POSSIBILITIES AND EFFECTS OF BIOMASS ENERGY CONVERSION IN RENEWABLE HYBRID SYSTEMS WITH COMBINED HEAT AND POWER

K. Brinkmann
University of Applied Sciences Trier, Germany
Umwelt-Campus Birkenfeld, Automation Department
P.O Box 1380, D-55761 Birkenfeld, fax: +49-6782-171454,
e-mail: klaus.brinkmann@envipro.de

ABSTRACT: This contribution presents a detailed analysis of the possibilities and effects of combined heat and power systems with biomass in combination with photovoltaic solar energy and wind power as hybrid systems. Foundations are general criteria for the dimensioning of such hybrid systems with combined heat and power, especially for private households as a calculation unit, concerning climate conditions in middle Europe. The criteria and foundations are presented and discussed in a mathematical manner, with respect to further applications in computer simulations. The influence of the solar or/and wind electrical energy contribution on the power to heat ratio leads to a differentiated point of view concerning the technical abilities of the different kinds of combined heat and power units. The consequences on the general possibilities and effects on the usage of biomass, including dimensioning and control mechanisms have been worked out and will be discussed.
Keywords: hybrid systems, combined heat and power generation, modelling

1. INTRODUCTION

The presented analysis is a consequent further step for a generalisation of a research project concerning a completely self-sufficient energy-supply system for summer/winter or mixed conditions, including a photovoltaic system and an additional equipment with combined heat and power like modern steam engines [1]. To reach this aim, such hybrid systems have been examined with the help of experimental investigations [2]. Additional theoretical analysis and computational simulations were helpful to build up process schemes with all necessary components and to determine their sizes [3].

2. HYBRID SYSTEM PRINCIPLES

Important for a successful implementation of such a hybrid system is to guarantee a gap free energy supply. The determination of the sizes of the components of the combined heat and power equipment including the heat exchanger depends on the time correlated functions of the insolation for the PV-plant as well as on the energy consumption of the private household. With respect to the stochastic behaviour of the energy production of the PV-plant, storage batteries for electrical energy are involved. The key-function for the dimensioning of the components is the time dependent ratio of electrical current to heat, with respect to the energy production of the PV-plant and/or wind energy converter. Following the perceptions based on a special combined heat with a steam engine presented in Seville [2], this paper presents a more general analysis of the combined influence of PV and wind on the different actually most used and discussed combined heat and power biomass systems. The PV-wind-system changes significantly the ratio of power to heat as well as the conditions for their dynamical behaviour. This has an effect on the necessary control concept [4]. Important is, in consequence of an additional stochastically electrical supply, the partial load ability of the combined heat and power equipment. The now presented analysis bases on the conditions for private households in Germany (middle Europe) as a calculation unit which could be scaled up. With the use of biomass, such hybrid systems enable a controllable energy-supply-system totally based on renewable sources.

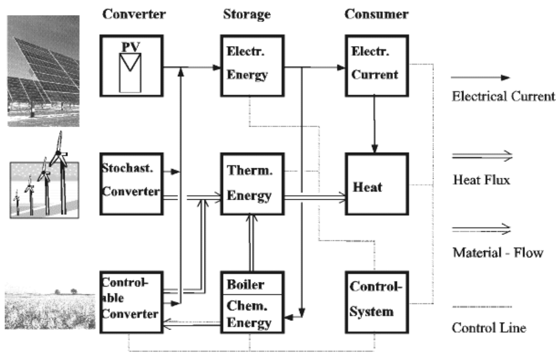

Figure 1: Fundamental Systematic of Hybrid Systems

Figure 1 shows the general realisation principle of hybrid systems with combined heat and power, the integration of additional converter is optional. Here the basic element is exemplary chosen to be a wind turbine. The additional converter to the wind turbine could be distinguished between *stochastic* and *controllable* converter. In each group, combinations of these converter are also possible. Possible ***stochastic converter*** are, apart form the basic element wind turbine, the following converter:

- *Photovoltaic System*
- *Small Hydro Power Plant*
- *Thermal Solar Collector (heat only).*

Thermal solar collectors could be used in the most cases for only a partially covering of the heat demand, and their required insolation area is in concurrence to the photovoltaic. So-called hybrid collectors for thermal as well as photovoltaic conversion are still in the research and development status. Basis for the use of controllable converter is in general also solar energy in stored form like biomass.

Possible controllable converter are:

- *Fuel Cell (H2, biogas reforming, etc.)*
- *Vegetable Oil Motor*
- *Biogas-Motor*
- *Stirling-Motor (external combustion of Biomass)*
- *Steam Engine (external combustion of Biomass)*
- *Thermoelectrically Converter (bio fuels)*
- *Geothermal-Converter.*

These converter are principally also suitable for combined heat and power. Decisive for the construction of a 'renewable' Hybrid System is the achievable of a secure supply situation, which could be evaluated by the quality of the "controllability". With other words, the system has to guarantee a sufficient variability to fulfil the individual energy requirements from the consumers view point. For this reason, the additional usage of biomass, especially with combined heat and power, is advantageous because their combustion is usually controllable [2].

But the unrestricted availability of most of such converter could only be guaranteed, if the storage of biomass fuels is sufficiently dimensioned and/or the delivery of the fuels is well correlated to the consumption. This is especially of importance, if the fuel is produced with the help of surplus stochastically produced electrical energy, to be stored as chemical energy. An example for this is the production of hydrogen with the help of an electrolyser. This hydrogen could afterwards be used in a controllable way, for example by a fuel cell or a gas motor with combined heat and power or simply for a heat boiler. If the heat demand of a consumer is not too high, it may also be possible to use electrical energy for heating purposes; in this cases it would be advantageous to integrate heat pump systems.

An important role in such hybrid systems comes to the energy storage equipments, because they have to serve as equaliser for the energy supply and therefore to unburden the controllable converter; this for electrical as well as for thermal energy. These storage systems have principally to be distinguished between storages, which can be refilled by the hybrid system itself and those who need a recharge from outside. The last ones are especially for chemical energy to supply the additional controllable converter, exceptional chemical fuels which could be produced internally with the stochastically converter.

Regarding the explanations concerning the energy storage systems, the following *classification of storage systems* gives an overview of the surely not completely possibilities:

a) Internally chargeable storage systems:

i) *Electrical Energy*

- Fly Wheel (short time)
- Condenser (short time)
- Storage Batteries (i.e. lead acid batteries)
- Hydrogen Fuel Cell with H2 -Storage

ii) *Thermal Energy*

- Sensitive Heat (i.e. water)
- Latent Heat (Paraffin i.e.)

iii) *Chemical Energy*

- Hydrogen (via Electrolyser)

b) Externally chargeable storage systems:

- Solid Fuels (wood, biomass-pellets i.e.)
- Liquid Fuels (bio oil, alcohols i.e.)
- Gaseous Fuels (H2 , biogas, clear-gas i.e.)

Depending on the dynamical behaviour of the consumer, a combination of these different storage systems may be advantageous, for example a fly wheel for short time peak demands and a fuel cell for normal middle range fluctuations. In cases with the possibility of a grid connection, an exchange of energy with other suppliers influences the dimensioning criteria for the electrical storage system, perhaps it is not necessary. The exchange and equalisation of energy supply with a grid interconnection needs a sufficient grid capacity. The problem of the grid integration of a growing amount of decentralised renewable energy supply systems would increase in future. This is strongly attached to the grid and conventional power plant control and regulatory strategies.

Not less important than the above mentioned components for a hybrid system is the *control syste*m. The effective coordination of all the components depends on this. Of course the energy storage is the boundary between the energy converter and the consumer, the energy storage management gets the key function of the control system. Even the lifetime of the storage batteries depends on a well working charge management system. The control system includes also as an important part the registration and indication of the working status, the energy flux balance and the control of all functions with error indications and alarm settings. Even the possibility to drive the system for test purposes with sufficient variability to influence the working situation manually in order to find malfunctions or to drive the system in a half automatic way to guarantee the minimum supply necessities, has to be implemented. A further task for a control system would be a so-called load management, which is able to switch on and off some power extensive consumer with the help of a priority list, in order to avoid a not necessarily simultaneous operation of for example the washing machine and the electric – hearth furnace. This kind of management would help to limit the maximum nominal power of such a hybrid system.

3. DIMENSIONING PRINCIPLES

In the following, the dimensioning principles for a hybrid system as shown in figure 1 with a PV-Plant as additional stochastically converter are demonstrated, especially for the conditions of private households as a calculation unit, exemplary concerning climate conditions in middle Europe.

The today's annual ratio of electrical to heat energy consumption of average private households in Germany is nearly one to ten. Essentially for the determination of the dimensioning criterion for hybrid system, as shown in figure 1, is the correlation of the time dependent consumption functions for electrical power as well as for heat [5]. With a wind turbine as additional stochastic converter to the photovoltaic system, it is necessary to correlate the effects of the stochastic parameters current consumption, heat consumption, insolation and wind energy.

An average household in Germany for 2,2 persons with 80 m² consumes annually 3146 kWh electrical energy. The seasonal consumption in winter is greater than in summer. It is possible to approximate the daily consumption as a cosines-function, with the whole year as period in kWh/d.

$$\overline{P}_{d,Current} = \left\{ 8,6 + 1,6 \cdot \cos\left(\frac{2\pi}{365} \cdot d \right) \right\},\ d \equiv day\ . \quad (1)$$

The daily power consumption in a typical week in summer is 7,439 kWh and for a typical week in winter 10,123 kWh. The following annual ratios are valid:

$$\frac{power}{heating} \approx 0,11 \quad and \quad \frac{power}{process - heat} \approx 0,56\ . \quad (2)$$

It is also possible to approximate the daily heat-consumption as a cosine-function with sufficient accuracy, similar to (1) in [kWh/d] [2], [5]:

$$\overline{P}_{d,heat} = \left\{ 15,4 + 78,36 \cdot \left(1 + \cos\left(\frac{2\pi}{365} \cdot d - 0,232 \right) \right) \right\}. \quad (3)$$

For a general private household, the following scaling could be used:

$$P_{general} = z \cdot P_{average} \quad \text{with} \quad (4)$$

$$z = \frac{annual \quad power - consumption}{3146 \quad kWh} \quad (5)$$

With these formulas for power and heat, an approximated daily ratio of power to heat can be given as:

$$\sigma(d) = \frac{P_{electrical}(d)}{P_{heat}(d)} \quad (6)$$

The function has a significant maximum in summer, as shown in figure 2 below, therefore the curve path of the expected power generation of a PV system is advantageously correlated to this characteristic.

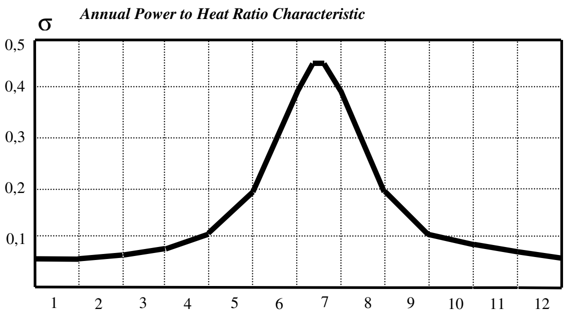

Figure 2: Annual Power to Heat Ratio

The annual power generation of a '1kWref-Plant' in Germany can be estimated by the following function:

$$\overline{P}_{d.PV}\left(1kW_{ref}\right) \cong \sum_{i=0}^{6} a_i \cdot d^i \quad \text{with} \quad (7)$$

$a_0 = 6,347505E-01$, $a_1 = 3,7224486E-03$

$a_2 = 1,818859E-04$, $a_3 = 2,818560E-06$

$a_4 = -3,168738E-08$ $a_5 = 9,383729E-11$

$a_6 = -8,807513E-14$,

whereas 1 kW_{ref} is defined as 1 kW-Peak divided through the so called performance ratio, which regards the individual efficiency conditions of a PV-plant [3]. In order to allow a simple conversion to individual different local conditions, the average time dependent insolation characteristic in Germany has been standardised to an annual total global insolation of 1000 kWh/m². In contrast to the PV, the typical wind energy production is less significant periodically dependent on the seasonal conditions and its approximation with a formula has more uncertainties. The same is observable for the short-time variations. Nevertheless, it is possible to realise a statistically equalised electrical energy production with the combination of wind power and PV energy as shown in figure 3.

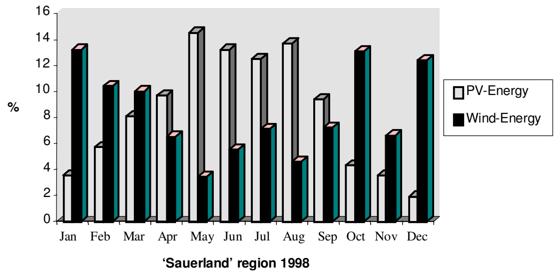

Figure 3: Combination of Wind and PV Energy

Because of these above mentioned reasons, it is advisable for the dimensioning of such hybrid systems, to estimate the energy production of the wind turbine with the help of a constant average value. With respect to a single representative household and the energy scale of the PV-plant, it is advantageous to calculate with a wind turbine, which average power production value is normalised to constant 1kW:

$$\overline{P}_{d.Wind} \cong 1kW\ . \quad (8)$$

To realise this in practise, the wind energy converter has to be dimensioned individually, with respect to the local conditions and amount of households.

The installation of a wind energy converter and a PV-Plant for the household results in an additional power supply and reduces the residual ratio of power to heat, which is left for the combined heat and power system:

$$\sigma(d)_{W,PV} = \frac{P_{electrical}(d) - P_{Wind}(d) - P_{PV}(d)}{P_{heat}(d)} \quad (9)$$

with $P_{Wind}(d) = \xi_W \cdot \overline{P}_{d,Wind}$,

$P_{PV}(d) = \xi_{PV} \cdot \overline{P}_{d,PV}(d)$ and

$\xi_{PV}, \xi_W \in R^+$ as scaling factors.

With respect to the possible degree of efficiency η of the combined heat and power, the realisable ratio of power to heat is limited to be smaller than υ :

$$\sigma_{W,PV} \leq \upsilon \quad with \quad \upsilon = \frac{\eta}{1-\eta}\ . \quad (10)$$

These information lead to a basic formula to determine the main components of the hybrid system. The following condition allows to adjust the wind energy converter and PV-Plant to the controllable engine with combined heat and power:

$$\xi_W \cdot \overline{P}_{d,Wind}(d) + \xi_{PV} \cdot \overline{P}_{d,PV}(d) \geq P_{electrical}(d) - \upsilon \cdot P_{heat}(d)\ . \quad (11)$$

This condition has to be fulfilled for every day of the year. To justify each of the parameter $\xi_W, \xi_{PV}, \upsilon$ to another, physical as well as economical influences have to be considered. Therefore, there exists no common optimal solution. Every hybrid system project requires an individual dimensioning with respect to formula (11).

For example, the addition of a wind energy converter with a statistically averaged constant power gain of 0,2 kW ($\xi_W = 0,2$, $\xi_{PV} = 2$) per household lowers the curve of the residual ratio characteristic as demonstrated in figure 4.

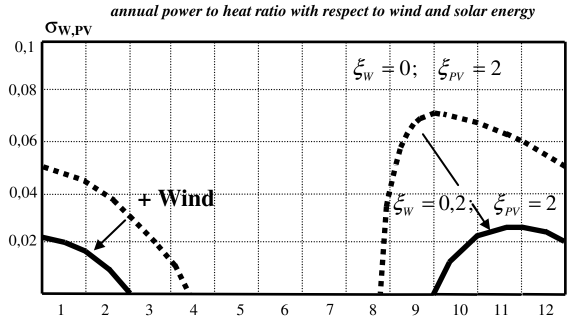

Figure 4: Ratio σ with Wind Energy and a PV-Plant

The PV-system is able to supply a household sufficiently with electrical energy during summer time, and an additional wind energy converter increases the availability. In consequence, the required capacities of storage batteries decrease. In this season, the combined heat and power system could be used nearly only for hot water production, or in very improbably situations with simultaneously low insolation and not sufficient wind. In winter time, the contribution of the PV is very weak. In this case, the combination of wind energy and combined heat and power builds the responsible supplies. In contrast to the summer time, there is a simultaneous demand on electrical power and heat, which implies the usage of such complex systems for combined heat and power, especially with biomass.

4. BIOMASS AND HYBRID SYSTEMS

A basic reception of the presented explanations to the dimensioning principles for 'renewable' hybrid systems is the fact, that the remaining expected requirements concerning the electrical efficiency of combined heat and power engine are very low. Even a modern steam engine, as shown in figure 5, is surely able to fulfil the worked out conditions [6].

Figure 4: Auxiliary Power Unit / Enginion Berlin [6]

It could be advantageous to combine carefully many households with a greater wind turbine, instead of many small, whereas the PV-systems are installable decentralised, preferably on each roof. But there are many different individual concepts possible.

As demonstrated in figure 4, a efficiency for the electrical energy of the combined heat and power unit of less than 5% would be sufficient, supported by a minimised electrical storage, primarily for short time peak demands.

Fuels, based on Biomass, could principally be used in two kinds of combustions, that means as 'internal' or 'external' combustion. Internal combustion is for example used by diesel engines, micro gas turbines etc., where the oxidation process works directly inside the machine, with liquid and gaseous fuels. In this way, the fuel cell could also be characterised as an internal combustion unit.

Solid biomass, like wood or straw, are not conditioned for an internal combustion. In these cases, the heat energy of their combustion has to be transferred to a working medium like steam or light gases, which could be used by an engine. This kind of 'external' combustion could be used for every kind of fuel. With respect to the power range of some kW, needed for private households, stirling engines and modern steam engines (figure 4) would be advantageous, as well concerning their flexibility as ecological facts. An important fact for future strategies is, that most of the usable biomass is originally solid.

5. CONCLUSION

Hybrid systems with combined heat and power in combination with PV+Wind and the use of Biomass have the potential to play an important role for future energy supplies based totally on *renewable sources*.

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