System Analysis and Applications with PySimulator

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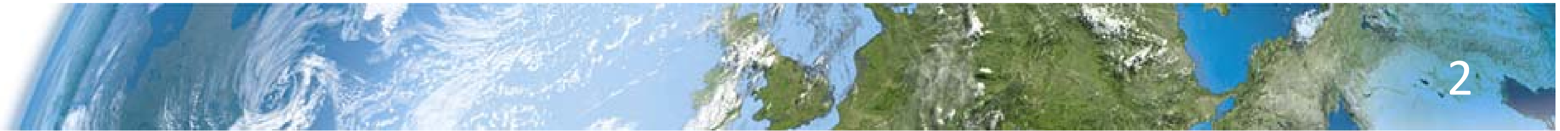
Objective

A generic framework to

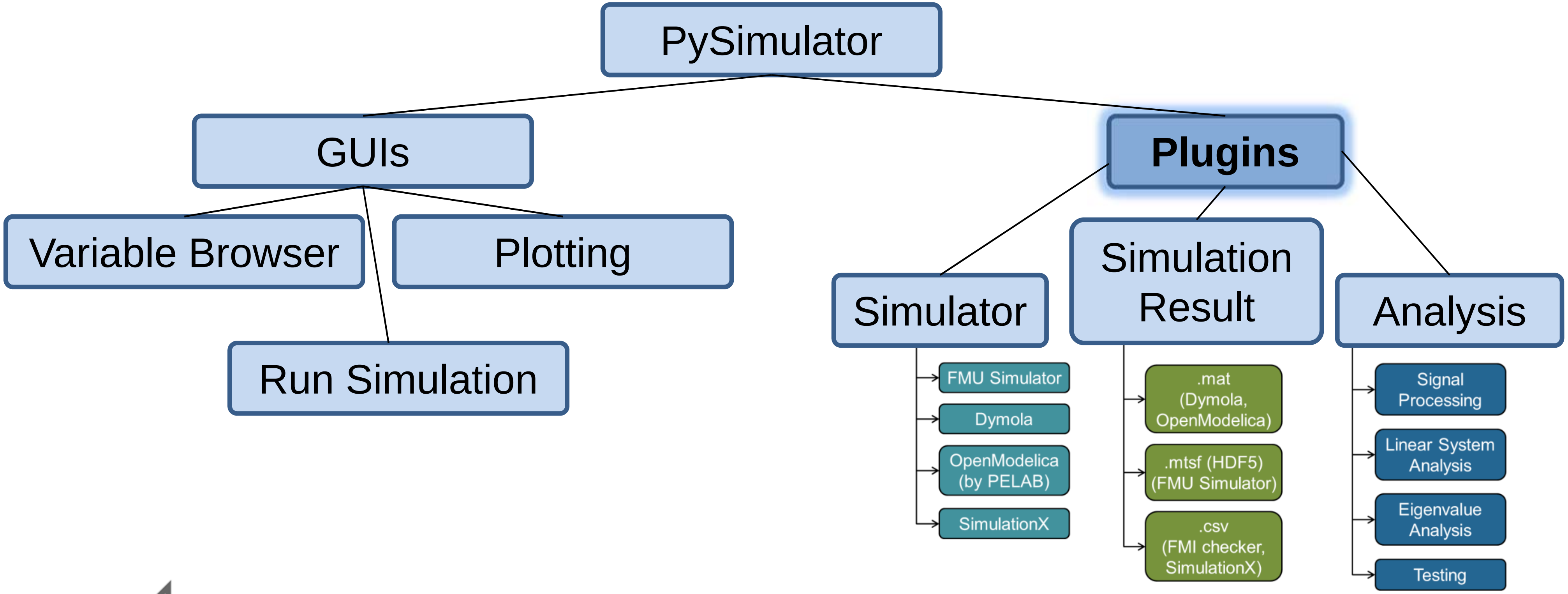
- **simulate** models (Modelica, FMI) with different engines / tools,
- manage (especially **reading**) the simulation results,
- **visualize** data (plotting) and
- to **analyze** models and result data:

⇨ **PySimulator**



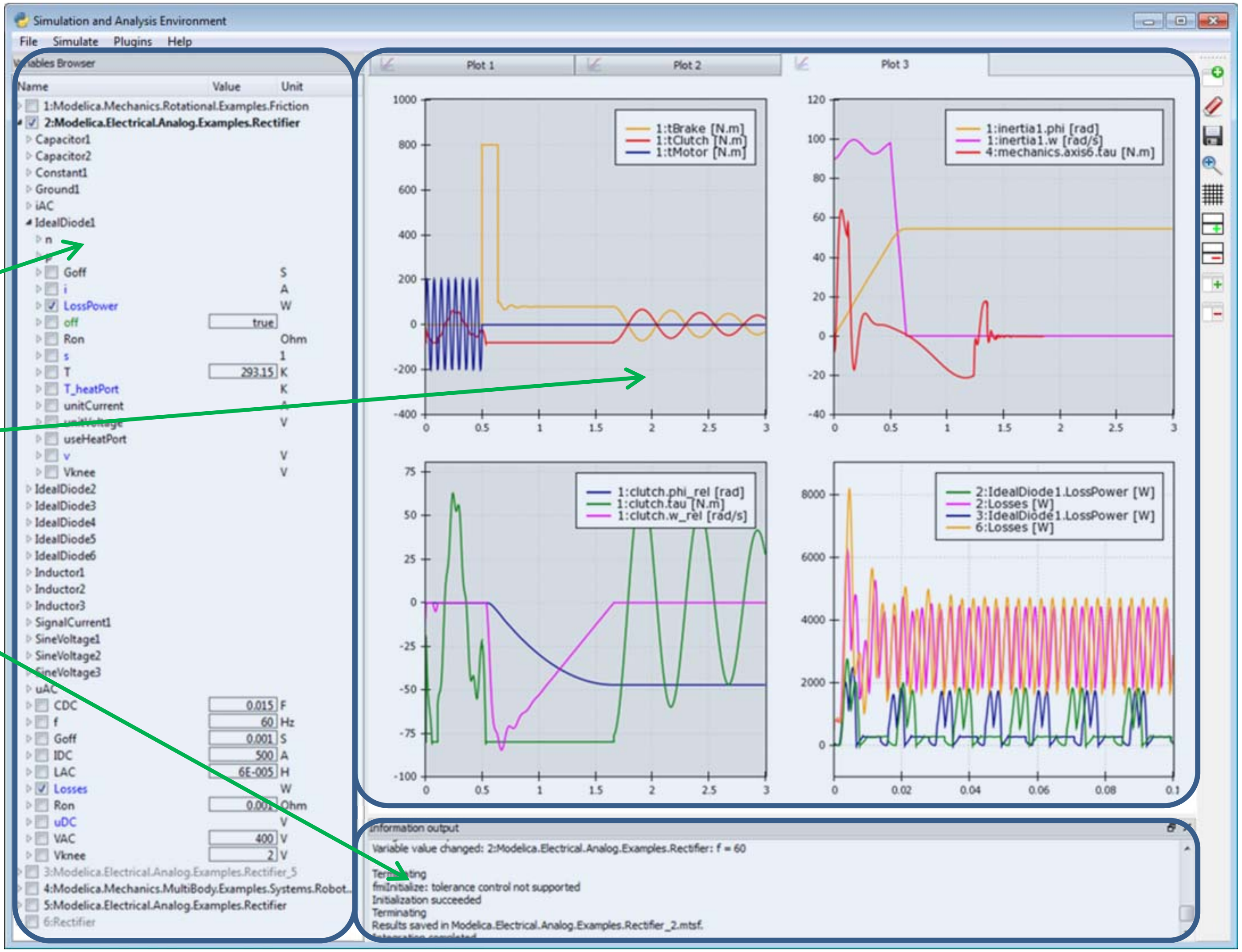
PySimulator

- **Open-Source** software (LGPL) in Python
- **User friendly** by GUIs and interactivity
- **Modular** with Plugin infrastructure



1 Graphical User Interface

- **Qt** framework by **PySide**
- **Variables**
- **Plots**
- **Console**



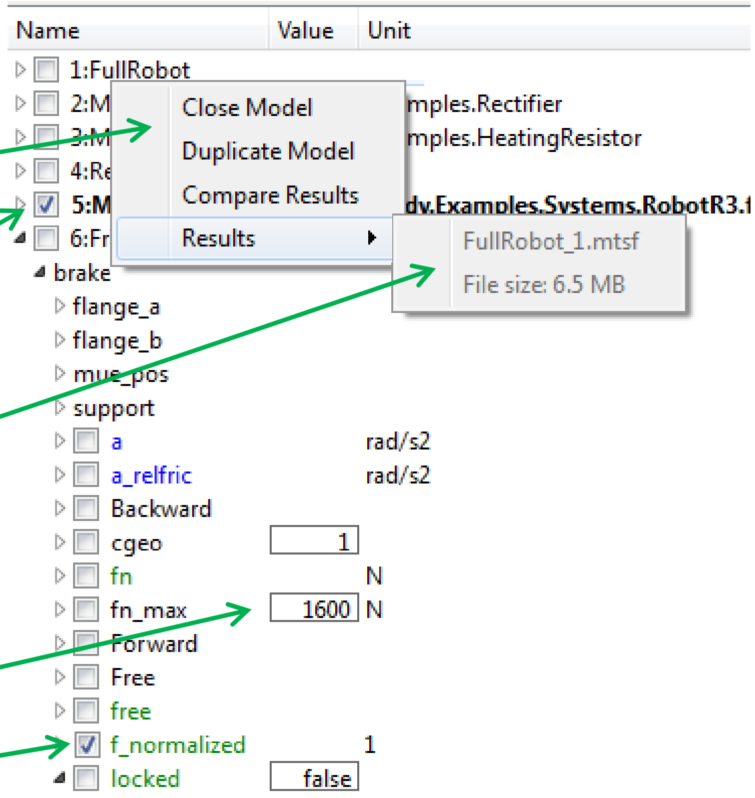
Name	Value	Unit
□ 1:Modelica.Mechanics.Rotational.Examples.Friction		
☑ **2:Modelica.Electrical.Analog.Examples.Rectifier**		
Capacitor1		
Capacitor2		
Constant1		
Ground1		
iAC		
IdealDiode1		
n		
p		
□ Goff		S
□ i		A
☑ LossPower		W
□ off	true	
□ Ron		Ohm
□ s		1
□ T	293.15	K
□ T_heatPort		K
□ unitCurrent		A
□ unitVoltage		V
□ useHeatPort		
□ v		V
□ Vknee		V
IdealDiode2		
IdealDiode3		
IdealDiode4		
IdealDiode5		
IdealDiode6		
Inductor1		
Inductor2		
Inductor3		
SignalCurrent1		
SineVoltage1		
SineVoltage2		
SineVoltage3		
uAC		
□ CDC	0.015	F
□ f	60	Hz
□ Goff	0.001	S
□ IDC	500	A
□ LAC	6E-005	H
☑ Losses		W
□ Ron	0.001	Ohm
□ uDC		V
□ VAC	400	V
□ Vknee	2	V
□ 3:Modelica.Electrical.Analog.Examples.Rectifier_5		
□ 4:Modelica.Mechanics.MultiBody.Examples.Systems.Robot...		
□ 5:Modelica.Electrical.Analog.Examples.Rectifier		
□ 6:Rectifier		

```
Variable value changed: 2:Modelica.Electrical.Analog.Examples.Rectifier: f = 60

Terminating
fmiInitialize: tolerance control not supported
Initialization succeeded
Terminating
Results saved in Modelica.Electrical.Analog.Examples.Rectifier_2.mtsf.
Integration completed
```

1.1 Variable Browser

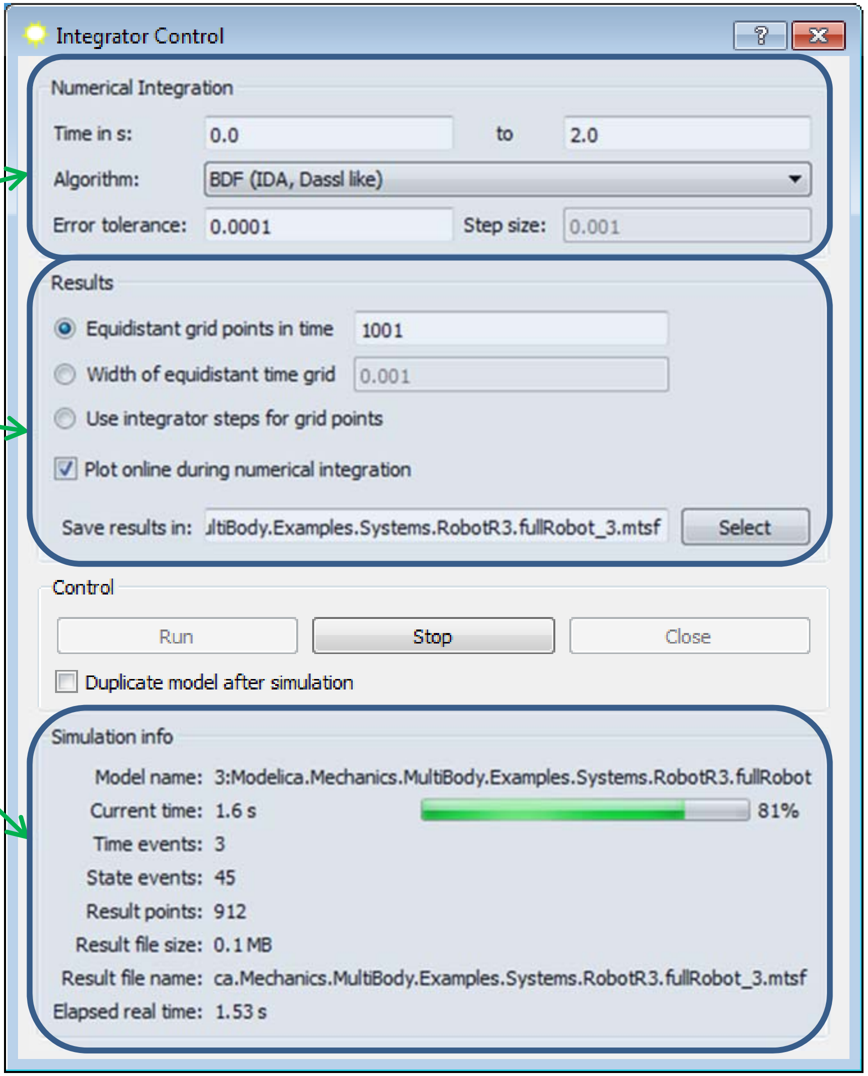
- Models and variables
  - Intuitive **tree-view**
  - Context **menus** from plugins
- Models
  - **Select** for simulation
  - Select for analysis on results
  - Unique **result file**
- Variables
  - Change **parameters**
  - **Select** for plotting
  - **Colors** for different **variability**
  - Detailed information on **lowest level**



Name	Value	Unit
□ 1:FullRobot		
□ 2:M		mples.Rectifier
□ 3:M		mples.HeatingResistor
□ 4:Re		
☑ 5:M		dy.Examples.Systems.RobotR3.f
□ 6:Fr		
brake		
flange_a		
flange_b		
mue_pos		
support		
□ a		rad/s2
□ a_relfric		rad/s2
□ Backward		
□ cgeo	1	
□ fn		N
□ fn_max	1600	N
□ Forward		
□ Free		
□ free		
☑ f_normalized	1	
□ locked	false	

1.2 Run Simulation

- **Generic** settings for
  - Simulation parameters and **integration algorithm**
  - **Results**: time grid, file name
  - Simulation progress and integration **statistics**
- Simulator **plugin:**
  - Provides **concrete** information



Integrator Control

Numerical Integration

Time in s: 0.0 to 2.0

Algorithm: BDF (IDA, Dassl like)

Error tolerance: 0.0001 Step size: 0.001

Results

● Equidistant grid points in time 1001

○ Width of equidistant time grid 0.001

○ Use integrator steps for grid points

☑ Plot online during numerical integration

Save results in: ıltiBody.Examples.Systems.RobotR3.fullRobot_3.mtsf

Control

☐ Duplicate model after simulation

Simulation info

Model name: 3:Modelica.Mechanics.MultiBody.Examples.Systems.RobotR3.fullRobot

Current time: 1.6 s 81%

Time events: 3

State events: 45

Result points: 912

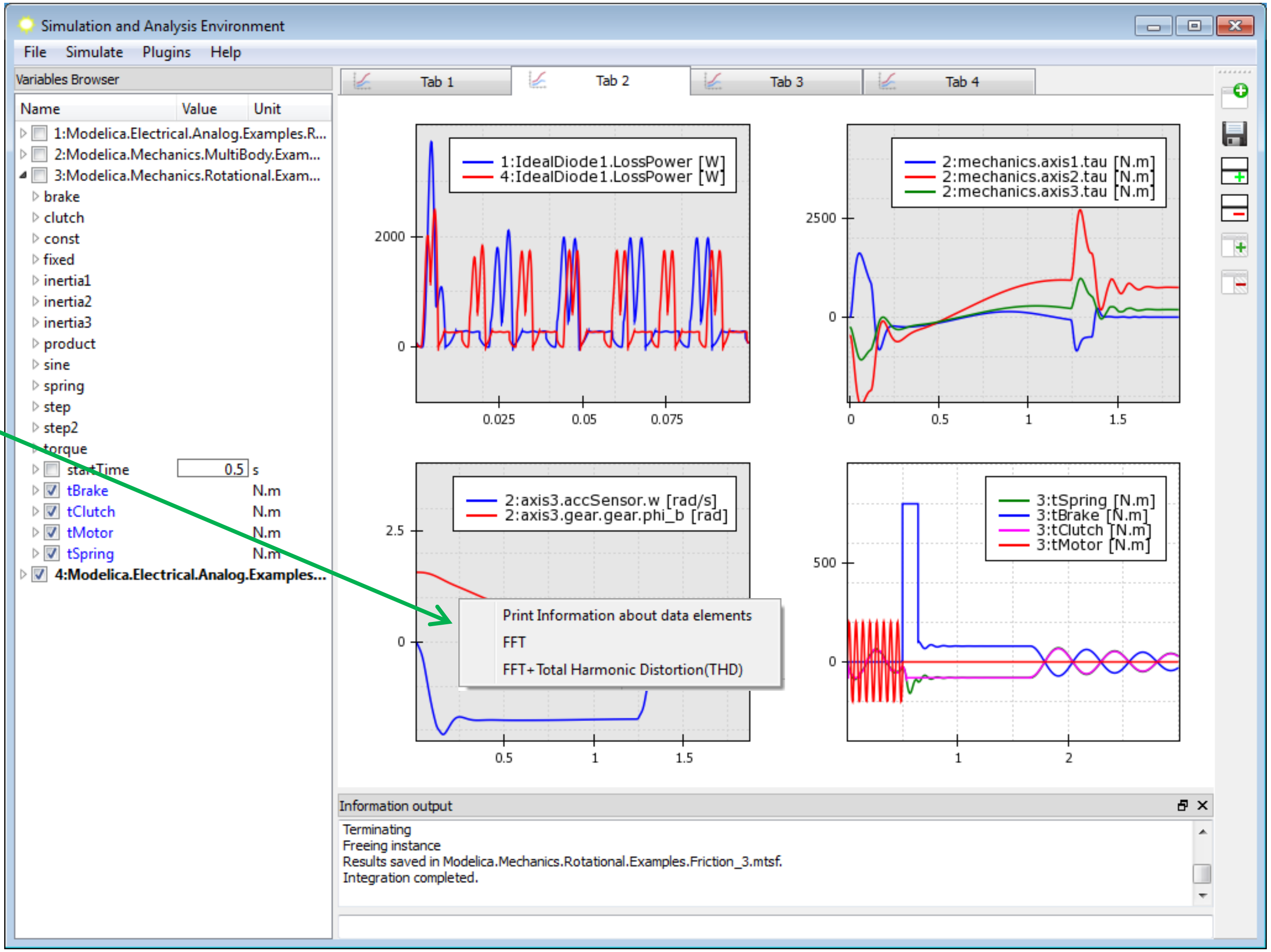
Result file size: 0.1 MB

Result file name: ca.Mechanics.MultiBody.Examples.Systems.RobotR3.fullRobot_3.mtsf

Elapsed real time: 1.53 s

1.3 Plotting of Variables

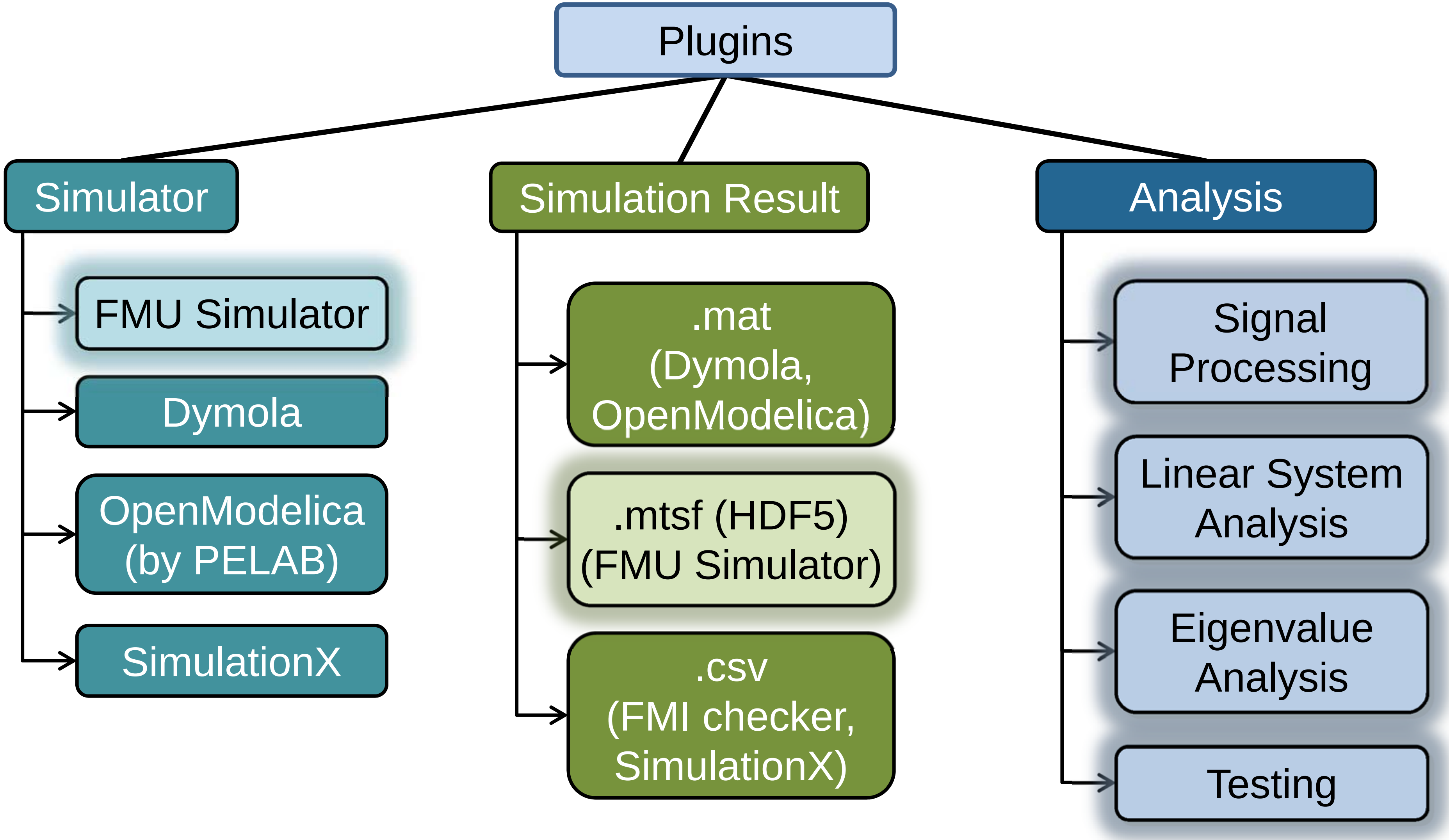
- Plot engine: **Chaco**
- **Tabs** and **Matrix plots**
- Context **menu** (plugins)
- **Interactivity**:
  - Panning
  - Zooming (all axes, per axis, selection)
  - Time selection


Simulation and Analysis Environment
File
Simulate
Plugins
Help
Variables Browser
Tab 1
Tab 2
Tab 3
Tab 4
1:IdealDiode1.LossPower [W]
4:IdealDiode1.LossPower [W]
2000
0
0.025
0.05
0.075
2:mechanics.axis1.tau [N.m]
2:mechanics.axis2.tau [N.m]
2:mechanics.axis3.tau [N.m]
2500
0
0
0.5
1
1.5
2:axis3.accSensor.w [rad/s]
2:axis3.gear.gear.phi_b [rad]
2.5
0
0.5
1
1.5
3:tSpring [N.m]
3:tBrake [N.m]
3:tClutch [N.m]
3:tMotor [N.m]
500
0
1
2
Print Information about data elements
FFT
FFT+Total Harmonic Distortion(THD)
Information output

Name	Value	Unit
▷ □ 1:Modelica.Electrical.Analog.Examples.R...		
▷ □ 2:Modelica.Mechanics.MultiBody.Exam...		
◢ □ 3:Modelica.Mechanics.Rotational.Exam...		
▷ brake		
▷ clutch		
▷ const		
▷ fixed		
▷ inertia1		
▷ inertia2		
▷ inertia3		
▷ product		
▷ sine		
▷ spring		
▷ step		
▷ step2		
▷ torque		
▷ □ startTime	0.5	s
▷ ☑ tBrake		N.m
▷ ☑ tClutch		N.m
▷ ☑ tMotor		N.m
▷ ☑ tSpring		N.m
▷ ☑ 4:Modelica.Electrical.Analog.Examples...		

```
Terminating
Freeing instance
Results saved in Modelica.Mechanics.Rotational.Examples.Friction_3.mtsf.
Integration completed.
```

2 Plugin Structure



Plugins

Simulator

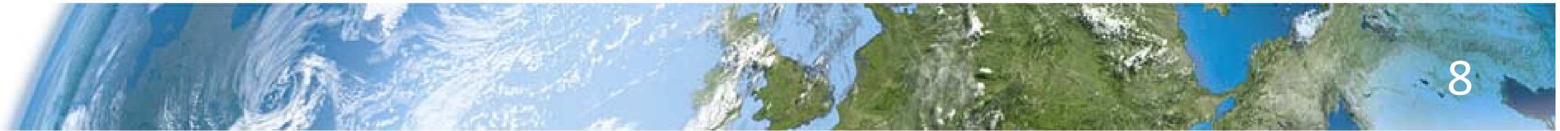
- FMU Simulator
- Dymola
- OpenModelica (by PELAB)
- SimulationX

Simulation Result

- .mat (Dymola, OpenModelica)
- .mtsf (HDF5) (FMU Simulator)
- .csv (FMI checker, SimulationX)

Analysis

- Signal Processing
- Linear System Analysis
- Eigenvalue Analysis
- Testing



2.1 FMU Simulator

- **FMU** = Functional Mockup Unit based on FMI

- Parse FMU model **description**
- Interface to FMU **binary**

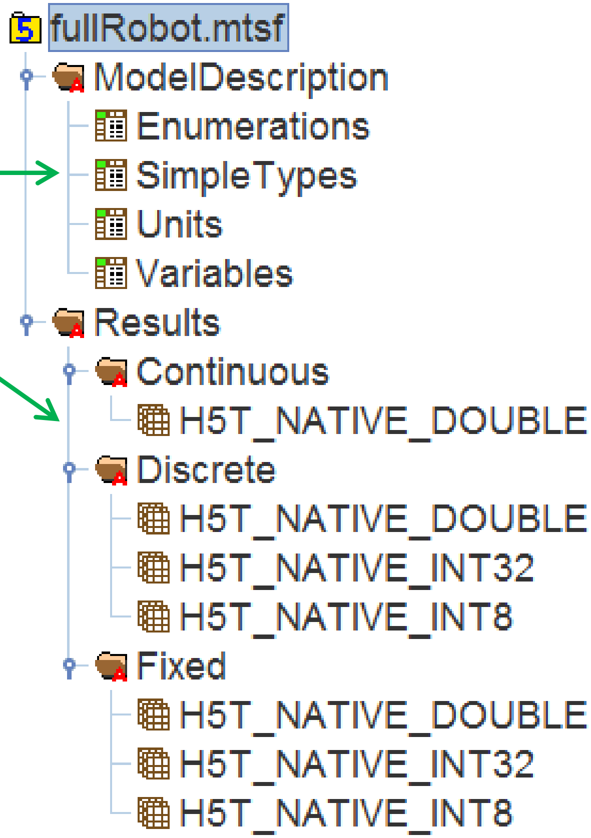
- **Integrator** based on Assimulo
  (includes interface to Sundials Solver Suite)

- **Results** stored in MTSF format
  - Full robot model from the Modelica Standard Library, 30 Mio. result points in time
    ➔**171 GBytes** result file

2.2 Standard Time Series File Format (MTSF)

- Naming: **M**odelica Association **T**ime **S**eries **F**ile Format
- Proposal for an **Open Standard** (DLR, Bausch-Gall)
- Basic File Format: **HDF5**
- Main concept:
  - **Model Description** (meta info) in few lists
  - Numeric data in **Time Series** matrices
- Test-Implementation in Python:
  - Writing and Reading of **large files:** proved.
  - Application in **PySimulator**
- **Participate** in the development of the Standard?

  → Contact us!

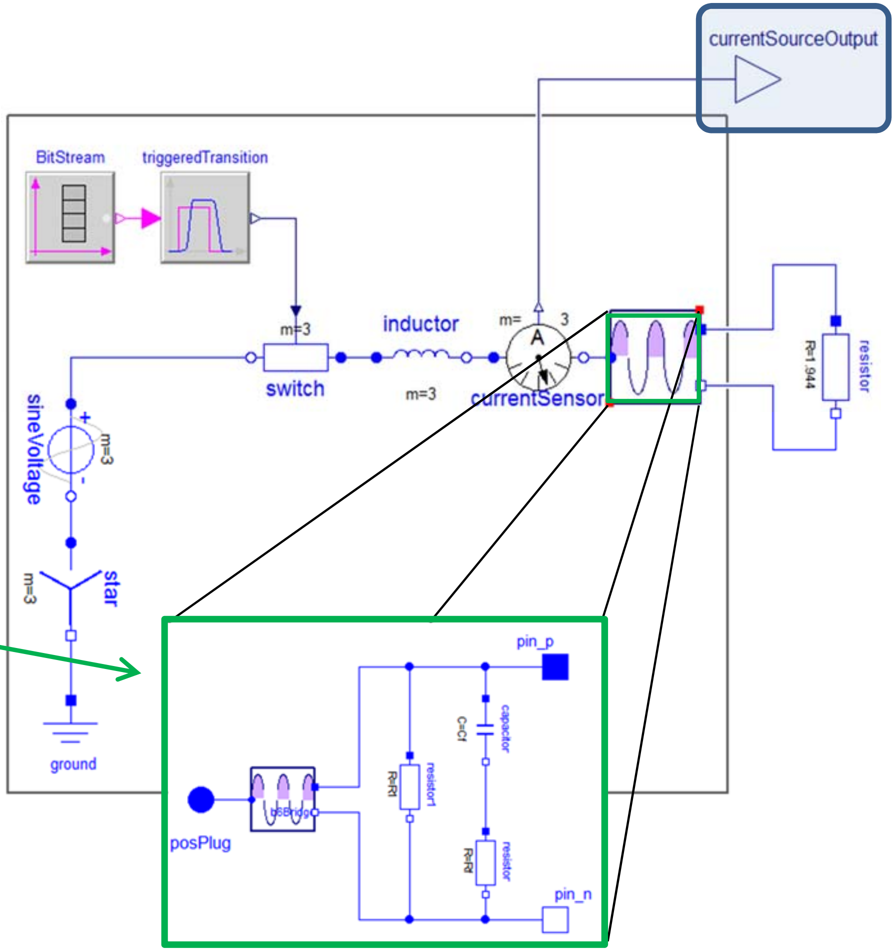


- fullRobot.mtsf
  - ModelDescription
    - Enumerations
    - SimpleTypes
    - Units
    - Variables
  - Results
    - Continuous
      - H5T_NATIVE_DOUBLE
    - Discrete
      - H5T_NATIVE_DOUBLE
      - H5T_NATIVE_INT32
      - H5T_NATIVE_INT8
    - Fixed
      - H5T_NATIVE_DOUBLE
      - H5T_NATIVE_INT32
      - H5T_NATIVE_INT8

3.1 Application: Energy Grid of an Airplane

- **Virtual testing** of aircraft power systems:
  - Standalone model-based test of an aircraft AC network

- **Rectifier unit** as a 230 V AC load

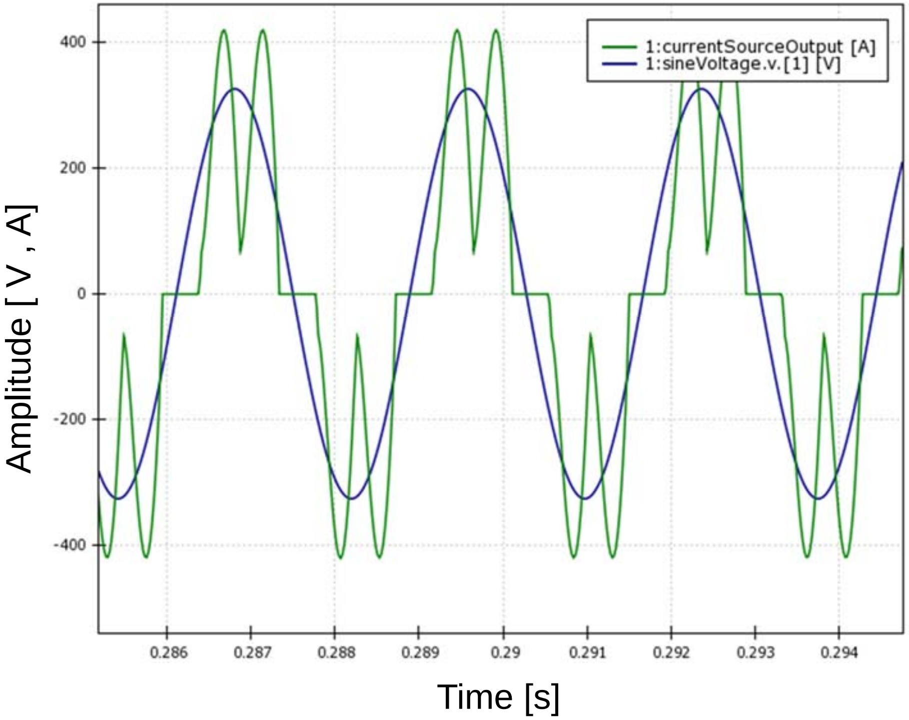


3.1 Application: Energy Grid of an Airplane

- Challenge: Nonlinear parts
  ➔ **Distortion** in power systems

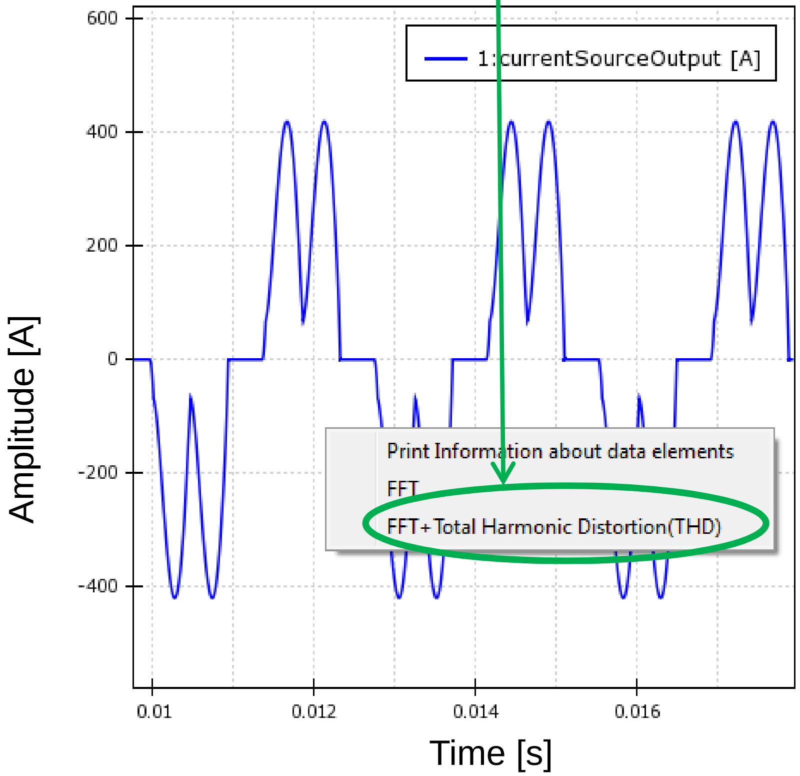
- One measure:
  Total Harmonic Distortion (**THD**)

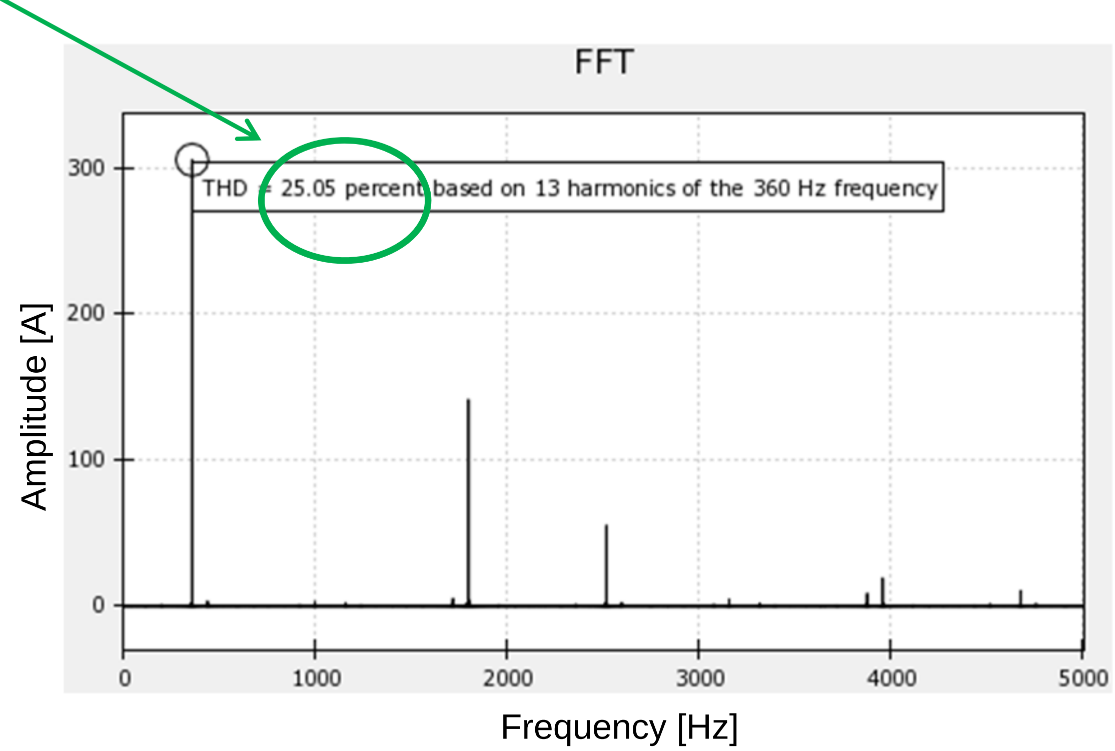
$$\mathrm{THD} = \frac{\sqrt{I_2^2 + I_3^2 + \cdots + I_n^2}}{I_1}$$



3.1 Application: Energy Grid of an Airplane

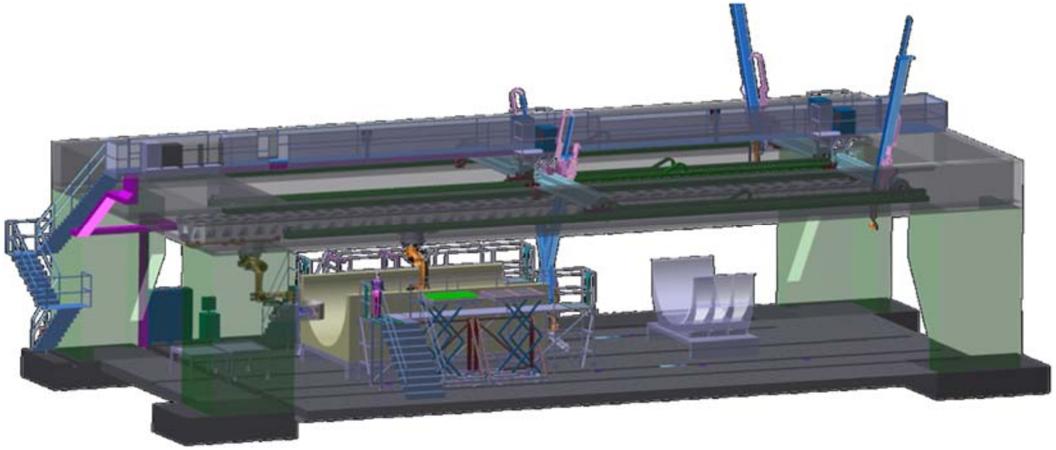
- Small **plugin** for THD based on FFT plugin


600
400
200
0
-200
-400
Amplitude [A]
1:currentSourceOutput [A]
Print Information about data elements
FFT
FFT+Total Harmonic Distortion(THD)
0.01
0.012
0.014
0.016
Time [s]


THD = 25.05 percent based on 13 harmonics of the 360 Hz frequency

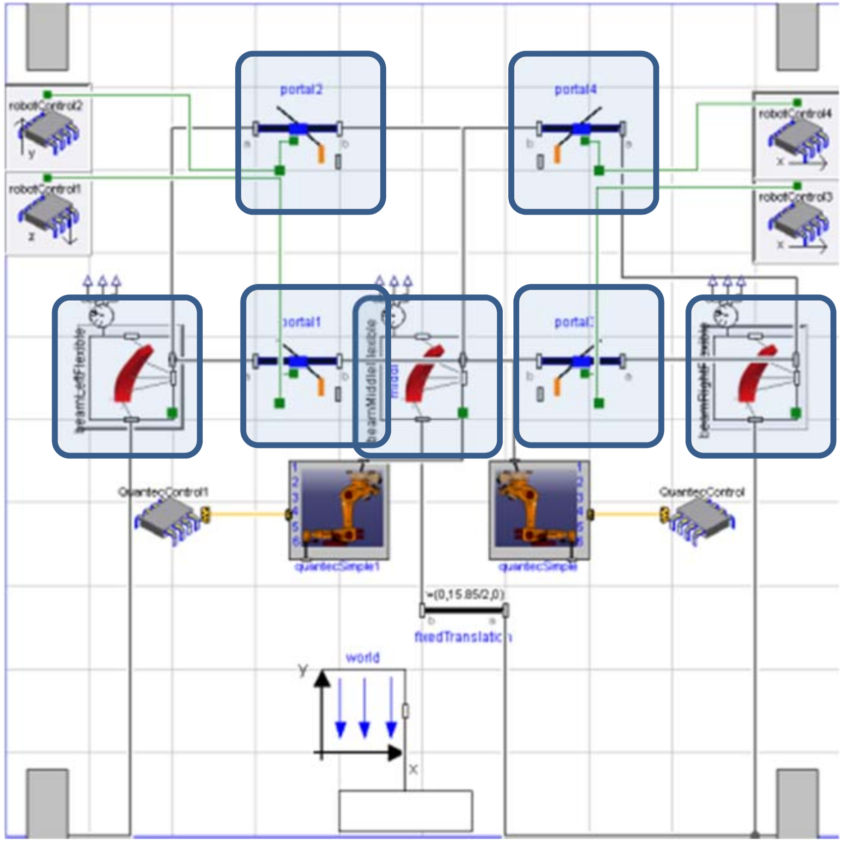
3.2 Application: Vibration Analysis

- **Vibration Analysis** of a mechanical system
- DLR Augsburg: Manufacturing of large carbon-fiber composite structures for airplanes by robots



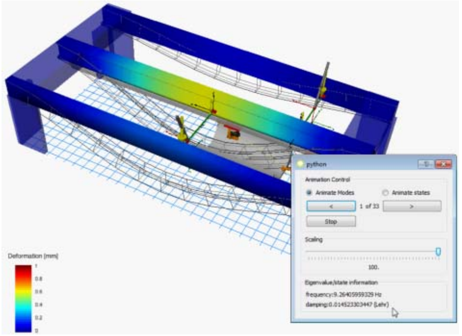
Dimensions: 30 m x 15 m x 7 m

Modelica model:

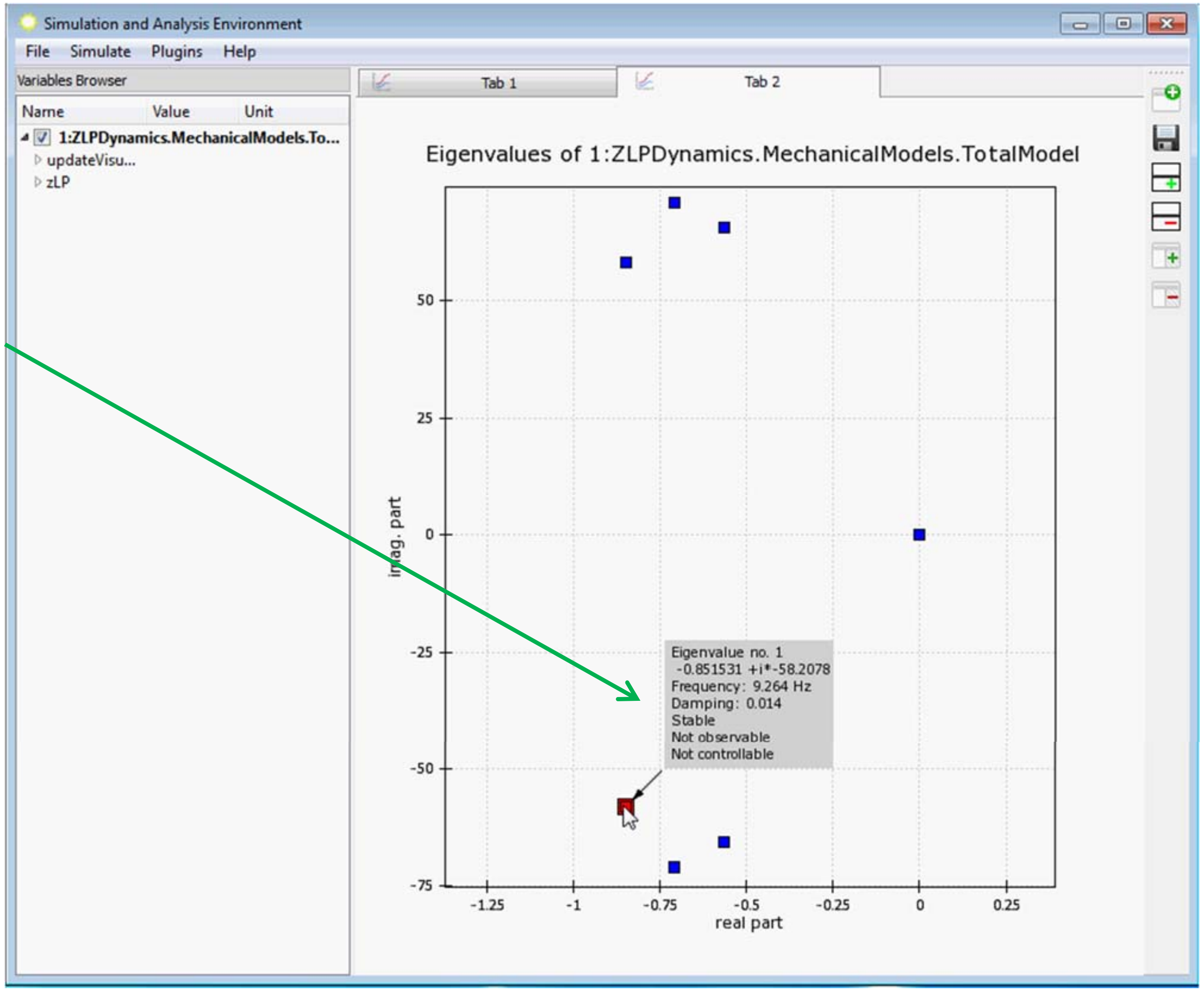


3.2 Application: Vibration Analysis

- Modelica → **FMU**
- **Linearization** at steady state
- **Eigenvalue** Analysis
- **Mode animation** (requires visualization of model, e.g. DLR SimVis)



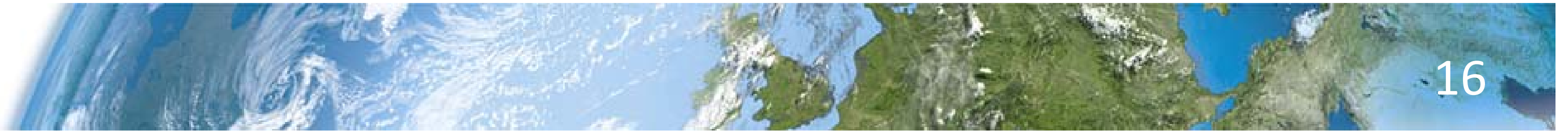
frequency:9.26405959329 Hz
damping:0.014523303447 (Lehr)



Eigenvalue no. 1
-0.851531 +i*-58.2078
Frequency: 9.264 Hz
Damping: 0.014
Stable
Not observable
Not controllable

3.3 Application: Automated Testing

- **Comparing** results:
  - for a Modelica model simulated by different tools
  - for a Modelica model and its corresponding FMU
  - for an FMU generated by different tools for the same model
  - for different versions of a model (same tool)
  - ...
- **Example:** PlanarMechanicsStandard.Examples.TwoTrackWithDifferentialGear (Modelica model) simulated by
  - OpenModelica → mat-file
  - Dymola → mat-file
  - SimulationX → csv-file
  - FMUSimulator (with FMU) → mtsf-file
- Under development:
  - Plugin for **automated numerical comparison** of all variables



4 Summary

- PySimulator: **Open Source** software in **Python**
- Brings together **simulation results** of different simulation tools:
  - Plotting
  - Analysis
  - Testing

- **Applications** from aerospace, electrics, robotics, mechanics, automated testing

- Simply extendable by **own plugins** – try it!
- **Download** and information: www.pysimulator.org