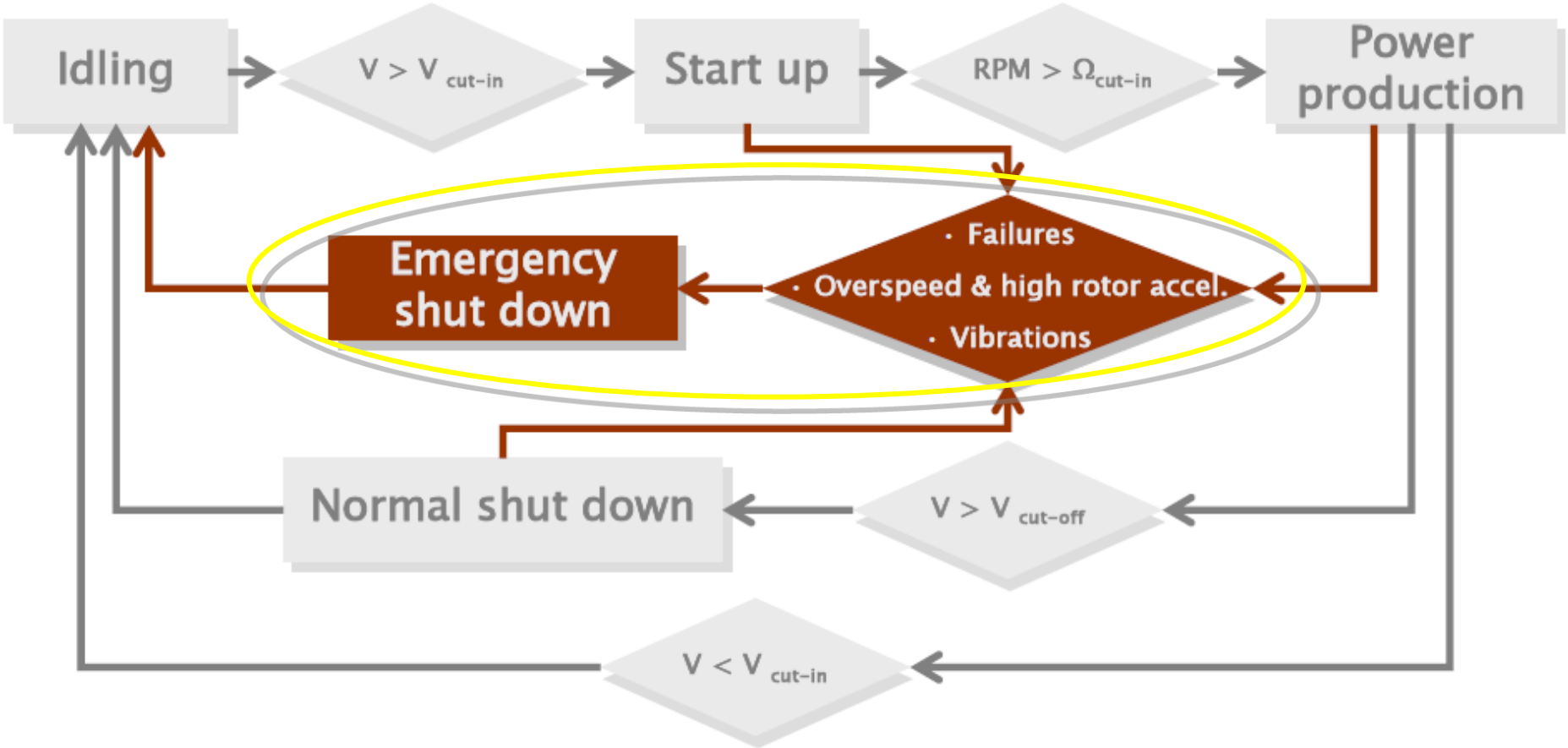




Wind Turbine Control& Safety System
一体化的风机控制及安全系统

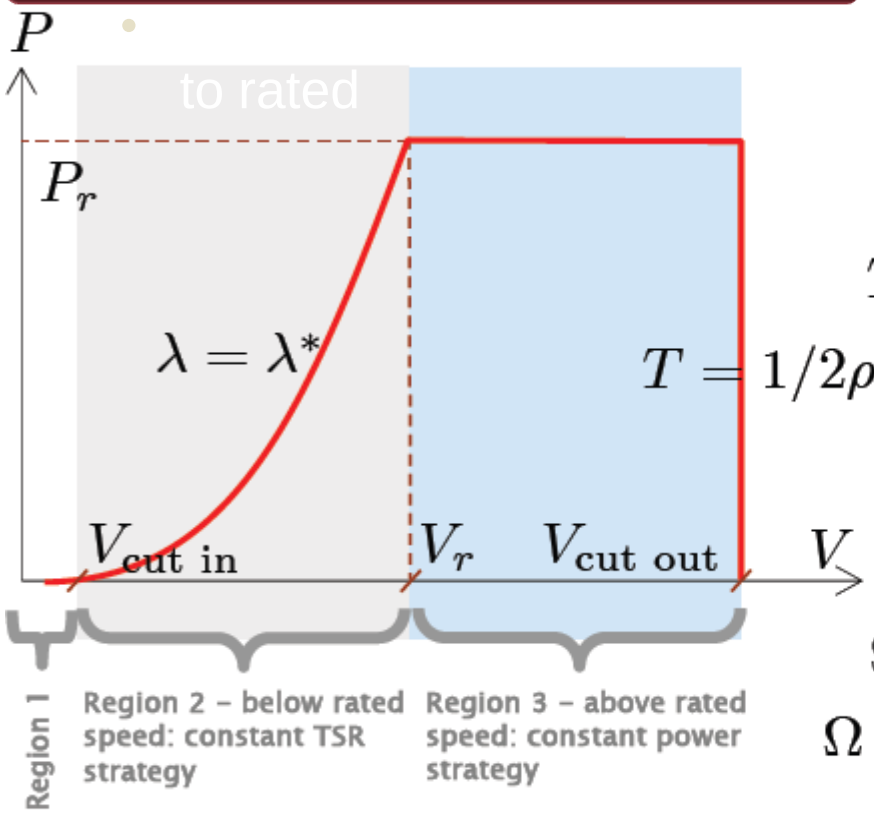


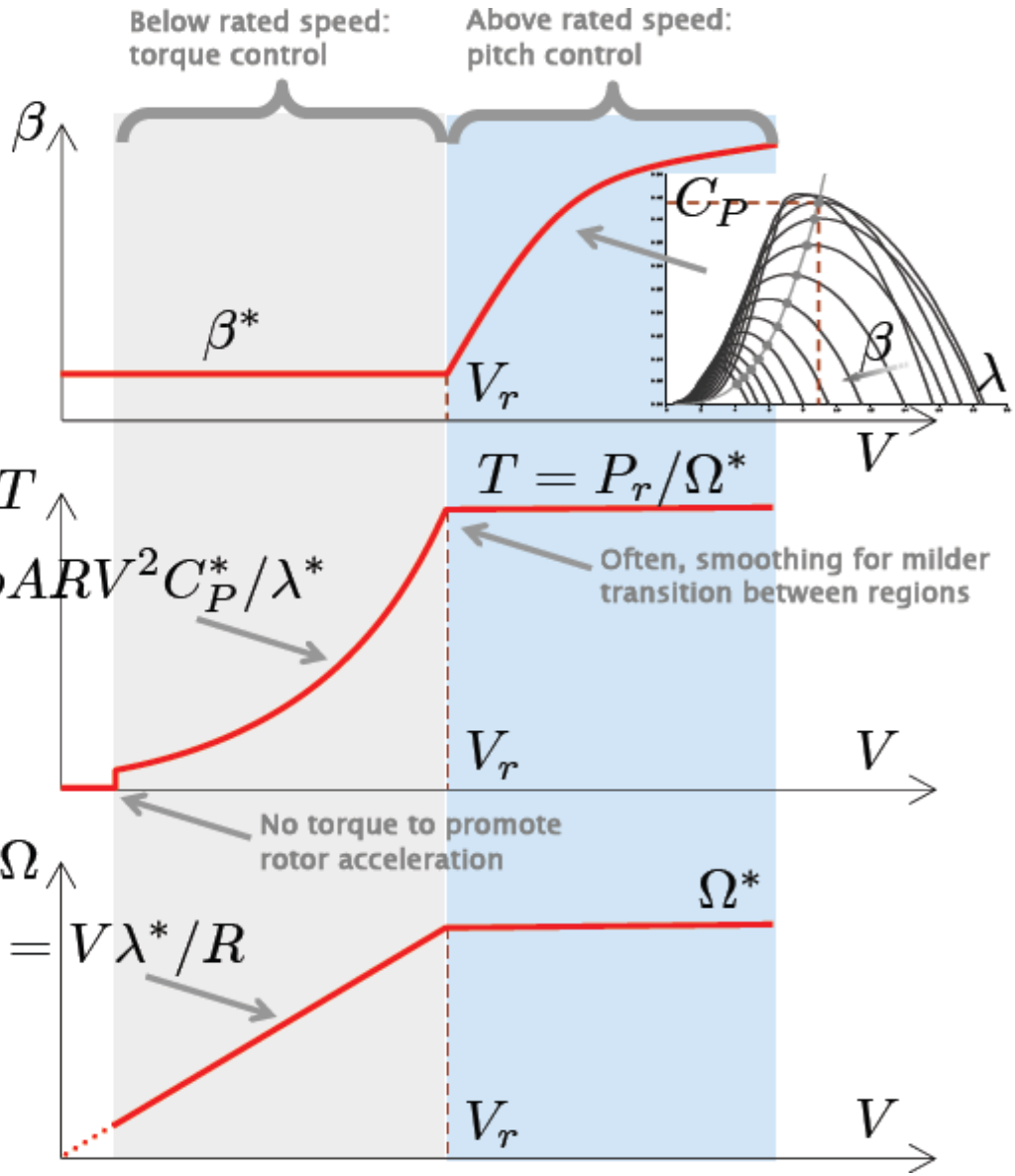




Wind Turbine Control Evolution
风机控制技术的不断发展

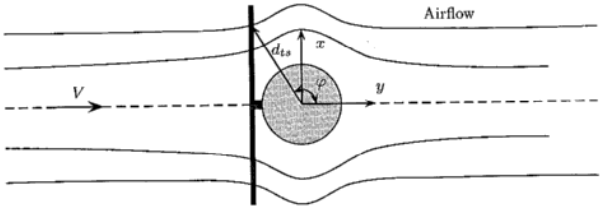
- Basic control goals
  - Region 2: maximize energy capture.



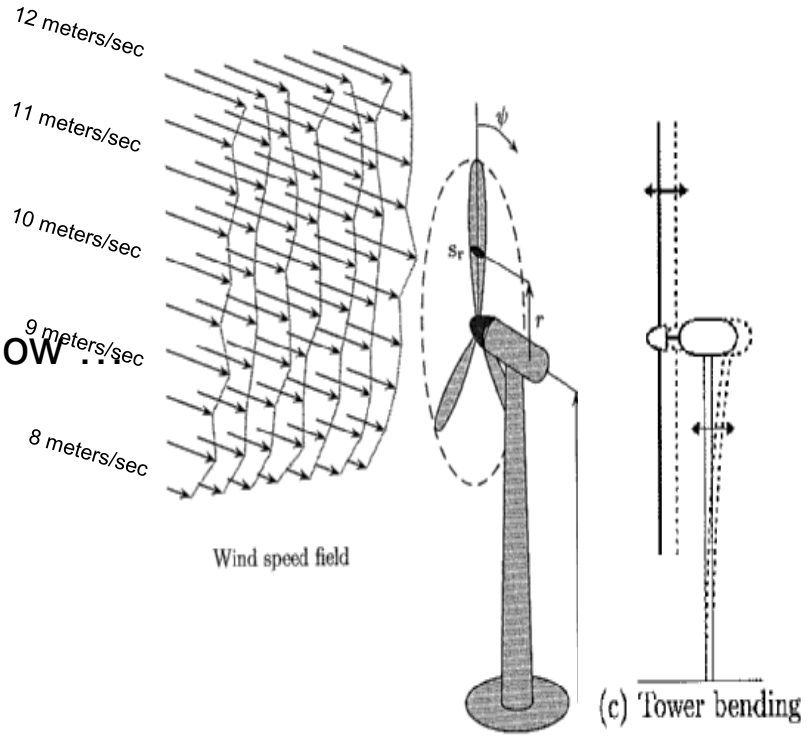


Wind Turbine Control Evolution
风机控制技术的不断发展

- Further control goals:
  - Extend the lifetime of turbine& smooth the pov
    - Fatigue damage reduction in turbulent wi
    - Gust load alleviation
    - Actuator duty cycle reduction
    - Disturbance rejection
    - Resonance avoidance
    - Periodic disturbance reduction
      - Gravity, wind shear, tower shadow ...

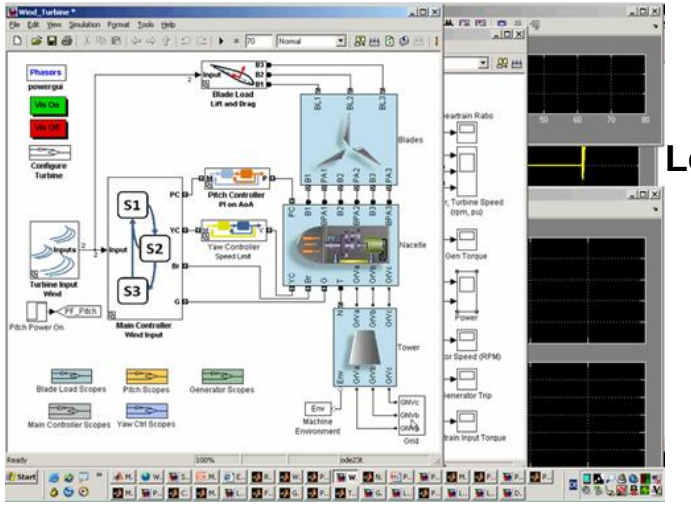


Effect of tower shadow on the airflow



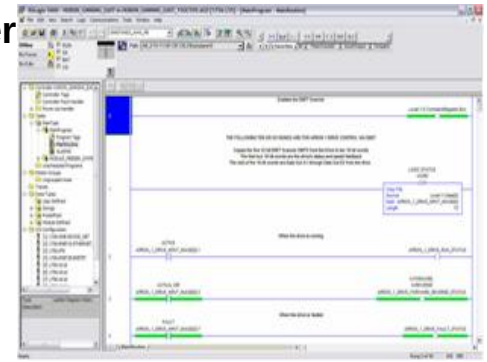
The dynamic multi axis CIP Motion based pitch control system by Rockwell Automation is ready.

Logix设计仿真以便风机控制的持续发展 Logix integrated virtual design for Wind Turbine Control Evolution



代码生成
Logix Decoder
/ ST

Logix 5000



Logix
Controller

The MathWorks™
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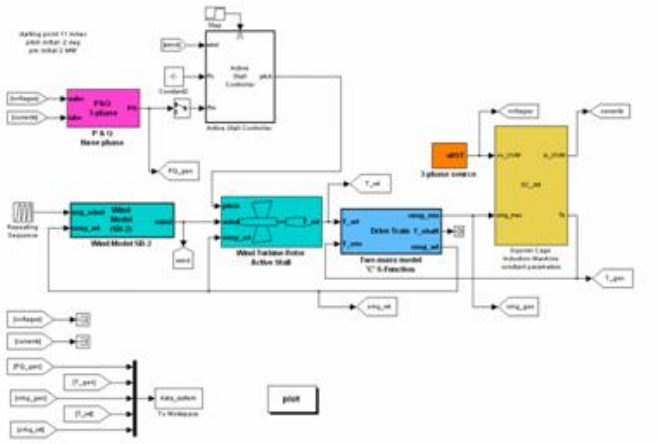
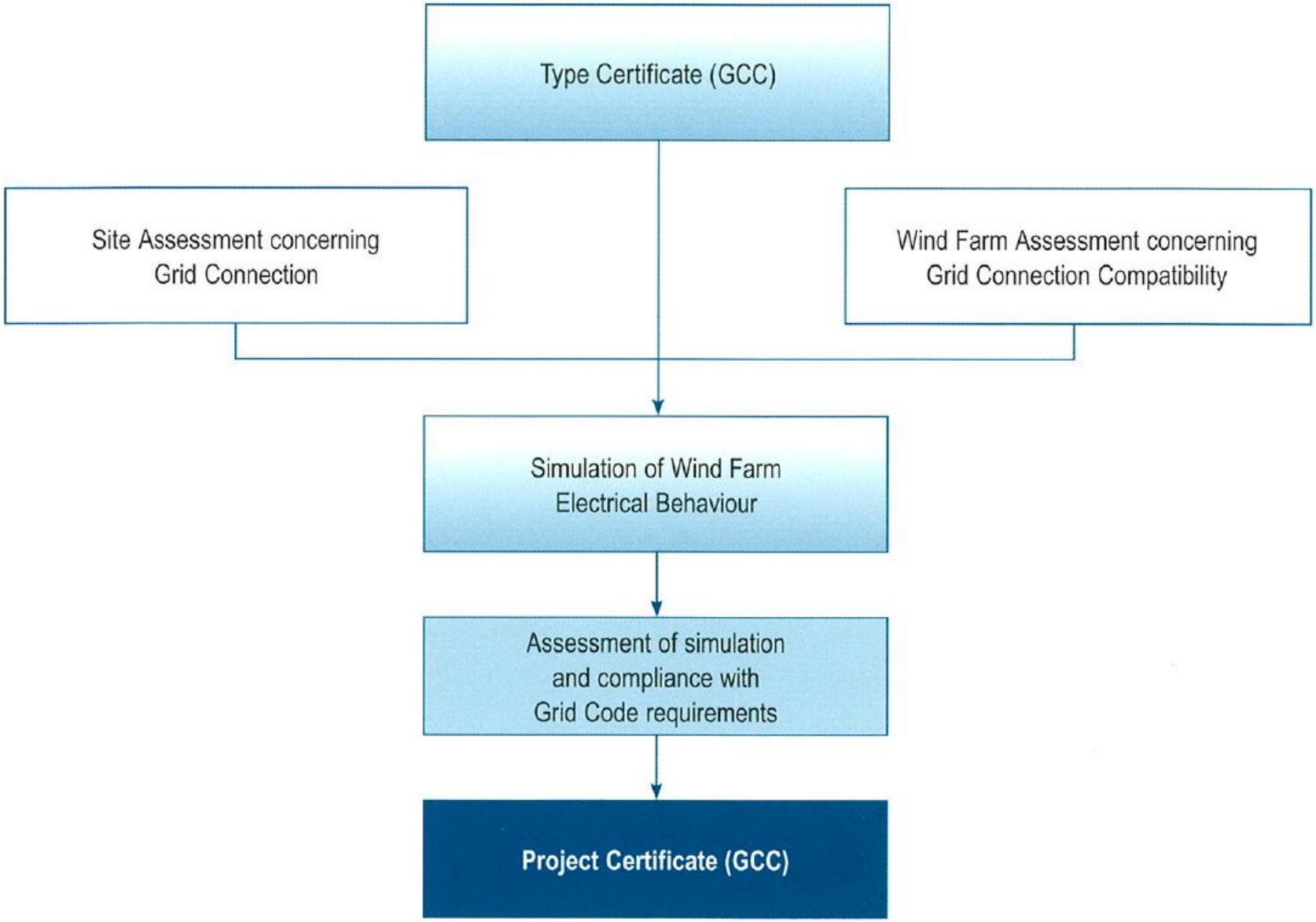


风机仿真
代码测试

美国国家电网并网要求 A bit more about The National Grid Code Compliance (GCC)



A bit more about The National Grid Code
美国国家电网并网要求

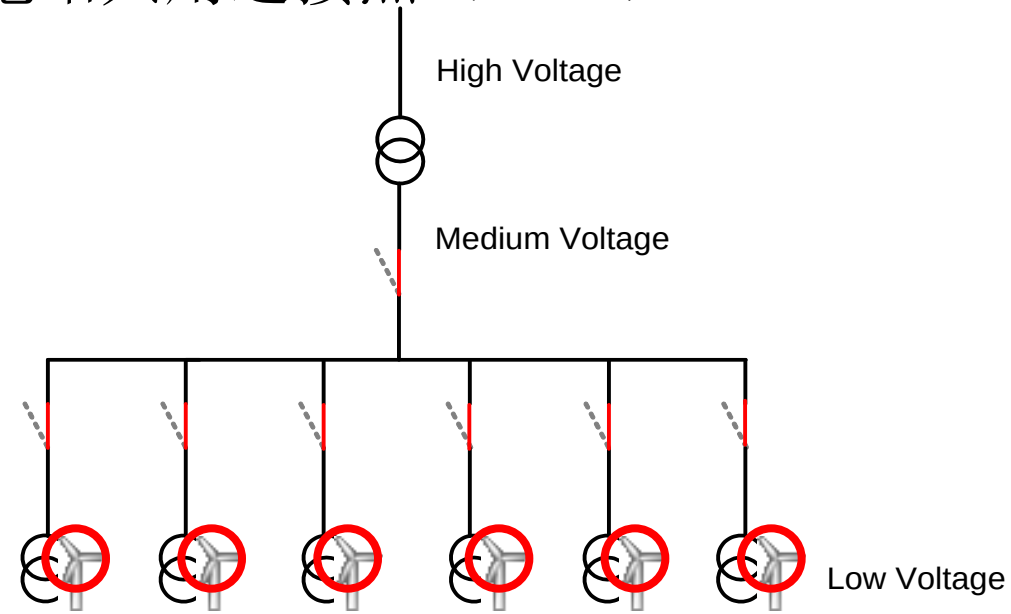
- Shift in requirements 对于风电机组更高的要求:

  Acceptable turbine behavior 可接受的风机行为

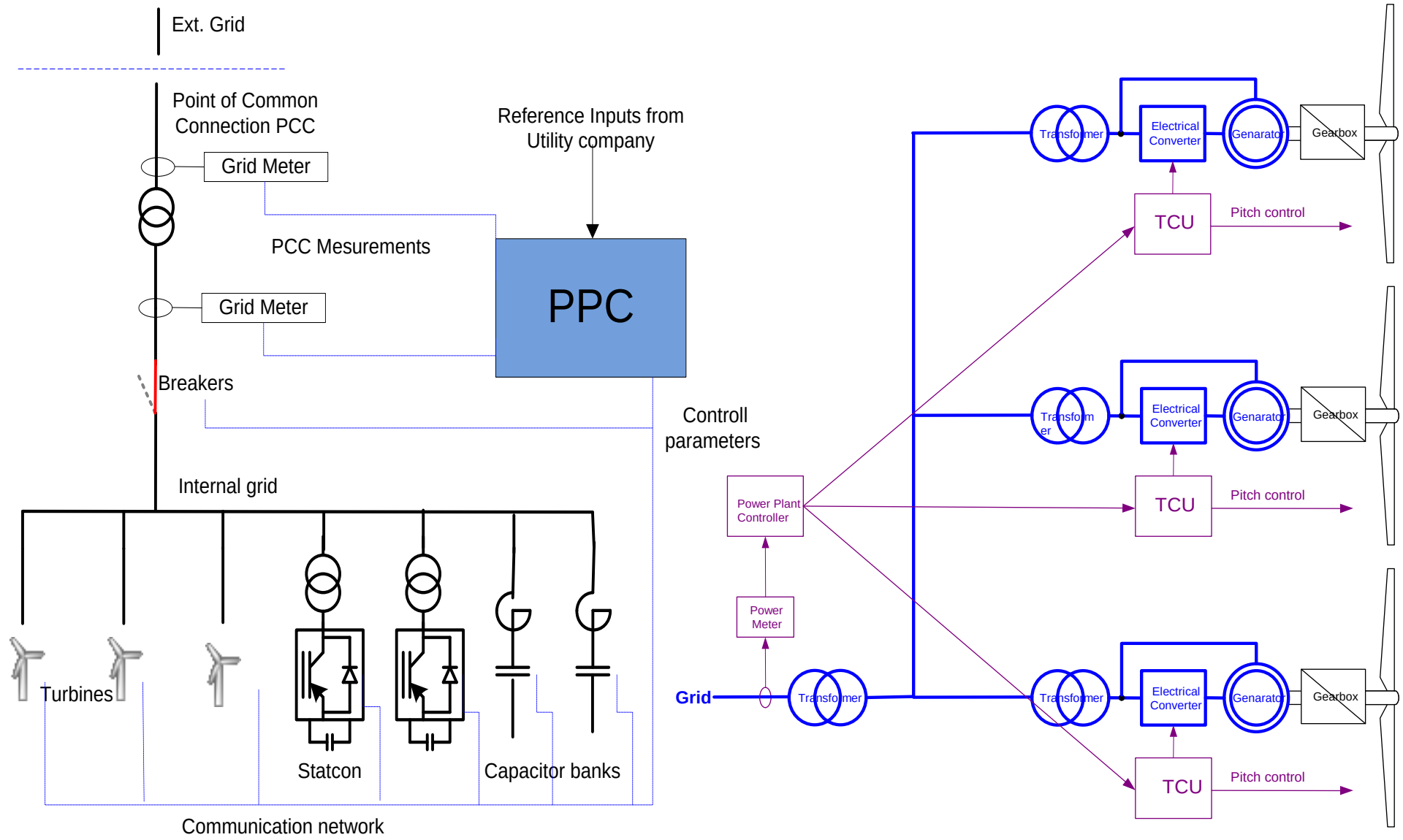
  ↓

  Controllable wind power plant behavior 可控制的风电场行为

- Focus moving from turbine connection point to Point Common Connection (PCC) in sub station 关注从风机接入点转向电站共用连接点（PCC）



PPC Principals by The National Grid Code
风场电站控制器（PPC）示意



Important PPC features by The National Grid Code
风场电站控制器（PPC）要求

- Deterministic control loops 控制的确定性
  - Frequency频率
  - Voltage.电压
  - Active power有功
  - Blind power无功
- Fast communication between PPC and TCU (converter), especial DFIG.

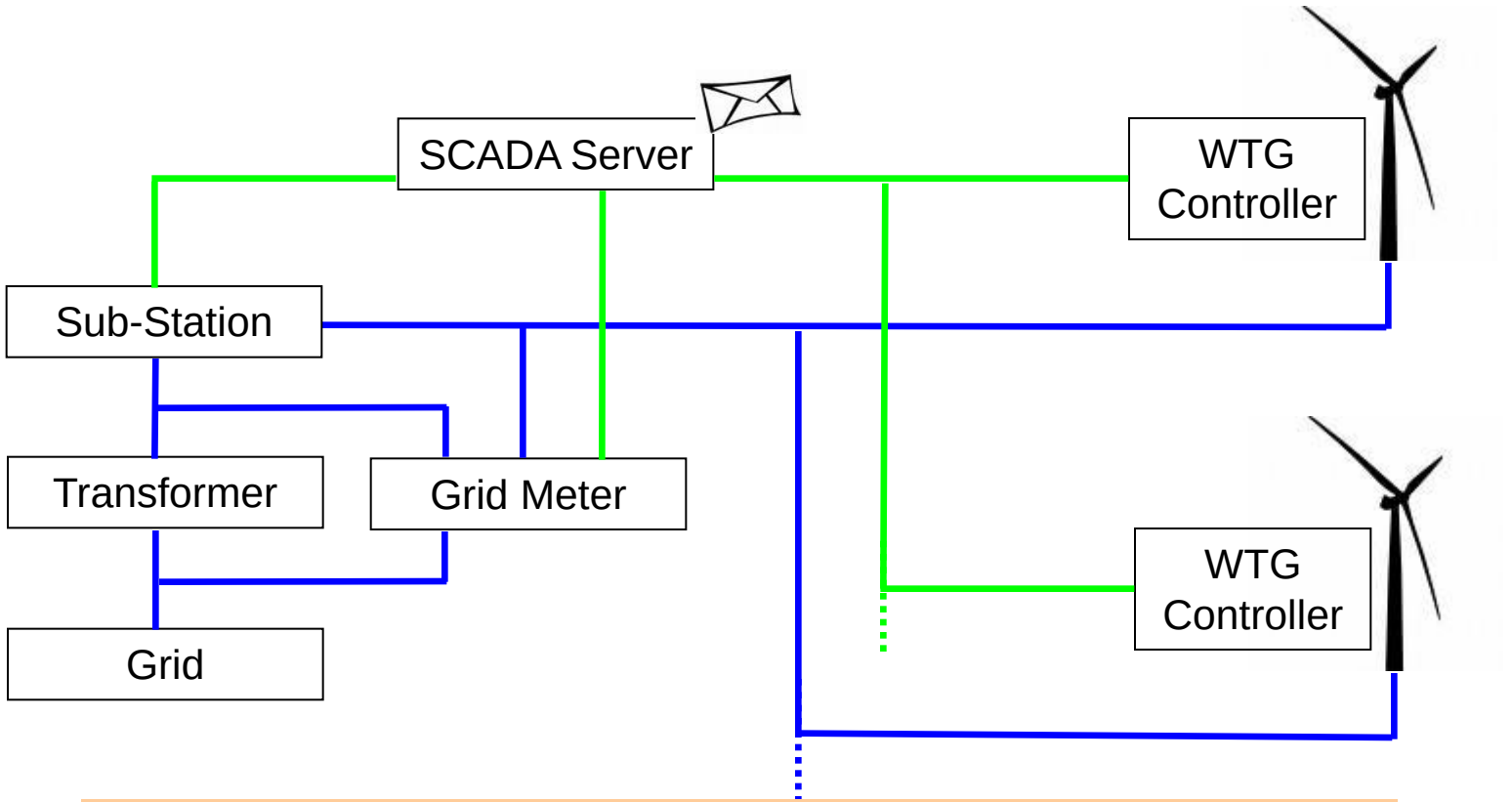
  对于DFIG机组，PPC 与 TCU (变流器) 之间的快速实时通讯
  - means fast regulation of blind power, thus grid compensation equipment (Statcon) can be dramatically reduced. It is not uncommon that Statcon adds 5-7% to total cost of a wind farm.意味着快速调制无功功率, 这样就可以大大减少电网补偿设备 (Statcon)。一般来说，Statcon会增加风场整体成本的5-7%。
- Open communication platform 开放式通讯平台
  - interface to various equipment is plug and play对于各类设备接口即插即用

风电场面临的挑战
Challenge Faced by a Wind Park

- **Wind Park management is # 1 challenge 风场管理是最大挑战**
  - 电网发出送电要求后的响应时间

    Power-on response time to request from the grid
    - 目前的要求是必须小于140ms Currently must be less than 140ms
  - E-ON 对2013以后的新增装机提出要求
    - 必须小于

Issue on Wind Park Management System
风场管理系统需要解决的问题

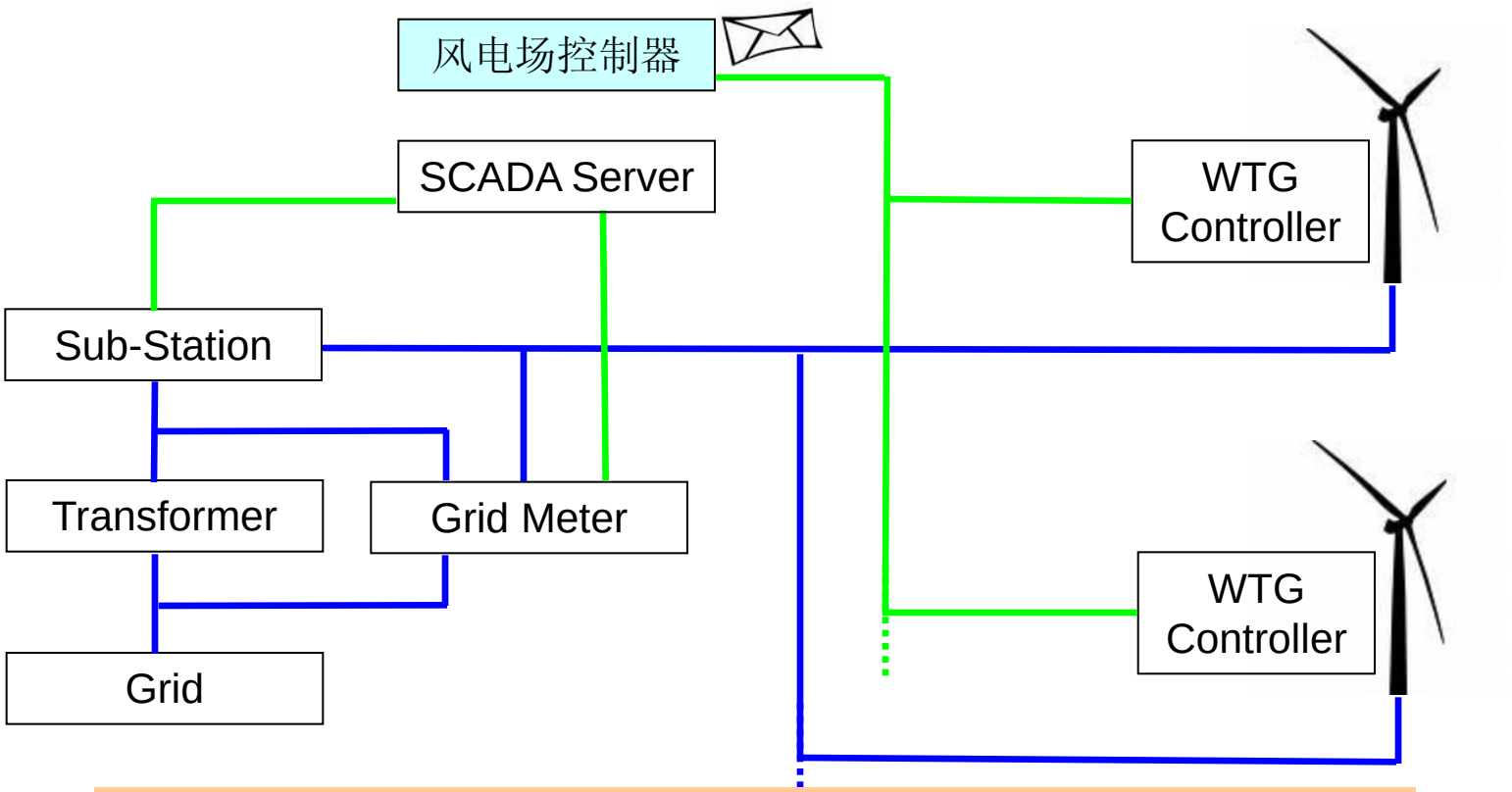


Grid 'power-on' request to WTG times > 50ms
电网送电要求到达风机的时间 > 50ms

通讯瓶颈

通讯的不确定性

One of Key Goals for Wind Park Management System
风场管理系统需要保证



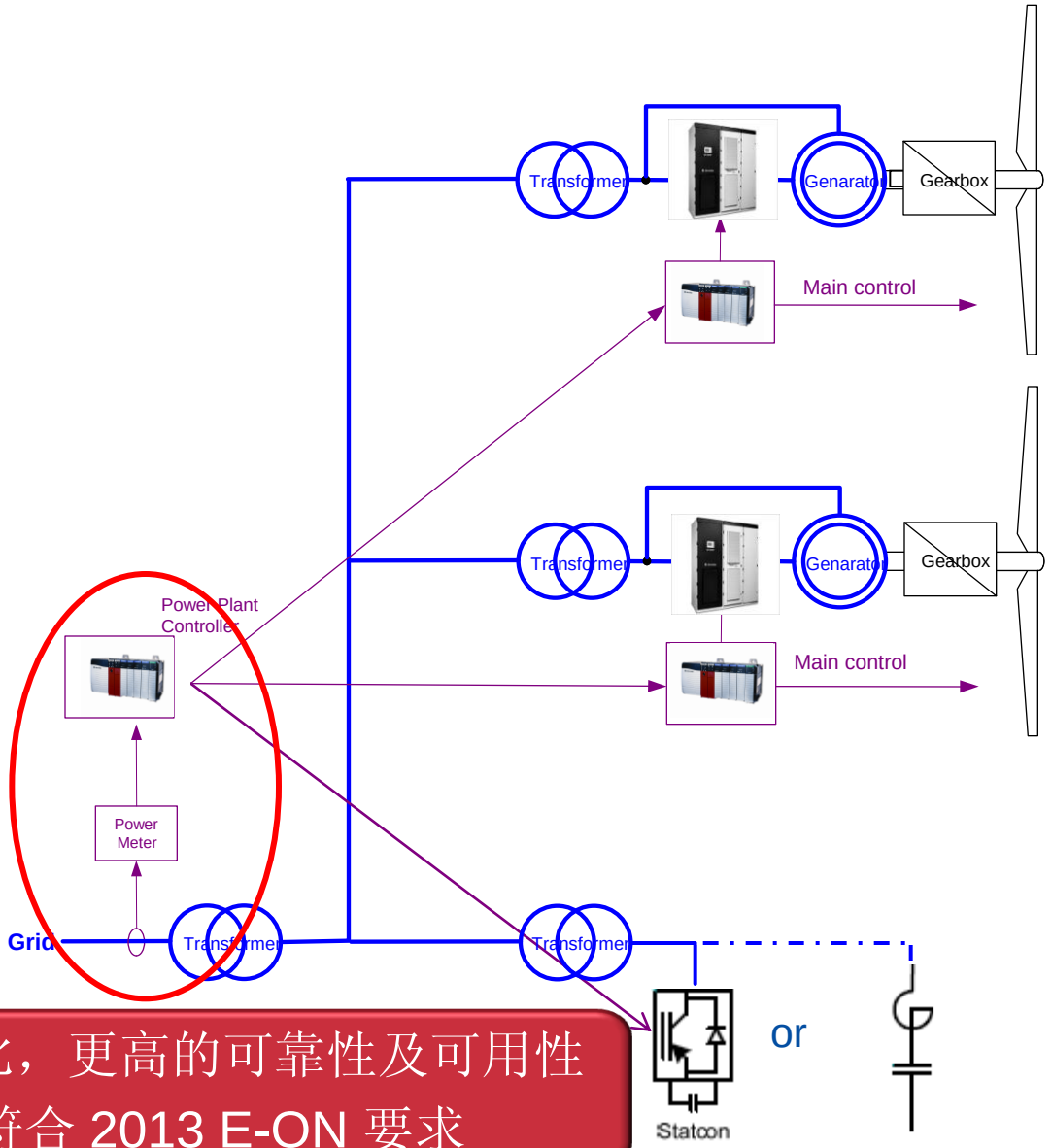
所有风机同步接收数据

< 50 ms

100 % 确定性

Wind Park Manage. by Rockwell Automation
罗克韦尔自动化风场管理系统简介

1. 开放、灵活的通讯以集成多种不同外部设备及信息
2. 正确的时间、正确的信息 (btw, CIP Sync optional ready)
3. 控制回路的确定性执行
4. 远程实时控制与数据采集分别给予不同优先
5. 冗余PPC方案可选
6. 风机及风场使用统一的标准工业以太网Ethernet/IP
7. XML 程序文件导入导出，用来生成外部代码
8. 风场电站调度安全保障



- 与传统基于PC的风场控制器相比，更高的可靠性及可用性
- < 50ms 的确定电力调度控制，符合 2013 E-ON 要求

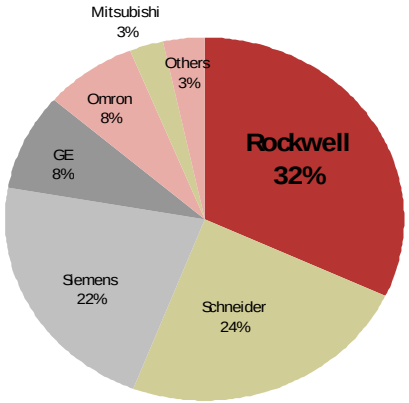
Rockwell Automation (RA) is Committed to working as a strategic partner for wind Turbine Maker

- RA provided a high quality, cost effective, advanced wind energy control& safety solution. 高质量、高性价比的先进风电控制方案
- RA built up a technical consultant team with right domain expertise and a proven engagement process to work for you. 应用开发团队及专业知识

most valued global provider of power, control & information solutions

中国大型PLC市场第一位

2009 China Large PLC Market Share (%) by 工控网市场报告



You Success!

We Success!

紧密合作！共创双赢！

Thanks! 谢谢！

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