# EFFECT OF PHOTOVOLTAIC SOLAR ENERGY ON COMBINED HEAT AND POWER HYBRID SYSTEMS

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ABSTRACT: This contribution presents an analysis of the effect of photovoltaic solar energy (PV) on the conditions for a combined heat and power system, which is an integrated part of a hybrid system to be used as a self-sufficient energy supply system. The interaction with the optional addition of a wind energy converter is included in this analysis, and also the possibility to use electric vehicles not only as consumers, but as well as a supporting part of the electrical energy storage system. The general criterion and foundations for the dimensioning of such systems, especially for private households in middle Europe, are presented and discussed. The influence of the solar 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 possible combined heat and power units.
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## 1. INTRODUCTION

The analysis presented here, is a consequent further step to generalise the results of a research project concerning a PV Hybrid System with a modern steam engine as the integrated combined heat and power unit [1]. This complex hybrid system has been examined theoretically, as well as with the help of experimental investigations [3].

The steam engine works with the principle of an external combustion and gives the possibility to use especially nearly every kind of biomass [2]. The result would be a complex energy supply system completely basing on renewable energy resources.

In order to increase the availability of electrical energy, it is advantageous to add a partial contribution from a wind energy converter [5]. In this case the capacity of the electrical storage system could be reduced to a minimum.

Trying to take care of the necessity to integrate traffic systems into a future energy supply strategy, the present analysis regards also electric vehicles as additional consumer of electrical energy. But this kind of vehicles can be seen as well as a positive supporting element, if they were bi-directional connected to such hybrid systems [6].

## 2. PV HYBRID SYSTEMS

Regarding the fact, that in contrast to the momentary dominating fossil energy supply, the usage of renewable sources causes more expenditure and complexity, therefore it lies 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 [3], 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 [2]. The necessity to combine 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 [5].

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.

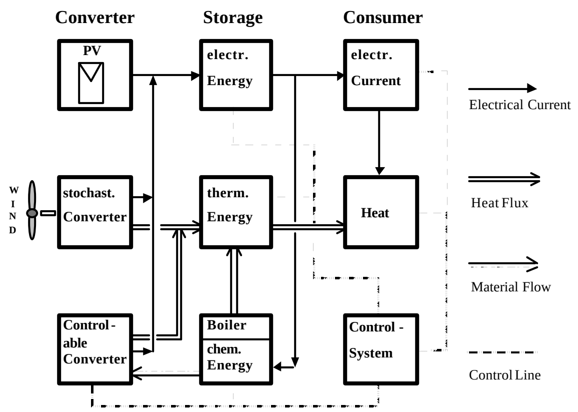


**Figure 1:** Principle Scheme of a Hybrid System

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 may be in concurrence to that of the photovoltaic plant.

Basis for the use of controllable converter is in general also solar energy in stored form like biomass.

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' Hybrid System is to achieve 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], [4].

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 electrolysis. 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 these cases it would be advantageous to integrate heat pump systems.

An important role in such hybrid systems comes to the energy storage equipment, 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 stores, 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, batteries in electric vehicles)
- Hydrogen Fuel Cell with $H_2$-Storage

ii) *Thermal Energy*
- Sensitive Heat (i.e. water)
- Latent Heat (Paraffin i.e.)

iii) C*hemical Energy*
- Hydrogen (via Electrolyser)

b) Externally chargeable storage systems:
- Solid Fuels (wood, biomass-pellets i.e.)
- Liquid Fuels (bio oil, alcohol i.e.)
- Gaseous Fuels ($H_2$, biogas, clear-gas i.e.)

Depending on the dynamically 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.

Not less important than the above mentioned components for a hybrid system is the *control system*. The effective co-ordination 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 [4], [7]. A good 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

Essentially for the determination of the dimensioning criterion for PV hybrid systems, as shown in figure 1, is the correlation of the time dependent consumption functions for the electrical power as well as for the heat.

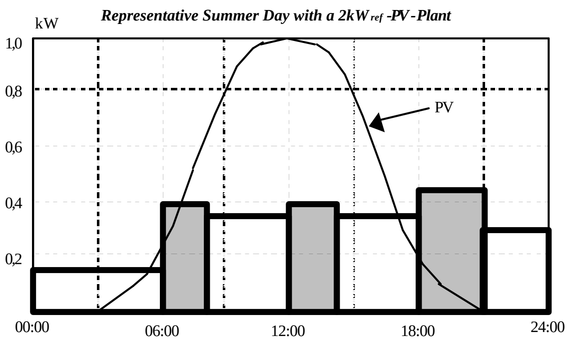


**Figure 2:** Private Household with a PV-plant

In climate conditions like in middle Europe, a supply of electrical energy from a PV-Plant is naturally most effective in summer, whereas in winter the combined heat and power unit has to be used, as can be seen in figure 2 and figure 3 for private households in Germany [3].

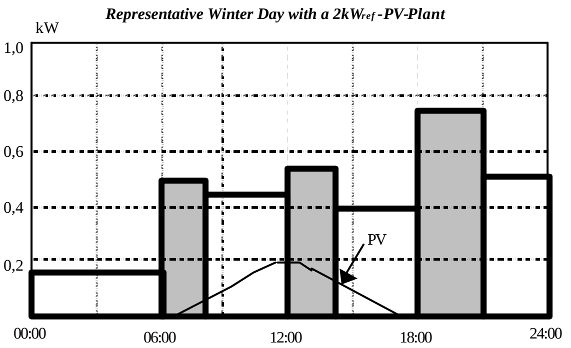


**Figure 3:** Private Household with a PV-plant

An average private household in Germany with 2,2 persons an 80 m² consumes annually 3146 kWh electrical energy. The annually averaged ratio of electrical energy to heat consumption is nearly 0,11 today. The time dependent consumption characteristics of current as well as for heat can be approximated with the help of cosines-functions [3].

Because of the strong correlation of the insolation to the sun's position, it can be shown with the help of simulations and mathematical approximations, that for an average private household a PV-Plant of 2,5 kWp would be sufficient to produce the needed electrical energy from April to August [3], [5]. Figure 2 demonstrates the necessity of the usage of storage batteries in order to equalise the fluctuation between consumption and insolation.

In contrast to the PV, the typical wind energy production, which can be used as an additional supply, as shown in figure 1, is less significant periodically dependent from the seasonal and daily conditions. An approximation with a formula has more uncertainties. As figure 2 and figure 3 show, a nearly constant contribution of a wind energy converter of 300-400 W for each private household may be sufficient. It can also be seen from the figures above, that a nominal electrical power rate of the combined heat and power unit of approximately 1 kW would be sufficient. A combination of these different components to a hybrid system increases the availability of electrical energy and reduces the necessary capacity of the battery storage system to a minimum [7].

## 4. PV AND COMBINED HEAT AND POWER

The important parameter for combined heat and power is the ratio of power to heat.

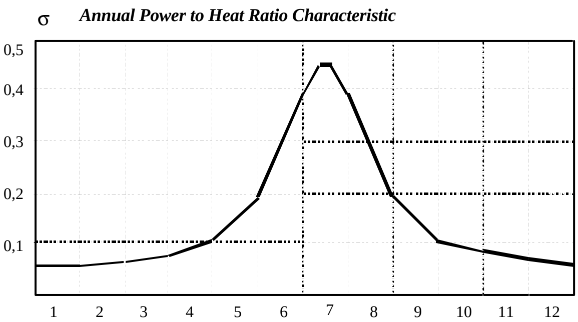


**Figure 4:** Annual Power to Heat Ratio

The time dependent characteristic curve of this value for an average private household in Germany, as a calculation unit, is shown in figure 4.

This curve is valid for the momentary building conditions. During the next decades, the shape of this function may be shifted up to higher values, because of modern regulations concerning heat isolation. But the principle character will not be changed remarkably.

With its maximum in summer, the annual energy supply characteristic of a PV-Plant is advantageously correlated to the portion of electrical energy.

The installation of PV-Plants and optionally a wind energy converter for a private households changes the curve in figure 4. The additional sources of electrical energy reduce the ratio of power to heat to

$$s_{PV,W} = \frac{P_{electrical} - P_{Wind} - P_{PV}}{P_{heat}} . \quad (1)$$

The dotted line in figure 5 shows the change of figure 4 to the residual ratio of power to heat with the contribution of a approximately 2,5 kWp PV-Plant for each private household.

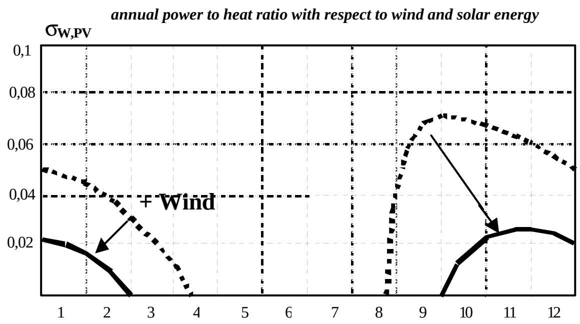


**Figure 5:** Power to Heat Ratio with PV and Wind

The PV-System is able to supply a household sufficiently with electrical energy during summer time. In winter time, the contribution of the PV-Plant is weak. In this case, an additional wind energy converter with a nearly constant contribution of 0,2 kW for each household results in a change to the solid line in figure 5.

The time period with sufficient electrical energy from these converter increases, the ratio *s* decreases significantly also in winter and because of the increasing availability, the necessary capacity of the storage batteries can be reduced to a minimum.

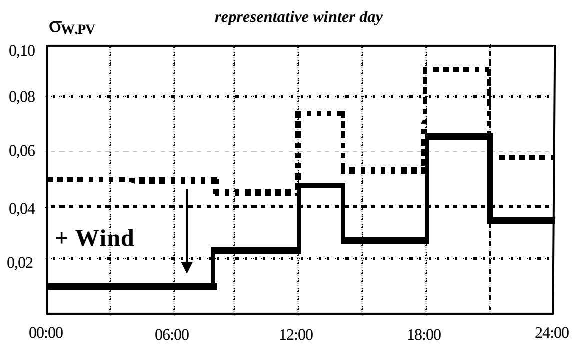


**Figure 6:** Power to Heat Ratio in Winter

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

$$s_{W,PV} \le u \qquad \text{with} \qquad u = \frac{h}{1-h} \,. \tag{2}$$

With $P_{Windref}$ and $P_{PVref}$ as power contributions from defined reference wind and solar energy converter, which can be approximated with the help of mathematical formulas, the basic formula to determine the main components of the hybrid system is given by:

$$x_W \cdot P_{Windref}(d) + x_{PV} \cdot P_{PVref}(d) \ge P_{electrical}(d) - u \cdot P_{Heat} \,. \tag{3}$$

This condition has to be fulfilled for every day of the year. To justify each of the parameter $x_W$ , $x_{PV}$ and $u$ to another, physical as well as economical influences have to be considered. Therefore, there exist no common optimal solution. Every hybrid system project requires an individual dimensioning with respect to formula (3).

But as an essential result of the given argumentation chain is the fact, that it is not necessary to call for a high electrical efficiency of the combined heat and power unit.

Depending on the dimensioning of the PV-Plant an efficiency of nearly 10% may be sufficient. The addition of wind energy lowers this value to nearly 5%, like in the examples as shown in figure 5 and figure 6.

This fact may be regarded especially with respect to research and development activities for biomass energy converter.

## 5. COMPLEX PV HYBRID SYSTEM STRUCTURES

But it would not be possible to build up a more effective, rational, and as far as possible renewable future energy supply system and structure, without a consequent integration of the transport and traffic technology. Most important for this is a complex and interconnected view of these problems as one whole not dividable unit.

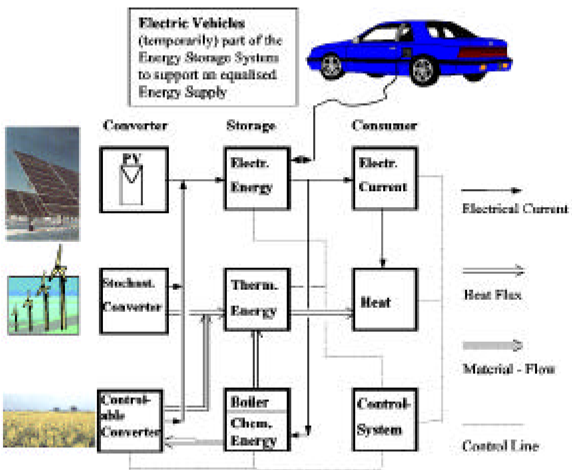


**Figure 7:** Complex Renewable Hybrid System

Because of the different stochastically and dynamically behaviour, it seems to be unavoidable for such supply systems to integrate sufficient energy storage capacities. A careful dimensioning of hybrid systems and their interconnections can help to reduce these capacities to an absolute minimum only for security. A special capacity would be necessary to cover the peak power short-time demands, in order to avoid an over dimensioning of the hybrid system converter. In this case electric vehicles could serve as (additional) storage capacities, if they were not used for driving [6].

It would be a great advantage, if many of such hybrid systems were integrated into a complex interconnecting structure with the possibility of grid equalisation. Then it would be possible to connect electric vehicles most of the time to a common electric line. Of course the part of $P_{electrical}$ in formula (3) increases, but on the other hand, this would also increase the availability of each hybrid system and help to decrease the amount of additional battery capacity, the better, the greater the complex system is. In this way, the electric vehicles serve as equaliser in the electric grid of hybrid systems.

Naturally, this purpose presupposes a bi-directional charge control management for the electric vehicles. It would be also necessary to define a minimum charge status to cut these batteries off the line, in order to reserve a minimum driving range. Further calculating simulations and experimental studies are necessary to find the best dimensioning of such systems.

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