Hochschule für Technik
und Wirtschaft Berlin

University of Applied Sciences

German Grid Code Compliance Assessment Practice

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Germany’s transition to renewable electricity generation

- Rapidly **increasing share of renewable energy sources (RES)** in total installed capacity and generation
  - around 50% of gross electricity consumption in 2022
  - mostly inverter based resources (wind and solar)
  - Substituting coal and gas based conventional power plants
- With **RES goal of at least 80%** in electricity generation by 2030

RES must *verifiably* **be capable of providing**:

- Frequency stability
- Voltage stability
- Ride-through capability
- Capability to survive systems splits / islanding **(new!)**

in an **inverter based resources dominated grid**

with little remaining synchronous generation for extended periods of time htw. Hochschule für Technik und Wirtschaft Berlin

Germany's approach to Grid code compliance verification

Step 1 – what to comply with Definition and quantification of required ancillary system services	
Technical Requirements	Technical connection standards like VDE-AR-N 41xx, EN50549

↓

Step 2 – how to check compliance Ensuring that the requirements are actually met	
Conformity Assessment	Verification procedure & certification per FGW Technical Guidelines 3, 4, 8

[1]FGW e.V. – Fördergesellschaft Windenergie und andere Dezentrale Energien

- **Government supported 3rd party verification & certification**
  - Verification of compliance with grid codes and government RES grid support incentives
  - Independence, impartiality, transparency
  - Competency and quality verified by accreditation
  - Risk reduction for manufacturers, plant developers/operators and TSO/DSO
  - Reduction of interconnection process times and costs

FGW 3-Step Compliance Assessment Process

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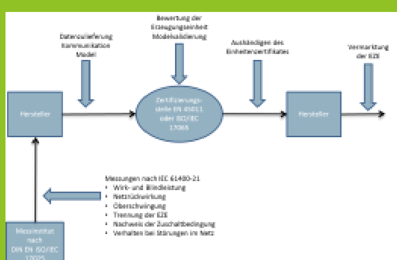
1.
Power Generation Unit assessment:
Grid code requirements
at unit terminals

2.
Power Generation System (=Plant**)** Assessment:
Grid code requirements
at plant connection point

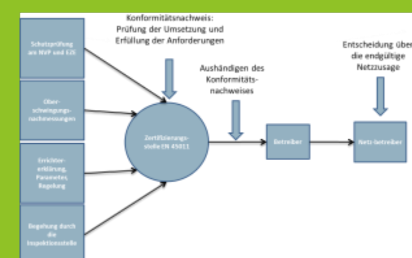
3.
Conformity Assessment after Commissioning

Power Generation Unit Assessment (premise)



Power Generation System Assessment (1. stage of conformity assessment prior to commissioning)

Conformity Assessment (6 months after commissioning, (2. stage of conformity assessment)



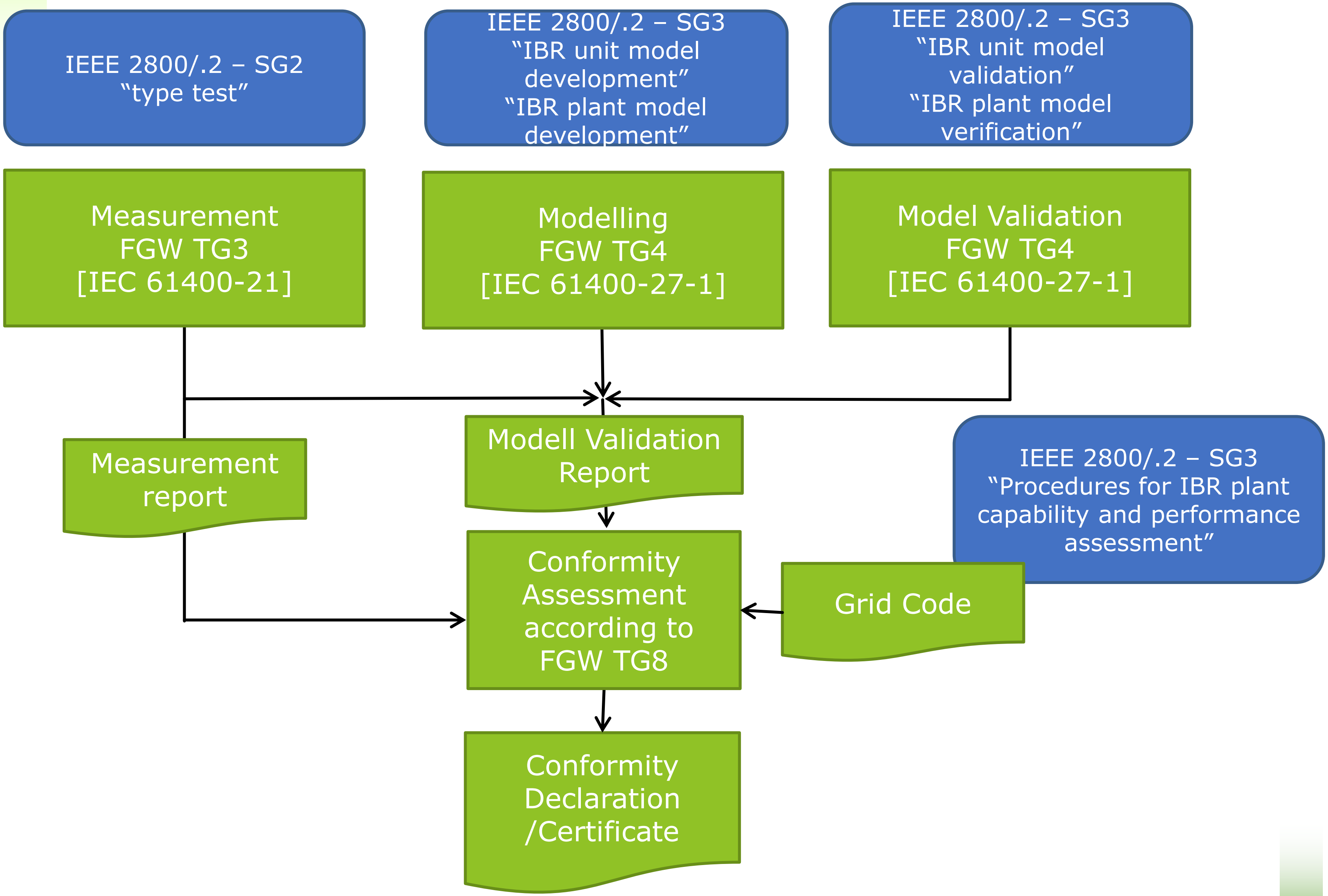
- Registry of FGW Certificates available at: https://wind-fgw.de/database/?lang=en

IEEE 2800/.2:
“IBR unit” and “supplemental IBR device”
“type test”

IEEE 2800/.2:
“IBR plant”
“design evaluation”
“as-built evaluation”

IEEE 2800/.2:
“IBR plant”
“post-commissioning monitoring and model validation”

Conformity assessment Power Generation Unit

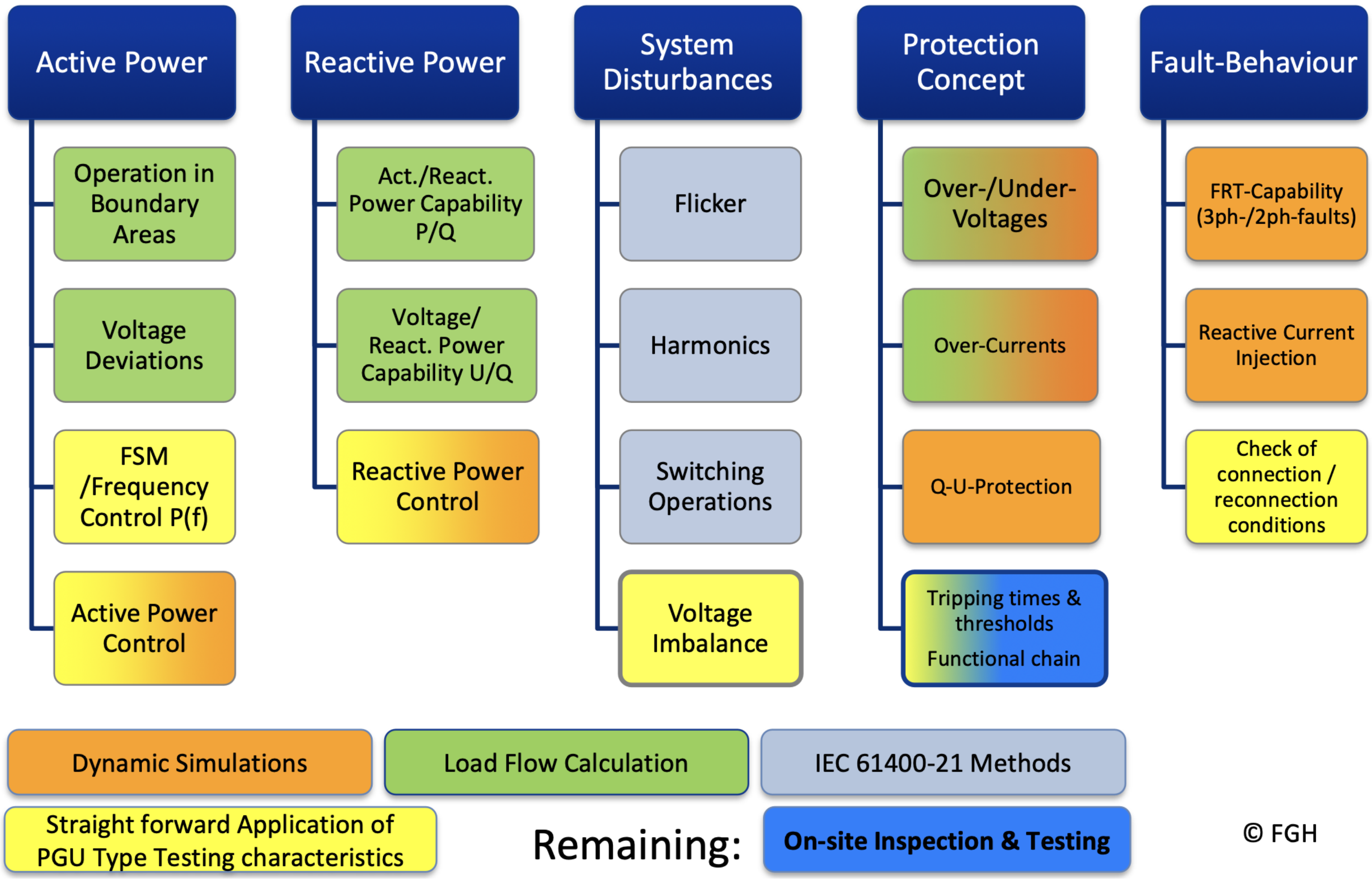


duration: 6 - 12 months

2023 ESIG Fall Technical Workshop

Broad range of assessment methods for plant certification

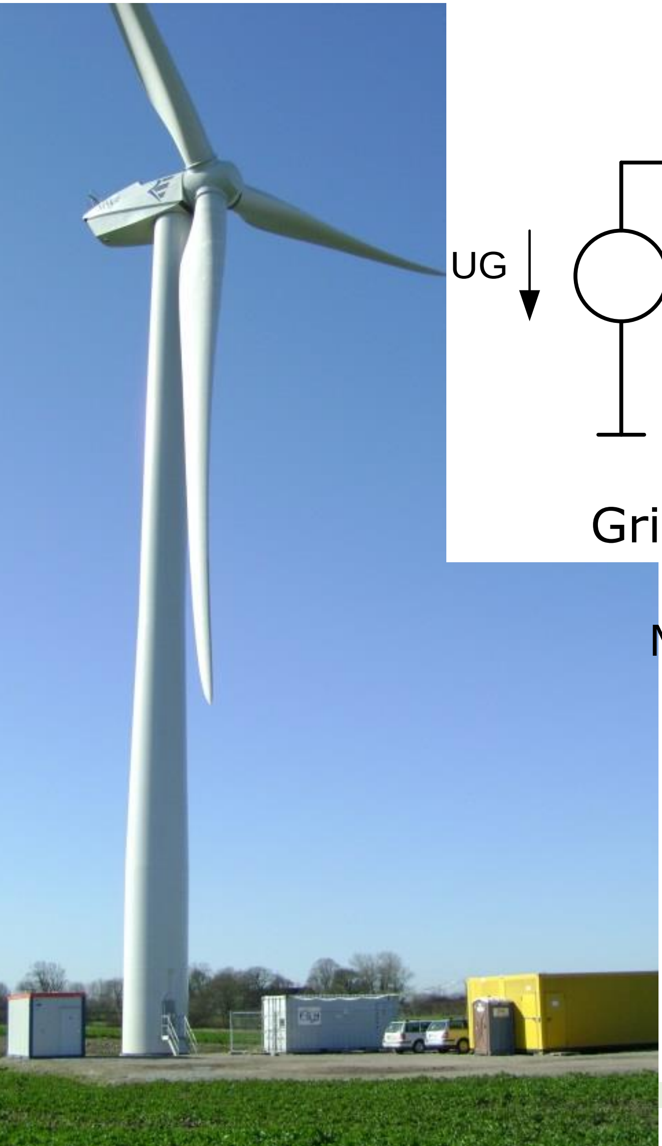
- The **unit certificate** as a basis for plant assessments:

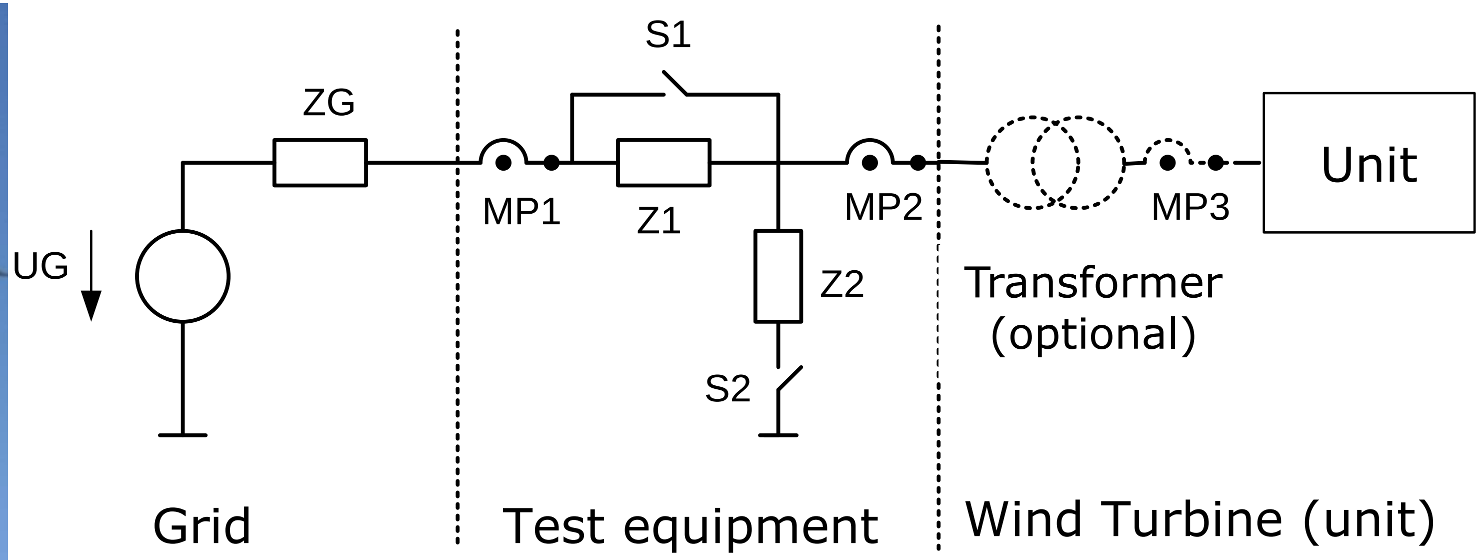


Mark Meuser: Grid code compliance verification acc. TR8. Approach Rationale Experiences. Presentation at IEEE P2008.2 WG. FGH Zertifizierungsgesellschaft mbH. April 2023.

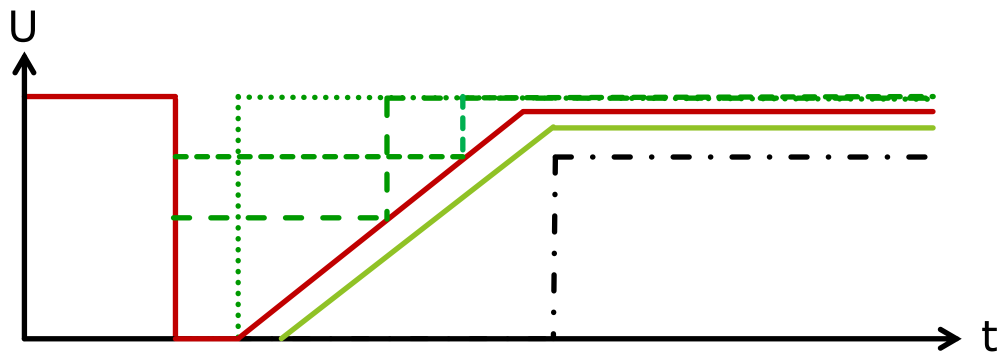
Grid Fault Measurement according to FGW und IEC

Example: Voltage Dip





Measurement setup according to IEC 61400-21 / FGW TG3



2023 ESIG Fall Technical Workshop

Standardized procedures / quantitative approach: detailed and aggregated plant model

Detailed plant model – need for grid connection approval

- Most grid code requirements apply to the plant connection point
- Model based on validated unit models. Plant controller and compensation need separate validated models.
- Grid code requirements and plausibility checks are performed.
- No comparison to measurements at plant level.

Aggregated Plant Models – for system studies (can be demanded by grid operator, but not used so far)

- Based on unit model.
- All evaluations are at the plant connection point
- Active and reactive power reference changes
  - Response to voltage and frequency changes, protection
  - Comparison to detailed (validated) plant simulation model (100 ms step size + 10 sec moving average filter)
- Balanced and unbalanced FRT
  - Response to voltage dips

Emerging requirements and use of EMT-Models

- For long, FGW TG4 required only RMS-Models.
  - Registry of FGW Certificates available at: https://wind-fgw.de/database/?lang=en
- In the latest release of TG4 (V10), EMT-Models have been added.
- EMT-Models are required:
  - If RMS-Model are not valid for short circuit ratios < e.g. 3
    - SCR-Ratio will decrease – open issue!
  - For offshore wind plants connected via HVDC
  - For locations of wind plants close to HVDC-stations
  - For the evaluation of frequencies above 5 Hz (if needed)

Differences to U.S. approach:

- Evaluation of negative sequence protection settings uses negative sequence RMS models
- Evaluation of negative sequence could be based on negative sequence loadflow-models as well

Backup Slides

Standardized procedures / quantitative approach: limitations

Standardized procedures + quantitative approach

- Aims to provide transparent and comparable criteria for evaluation
- Cost and time efficient, allows automated evaluation
- De-risking for manufacturer, plant operator & TSO/DS=

▶ **Limitations**

- Definition of "transient" areas that can be excluded due to limitations of the applied positive sequence (RMS) models to some extent arbitrary
- Model limitations
  - Fault currents difficult to model especially for DFIG- Turbines
  - Transformer saturation not handled by RMS-models
  - Post-fault active power recovery can be impacted by wind speed changes -> some expert opinion necessary
  - Post-fault active power changes due to eigenfrequency of drive train are difficult to model accurately (depends on pitch angle, fault conditions,…)

Different Focus of RMS and EMT-Models WECC - FGW

- **Joint Work in WECC 2nd generation models and IEC 61400-27**
  - Generic models available from WECC and IEC
  - Manufacturer specific positive (and negative) sequence models usually used in Germany
- **Different focus of RMS models WECC/IEEE and FGW/IEC**

  WECC /USA:
  - slightly simpler version of the models for system studies
  - measurement of operating plants, evaluation of fault events
  - Validation based on expert opinion

  IEC/Europe:
  - slightly more detailed models for connection studies, model validation based on measurement
  - measurement of FRT-tests of unit
  - Validation based on standardized procedures (unit model only, no validation of plant model)
  - Plant Model based on validated unit model, for connection studies
- **Different focus of EMT models WECC/IEEE and FGW**
  - WECC: negative sequence evaluation for connection studies
  - FWG: connection studies for HVDC-connected units

IEEE 2800/.2:
Paradigm change in U.S. towards more plant conformity assessment using models

Unit models

- All evaluations at the turbine terminals (LV or MV at manufacturers choice). Some grid code requirements - like reactive current ramp rates during FRT - apply to the unit terminals.

Unit models - normal operation

- Active and reactive power capability diagram (PQ)
  - Comparison to measurements, (steady state)
- Active and reactive power reference changes
  - Comparison to measurements (<10ms + 15 sec moving average)
  - Different acceptance criteria for transient periods and steady state operation
- Response to frequency changes
  - Comparison to measurements (internal frequency ref. change)

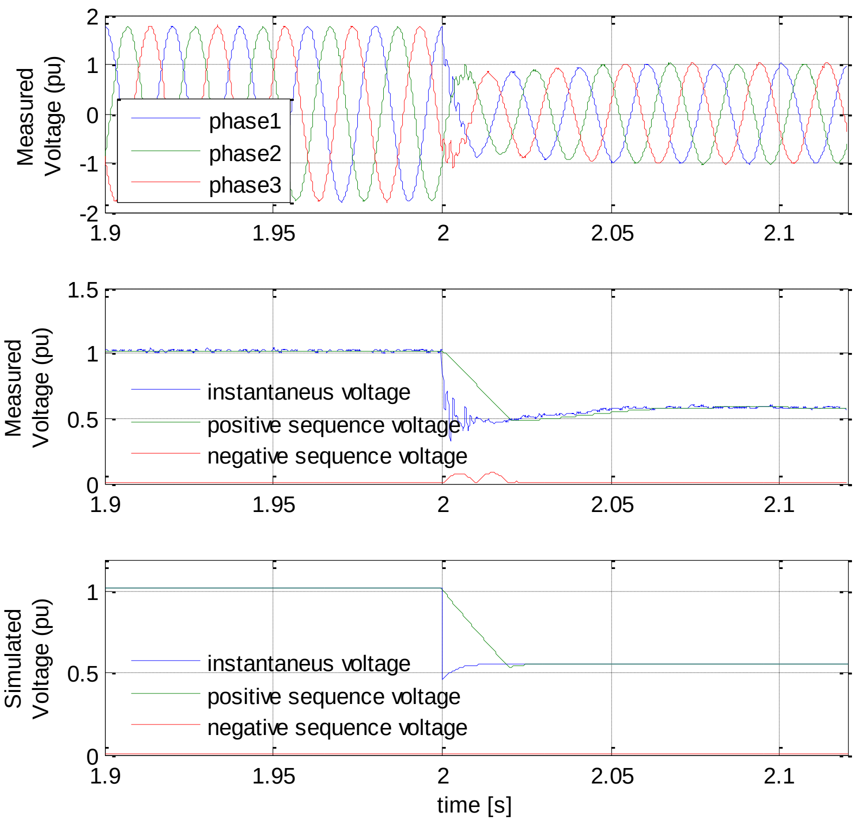
Unit models – FRT

- Active and reactive current response to voltage dips
- balanced & unbalanced faults, evaluation of positive & negative sequence currents.
  - Comparison to measurements (<10ms + 15 sec moving average)

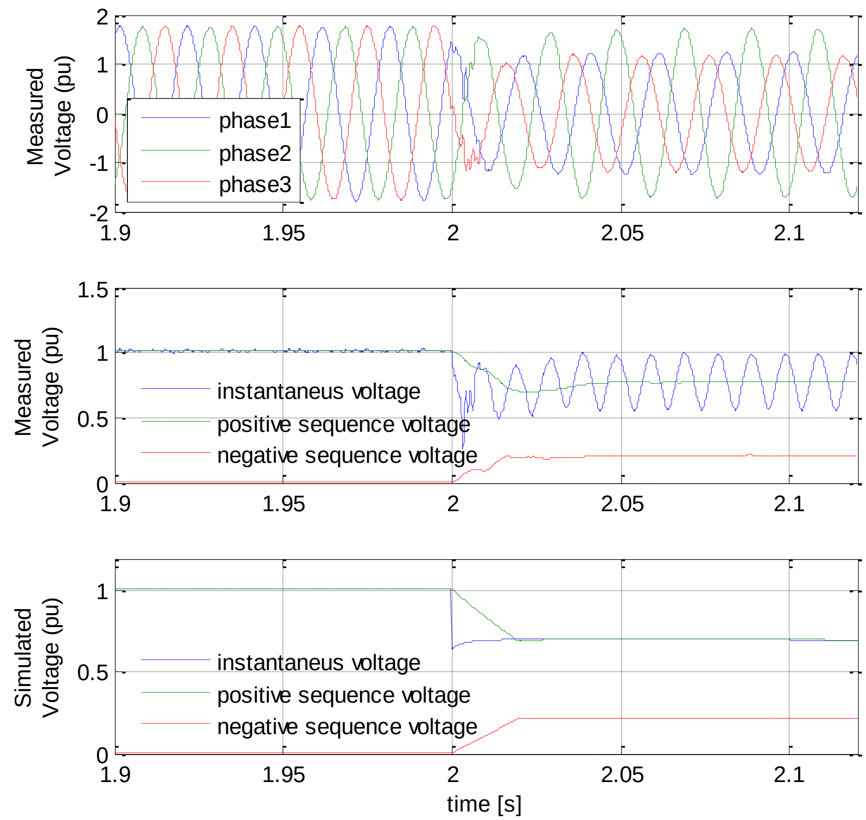
FGW TG4 & IEC 61400-27-1
Positive and negative sequence representation

- In order to compare measurement and simulation, the positive (and if required: negative) sequence of measurement values (voltage, current) is compared to the equivalent (filtered) RMS simulation value.

Balanced fault

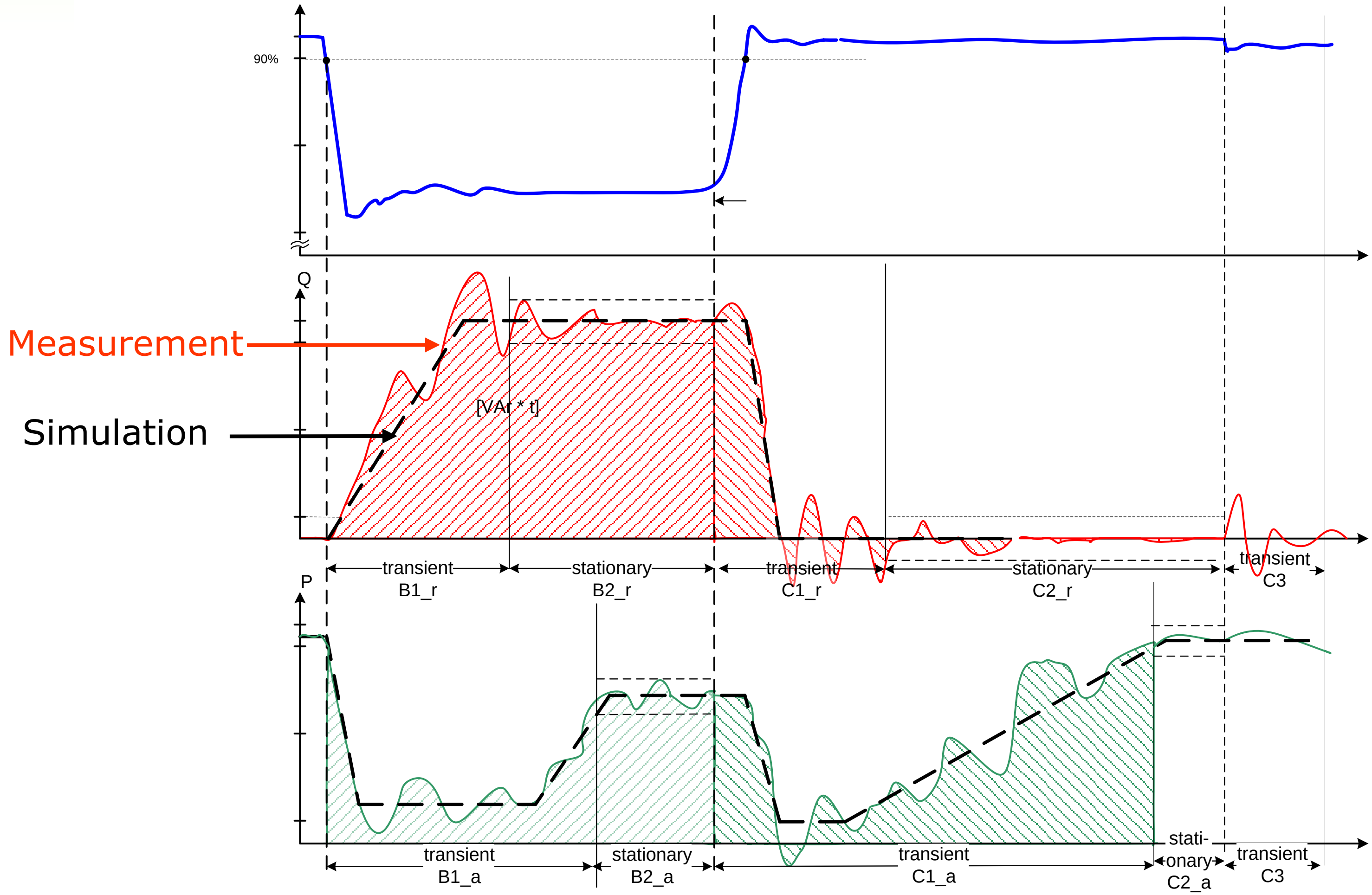


Unbalanced fault



German Validation Standard FGW TG4: transient and stationary periods

Voltage dip, example of voltage, reactive power and active power

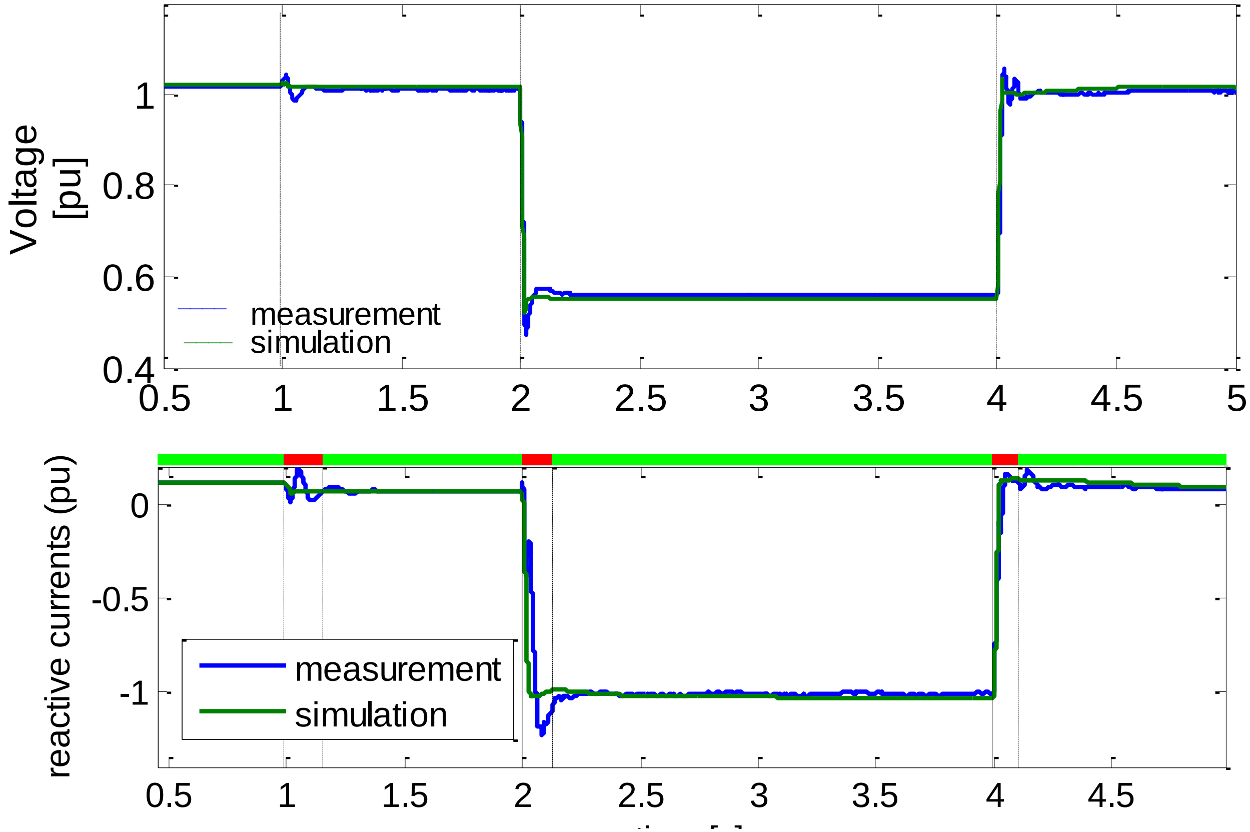


The measured event is divided into transient and stationary periods

Note that IEEE P2800.2 is currently not aiming for quantitative pass/fail criteria - but engineering judgement.

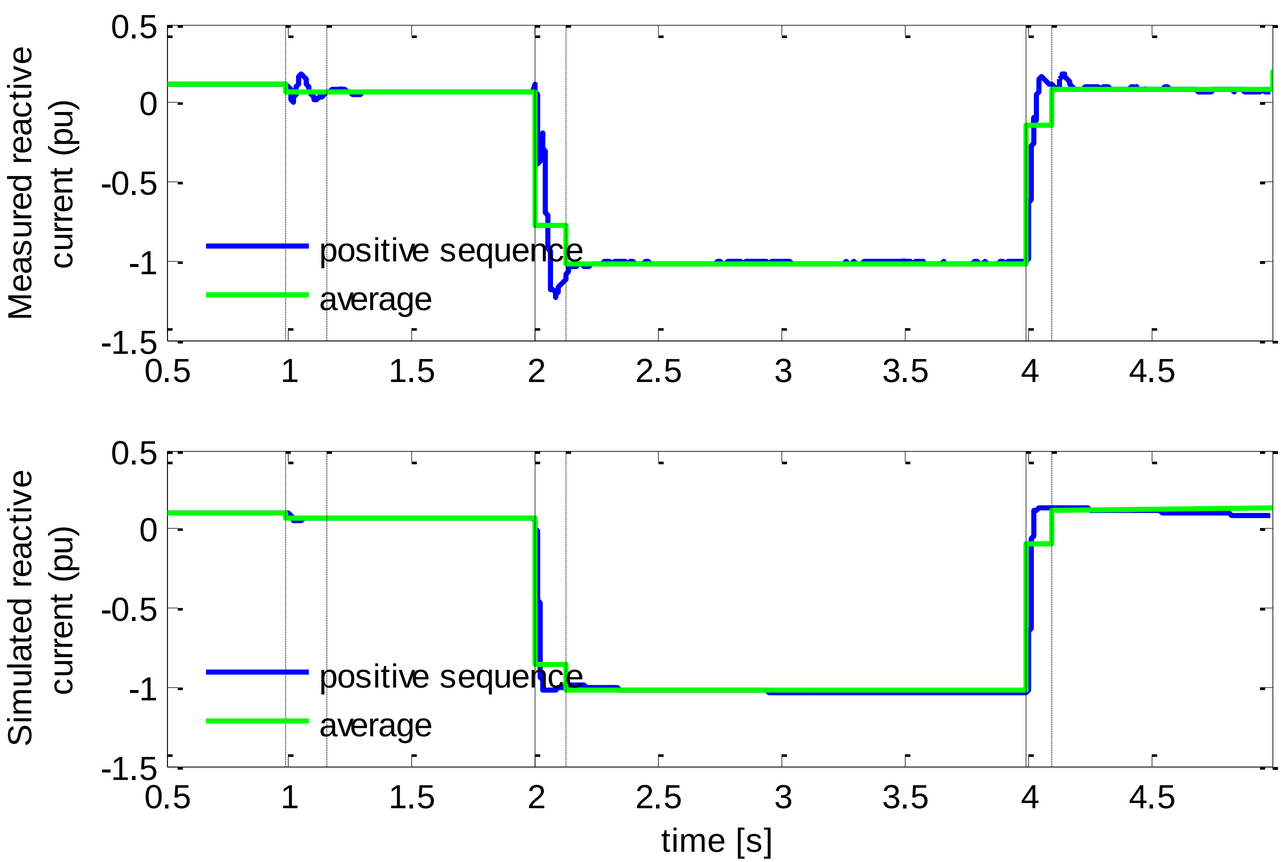
Validation Example: balanced fault
1. comparing measurement and simulation

- Comparison of measurement and simulation of reactive currents of a balanced voltage dip down to 45 % rated voltage.
- The reactive power is changed as the voltage changes.
- Transient periods are highlighted with red color, steady state periods green

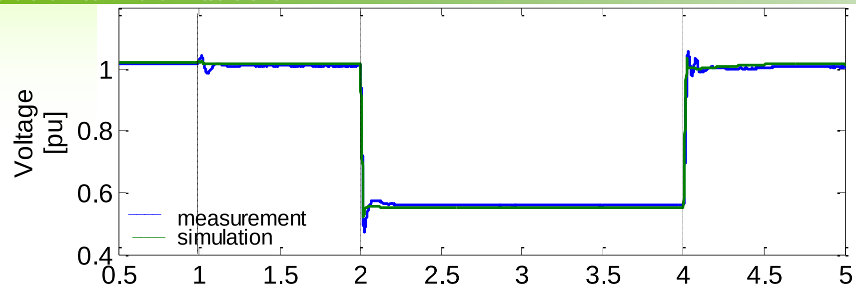


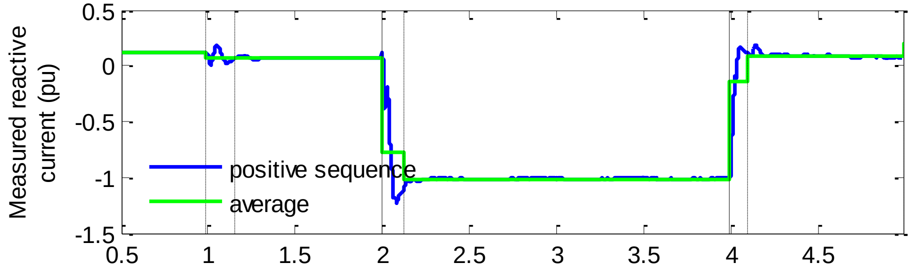
Validation Example: balanced fault
2. Calculating averages of transient and stationary ranges

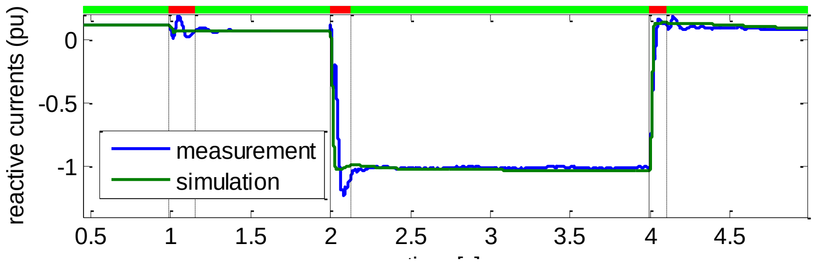
- Calculation of averages for steady state and stationary ranges for measurement (subplot 1) and simulation (subplot 2)

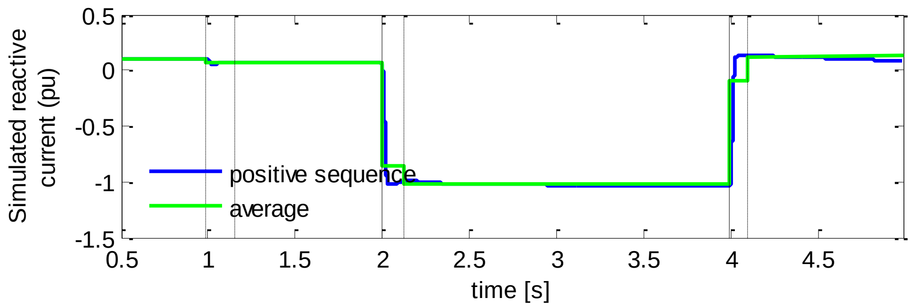


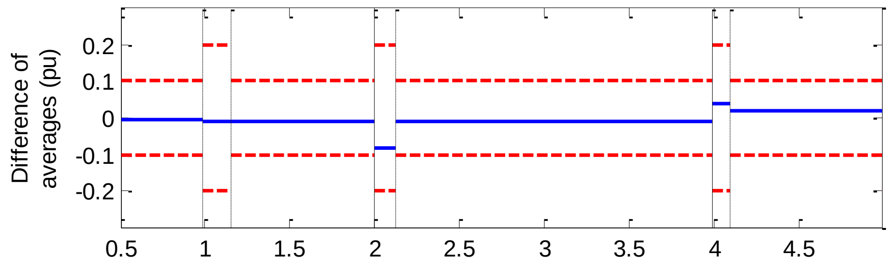
Validation Example: balanced fault
3. Comparison of averages and positive sequence

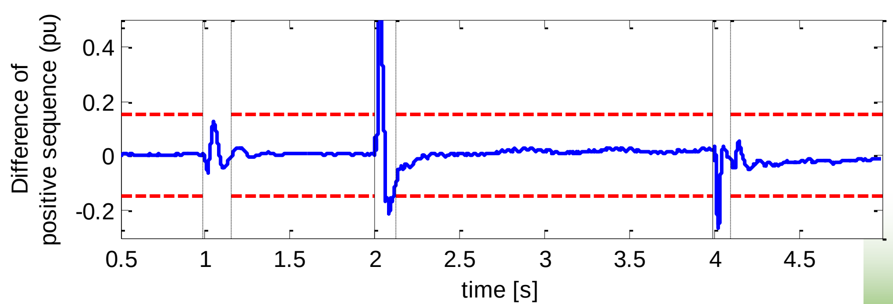












- Calculating the difference of
  - average values (subplot1) and
  - positive sequence values (subplot 2)
  - of measurement and simulation (blue) compared to allowed limits (red)