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Simulation of on-site generation CHP systems for large-scale data centre

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Abstract

The increasing use of information technology services causes a raising energy demand of data centres. To cover the requirement and respond to the energetic and environmental goals, fossil fuels need to be replaced by renewable energy sources, and methods to increase the process effectivity have to be applied. The complex integration of different energy systems to the technical infrastructure of the data centres is challenging. Within the RenewIT project [1], fourteen thermal and electrical power supply concepts for data centres have been investigated. Regarding intermediate results of the project, the four concepts with CHP provide the most promising solutions. One of the concepts with combined heat and power production (CHP), the system with syngas reciprocating internal combustion engine system, is presented to show the methodology of modelling and simulating non-series products with EBSILON [2], transfer the complex part load behaviour into a correlation equation of heat and power and integrate this information into TRNSYS [3] to increase data processing and minimize computing time.

Keywords – Data Centres, simulation, TRNSYS, EBSILON, CHP, power, heat, cold supply

1. Introduction

The energy consumption of data centres in Germany amounts 10.000 GWh/a and is raising up to 3 % each year [4]. The effect of methods to increase the efficiency of data centres is not enough to fulfil the energy and environmental goals being set. Therefore, investigations within the RenewIT project are based on a holistic approach to cover the energy demand of data centres mainly with renewable energy (> 80 %). Fourteen thermal and electrical power supply concepts for data centres have been developed (Table 1).

Concepts with thermal and electrical energy storage, CHP, renewable energy sources and other solutions are considered.

Table 1: Characteristics of energy supply systems for data centres [5]

No. concept/scheme	liquid-cooled server	free cooling				chiller		cold storage			district cooling	national power grid	battery storage		renewable energy sources for power and possibly heat production				heat storage		heat feed-in	heat pump for temperature rise
		air	cooling tower	sea water	aquifer	compression	absorption	buffer, cold water	ice	cold water	district cooling	national power grid	lead acid	lithium ion	PV	wind	waves	CHP with biomass	buffer, warm water	warm and hot water		
1		x	x			x			x			x										
3		x	x				x	x				x						C	x		x	
4	x	x									x	x									x	x
5		x	x			x		x				x										
6		x				x		x				x	x		x	x						
7		x				x				x		x										
8		x				x		x				x		x								
9		x					x	x				x						G/ C		x	x	
11		x					x	x										St	x		x	
12				x								x					x					
13		x			x							x									x	x
14		x				x				x		x		x								
15		x					x	x				x						FC	x		x	
16		x					x		x			x	x									

C… CHP
G… Gas synthesis
St… Steam power plant
FC… Fuel cell

Concepts with thermal and electrical energy storage
Concepts with CHP
Concepts with renewable energy sources (except air)
Concepts with other solutions

Out of fourteen concepts [5] investigated, the four concepts 3, 9, 11 and 15 with CHP provide the most promising solutions concerning the main evaluation criteria of (non-renewable) primary energy demand per IT power capacity $Pe_{DC,nren}$, renewable energy ratio RER and power usage effectiveness PUE [5]. The non-renewable primary energy is defined as the required energy to supply one unit of delivered energy, including the non-renewable energy required for extraction, processing, storage, transport, generation, transformation, distribution and other operations necessary for delivery to the Data Centre. The renewable energy ratio is calculated as the ratio of primary energy of all energy inputs to contribute to cover the end energy demand and the total primary energy of all the energy needs. The power effectiveness ratio is the total energy of the Data Centre divided by the IT energy consumption [6].
Since the concepts with CHP show such exceptional results, great efforts have been made to increase the efficiency of software used to model and simulate these concepts.

2. Method

One of the concepts with CHP, the system with syngas reciprocating internal combustion engine (concept 9), is presented illustrative in this paper to show the methodology of modelling the concepts. Figure 1 demonstrates the thermal scheme of this system.

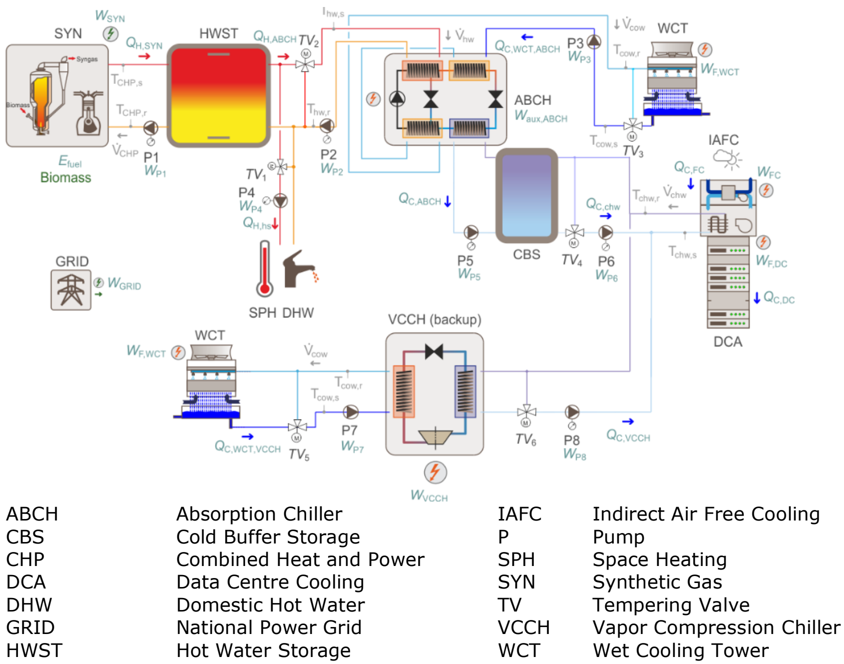

Figure 1: Thermal scheme of system with syngas reciprocating internal combustion engine (concept 9) [5]

A gasifier generates syngas. Part of the heat from the CHP is used to dry the solid biomass before entering the gasifier. The remaining heat drives a single-effect absorption chiller during summer and supplies space heating for offices or buildings close to the data centre during winter. With the hot water storage (HWST), generation of heat, power and cooling is decoupled from the heating and cooling demand. In winter, indirect air free cooling provides the cooling demand of the data centre. For transient investigations of the interaction between the subsystems of concept 9 (Figure 1), TRNSYS modelling software is used. Each of the eight subsystems has a complex transient behaviour. Except for the CHP subsystem with syngas reciprocating internal combustion engine (SYN), the elements of concept 9 are series products that can be modelled and parameterized in TRNSYS. Whereas the CHP subsystem (SYN) is a custom-made device without a suitable model being available.

Additionally, in the framework of the project various parametric studies of the thermal and electrical power supply concepts are conducted in TRNSYS to investigate the influence of data centre power, location, etc. Calculating the detailed subsystem of the CHP within these studies would have extended the computing time enormously. To get the information needed for modelling the CHP subsystem and transfer the output to TRNSYS, a new method was developed.

Figure 2 shows the methodology used. The first step is modelling and simulating the non-series product of the CHP subsystem with the syngas reciprocating internal combustion engine (SYN) in EBSILON. Then the complex part load behaviour is transferred into a correlation equation of heat and power, and finally this information is integrated into TRNSYS in order to minimize computing time.

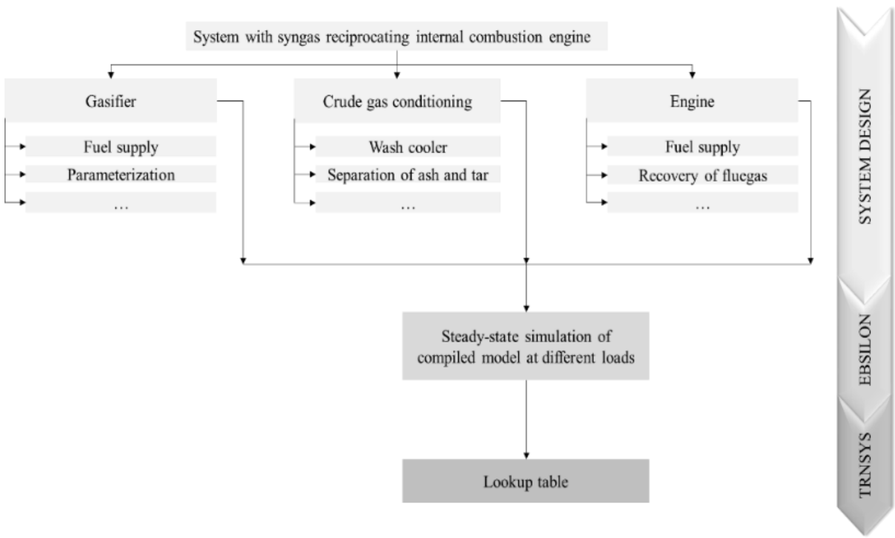

Figure 2: Methodology to increase the effectivity of TRNSYS simulations using EBSILON

The challenge was to design the CHP subsystem and generate as much information as possible with the poor available data from literature and data sheets by the manufacturers. The main advantages of using EBSILON to analyse the steady-state part load behaviour are the provided library of elements needed to model the CHP subsystem as well as the flexibility of assembling basic elements to build individual systems as shown in Figure 3 for an example system with syngas reciprocating internal combustion engine. The main elements of the model are the solid biomass conversion, the conditioning of the crude gas and the energy conversion to heat and power in a heat-driven natural gas-fed CHP plant. Besides the CHP plant, each element of the model had to be parameterized individually due to the lack of standardized data of this concept.

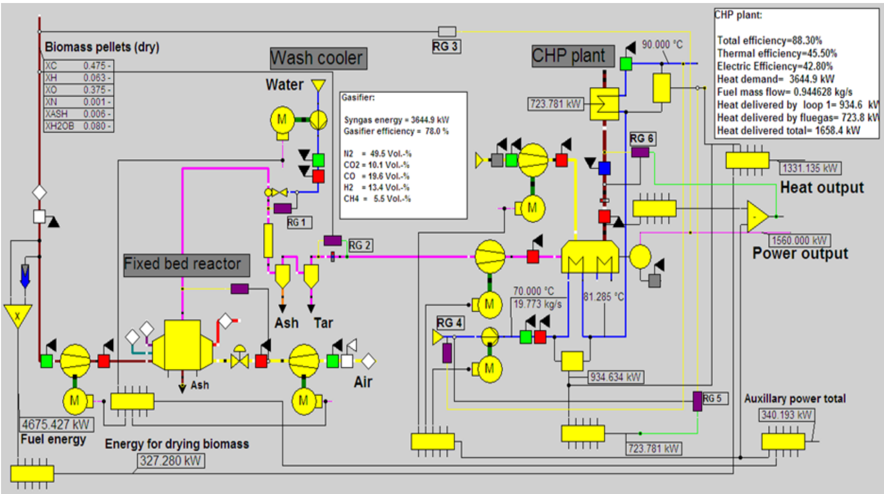

Figure 3: EBSILON model of synthetic gas reciprocating engine CHP plant based on Table 1

The CHP subsystem for concept 9 has been modelled in four power ranges based on the natural gas-fed engines selected from datasheets by the manufacturers (Table 2). Actually, using synthetic gas as fuel requires synthetic gas-fed engines. Since these engines are custom-made devices based on natural gas-fed engines and no datasheet is available, the parameters of natural gas-fed engines listed in Table 2 are considered for modelling instead.

The two relevant outputs of these simulation are the derivation of the relation between the electrical and the thermal efficiency of the system for different loads as well as the power to heat ratio at different power ranges. To use this information in TRNSYS efficiently for further transient calculations, correlation equations summarize the information.

Table 2: Key Data (electrical power output W_{CHP}, thermal power output $\dot{Q}_{CHP}$, fuel energy E_{fuel}, electrical efficiency η_{el}, thermal efficiency η_{th}, total efficiency η_{ges}) of natural gas-fed engines [7]

No.	type	engine	W_{CHP} [kW]	$\dot{Q}_{CHP}$ [kW]	E_{fuel} [kW]	η_{el} [kW]	η_{th} [kW]	η_{ges} [kW]
1	ENERGIN M06 CHP G173	gas Otto engine	173	264	483	35.8	54.7	90.5
2	8V4000 L33-110	gas Otto engine	849	948	2054	41.3	46.2	87.5
3	16V4000 L33-100	gas Otto engine	1560	1662	3649	42.8	45.5	88.3
4	12V32GD	gas Diesel engine	5299	5179	11907	44.5	43.5	88.0

Figure 4 shows the TRNSYS scheme of the heating macro for the concept 9. The electrical, thermal and the total efficiencies of the CHP system at different loads are fed into the lookup table of the heating macro. From this table, the needed efficiency of the CHP system is calculated in order to determine the amount of heat $\dot{Q}_{CHP}$ and electricity W_{CHP} produced by the CHP in the simulation.

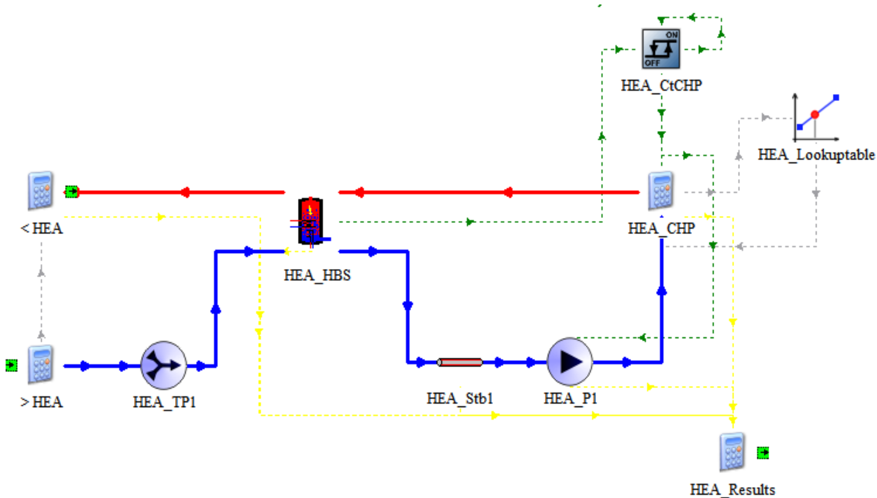

Figure 4 TRNSYS scheme of the heating macro for the concept 9

The following equations are used for calculating the amount of heat and electricity produced:

$$\phi_H = \frac{\dot{Q}_{CHP}}{\dot{Q}_{H,max,CHP}} \tag{1}$$

$$\phi_{el} = \frac{P_{el}}{P_{el,max,CHP}} \quad (2)$$

$$\phi_{max} = max(\phi_H, \phi_{el}) \quad (3)$$

$$\dot{Q}_{H,eff} = \dot{Q}_{H,max,CHP} \cdot \phi_{max} \quad (4)$$

$$\dot{E}_{fuel} = \frac{\dot{Q}_{H,eff}}{\eta_{th}} \quad (5)$$

$$P_{el,eff} = E_{fuel} \cdot \eta_{el} \quad (6)$$

Here, ϕ_H and ϕ_{el} are the load factors in terms of heat and power respectively, $\dot{Q}_{CHP}$ and P_{el} are the required amount of heat and power to be delivered by the CHP, $\dot{Q}_{H,max,CHP}$ and $P_{el,max,CHP}$ are the maximum amount of heat and power produced by the CHP, $\dot{Q}_{H,eff}$ and $P_{el,eff}$ are the generated heat and power and $\dot{E}_{fuel}$ is the enthalpy delivered by the fuel.

3. Results and Discussion

The results of the design and part load steady state simulations of the system with synthetic gas reciprocating engine using EBSILON are depicted in Figure 5 and Figure 6. Figure 5 shows the electrical and thermal efficiency of the system at different loads. These efficiencies are calculated as the ratio of electrical power or heat and the product of the net calorific value and the mass flow of the raw fuel, in this case solid biomass pellets at normed conditions. For validation, values based on literature for the efficiencies of the main subsystems, synthetic gas fed CHP engine and the gasifier, are compared to the results of the simulation (Table 3). It can be seen that the electrical efficiency of the CHP engine differ for 100% load. Due to a high dependency of the thermal and electrical efficiency ratio and the load case (Table 3) [8], it might be possible that the compared results are based on different load cases and therefore lead to this deviation.

Table 3: Validation of the simulation results of the main subsystems of the synthetic gas reciprocating engine CHP plant (Figure 3) based on [9]

	Values based on literature [9]	Simulation results			
		100% load	75% load	50% load	25% load
Gasifier	78	78			
Thermal efficiency CHP-engine	46	46	46	47	48
Electrical efficiency CHP-engine	35	43	42	40	36

This typical dependency of the CHP engine subsystem determines the overall behaviour of the synthetic gas reciprocating engine CHP plant as illustrated in Figure 5. The thermal efficiency increases and the electrical efficiency declines with decreasing load.

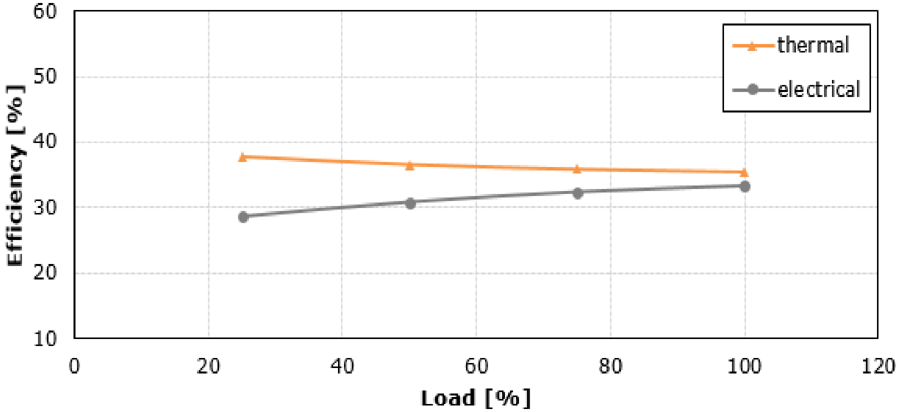

Figure 5: Electrical and thermal efficiency of synthetic gas reciprocating engine CHP plant with different loads

In Figure 6 the results of simulating the synthetic gas reciprocating engine CHP plant in different power ranges are summarized by the power to heat ratio at different CHP power outputs.

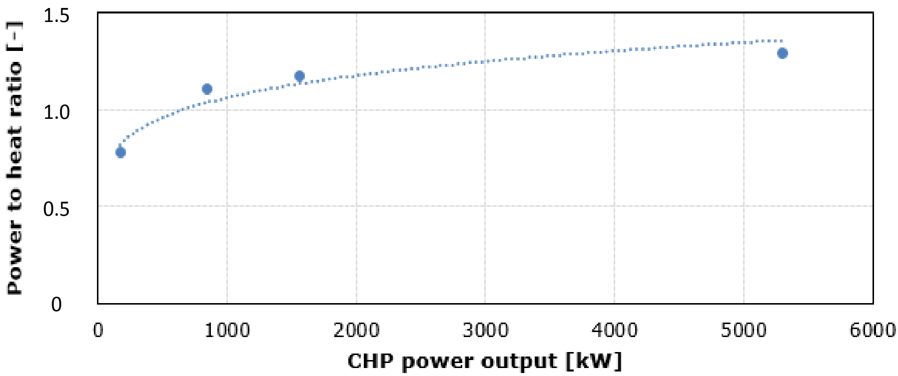

Figure 6: Power to heat ratio at different sizes of synthetic gas reciprocating engine CHP plants

To transfer these results into the macro that was modelled in TRNSYS using a look-up table function, the following correlation equation 7 is derived from the electrical power P_{el} and thermal power $\dot{Q}_{CHP}$ generated by the system with synthetic gas reciprocating engine and can be described with a potential approach as follows:

$$P_{el} = 0.327 \cdot \dot{Q}_{CHP}^{\ 1.172} \tag{7}$$

4. Conclusion

Regarding intermediate results of the RenewIT project, based on the fourteen concepts developed the four concepts with CHP subsystems provide the most promising solutions. For one of these concepts, the concept with syngas reciprocating internal combustion engine subsystem, an effective methodology of simulation is presented. The concept is modelled and simulated with TRNSYS for transient calculations and parametric studies. To model the non-series CHP subsystem of the concept, the provided system library of TRNSYS is not sufficient. Therefore, EBSILON is used to calculate the part load behaviour of the subsystem at four different power ranges. As a result of the part load EBSILON simulations, a correlation equation describing the relationship between the thermal and electrical output is presented. In addition, the power to heat ratio at different power ranges of the CHP subsystem can be derived. These information provided by the EBSILON simulations are exported to the TRNSYS model for further calculations. With this approach, a major contribution has been achieved to and minimize computing time.

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