RaPId - Rapid Parameter Identification

An open source software for model identification and validation leveraging Modelica and FMI Technologies

Tin Rabuzin on behalf of:

E-mail: rabuzin@kth.se

Prof. Dr.-Ing. Luigi Vanfretti

E-mail: luigiv@kth.se

Web: http://www.vanfretti.com

luigiv@kth.se

Associate Professor, Docent

Electric Power Systems Dept.

KTH

Stockholm, Sweden

Luigi.Vanfretti@statnett.no

Special Advisor in Strategy and Public Affairs

Research and Development Division

Statnett SF

Oslo, Norway

iTesla

Outline

- Background and Motivation
  - Modelica and Power System Modeling
  - Why do we need Model Validation?
  - Software Requirements
- RaPId Overview
- Use Cases
  - Generator Aggregation
  - Excitation system identification
  - N44 - Small Signal Model Calibration
- Conclusions and Recommendations

Present challenges, limitations and possible solution

POWER SYSTEM MODELING

Power System Modeling

- The **order of computations is decided at modelling time**

Acausal	Causal

`R*I = v;`	`i := v/R;`
	`v := R*i;`
	`R := v/i;`

- Most tools make **no difference between “solver” and “model”** – in many cases solver is implanted in the model

- There is **no guarantee** that the same standardized model is implemented in the same way across different tools
- Even in Common Information Model (CIM) v15, **only block diagrams** are provided instead of equations

- Mod ... whose param ... **specific “data fo**
- For large ... this **requires translation** into the internal data format of each program

MODELICA

ENTSO-E has recognized the Modelica approach and it will be used in [IOP Tests in July]

Modelica and Power Systems

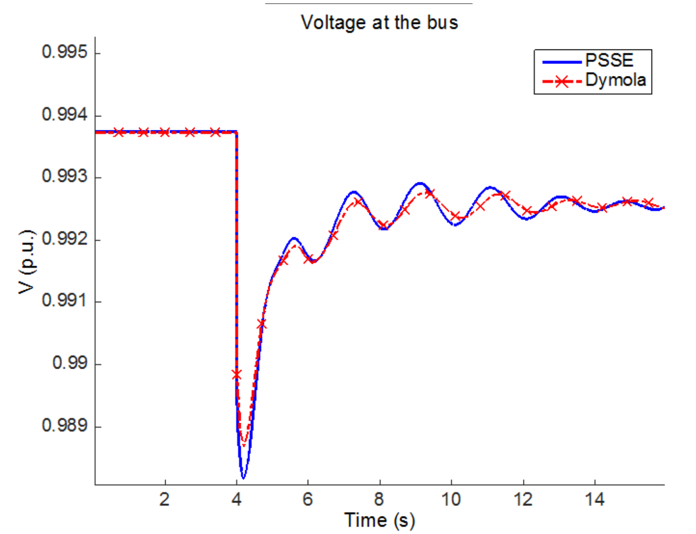
- **Modelica** is an open standardized modeling language among all Modelica compliant IDEs
  - Modelica Language Specification: https://www.modelica.org/documents/ModelicaSpec33.pdf
- **iPSL** is an open-source Modelica library for power systems
  - It contains a set of **power system components** for **phasor time domain** modeling and simulation
  - Models have been **validated** against a number of reference tools
- **iPSL** allows:
  - **Unambiguous** model exchange
  - Formal **mathematical description** of models
  - Exploitation of **object-oriented** paradigms
  - **Separation** of **models** from IDEs and **solvers**

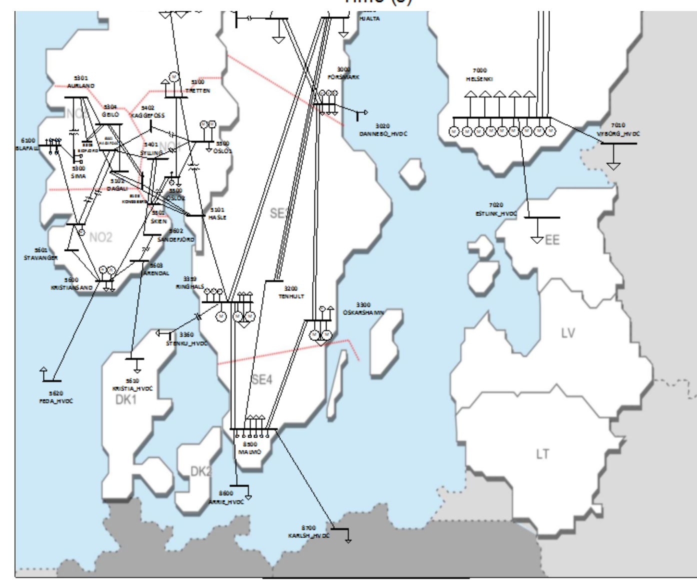
iTesla Power Systems Library
iPSL

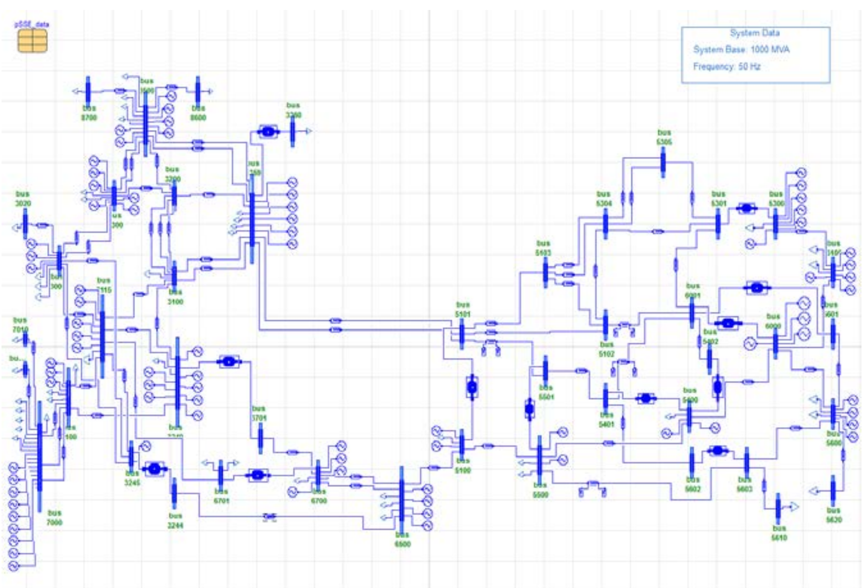
Modelica Models of Power Systems

Modelica model of Nordic44 system

- Modelica can be used to build models of various sizes
- Norwegian TSO Statnett provided a PSS/E model of Nordic44 system
- The same model was implemented in Modelica and validated against a reference software, PSS/E







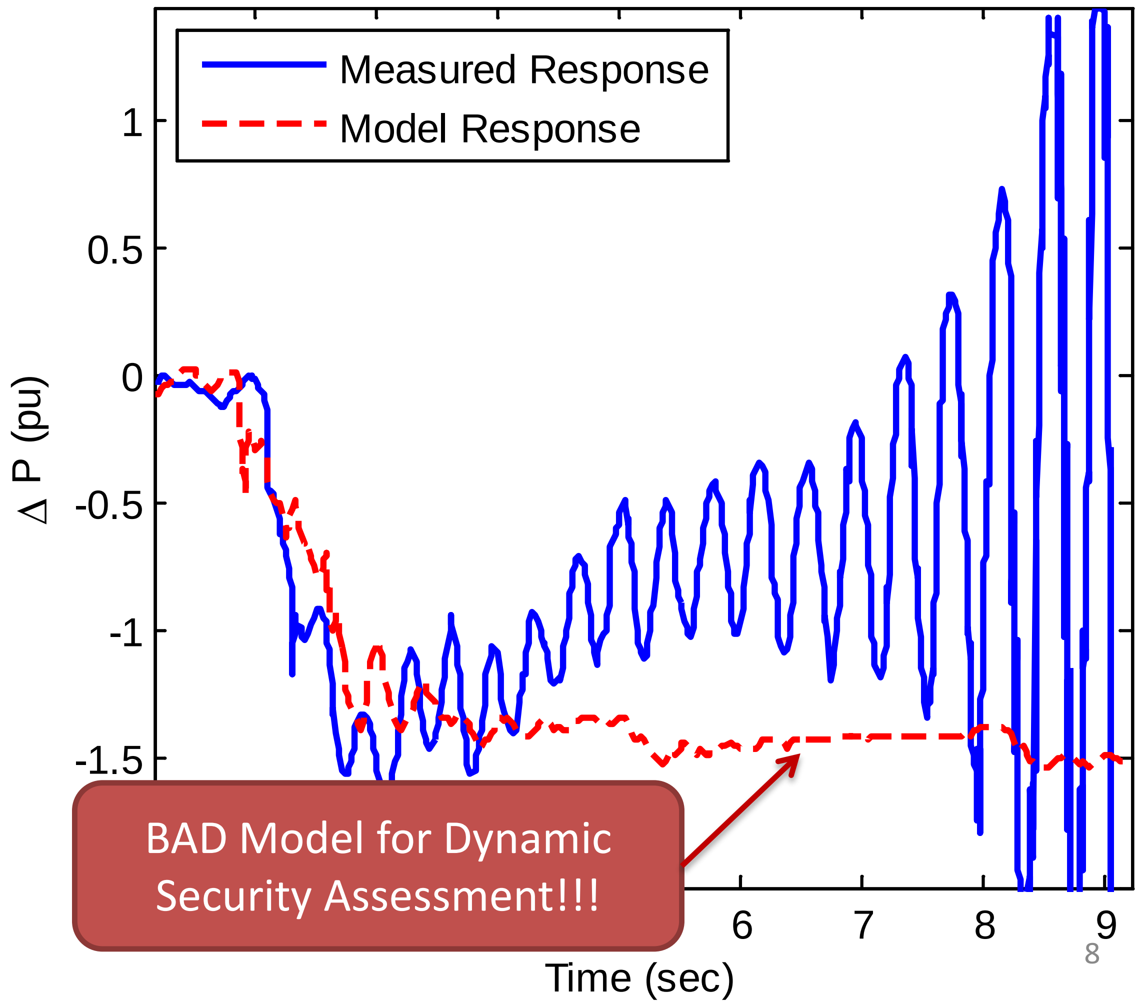
Assume that you have a “good enough” model, then what?

WHY POWER SYSTEM MODEL VALIDATION?

Why “Model Validation”?

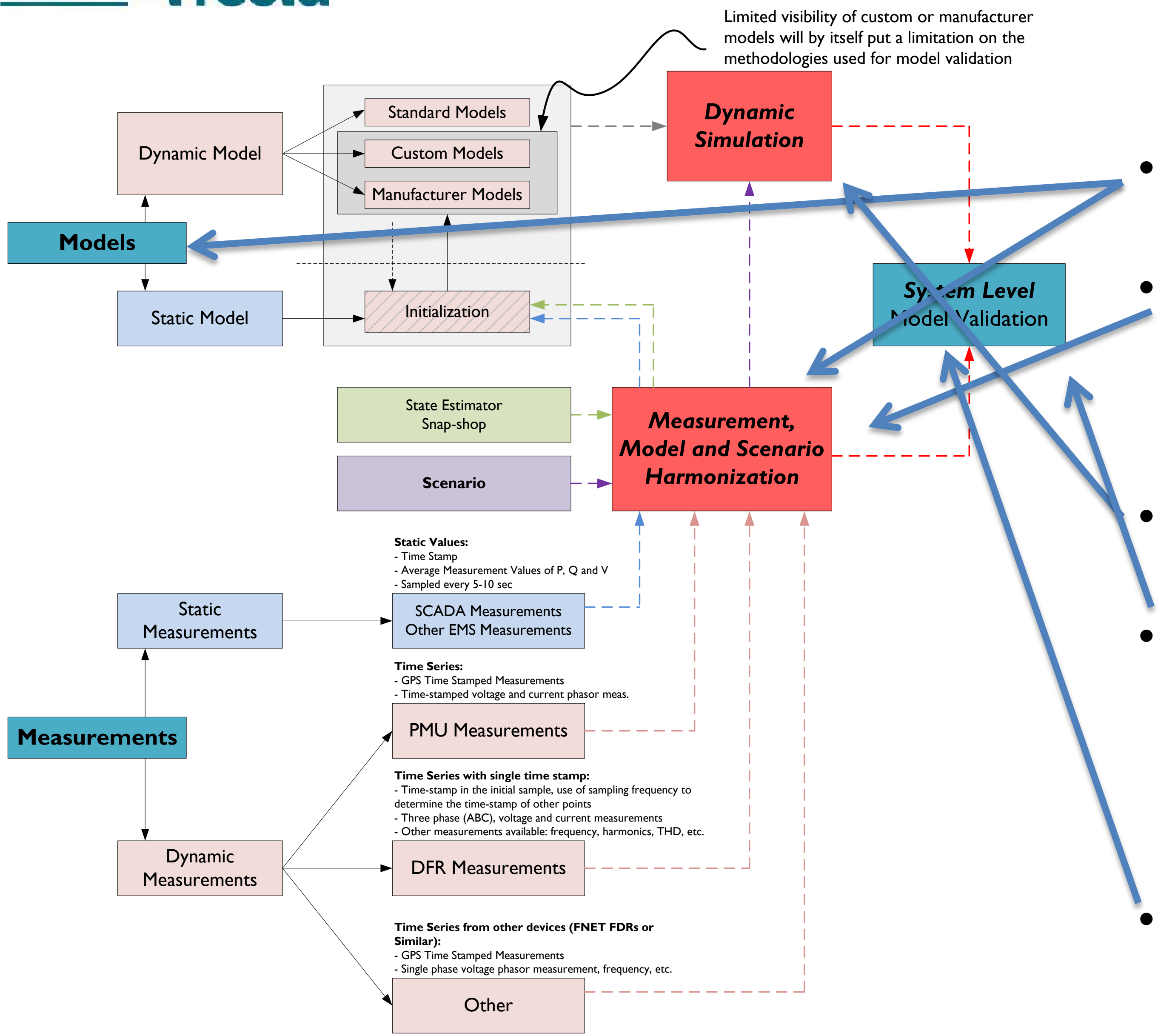
- **iTesla tools aim to perform “security assessment”**
- The quality of the models used by off-line and on-line tools will affect the result of any SA computations
  - *Good model*: approximates the simulated response as “close” to the “measured response” as possible
- Validating models helps in having a model with “good sanity” and “reasonable accuracy”:
  - Increasing the capability of reproducing actual power system behavior (better predictions)

US WECC
Break-up in 1996



BAD Model for Dynamic Security Assessment!!!

What is required from a SW architecture for model validation?



- Support “harmonized” dynamic models
- Process measurements using different DSP techniques
- Perform simulation of the model
- Provide optimization facilities for estimating and calibrating model parameters
- Provide user interaction

A model validation and parameter identification SW

THE RAPID TOOLBOX

What is RaPId?

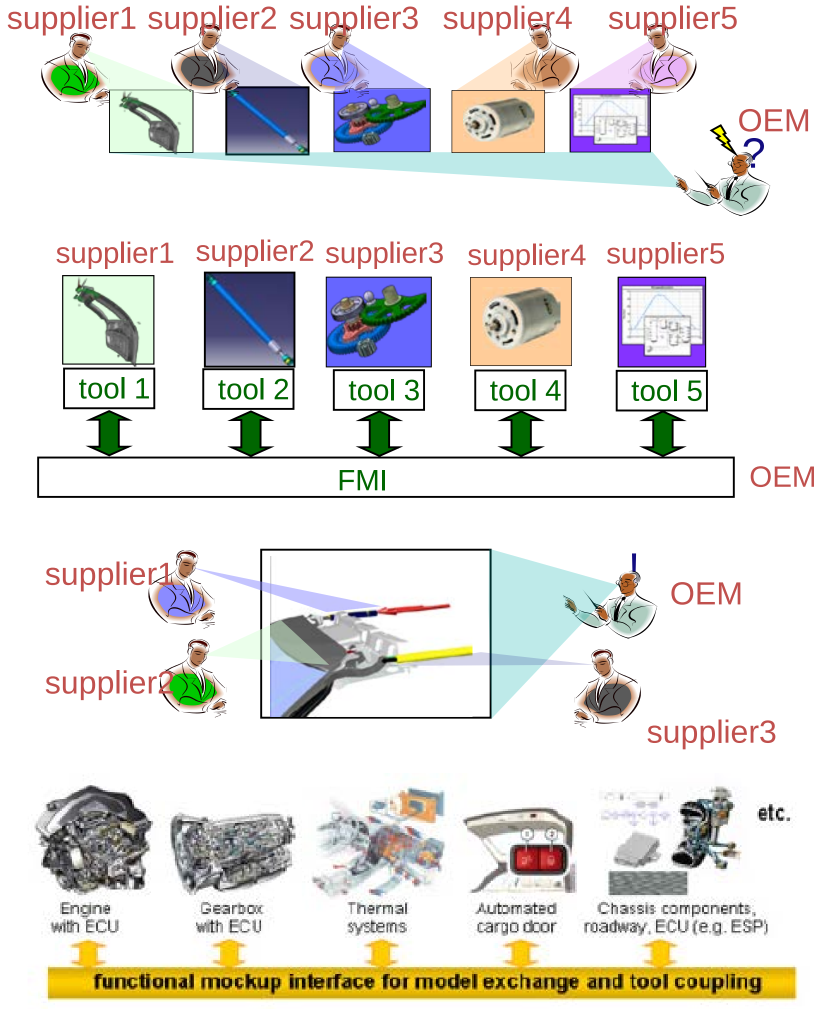
- **RaPId** is a toolbox providing **a general framework for parameter identification**
- **Any model** made available through a **Functional Mock-Unit (FMU)** in the Simulink environment, is characterized by a certain number of parameters whose values can be independently chosen.
- **RaPId** attempts to **tune the parameters** of the model so as to satisfy the user-defined fitness function

Coupling Models with Simulation & Optimization: **FMI and FMUs**

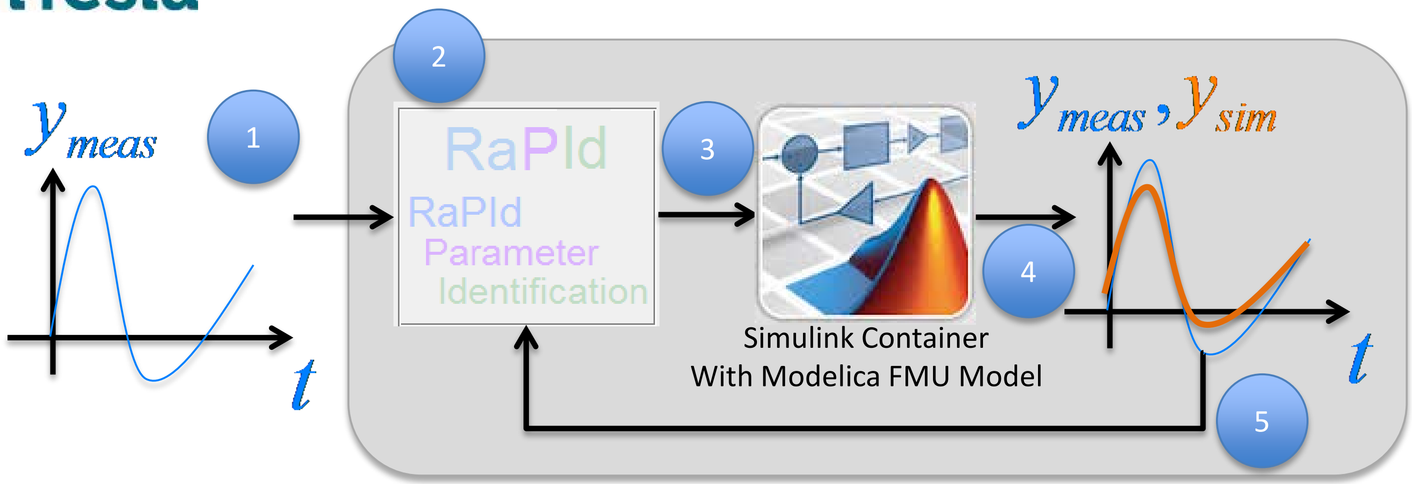
- **FMI** stands for **F**unctional **M**ock-up **I**nterface:
  - *FMI is* ***a tool independent standard*** to support both model exchange and co-simulation of dynamic models using a combination of xml-files and C-code, originating from the automotive industry

The FMI Standard is now supported by 40 different simulation tools.

- A **F**unctional **M**ock-up **U**nit (**FMU**) is a model which has been compiled using the FMI standard definition



How does RaPId work?



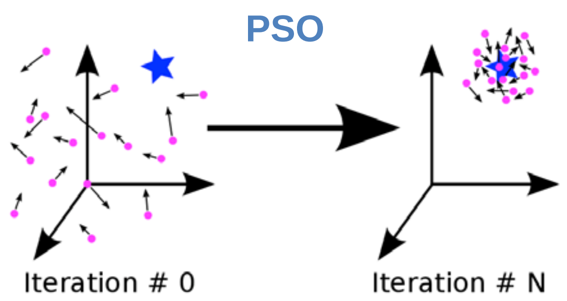
1. Output (and optionally input) measurements are provided to RaPId by the user.
2. At initialization, a set of parameters is pre-configured (or generated randomly by RaPId)
3. The model is simulated with the parameter values given by RaPId.
4. The outputs of the model are recorded and compared to the user-provided measurements
5. A fitness function is computed to judge how close the measured data and simulated data are to each other

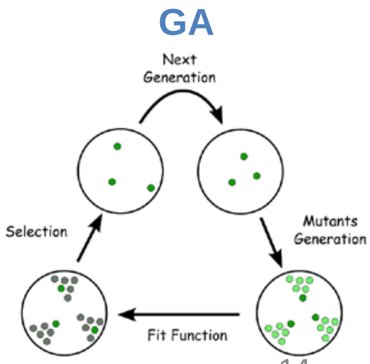
2′ **Simulations continue until a min. fitness or max no. of iterations (simulation runs) are reached.**

Plug-in Architecture

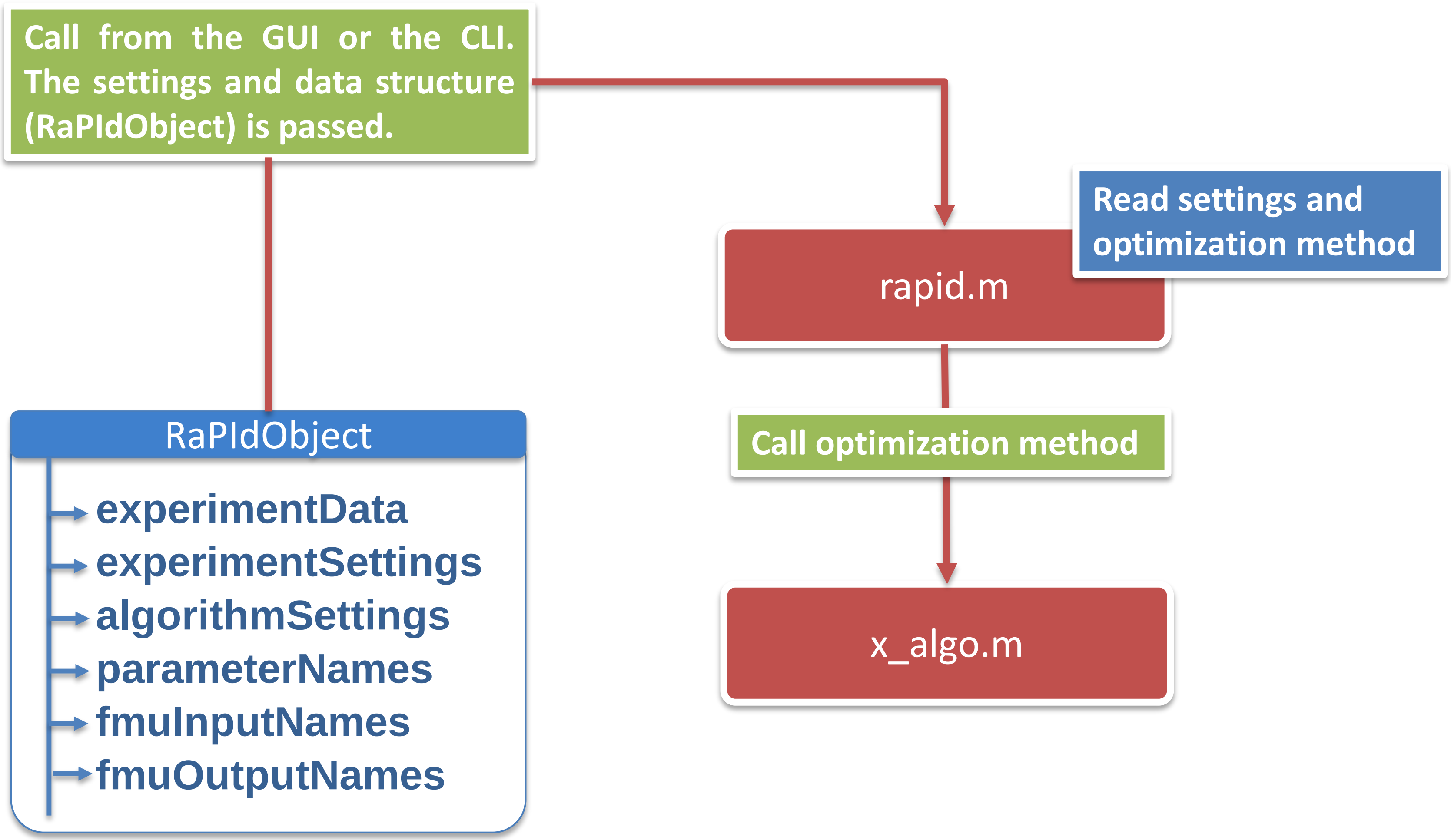
- **RaPId** was developed in **MATLAB**.
  - The MATLAB code acts as ***wrapper*** to provide interaction with several other programs (which may not need to be coded in MATLAB).
- Optimization process can be set up and ran from the **GUI** or more advanced users can simply use **MATLAB scripts** for the same purpose
- **Plug-in Architecture:**
  - **Completely extensible and open architecture** allows advanced users to add:
    - Identification methods
    - Optimization methods
    - Specific objective functions
    - Solvers (numerical integration routines)

- A number of optimization algorithms are available:
  - Particle Swarm Algorithm (PSO)
  - Genetic Algorithm (GA)
  - Naïve method
  - Knitro Algorithm

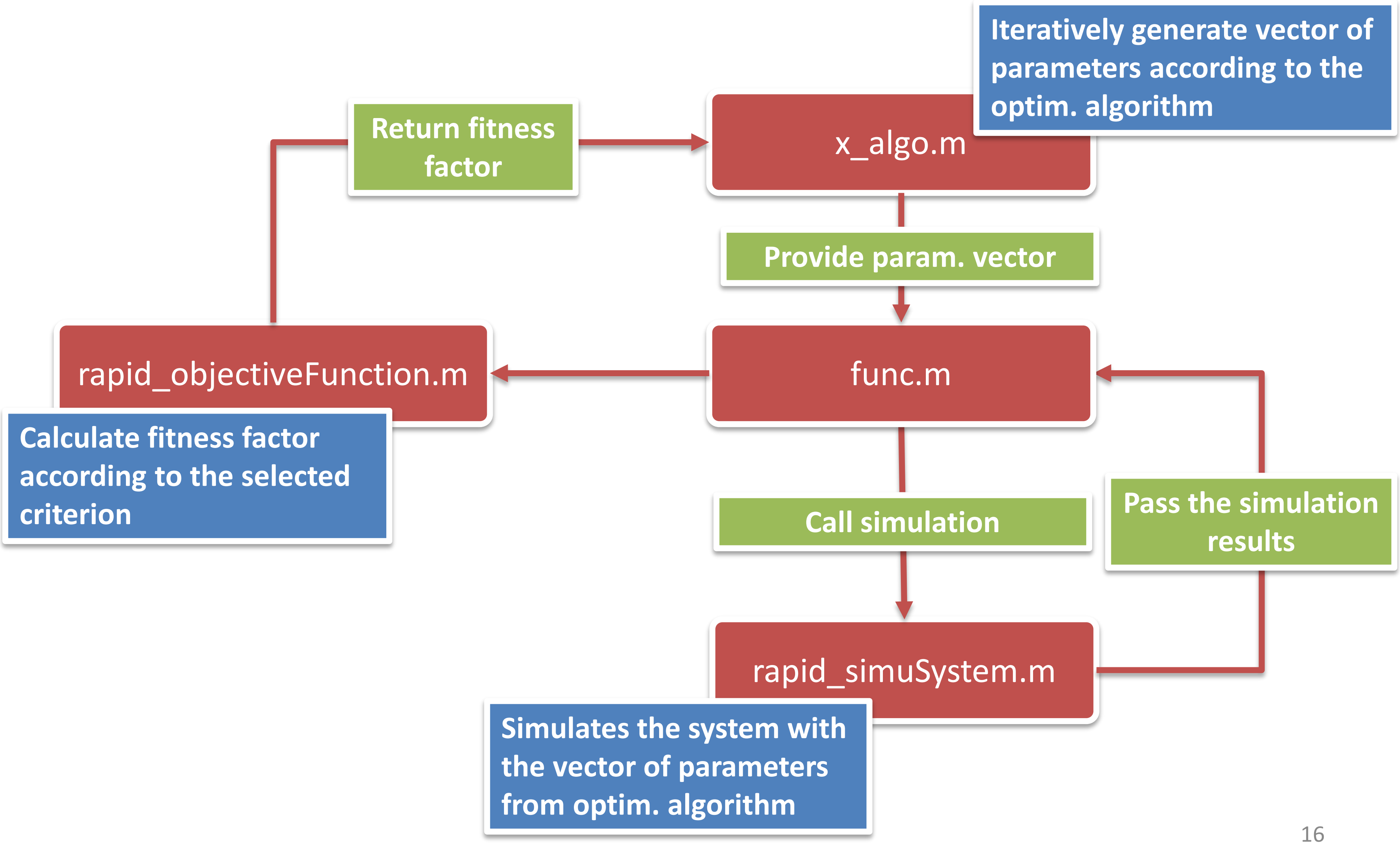




Implementation Overview



Implementation Overview



Parameter and Mode Estimation

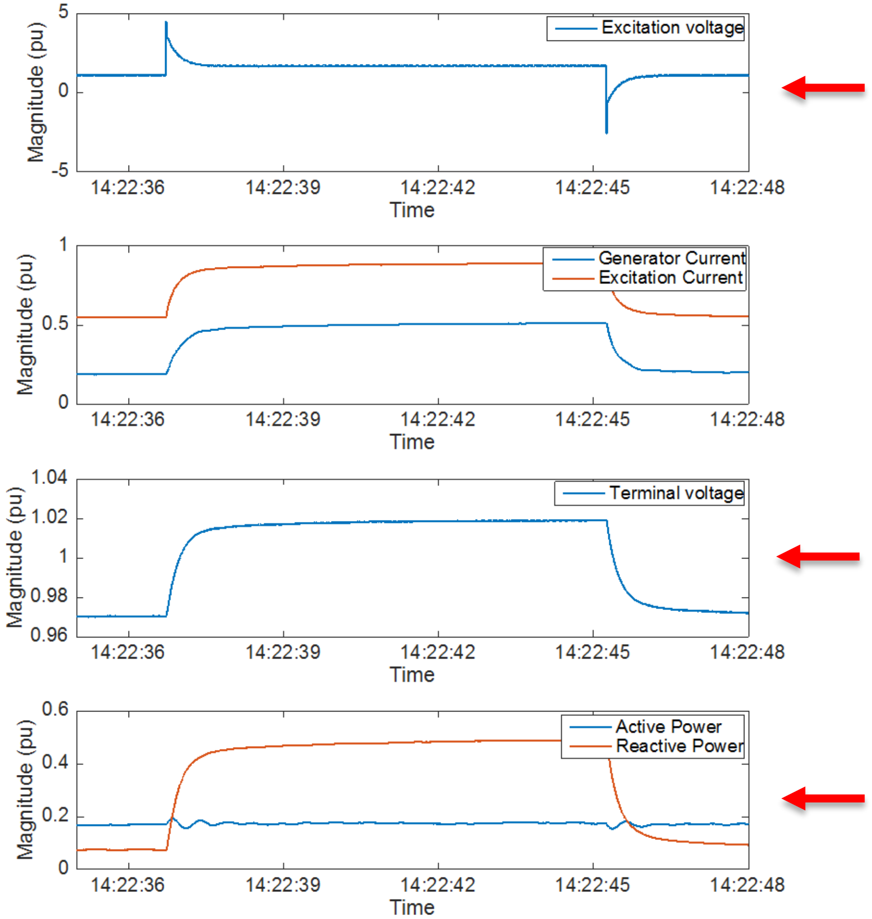
USE CASES

Excitation system identification

Problem Formulation

- This use case deals with the **parameter identification of the excitation system**
- Estimation is based on the **real data** acquired on the hydro-power plant Mostar
- Measurements were acquired during the **disturbance to the voltage reference** of the Automatic Voltage Regulator (AVR)
- The disturbance was in form of successive **5% step increase and decrease** of the voltage reference
- It will be illustrated how estimation can be performed with **limited information**:
  - No approx. **exciter parameters** known
  - **Governor model** is unknown
  - **Plant and system configurations** surrounding the generator are unknown

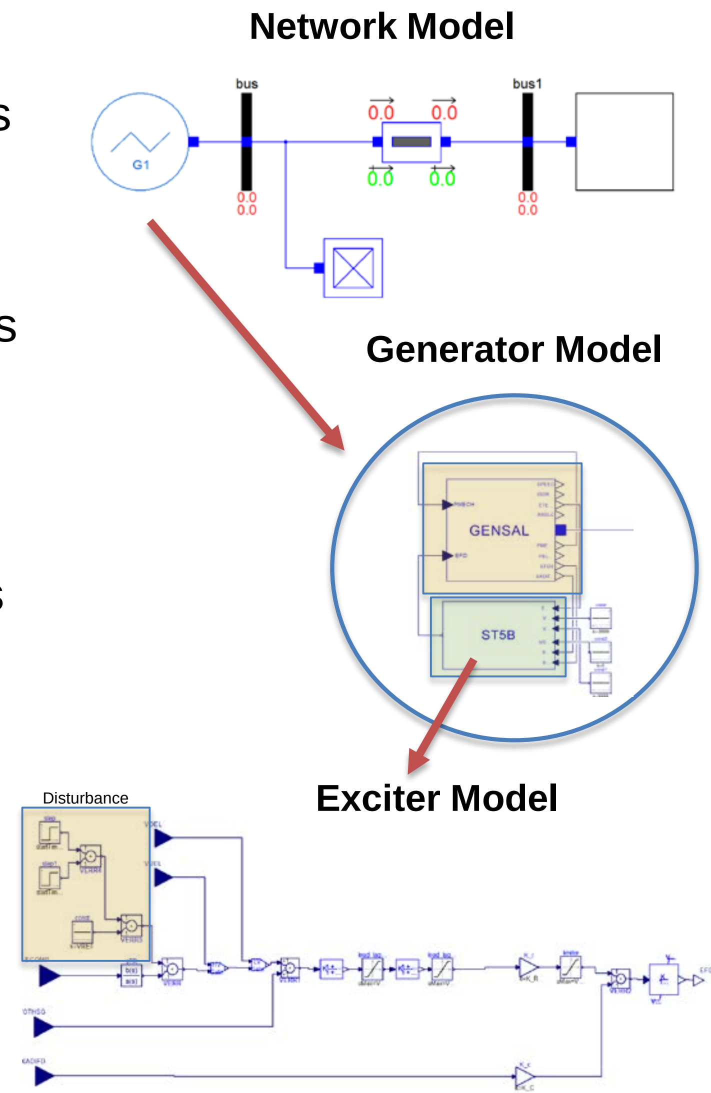
Measurements from the AVR



Excitation system identification

Modelica Model for Validation

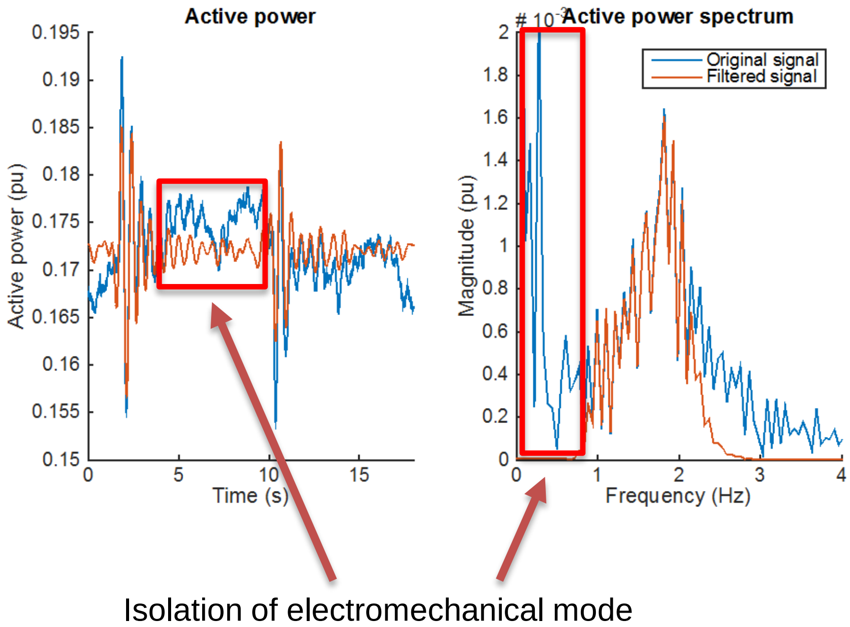
- The simple model of the power system was built in Modelica
- The generator whose excitation parameters were identified is connected to the infinite bus through the line
- The load is connected to the generator bus
- The model of the excitation system is a simplified model based on the excitation system manufacturer’s recommendations



Excitation system identification

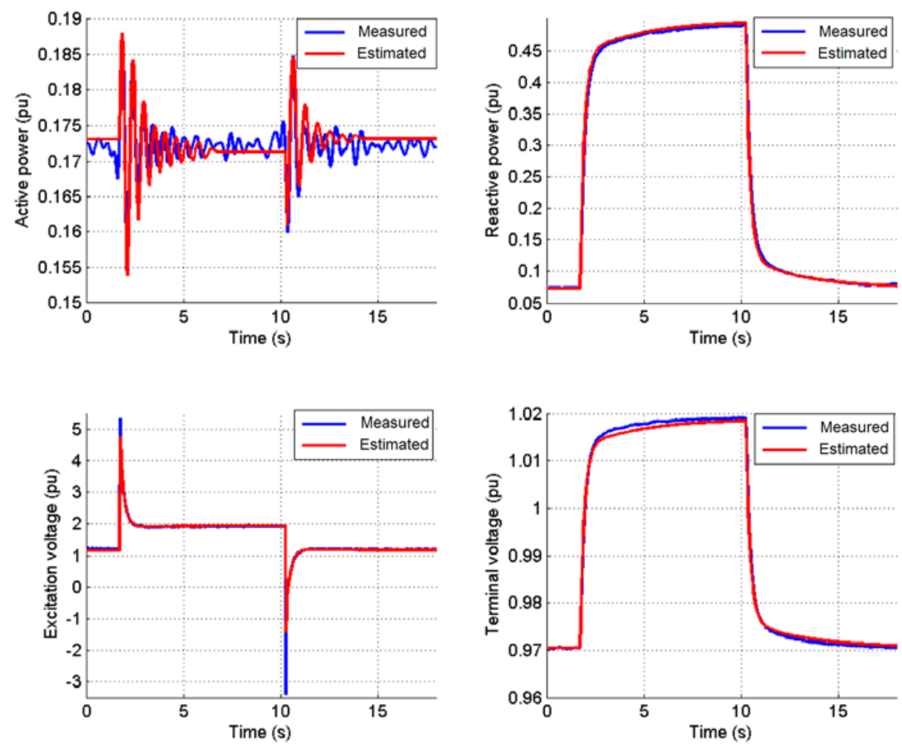
Measurement Pre-processing

- As it could be seen on the previous two slides, no turbine governor has been used in the model of the power system
- If the measurement of the active power is observed, in addition to the electromechanical mode of oscillation, the slower mode related to the turbine governor can be observed
- The bandpass filter was applied to the signal to isolate the electromechanical mode of the oscillation



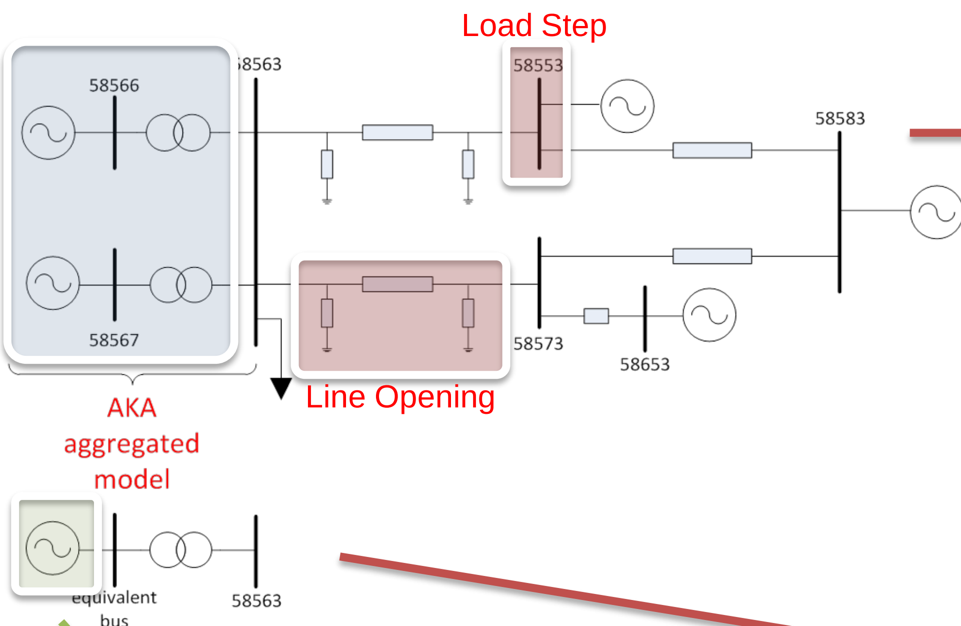
Excitation system identification

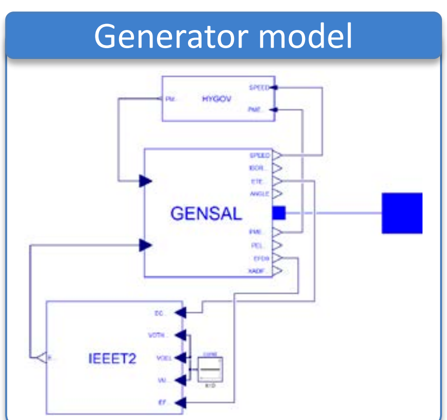
Simulation and Results

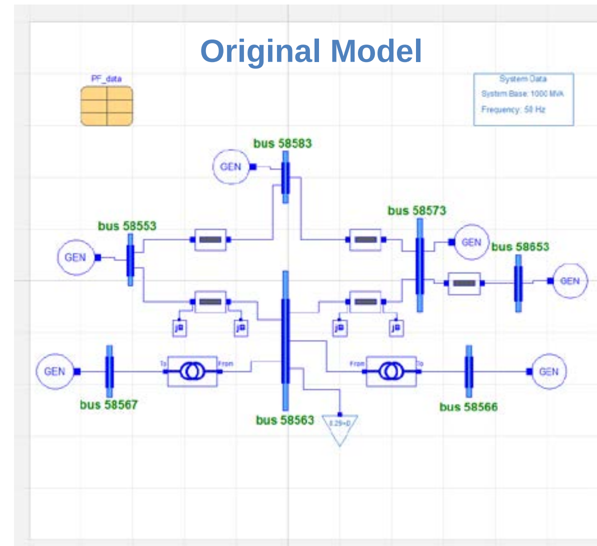


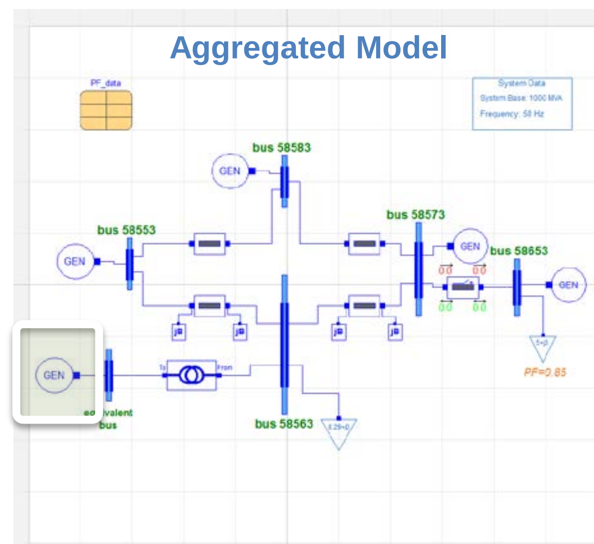
Generator Aggregation

Problem Formulation

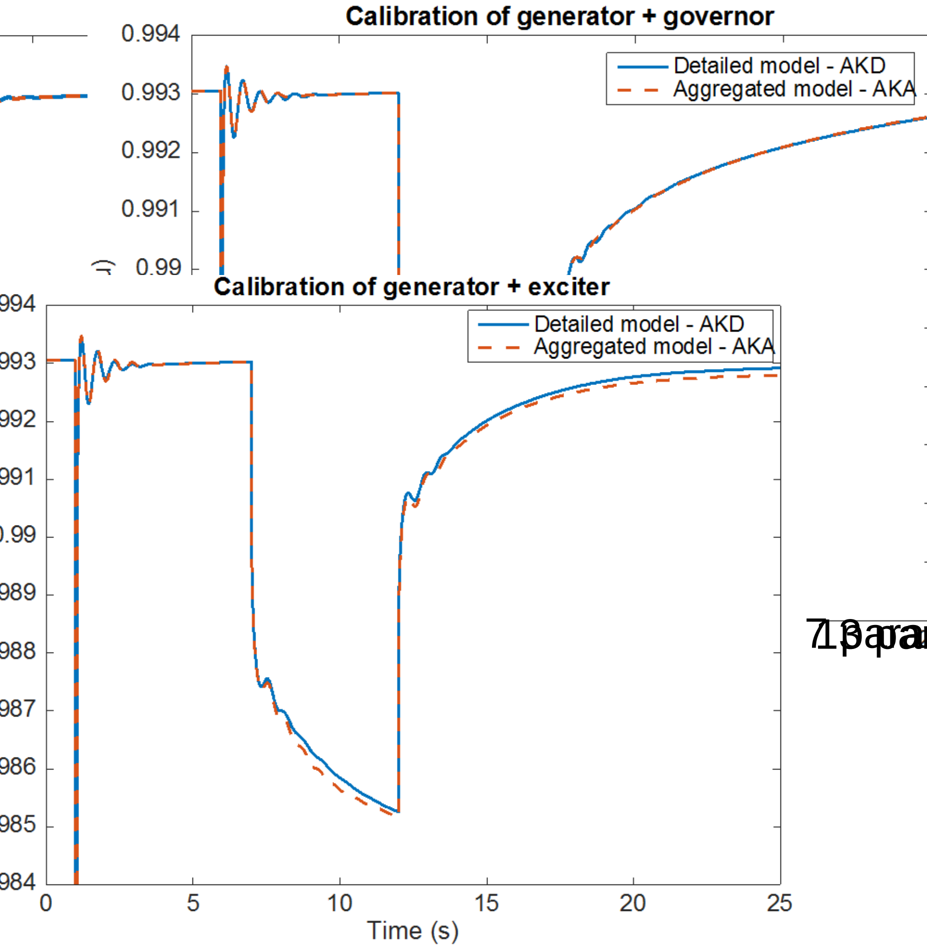


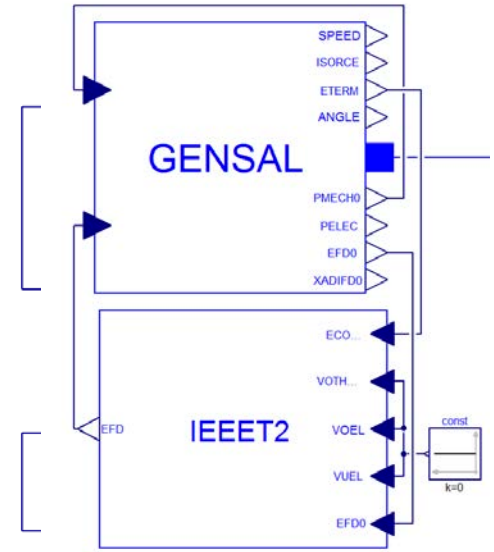






Generator Aggregation



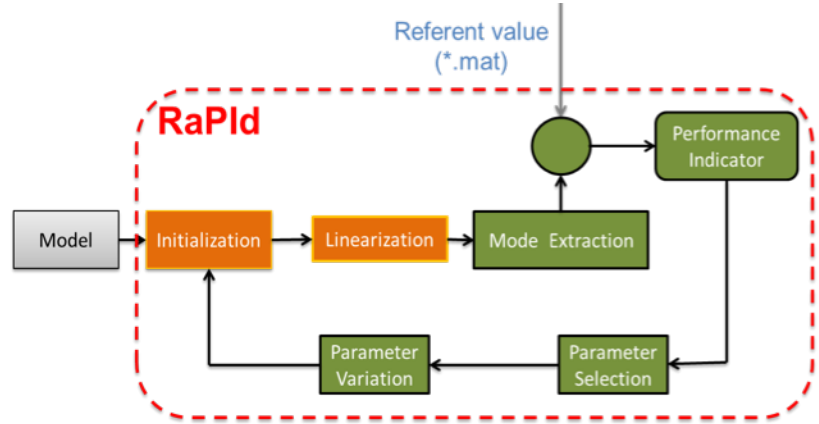


7 parameters calibrated in 4 consecutive simulations

13 parameters calibrated in 6 consecutive simulations

Nordic44 – Small Signal Model Calibration

- Previous examples used time domain response of the systems to perform validation
- In this example, in addition to the time domain response, small signal characteristic of the system will be used as well



- RaPId will perform the linearization of the system and extract the mode of the system with currently set parameters

- The fitness function (performance indicator) which is used with small signal analysis is an Euclidean distance between the measured and the pole obtained from the linearization of the system:

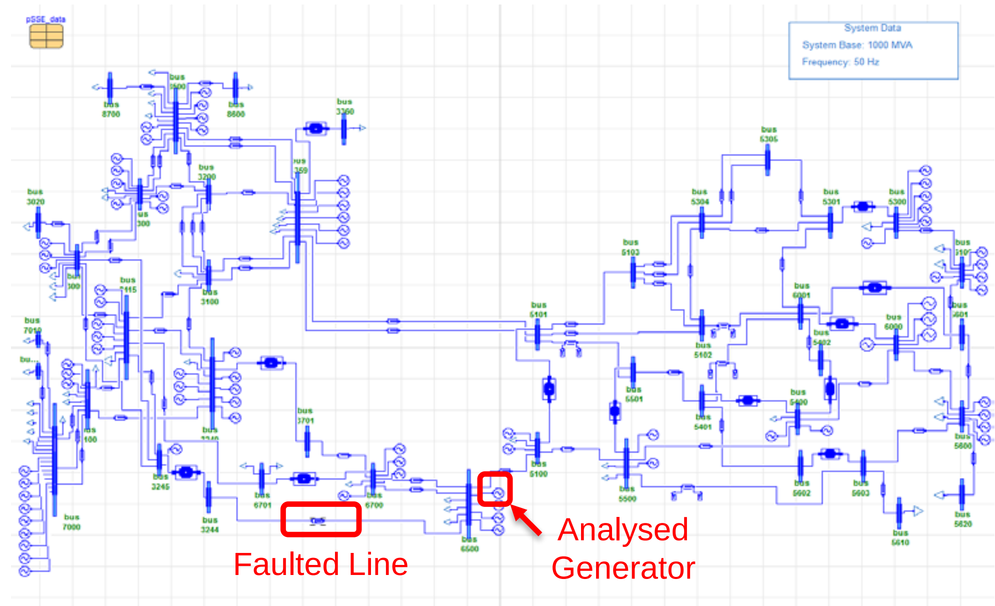
$$PI = \left\| s_{model} - s_{ref} \right\| = \sqrt{\left(\sigma_{model} - \sigma_{ref}\right)^2 + \left(\omega_{model} - \omega_{ref}\right)^2}$$

- In RaPId, it is also possible to perform validation using both the time domain and small signal performance integrator. This is done by merging the two criterias into one using weighting coefficients:

$$PI = w_1 PI_{\substack{small \\ signal}} + w_2 PI_{\substack{time \\ domain}}$$

Nordic44 – Small Signal Model Calibration

- The **calibration of the generator inertia** in the N44 system has been carried out on the marked generator
- The **disturbance** is introduced to the system in form of **line opening** between buses 3244 and 6500
- **Three signals** are used for parameter estimation:
  - Terminal voltage magnitude
  - Terminal voltage angle
  - Active power transfer over the faulted line



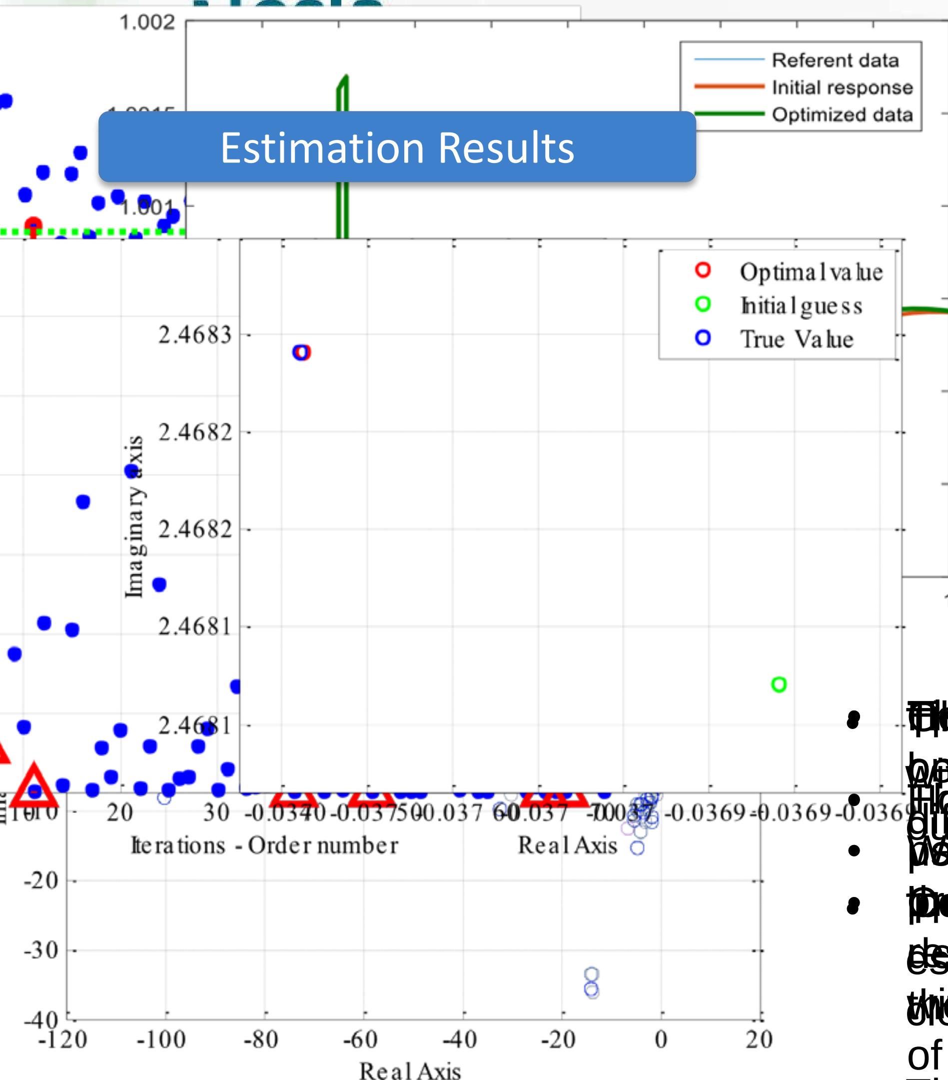
- The calibration is carried out with the following setting of performance indicator:

$$PI = w_1 PI_{\substack{small\\signal}} + w_2 PI_{\substack{time\\domain}}, \qquad w_1 = 1000, \qquad w_2 = 1$$

- The large difference between two weighing factors is due to the numerical difference between the two performance indicators (small signal and time domain)
- The true value of the estimated generator inertia is 3.556 and the starting guess is 4.556

Nordic44 – Small Signal Model Calibration

Estimation Results



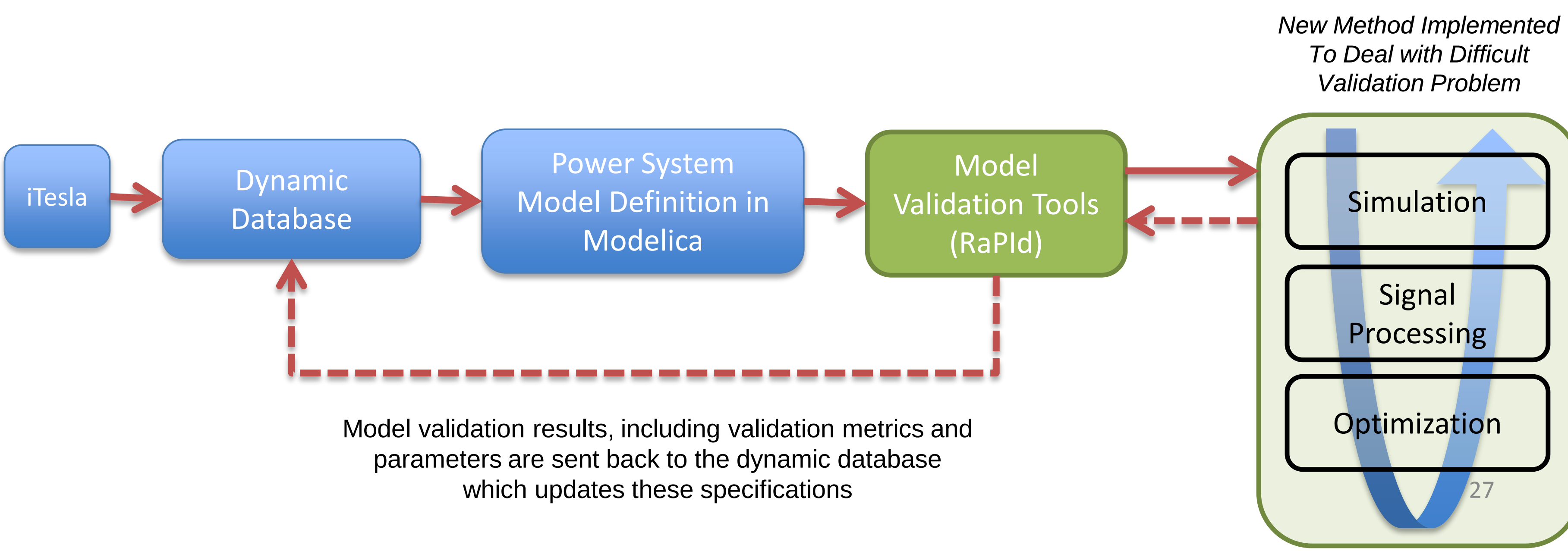
of the two systems

- The dots marked in red are parameter values currently giving optimum and the ones in blue are just attempts by the algorithm

Modelica and FMI

Modern computer technologies opening new opportunities

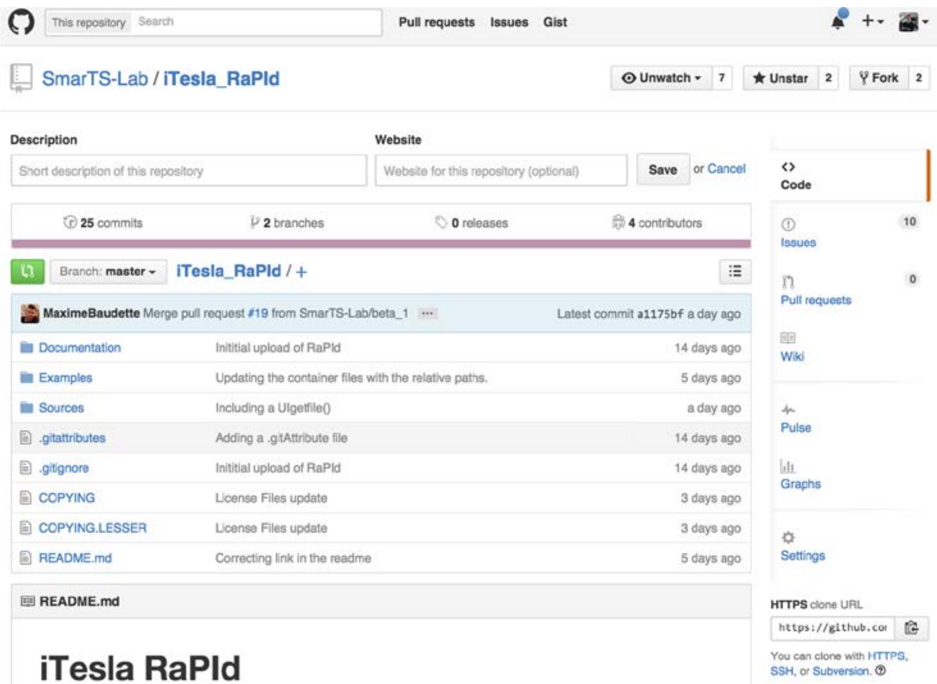
- Validating power system models requires to develop new methods and new tools itself:
  - The tools for model validation can be built independent from a **specific power system simulator**, thanks to the development of the Modelica library which allows to run the models with different tools and using FMUs.
  - Model validation tools developed in this approach will provide additional flexibility to couple **in a modular fashion**: simulation, optimization and signal processing tools.

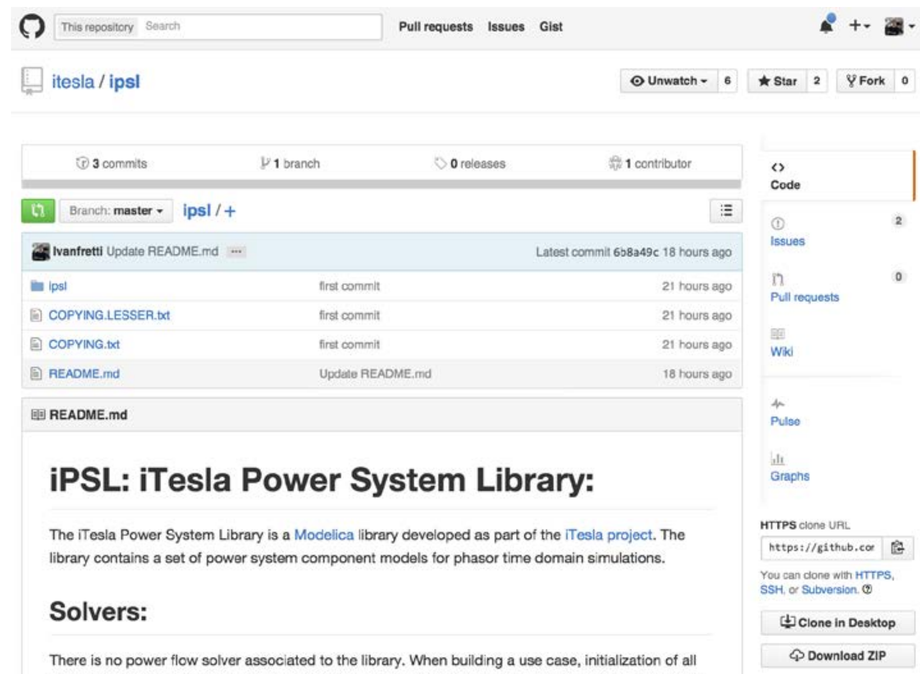


Conclusions and Looking Forward

- Modeling power system components with Modelica (as compared with domain specific tools) is very attractive:
  - Formal mathematical description of the model (equations)
  - Allows model exchange between Modelica tools, with consistent (unambiguous) simulation results
- The FMI Standard allows to take advantage of Modelica models for:
  - Using Modelica models in different simulation environments
  - Coupling general purpose tools to the model/simulation (case of RaPId)
- There are several challenges for modeling and validating “large scale” power systems using Modelica-based tools:
  - A well populated library of typical components (and for different time-scales)
  - **Support/linkage with industry specific data exchange paradigm (Common Information Model - CIM)**
- Rapid provides **a general framework** for validation of models available through the FMI interface:
  - Models can be validated at different levels
  - Its architecture is completely modular
  - It is not tied to the domain specific tools

RaPId and iPSL! Now Available as OSS!





Download at:

https://github.com/SmarTS-Lab/iTesla_RaPId

Download at:

https://github.com/itesla/ipsl