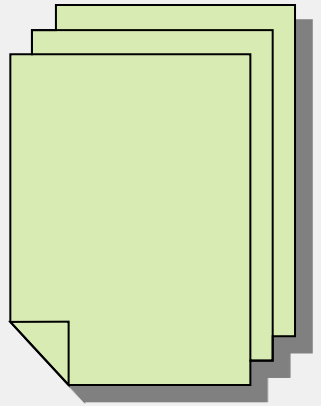
DIgSILENT GridCode

DIgSILENT REP Meeting
23-25 September 2013 - Gomaringen (Germany)

Type of requirements defined in a Grid Code

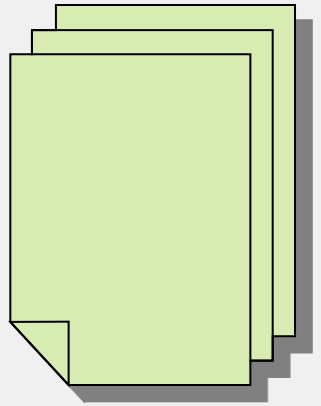
Typical requirements:

- **General requirements and general data:**
  - Geographical area and system limits: voltage and power ratings
  - Specification on the Point of Connection (POC, PUC, PCC, PC…)
  - Short-Circuit Power (S_k'') requirements
  - Grounding systems
- **Steady State performance:**
  - Frequency
  - Voltage
  - Active and Reactive Power
  - Power Quality parameters



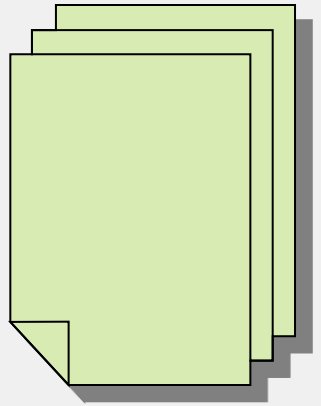
Type of requirements defined in a Grid Code

- **Dynamic performance:**
  - Frequency gradients and power ramp rates
  - Start-Stop
  - Islanding with load requirements
  - Control of active power/frequency
  - Control of reactive power capability:
    - Power factor control mode
    - Reactive power control mode
    - Voltage control mode
  - Fault ride through – FRT
  - Temporary overvoltage – TOV
  - System and relay protection
  - Run-Back
  - Inertial response



Type of requirements defined in a Grid Code

- **Communication and control interface:**
  - Plant status information
  - Meteorological information
- **Others:**
  - Simulation models: integration and design
  - System planning simulation models
  - Certification/Requirements verification
  - Model Validation
  - Commissioning
  - Performance testing



Common features in worldwide Grid Codes

New grid code requirements are rising around the world, with the following features:

- Specific requirements for every country: due to country-specific network characteristics, islanded systems, strong/weak interconnected systems…
- Specific requirements for every technology: conventional power plants, wind power, solar power, hydro, combined-cycle gas turbine facilities…
- Specific requirements for every voltage level: low, medium, high voltage level…
- Specific requirements on the maximum power: ENTSO-e grid code is defining requirements for units with maximum capacity higher or equal to >**800W**
- Lack of information supporting the interpretation of requirements: are requirements defined at the PCC? Are requirements defined at HV, MV or LV side? Which measurements? How to verify them?
- Poorly defined measurement and validation methods: based on smart-eyes, absolute or relative errors, averages, IEC methods, country-specific methods, certification procedures, etc…

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Specific algorithms and parameters are required for every specific requirement

GRID CODE tracking is required to update parameters in every country

Common features in worldwide Grid Codes

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No international agreement on measurement, verification or validation methods

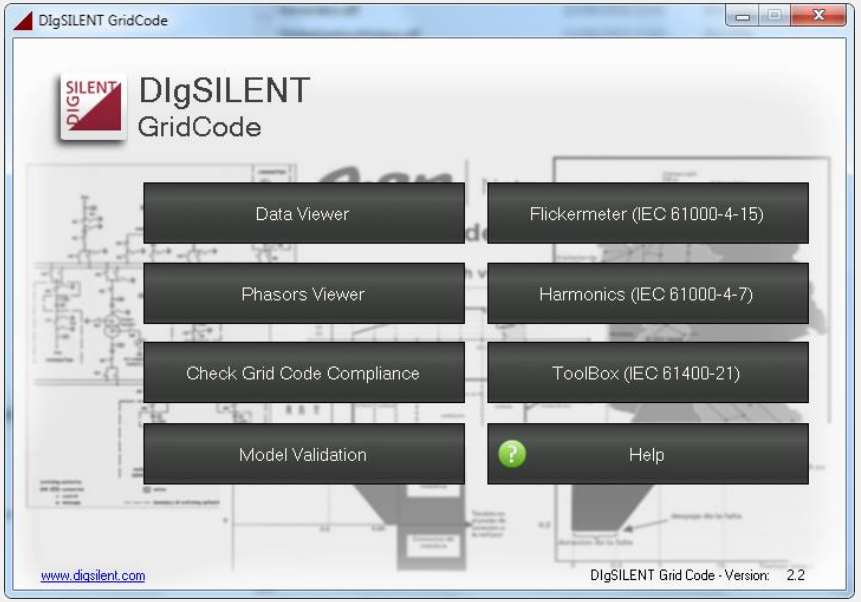
Model validation is important to improve reliability of dynamic simulations

DIgSILENT GridCode

DIgSILENT GridCode

DIgSILENT GridCode is a tool designed for the off-line verification of Grid Code requirements in power plants, covering the following topics from the **LIST**:

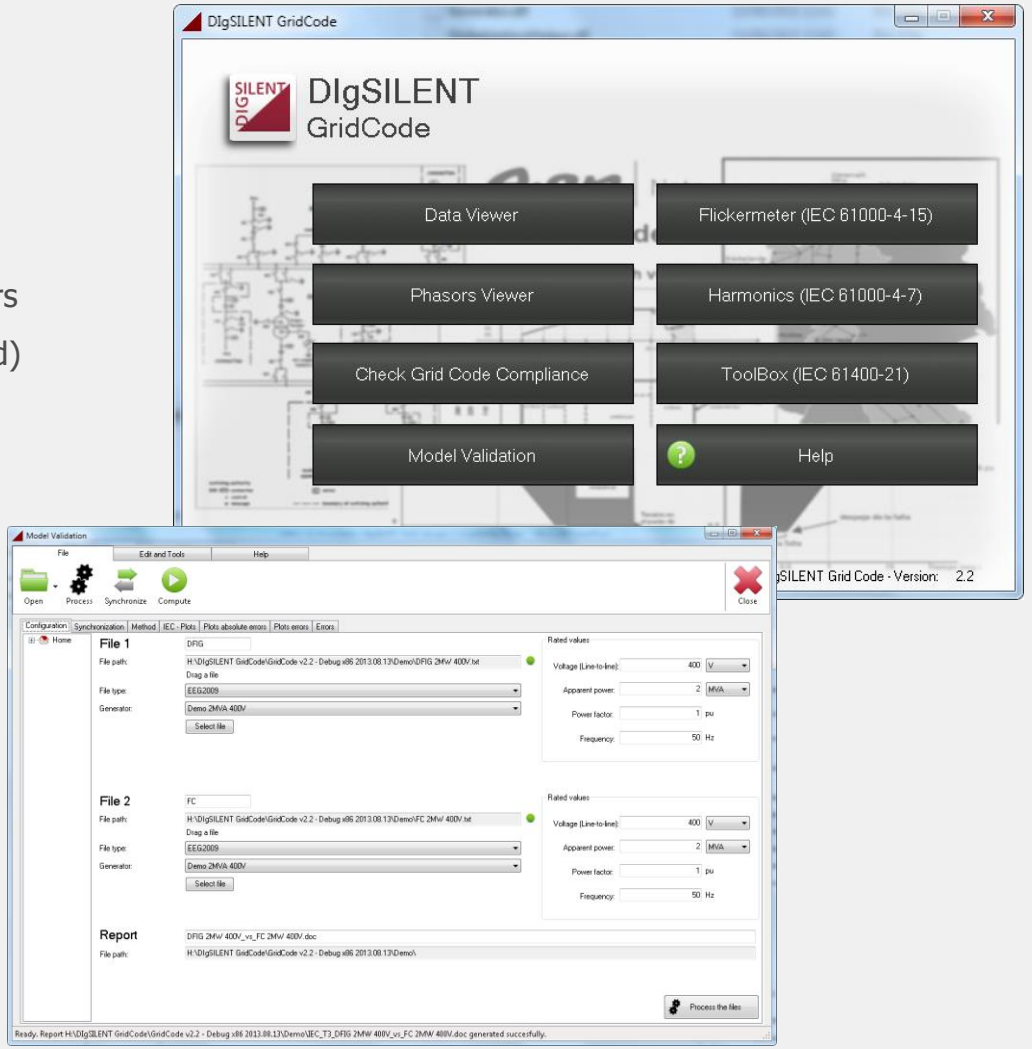
- STEADY-STATE PERFORMANCE:
  - Power Quality parameters
- DYNAMIC PERFORMANCE:
  - Step response
  - FRT
  - TOV
- OTHERS:
  - Requirements verification
  - Model Validation
  - Performance testing



DIgSILENT GridCode

DIgSILENT GridCode is offered:

- Workstation, single user
- Maintenance → 12%/year
- Additional users → PF reductions
- Current customers:
  - Wind and PV Generator Manufacturers
  - Measurement laboratories (accredited)
  - Field Testing consultants

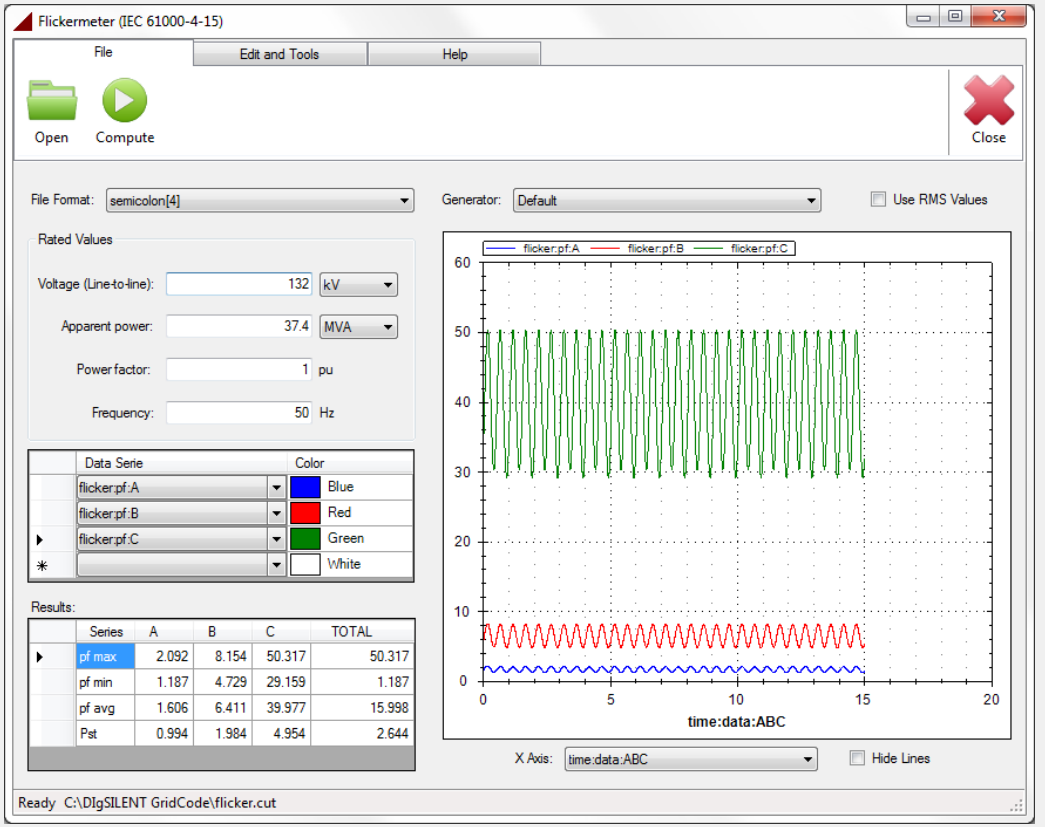


DIgSILENT GridCode:

ANALYSIS OF STEADY-STATE PERFORMANCE

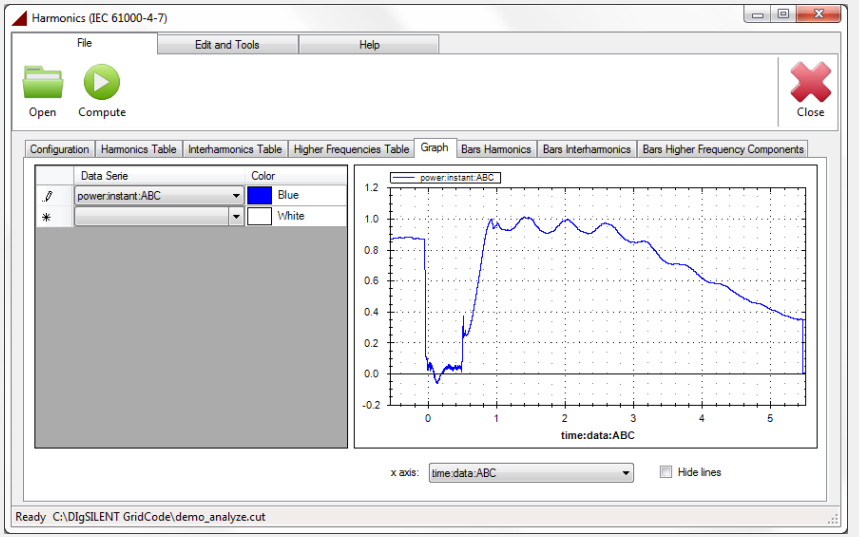
IEC 61000-4-15 Flickermeter

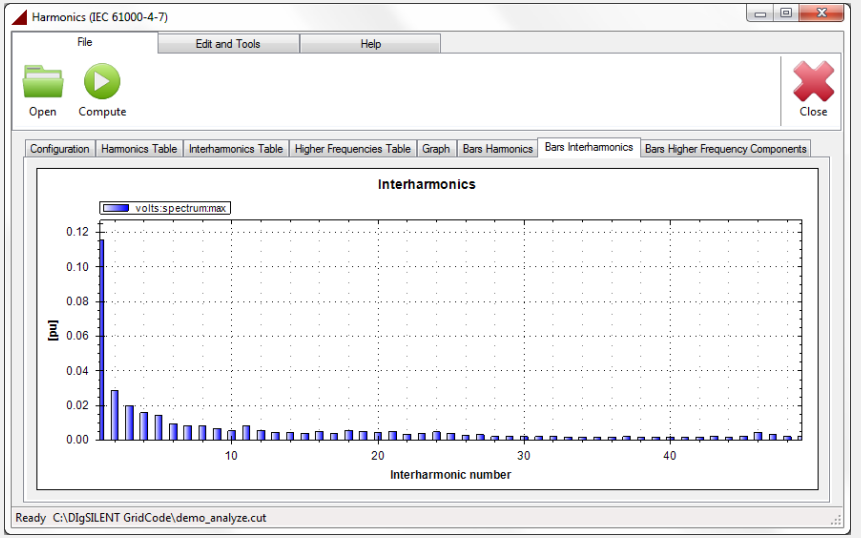
- IEC 61000-4-15
- File resampling
- Visualization of instant flicker (PF)
- Pst phase, min, max and avg
- Export plotted data to csv file
- Copy/paste graphics



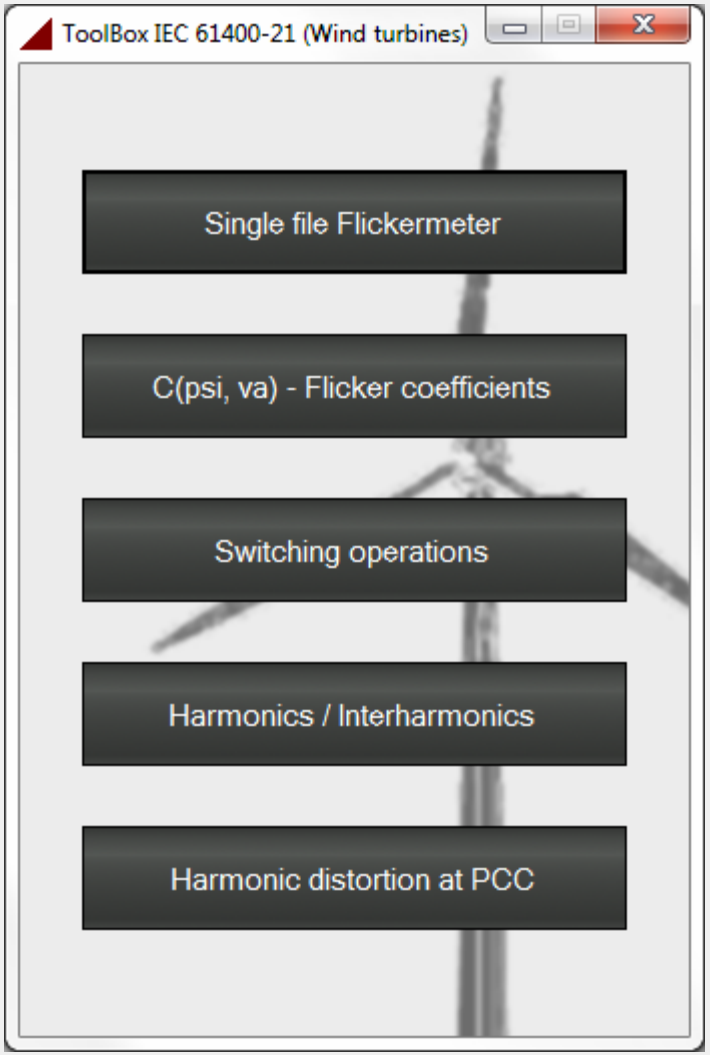
IEC 61000-4-7 Voltage Harmonics

- IEC 61000-4-7
- Harmonics, Inter-harmonics, Higher frequency components
- Export graphics to csv file
- Copy/paste graphics
- Bar plots
- Time evolution of harmonics, inter-harmonics and higher frequency components
- Several files can be analyzed in a row





IEC 61400-21 Toolbox



Assessment of power quality characteristics of grid connected wind turbines:

- Flicker emission
- Flicker coefficients
- Flicker emission during switching operations
- Current harmonics emissions

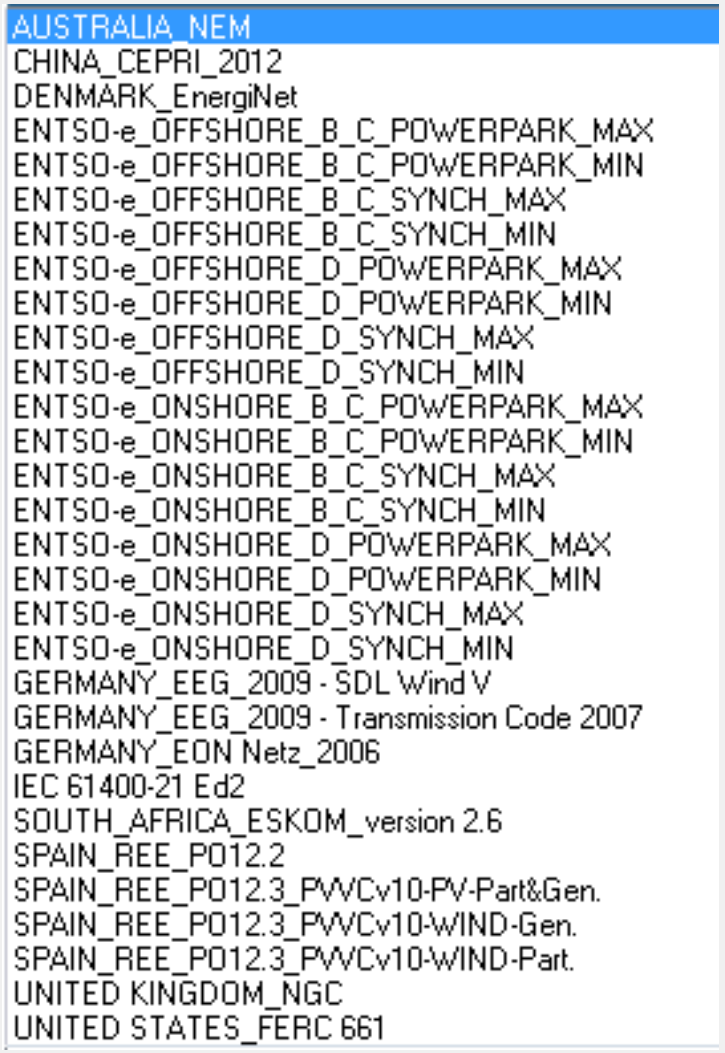
DIgSILENT GridCode:

ANALYSIS OF DYNAMIC PERFORMANCE

DYNAMIC PERFORMANCE

DIgSILENT GridCode includes the verification of compliance according to the following Grid Codes:

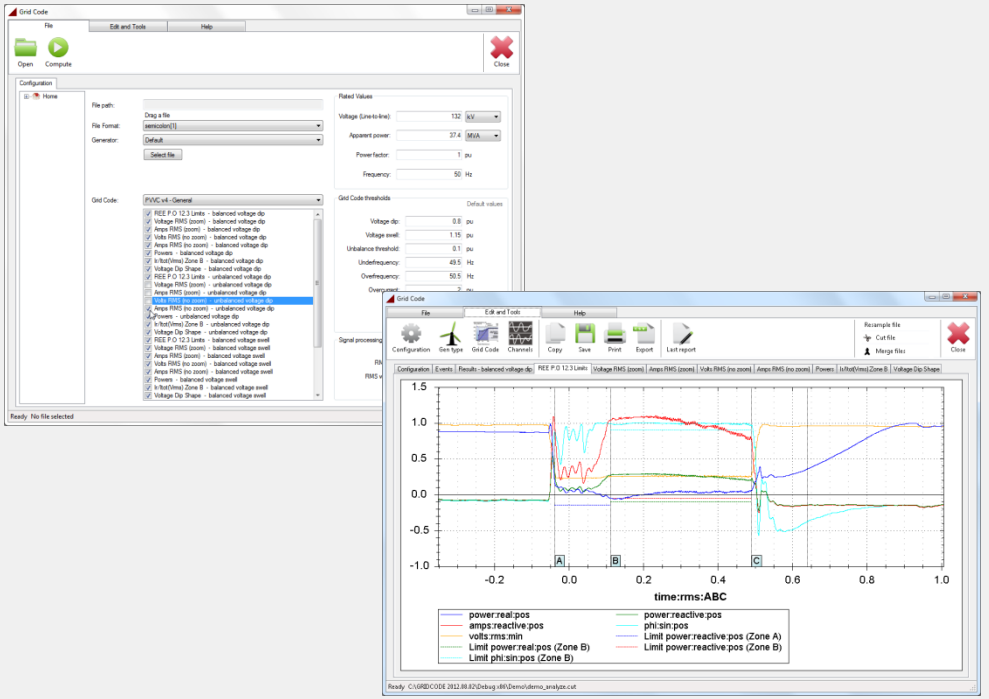
- Australia (NEM)
- China (CEPRI)
- Denmark (EnergiNet)
- ENTSO-e grid code:
  - Types B, C, D
  - Conventional generation, wind power plants, offshore power plants
- Germany (EEG2009 – SDL+Transmission, EOn)
- IEC 61400-21 Ed 2
- South Africa (Eskom)
- Spain (REE)
- England (NGC)
- US (FERC)

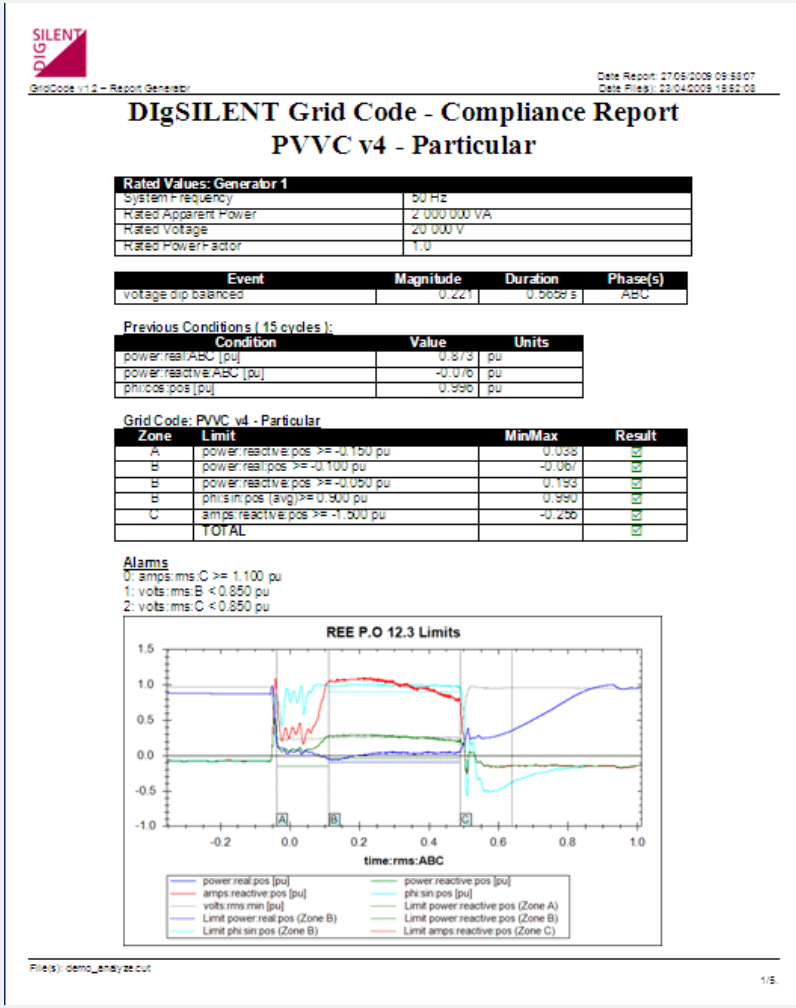


FAULT RIDE THROUGH ANALYSIS

Example of fault ride through (FRT) analysis:

- Select input measurement or simulation files
- Enter channel configuration
- Select country
- Process data
- Get automatic report (MS Word format)





FAULT RIDE THROUGH ANALYSIS

Example of fault ride through (FRT) analysis:

- Output data depends on the country → Example Germany

DIgSILENT Grid Code - Compliance Report
GERMANY_EEG_2009 - SDL Wind V

Rated values: Demo 2MVA 20kV	
System frequency	50 Hz
Rated apparent power	2.0 MVA
Rated voltage	20.0 kV
Rated power factor	1.0

Event	Magnitude	Duration	Phase(s)
balanced voltage dip	0.221	2.1273	A B C

Results for event: balanced voltage dip

Initial conditions: 15 cycles

Condition	Value	Units
power:real:ABC	0.873	pu
power:reactive:ABC	-0.076	pu
volts:frequency:A	49.912	Hz
volts:abs:pos	0.970	pu
amps:abs:pos	0.903	pu
amps:reactive:pos	-0.078	pu

Results:

Zone	Limit	Value	Units	Result
A	starting time [s]	-0.055	s	
A	response time [s] <= 0.03 s	-0.055	s	☑
A	transient time (tt) [s] <= 0.06 s	0.005	s	
B	signal stable tt-end [YES=1 / NO=0]	0.000	none	☒
B	ΔI = |Ir(t2) - Ir(prefault)|	0.049	pu	
B	ΔU = |U(t2) - U(prefault)|	0.068	pu	
B	K SDL Wind V	-1.552	none	
B	K Transmission Code 2007	0.726	none	
C	starting time [s]	2.072	s	
C	Power rising time (P0-5%) [s] <= 5s	5.492	s	☑
C	Power recovery (average 5s) [pu] >= 0.43 pu (1/2 P0) (Not enough time: Measured until end of file.)	0.349	pu	☒
C	Power recovery full range [YES=1 / NO=0]	0.000	none	☒
C	U-Q protection - consumption [s] < 0.5s	1.547	s	☒
TOTAL				☒

Short circuit currents:

Time	Current	Time [s]	Value	Units
Init - t0	Peak current phase A	-0.0354	73.828	A
Init - t0	Peak current phase B	-0.0354	78.904	A
Init - t0	Peak current phase C	-0.0354	102.966	A
Init - t0	Half-period RMS current phase A	-0.0354	181.816	A
Init - t0	Half-period RMS current phase B	-0.0354	193.823	A
Init - t0	Half-period RMS current phase C	-0.0354	77.169	A
Init - t0	Half-period RMS current max(A,B,C)	-0.0354	193.823	A
Init - t0	Full-period RMS current phase A	-0.0354	120.620	A
Init - t0	Full-period RMS current phase B	-0.0354	117.036	A
Init - t0	Full-period RMS current phase C	-0.0354	65.442	A
Init - t0	Full-period RMS current max(A,B,C)	-0.0354	120.620	A
Init - t0	Full-period neg sequence current	-0.0354	33.891	A
Init - t0	Full-period pos sequence current	-0.0354	87.167	A
Init - t0	Full-period zero sequence current	-0.0354	0.309	A
t0 - t1	Peak current phase A	0.0946	237.782	A
t0 - t1	Peak current phase B	0.0946	30.372	A
t0 - t1	Peak current phase C	0.0946	114.015	A
t0 - t1	Half-period RMS current phase A	0.0946	200.744	A
t0 - t1	Half-period RMS current phase B	0.0946	194.149	A
t0 - t1	Half-period RMS current phase C	0.0946	68.215	A
t0 - t1	Half-period RMS current max(A,B,C)	0.0946	200.744	A
t0 - t1	Full-period RMS current phase A	0.0946	54.206	A
t0 - t1	Full-period RMS current phase B	0.0946	49.524	A
t0 - t1	Full-period RMS current phase C	0.0946	57.568	A
t0 - t1	Full-period RMS current max(A,B,C)	0.0946	57.568	A
t0 - t1	Full-period neg sequence current	0.0946	14.555	A
t0 - t1	Full-period pos sequence current	0.0946	49.425	A
t0 - t1	Full-period zero sequence current	0.0946	11.789	A
t2 - end	Peak current phase A	2.0519	81.178	A
t2 - end	Peak current phase B	2.0519	90.313	A
t2 - end	Peak current phase C	2.0519	87.913	A
t2 - end	Half-period RMS current phase A	2.0519	63.162	A
t2 - end	Half-period RMS current phase B	2.0519	65.387	A
t2 - end	Half-period RMS current phase C	2.0519	60.779	A
t2 - end	Half-period RMS current max(A,B,C)	2.0519	65.387	A
t2 - end	Full-period RMS current phase A	2.0519	60.706	A
t2 - end	Full-period RMS current phase B	2.0519	62.562	A
t2 - end	Full-period RMS current phase C	2.0519	59.007	A
t2 - end	Full-period RMS current max(A,B,C)	2.0519	62.562	A
t2 - end	Full-period neg sequence current	2.0519	1.961	A
t2 - end	Full-period pos sequence current	2.0519	60.578	A
t2 - end	Full-period zero sequence current	2.0519	0.117	A

Legend:

- init: start of dip
- t0: 20ms after starting of voltage dip
- t1: 150ms after starting of voltage dip
- t2: 20ms before voltage dip end
- end: end of the voltage dip

Figure 1 - Voltage Support

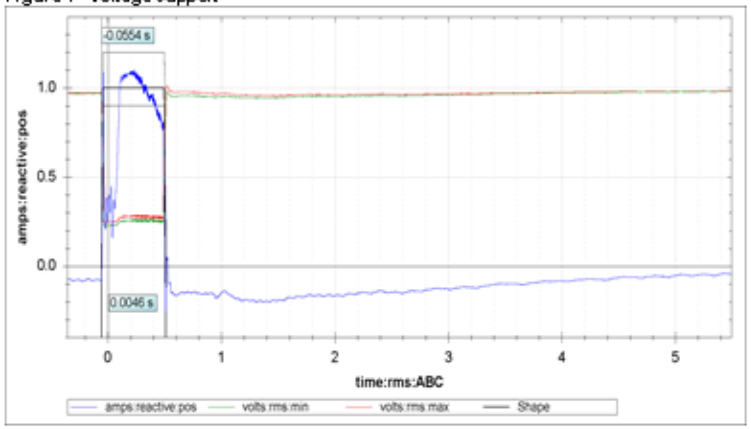


Figure 2 - Volts RMS

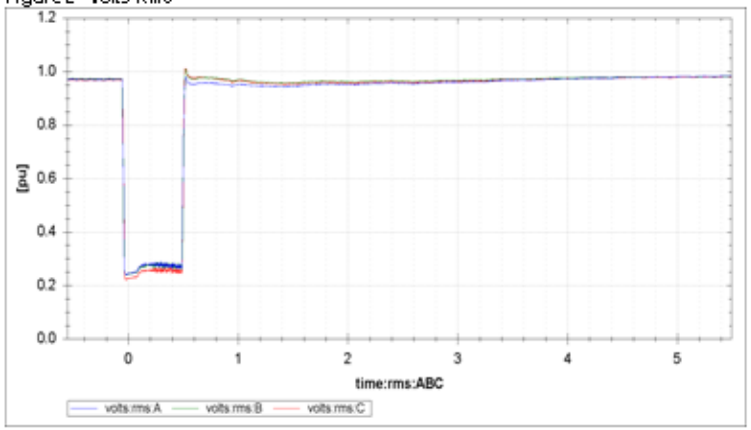


Figure 3 - Volts RMS Zoom

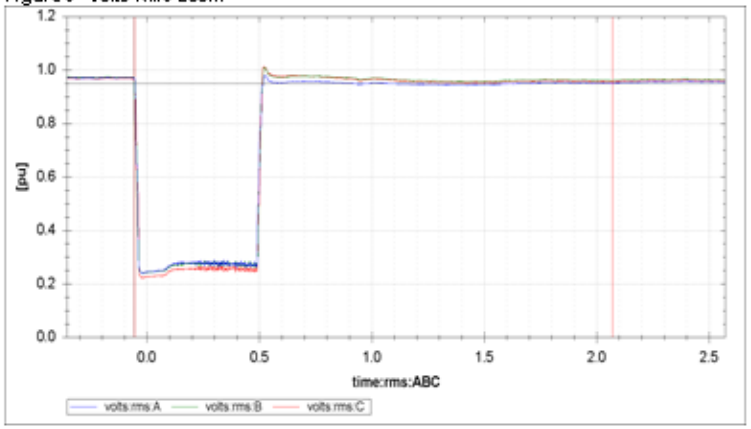


Figure 4 - Voltage Dip Shape

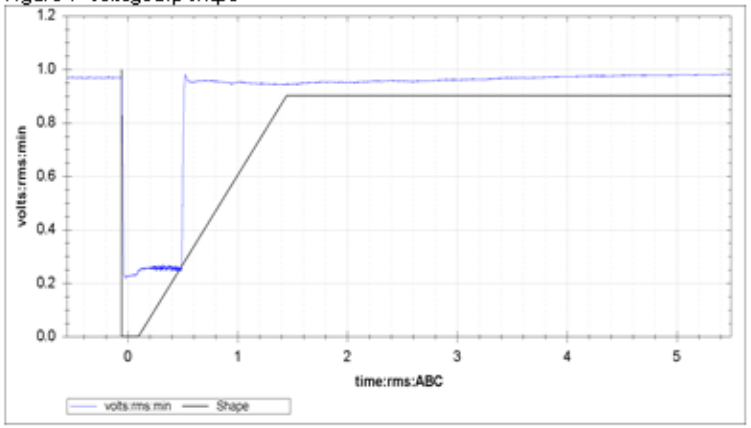


Figure 5 - Powers

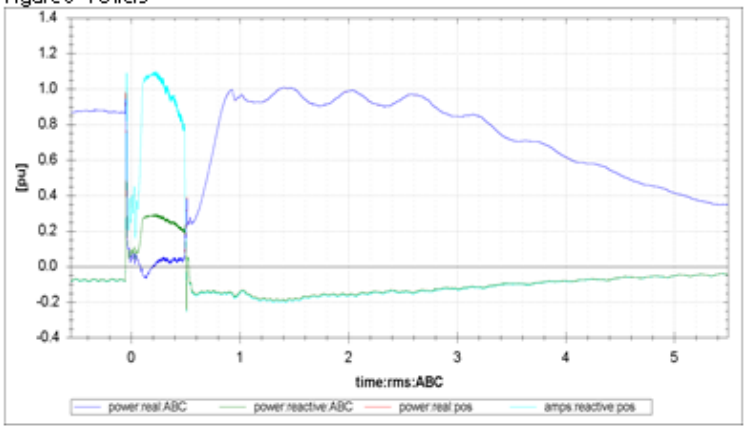


Figure 6 - Active Power Restoration

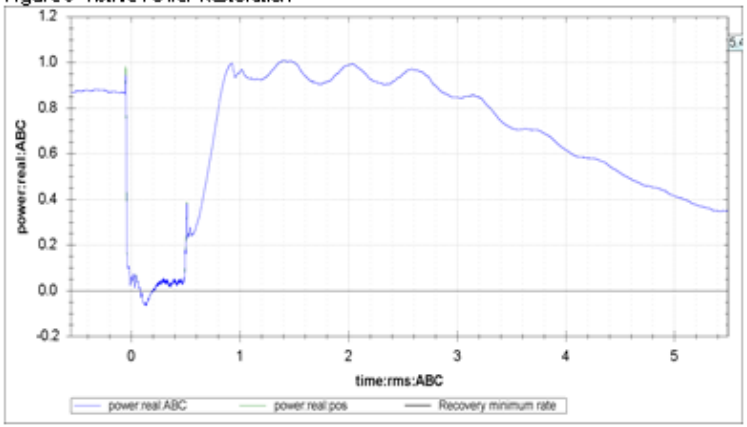
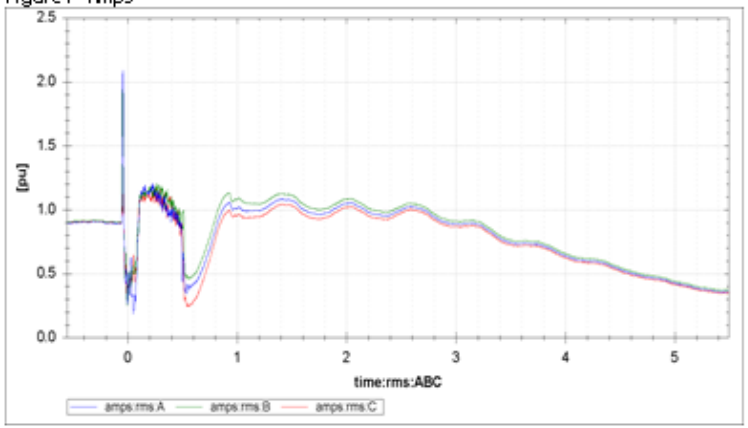


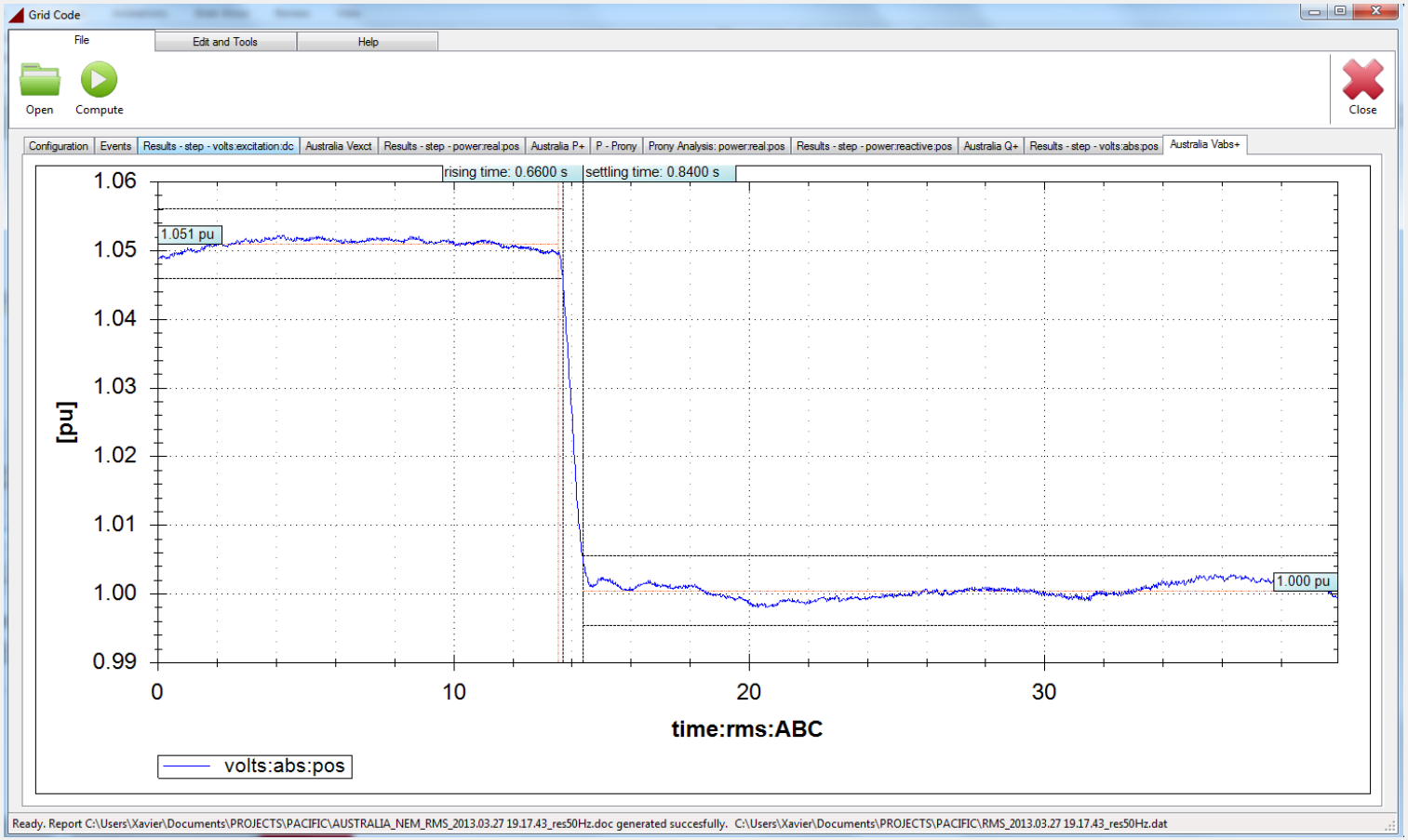
Figure 7 - Amps



STEP ANALYSIS

Example of new function → **"Step Detection"**

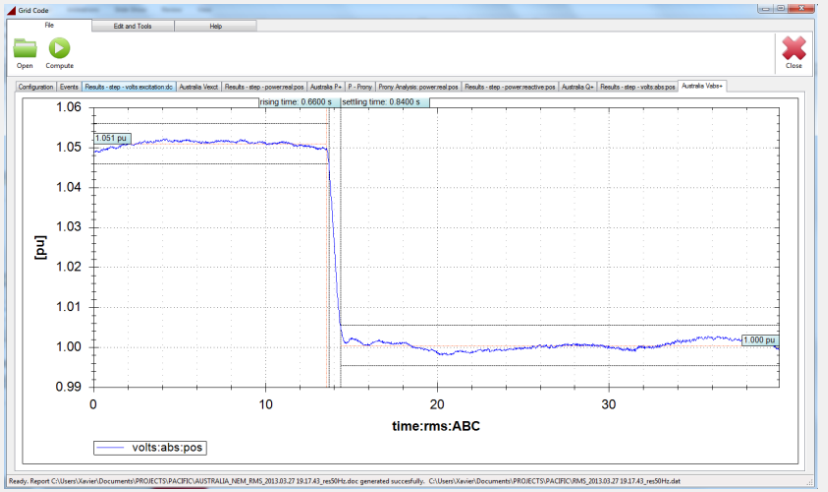
Developed in collaboration with DIgSILENT Pacific for testing conventional generation

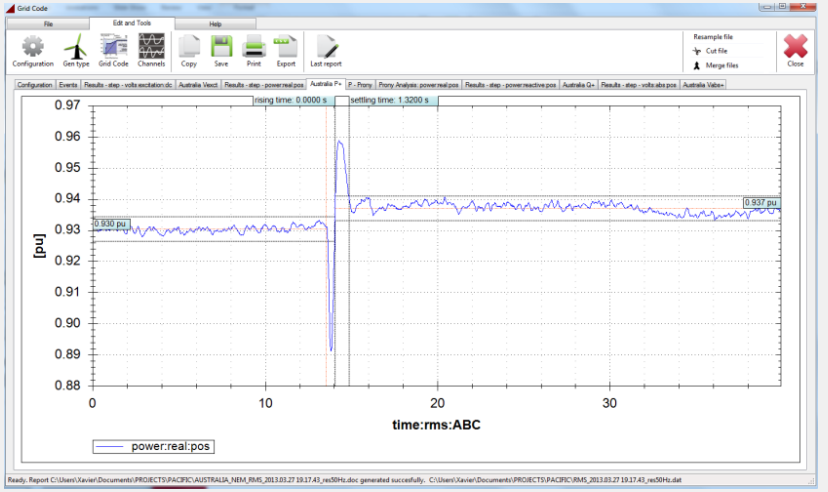


STEP ANALYSIS

Step detection is based on sophisticated signal processing algorithms detecting fast transients in the signal. The step event is defined by different characteristics:

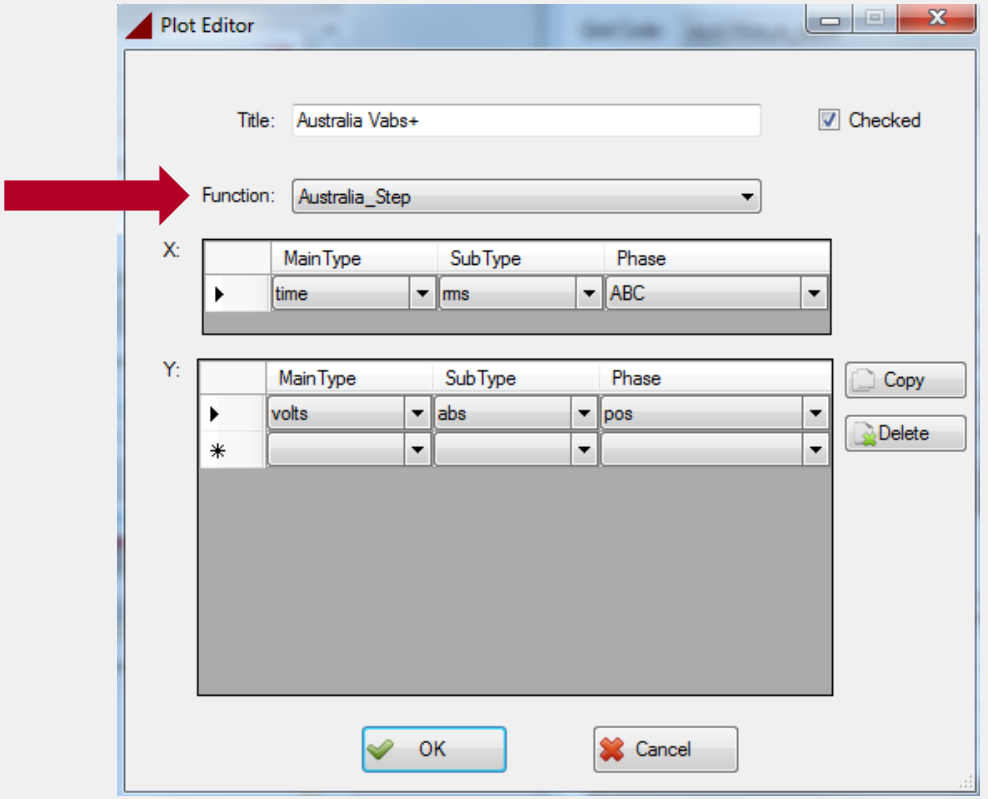
- **Start**: the knee-point is accurately detected
- **Settling band**: computation of average values before and after the events allow defining a tolerance band around them
- **Settling-time**: defined when the signal enters and remains within the settling band
- **Rising-time**: time between the moment the signal leaves the tolerance band before the event and the time it enters the settling band for the first time





STEP ANALYSIS

New function to display rising, settling times and settling values on plots



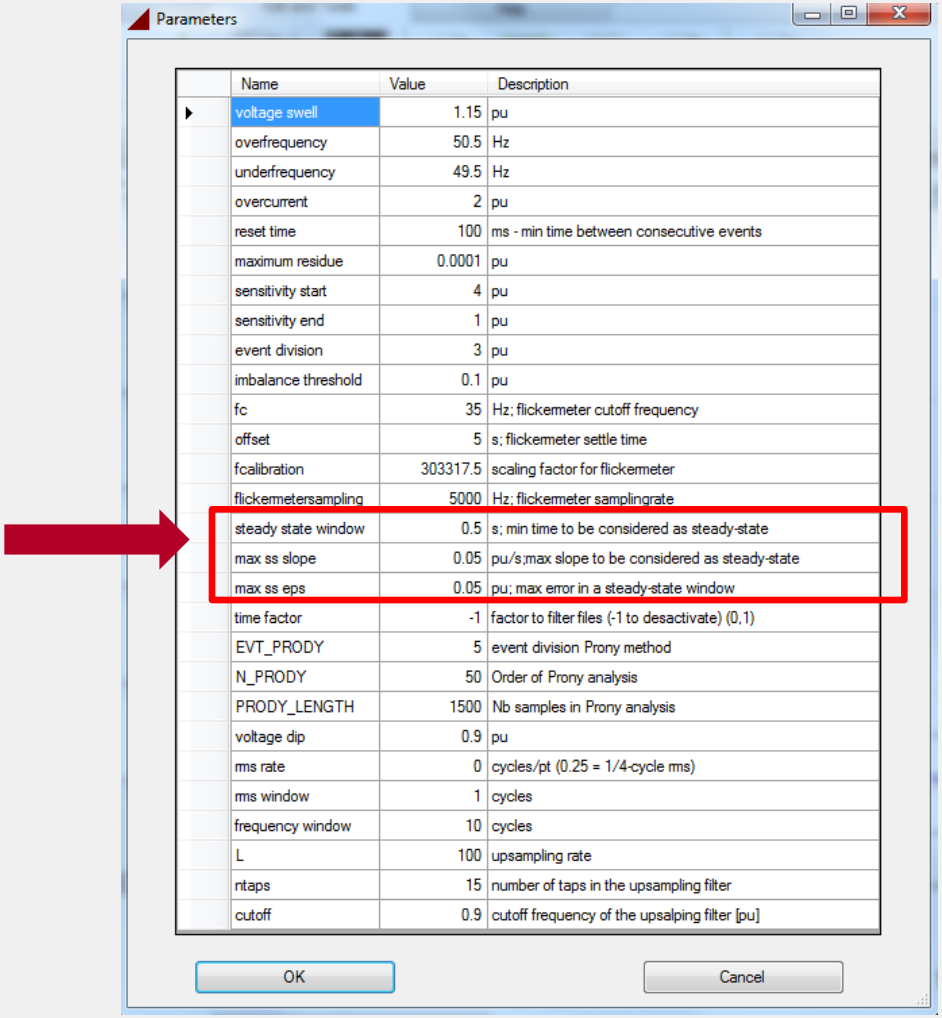
STEP ANALYSIS

Important configuration parameters for step detection:

- **Steady state window:** defines the minimum duration of a steady-state

- **Max ss slope:** maximum slope of linear approximation of the curve during a steady-state

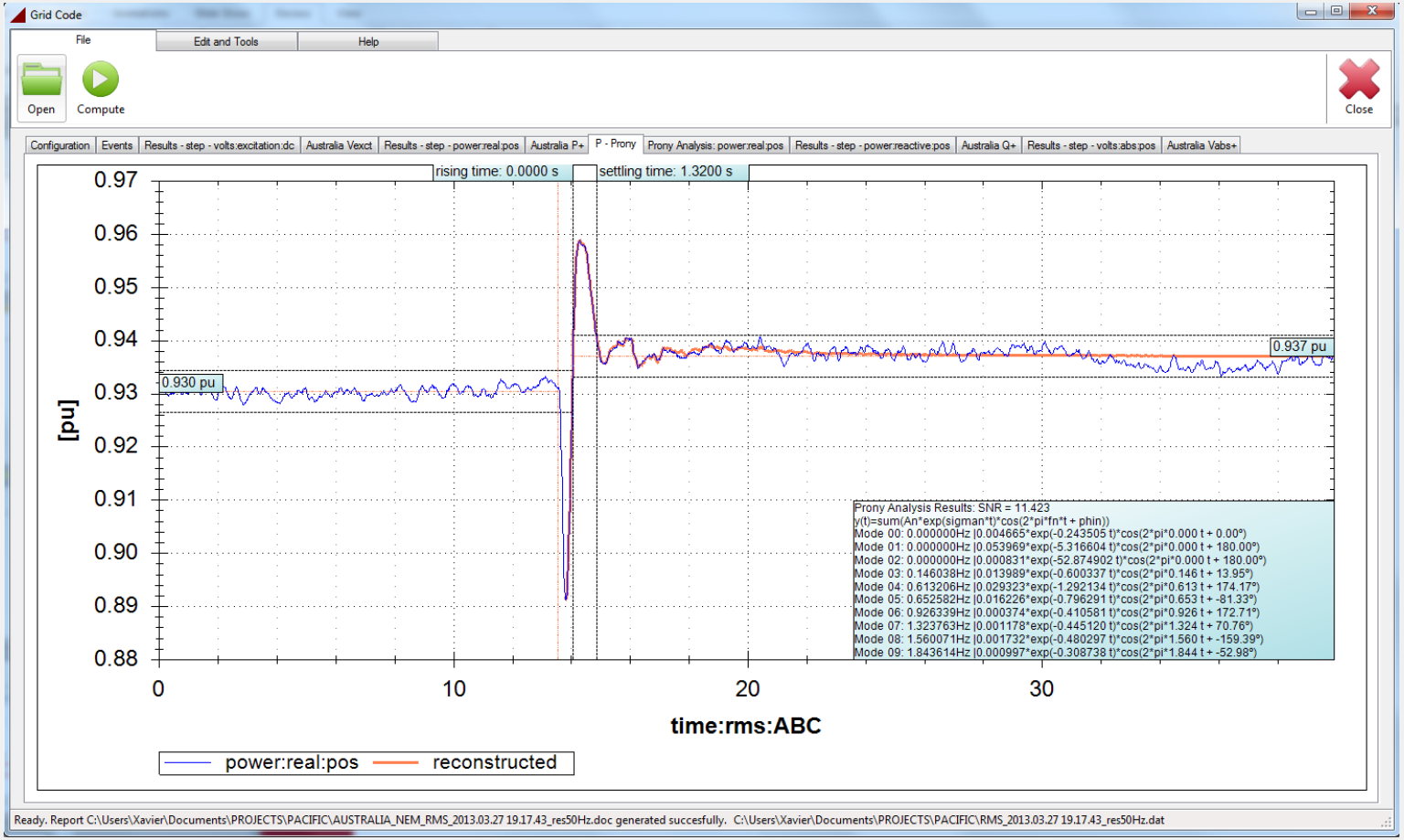
- **Max ss eps:** maximum error between the linear approximation and the curve during a steady-state



STEP ANALYSIS / PRONY'S METHOD

Example of new function → **"Step Detection / Prony Method"**

Developed in collaboration with DIgSILENT Pacific for testing conventional generation



STEP ANALYSIS / PRONY'S METHOD

Prony analysis (Prony's method) was developed by Gaspard Riche de Prony in 1795. However, practical use of the method awaited the digital computer.

Similar to the Fourier transform, Prony's method extracts valuable information from a uniformly sampled signal and builds a series of damped complex exponentials or sinusoids.

This allows for the estimation of frequency, amplitude, phase and damping components of a signal. [Wikipedia]

Prony's method requires solving ill-conditioned systems (inversion of non-square complex matrix)

$$\hat{f}(t) = \sum_{i=1}^{N} A_i e^{\sigma_i t} \cos(2\pi f_i t + \phi_i)$$
$$= \sum_{i=1}^{N} \frac{1}{2} A_i e^{\pm j\phi_i} e^{\lambda_i t}$$

STEP ANALYSIS / PRONY'S METHOD

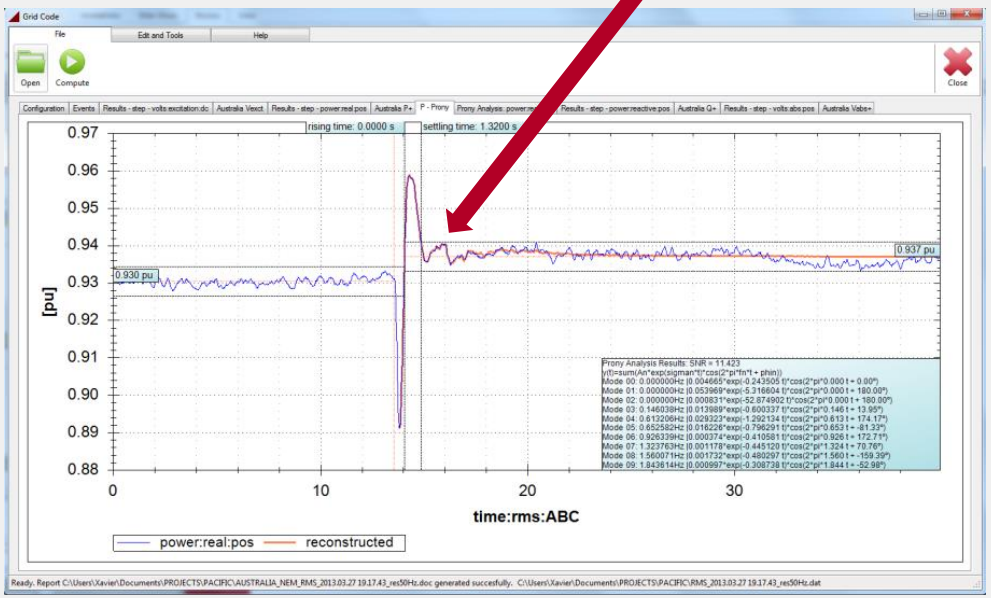
Prony analysis allows finding the different modes of a generator using its step response. Prony's components are calculated for the active power only.

Results are influenced by the selected window (length, start point) and the order of the method (→ higher order means better accuracy but added computational burden).

	Frequency [Hz]	Damping	Amplitude [pu]	Phase [°]
▸	0.000	-0.2435	0.0047	0.0000
	0.000	-5.3166	0.0540	180.0000
	0.000	-52.8749	0.0008	180.0000
	0.146	-0.6003	0.0140	13.9451
	0.613	-1.2921	0.0293	174.1664
	0.653	-0.7963	0.0162	-81.3296
	0.926	-0.4106	0.0004	172.7057
	1.324	-0.4451	0.0012	70.7601
	1.560	-0.4803	0.0017	-159.3890
	1.844	-0.3087	0.0010	-52.9782
	2.136	-0.1914	0.0004	-139.3453
	2.251	-3.1520	0.0178	30.6832
	2.437	-0.5897	0.0010	-175.6231
	2.709	-0.3871	0.0005	5.7370
	2.978	-0.5575	0.0005	38.9010
	3.285	-0.2899	0.0003	12.0166
	3.599	-0.3931	0.0002	18.5097
	3.846	-0.5511	0.0004	73.8962
	4.132	-0.1745	0.0003	178.8686
	4.231	-5.4805	0.0055	44.9502
	4.404	-0.5472	0.0002	-146.5116
	4.749	-0.4535	0.0003	148.7113
	4.931	-0.6680	0.0002	-170.2116
	5.240	-0.5177	0.0004	106.7503
	5.540	-0.4798	0.0002	173.2372
	5.741	-0.9260	0.0004	-164.1206
	6.021	-0.6062	0.0003	-117.2947
	6.188	-0.9399	0.0006	-2.5142

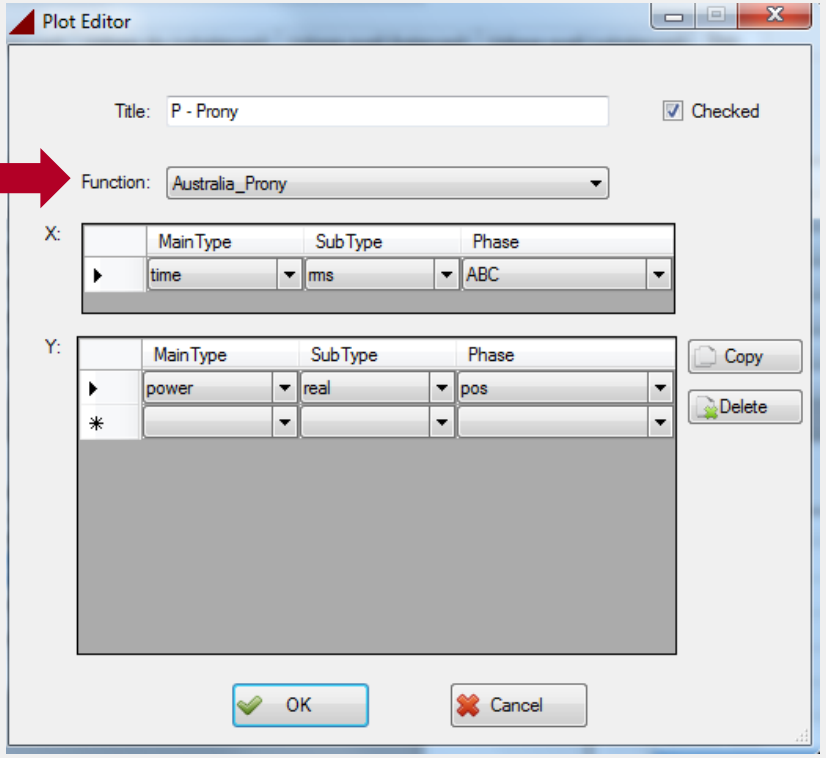
Generator modes sorted by frequencies

Reconstructed signal using Prony's components



STEP ANALYSIS / PRONY'S METHOD

New function to display Prony Analysis results on plots



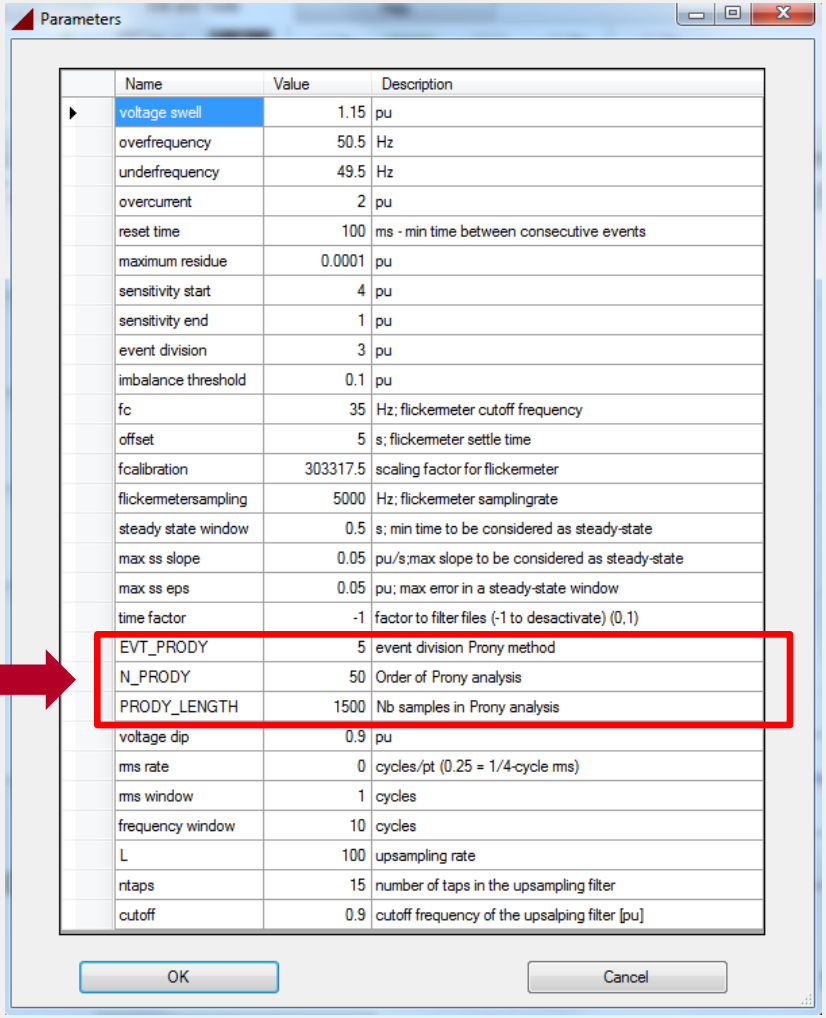
STEP ANALYSIS / PRONY'S METHOD

Important parameters for Prony Analysis:

- **EVT_PRODY:** defines the delay when to start the analysis respect to the beginning of the event. The analysis start at 1/EVT_PRODY from the beginning of the event

- **N_PRODY:** Prony analysis order → N/2 modes

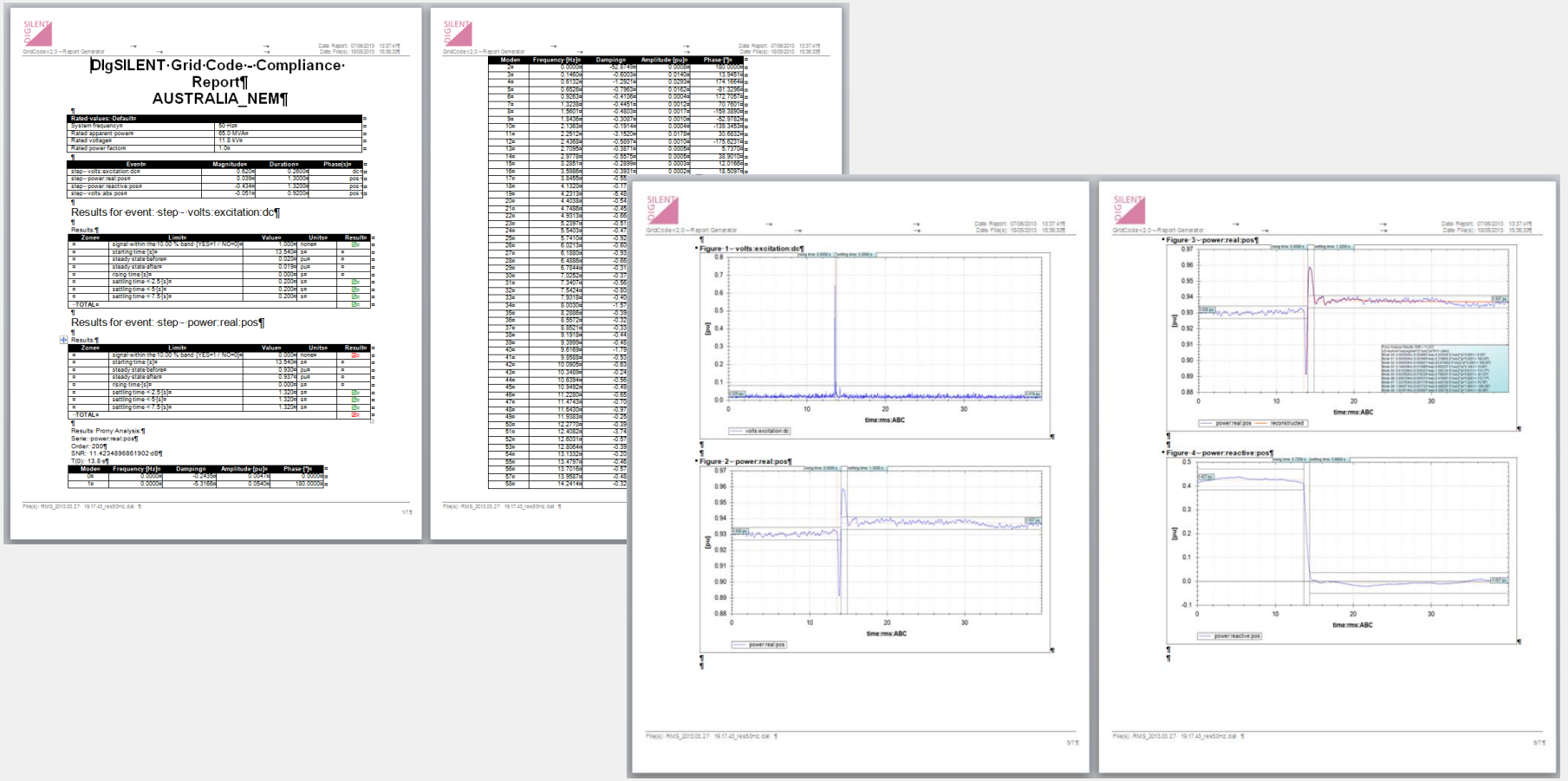
- **PRODY_LENGTH:** maximum number of samples in the analyzed window



Name	Value	Description
voltage swell	1.15	pu
overfrequency	50.5	Hz
underfrequency	49.5	Hz
overcurrent	2	pu
reset time	100	ms - min time between consecutive events
maximum residue	0.0001	pu
sensitivity start	4	pu
sensitivity end	1	pu
event division	3	pu
imbalance threshold	0.1	pu
fc	35	Hz; flickermeter cutoff frequency
offset	5	s; flickermeter settle time
fcalibration	303317.5	scaling factor for flickermeter
flickermetersampling	5000	Hz; flickermeter samplingrate
steady state window	0.5	s; min time to be considered as steady-state
max ss slope	0.05	pu/s;max slope to be considered as steady-state
max ss eps	0.05	pu; max error in a steady-state window
time factor	-1	factor to filter files (-1 to desactivate) (0,1)
EVT_PRODY	5	event division Prony method
N_PRODY	50	Order of Prony analysis
PRODY_LENGTH	1500	Nb samples in Prony analysis
voltage dip	0.9	pu
rms rate	0	cycles/pt (0.25 = 1/4-cycle rms)
rms window	1	cycles
frequency window	10	cycles
L	100	upsampling rate
ntaps	15	number of taps in the upsampling filter
cutoff	0.9	cutoff frequency of the upsalping filter [pu]

STEP ANALYSIS / PRONY'S METHOD

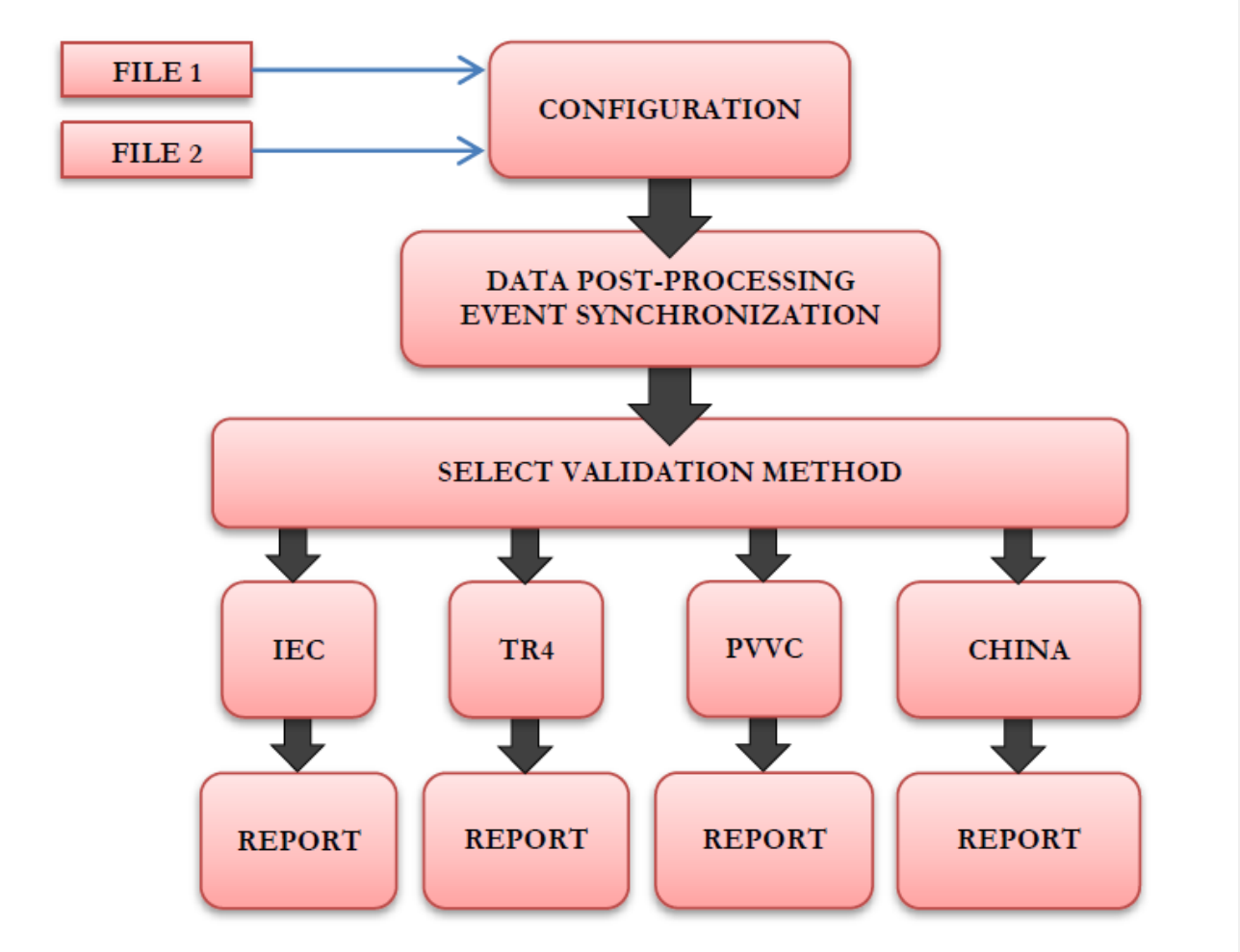
Results are reported in Word format.



DIgSILENT GridCode:

MODEL VALIDATION

MODEL VALIDATION



MODEL VALIDATION METHODS

DIgSILENT GridCode includes the following model validation methods:

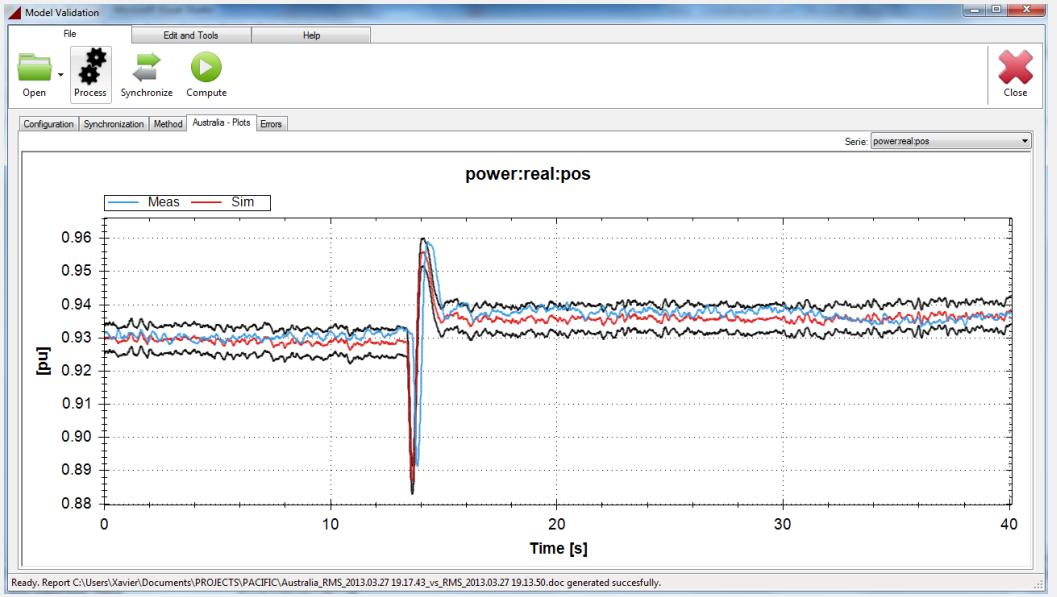
- **AUSTRALIA AEMO (Rev. 1.0 - 29.02.2008)**
  - Reference: "Generating system model guidelines".
  - Published by: Australian Energy Market Operator. Australia.
- **CHINA CEPRI (June 2012)**
  - Reference: Internal method applied by the "Wind Power Grid Interconnection Research and Evaluation Center".
  - Published by: China Electric Power Research Institute.
- **GERMAN FGW - TR4 (Rev. 5 – 2010.03.22)**
  - Reference: "Technical Guidelines for Power Generating Units - Part 4: Demands on Modeling and Validating Simulation Models of the Electrical Characteristics of Power Generating Units and Systems".
  - Published by: FGW e.V. - Fördergesellschaft Windenergie und andere Erneuerbare Energien. Germany.
- **IEC-61400-27-1 (CD1 2011.12.23)**
  - Reference: "Wind turbines – Part 27-1: Electrical simulation models – Wind turbines".
  - Published by: International Electrotechnical Commission – WG27.
- **SPANISH AEE – PVVC (Rev. 10 – 2012.01.26)**
  - Reference: "Procedimientos de verificación, validación y certificación de los requisitos del P.O.12.3 sobre la respuesta de las instalaciones eólicas y fotovoltaicas ante huecos de tensión".
  - Published by: Comité Técnico de Verificación de la Asociación Empresarial Eólica. Spain.

AUSTRALIA AEMO (Rev. 1.0 - 29.02.2008)

Example of model validation with the new "Australian Method":

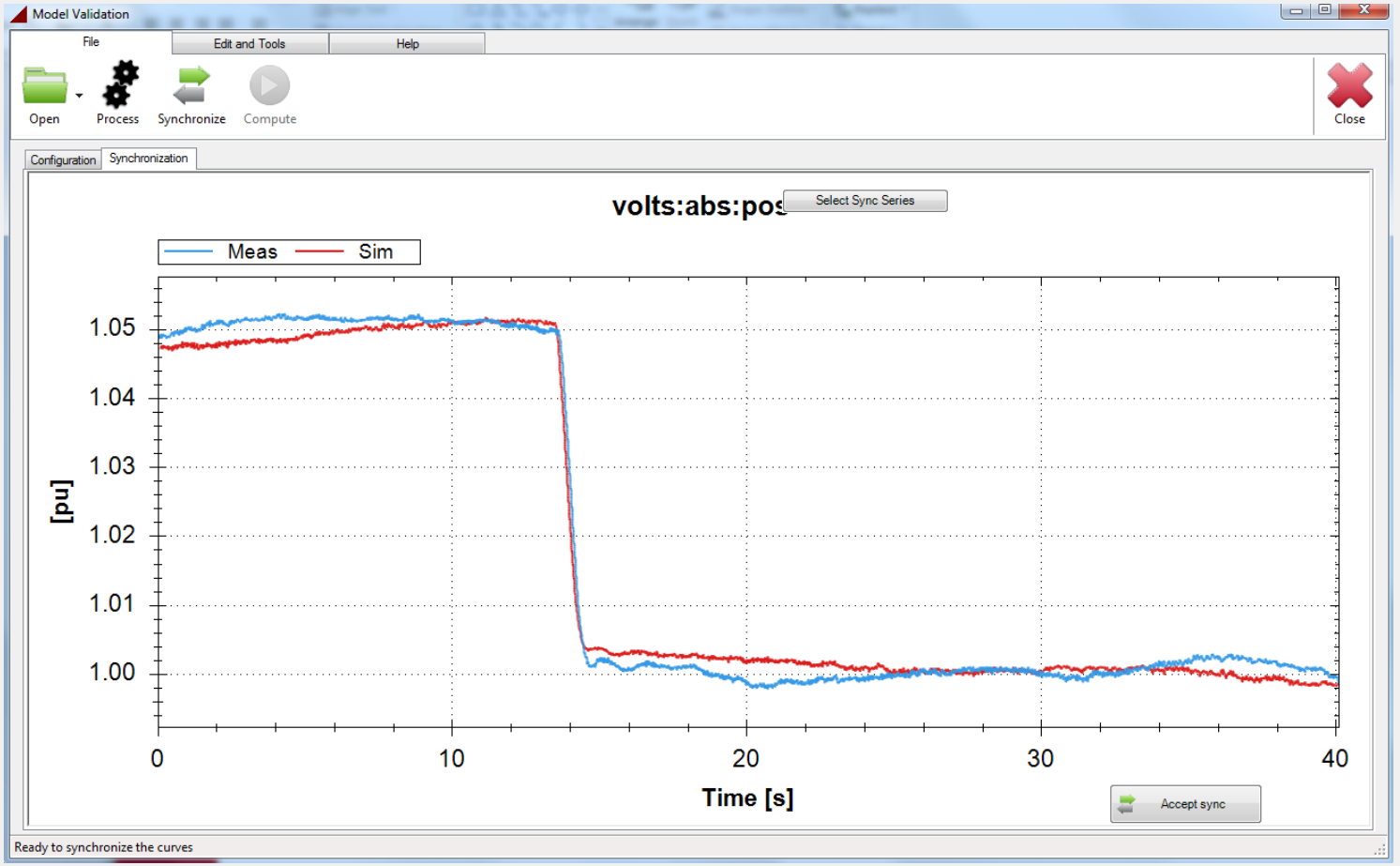
- Select files
- Synchronize Measurements and Simulation files
- Select method
- Process data
- Get automatic report (MS Word format)

Developed in collaboration with DIgSILENT Pacific for testing conventional generation



AUSTRALIA AEMO (Rev. 1.0 - 29.02.2008)

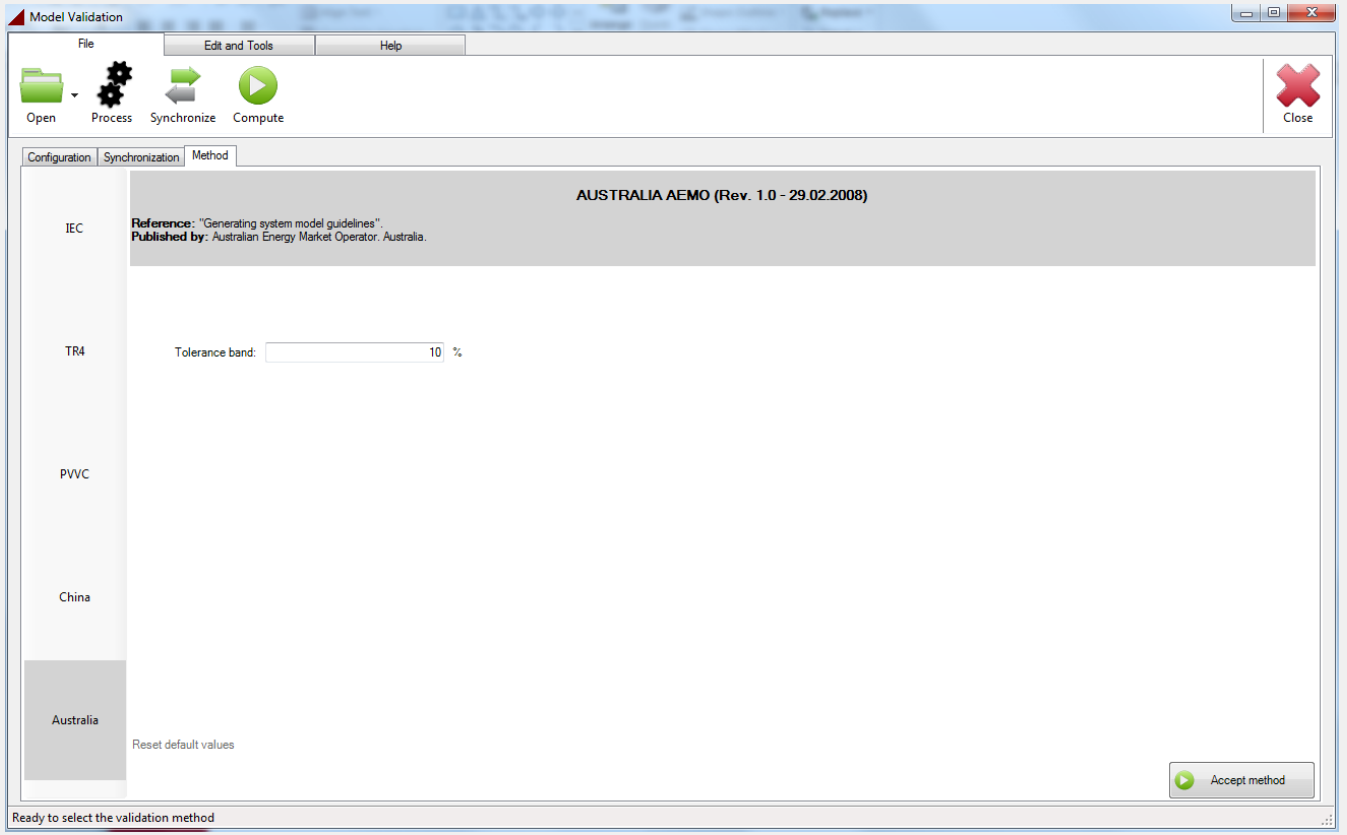
Signals Synchronization for accurate comparison



AUSTRALIA AEMO (Rev. 1.0 - 29.02.2008)

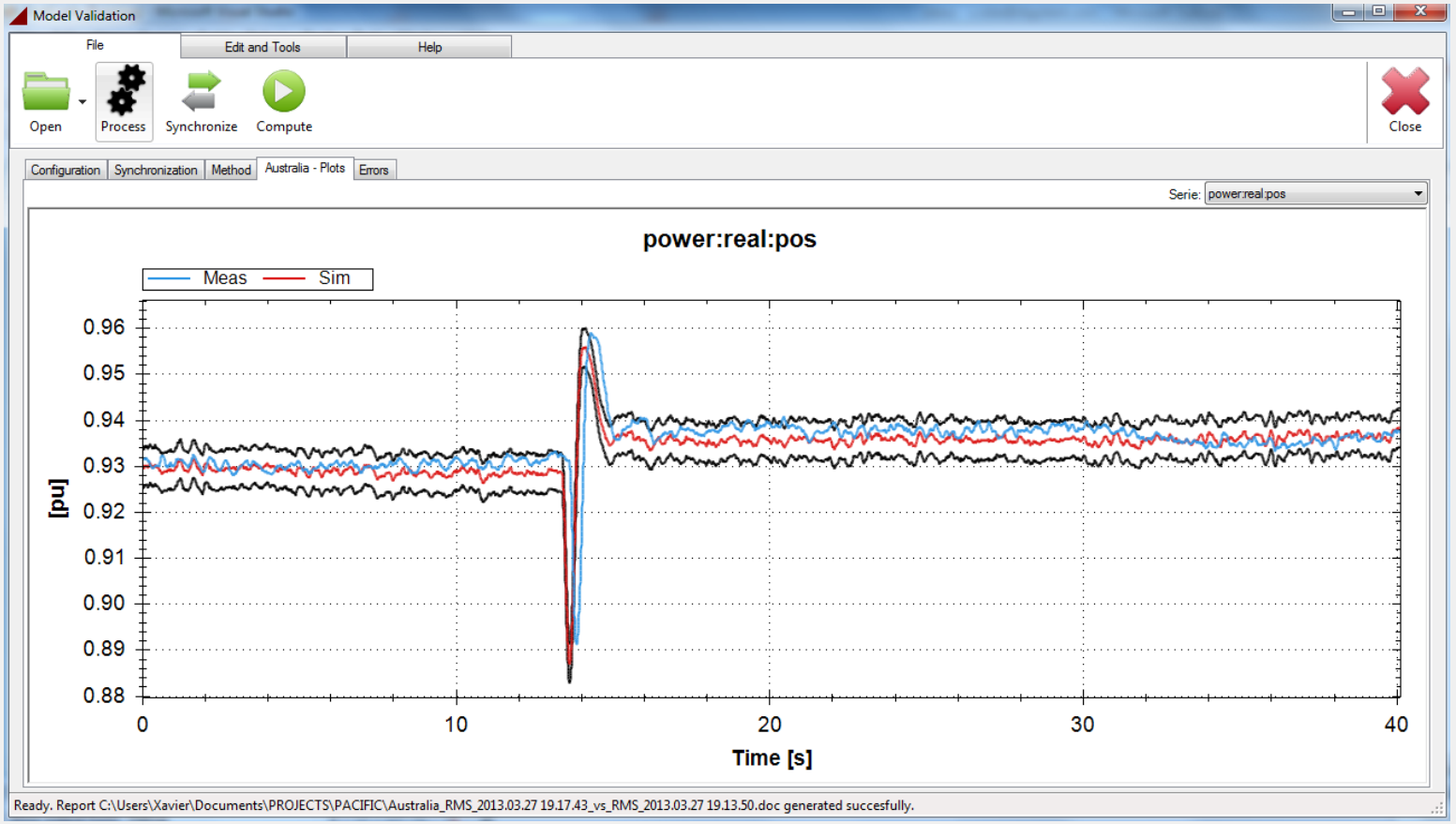
New "Australian Method"

Definition of tolerance band = maximum error



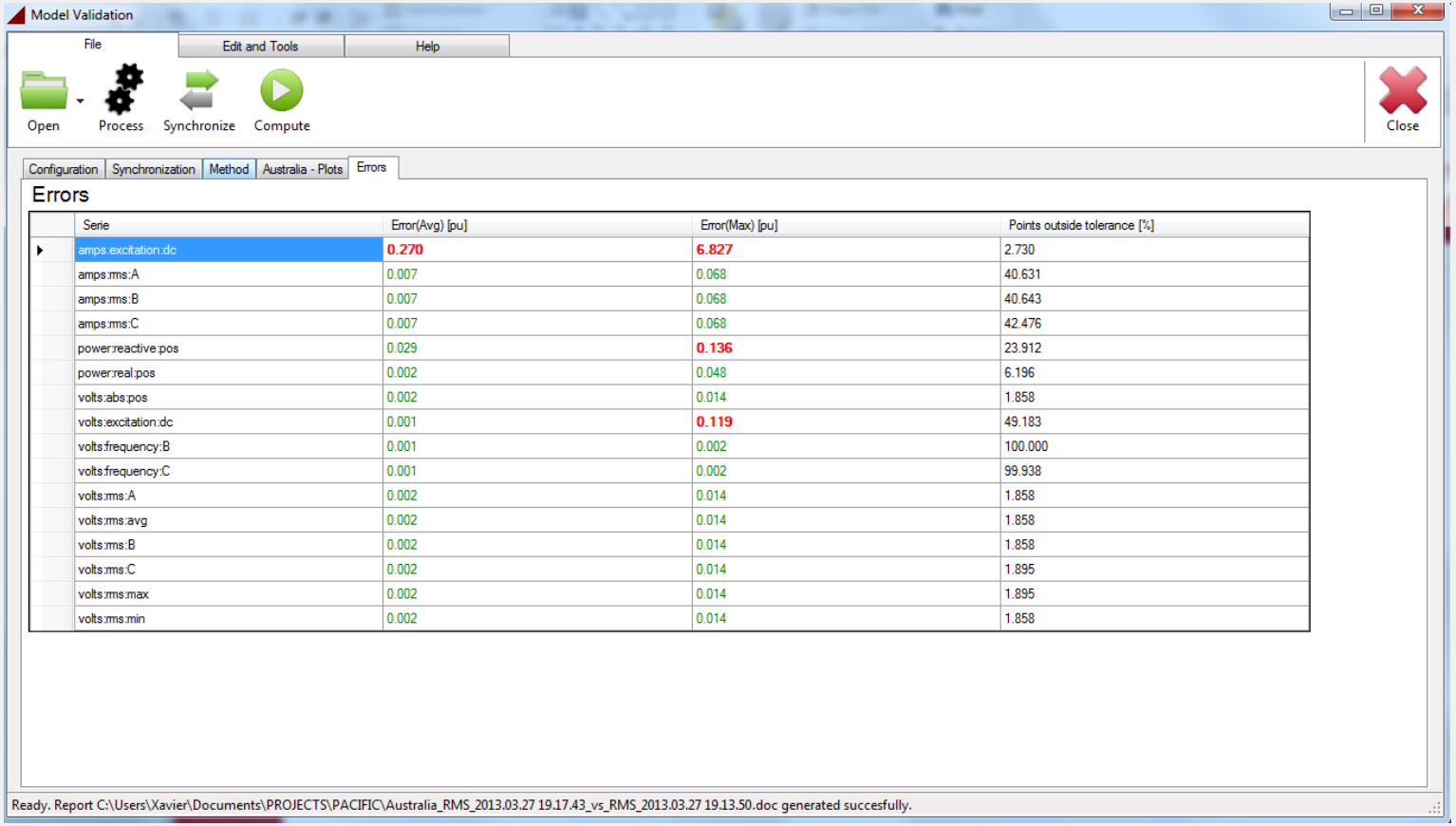
AUSTRALIA AEMO (Rev. 1.0 - 29.02.2008)

Results



AUSTRALIA AEMO (Rev. 1.0 - 29.02.2008)

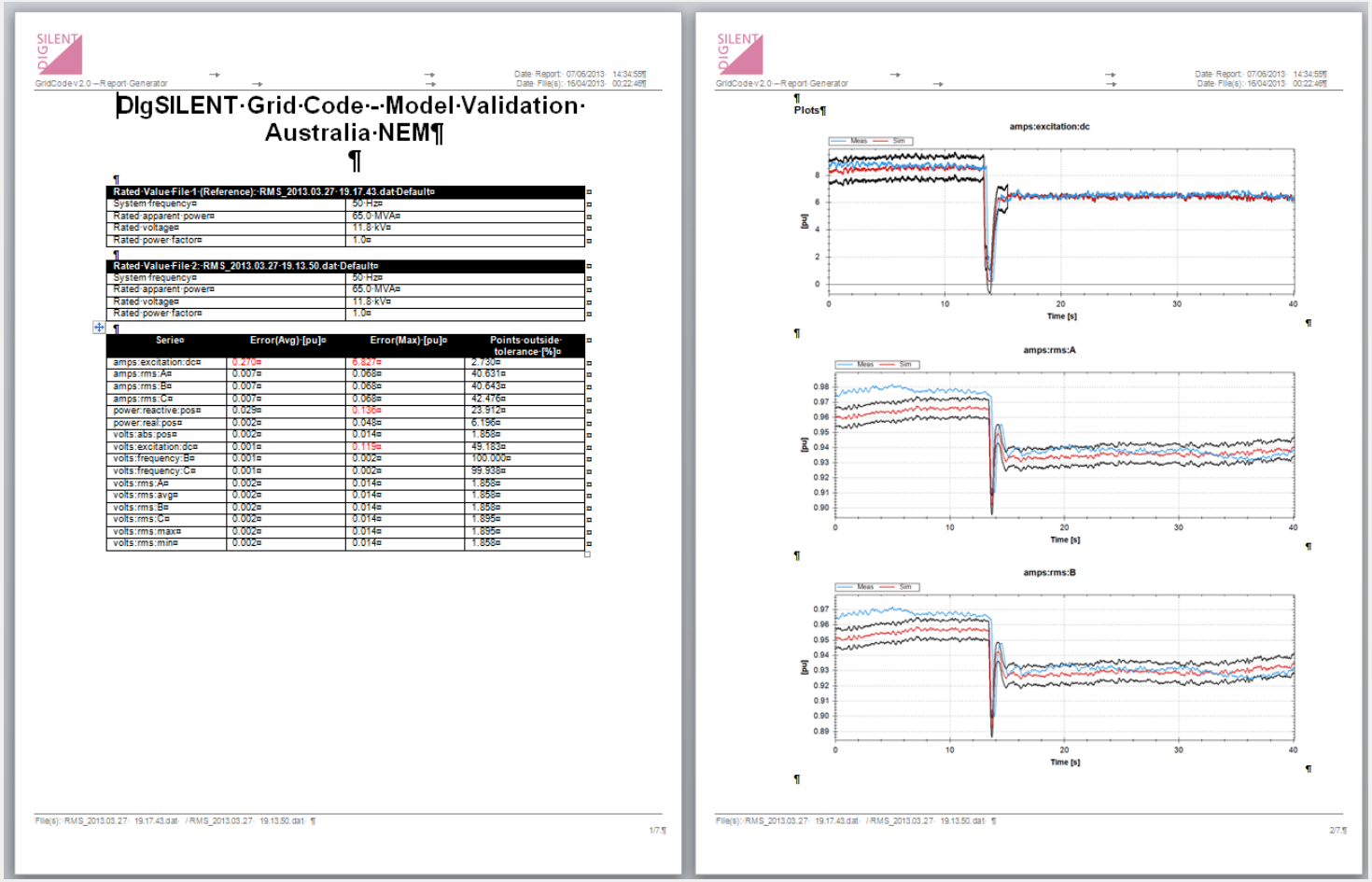
Results – Error calculations



Serie	Error(Avg) [pu]	Error(Max) [pu]	Points outside tolerance [%]
amps:excitation:dc	0.270	6.827	2.730
amps:rms:A	0.007	0.068	40.631
amps:rms:B	0.007	0.068	40.643
amps:rms:C	0.007	0.068	42.476
power:reactive:pos	0.029	0.136	23.912
power:real:pos	0.002	0.048	6.196
volts:abs:pos	0.002	0.014	1.858
volts:excitation:dc	0.001	0.119	49.183
volts:frequency:B	0.001	0.002	100.000
volts:frequency:C	0.001	0.002	99.938
volts:rms:A	0.002	0.014	1.858
volts:rms:avg	0.002	0.014	1.858
volts:rms:B	0.002	0.014	1.858
volts:rms:C	0.002	0.014	1.895
volts:rms:max	0.002	0.014	1.895
volts:rms:min	0.002	0.014	1.858

AUSTRALIA AEMO (Rev. 1.0 - 29.02.2008)

Results are reported in Word format.



DIgSILENT·Grid·Code·-·Model·Validation·Australia·NEM¶

¶

Rated·Value·File·1·(Reference):·RMS_2013.03.27·19.17.43.dat·Default¤	
System·frequency¤	50·Hz¤
Rated·apparent·power¤	65.0·MVA¤
Rated·voltage¤	11.8·kV¤
Rated·power·factor¤	1.0¤

Rated·Value·File·2:·RMS_2013.03.27·19.13.50.dat·Default¤	
System·frequency¤	50·Hz¤
Rated·apparent·power¤	65.0·MVA¤
Rated·voltage¤	11.8·kV¤
Rated·power·factor¤	1.0¤

Serie¤	Error(Avg)·[pu]¤	Error(Max)·[pu]¤	Points·outside·tolerance·[%]¤
amps:excitation:dc¤	0.270¤	6.827¤	2.730¤
amps:rms:A¤	0.007¤	0.068¤	40.631¤
amps:rms:B¤	0.007¤	0.068¤	40.643¤
amps:rms:C¤	0.007¤	0.068¤	42.476¤
power:reactive:pos¤	0.029¤	0.136¤	23.912¤
power:real:pos¤	0.002¤	0.048¤	6.196¤
volts:abs:pos¤	0.002¤	0.014¤	1.858¤
volts:excitation:dc¤	0.001¤	0.119¤	49.183¤
volts:frequency:B¤	0.001¤	0.002¤	100.000¤
volts:frequency:C¤	0.001¤	0.002¤	99.938¤
volts:rms:A¤	0.002¤	0.014¤	1.858¤
volts:rms:avg¤	0.002¤	0.014¤	1.858¤
volts:rms:B¤	0.002¤	0.014¤	1.858¤
volts:rms:C¤	0.002¤	0.014¤	1.895¤
volts:rms:max¤	0.002¤	0.014¤	1.895¤
volts:rms:min¤	0.002¤	0.014¤	1.858¤

Plots¶

amps:excitation:dc

amps:rms:A

amps:rms:B

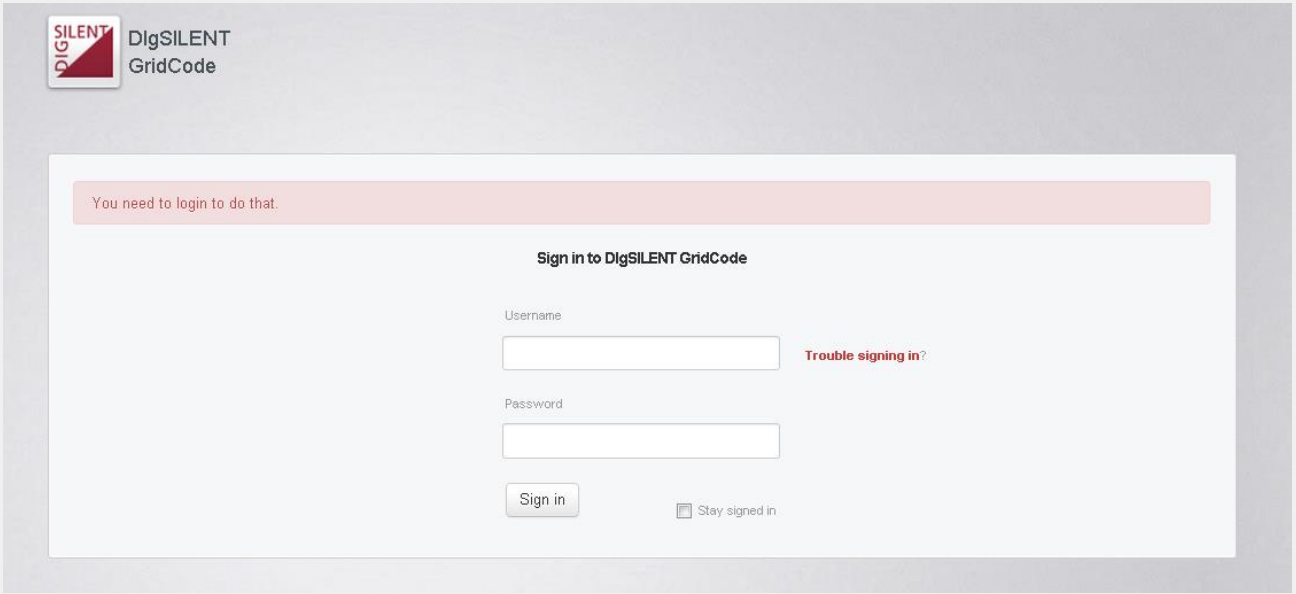
NEW!

STORING GRID CODES

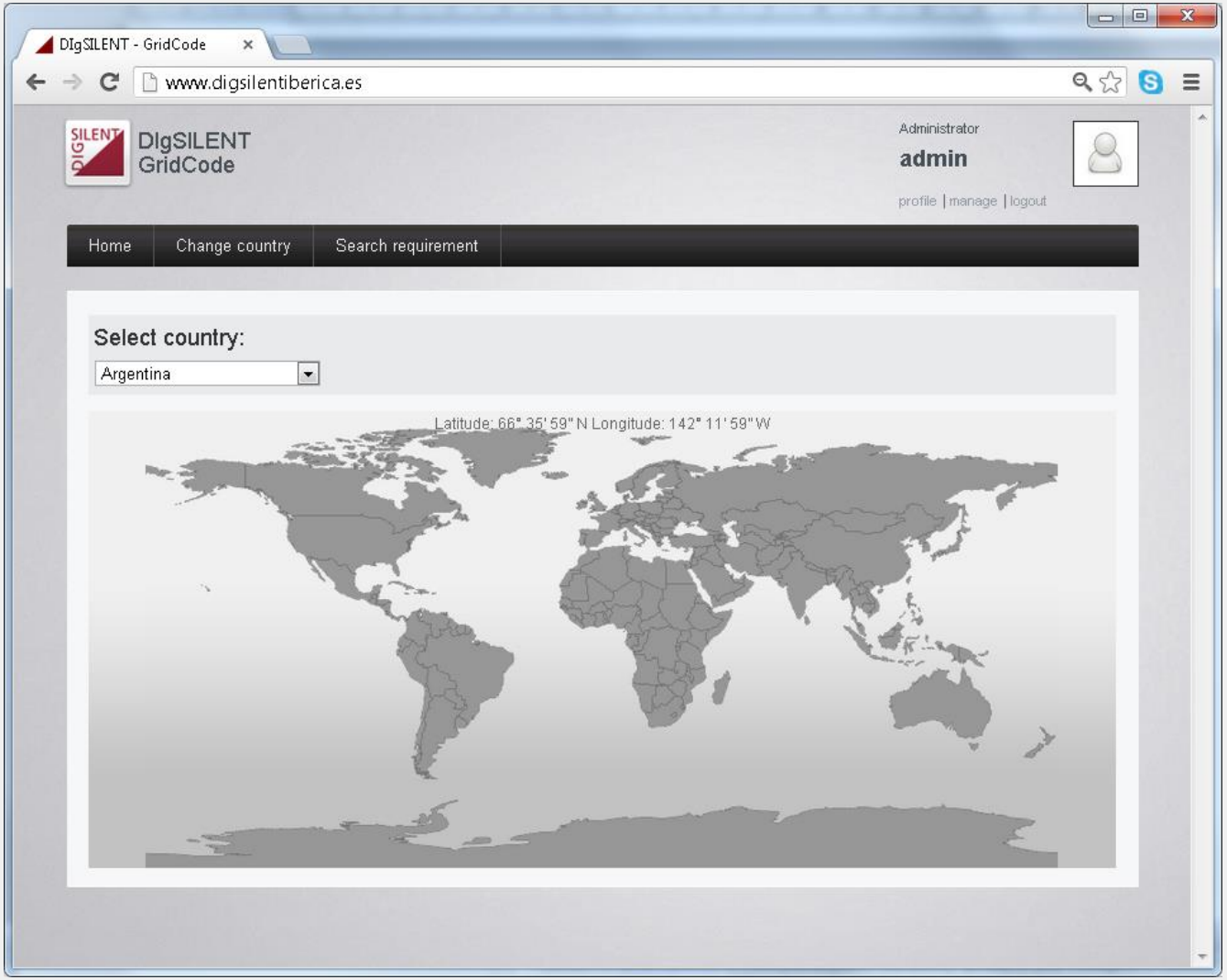
Grid codes have been tracked for years in different countries and analysis have been performed.

A new tool has been designed to store REQUIREMENTS and allow the consultation of different Grid Codes around the world.

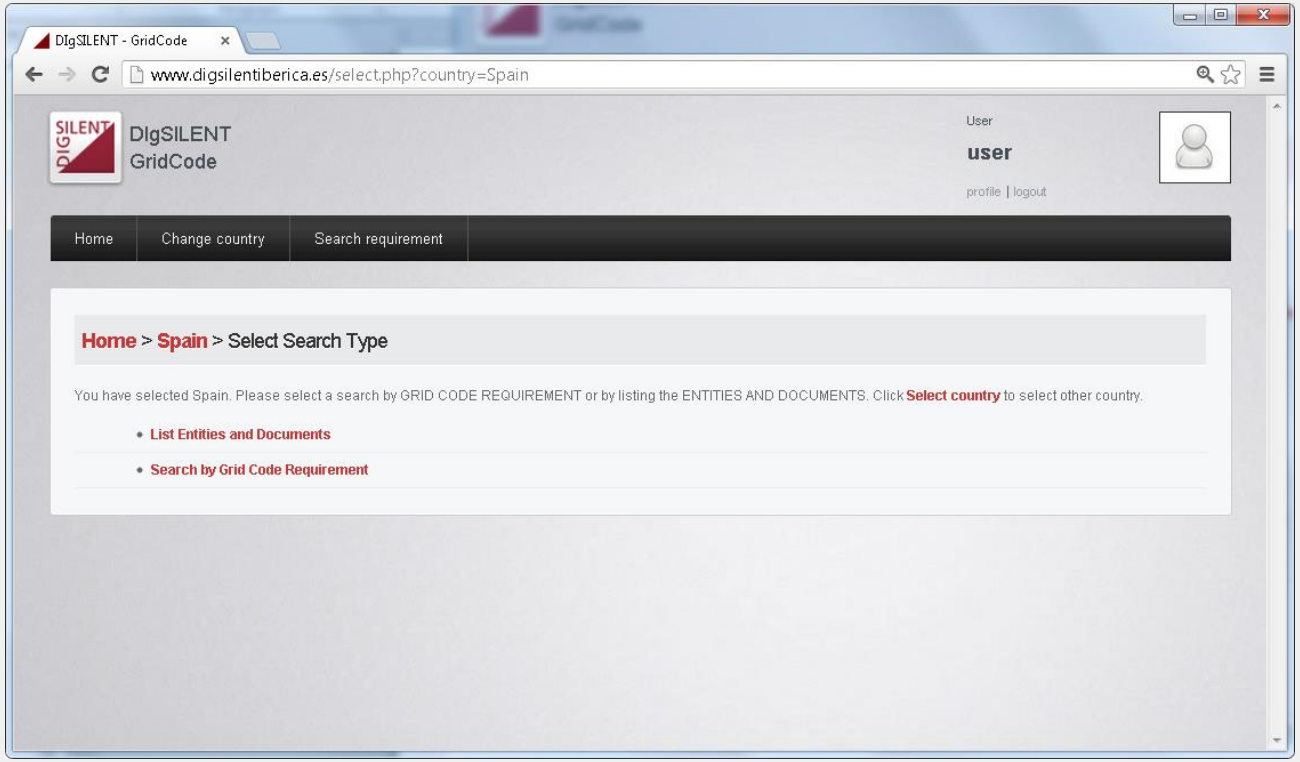
Yearly subscription, web access through login and password.



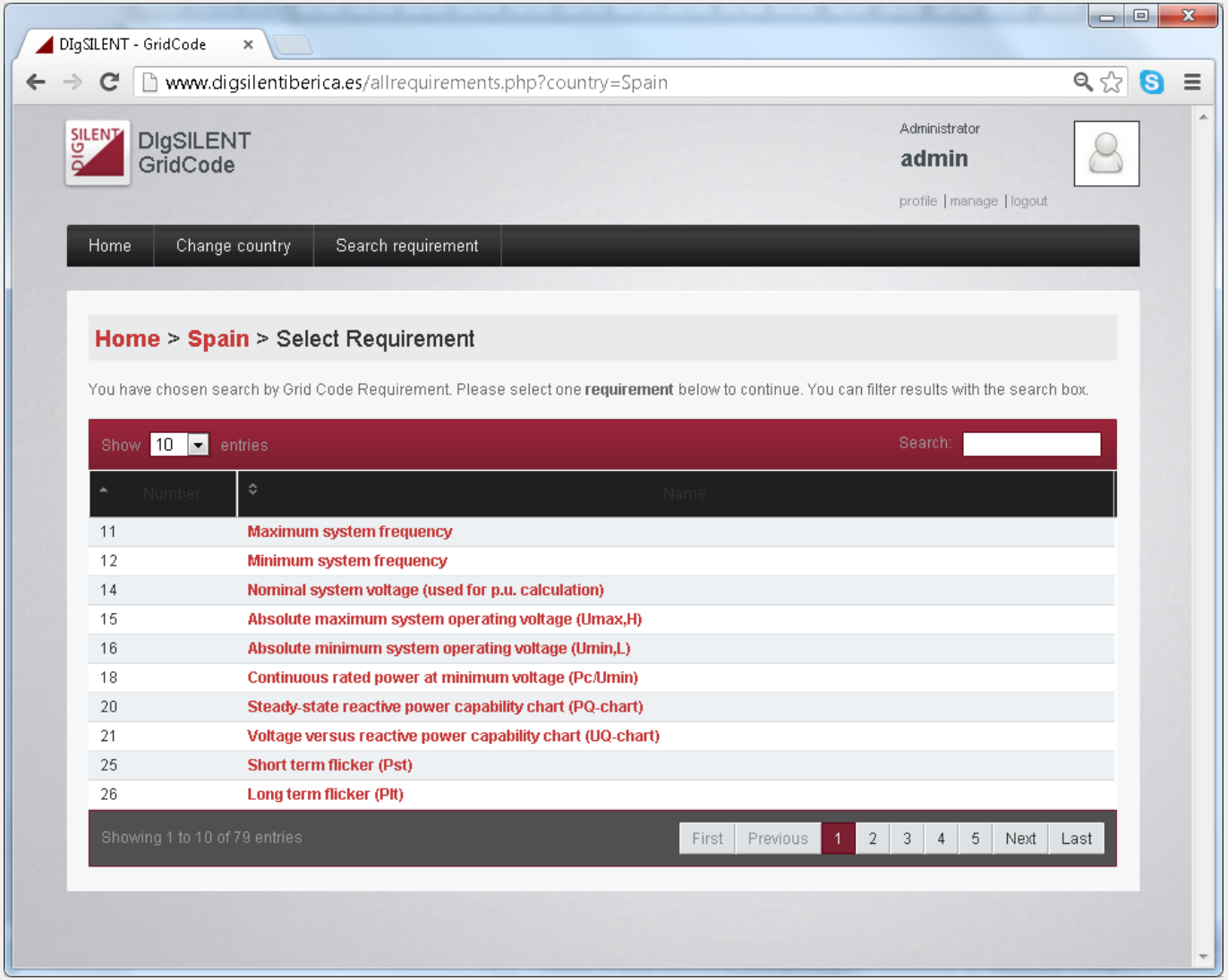
STORING GRID CODES



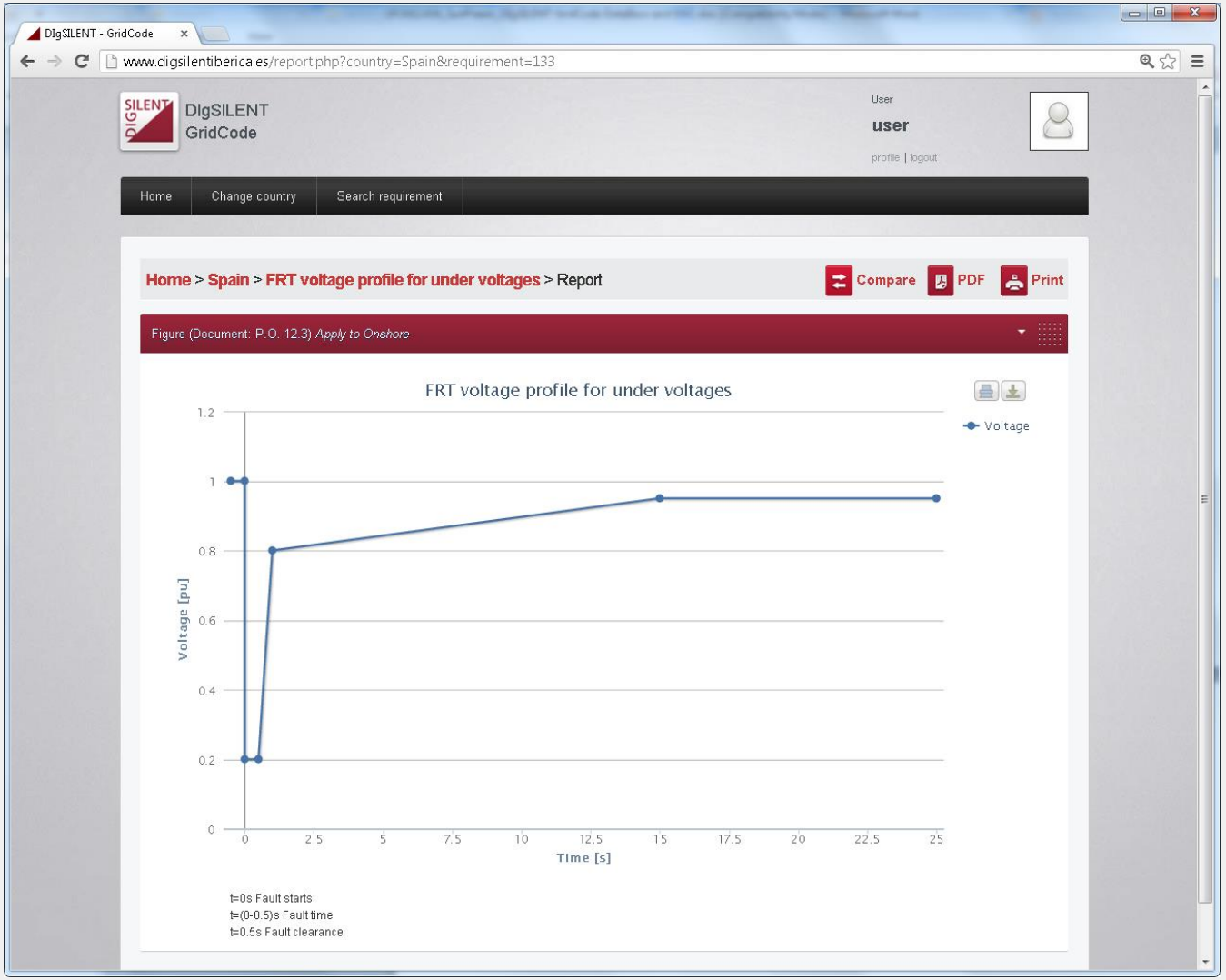
STORING GRID CODES



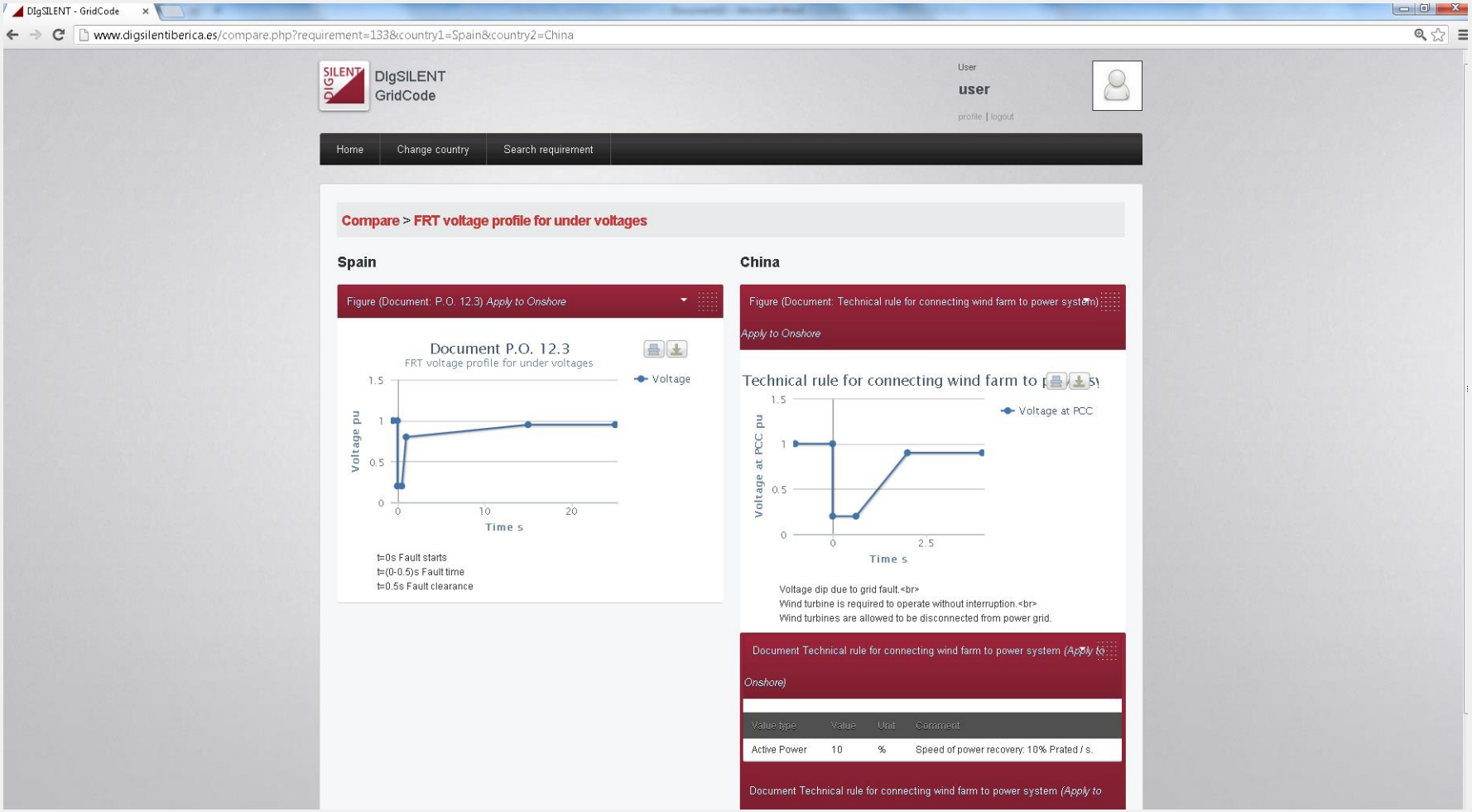
STORING GRID CODES



STORING GRID CODES



STORING GRID CODES



Thank you for your attention

Contact details

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Website: www.digsilent.com