MODEL-DRIVEN OPTIMIZATION OF BIOMASS CHP PLANT DESIGN

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Abstract. Steady state 0D/1D models are useful to check, validate and improve through simulation the energy performances of existing heat and/or power plants. They are also used to find the best design that meets required economical criteria.
A library of fully static 0D thermal-hydraulics component models was built. It contains the models of a grid furnace, gas combustion chamber, electrical boiler, steam boiler, multifunctional heater, waterwall gas/water steam exchangers, tubular air heater, steam turbine, condenser, aero-condenser, pump, drum, valves, pipes, gas turbine, compressor, kettle boiler, mixer and splitter etc...
This library now enables us to build models of any CHP plant. A 0D multi configurations steady state model of a combined heat and power biomass plant was built, the plant satisfies the steam demand during all the year and produces electricity with its remaining energy.
Model was built by connecting the component models in a technological way, so that its topology reflects the process flow diagram of the plant.
A generic model was developed for design optimisation of CHP biomass plants. This model includes all typical configurations, thus enabling its use through a user-friendly Excel interface. With this interface, comparisons between various architectures according to given criteria and constraints are easy, thus helping the user to define the best design.
The model was then able to compute precisely the distribution of the steam/water mass flow rates, pressure and temperature across the network, the exchangers thermal power, and the performance parameters of all the equipments. It converges very quickly, provided that the iteration variables are properly fed in by the user (approx. 5% of the total number of variables).

1 Introduction

Modelling and simulation play a key role in the design phase and performance optimization of complex energy processes.

Steady state 0D/1D models are useful to check, validate and improve through simulation the energy performances of existing heat and/or power plants. They are also used to find the best design that meets required economical criteria.

The modelling and simulation of the plant was originally carried out with LEDA. LEDA is a tool developed and maintained by EDF since 1982 for the modelling and simulation of the normal or incidental operation of nuclear and conventional thermal plants.

For present and future models, we are using MODELICA modelling tool. New blocks and models are being developed with Modelica and standard guidelines have been adopted for power plants modelling. It is now used at EDF-R&D as well as in some Engineering Departments.

Modelica models are used by EDF to improve its knowledge about existing or future types of power plants, check the design performances and understand important transients situations.

Besides technical benefits of Modelica, it is likely that using a free and non proprietary language will promote partnerships around joint R&D and engineering projects, thus giving the opportunities to share development costs between participants.

The steady State CHP multi-configuration Biomass model was built in 2007 and improved in 2008 with the commercial tool Dymola, as it is the most advanced Modelica based tool up to now.

The Excel interface was developed by EDF R&D. It allows to an operator to carry out parametric studies without Dymola software.

2 Modelling practices at EDF

Modelling and simulation play a key role in the design phase and performance optimization of complex energy processes. EDF traditionally used steady state models in order to check precisely the performances and the design given by manufacturers. EDF used dynamic models to check automation and operating procedures and to optimise design for a specific operation.

In order to improve the performance of its simulation tools while reducing their cost, EDF R&D made the decision to replace LEDA with Modelica and the commercial tool Dymola.

Application fields

- Nuclear power plants.
- Thermal fossil fired power plants (pulverized coal, fluidized bed, ...).
- Combined heat and power plants.
- Waste to energy.

Utilization fields

- Operation and maintenance.
- Design and analysis.
- Innovative technologies.

3 EDF Modelica Library

3.1 Component models

A library of fully static 0D thermal-hydraulics component models was built. It contains the models of a grid furnace, gas combustion chamber, boiler, electrical boiler, steam boiler, multifunctional heater, waterwall gas/water steam exchangers, tubular air heater, steam turbine, condenser, aero-condenser, pump, drum, valves, pipes, gas turbine, compressor, kettle boiler, mixer and splitter etc...

The model equations take into account the non-linear and the state-of-the-art physical behaviour of each important phenomenon.

3.2 The thermodynamic properties

Properties of flue gases

The thermo-physical properties of the flue gases (for the exchangers, gas turbines, compressors, gas combustions chambers, …..) were computed using Fortran subroutines called MONOMELD.

Properties of water and steam

The properties for water and steam were computed from polynomials defined by the international standard IAPWS-IF97. The efficient original Modelica implementation of H. Tummescheit was used.

4 Biomass CHP steady state model

Recent developments of environmental concerns drove states to promote renewable energies and energy efficient solutions. Some invitations to tender often are proposed so as to create new biomass CHP plants at the best operating cost.

4.1 Users Requirements

Companies answering to these invitations to tender for biomass CHP plants shall be able to choose the best configurations for the plants in order to reach the following criteria:

- The yearly average efficiency (steam + electricity) is greater than 50%;
- The plant is able to satisfy the steam demand of the customer (usually an industry) at all time;
- The yearly biomass consumption is fixed;
- The return on investment time is as low as possible.

Usual studies for this type of issue only give an efficiency at nominal point for one or two plant configurations. Models are able to provide various configurations and what-if studies in order to broaden the range of efficiency calculations and help the company to choose the best investment.

One of these companies asked us to assist them by creating and using a thermodynamic model of Biomass CHP plant.

4.2 Building the model

This model uses the static 0D thermal-hydraulics component models library. It is a fully static model. It needs to use the thermodynamic properties (flues gases, water and steam).

The full model is built by connecting the component models in a technological way, so that its initial topology reflects the functional schema of the more complex plant (see Figure 1 in the appendix).

In order to be able to answer to many different situations, we created some variables in some of the component model enabling to switch itself on or off.

This multi configurations steady state model of a combined heat and power biomass plant contains 96 elementary models, generating 2162 variables and 460 non-trivial equations.

4.3 Multi – configuration calculations at normal operating condition

First the model is able to give figures at nominal point for various situations.
The same model can simulate 9 different plant configurations:

- w/wo air heater,
- w/wo reheaters,
- w/wo water heating.

NB: any fuel can be set into the grid furnace, but its physical equations are ideal for solid fuels (coal, waste, biomass etc.).
The plant works with a fixed biomass flow rate, it satisfies the steam demand during all the year and produces electricity with its remaining energy.
We make an inverse calculation with DYMOLA setting the nominal parameters to their expected value in the plant project.
The results given by the model are :

- The efficiency at nominal point (steady state calibration),
- The electric power produced.

These results at nominal point are a first step to choose the best configuration regarding the investment cost of each type of plant.

4.4 Model calibration

The calibration phase consists in setting the maximum number of thermodynamic variables to known measurement values (enthalpy, pressure, mass flow rates), taken from on-site sensors during performance tests. This method ensures that all needed performance parameters, size characteristics and output data can be computed.

For this study, the calibration of the model was made based on data obtained from turbine production maker simulation. The model was then able to compute precisely the distribution of water and steam mass flow rates, pressure and temperature across the network, the exchangers thermal power, and the performance parameters of all the equipments. It converges very quickly, provided that the iteration variables (approx. 5 % of the total number of variables) are properly fed in by the user.

The main computed performance parameters are :

- the ellipse law coefficients of the turbines,
- the isentropic efficiencies of the turbines,
- the pressure drop correction coefficients of the exchangers and of the pipes between pieces of equipment.

Etc.

The main computed outputs are :

- electric power production
- thermal power of exchangers,

- temperatures and pressures in places where no sensor is installed.

Etc.

4.5 What-if steam demand varies?

The results given at nominal point are not consistent to know precisely the average performance on a one-year operation.
Consequently, we use what-if ability of DYMOLA/MODELICA model in order to realize the following computations :

- What-if simulation varying any parameter: e.g. steam flow rate,
- Economic study on a one-year typical steam demand (what-if quasi-static simulation).

For that, a predictive model has been developed based on the nominal dimensioning model.

The forecast of steam demand is defined as a load curve with 365 values of flow rate (one per day). It is based on measurements made by the customer on a past year considered as normal. The variation of the steam flow rate makes the global efficiency vary and changes the electric power produced.

Hence the best yearly average figures (global efficiency, electric power) are given by the model.

It gives a much better forecast of the incomes that will be generated by the plant.

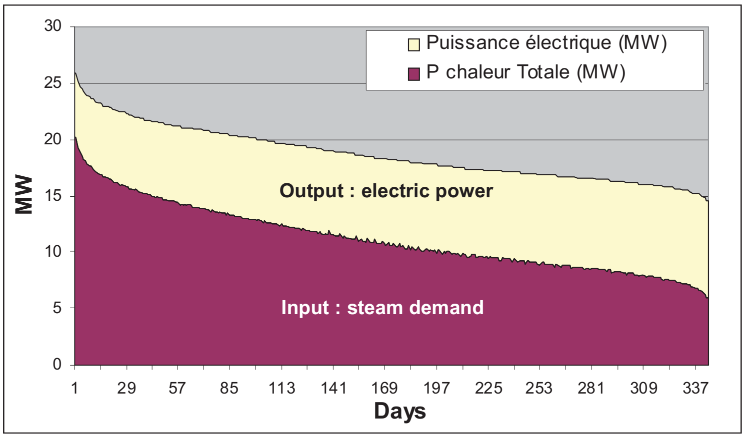
4.6 Creation of a tool for non-modeller

The executable file of the model has been integrated in an easy-to-use Excel sheet for non-modelers, and it was given to our customer.
With this tool, one who is not used dealing with models can make calculations on any plant configuration and launch what-if calculation varying steam demand.
Two files have been created, one for dimensioning biomasse CHP plant, one for predictive year calculations.

4.7 Simulation results

4.7.1 Data Input

- Yearly biomass consumption,
- Yearly load curve (steam demand)
- CHP Global efficiency : > 50 %

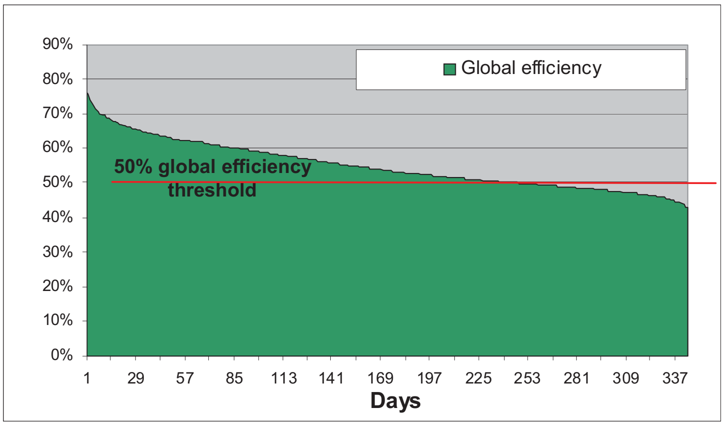


4.7.2 Data output

After calibration, the model allows us to make what-if simulation and provides to the plant operators :

- Electric power,
- The performances of the equipments (for example boiler performances),
- The global efficiencies of the water/steam cycles,

- The gains or extra costs associated with the varying operating conditions of the unit (condenser pressure, exhaust temperature, excess air, fouling coefficients…),
- The best operating point with respect to the various operating conditions of the unit.



5 Conclusion

The Steady State CHP biomass model shows the capacity of Modelica based tools to perform steady state direct and inverse computations for the sizing of power plants.

To even further reduce the effort required to do Modelica modelling and simulation for such systems, it is necessary to provide more advanced tool functionalities to handle efficiently the iteration variables, and trace the automatically generated numerical system back to its original mathematical equations, as declared by the user with the Modelica language.

Nevertheless, this work shows that the Modelica technology is mature enough to replace proprietary solutions such as LEDA for the steady state modelling and simulation of power plants.

The another advantage is the capacity to adapt an Excel file simulator for parametric studies. With this tool, a non-specialist in modeling can find the best efficient CHP on one year simulated work.

6 References

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Appendix

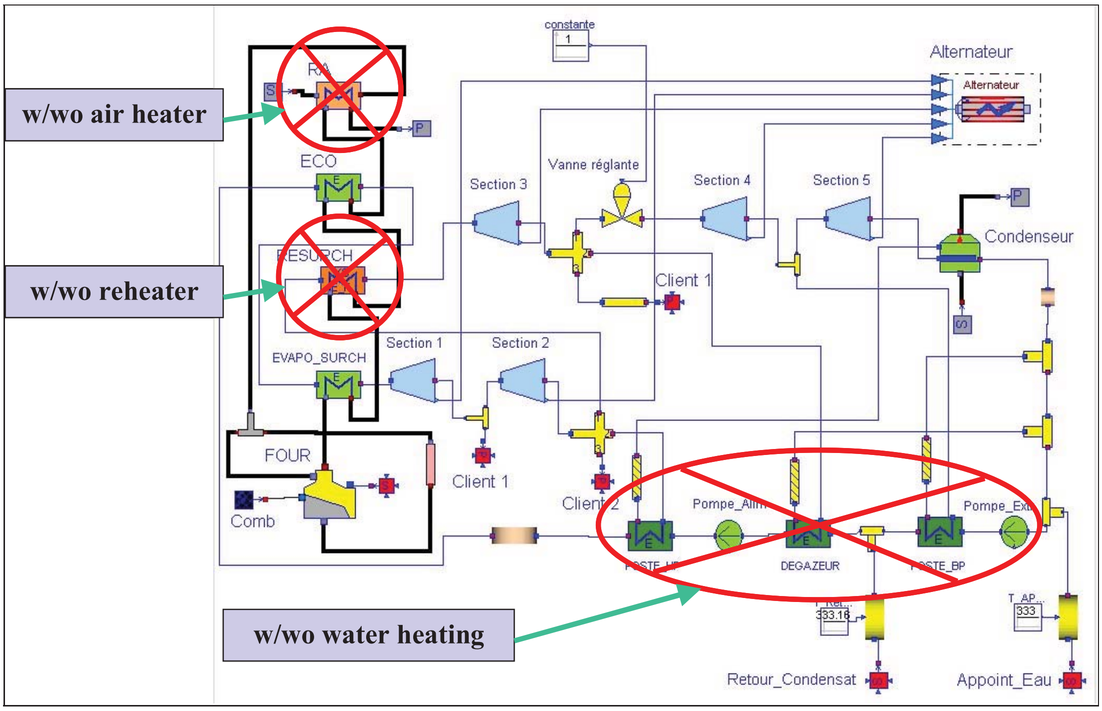

Figure 1 : Dymola steady state model of a biomass CHP plant

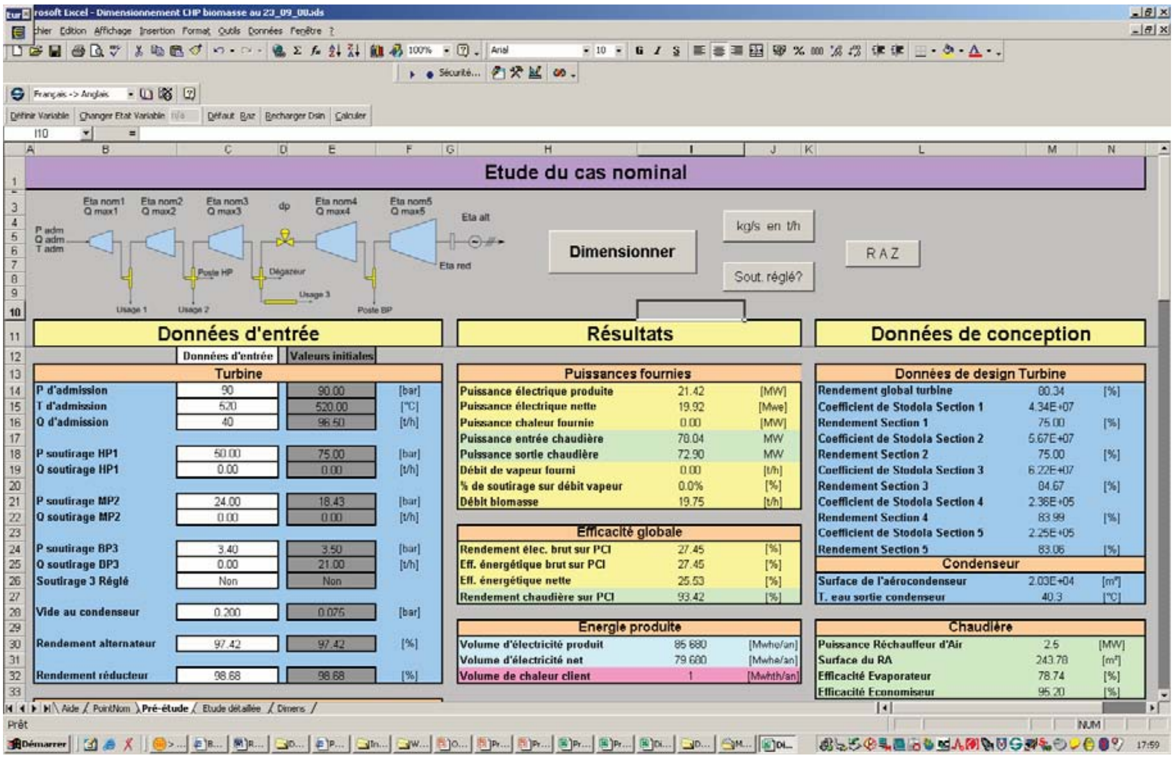

Figure 2 : Excel interface to compare various biomass CHP architectures in nominal case

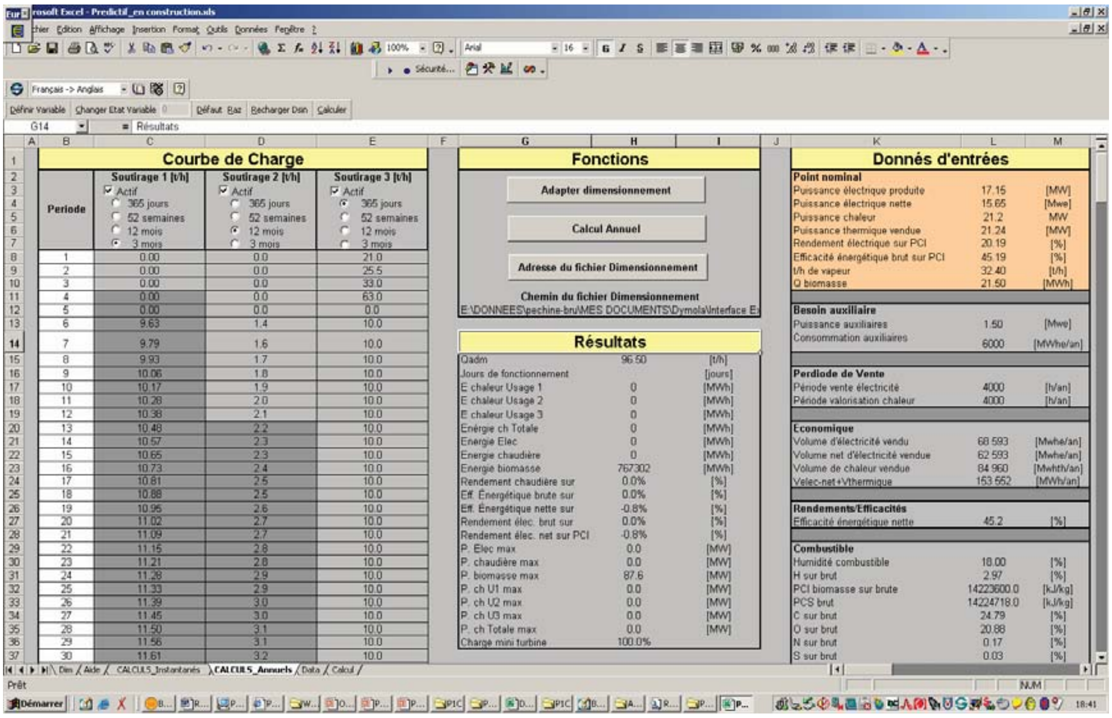

Figure 3 : Excel predictive interface of energy production calculation with integration of one year load curve