DIgSILENT GridCode:

Model validation according to the German Grid Code and FGW-TR4

DIgSILENT Ibérica
Madrid, 15 February 2012

Model Validation according to the German Grid Code

German rules for generating plants connected to the grid can be found in:

- Law Renewable Energy Sources Act, EEG → Act on priority granting to renewable energy sources (Renewable Energy Sources Act, EEG)
- Ordinance on System Services from Wind Power Plants (SDLWindV)
- Verband der Netzbetreiber e. V. - VDN - beim VDEW (BDEW): TransmissionCode 2007, Der Verband der Netzbetreiber e. V. - VDN - beim VDEW (BDEW)
- FGW e.V. - Fördergesellschaft Windenergie und andere Erneuerbare Energien:
  - TECHNICAL GUIDELINE FOR POWER GENERATING UNITS. PART 3: DETERMINATION OF ELECTRICAL CHARACTERISTICS OF POWER GENERATING UNITS CONNECTED TO MV, HV AND EHV GRIDS. REVISION 21 (March 2010).
  - TECHNICAL GUIDELINE FOR POWER GENERATING UNITS. PART 4: DEMANDS ON MODELING AND VALIDATING SIMULATION MODELS OF THE ELECTRICAL CHARACTERISTICS OF POWER GENERATING UNITS AND SYSTEMS. REVISION 5 (March 2010).
  - TECHNICAL GUIDELINE FOR POWER GENERATING UNITS. PART 8: FOR THE CERTIFICATION OF ELECTRICAL CHARACTERISTICS OF POWER GENERATING UNITS AND FARMS IN THE MEDIUM-, HIGH– AND HIGHEST-VOLTAGE GRIDS. REVISION 5 (July 2011).

Model Validation according to the German Grid Code

Procedure for model validation TR4:

- STEP 1: LVRT Field testing of the wind turbines according to the measurement procedures by FGW TR3 and German Grid Code.
- STEP 2: The dynamic simulation model is built.
- STEP 3: Simulations are executed reproducing the same events (voltage dips) performed during field testing.
- STEP 4: Results obtained from every simulation case are compared against the corresponding field test measurements → RMS simulation results are compared against processed data from field testing:
  - Reactive Current, positive and negative sequence (Ir+, Ir-)
  - Active Power, positive and negative sequence (P+, P-)
  - Reactive Power, positive and negative sequence (Q+, Q-)
- STEP 5: The validation method is complex, every data series is divided into three periods (A, B and C). During each period, transient (TS) and steady state (SS) intervals are defined depending on fast changes or settled values (when the value settles within ±10% of its steady state value). The global error is calculated from the weighted average over the errors calculated in every interval. Error thresholds are in the following table, where:

Electrical parameters	F1	F2	F3	FG
Active Power Pos Seq ($\Delta P^{+}/P_N$)	0.10	0.20	0.15	0.15
Active Power Neg Seq ($\Delta P^{-}/P_N$)	0.10	0.20	0.15	0.15
Reactive Power Pos Seq ($\Delta Q^{+}/Q_N$)	0.07	0.20	0.10	0.15
Reactive Power Neg Seq ($\Delta Q^{-}/Q_N$)	0.07	0.20	0.10	0.15
Reactive Current Pos Seq ($\Delta Ir^{+}/I_N$)	0.10	0.20	0.15	0.15
Reactive Current Neg Seq ($\Delta Ir^{-}/I_N$)	0.10	0.20	0.15	0.15

- F1: Maximum deviation of the mean values for SS
- F2: Maximum deviation of the mean values for TS
- F3: Maximum deviation of Pos/Neg for SS
- FG: Total error as mean value of the weighted errors

In case of 2PH dips, it is admitted:

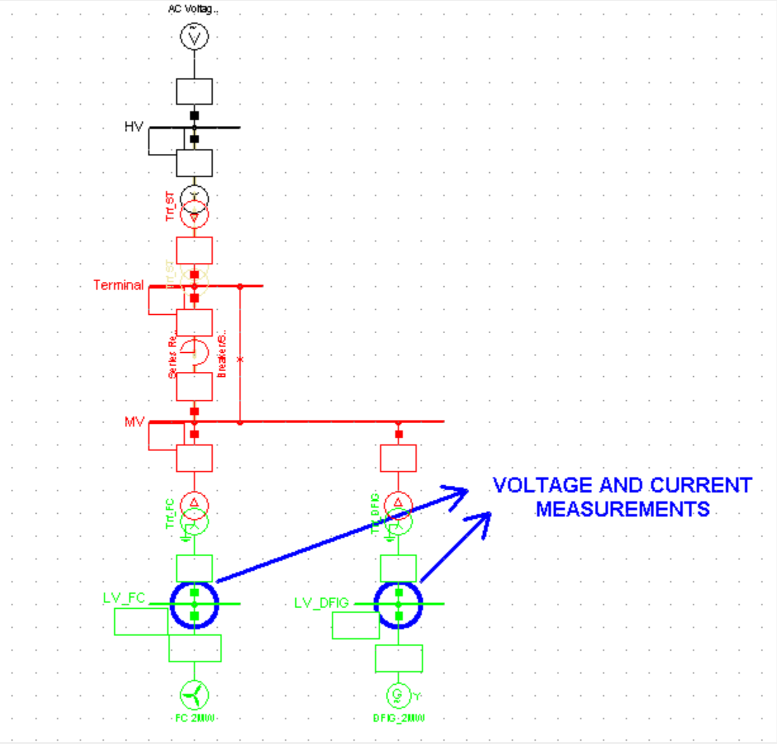
→ F1, F2, F3, FG x 1.50 (for the Pos Seq variables)

→ F1, F2, F3, FG x 2.00 (for the Neg Seq variables)

STEP 1: Building the example to test the German Case: DFIG model against FC model

To avoid using field measurements to illustrate the German method, the behavior of the dynamic model of a Doubly Fed Induction Generator (DFIG) is validated against the dynamic model of a Full Converter (FC) wind turbine. The following example is built in DIgSILENT PowerFactory 14.1.2 (x86). The project includes two wind turbine models from the DIgSILENT PowerFactory global library templates:

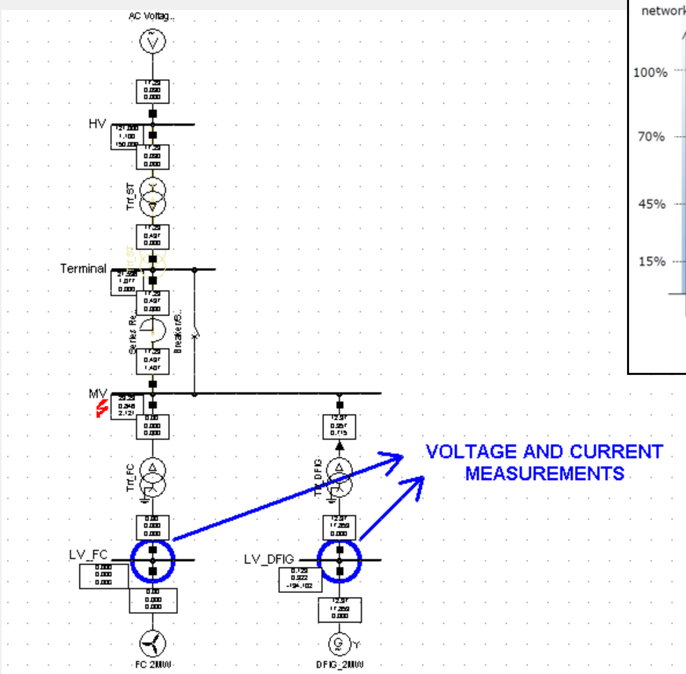
- 1xDFIG, rated 2MW
- 1xTRF DFIG 400V/20kV, rated 2.22 MVA
- 1xFC, rated 2MW
- 1xTRF FC 400V/20kV, rated 2.3 MVA
- PCC Voltage 110kV
- Substation TRF 110/20kV, rated 80MVA

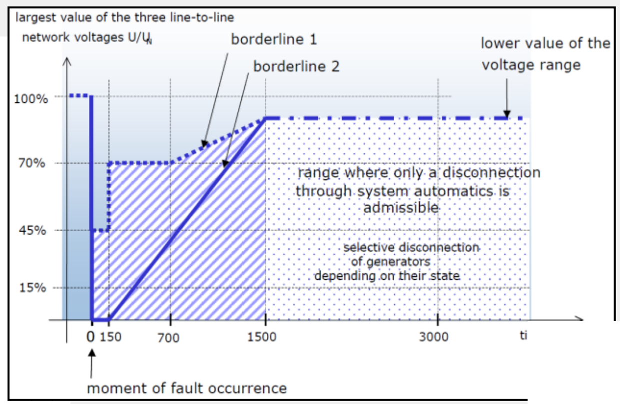


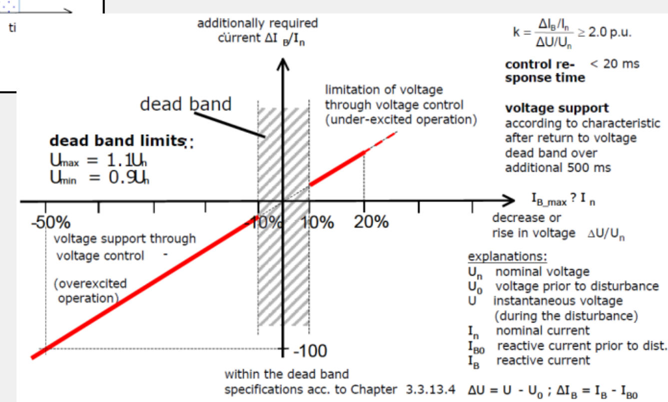
Example of Model Validation according to the German Grid Code

STEP 2: Simulation of LVRT events according to the German Grid Code:

- RMS simulation – 1ms time step
- Events → T_{init} = 0s, $T_{open//switch}$ = 1s, $T_{dip\ init}$ = 2s, $T_{dip\ end}$ = 2.15s; $T_{close//switch}$ = 4.15 s; $T_{end\ sim}$ = 7.15 s
- Filtering RMS results (low pass filter, cut off 15Hz) → export signals
- Voltage dip location: at the Wind Farm MV terminal, 20kV side → serial reactance with parallel switch
- Voltage dip measurements → at the LV side of the wind turbines







Example of Model Validation according to the German Grid Code

STEP 2: Simulation of LVRT events according to the German Grid Code:

The field and simulation tests are included in the TR3-TR4 procedure:

Dip	Remaining voltage	Dip duration	Operating Point
3 PH	0 %	150 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn
	20 %	550 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn
	50 %	950 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn
	75 %	1400 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn
2 PH	0 %	150 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn
	20 %	550 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn
	50 %	950 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn
	75 %	1400 ms	0.1Pn < P < 0.3Pn
			P> 0.9 Pn

Example of Model Validation according to the German Grid Code

STEP 3: Export required signals from VIs in DIgSILENT PowerFactory:

Three phase fault at MV side, 0% remaining voltage, 150ms

Exported signals, textfile, white space/tab separated format:

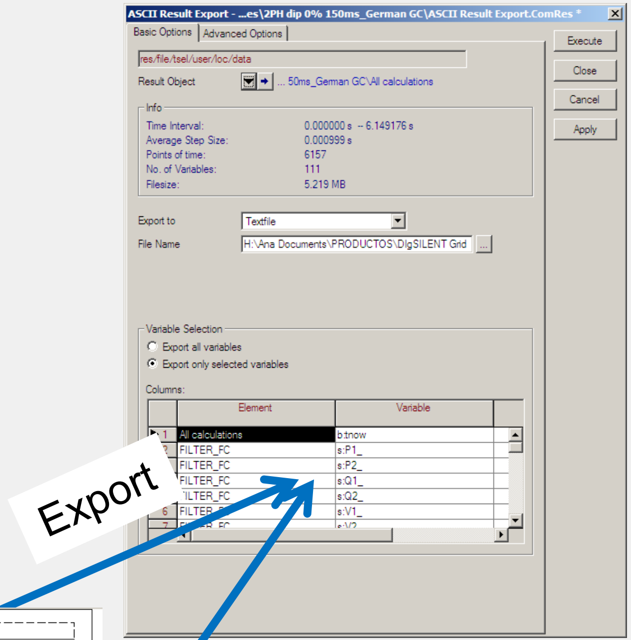
$P^{+}(t)$, $P^{-}(t)$

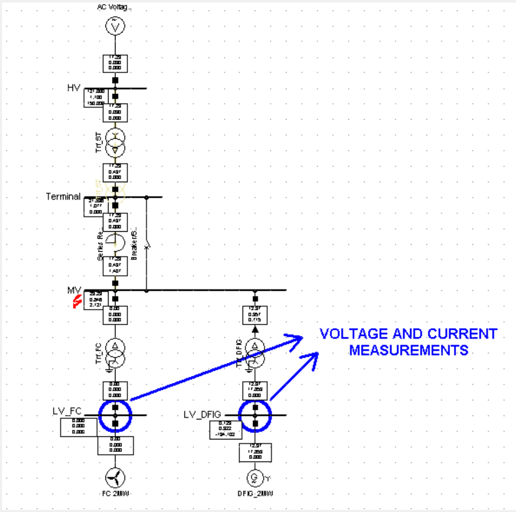
$Q^{+}(t)$, $Q^{-}(t)$

$V^{+}(t)$, $V^{-}(t)$,

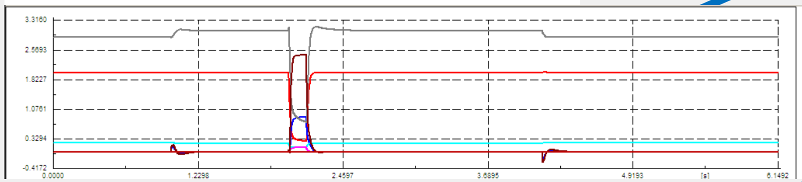
$I_p^{+}(t)$, $I_p^{-}(t)$,

$I_q^{+}(t)$, $I_q^{-}(t)$

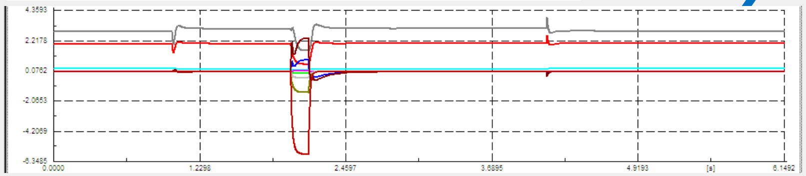




Voltage dip 0% - DFIG



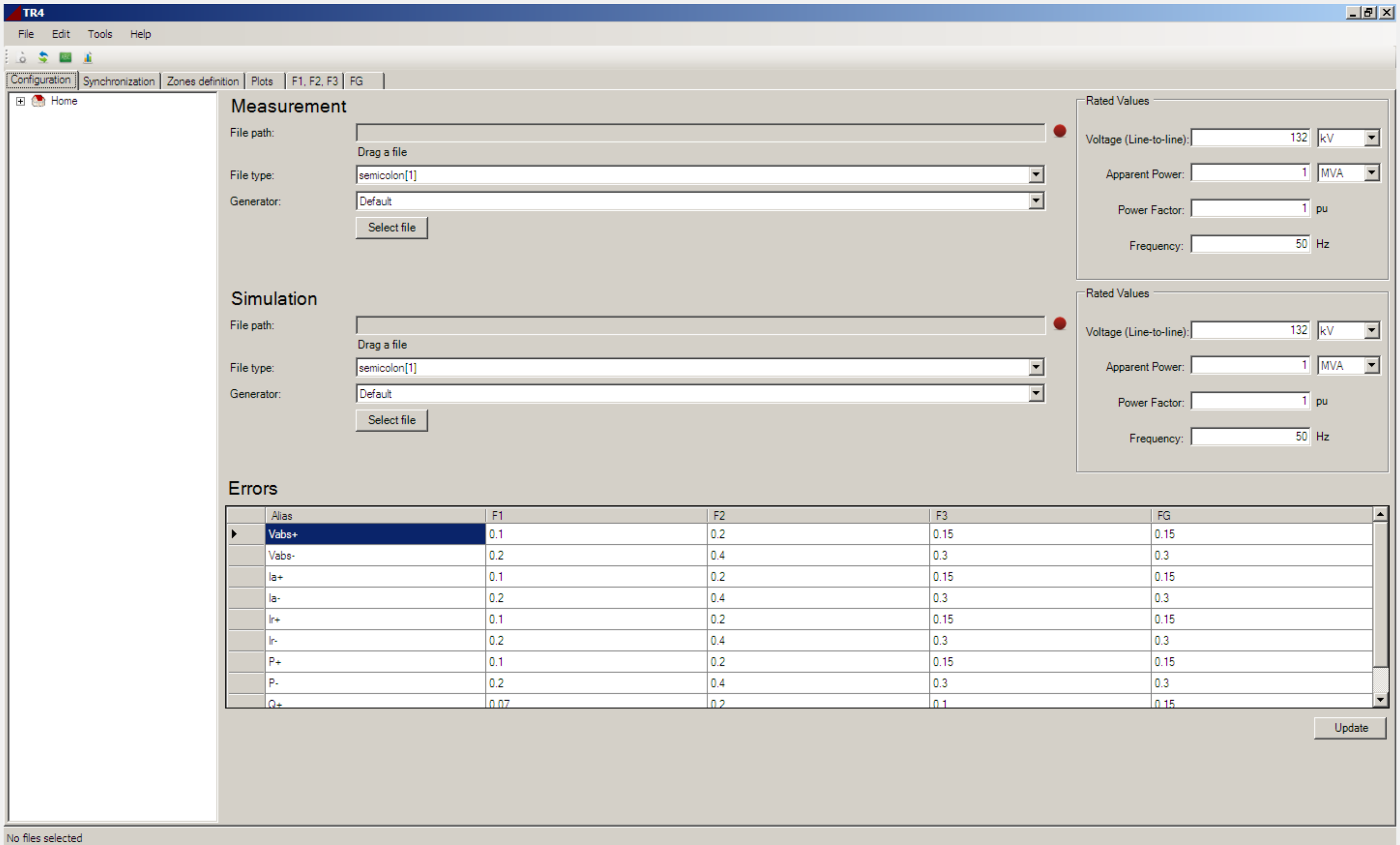
Voltage dip 0% - FC



Example of Model Validation according to the German Grid Code

STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

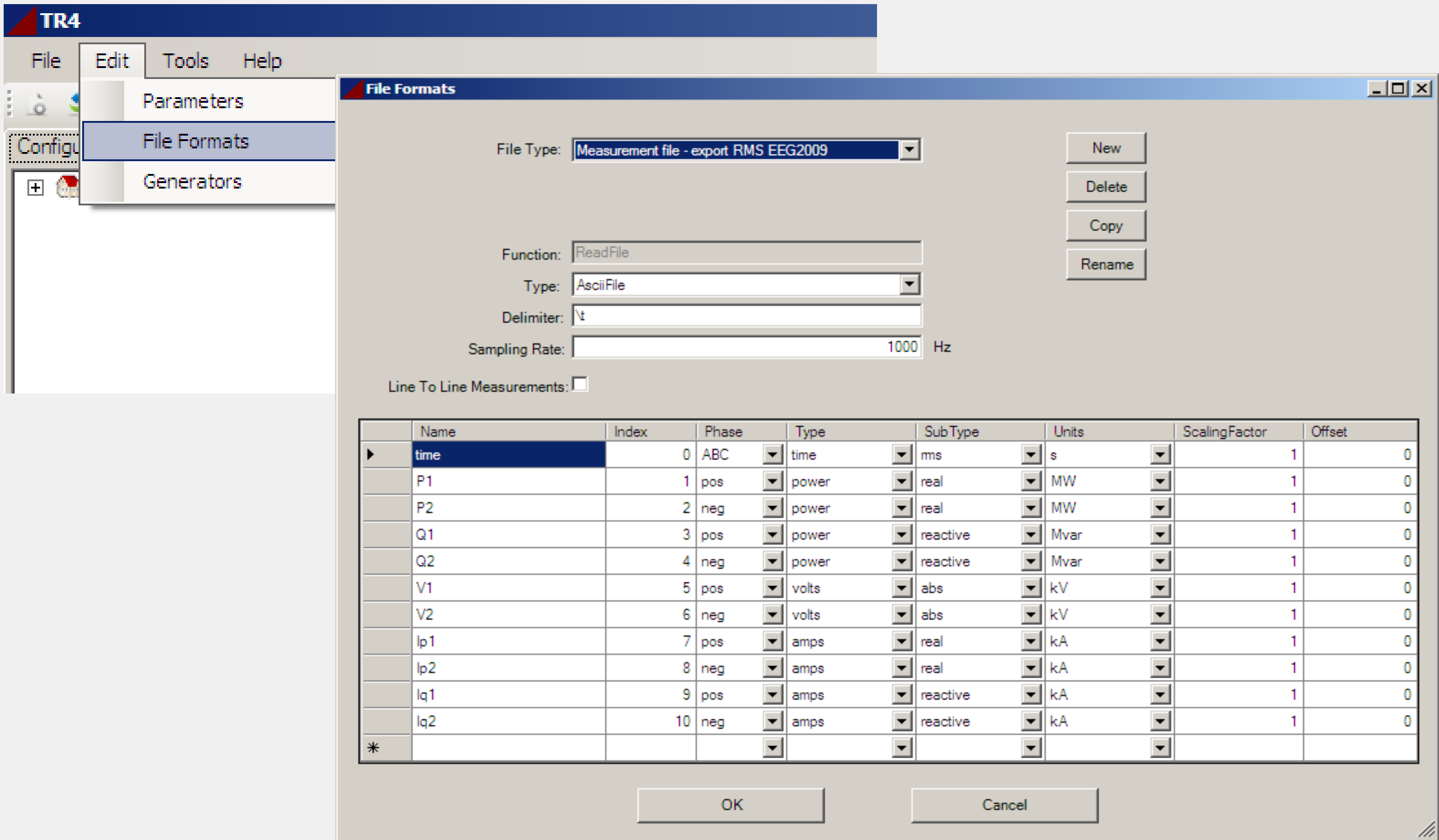
Default window:



Example of Model Validation according to the German Grid Code

STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

STEP 4.1: File Types & Channels Editor → Create File Type to read DIgSILENT PowerFactory exported results.

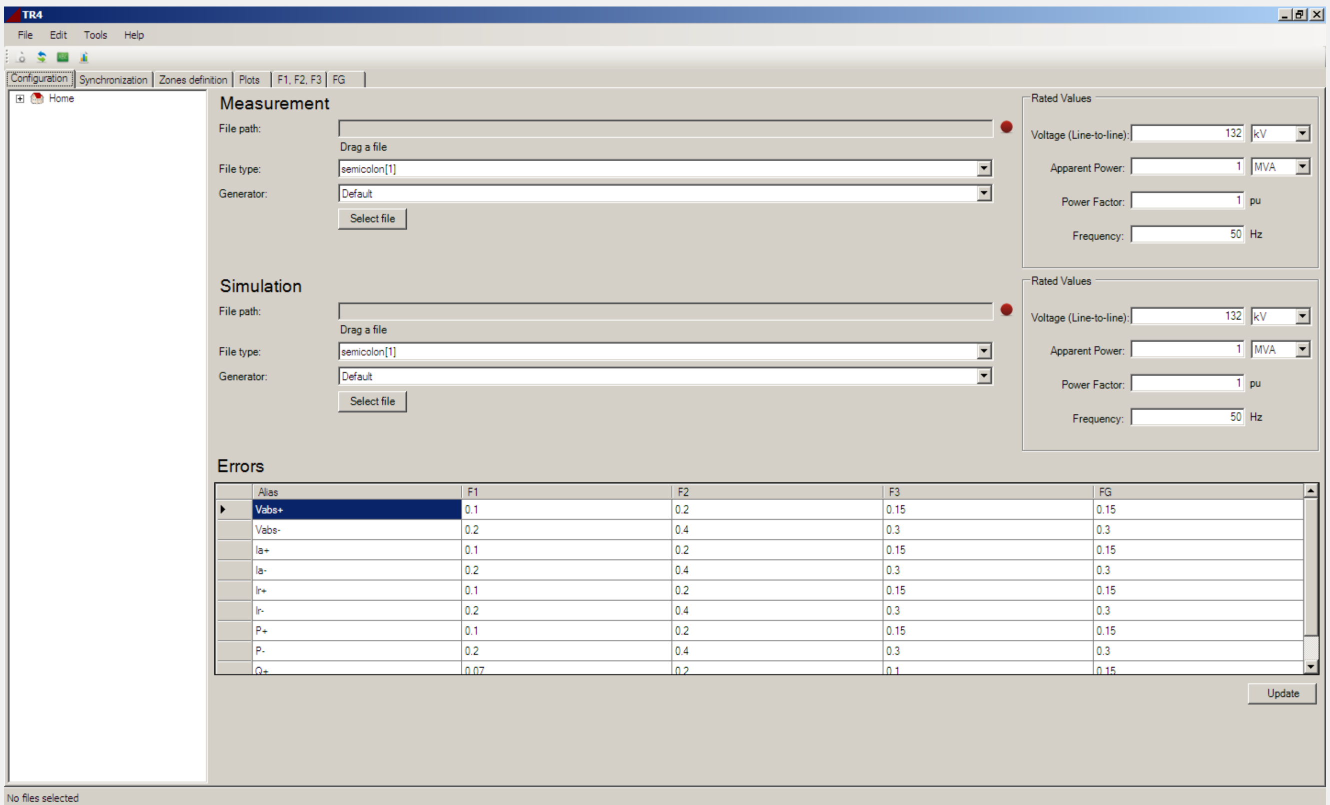


Example of Model Validation according to the German Grid Code

STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

STEP 4.1: File Types & Channels Editor

STEP 4.2: Open file 1 and 2 to compare, select file format and base values.

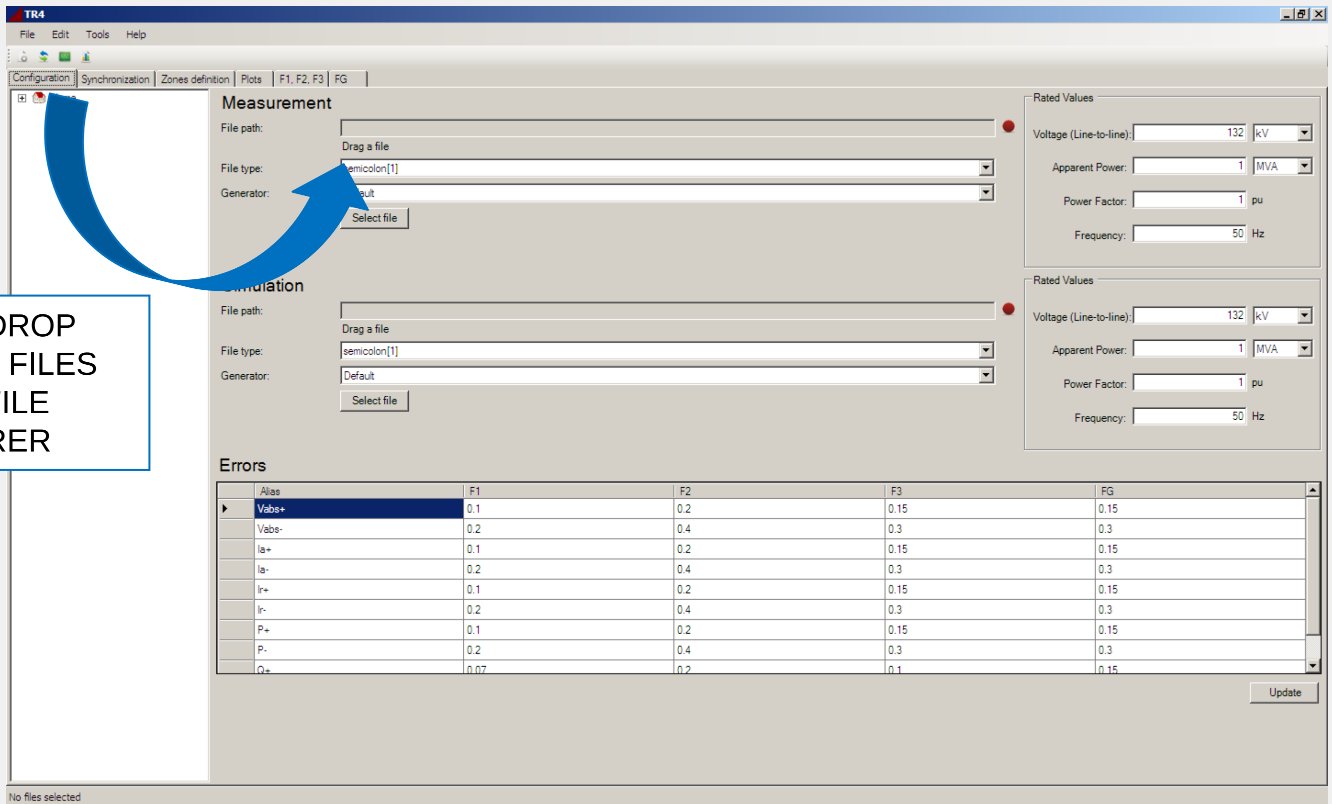


Example of Model Validation according to the German Grid Code

STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

STEP 4.1: File Types & Channels Editor

STEP 4.2: Open file 1 and 2 to compare, select file format and base values.



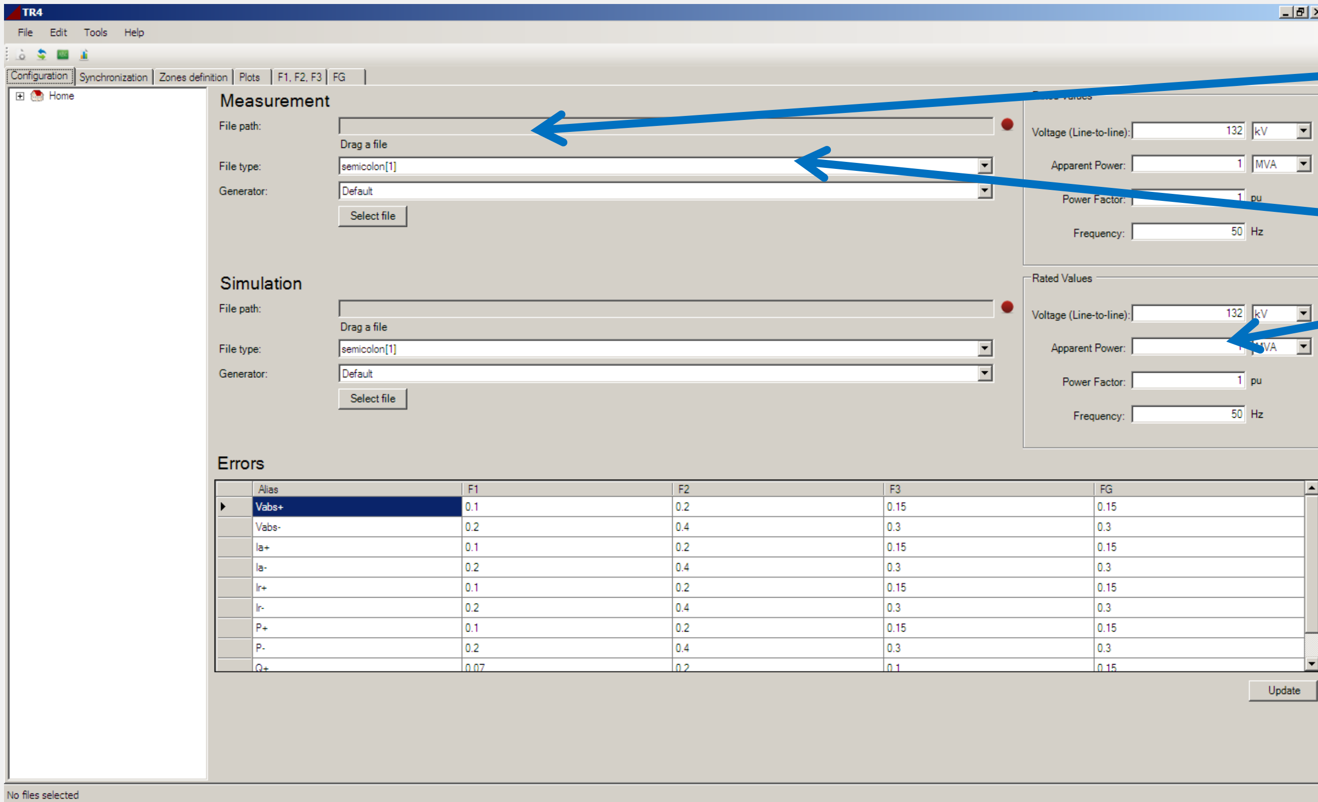
DRAG & DROP SELECTED FILES FROM FILE EXPLORER

Example of Model Validation according to the German Grid Code

STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

STEP 4.1: File Types & Channels Editor

STEP 4.2: Open file 1 and 2 to compare, select file format and base values.



OR SELECT FILES:
File 1: Measurement file
File 2: Simulation file

Select File Format

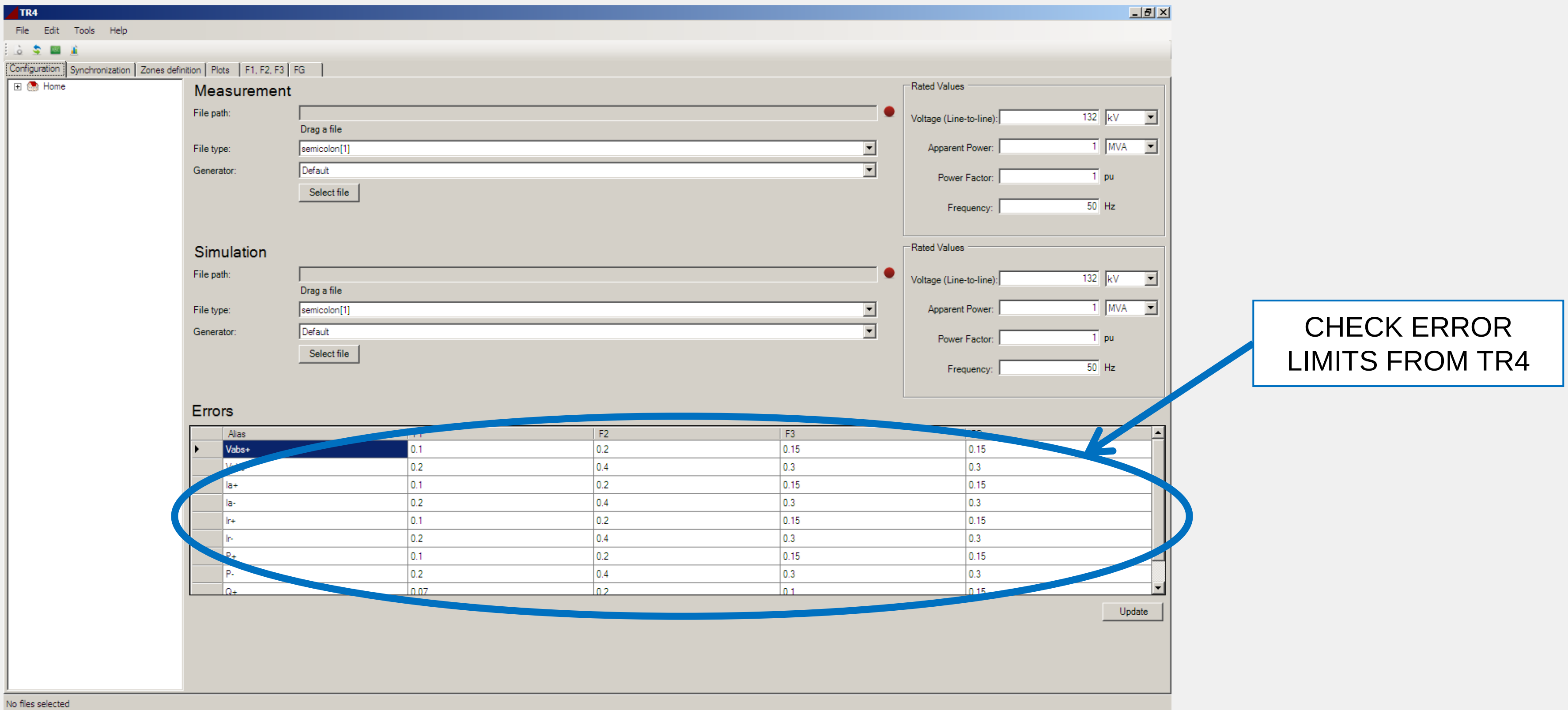
Select Base Values

Example of Model Validation according to the German Grid Code

STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

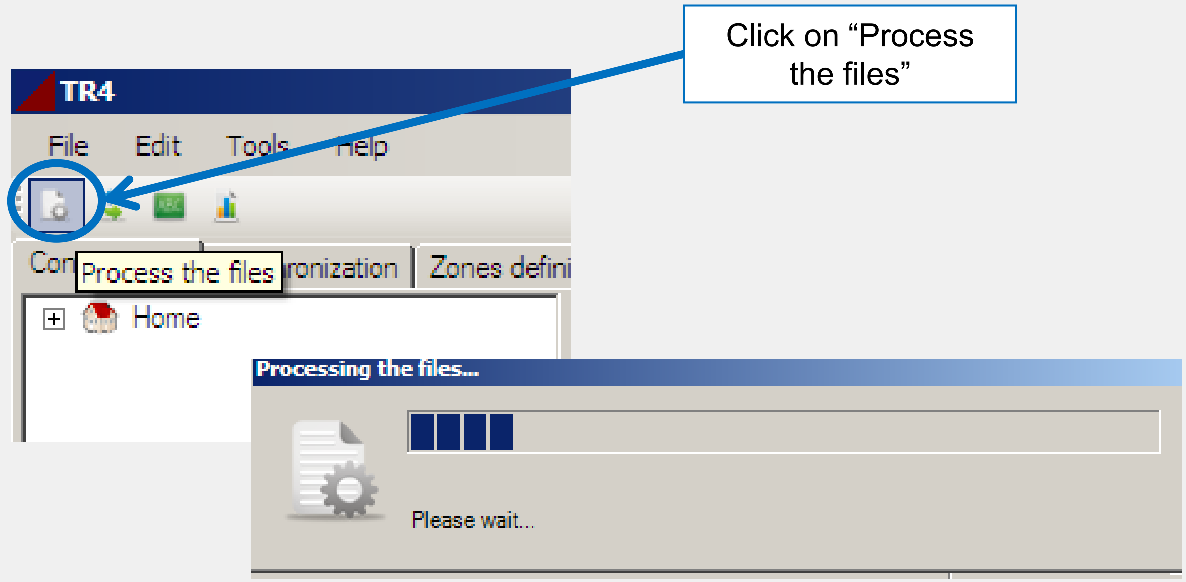
STEP 4.1: File Types & Channels Editor

STEP 4.2: Open file 1 and 2 to compare, select file format and base values.



STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

- STEP 4.1: File Types & Channels Editor
- STEP 4.2: Open file 1 and 2 to compare, select file format and base values.
- STEP 4.3: Process the files



Example of Model Validation according to the German Grid Code

STEP 4: Analysis with DIgSILENT GridCode → **TR4 TOOL**

STEP 4.1: File Types & Channels Editor

STEP 4.2: Open file 1 and 2 to compare, select file format and base values.

STEP 4.3: Process the files

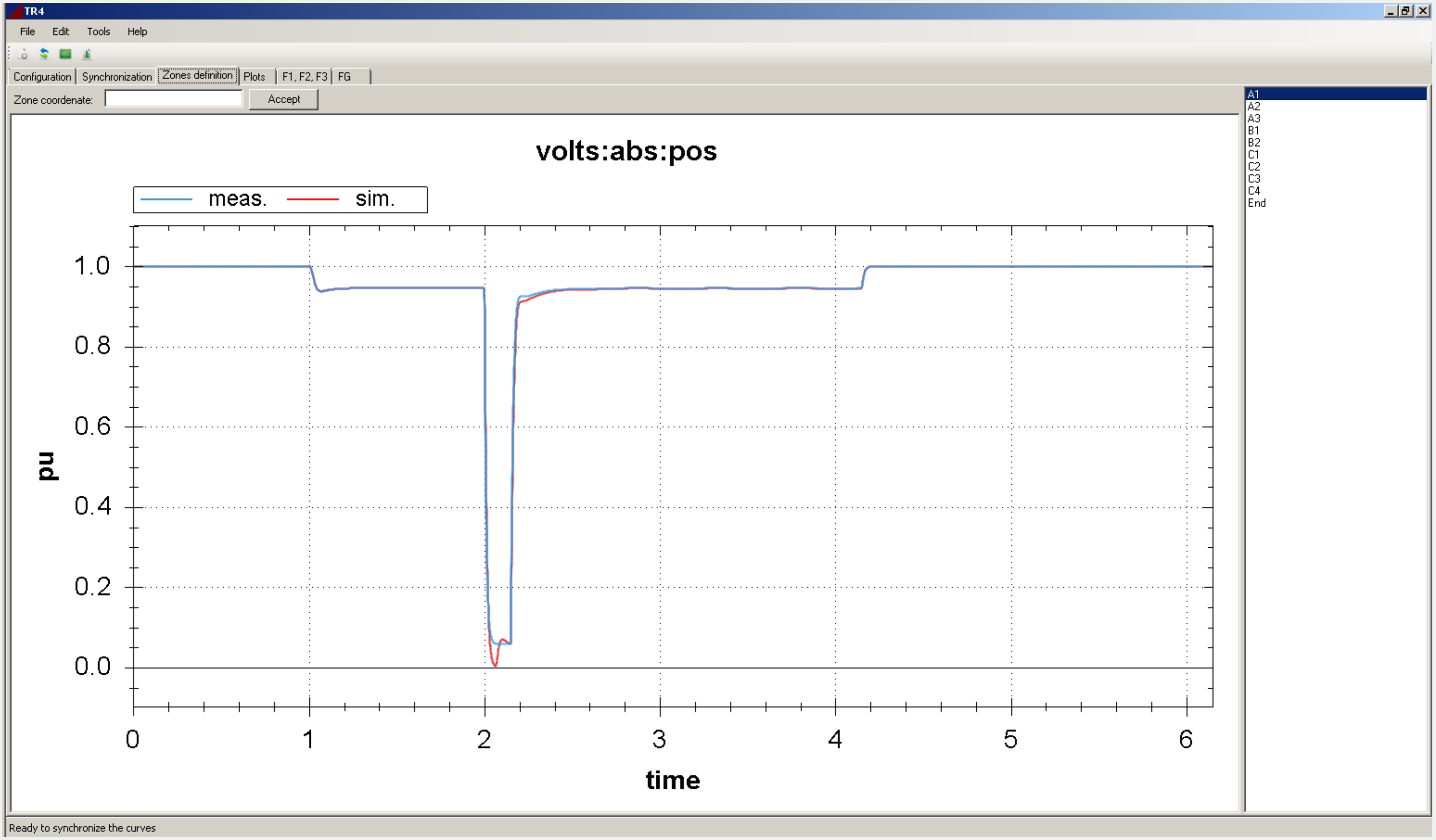
STEP 4.4: Synchronization

Move manually File 2 using arrow keys or by cursor selection

Accept manual synchronization to continue the analysis

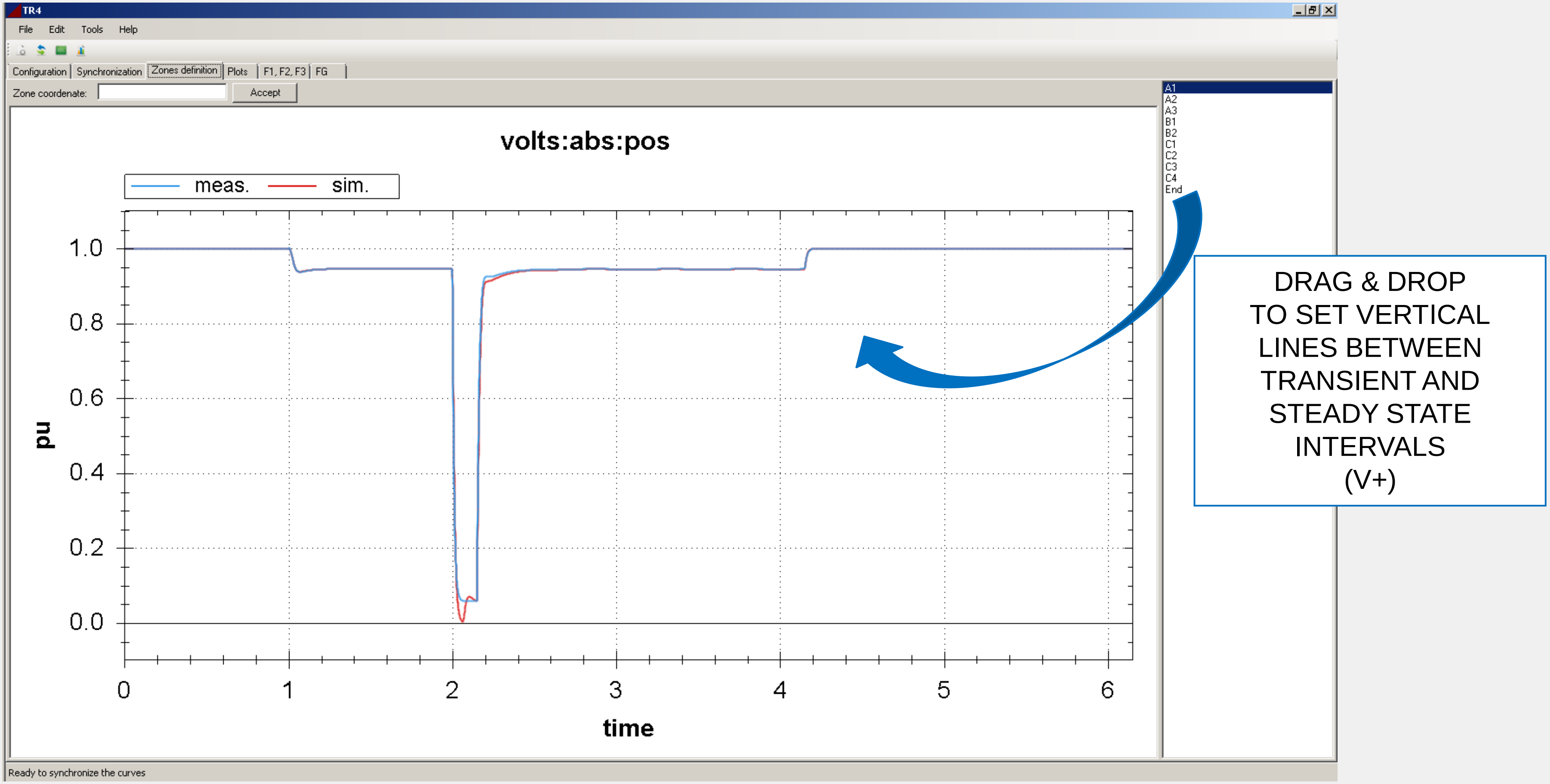
Example of Model Validation according to the German Grid Code

STEP 5: Define the zones A, B and C



STEP 5: Define the zones A, B and C

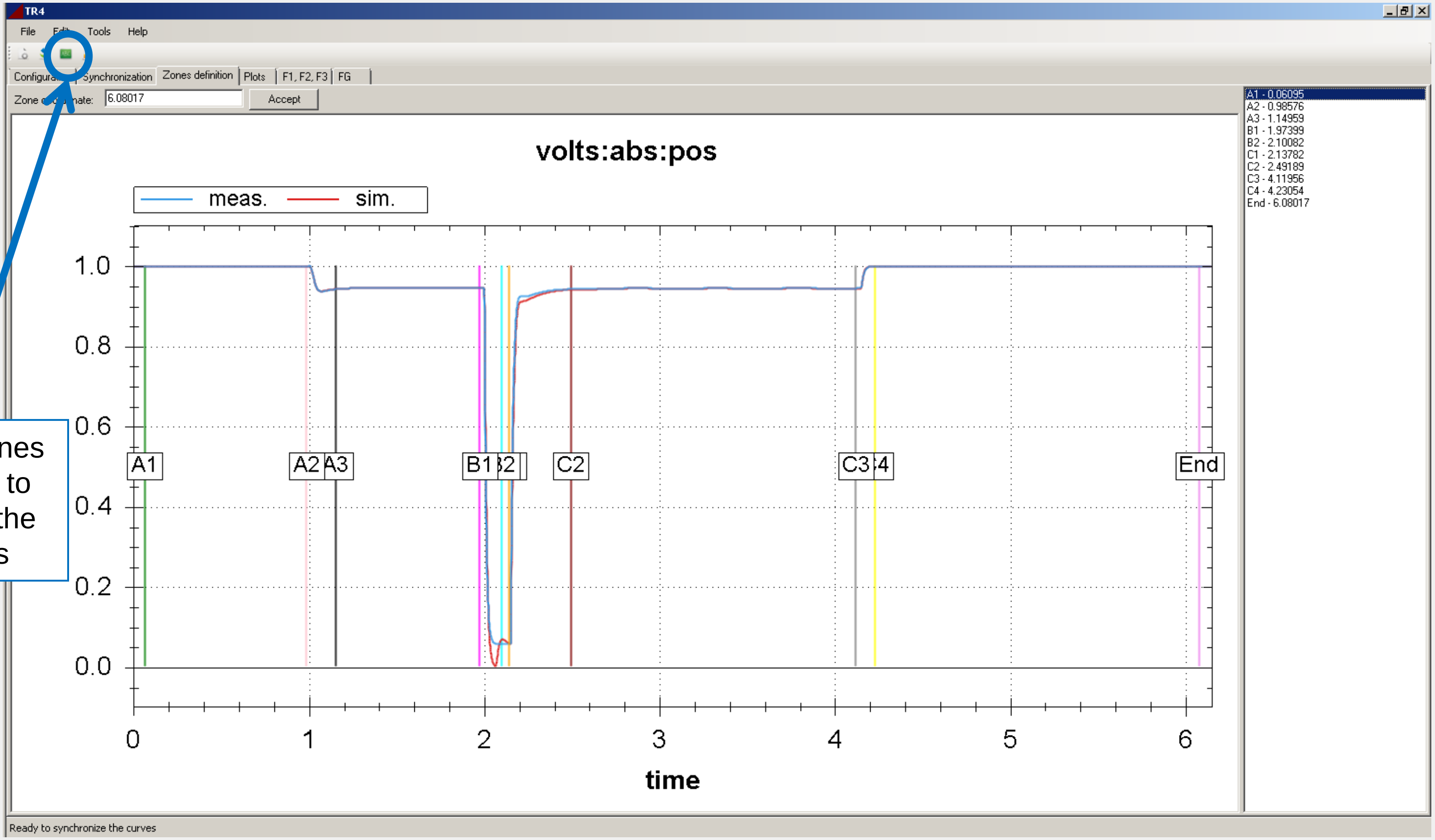
STEP 5.1: Drag and drop vertical lines A1, A2, A3, B1, B2, C1, C2, C3, C4 and End



Example of Model Validation according to the German Grid Code

STEP 5: Define the zones A, B and C using positive sequence voltage series.

STEP 5.1: Drag and drop vertical lines A1, A2, A3, B1, B2, C1, C2, C3, C4 and End



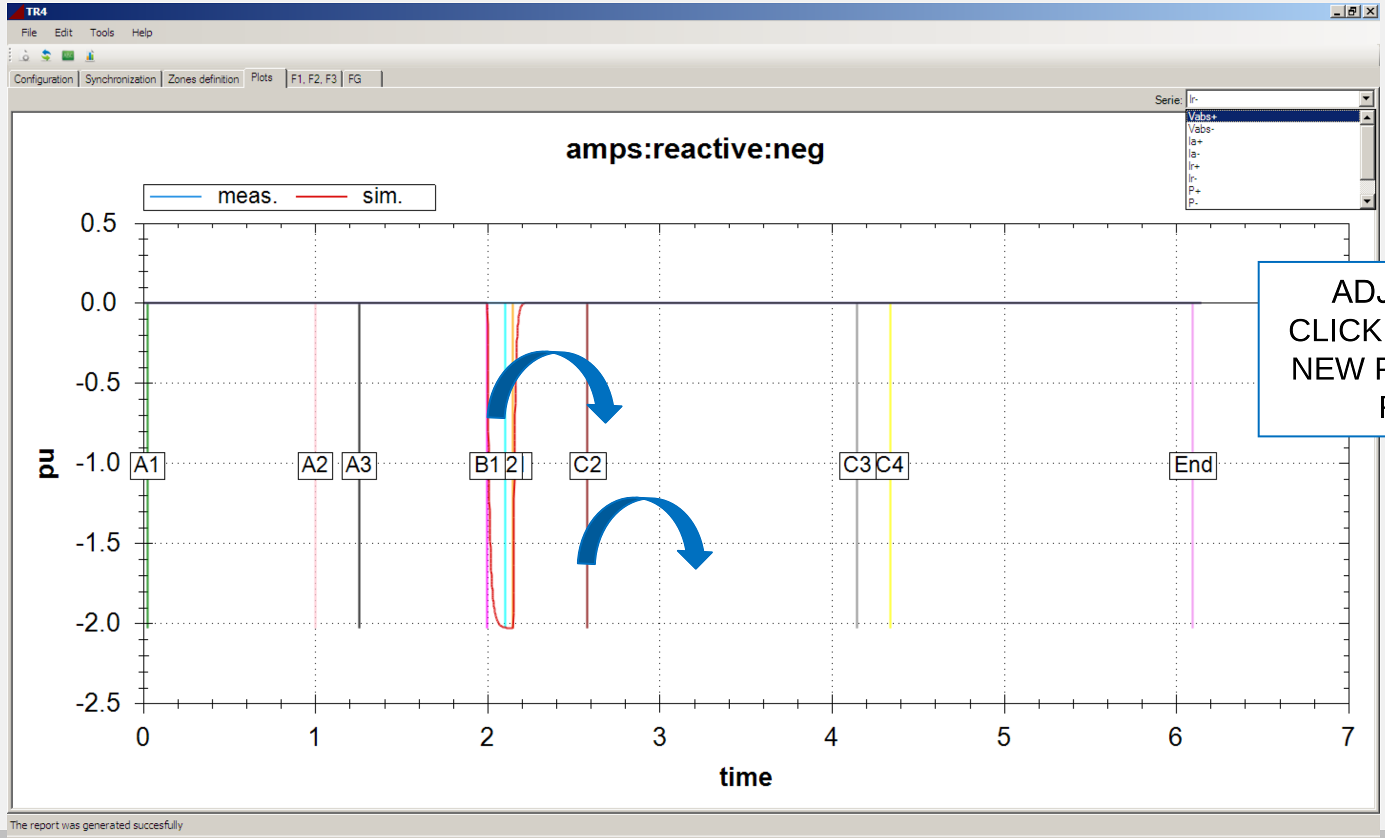
Accept zones definition to continue the analysis

Example of Model Validation according to the German Grid Code

STEP 5: Define the zones A, B and C

STEP 5.1: Drag and drop vertical lines A1, A2, A3, B1, B2, C1, C2, C3, C4 and End

STEP 5.2: Check plots to adjust transient zones in the rest of data series (P, Q, Ip, Iq)



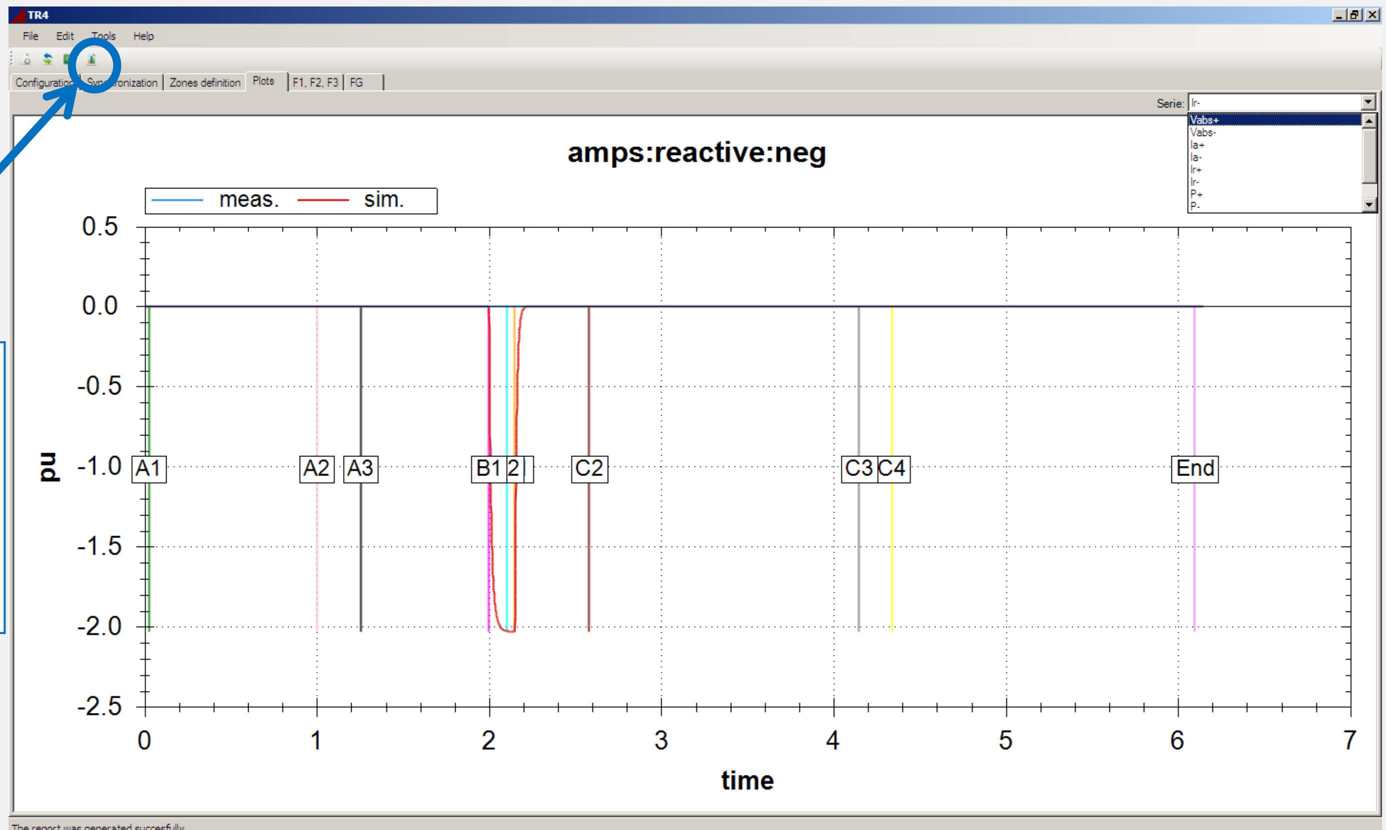
ADJUST B2, C2… CLICK AND DRAG TO A NEW POSITION WHEN REQUIRED

Example of Model Validation according to the German Grid Code

STEP 5: Define the zones A, B and C

STEP 5.1: Drag and drop vertical lines A1, A2, A3, B1, B2, C1, C2, C3, C4 and End

STEP 5.2: Check plots to adjust transient zones in the rest of data series (P, Q, Ip, Iq)



Accept zones definition in all data series to continue the analysis: Click on GENERATE REPORT

Example of Model Validation according to the German Grid Code

STEP 6: Analysis of results→ Summary of results is reported in table format

STEP 6.1: F1: Maximum deviation of the mean values → Steady State Areas

F2: Maximum deviation of the mean values → Transient State Areas

F3: Maximum deviation of Pos/Neg → Steady State Areas

F1, F2 and F3

TR4

File Edit Tools Help

Configuration | Synchronization | Zones definition | Plots | F1, F2, F3 | G

F1, F2

Serie	A1 (F1)	A2 (F2)	A3 (F1)	B1 (F2)	B2 (F1)	C1 (F2)	C2 (F1)	C3 (F2)	C4 (F1)
Vabs+	0	0	0	0.002	0	0.006	0	0	0
Vabs-	0	0	0	0.093	0.112	0.004	0	0	0
Ia+	0	0.004	0.001	**0.313**	**0.258**	0.044	0.013	0.012	0.007
Ia-	0	0	0	0.128	0.155	0.005	0	0	0
Ir+	0	0.001	0	0.036	0.024	0.068	0	0.002	0
Ir-	0	0	0	**1.718**	**2.071**	0.065	0	0	0
P+	0	0.005	0.001	0.153	**0.133**	0.023	0.012	0.011	0.007
P-	0	0	0	0.045	0.056	0.002	0	0	0
Q+	0	0.001	0	0.02	0.013	0.066	0	0.002	0
Q-	0	0	0	**0.603**	**0.75**	0.023	0	0	0

F3

Serie	A1	A3	B2	C2	C4
Vabs+	0	0	0.001	0.001	0
Vabs-	0	0	0.11	0	0
Ia+	0	0.004	**0.258**	0.024	0.012
Ia-	0	0	0.152	0	0
Ir+	0	0	0.024	0.002	0.001
Ir-	0	0	**2.03**	0	0
P+	0	0.004	0.133	0.022	0.012
P-	0	0	0.055	0	0
Q+	0	0	0.013	0.002	0.001
Q-	0	0	**0.736**	0	0

Example of Model Validation according to the German Grid Code

STEP 6: Analysis of results→ Summary of results is reported in table format

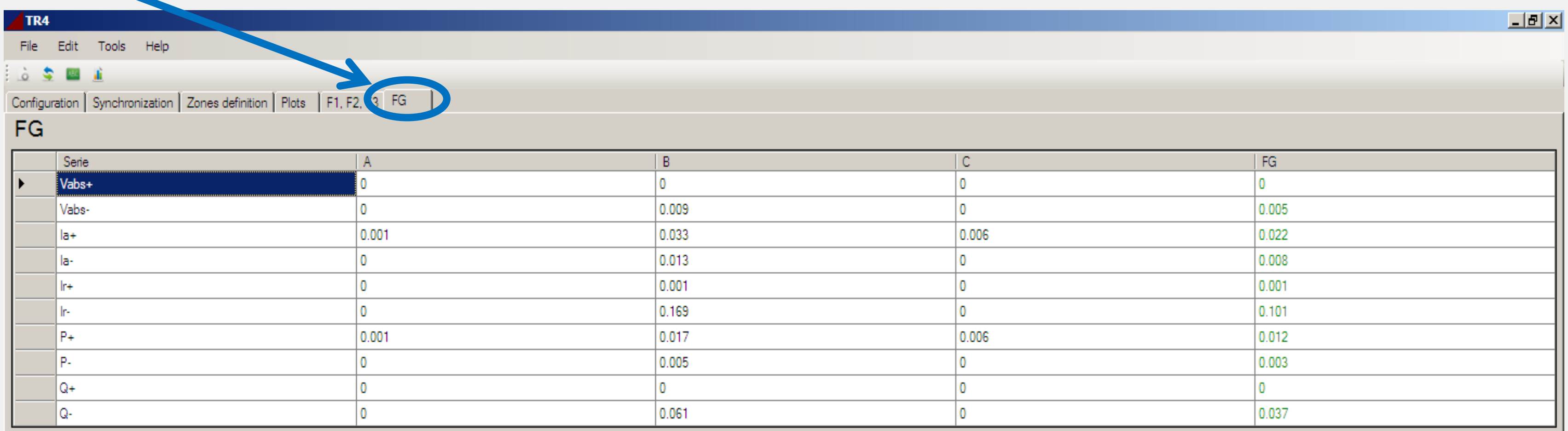
STEP 6.1: F1: Maximum deviation of the mean values → Steady State Areas

F2: Maximum deviation of the mean values → Transient State Areas

F3: Maximum deviation of Pos/Neg → Steady State Areas

STEP 6.2: FG: Total error as mean value of the weighted errors

FG



Serie	A	B	C	FG
Vabs+	0	0	0	0
Vabs-	0	0.009	0	0.005
Ia+	0.001	0.033	0.006	0.022
Ia-	0	0.013	0	0.008
Ir+	0	0.001	0	0.001
Ir-	0	0.169	0	0.101
P+	0.001	0.017	0.006	0.012
P-	0	0.005	0	0.003
Q+	0	0	0	0
Q-	0	0.061	0	0.037

STEP 7: REPORTING

Results are reported in Word format.

DIgSILENT Grid Code - Model Validation TR4

FILES:
MEAS 1
SIM 2

AVERAGE ERRORS TYPE F1(steady-states) & F2(transients) [%]

Serie	A1 (F1)	B1 (F2)	B2 (F1)	C1 (F2)	C2 (F1)
Vabs+	0.0	1.6	0.8	1.4	0.3
Vabs-	0.5	4.0	2.5	1.0	0.5
Ia+	0.7	5.1	1.4	3.4	1.1
Ia-	0.6	4.8	4.0	6.9	0.6
Ir+	0.0	6.0	0.4	3.5	0.5
Ir-	0.4	16.4	2.1	6.3	0.4
P+	0.8	2.1	0.1	3.2	0.9
P-	0.0	3.0	3.3	2.5	0.0
Q+	0.0	4.6	0.1	1.9	0.5
Q-	0.0	1.4	2.0	2.2	0.0

ERRORS TYPE F3(maximum errors - steady-states) [%]

Serie	A1	B2	C2
Vabs+	0.7	2.5	1.5
Vabs-	0.8	4.3	0.9
Ia+	2.0	13.8	4.3
Ia-	0.9	10.6	0.9
Ir+	1.2	7.0	1.7
Ir-	0.9	8.1	0.9
P+	2.1	8.8	3.9
P-	0.0	4.5	0.0
Q+	1.2	4.5	1.8
Q-	0.0	5.2	0.0

ERRORS TYPE FG(weighted errors) [%]

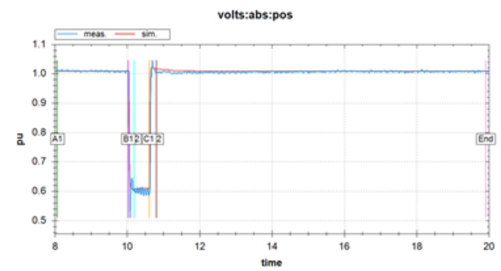
Serie	A	B	C	FG
Vabs+	0.0	0.4	0.0	0.2
Vabs-	0.4	1.3	0.0	0.8
Ia+	0.7	0.3	0.0	0.2
Ia-	0.6	2.1	0.0	1.3
Ir+	0.0	0.2	0.0	0.1
Ir-	0.4	1.0	0.0	0.6
P+	0.7	0.0	0.0	0.1
P-	0.0	1.8	0.0	1.1
Q+	0.0	0.0	0.0	0.0
Q-	0.0	1.1	0.0	0.7

GridCode v1.2 – Report Generator
Date Report: 07/12/2011 10:39:49
Date File(s): 01/12/2011 09:05:29

ZONES DEFINITION [s]

Series	A1	B1	B2	C1	C2	End
Vabs+	8.069	10.029	10.193	10.607	10.803	19.907
Vabs-	8.069	10.029	10.193	10.607	10.803	19.907
Ia+	8.069	10.029	10.193	10.607	12.014	19.907
Ia-	8.069	10.029	10.193	10.607	10.803	19.907
Ir+	8.069	10.029	10.193	10.607	10.803	19.907
Ir-	8.069	10.029	10.260	10.607	10.803	19.907
P+	8.069	10.029	10.193	10.607	12.003	19.907
P-	8.069	10.029	10.193	10.607	10.803	19.907
Q+	8.069	10.029	10.193	10.607	10.803	19.907
Q-	8.069	10.029	10.193	10.607	10.803	19.907

PLOTS



Example of Model Validation according to the German Grid Code

CONCLUSIONS

The German Method as proposed in the TR4 is verified with DIgSILENT GridCode, comparing two wind turbine models that separately can fulfill the requirements of the German Grid Code. The DIgSILENT GridCode tool is very flexible:

- Different file formats can be configured.
- Different data series can be compared: from measurements, simulations, etc.
- Data series compared are defined by TR4. Active current is also included in the comparison although TR4 does not require it.
- Manual synchronization is a good approach to overlap both series.
- Zone definition is a user-friendly process:
    - Drag and drop the bar.
    - Adjust the area definition for every data series.
- A summary of results in table format is shown.
- A report is automatically generated in Microsoft Word© format.
- More validation methods are rising worldwide and will be included in next versions: IEC61400-27 validation method

DIgSILENT GridCode Contact

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