IEEE-PES meeting

# *Modelling of Wind Power Plants*

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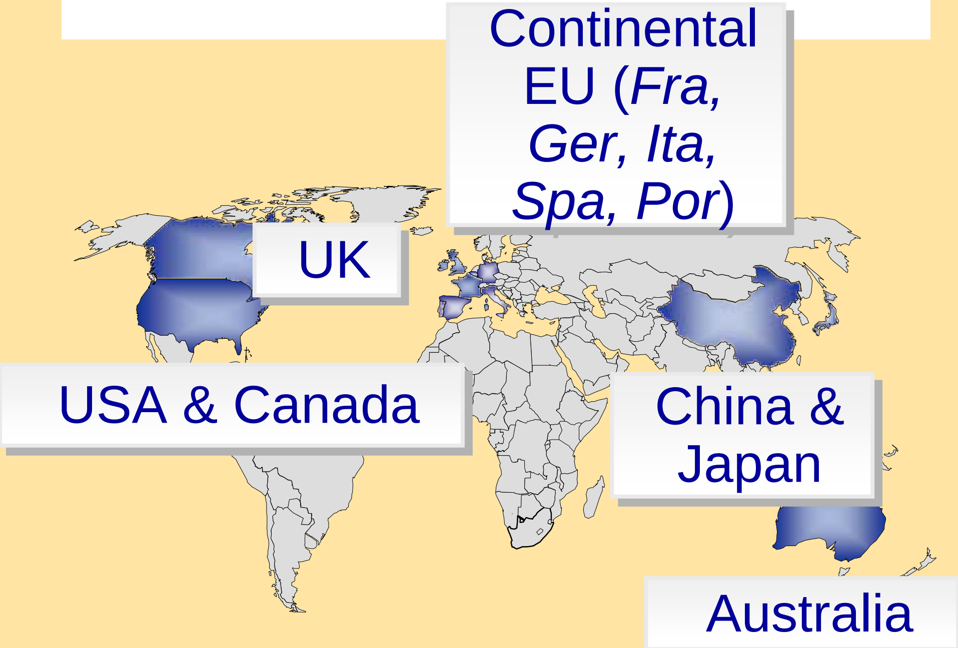
REpower SAS

10th Feb 2010

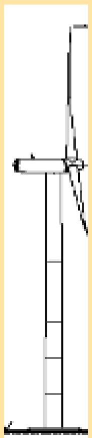
# *Company in brief*




| | |
|---|---|
| **Employees world-wide** | 1900 |
| **Markets** | |
| **Quoted on S-E since** | 2002 |
| **EBIT (FY 2008-09)** | 76.9 M€ |
| **EBIT-Margin (expected)** | 7.5 % |

# Company's portfolio

REpower Systems



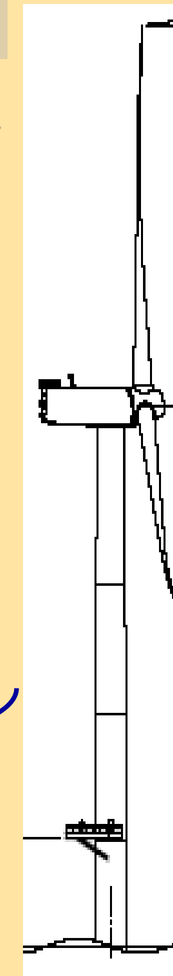
MM82 | MM92 | 3XM | 5M | 6M

*2.05 MW* → *6.15 MW*

**Rotor diameter: 82 m** → **Rotor diameter: 126 m**

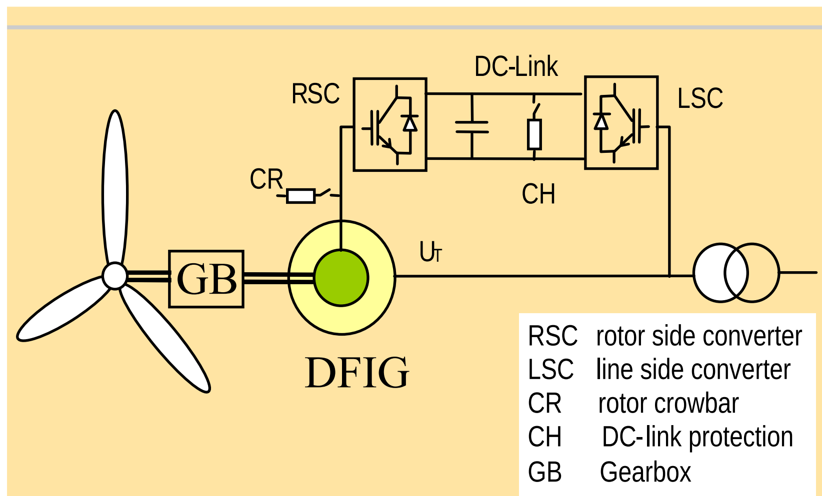
**Installed power**

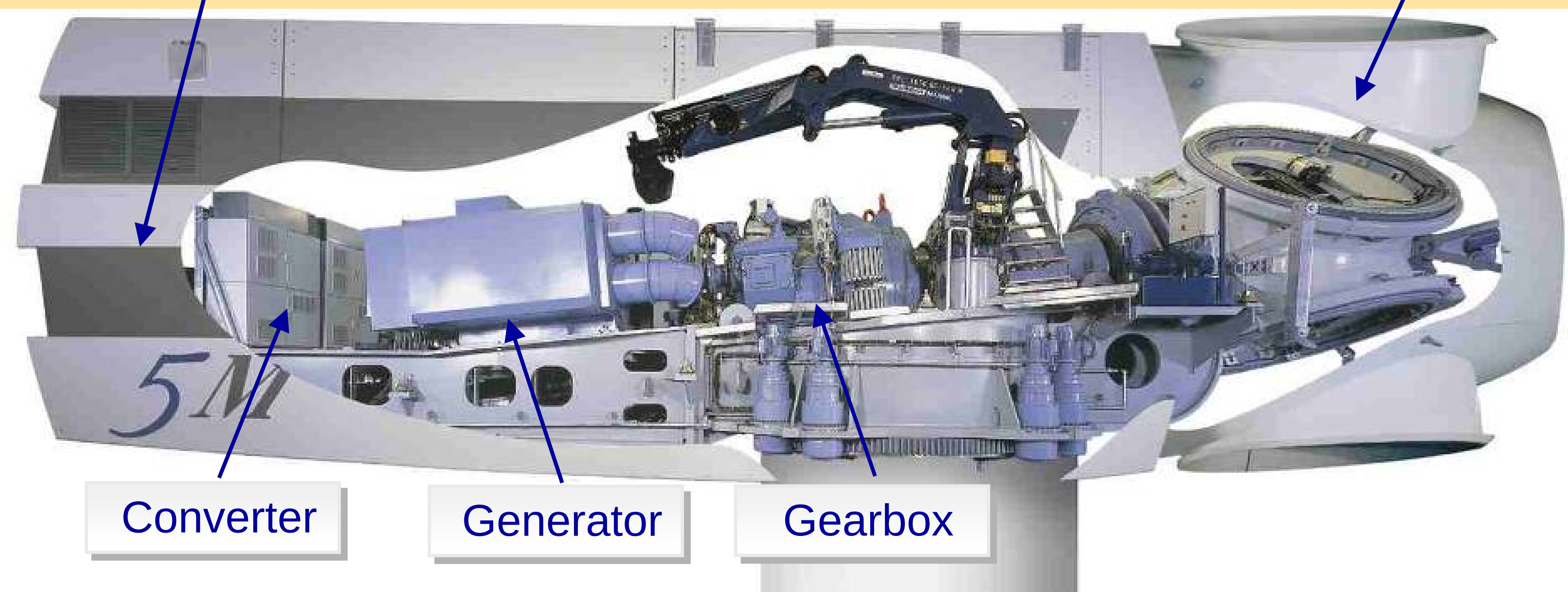
| MM82 | MM92 | 3XM | 5M | 6M |
|---|---|---|---|---|
| 1326 MW | 2350 MW | 9.9 MW | 85 MW | 18 MW |



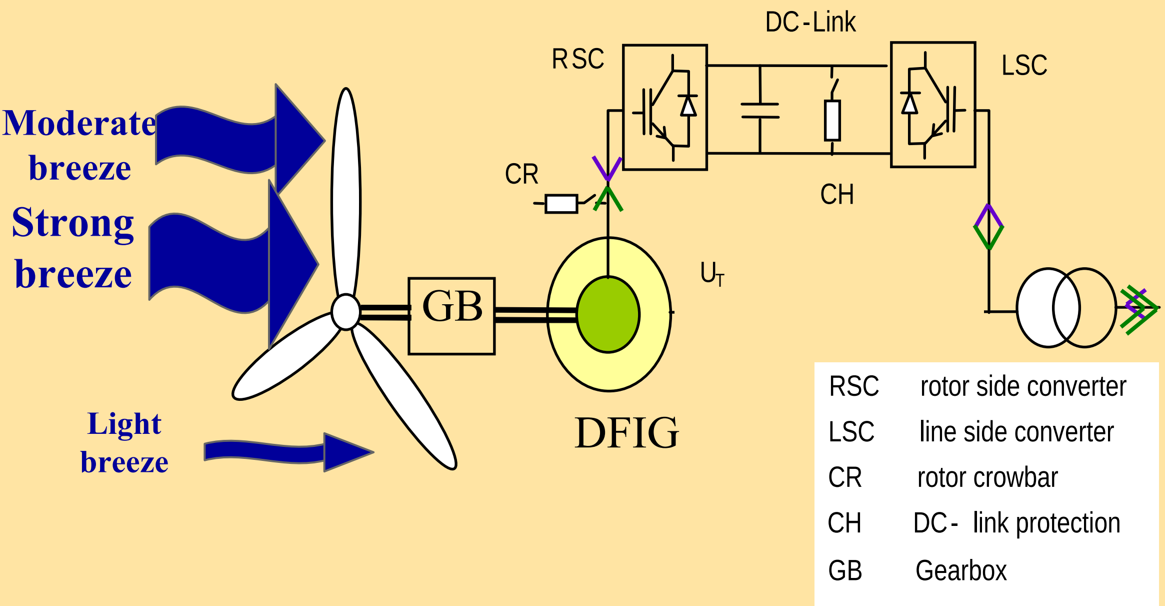
**Common *DFIG*-based platform**

# Common DFIG-based platform



# DFIG Operation Principle

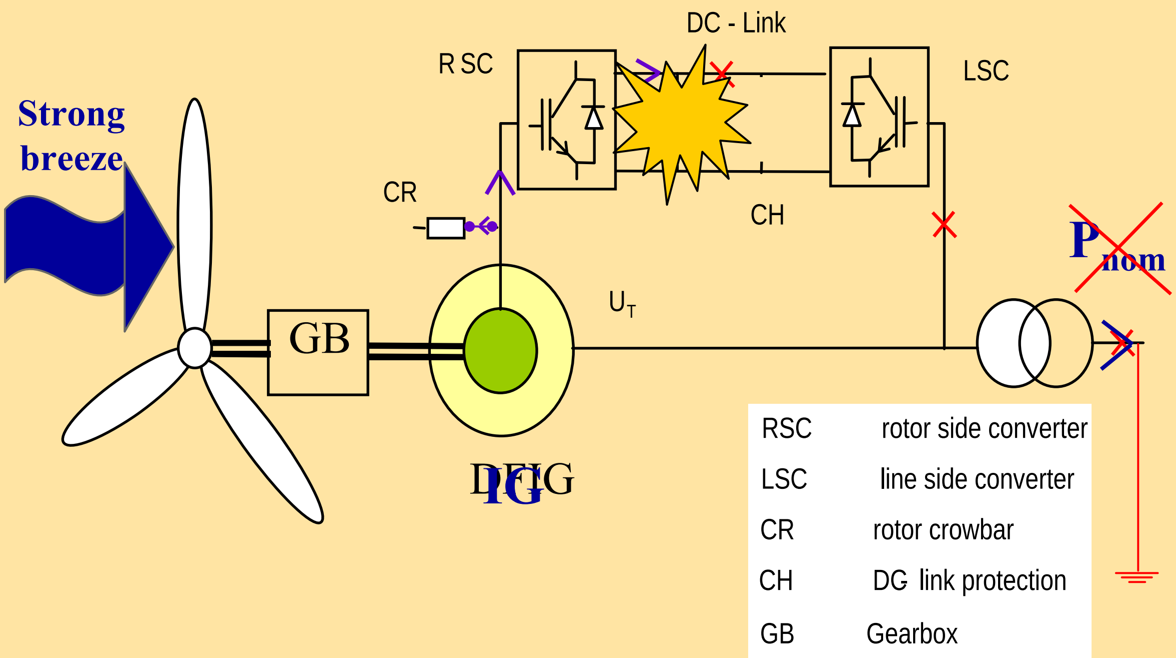



**1) Rotor fed by converter (adapts $U_{stat}$ and $f_{stat}$ to $U_{grid}$ and $f_{grid}$)**

**2) Stator is connected and provides power: $P_{net} = P_{stat} - P_{rot}$**

**3) To keep 50 Hz on stator, rotor field inverts, rotor provides power: $P_{net} = P_{stat} + P_{rot}$**

# *Protection principle during grid fault (nominal op')*




**1) Fault on the grid <u>w/o protection</u>:**

- **Rotor currents charge DC-Link**
- **DC-Link power cannot flow outside**
- **Too high DC voltage => destruction**

**2) Fault on the grid <u>w/ crowbar</u>:**

- **Rotor currents charge DC-Link**
- **CR short-circuits rotor, (RSC in diode mode) => DC-Link energy dissipated**
- **Crowbar => Induction generator**

**3) Fault on the grid <u>w/ chopper</u>:**

- **Rotor currents charge DC-Link**
- **CH dissipates DC-Link additional energy**
- **Generator control possible => <u>grid support possible</u>**

# Agenda

- Need of wind turbine models
- Approach of model validation in Germany
- Model insight
- Comparison between simulation results and measurements
- Benefits and future of wind-turbine modelling

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# *Need of wind turbine models*

## Reasons & Objectives of making models

| Reasons | Objectives of model |
|---|---|
| | |

***The model accuracy has been standardized in Germany***

# Agenda

- Need of wind turbine models
- **Approach of model validation in Germany**
- Model insight
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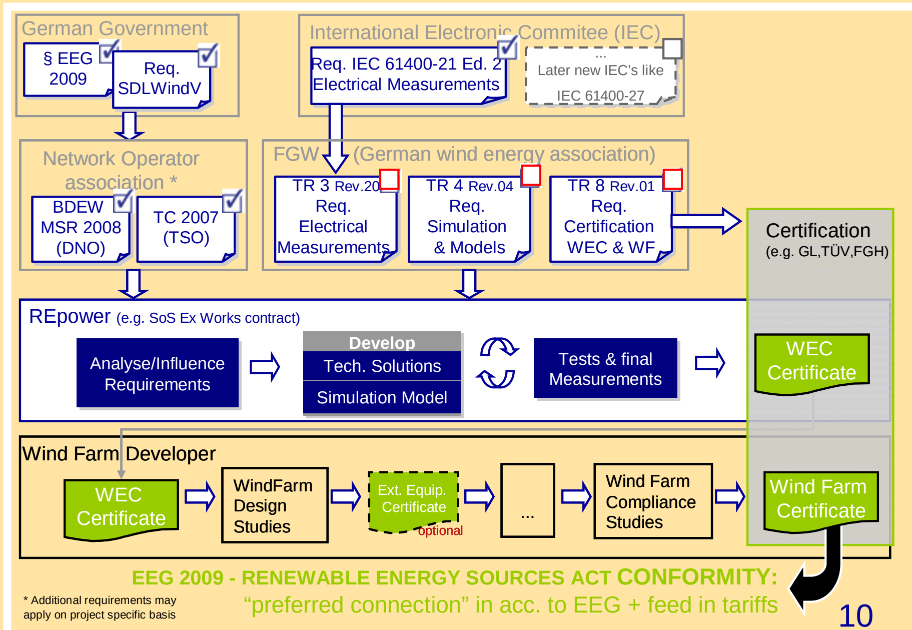
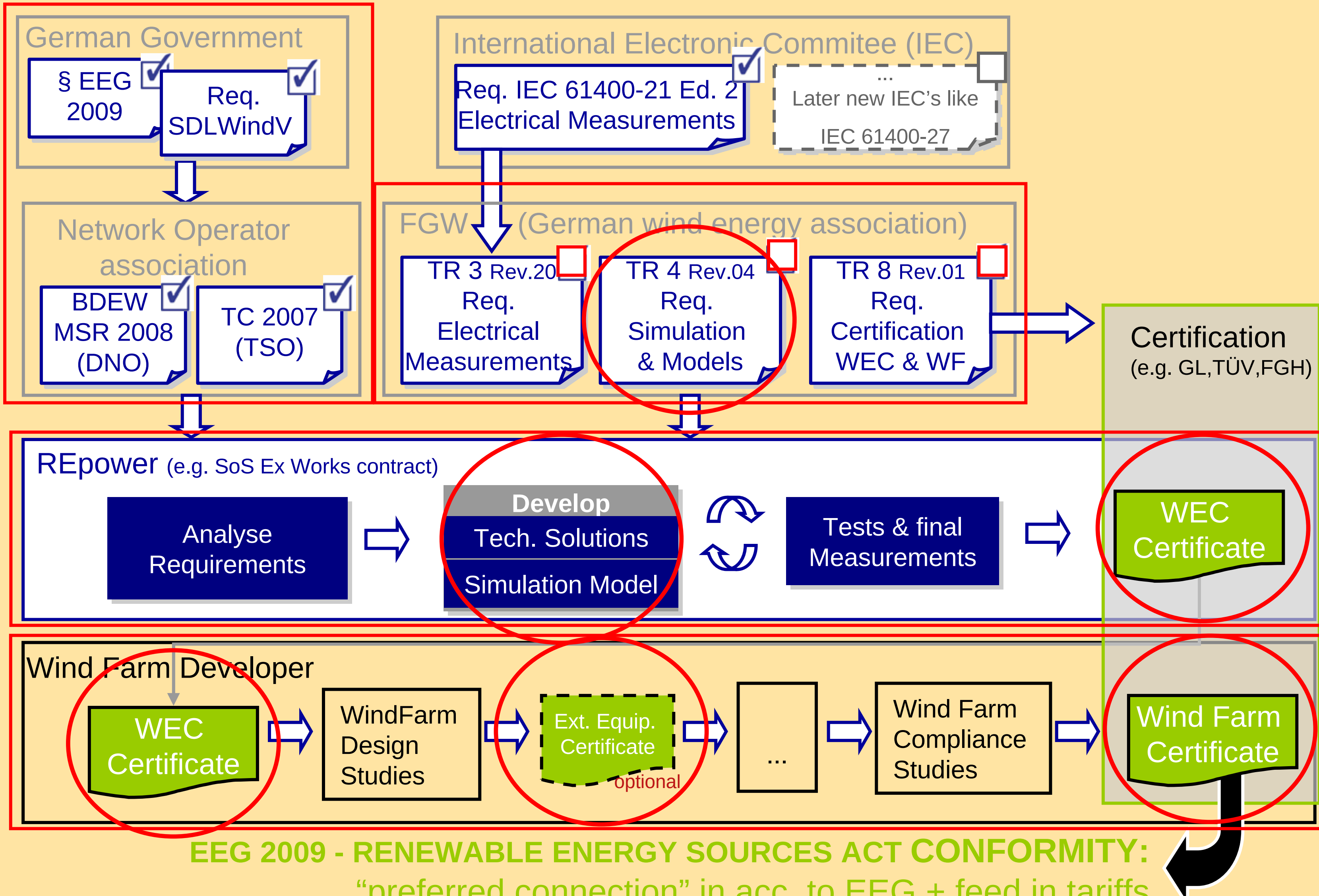


# Approach of model validation in Germany

## WEC model validation in the entire process




EEG 2009 - RENEWABLE ENERGY SOURCES ACT **CONFORMITY:**
"preferred connection" in acc. to EEG + feed in tariffs

# *Approach of model validation in Germany*

## Overview of the German technical guideline: *TR4*

### *WHO is concerned ?*

- **All renewable system manufacturers (Wind, PV, biomass,...) => same modelling and certification requirements**

### *WHAT is concerned ?*

- **RMS model of the renewable system**

### *WHERE is the focus on ?*

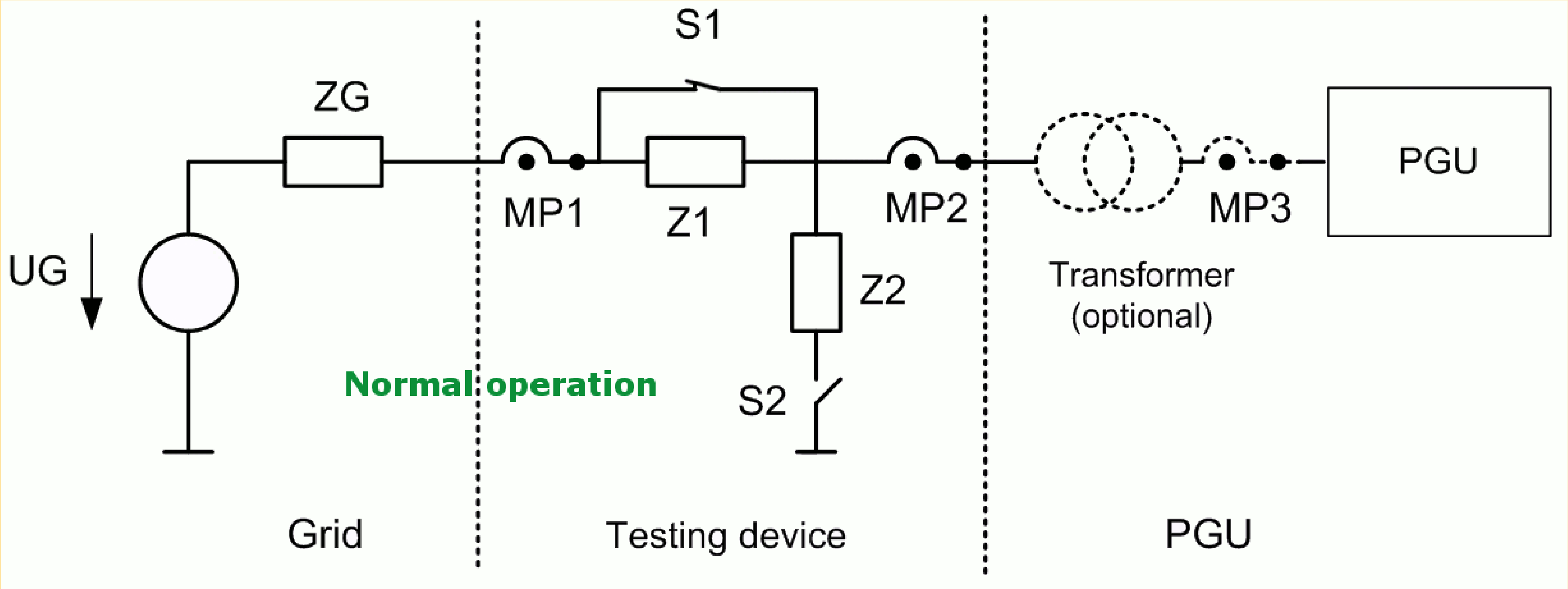
- **Model accuracy compared to standardized measurements acc. to *TR3* (equ. to *IEC 61400-21 2nd Ed*) during FRT-Tests**

- **Definition of baseline requirements**

## 5-Step method to validate the single WEC model

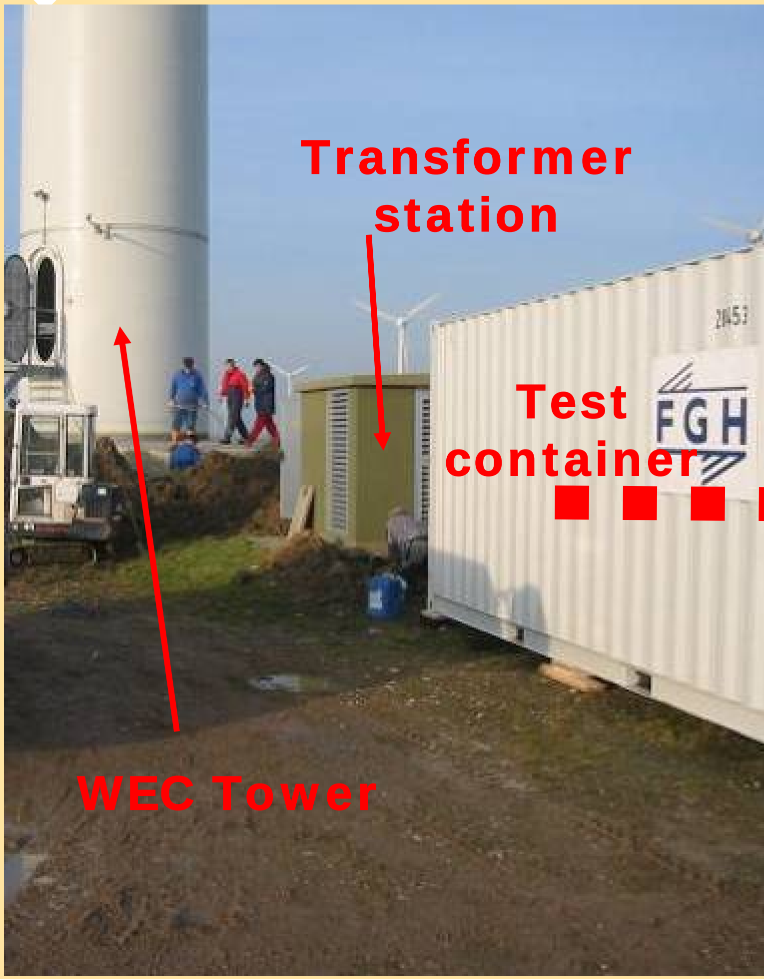
# 1°)

**Validation through FRT-Test**



## *Approach of model validation in Germany*

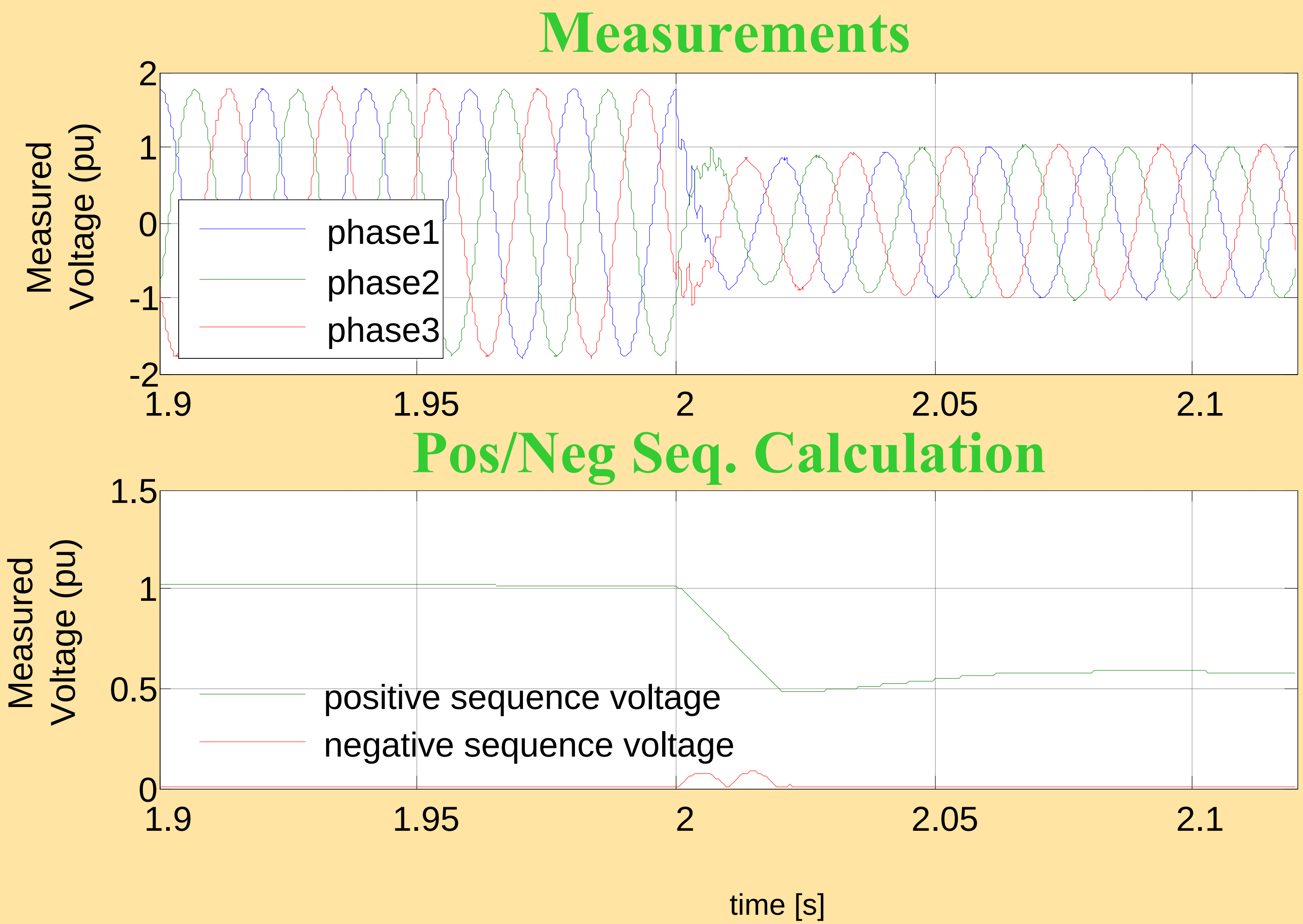
### 1°) Real test-field




# Approach of model validation in Germany

## 1°) FRT-Measurement Results

***Balanced fault***
**=============>**



# Approach of model validation in Germany

## 2°) Measurement & Result formatting (*arbitrary example*)

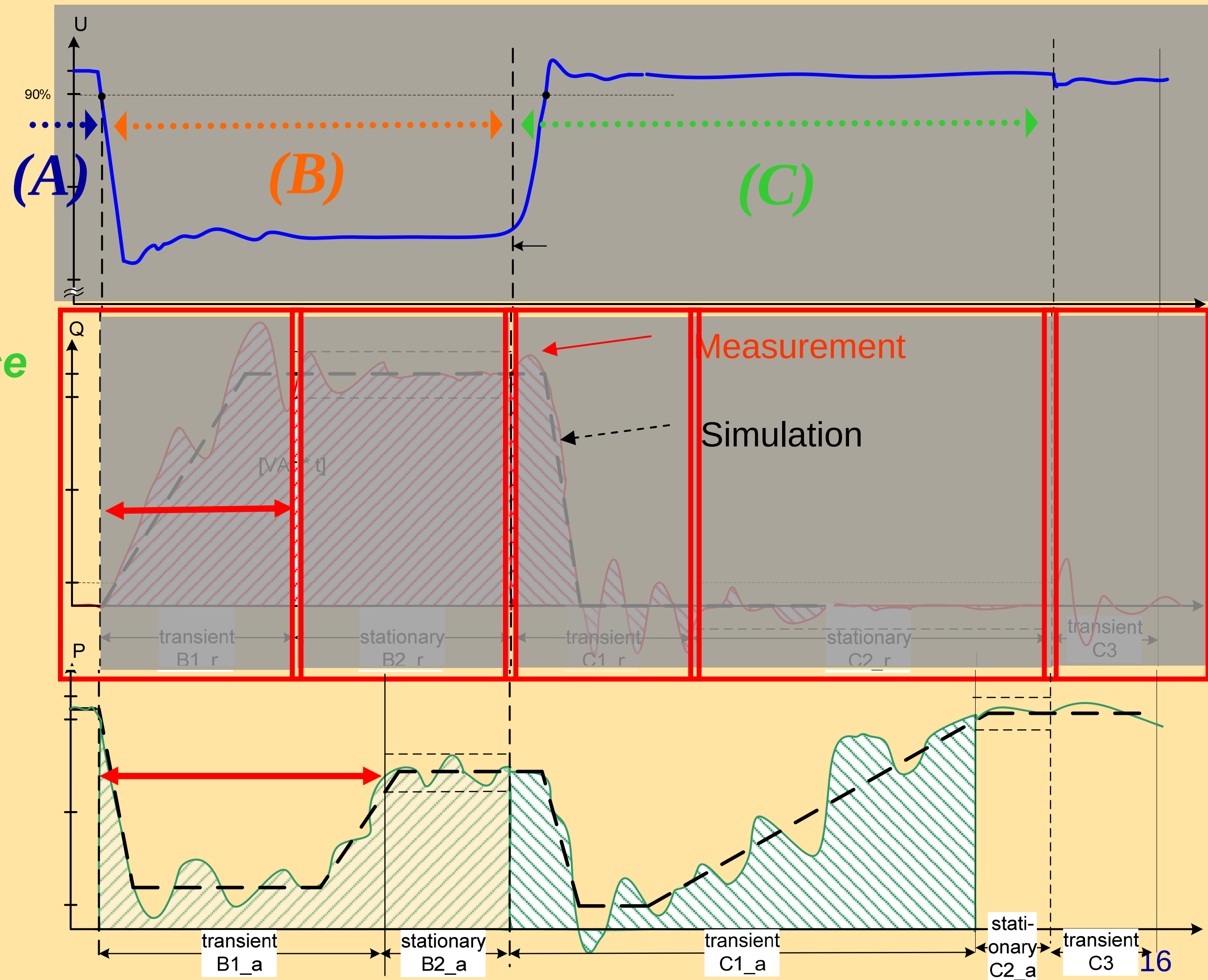
**> 2.1) Definition of start and end of the following periods:**

- ***(A): Before fault***
- ***(B): During fault***
- ***(C): After fault clearance***

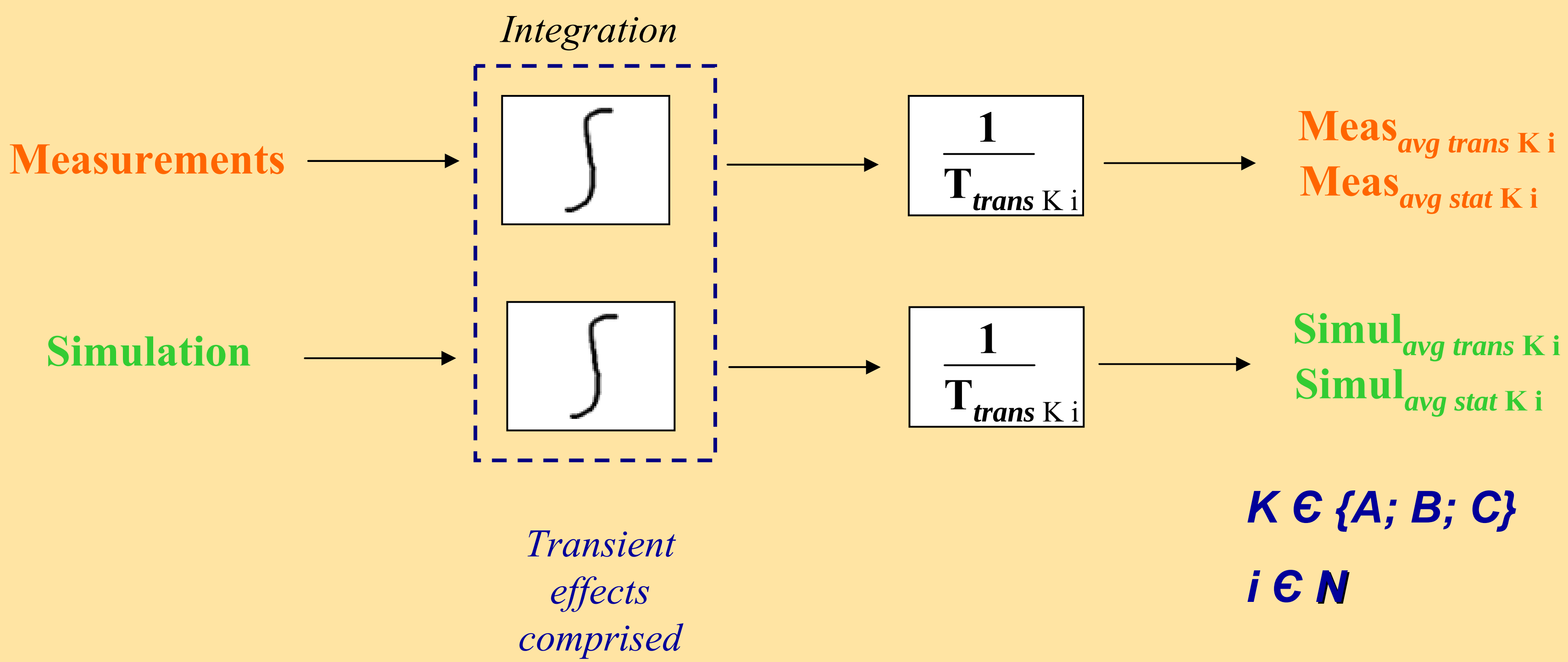
**> 2.2) Identification of intervals:**

-***Stationary***

-***Transient***



## 3°) Calculating averages for each interval and for P, Q, $I_r$

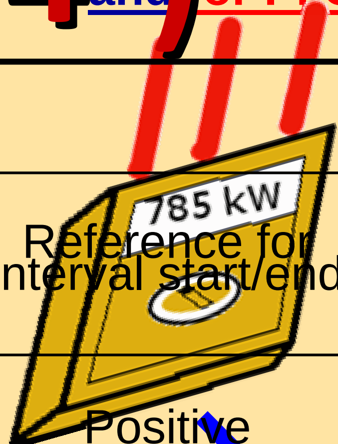


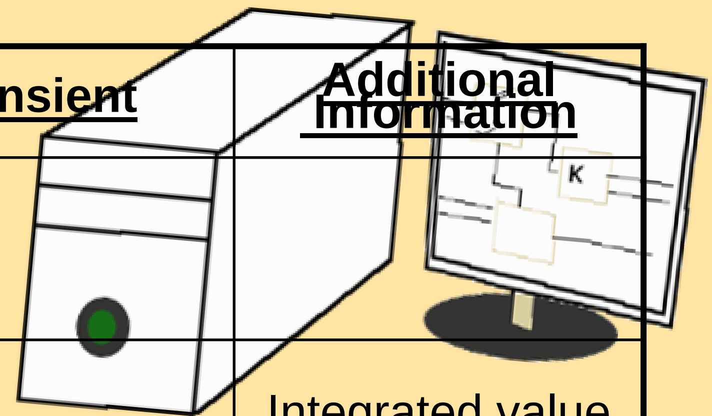

***K Є {A; B; C}***

***i Є N***

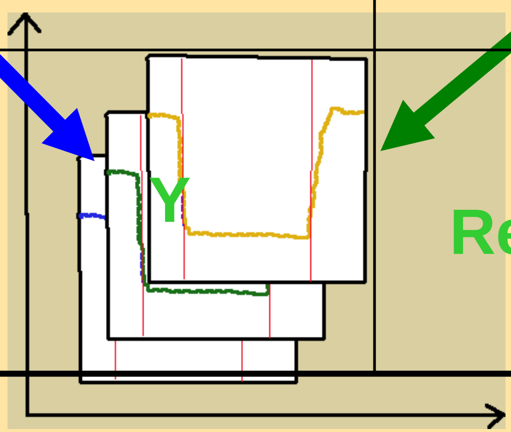
# Approach of model validation in Germany

## 4°) Comparison of measurement and simulation in each interval and for P, Q, $I_r$



| | Stationary | Transient | Additional Information |
|---|---|---|---|
| Reference for interval start/end | Measurement | | |
| Positive sequence **averages*over interval** | Y | Y | Integrated value => transient effects taken into account |
| **Instantaneaous values** of positive sequence | Y | Not Required | 50 Hz component only (harmonics not needed for stability studies) |



* average values calculated over the considered interval duration

## 5°) 5°) Quality assessment of the simulation model for P, Q, $I_r$

• **Transient intervals**

*Average evaluation*

$$\sum_{i \subset K} \left( Meas_{avg\ trans\ K\ i} - Simul_{avg\ trans\ K\ i} \right) = E_{Trans\ K}$$

*K Є {A; B; C}*

*i Є N*

• **Stationary intervals**

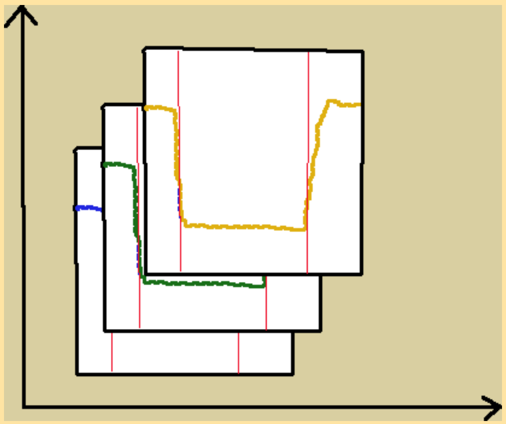
*Average evaluation*

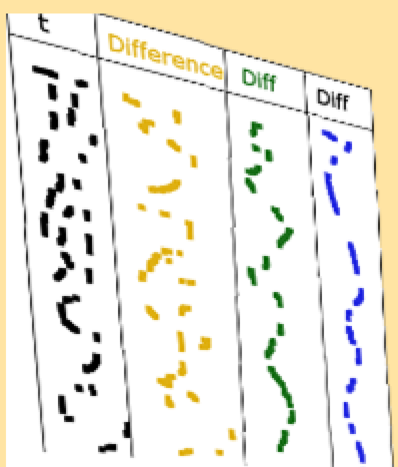
$$\sum_{i \subset K} \left( Meas_{avg\ stat\ K\ i} - Simul_{avg\ stat\ K\ i} \right) = E_{Stat\ K}$$

*Positive sequence evaluation*

$$\max_{t_i \in \text{(stationary interval)}} \left( Meas_{pos\ seq}(t_i) - Simul_{pos\ seq}(t_i) \right) = E_{Stat\_pos\ K}$$

## 5°) Quality assessment of the simulation model for P, Q, $I_r$






***Calculated deviations:***

- **Mean values during transient intervals ($E_{Trans\ K}$)**
- **Mean values during stationary intervals ($E_{Stat\ K}$)**
- **Positive sequence values during stationary intervals ($E_{Stat\_pos\ K}$ )**

***Total error of simulation model***

## 5°) Quality assessment of the simulation model for P, Q, $I_r$

**Calculation of a global deviation for the entire FRT-Test**

**SM total error = $C_A$ x $E_A$ + $C_B$ x $E_B$ + $C_C$ x $E_C$**

| Deviation | Weight |
| --- | --- |
| Before fault ($E_A$) | 10 % ($C_A$) |
| During fault ($E_B$) | 60 % ($C_B$) |
| After fault ($E_C$) clearance | 30 % ($C_C$) |

$$E_K = \sum_{K=A}^{K=C} \left(E_{Trans\,K} + E_{Stat\,K}\right)$$

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- Need of wind turbine models
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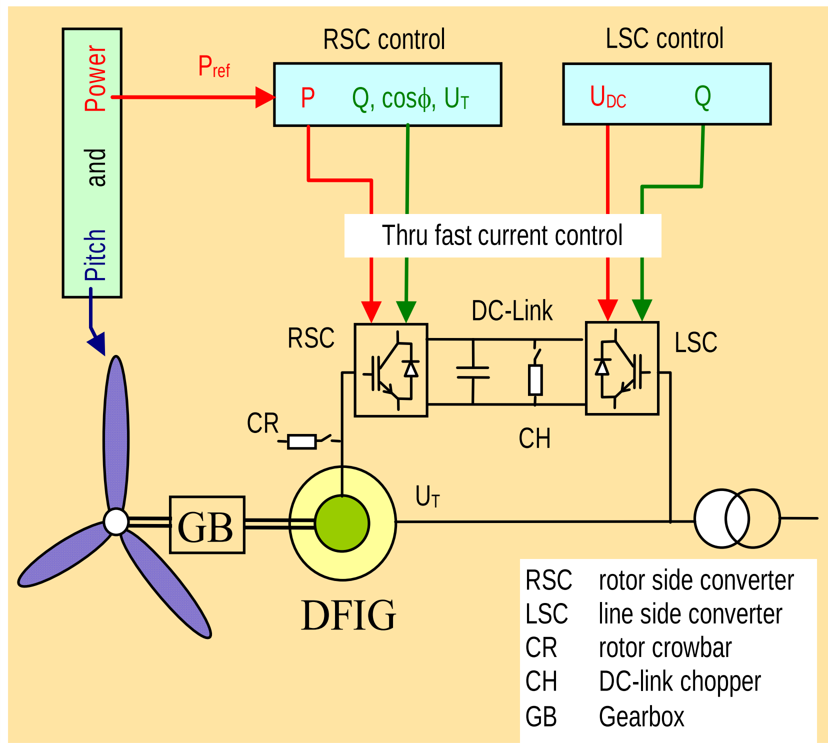
- **Model insight**
- Comparison between simulation results and measurements
- Benefits and future of wind-turbine modelling



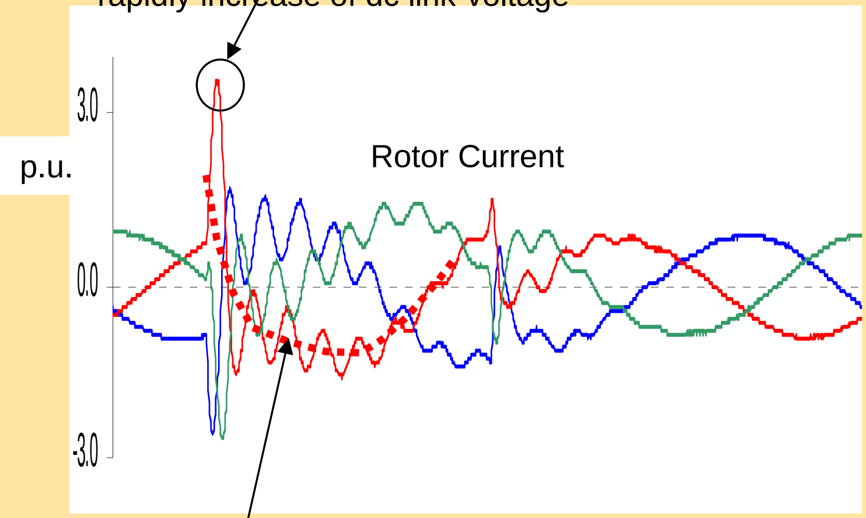
## Available simulation model types

| Generator detail level | Type | Applications | Remarks |
|---|---|---|---|
| Full Order Model (FOM) | EMT | - Fast transients<br>- Electro magnetic interferences | Crowbar firing capabilities |
| Enhanced Reduced Order Model (E/ROM) | Usually RMS | - System integration<br>- Stability studies | Crowbar firing capabilities |
| Reduced Order Model (ROM) | Usually RMS | - System integration<br>- Stability studies | Quick simulation time |

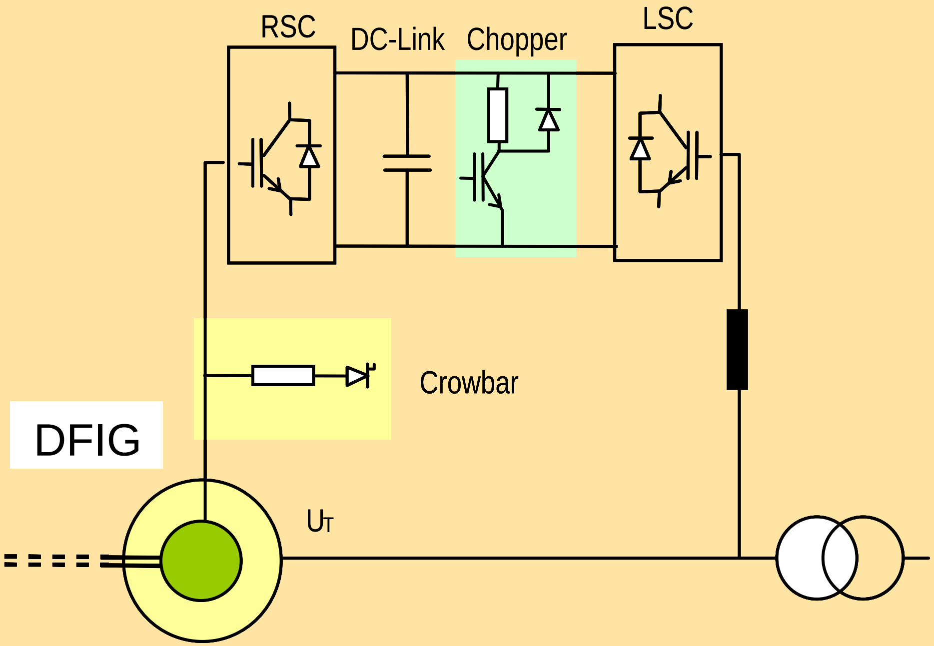
Complexity ↑

## Difference between ROM and FOM: rotor current calculation

Alternating component decisive in Crowbar activation: rapidly increase of dc link-voltage



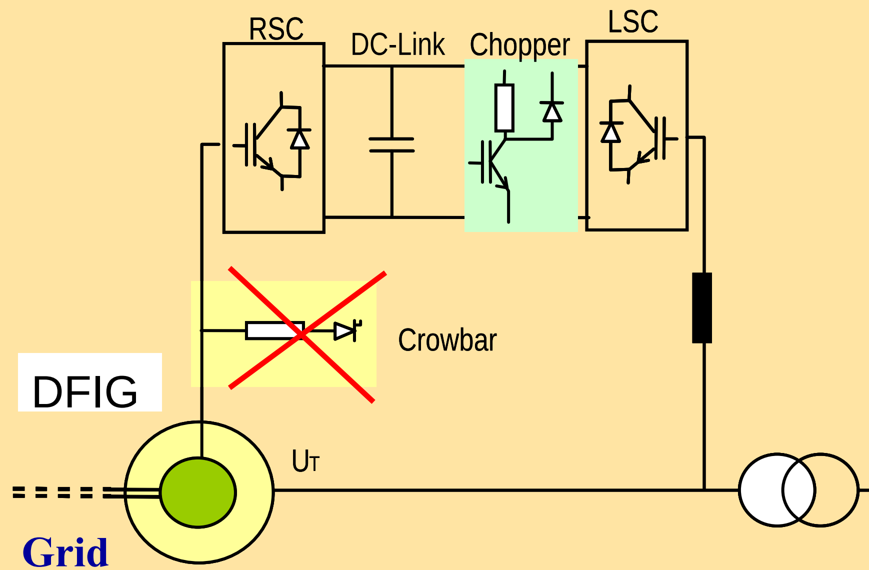

Reduced order DFIG model triphase

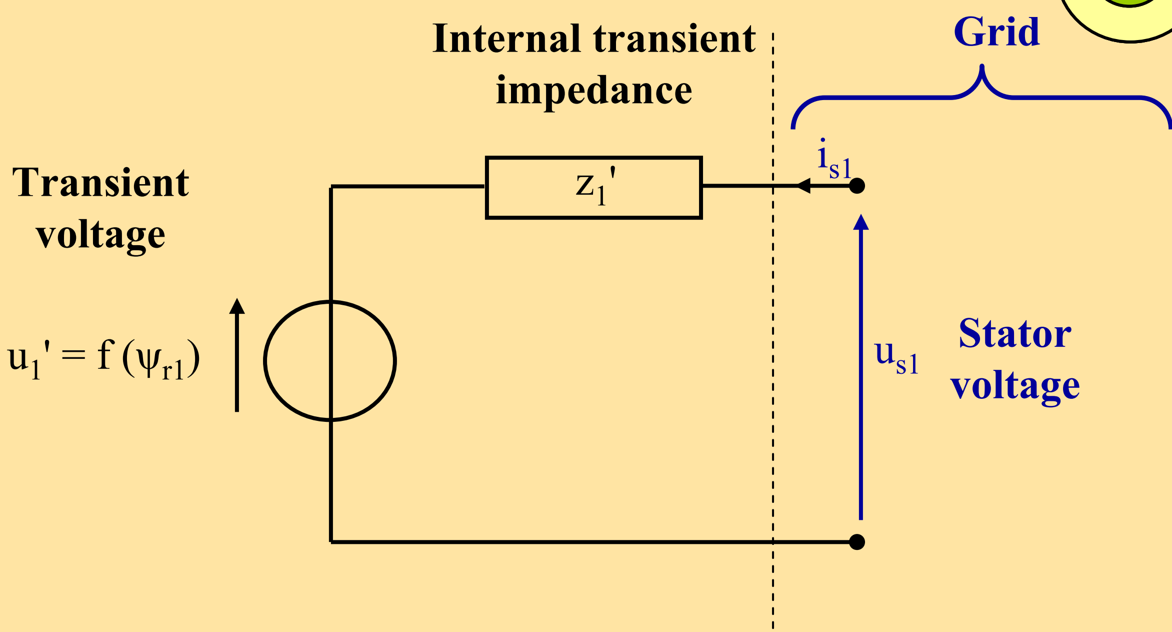


# *Model insight*

## ROM Model (*RMS*) features

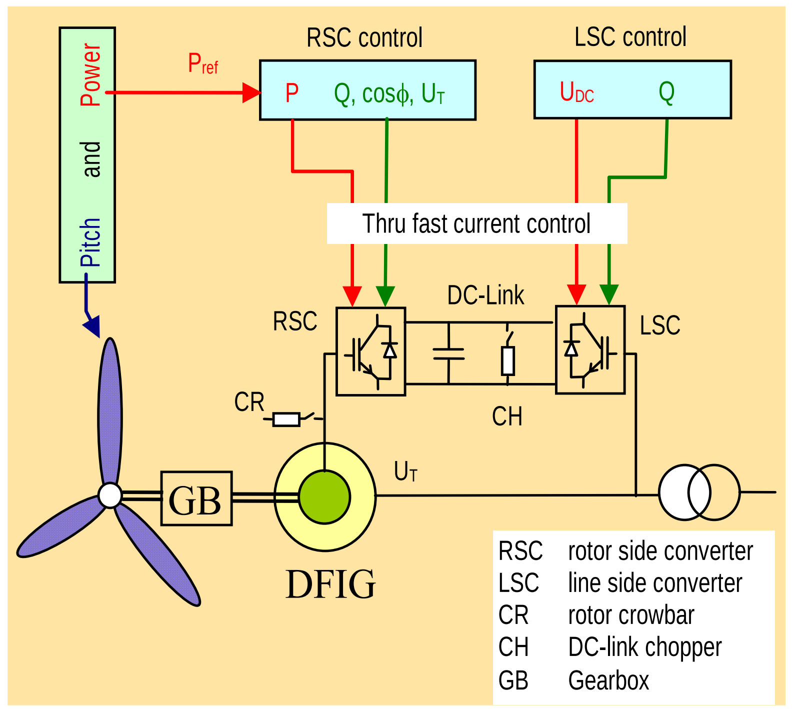
- *Simplified* FOM Model
- No crowbar firing capabilities (not needed anymore however)
- Positive sequence component modelled as a Thevenin source



## Features of REpower's simulation model (German *TR4*)

| | |
|---|---|
| -Model type | *RMS* |
| -Maximal step size | *10 ms* |
| -WEC-transformer | *included** |
| -Freq. protection | *included* |
| -Volt. protection | *included* |
| -Harmonics | *not included* |
| -Flicker | *not included* |
| -Aerodynamic & pitch control | *included** |




** not compulsary*

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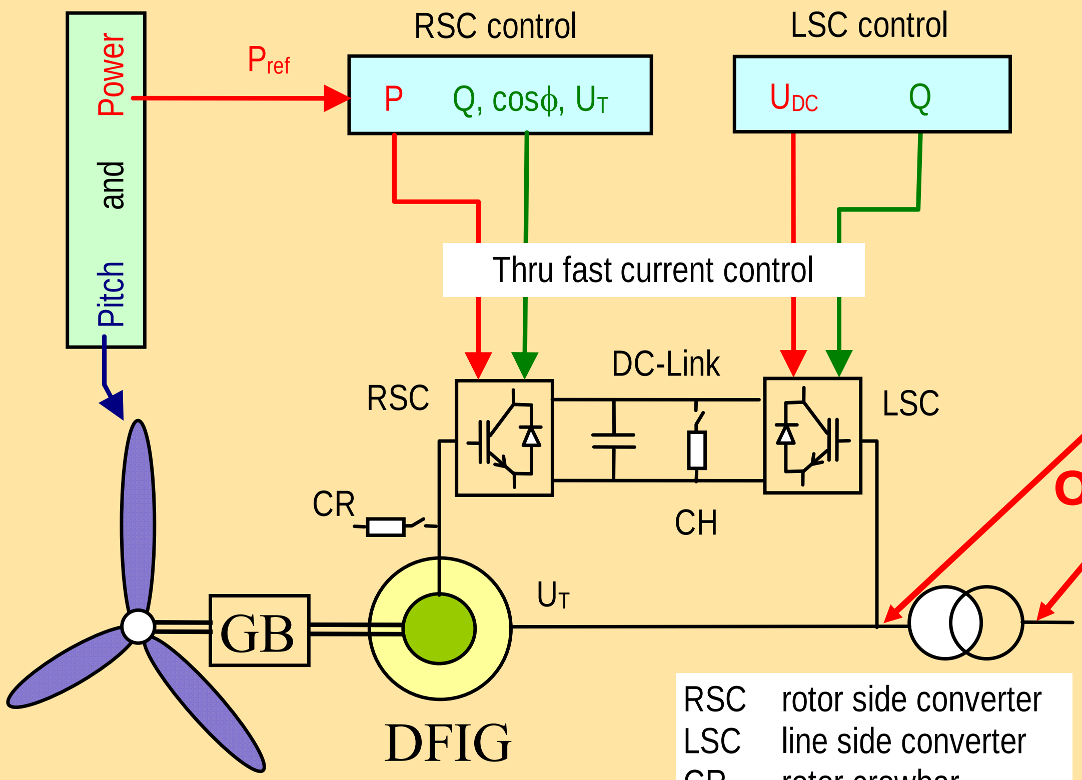
# Comparison between measurements and simulation results

## Compared items between simulation and measurement

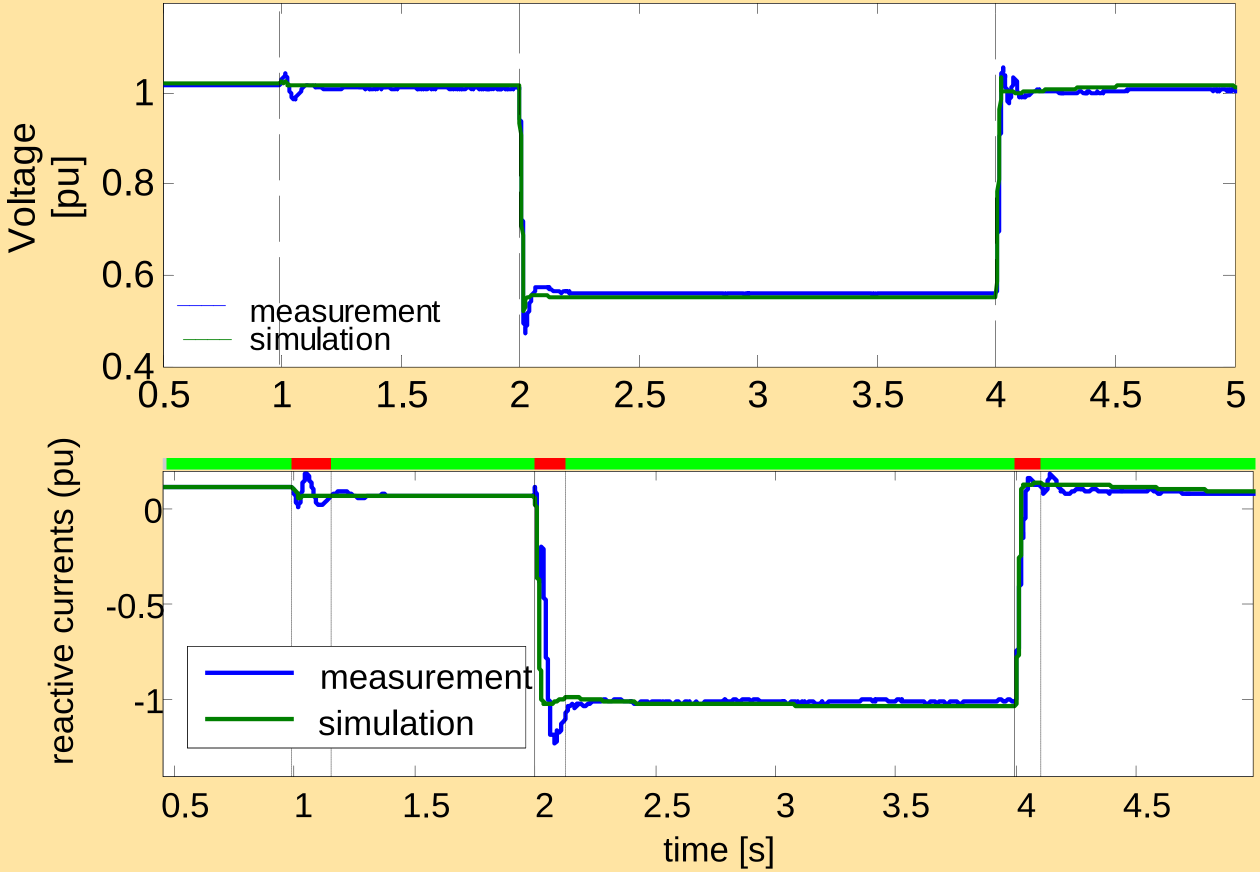



| | |
|---|---|
| RSC | rotor side converter |
| LSC | line side converter |
| CR | rotor crowbar |
| CH | DC-link chopper |
| GB | Gearbox |

# *Comparison between measurements and simulation results*

## Balanced voltage dip down to 45%

### 2°) Measurement & Result formatting



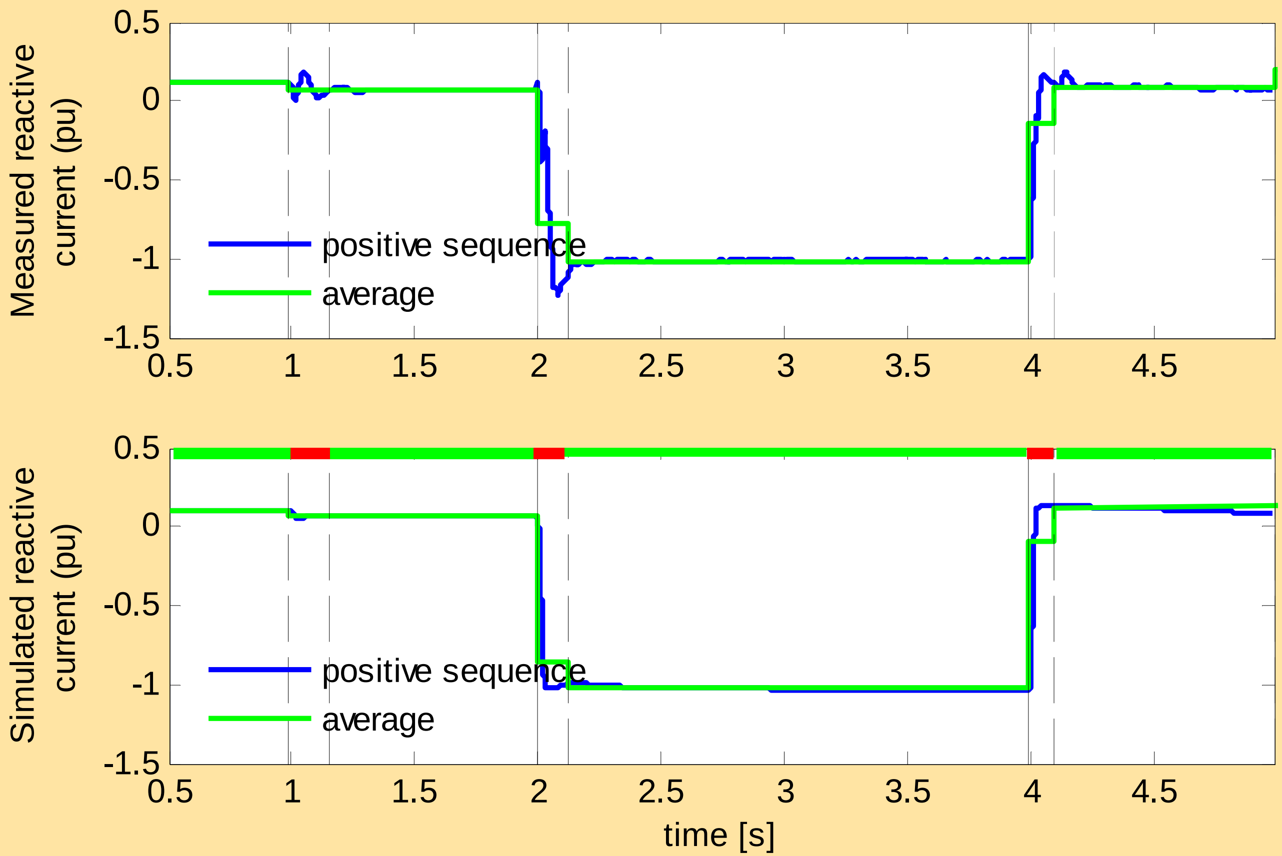

=> $U_{WEC}(t)$

=> $I_r(t)$

# *Comparison between measurements and simulation results*

## Balanced voltage dip down to 45%

### 3°) Calculating averages for each interval



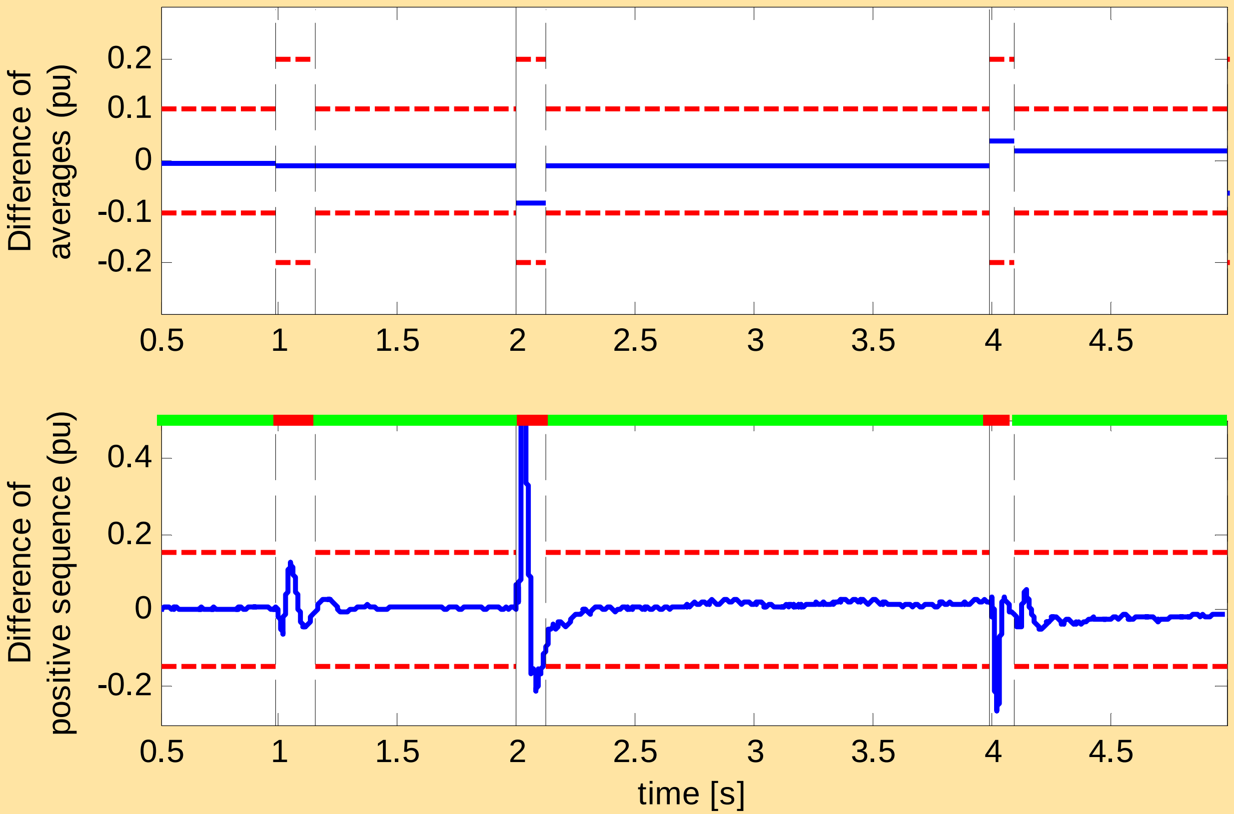

=> $I_{r\ Meas}(t)$

=> $I_{r\ Sim}(t)$

## *Comparison between measurements and simulation results*

### Balanced voltage dip down to 45%

**5°) Assessing model**




=> $I_{r\ Avg}(t)$

=> $I_{r\ Pos}(t)$

- - - - Allowed limits

—— Differences simul. / meas.

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- Need of wind turbine models
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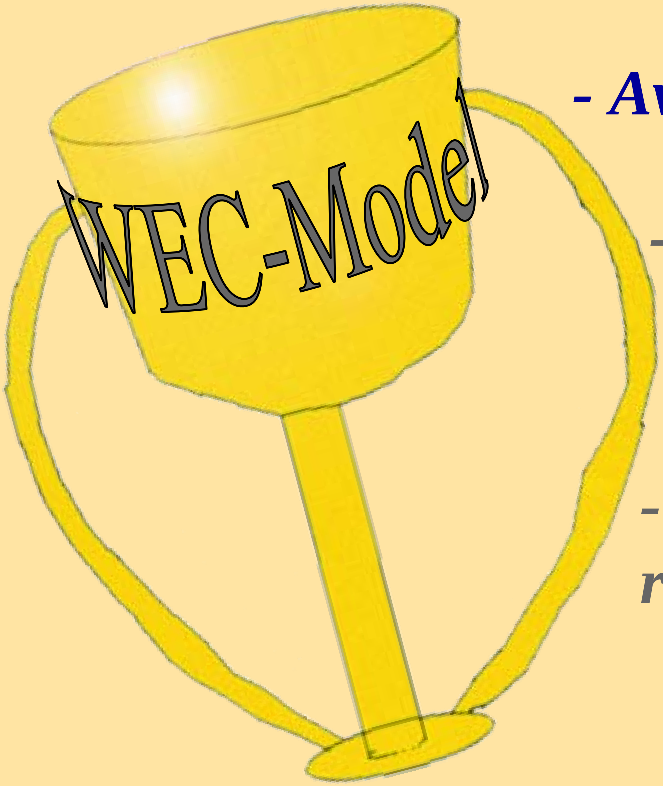
- **Benefits and future of wind-turbine modelling**

## Benefits of wind-turbine modelling

**Goals of keeping modelling**




- *Avoid expensive equipments*
- *Better integration into the grid*
- *Simulation of complete wind-farms*
- *Simulation of scenarios not testable in reality (stability risks)*

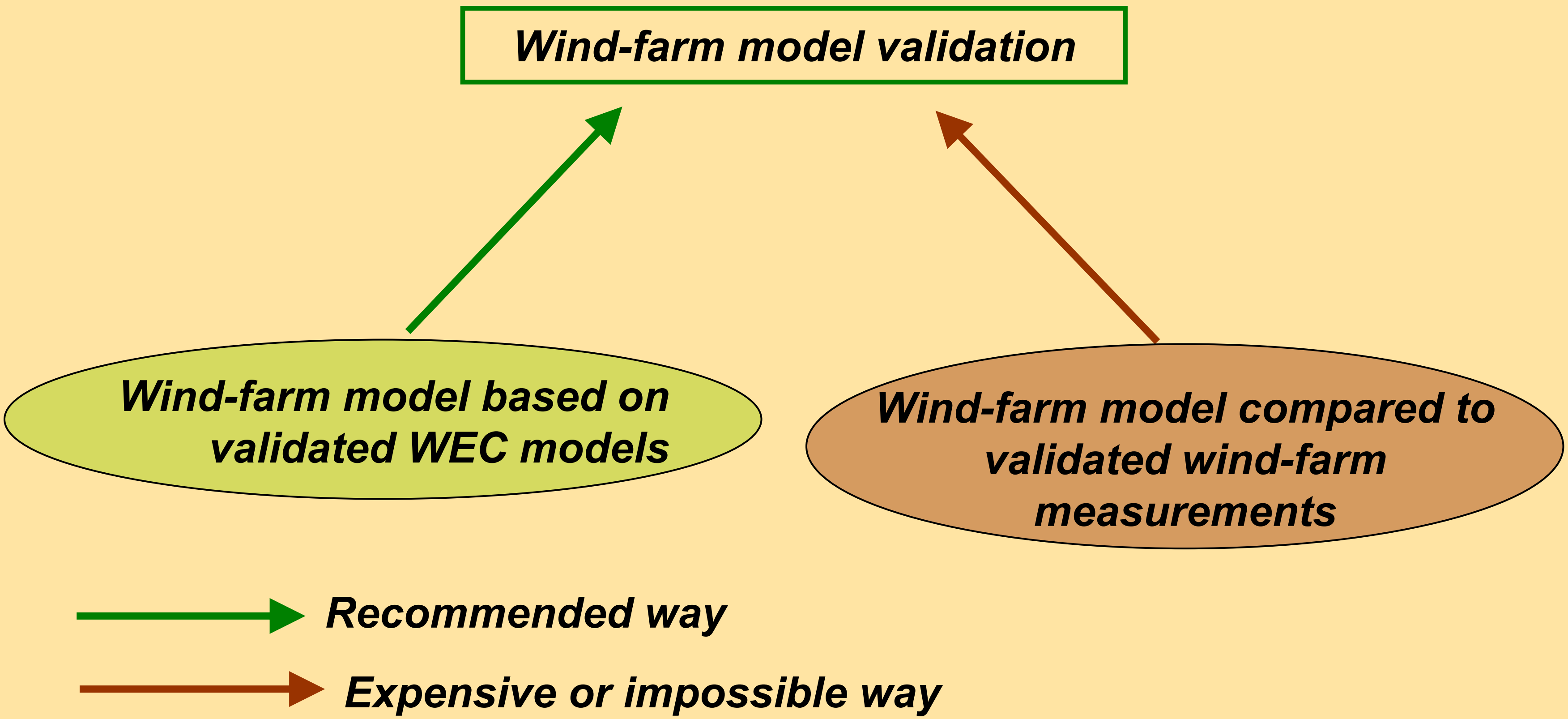
# Future of wind-turbine modelling

## External equipments included in wind-farm model

REpower Systems

## Future process for validating wind-farm model in Germany

**Forecast release of the technical guide-line: end 2010**



# Thanks for your attention !

# Thanks for your attention !

**Backup slides**

Equations can be found in:

"***Validation of an RMS DFIG Simulation Model according to New German Model Validation Standard FGW TR4 at Balanced and Unbalanced Grid Faults***"

Jens Fortmann, Stephan Engelhart, Jörg Kretschmann, Christian Feltes, Prof I Erlich.