



OpenIPSL

A Modelica Library for Power Systems Simulation

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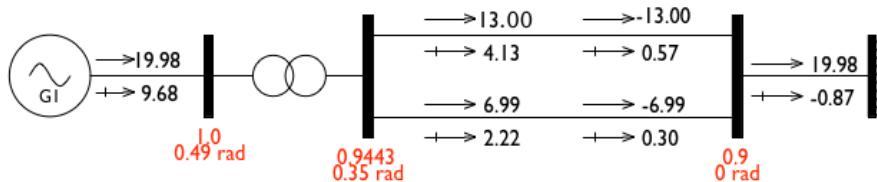
<https://www.kth.se/profile/luigiv/>

Hands-on Examples!

Please follow these slides to carry out the examples.

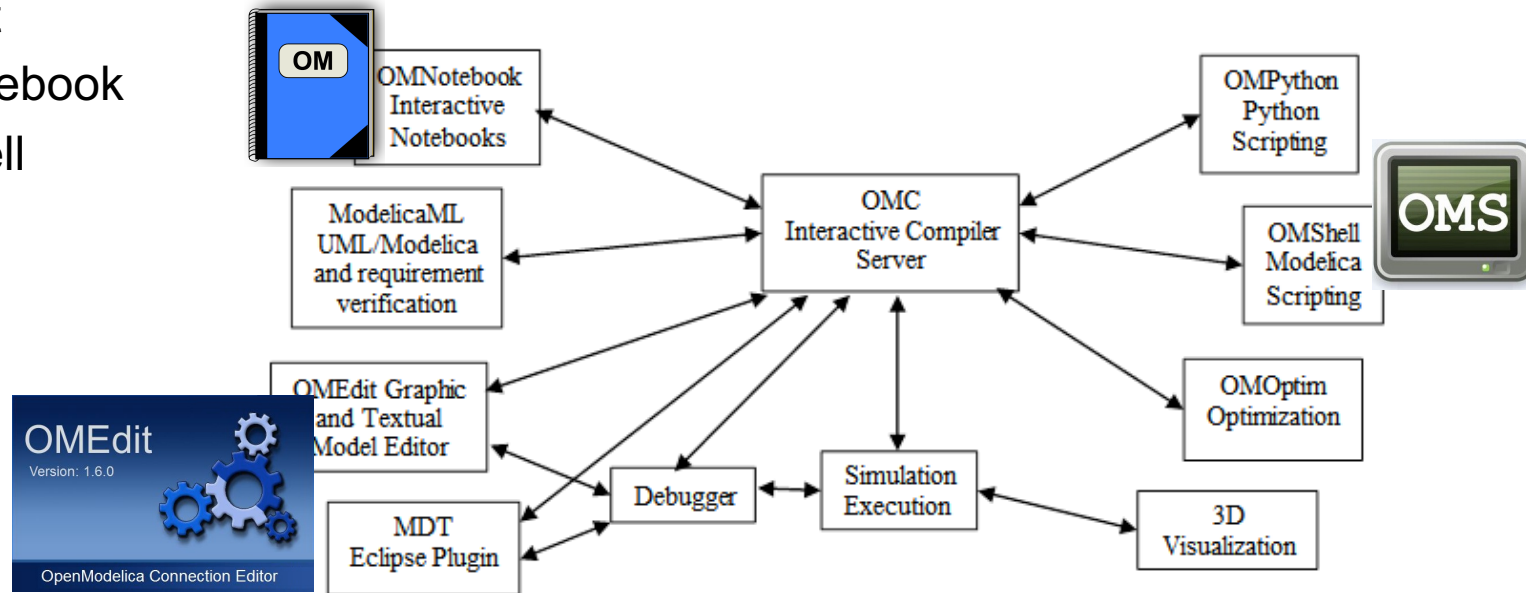
Workshop Goals

- To provide a brief introduction to the Open-Instance Power System Library
- To learn about modelling and simulation using OpenIPSL and OpenModelica
- To compare the results of OpenIPSL's accuracy with a reference domain specific simulation software (PSAT).
- To complete, at least 1 out of 3 examples, using OMEdit.
- To complete the OMNotebook example.



The OpenModelica Environment

- OpenModelica is an entire environment, which at its core has the OpenModelica Compiler (OMC).
- There are many ways to interact with the compiler, and in this tutorial, we will use some of them, mainly:
 - OMEdit
 - OMNotebook
 - OMShell



- See more here: <https://www.openmodelica.org/openmodelicaworld/tools>



Download the OpenIPSL Source!



Go to our Github repo:

https://github.com/SmarTS-Lab/OpenIPSL/releases/tag/Tutorial_ModelicaConf2017

Note: The files will also be available on a USB stick(s) that we can circulate on the day of the tutorial.

Please ask me for it if you need it.

Pre-release

Tutorial_Mo...
d7e59d5

Tutorial for the 12th Modelica Conference @ Prague

Ivanfretti released this 9 days ago



This release of OpenIPSL's "Tutorial" was prepared for a tutorial at the 12th Modelica Conference in Prague on May 15th, 2017.

The preparatory work that needs to be done prior to the tutorial can be found in this .pdf:

[OpenIPSL_Tutorial_Prep.pdf](#)

The slides with the hands-on examples, explained step by step, can be found here:

[OpenIPSL_HandsOn_Examples.pdf](#)

The presentation for the first part of the tutorial will be made available after the event to the participants only.

Downloads

[Source code \(zip\)](#)

[Source code \(tar.gz\)](#)

[Click Here!](#)



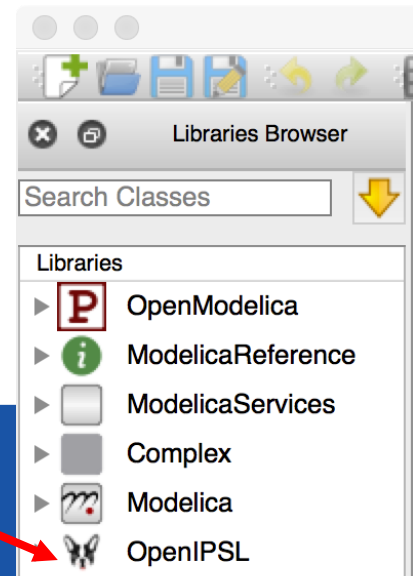
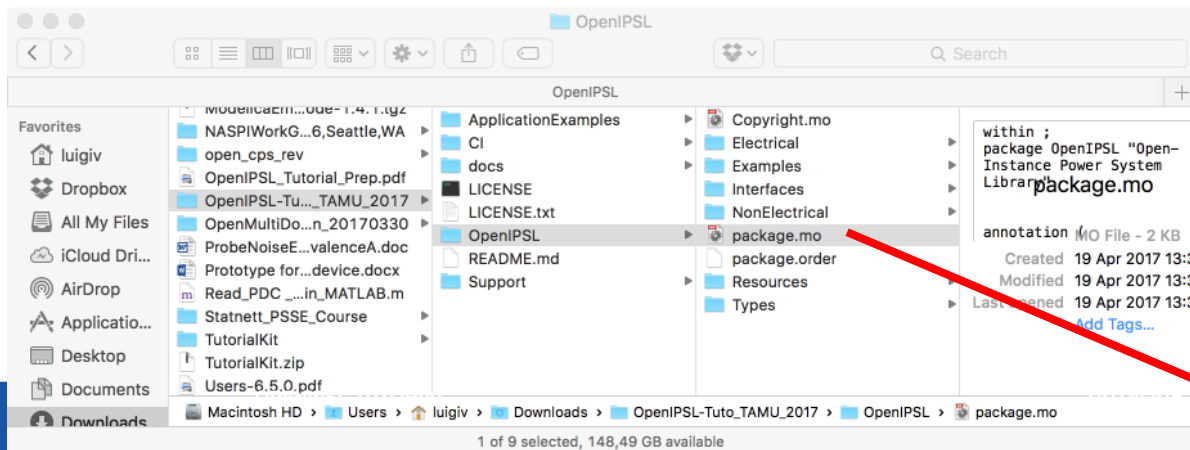
Load the OpenIPSL to OMEdit

External libraries, such as OpenIPSL, must be loaded in OMEdit to be used:

- Unzip the .zip file downloaded at the previous step when clicking on “Source code (.zip)”
- Open OpenModelica Connection Editor (OMEdit)
- Browse Windows Explorer to the location of the unzipped folder
- Drag & drop the **package.mo** file to the **Library Browser** in OMEdit.

On-line documentation for OMEdit can be found here:

<https://openmodelica.org/doc/OpenModelicaUsersGuide/v1.11.0/omedit.html>





Load the Tutorial package to OMEdit



The tutorial package contains all the examples for the tutorial, and depends on models from OpenIPSL. You must **first** load OpenIPSL (see the previous step).

- Go to the uncompressed .zip file, and to the following directory **`./.../ApplicationExamples/_Tutorial/Tutorial`**
- Drag & drop the **package.mo** file to the **Library Browser** in OMEdit.

The screenshot shows a file explorer window titled 'Tutorial' with the following directory structure:

- ApplicationExamples
 - CI
 - docs
 - LICENSE
 - LICENSE.txt
 - OpenIPSL
 - README.md
 - Support
- _Tutorial
 - AKD
 - IEEE9
 - IEEE14
 - KundurSMIB
 - N44
 - Namsskogan_Grid
 - OpenCPSD5d3B
 - PSAT_Systems
 - SevenBus
 - TwoAreas
- Command Lists.txt
- OpenModelica...ion Editor.Ink
- PSAT_dyn_PSS.csv
- PSAT_dyn.csv
- Tutorial
- Copyright.mo
- Example_1
- Example_2
- Example_3
- OMNotebook
- package.mo
- package.order
- Working_Example

The path at the bottom of the file explorer is: Macintosh HD > Users > luigiv > Downloads > OpenIPSL-Tuto_TAMU_2 > ApplicationExamples > _Tutorial > Tutorial

The OMEdit Library Browser window is open on the right, showing a list of libraries. A red arrow points from the 'package.mo' file in the file explorer to the 'Tutorial' library entry in the Library Browser. The 'Tutorial' library is currently selected and highlighted.

Libraries Browser

Search Classes

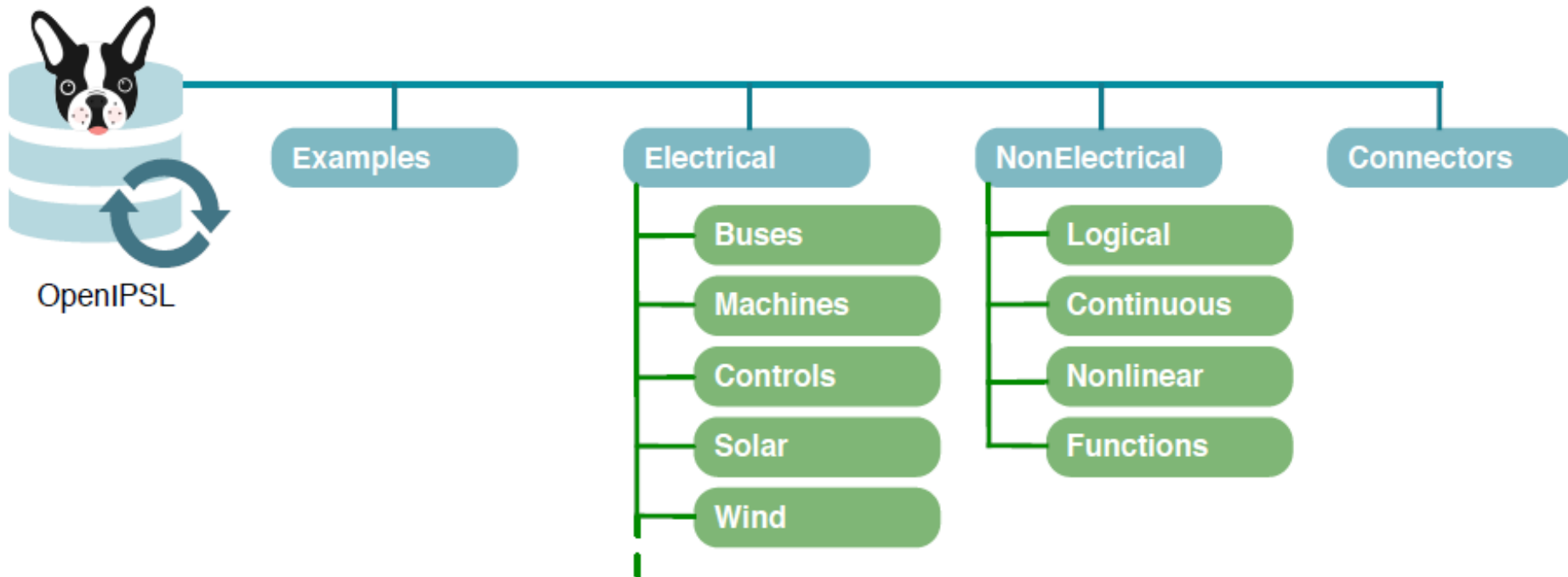
Libraries

- OpenModelica
- ModelicaReference
- ModelicaServices
- Complex
- Modelica
- OpenIPSL
- Tutorial



Library introduction

OpenIPSL is divided in four main categories:

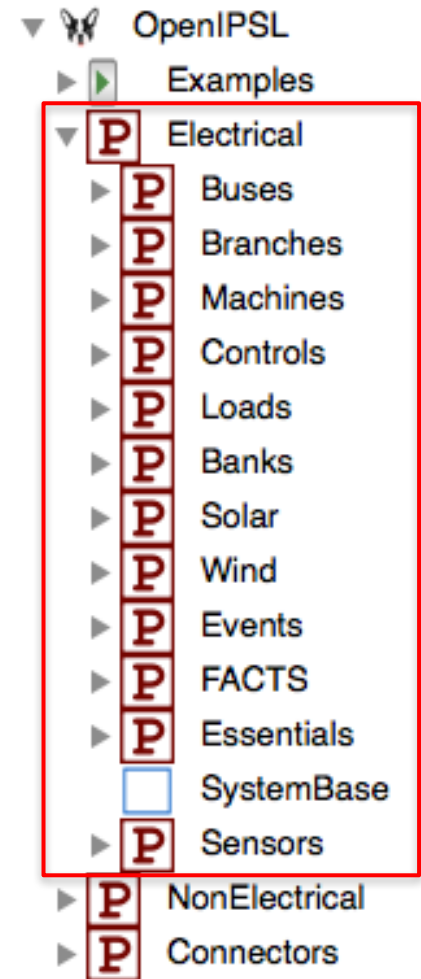




Library introduction

Electrical

- The *Electrical* package contains most of the components that comprise an actual power network
- E.g., electrical machines, transmission lines, loads, excitation systems, turbine governors, etc.
- These are used to build the power system network models





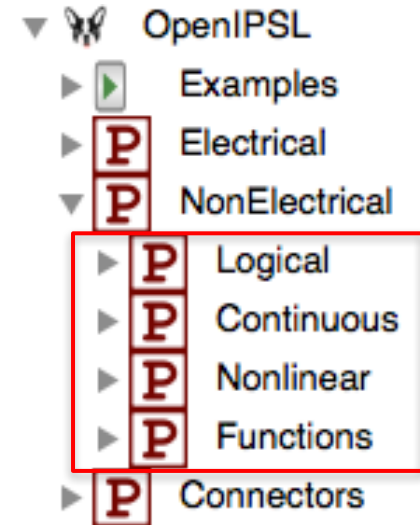
Library introduction

NonElectrical

- The *NonElectrical* package is comprised by functions, blocks or models, which are used to build the aforementioned power system component models : Transfer functions, logical operators, etc.
- They perform specific operations which were not available in the Modelica Standard Library (MSL)

Connectors

- The *Connectors* package contains a set of specifically developed Modelica connectors to harmonize the models in this library (e.g. *PwPin* a connector, which contains voltage and current quantities in phasor representation)

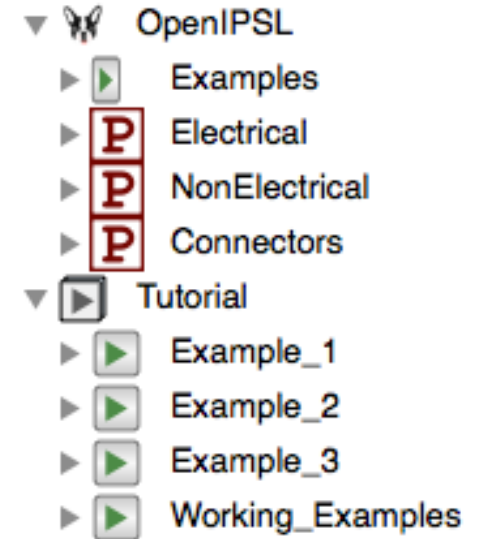




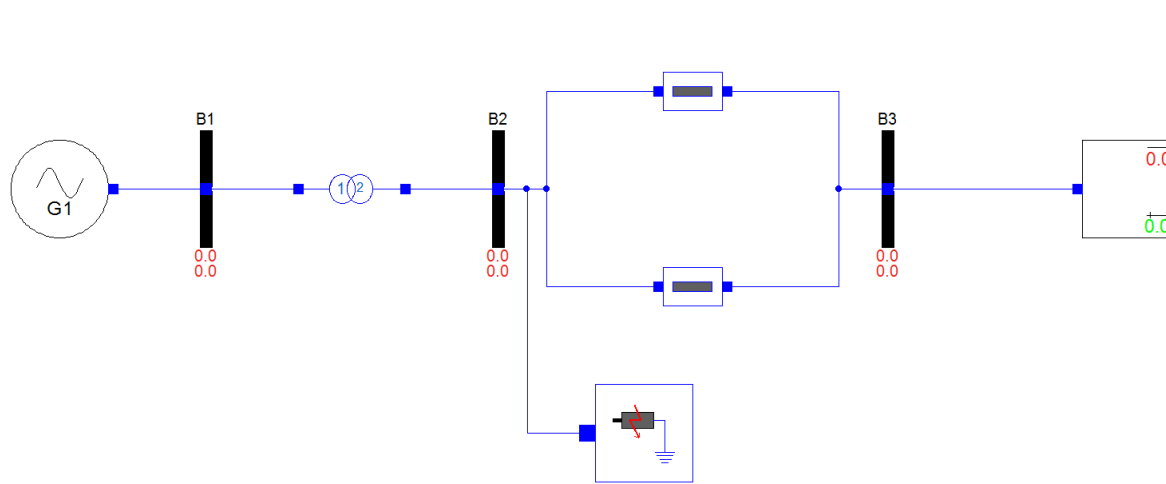
Library introduction

Examples

- In this workshop, the *Tutorial* package will be used to showcase the possibilities of the library
- In the packages *Example_1*, *Example_2* and *Example_3* prepared use cases can be found where steps to build the models are described
- Package *Working_Examples* and corresponding sub-packages will be used by attendees of the workshop to create use cases on their own



Example 1*

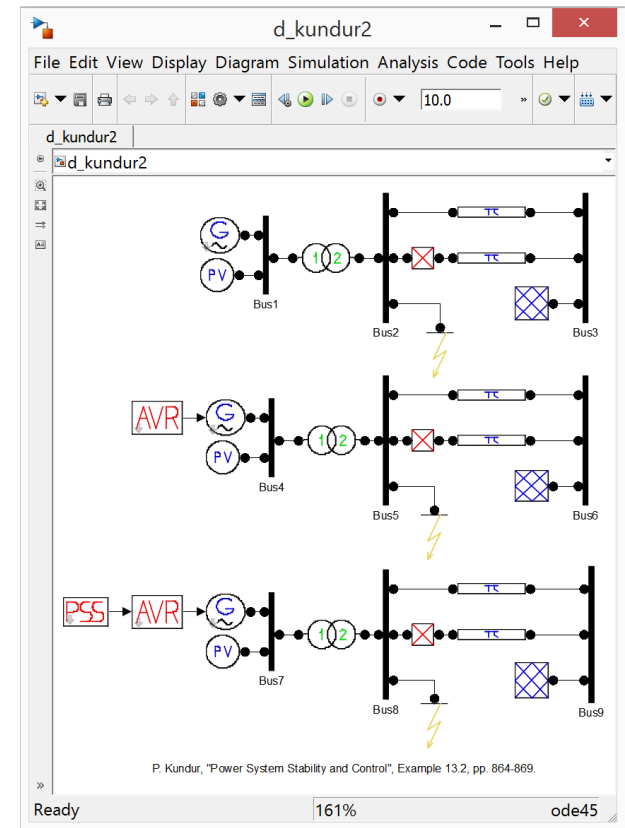


- Single Machine Infinite Bus (SMIB) system
- Analysis of the transient stability of the system including the effects of rotor circuit dynamics and excitation control
- Four machines represented by one connected via transformer and parallel lines to the infinite bus

Example 1

Power flow

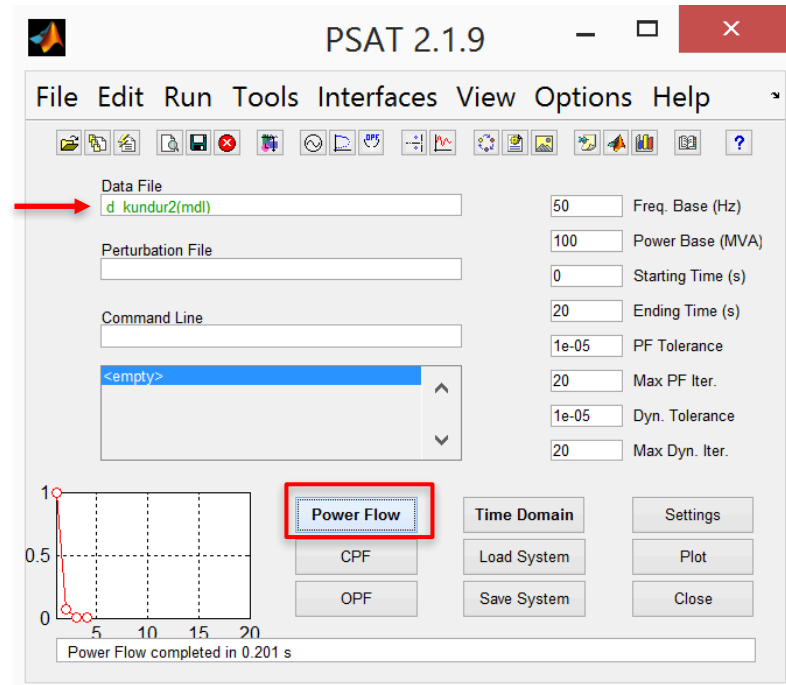
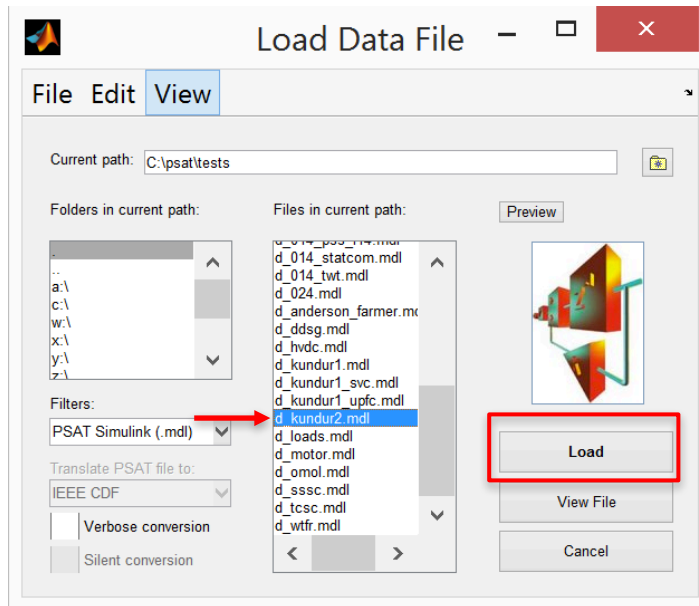
- Power flow results were obtained by PSAT
- Prepared Example 1 already exists in PSAT and can be used for power flow calculations and dynamic simulations



Example 1

Power flow

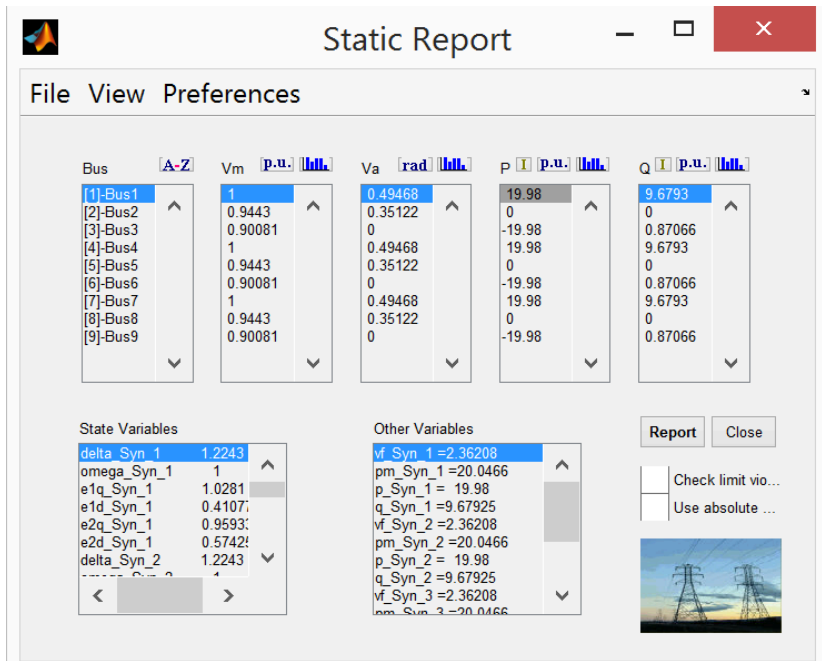
- Example 1 is loaded and the power flow calculations are executed



Example 1

Power flow

- Static Report can be accessed where all of the power flow results are listed along with the initial values of various state variables of the models
- In this tutorial, there is no need to run the power flow in PSAT since the data will be provided, but feel free to explore PSAT later



The screenshot shows the 'Static Report' window with the following data:

Bus	Vm [p.u.]	Va [rad]	P [p.u.]	Q [p.u.]
[1]-Bus1	1	0.49468	19.98	9.6793
[2]-Bus2	0.9443	0.35122	0	0
[3]-Bus3	0.90081	0	-19.98	0.87066
[4]-Bus4	1	0.49468	19.98	9.6793
[5]-Bus5	0.9443	0.35122	0	0
[6]-Bus6	0.90081	0	-19.98	0.87066
[7]-Bus7	1	0.49468	19.98	9.6793
[8]-Bus8	0.9443	0.35122	0	0
[9]-Bus9	0.90081	0	-19.98	0.87066

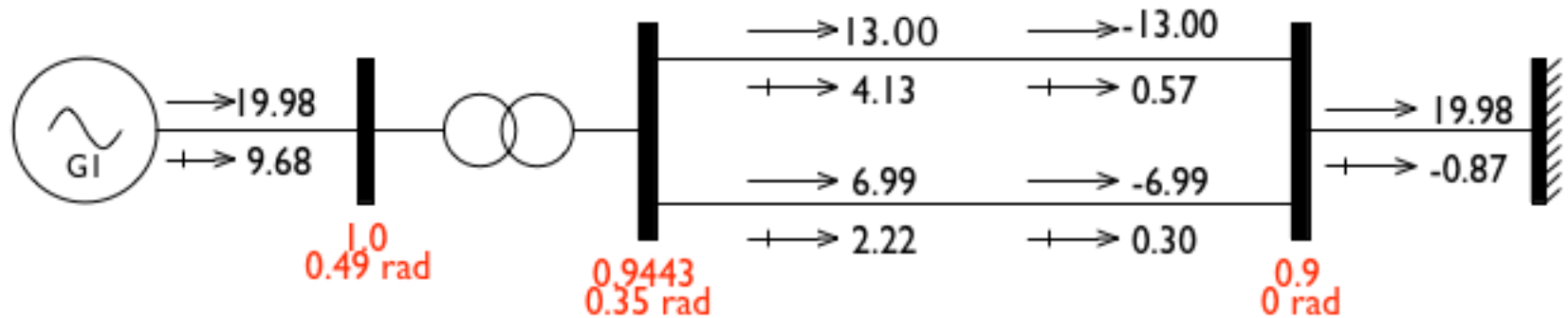
State Variables	Value
delta_Syn_1	1.2243
omega_Syn_1	1
e1q_Syn_1	1.0281
e1d_Syn_1	0.4107
e2q_Syn_1	0.9593
e2d_Syn_1	0.5742
delta_Syn_2	1.2243
omega_Syn_2	1
e1q_Syn_2	1.0281
e1d_Syn_2	0.4107
e2q_Syn_2	0.9593
e2d_Syn_2	0.5742

Other Variables	Value
vf_Syn_1=2.36208	2.36208
pm_Syn_1=20.0466	20.0466
p_Syn_1=19.98	19.98
q_Syn_1=9.67925	9.67925
vf_Syn_2=2.36208	2.36208
pm_Syn_2=20.0466	20.0466
p_Syn_2=19.98	19.98
q_Syn_2=9.67925	9.67925
vf_Syn_3=2.36208	2.36208
pm_Syn_3=20.0466	20.0466
p_Syn_3=19.98	19.98
q_Syn_3=9.67925	9.67925

Example 1

Power flow

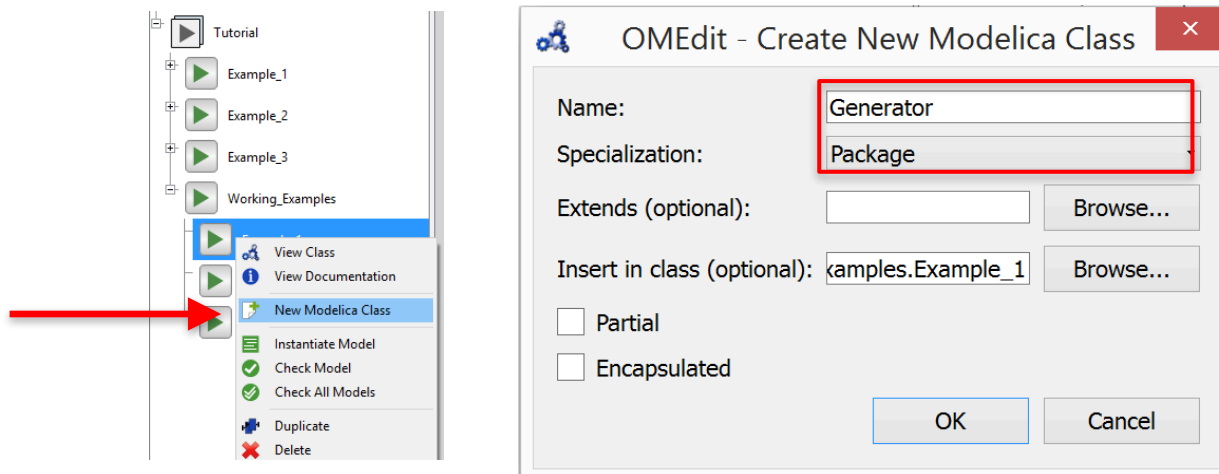
- The summary of all of the relevant data from the power flow is given on the figure below



Example 1

Generator model – Step 1

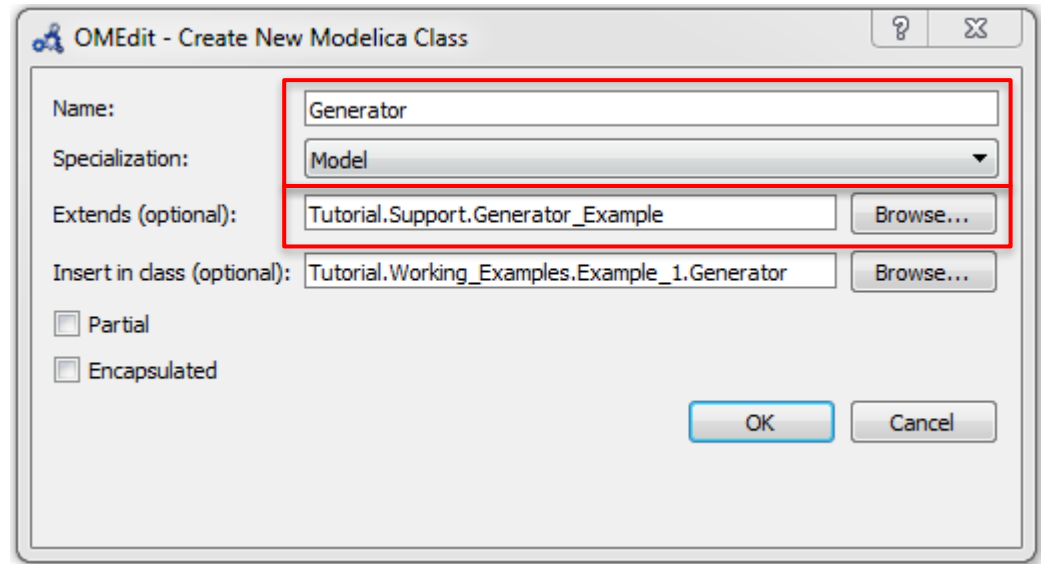
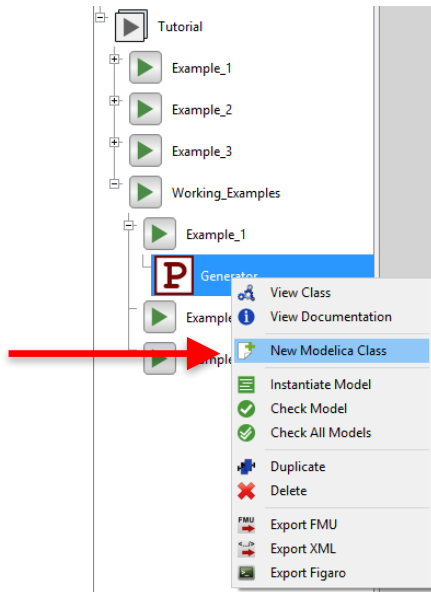
- First, the package where the generator model will be located has to be created
- This is done by right clicking on the *Example_1* in the *Working_Examples* package
- The package should be named *Generator*



Example 1

Generator model – Step 1

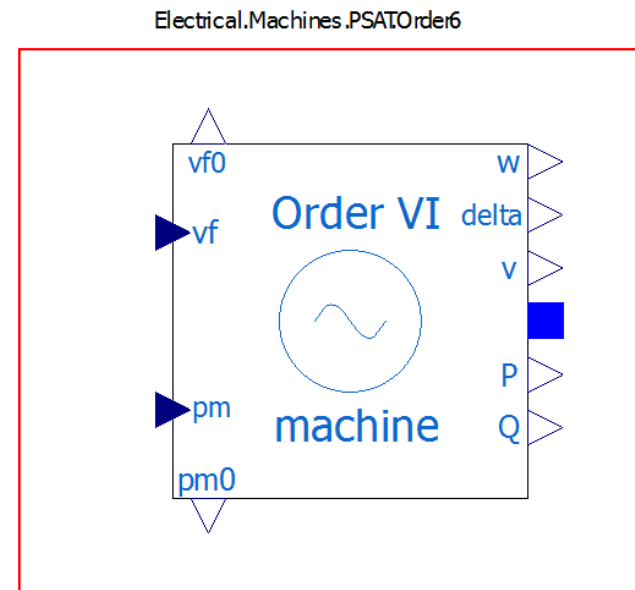
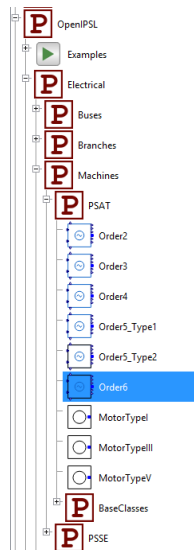
- Within the *Generator* package, model of the generator shall be created
- Extends from *Tutorial.Support.Generator_Example*



Example 1

Generator model – Step 1

- 6th order model of the generator from the PSAT is used
- The model is added by dragging the generator from the library and dropping it to the model

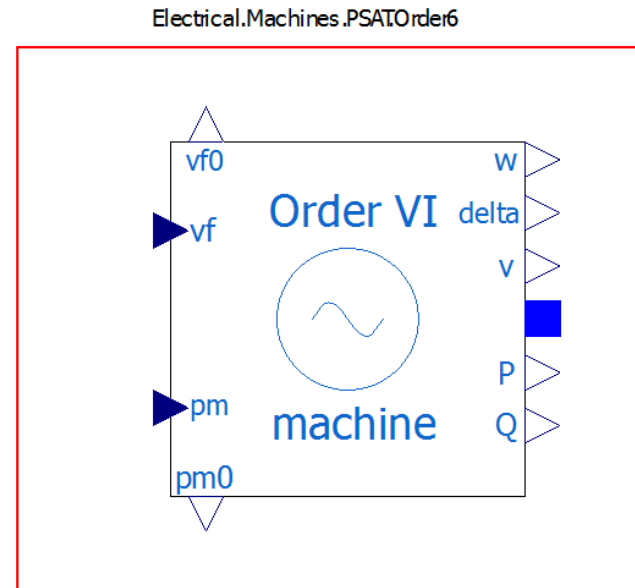


Example 1

Generator model – Step 1

- Parameters of the generator are given in the table

S_n	2220	x''_q	0.25
V_n	400	$T'_{d,0}$	8
r_a	0.003	$T'_{q,0}$	1
x_d	1.81	$T''_{d,0}$	0.03
x_q	1.76	$T''_{d,0}$	0.07
x'_d	0.3	T_{aa}	0.002
x'_q	0.65	M	7
x''_d	0.23	D	0



Example 1

Generator model – Step 1

- Power flow results:

V_0	V_0
$angle_0$	angle_0
P_0	P_0
Q_0	Q_0
V_b	V_b
S_b	Do not edit
f_n	Do not edit

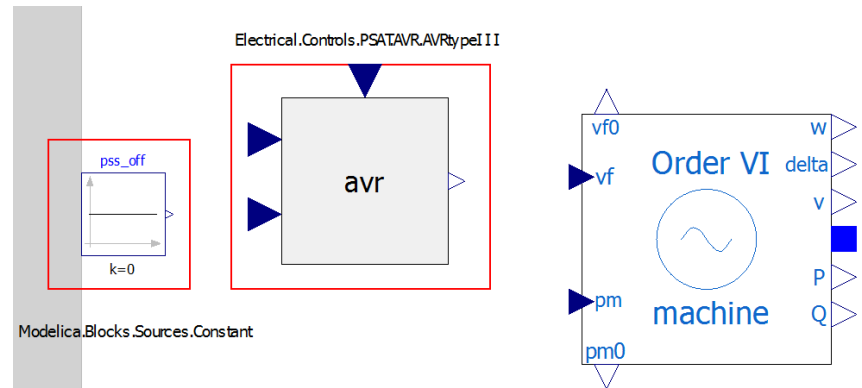
Note: Using the variables (V_0 , $angle_0$, etc.) allow to propagate the parameters to the “upper layer” of the generator component

Example 1

Generator model – Step 2

- PSAT model of the AVR Type III is used
- Constant block pss_off will be used as a zero input to the PSS input signal of the AVR since the PSS is not used
- Parameters:

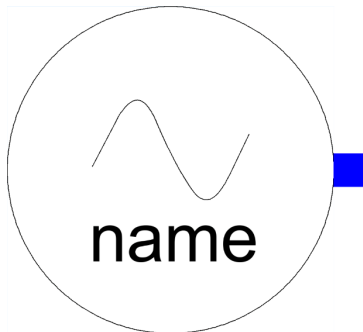
$v_{f,max}$	7
$v_{f,min}$	-6.4
K_0	200
T_2	1
T_1	1
T_e	0.0001
T_r	0.015



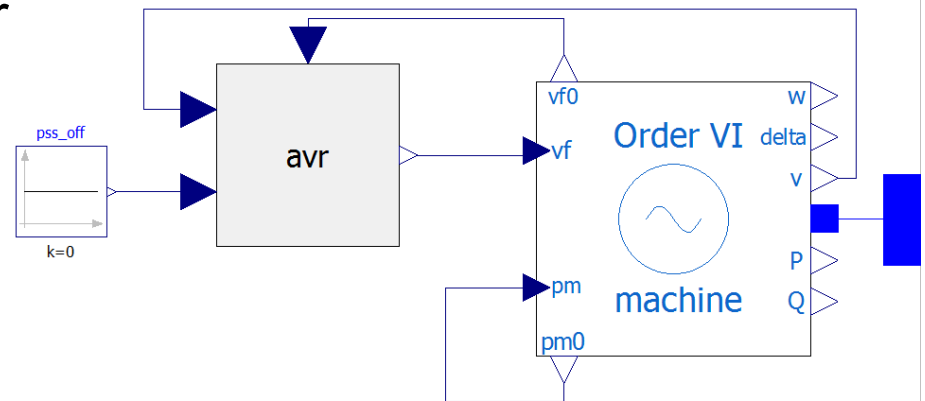
Example 1

Generator model – Step 3

- To finish the generator model, different signals need to be connected
- Optionally, icon of the generator model can be altered



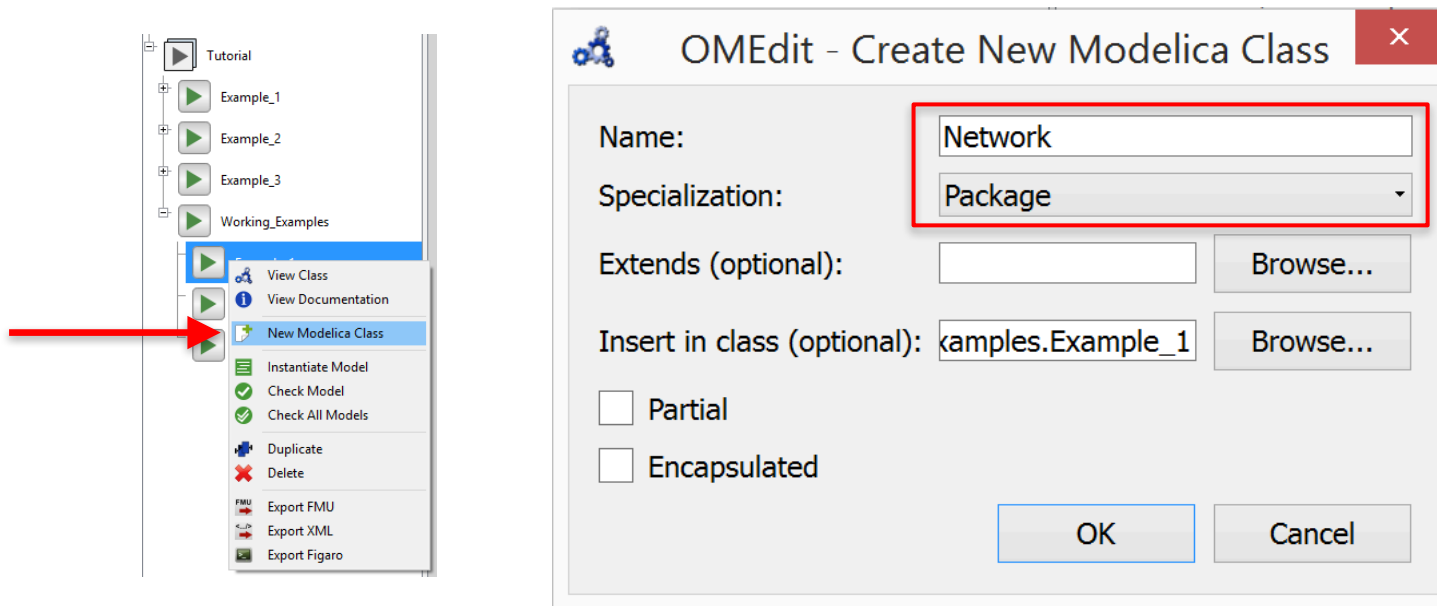
1. Machine's terminal voltage to AVR's input signal
2. AVR's output field voltage to machine's input field voltage
3. Initially calculated mechanical power to input signal of the machine's mechanical power
4. Machine's power terminal to the generator model power terminal
5. Constant `pss_off` to the PSS input at the AVR
6. Initial generator field voltage to initial AVR field voltage



Example 1

Network model – Step 1

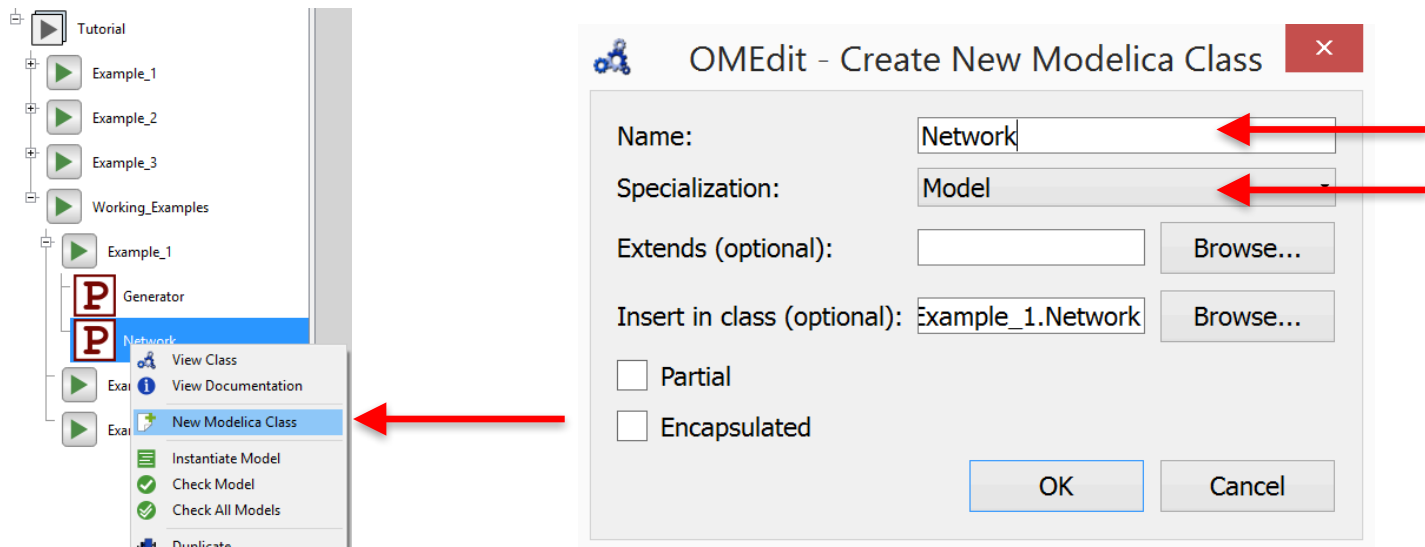
- Network package will be created in the *Example_1* package
- This package is created by right clicking on the *Example_1* in the *Working_Examples* package



Example 1

Network model – Step 1

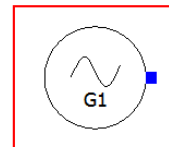
- Network model will be created in the *Network* package
- This package is created by right clicking on the *Network* package
- The name of the network model will be *Example_1*



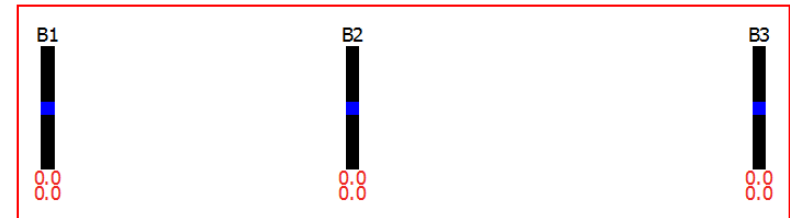
Example 1

Network model – Step 1

- Created generator model (name it machine) and three bus models are added to the network model

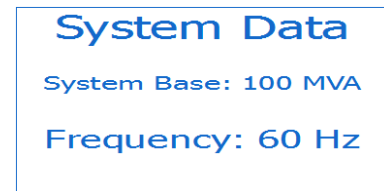


Electrical.Buses.Bus



- Also, model *OpenIPSL.Electrical.SystemBase* shall be added to the network model which defines base parameters for all of the components in the network model

S_b	100
f_n	60



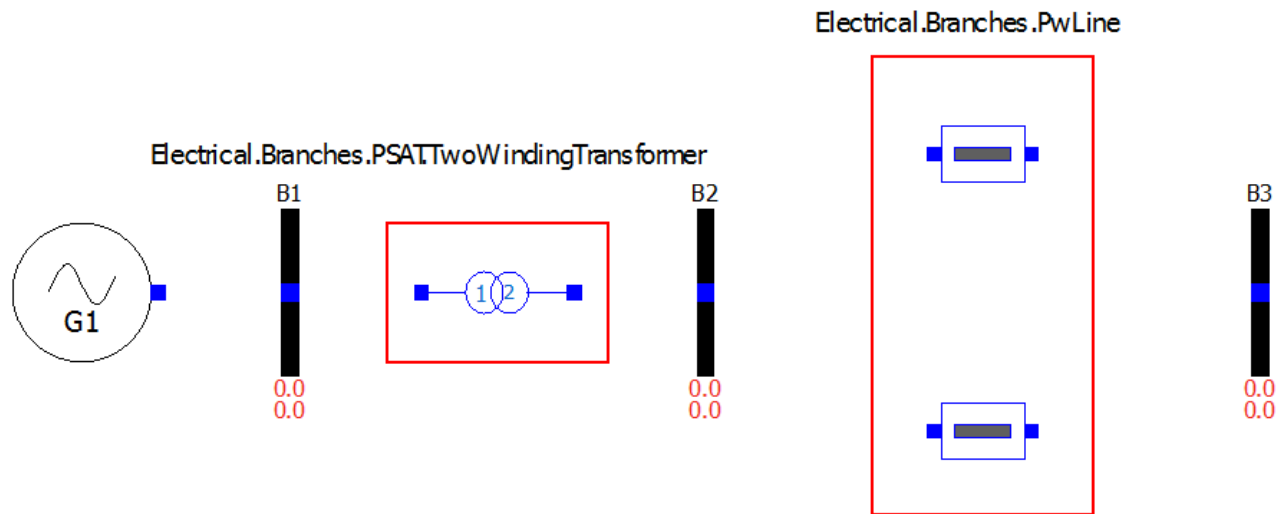
- In *text view* add the **inner** keyword in front of the component declaration

```
inner OpenIPSL.Electrical.SystemBase SysData
```

Example 1

Network model – Step 2

- Transformer and line models are added



Example 1

Network model – Step 2

- Transformer and line parameters

Transformer

S_b	Do not edit	f_n	Do not edit
S_n	2220	kT	1
V_b	400	x	0.15
V_n	400	r	0

Line 1

R	0.0	G	0.0
X	$0.5 \cdot 100 / 2220$	B	0.0
S_b	100		

Line 2

R	0.0	G	0.0
X	$0.93 \cdot 100 / 222$ 0	B	0.0
S_b	100		

Example 1

Network model – Step 3

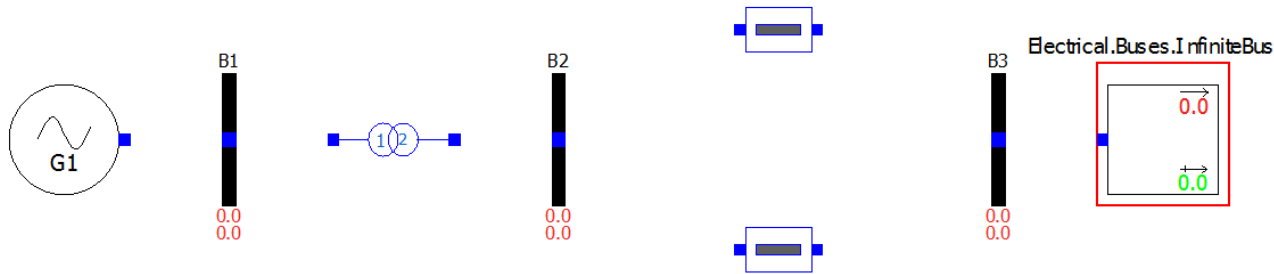
- Infinite bus is added
- Power Flow results are implemented

G1

V	1	angle	0.4946
P	1997.999	Q	967.92

Infinite bus

V	0.90081	angle	0
P	-1998	Q	87.066



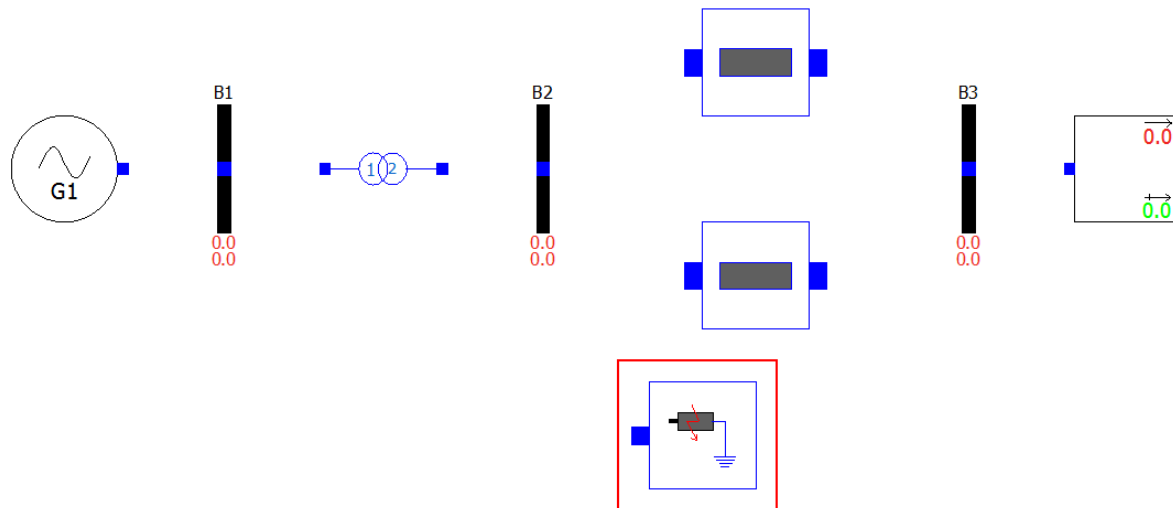
Example 1

Network model – Step 4

- 3-phase-to-ground fault is added

Fault

R	0	t_1	0.5
X	$0.01 * 100 / 2220$	t_2	0.57

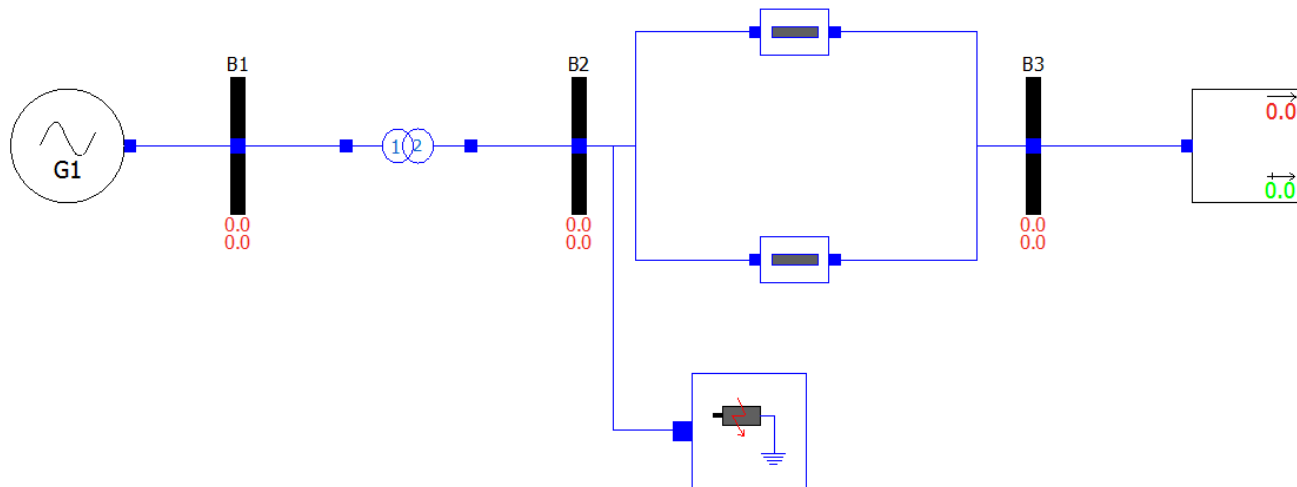


Electrical.Events.PwFault

Example 1

Network model – Step 5

- The network model is completed by connecting all of the components
- Now, the model can be simulated and linearized



Example 1

Simulation

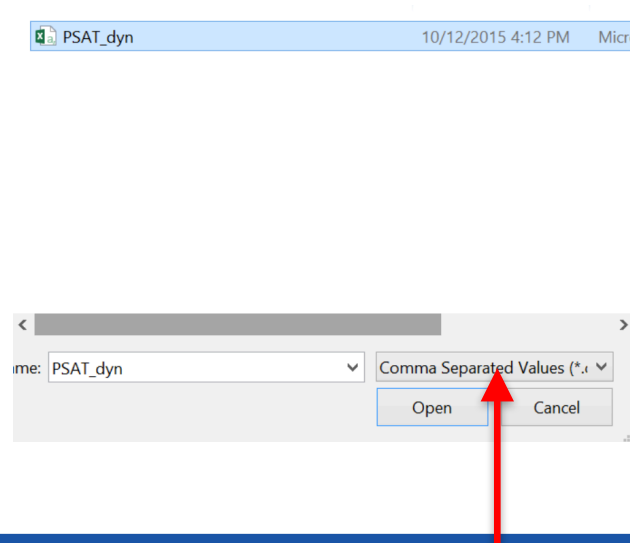
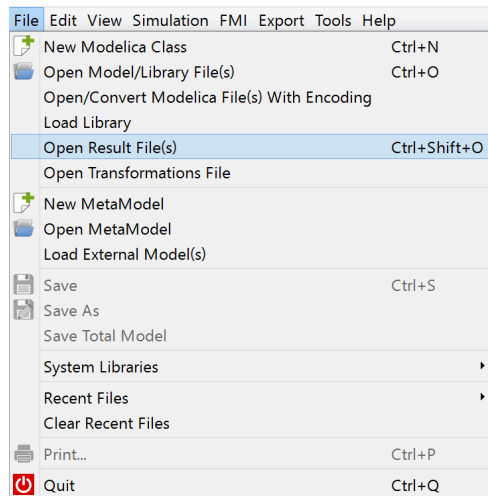
- System will be simulated with 3-phase-to-ground fault at $t=0.5s$ with a duration of 70ms
- Simulation results will be compared with the reference results from the PSAT that will be loaded first
- PSAT results are provided in a file “PSAT_dyn.csv”
- To load the file, the view should be switched to “Plotting” tab



Example 1

Simulation

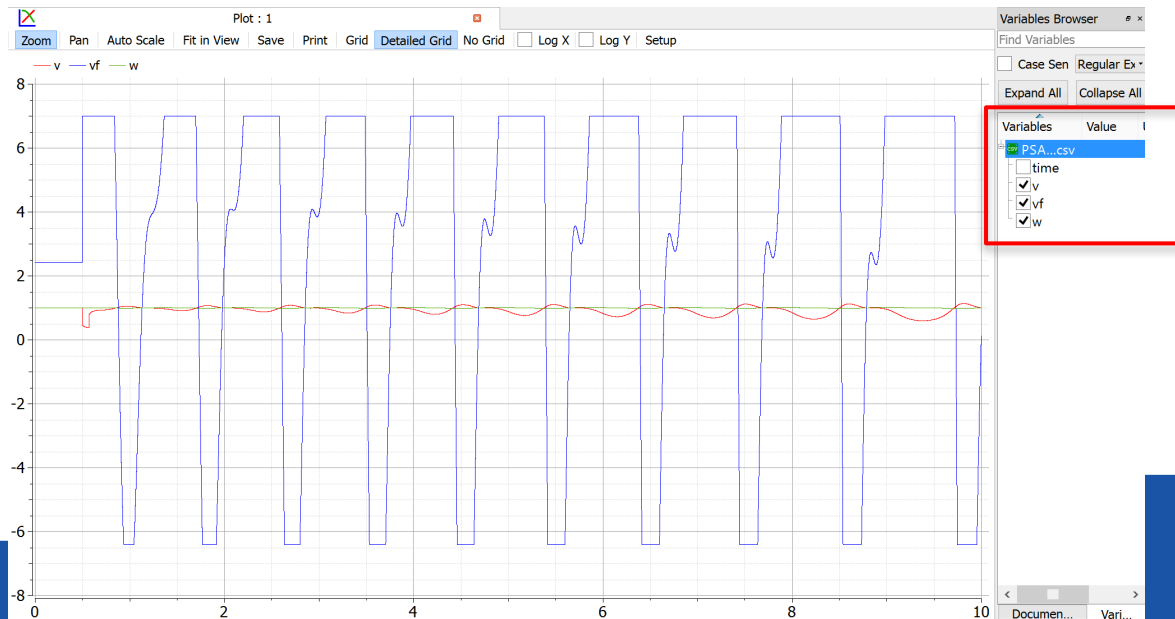
- Result file can be opened by navigating the menu to File->Open Result File(s)
- In the pop-up menu, one has to select “Comma Separated Values” as a file type, navigate to the directory where the file is located and open it



Example 1

Simulation

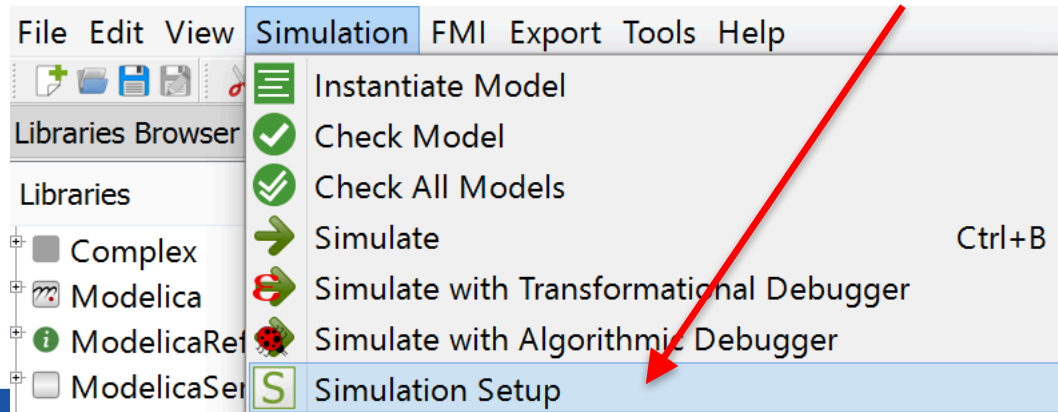
- In the variable browser, three waveforms from the PSAT results are loaded which can be displayed on the plot as it is shown in the figure below
- Loaded waveforms are generator terminal voltage, excitation field voltage and the generator speed



Example 1

Simulation

- Before the simulation, solver and its parameters are set to be the same as in the PSAT
- Solver is chosen to be Runge-Kutta with a fixed step
- More solvers can be chosen in Modelica (depending on the tool), however, to match the model's response with the one in PSAT choice of the solver is limited



Example 1

Simulation

- Simulation time is set to 10s and the tolerance of the solver is set to $1e-6$
- The time step is set to 0.0001



Simulation Setup - OpenIPSL.Examples.Machines.PSSE.GENSAL

General Output Simulation Flags Archived Simulations

Simulation Interval

Start Time: 0

Stop Time: 10

Number of Intervals: 500

Interval: 0.0001

Integration

Method: rungekutta

Tolerance: $1e-6$

DASSL Options

Jacobian: Colored Numerical

Root Finding

Restart After Event

Initial Step Size:

Maximum Step Size:

Maximum Integration Order: 5

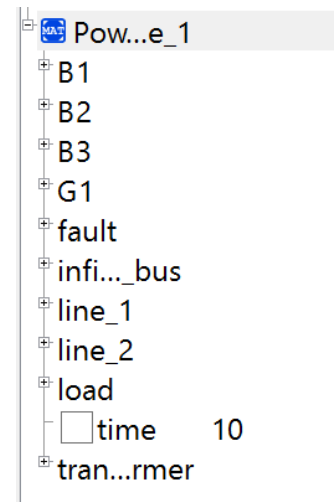
Example 1

Simulation

- By pressing the “Simulate” button on the toolbar, simulation of the model is executed



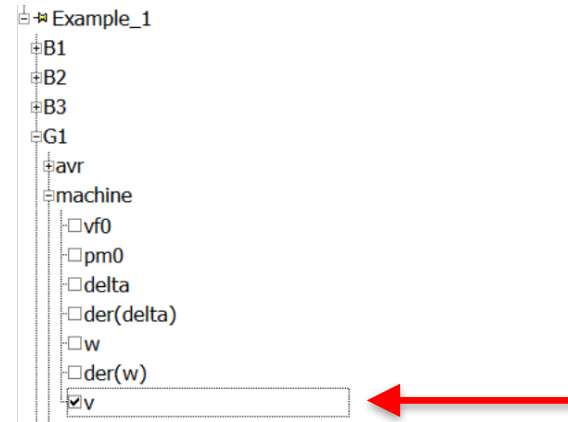
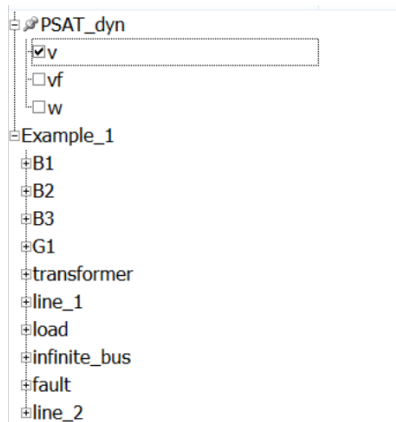
- Once the simulation is completed, the Variable Browser is populated with the simulation results



Example 1

Simulation

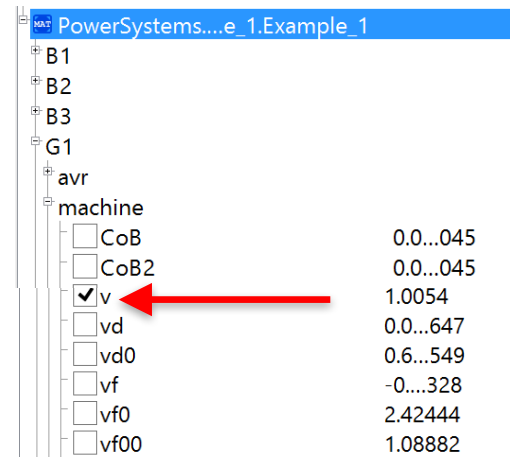
- To display the simulation results or compare it with the results from PSAT, one can mark the check-box next to the variable which will be shown on the plot
- To show the terminal voltage of the generator in PSAT and modelica, variables “PSAT_dyn.v” and “Example_1.G1.machine.v” have to be selected



Example 1

Simulation

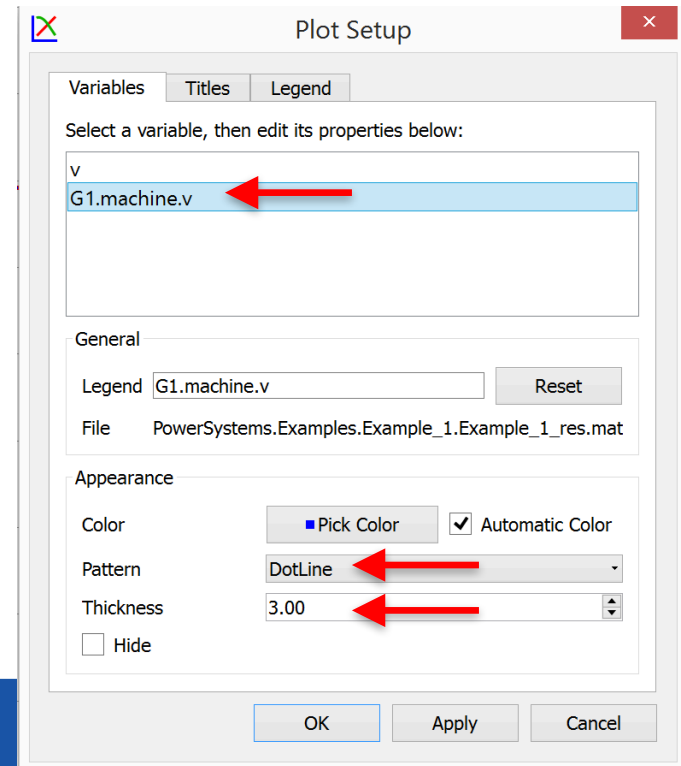
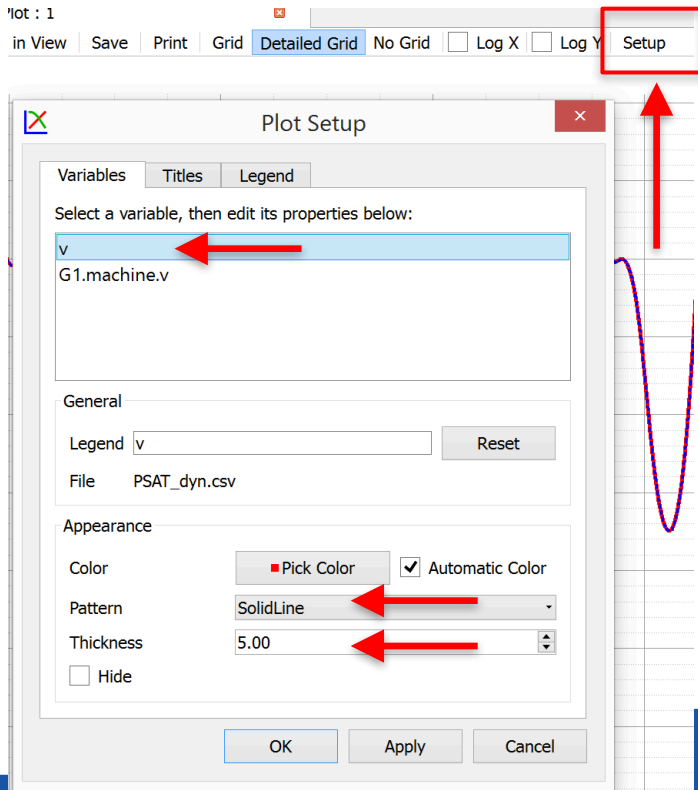
- To display the simulation results or compare it with the results from PSAT, one can mark the check-box next to the variable which will be shown on the plot
- To show the terminal voltage of the generator in PSAT and modelica, variables “PSAT_dyn.csv.v” and “G1.machine.v” have to be selected



Example 1

Simulation

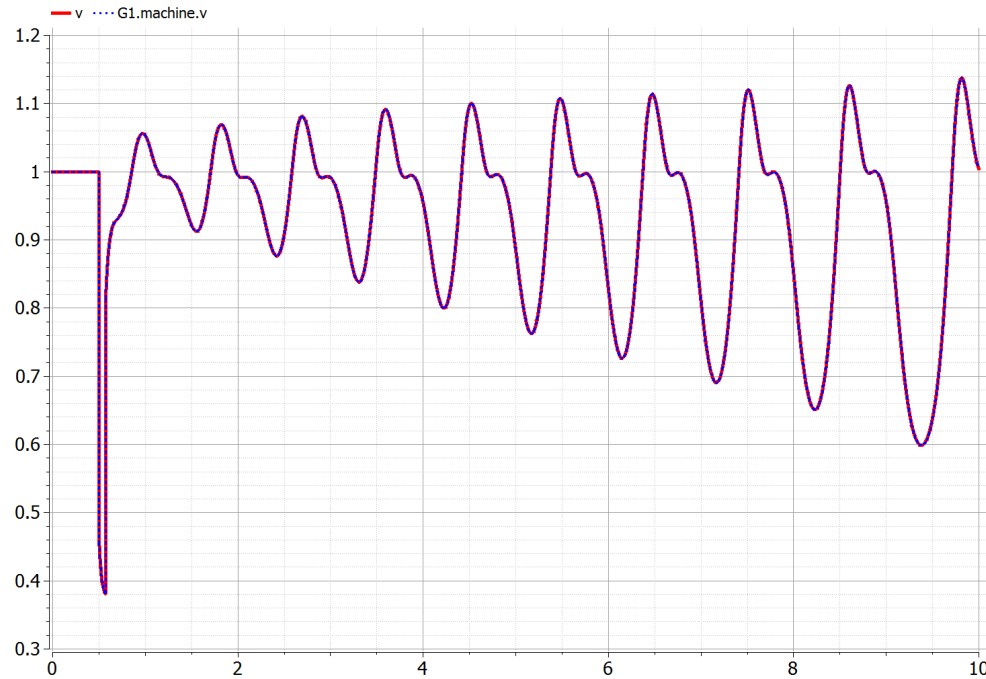
- To be able to distinguish different signals, let's adjust the thickness and the pattern of the signal line



Example 1

Simulation

- Previous steps produce the plot shown in the figure below showing that the Modelica produces the same simulation results as the PSAT does





Using OMNotebook for Interactive Analysis

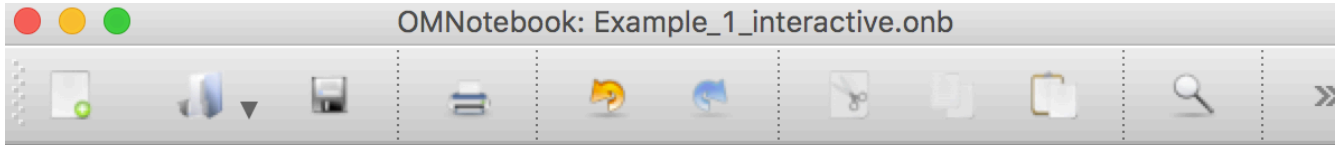
The OpenModelica installation includes a very handy tool called OMNotebook.

OMNotebook allows you to interact with the OpenModelicaCompiler (OMC), and at the same time analyze the model. This gives you a basic “lab notebook” where you do your tests before you create a script for automated analysis (called .mos scripts).

We use OMNotebook next to load the model developed, and simulate it interactively.



Loading and Simulating your Model



Example 1 - Interactive Analysis using OMNotebook
Prof. Luigi Vanfretti, 2017-04-19

```
//Set the current working directory to your installation
cd("/Users/luigiv/Downloads/OpenIPSL-Tuto_TAMU_2017/");
//Load the standard MSL
loadModel(Modelica);
//Load the OpenIPSL
loadFile("../OpenIPSL/package.mo");
// list(OpenIPSL) //enable to check if the library is being loaded
[done]
```

```
// Load the tutorial
cd("../ApplicationExamples/_Tutorial/Tutorial/");
loadFile("package.mo");
//Check everything is in the model
list(Tutorial.Example_1.Example_1);
[done]
```

```
// Instantiate the model of the network
instantiateModel(Tutorial.Example_1.Example_1);
// Simulate the model
simulate(Tutorial.Example_1.Example_1, stopTime=5);
```

Set your patch to where your tutorial .zip is available.

Evaluate each cell using "Shift+Enter"

Instantiate and Simulate the Model



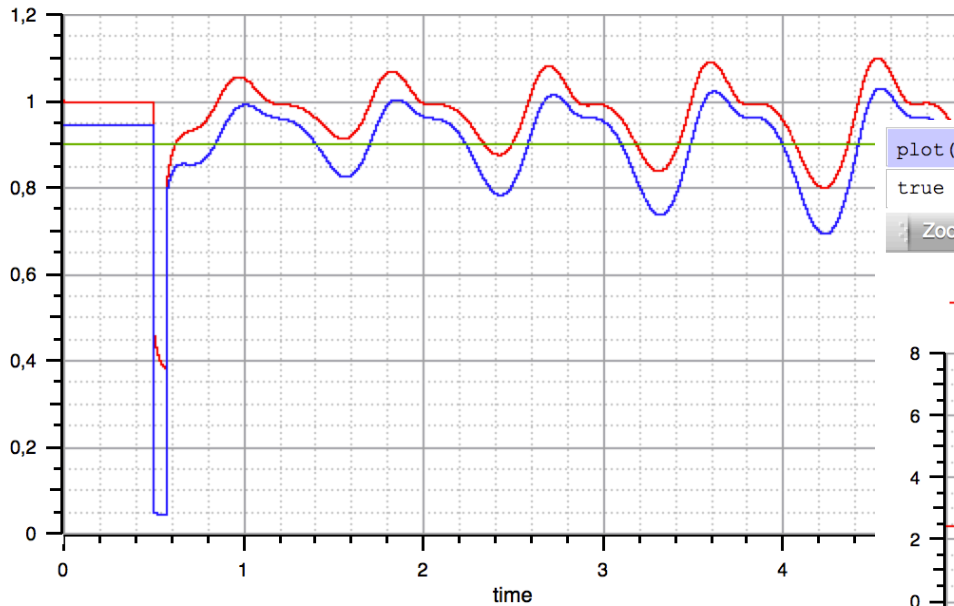
Plotting in OMNotebook

```
// What can you plot!  
plot({B1.V,B2.V,B3.V})
```

true

Zoom Pan Auto Scale Fit in View Save Print Grid >>

— B1.V — B2.V — B3.V

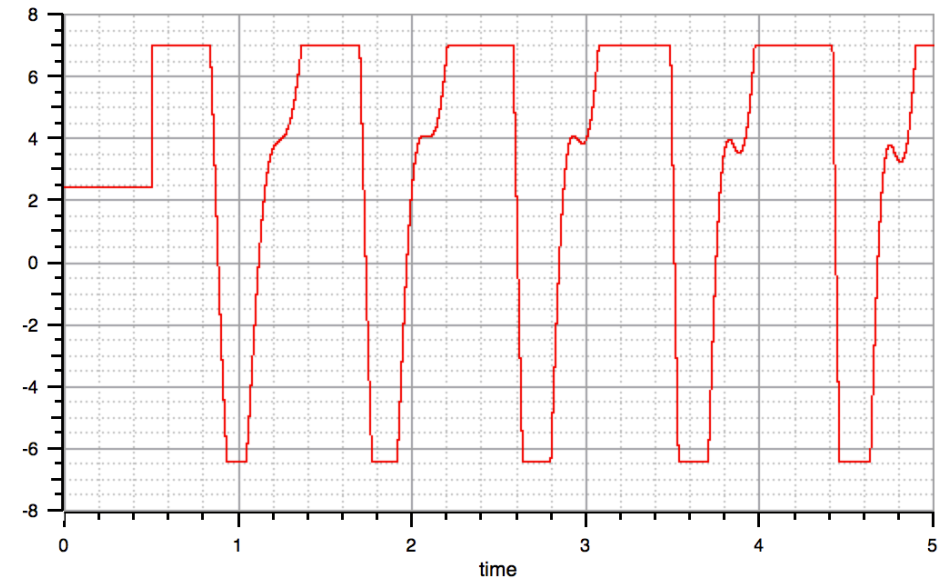


```
plot(G1.avr.vf)
```

true

Zoom Pan Auto Scale Fit in View Save Print Grid >>

— G1.avr.vf





Parametric Sweep and Simulation using OMNotebook

- Using OMNotebook, we can interact with the OMC in order to analyze the behavior of the system.
- The AVR's output looks saturated.
- The type of instability that we are observing it is typically due to negative feedback from the AVR. This was shown in the early 1900's by Concordia and De Mello!
- A parametric sweep is used in OMC to simulate the system's response for different values of the gain of the AVR, namely, K_0 .



Parametric Sweep and Simulation using OMNotebook

Example 1 - Parametric Sweep
Prof. Luigi Vanfretti, 2017-04-19

```
//Set the current working directory to your installation
cd("/Users/luigiv/Downloads/OpenIPSL-Tuto_TAMU_2017/");
//Load the standard MSL
loadModel(Modelica);
//Load the OpenIPSL
loadFile("../OpenIPSL/package.mo");
// list(OpenIPSL) //enable to check if the library is being loaded
// Load the tutorial
cd("../ApplicationExamples/_Tutorial/Tutorial/");
loadFile("package.mo");
// Build the model once
buildModel(Tutorial.Example_1.Example_1);
```

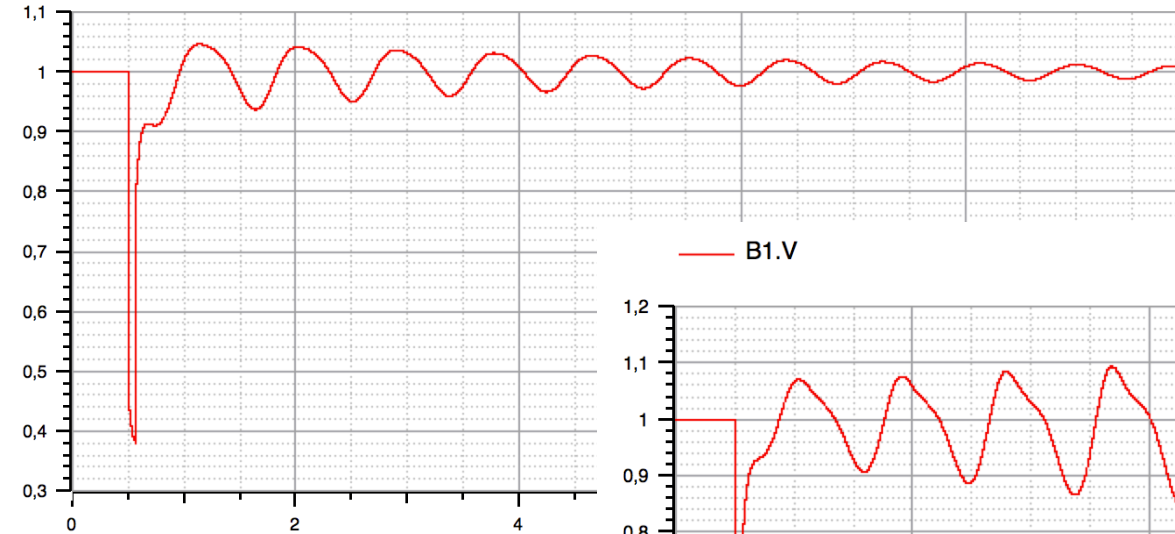
```
// Do the parametric sweep using a loop
getErrorString();
for i in 1:10 loop
  // We update the parameter using value
  value := i*10;
  // call the generated simulation code to produce a result files %i%_res.mat
  system("../Tutorial.Example_1.Example_1 -override=G1.avr.K0="+String(value)+" -r=Example_1_parametric"
+ String(i) + "_res.mat");
  getErrorString();
end for
```

```
""
```

```
plot({B1.V}, fileName="Example_1_parametric1_res.mat")
```

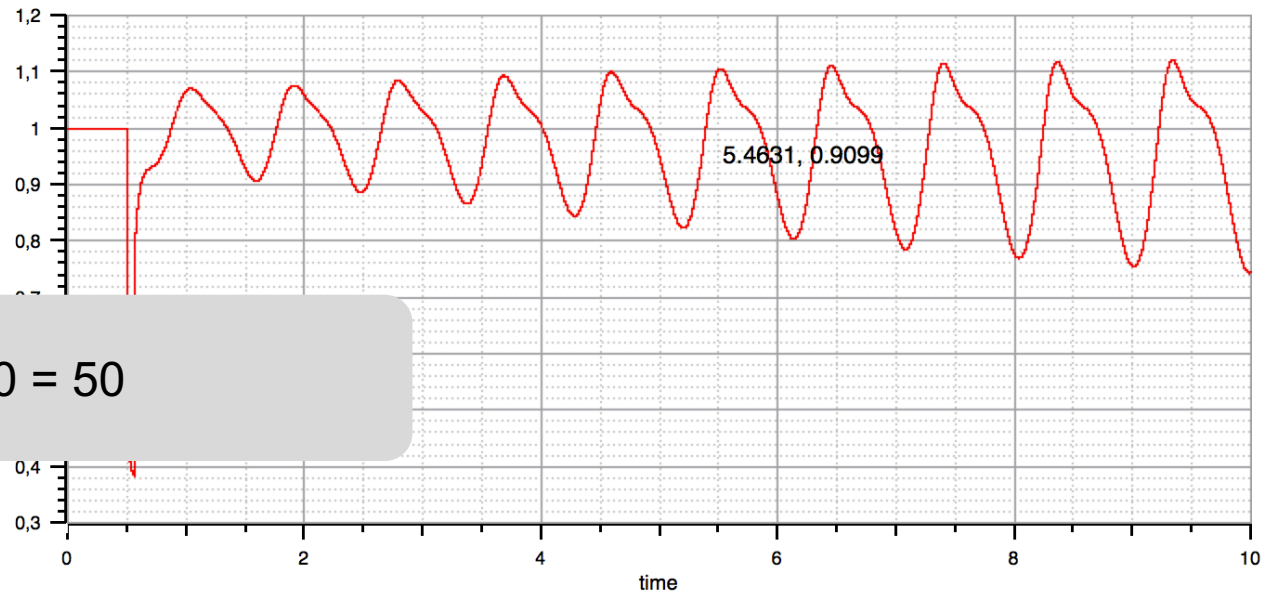
Parametric Sweep and Simulation using OMNotebook

B1.V



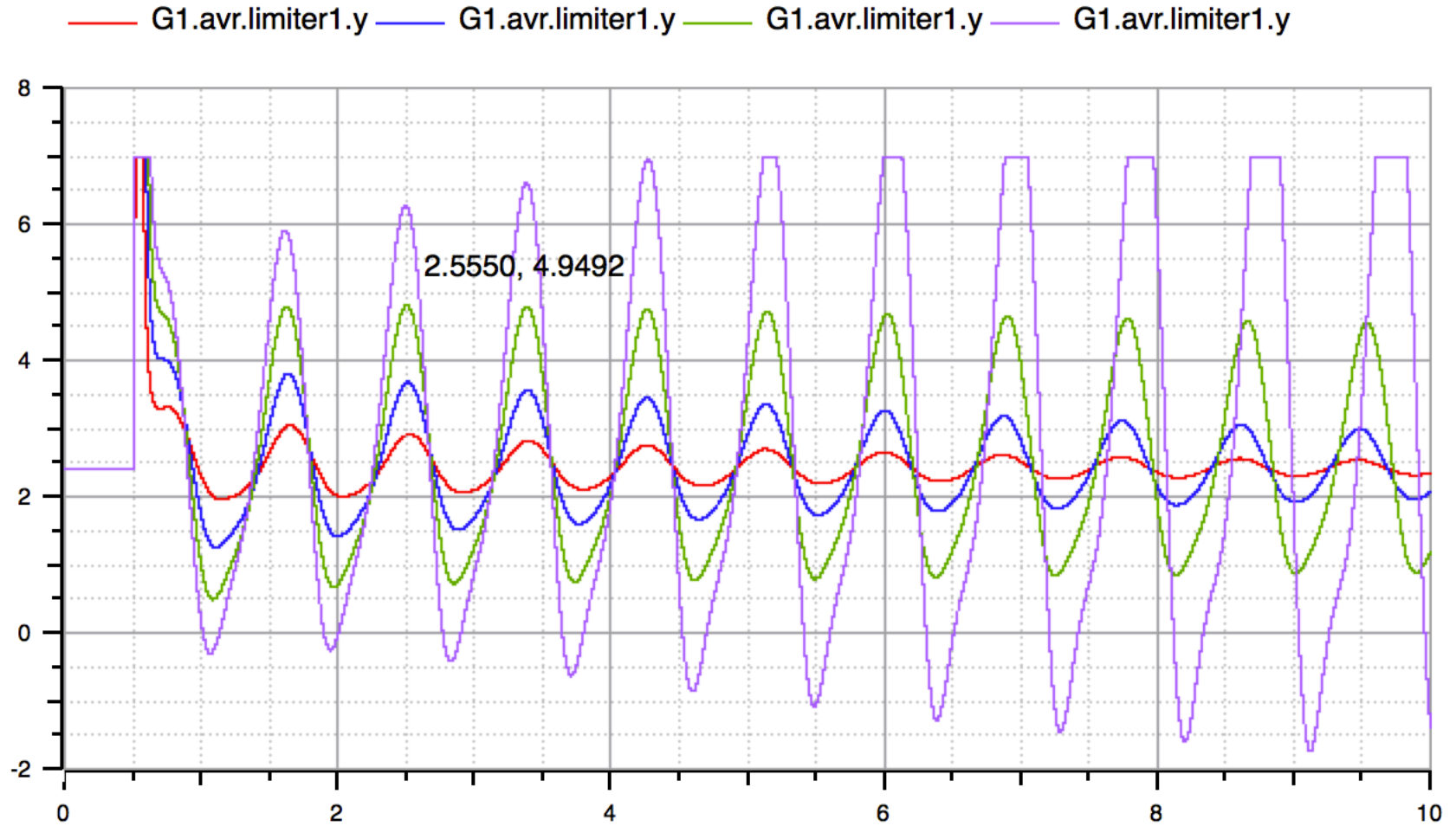
$K0 = 10$

B1.V



$K0 = 50$

Parametric Sweep and Simulation using OMNotebook





Linear Analysis

Let's now do a bit more analysis on the system's stability by using linear analysis.

This will allow us to determine the system's damping with the current value of the AVR's gain ($K=200$).

Two methods are shown in the following slides, using OMNotebook and the OMSHELL (optional).

```
// Instantiate the model of the network  
instantiateModel(Tutorial.Example_1.Example_1);  
// Linearize the model  
linearize(Tutorial.Example_1.Example_1, stopTime=0);
```




Linear Analysis

```
list(linear_Tutorial_Example__1_Example__1)
```

```
"model linear_Tutorial_Example__1_Example__1
  parameter Integer n = 9;
  // states
  parameter Integer k = 0;
  // top-level inputs
  parameter Integer l = 0;
  // top-level outputs
  parameter Real x0[9] = {2.420701642076922, 1, 0, 1.224247464404018, 0.4107654957816429, 1.02748702363574,
0.5742496657902401, 0.9593327097152915, 1};
  parameter Real u0[0] = {i for i in 1:0};
  parameter Real A[9, 9] = [-10000, -2000000, 10000, 0, 0, 0, 0, 0, 0; 0, -66.66666666666667, 0,
-9.193997621986762, 6.549112611627166e-15, 0, 29.25536745530336, 33.36361865698515, -5.06776165969379e-16;
0, 0, -1, 0, 0, 0, 0, 0, 0; 0, 0, 0, 0, 0, 0, 0, 0, 376.9911184307751; 0, 0, 0, 0.4610796242587042, -1, 0,
-1.489428945747467, 0.006336424213860586, -1.215373955322828e-17; 0.12496875, 0, 0, -0.2257865911752657,
6.023845086408405e-17, -0.125, -0.001104105716065041, -0.266889889874036, 3.011922543204202e-17; 0, 0, 0,
2.62155903181871, 14.28571428571428, 0, -22.75415595943628, 0.03602698808039422, -6.910248039557863e-17;
0.008333333333333333, 0, 0, -2.972830759729272, 7.931326599823655e-16, 33.33333333333334,
-0.01453726466937616, -36.84735278837885, 3.965663299911827e-16; -0, -0, -0, -0.1593501250388591,
8.249174533413525e-17, -0, 0.06000759107001079, -0.1730203086038577, 1.487405919582988e-17];
  parameter Real B[9, 0] = zeros(9, 0);
  parameter Real C[0, 9] = zeros(0, 9);
  parameter Real D[0, 0] = zeros(0, 0);
```



Linear Analysis

Now we copy and paste the A matrix of the model defined above, the assignment `A:= [...]`; makes the A matrix available to the OpenModelicaCompiler.

Once in the OMC, we use the MSL mathematical functions to compute the eigenvalues and eigenvectors!

```
A := [-10000, -2000000, 10000, 0, 0, 0, 0, 0, 0; 0, -66.66666666666667, 0, -9.193997621986762,
6.549112611627166e-15, 0, 29.25536745530336, 33.36361865698515, -5.06776165969379e-16; 0, 0, -1, 0, 0, 0,
0, 0, 0; 0, 0, 0, 0, 0, 0, 0, 376.9911184307751; 0, 0, 0, 0.4610796242587042, -1, 0, -1.489428945747467,
0.006336424213860586, -1.215373955322828e-17; 0.12496875, 0, 0, -0.2257865911752657, 6.023845086408405e-17,
-0.125, -0.001104105716065041, -0.266889889874036, 3.011922543204202e-17; 0, 0, 0, 2.62155903181871,
14.28571428571428, 0, -22.75415595943628, 0.03602698808039422, -6.910248039557863e-17;
0.008333333333333333, 0, 0, -2.972830759729272, 7.931326599823655e-16, 33.33333333333334,
-0.01453726466937616, -36.84735278837885, 3.965663299911827e-16; -0, -0, -0, -0.1593501250388591,
8.249174533413525e-17, -0, 0.06000759107001079, -0.1730203086038577, 1.487405919582988e-17];
```

```
[done]
```

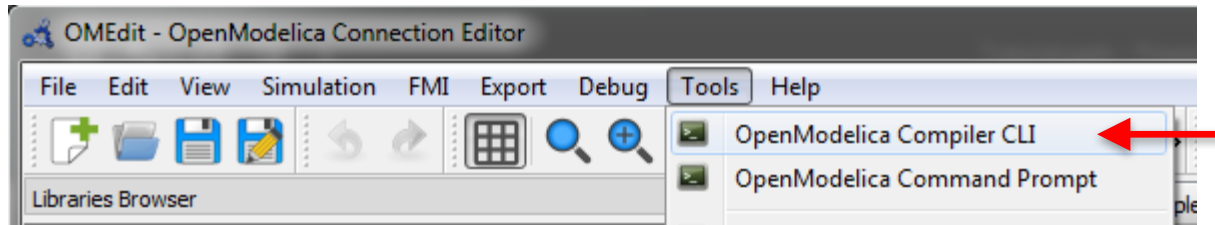
```
(eval, vec) := Modelica.Math.Matrices.eigenValues(A);
eval
```

```
{{-10000.00533773918, 0.0}, {-74.9958055563845, 0.0}, {-15.08153495326777, 13.52584213953},
{-15.08153495326777, -13.52584213953}, {-21.1415314117239, 0.0}, {0.351753399829141, 8.06568059314465},
{0.351753399829141, -8.06568059314465}, {-1.790937600311332, 0.0}, {-1.0, 0.0}}
```

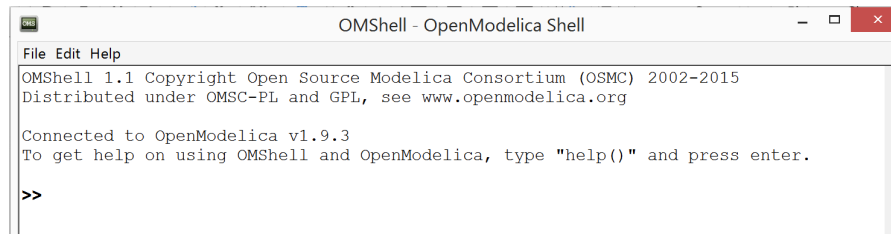
Example 1 – Linearization using OMShell

Linearization

- To linearize the system, OpenModelica scripting will be needed



- Along with the library, a set of commands was provided (Command_List.txt) to linearize the model and extract the A matrix



```
OMShell 1.1 Copyright Open Source Modelica Consortium (OSMC) 2002-2015
Distributed under OSMC-PL and GPL, see www.openmodelica.org

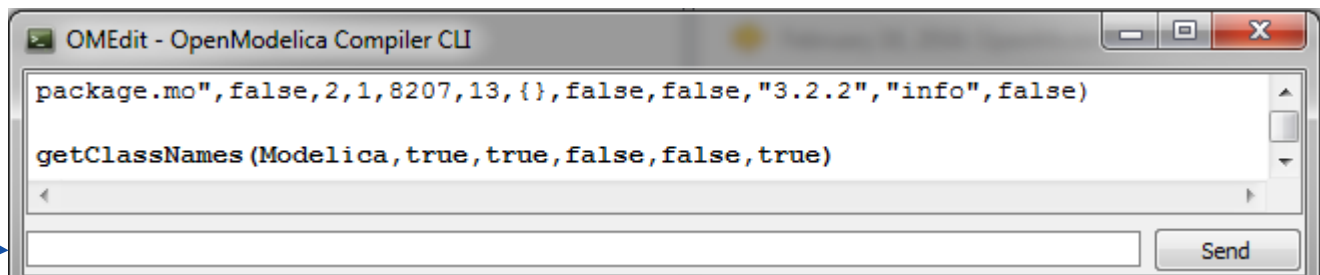
Connected to OpenModelica v1.9.3
To get help on using OMShell and OpenModelica, type "help()" and press enter.
>>
```

Example 1 – Linearization using OMShell

Linearization

- Copy and paste each line from the Command_List.txt for Example 1 to the command prompt in OpenModelica

```
# Example 1  
linearize(Tutorial.Example_1.Example_1,stopTime=0.0)  
loadFile("linear_Tutorial.Example_1.Example_1.mo")  
(a) := getParameterValue(linear_Tutorial_Example__1_Example__1,"A")  
  
(eval,eval) := Modelica.Math.Matrices.eigenValues(A);
```

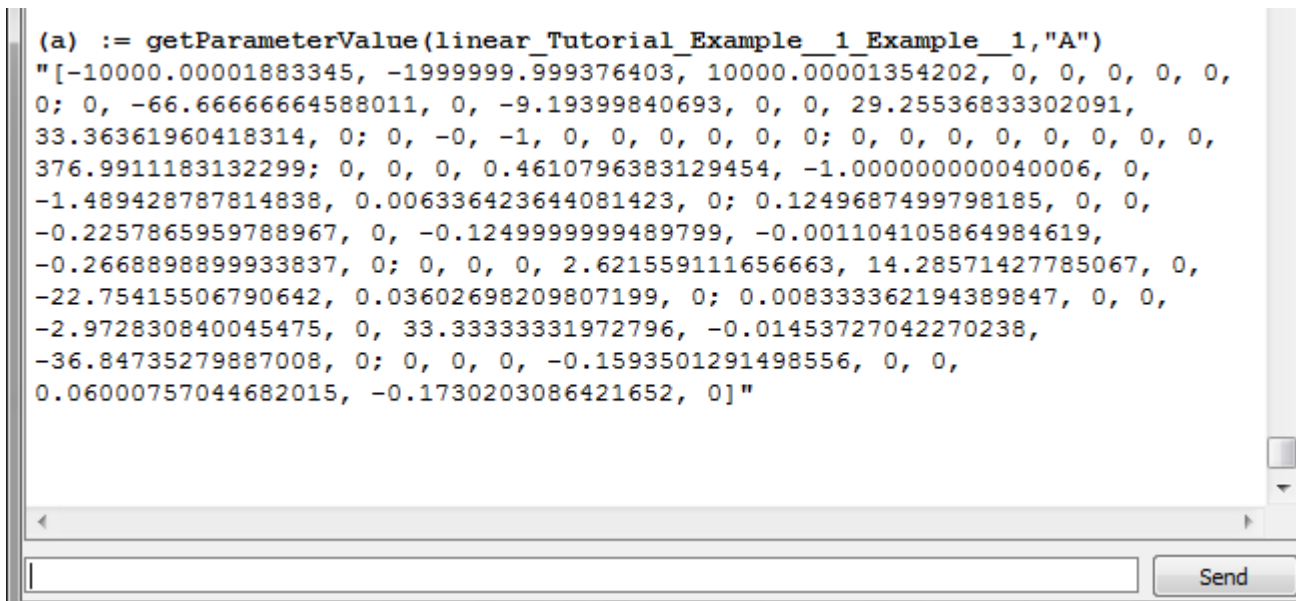


Example 1 – Linearization using OMShell

Linearization

- The third command will save the A matrix of the linearized state-space model in the variable `a` as a string

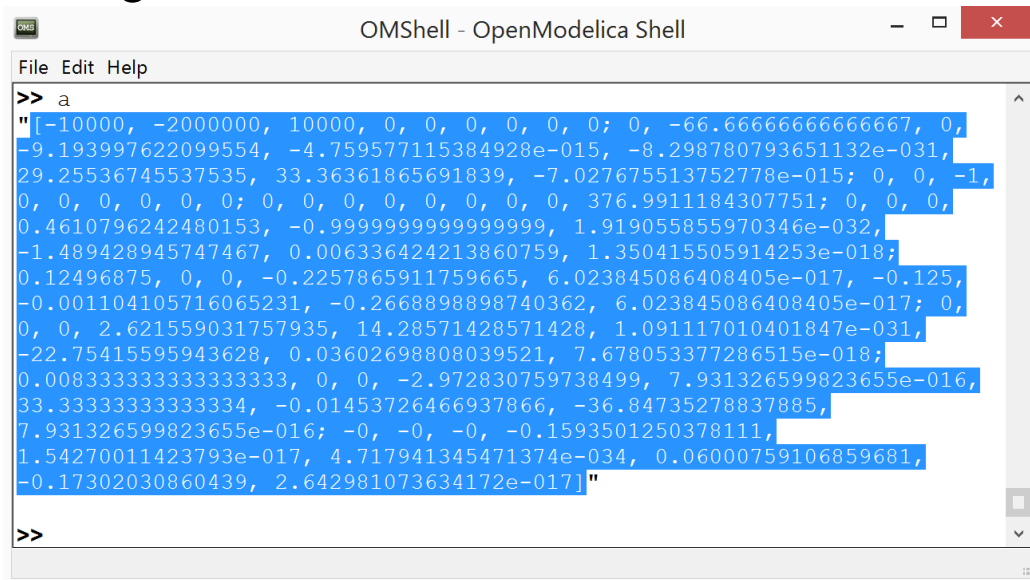
```
(a) := getParameterValue(linear_Tutorial_Example_1_Example_1,"A")
"[-10000.00001883345, -1999999.999376403, 10000.00001354202, 0, 0, 0, 0, 0, 0,
0; 0, -66.66666664588011, 0, -9.19399840693, 0, 0, 29.25536833302091,
33.36361960418314, 0; 0, -0, -1, 0, 0, 0, 0, 0, 0; 0, 0, 0, 0, 0, 0, 0, 0,
376.9911183132299; 0, 0, 0, 0.4610796383129454, -1.000000000040006, 0,
-1.489428787814838, 0.006336423644081423, 0; 0.1249687499798185, 0, 0,
-0.2257865959788967, 0, -0.1249999999489799, -0.001104105864984619,
-0.2668898899933837, 0; 0, 0, 0, 2.621559111656663, 14.28571427785067, 0,
-22.75415506790642, 0.03602698209807199, 0; 0.0083333362194389847, 0, 0,
-2.972830840045475, 0, 33.33333331972796, -0.01453727042270238,
-36.84735279887008, 0; 0, 0, 0, -0.1593501291498556, 0, 0,
0.06000757044682015, -0.1730203086421652, 0]"
```

A screenshot of the OMShell terminal window. The terminal displays a command to retrieve the A matrix of a linearized state-space model. The output is a long string of numbers representing the matrix elements, enclosed in quotes. The terminal window has a scroll bar on the right and a 'Send' button at the bottom right.

Example 1 – Linearization using OMShell

Linearization

- Copy the output from the previous command without the quotation marks by pressing Ctrl+C

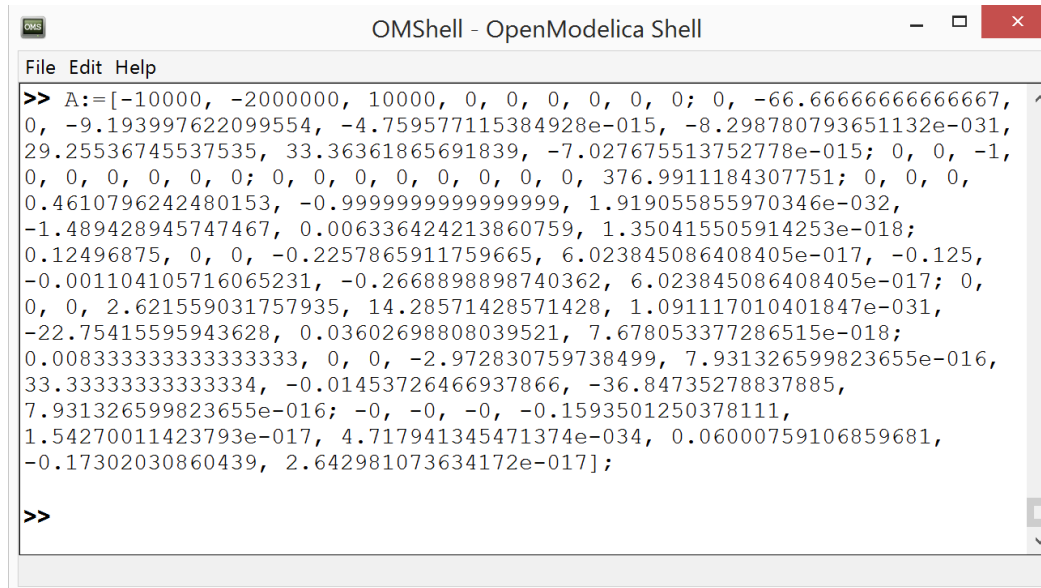
A screenshot of the OMShell (OpenModelica Shell) window. The window title is 'OMShell - OpenModelica Shell'. The menu bar contains 'File Edit Help'. The main text area shows a command prompt '>> a' followed by a large block of numerical data enclosed in double quotes. The data is a long list of numbers, including integers, floating-point numbers, and scientific notation, separated by commas and semicolons. The prompt '>>' is visible at the bottom of the window.

```
>> a
"[-10000, -2000000, 10000, 0, 0, 0, 0, 0, 0; 0, -66.66666666666667, 0,
-9.193997622099554, -4.759577115384928e-015, -8.298780793651132e-031,
29.25536745537535, 33.36361865691839, -7.027675513752778e-015; 0, 0, -1,
0, 0, 0, 0, 0, 0; 0, 0, 0, 0, 0, 0, 0, 0, 0, 376.9911184307751; 0, 0, 0,
0.4610796242480153, -0.9999999999999999, 1.919055855970346e-032,
-1.489428945747467, 0.006336424213860759, 1.350415505914253e-018;
0.12496875, 0, 0, -0.2257865911759665, 6.023845086408405e-017, -0.125,
-0.001104105716065231, -0.2668898898740362, 6.023845086408405e-017; 0,
0, 0, 2.621559031757935, 14.28571428571428, 1.091117010401847e-031,
-22.75415595943628, 0.03602698808039521, 7.678053377286515e-018;
0.008333333333333333, 0, 0, -2.972830759738499, 7.931326599823655e-016,
33.33333333333334, -0.01453726466937866, -36.84735278837885,
7.931326599823655e-016; -0, -0, -0, -0.1593501250378111,
1.54270011423793e-017, 4.717941345471374e-034, 0.06000759106859681,
-0.17302030860439, 2.642981073634172e-017]"
>>
```

Example 1 – Linearization using OMShell

Linearization

- To save the matrix A as a matrix of Real values type $A :=$ and then press Ctrl+V to paste the copied matrix

A screenshot of the OMShell (OpenModelica Shell) window. The window title is 'OMShell - OpenModelica Shell'. It has a menu bar with 'File', 'Edit', and 'Help'. The main text area contains a long list of numerical values in a matrix format, starting with '>> A:=[-10000, -2000000, 10000, 0, 0, 0, 0, 0, 0, 0; 0, -66.66666666666667, 0, -9.193997622099554, -4.759577115384928e-015, -8.298780793651132e-031, 29.25536745537535, 33.36361865691839, -7.027675513752778e-015; 0, 0, -1, 0, 0, 0, 0, 0, 0; 0, 0, 0, 0, 0, 0, 0, 0, 0, 376.9911184307751; 0, 0, 0, 0.4610796242480153, -0.9999999999999999, 1.919055855970346e-032, -1.489428945747467, 0.006336424213860759, 1.350415505914253e-018; 0.12496875, 0, 0, -0.2257865911759665, 6.023845086408405e-017, -0.125, -0.001104105716065231, -0.2668898898740362, 6.023845086408405e-017; 0, 0, 0, 2.621559031757935, 14.28571428571428, 1.091117010401847e-031, -22.75415595943628, 0.03602698808039521, 7.678053377286515e-018; 0.008333333333333333, 0, 0, -2.972830759738499, 7.931326599823655e-016, 33.33333333333334, -0.01453726466937866, -36.84735278837885, 7.931326599823655e-016; -0, -0, -0, -0.1593501250378111, 1.54270011423793e-017, 4.717941345471374e-034, 0.06000759106859681, -0.17302030860439, 2.642981073634172e-017];'. The prompt '>>' is visible at the bottom of the text area.

```
>> A:=[-10000, -2000000, 10000, 0, 0, 0, 0, 0, 0, 0; 0, -66.66666666666667,
0, -9.193997622099554, -4.759577115384928e-015, -8.298780793651132e-031,
29.25536745537535, 33.36361865691839, -7.027675513752778e-015; 0, 0, -1,
0, 0, 0, 0, 0, 0; 0, 0, 0, 0, 0, 0, 0, 0, 0, 376.9911184307751; 0, 0, 0,
0.4610796242480153, -0.9999999999999999, 1.919055855970346e-032,
-1.489428945747467, 0.006336424213860759, 1.350415505914253e-018;
0.12496875, 0, 0, -0.2257865911759665, 6.023845086408405e-017, -0.125,
-0.001104105716065231, -0.2668898898740362, 6.023845086408405e-017; 0,
0, 0, 2.621559031757935, 14.28571428571428, 1.091117010401847e-031,
-22.75415595943628, 0.03602698808039521, 7.678053377286515e-018;
0.008333333333333333, 0, 0, -2.972830759738499, 7.931326599823655e-016,
33.33333333333334, -0.01453726466937866, -36.84735278837885,
7.931326599823655e-016; -0, -0, -0, -0.1593501250378111,
1.54270011423793e-017, 4.717941345471374e-034, 0.06000759106859681,
-0.17302030860439, 2.642981073634172e-017];

>>
```

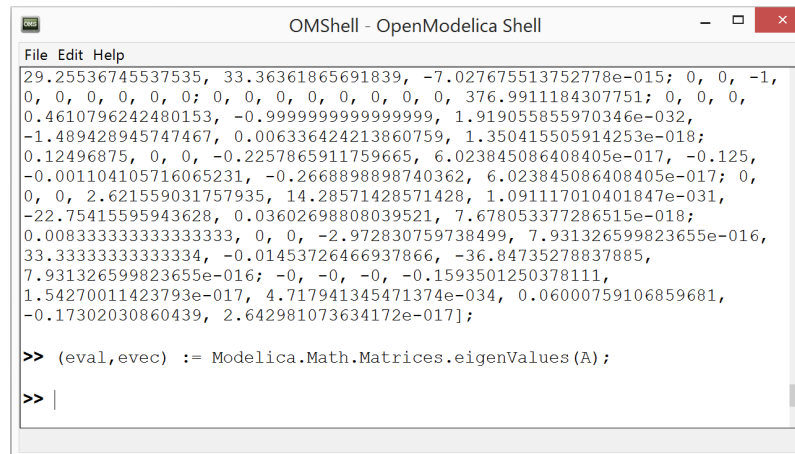
Example 1 – Linearization using OMShell

Linearization

- It is known that the eigenvalues of the linearized system can be found by solving the following equation:

$$\det(A - \lambda I) = 0$$

- This can be done by executing the last command
(eval, evec) := Modelica.Math.Matrices.eigenValues(A);



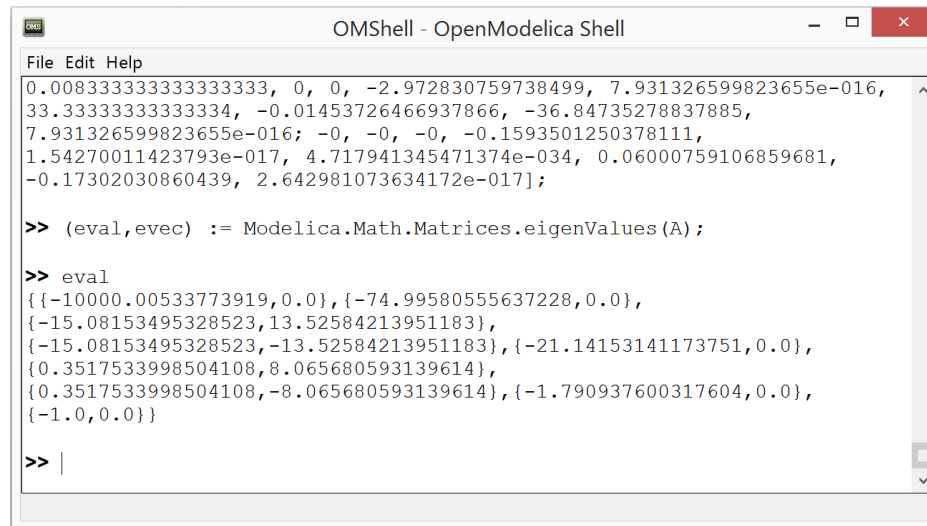
```
OMShell - OpenModelica Shell
File Edit Help
29.25536745537535, 33.36361865691839, -7.027675513752778e-015; 0, 0, -1,
0, 0, 0, 0, 0, 0; 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 376.9911184307751; 0, 0, 0,
0.4610796242480153, -0.9999999999999999, 1.919055855970346e-032,
-1.489428945747467, 0.006336424213860759, 1.350415505914253e-018;
0.12496875, 0, 0, -0.2257865911759665, 6.023845086408405e-017, -0.125,
-0.001104105716065231, -0.2668898898740362, 6.023845086408405e-017; 0,
0, 0, 2.621559031757935, 14.28571428571428, 1.091117010401847e-031,
-22.75415595943628, 0.03602698808039521, 7.678053377286515e-018;
0.008333333333333333, 0, 0, -2.972830759738499, 7.931326599823655e-016,
33.33333333333334, -0.01453726466937866, -36.84735278837885,
7.931326599823655e-016; -0, -0, -0, -0.1593501250378111,
1.54270011423793e-017, 4.717941345471374e-034, 0.06000759106859681,
-0.17302030860439, 2.642981073634172e-017];

>> (eval, evec) := Modelica.Math.Matrices.eigenValues(A);
>> |
```


Example 1 – Linearization using OMShell

Linearization

- The eigenvalues are now stored in the eval variable and they can be listed by executing `eval`
- Groups of numbers are listed where the first number is real part of the system's pole and the second one is the imaginary part

A screenshot of the OMShell (OpenModelica Shell) terminal window. The window title is 'OMShell - OpenModelica Shell'. The terminal shows the execution of the `eigenValues` function and the `eval` command. The output of `eval` is a list of complex eigenvalues, where each pair of numbers represents the real and imaginary parts of a pole.

```
OMShell - OpenModelica Shell
File Edit Help
0.008333333333333333, 0, 0, -2.972830759738499, 7.931326599823655e-016,
33.333333333333334, -0.01453726466937866, -36.84735278837885,
7.931326599823655e-016; -0, -0, -0, -0.1593501250378111,
1.54270011423793e-017, 4.717941345471374e-034, 0.06000759106859681,
-0.17302030860439, 2.642981073634172e-017];

>> (eval,vec) := Modelica.Math.Matrices.eigenValues(A);

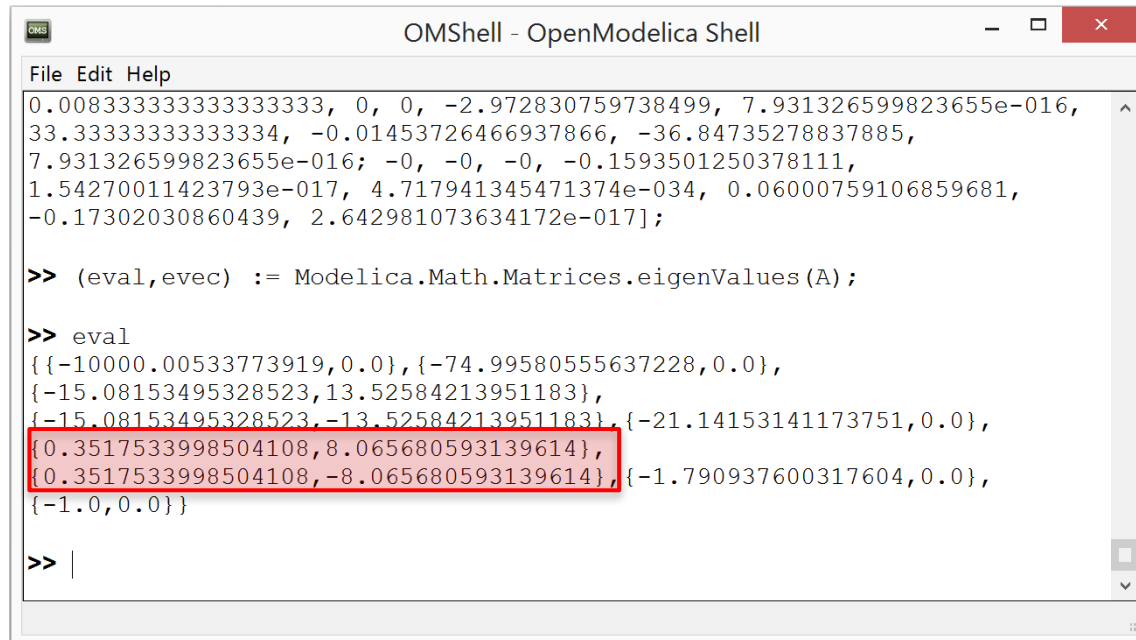
>> eval
{{-10000.00533773919,0.0},{-74.99580555637228,0.0},
{-15.08153495328523,13.52584213951183},
{-15.08153495328523,-13.52584213951183},{-21.14153141173751,0.0},
{0.3517533998504108,8.065680593139614},
{0.3517533998504108,-8.065680593139614},{-1.790937600317604,0.0},
{-1.0,0.0}}

>> |
```

Example 1 – Linearization using OMShell

Linearization

- It can be seen that the pair of conjugate poles exists on the right side of the stability plane and thus, the behavior of the system is unstable



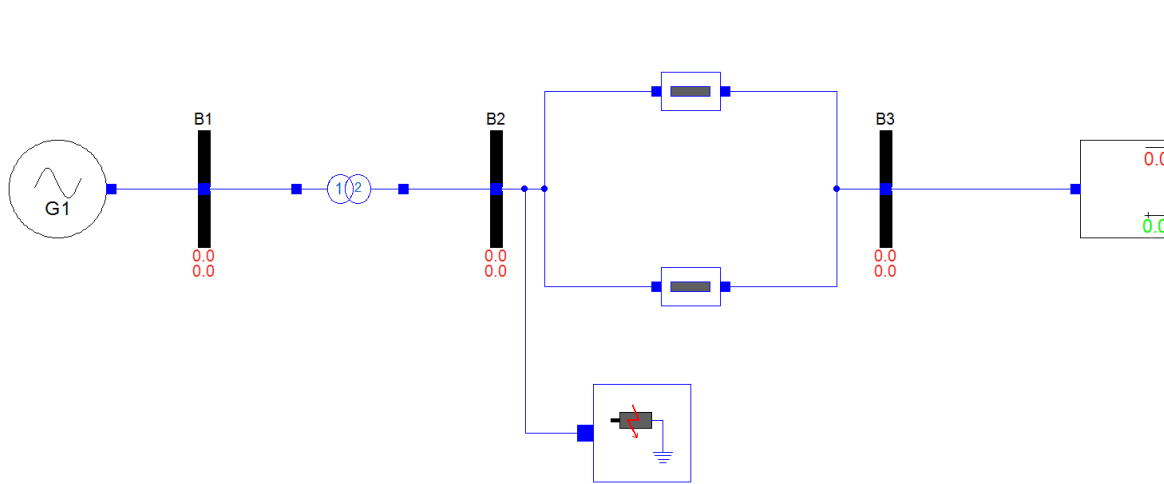
```
OMShell - OpenModelica Shell
File Edit Help
0.008333333333333333, 0, 0, -2.972830759738499, 7.931326599823655e-016,
33.333333333333334, -0.01453726466937866, -36.84735278837885,
7.931326599823655e-016; -0, -0, -0, -0.1593501250378111,
1.54270011423793e-017, 4.717941345471374e-034, 0.06000759106859681,
-0.17302030860439, 2.642981073634172e-017];

>> (eval, evec) := Modelica.Math.Matrices.eigenValues(A);

>> eval
{{-10000.00533773919, 0.0}, {-74.99580555637228, 0.0},
{-15.08153495328523, 13.52584213951183},
{-15.08153495328523, -13.52584213951183}, {-21.14153141173751, 0.0},
{0.3517533998504108, 8.065680593139614},
{0.3517533998504108, -8.065680593139614}, {-1.790937600317604, 0.0},
{-1.0, 0.0}}

>> |
```

Example 2

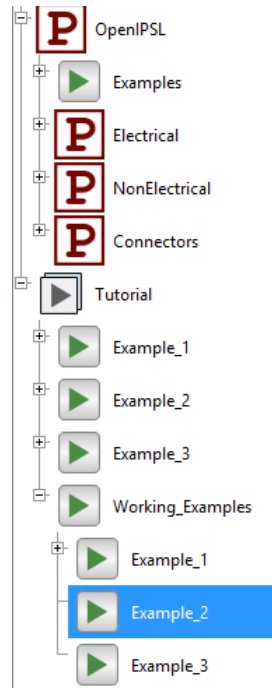


- In the Example 1, it was shown that the system was unstable with a pair of poles on the right side of the stability plane
- In the Example 2, Power System Stabilizer (PSS) will be added to the generator in order to stabilize the system



Example 2

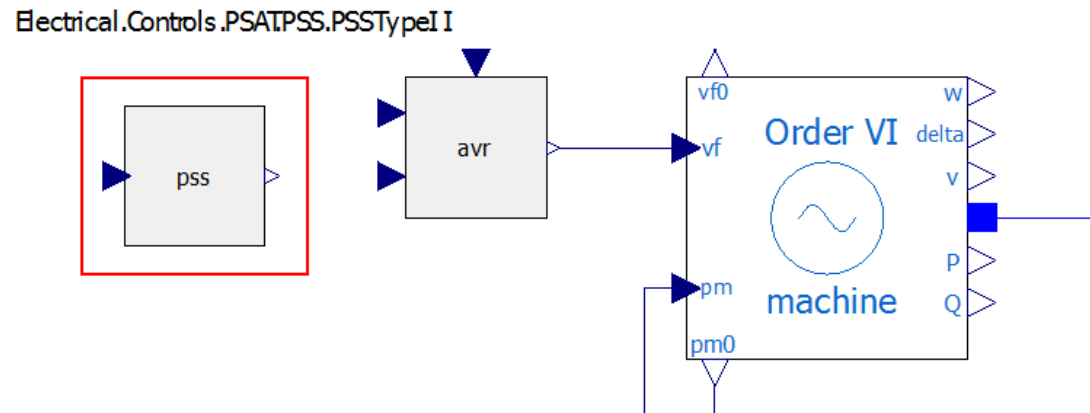
- The work on Example 2 should continue with the files prepared in a package Tutorial.Working_Examples.Example_2



Example 2

Generator model – Step 1

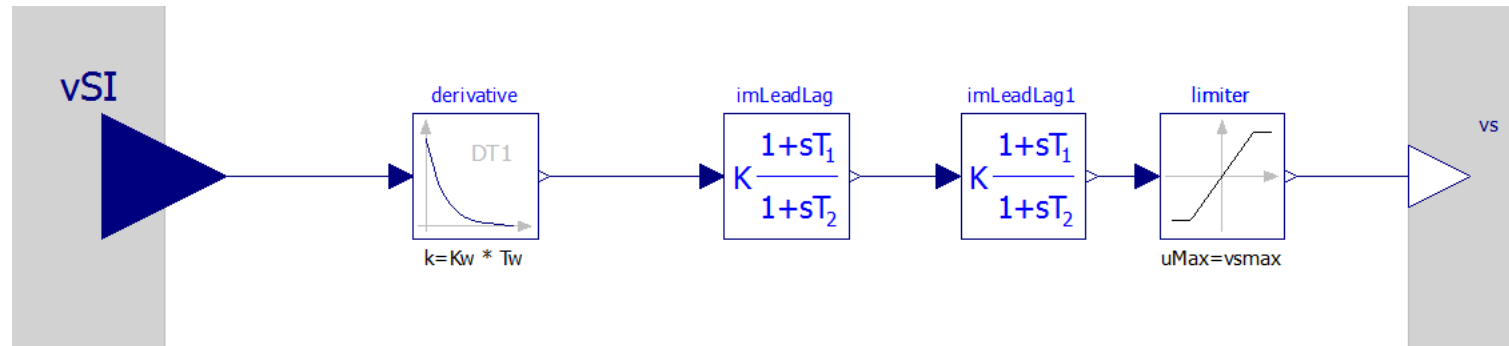
- The first step is to add the model of the PSS Type II and the summation block to the model of the generator



Example 2

Generator model – Step 1

- The internal control structure of the PSS can be accessed by right-clicking on the PSS block and selecting “View Class”



Example 2

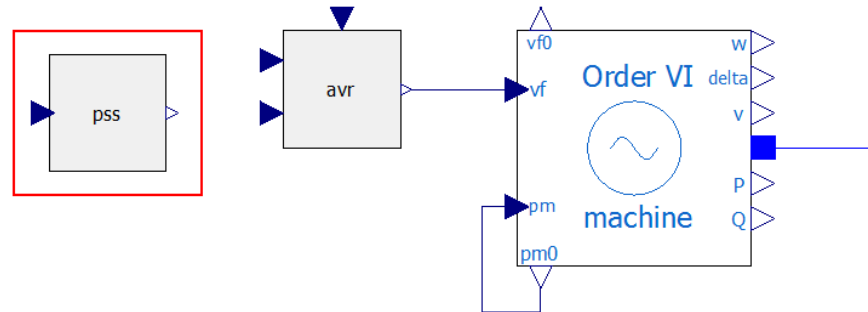
Generator – Step 1

- PSS should be parameterized as shown in the table

PSS

$v_{s,max}$	0.2	T_1	0.154
$v_{s,min}$	-0.2	T_2	0.033
K_w	9.5	T_3	1
T_w	1.41	T_4	1

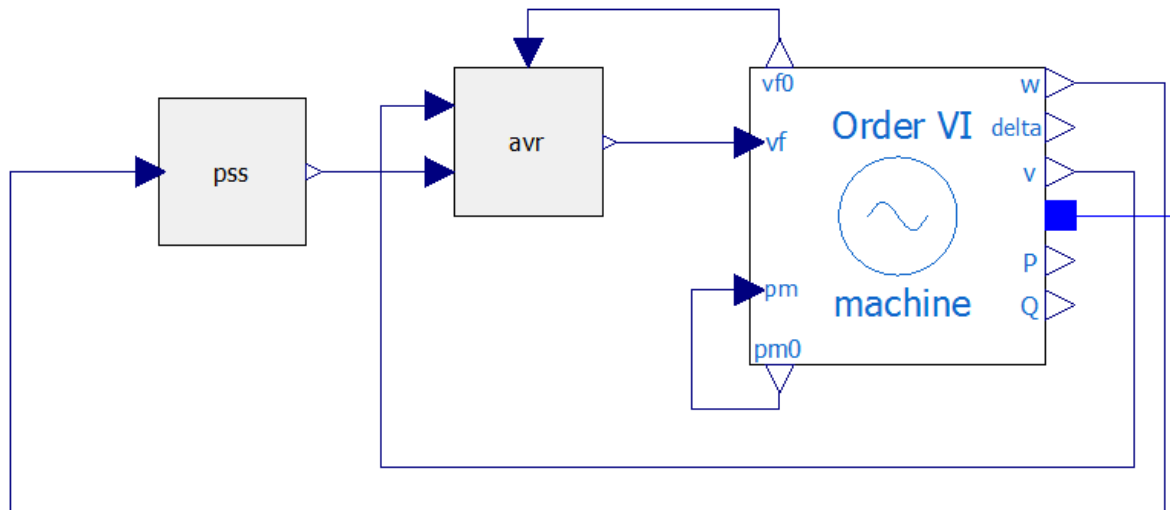
Electrical.Controls.PSATPSS.PSSTypeI I



Example 2

Generator – Step 2

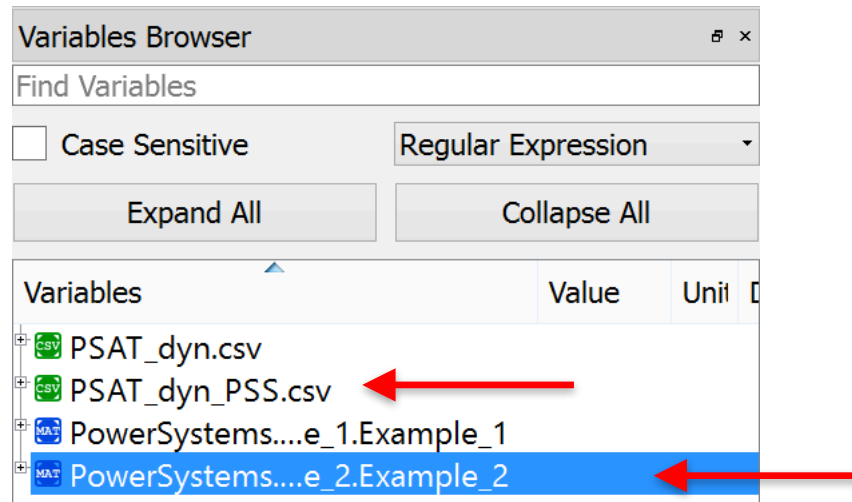
- When the signals of the generator model are connected as shown, model of the generator is completed



Example 2

Simulation

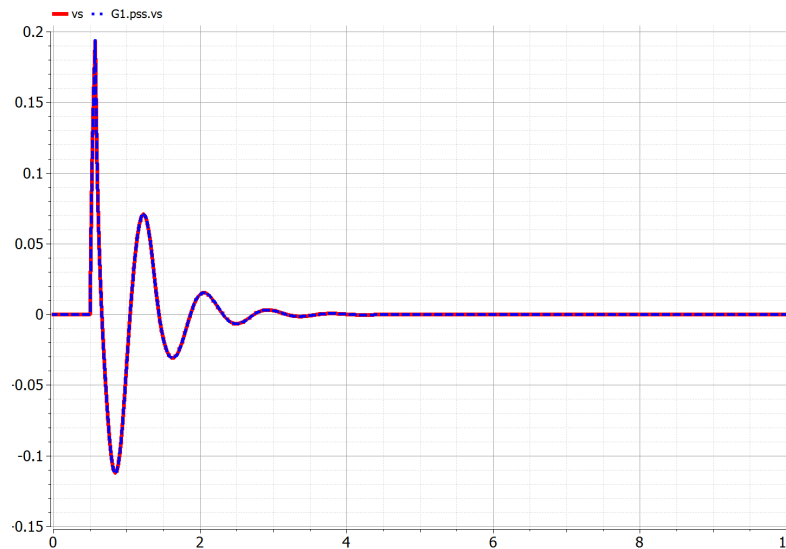
- Simulation steps can be repeated as it was shown in the Example 1
- This time, reference simulation results from the PSAT can be found in the file “PSAT_dyn_PSS.csv”
- After the simulation is executed, variable browser should look as it is shown below



Example 2

Simulation

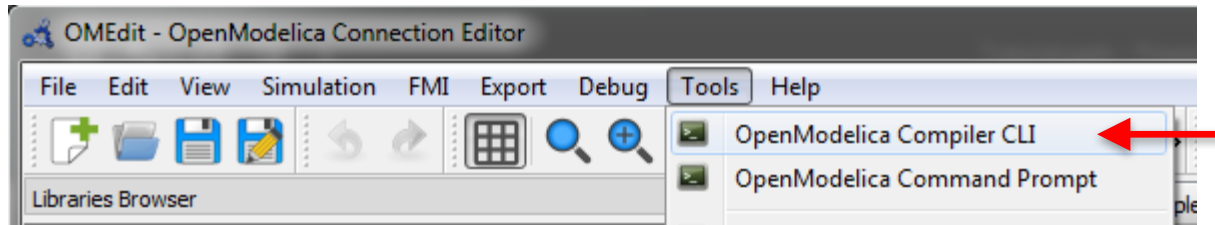
- Simulation results can be plotted again
- Comparison of the PSAT and Modelica simulation results of the PSS signal is shown on the figure below



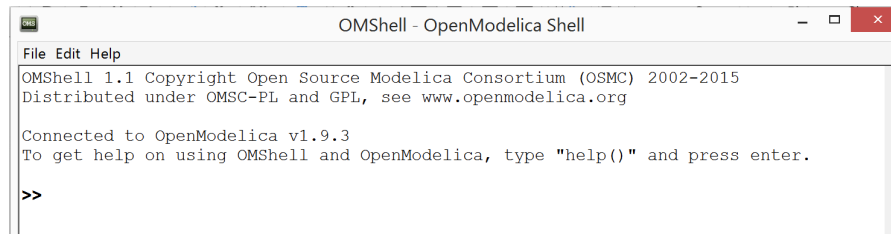
Example 2

Linearization

- To linearize the system, OpenModelica scripting will be needed



- Along with the library, a set of commands was provided (Command_List.txt) to linearize the model and extract the A matrix



```
OMShell 1.1 Copyright Open Source Modelica Consortium (OSMC) 2002-2015
Distributed under OMSC-PL and GPL, see www.openmodelica.org

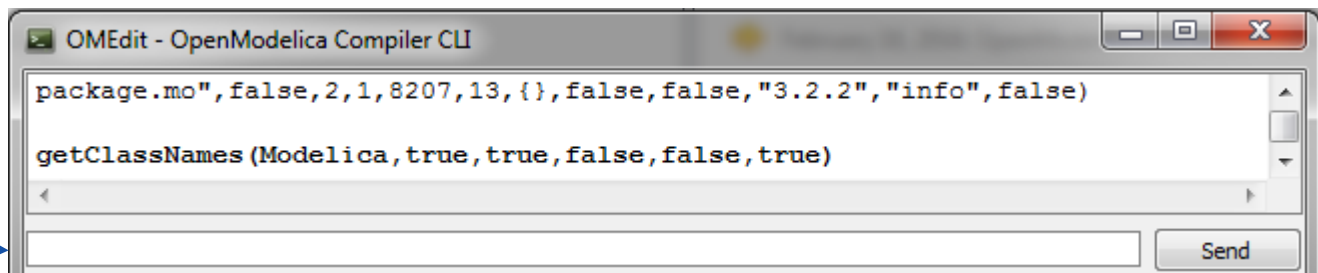
Connected to OpenModelica v1.9.3
To get help on using OMSHELL and OpenModelica, type "help()" and press enter.
>>
```

Example 1

Linearization

- Copy and paste each line from the Command_List.txt for Example 1 to the command prompt in OpenModelica

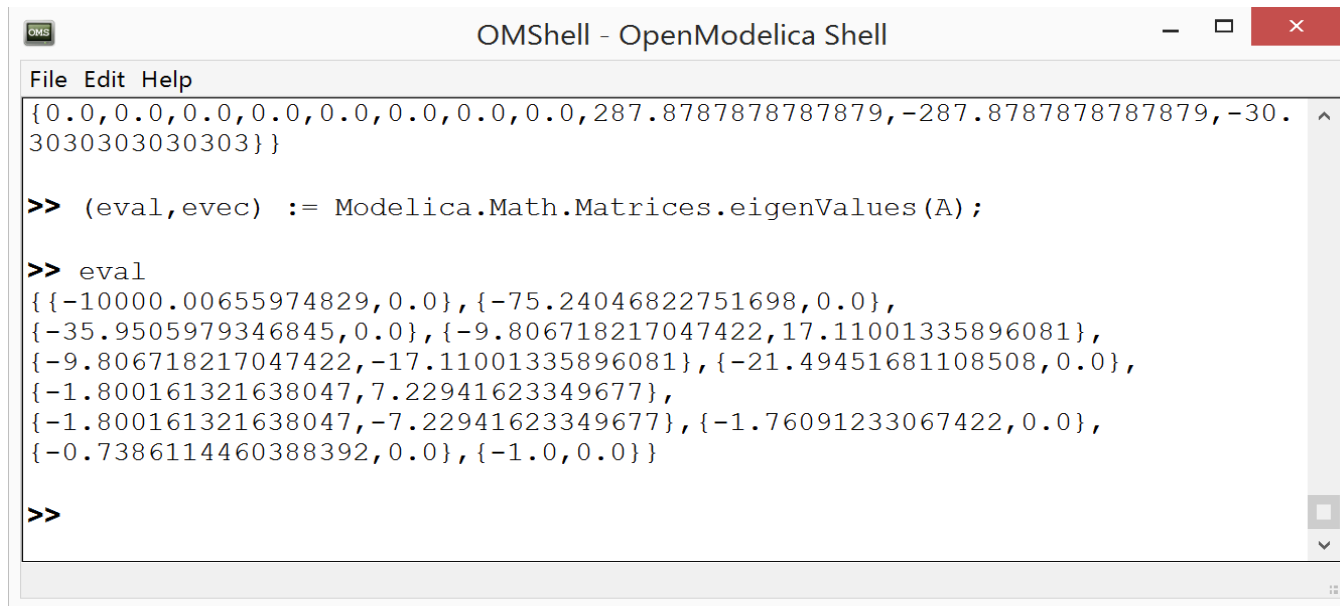
```
# Example 2  
linearize(Tutorial.Example_2.Example_2, stopTime=0.0)  
loadFile("linear_Tutorial.Example_2.Example_2.mo")  
(a) := getParameterValue(linear_Tutorial_Example__2_Example__2, "A")  
(eval, evec) := Modelica.Math.Matrices.eigenValues(A);
```



Example 2

Linearization

- The rest of the steps shall be repeated as it was shown in Example 1
- The same procedure with a linearized system from Example 2 results in the new set of eigenvalues

A screenshot of the OMS Shell (OpenModelica Shell) terminal window. The window title is 'OMShell - OpenModelica Shell'. The terminal shows a list of eigenvalues and the execution of a command to calculate the eigenvalues of a matrix A. The output shows a list of complex eigenvalues.

```
File Edit Help
{0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,287.8787878787879,-287.8787878787879,-30.
3030303030303}}

>> (eval,eval) := Modelica.Math.Matrices.eigenValues(A);

>> eval
{{-10000.00655974829,0.0},{-75.24046822751698,0.0},
{-35.9505979346845,0.0},{-9.806718217047422,17.11001335896081},
{-9.806718217047422,-17.11001335896081},{-21.49451681108508,0.0},
{-1.800161321638047,7.22941623349677},
{-1.800161321638047,-7.22941623349677},{-1.76091233067422,0.0},
{-0.7386114460388392,0.0},{-1.0,0.0}}

>>
```

Example 2

Linearization

- The conjugate pair of poles that was on the right side of the plane in Example 1 was, by introducing the PSS, moved to the left side of the stability plane and, thus, the system is now stable

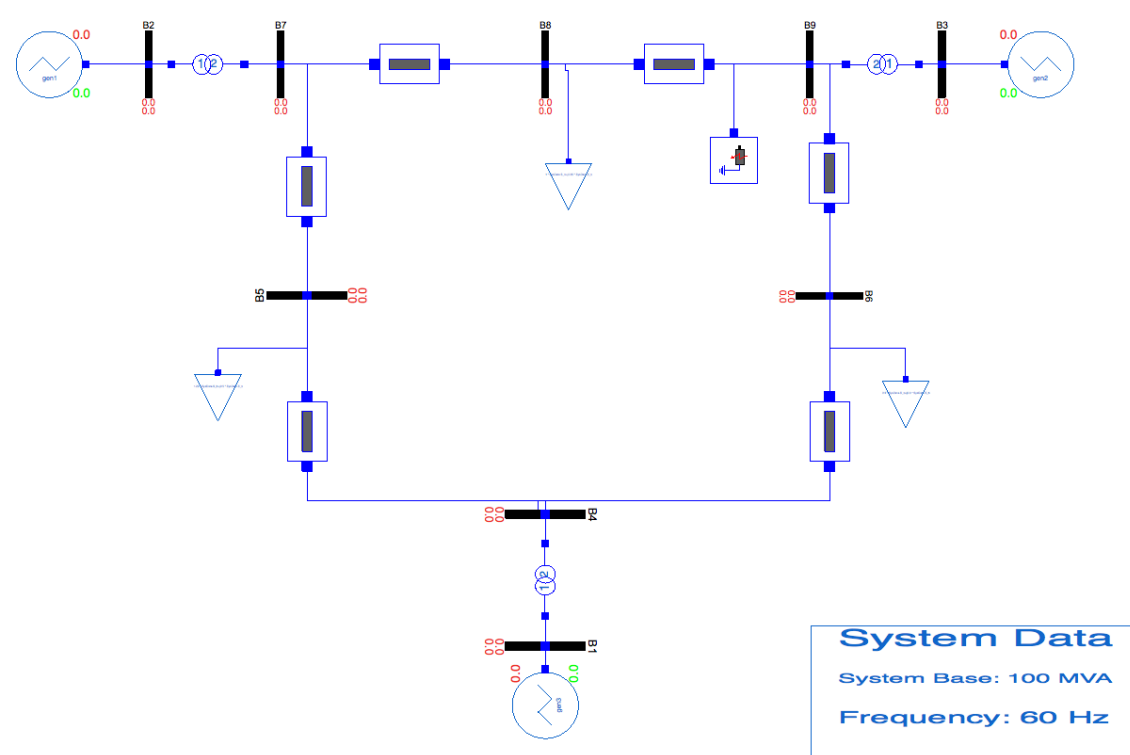
```
OMShell - OpenModelica Shell
File Edit Help
{0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,287.8787878787879,-287.8787878787879,-30.3030303030303}}

>> (eval,vec) := Modelica.Math.Matrices.eigenValues(A);

>> eval
{{-10000.00655974829,0.0},{-75.24046822751698,0.0},
{-35.9505979346845,0.0},{-9.806718217047422,17.11001335896081},
{-9.806718217047422,-17.11001335896081},{-21.49451681108508,0.0},
{-1.800161321638047,7.22941623349677},
{-1.800161321638047,-7.22941623349677},{-1.76091233067422,0.0},
{-0.7386114460388392,0.0},{-1.0,0.0}}

>>
```

Example 3



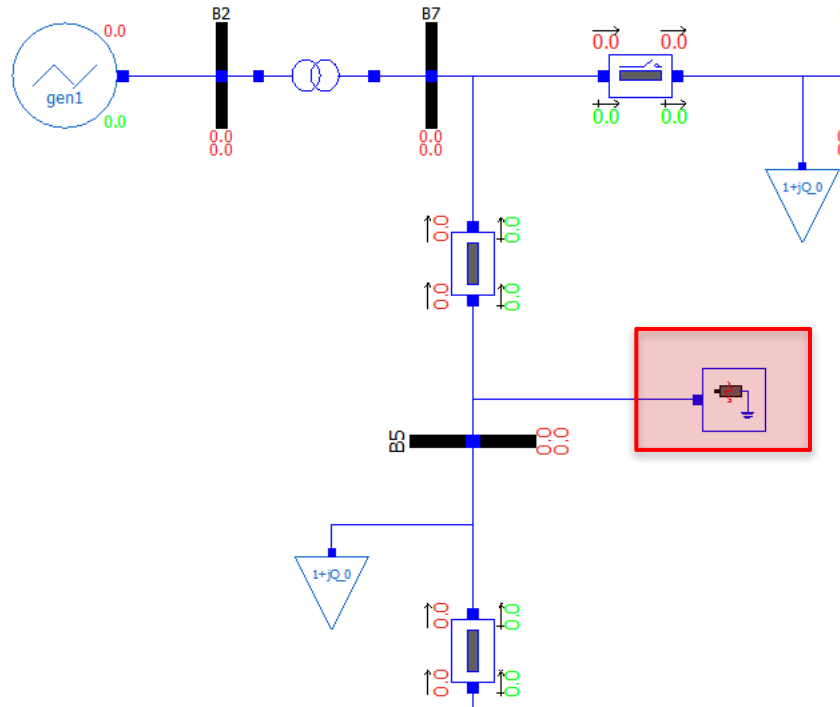


Example 3

- Example 3 contains the model of the IEEE 9 Bus system
- It is pre-configured with all of the power flow and dynamic data
- In the previous two examples, you learned how to build the models of the power system, introduce the faults, run the dynamic simulations and perform the linearization of the model
- In Example 3 you are free to explore the model and introduce various faults

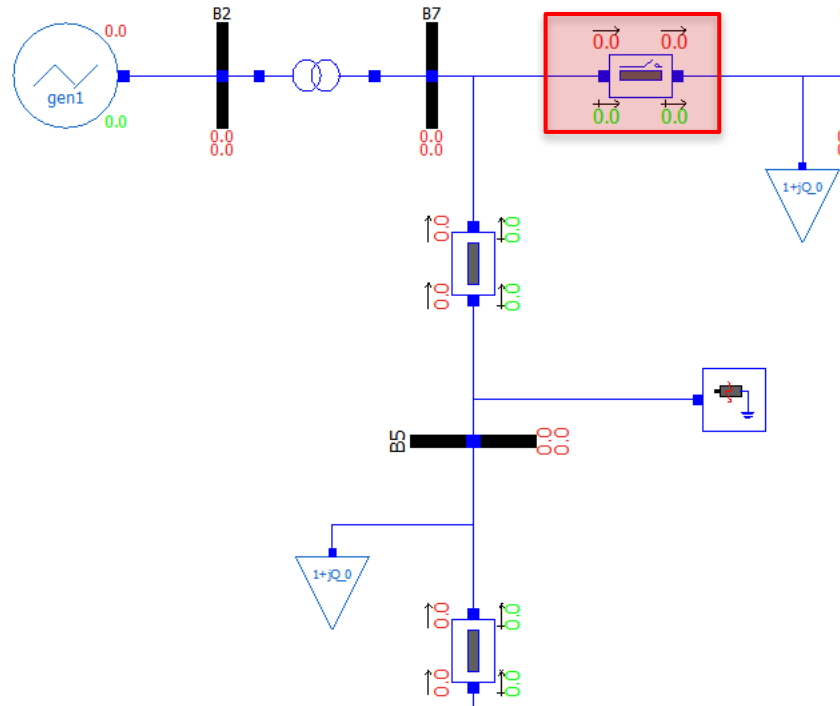
Example 3

- You can, for instance, introduce the bus fault ...



Example 3

... or open the line at the given time instant*



Example 3

- Step disturbance to the voltage reference of the generators can be introduced by setting the desired `refdisturb_x` parameter to `true`

OMEdit - Component Parameters - gen1 in iPSL.Examples.Exa... X

Parameters

General Modifiers

Component

Name: gen1
Path: iPSL.Examples.Example_3.Generation_Groups.Gen1

AVR Disturbance

height_1 0.05
tstart_1 2
refdisturb_1 true

Power flow data

V_b	18	Base voltage of the bus (kV)
V_0	1.025	Voltage magnitude (pu)
angle_0	0.160490018910725	Voltage angle (deg)
P_0	1.63	Active power (MW)
Q_0	0.001552891584958	Reactive power (MVar)
S_b	SysData.S_b	System base power (MVA)
fn	SysData.fn	System Frequency (Hz)

OK Cancel



Questions?

Thanks to all current and former OpenIPSL Developers @ KTH



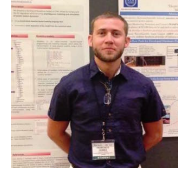
Luigi Vanfretti



Achour
Amazouz



Mohammed
Ahsan Adib Murad



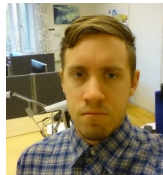
Francisco José
Gómez



Giuseppe
Laera



Tin Rabuzin



Jan Lavenius



Le Qi



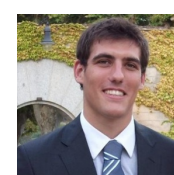
Maxime
Baudette



Mengjia Zhang



Tetiana
Bogodorova



Joan Russiñol
Mussons

Join us!