

Modeling for control of Multi Energy Systems based on a physical description in Modelica: application to a city district

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Introduction

Modelica language

Model of a multi-energy system in Modelica

Model order reduction

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► Motivation:

- Control multi-energy systems to reduce energy consumption.
- The complexity of multi-energy models.
- Simulation costs of these models.

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- The complexity of multi-energy models.
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► Goals:

- Model reduction while compromising between computational time and model accuracy.
- Obtain models adapted for control strategies.
- Apply a control strategy on a city district model to flatten the curve of electrical consumption.

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Modelica:



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- ▶ Models are described with algebraic differential equations (DAE) and ordinary differential equations (ODE). These equations are acausal.

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Dymola:



- ▶ Dymola is a commercial environment that can simulate models written with Modelica language.
- ▶ Models can be created with codes or by connecting elementary models from existing libraries.

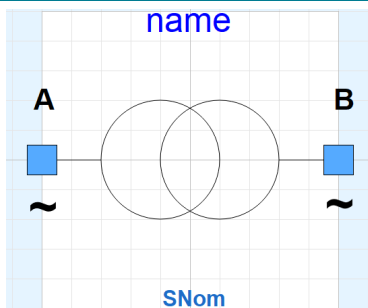


Figure 1: "mytransformer" component from PowerSysPro library

```
model myTransformer "Transformer with fixed voltage ratio"
  extends PartialModels.myPartialTransformer;
protected
  parameter Complex k = CM.fromPolar(UNomB / UNomA, theta) "Complex ratio of ideal transformer";
  parameter Types.myComplexImpedance Z = Complex(R, X) "Series impedance of phase conductor";
  parameter Types.myComplexAdmittance Y = Complex(G, B) "Shunt admittance at primary side";
equation
  assert(UNomB / UNomA < 1, "Voltage at port A should be higher then voltage at port B for " + getInstanceName());
  terminalA.i + terminalB.i * CM.conj(k) = Y * terminalA.v;
  terminalA.v - terminalB.v / k = -Z * CM.conj(k) * terminalB.i;
  0
end myTransformer;
```

Figure 2: "mytransformer" code in Modelica language

Modelica language

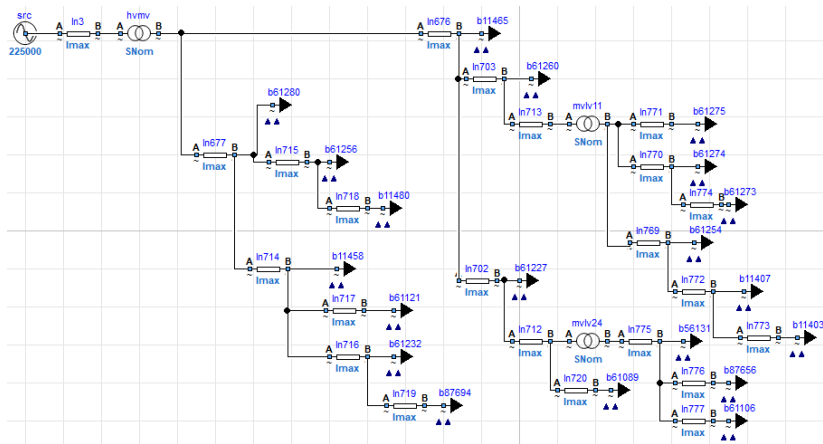


Figure 3: Example "LargerNetwork" from PowerSysPro library: components are connected to form an electrical grid model

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Modeling a city district

PowerGrid use case:

- ▶ The district is located in the suburbs of Paris.
- ▶ The district is composed of **720 buildings** connected to the **electrical grid**. 362 of these buildings are connected to the **heating network**. Some buildings are local producers.

Modeling a city district

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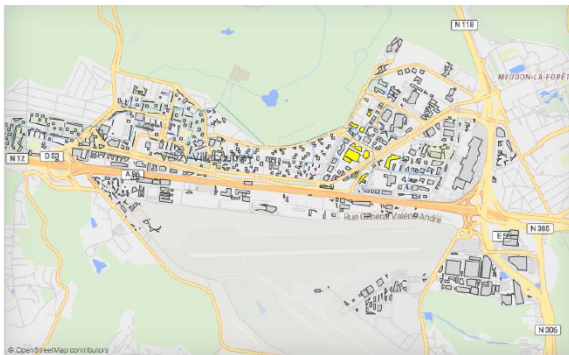


Figure 4: The PowerGrid system

► Description of the use case:

- A smaller use case is used to test the order reduction methods before applying them to the PowerGrid model.
- This use case is composed of **20 buildings** connected to the **electrical grid**. 12 of these buildings are connected to the **heating network**.
- The buildings are local producers. They produce energy through PV panels.
- A heat pump assisted by a storage tank feeds the heating network.

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► Modelica modeling:

- The system is modeled with Modelica language. It is simulated in Dymola environment.
- EDF R&D libraries are used: PowerSysPro for the electrical grid, BuildSysPro for the buildings, and MixSysPro for the heating network.

Modeling a city district

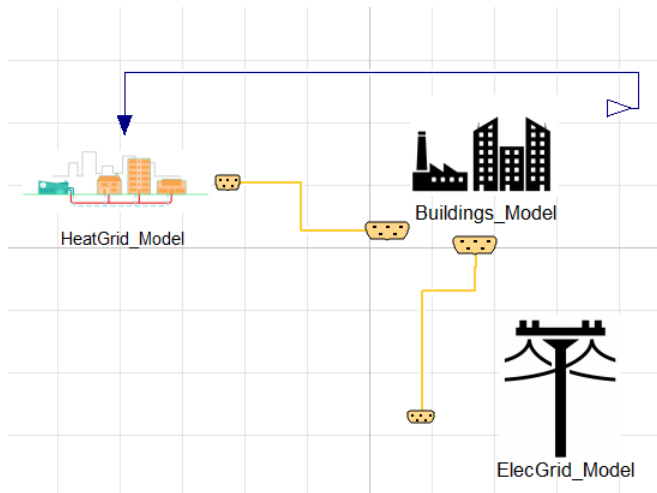


Figure 5: The city district model in Dymola

Modeling a city district

- ▶ Each of the 20 buildings exchanges the active power P_{elec} and reactive power Q_{elec} with the electrical grid.
- ▶ Each of the 12 buildings exchanges the heater's and hot water power consumption P_{DHN} with the heating network.

$$\begin{cases} P_{total_elec} [W] = P_{elec_heater} + P_{elec_hotwater} + P_{elec_specificconsumptioncons} - P_{PV_production} \\ Q_{total_elec} [VAR] = Q_{elec_heater} + Q_{elec_hotwater} + Q_{elec_specificconsumption} - Q_{PV_production} \\ P_{total_DHN} [W] = P_{DHN_heater} + P_{DHN_hotwater} \end{cases}$$

Modeling a city district

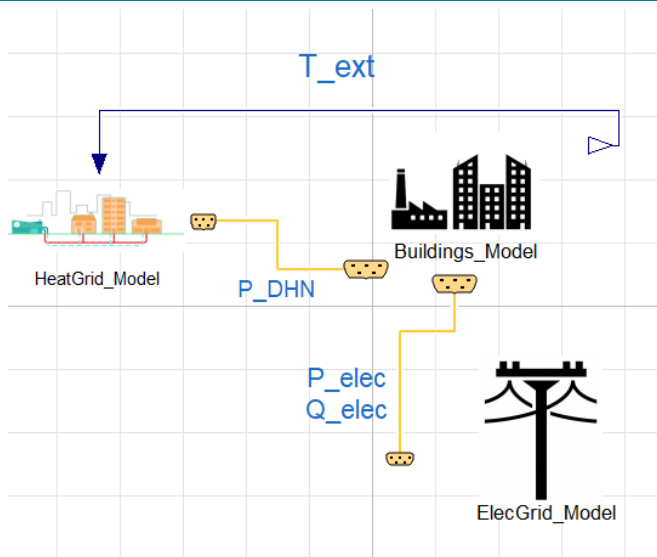


Figure 6: The city district model in Dymola

Modeling a city district

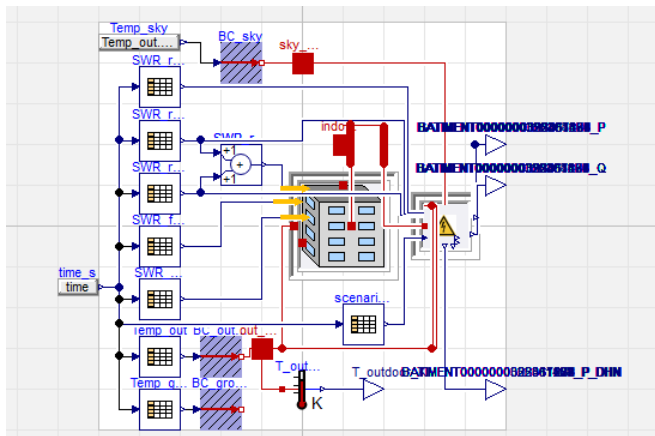


Figure 7: Buildings model

Modeling a city district

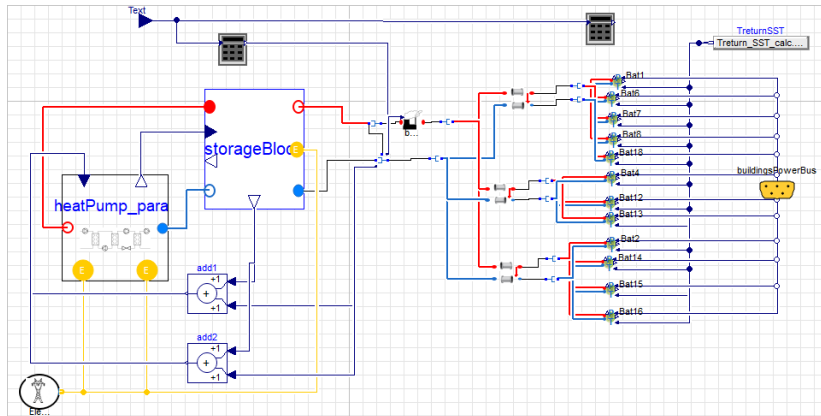


Figure 8: Heating network model

► Objectives of the multi-energy system:

- Study the interactions between the consumers and the producers of energy.
- Study the flexibility that the heating network and the PV production can bring to the electrical grid.

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▶ Application:

- Develop methods to simplify complex multi-energy models.

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Objectives

State of art

Energy-based ranking method

Future works

► Objectives:

- Reduce the complexity of complex models.
- Obtain a model with good computational time and good accuracy.
- Obtain a model for control at different scales of time in a bottom-up approach.
- Find convenience methods for models in Modelica.

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- Reduce the complexity of complex models.
 - Obtain a model with good computational time and good accuracy.
 - Obtain a model for control at different scales of time in a bottom-up approach.
 - Find convenience methods for models in Modelica.
- The challenge is to apply conventional order reduction methods to Modelica models.

► Conventional methods:

- Balanced truncation or Moore's method [1].
- Singular perturbation.
- State aggregation for a Markov chain. [2]
- Bond-graph methods: energy-based ranking method.

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- Balanced truncation or Moore's method [1].
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- Bond-graph methods: energy-based ranking method.

The energy-based ranking method will be applied to the city district. The idea of an energy-based ranking of Modelica components was elaborated in the thesis work of Sodja [3].

Model order reduction - Energy-based method

- ▶ The energy-based ranking method consists of ranking the components in the model for an energy criterion.
- ▶ Reducing the model is done by replacing or removing components with low energy contribution.

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Energy flux of component i is the sum of all the energy exchanged with other components k :

$$\dot{E}_i(t) = - \sum_{k=1}^n \dot{E}_{i,k}(t)$$

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Energy flux of component i is the sum of all the energy exchanged with other components k :

$$\dot{E}_i(t) = - \sum_{k=1}^n \dot{E}_{i,k}(t)$$

The energy flowing through a component i during a given interval is called **activity**, the energy ranking criteria:

$$A_i = \int_{t_1}^{t_2} |\dot{E}_i(t)| dt$$

Modelica models' case:

- ▶ Components in Modelica use connectors to connect in a model. They exchange some variables.
- ▶ The exchanged information between components is used to calculate the energy flux hence the activity.

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Examples of connectors from Modelica standard library:

- ▶ Energy flux of an electric component: $\dot{e} = v \cdot i$

```
connector Pin "Pin of an electrical component"  
  SI.ElectricPotential v "Potential at the pin" ⚭ ;  
  flow SI.Current i "Current flowing into the pin" ⚭ ;  
  ⚭  
end Pin;
```

- ▶ Flux d'énergie d'un composant thermique: $\dot{e} = Q_{flow}$

```
partial connector HeatPort "Thermal port for 1-dim. heat transfer"  
  Modelica.SIunits.Temperature T "Port temperature";  
  flow Modelica.SIunits.HeatFlowRate Q_flow  
  "Heat flow rate (positive if flowing from outside into the component)";  
  ⚭  
end HeatPort;
```


► City district case:

- Components are the buildings.
- The activity is calculated by integrating the total power P of the building for a one-year simulation.
- A building can be removed or replaced.
- Buildings with low **activity** are replaced with an empty model. They can be replaced with a constant like the maximum or the mean of their power consumption.

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► Steps:

1. Simulate the complete building model and calculate the activity of each building.
2. Replace low activity buildings with an empty model.
3. Simulate the reduced model.
4. Calculate the error caused in the electrical grid model and the heating network.

1. Activity calculation of the building:

- ▶ Activity is calculated during simulation.
- ▶ For each building the following activities are calculated:

$$\begin{cases} E_{P_{total_elec}} = \int_0^{1year} |P_{total_elec}| dt \\ E_{Q_{total_elec}} = \int_0^{1year} |Q_{total_elec}| dt \\ E_{P_{total_DHN}} = \int_0^{1year} |P_{total_DHN}| dt \end{cases}$$

- ▶ Each building contributes to the total energy. The relative value of the building's activity gives an idea of the global error between the complete and the reduced models that might cause removing the building.

Model order reduction - Energy-based method

Activity ranking for electrical energy

Building	Activity [KWh]	Relative [%]	Accumulated [%]	Heating Type
B20	2.27E+06	26%	26%	Elec
B15	1.29E+06	15%	41%	DHN
B16	8.90E+05	10%	51%	DHN
B14	6.27E+05	7%	58%	DHN
B12	6.18E+05	7%	65%	DHN
B17	6.12E+05	7%	72%	Elec
B13	5.26E+05	6%	78%	DHN
B3	4.00E+05	5%	82%	Elec
B6	3.25E+05	4%	86%	DHN
B11	2.59E+05	3%	89%	Elec
B18	2.23E+05	3%	91%	DHN
B5	1.97E+05	2%	94%	Elec
B9	1.51E+05	2%	95%	Elec
B10	1.43E+05	2%	97%	Elec
B4	9.53E+04	1%	98%	DHN
B19	7.67E+04	1%	99%	Elec
B8	5.07E+04	1%	100%	DHN
B7	1.36E+04	0%	100%	DHN
B2	1.36E+04	0%	100%	DHN
B1	1.35E+04	0%	100%	DHN
TOTAL	8.80E+06			

Activity ranking for thermal energy

Building	Activity [KWh]	Relative [%]	Accumulated [%]	Heating Type
B15	1,43E+06	22%	22%	DHN
B12	1,17E+06	18%	39%	DHN
B16	8,32E+05	13%	52%	DHN
B13	8,03E+05	12%	64%	DHN
B14	7,87E+05	12%	76%	DHN
B6	6,46E+05	10%	85%	DHN
B18	4,76E+05	7%	93%	DHN
B4	2,64E+05	4%	96%	DHN
B8	1,18E+05	2%	98%	DHN
B7	4,89E+04	1%	99%	DHN
B1	3,80E+04	1%	100%	DHN
B2	3,01E+04	0%	100%	DHN
TOTAL	6,65E+06			

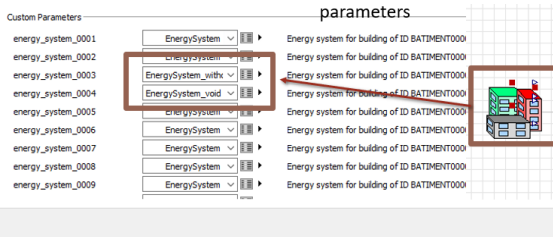
- Buildings ranked at last will be replaced with an empty model.

2. Replacing models in Dymola:

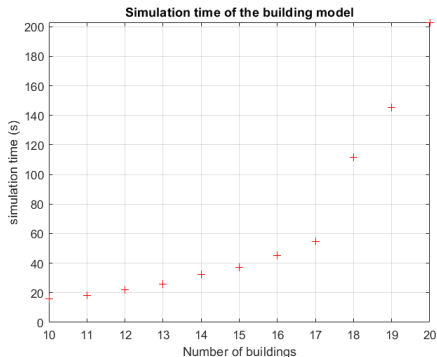
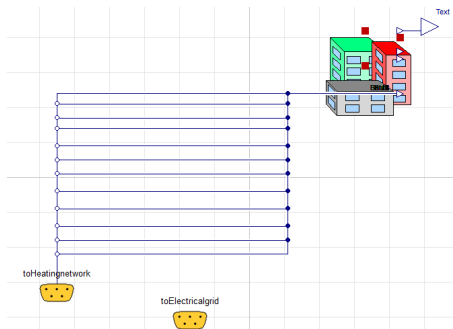
- ▶ The models in Modelica are object-oriented; therefore, many characteristics can be used. By using the keyword **replaceable**, models can be recreated with a different type. In buildings example, the new type is, for example, an empty model of the building.
- ▶ At an upper level, models can be changed with the keyword **redeclare**.

2. Replacing models in Dymola:

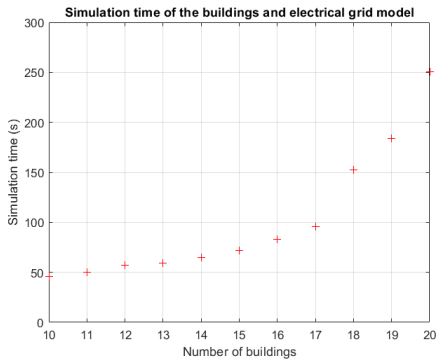
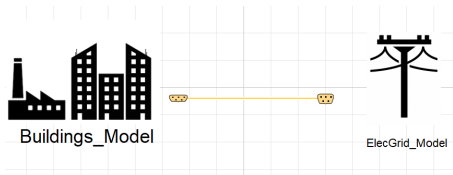
- ▶ The models in Modelica are object-oriented; therefore, many characteristics can be used. By using the keyword **replaceable**, models can be recreated with a different type. In buildings example, the new type is, for example, an empty model of the building.
- ▶ At an upper level, models can be changed with the keyword **redeclare**.
- ▶ The user only has to choose from a list, the new model of the building. In the reduction of the model case, the user will select an empty model for unwanted buildings.



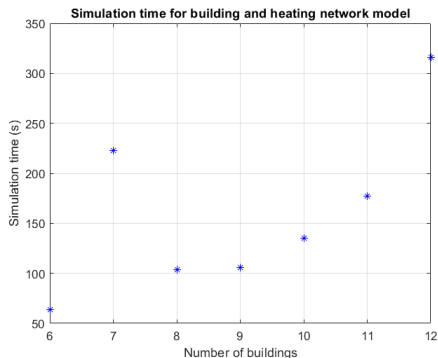
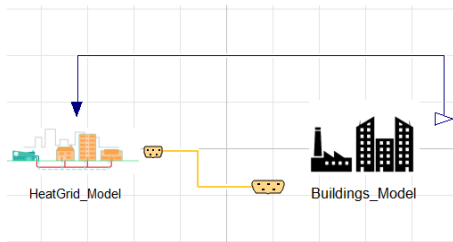
3. Simulating the reduced model: a. Simulating the buildings model



b. Simulating the buildings with the electrical grid model



c. Simulating the buildings with the heating network model



4. Error caused by model reduction:

- ▶ Electrical grid:
 - Current on all grid lines should not exceed the I_{max} of the line.
 - Voltage should stay within the limits of $\pm 10\%$ in LV lines and $\pm 5\%$ in MV lines.
 - Local and global errors for current and voltage between the complete and reduced models should be minor.

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 - Local and global errors for current and voltage between the complete and reduced models should be minor.
- ▶ Heating network:
 - Local and global errors for the temperature and the mass flow between the complete and reduced models should be minor.

Criteria used to calculate errors:

► **Electrical grid:**

$$\begin{cases} CI_{\infty}(\text{line } i) = \frac{\|I(t) - I_{red}(t)\|_{\infty}}{\|I(t)\|_{\infty}} * 100 \\ CU_{\infty}(\text{line } i) = \frac{\|U(t) - U_{red}(t)\|_{\infty}}{U_{nom}(t)} * 100 \end{cases}$$

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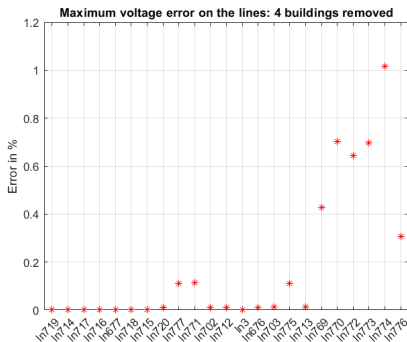
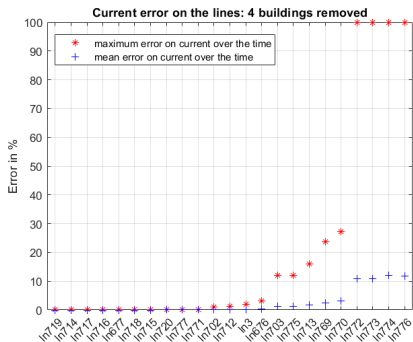
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► **Heating network:**

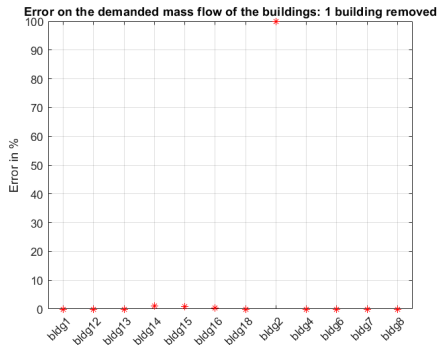
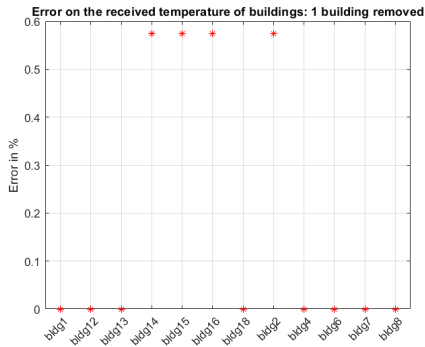
$$\begin{cases} CT_{\infty}(\text{line } i) = \frac{\|T(t) - T_{red}(t)\|_{\infty}}{\|T(t)\|_{\infty}} * 100 \\ C\dot{m}_{\infty}(\text{line } i) = \frac{\|\dot{m}(t) - \dot{m}_{red}(t)\|_{\infty}}{\|\dot{m}(t)\|_{\infty}} * 100 \end{cases}$$

Electrical grid



Note: We verified that the current and the voltage of the lines of the reduced model don't exceed the limit values.

Heating network



- ▶ Choose the number of buildings to eliminate by compromising between simulation time and the accuracy of the model.
- ▶ Test on different model scales and scenarios.

Thanks for your attention

- [1] E.-J. Kim, G. Plessis, J.-L. Hubert, and J.-J. Roux, “Urban energy simulation: Simplification and reduction of building envelope models,” *Energy and Buildings*, vol. 84, pp. 193–202, 2014.
- [2] K. Deng, S. Goyal, P. Barooah, and P. G. Mehta, “Structure-preserving model reduction of nonlinear building thermal models,” *Automatica*, vol. 50, no. 4, pp. 1188–1195, 2014.
- [3] A. Sodja, “Object-oriented modelling and simulation analysis of the automatically translated models,” Ph.D. dissertation, PhD thesis, University of Ljubljana, Fac. of El. Eng, 2012.