DIMENSIONING PRINCIPLES OF HYBRIDSYSTEMS BASED ON RENEWABLE ENERGIES INCLUDING WIND TURBINES AND COMBINED HEAT AND POWER

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ABSTRACT: This contribution presents general criterion for the dimensioning of hybridsystems, which are completely based on renewable energies, including wind energy converter and an equipment for combined heat and power. The principles are demonstrated as well in a general manner as specially for the conditions of private households, exemplary concerning climate conditions in middle Europe. The criterion and foundations are presented in a mathematical manner. Essentially the influence of the stochastic energy supplies like Wind Turbines and PV-Generators, and their combination, on the residual ratio of power to heat for the combined heat and power is worked out. This paper presents a list of the most important components and the process scheme of such hybridsystems. The way to determine the sizes of the components will be demonstrated. With the use of biomass, such hybridsystems enable energy-supply-systems, totally based on renewable sources.
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1. GENERAL PRINCIPLES

An extensive usage of renewable energy sources implies, because of their local and time dependant stochastically behaviour, a decentralised supply structure. Thereby, the different possibilities of renewable energy converter are to be combined with respect to their complementary character, resulting in so-called hybridsystems.

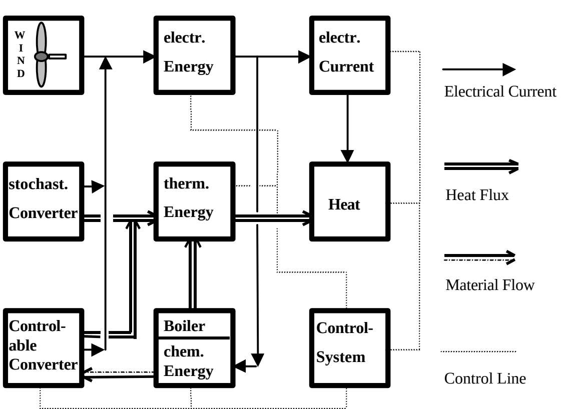

Figure 1: principle scheme of a hybridsystem

Regarding the fact, that in contrast to the momentary dominating fossil energy supply, the usage of renewable sources causes more expenditure and complexity, it lies therefore in the nature of the needed technology, to handle these renewable sources effectively and rationally, even if these energies are endlessly available on the human time scale. To reach a most effective exploitation of renewable primary energy sources, it is very important to pay attention not only to the electrical energy, but in the same way to the heat demand [1], [2], because the heat demand is in the most cases a multiple higher than that of electrical current. This implies the necessity of an integration of the principle of combined heat and power, whenever it is possible [3]. The necessary combination of renewable energy converter is given because of the stochastically character of their availability, how it can be seen for example for wind and solar energy.

Figure 1 shows the general realisation principle of hybridsystems with combined heat and power, the integration of additional converter is optional. 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 [4].

Possible ***controllable converter*** are:

- *Fuel Cell (H_2, 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' Hybridsystem 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 [4].

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

2. PHYSICAL FOUNDATIONS

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 hybridsystem, as shown in figure 1, is the correlation of the time dependent consumption functions for electrical power as well as for heat [2].

With a photovoltaic system as additional stochastic converter to the wind turbine, 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. 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.

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

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], [3], [4]:

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

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 could be given:

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

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.

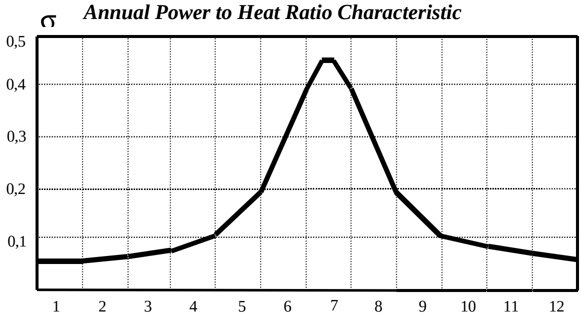

Figure 2: annual power to heat ratio

The annual power generation of a '1kW$_{ref}$-Plant' in Germany can be estimated by the following function:

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

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

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

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

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

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].

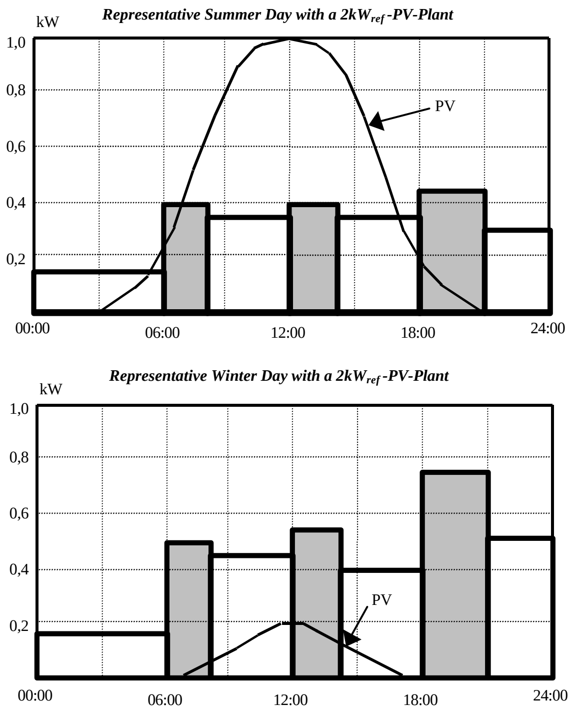

Figure 3: private household with a PV-plant in Germany

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 form the seasonal conditions and its approximation with a formula has more uncertainties. The same is observable for the short-time variations.

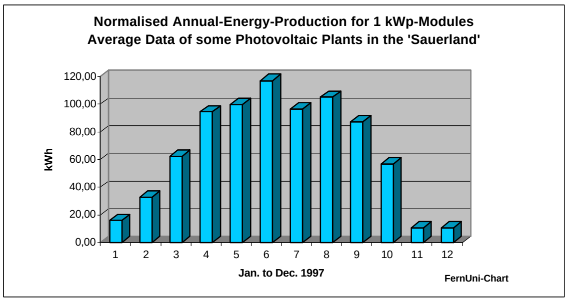

Figure 4: normalised energy production of PV-systems

Figure 5 shows the annual energy production of several wind energy converter in the region 'Sauerland' in middle Germany 1997 [5]. This shape is typical, but it shows also, that the month January is weak and breaks the symmetry of the envelop curve. The same phenomenon can be seen in figure 6 for the month November. Nevertheless, it is possible to realise a statistically equalised electrical energy production with the combination of wind power and PV energy.

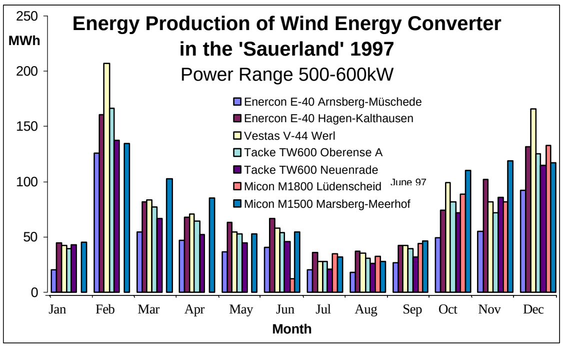

Figure 5: annual energy production of wind turbines

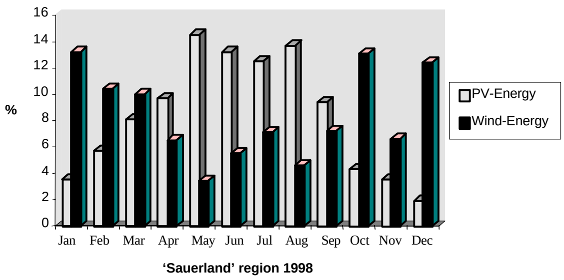

Figure 6: combination of wind and PV energy

Because of these above mentioned reasons, it is advisable for the dimensioning of such hybridsystems, 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:

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

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

3. DIMENSIONING PRINCIPLES

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:

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

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

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

$x_{PV}, x_W \in R^+$ as scaling factors.

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

$$s_{PV} \leq u \quad \text{with} \quad u = \frac{h}{1-h} \,. \qquad (10)$$

For example, the usual electrical efficiencies of realised combined heat and power systems for the usage of biomass with piston-type steam engines are today about 16% [2], [4]. These information lead to a basic formula to determine the main components of the hybridsystem. The following condition allows to adjust the wind energy converter and PV-Plant to the controllable engine with combined heat and power:

$$x_W \cdot \overline{P}_{d,Wind}(d) + x_{PV} \cdot \overline{P}_{d,PV}(d) \geq P_{electrical}(d) - u \cdot P_{heat}(d) \,. \quad (11)$$

This condition has to be fulfilled for every day of the year. To justify each of the parameter x_W, x_{PV}, u to another, physical as well as economical influences have to be considered.

Therefore, there exists no common optimal solution. Every hybridsystem project requires an individual dimensioning with respect to formula (11).

In order to demonstrate the advantageous correlation between wind and solar energy for the supply of private households, figure 7 below shows the residual ratio of power to heat, if a PV-plant is already installed ($x_{PV} = 2$, $x_W = 0$). Together with figure 5 it becomes obvious, that it is possible to reduce this ratio nearly to zero.

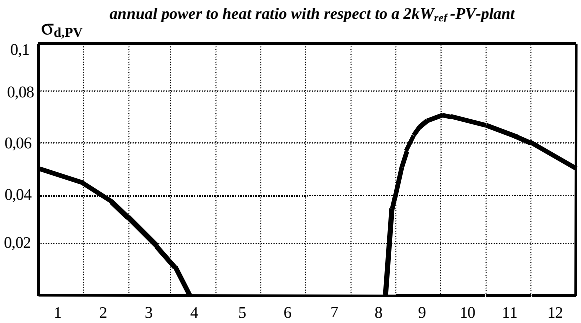

Figure 7: residual power to heat ratio with a PV-plant

For example, the addition of a wind energy converter with a statistically averaged constant power gain of 0,2 kW ($x_W = 0,2$, $x_{PV} = 2$) per household lowers the curve of the residual ratio characteristic as demonstrated in figure 8.

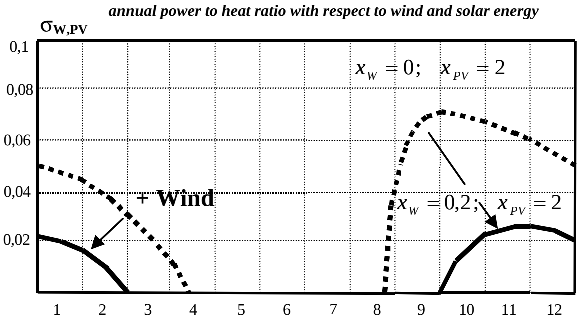

Figure 8: residual ratio with wind energy and a PV-plant

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.

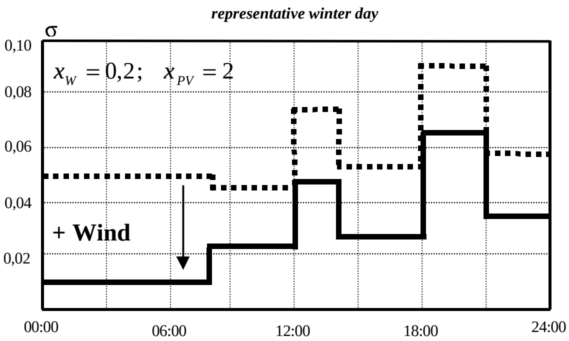

Figure 9: power to heat ratio for private households

The figure 9 above shows simplified the power demand of an average private household in Germany for a typical day in winter. The contribution of the PV system is negligible. The ratio of power to heat is not high, because of the dominating demand on heating. The dotted line is the usual ratio, whereas the solid line is the result of a contribution of wind energy. A basically reception of the presented explanations to the dimensioning principles for 'renewable' hybridsystems is the fact, that the remaining expected requirements concerning the electrical efficiency of combined heat and power engine are very low. A modern steam engine is surely able to fulfil the worked out conditions [4]. Storage batteries for electrical energies are necessary to guarantee a gap free energy supply. Even the average required power for a private household is in most cases less than 1 kW, short time demands of more than 10 kW are possible (table 1).

kW	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8
%	84	10,9	3,28	1,98	0,54	<0,15	<0,05	< 0,05

Table 1: classification of the electrical power demand

But the equalised power conversion with the combination of wind and solar energy minimises the required capacity of storage batteries.

It could be advantageous to combine carefully many households with a greater wind turbine [6], instead of many small, whereas the PV-systems are installable decentralised, preferably on each roof. But there are many different individual concepts possible.

4. CONCLUSION

This paper presents the main dimensioning principles for a hybridsystem with a wind turbine, PV-plant and an equipment for combined heat and power. The combination of wind to solar energy is able to equalise and lower the ratio of power to heat for private households nearly to zero. In consequence, the requirements for the combined heat and power concerning the electrical efficiency are easy to fulfil, especially with the use of biomass. The combination of these converter leads in summary to a controllable power supply system completely based on renewable energy sources.

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