Conference Proceedings

EuroSun 2016
Palma de Mallorca (Spain), 11 - 14 October 2016

Industrial Integration of Mid-Temperature Solar Heat – First Experiences and Measurement Results

Alois Resch[1], **Rudolf Kraft**[1]

[1] Fachhochschule Oberösterreich Forschungs & Entwicklungs GmbH, A-4600 Wels

Abstract

The integration of solar thermal energy at mid-temperature level (up to 200 °C) in industrial applications has an enormous potential. Developing a flexible simulation environment within the software MATLAB/Simulink for various kinds of industrial processes is therefore one of the main goals of the present project work. Furthermore, a modular hydraulic system has been developed and installed at the University of Applied Sciences Upper Austria, which provides the possibility to recreate processes on a laboratory scale in order to gain measurement data for verifying and adjusting the simulation environment. A centerpiece of the hydraulic system is a concentrating solar collector (Fresnel system) driven by thermal oil, which is currently being operated within a long-term measurement to achieve a comprehensive characterization at the location of Wels, Austria.

By the end of this project work a simulation environment with unique reliability will be available, which will highly support the integration of mid-temperature solar energy in industrial processes.

Keywords: *Fresnel, mid-temperature, solar thermal, industrial processes*

1. Introduction

Solar thermal energy is worldwide already well established for applications like domestic hot water generation, where temperatures of up to 100 °C are required. For temperatures beyond this limit there is still a huge potential for the substitution of fossil fuels by solar energy. Therefore, the present project was started to investigate the integration of mid-temperature solar thermal energy (up to 200 °C) for various applications in the industrial sector.

The centerpiece of this project is a modular hydraulic system consisting of several heat sources and heat sinks that can be combined in a very flexible way by a loop to be able to emulate different cases of application, like solar cooling, solar district heating or industrial process heat. One hydraulic loop works with water and can handle configurations up to 95 °C, whereas the second loop is driven by thermal oil for applications up to 200 °C. The central mid-temperature heat source is a Fresnel collector with an aperture area of 22 m², which provides the heat to the thermal oil loop by a plate heat exchanger. One of the heat sinks is an absorption chiller with a cooling power of 19 kW, driven by the water loop with temperatures up to 95 °C.

doi:10.18086/eurosun.2016.02.11 Available at http://proceedings.ises.org

In parallel to the hydraulic investigation of these applications another main task of this project is to develop a dynamic simulation of the entire hydraulic system using the software MATLAB/Simulink. After a deep verification of the simulation environment by matching the simulation results with the measurement results, it will be extended to a “hardware-in-the-loop” system, so that single hydraulic components can be characterized with a simulated environment.

By the end of this project work a verified and well tested simulation environment will be available to analyze and optimize the integration of solar thermal energy in industrial processes. Applications with a thermal power of up to 50 kW can also be demonstrated and measured on the modular hydraulic testing center.

2. Functional requirements

The designing phase of this system started with a definition of the functional requirements. The three main limitations in functionality are the following:

- Heat transfer medium only in liquid phase (steam or gas applications are not considered)
- Maximum application temperature: 200 °C
- Maximum thermal power: 50 kW

The required operation modes of this test stand were summarized in flow charts like the one that is displayed in Fig. 1.

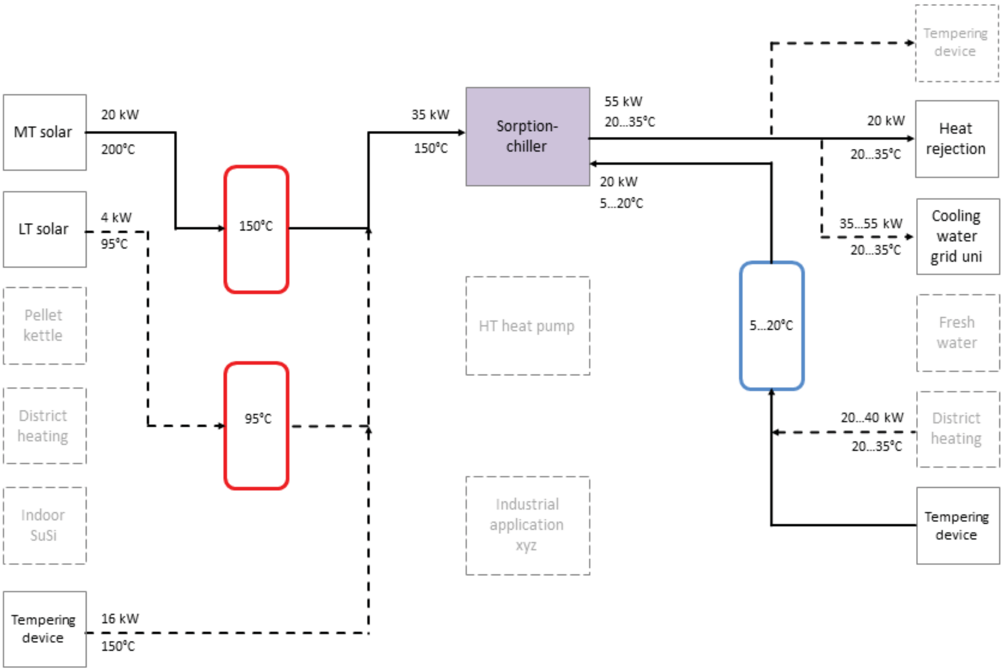

Fig. 1. Flow chart of operation mode “sorption chiller”

Using this kind of flow charts for describing the various configurations within the hydraulic system (heat sinks and heat sources) provides an appropriate overview of the thermal energy flow and shows the activated parts for each operation mode. The implemented components are the following:

- MT Solar: Mid-Temperature solar thermal collectors; 11 m² vacuum tube collectors + 22 m² Fresnel collector
- LT Solar: Low-Temperature solar thermal collector; optional flat plate collectors (up to 8 m²)

- Pellet boiler: 15 kW
- District heating: interface to the local district heating supplier (optional)
- Indoor SuSi: Connection to the available indoor sun simulator (optional)
- Tempering device: provides heating and cooling power at a precise temperature
- Heat rejection: optional connection of heat rejection for sorption chiller
- Cooling water grid uni: university´s internal cooling water for all kinds of heat rejection; constant temperature of 15 °C is provided
- Fresh water connection
- Thermal oil storage: two tanks with a volume of 1,300 liters
- Cold water storage: tank with a content of 1,000 liters; used as cooling load
- Hot water storage: tank with a content of 1,000 liters; used as storage for the low-temperature solar thermal collectors resp. as heat source for all water applications
- Sorption chiller: Cooling power of 19 kW

3. Hydraulic concept, simulation and engineering

The basic hydraulic concept of connecting the mentioned high number of heat sources and heat sinks by a loop is illustrated in Fig. 2. Depending on the required operation mode each branch of the loop (collector, district heating…) can be either activated or by-passed, providing the possibility to realize various combinations of the hydraulic components. This first loop is driven with silicon oil, so that all applications with temperatures between 100 °C and 200 °C can be operated without exceeding the boiling point of the fluid.

The second loop driven with water for low temperature applications is realized in a similar way, including a tempering device, water storage, the district heating interface and the absorption chiller.

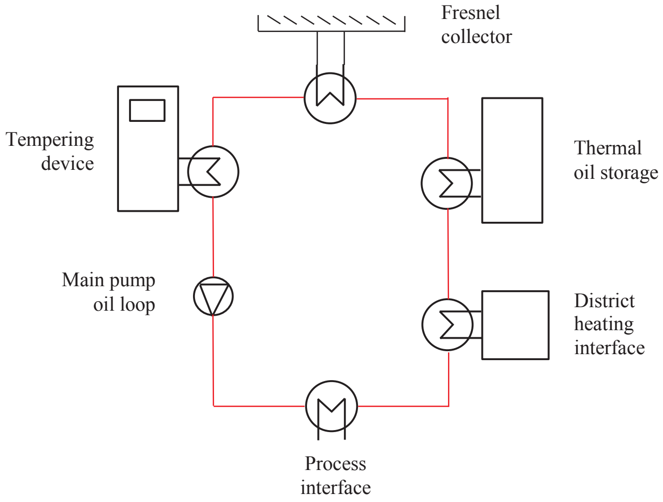

Fig. 2. Hydraulic concept of the thermal oil loop

All heat exchangers are equipped with temperature sensors on the inlet and outlet. In combination with a precise mass flow measurement in each separate hydraulic circuit all heat transfers (positive and negative) can be measured very exactly.

Basing on the hydraulic concept, first calculations of the system have been performed to quantify the main parameters like pipe dimensions, pressure losses, pump dimensions, mass flows etc. These first designing results have been used as initial information to set up the hydraulic circuits within the simulation software MATLAB/Simulink. The following Fig. 3 displays a segment of the simulation of the water loop with the collector circuit and its interface to the hydraulic ring (heat exchanger in red). With this detailed simulation the hydraulic engineering of the entire system could be finalized in a much more precise way. Furthermore, the simulation of different control strategies for all possible combinations of heat sinks and sources provided valuable information for a reliable and safe operation of the system.

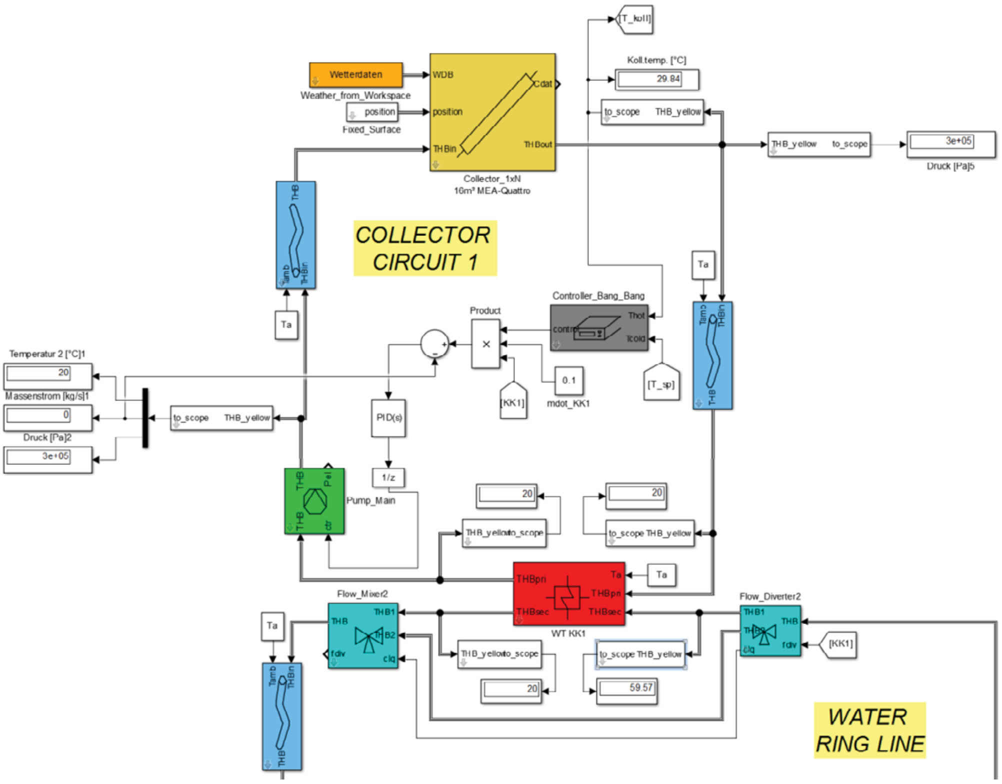

Fig. 3. Simulation segment of the water loop in MATLAB/Simulink

The basis for the final engineering of this test bench was the detailed hydraulic schematic, which cannot be illustrated within this paper due to its complexity and dimension. Nevertheless, the following numbers of implemented appliances and fittings shall demonstrate the scale of this hydraulic system:

- 14 pumps: speed-controlled
- 27 valves: 3-way, mainly motor driven
- 14 plate heat exchangers
- 300 m of pipes
- 10 mass flow meters
- 69 temperature sensors

4. Selected components in detail

4.1. Concentrating collector

The main solar heat source of this test stand is a Fresnel collector shown in Fig. 4. It works with 110 planar mirrors (dimension 70 mm x 2860 mm) reflecting the sunlight to the linear absorber, which consists of a steel pipe with selective coating, a glass cover and a secondary reflector. The collector has a total dimension of 5.8 m x 4.6 m (gross area 26.68 m², mirror area 21.68 m²) and a weight of 740 kg.

Fig. 4. Installed Fresnel collector [Fresnex, 2015]

4.2. Thermal oil storage

Two tanks with a volume of 1,300 liters each are used as mid-temperature storages. Mineral heat transfer oil serves as storage medium, whereas the oil is not stored stationary in the tanks. During each charging or discharging cycle the thermal oil is pumped from one tank into the other one, ensuring that the temperature at the heat exchanger to the loop is always constant for the cycle time. The empty volumes of the tanks are filled with Nitrogen to achieve a passivation of the oil surfaces.

As the implemented pump is not able to turn its direction of rotation, an external hydraulic solution had to be found to be able to change the flow direction between the two tanks. Therefore, two motor driven 3-way-valves (V901 and V902) were installed, see Fig. 5.

Temperature sensors and filling level sensors are also implemented in the construction of the tanks in order to guarantee a safe and well monitored operation of the mid-temperature storages.

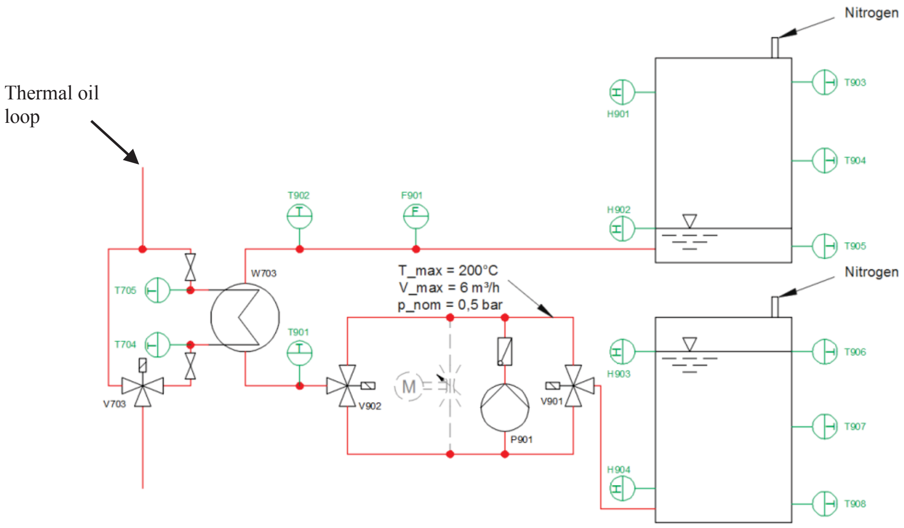

Fig. 5. Hydraulic implementation of thermal oil storages

4.3. Control and measurement equipment

The main goal of this test stand is to quantify the transfer of thermal power as precise as possible. The necessary information of mass flow and temperature difference is gained by using the following measurement equipment:

- Magnetic inductive flow meters for all water circuits: accuracy < 0.2 % of measured value
- Coriolis flow meters for all thermal oil circuits: accuracy < 0.1 % of measured value
- Temperature sensors PT100 1/10 DIN

The data of all sensors in the system are centralized by a programmable logic controller (PLC), which operates and controls all appliances and components of the test stand by applying appropriate control algorithms.

As the testing center will be used for research tasks as well as for demonstration and teaching purposes, operation and measurement of this complex system must be possible in a simple way. Therefore, the creation of full system visualization was mandatory. The visualized low temperature part can be seen in the following Fig. 6.

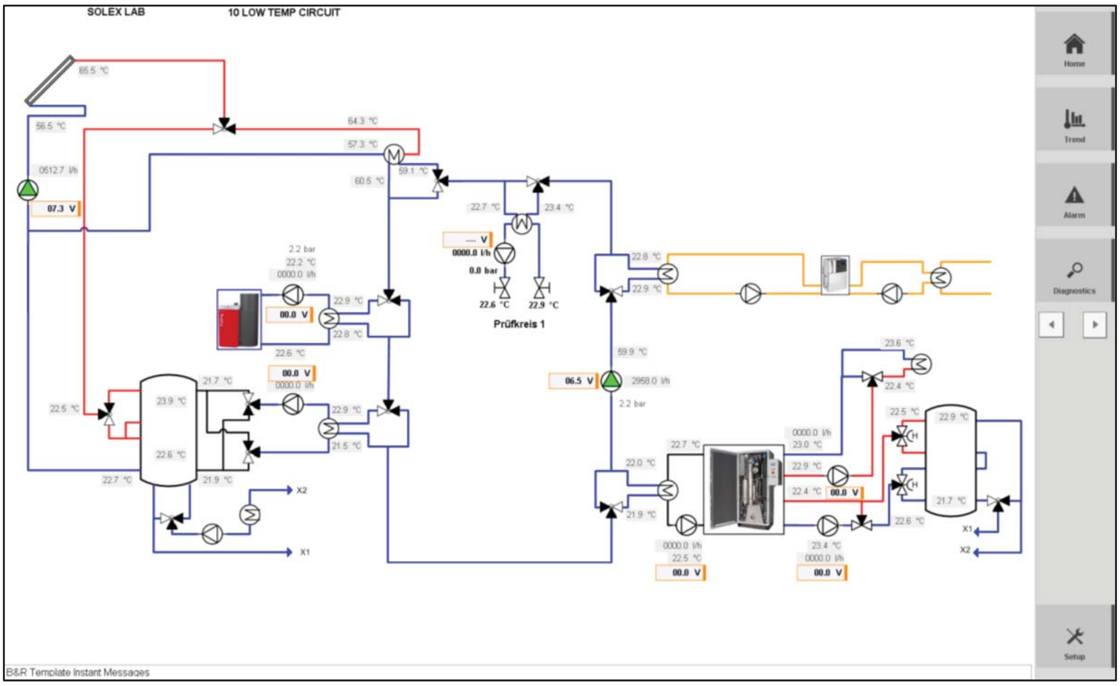

Fig. 6. Visualization of the low temperature part of the testing center

5. Start-up phase and first measurement results

During the start-up phase of the entire hydraulic system each branch and each hydraulic combination was tested thoroughly. Algorithms for the mass flow control had to be implemented, as well as various safety strategies to ensure reliable operation within the specified limits of the test stand.

Exemplary among all performed start-up measurements, Fig.7 illustrates the hydraulic configuration for the operation mode "pellet boiler characterization". Only the components drawn in solid line are activated in this setup, whereas all other parts of the low temperature system are by-passed or inactive (dotted line). The pellet boiler provides its heat via the plate heat exchanger to the water loop, where the energy is transferred to the heat exchanger of the hot water storage by the main pump. Furthermore, the pump of the hot water storage circuit feeds the transferred thermal energy into the tank.

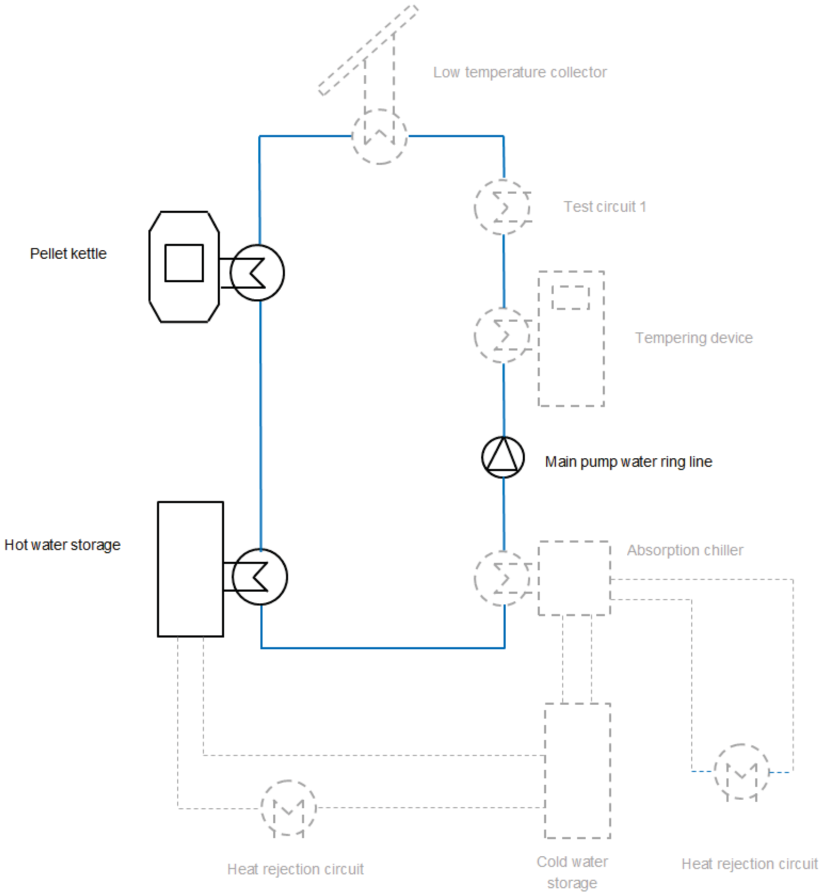

Fig. 7. Hydraulic setup for the characterization of a pellet boiler

Due to the mentioned speed-controlled pumps and the available tempering device, the pellet boiler can be driven with all possible thermal loads between 1 and 20 kW as well as a wide range of return flow temperatures between 10 °C and 95 °C.

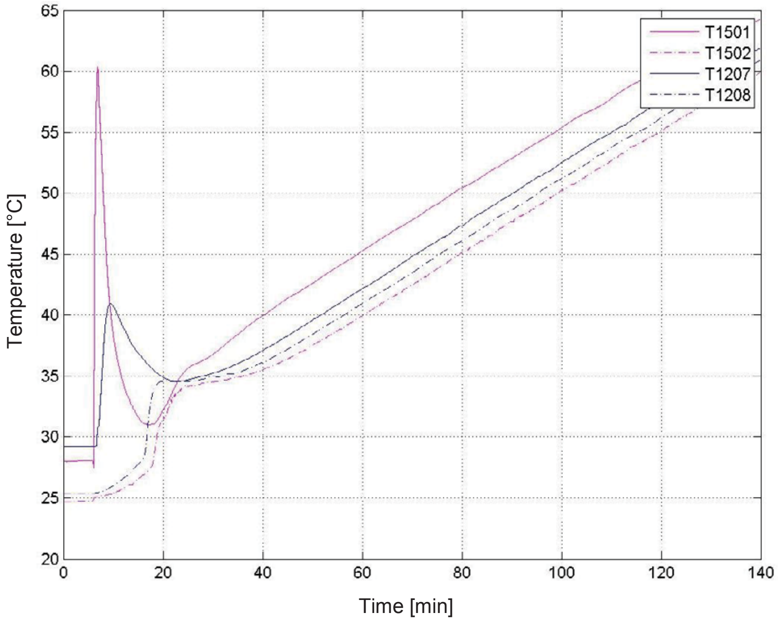

Fig. 8. Temperature rise during the characterization of a pellet boiler

For this described start-up measurement the hot water storage tank had an average temperature of 27 °C. The pellet boiler was pre-heated to an internal temperature of 67 °C. After starting the heat transfer from the boiler to the storage tank, the temperature rise displayed in Fig. 8 could be observed. After a stabilizing phase in the first 20 minutes of the measurement the temperatures rise constantly.

The temperature sensor T1207 is located in the storage tank at the height of the outlet connector. During the measurement period between "minute 30" and "minute 110" this sensor shows a temperature increase from 35 °C to 55 °C. Assuming that around 800 liters of the content of the storage is circulated in this configuration, the required thermal power can be calculated as follows:

$$P = \frac{m * c_p * \Delta T}{t} = \frac{800\ kg * 4.187\ \frac{kJ}{kg * K} * 20\ K}{80 * 60\ s} = 13{,}96\ kW \qquad \text{(eq. 1)}$$

The pellet boiler has a nominal power of 15 kW, meaning that the start-up measurement shows reasonable results.

6. Outlook and further work

The long-term aim of this entire project is to increase the use of mid-temperature solar energy to substitute fossil fuels in various industrial processes by providing a flexible and dynamic simulation environment. The basis for this simulation environment was already created during the engineering process for the hydraulic test stand, but further refining and extension has to be done. Moreover, new simulation models have to be created within the used CARNOT-blockset of MATLAB/Simulink to be able to apply the simulation environment for a large number of industrial processes.

In parallel to this simulation work all possible operation modes of the test stand have to be measured and characterized in a more detailed way and in long-term operation in order to gain statistical relevant amount of data. This experimental information will afterwards be used to verify and adjust parameters in the simulation environment, which provides the opportunity to realize a high precision and dynamic simulation tool for a substantial number of different industrial processes in the mid-temperature range.

7. Acknowledgements

The described work is carried out within the project "SOLEX – Solare Exergiebereitstellung", which is partially funded by the program "COIN-Aufbau", supported by the Austrian FFG (Forschungsförderungsgesellschaft).

8. References

Fresnex GmbH, Brown-Boveri-Straße 1, 2351 Wiener Neudorf, Austria, 2015