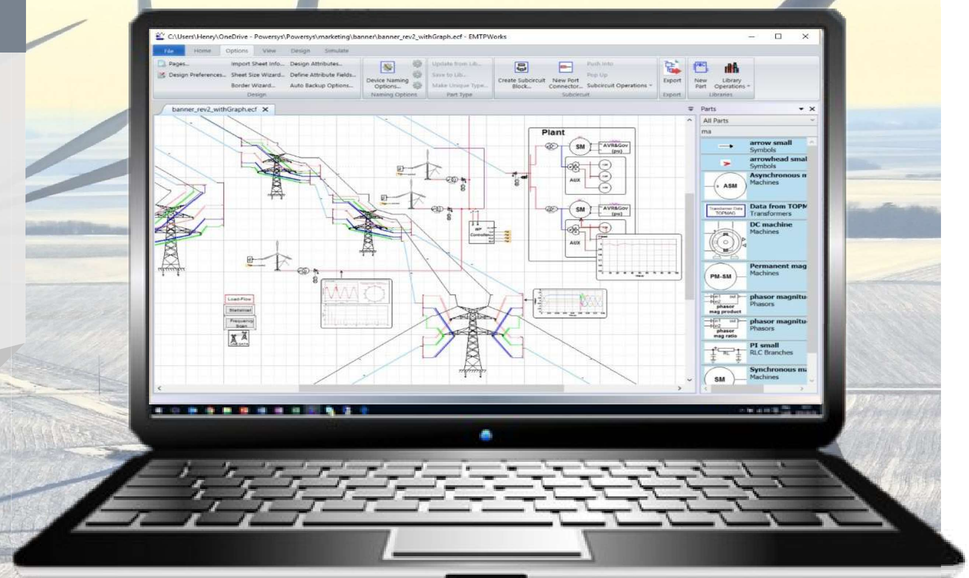
Webinar:

E-interconnect tool

Willy Nzale, PhD
willy.nzale@emtp.com



More info

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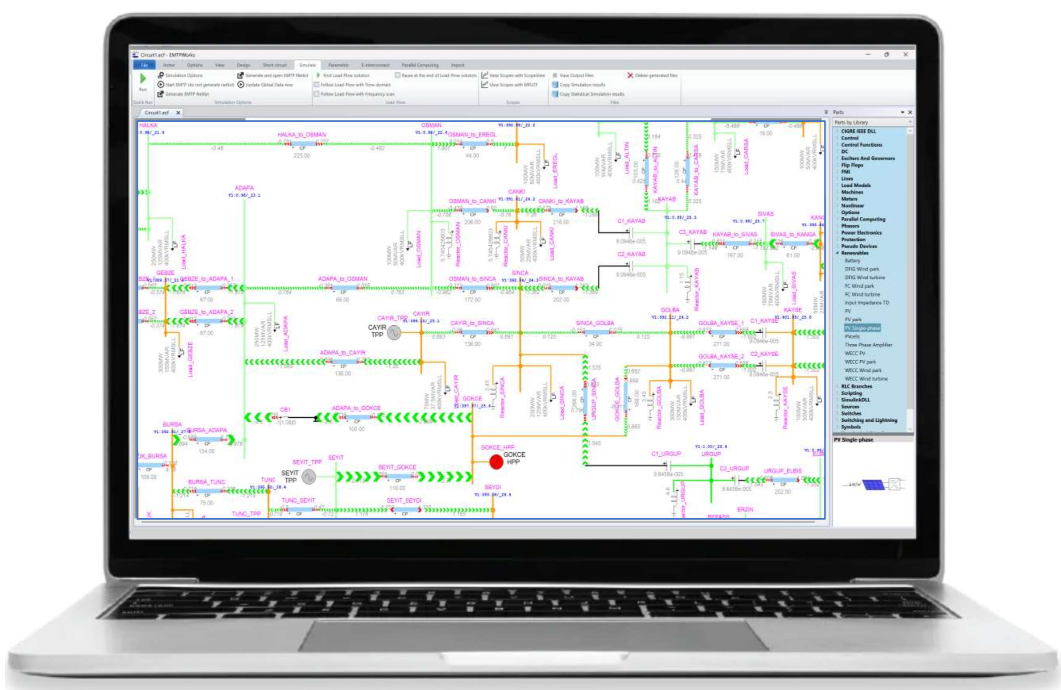
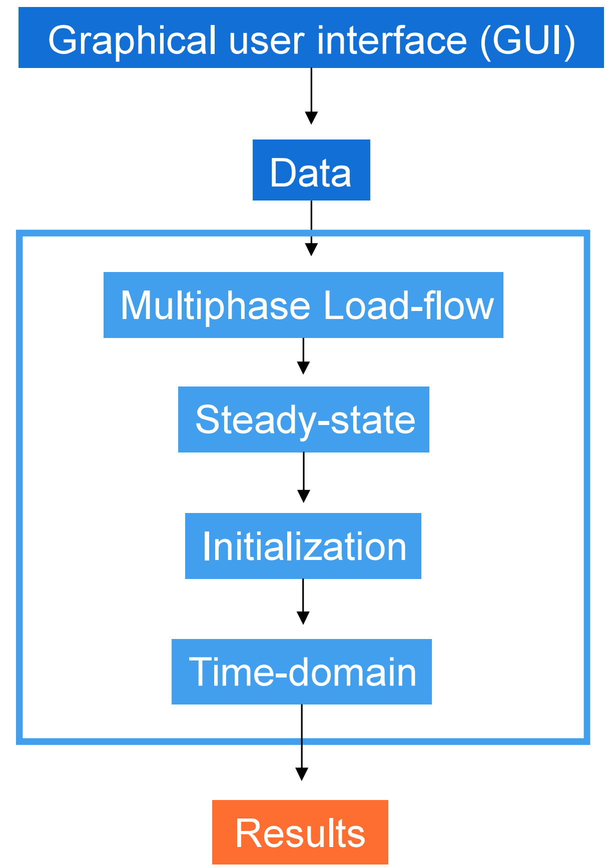
EMTP capabilities

- The same design can be used for **load-flow, steady-state, time-domain and frequency scan** simulation.
- Fully initialized => flat start

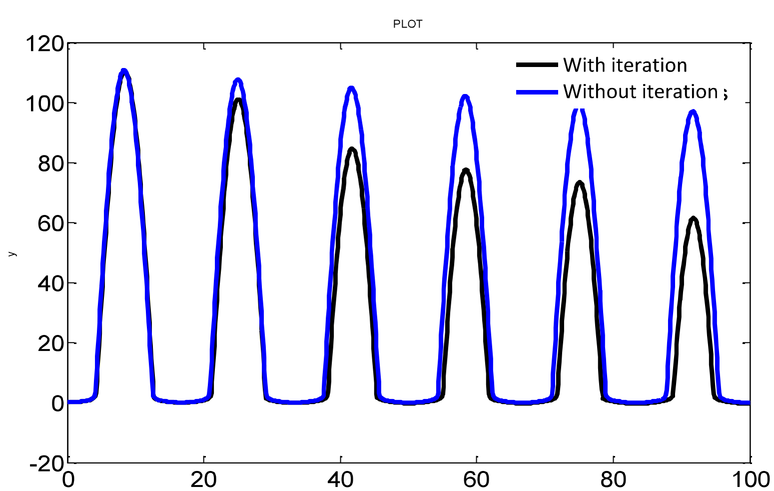




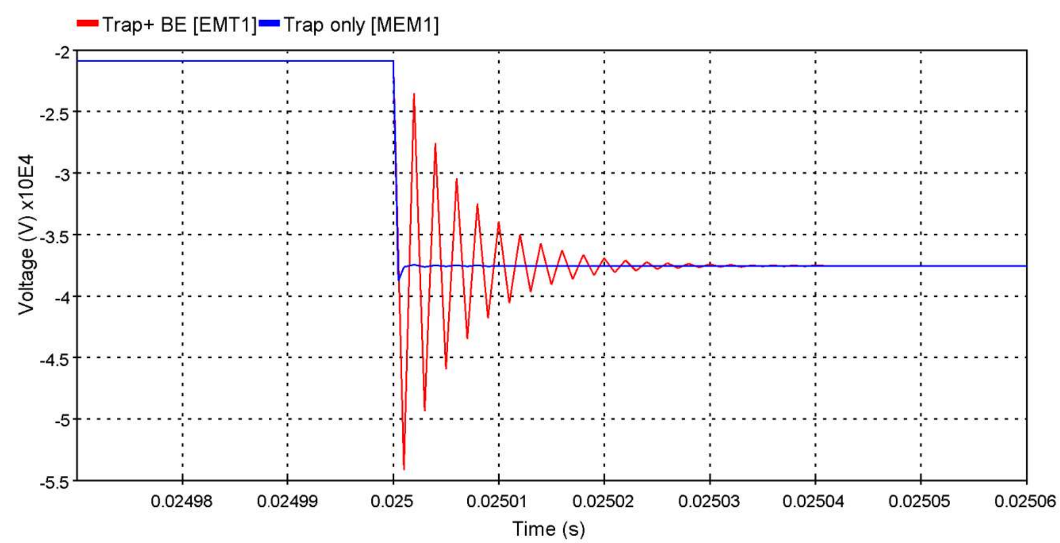
EMTP capabilities

- EMTP® provides a superior mathematical solver
  - Fully iterative solver for non-linear power components (IGBT, surge-arrester, saturation, etc)
  - Iterates control when algebraic loops are present
  - Use multiple integration methods (trapezoidal and Backward Euler) to avoid numerical problems

=> Much larger time-steps can be used to reach the same precision

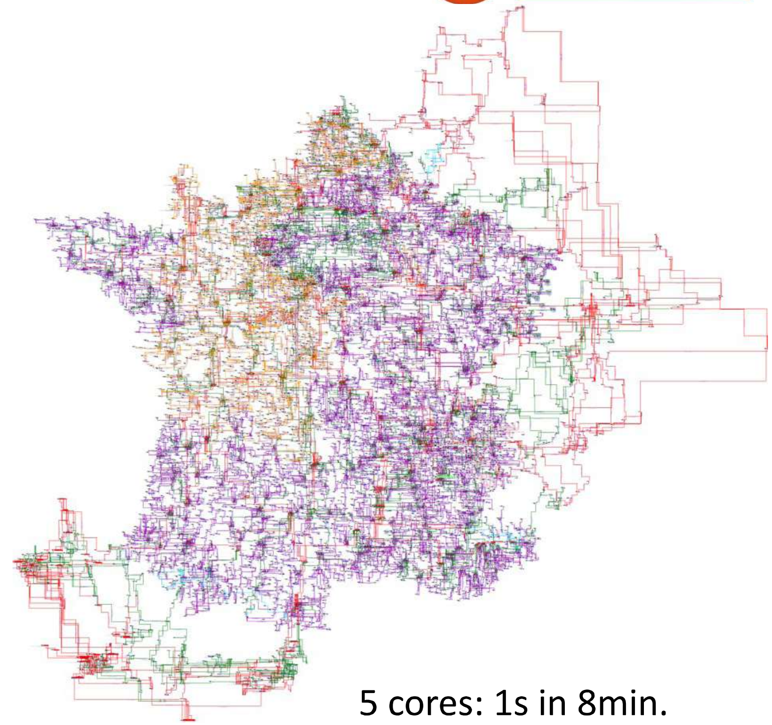


$\Delta t = 100\ \mu s$



EMTP capabilities

- The fastest EMT solver on the market, even faster than most real-time software
  - Uses innovative sparse matrix solver to achieve more with less hardware.
  - Can simulate faster than real-time up to 700 buses per CPU
  - Multi-time-mesh parallel computing can be leveraged to achieve the unthinkable (i.e. simulating the entire NYISO footprint faster than real time)



5 cores: 1s in 8min.

EMTP capabilities

- No compiler required
- Database management and versioning available
- Contingency tool available
- Modern graphical user interface
- PSS/E and CIM import tool
- Cosimulation capabilities
- Python, C#, Matlab APIs
- Compatible with CIGRE/IEEE DLLs
- Advanced libraries (machine controls, IBRs, HVDC, GFM)
- EMTP-DSA
- EMTP Online Connection tool

Agenda

1. Introduction: IBR model verification approach
2. E-interconnect tool: definition and objective
3. Description of the tool: setup and analysis
4. Analysis results
5. Summary and conclusion: key features of the tool

1. INTRODUCTION

Introduction

- Increasing number of IBRs in modern power systems
- Need to validate the behaviour of IBR before interconnection
- Battery of tests designed to check requirements: the grid code
- IEEE2800: uniform technical minimum requirements for the interconnection, capability, and lifetime performance of inverter-based resources interconnecting with transmission and sub-transmission Systems.
  - ➢ How to conduct tests
  - ➢ What is to be checked in each test
  - ➢ What are the reference or threshold values (customizable)

1. Introduction: the tests

EMTP®

- Categories of tests discussed in IEEE2800 standard:

  - Initialization tests: verify flat start.
  - Step change tests (Q, PF, P, V): evaluate IBR performance during step changes in reference quantities.
  - Ride through tests (V, f, theta): check if IBR remains connected following disturbances from the grid.
  - System protection tests: validate protection settings.

1. Introduction: the configurations

IBR model settings for interconnection tests (configurations)

Control mode:
- Q control
- PF control
- V control

Operation settings:
- V reference (1pu, 0.94pu, 1.06pu,…)
- PF reference (1, +0.95, -0.95,…)
- Q reference (0, Qmin, Qmax,…)

Production level:
- Pmax
- Pmin

Each combination defines a simulation configuration.

Examples:

1. Q control + Q reference set to 0 + Production Pmax
2. PF control + PF reference set to 1 + Pmin

1. Introduction: the scenarios

- A scenario is specific to a test. It defines any modification (or set of modifications) in the test circuit which is not related to the IBR model.
- A test may require several scenarios.
- Example for a fault ride through test (FRT) :

  Scenario 1: 3 phases ungrounded fault at POI with no impedance.

  Scenario 2: single phase to ground fault with 20 ohms fault resistance.

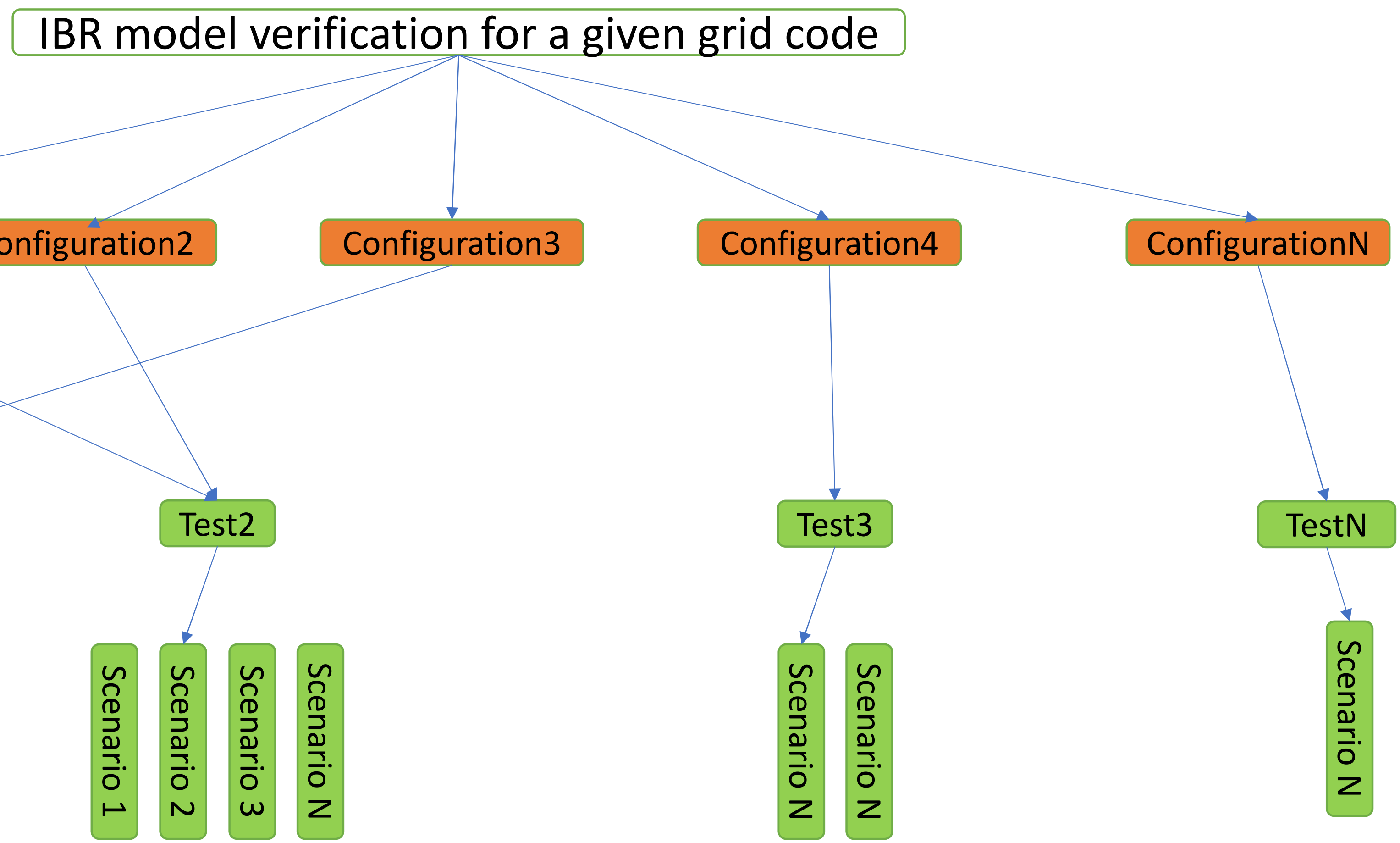
  Scenario 3: phase to phase fault…

- Example for a grid frequency ride through test :

  Scenario 1: Grid frequency varies from 60Hz to 59.4 Hz.

  Scenario 2: Grid frequency varies from 60Hz to 60.6 Hz.

1. Introduction: understand the challenge



1. Introduction: the challenge

- A full interconnection verification study on a given IBR model consists of:

  - creating circuits in an EMT software to simulate all the possible combinations of tests, configurations and scenarios.
  - simulating the circuits.
  - extracting and analyzing simulation results one by one.
  - conclude on the compliance of the model with the requirements of the grid code.

1. Introduction: the challenge

- Manual process faces the following issues:
  - Tedious (boring, slow, repetitive)
  - Fastidious (attention to detail, meticulous)
  - Time consuming
  - Prone to human errors
  - Lack of efficiency (process must be restarted from scratch each time the model is updated).

This is when **E-interconnect** comes in !

2. E-interconnect tool: definition and objective

2. E-interconnect tool

- E-interconnect is a tool that automates the execution of tests and concludes if the IBR model meets the requirements for interconnection to existing grids.

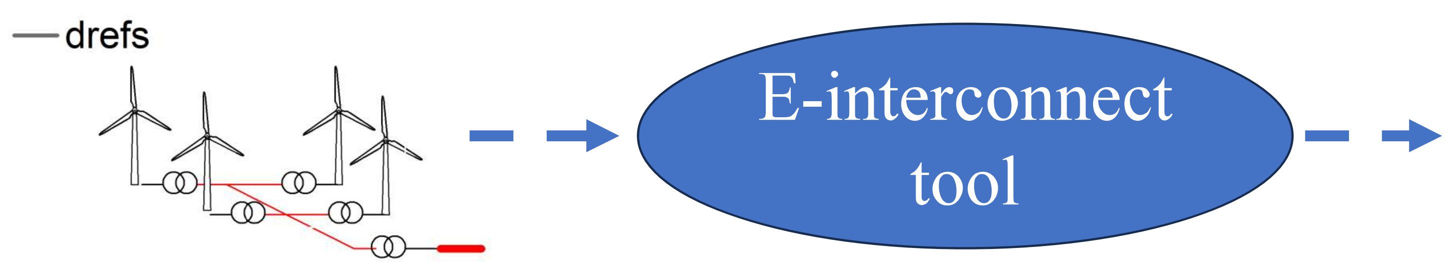
- The current version of the tool implements the requisites prescribed in IEEE2800 standard.

- The tool can be easily adapted for any other grid code (with different requirements and tests definition).

2. E-interconnect tool

Input: IBR model

Output: analysis report

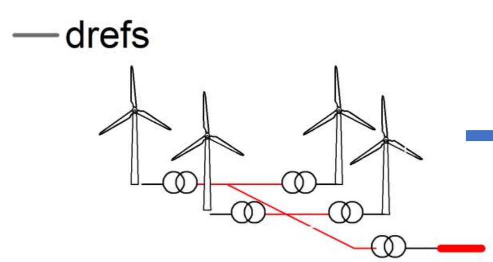


Executive summary

The IBR model has been verified, and the conclusions are:

- **Flat start test (FlatStart): ok**
- **Reactive power control test (Qcontrol): not ok**
- **Power factor control test (PFcontrol): not ok**
- **Voltage magnitude control test (Vcontrol): not ok**
- **Active power control test (Pcontrol): ok**
- **Voltage magnitude ride through test (VRT): not ok**
- **Voltage frequency ride through test (FreqRT): ok**
- **Voltage angle ride through test (AngleRT): ok**
- **Short circuit ratio test (SCR): ok**

Input: IBR model



E-interconnect tool tasks:

1. Create .ecf files (for all tests and for all configurations).
2. Run simulations in EMTP.
3. Generate waveforms.
4. Perform calculations to check requirements.
5. Print results in Word report.

Output: Word report

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- Short circuit ratio test (SCR): ok

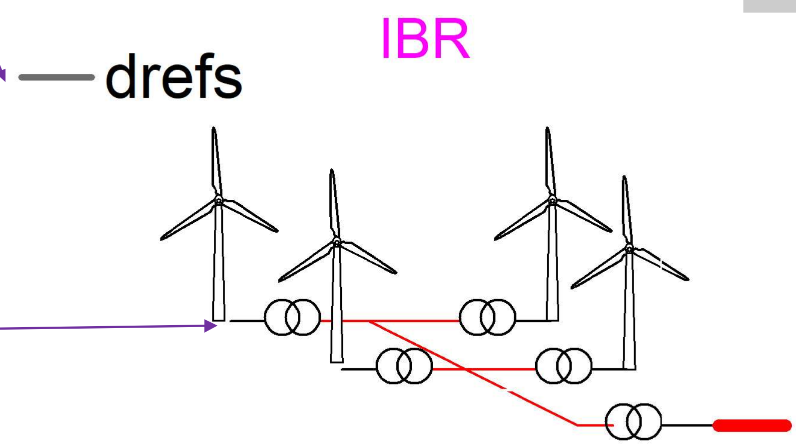
2. E-interconnect tool: IBR model preparation

IBR model should be saved inside a lib (**.clf**) file or inside a circuit (**.ecf**) file.

Parameter	Value	Comment
Pref	50	Active power reference (MW)
Qref	0	Reactive power reference (Mvar)
PFref	1	Power factor reference
Vref	1	Voltage reference (pu)
ControlMode	2	2=Qmode 1=PFmode 0=Vmode

Input bundle pin for deviations:
drefs
- dVref
- dPref
- dQref
- dPref

Name of IBR device



Output bundle pin for observables

Power pin

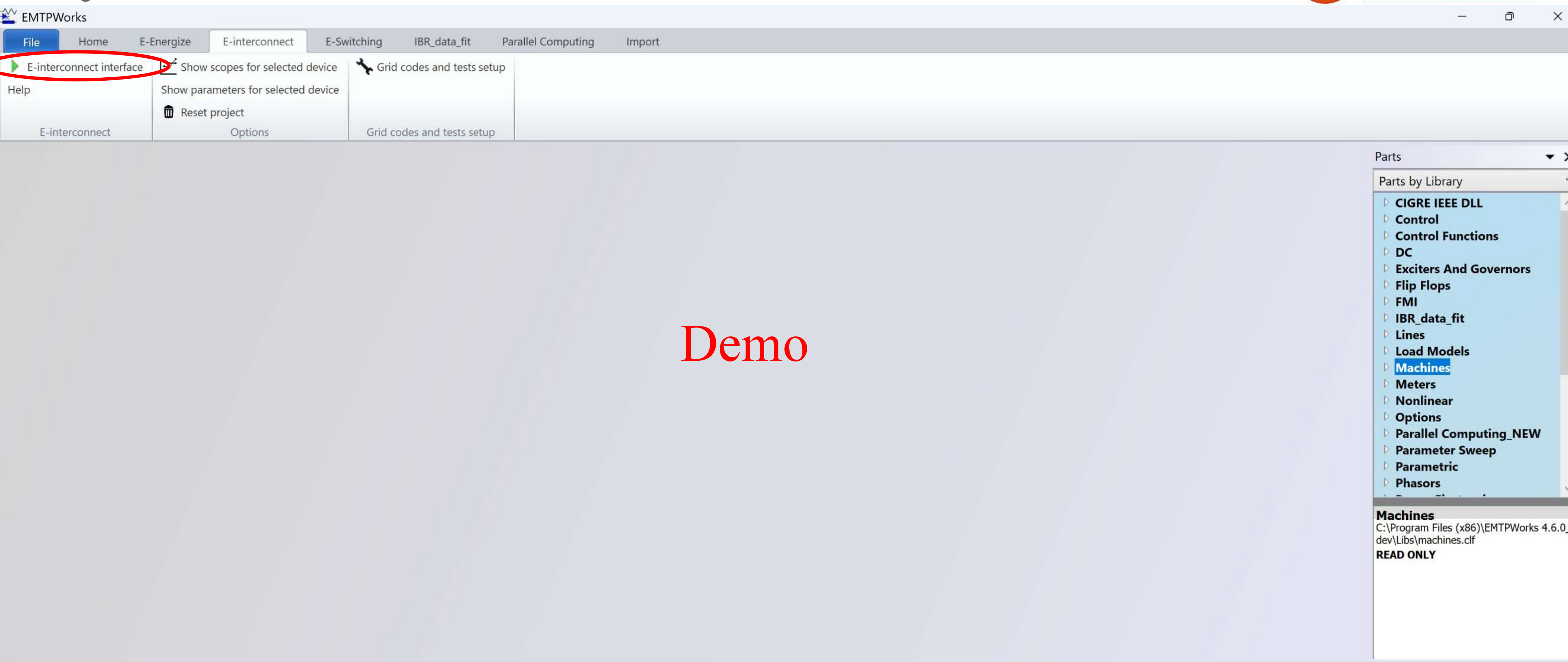
Connected to the IBR

3. Description of the tool: setup and analysis

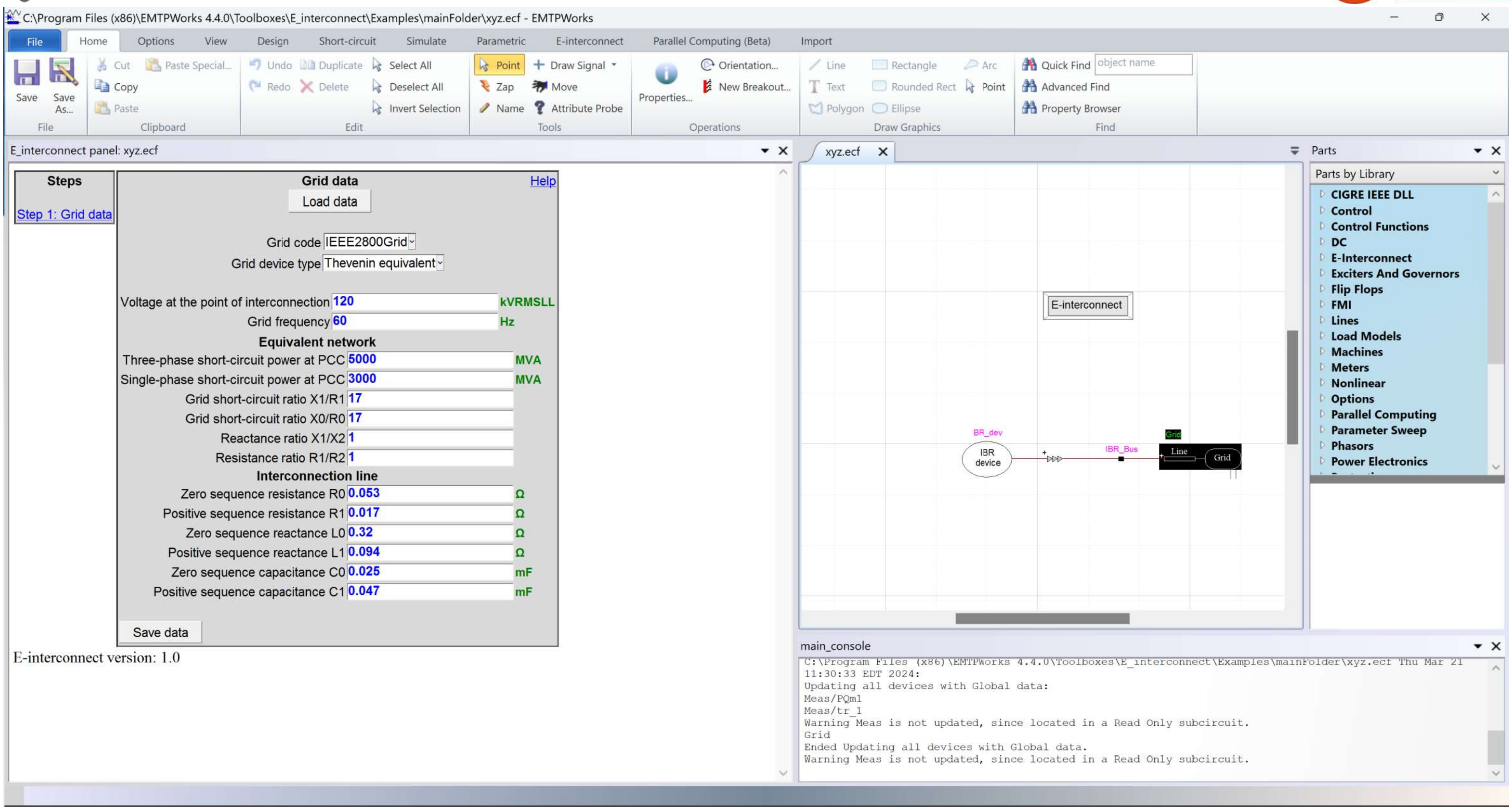
3. Description of the tool

- E-Interconnect tool is set up in 6 steps:
  - Step 1: Define the grid at POI (mandatory)
  - Step 2: Define IBR model to be evaluated (mandatory)
  - Step 3: View/modify configurations (optional)
  - Step 4: View/modify tests to be performed (optional)
  - Step 5: View/modify test parameters and validation criteria (optional)
  - Step 6: View/modify analysis options (optional)

3. Description of the tool: launch

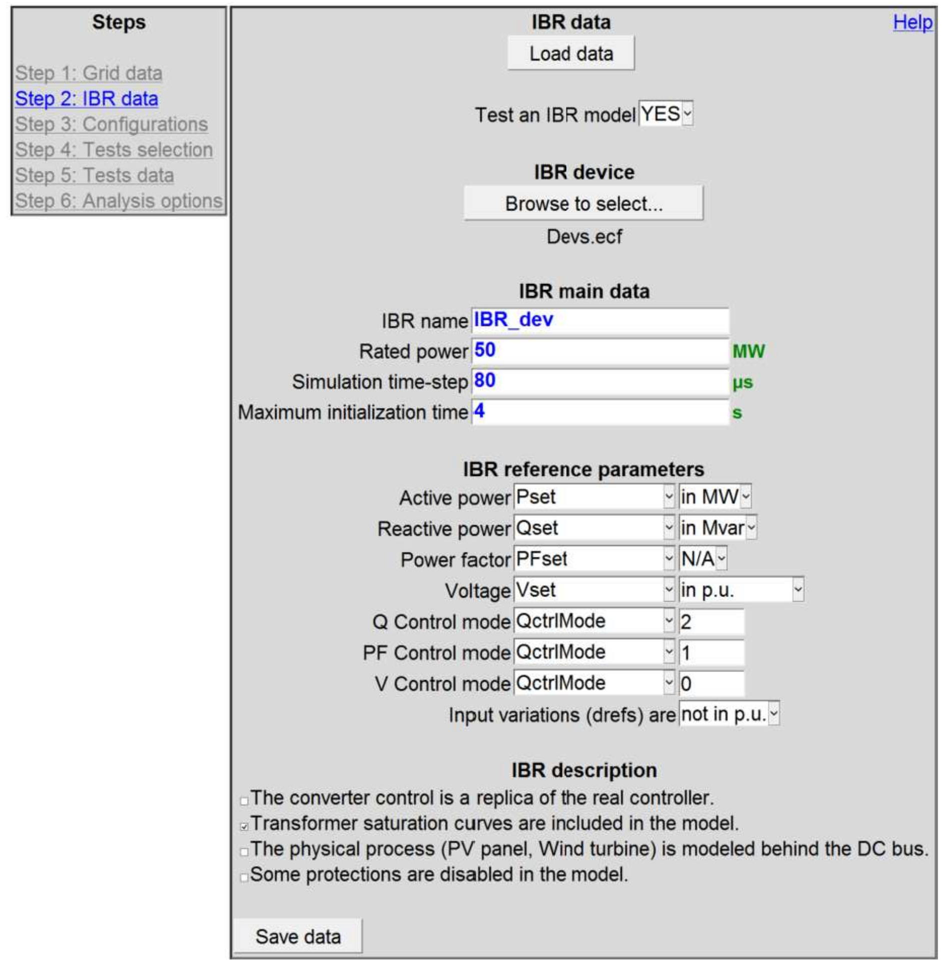


3. Description of the tool: step 1

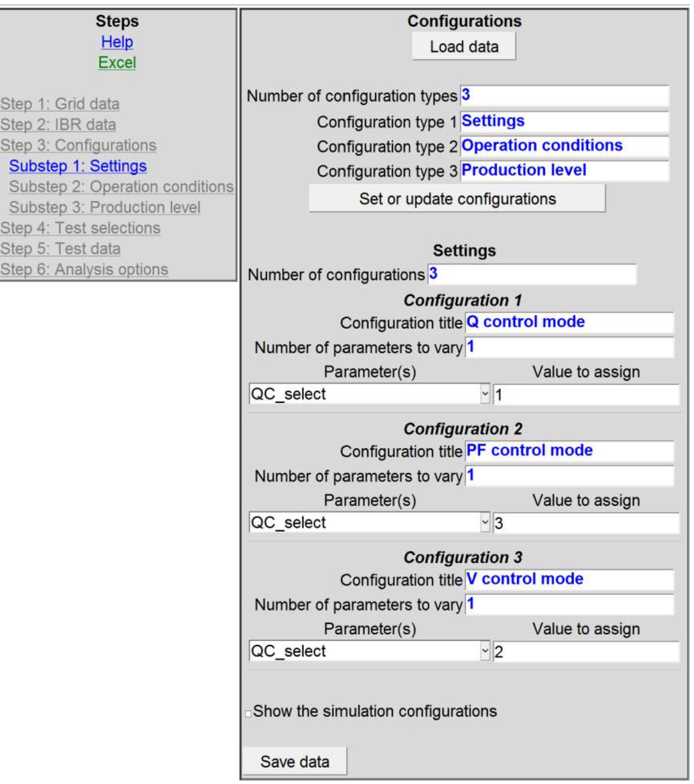


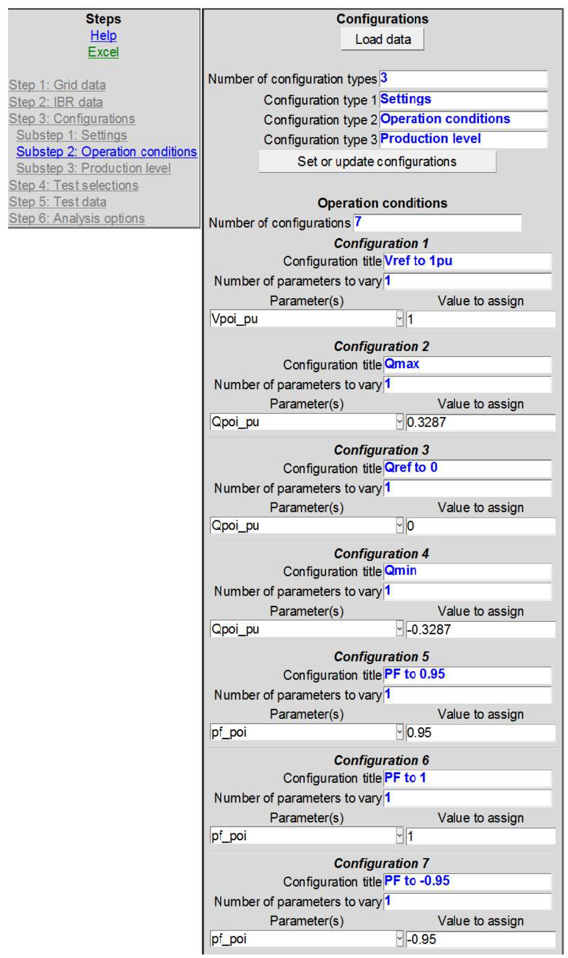
3. Description of the tool: step 2

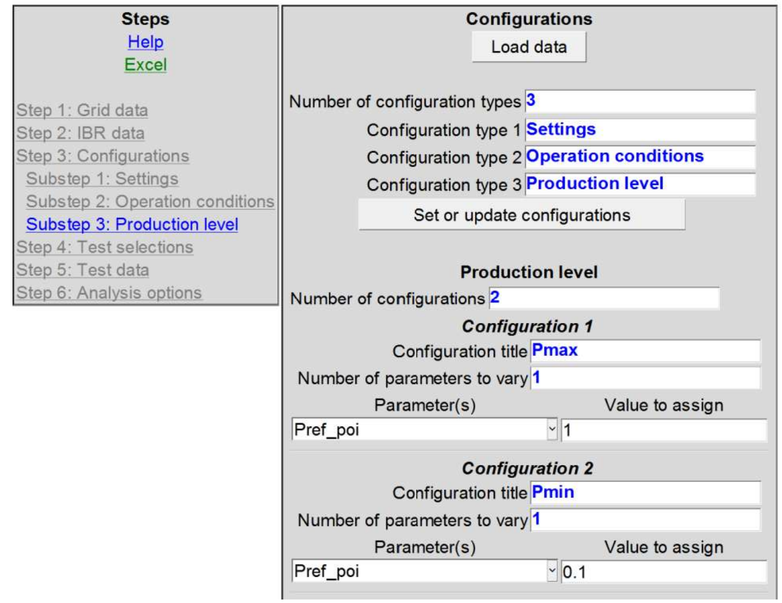
Select the IBR model to be tested and provide some information.



3. Description of the tool: step 3



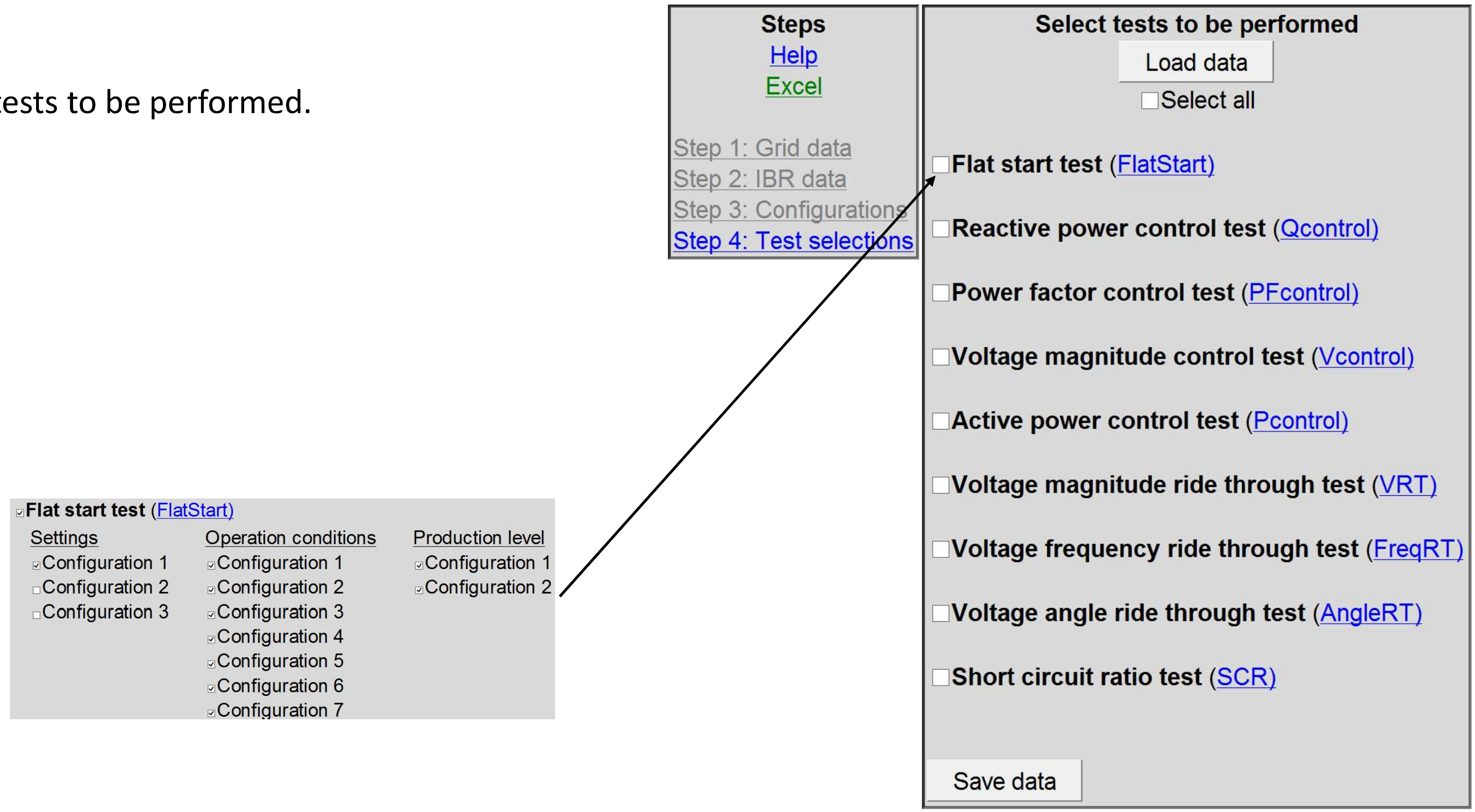




Define the operation modes for which the IBR model should be tested.

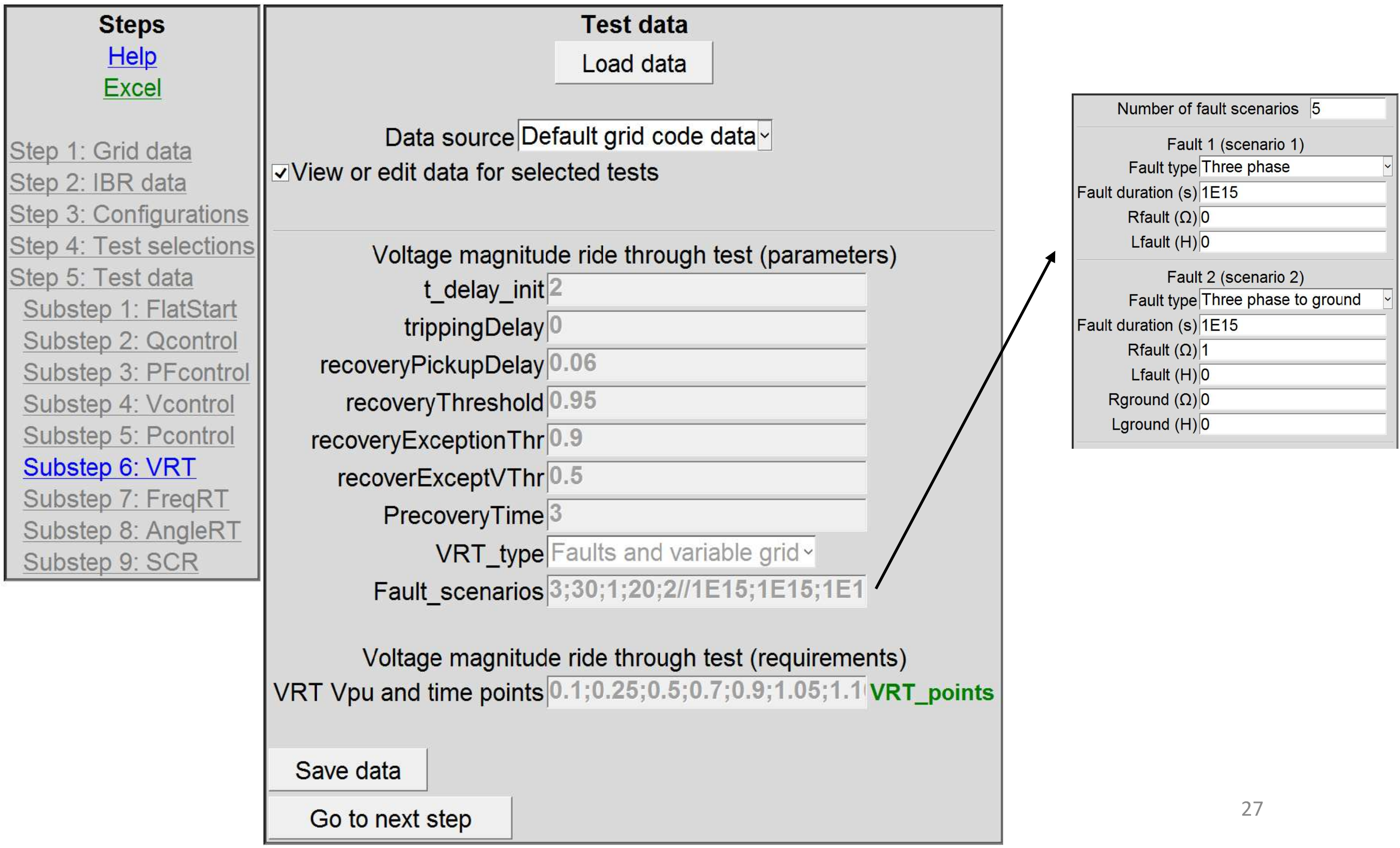
3. Description of the tool: step 4

Select the tests to be performed.



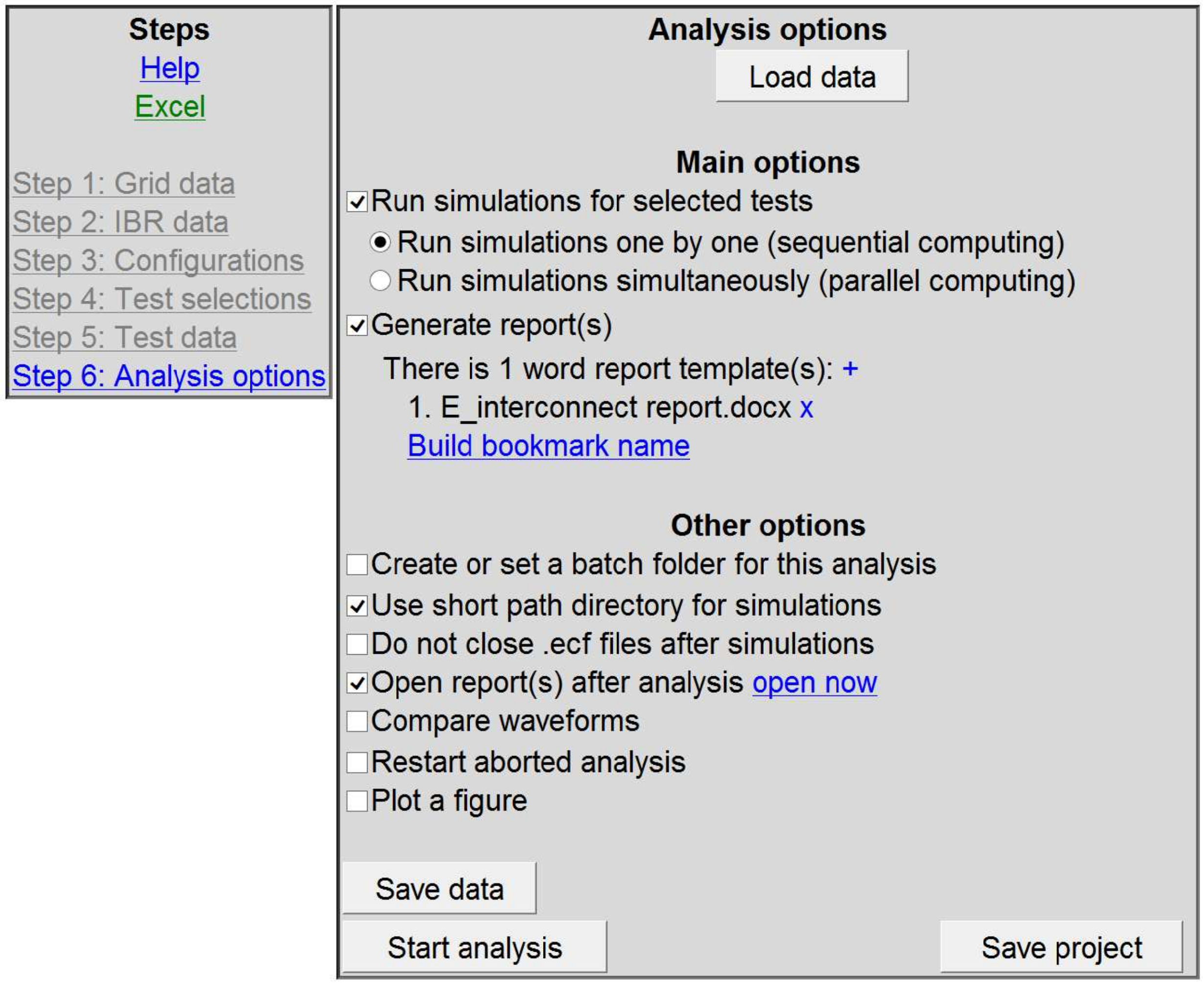
3. Description of the tool: step 5

Check (and eventually modify) some parameters that define the tests to be performed.



3. Description of the tool: step 6

Define analysis options.



4. Analysis results

4. Analysis results: files generated

- **1_runs** — All simulated .ecf files, for all tests and for all operating modes (configurations).
- **2_reports** — Word report(s) generated during analysis.
- **Errors.log** — File listing potential errors that have occurred during analysis.
- **Report.log** — Quick report summarizing all tasks performed by the E-interconnect tool.

4. Analysis results: Example of report

EMTP E-interconnect report

E-interconnect report

21/3/2024, 6:40:12

This is an automatically generated report by the E-Interconnect toolbox version 1.0 in EMTP 4.2.1

Grid:

- Code: IEEE2800Grid.
- Device type: Default.
- Voltage: 115kVRMSLL.
- Frequency: 60Hz.
- Three phase short-circuit power: 594.6MVA.
- One phase short-circuit power: 407.8MVA.
- Short-circuit ratio X1/R1: 5.5.
- Short-circuit ratio X0/R0: 3.7.
- Line zero sequence resistance: 0.053Ω.
- Line positive sequence resistance: 0.017Ω.
- Line zero sequence reactance: 0.32Ω.
- Line positive sequence reactance: 0.094Ω.
- Line zero sequence capacitance: 0.025mF.
- Line positive sequence capacitance: 0.047mF.

IBR model:

- IBR name: Coromuel.
- Rated power: 50MVA.
- Simulation time-step: 80µs.
- Maximum initialization time: 4sec.
- Location: C:\Willy_Nzale\PGSTech\Henry\E_interconnect\NewApproach_October2022\Benchmark_tests\coromuel\case3\1_setup_Park\DesignFolders\Devs.ecf

* Transformer saturation curves are included in the model.

4. Analysis results: Example of report

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4. Analysis results: Example of report

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4. Analysis results: Example of report

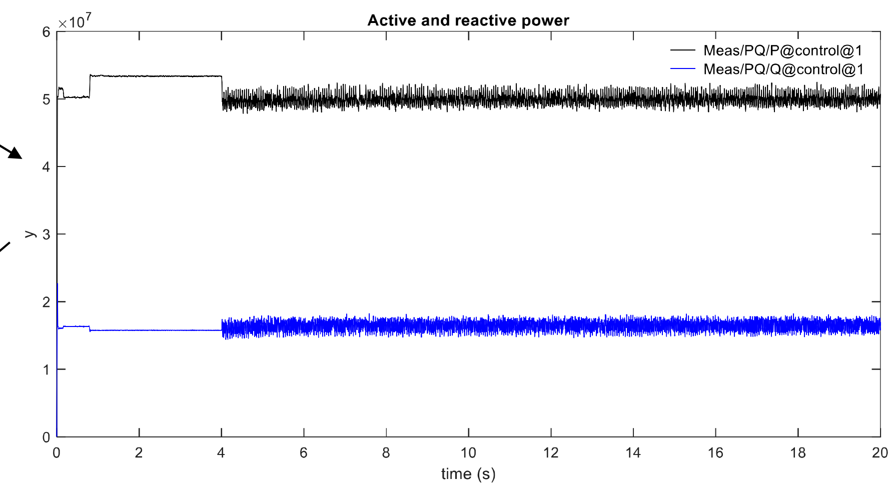
Flat start test.

Code name: FlatStart

Description: This test verifies that the model initializes correctly, and the power quantities remain constant.

Listing of parameters:

Parameters	Values	Comments
margin	0.05	A signal for which the per unit value varies between (1-margin) and (1+margin) is considered constant.
t_start	10	The signal begins to be observed from this moment (in seconds): must be greater than the model initialization time.
t_delay	10	The signal is observed during this delay (in seconds).



Active power after initialization is constant and equal to 50.09 MW.

Reactive power after initialization is constant and equal to 16.46 Mvar.

Flat start test is OK: 0 issue found!

4. Analysis results: Example of report

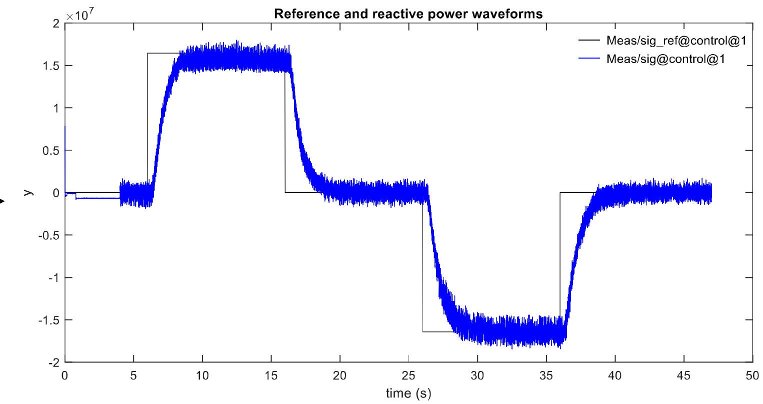
Reactive power control test.

Code name: Qcontrol

Description: This test verifies that the model complies with reactive power regulation requirements.

Listing of parameters:

Parameters	Values	Comments
t_delay_init	2	The first step is applied after the model initialization time plus this delay.
y_drefs_type	2	Set to 1 to apply step variations (y_drefs) in pu; set to 2 to apply in Mvar or kvar or var.
steps_mode	1	Set to 1 to define the steps using t_delay_init, y_drefs and delay_steps. Set to 0 to define the steps using x_steps and y_drefs.
x_steps	5;15;25;35	Time-points at which step changes occur (used when steps_mode=0).
y_drefs	0.3287;-0.3287;-0.3287;0.3287	Reference signal variations (in pu) from previous value to the next one. Actual signal value at a given time is equal to initial value plus the sum of all variations from the beginning.
delay_steps	10	Delay (in seconds) between consecutive variations (used when steps_mode=1 to calculate time-points of step changes).
checked_steps	1;3	Listing of step change numbers (orders) that will be checked during test validation.



Step change number 3:

Requirement	Value	Reference	Conclusion
Reaction time (ms)	356.16	200	not ok
Response time (s)	2.55	5	ok
Steady state error (%)	1.32	5	ok
Damping ratio	0.81	0.3	ok

Reactive power control test is not OK: 3 issue(s) found!

4. Analysis results: Example of report

Voltage magnitude ride through test.

Code name: VRT

Description: This test checks the capability of the IBR park to ride through grid voltage variations.

Listing of parameters:

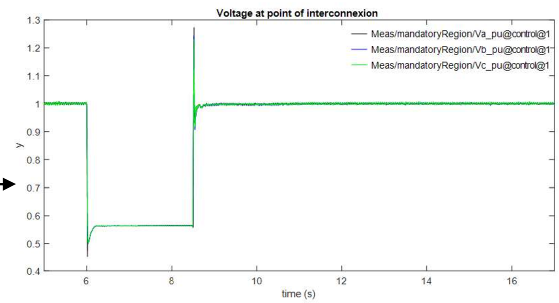
Parameters	Values	Comments
t_delay_init	2	The disturbance is applied after the model initialization time plus this delay (in seconds).
trippingDelay	0	Delay between the tripping order time and the actual tripping time.
recoveryThreshold	0.96	Power is considered recovered when its final value in p.u. is greater than this percentage of its value before disturbance.
recoveryExceptionThr	0.9	When an exception condition is satisfied, power is considered recovered when its final value in p.u. is greater than this percentage of its initial value.
recoverExceptVThr	0.5	An exception occurs when voltage drops to a value less than this value (in pu).
PrecoveryTime	3	Following a disturbance, if this delay is elapsed and the power has not recovered yet, the recovery is considered as failed.
VRT_type	2	0=implement VRT using the variable voltage grid device and using volt-time points of the LVRT/HVRT characteristic;1=Implement VRT using fault devices;2=use fault devices for LVRT and variable grid for HVRT.
Fault_types	3;30;1;20;2	Array of fault types to apply (one for each simulation). This data is used when VRT_type=1 or 2. Also 1=single-phase fault;3=three-phase fault;30=three-phase to ground fault;2=phase-phase fault;20=phase-phase to ground fault

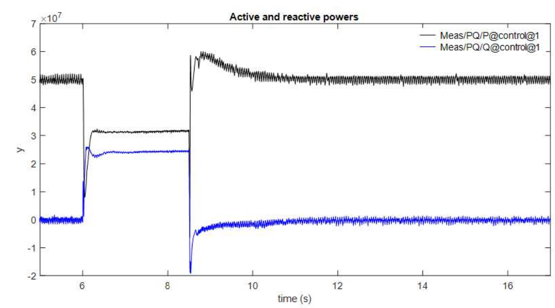
VRT scenario 2: three-phase to ground fault:

***Phase fault impedance: R = 24Ω and L = 0H.**

***Ground fault impedance: R = 0Ω and L = 0H.**

Voltage and power waveforms are shown below:





Before fault: P = 49.3 MW, Q = -0.5 Mvar, V = 1.000 pu.

Fault occurs at t = 6 sec.

Minimum and maximum phase voltages during fault are respectively 0.453 pu and 1.002 pu. The IBR must stay connected for at least 2.50 sec.

After fault: P = 48.4 MW, Q = 0.4 Mvar, V = 0.999 pu.

IBR park does restore power after disturbance.

4. Analysis results: efficiency comparison

Example of analysis run on 9 tests (46 simulations).

Performed by an expert engineer with excellent knowledge of EMTP.

Performed by the E-interconnect tool.

Task	Manual	E-interconnect Tool	Speed up
Circuits creation	9h 12min	9 min	× 61
Simulation runs	4h 40 min	4h 40 min	× 1
Tests validation and report generation	26h 50 min	1h 43min	× 16
Total	40h 42min	6h 32min	× 6

Can be split

Observation: an expert must dedicate more than a week of hard work full-time (8 hours per day) to carry out the study and deliver a report that could contain errors, whereas the proposed tool can do it autonomously in less than a night and deliver a more reliable study report.

5. Summary and conclusion: key features of the tool

Conclusion

- E-interconnect tool to automate the validation of IBR models.
- Very high flexibility level:
  - Custom grid device
  - Custom reports (word document, figures, validation scripts)
  - Adjust validation criteria (engineering judgement)
  - Split analysis (partial run several times).
  - Etc…
- Waveforms comparison option:
  - Current simulation vs Reference data (.dat)
  - Current simulation vs Another simulation (model version, etc…)
- Restart aborted analysis
- Plot figures after analysis
- The tool offers a common platform for evaluating the performance of IBRs that can be used by all stakeholders involved in the process (TSO, park owner, etc.)

Questions?