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 Engelhardt, Jörg Kretschmann, Christian Feltes, Prof. I. Erlich

Abstract-- **There is an increased international interest in the validation of simulation models for grid integration studies. Several countries (Spain, Australia, UK, Germany) have requirements for simulation models now as part of their grid code.**

In Germany, triggered by the new renewable energy law (EEG), an effort has been going on to create a standard for validating electrical simulation models of wind turbines. The model validation approach chosen will be described. The aim of this validation approach is quantify the error between measurement and simulation. This is necessary in order to give a reliable figure for the model uncertainty for the use of the model in studies.

Results of FRT-measurements with balanced and unbalanced faults of a 2 MW turbine will be compared to the results of an RMS DFIG model. It can be shown that the validation approach can be applied with success both to balanced and unbalanced faults. An IEC effort has recently been started to create an international standard for wind turbine modeling and model validation. The validation approach presented could contribute to the proposed IEC simulation standard.

***Index Terms*—Wind Energy, Standards, Measurement, Control**

I. INTRODUCTION

Simuation models for wind turbines have become a standard requirement for the approval of grid access in several countries with considerable wind energy contribution. Besides measurements, the analysis of the reaction of the electrical system to disturbances is usually part of grid access studies.

Along with the requirement for simulation models, there has been an increasing demand for assuring the proximity of model and physical turbine behavior

Two steps are necessary to evaluate the accordance of a model with reality

- a clear definition of the measurements necessary to evaluate the capabilities of an installation
- a methodology to compare measurement and simulation and to quantify the deviation between both

The first requirements for the test of FRT- capabilities of wind turbines had been specified by the FGH in Germany [1]. On an international level, the IEC 61400-21 ed. 2 [2] describes measurement requirements for wind turbines. In Germany joint measurement requirements for renewable power sources like wind energy, solar energy and biomass have been defined in the FGW TR3 [3]. It is based on [2], with some extensions to cover specific requirements of the current grid codes and regulations [11] in Germany.

The model validation Standard that corresponds to the measurement standard is the FGW TR4 [4]. The FGW TR4 is a ‘grey box’ approach with respect to the model description. A manufacturer is required to provide a model and a model description. The results of simulations are compared to measurements. If the deviation between measurement and simulation is in within certain limits, the model is accepted as validated.

An independent certification body must certify the validation based on the FGW TR8 [5]. In order to be able to verify the validation, the manufacturer needs to hand in a model as well as a description of the simulation model, that allows for a basic understanding of the turbine functions.

The assumptions and requirements of the validation standard FGW TR4 will be explained, and the results of FRT-measurements according to FGW TR3 will be compared to simulation results based on a generic modeling approach.

II. VALIDATION APPROACH

The intention of a model validation is to prove, that a simulation model with sufficient accuracy represents reality. Depending on the requirements, different types of simulation models may be required. For basic design studies, load flow and short circuit models will be used. For system integration studies and stability studies, RMS models will be used, while EMT models are necessary to study the

---

J. Fortmann is with REpower Systems AG, 24768 Rendsburg, Germany (e-mail: j.fortmann@repower.de);
I. Erlich is with the University Duisburg-Essen, 47057 Duisburg, Germany (e-mail: istvan.erlich@uni-due.de);
C. Feltes is with the University Duisburg-Essen, 47057 Duisburg, Germany (e-mail: christian.feltes@uni-due.de)
S. Engelhardt is with Woodward SEG, 47906 Kempen, Germany (e-mail: stephan.engelhardt@woodward.com);
J. Kretschmann is with Woodward SEG, 47906 Kempen, Germany (e-mail: joerg.kretschmann@woodward.com,);

effect of fast transients and electromagnetic interference.

A. EMT and RMS - models

The focus of the TR4 is the validation of RMS models. The German validation and certification approach is based on FRT-measurements at individual turbines, denominated as power generation units (PGUs). Such a kind of test can not be performed at large wind farms without risks for voltage stability in the grid, and testing equipment would not be economically viable. As a result, the concept for approving the grid access of a wind farm is based on modeling, validating and certifying the simulation model of a single PGU. Based on such a certified model, an entire wind farm, a power generation system (PGS) can be modeled. Additional equipment within the PGS like Statcoms, or passive reactive power compensation components will need separate testing and certification like PGUs.

One option would be to compare measurements – which are 3 phase instantaneous measurements - with an EMT-models, that yields three-phase values as well. But because RMS-models are needed for system studies, a validated EMT – model would have to be simplified and converted into an RMS model to be used for RMS-studies. At this point a second validation of the RMS model would be necessary. The simplified RMS model could be compared to an EMT-model, but then the errors would accumulate (from measurement to EMT to RMS). It is therefore required in the FGW TR4 to compare measurements directly to RMS modeling data.

B. Positive and negative sequence of voltages and currents

Switching transients and higher frequency components of currents affect the power quality, but they are not relevant for system stability studies. Therefore, only the fundamental frequency measurement and simulation needs to be compared.

In a three phase grid, the majority, of grid faults are single or two phase faults. They lead to unbalanced voltages and currents in the grid. In order to represent such conditions, it is common to use positive, negative and zero sequence components of voltages and currents. Three phase faults have the most severe impact on synchronous generators. But unbalanced faults can have a major impact on modern PGUs like wind turbines that have inverters connected to the grid, such as full size inverter turbines or DFIG turbines. Therefore, the German grid codes like [9] require models that can represent balanced and (in future) also unbalanced faults.

A description of the calculation of positive sequence values from three phase measurement values can be found in [2]. If a PGU is connected to the grid using a DYN transformer with the star point connected to ground on the low voltage side, the zero sequence component of the voltage can be ignored at the PGU. That means that single phase to ground and two phase to ground faults in the grid translate to phase to phase faults at the PGU.

An example of a measurement of a voltage dip with phase measurements, a calculated instantaneous voltage and positive and negative sequence representation of voltages can be found in Fig. 1 and Fig. 2, subplot 1 and 2 for a three phase and a two phase fault. For the description of the measurement points please refer to Fig. 3.

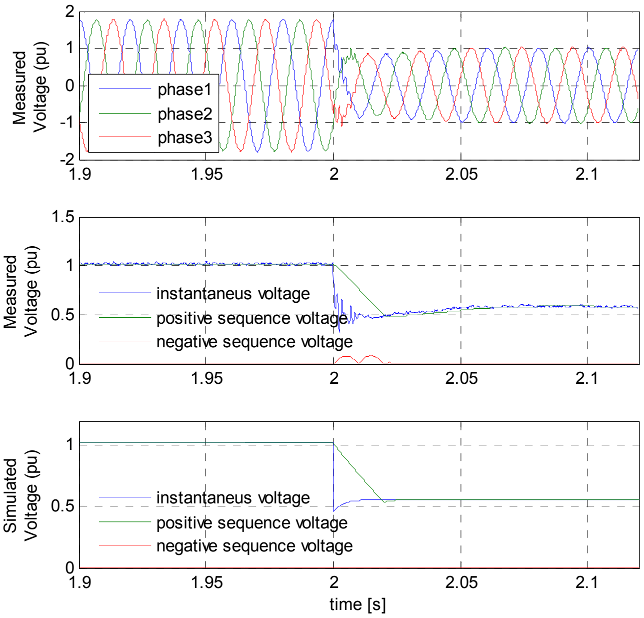

Fig. 1. Measured voltage at measurement point 2 for a symmetric voltage dip. (1) measured voltage of the 3-phases, (2) instantaneous voltage, positive and negative sequence of measured voltage, (3) instantaneous voltage, positive and negative sequence voltage of simulation

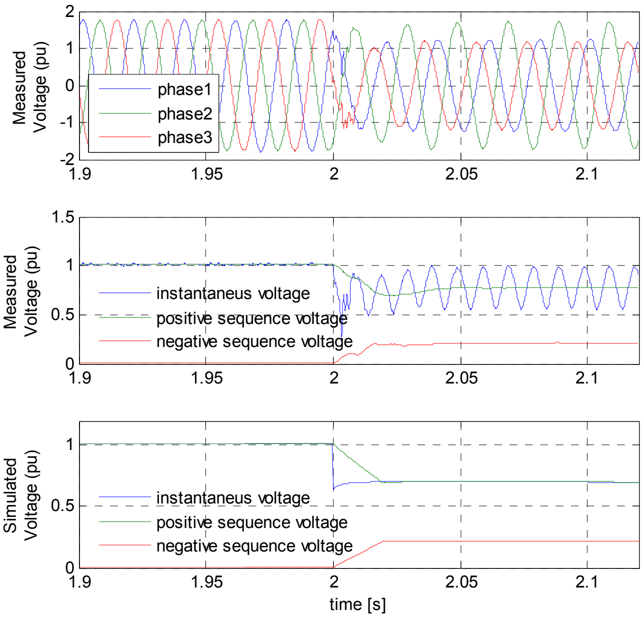

Fig. 2. Measured voltage at measurement point 2 for a 2-phase voltage dip. (1) measured voltage of the 3-phases, (2) instantaneous voltage, positive and negative sequence of measured voltage, (3) instantaneous voltage, positive and negative sequence voltage of simulation

A simulation equivalent for a RMS model still has an “instantaneous” behavior, that means it also contains higher frequency components, even if the positive and negative sequence are modeled separately. As a result, a 50 Hz filtering of the simulated values is necessary in order to have an equivalent to positive and negative sequence values of measurements. The results of simulations of a voltage dip are shown in Fig. 1 and Fig. 2, subplot 3. for a three phase and a two phase fault.

C. *Measurement setup*

According to [2] and [4], FRT – tests should be performed using the measurement setup described in Fig. 3. A PGU is connected to the grid through a testing device. The testing device is designed to reduce the voltage at the PGU to a specified level within a very short period of time. During normal operation, switch S1 is closed and switch S2 is open. In order to reduce the impact of activating impedance Z2 on the grid, in a first step switch S1 is opened. This connects a serial impedance Z1 in line with the PGU. After the transients have decayed, switch S2 is closed and the short circuit impedance Z2 is connected in parallel to the PGU. This causes a voltage dip at the PGU. After 150ms..2000 ms depending on the tests required, switch S2 is opened again. The voltage at the PGU then recovers. A short time later, switch S1 is closed, and normal operation is resumed.

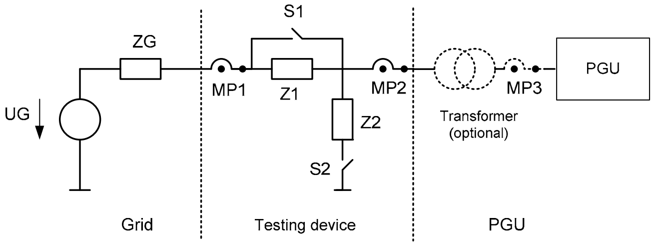

Fig. 3. Setup to measure the effect of voltage dips on a power generation unit, for example a wind turbine.

D. *Required Measurements*

Three phase measurements of voltages and currents must be performed at least at the measurement points MP1 and MP2. Measurements at MP2 describe the behavior of the PGU at its terminals. MP1 is necessary to calculate the data of the grid representation needed for the simulation.

It is necessary to measure the wind speed before the voltage dip. Compared to rates of change of wind speed, voltage dips represent very short periods of time. As a result, the wind speed can generally be assumed to be constant during a voltage dip. In case the measurements are performed at turbulent sites or if there are fast changes of wind speed during measurements, it may be necessary to measure the wind speed during the test. This is the case if the behavior of the active power of a wind turbine can not be modeled with the needed accuracy.

An additional measurement point MP3 is proposed for PGU connected at low voltage to a test device with medium voltage terminals. Further turbine measurement data (low voltage, rotor speed, pitch angle) can be measured to add additional confidence to the model. Additional measurements are required in case they are necessary to explain the turbine behavior.

III. QUANTIFICATION OF SIMULATION - ERROR

In order to describe how well a simulation model is able to represent its physical counterpart, it is necessary to (a) define an allowed error between measurement and simulation and (b) to define criteria for quantifying the deviation between measurement and simulation.

A. *Defining periods before, during and after the voltage dip*

FRT – Tests can be divided in three periods

(A) Period ‘A’: before the voltage dip. A pre-fault measurement and simulation time of 2 seconds is recommended to show that the turbine is operating at stationary conditions. During this period, the switch S1 will be opened. A time of 1 second between opening of S1 and the begin of the voltage dip is recommended to make sure all transients from switching in the impedance Z1 have decayed.

(B) Period ‘B’: after begin of the voltage dip until the begin of the voltage recovery. The duration of this period depends on the grid code requirements and may be between 140ms at 0% remaining voltage up to several seconds at 75% remaining voltage.

(C) Period ‘C’: After the begin of the voltage recovery. Measurement and simulation should not end before all transients of active and reactive power have ended. It is recommend not to close switch S1 before the transients have become very small, otherwise the switching process must be modeled as well.

B. *Defining Transient and stationary intervals*

During each of these periods there are transient and stationary intervals. The begin of a transient interval according to TR4 is defined by a fast change of a measured value or a setpoint. The end of a transient period is reached when the measured value stays within ±10% of its stationary value (see Fig. 4). Transient intervals are related to physical effects, that are not modeled in such detail in the simulation model.

Transients in reactive power or reactive currents are often due to electromagnetic phenomena like

- switching of inductive or capacitive loads,
- changes of the grid voltage
- saturation effects of inductances and transformers.

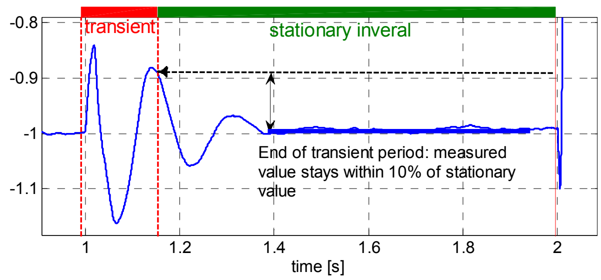

Fig. 4. Definition of transient intervals: A transient interval begins when a measured value or a setpoint changes within a short period of time. A transient interval ends when the measured value remains within a range of +-10% of the stationary value

Transients in active power are often linked to electro mechanic and control phenomena like

- drive train oscillations
- the operation of protection devices of the inverter such as a crowbar.

The start of transient intervals in an FRT-test are switching operations of the serial impedance (during period A and C before and after the voltage dip) and of the short circuit impedance at the start and end of the voltage dip (period B). As a result of the different underlying phenomena, the duration of transient intervals may be different for active and reactive currents

C. Comparison of average values

The average values for each interval – both transient and stationary - are calculated as a figure of how close the model matches the energy transferred to grid. Using this approach, transient effects are not neglected. The model – even though it does not model oscillations, for example of the reactive power – must have the same average energy transfer as the measurement.

The difference of measured and simulated average may not exceed given limits for transient and stationary periods. During normal operation and after voltage recovery, the difference of active and reactive power is compared. During faults, due to the low voltage large errors in the current would be allowed. Therefore it is also necessary to validate the reactive current. The allowed deviation between measurement and simulation is given in Table I as F1 for transient periods and F2 for stationary periods. See Fig. 11 for an example of the calculation of average values of measurement and simulation.

D. Comparison of positive sequence values

During stationary intervals, in addition to the averages it is also necessary to compare the positive sequence values of active power, reactive power and reactive currents. The allowed deviation between measurement and simulation is given in Table I as F3

TABLE I

ALLOWED DEVIATION BETWEEN MEASUREMENT AND SIMULATION FOR ACTIVE POWER, REACTIVE POWER AND REACTIVE CURRENT

Electrical quantity	**F1**	**F2**	**F3**	**FG**
Active power, reactive power, $\Delta P/P_N$, $\Delta Q/P_N$	0,07	0,20	0,10	0,15
Reactive current, $\Delta I_R/I_N$	0,10	0,20	0,15	0,15

With:

F1 Deviation of averages during stationary intervals
F2 Deviation of averages during transient intervals
F3 Deviation of positive sequence values during stationary intervals
FG Global deviation as weighted average of P, Q, and Ir

E. Calculating a weighted average of the deviation

In order to define a global deviation, a weighted deviation has been defined. Within each period A, B and C, the average deviation is calculated based on the sum of transient and stationary periods. The deviations during period A (before voltage dip) are weighted with 10%, the error during period B (during voltage dip) with 60% and the error during period C (following the voltage dip) with 30%. The global deviation can be calculated as

$$e_g = \frac{0.1}{t_A}\sum_{iA} e_{iA} t_{iA} + \frac{0.6}{t_B}\sum_{iB} e_{iB} t_{iB} + \frac{0.3}{t_C}\sum_{iC} e_{iC} t_{iC}$$

with

e_g = global deviation
t_A = duration of period A
i_A = number of intervals (transient+stationary) in period A
e_{iA} = deviation of each interval in period A
T_{iA} = duration of each interval in period A

The deviations will be stated in a report as shown in Fig. 5 for active power, reactive power and reactive current, once for each voltage level during FRT-tests. The tests need to be performed both for rated power and partial power. For voltage dips down to zero voltage, active or reactive power is not defined, therefore they are not stated for this test.

average deviation per sector

voltage dip	**A**	**B**	**C**	**weighted**
0%		╳		╳
25%				
50%				
75%				

maximum deviation during stationary operation

voltage dip	A	B	C
0%		╳	
25%			
50%			
75%			

Fig. 5. The deviation between measurement and simulation is recorded separately for active power, reactive power and reactive currents. Individual measurements are necessary for rated power (> 90%) and partial power (10% .. 40%). A weighted deviation is calculated to quantify the quality of the model

As a summary, the process of validation for FRT-Tests consists of the following steps

1. defining start and end for periods A, B and C before, during and after the FRT-Test
2. identifying transient and stationary intervals during periods A, B and C
3. comparing the difference of the averages for measurement and simulation for each interval with an allowed limit
4. comparing the difference of the positive sequence values of each stationary interval with an allowed limit
5. Calculating a global deviation based on a weighted average over the entire FRT-Test.

IV. MODEL OF THE DFIG

A detailed description of a wind turbine with DFIG and its positive sequence representation can be found in [7]. The negative sequence representation of a DFIG as described in [6] with the following equations has been used:

A. EMT-model representation

The equations of a DFIG for EMT simulation are

Positive sequence components in positive synchronous reference frame:

$$\underline{u}_{S1} = r_S \underline{i}_{S1} + \frac{d\underline{\psi}_{S1}}{dt} + j\omega_0 \underline{\psi}_{S1} \tag{1}$$

$$\underline{u}_{R1} = r_R \underline{i}_{R1} + \frac{d\underline{\psi}_{R1}}{dt} + j(\omega_0 - \omega_R)\underline{\psi}_{R1} \tag{2}$$

$$\underline{\psi}_{S1} = l_S \underline{i}_{S1} + l_h \underline{i}_{R1} \tag{3}$$

$$\underline{\psi}_{R1} = l_h\, \underline{i}_{S1} + l_R\, \underline{i}_{R1} \tag{4}$$

Negative sequence components in negative synchronous reference frame:

$$\underline{u}_{S2} = r_S \underline{i}_{S2} + \frac{d\underline{\psi}_{S2}}{dt} - j\omega_0 \underline{\psi}_{S2} \tag{5}$$

$$\underline{u}_{R2} = r_R \underline{i}_{R2} + \frac{d\underline{\psi}_{R2}}{dt} - j(\omega_0 + \omega_R)\underline{\psi}_{R2} \tag{6}$$

$$\underline{\psi}_{S2} = l_S \underline{i}_{S2} + l_h \underline{i}_{R2} \tag{7}$$

$$\underline{\psi}_{R2} = l_h\, \underline{i}_{S2} + l_R\, \underline{i}_{R2} \tag{8}$$

with $l_S = l_h + l_{\sigma S}$ and $l_R = l_h + l_{\sigma R}$

Equation of motion:

$$\frac{d\omega_R}{dt} = \frac{1}{\theta_m}\left(\operatorname{Im}\left[\left(\underline{\psi}_{S1} + \underline{\psi}^*_{S2,1}\right)\times\left(\underline{i}_{S1} + \underline{i}^*_{S2,1}\right)\right] + t_m\right) \tag{9}$$

with

$$\underline{\psi}^*_{S2,1} = \left(\underline{\psi}_{S2}\exp(-j2\omega t)\right)^* \tag{10}$$

$$\underline{i}^*_{S2,1} = \left(\underline{i}_{S2}\exp(-j2\omega t)\right)^* \tag{11}$$

B. RMS-model representation

In [7] a model reduction for RMS simulations is described. Setting the stator flux derivative to zero

$$\frac{d\underline{\psi}_{S1}}{dt} = 0 \tag{12}$$

(1) can then be transformed with (3) and (4) to

$$\underline{u}_{S1} = \underline{z}_1{}'\, \underline{i}_{S1} + \underline{u}_1{}' \tag{13}$$

with

$$\underline{z}_1{}' = r_S + j\omega_0\left(l_S - \frac{l_h{}^2}{l_R}\right) \tag{13}$$

as the internal transient impedance and

$$\underline{u}_1{}' = j\omega_0 \frac{l_h}{l_R}\underline{\psi}_{R1} = j\omega_0 k_R \underline{\psi}_{R1} \tag{14}$$

as the corresponding transient driving Thévenin voltage source. Replacing $\underline{i}_R$ in (2) with (4) yields the differential equation for the rotor flux in (15)

$$\frac{d\underline{\psi}_{R1}}{dt} = -\frac{r_R}{l_R}\underline{\psi}_{R1} - j(\omega_0 - \omega_R)\underline{\psi}_{R1} - k_R r_R \underline{i}_{S1} + \underline{u}_{R1} \tag{15}$$

As described in [6], the reduced order negative sequence representation of a DFIG

$$\frac{d\underline{\psi}_{R2}}{dt} = -\frac{r_R}{l_R}\underline{\psi}_{R2} + j(\omega_0 + \omega_R)\underline{\psi}_{R2} + k_R r_R \underline{i}_{S2} + \underline{u}_{R2} \tag{16}$$

can then be further reduced neglecting any specific negative phase sequence control. In this case, the negative sequence rotor voltage $\underline{u}_{R2}$ can be set to zero. The internal transient impedance $\underline{z}_2{}'$ for DFIG systems without negative sequence control can then be modified to

$$\underline{z}_2{}' = r_S + \frac{r_R}{2} - j\omega_0\left(l_S - \frac{l_h{}^2}{l_R}\right) \tag{17}$$

The resulting structure for the simulation model is shown in Fig. 2.

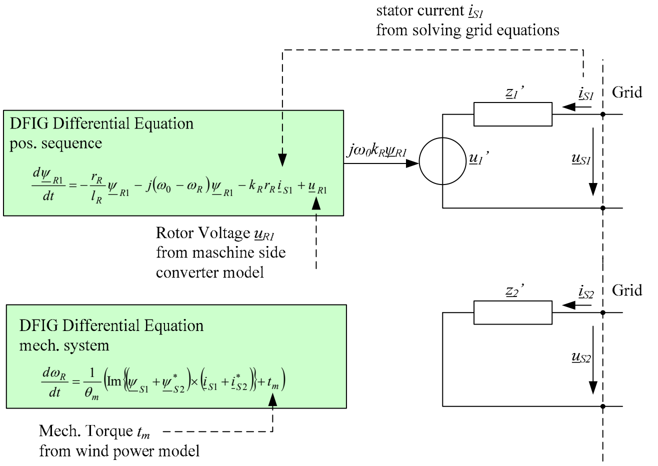

Fig. 6. Reduced order representation of a DFIG with positive and negative sequence representation for RMS simulation

C. Reactive Power Control/Voltage Control

German grid codes and regulations ([9],[10]) require wind turbines to feed in reactive power during grid faults as in Fig. 7. A continuous voltage control scheme as described in [12] has been used for measurement and simulation.

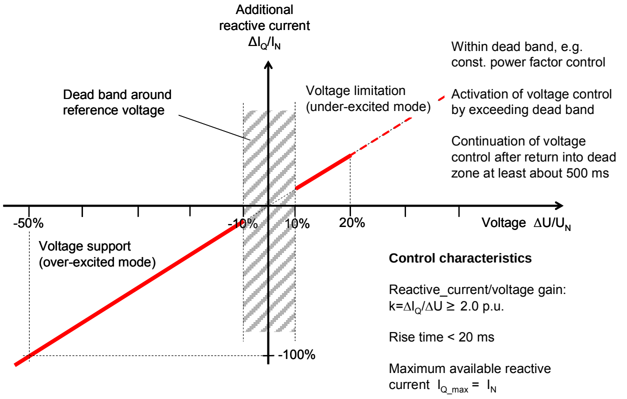

Fig. 7. Reactive power demand according to E.ON [9]

Each turbine is equipped with a continuously acting

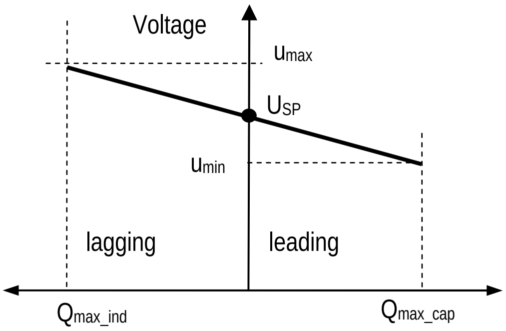

Fig. 8. Continuously acting voltage control at turbine level. The reactive power output is a function of the voltage at the wind turbine terminals

voltage controller with proportional control of the reactive power as a function of the measured voltage (see Fig. 8).

A centralized wind farm controller receives setpoints from the system operator. This setpoint can be a power factor, a reactive power setpoint or a voltage setpoint of a voltage static. The wind farm controller sends voltage setpoints to each turbine using a PI control. (see Fig. 9)

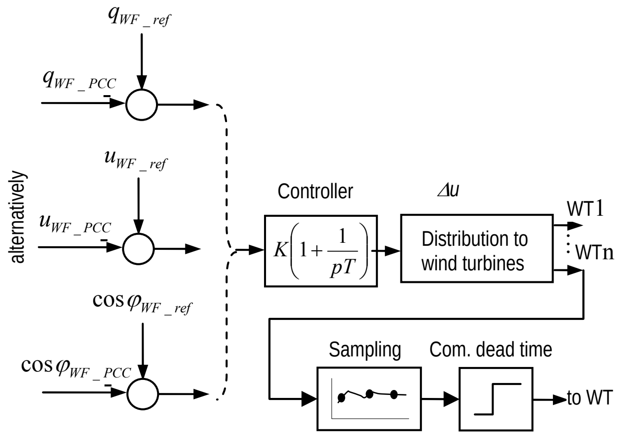

Fig. 9. Continuous voltage control with centralized wind farm controller.

The reaction to grid faults of this control structure is similar to a voltage controller with a deadband around rated voltage, but it has advantages at small voltage changes due to a faster reaction under such conditions [13].

V. VALIDATION RESULTS

The measurements of a three phase and a 2 phase voltage dip down to 45% rated voltage for 2000 ms has been compared to simulations:

A. 3-phase fault

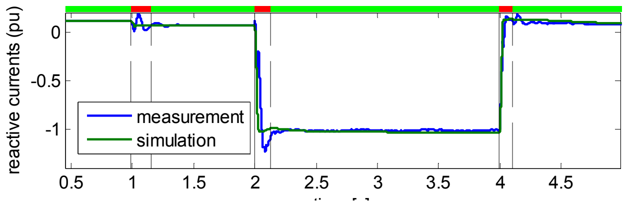

Fig. 10: Measurement and simulation of reactive currents of a FRT-Test with a voltage dip down to 45 % rated voltage. The voltage setpoint has been set to unity, the reactive power is changed as the voltage changes. Transient periods are highlighted with red color, stationary periods green.

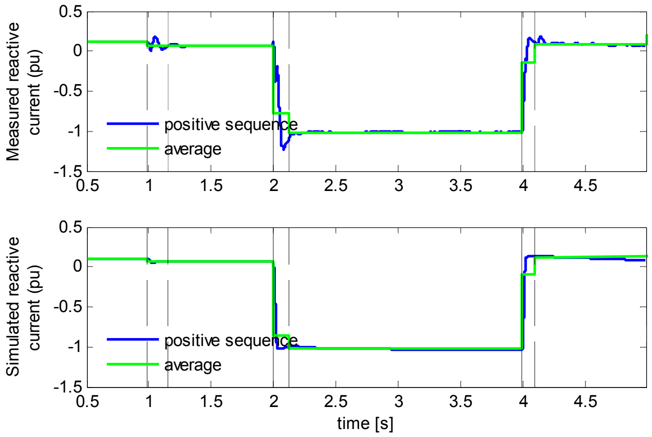

Fig. 11 Measured (1) and simulated (2) reactive current at measurement point 2 for a symmetric voltage dip. The average values are calculated for each interval (doted lines) for measurement (1) and simulation (2). Transient periods start at =1, t =2 and t = 4 seconds.

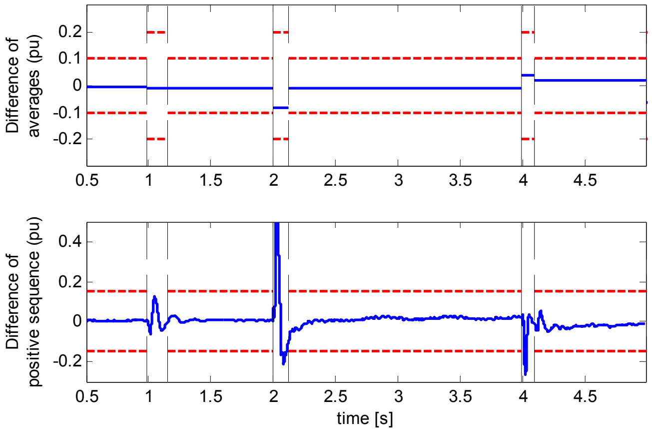

Fig. 12. Difference between measurement and simulation of reactive currents at measurement point 2 for a symmetrical voltage dip as well as allowed tolerance. In (1), the difference of averages values (blue) and the allowed tolerance (red) is shown, in (2) the difference of positive sequence values (blue) and allowed tolerances for the stationary intervals (red) is displayed.

B. 2-phase-fault

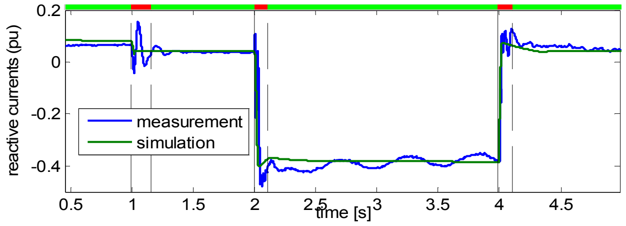

Fig. 13. Measurement and simulation of reactive currents of a FRT-Test with a voltage dip down to 45 % rated voltage. The voltage setpoint has been set to unity, the reactive power is changed as the voltage changes. Transient periods are highlighted with red color, stationary periods green.

C. Errors

Differences between measurement and simulation can arise from different sources. The most important of them are

- The allowed tolerance of measurement equipment is usually 1% for voltage and current transformers [2], additional errors can arise from A/D – conversion and digital postprocessing. This alone can lead to a possible error of 2% in measured active and reactive power
- The measurement accuracy is usually not specified for transient effects, additional errors can arise from there.
- The measurement and control equipment of PGU does not usually have the same accuracy as calibrated measurement equipment – an additional error of 1 % could be expected.
- The tolerances of PGU component parameters can easily vary by several percent.

If the accuracy requirements of models become too high, manufacturers could be encouraged to tune parameters to a specific individual turbine and a specific condition being tested. But this would not guarantee the same parameters are valid for other locations and other turbines.

Turbine data, model data and simulation environment data will always have some uncertainty. It is therefore important to state the expected uncertainty so it can be taken into account for studies.

VI. SUMMARY

The process of model validation in Germany has been described and applied to the measurement and simulation of reactive currents of a three phase and a two phase grid voltage dip down to 45% rated voltage. For simulation a simplified DFIG model with support for unbalanced faults and continuous voltage control has been used. The model shows a good correlation with the measurements, but it should be noted that FRT-Tests down to lower voltages and the validation of active power is still more demanding.

The validation process described could contribute to the proposed IEC modeling effort starting this year

VII. REFERENCES

[1] FGH: Z501-1 Prüfverfahren zum Nachweis des Verhaltens von DEA bei Fehlern im Netz, Rev. 1 02/2005.

[2] IEC: IEC 61400-21 ed. 2, Wind turbine generator systems – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines

[3] FGW: Technische Richtlinien für Erzeugungseinheiten Teil 3 Bestimmung der Elektrischen Eigenschaften von Erzeugungseinheiten am Mittel-, Hoch- und Höchstspannungsnetz s. Revision 19, 14. Januar 2009

[4] FGW: Technical Guidelines for Power Generating Units. Part 4 Demands on Modeling and Validating Simulation Models of the Electrical Characteristics of Power generation Units and Systems. Revision 4, September 15th, 2009

[5] FGW: Technische Richtlinien für Erzeugungseinheiten Teil 8 Zertifizierung der Elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen am Mittel- Hoch- und Höchstspannungsnetz, Revision 1, 15. September 2009

[6] S. Engelhardt, C. Feltes, J. Fortmann, J. Kretschmann, I. Erlich: Reduced Order Model of Wind Turbines based on Doubly-Fed Induction Generators during Voltage Imbalances, 8th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms, Bremen 2009

[7] I. Erlich, J. Kretschmann, J. Fortmann, et al., "Modeling of Wind Turbines based on Doubly-Fed Induction Generators for Power System Stability Studies", Modeling of Wind Turbines Based on Doubly-Fed Induction Generators for Power System Stability Studies, IEEE Transactions on Power Systems, Volume 22, Issue 3, Aug. 2007 Page(s):909 – 919

[8] Feltes, C.; Engelhardt, S.; Kretschmann, J.; Fortmann, J.; Koch, F.; Erlich, I.: „High voltage ride-through of DFIG-based wind turbines", Power and Energy Society General Meeting, 2008 IEEE, 20-24 July 2008 Page(s):1 – 8

[9] E.ON Netz GmbH, "Grid Code High and Extra high voltage", online: http://www.eon-netz.com/, Bayreuth, 2006

[10] BDEW: Technische Richtlinie Erzeugungsanlagen am Mittelspannungsnetz, Juni 2008

[11] Verordnung zu Systemdienstleistungen durch Windenergieanlagen (Systemdienstleistungsverordnung – SDLWindV), BMU, Germany-27.05.2009

[12] J. Fortmann, M. Wilch, I. Erlich, F. Koch: "A novel centralised wind farm controller utilising voltage control capability of wind turbines", PSCC Power System Computation Conference 2008, July 2008, Glasgow

[13] I. Erlich, J. Fortmann, S. Engelhardt, J. Kretschmann: "Spannungsregelung mit moderner WEA-Technik", Kassler Symposium für Energietechnik 2009, Fraunhofer IWES, 2009

VIII. BIOGRAPHIES

Jens Fortmann (1966) received his Dipl.-Ing. degree in electrical engineering from the Technical University Berlin, Germany, in 1996. From 1995 to 2002 he worked on the simulation of the electrical system and the control design of variable speed wind turbines at the German wind turbine manufacturers Suedwind and Nordex Energy. Since 2002 he is with REpower Systems AG, Germany presently as team leader of model and system development for the simulation and implementation of new technologies for improved grid compatibility of wind turbines like voltage control and ride-through of grid faults. He is currently the head of the FGW working group that specifies the model validation guideline TR4

Stephan Engelhardt (1967) received his Dipl.-Ing. degree in electrical engineering from the University Hannover, Germany, in 1997. Since 1997 he is with Woodward SEG GmbH & Co. KG, Kempen/Germany, presently head of the group Converter Technology and responsible for system designs and simulations, control strategies and patents.

Christian Feltes (1979) received his Dipl.-Ing. degree in electrical engineering from University of Duisburg-Essen/Germany in 2005. Since January 2006 he is doing his Ph.D. studies in the Department of Electrical Power Systems at the same University.

His research interests are focused on wind energy generation, control, integration and dynamic interaction with electrical grid.

Jörg Kretschmann (1958) received his Dipl.-Ing. degree in electrical engineering from the Technical University Berlin, Germany, in 1986. In the period of 1986 to 1988 he worked for engineering department of AEG-Kanis in Essen, manufacturing of synchronous generators up to 200 MVA. Since 1988 he is with Woodward SEG GmbH & Co. KG, Kempen/Germany, as a designing engineer for speed-variable applications: uninterruptible power supply, shaft alternators, DFIG for wind turbines. His main field is simulation of power converter systems, design of power components, passive grid-filter.

Istvan Erlich (1953) received his Dipl.-Ing. degree in electrical engineering from the University of Dresden/Germany in 1976. After his studies, he worked in Hungary in the field of electrical distribution networks. From 1979 to 1991, he joined the Department of Electrical Power Systems of the University of Dresden again, where he received his PhD degree in 1983. In the period of 1991 to 1998, he worked with the consulting company EAB in Berlin and the Fraunhofer Institute IITB Dresden respectively. During this time, he also had a teaching assignment at the University of Dresden. Since 1998, he is Professor and head of the Institute of Electrical Power Systems at the University of Duisburg-Essen/Germany. His major scientific interest is focused on power system stability and control, modeling and simulation of power system dynamics including intelligent system applications.