An Open-Source Implementation of IEEE Test Cases using a Simplified Time-Domain Approach for Steady State Calculations

Joy El Feghali, Gautier Bureau, Julien De Sloovere, Baptiste Letellier, Ian Menezes, Florentine Rosière, Marco Chiaramello

http://www.dynawo.org

https://github.com/dynawo/dynawo

rte-dynawo@rte-france.com

Outline

1. Introduction to power system simulations
2. Dynaωo and the DynaFlow approach
3. Implementation of the IEEE 14-bus and the IEEE 57-bus systems
4. Test cases :
    - (a) IEEE 14-bus with current limit automatons : increase in power consumption
    - (b) IEEE 57-bus with HVDC line and phase shifter control : line contingency
5. Conclusion

Introduction to Power System Simulations

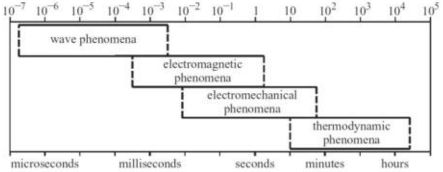
Transmission System Operators

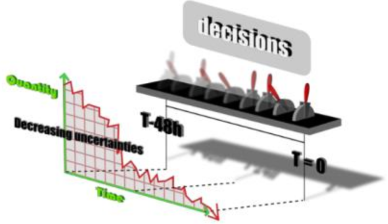
- “Entities operating independently from the other electricity market players and responsible for the bulk transmission of electric power on the main high voltage electric network”
  - Non-discriminatory and transparent access to the electricity grid
  - Safe operation and maintenance of the system
  - Grid infrastructure development
- RTE – French Transmission System Operator
  - In charge of the largest European network (more than 100 000 kms of EHV and HV lines – 400 to 63 kV, 2 600 substations, peak load served > 100 GW).
  - Ensuring a stable and secure operation means:
    - **Adequacy** – Acceptable steady-state (thermal overloads, voltage values for materials)
    - **Stability** – Stable and possible transition between two operating points. Dynamic stability (transient, voltage, small-signal, frequency, etc.) ensured by time-domain simulations.

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

Power System Simulations

- Done at different time-scale on a regular basis to ensure adequacy and stability
    - Static and dynamic security assessment (simulating all network contingency every 15’)
    - Day, week and month ahead assessment with static simulations (steady-state calculation, short-circuit calculation) as well as time-domain simulations (voltage or transient studies) on different scenarios.
    - Planning studies (from a few years to 20 years ahead studies).
    - Design ad’hoc stability studies (insertion of new components – hvdc links, offshore wind parks, etc.)
- Analysis of the system during transitions or at steady-state following a transition
    - Triggered by the normal evolution of the system (load change, production scheduled change, etc.) or by sudden change (generator tripping, short-circuit, etc.)
    - Involves a large range of phenomena with different time constants.

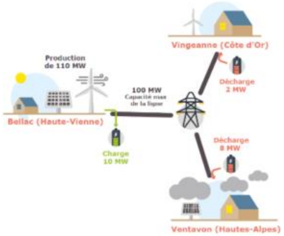


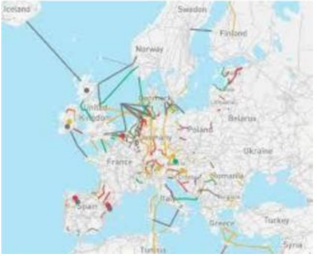


Challenges and needs

- A system evolving at a very high pace due to a global demand for cleaner energy
  - Massive integration of renewable energy sources (RES).
  - High-voltage direct current (HVDC) links boom.
  - Deep evolution of the consumption uses (active consumers, electric vehicle, microgrids, etc.)
- A complete switch from an easy-to-predict and physically-driven system to a more complex, unpredictable and numerically-driven system
  - Forces system operators to find efficient and complex ways to control it
  - Leads to the development of advanced special protection, control and regulation schemes deeply modifying the system behavior, its dynamics and its stability.

⇨ All of this advocates for more collaboration, more transparency and more flexibility.



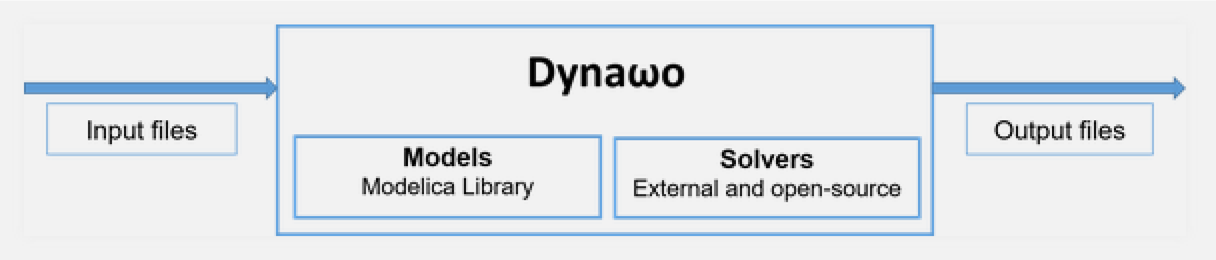


02

Dynaωo and the DynaFlow Approach

Dynaωo

- A hybrid C++/Modelica open-source 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.

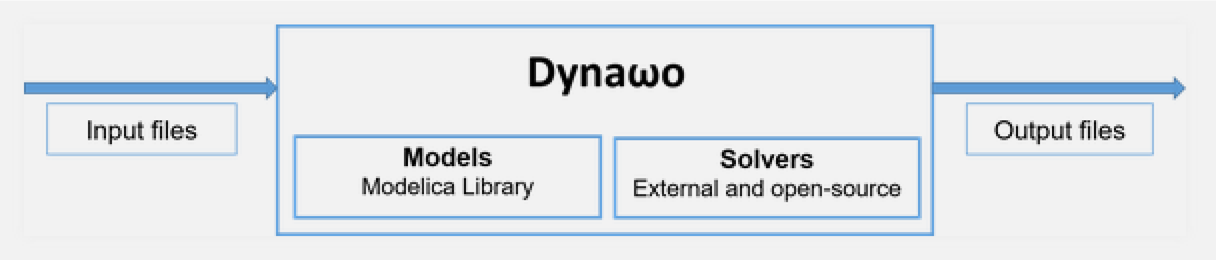


⇨ In order to ensure flexibility, transparency and quality without degrading the performances compared to classical power system simulation tools.

DYNAFLOW DYSYM DYNAWALTZ DYNASWING DYNAWAVE

Dynawo

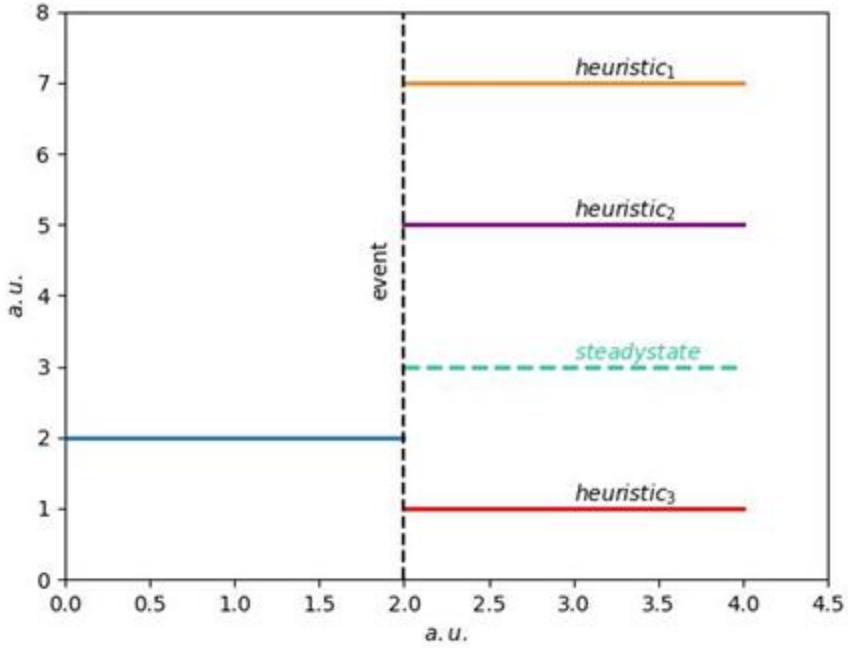
- A hybrid C++/Modelica open-source suite of simulation tools based on two core principles:
  - Using as much as possible a high-level modeling language (Modelica) for the modeling side.
  - A strict separation between the modeling and solving parts.



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

DYNAFLOW DYSYM DYNAWALTZ DYNASWING DYNAWAVE

Classic Power Flow Approaches vs. DynaFlow



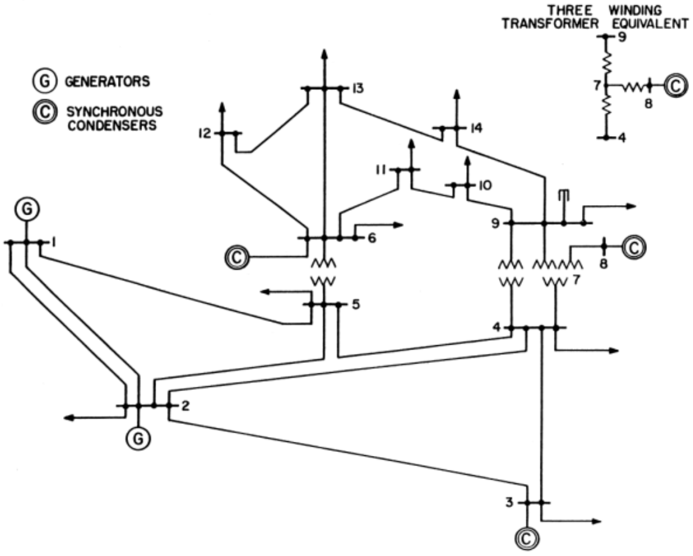
Such an approach **cannot capture all the complexity** and interactions existing between all the different controls. **Different heuristics** choices **can lead** to **different** mathematically **acceptable final states.**

Dynaflow is a new open source steady-state simulation tool that aims at calculating the steady-state point by using a simplified time-domain simulation

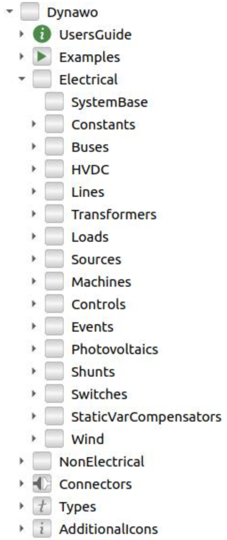
03

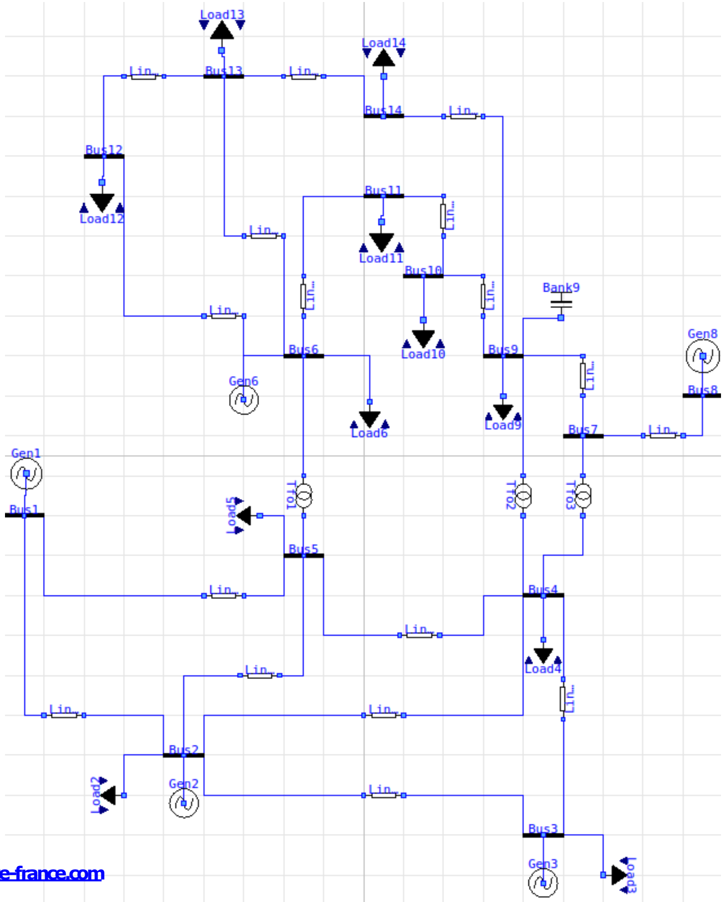
Implementation of the IEEE 14-Bus and the IEEE 57-Bus Systems

Modified IEEE 14-Bus System with Dynawo library



Simplified models


- Dynawo
  - UsersGuide
  - Examples
  - Electrical
    - SystemBase
    - Constants
    - Buses
    - HVDC
    - Lines
    - Transformers
    - Loads
    - Sources
    - Machines
    - Controls
    - Events
    - Photovoltaics
    - Shunts
    - Switches
    - StaticVarCompensators
    - Wind
  - NonElectrical
  - Connectors
  - Types
  - AdditionalIcons



813
equations/variables

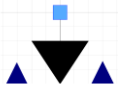
Component Models for the IEEE 14-bus system

Generators + controls:

$$P_{Gen} = P_{Ref} + P_{Nom} K_{Gover} N$$

$$U = U_{Ref}$$

Loads:

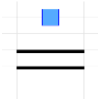


$$t_{filter} \frac{dU_{Filtered}}{dt} = U - U_{Filtered}$$

$$P = P_{Ref} \left(\frac{U}{U_{Filtered}} \right)^{\alpha}$$

$$Q = Q_{Ref} \left(\frac{U}{U_{Filtered}} \right)^{\beta}$$

Shunt:

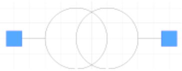


$$Q = BU^2$$

Switch-off signals

Current limit automaton

Transformers:



$$r^2 \underline{V_1} = r\underline{V_2} + \underline{Z}\underline{I_1}$$

$$\underline{I_1} = r\left(\underline{Y}\,\underline{V_2} - \underline{I_2}\right)$$

```
                  I1   r                 I2
  U1,P1,Q1  -->---oo----R+jX-------<--  U2,P2,Q2
 (terminal1)                  |        (terminal2)
                             G+jB
                              |
                             ---
```

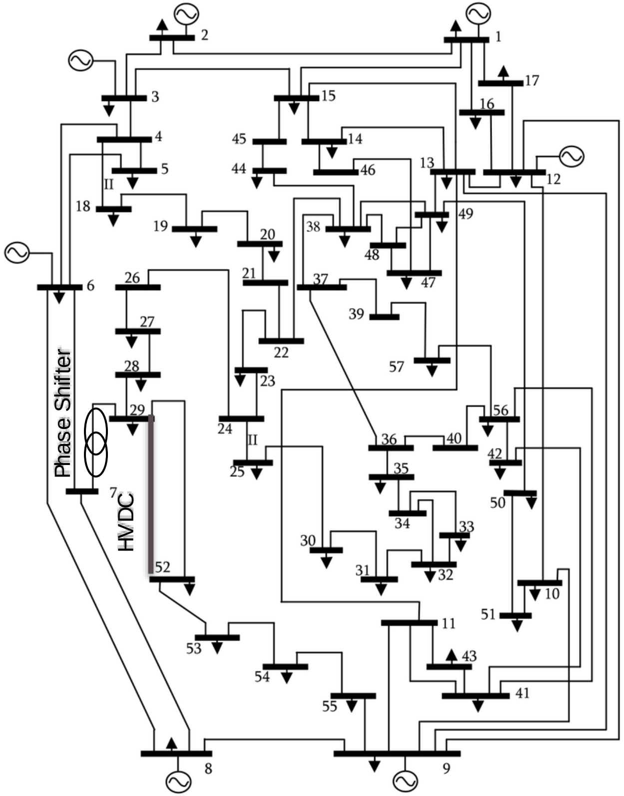
Lines:

$$\underline{Z}\left(\underline{I_2} - \underline{Y}\,\underline{V_2}\right) = \underline{V_2} - \underline{V_1}$$

$$\underline{Z}\left(\underline{I_1} - \underline{Y}\,\underline{V_1}\right) = \underline{V_1} - \underline{V_2}$$

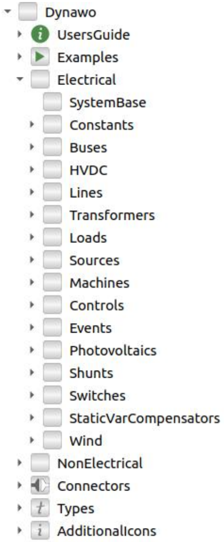
```
              I1                       I2
(terminal1)  -->-------R+jX-------<--  (terminal2)
                 |              |
                G+jB           G+jB
                 |              |
                ---            ---
```

Modified IEEE 57 -Bus System with Dynawo library



Simplified models

Text in Open Modelica


- Dynawo
  - UsersGuide
  - Examples
  - Electrical
    - SystemBase
    - Constants
    - Buses
    - HVDC
    - Lines
    - Transformers
    - Loads
    - Sources
    - Machines
    - Controls
    - Events
    - Photovoltaics
    - Shunts
    - Switches
    - StaticVarCompensators
    - Wind
  - NonElectrical
  - Connectors
  - Types
  - AdditionalIcons

2859 equations/variables

04

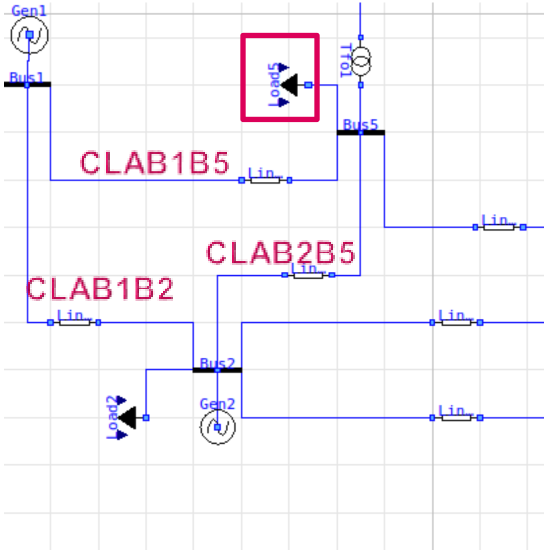
Test Cases

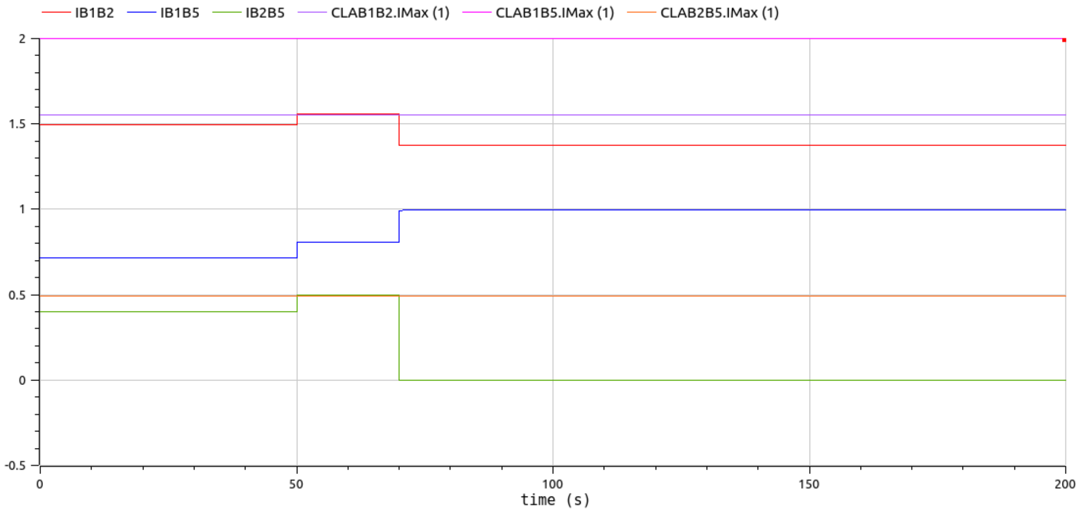
Test Case IEEE 14-bus : Curent limit automatons

Set of parameters 1

Controller	I_{Max} *(p.u.)*	t_{lag} *(s)*
CLAB1B2	1.55	30
CLAB1B5	2.00	50
CLAB2B5	0.49	20

Increase in Load 5 consumption of 0.3 pu at $t = 50\ s$





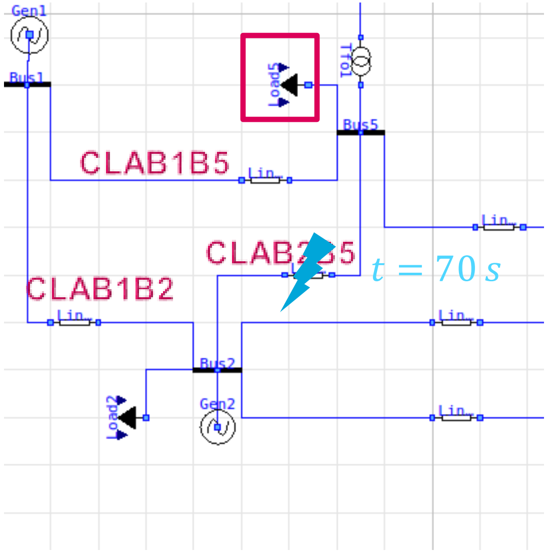
http://www.dynawo.org – rte-dynawo@rte-france.com

Test Case IEEE 14-bus : Curent limit automatons

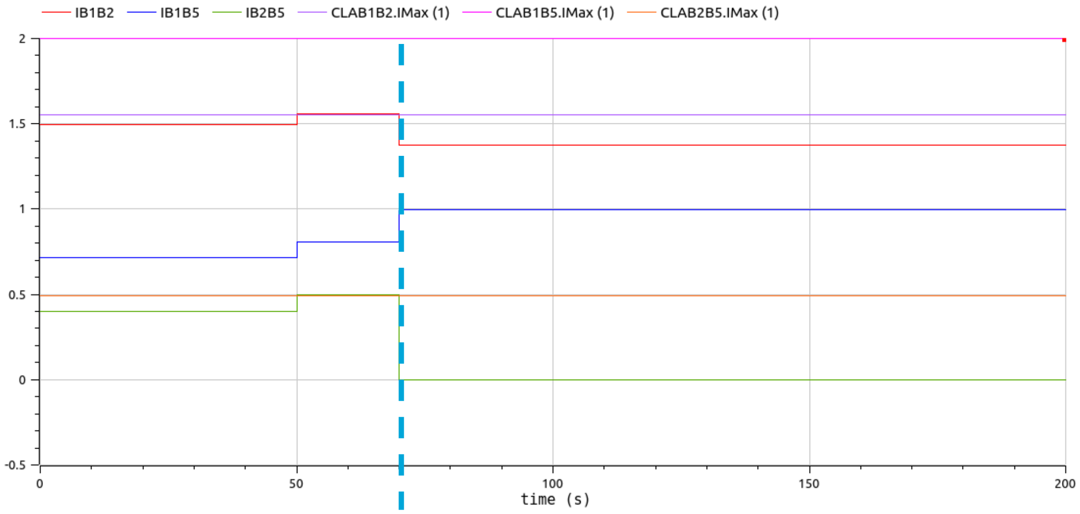
Set of parameters 1

Controller	I_{Max} *(p.u.)*	t_{lag} *(s)*
CLAB1B2	1.55	30
CLAB1B5	2.00	50
CLAB2B5	0.49	20

Increase in Load 5 consumption of 0,3 pu at $t = 50\ s$



$t = 70\ s$



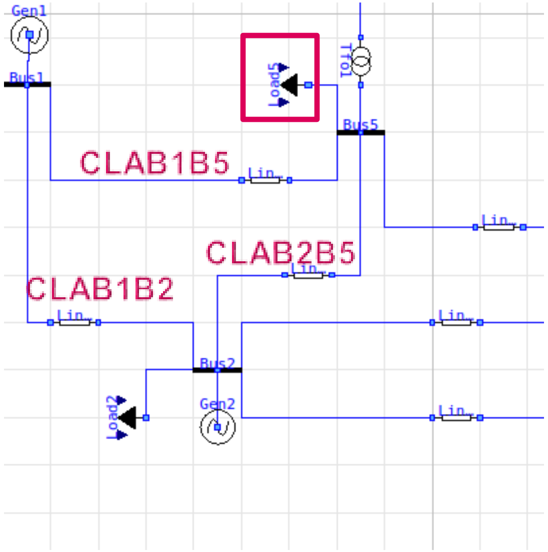
$t = 70\ s$

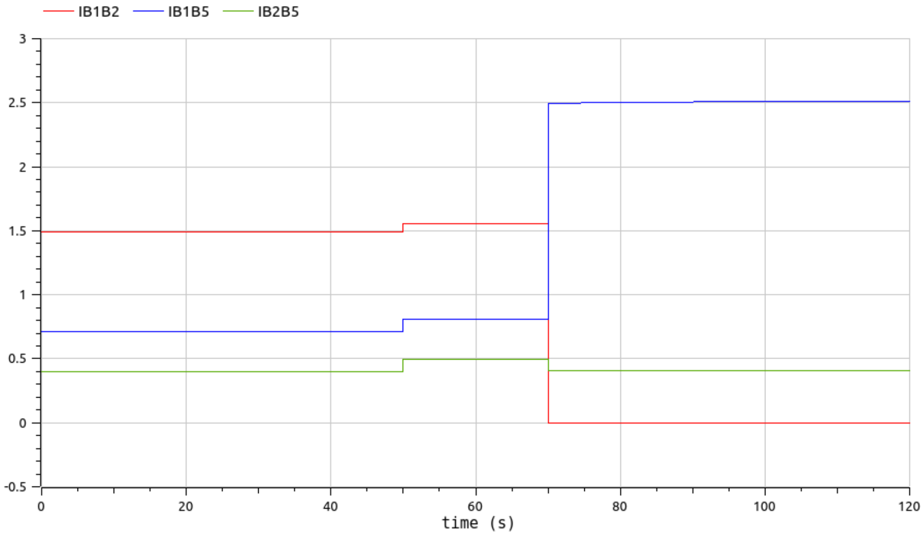
Test Case IEEE 14-bus : Curent limit automatons

Set of parameters 2

Controller	I_{Max} (p.u.)	t_{lag} (s)
CLAB1B2	1.55	20
CLAB1B5	2.00	50
CLAB2B5	0.49	30

Increase in Load 5 consumption of 0,3 pu at $t = 50\ s$



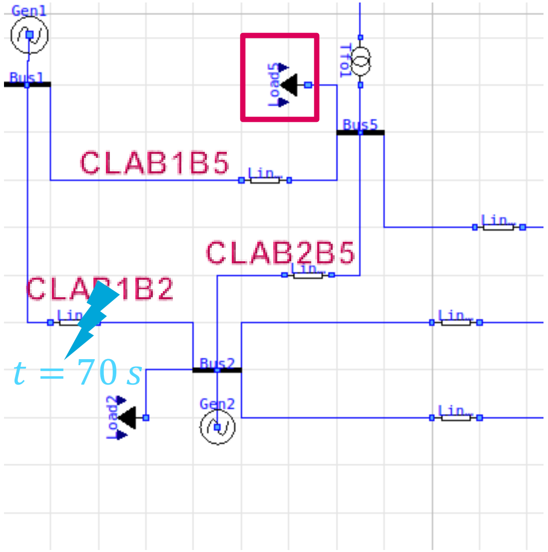


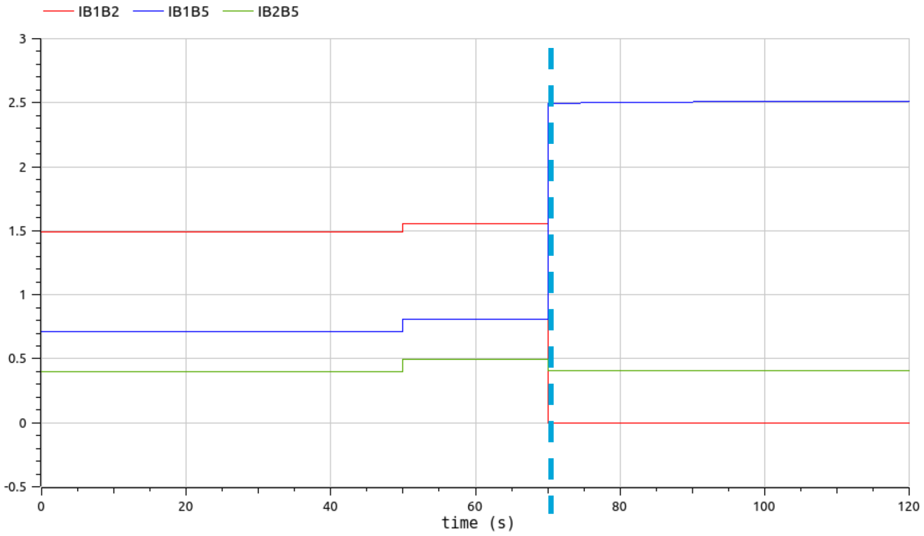
Test Case IEEE 14-bus : Curent limit automatons

Set of parameters 2

Controller	I_{Max} $(p.u.)$	t_{lag} (s)
CLAB1B2	1.55	$\boxed{20}$
CLAB1B5	2.00	50
CLAB2B5	0.49	$\boxed{30}$

Increase in Load 5 consumption of 0,3 pu at $t = 50\ s$





$t = 70\ s$

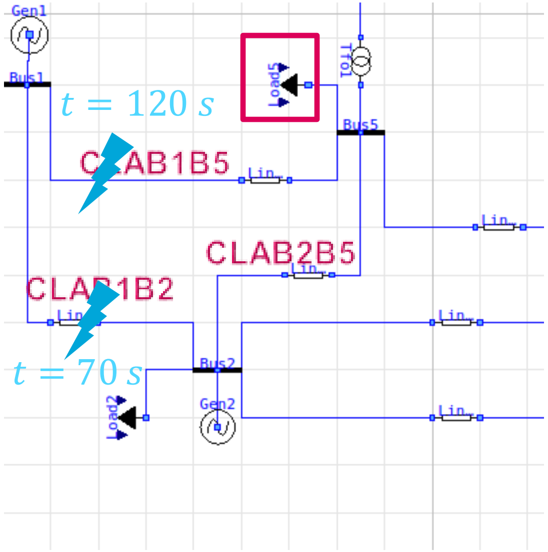
http://www.dynawo.org – rte-dynawo@rte-france.com

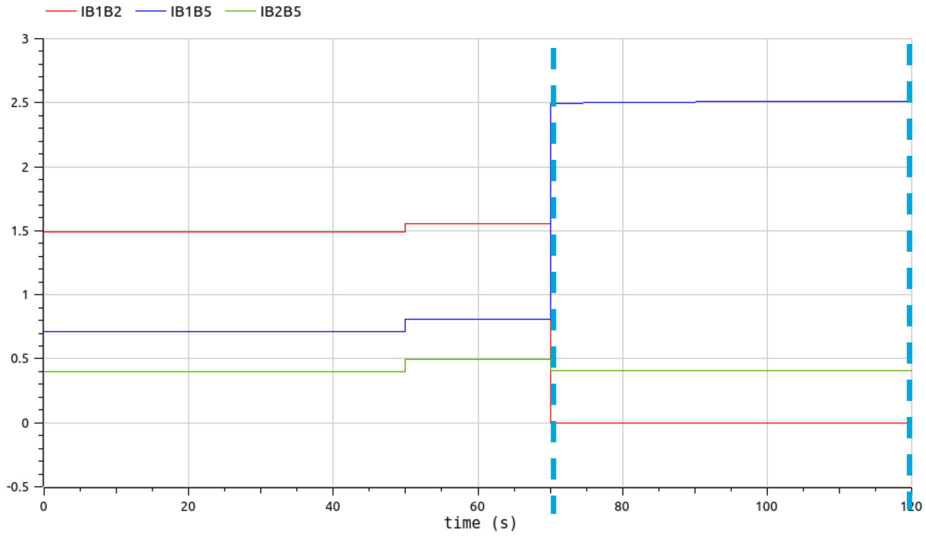
Test Case IEEE 14-bus : Curent limit automatons

Set of parameters 2

Controller	I_{Max} (p.u.)	t_{lag} (s)
CLAB1B2	1.55	20
CLAB1B5	2.00	50
CLAB2B5	0.49	30

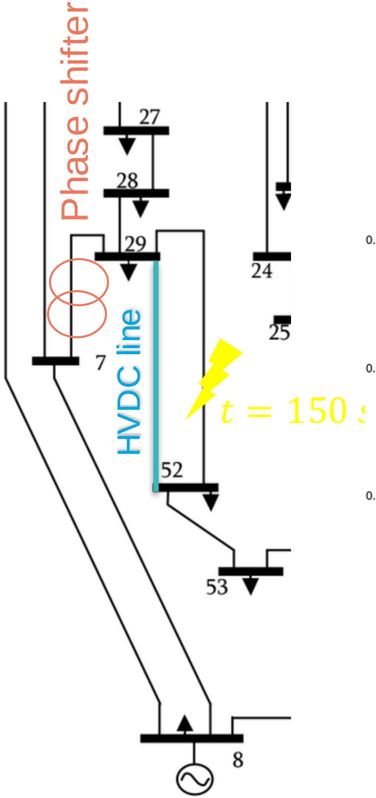
Increase in Load 5 consumption of 0,3 pu at $t = 50\ s$

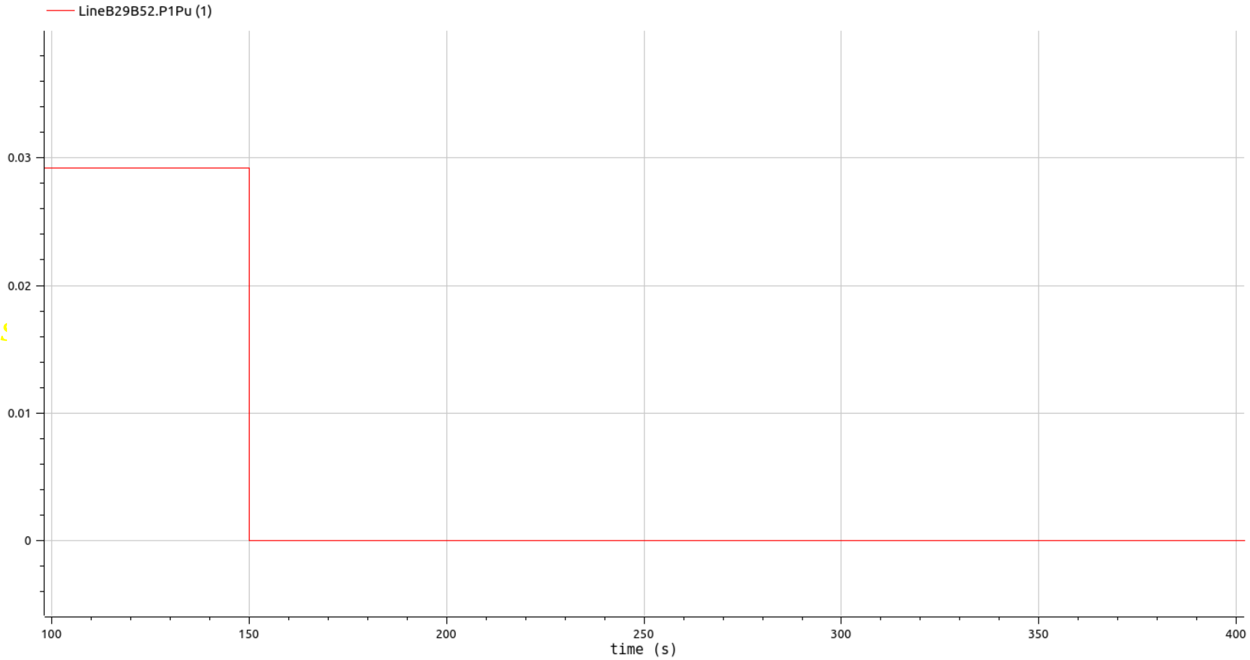




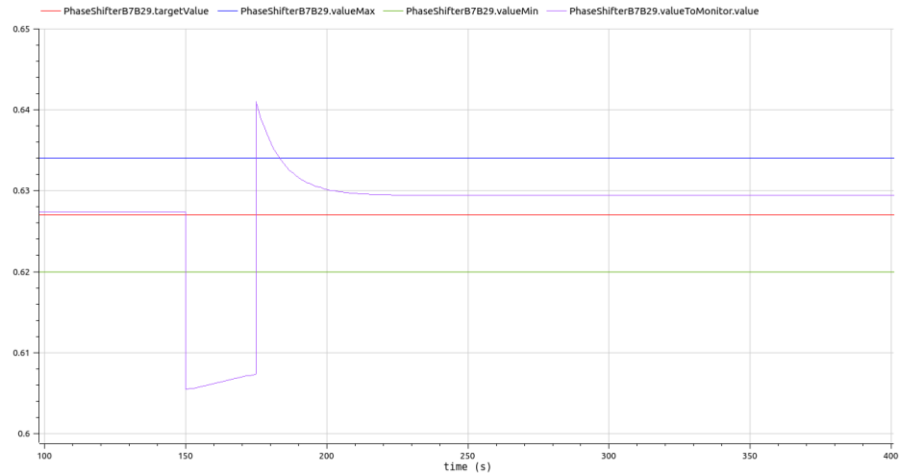
$t = 70\ s$ $t = 120\ s$

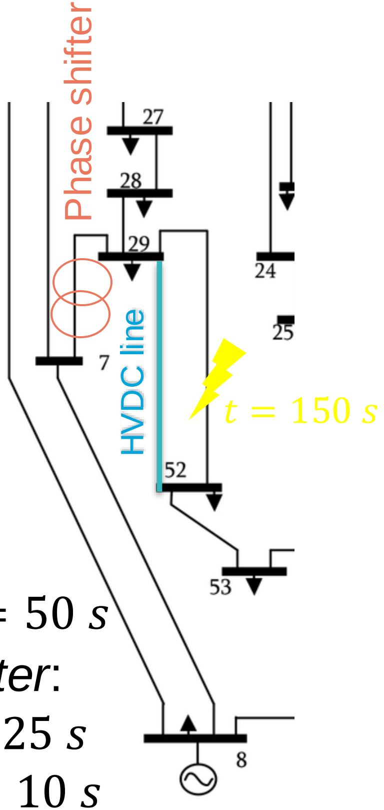
Test Case IEEE 57-bus : Line contingency

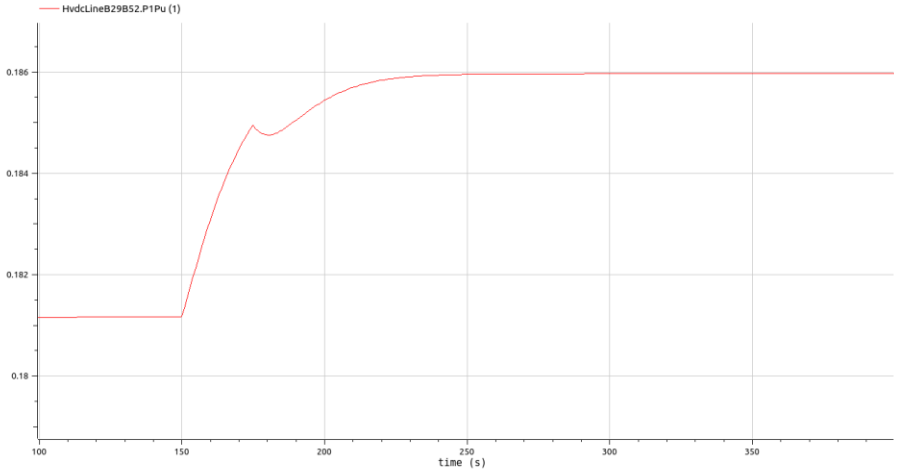




Test Case IEEE 57-bus : Line contingency







HVDC:

$t_{filter} = 50\ s$

Phase shifter:

$t_{1st} = 25\ s$

$t_{Next} = 10\ s$

05

Conclusion

Conclusions:

- Electrical grid is changing: more special protection schemes, HVDC, controls, renewable energies…
- Final steady state depends on the different dynamics of the system. These dynamics should be represented and cannot be seen with a static load flow approach.
- Simplified modeling for steady-state calculations can be done with Dynaωo Modelica library and simulations can be done using the time-domain DynaFlow approach.
- Modeling and simulation are done using OpenModelica
- Other phenomena like voltage stability and transient stability can be simulated using Dynaωo with more detailed models of components.

Thank you !

http://www.dynawo.org

https://github.com/dynawo/dynawo

rte-dynawo@rte-france.com