Le réseau
de transport
d'électricité

An Open-Source Exercise Package for Electric Power System Teaching using the Dynaωo Modelica Library

03/02/2025 - OpenModelica Workshop 2025

Gilles Aouizerate, **Joy El Feghali,** Petros Aristidou, Sylvestre Prabakaran, Gautier Bureau, Baptiste Letellier, Julien De Sloovere, Florentine Rosiere, Marco Chiaramello

R&D department, RTE Réseau de transport d'électricité, France

Dynawo simulation tool

A hybrid C++/Modelica open-source (github) suite of simulation tools based on two core principles:

- Using as much as possible a high-level modeling language (Modelica) for the modeling side.
- A strict separation between the modeling and solving parts.

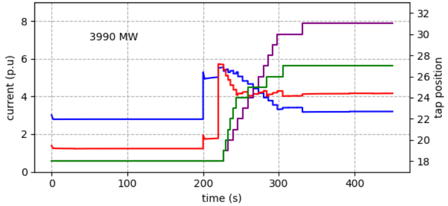
Input files

Dynawo

Models
Modelica Library

Solvers
External and open-source

Output files



Using OpenModelica as a graphical user interface to build unitary models in Modelica language & the OpenModelica Compiler for models library compilation

In order to ensure flexibility, transparency and quality without degrading the performances compared to classical power system simulation tools.

http://dynawo.org – rte-dynawo@rte-france.com

Overview

- Motivations
- Introduction to the Five-Bus system example
- Case 2 : Voltage set-point increase
- Case 3: Voltage dip in external system
- Case 4: Line fault
- Conclusion

Motivations

- **Need for training:** Increasing complexity in managing electric power system stability due to fast-changing technologies (high penetration of power electronics connected to the grid).
- **Objective:** Provide tools for teaching computational methods in power systems.
- **Solution:** Open-source exercise package developed by RTE using the Dynawo Modelica library.
- **Features:**
  - Models and simulations for various aspects of power systems stability.
  - Helps students understand the behavior of synchronous Generators, Governors, Automatic Voltage Regulators, and Power System Stabilizers during system dynamics and faults.
- **Collaboration:** Developed in collaboration with the Sustainable Power Systems Laboratory of Cyprus University of Technology.

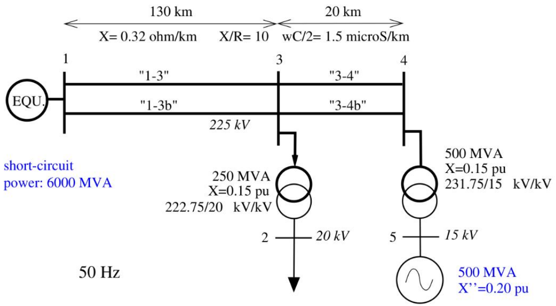
Five Bus System Overview

Five-bus example overview

- <u>Source:</u> this case study is widely inspired by Pr Thierry Van Cutsem online teaching website and Pr Petros Aristidou's course on *Control and Operation of Electric Power Systems*.

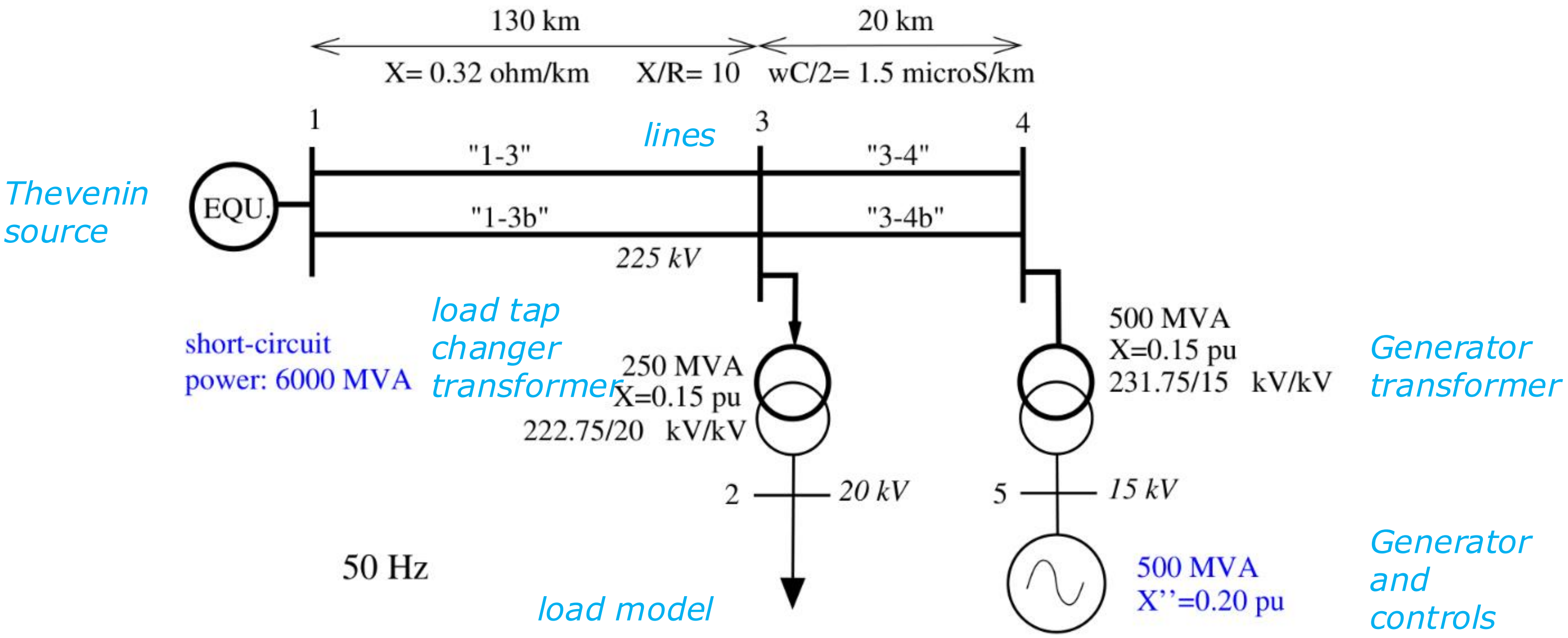
- The system model consists of the following components:

1. A *Thevenin source* representing the external system at bus 1
2. A *Generator* at bus 5: synchronous machine (a RES could also be added to the system) with automatic voltage regulator, excitation system, overexcitation limiter, speed governor and steam turbine
3. A *load model* at bus 2: a constant admittance and 2 equivalent motors
4. A *load tap changer transformer* between bus 3 and 2 controlling voltage at bus 2
5. A *fixed ratio transformer* between bus 4 and bus 5
6. 2 sets of 2 parallel *lines* respectively connecting bus 1 to bus 3 and bus 3 to bus 4



Five- bus example overview

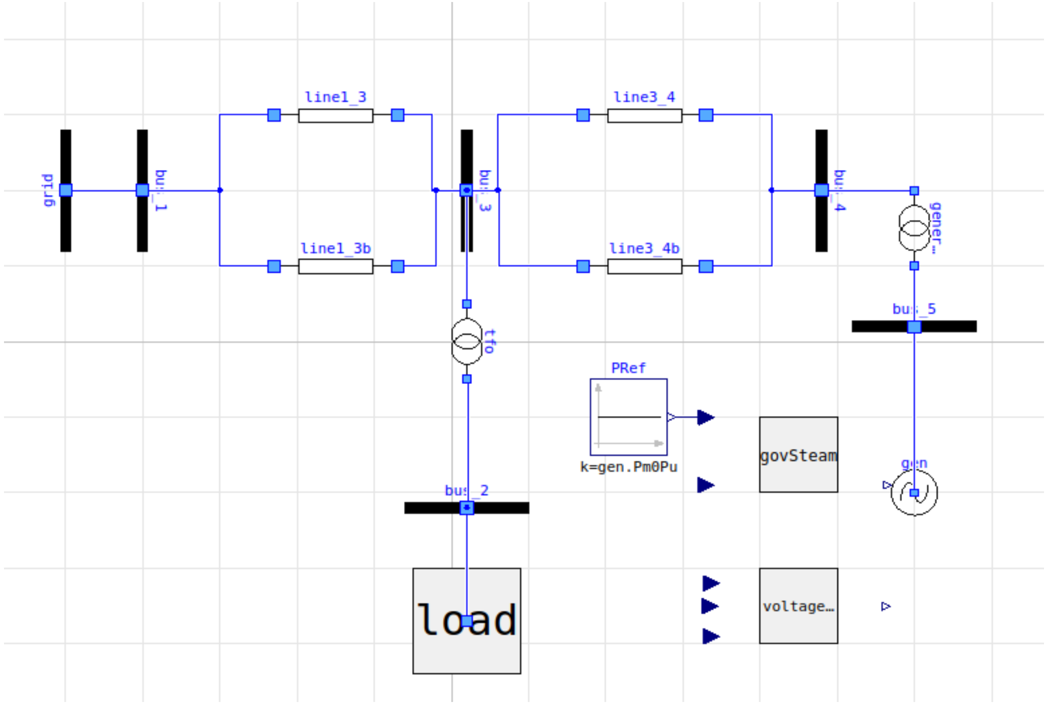
Global schematic view



[Source : *Control and Operation of Electric Power Systems, Dr Pertos Aristidou]*

Five-bus example overview

Implementation using Dynawo Modelica library



Generator model

A synchronous generator is modeled

Dynamic behavior swing equation :

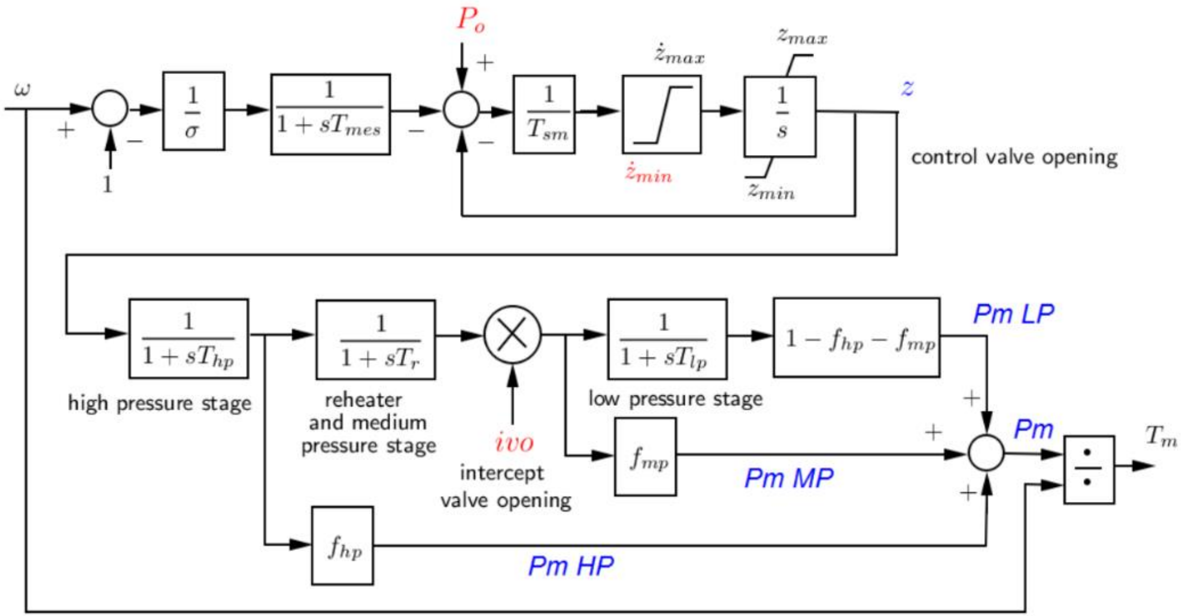
$$2\,H\,d\omega/dt = Tm - Te$$

Inputs : Mechanical power *Pm*, exciter voltage *efd*, reference frequency *ωref*

Outputs : frequency *ω*, stator voltage, current, reactive power *UStator, IStator, QStator,* rotor current *IRotor,* active and reactive power generated *PGen, QGen*

Speed governor and steam turbine

Schematic view

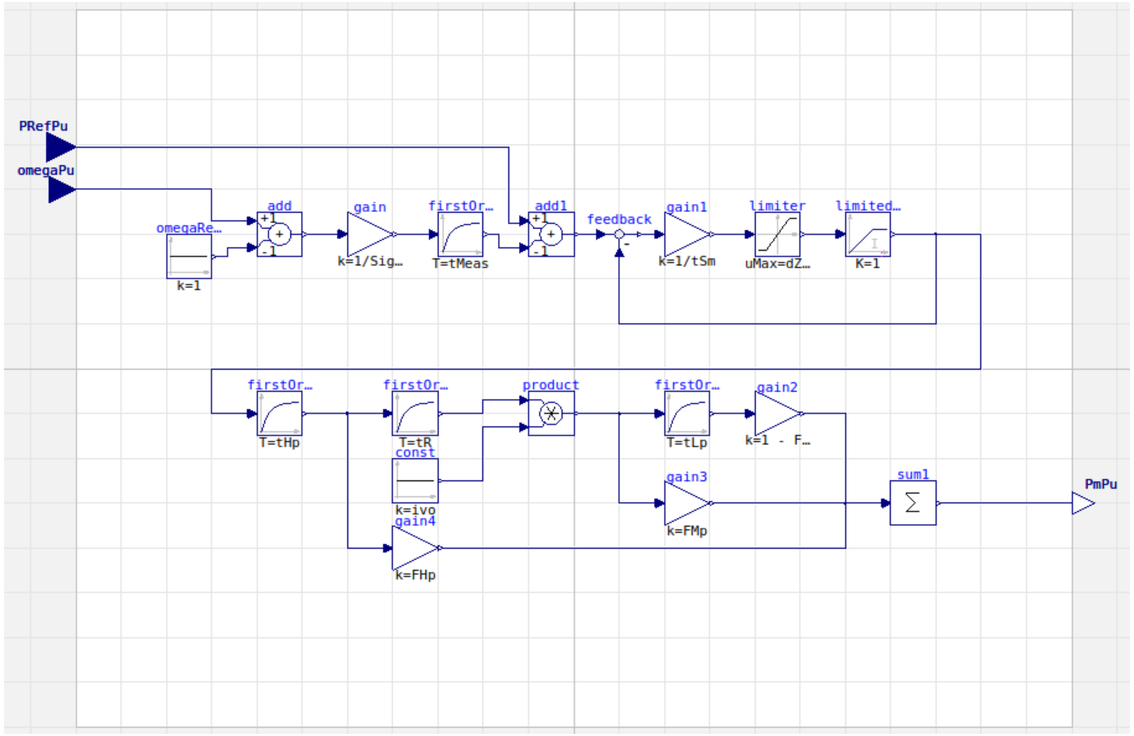


[Source : *Control and Operation of Electric Power Systems, Dr Pertos Aristidou]*

Speed governor and steam turbine

Implementation using Dynawo's Modelica library

Inputs :
- Reference power *Pref*
- Frequency *ω*

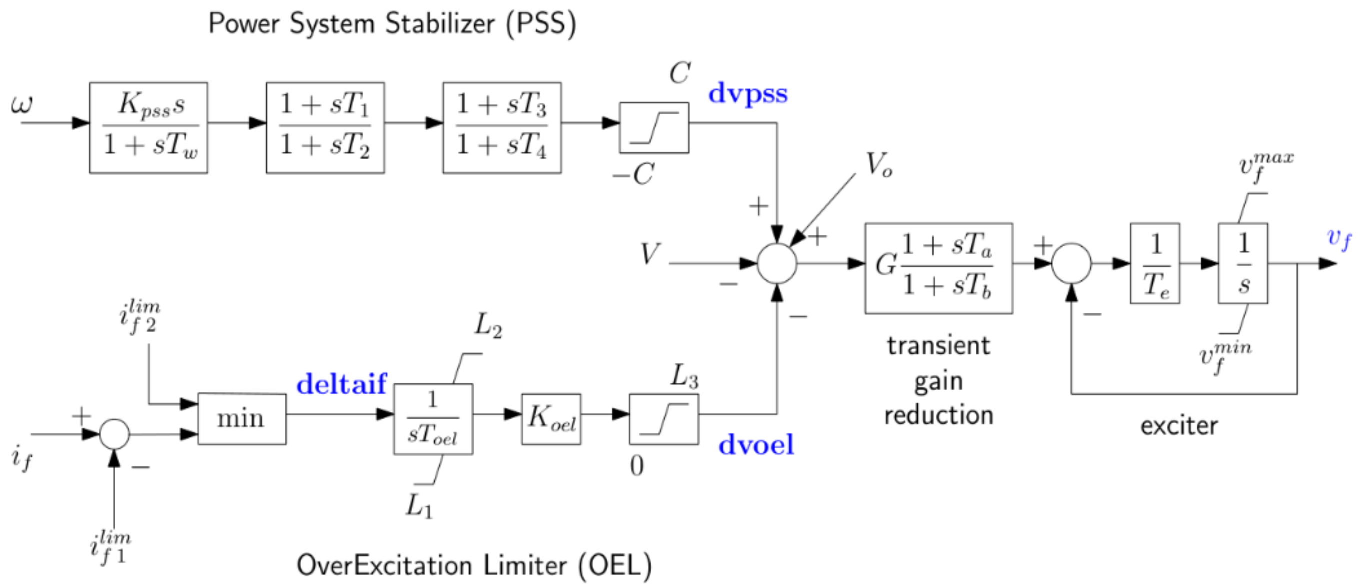


Output:
- Mechanical power *Pm*

http://dynawo.org – rte-dynawo@rte-france.com

Automatic voltage regulator, excitation system, with overexcitation limiter and Power System Stabilizer

Schematic view

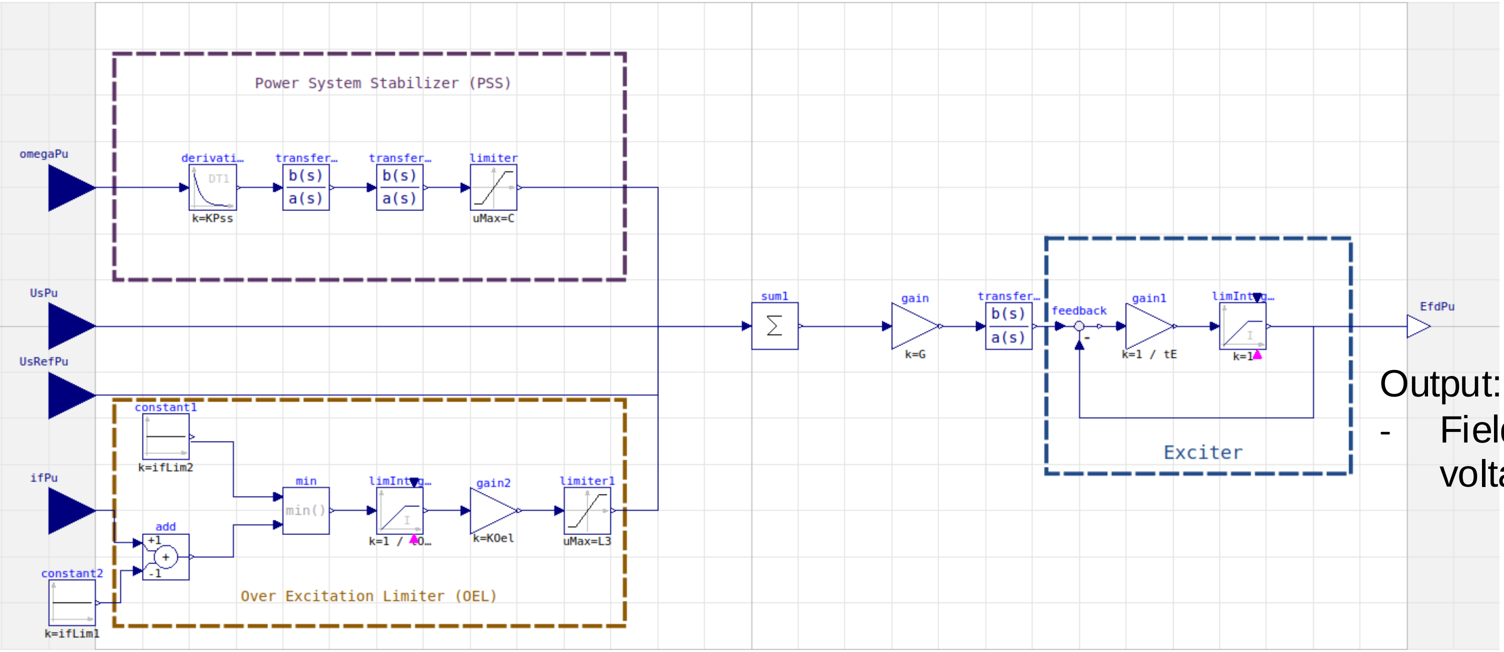


[Source : *Control and Operation of Electric Power Systems, Dr Pertos Aristidou]*

Automatic voltage regulator, excitation system, overexcitation limiter

Implementation using Dynaωo's Modelica library

Inputs :
- Reference frequency *ωref*
- Reference stator voltage power *Usref*
- Stator voltage power *Us*
- Field current *Ifd*



Output:
- Field voltage *e*

http://dynawo.org – rte-dynawo@rte-france.com

Load and tap changer transformer

Load :

- Constant admittance (alpha beta load, with alpha = beta =2)
- Two motors

```
                 isPu          umPu  irPu
terminal ------>----Rs+jXs---.----->--Rr+jXr------.
                             |                    |
                            jXm               Rr(1-s)/s
                             |                    |
           -----------------------------------------
```

Transformer tap changer :

- Transformer with variable tap
- Tap changer control: controls the tap of the transformer by monitoring the voltage at bus 2 respecting to the maximum and minimum thresholds

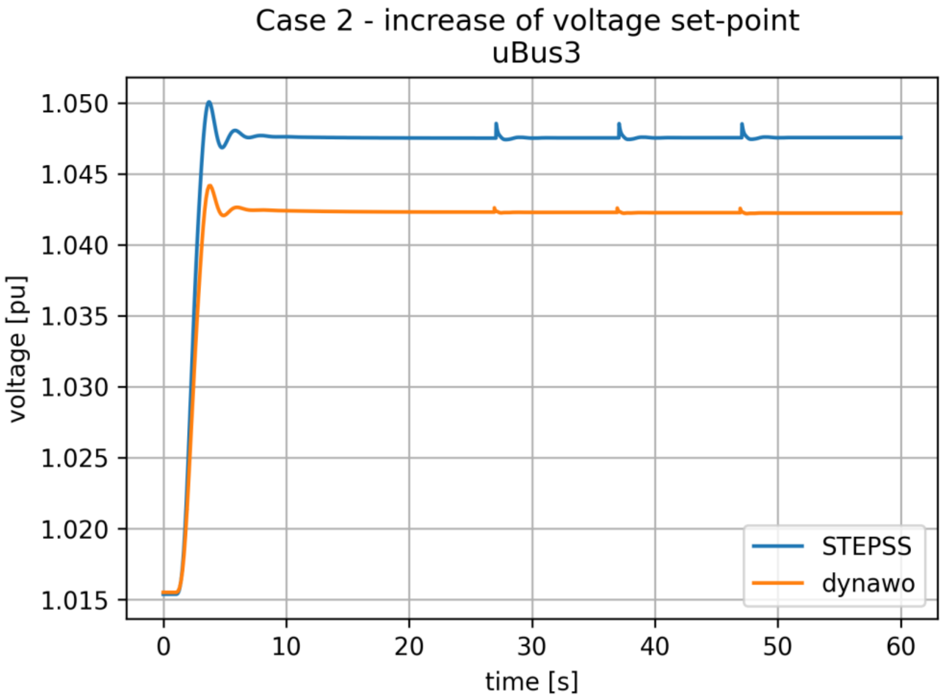
02 Case 2

Case 2

- **Operating point 1**
- **Disturbance:** increase of voltage set-point UsRef by 0.05 pu in 2 seconds at t = 1 second.
- **Expected tasks:** observe the transient side effects of the tap changer transformer and comment on the evolution of Bus 3 voltage magnitude, and of the generator active and reactive power.

Case 2

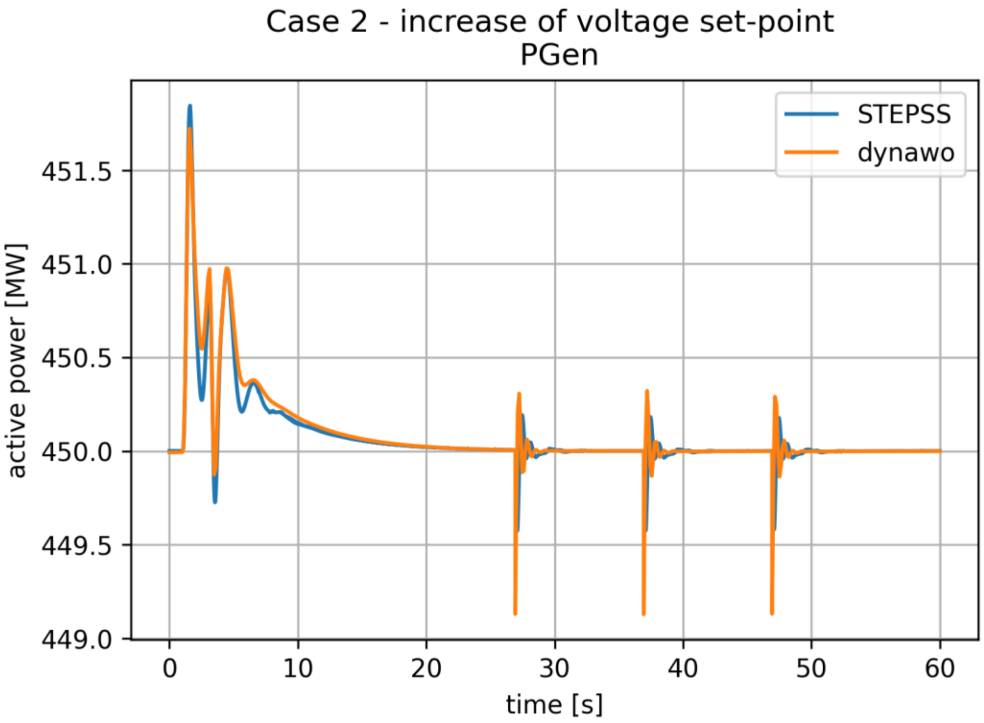
Bus 3 voltage magnitude



http://dynawo.org – rte-dynawo@rte-france.com

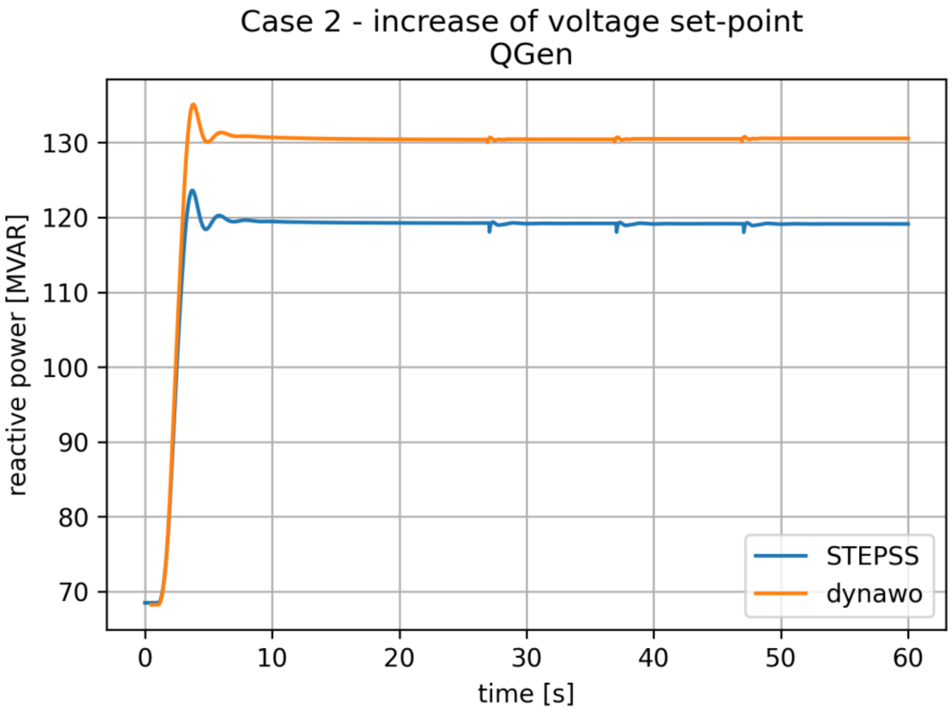
Case 2

Generator active power



Case 2

Generator reactive power



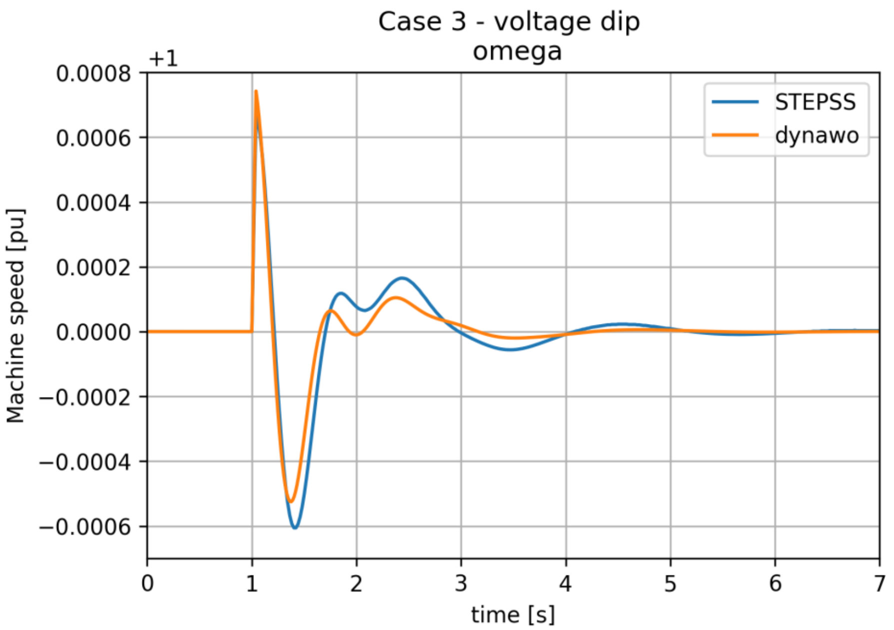
03 Case 3

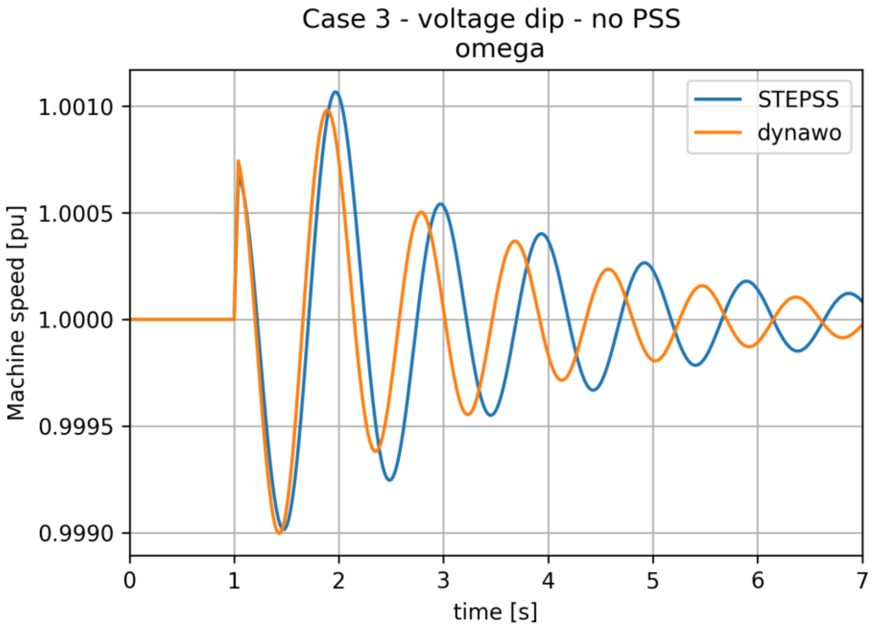
Case 3

- **Operating point 1**
- **Disturbance:** voltage dip in the external system simulated by a decrease of the Thévenin voltage by 0.20 pu for 0.04 seconds at t = 1 second.
- **Expected tasks:** observe the effects of the PSS and comment on the evolution of Bus 3 voltage magnitude, and of the generator rotor speed

Case 3

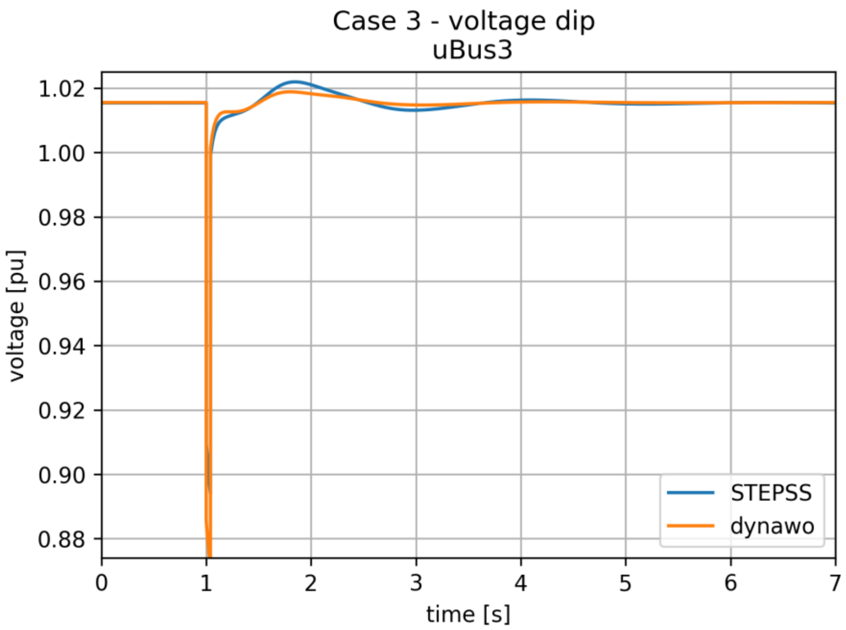
Generator rotor speed (with or without PSS)

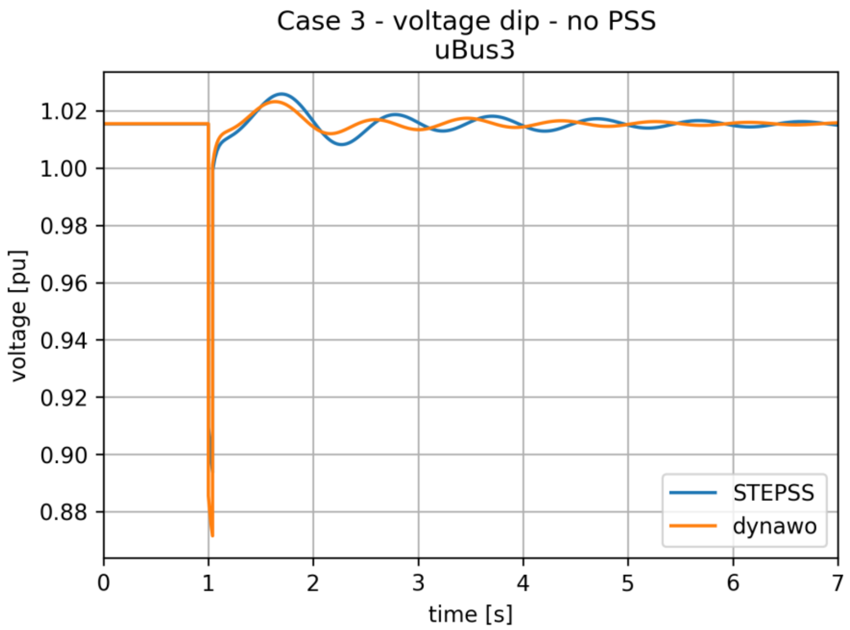




Case 3

Bus 3 voltage magnitude (with or without PSS)





http://dynawo.org – rte-dynawo@rte-france.com

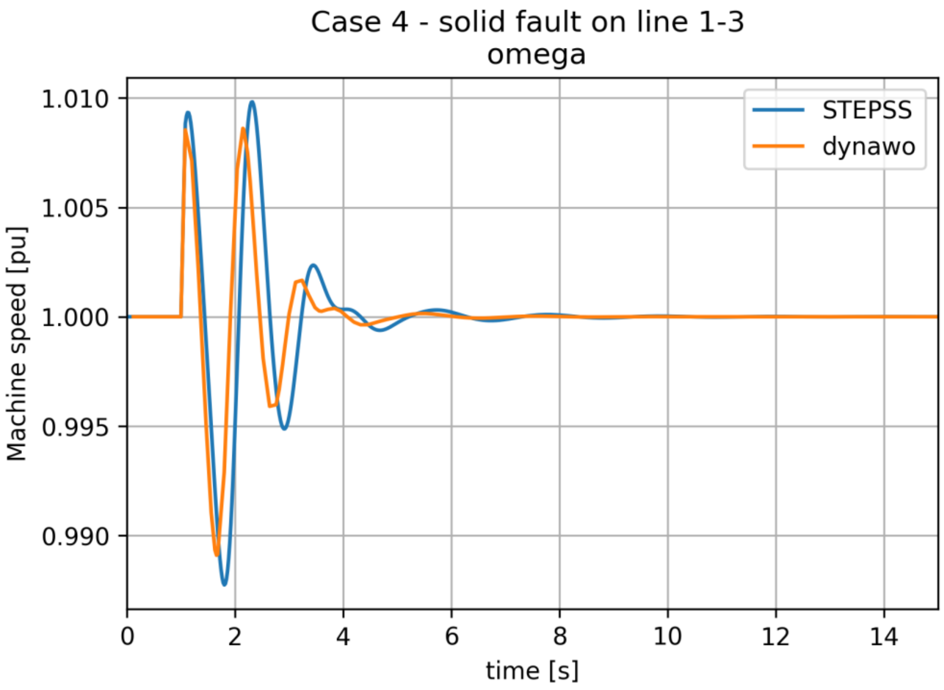
04 Case 4

Case 4

- **Operating point 1**
- **Disturbance:** solid fault on line 1-3, cleared after 4 cycles (0.08 s) by opening the faulted circuit.
- **Expected tasks:** observe and comment on the evolution of Bus 5 voltage magnitude, and of the generator rotor speed

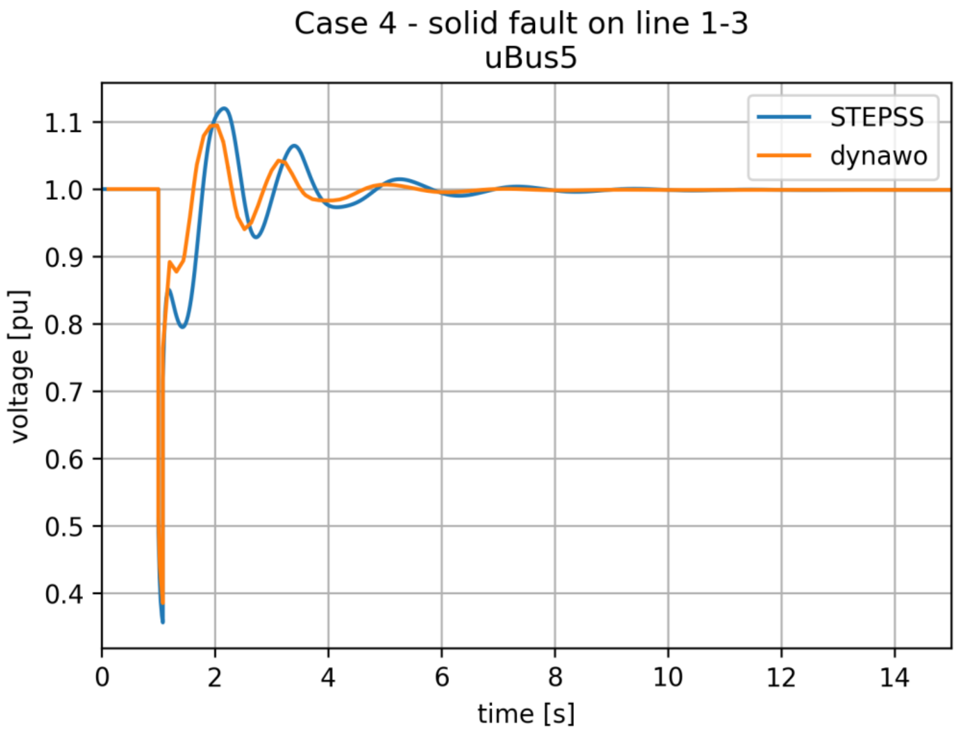
Case 4

Generator rotor speed



Case 4

Bus 5 voltage magnitude



http://dynawo.org – rte-dynawo@rte-france.com

05 Conclusions and future work

Conclusions and future work

- **Summary:** Dynaωo enables teaching stability phenomena effectively, similar to traditional tools, while offering the flexibility to adapt to modern and future technologies.
- **Improvements:** fix the observed discrepancies (steady state response level in case 2, oscillatory period in case 3 and 4) by parametric adaptation in the use case.
- **Future work:** extend the exercise package to other case studies adapted from existing teaching material and/or new case with state-of-art technologies and propose a pure Dynaωo version of the package.
- **Availability:** the package is under open-source license and will be made available with proper documentation on Dynaωo's project GitHub repository.

Acknowledgement

- Thanks to Professor Petros Aristidou for his guidance and suggestions

Q & A

GitHub page : https://dynawo.github.io/
GitHub repository : https://github.com/dynawo/dynawo
Contact us :rte-dynawo@rte-france.com