

An Open-Source Benchmark of IEEE Test Cases for Easily Testing a New Approach for Steady State Calculations in Power Systems

Joy El Feghali¹ Quentin Cossart¹ Gautier Bureau¹ Baptiste Letellier¹ Ian Menezes¹
Florentine Rosiere¹ Marco Chiaramello¹

¹R&D department, RTE Réseau de transport d'électricité, France
{joy.elfeghali,quentin.cossart,marco.chiaramello}@rte-france.com

Abstract

Power systems modeling and simulation are essential to conduct studies on the electrical transmission system and ensure its security. For this purpose, RTE, the French Transmission System Operator (TSO), is developing Dyna ω , a hybrid Modelica/C++ open-source suite of simulation tools for power systems. Most power systems models for Dyna ω are developed in the Modelica language using the Dyna ω Modelica library. This paper presents a full Modelica standard electrical power system benchmark implemented using the Dyna ω library. The IEEE 14-bus system benchmark is modeled here for steady-state calculation, with an approach that replaces the static load flow. Two test cases are simulated using the OpenModelica environment showing differences in the final steady-state result. We show flexibility in modeling with this library where different system behaviors can be observed and where models with different levels of details can be replaced depending on the application: steady-state calculation, long-term stability, or short-term stability.

Keywords: Modelica, IEEE 14-bus benchmark, power systems simulation, steady-state calculations, Dyna ω .

1 Introduction

The electrical transmission system is facing many challenges due to power electronic devices added to the system to connect renewable energy sources and HVDC links. Also, the control of the system is getting more complex due to the increasing use of controllers, with both discrete and continuous behaviors. The transmission system operator has to adapt the system to all these changes and ensure consumers good quality and availability of electricity. The need for a simulation tool that considers all the new dynamics introduced to the electrical system is primordial to conduct studies to face all the challenges. This is true even for the calculation of steady states where the different dynamics of the system can interact and influence the reached steady state. Moreover, this simulation tool should be flexible to adapt to the quick changes in the power system's environment.

RTE, the French electricity Transmission System Operator (TSO), is developing Dyna ω , a hybrid Modelica/C++ open-source suite of simulation tools for power

systems (Guironnet, Saugier, et al. 2018). The tools' objective is to conduct various studies like steady-state calculations, long and short-term stability, and short-circuit calculations while considering the different dynamics on the system depending on the study (Dyna ω 2023). Dyna ω uses the equation-based Modelica language (Fritzson and Engelson 1998) for the modeling part of power systems. Physical and acausal modeling are possible with the Modelica language, and it is an advantage to implement the model in an understandable and usable way. However, the solving part is separated from the modeling part, a choice made to obtain a flexible simulation tool for several applications (Guironnet, Rosière, et al. 2021). Some results of comparison of Dyna ω against other existing tools can be found in (Marin et al. 2022).

In this paper, we show that the Modelica Dyna ω library can be used on its own, to model common electrical transmission system test cases on Modelica modeling environments (here OpenModelica). In particular, the IEEE 14-bus system is modeled with the Dyna ω library, and its different components are presented. The IEEE 14-bus system is successfully implemented in the literature using other Modelica libraries like in (Adib Murad, Gómez, and Vanfretti 2015) and (Fernandes et al. 2018), and results show that it can be simulated in Modelica simulation environments. Also, several open-source electrical power system libraries are available in Modelica language ((Winkler 2017), (Bartolini, Casella, Guironnet, et al. 2019)). In this paper, we focus on the flexibility in modeling offered by the Dyna ω Modelica library, with an extensive choice for modeling depending on the purpose of the study, either long-term or short-term simulation, and on the time constant of the available components. Indeed, short-term simulations use high-detail models.

Steady-state calculations are highlighted in this paper. In particular, the DynaFlow approach that considers the dynamics of the components for the steady-state calculation is shown to give more realistic results than classical approaches like static load flow (Cossart et al. 2021). Several test cases can be easily created using the Dyna ω library to observe the impact that have the different dynamics of the system on the final steady state. In particular, two test cases are performed in this paper to calculate the final steady state after occurred events on the system. The

first test case is a line contingency, and the second is an increase in power consumption that activates current limit automats depending on their reaction time. Here, components are modeled in a chosen detail level for the calculation of steady states.

This paper is organized as follows: section two presents the Dynaω Modelica library and focuses on the models for the calculation of steady states and the physical phenomenon studied. The third section focuses on the IEEE 14-bus implementation with the Dynaω library. Two test cases and their simulation results using the IEEE 14-bus model are presented in the fourth section. Finally, a conclusion and perspectives are given in section five.

2 Dynaω Modelica Library

The Dynaω Modelica library comprises several models for the same element, with different levels of details depending on the application.

The main components found in the electrical transmission system are synchronous machines, lines, buses, loads, controllers, transformers, HVDC, photovoltaics, and wind power plants. Mainly models of machines, loads, and controls vary depending on the study we would want to achieve. It is important to note that, at the library level, the models are divided by component type and not by application purpose.

Dynaω Modelica library (Figure 1) contains a wide range of models to describe power systems. A combination of models with different levels of detail is possible, and it is one of the advantages of this library that creates flexibility to switch between component models. Multiple test cases can thus be modeled, and the user can create models without limiting to any application.

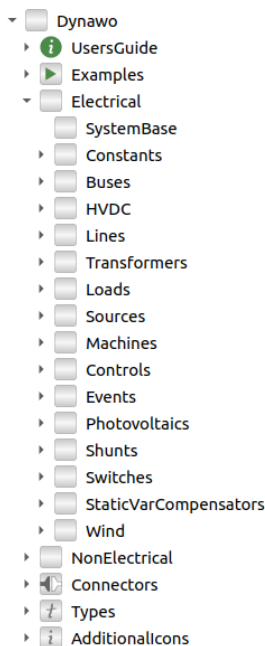


Figure 1. Dynaω library in OpenModelica

Dynaω library offers models to calculate steady states while properly taking into account the interactions between continuous and discrete controllers. The approach differs from static load flow calculation by considering the dynamics of systems like controllers and HVDC that impact the final steady state (Cossart et al. 2021). The focus will remain on the final steady-state result for voltage and currents that should not cross threshold limits. But with this approach, steady state is obtained through a time-domain simulation.

Models for steady-state calculations contain the minimum details needed to perform the study. Fast dynamics are neglected, and transitory phenomena are not taken into account in modeling since only the final steady state is important. These models are put in the DynaFlow category. Other phenomena can be observed by replacing components with more detailed models. DynaFlow simulations will thus use a higher time step (e.g. few seconds) compared to simulations with more detailed models considering fast dynamics (e.g. few milliseconds).

The following part presents the IEEE 14-bus system modeled with the Modelica language (using models from the Dynaω library) and simulated with the OpenModelica environment for the calculation of steady state. The model has been integrated within the package `Examples.DynaFlow` and can be found on <https://github.com/dynawo/dynawo/tree/master/dynawo/sources/Models/Modelica/Dynawo>.

3 Implementation of IEEE 14-bus System using Dynaω Modelica Library

3.1 Description of the IEEE 14-Bus System

The IEEE 14-bus system (Figure 2) is a standard test case in the power system community. It represents a simple approximation of the American Electric Power system in the early 1960s (Kodsi and Canizares 2003). The IEEE 14-bus test case system comprises 14 buses, 2 generators, 3 synchronous condensers, 1 shunt, 3 transformers, 17 lines, and 11 loads.

The three transformers separate the system into two parts with two voltage levels: 69 kV and 13.8 kV. The lower part of the system presented in Figure 2 corresponds to 69 kV, and the upper part corresponds to 13.8 kV.

The benchmark is modeled using the Dynaω Modelica library on the OpenModelica tool (Figure 3). Since a steady-state calculation test case is used, the chosen models for components comprise the minimum details for simulation, considering the interactions of the components for steady-state calculations. Models of components that form the IEEE 14-bus system are presented in the following part.

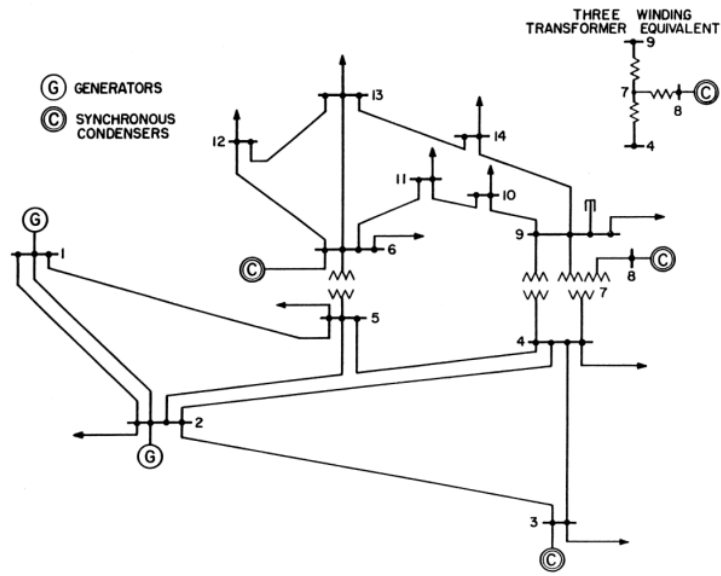


Figure 2. IEEE 14-bus benchmark

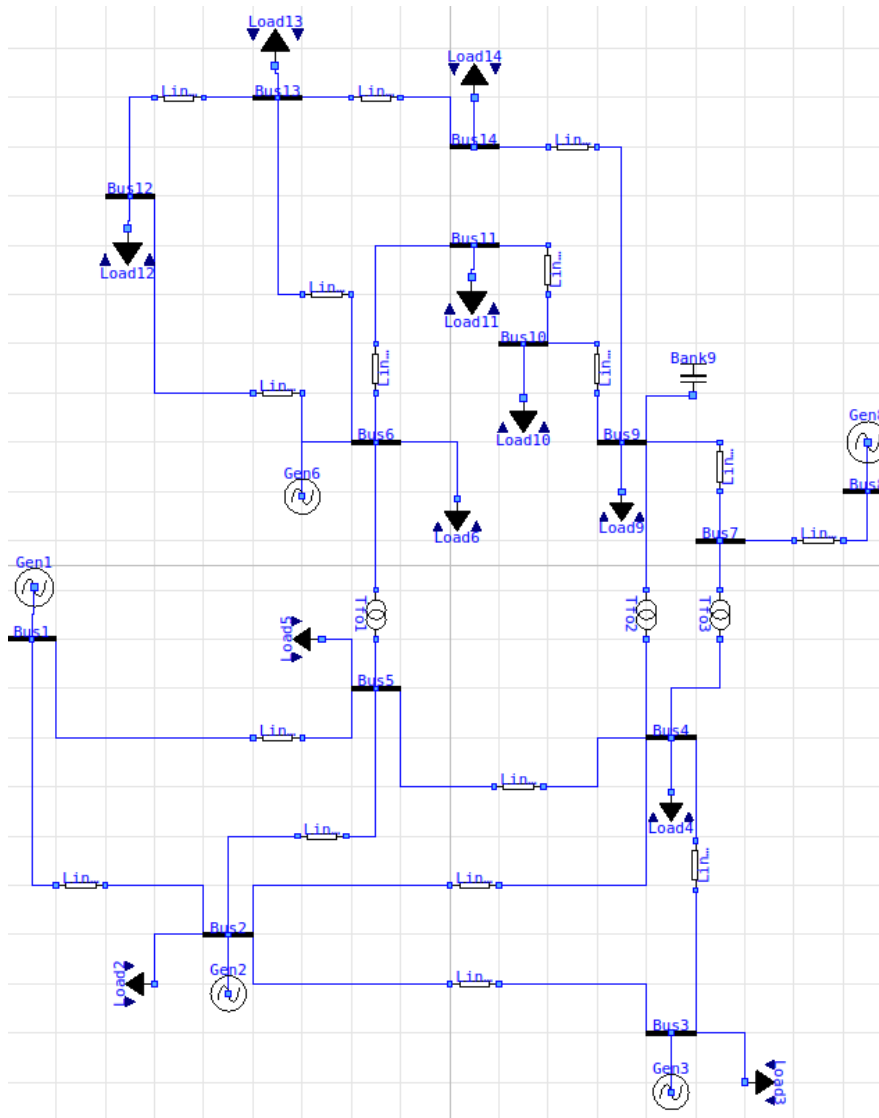


Figure 3. IEEE 14-bus model on OpenModelica

3.2 Models

Power systems models are developed in the Dynawo Mod-
elica library. The models presented in this section have the
lowest level of detail. These models can easily be replaced
with other complex models since the connections ports, in-
put, and output variables are common for each component
model. These models are used to simulate the test cases
presented in section 4. Other models are indeed available
in the library to perform other test cases.

3.2.1 Generators

On Figure 3, generator 3, 6 and 8 are synchronous
condensers. The same model is used for all the
generators and the synchronous condensers, but
the produced power of the latter is set to zero.
GeneratorPV, the model of these generators con-
taining minimum details is found within the package
Dynawo.Electrical.Machines.SignalN. An
input "signal N" described below is used in this generator
model for primary frequency regulation.

These components can adjust their reactive power Q_{Gen}
to maintain the voltage U at a certain reference level U_{Ref} .
This model regulates the voltage unless the reactive power
of the generator hits its limits at Q_{Min} or Q_{Max} (Equa-
tion 1). The active power P_{Gen} is modified by the fre-
quency regulation model through the signal N variable
(Equation 2, Equation 3). P_{Ref} is the set point active power
and P_{Nom} is the nominal active power.

$$\begin{cases} Q_{Gen} = Q_{Max} & \text{if maximum generation} \\ Q_{Gen} = Q_{Min} & \text{if maximum absorption} \\ U = U_{Ref} & \text{if not} \end{cases} \quad (1)$$

$$P_{GenRaw} = P_{Ref} + P_{Nom} * K_{Gover} * N \quad (2)$$

$$P_{Gen} = \begin{cases} P_{Max} & \text{if } P_{GenRaw} > P_{Max} \\ P_{Min} & \text{if } P_{GenRaw} < P_{Min} \\ P_{GenRaw} & \text{if not} \end{cases} \quad (3)$$

3.2.2 Active Power Control

For steady-state calculations, the active power control
of the generators is adjusted with a variable signal N
to balance the active power mismatch between
generation and consumption. The purpose is to regu-
late the frequency. All the generators are connected
to the SignalN model found within the package
Dynawo.Electrical.Controls.Frequency.

When using this model, the frequency is not explicitly
modeled. Instead, a voltage angle reference node is
set to balance the equations. All generators receive the
same signal N control, the generation power depends
on the participation percentage of each generator K_{Gover}
(Equation 2). This value is set to zero for synchronous
condensers.

3.2.3 Current Limit Control

A model CurrentLimitAutomaton (CLA)
for controlling the current of a component
is available in the library within the package
Dynawo.Electrical.Controls.Current.

This controller will open one or several components
when the current stays above a predefined threshold I_{Max}
during a certain amount of time t_{lag} on a monitored component
like a line or a transformer.

3.2.4 Loads

Loads are modeled as $\alpha\beta$ restorative loads. In the
model LoadAlphaBetaRestorative found within
the package Dynawo.Electrical.Loads, the load
restoration emulates the behavior of a tap changer trans-
former that connects the load to the system and regu-
lates the voltage at its terminal (Equation 4 – Equation 7).
After an event, the load goes back to its initial active
power P and reactive power Q respecting the time constant
 t_{filter} unless the filtered voltage amplitude at the terminal
 $U_{Filtered}$ is below U_{Min} or above U_{Max} . In these cases,
the load behaves as a classical $\alpha\beta$ load. The variation of the
load voltage and power is not instantaneous, which im-
pacts the final steady-state value, a phenomenon not con-
sidered with static load-flow calculation. P_{Ref} and Q_{Ref}
are the set point active and reactive power.

$$t_{filter} * \frac{U_{FilteredRaw}}{dt} = U - U_{FilteredRaw} \quad (4)$$

$$U_{Filtered} = \begin{cases} U_{Max} & \text{if } U_{FilteredRaw} \geq U_{Max} \\ U_{Min} & \text{if } U_{FilteredRaw} \leq U_{Min} \\ U_{FilteredRaw} & \text{if } U_{Min} \leq U_{FilteredRaw} \leq U_{Max} \end{cases} \quad (5)$$

$$P = P_{Ref} \left(\frac{U}{U_{Filtered}} \right)^\alpha \quad (6)$$

$$Q = Q_{Ref} \left(\frac{U}{U_{Filtered}} \right)^\beta \quad (7)$$

3.2.5 Transformers

For simplification purposes, the three-winding trans-
former of Figure 2 is modeled as a two-winding trans-
former in the IEEE 14-bus test case model as in Figure 3.

The TransformerFixedRatio model of the
Dynawo.Electrical.Transformers package
represents a two-winding transformer with a fixed ratio r
(Figure 4). This model is used for the three transformers
in the IEEE 14-bus model.

Equation 8 and Equation 9 describe the behavior of this
component with respect to conventions taken as in Fig-
ure 4.

$$r^2 \underline{V}_1 = r \underline{V}_2 + \underline{Z} \underline{I}_1 \quad (8)$$

$$\underline{I}_1 = r (\underline{Y} \underline{V}_2 - \underline{I}_2) \quad (9)$$

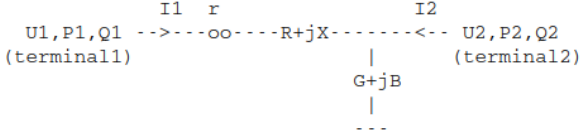


Figure 4. Transformer model

3.2.6 Lines

Lines are modeled with the model `Line` of the package `Dynawo.Electrical.Lines.Line`. This model represents a classical π line (Figure 5).

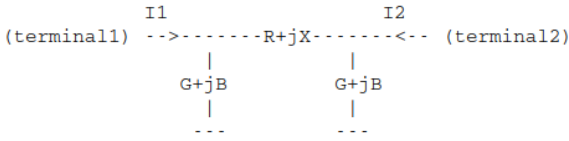


Figure 5. Line model

The model of the line represents the voltage drop between terminal 1 and terminal 2 (Equation 10 and Equation 11).

$$\underline{Z}^*(I_2 - \underline{Y} V_2) = V_2 - V_1 \quad (10)$$

$$\underline{Z}^*(I_1 - \underline{Y} V_1) = V_1 - V_2 \quad (11)$$

3.2.7 Shunt

A shunt model is connected to bus 9. The model `ShuntB` of the package `Dynawo.Electrical.Shunts` represents a shunt with constant susceptance and voltage-dependent reactive power Q (Equation 12).

$$Q = BU^2 \quad (12)$$

3.2.8 Buses

The model `Bus` of the package `Dynawo.Electrical.Buses` is used to model all the buses of the system. The bus does not add any equations to the system. It is used to connect several components into one node.

3.2.9 Switch-Off Equations

Switch-off equations for each component are also included in the IEEE 14-bus model. These equations have the purpose of determining if the component is connected to the electrical transmission system or not. These equations are put in the extended IEEE 14-bus model to enable connecting and disconnecting lines to simulate different test cases.

The number of switch-off signals differs from one component to another. Loads, transformers, lines, and shunts have two switch-off signals. Generators have three switch-off signals. When the switch-off is activated, some values

in the disconnected model are set to zero like current I , active power P , and reactive power Q .

4 Test Cases

In this section, two test cases are presented to highlight the use of Dynawo Modelica library for benchmarks like the IEEE 14-bus system, the advantage of the DynaFlow steady-state approach over a static load flow calculation, and the ease of adding models and creating different test cases to observe multiple phenomena.

Test cases are chosen in the transmission electrical grid context, where studies focus on the state of the system after a loss of a line or a generator that may cause a variation in voltage, current, and frequency, with values that may become critical to the system. Controllers present in the system react to these changes.

The first test case describes the behavior of the system after an occurrence of a line contingency. This simulation highlights the use of the library to observe commonly studied phenomena on the electrical grid. The second test case describes the interaction of multiple current limit automotons after an increase in load consumption. For the second test case, two simulations are done with different parameters, resulting in different final steady states. These simulations highlight the importance of representing the dynamics of the system and performing a time-domain simulation while calculating the final steady state.

The initial data for generators and the simulation solver needed to perform the simulation are given. Then, the results of the two test cases are presented after a DynaFlow time-domain simulation of the model presented in the previous section.

4.1 Data

The data used corresponds to the available online data for IEEE 14-bus system. In Table 1, initial values for the five generators are given.

Table 1. Initial values for generators

Generator	$P_{Gen} (MW)$	$Q_{Gen} (Mvar)$	$U (kV)$	$\Theta (^\circ)$
1	232.39	-16.55	73.14	0.00
2	40.00	43.56	72.11	-4.98
3	0.00	25.07	69.69	-12.73
6	0.00	12.73	14.77	-14.22
8	0.00	17.62	15.04	-13.36

4.2 Simulation Solver

The solver used in OpenModelica is Euler with a 10 s step and a 10^{-6} tolerance. An additional translation flag, "`-daeMode`", is added to the model. `klu` is chosen as a linear solver and `kinsol` as a non-linear solver. The simulation time is 200 s.

4.3 Test Case with Line Contingency

The test case simulates a loss of a line. We are interested in studying how the electrical transmission system will behave after a loss of a line and if the model describes the phenomenon well. The line contingency between bus 1 and bus 5 occurs at time $t = 100$ s. In the model, the value of the switch-off signal of the line becomes `true` which causes the values of active power, reactive power, and current to drop to zero on both line terminals. For example, Figure 6 shows the line's active power on terminal 1, here given in per unit with S_{Ref} base.

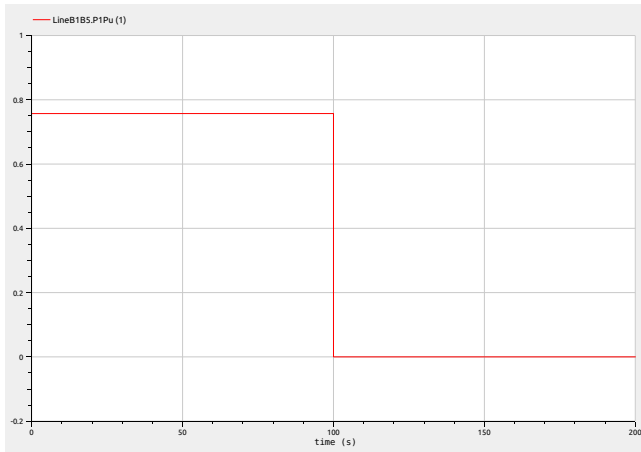


Figure 6. Line contingency test case: Active power of the line Bus1-Bus5 at terminal 1 in per unit (base S_{Ref})

The increase of the active power is immediate for generator 1 when the line is disconnected at time $t = 100$ s, as seen in Figure 7. Generator 2 has a similar behavior as generator 1. The power of the three other synchronous condensers remains at 0. Since one line is lost, active losses on the other lines will increase, and since the consumption demand remains the same, the active power production of generators will increase to satisfy the consumption demand and thus regulate the frequency. The active power variation is caused by the generator's primary frequency regulation, which adjusts the active power to balance power generation and consumption. The voltage angles have also changed for all the generators except for generator 1, which corresponds to the reference node. The value of the reactive power also changes to maintain the voltage at the same level U_{Ref} when reactive losses increase on the lines. Steady-state values at the end of the simulation are given in Table 2.

The restoration phenomenon of loads modeled in Equation 4 – Equation 7 can be observed, for example, for load 5 in Figure 8. The active power of the load (given in per unit with S_{Ref} base) drops after the loss of line Bus1-Bus5 since the voltage has decreased. The active power of the load goes back to its initial value after the event.

In Table 3 and Table 4, the power flow is observed at all the lines at the initial and final time of the simulation. Since the line between bus 1 and bus 5 is disconnected

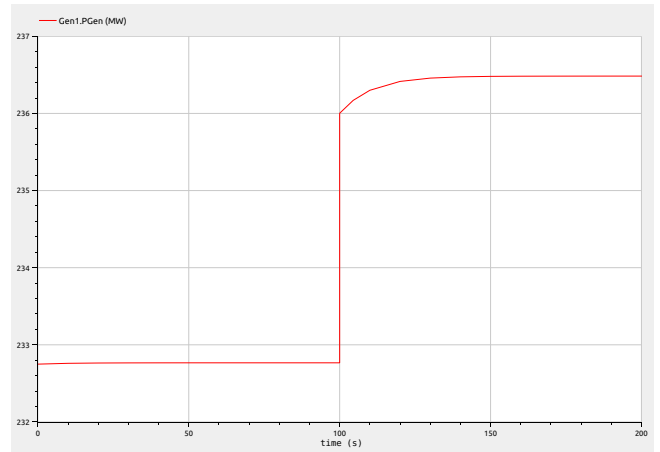


Figure 7. Line contingency test case: Generator 1 active power in MW

Table 2. Final values for generators

Generator	P_{Gen} (MW)	Q_{Gen} (Mvar)	U (kV)	Θ ($^{\circ}$)
1	236.48	-37.22	73.14	0.00
2	43.79	75.33	72.11	-7.60
3	0.00	30.08	69.69	-17.34
6	0.00	21.26	14.77	-19.43
8	0.00	19.90	15.04	-19.58

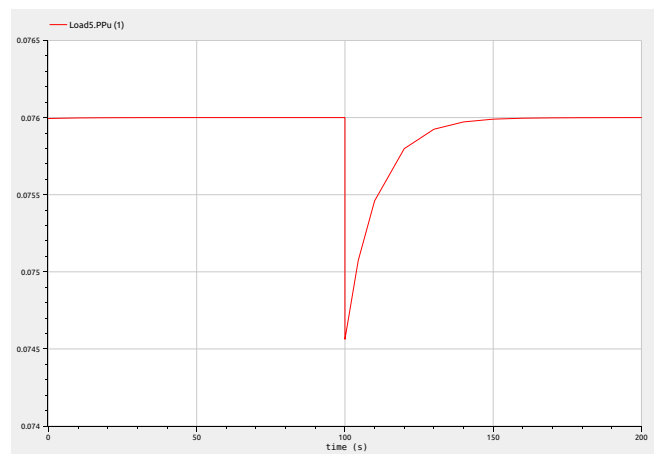


Figure 8. Line contingency test case: Load 5 active power in per unit (base S_{Ref})

from the system, the power is distributed to all the other lines. Then, power values of each line differ from Table 3 to Table 4. After the contingency, bus 1 is connected only to bus 2, and all the generated power is transmitted in the line between these two buses.

The result can be obtained with a static load flow starting with the correct initial conditions: without line Bus1-Bus5. The advantage of the DynaFlow approach is the possibility of observing the system's evolution in time (like the load restoration phenomena) and the occurrence of events that may change the final steady-state result.

Table 3. Initial power flow values for lines

Line	$P_1(MW)$	$P_2(MW)$	$Q_1(Mvar)$	$Q_2(Mvar)$
Bus1-Bus2	157.05	-152.74	-20.57	27.87
Bus1-Bus5	75.71	-72.94	3.86	2.28
Bus2-Bus3	73.34	-71.01	3.59	1.60
Bus2-Bus4	56.33	-54.64	-1.50	3.01
Bus2-Bus5	41.72	-40.81	1.19	2.09
Bus3-Bus4	23.56	-23.19	-4.85	4.48
Bus4-Bus5	61.67	-61.15	-14.13	15.76
Bus6-Bus11	7.36	-7.31	3.70	-3.58
Bus6-Bus12	-7.74	7.81	-2.38	2.53
Bus6-Bus13	-17.55	17.76	-6.86	7.28
Bus7-Bus8	0	0	-17.17	17.63
Bus7-Bus9	-28.25	28.25	-5.01	5.82
Bus9-Bus10	-5.25	5.26	-4.09	4.12
Bus9-Bus14	-9.30	9.42	-3.28	3.53
Bus10-Bus11	3.77	-3.76	1.75	-1.72
Bus12-Bus13	1.59	-1.58	0.76	-0.75
Bus13-Bus14	5.62	-5.57	1.81	-1.71

Table 4. Final power flow values for lines

Line	$P_1(MW)$	$P_2(MW)$	$Q_1(Mvar)$	$Q_2(Mvar)$
Bus1-Bus2	236.48	-226.64	-37.22	61.44
Bus1-Bus5	0	0	0	0
Bus2-Bus3	86.87	-83.61	2.44	6.66
Bus2-Bus4	83.61	-79.89	-1.94	9.64
Bus2-Bus5	78.24	-75.04	0.69	5.42
Bus3-Bus4	10.67	-10.59	-5.50	4.43
Bus4-Bus5	24.95	-24.84	-13.08	13.41
Bus6-Bus11	6.13	-6.08	4.88	-4.77
Bus6-Bus12	-7.62	7.69	-2.56	2.71
Bus6-Bus13	-16.94	17.15	-7.48	7.88
Bus7-Bus8	0	0	-19.32	19.91
Bus7-Bus9	-29.43	29.43	-4.28	5.16
Bus9-Bus10	-6.46	6.48	-2.88	2.92
Bus9-Bus14	-10.04	10.17	-2.48	2.76
Bus10-Bus11	2.55	-2.54	2.95	-2.92
Bus12-Bus13	1.47	-1.46	0.94	-0.93
Bus13-Bus14	4.91	-4.86	2.61	-2.51

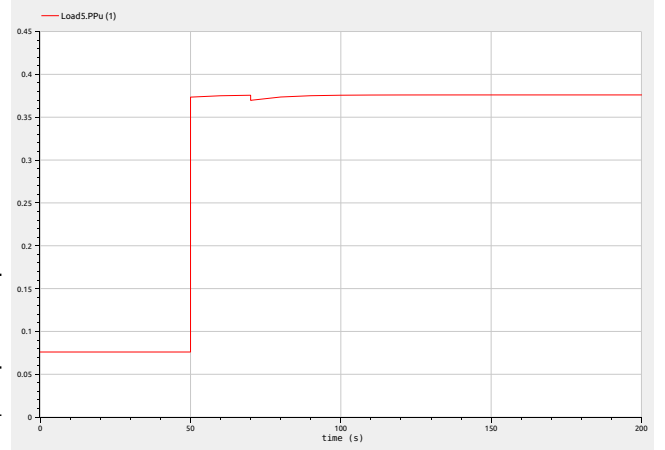
In fact, in both approaches, we are interested in the final steady state. However, phenomena observed with DynaFlow, like the interaction of multiple discrete and continuous components, can change the final result, which can not be seen with a static load flow.

4.4 Test Case with Current Limit Automaton

In this part, values are given in per unit (p.u.). For power values, the p.u. base is the reference apparent power S_{Ref} . The p.u. base is the nominal voltage at the line U_{Nom} for voltage values. For current values, the p.u. base is deduced from S_{Ref} and U_{Nom} .

The test case simulates an increase in the current due

to increased consumption of load 5 of 0.3 p.u. at $t = 50$ s (Figure 9). A current limit controller is available on each of the lines: CLAB1B2 for line Bus1-Bus2, CLAB2B5 on line Bus2-Bus5, and CLAB1B5 on line Bus1-Bus5. Increasing load consumption can thus cause a line loss if we reach the maximum allowed current I_{Max} . In this test case, we observe how the reaction time t_{lag} of each controller and the line's maximal current I_{Max} are important and impact the final steady-state result. In fact, when one of the controllers reacts to disconnect a component, the current variation impacts other lines.

**Figure 9.** Increased consumption with CLA test case: Load 5 active power in per unit (base S_{Ref})

In the first simulation, we take parameters for each controller as in Table 5.

Table 5. Parameters of the CurrentLimitAutomaton for case 1

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

After the event at $t = 50$ s, the current on the lines increases as seen in Figure 10. However, for line Bus1-Bus2 and line Bus2-Bus5, the current is now higher than the allowed I_{Max} . The controller CLAB2B5 will react after 20 s to disconnect the line Bus1-Bus2, before the controller CLAB1B2 that can only interfere after 30 s. The disconnection of line Bus2-Bus5 decreases the current of line Bus1-Bus2, which is now below the $I_{Max} = 1.55$ p.u. The current of line Bus1-Bus5 increases but stays below $I_{Max} = 2$ p.u. The final steady state is reached after the restoration of the loads. Here, the system can operate after the loss of the line.

If we change the reaction time of CLAB1B2 to 20 s and the reaction time of CLAB2B5 to 30 s as in Table 6, different results are obtained. In this case, after the increase of the power of load 5 at time $t = 50$ s, all the currents in-

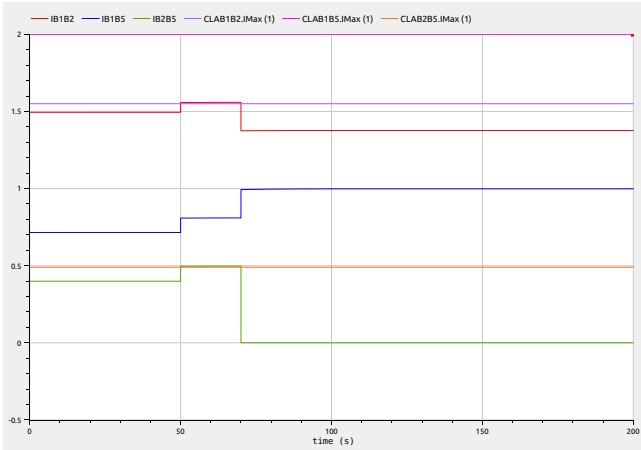


Figure 10. Increased consumption with CLA test case: Current for lines Bus1-Bus2, Bus1-Bus5, and Bus2-Bus5 in per unit

crease. However, the controller CLAB1B2 will react before the controller CLAB2B5, and line Bus1-Bus2 is thus disconnected at $t = 70$ s. The current of line Bus2-Bus5 decreases below the $I_{Max} = 0.49$ p.u., and the current of line Bus1-Bus5 increases above the $I_{Max} = 2$ p.u. After 50 s (at $t = 120$ s), CLAB1B5 will react to decrease the current by disconnecting line Bus1-Bus5. But this event disconnects generator 1 since there are no more lines connected. All the generated power should now come from generator 2. The simulation fails and stops at $t = 120$ s. Here, the system can not operate after the loss of the two lines Bus1-Bus2 and Bus1-Bus5, and generator 1.

Table 6. Parameters of the CurrentLimitAutomaton for case 2

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

We conclude that the final steady state result depends on the different controllers with different time constants available in the system. Indeed, other parameters would have given us other final steady states. The final steady state calculation with the DynaFlow approach after time-domain simulation gives realistic results of components' interactions (like causing system failure) that cannot be seen when performing a static load flow. In fact, it is difficult to reproduce the final steady state with one static load flow calculation because values are not calculated in a time domain. For instance, several initial conditions should be taken into account to represent the reaction of each current limit automaton. Also, no flexibility in changing the reaction time is available. A time-domain simulation allows changing parameters and testing different cases for final steady-state calculations.

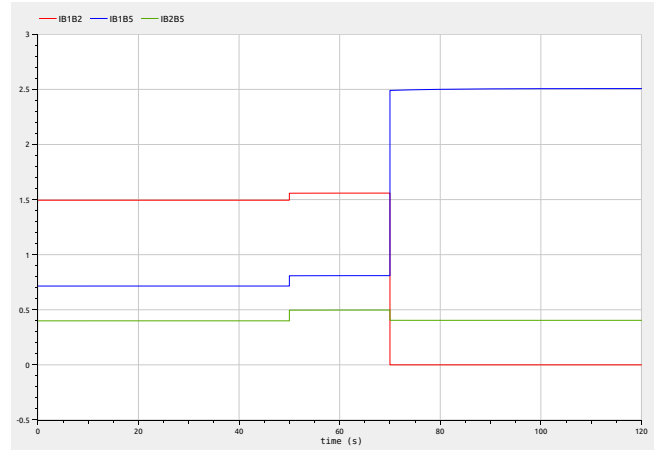


Figure 11. Increased consumption with CLA test case: Current for lines Bus1-Bus2, Bus1-Bus5, and Bus2-Bus5 in per unit

5 Conclusion and future works

The Dynaω library is an open-source Modelica library with an extensive choice of models that offers flexibility in modeling depending on the desired application. Steady-state calculations, long-term stability, short-term stability, and short-circuit studies can be done. The library also offers the flexibility of combining different models with different levels of detail.

In this paper, models from the Dynaω Modelica library are presented for steady-state calculations with a time-domain simulation approach that considers dynamic phenomena not taken into account with static load flow. Two different test cases are developed in this paper using the IEEE 14-bus system benchmark. Different simulations are performed, and we show that final steady-state results depend on the different dynamics present in the system and the parameters that can be modified easily using the library. These test cases show the importance of the approach that considers the system's dynamics. The Dynaω Modelica library allows modeling several test cases for different system studies and behaviors of the system while mixing different dynamic models.

Other test cases can be developed based on the IEEE 14-bus benchmark test cases presented in this paper by adding other controllers to the system, like phase shifters or tap changers for transformers, with models available in the library. Also, IEEE benchmarks with higher nodes, like IEEE 30-bus and IEEE 57-bus systems, will be added to the library. Benchmarks like the Nordic 32-bus system and RVS are modeled with the Dynaω Modelica library and are not presented in this paper but are available on the GitHub repository. These models are used for voltage stability studies (long-term stability) where more detailed component models are used. Future works for this library include adding more detailed models and controls, for example, renewable energy control systems, to study their impact on the electrical transmission system.

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